C. ASSESSMENT OF ATLANTIC SURFCLAM

Report of the Invertebrate Subcommittee (see Appendix C1 for membership)

1.0 TERMS OF REFERENCE (TOR) AND SUMMARY

1. Characterize the commercial and recreational catch including landings and discards. *Completed, see Section C3.*

2. Estimate fishing mortality, spawning stock biomass, and total stock biomass for the current year and characterize the uncertainty of those estimates. If possible, also include estimates for earlier years. *Completed, see Section C5.*

3. Either update or redefine biological reference points (BRPs; proxies for B_{MSY} and F_{MSY}), as appropriate. Comment on the scientific adequacy of existing and redefined BRPs. *Completed, see section C6. Biomass reference points were updated based on new estimates of historical biomass levels and criteria in the Surfclam and Ocean Quahog Fisheries Management Plan. Fishing mortality reference points did not require updating. Current reference points were adequate for this assessment because stock biomass is relatively high and fishing mortality rates are low. However, it was noted that implicit assumptions about* B_{MSY} *and biomass during 1999 may not be valid and should be reevaluated.*

4. Evaluate current stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 3). *Completed, see section C7. The stock is not overfished and overfishing is not occurring.*

5. Recommend what modeling approaches and data should be used for conducting single and multi-year stock projections, and for computing TACs or TALs. *Completed, see Section C8. A consistent set of stock assessment modeling, integrated bootstrap and stochastic projection software is now available that can deal with auto correlated recruitment patterns in surfclam. It is not necessary to describe approaches for setting TAC or TAL levels because the fishery is managed with constant quota levels.*

6. If possible:

    a. Provide numerical examples of short term projections (2-3 years) of biomass and fishing mortality rate, and characterize their uncertainty, under various TAC/F strategies. *Completed, see Section C9. Example projections under a wide range of scenarios indicate that surfclam biomass will decline over the next 2-3 years to levels near the* B_{MSY} *proxy level that used is used by managers as a target. The recent and expected declines are due to poor recruitment and slow growth. There is no indication that the stock will become overfished or that overfishing will occur. Uncertainty is very high, particularly for longer term projections.*

    b. Compare projected stock status to existing rebuilding or recovery schedules, as appropriate. *Not relevant. surfclam are not overfished and no rebuilding schedule exists.*

7. Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in recent SARC reviewed assessments. *Completed, see Section C10.*

Plain terms summary

1) The following abbreviations are used to identify stock assessment and fishing regions for surfclam (Figure C1).

Region (south to north)	Abbreviation
Southern Virginia	SVA
Delmarva	DMV
New Jersey	NJ
Long Island	LI
Southern New England	SNE
Georges Bank	GBK

2) Overall, total surfclam biomass has declined during recent years due to slow growth and poor recruitment, particularly in southern regions. Despite declines, total stock biomass is still at a relatively high level. Fishing mortality is low in all regions.

3) Stock conditions are relatively good in northern regions such as LI, SNE and GBK where the bulk of the stock was found during 2005 and little fishing occurs. Stock conditions are poorer in southern regions, DMV and SVA in particular, where fishing has occurred since the 1980's and a relatively small fraction of the stock was found during 2005. Conditions in NJ, where most of the fishing and a large fraction of the stock occur, are intermediate.

4) The surfclam stock is not overfished and overfishing is not occurring. Overfishing and overfished stock conditions are not likely to occur in the near future.

5) Total landings from the EEZ stock during 2005 were less than the quota due, based on industry sources, to market factors.

6) The majority of landings during recent years were from the NJ region although some landings were also taken from DMV in the south. Landings in the northern SNE and LI regions increased during recent years were minor. No fishing occurs on GBK due to risk of paralytic shellfish poisoning (PSP).

7) Over time, surfclam biomass has shifted towards the north. During 2005, the largest fraction of stock biomass was in GBK, rather than in NJ or DMV.

8) Fishing effort and catch have shifted north during recent years as catch rates in the south have declined.

9) Total fishing effort increased during recent years while landings per unit effort (LPUE) decreased for the fishery as a whole.

10) LPUE has declined in NJ and drastically in DMV. LPUE in the LI region appears to be increasing.

11) Growth rates for surfclam in NJ, and particularly in DMV, have slowed in recent years so that the age at recruitment to the fishery has increased by 1-2 years. Delayed recruitment and slower growth after reaching fishable size reduce potential fishery yield by a substantial amount. Slower growth is due to environmental factors.

12) Recruitment has declined during recent years for the stock as a whole and is at or near record low levels in most regions.

13) Stock biomass for the entire stock was at record high levels during the late 1990s. Since then stock biomass has declined. In 2005, total stock biomass was about the same as before the peak.

14) Biomass trends for NJ were similar to trends for the entire stock. Biomass trends for DMV indicate steeper and continuous declines since the record high levels for DMV during the early 1980s.

15) Recent declines in biomass are due to negative surplus production. This means that factors that increase stock biomass including growth and recruitment have not been large enough to offset natural (not related to fishing) losses.

16) Fishing mortality rates are low in all regions. The environment, rather than fishing, apparently caused the recent declines in biomass.

2.0 INTRODUCTION

This stock assessment for the offshore subspecies of Atlantic surfclam (*Spisula solidissima solidissima*) was prepared for SAW/SARC-44 along with a stock assessment for ocean quahog (*Arctica islandica*). No information is provided about the smaller coastal form (*S. s. similis*) that occupies relatively southern inshore habitats (Hare and Weinberg 2005). The geographic distributions of the two subspecies overlap to a limited extent in the south and in some inshore waters to the north. However, *S. s. similis* is reproductively isolated from *S. s. solidissima* and not important to the commercial fishery.

The same methods were used in the assessments for surfclam and ocean quahog although the surfclam assessment was completed after the ocean quahog assessment and incorporates a number of improvements. Interested persons and reviewers should read the ocean quahog assessment (i.e., Assessment A in this volume) first because the methods used for both species are described there in detail. Improvements to methods for surfclam and other details relevant only to surfclam are described below.

Distribution and biology

Atlantic surfclam is a relatively large fast growing bivalve distributed in the western North Atlantic Ocean, along the coast of North American from the southern Gulf of St. Lawrence to Cape Hatteras (Figure C1). Individuals larger than 16 cm shell length (SL) are relatively common in NEFSC surveys. Commercial concentrations are found primarily off New Jersey, the Delmarva Peninsula, and on Georges Bank. Surfclam are found from the intertidal zone to a depth of about 60 m but densities are low at depths greater than 40 m. See Cargnelli et al. (1999) for a complete review of life history and distributional information. The distribution of Atlantic surfclam and the distribution of a related species (*S. similis*) overlap in the south and some inshore waters to the north (Hare and Weinberg 2005).

It is likely that all Atlantic surfclam along the northeast coast belong to the same biological population. Surfclam are common in both inshore state (≤ 3 mi from shore) and offshore federal waters. Federal waters consist of the Exclusive Economic Zone (EEZ), between 3 and 200 mi from shore. The stock assessment applies only to the EEZ segment of the surfclam population in federal waters, however, because the EEZ is the management unit specified in the Fishery Management Plan for the Atlantic Surfclam and Ocean Quahog Fisheries (FMP). Surfclam in New Jersey and New York state waters support valuable fisheries that are managed by state authorities.

Surfclam in the EEZ are managed as a unit stock but there is substantial regional variability in exploitation rates and biological characteristics. A variety of calculations and estimates in this assessment are presented for smaller stock assessment regions which are defined below (Figure C1). Previous assessments separated the New Jersey (NJ) region into Northern New Jersey (NNJ) and Southern New Jersey (SNJ) components. In this assessment, the NJ region is treated as a single entity. SNJ and NNJ were combined to simplify the assessment and because data for SNJ were too limited and variable to be analyzed separately.

