B. Stock assessment for ocean quahogs (*Arctica islandica*)

Invertebrate Subcommittee[1]
SAW/SARC 48

1 See Appendix B1 for committee members. The lead authors were Larry Jacobson and Toni Chute, Northeast Fisheries Science Center, Woods Hole, MA.

Terms of Reference

1. **1.** Characterize commercial catch including landings, effort, and discards.
2. **2.** Estimate fishing mortality, spawning stock biomass, and stock biomass for the current and previous years. Characterize uncertainty of the estimates.
3. **3.** Update or redefine biological reference points (BRPs; estimates or proxies for *BMSY*, *BTHRESHOLD*, and *FMSY*). Comment on the scientific adequacy of existing and redefined BRPs.
4. **4.** Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 3).
5. **5.** 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).
    a. Provide numerical short-term projections (3-4 years). 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 assessment (alternate states of nature).
    b. If possible, comment on the relative probability of the alternate states of nature and on which projections seem most realistic.
    c. Describe this stock's vulnerability to becoming overfished, and how this could affect the choice of ABC.
6. **6.** Review, evaluate and report on the status of SARC/Working Group research recommendations listed in recent SARC reviewed assessments. Identify new research recommendations.

Clarification of terms used in the terms of reference:

(The text below is from DOC National Standard Guidelines, Federal Register, vol. 74, no. 11, January 16, 2009)

Acceptable biological catch (ABC) is a level of a stock or stock complex's annual catch that accounts for the scientific uncertainty in the estimate of (overfishing limit) OFL and any other scientific uncertainty…" (In other words, OFL ≥ ABC.

ABC for overfished stocks. For overfished stocks and stock complexes, a rebuilding ABC must be set to reflect the annual catch that is consistent with the schedule of fishing mortality rates in the rebuilding plan.

NMFS expects that in most cases ABC will be reduced from OFL to reduce the probability that overfishing might occur in a year.

ABC refers to a level of ''catch'' that is ''acceptable'' given the ''biological'' characteristics of the stock or stock complex. As such, (optimal yield) OY does not equate with ABC. The specification of OY is required to consider a variety of factors, including social and economic factors, and the protection of marine ecosystems, which are not part of the ABC concept.

Executive Summary

A) This assessment for ocean quahog in the US EEZ is based on biological information, fishery-dependent data for 1978-2008 and NEFSC clam survey data for 1982-2008. Based on assessment data, the ocean quahog population is an unproductive stock with infrequent and limited recruitment. After three decades of fishing at a relatively low *F*, the stock as a whole it is being fished down towards its target biomass reference point, which is defined as 50% of biomass during 1978 (pre-fishery) based on assessment recommendations.

B) Ocean quahogs in the US EEZ are not overfished and overfishing is not occurring. Total fishable stock biomass (all regions) during 2008 was 2.905 million mt, which is above the current and recommended management target of 1.790 million mt. The fishing mortality rate during 2008 for the exploited region (all areas but GBK) was $F = 0.01$ y^{-1}, which is below the current $F_{25\%} = 0.0517$ y^{-1} and recommended $F_{45\%}=0.0219$ threshold reference points. The recommended $F_{45\%}$ mortality threshold is based on harvest policies for long lived West Coast groundfish, which are probably more productive than ocean quahogs. The $F_{45\%}$ recommendation should be revisited in the next assessment.

C) Fishing effort declined in the EEZ fishery from about 40 thousand hours per year during 1990-1995 to about 25 thousand hours per year recently. The number of active vessels in the EEZ in 2008 was the lowest level on record. LPUE for the EEZ stock as a whole has been stable since 1982 but is currently higher in northern areas (LI and SNE) than in the south (NJ and DMV). Landings have declined since the peak of 22,000 mt during 1992 to 15,000 mt during 2009.

D) The ocean quahog fishery has shifted north over the last two decades as catch rates declined in the original fishing grounds off Delmarva and New Jersey. In the 1980s, the bulk of the fishing effort was off Delmarva and southern New Jersey, with some fishing off southern New England. In the early 1990s effort fell by half in the Delmarva region while effort increased south of Long Island until about 40% of total effort was concentrated there. By the late 1990s, most of the fishing effort had moved to the Southern New England region. In the early 2000s, the majority of fishing effort was in the Long Island region. By the late 2000s only 22% of total effort was in the Delmarva and New Jersey regions.

E) Cooperative ocean quahog depletion experiments conducted in connection with the 1997-2008 NEFSC clam surveys were used to estimate the efficiency of the NEFSC survey dredge. Results of depletion experiments are important in estimating biomass and fishing mortality. Three more successful depletion experiments were carried out this year for a total of 15. Based on all experiments to date, the median NEFSC survey dredge efficiency is 0.169.

F) During the 2008 NEFSC clam survey, which consisted of 453 stations, the electrical cable powering the dredge pump was replaced at station 241 with a longer one, and the dredge pump was replaced at station 170. As a result, special analyses were conducted to determine the effects of these changes on survey catch rates. Based on the results, effects of the replacement electrical cables and pumps on catches during the 2008 survey could not be distinguished statistically from zero.

G) Dredge tows completed during the 2008 survey tended to be shorter than tows from the 1997, 1999, 2002 and 2005 surveys although differences between 2008 and 2002 were small. Considerable effort was devoted to examining sensor data to determine why survey tows during 2008 were shorter than in previous surveys. The evidence was inconclusive.

H) The estimates of biomass and fishing mortality for the EEZ stock in this assessment do not include the Maine "mahogany" quahog fishery. Maine stock biomass is small (~1% relative to the rest of the EEZ) with fishing effort concentrated in a small area. A stock assessment for ocean quahogs in Maine waters is presented as Appendix B2.

I) Current BRPs were reviewed. The current threshold reference point for fishing mortality $F_{25\%}$=0.0517 y^{-1} is a poor proxy for F_{MSY} in a long-lived species like ocean quahog with natural mortality rate M=0.02 y^{-1}. In absence of simulations for ocean quahog, the best available information is Clark's (2002) simulation analyses of F_{MSY} proxies applicable to long lived West Coast groundfish and a follow-up workshop report (PFMC 2000, reproduced here as Appendix B7). The workshop report recommends an F_{MSY} proxy of $F_{40\%}$ for relatively productive Pacific whiting and flatfish, $F_{45\%}$ for other groundfish, and $F_{50\%}$ for *Sebastes* spp. (rockfish) and *Sebastolobus* spp. (thornyheads). The Invertebrate Subcommittee could not choose between $F_{40\%}$ and $F_{50\%}$ as F_{MSY} proxies. After discussion, $F_{45\%}$ was recommended as the F_{MSY} proxy for ocean quahogs. New recommended reference points are not referred to as MSY reference points because the productivity of the ocean quahog stock is currently unknown.

J) The new recommended biomass target of 1.837 million mt is one-half of the 1978 pre-fishery biomass (virgin biomass probably fluctuated due to infrequent recruitment). The new recommended $B_{Threshold}$ which is 40% of the 1978 biomass (1.432 million mt), which can be compared to the current $B_{Threshold}$ which is 25% of virgin biomass. The recommended $B_{Threshold}$ is ad hoc, but probably better than the current value.

K) Managers will have to decide whether the new fishing mortality threshold should be compared to estimated fishing mortality for the exploited portion of the stock (excluding GBK where no fishing takes place) or to the whole stock. Fishing does not occur on GBK (which current contains about 45% of stock biomass) because of the risk of PSP (paralytic shellfish poisoning).

   a. The current FMP requires comparison of the threshold reference point to fishing mortality in the exploited portion of the stock only. Most other FMPs compare reference points to mortality rates for the whole stock.

   b. This current approach should help maintain higher productivity for a sessile spatially non-homogenous stock like ocean quahogs. MSY theory is difficult to apply to stocks like ocean quahogs because MSY mortality levels for the stock as a whole result in under-exploitation of the unfished portion (with foregone yield) while the fished portion of the stock is over exploited (resulting in foregone yield).

c. Industry sources expect ocean quahog fishing to begin on Georges Bank soon. This assessment contains no direct advice on harvest of ocean quahogs across the entire stock. Almost all fishery calculations use growth curves and other data for the currently exploited portion of the stock. Harvest policies for ocean quahog should be reconsidered when and if a fishery develops on Georges Bank

L) KLAMZ model projections were run with varying "states of nature", a range of possible values for natural mortality (M=0.015, 0.02 and 0.025) and biomass levels. The projections were also run with four landings policies (status quo, FMP minimum quota, FMP maximum quota, and FMP current quota) and five target fishing mortality policies ($F_{0.1}$, $F_{25\%}$, $F_{40\%}$, $F_{45\%}$ and $F_{50\%}$). Both stochastic and deterministic (which approximate median values from stochastic projections) results indicate that overfished (low biomass) stock conditions and overfishing are not likely to occur by 2015 <u>*at current catch levels*</u> under any of the states of nature.

M) In 2008, fishable stock biomass in SVA, DMV and NJ was less than half of pre-fishing (1978) levels. In contrast, stock biomass in the more northern regions of LI and SNE increased after 1978 to due to a recruitment event and growth, and then began to decrease in the early 1990s when recruitment declined and the fishery gradually began to move north into these areas. The LI, SNE and GBK regions contained about 67% of total fishable biomass during 1978 and contained about 84% of the total fishable biomass during 2008. The GBK region, which is currently not fished due to risk of PSP contamination, contained about 32% of total fishable biomass during 1978 and about 45% during 2008.

N) Recruitment events appear to be localized and episodic (i.e. often separated by decades) although survey length composition data show that a very low level of recruitment occurs on a continuous basis. Based on survey length composition data and published studies, some recruitment has been evident in LI, SNE and GBK during recent years. The potential contribution of recent recruitment to stock biomass and productivity is unknown.

O) Fishing mortality rates are relatively low for the ocean quahog stock as a whole and stock biomass is relatively high. However, ocean quahogs are an unproductive stock that is likely vulnerable to overfishing. If overfished (depleted biomass) conditions occur, one or more decades will be required to rebuild the stock.