There is uncertainty about the timing of annual mark (annulus) formation in surfclam chondrophores, which are cut from shells and used to age surfclams taken in NEFSC clam surveys. There is additional uncertainty about indentifying the first annual mark (Jacobson et al. 2006). Despite these questions of interpretation, surfclam annual rings are relatively easy to count. In this assessment, the number of annual marks and age are assumed to be the same and the assumed birth date is January 1 so that, for example, a member of the 2004 year class taken during the 2005 NEFSC clam survey would be age 1 at the time of capture and expected to show one ring. Ages for surfclams taken in the commercial fishery that operates year round are more uncertain. Surfclams age 20+ are relatively common and the maximum observed age exceeds 35. See Jacobson et al. (2006) for information about procedures used to estimate surfclam age.

Surfclams are capable of reproduction at age 1, although full maturity may not be reached until age 2. Spawning occurs during late summer and early fall. Eggs and sperm are shed directly into the water column. Recruitment to the bottom occurs after a planktonic larval period of about three weeks.

Weinberg (1998) and Weinberg and Helser (1996) show that growth rates vary among regions, over time and in response to surfclam density levels. Based on NEFSC clam survey data (Figure C2), growth rates appear to have declined for surfclams in the southern DMV region and to a lesser extent in the NJ region since 1993. Slower growth in surfclams in DMV during recent years coincides with mortality in near shore areas off DMV probably due to warm water (Weinberg 2005) and lower occurrence of surfclams with 25+ annual marks in survey data (Figure C2).

Length-weight parameters used in this assessment to convert numbers of surfclams of different shell lengths in surveys to meat weight equivalents are region specific and based on fresh (unfrozen) material (Table C1). Length-weight parameters vary among locations and over time. Although length-weight data are collected periodically during NEFSC clam surveys, recent assessments used the same length-weight relationship for the sake of simplicity and consistency (NEFSC 2003). A simple and consistent approach is used because length-weight data are not available for the commercial catch (which targets clams with high meat yield) and because length-weight information for early surveys was based on frozen material.

Management

The fishery for Atlantic surfclams and ocean quahogs in the EEZ are unique in being the first US fishery 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, which was 26.2 thousand mt meats per year during 2001-2005, and mandatory logbooks that describe each fishing trip. See Murawski and Serchuk (1989) and Serchuk and Murawski (1997) for detailed information about history, management and fishery operations. MAFMC (2006) describes recent fishery conditions and management for both surfclams and ocean quahogs.

Previous assessments

Stock assessments are generally done after NMFS clam surveys, which are conducted every 2-3 years. In the most recent stock assessment for surfclam, NEFSC (2003) 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). The stock was characterized as declining from a relatively high biomass level at the rate of about 5% per year due to negative surplus production and, in particular, relatively low recruitment. Conclusions from this stock assessment are similar. See NEFSC (1993; 1995; 1998; 2000) for earlier surfclam stock assessments.

Beginning with NEFSC (1998), the primary emphasis in surfclam stock assessments was: 1) use of sensors to evaluate survey dredge performance; 2) estimating survey dredge efficiency via cooperative “depletion studies”; and 3) calculation of efficiency corrected swept-area biomass. Previous stock assessments used stock assessment models with variable results. In this assessment, data from all available depletion studies are analyzed using consistent and improved methods. The updated information is used in a stock assessment model that is successfully applied to the stock as a whole and to the important DMV and NJ regions.

3.0 COMMERCIAL CATCH (TOR-1)

In using landings data for surfclams, 1 industry standard bushel (1.88 ft^3) was assumed to produce 17 lbs or 7.711 kg of useable meats. 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 cages (1 cage = 32 industry bu). LPUE data, however, are reported in this assessment as landings in bushels per hour fished.

As in previous assessments (NEFSC 2003), catch in all stock assessment analyses is the sum of landings plus a 12% upper bound for incidental mortality that may occur during fishing operations (i.e. assumed catch = 1.12 times landings). It is important to realize that the 12% figure is an upper bound and that actual incidental mortality is likely to be lower. Incidental mortality in the surfclam and ocean quahog fisheries is likely lower than might be expected because the total area fished is modest. The total area fished is relatively low because fishermen operate efficiently under ITQ management and target only areas of highest density. Moreover, the ITQ fishery operates with little or no regulation induced inefficiency (e.g. inefficiency due to area closures, trip limits, size limits, etc.). Discard of small surfclams occurred during 1982-1990 when size limits were used to regulate the surfclam fishery (Table C2) but are currently near zero. Recreational catch is near zero.

Size selectivity of commercial clam dredges and harvesting equipment has not been characterized quantitatively in detail. Based on commercial length data and experimental results, NEFSC (2003) assumed that surfclams in NJ were fully available to the commercial fishery at 120 mm SL and that surfclams in other regions were fully available to the commercial fishery at 110 SL.

In this assessment, surfclams 120+ mm SL are assumed to be the fishable stock in all regions. In contrast, that NEFSC (2003) used 120+ mm for NJ and 110+ mm SL for other regions. Fishing mortality estimates in this assessment, for example, compare total catch (landings plus an assumed 12% upper bound for incidental mortality) to the fishable stock 120+ SL. The bulk of the fishery and much of the stock occurs in NJ, where NEFSC (2003) assumed recruitment at 120 mm SL. Based on commercial length data in NEFSC (2003) and shown below, there is no strong evidence that size at recruitment differs among regions. Consistent use of 120 mm SL simplifies the assessment and makes biomass and fishing mortality estimates for combined regions easier to interpret.

Age at recruitment

Age at recruitment to the surfclam fishery depends on growth rates and, in particular, the ages at which surfclams reach 120 mm SL. Growth curves used in stock assessment modeling (described later) fit to survey age data indicate that surfclam recruited to the DMV fishery at about age 5 ½ y during 1982-1992 and at about age 7 ½ y during 1994-2005. Growth curves for NJ show that surfclams reached 120 mm SL and recruited to the fishery at about age 5 y during 1982-1992 and at about age 6 y during 1994-2005. Changes in age at recruitment should have substantial effect on potential fishery yield. Assuming a natural mortality rate of M=0.15 y^{-1}, for example, numbers of recruits to the fishery per surviving larvae would be 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 due to slower growth after recruitment to the fishery occurs.

Landings, fishing effort and prices

Landings and fishing effort data for 1982-2005 were from mandatory logbooks. Data for earlier years were from NEFSC (2003) and MAFMC (2006).

Landings data for surfclams are relatively accurate in comparison to other fisheries because of a comprehensive system for tracking landings in the ITQ fishery. Effort data are, however not reliable for 1985-1990, due to regulations that restricted the duration of fishing to 6 hr. Effort data are relatively reliable during later years.

Surfclam landings were primarily from the US EEZ during 1965-2002 (Table C3 and Figure C3). EEZ landings peaked during 1973-1974 at about 33 thousand mt. EEZ landings were relatively high during 2001-2005 and varied between 21 and 25 thousand mt. Landings reached the quota in most years but were less than the quota during 2005 because of limited markets (according to industry sources).

The bulk of EEZ landings were from DMV during 1979-1980 and from NJ during every year since 1981 (Table C4 and Figure C4). During 2001-2005 DMV landings were modest with relatively small amounts reported from the LI and SNE regions. Trends in fishing effort were similar (Table C5 and Figure C5).

Nominal exvessel prices for the inshore and EEZ fisheries increased from about \$8 bu^{-1} during 1982 to \$10 bu^{-1} during 1994 and then declined to about \$9.50 bu^{-1} during 2000-2005 (Figure C6). Using 1980-1982 as a basis, prices declined in real terms from about \$9 bu^{-1} during 1982 to about \$5 bu^{-1} during 2005. Based on industry sources (D. Wallace, pers. comm.), the “break-even” price for surfclams during 2005 (i.e. price necessary to cover variable costs such as fuel, crew shares, food, etc.) was about \$4-\$5 bu^{-1} (nominal, 2005 dollars).

Landings per unit effort

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 C6 and Figure C7). In addition, standardized LPUE indices (Table C7 and Figure C7) were computed from a log-linear GLM model with year, month and vessel effects for each region (see Assessment A. Ocean quahog, in this Report). GLM models were fit to tow by tow logbook data for vessels in size class 3 and 4 (51-150 and 151-500 GRT) which are the bulk of the EEZ fishery. There were no records with zero catch and it was not necessary to add a constant before applying the log transformation to the data. Year effects were used as the index of LPUE after they were adjusted to the average of June catch rates for a single vessel that fished in all regions.

For surfclams, year, vessel and month effects were statistically significant for all regions. Although month effects were statistically significant, they were small, of little practical importance and because they did not show meaningful seasonal trends.

Trends in nominal and standardized LPUE were similar (Figure C7). In particular, LPUE declined steadily from peak levels during 1994 to relatively low levels during 2005 in the DMV region. LPUE declined slowly but steadily in the NJ region during 1991-1995 and in LI after 2000. LPUE levels during 2005 were at or near record lows. In contrast to other regions, LPUE levels in SNE increased rapidly after 1998 as the small fishery in SNE developed.

LPUE is not an ideal measure of fishable biomass trends for sessile and patchy stocks like surfclam because fishermen target high density beds and change their operations to maintain relatively high catch rates as stock biomass declines (Hilborn and Walters 1992). However, trends in LPUE and fishable biomass based on the NEFSC clam survey were similar during recent years for DMV and NJ where fishing has been heaviest and fishing grounds are widespread (Figure C29). In contrast, LPUE and survey trends were not similar for LI and SNE where less fishing has occurred and the fishery is not as widespread. The correlation in trends for DMV and NJ was likely due to reduced surfclam densities in many habitat areas where significant densities occurred. Previous assessments noted that the fishery in DMV and NJ and surfclam stock overlap relatively completely.

Spatial patterns in fishery data

Average landings, fishing effort and LPUE per year from logbooks were calculated for ten-minute squares (TNMS) during 1981-1990, 1991-1995, 1996-2000, and 2001-2005. For plots, data for TNMS with very low levels of landings and data for TNMS outside the range of the fishery (obvious errors) were omitted.

Spatial patterns in fishery data (Figure C8 to C9) show relatively high landings and fishing effort in the south mostly offshore in DMV and SVA during 1981-1990 with some activity near shore in NJ and in northern regions of SNE south of Cape Cod. In later years, fishing activity was mostly in NJ. During 1991-1995, there were no landings or effort in SVA or SNE, reduced activity in DMV, and increased activity in NJ with expansion to offshore regions. During 1996-2000, activity in DMV decreased and the fishery moved north with some activity off southern LI. During 2001-2005, landings and effort increased in DMV and SNE with some activity SNE southeast of Cape Cod.

TNMS with relatively high LPUE levels (Figure C10) were mostly off NJ and DMV in all years. During 2001-2005, LPUE levels were high in offshore NJ, with several areas of high LPUE in DMV and SNE southeast of Cape Cod.

Important TNMS

TNMS “important” to the fishery were identified by choosing the twenty TNMS with the highest mean landings per year during 1981-1990, 1991-1995, 1996-2000 and 2001-2005 (see Assessment A. Ocean quahog, in this Report). Trends in landings, effort and LPUE were plotted (Figures C11-C13) for each to show changes in conditions within individual TNMS. Compared to less productive ocean quahog, landings, effort and LPUE were relatively high for some TNMS after many years of fishing activity.

Fishery length composition

Taken together, port sample length data for DMV and NJ in the south indicate that the surfclam stock consisted of a wider range of sizes during the early 1980s (Figure C14 to C3-15). As expected, the port sample data for both regions appear to reflect the relatively strong 1991 year class which would have recruited to the fishery during the early and mid-1990s (see below). Although sampling levels are low and the data are difficult to interpret, smaller surfclam in landings from DMV and NJ during 2005 might be due to recruitment of the 1998 year class at age 7 (see below).

Port samplers routinely collected shell length measurements for 30 randomly selected surfclams from landings after selected fishing trips. Numbers of trips sampled and numbers measured were low (Table C8), particularly during recent years and care is required in interpreting trends. Numbers of trips sampled is probably the best measure of the potential information in port sample length data because lengths tend to be similar for individuals from the same trip (Pennington et al., 2002).

Commercial length composition data for DMV indicate that surfclams landed during 1982-2005 were mostly 120+ mm SL during most years although smaller individuals were evident during 1992-1994 and 2005 (Figure C14). The apparent reduction in shell length during 2005 is difficult to interpret due to modest sampling (Table C8). Relatively large surfclams were landed in DMV during 1982-1985 indicating that large surfclams were more common in DMV at that time.

There were more port samples from NJ than DMV during most years (Table C8). Commercial length composition data for NJ indicate that most of the surfclams landed during 1982-2005 were at least 120 mm SL, although smaller individuals were evident during 1982-1985, 1993-1998 and 2005 (Figure C15).

Port sample data for LI are limited to 1983, 1993 and 2005 (Figure C16) and samples sizes are modest (Table C8). The data for 2005 show substantial numbers of small individuals. However, the data suggest that most of the landings in LI are at least 120+ mm SL.

Port sample data for SNE are limited to 1982-1990 (Figure C17) and samples sizes are modest (Table C8). The data suggest that most of the landings in SNE are at least 120+ mm SL.

Fishery age composition

Fishery age composition data for DMV and NJ during 2005 (Figure C18) from port sample lengths and survey age-length keys indicate that most of the 2005 landings were ages 5+ y. The strong 1992 (age 13 y in 2005) and 1998 (age 7 in 2005) year classes were important to the fishery during 2005.

Apparently strong year classes in the fishery length and age composition data for DMV and NJ may have due to low port sampling in some years and lack of age data for the commercial catch. However, survey age composition data (described later) suggest the same recruitment patterns.

Fishery age composition data for DMV and NJ do not show evidence of strong incoming year classes that would recruit to the fishery prior to 2010 (Figure C18). However, small surfclam are not selected by commercial dredges.

4.0 NEFSC CLAM SURVEY TREND DATA

NEFSC survey strata used to track surfclam trends (Table C9) are different than used for ocean quahog because surfclams live in relatively shallow water where ocean quahog are usually not found. After borrowing to fill holes (survey strata with no tows, see Assessment A. Ocean quahog, in this Report) a few holes remained (Table C9). Remaining holes were filled for swept-area biomass calculations but not for trend analysis using a model described below. As pointed out earlier (i.e., see Assessment A. Ocean quahog, in this Report NEFSC), NEFSC survey data are used only from surveys during 1986-2002 because of limited sampling during other years.

A cooperative surfclam survey was conducted in SVA, DMV and NJ during 2004 (Weinberg et al. 2005). It is used in calculation of swept area biomass but not for trend analysis.

Tows with poor survey dredge performance

NEFSC developed a set of objective criteria based on sensor data used to identify NEFSC clam survey tows with poor dredge performance (see Assessment A. of this Report). These criteria were used in this assessment to identify tows in the 2005 survey with poor dredge performance.

Dredge performance during the 2002 survey

Sensor data from the 2002 survey review were reviewed to see if dredge performance problems during 2005 also occurred during 2002. If so, the dredge performance issues might occur during most surveys.

Because of time constraints the review for 2002 was limited to a visual inspection of sensor data plots for a sample (213 out of 556) of stations. Details are available in Appendix C2 but the visual criteria used to judge dredge performance were the same as used in a preliminary analysis of the 2005 SSP data. In particular, manifold pressure and angle of attach were reviewed for significant deviations from "normal" values.

In general, results showed that poor dredge performance problems are likely to arise due to a number of factors that affect either manifold pressure or the angle of attack for the dredge while in operation on the bottom. The main reason for a poor dredge performance differed during 2002 and 2005 (Appendix C3). Compared to the survey during 2002, the 2005 survey had a high number of poor incidents due to manifold blockage that occurred when a screen over the pumps water intake failed and allowed small stones to lodge in the manifold nozzles. In 2002 the main problem was the dredge pump being shut off early.

It is important to realize that most of the tows with poor dredge performance would have been excluded from stock assessment analyses anyway due to haul and tow data routinely collected by the survey watch chief or chief scientist at each station. After tows with haul or gear problems were omitted, many of the remaining tows with poor dredge performance would be excluded from trend and swept area biomass calculations because they were nonrandom (Figures C19-C20).