Introduction

Ocean quahogs (*Arctica islandica*) in the US Exclusive Economic Zone (EEZ, federal waters only) and a small component in Maine (MNE) state waters are regarded as a single stock. However, the EEZ and MNE components have different biological characteristics and support different fisheries that are managed separately. The EEZ fishery (with landings of about 15,000 mt meats during 2008) is managed by under a single individual transferable quota (ITQ) system that was established for ocean quahog and Atlantic surfclam (*Spisula solidissima*) in 1990. Murawski and Serchuk (1989) and Serchuk and Murawski (1997) provide detailed information about the history and operation of the EEZ fishery. The smaller MNE fishery (with landings of about 200 mt meats during 2008) is managed under a separate quota system. This report focuses primarily on the ITQ fishery but includes a brief summary of key results for ocean quahogs in Maine waters. Appendix B2 gives detailed stock assessment information about ocean quahogs in Maine waters.

The ocean quahog stock is often broken down into smaller regions (listed below) based on biology, fishery characteristics, and history. These designated regions are important in understanding the fishery but have no legal importance beyond the distinctions between Maine, Georges Bank (GBK, see below) and the EEZ as a whole.

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

Entire stock vs. the exploited region

Data and analysis for ocean quahogs in the EEZ are presented in this assessment for the "entire" or "whole" stock and for the "exploited region" only (Figure B1). "Entire" and "whole" stock refers to ocean quahogs in the entire EEZ. The "exploited region", in contrast, excludes Georges Bank (GBK) because the GBK region has been closed to ocean quahog harvesting since 1990 when paralytic shellfish poison (PSP) was detected. The Mid-Atlantic Bight (DMV to LI) includes most of the exploited region where the fishery originally operated.

Interest in reopening GBK for ocean quahog fishing has increased recently because catch rates on southern fishing grounds are relatively low and a large fraction (nearly 50%) of the fishable biomass is found there. Sampling was carried out during 2008 to determine if PSP is still a problem. Industry sources expect the fishery on GBK to reopen in the near future.

Fishable stock vs. exploited region

The "fishable stock" and "exploited region" are not synonymous for ocean quahogs in this report. "Fishable" ocean quahogs are quahogs large enough to be taken in the commercial fishery based on the size selectivity curve for commercial fishing gear (Figure B2).

Units of measurement

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

Vessel size categories and units of measure for ocean quahogs used in this assessment are described below. Commercial data are reported in units of "industry bushels" in logbooks and often converted to saleable meat weights (which include all soft tissues within the shell) for use in this assessment.

Unit	Equivalent
Industry or Mid-Atlantic bushel (Industry bu)	1.88 ft^3
Maine (US standard) bushel (Maine bu)	1.2448 ft^3
Industry bushels x 10	Pounds meat wt
Industry bushels x 4.5359	Kilograms meat wt
Maine bushel	0.662 industry bushels
Cage	32 Industry bushels
Vessel ton class 1	1-4 gross registered tons (GRT)
Vessel ton class 2	2-50 GRT
Vessel ton class 3	51-150 GRT

Previous assessments

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

Fishing mortality rates during 2005 for the MNE stock component was near the $F_{0.1}$ level (NEFSC 2007a).

Biological characteristics[2]

Ocean quahogs are common in the eastern Atlantic as far south as Spain, around Iceland, and in the western Atlantic as far south as Cape Hatteras (Theroux and Wigley 1983; Thorarinsdottir and Einarsson 1996; Lewis et al. 2001). They can be found at depths of 10-400 m, depending on latitude (deeper water habitats are utilized in the south, Theroux and Wigley 1983; Thompson et al. 1980).

The US stock is almost completely within the EEZ at depths of 25-95 m. Dahlgren et al. (2000) found no genetic differences between samples taken along the US coast from Maine to Virginia based on mitochondrial cytochrome *b* gene frequencies.

The natural mortality rate and longevity of ocean quahogs are uncertain. Ocean quahogs are certainly long-lived. Individual specimens are commonly aged at over 200 yrs (Jones 1980; Steingrimsson and Thorarinsdottir, 1995; Kilada et al., 2007; Strahl et al. 2007). Early studies of populations off New Jersey and Long Island (Thompson et al. 1980; Murawski et al. 1982) demonstrate that clams ranging in age from 50-100 years are common. Wanamaker et al., (2008) aged two ocean quahogs at 287 and 405 y, making the latter specimen possibly the oldest non-colonial animal ever documented. Based on longevity estimates of around 200 y, adult ocean quahogs in the EEZ and off Iceland are assumed to die from natural causes at the rate of about 2% annually (instantaneous rate of natural mortality M=0.02 per year). In particular, about 1% of a cohort is expected to survive after 230 y when M=0.02. Kilada et al estimated M to be 0.03 and 0.10 for the Sable Bank and St Mary's Bay populations in Canadian waters based on age–frequency data for unexploited populations.

Ocean quahogs grow slowly after the first years of life (Lewis et al. 2001; Kilada et al. 2007). Maximum size is typically about 110 mm in shell length (SL) although larger specimens are

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

found. Individuals large enough to recruit to the fishery grow only 0.51-0.77% per year in meat weight and < 1 mm per year in shell length (Figure B3). Growth is faster in GBK than further south in the MAB (Figure B3).

Maturity and recruitment information for ocean quahogs in the US EEZ is scant (see review in Cargnelli et al. 1999) but size and age at maturity appear to be variable. Off Long Island, the smallest mature quahog found was a male 36 mm long and 6 years old; the smallest and youngest mature female was 41 mm long and 6 yr old (Ropes et al. 1984). Some clams in this region are still sexually immature at ages of 8-14 years (Thompson et al. 1980; Ropes et al. 1984). Females are more common than males among the oldest and largest individuals in the population (Ropes et al. 1984; Fritz 1991).

The shell length maturity relationship used in this assessment (Figure B2) is from data for Icelandic ocean quahogs (Thorarinsdottir and Jacobson, 2005). The curve indicates that 10%, 50% and 90% of female ocean quahog mature at 40, 64, and 88 mm SL (2, 19, and 61 y, based on the growth curve in Lewis et al., 2001 for MAB). Based on the size range of samples (G. Thorarinsdottir, pers. comm.), the maturity curve is probably valid for ocean quahog in the size range used to estimate fishing mortality. Maturity occurs at roughly 10 mm before, and about 10 years before, recruitment to the fishery (Figure B2).

Shell length-meat weight (SLMW) relationships are important for ocean quahogs because survey catches in number are converted to meat weights based on shell length for many analyses. SLMW relationships in this assessment are region-specific (Table B9) and the same as in the last assessment (NEFSC 2007a). They were estimated using a mixture of frozen and fresh samples. Relationships were re-estimated based on large number of fresh samples taken during the 1997-2008 surveys (Appendix B8). The updated relationships will be used in the next ocean quahog assessment but were not ready in time for use here.

Recruitment patterns

Recruitment events are regional and infrequent in ocean quahog (Powell and Mann 2005, Harding et al. 2008). Small ocean quahogs in survey length composition data indicate that recruitment occurs at a very low level during most years, particularly in northern areas (Figures B24 through B29). However, survey data collected during 1982-2008 show only three noteworthy recruitment events in LI, SNE and GBK (Figures B25 through B27) over regional spatial scales. Because growth is so slow, there are delays of one to three decades between larval settlement and production of recruits to the fishery. Ocean quahogs reach 64 mm SL (50% maturity) at age 12 y in GBK and 19 y in MAB (Figure B2). In contrast, ocean quahogs reach 73 mm (50% commercial selectivity) at age 13 y in GBK and 28 y in MAB (Figure B3). Each of the three recruitment events observed since 1980 were produced while spawning biomass in the same region was unfished or nearly unfished. Recruitment patterns in ocean quahog at reduced biomass levels after fishing are a major uncertainty (NEFSC 2007a).

Commercial and Recreational Catch
(TOR-1)

Mandatory logbooks have been the principle source of fishery data (landings, fishing locations and fishing effort) for the ITQ fishery since 1980. Landings and quotas for the ITQ fishery are reported in different units than landings and quotas for the fishery off Maine. In particular, "industry" bushels (1.88 ft^3) are used for the ITQ component and "Maine" bushels (1.2448 ft^3) are used for the Maine component. Biomass and landings from both fishery components are reported in this assessment as meat weights, unless otherwise noted.

Total EEZ landings (including both ITQ and Maine fishery components) were relatively high during 1987-1996 with a peak of 22,500 mt meats (Tables B1 and B2; Figure B4) or 4.9 million ITQ bushels (see Table B3 for all landings in bushels) during 1992. After 1996, landings declined to a low of about 15,000 mt during 2000 and then increased again to a high of 19,000 mt during 2003. Landings declined after 2003 to about 14,000 mt during 2005, the lowest level since 1981. After 2005, landings increased slightly to about 15,500 mt. Industry sources report that low landings during the most recent years were due to low market demand. Landings by the Maine component of the fishery were only 1.2% of total EEZ landings during 1990-2008.

Landings from Maine waters increased steadily from 75 mt in 1992 to relatively high levels (≥ 326 mt annually) during 2000-2003 (Tables B2 and B3). Maine landings decreased after 2003, but remained over 300 mt through 2007. Only 201 mt were landed in 2008, the lowest level since 1997.

Landings by the ITQ component averaged 83% of the EEZ quota during 1990-2008 (Table B1). In contrast, the 100,000 Maine bushel quota allocated for ocean quahog in Maine waters was usually exhausted during 1999-2008 with vessels leasing ITQ shares in some years to harvest more than 100,000 mt meats from Maine waters (Tables B2 and B3).

Landings of quahogs from state waters south of Maine are effectively zero because ocean quahogs are found offshore in relatively deep water. There are no recreational landings of ocean quahogs because commercial clam dredges are required to harvest them, and because they provide an industrial product with no recreational value.

Prices

Nominal ex-vessel prices for ITQ ocean quahog landings (expressed as dollars per ITQ bushel) increased by about 66% after 1990 (Table B4 and Figure B5). In real terms, prices stayed fairly stable except for a 30% jump from 2000 to 2001, followed by a steady decline. Prices during 2006-2008 stabilized at about $3.20 a bushel.

Prices for ocean quahog harvested in Maine waters (expressed as dollars per ITQ bushel for the sake of comparison) were roughly ten times higher than prices for ocean quahogs harvested in the rest of the EEZ (Table B4 and Figure B5). In real dollars, Maine prices have fallen about 50% since their peak in the early nineties.

Fishing effort

Total hours fished annually in the ITQ fishery component decreased from a peak of about 40,000 hr per year during 1991-1994 to about 30,000 hr per year during 1996 to 2004, and then to about 20,000 hr per year during 2005-2008 (Table B5 and Figure B6). The total number of trips in the ITQ fishery decreased steadily from about 3000 trips per year during 1991 to about 1200 trips per year during 2008 (Figure B7). In contrast, hours fished and trips increased in the Maine fishery component during 1991-2005, but declined afterward. The number of active permits (vessels with landings during the year in question) in the ITQ fishery remained relatively constant during 1996-2003 but declined by 50% from 2004 to 2006 and has remained stable at around 30 permits ever since (Figure B8). The number of active permits and fishing effort (hours fished and numbers of trips) is high in Maine waters relative to other regions in the EEZ.

Landings per unit effort (LPUE)

LPUE (expressed in bushels landed per hour fished) in the ocean quahog fishery is a better measure of fishing success than a measure of stock abundance because changes in abundance or biomass may be masked by movement of fishing effort to areas where ocean quahog density and catch rates remain high. In spite of these potential problems, LPUE and NEFSC clam survey data are highly correlated for southern areas (DMV and NJ) where significant levels of fishing occurred over long periods of time (NEFSC 2007a).

LPUE declined by about 60% in the DMV and NJ regions after the mid-1980s to about 60-80 bushels per hour in recent years (Table B6 and Figure B9). LI and SNE show relatively high LPUE levels of about 160 and 180 bushels per hour that have been relatively stable since 2000. The LPUE for the ITQ fishery as a whole has been remarkably constant since the early 1980s (Table B6) at between 100 and 150 bushels per hour because the fishery moves to new grounds when LPUE declines.

The break-even LPUE (where variable costs and revenues are the same) reported in NEFSC (2004) for the EEZ fishery was 80 bushels h^{-1}. This estimate was higher than previously reported (NEFSC 2001) because of inflation, increased steaming time to relatively distant fishing grounds, operation of new larger vessels, and increased costs for food, fuel, insurance, etc. It was not possible to update the estimate of break-even LPUE because of extreme variability in the price of fuel.

In the Maine fishery (Figure B10), standardized LPUE increased to over 6 bushels an hour during 1991-2000, and decreased afterwards, and has fluctuated between 4 and 5.5 bushels per hour for the last 8 years.

NEFSC (2007a) standardized LPUE data by adjusting for vessel, month and vessel size effects. Estimated trends were very similar to trends in nominal LPUE. Standardized LPUE data are not presented in this assessment.

Spatial patterns in fishery data

Spatial patterns are important in interpreting fishery data and in managing fisheries for sessile and unproductive organisms like ocean quahogs. The ocean quahog stock is a complicated spatial mosaic with scattered productive and profitable fishing grounds where abundance is high and where fishing mortality tends to be concentrated. The size of a productive ocean quahog fishing ground appears to be less than the size of a ten-minute square (TMS, 10' x 10' ≅ 100 nm^2), which is the smallest spatial strata reported on logbooks and used in this stock assessment. As described in NEFSC (2004), spatial patterns in cumulative landings, cumulative effort and LPUE reflect a shift in the distribution of the fishery to offshore and northern grounds. During the 1980s, nearly all of the landings and fishing effort were from the southern DMV and NJ regions. As LPUE declined there, fishing effort and landings shifted offshore and north to the LI and SNE regions. During 2008, the southern DMV and NJ regions accounted for only about 15% of landings and fishing effort while the bulk of landings and effort (outside of Maine waters) were from LI.

Fishery data by ten-minute square (TMS)

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

Landings (Figure B11) during 1981-1990 were concentrated in relatively few TMS that were primarily in the south and relatively inshore. Over time, TMS with highest landings shifted offshore and north. Landings during 2001-2008 were concentrated in the LI region.

Fishing effort (Figure B12) was concentrated in a few southern TMS during 1980-1990 with three adjacent TMS having effort levels higher than 1,000 h per year and appreciable fishing effort south of 38^o N. Fishing effort spread into additional offshore and northern TMS during 1991-1995 and 1996-2000. After 1995, there were few or no TMS with effort levels above 1000 h per year. During 2001-2008, there was no fishing effort south of 38^o N.

LPUE (Figure B13) was relatively high inshore and south during 1980-1990 with ten TMS that had LPUE $\geq$ 161 ITQ bushels h^{-1}. LPUE in the area below 40^o S was generally high. LPUE declined in the south and fishing effort spread northward during 1991-1995 where LPUE was relatively high. During 1996-2000, the fishery continued to move northward into the SNE region where catches were profitable. By the 2001-2005 time period, LPUE was often $\leq$ 80 ITQ bushels h^{-1} below 40^o S.

Trends for important TNMS

Trends in landings and LPUE during 1980-2005 were plotted for individual TMS that were important to the fishery (Figures B14 through B16). Important TMS were selected by sorting TMS according to total cumulative landings during 1980-1990, 1991-1995, 1996-2000, 2001-2005 and 2006-2008 and then selecting the top 20 TMS during each time period. All of the TMS selected in this manner were combined to form a single a single set of TMS that were important to the fishery at some time during 1980-2008.

Trends in LPUE for individual TMS tend to be relatively high during the first years of exploitation and then tend to decline as effort, annual landings and cumulative landings increase over time (Figures B14 through B16). Decreasing trends in LPUE appear strongest in southern areas such as TMS 377422 to 397326 with the longest history of exploitation. LPUE does not appear to increase in a TMS once fishing effort decreases.

Unlike LPUE which is highest in the first years of exploitation, landings and fishing effort tend to peak after 5-10 years of exploitation while LPUE is still relatively high and then to decrease over a 5-10 y period as grounds are fished down (Figures B14 through B16). In some TMS with low recent LPUE levels (e.g. TMS 387443-397316), fishing effort has increased recently with some increase in landings.

Bycatch and discard

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

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

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

Commercial size selectivity

The commercial fishery selectivity curve used in this assessment is from Thorarinsdottir and Jacobson (2005) who estimated selectivity of commercial dredges that harvest ocean quahogs off Iceland. Based on this commercial selectivity curve ($s_L = 1/\left(1+e^{7.63-0.105L}\right)$ where L is shell length in mm) about 10%, 50% and 90% of ocean quahogs are available to the fishery at 51, 72, and 93 mm SL (9, 28 and 86 y, based on the growth curve for MAB in Figure B3).

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

Commercial size-composition data

Commercial length composition data collected by port agents from landings samples (Table B7) indicate that the size composition of ocean quahogs captured in the DMV region differed during 1987-1994, 1995-2000 (when they were smaller) and 2001-2008 (Figure B17). Lengths for DMV during 1987-1994 and 2001-2008 were similar. The only exception is 2007, when port samples from the DMV region showed slightly larger harvested quahogs.

Commercial length composition data for NJ were stable during 1982-2002 with smaller ocean quahogs landed during 2003-2008 (Figure B18). Length data for LI include relatively high proportions of large individuals (11-12 cm SL) during 1997-1999 (Figure B19). Length data for SNE during 1998-2005 were generally stable but with smaller ocean quahogs landed during 1997-2000 (Figure B20). According to NEFSC (2004), smaller sizes landed from SNE during 1997-2000 were due to vessels targeting specific beds with relatively small ocean quahogs that had relatively high meat yield.

Port sampling levels were increased in the SNE and LI regions during recent years due to increased landings and fishing effort levels (Table B7). Increased port sample frequencies reflect movement of the fishery onto northern grounds in SNE and LI.

Mortality and Stock Biomass
(TOR-2)

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

NEFSC clam surveys

Survey data used in this assessment were from surveys conducted during 1982-2008 by the *R/V Delaware II* during the summer (June-July), using the standard NEFSC survey hydraulic dredge with a submersible pump. The current survey dredge which has been used since 1982 has a 152 cm (60 in) blade and 5.08 cm (2 in) mesh liner to retain relatively small ocean quahogs and Atlantic surfclams. The survey dredge differs from commercial dredges in that it is smaller (5 ft blade instead of 8-12.5 ft), has a small mesh liner, and the pump is mounted on the dredge instead of the deck of the vessel. The survey dredge is useful for ocean quahogs as small as 50 mm SL (size selectivity described below). Changes in ship construction, winch design, winch speed and pump voltage that may have affected survey dredge efficiency are summarized in Table A7 of NEFSC (2004). Each of these factors has been constant since the 2002 survey.

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 B1). Most ocean quahog 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 (Table B8). Strata not sampled during a particular survey are "filled" for assessment purposes by borrowing data from the same stratum in the previous and/or next survey, if data are available (NEFSC 2004). Survey data are never borrowed from surveys further back than the previous survey 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 2007a).

Surveys follow a stratified random sampling design, allocating a pre-determined number of tows to each stratum. Stations used to measure trends in ocean quahog abundance are either random or nearly random. The few "nearly" random tows were added in 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 but not used to estimate relative trends in ocean quahog abundance.

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

Occasionally, randomly selected stations are found too rocky or rough to tow. Beginning in 1999, these cases trigger a search for fishable ground in the vicinity (0.5 nm) of the original station (NEFSC 2004). If no fishable ground is located, the station is given a special code (SHG=151) and the research vessel moves on to the next station. The proportion of random stations that cannot be fished is an estimate of the proportion of habitat in a stratum or region that is not suitable habitat for ocean quahog. These estimates are used for calculating ocean quahog swept-area biomass (see below).