Based on rates of occurrence during the 2002 and 2005 surveys, it was hypothesized that poor dredge performance occurs regularly during NEFSC clam surveys. Random stations during the 2002 and 2005 surveys with poor dredge performance and not otherwise were therefore used in estimation of survey trends for surfclam. In practical terms, it would have been impossible to exclude such tows consistently in all years because sensors were not used prior to 1997. As shown below, tows with poor dredge performance during 2002 and 2005 had an imperceptible effect on survey trend indices and swept area biomass estimates with the exception of the LI area during 2005.

Survey dredge performance during depletion studies

Based on data for 2002 and 2005 surveys, the frequency of tows with poor dredge performance[29] was relatively high during depletion experiments by the *R/V Delaware II*, probably because repeated tows in the same area loosened sediments which obstructed

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[29] During the 2005 survey, tows with poor dredge performance occurred at survey stations: 1, 2, 14, 17, 20-26, 28, 29-34, 45, 48, 56, 58, 67, 75, 76, 108, 218, 225, 262, 282, 405, 411, 413, 414, 417, and 422-424. Based on a sample from the 2002 survey, tows with poor dredge performance occurred at survey stations: 4, 32, 42, 44, 45, 52, 76, 82, 90, 101, 103, 105, 106, 111, 118, 125, 137, 140, 141, 218, 250, 254, 278, 360, 368, 382, 386, 394, 458, 496, 498, and 506.

the intake and exhaust nozzles on the survey dredge. Surfclam depletion experiments by the *R/V Delaware II* during the 1997, 1999 and 2002 surveys were therefore not used in this stock assessment.

Based on the sampled tows and visual analysis, the frequency of tows with poor dredge performance (Table C10) during 2002 was about 15%, almost twice as high as in 2005 (8%). In both cases, roughly 30% of the tows with poor dredge performance were made during depletion experiments.

In contrast to trend analysis, 2005 survey stations with poor dredge performance and not otherwise were excluded from swept-area biomass calculations. The goal of swept-area biomass calculations was to obtain the best biomass estimate possible and consistency from year to year was not as important. No stations with poor dredge performance were omitted from the 2002 survey because not all stations were examined and the determination was subjective.

Imputed survey data for remaining holes

Negative binomial GLM models were fit to survey catch data for surfclam to impute survey data for remaining holes (Table C9). Imputed data were used only in swept area biomass calculations and were not used in trend analysis due to lack of time and because the approach was experimental. Effects of imputed values on survey trends and swept-area biomass were minor because most holes had already been filled by borrowing (Table C12). Residual plots for SVA, GBK, and SNE (Figures C21-C23 suggest that the model was a reasonable approach that performed acceptably. Pending further evaluation, imputed survey data might be used in place of borrowing for future surfclam assessments.

Models used to impute missing survey data were fit in Splus using the glm.negbin() function available in the MASS library of functions for Splus and R statistical analysis software (Venables and Ripley 1997). The linear predictor had categorical year and stratum effects and the log link was employed so that year and stratum effects were multiplicative. Parameters were estimated by maximum likelihood assuming that the observed survey data were drawn from a negative binomial distribution with mean estimated by the model and a variance parameter common to all observations. The primary advantage of the negative binomial model was that it accommodated noisy data and tows with zero catch in a natural manner without adding constants and taking logs or otherwise changing the data.

A separate model was fit to tow by tow mean kg/tow (standardized using Doppler tow distances) for surfclam 120+ mm SL in each stock assessment region. All data for successful random tows during 1982-2002 were used. The imputed values used to fill remaining holes were predictions from the model for year and strata combinations missing in the original survey data.

2005 survey results

Based on CVs for means in stratified random sampling, the 2005 NEFSC clam survey was reasonably precise for well sampled regions (Table C11). Of particular interest, small recruit surfclams (50 to 119 mm SL) were taken from near shore strata in southern DMV (Figure C4.6) where warm water probably caused extensive mortality during 1999-2004 (Weinberg 2005; Weinberg et al. 2005). However, no large fishable surfclams (120+ mm) were found in near shore strata off southern DMV (Figures C24-

C25). See NEFSC (2005) for a summary of survey station locations and catches during the 2005 NEFSC clam survey.

Survey trends

Survey trend data (Figures C26–C28) were more variable for small surfclams than for large surfclams. Based on survey trend data, fishable biomass (120+ SL) declined in southern regions SVA, DMV and NJ. The decline in SVA was gradual beginning in the mid-1980s. The declines in DMV and NJ were relatively rapid beginning in the mid-1990s. Fishable biomass in LI may have increased gradually after 1982 but the survey data are variable and difficult to interpret.

Recruitment indices 2005 were at or near record lows for all regions surveyed with the exception of LI and GBK which was not surveyed in 2005 (Figures C26-C27). During the 2002 survey, recruitment in GBK was relatively high.

With the exception of LI during 2005, tows with poor dredge performance during 2002 and 2005 had an imperceptible effect on estimated trends in fishable biomass (Figure C28).

Year effects and the 1994 survey

Trends in NEFSC survey data (Table C11) for small recruit surfclams (mean n tow-1, 50-119 mm SL) and large fishable surfclams (mean kg tow, 120+ mm SL) showed some evidence of year effects when estimates for the same year and region increased or decreased together (Figure C26). Year effects in NEFSC clam survey may be due to changes in survey dredge equipment or protocols between surveys (NEFSC 2003).

Based on survey trend data, it was decided to include the 1994 survey in all analyses for surfclam. In contrast, previous surfclam assessments (NEFSC 1998; 2000; 2003) included 1994 survey data in graphics but excluded the data from swept area biomass and other analyses because of hypothesized year effects that may have increased catch rates. In particular, the voltage supplied to the pump on the dredge was reportedly set at 480 V, rather than 460 V as specified and higher voltage during the 1994 survey may have increased catch rates (NEFSC 2003). However, based on additional survey data there is insufficient evidence of a year effect during the 1994 survey for surfclam. Moreover, field tests with the survey dredge operating with 460 and 480 V were inconclusive (J. Weinberg, pers. comm.). Additionally, a comparison of tows during the 2002 and 2005 survey with good and poor dredge efficiency suggested that surfclam catches were not sensitive to dredge performance (Appendix C3).

The decision to use 1994 survey data for surfclams in stock assessment analyses does not apply to ocean quahogs. Evidence for a strong year effect due to high voltage appears stronger for ocean quahogs (see Assessment A. in this Report).

Survey length and age data

Survey length composition data show a wide range of lengths for surfclam in SNE, LI, and NJ with relatively few large surfclam in DMV and a relatively narrow range of lengths in GBK (Figures C30-C34). Survey length data for LI during 2005 was too variable to be interpreted. It may be possible to track a recruitment event in the survey length data for LI beginning in 1983. Length data for SVA are scant.

Survey age composition data for NJ and DMV show the strong 1992 and 1998 year classes relatively consistently and clearly (Figure C34b). During 2005 these two year classes dominated the population as 7 and 13 year-olds. There is some evidence of a recruitment event in the age composition data for age 2 surfclams in DMV during 2005.

5.0 STOCK BIOMASS AND FISHING MORTALITY (TOR-2)

Efficiency corrected swept area biomass estimates were based on NEFSC and cooperative clam survey data for 1997, 1999, 2002, 2004 and 2005 and cooperative depletion experiments. They are a key source of information about the scale (magnitude, thousand mt) of surfclam biomass during recent years in this assessment.

Efficiency corrected swept area estimates are relatively direct, model-free and independent estimates of biomass and fishing mortality. Surfclams have proven difficult to model in some cases (e.g. NEFSC 2003) and it is useful to have another method available for estimating recent biomass and fishing mortality. Fishing mortality, in particular, can be estimated on a regional basis as the ratio of catch and efficiency corrected swept area biomass. Fishing mortality rates are low for surfclams and the June survey occurs when the stock is near the average annual level so that the ratio of catch and biomass gives nearly the same result as solving the catch equation exactly. Swept area biomass and fishing mortality estimates were not made for years with surveys prior to 1997 because no sensor-based tow distance data were available.