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

Survey tow distance and gear performance in trend analysis

For trend analysis, tow distances are based on start and stop locations recorded for each tow. The catch at each station is standardized to a "nominal" tow distance of 1.5 nm for trend analysis.

"Successful" tows suitable for trend analysis are identified using "HG" (haul and gear) database codes ≤ 36, which are recorded at sea by the watch chief following each tow based on criteria used consistently since the late 1970's. Sensor data are not used to calculate tow distance for trend analyses because sensor data are not available prior to 1997. Sensor data are used, however, to calculate tow distance and monitor gear performance during tows for depletion, repeat station and other types of experimental studies conducted since 1997 (see below).

Survey tow distance and gear performance based on sensor data

After the 1994 survey, sensors were used to monitor depth (ambient pressure), differential pressure, voltage, frequency (hertz) and amperage of power supplied to the dredge, *x*-tilt (port-starboard angle), *y*-tilt (fore-aft angle, effectively the "angle of attack" of the dredge) and ambient temperature during survey fishing operations. At the same time, sensors on board the ship monitor electrical frequency, GPS position, vessel bearing and vessel speed. Most of the sensor data are averaged and recorded at 1 second intervals.

Good tows have characteristic sensor data patterns that are easy to interpret (Figure B31). Anomalous patterns indicate potential problems with the tow or sensors. Differential pressure, amperage and *y*-tilt can be particularly important. Differential pressure is the pressure of water pumped through jets in front of the dredge blade to loosen the sediments. Amperage measures the work done by the pump in moving water through the jets. If water is blocked at the entrance to the pump, then both amperage and differential pressure will be low. If water is blocked downstream of the pump, then amperage will be low and differential pressure will be high. As described below, *y*-tilt can be used to determine if the dredge is on the bottom with the blade in the sediment.

NEFSC (2007a) developed a quantitative system for identifying tows with poor performance based on *y*-tilt and differential pressure sensor data that was applied to the 2005 NEFSC clam survey (see Appendix A3 in NEFSC 2007a). The *y*-tilt criterion which was part of this quantitative system was dropped after reconsideration in this assessment (Appendix B3) for 3 reasons: i) the *y*-tilt sensors appear to be strongly affected by vibration, ii) the existing procedure for calculating tow distances (see below) already indentifies periods when the dredge is not fishing, and iii) because the standard database "SHG" code eliminates many of the problematic tows before sensor data are examined. The revised criteria based on differential pressure only was applied to the 2008 and retroactively to 2005 surveys (but not to the 1997-2002 surveys due to lack of time).[3,4] Affects on the 2005 survey were modest with only one additional tow shifted from the poor to good performance categories.

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3 The criterion for differential pressure is a time-weighted approach that penalizes problematic high and low pressures. The weights depend on the extent of the deviation from normal operating range of 35-40 psi. The weighting system for differential pressure data P_t is:

$W_t = 2 * (P_t - 40)/40$ when the differential pressure $P_t > 40$ psi

$W_t = 2 * ((35 - P_t)/35 \times 0.83)$ when $P_t < 35$ psi

$W_t = 1$ otherwise

A tow is judged to have poor performance when the weighted time outside the normal range > 25%. See Appendix B3 for more information.

4 Stations with poor performance based on sensor data in the 2005 survey: 1, 2 , 4,17,20,22,23,24,25,26,28,29,30,31,32, 33,34,45,48,56,58,67,75,76,108,218,225,262,282,405,411,413,414,417, 422,423,424.
Stations in the 2008 survey: 15, ,29,35,43,45,48,52,65,95,99,119,137,138,141,150,164,165,169,175,197,198,206,209,226,227,229,241,242,245, 246,248,249,250,252,254,257,258,262,263,288,290,291,293,305,306,307,308,309,310,317,326,358,366,394,402, 403,424,430,433,434,435,436,437,438,448,452,453.

Survey gear selectivity

NEFSC (2004) estimated selectivity curves for ocean quahogs in the NEFSC clam dredge based on catches by a commercial dredge with a chicken-wire mesh liner during 2003 and survey catches in the same area during 2002. The selectivity curve $s_L = 1/\left(1 + e^{8.122 - 0.119L}\right)$ indicates that 50% of ocean quahogs are fully available to the NEFSC clam dredge at about 68 mm SL, which can be compared to about 73 mm for commercial dredges (Figure B21). The survey dredge tends to take smaller ocean quahogs than commercial dredges because of the relatively small 50 mm (2 in) liner in the survey dredge. Based on sizes retained by the survey dredge (NEFSC 2004), the survey dredge selectivity curve is reliable for ocean quahogs ≥ 50 mm SL.

Survey, stock and fishable abundance and biomass

The survey size selectivity curve with survey catch and size composition data for ocean quahogs ≥ 50 mm SL was used to estimate relative abundance and size composition for the stock as a whole. In particular, $N_L = n_L / s_L$ where N_L is mean stock numbers or biomass per tow at length L in the stock as a whole, n_L is survey catch and s_L is survey selectivity.

Abundance and length composition for the fishable stock (i.e. of a size available to the fishery) were estimated by adjusting stock estimates for fishery selectivity. In particular, $\eta_L = \phi_L N_L$ where η_L is fishable abundance and ϕ_L is fishery selectivity. Fishable abundance can be estimated directly from survey data for ocean quahogs ≥ 50 mm SL using $\eta_L = n_L \phi_L / s_L$ (Figure B21).

Calculations of stock abundance and biomass occasionally produce very large estimates for small sizes where selectivity is small (near zero) when ratios n_L / s_L become very large. Calculation of fishable abundance and biomass from ocean quahog survey data does not suffer from this problem because the adjustment for small sizes is relatively modest (Figure B21).

Survey Trend Results

Based on survey data, abundance and biomass of relatively large quahogs (70+ mm SL) declined during 1997-2008 in all areas but GBK (Table B10 and Figures B22 and B23). The declines in southern areas where the bulk of fishing has occurred (DMV and NJ) appear clear. The apparent trends in SNE and LI since 1997 are not as clear and may be due to sampling error or changes in survey catchability.

Based on survey data for small ocean quahogs (< 70 mm SL, Table B11 and Figure B24), recruitment during 1997-2008 was about average in DMV, higher than average in NJ, SNE and GBK, and below average in LI.

Survey length composition data (Figures B25 through B29) and the distribution of catches in the 2008 survey (Figure B30, lower panel) provide additional information about recruitment. In particular, survey length composition data for LI for 1982 are bimodal with a lower mode at 65-70 mm SL in 1982 due to a strong recruitment event. Based on the growth curve for the MAB (Figure B3), ocean quahogs 65-70 mm SL are about 21-26 y old. The mode gradually shifted to the right over time as the year class grew. By 2005 (23 y later), the strong year class had grown to be indistinguishable from other ocean quahogs in the region. This historical recruitment event is evident in recruit trends for LI, which increased during the 1960-1970's and generally decreased afterwards (Figure B24).

Survey size composition data for SNE during 2005 and 2008 (Figure B26) show a recent recruitment event that is also apparent in the survey trend data for the same years (Figure B24). The lower mode during 2005 and 2008 was at approximately 50-60 mm SL. Based on the MAB growth curve, ocean quahogs 50-60 mm SL are about 9-15 y old. This strong year class is located southeast of Cape Cod based on catch locations in the 2008 survey (Figure B30, bottom panel). LPUE data show relatively high catch rates in the corresponding TMS southeast of Cape Cod at approximately 40^{o} 30' N 69^{o} 40'E (Figure B13).

Size composition data from the 2008 survey show an apparent recent recruitment event in the GBK region as there is a strong mode at about 60-65 mm SL (Figure B25). Based on a growth curve for GBK from Lewis et al. (2001), ocean quahogs 60-65 mm SL on GBK are 7-10 y old. Small ocean quahogs appear sporadically in survey length composition data for GBK during 1982-2002.

The geographic distribution of survey catches for small ocean quahogs (<70 mm SL, Figure B30) and trends for the same sizes (Figure B24) show that small ocean quahogs are most common in the north (LI, SNE and GBK). Large ocean quahogs (70+ mm SL, Figure B30) have the highest densities in the SNE and GBK regions although appreciable densities are also found in LI and offshore in the NJ region.

2008 clam survey

The 2008 clam survey consisted of 453 stations. The total number of useful random stations (with database HG codes ≤ 36) was 337. There were 97 useful nonrandom stations of which three were to identify areas of high recruitment, seven were test tows, and 87 were repeat tows to test for gear effects or setup tows for commercial depletion experiments.

As described below, sensor data (Figure B31) provide additional useful information about gear performance. GPS position information, speed- and course over ground, and amperage data are available for all stations in the 2008 survey. Survey sensor package (SSP) data from the 2008 survey are available for stations 1-405 and backup sensor data are available for tows 406-453. The backup sensor data include ambient pressure but not y-tilt, manifold pressure or voltage.

There were at least three potentially important events during the 2008 clam survey that might affect dredge gear performance and capture efficiency (Figures B32 and B33): a new pump was installed on the dredge and used starting at station 170 due to failure of the original equipment, a new electrical cable to send power to the pump was installed and first used at station 241 so that the dredge could be deployed in relatively deep water, and a new SSP sensor data package was installed and first used at station 270. Mean differential pressure, voltage and amperage calculated for each tow during periods when the dredge was fishing effectively (smoothed y-tilt ≤ 5.16^{o}, see below) reflect each of these events (Figure B33). Based on these data, and in comparison to previous surveys (Figure A29 in NEFSC 2007a), sensor data indicate no major gear performance issues during the 2008 clam survey.

Tow distance

The NEFSC survey dredge is assumed to be effectively fishing when the angle of attack (y-tilt, after smoothing with a 7-second moving average) is less than 5.16^{o}. The 5.16^{o} figure is a standard criterion which corresponds to the dredge blade extending 1 inch into the sediments based on the geometry of the dredge (NEFSC 2003). The criterion was selected based on sensitivity analysis; tow distance estimates were not sensitive to small changes in the critical angle around 5.16^{o} (NEFSC 2003). Tow distances from sensor data are not used in trend analysis but are very important in depletion studies and other types of studies where absolute estimates of quahog density are required.