NEFSC clam survey trend data are the main source of information about trends in fishable biomass and recruitment since 1982. Survey data (mean kg/tow, based on sensor tow distances) for trend and swept area analyses were from random stations with no problems recorded on standard survey logs. Some survey stations with poor dredge performance identified using sensors during 2005 were omitted from swept area biomass calculations. As described above, negative binomial GLM models were used to impute missing survey data used to fill remaining holes in NEFSC data.

The KLAMZ delay-difference stock assessment model was used to make estimates for surfclams in DMV, NNJ and for the entire stock. The assessment model is advantageous because it estimates long term biomass and fishing mortality levels during 1982-2005, “balances the books” to ensure that all assumptions can be reconciled, and smoothes out measurement errors in swept area biomass and survey trend data. The KLAMZ model was not applied to SNE, LI and GBK in this assessment because the survey data are difficult to interpret and very little fishing has occurred in northern regions.

In the previous assessment (NEFSC 2003), the KLAMZ model was used only for DMV because it did not give reasonable results for southern and northern New Jersey (which were modeled separately). The KLAMZ model and data used in this assessment involve improvements that enhance model performance. In particular, the southern and northern New Jersey regions are combined in this assessment to form the NJ region with relatively precise survey data. Additional survey data for 2004 and 2005 are available and show clear trends over the last decade.

All of the methods for estimating surfclam biomass and fishing mortality levels and calculating variances are described in Assessment A. Ocean Quahogs, in this same Report. A few differences in methodology for surfclams are described below where relevant.

Survey and commercial dredge efficiency

As for ocean quahogs (in Assessment A. Ocean Quahogs of this Report), the best estimate of survey dredge efficiency for surfclams in this assessment was the median of estimates from all available depletion studies (Table C13). In particular, the best estimate of efficiency for commercial dredges was the median E=0.765 (mean 0.704, CV=0.081, n=19) and the best estimate for the NEFSC survey dredge was e=0.226 (mean=0.262, CV=0.17, n=16).

All commercial efficiency estimates for surfclam in this assessment were from Rago et al.'s (2006) "Patch" model fit to data from depletion studies by commercial vessels. Survey dredge efficiencies were estimated for depletion experiments with setup tows by *R/V Delaware II* during NEFSC clam surveys. In contrast to ocean quahog and as described above, depletion studies carried out entirely by the *R/V Delaware II* were not used because of problems with survey dredge performance during repeated tows in the same location. A variety of *ad-hoc* estimators for survey dredge efficiency used by NEFSC (2003) for surfclams were not used in this assessment because they have unknown statistical characteristics and were not necessary.

Eight new depletion studies have been carried out since the last assessment, three during 2004 and five during 2005 (Table C14). Additionally, it was necessary to reanalyze depletion experiment data from fourteen depletion experiments during 1997-1999 so that consistent methodology and corrected estimators were used in all cases.

Assumed length at full recruitment

The most important difference in estimating dredge efficiencies for surfclam in this assessment and in the previous assessment was the assumed length at full recruitment to the commercial gear used in each depletion experiment. Surfclams were assumed in this assessment to be fully recruited to commercial gear used in depletion experiments at 150 mm SL.[30] Elsewhere, in mortality and biomass calculations for this assessment, surfclams are assumed to recruit to the commercial fishery and become fishable at about 120 mm SL. However, full recruitment is likely to occur at some larger size.

Depletion experiments for surfclams included vessels that specialize in surfclam (e.g. *F/V Jersey Girl* in Table C14) and vessels that specialize in ocean quahog (e.g. *F/V Lisa Kim*). Gear on quahog vessels is designed to catch relatively small ocean quahog efficiently. Thus, surfclams likely recruit to gear on ocean quahog vessels at a smaller size than gear used on surfclam vessels. However, it was important too choose an assumed length at full recruitment that was high enough to assure full recruitment to both types of gear in all experiments. A single length criterion was important for the sake of efficient data processing and consistency of surfclam density estimates.

NEFSC (2005) used 90 mm SL as the assumed size at full recruitment for ocean quahog because commercial selectivity at that size was at least 85% at 90 mm SL based on a commercial fishery selectivity curve. No directly estimated selectivity curves are available for surfclams. However, a "relative" selectivity curve that relates catches in commercial surfclam gear to catches in the NEFSC survey dredge indicates that 85% relative selectivity occurs at 145-150 mm SL (Figure C30 in NEFSC 2004). A review of

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[30] Surfclam appear to recruit to the NEFSC survey dredge by about 120 mm SL. Surfclam recruit to the NEFSC survey dredge at smaller sizes that to commercial dredges because the survey dredge is made with closely spaced bars and a wire mesh liner. Moreover, survey catches are not sorted mechanically on a shaker table to remove trash and undersized objects.

length data from surfclam depletion experiments with setup tows indicated that 150 mm SL would suffice as the assumed size of full selectivity in all experiments.

The disadvantage in choosing a relatively large assumed size at full recruitment was that data from the SC2002-4, SC2004-3 and SC2005-6 depletion experiments were not useable. In these experiments, catches of surfclams 150+ mm SL were either zero or too low and variable.

Relationships between efficiency and other variables

There were no clear relationships between Patch model estimates and environmental variables such as depth and sediment size (Figure C35 and C36). With one exception, there were no clear relationships among Patch model estimates themselves (Figure C35 and C36).

The apparent negative relationship between estimates of efficiency and initial surfclam density from the Patch is potentially important (Figure C36). However, the pattern is readily explained as an artifact of the natural statistical correlation between the two parameters in the Patch model. Sites for depletion experiments are chosen to have relatively high surfclam densities. If efficiency decreases at high surfclam densities and experiments are conducted at sites with high density, then mean efficiency for the stock as a whole (in areas of high and low density) might be underestimated. If efficiency is underestimated, then stock biomass might be overestimated and fishing mortality under estimated.

As described in Rago et al. (2006) and illustrated by a typical bivariate likelihood profile for density and efficiency estimates from the Patch model (Figure C37), uncertainty in initial density and efficiency estimates take the form of an elongated "banana" shaped region so that lower estimates of initial density are associated with higher estimate of efficiency and *vice-versa*. In other words, sets of parameters with density low and efficiency high tend to fit the data from a depletion experiment as well as sets with density high and efficiency low. This type of statistical correlation is common in nonlinear parameter estimation (Bard 1974). In linear regression modeling, it takes the form familiar statistical correlation between estimates of the slope and intercept of the regression line.

A simple simulation analysis using linear regression and a simulated Leslie-Davis depletion experiment showed the same relationship between efficiency and density estimates, although no relationship was included in the simulation scenario. The Patch model is quite similar to a linear regression problem because, in effect, it is the result of applying Leslie-Davis depletion models to a number of depletion experiments sites simultaneously (Rago et al. 2006). Leslie-Davis depletion models were fit originally by simple linear regression (Ricker 1975).

Sensitivity of Patch model estimates to smoothing position data

As described in Assessment A. Ocean quahogs, in this Report, position data from depletion experiments was smoothed and interpolated prior to use in the Patch model. NEFSC (2006) carried out a number of analyses to determine the sensitivity of Patch estimates to assumptions and procedures but did not consider smoothing.

Procedures and equipment improved steadily in each survey. Precision of position data was relatively low for 1997 depletion experiments because Loran was used to measure location (accuracy 30-40 ft) and position data were recorded at relatively long time intervals (e.g. 1 minute). In later years, more precise differential GPS was used to measure location to a precision of about 6-9 ft and at shorter intervals of 1-6 seconds.

To accommodate differences in precision of location data among depletion experiments, the Patch model was fit with and without smoothing to data from one surfclam depletion experiment in each survey year. Results (Table C15) show that smoothed data produces higher estimates of initial density and lower estimates of dredge efficiency than unsmoothed data. Area swept during each depletion tow decreased by 1-20% when using smoothed data (Table C15).

Building a bridge

Assessment A. Ocean quahogs, of this Report (see Tables A14-A15) evaluated effects of the many changes made in estimation of dredge efficiency for ocean quahog. Results from those analyses for ocean quahog are probably also applicable to surfclam.

As with ocean quahog and with the exception of experiments in 2002, revised efficiency estimates for surfclam were lower and more precise (lower CVs) than estimates previous estimates (Table C16). However, care is required in making comparisons with efficiency estimates in NEFSC (2003) because previous estimates were from a variety of estimation procedures. In addition, previous estimates from the Patch model were usually made under different assumptions, data for different sizes of surfclam were included and less accurate formulas may have been used.

Efficiency corrected swept area biomass

The best estimate of survey dredge efficiency (*e*=0.226) was used to estimate efficiency corrected swept area biomass (Table C17) and fishing mortality (Table C18) for surfclams 120 mm SL is 1997, 1999, 2002 and 2005.

2004 Cooperative Survey

Additional information was available from a cooperative survey carried out during 2004 by the *F/V Lisa Kim* in SVA, DMV and NJ (Weinberg et al. 2005). Swept-area biomass estimates in Weinberg et al. (2005) were recalculated using the median commercial dredge efficiency (*E*=0.714, Table C19) from six depletion experiments by the *FV Lisa Kim* during 2004-2005 (Table C14). The updated calculations excluded some nonrandom tows that may have been used inadvertently by NEFSC (2003).

Cooperative 2004 survey analyses in this assessment used catch data for surfclams 120+ mm SL (all sizes in the fishable biomass) because the *F/V Lisa Kim* normally targets ocean quahog and is equipped to catch relatively small commercial size ocean quahog, which are smaller than commercial size surfclam. As described above, the assumed size at full recruitment was 150 mm SL in other analyses because commercial vessels were used in some experiments that target surfclams use gear that retains larger clams. Survey length composition data from the depletion experiments indicated that surfclams probably recruited to the dredge on the *F/V Lisa Kim* at about 120 mm SL.

Results from the 2004 survey (Table C20) confirmed downward trends in biomass evident in biomass estimates for DMV and NJ based on NEFSC surveys during 1997-2005 (Table C21; Figure C38). In particular, the 2004 estimates from the cooperative survey were nearly intermediate between biomass estimates from the 2002 and 2005 NEFSC surveys. The 2004 survey did not cover all strata in SVA and catch rates for SVA were too variable to be used in estimating biomass (Figure C38).

KLAMZ modeling

KLAMZ delay-difference models for surfclam biomass dynamics were similar to those used by in the Ocean quahog Assessment (see Assessment A. of this Report) for ocean quahog.[31] A few changes were made to model surfclams more realistically. These changes involved configuration of survey trend data, assumptions about recruitment, growth patterns that changed over time, and application to the stock as whole as well as to individual regions. Surfclams require slightly different modeling approaches because more data are available, surfclams are inherently more productive and their population dynamics are more variable, surfclams grow relatively quickly, growth varies over time, surfclams have a higher assumed natural mortality rate (M=0.15 y^{-1} instead of 0.02 y^{-1}), and recruitment patterns are substantially different. Many of these factors appear to be influenced by density dependent factors (Weinberg 1998), oceanographic conditions and bottom temperatures in particular (Weinberg 2005).

The most important challenges in modeling surfclams stem from variability in NEFSC clam survey data for recruits and fishable sizes, and lack of survey data between triennial NEFSC clam surveys. In a nutshell, recruitment trend data change too rapidly to be readily tracked by the triennial survey data. LPUE trend data are available and can be compared to model results but were not used in fitting KLAMZ models for surfclams due to well known problems relating commercial catch rates and trends in stock biomass (Hilborn and Walters 1992). Catch data used in KLAMZ models for surfclams included discards that occurred prior to 1993 when size limits were used to manage the fishery (Table C2).

Despite problems, a number of factors enhance the utility of the KLAMZ model for surfclam. Most importantly, direct estimates of stock biomass based on depletion studies and swept area estimates are easily incorporated in the assessment model. The KLAMZ model is flexible and has a number of features that can be used to take advantage of various aspects of surfclam biology. Landings data for surfclams are relatively accurate because of accounting procedures inherent in the ITQ fishery management program. Survey data for surfclams include CVs that characterize sampling variability and that can be used to determine when the model fits the survey data “too well” (i.e. better than could be expected based on the inherent precision of the data). Auxiliary information is available for many important parameters (e.g. survey dredge efficiency and swept area biomass and growth). Surfclams are relatively long lived (~35 y) and expected rates of change in fishable stock biomass are lower for relatively long-lived organisms.

Year effects and correlated measurement errors (the same year effect in survey data for recruits and fishable size groups in the same year) are a concern in using survey data for surfclams. Simulation analyses have not been carried out using the KLAMZ model, but detailed simulation analyses with the abundance-based Collie Sissenwine model (ASMFC 2006) which is similar to KLAMZ showed that model performance (mean squared error, bias and variance) actually improved when survey data for recruits and fishable size groups had strong correlated year effects.

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[31] See Appendix A5 of the ocean quahog assessment (NEFSC 2007) for a complete technical description of the KLAMZ model.

Growth curves

Growth is a key part of biomass dynamics in the KLAMZ delay-difference model. Survey data for surfclams in KLAMZ models (particularly for new recruits) are calculated based on assumptions about growth.

The Schnute-Deriso delay difference equation in the KLAMZ model (Schnute 1985) uses a version of the von Bertalanffy model for growth in weight with two parameters. In particular, $\rho = e^K$ where K is from a von Bertalanffy model for weight, and $J_t = W_{k-1,t} / W_{k,t}$, where $W_{k,t}$ is predicted weight at age k when recruitment occurs based on the growth curve for year t. The von Bertlanffy parameters W_{max} and t_0 are implicit in J_t. In delay-difference model calculations (Schnute 1985), the parameters J_t may change over time but K is constant in all years.

Survey mean length at age data for NJ and DMV in each survey (Figure C2) were converted to mean weights at age in each survey by applying region specific length-weight relationships (Table C1). The growth curves used different W_{max} and t_0 parameters for 1982-1992 and 1994-2005, but used the same K parameter in all years (Table C22). Growth parameters for NJ were used also in modeling the whole stock.

Survey indices

NEFSC clam survey data in the KLAMZ model were for recruit (Table C23) and fishable size groups (Table C11). The recruit index was mean kg/tow for surfclam in the survey that were 120 to L_{k+1} mm SL, where L_{k+1} is the predicted size at age k+1 and k is the predicted age at recruitment (L_k = 120 mm SL) based on a growth curve. The fishable index was survey mean kg/tow for surfclams 120+ mm SL. Recruit trend data were assumed to track trends in the biomass of new recruits. Trend data for fishable surfclams were assumed to track trends in total fishable biomass (new recruits plus survivors from the previous year). 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 described above, survey data for surfclams 120 to L_{k+1} mm SL were used in both the recruit and fishable biomass trend indices. This strategy was intentional and meant to link the relatively noisy recruit and more stable fishable survey data indices in the model, to reduce potential problems stemming from uncertainty about where to split the index for fishable biomass, and to help insure that the survey scaling factor for both recruit and fishable indices would be about the same. 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.

NEFSC (2003) used a more complicated system of survey trend data for prerecruits, recruits and remaining fishable size groups. Fishable sizes were 100+ or 120+ mm SL, depending on area. Prerecruit size groups were L_{k-1} to either 100 or 120 mm SL based on region specific von Bertalanffy growth curves. The prerecruit index was lagged in the model by one year so that data collected in year t would be used in the model to estimate recruitment in year t+1. The prerecruit index was not used in this assessment because it is highly variable for surfclams with noisy trends that are difficult to resolve given the rest of the survey and catch data in the model.

For convenience in interpreting model results, survey mean kg/tow data 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 the average ratio of the survey data and efficiency corrected swept area biomass during 1995-2005 surveys (see below and Table C25). With this adjustment, the survey scaling factors for fishable biomass trends estimated in the KLAMZ model are expected to be close to one. The adjustment to the survey data did not affect biomass or fishing mortality estimates.

Survey dredge efficiency and swept-area biomass

Following NEFSC (2003), efficiency corrected swept area biomass estimates were included in the assessment model as a measure of scale but not as measures of trend. In fitting the model, 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 = 0.5. The relatively large CV means that the prior information about the scaling parameter was relatively "weak". However, experience shows that the prior information tends to have a strong impact when survey data are limited and there is little other information in the model data about biomass scale.