The procedures used to calculate 2008 survey tow distances were the same as in NEFSC

(2007a). The first step was to replace missing speed over ground and inclinometer data (which occur infrequently) for each station with interpolated values from a cubic spline. The second step was to smooth the original plus interpolated speed over ground and inclinometer data using a centered seven second moving average (e.g. the smoothed value for $t = 3$ seconds was the average for $t = 1$ to 7 seconds).[5] The final step was to compute the effective tow distance for each tow d_j using:

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

where t is for a one-second time interval, δ_t was a dummy variable equal to one when the dredge was fishing effectively (smooth y-tilt $\leq 5.16^o$), zero otherwise, s_t was smoothed speed over ground (knots) and 3600 is the number of seconds per hour.

Tows during the 2008 survey tended to be shorter than tows during the 1997, 1999, 2002 or 2005 surveys although differences between 2008 and 2002 were relatively small (Figure B34 and see below). Median tow distances for 1999 to 2005 are similar and longer (0.19-0.22 nm). As pointed out in NEFSC (2003), the median tow distance for 1997 (0.26 nm) was larger than median tow distances from other surveys because a slower winch was used to retrieve the survey dredge (Table C7 in NEFSC 2003).

Year	Median Tow Distance (NM)
1997	0.26
1999	0.22
2002	0.19
2005	0.21
2008	0.16

The relatively short tow distance during 2008 triggered a detailed analysis of all available data to determine the possible causes.

Tow distance and depth

Relationships between tow distance and depth differed among surveys (Figure B35). As expected based on medians, tow distance was relatively low during 2008 at all depths (Figure B35). Regression relationships for depth and tow distance were statistically significant and the best model for the entire set includes separate regression lines for each survey (NEFSC 2007a). However, a single regression model (see below) fit to all of the available data (surveys combined) might be useful in future for predicting tow distance based on depth (Figure B36). The combined model indicates that tow distance increases by 0.0014 nm (2.6 meters) for each additional meter of depth.

Parameter	Estimate	SE
Intercept	0.1635	0.003
Depth	0.0014	0.0001
Residual standard error		0.0479

5 Steps 1-2 were done in SAS (note that interpolation precedes smoothing). proc expand data=sdata1 out=sdata2 to=second; by station; ID TowTime; convert TiltY=SmoothAngle / transform=(cmovave 7); convert GPS1_SOG=SmoothSOG / transform=(cmovave 7); run;

Residual degrees of freedom	1497
Multiple R^2	22%

Short tow distance in 2008 survey

Considerable effort was devoted to examining sensor data to determine why survey tows during 2008 were shorter than in previous surveys. A number of possible explanations were considered and four principal hypotheses were examined: 1) the dredge during 2008 may have been towed at relatively high angle of attack (high *y*-tilt) possibly due to minor differences in gear; 2) *y*-tilt sensors were not calibrated during 2008 in the same manner as during 2005; 3) survey protocols differed slightly in the two surveys; or 4) tow distance estimates from SSP sensor data are sensitive to assumptions about the critical angle for effective fishing. Unfortunately, it was not possible to completely eliminate any of these possible explanations.

If *y*-tilt sensors were calibrated so that the apparent *y*-tilt based on sensors was greater than the actual *y*-tilt, then distance estimates based on sensor data may be too low during 2008 but survey data trends would be unaffected. On the other hand, if the angle of attack was actually higher during 2008 or survey protocols differed, then the distance estimates for 2008 should be unbiased but trend estimates may be affected to the extent that the efficiency of the dredge changed.

Station records for successful random tows (survey SHG codes ≤136) indicate that the average duration (based on start and stop times recorded on the bridge), average nominal tow distance (based on ships GPS start and stop locations) and average depth were similar for the 2005 and 2008 surveys. Survey personnel were interviewed but could not recall any changes in protocol. The captain of the R/V Delaware was involved in both the 2005 and 2008 surveys. The chief scientist and watch chiefs were very familiar with clam survey operations. The crewman who operated the winch during 2005 was present in 2008 and on duty 12 h each day, and trained the new operator. The winch and hawser were the same as during the 2005 survey.

Incorrect calibration or mechanical errors affecting y-tilt sensor were considered as a potential cause for the apparently shorter tow distances. To test this hypothesis, tow distance was plotted against depth in the 2008 survey for successful random tows using different symbols for tows with the original and replacement SSP equipment (Figure B37). The relationships between depth and tow distance were very similar indicating that the units were calibrated and working in the same manner. It is still possible, however, that both of the *y*-tilt sensors used during 2008 were calibrated incorrectly.

Tests show that tow distance estimates are not sensitive to the critical angle (5.16^o) assumed in tow distance calculations. A sensitivity analysis in NEFSC (2003) was repeated using data from the 2005 and 2008 surveys (Figure B38). Results indicate that median tow distances for all of the surveys since 1997 are robust to assumptions about critical angle in the range of 4-6^o, which includes the current 5.16^o criterion.

Additional analyses used sensor data from successful random tows during the 2005 and 2008 surveys (Figure B39). All of these analyses used sensor data that were collected between the first and last seconds of each tow during which the smoothed *y*-tilt was less than or equal to 5.16^o (while the dredge was potentially fishing). In particular, the proportion of time on bottom that the dredge was effectively fishing (i.e. proportion of time between the first and last seconds of the tow with smoothed *y*-tilt ≤ 5.16^o), depth, speed over ground, and the mean and standard deviation of unsmoothed *y*-tilt and *x*-tilt were calculated for each tow. The statistical distribution of each variable in each survey was described graphically using box plots with notches that approximate 95% confidence intervals for each median (Figure B39). In addition, linear correlation coefficients were calculated between each pair of variables in each survey (Tables B12 and B13).

Based on box plots (Figure B39) distributions of speed over ground while dredges were potentially fishing were similar for 2005 and 2008 although median speed over ground was slightly lower during 2008. Median time on bottom (difference between the first and last second when the dredge was effectively fishing) was lower in 2008 by about 0.01 hr (36 seconds, which amounts to about 12% of a five minute tow). The proportion of time that the dredge was effectively fishing was lower during 2008. In particular, the median proportions differed by only about 0.01 but the distribution of the proportions was skewed towards smaller values in 2008.

The median *y*-tilt was about 2.5^o during 2005 and 3.7^o during 2008 (Figure B39). As expected, these values were less than the 5.16 ^{o} criterion used to estimate tow distance. The standard deviations for *y*-tilt measurements were similar during both surveys.

The biggest and most surprising (though possibly least important) difference between the 2005 and 2008 surveys was between *x*-tilt measurements (Figure B39). In particular, *x*-tilt values were almost always negative during 2005 and almost always positive during 2008. The standard deviations for *x*-tilt measurements were similar in both surveys. It is possible that the reversal of sign was due to changes in the orientation of the *x*-tilt sensors within the SSP package during 2005 and 2008.

There were 19 out of 36 "substantial" correlations among sensor variables from the 2008 survey compared to 5 out of 29 for the 2005 survey (Tables B12 and B13). In this analysis, "substantial" correlations had an absolute value ≥ 0.5. Many of the substantial correlations were expected (i.e. correlations involving tow time, proportion of time effectively fishing, y-tilt, SD y-tilt and depth). However, several of the substantial correlations were surprising and may help explain the short tow distances during 2008.

Tow time and proportion of time effectively fishing were positively correlated during 2008 but not during 2005. This result suggests the dredge performed better during longer tows during 2008.

The negative correlation between tow time and speed over ground during 2008 (but not 2005) was surprising because survey protocols are designed to achieve both a constant time (5 minutes) at specified speed (1.5 kt). In the experience of survey personnel, start and stop times used for this purpose are clear and easy to determine. In principle, speed over ground could have been determined very accurately on the bridge based on GPS. The correlation in 2008 suggests, however, that tow time and speed may have been adjusted to obtain the desired distance.

The negative correlation between *x*-tilt and *y*-tilt and between *x*-tilt and depth during 2008 (but not 2005) indicates that dredge performance during 2008 was more sensitive to depth. The positive correlations between *y*-tilt and speed over ground as well as between the SD of *y*-tilt and speed over ground indicate that dredge performance was more sensitive to speed during 2008 than during 2005.

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 during the NEFSC survey. As described above, the original ("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.

Two types of repeat tows were carried out in connection with the 2008 NEFSC clam survey to quantify the potential effects of changes in the pump and electrical cables used on the survey dredge. "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 cable or plump) and afterwards by the *F/V Endeavor*.

Ratio estimators and a linear model analysis (see below) indicate potential cable and pump effects for ocean quahog tows during the 2008 survey were not significantly different from zero. The two ratio estimator and linear model analyses were not completely independent because they used almost the same survey data.

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 end of the 2005 survey and beginning of the 2008 survey, 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.

DE2DE2 repeat stations

Ocean quahog catches (50+ mm SL) were standardized using sensor tow distance to a standard area swept (5 ft x 0.15 nm = 4557 ft^2 = 423 m^2) for use in all analyses. If the sensor based tow distance was missing for a station, then the median tow distance for successful random tows during 2008 was used instead. Pairs of stations were omitted if either tow was "unsuccessful" based on sensor data (NEFSC 2007a) or had a database HG code > 36. DE2DE2 repeats with zero quahog catch in both tows would not affect estimates and were also omitted. Based on these criteria, repeat station data were available for 17 DE2DE2 repeat stations (Table B14).

The DE2DE2 repeat station data were more useful for detecting potential cable effects than pump effects. All of the original tows were made with the old cable and all of the repeat tows were made with the new cable. Five of the original tows were made with the old pump and all of the repeat tows were made with the new pump (Table B14). Fortunately, differential pressure data indicate that pump effects were likely minor because differential pressure was within the normal operating range before and after the new pump was installed (Figure B33).