Recruitment assumptions

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 possibility of strong year classes in surfclams 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 was used primarily to fill gaps in information due to not having a recruit index for each year, to avoid excessive variation in recruitment and to ensure that some recruitment was estimated for each year.

In modeling surfclam population dynamics with random walk recruitment, it is important to control the "random walk recruitment variance" σ_R^2 (NEFSC 2003) 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 change randomly and more widely from one year to next.

Following NEFSC (2003), initial KLAMZ model runs assumed a 20% CV for steps in the random walk so that $\ln(\sigma_R^2) = \ln(0.2^2)$. The constraint was relaxed gradually in subsequent runs until the model was just able to fit the survey data without pattern in residuals. In final runs, $\ln(\sigma_R^2) = \ln(0.3^2)$ for NJ and the entire stock, and $\ln(\sigma_R^2) = \ln(0.35^2)$ for DMV. In each case, the CV for fit to the survey data (residual CV) was compared to CVs for the actual survey data to determine if σ_R^2 was too large and the model was fitting the survey data more closely than could be expected based on the precision of the survey data. The goal was basically to find the simplest model (fewest effective recruitment parameters) that would adequately explain the survey data for surfclam. Choices were subjective but had only modest effects on biomass and fishing mortality estimates for surfclam, because many different recruitment patterns imply similar biomass and recruitment levels.

Results-whole stock

Survey data for the entire stock in the KLAMZ model were filled as described above. However, no provision was made for filling remaining holes that could not be filled by borrowing (Table C9). Mean surfclam densities for strata with data (original or filled) were used to compute the weighted mean density for the stock as a whole (i.e. strata with no data were ignored in computing the mean density for the stock as a whole). However, the mean density for the stock as a whole was applied to the entire stock area, which included the area of strata with no data. The effects of remaining wholes were reduced in whole stock runs because remaining wholes were a relatively small proportion of the total number of strata and total area of the stock.

The KLAMZ model fit survey biomass trend data reasonably well although the fishable biomass trend datum for 1994 was not completely reconciled in the model fit (Figure C40). The model fit the recruit index better than the fishable biomass index, although the latter was more precise based on survey CVs. LPUE and swept area biomass trends did not affect model estimates, but estimated biomass trends from the model were similar to trends in LPUE after 1999 and to trends in swept area biomass for in all years.

The survey scaling parameter for the scaled fishable biomass index was Q=1.26 and reasonably close to one. The survey scaling parameter for efficiency corrected swept area biomass was Q=0.99 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 suggest that surfclam biomass increased from 1981-1997 to record high levels due to high surplus production (relatively good recruitment and fast growth rates) which occurred during the mid 1980s and early 1990s (Table C24 and Figure C41). Surplus production declined steadily after 1993 as recruitment declined, the stock aged and growth rates slowed. Surplus production was negative after 1997 while stock biomass declined steadily. By 2005, stock biomass had declined to about the same level as in 1986-1992 but was still relatively high in historical terms. Fishing mortality rates were much lower than natural mortality and probably inconsequential during 1981-2005.

Bootstrap analysis (2000 iterations) indicated a tendency towards negative bias in biomass and fishing mortality estimates during peak recruitment years, but good model performance and little bias overall. CVs and confidence intervals from bootstrapping indicate that biomass and fishing mortality estimates were reasonable precise, particularly for recent years (Table C24; Figures C42-C43), probably due to the swept area biomass data for 1997-2005. Recruitment was estimated less precisely than biomass and fishing mortality (Table C24; Figure C44). The model did not completely converge during a substantial fraction of bootstrap runs (roughly 50%), due to uncertainty in estimated recruitments (Table C24). In other words, a range of recruitment patterns probably explained the survey data equal well.

Results-DMV and NJ

The KLAMZ model for DMV fit survey index data quite well (Figure C45). The model for NJ fit reasonably well although the fishable biomass indices for NJ during 1994 and 1997 were not reconciled (Figure C46). Survey scaling factors for scaled fishable biomass trends and efficiency corrected swept area biomass were reasonably close to one in all cases.

Model results for DMV indicate that biomass declined continuously from relatively high levels during the early 1980s due to declining recruitment, slow growth, and surplus production levels that were usually negative (Figure C47). Model results for NJ were similar to results for the whole stock but biomass declined more steeply during recent years to lower levels during 2005 (Figure C48). Fishing mortality appears to have been a minor factor in both areas during 1981-2005 (Figures C47-C48).

Stock biomass by region

Average ratios for survey data (Doppler standardized) and efficiency corrected swept area biomass were calculated for each region (Table C25) and used to rescale survey trend data to approximate swept area biomass levels (Table C23). The proportions of swept area biomass in each region were used to prorate fishable biomass estimates from the KLAMZ model for the entire stock during years with NEFSC clam surveys into regional components. Results clearly show the shift over time in biomass from southern to northern regions (Figures C49 to C50).

Recruitment parameters

Recruitment estimates for surfclam from the KLAMZ model were made with limited survey data and are complicated to interpret. Under these conditions, recruitment estimates for surfclam should probably be regarded as "nuisance" parameters of less interest than biomass and fishing mortality estimates. As nuisance parameters, recruitment estimates basically amount to adjustments in the KLAMZ model that implicitly account for model misspecification, survey noise, survey year effects, changes in recruitment, natural mortality and variability in growth not explicitly included in the modeling framework.

Proportions of total fishable biomass at various density levels

As described in the first assessment in this Report (A. Ocean quahogs), best biomass estimates and survey data were combined to partition best biomass estimates into components found in areas with relatively high and low biomass density levels. Biomass density is important to profitability of the ocean quahog fishery because it determines commercial catch rates. Biomass density was measured as survey catch per tow (fishable kg/tow) because commercial catch rate data for random locations and the entire stock area were not available.

Results (Table C26) show reductions in stock within high density areas in the southern DMV and SVA regions. During 2005 (Table C27), the largest component (29% or 47 thousand mt meats) of total fishable stock biomass was on GBK in the highest (25+ kg/tow) biomass density category. In contrast, stock biomass levels in density categories larger than 10 kg/tow were low for other regions.

6.0 BIOLOGICAL REFERENCE POINTS (TOR-3)

According to the Surfclam and Ocean Quahog FMP, overfishing occurs whenever the fishing mortality rate on the entire stock is larger than F_{MSY}. The stock is overfished if total biomass falls below $B_{Threshold}$ (estimated as ½ B_{MSY}). When stock biomass is less than the biomass threshold, the fishing mortality rate threshold is reduced from F_{MSY} in a linear fashion to zero.

The current best proxy for F_{MSY} is $F = M = 0.15\ y^{-1}$. The proxy for B_{MSY} is one-half of the estimated fishable biomass during 1999 which was estimated to be 1,460 thousand mt in this assessment based on KLAMZ model results for the entire stock. Revised biomass reference points are higher than previous values (see table below) because of new information about the efficiency of the dredge used in NEFSC clam surveys.

Reference Point	Last assessment	Revised
F_{MSY}	M=0.15 y^{-1}	Same
B_{1999}	1,460 thousand mt meats	1,799 thousand mt meats
B_{MSY} =½B_{1999} (target)	730 thousand mt meats	900 thousand mt meats
$B_{Threshold}$ = ½ B_{MSY}	365 thousand mt meats	490 thousand mt meats

Status determinations by comparisons of biomass estimates and biomass reference points are almost unaffected by new information about dredge efficiency because the changes in biomass estimates and the B_{MSY} proxy “cancel out” when current biomass is compared to or divided by the B_{MSY} proxy (Figure C51). Comparison of fishing mortality estimates and the F_{MSY} proxy are more sensitive because fishing mortality estimates depends on dredge efficiency but the F_{MSY} proxy does not (Figure C52).

Fortunately, conclusions in this assessment about fishing mortality and reference points are robust because fishing mortality rates for the stock are relatively low. In particular, conclusions about stock status would not change unless either the mortality estimate or threshold was changed by 7 fold (Figure C52).