The null hypothesis of no cable effect was not rejected because the ratio estimator (sum of catches with new cable / sum of catches with old cable) for DE2DE2 repeat stations was 0.8 (SE 0.22) and the 95% confidence interval (0.36, 1.23) included one (Figure B40).

DE2FV repeat stations

The repeat stations used in this analysis included random and nonrandom stations occupied by the Delaware originally during the survey and later by the commercial vessel (Table B15). Some of the survey stations were setup tows for depletion experiments that could be treated as if they were repeated by the first one or two tows in the ensuing commercial depletion experiment (see below). Length composition data were used to calculate numbers of quahogs 90 mm SL or larger, which were adjusted to the same area swept (423 m^2).

Only quahogs over 89 mm SL were used because commercial and survey selectivity curves indicate that ocean quahogs are at least 85% selected at 90 mm SL and the 90 mm cutoff is used in commercial depletion studies that involve the *R/V Delaware II* and a wide range of commercial vessels.

Forty-five stations had survey or commercial catches larger than zero (Table B15 and Figure

B41). Ratio estimators (sum of survey catches / sum of commercial vessel catches) are given below. The difference between the ratio estimators for the new pump with the old and new cables is 0.3520-0.2849=0.0671, the variance is 0.008+0.0006=0.0086, and the 95% confidence interval is (-0.11, 0.24). Thus, DE2FV ratio estimators indicate that the new cable reduced capture efficiency by about (0.3520 - 0.2849) / 0.3520=20% but the difference is not statistically significant (see below). The ratio estimate 0.31 for all of the data indicates that the capture efficiency for the survey dredge was about 31% of the capture efficiency for the commercial dredge.

DE2 configuration	Ratio	N	Var	SE	CV	Low 95% CI	Hi 95% CI	Bias
New pump-Old cable	0.3520	14	0.0080	0.0893	0.2538	0.1769	0.5271	0.0040
New pump-New cable	0.2849	28	0.0006	0.0238	0.0835	0.2383	0.3316	0.0016
Old pump-Old cable	0.4798	3	0.0708	0.2661	0.5546	-0.0418	1.0013	-0.0200
All	0.3183	45	0.0015	0.0386	0.1211	0.2427	0.3939	0.0013

Linear model analysis

Step-wise linear models were fit to the DE2FV data to refine estimates and produce variances that characterize uncertainty in estimated pump and cable effects. The dependent variable was the log of survey catch / commercial catches. Records with zero survey or commercial catches were omitted from linear models because the log of the catch ratio was undefined. A total of 41 observations were available for linear model analysis. Sample size was N=24 for pairs that had survey tows with the new pump and new cable, N=14 for survey tows with the new pump and old cable, and N=3 for survey tows with the old pump and old cable (Table B15).
Models considered in the analysis ranged from:

logRatio ~ 1

that hypothesizes a constant log ratio with no pump or cable effects to

logRatio ~Pump*ElecCable

that hypothesizes pump and electrical cable effects plus their interaction (i.e. different cable effects for each type of pump). The “best” model with the lowest AIC score was identified and estimated by the stepwise search.

The best linear model was the simplest case with logR = -1.277 (se 0.116, $p<e^{-13}$) indicating a constant log ratio with no pump or cable effects. The ratio of survey/commercial catches implied by this model is $e^{-1.277} = 0.28$ (CV=0.12) with an approximate 95% CI (0.22-0.35).

Depletion studies and survey dredge efficiency

Survey dredge efficiency estimates are important in this assessment because they help scale relative trends to actual biomass levels in modeling and because they can be used to estimate swept-area biomass directly. By definition, dredge efficiency estimated in depletion experiments is the probability of capture (i.e. of being handled on deck) for an ocean quahog that is in the path of the dredge and large enough to fully selected by the gear. Effects of shell length and size selectivity on catches and efficiency estimates are accommodated in depletion study analyses by restricting analysis to ocean quahogs 90 mm SL or larger, which have high size selectivity (≥ 0.85) in both survey and commercial clam dredges (Figure B21).

In brief, depletion experiments usually begin with “setup” tows by the *R/V Delaware II* during the NEFSC clam survey. “Survey density” is calculated for each tow by dividing the catch by area swept, which is the dredge width times the distance traveled while the dredge was effectively fishing based on sensor data (i.e. where while y-tilt $\leq 5.16^{o}$).

Mean survey density for each depletion experiment site is calculated by averaging the survey density from each setup tow. After the setup tows are completed, additional overlapping tows are made repeatedly by the same or different vessel over the area immediately adjacent to the setup tows until a significant decline in catch per tow is noted. Care is taken to ensure that setup tows are close to each other with little or no overlap and close to the corresponding depletion tows.

Vessel position is used as a proxy for dredge position during depletion experiments. Experiments during 1997-1998 used Loran-C to track the position of the depletion vessel with positions recorded by hand on datasheets at 30 second intervals. GPS with stored data has been used since 2002 to record position data at 6-30 second intervals. Setup tows have always been tracked by GPS at 1 second intervals. In other words, the frequency and type of information has been consistent for setup tows by the *R/V Delaware II* but has varied for depletion tows by commercial vessels.

One "Delaware II" depletion experiment has been completed for ocean quahog (experiment OQ1999-01 DE2 in Tables B16 and B17). In Delaware II depletion experiments, the research vessel carries out both the setup and depletion tows.

A relatively large number of commercial depletion experiments have been carried out (Tables B16 and B17). Commercial depletion experiments use a commercial vessel to make depletion tows after setup tows are made by the *R/V Delaware II*. Commercial depletion experiments are the preferred approach to estimating survey dredge efficiency because commercial dredges perform consistently with high efficiency and deplete the experimental site faster. Commercial dredges are inherently more efficient than the NEFSC survey dredge because water jets run at higher pressure on commercial boats and commercial dredges are heavier and less prone to vibration. Moreover, they are larger so that there is less uncertainty about their location. Bar spacing and sorting equipment on deck are usually adjusted to enhance retention of relatively small ocean quahogs before a depletion study. However, even with these adjustments to gear, commercial dredges catch relatively lower proportion of small quahogs than survey dredges, which have a small mesh liner.

In Delaware II depletion experiments, the survey dredge efficiency is estimated directly. In commercial depletion studies with setup tows, the estimated survey dredge efficiency (e) is:

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

where D is the estimated density from the Patch model and d is the mean survey density for the site. One disadvantage of commercial depletion experiments is the extra variance in estimated dredge efficiency due to the variance in mean survey density d. Variance of mean survey density tends to be high because the number of setup tows is typically 3-5 (Table B16).

Survey dredge efficiency estimates are available in NEFSC (2007a) for 12 depletion experiments with setup tows (11 commercial and 1 Delaware II), out of 16 total depletion experiments conducted during 1997 and 2005 (Tables B16 and B17). Three additional new commercial depletion experiments with setup tows were carried out (OQ2008-3 in SNE and OQ2008-1 and OQ2008-2 in LI, Figure B32) following the 2008 NEFSC clam survey by the *F/V Endeavor* with scientific staff from Haskin Shellfish Research Laboratory and NEFSC (Tables B16 and B17; Figures B42 through B44).

As described above, the electrical cable and pump were replaced during the 2008 survey (Figure B32). The original electrical cable and new pump were used for setup tows during the first experiment (OQ2008-01), while the new electrical cable and new pump were used during the second and third experiments (OQ2008-02 and OQ2008-03).

2008 depletion experiment methods

The *F/V Endeavor* used a 12.5 ft clam dredge that operated at a differential pressure of about 60 psi (measured at depth in the manifold of the dredge). At each depletion site, the number of bushels of clams was counted for every tow and fractional bushels were estimated by eye. In addition, one full bushel was counted and measured and an additional full bushel was counted on every fifth tow, beginning with tow two.

The survey sensor package (including GPS) was mounted on the dredge used by the F/V Endeavor during 2008, but was operational at only 106 out of a total of 232 stations due to lack of time between tows to charge batteries (particularly during depletion tows) and lack of staff to operate the unit on leg 3 of the survey. The total number of stations (232) includes stations used for ocean quahog and Atlantic surfclam depletion experiments, repeat tows, and surfclam size selectivity studies.

The start and end of fishing (when the dredge was on the bottom) was easy to determine by visual examination of SSP y-tilt and pressure sensor data. Based on SSP data, the angle of attack for the commercial dredge used by the F/V Endeavor was not prone to excess variability in y-tilt (Figure B45).

To determine tow distance at stations without SSP data, a backup pressure (depth) sensor and a backup GPS were used. The resolution of the backup pressure sensor is 4-5 meters. Backup pressure and GPS data were recorded every five seconds, in contrast to every second on the SSP. For these reasons, backup sensor data are more difficult to use in estimating dredge paths.

To develop a means to estimate tow start and stop time using backup sensor data, times on and off bottom from SSP data for OQ2008- 1 and OQ2008-02 (34 stations total) were compared to visually determined times on and off bottom from backup pressure sensor and backup GPS data. Visually determined time off bottom estimates were similar to time-off-bottom estimates based on SSP data. However, subjectively determined time-on-bottom values were greater than the SSP time on bottom values about 15-20 seconds. Time on bottom was difficult to judge because the commercial dredge was deployed using winches that do not spool freely as the dredge is deployed.

After some experimentation, 15 seconds were subtracted from the subjective time on bottom estimates from backup sensor data. The adjusted time on bottom estimates for the 34 test stations differed from SSP time on bottom values by only 4 seconds on average, with positive differences as likely as negative differences. This alternate approach was used to identify time on and off bottom based on backup sensors for all commercial tows.

See Appendix B4 for a detailed description of the cooperative survey work by the *F/V Endeavor* during 2008 and calculation of tow distances.

Patch model

The Patch model (Rago et al. 2006) was used to analyze all of the depletion experiment data used in this assessment (Table B16). Estimates for the 1997-2005 surveys are from NEFSC (2007a). Estimates for the 2008 survey (Tables B16 and B17) are described below. The Patch model is a standard approach used in NEFSC stock assessment work for a variety of shellfish and sedentary demersal finfish including Atlantic sea scallops NEFSC (2004b), ocean quahog (NEFSC 2004; 2007a), Atlantic surfclam (NEFSC 2003; 2007a) and goosefish (NEFSC 2005). The most important characteristics of the Patch model are that it is spatially explicit and it is not necessary to assume that ocean quahogs mix randomly across the entire site after each depletion tow.

The Patch model estimates three parameters for each depletion experiment: initial ocean quahog density D; depletion dredge efficiency e, and a measure of variance k in catch data. Cell width in the Patch model was assumed to be twice the dredge width. The "gamma" parameter in the Patch model, used to measure indirect effects on catches (e.g. ocean quahogs lost from the study site without being counted on deck), was fixed at the ratio of the dredge width and cell width (γ=0.5) so that no indirect effects were assumed to occur.

Parameters are estimated by maximizing the likelihood of the observed catch data under the assumptions that the dredge path is known and that the catches are sampled from a negative binomial distribution. In computing the likelihood for the catch in each tow, the model considers the number of times each grid sampled during the tow had been sample during previous tows and adjusts the predicted catch for each tow accordingly. Likelihood profiles are used to compute confidence intervals for all model estimates and residual plots (observed – predicted catches) are used to judge model fit.

Modeling procedures

Revised procedures described in the last ocean quahog assessment (NEFSC 2007a) were used without modification for ocean quahog in this assessment. In particular, latitude and longitude data generated during the tows by GPS were smoothed with cubic splines (Figures B46 through B48). The smoothed latitude and longitude position data were interpolated along straight lines between the smoothed points to a distance of 5 ft. The grid size for 2008 commercial depletion experiments was 25 ft because the dredge was 12.5 ft wide.

As described above, SSP data were available for the OQ2008-1 and OQ2008-3 experiments, but not for the OQ2008-2 experiment. Patch model analyses in this assessment used the adjusted tow paths based on backup sensor data described above, instead of tow paths based on SSP data, to enhance interpretation and comparability of results. Otherwise, differences in start time calculations would have been confounded with effects of different electrical cables.

Survey dredge efficiency and other Patch model estimates

There were 2-4 setup and 17 depletion tows for depletion experiments completed during 2008 (Tables B16 and B17). All of the setup tows used in the analysis were located within approximately 300 m of the depletion tows. All setup tows for the same site used the same combination of electrical cable and pump. All setup tows used in the analysis were successful based on HG codes and analysis of sensor data (Appendix B3). Sensor tow distances were available for all setup tows with the exception of station 355 in OQ2008-03, which used the median tow distance for all successful tows during 2008.

Patch model fit to commercial depletion catch data was poor for OQ2008-1 but reasonably good for OQ2008-2 and for OQ2008-3 (Figures B49 through B51). Commercial dredge efficiency estimates for the OQ2008-1 and OQ2008-3 experiments were on their upper feasible bound (1.0). The area in Long Island where the OQ2008-1 and OQ2008-3 experiments was conducted has a relatively thin layer of sand on top of peat. The thin layer of sand tends to concentrate ocean quahogs near the surface where they are easy to catch (Pers. comm. E. Powell, Rutgers Shellfish Research Laboratory, Port Norris NJ).

The average survey dredge efficiency estimate for 2008 was 0.320 and estimates ranged from 0.207 to 0.467 (Table B17). The mean estimate for 2008 is relatively high compared to the "best" median estimate of 0.165 and mean estimate of 0.248 from the twelve depletion studies completed during 1997-2005 (Table B17). However, the individual and mean estimates for 2008 fall well within the range and distribution of estimates from depletion studies during 1997-2005 (Table B17).

The mean Patch model density estimate for 2008 was 0.091 quahogs per ft^2, which is similar to the estimate 0.097 quahogs per ft^2 in NEFSC 2007a from earlier studies (Table B17).

With the new data (N=15), the new median best estimate of survey dredge efficiency is 0.169 (mean 0.264, Table B18). A 90% confidence interval calculated by bootstrapping the fifteen estimates (15,000 iterations) had bounds of 0.154-0.285.

Based on Patch model estimates (Table B18), The *F/V Endeavor* appears to have consistently high efficiency for ocean quahogs. The estimates of commercial efficiency for 2008 experiments ranged 0.78 to 1.0.

Uncertainty and sensitivity

A vessel towing at 3 knots (a typical commercial tow speed) will travel 25 ft (the width of the grids used in analysis of 2008 depletion study data, see below) in 4.9 seconds (NEFSC 2007a). Thus, variability in start time estimates adds uncertainty to position data that may affect Patch model estimates to some (probably minor) degree.

As described above, the electrical cable and pump were replaced during the 2008 survey. The original electrical cable and new pump were used for setup tows during the OQ2008-01 experiment, while the new cable and new pump were used during the OQ2008-02 and OQ2008-03 experiments. Different cables (and any other gear differences in general) may cause changes in actual dredge efficiency if pump voltage and pressure change. The variance of survey dredge efficiency estimates has not been fully characterized, but is probably substantial based on the variability of estimates within and between years (Table B16). For these reasons, it is probably better to view the full set of depletion experiment dredge efficiency estimates as a distribution with an underlying mean and variance (Table B18). Individual estimates and estimates for a single survey are too imprecise to be used directly in making survey-specific estimates of survey dredge efficiency.

The accuracy of position information, smoothing, choice of grid size and assumptions about indirect effects are important considerations and uncertainties. The accuracy of position data for the ship as a proxy for position of the dredge probably depends on many factors and has probably varied among depletion experiments (NEFSC 2007a). Sensitivity analyses in NEFSC (2007b) showed that smoothed position data produce higher estimates of initial density and lower estimates of dredge efficiency than unsmoothed position data.

Dredge efficiency is harder to estimate for ocean quahogs than Atlantic surfclams (NEFSC 2007b) because ocean quahogs are found in deeper water (which makes dredge position data less reliable) and because they burrow deeper into sediments depending on environmental conditions (and are probably sampled less efficiently).

Results indicate that uncertainty in Patch model estimates is greater than depicted in likelihood profile confidence intervals (Figures B49 through B51). Preliminary results seem to indicate that the statistical properties of estimates vary among experiments in a complicated manner that depends on the spatial distribution of depletion tows, number of tows, accuracy of position data and on the density, variance in density and spatial distribution of ocean quahogs.

The gamma parameter is theoretically estimable but estimation has proven difficult in practice because the estimate for gamma is correlated with other estimates in the model and dependent on assumptions about cell size (Rago et al. 2006). Efficiency and density estimates from the Patch model tend to decrease as the assumed level of γ and indirect effects increases (Rago et al. 2006).

Assumptions about grid size reflect a compromise between the accuracy of position data and the tenability of the assumption that animals mix within cells after each tow. Patch model estimates for ocean quahog are moderately sensitive to the changes in the assumed grid size. In particular, efficiency estimates tend to increase and density estimates tend to decrease as the grid size increases (NEFSC 2007a).

Efficiency corrected swept area biomass

Efficiency corrected swept area biomass (ESB) was estimated for years when NEFSC clam surveys collected sensor data (1997, 1999, 2002, 2005 and 2008) (Table B19). ESB results are used primarily as prior information for use in fitting other stock assessment models.

ESB for ocean quahog (Table B19) was calculated:

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

where:

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

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

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

Habitat area for ocean quahogs in each region was estimated:

$$A' = Au$$

where $\underline{u}$ is the proportion of random tows in the region not precluded by rocky or rough ground (ocean quahogs occupy smooth sandy habitats), and *A* is the total area computed by summing GIS area estimates for each survey stratum in the region. Estimates for *u* in this assessment are the same as in NEFSC (2007a).

Mean catch per standard tow ($\bar{\chi}$) is the stratified mean catch of fishable ocean quahog for individual tows after adjustment to standard tow distance based on tow distance measurements from sensor data (d_s):

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

Only random tows were used in calculations of ESB. Tows without sensor data, with gear damage or poor pump performance were excluded from ESB calculations. Following NEFSC (2004a), and as described above, tow distance was measured for each station assuming that the dredge was fishing when the blade penetrated the substrate to a depth of at least one inch. Thus, the tow distance at each station was the sum of the distance covered while the dredge angle was ≤ 5.16^{o}.

ESB estimates for the entire ocean quahog stock during 1997-2005 (Table A15, NEFSC 2004a) were computed using a formula that facilitated variance calculations (see below):

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

Catch-ESB Mortality estimates

Fishing mortality rates were estimated directly from the ratio of catch (landings plus an assumed 5% incidental mortality allowance) and ESB data for each region and year (Table B20). The primary purpose for these calculations was as a check on model based fishing mortality estimates. Ocean quahog biomass levels may change slowly, fishing and natural mortality rates are low for ocean quahogs, and the survey during June provides a good approximation to average biomass. It was advantageous to use the ratio estimator because the surveys occur in June and because it was easy to include a wide range of uncertainties in variance calculations (see below).

Uncertainty in ESB and mortality estimates

Variance estimates for ESB and related mortality estimates are important in using and interpreting results (Tables B19 and B20; Figures B52 and B53). Formulas for estimating ESB and mortality for a single region are products and ratios of constants and random variables. Random variables in calculations are typically non-zero (or at least non-negative) and can be assumed to be approximately lognormal. Therefore, we estimated uncertainty in ESB and related mortality estimates using a formula for independent lognormal variables in products and ratios (Deming 1960):

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

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

CV estimates for terms used in ESB and related estimates (Tables B19 and B20) were from a variety of sources and were sometimes just educated guesses. The CV for best estimate of survey dredge efficiency (e) was 0.21, calculated by bootstrapping the median (15,000 bootstrap iterations) (Table B18). For lack of better information, CVs for sensor tow distances (d), area swept per standard tow (a), total area of region (A), percent suitable habitat (u), and catch were all assumed to be 10%. The CV for area swept (a) is understood to include variance due to Doppler distance measurements and variability in fishing power during the tow due, for example, to rocky or muddy ground.