Critique

Current reference points for surfclams suffice for use in this assessment because surfclam biomass is relatively high (at near average levels) and fishing mortality is low. However, biomass referenced points should be reconsidered the next time the stock is assessed.

Use of ½ B_{1999} as a proxy for B_{MSY} implicitly assumes that the stock was at carrying capacity during 1999. The carrying capacity assumption should be reevaluated based on the longer time series of data that are currently available. In addition, it may be useful to consider possible climate change effects on B_{MSY} and F_{MSY} proxies as evidenced by loss of surfclams in the south near the coast of the Delmarva Peninsula (Weinberg 2005).

7.0 STOCK STATUS (TOR-4)

The Atlantic surfclam stock is not overfished and overfishing is not occurring. Estimated fishable stock biomass during 2005 (120+ mm shell length, SL) was 1,170 thousand mt meats, which is above the management target of ½ 1999 biomass = 900 thousand mt meats (Figure C51). Estimated fishing mortality during 2005 was F= 0.0192 y^{-1}, which is below the management threshold $F_{MSY} \cong M = 0.15\ y^{-1}$ (Figure C52).

8.0 PROJECTION METHODS (TOR-5)

For the first time, a fully integrated assessment model, variance estimation and stochastic projection approach was used to provide example projections for surfclam stock biomass and fishing mortality. In particular, simulation runs for projection analysis were carried out using the same delay difference equation as used in the KLAMZ model and were initialized exactly as in the last year of each bootstrap run.

Projections can be made for assumed levels of constant fishing mortality or assumed constant catch levels, and can be carried out for time periods of any length. In projections for surfclams with assumed levels of catch, likely levels of incidental mortality should be considered and probably included. For example, constant quota levels can be increased by 12% to accommodate incidental mortality and to obtain a more realistic estimate of fishery impacts. A large number of individual stochastic simulation runs (e.g. 1000) should be carried out in projection analysis. Normally, the number of simulation runs is the same as the number of bootstrap runs because bootstrap results are saved for later use by the projection software. It is possible, however, to make more than one projection from each bootstrap run.

Each simulation run in the projection analysis starts with the terminal conditions estimated in one bootstrap run. Thus, uncertainty about current stock biomass, age structure, recent recruitments and other factors is included in the projection analysis.

Uncertainty in future conditions is included by simulating random future recruitments. For surfclams, random recruitments (R_t) were chosen to mimic a random walk with user specified mean and lag-1 autocorrelation. Projected recruitments were modeled as a random walk to match assumptions in the stock assessment model. As described above, the random walk recruitment assumption in the stock assessment model was pragmatic and may not be ideal from a biological perspective. The algorithm for surfclams in this assessment was:

$$
\begin{aligned}
&\sigma = \sqrt{\ln\left(CV^2 + 1\right)} \\
&b = \frac{\sigma^2}{2} \\
&s = \sqrt{1 - \rho^2} \\
&j_t \sim N(0,1) \\
&\delta_t = s j_t \\
&\gamma_t = \rho\gamma_{t-1} + \delta \\
&R_t = \overline{\mathrm{R}}\mathrm{e}^{\gamma_t\sigma - b}
\end{aligned}
$$

where j_t is drawn from the standard normal distribution, ρ is the lag-1 autocorrelation for successive log scale recruitments [i.e. the correlation of $\ln(R_t)$ and $\ln(R_{t+1})$, specified by the user], σ is the standard deviation of log scale recruitments based on an arithmetic scale CV (specified by the user), $\overline{R}$ is the mean arithmetic recruitment (specified by the user), and b is a bias correction factor. The term γ_t is normally distributed with mean zero, standard deviation 1.0 and lag-1 autocorrelation ρ. At the end of the projection analysis, the model calculates the means and CVs for biomass, recruitment, catch and fishing mortality at the beginning of each year.

Based on the KLAMZ model run for the entire stock, ρ=0.72, CV=0.53, and $\overline{R}$ = 121 thousand mt in example projection calculations. The simulation runs were for 2005-2015 (10 y beyond the last year in the KLAMZ model).

Procedures for setting TAL and TAC levels

It is not necessary to describe approaches for setting TAC or TAL levels in the surfclam fishery because it is managed using constant quota levels.

9.0 EXAMPLE PROJECTIONS (TOR-6)

Example projections were carried out assuming the following conditions during 2006-2015: i) constant fishing mortality = 0.15; ii) constant landings at the minimum quota level = 1.85 million bu; iii) constant landings at mean level during 2003-2005; and iv) constant landings at the maximum quota level = 3.4 million bu. In each case, landings in bushels were converted to meat weights and increased by 12% to account for potential incidental mortality during fishing.

Results (Table C28 and Figure C53) indicate that current downward trends in biomass will persist during the next few years because of the tendency for runs of good and bad recruitment in surfclams. Declines are largest for the F=0.15 scenario. Results for the status quo and maximum quota scenarios are very similar.

Projected biomass levels out by about 2015 in all scenarios. However, CVs are very large in all years and, in particular, larger than 250% after 2008. The high CV levels indicate very high uncertainty in projected results, particularly after 2008.

10.0 RESEARCH RECOMMENDATIONS (TOR-7)

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

i) Consider using year-, region- or episodic natural mortality rates. *This was discussed in the working group but deferred until a later assessment when the necessity for incorporating this feature might be more pressing.*

ii) Develop a forward casting age-structured, numbers-based stock assessment model. *This work is in progress for sea scallop, ocean quahog and surfclam. In the interim, the KLAMZ model is implicitly age structured and numbers based, although it does not make full use of survey and fishery age or length data. NEFSC convened an age readers workshop during 2006 (Jacobson et al. 2006) to address questions about age data and results will be useful in formulating the new model. NEFSC has begun to characterize variability in survey length data and the results are expected to be useful in modeling as well.*

iii) Reconcile survey trends for pre- and new- recruits relative to trends in survey data for older recruits. *Pre-recruit survey indices were not used for modeling in this assessment because they are too variable. Survey data procedures for modeling were redesigned to ease interpretation.*

iv) Reconcile survey data with consistently declining trends in LPUE during the last decade. *Recent trends in survey and LPUE data were similar in this assessment for southern regions, where fishing is heaviest, and for the stock as a whole.*

v) Focus on analysis of declining LPUE trends and examine new approached for describing fishing power among commercial clam vessels. *This issue was addressed by standardizing LPUE data in models that included individual vessel effects. Thus, it was not necessary to characterize fishing power based on GRT, horsepower, etc.*

vi) 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. Sampling rates for length data should be increased particularly for new northern fishing grounds. All available survey age, length and commercial length data were used at least qualitatively in this assessment to characterize and predict recruitment.*

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

viii) Consider using a sensor that tracks dredge position, rather than the ships position, during surveys and depletion studies. *New acoustic sensor equipment was tried experimentally during the 2005 survey but with poor results.*

ix) Conduct surveys more frequently than every three years in critical areas. *A cooperative survey in the SVA, DMV and NJ areas was carried out during 2004, in the interim between the 2002 and 2005 NEFSC clam surveys.*

x) Select a new set of fixed stations in unfished areas to monitor dredge efficiency changes between surveys. *Fixed station analysis was abandoned in this assessment due to variable environmental conditions that may affect density in unfished areas.*

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

xii) Consider new methods to estimate variability in the spatial distribution of biomass. *All depletion studies were reanalyzed for this assessment producing estimates of the negative binomial parameter k, which measures spatial patchiness in the density of surfclams within depletion study areas. However, this topic is of relatively low importance.*

xiii) Continue to bring outside experts to Invertebrate Working Group meetings. *One outside expert was included in each of the meetings for this assessment.*

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

a) 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)?

b) Improve collection and use of port sample data form the commercial fishery.

c) 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.

d) 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.
e) Determine the size selectivity of survey and commercial fishing equipment experimentally.
f) 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.
g) 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).
h) Further investigate spatial trends in survey data.
i) Devote sufficient time and resources to fully develop and improve dynamic population models.
j) Review the technical basis of the current B_{MSY} proxy given new data and possible climate effects.
k) Utilize New Jersey and New York inshore clam survey data more fully in the EEZ surfclam assessment.

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