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

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

"VPA" estimates

VPA estimates of biomass and fishing mortality (Figure B54) for ocean quahogs are useful as a way to verify estimates from the KLAMZ model and for regions where the KLAMZ model is not applicable (see below). Surprisingly, for such a crude approach, VPA biomass estimates for the stock in the exploited region are similar to survey trends (not used in calculating VPA) and estimates from other more sophisticated modeling approaches (Figure B55).

Assuming no recruitment and that growth exactly balances natural mortality, ocean quahog biomass on January 1st and annual fishing mortality rates can be estimated for each region using a simple virtual population analysis or "VPA" approach (NEFSC 2004a). Efficiency corrected swept-area biomass estimates for 2002, 2005 and 2008 are averaged and used as the estimated biomass in 2005 which "anchors" the calculations as they work forward and backward in time. Averages for 2002-2008 are used in place of the 2005 ESB because the estimates for individual years are not precise (Table B19).

The VPA biomass estimate for January 1, 2005 is:

$$b_{2005} = \frac{B_{2002} + B_{2005} + B_{2008}}{3} - \frac{C_{2005}}{2}$$

where b_y is the VPA biomass estimate for January 1 in year y, B_y is the efficiency corrected swept area biomass for June in year y, C_{2005} is total catch weight (landings plus a 5% allowance for incidental mortality). The first ratio on the right-hand side is average efficiency corrected swept-area biomass during 2002-2008 and used as an estimate of biomass in June of 2005. Catch for 2005 is divided by two prior to subtraction because NEFSC clam surveys occur during June, when the year is half over.

Biomass estimates for years before 2005 (up to the beginning of 2009) were calculated:

$$b_{y<2005} = b_{2005} + \sum_{i=y}^{2004} C_i$$

Biomass estimates for years after 2005 were calculated:

$$b_{y>2005} = b_{2005} - \sum_{i=2005}^{y-1} C_i$$

Fishing mortality rates from VPA estimates were calculated by solving the catch equation with instantaneous rates for natural mortality and somatic growth both zero. Based on these equations, the VPA biomass estimate for GBK ocean quahogs is the mean of ESB estimates for 2002, 2005 and 2008 (1,651 thousand mt meats) because no catch occurs there.

KLAMZ model

KLAMZ (technical description in Appendix B6) is a forward projecting stock assessment model based on the Deriso-Schnute delay-difference equation (Deriso 1980; Schnute 1985; Quinn and Deriso 1999). The delay-difference equation is an implicitly age structured population dynamics model that is mathematically identical to common age-structured models if fishery selectivity is "knife-edged", somatic growth follows the von Bertalanffy equation, and natural mortality is the same for all individuals in the modeled population. Knife-edge selectivity means that all individuals alive in the model during the same year experience the same fishing mortality rate. Natural mortality rates and growth parameters can change from year to year in the KLAMZ model but are assumed to be the same for all individuals alive during each year. The model is implemented in AD Model Builder and Excel but only the AD Model Builder version was used in this assessment.

The main assumptions in the KLAMZ model for ocean quahog are: recruitment is the same in all years (and possibly zero) or follows a "step" pattern with one constant level during early years and a different constant level during later years (see below); fishery selectivity is knife-edged; the natural mortality rate is low or constant, and growth in weight can be described by a von Bertalanffy growth curve. Recruitment is assumed to follow a simple function (and inevitably estimated to be very low for ocean quahogs) because no reliable recruitment index current exists, recruitment levels appear to be very low based on survey data, and trends in stock dynamics appear primarily due to fishing mortality.

Recruitment to the ocean quahog fishery is not knife-edged and actually occurs at sizes of about 51-86 mm SL (Figure B21). Under these circumstances, KLAMZ can be used to track trends in fishable (instead of total) biomass. Fishable biomass is dominated by relatively large individual ocean quahogs that are readily captured. Survey data used in the KLAMZ model are in units of mean kg per standard tow for the "fishable" portion of survey catches (Table B10).

Despite simplifying assumptions, KLAMZ has proven to be a relatively robust model with little or no retrospective bias which has been used successfully in for a relatively large number of stocks. It provides useful estimates of long-term biomass and fishing mortality, performs relatively well with very limited information about age and growth and when explicitly age-structured models are difficult to apply. One of the chief reasons for the utility of the KLAMZ model is statistical simplicity. The model used for ocean quahog, for example, estimates only 2-4 parameters.

Model configurations

KLAMZ model estimates were for ocean quahogs in the DMV, NJ, LI and SNE regions or for the stock in the exploited region (entire stock less GBK) during 1977-2008. The model was not used for SVA because survey data for SVA are noisy and incomplete. Configurations of the KLAMZ model for ocean quahog in each region were similar to the "best" configurations identified in the last assessment (NEFSC 2007a) following a thorough analysis of a wide range of alternate configurations. Changes are highlighted in the descriptions below. The most important changes are use of the step function recruitment pattern for LI, SNE and the exploited region. A KLAMZ model was applied to the stock in the exploited region for the first time in this assessment.

Data used in KLAMZ models for ocean quahog in this assessment were: NEFSC clam survey biomass trends and associated CV's for 1982-2008 (mean kg per tow of fishable biomass by region and year, Table B10); efficiency corrected swept-area biomass estimates for 1997-2008; and catch during 1977-2008 (landings in Table B2 with amounts for region unknown prorated by region with landings, plus a 5% allowance for incidental mortality). LPUE data are included in the model (Table B6) but only for comparative purposes (i.e. they had nil effect on model estimates). Catch data for ocean quahogs were assumed accurate and not estimated in the model. Efficiency corrected swept-area biomass (ESB) estimates for 1997-2008 are used as "prior" information that helps scale of model estimates, but were not used to measure trends because the survey data provides trend information (see below).

NEFSC clam survey and swept-area biomass data for 1994 were omitted for all stock areas because electrical voltage supplied to the pump on the survey dredge was set to 480 v, rather than 460 v, artificially increasing dredge efficiency during the 1994 survey (NEFSC 2004). In addition, survey and swept area biomass data for GBK during 1982-1984, 1989, 2002 and 2005 were also omitted because of poor survey coverage during those years.

Assumptions about growth are the same as in the last assessment. In particular, the growth parameters $\rho = e^K$ (where K=0.0176 is the von Bertalanffy growth parameter for weight), $J_t = w_{k-1}/w_k$ = 0.9693 (where w_j is predicted weight at age j) are constant and the same for all regions (NEFSC

2004). These growth parameters mean that quahogs in the model are slow growing, and that quahogs recruit to the fishery (reach 70 mm SL) at age k=26 (Figure A62, NEFSC 2004). Growth patterns differ among regions (Lewis et al. 2001) but ocean quahogs are difficult to age and there is too little information available to use region-specific growth curves (NEFSC 2000). The MAB growth curve was used for all regions where fishing occurs and the growth curve for GBK was used in the model for GBK (Lewis et al., 2001; Figure B3). The assumed natural mortality rate was M=0.02 y^{-1}, except in sensitivity analyses.

An assumed level of variance in instantaneous somatic growth rates (IGR) for old recruits is used to help estimate the initial age structure of ocean quahogs in the initial years of the model (Appendix B6). However, as described in NEFSC (2007a), this constraint is unimportant because estimated age structures were stable due to assumptions about recruitment and low mortality rates.

ESB data are important in KLAMZ models for ocean quahogs as a source of information about biomass scale. To use ESB data as a measure of scale while ignoring trend (see Appendix B6), the likelihood component for trends in ESB data were set to 10^{-6} so that the survey scaling parameter Q was calculated but the trend was ignored. Information in ESB data about biomass scale is contained in the estimated survey scaling parameter Q.

As described in Appendix B6, the likelihood of the survey scaling factor is calculated assuming that estimates of Q are from a lognormal distribution:

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

where L is the negative log likelihood, $\varphi = \sqrt{\ln(1 + CV)}$ and $\tau = \ln(\overline{q}) - \frac{\varphi^2}{2}$ is the mean of the log normal distribution. For ocean quahog ESB data, the mean of the prior $\overline{q} = ln(1) = 0$ if ESB data measure stock biomass accurately and CV=0.21 is the bootstrap coefficient of variation (standard deviation / mean) for the median survey dredge efficiency used in calculating ESB (Table B18).

Parameters estimated

KLAMZ models for ocean quahog in this assessment estimate two to four parameters by maximum likelihood and numerical optimization. The parameters potentially estimated are logarithms of: 1) biomass at the beginning of 1977, 2) escapement biomass (total biomass less biomass of new recruits) at the beginning of 1978, and 3) annual recruitment biomass (which is assumed constant over time for each region with one parameter or constant during two time periods with two parameters). In models where recruitment was too low to estimate, recruitment was fixed at an assumed value near zero (1 kg y^{-1}) which reduced the number of parameters estimated.

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

Variance estimates

Variances for biomass and fishing mortality estimates and for model parameters can be estimated by the delta method using exact derivatives calculated by AD Model Builder libraries, by bootstrapping, or by MCMC (Appendix B6). Estimates in this assessment were from the delta method or bootstrapping.

KLAMZ Results-DMV

As in previous assessments (NEFSC 2004; 2007a), estimated recruitment was near zero and hard to estimate in preliminary runs for DMV. The annual recruitment level was therefore fixed at very low value (1 kg y^{-1}) in final runs. Survey data generally indicate that recruitment has been low in DMV since 1978 (Figure B24) although some small ocean quahogs are present (Figure B30).

The KLAMZ model for ocean quahog in the DMV area (Figure B56) fit NEFSC survey and LPUE data well (LPUE data did not affect model estimates). The CV of arithmetic scale residuals (26%) for NEFSC survey data was smaller than the mean CV (35%) for mean kg/tow survey data but within the range of observed values (21%-53%). The estimated survey scaling parameter for ESB data was Q=0.96 indicating that the model was able to match the observed ESB biomass levels on average during 1995-2008 using the catch data and trends in NEFSC survey data.

Based on KLAMZ model results, biomass of ocean quahogs in DMV declined steadily after 1978 (Figure B56). Estimated fishable biomass during 2008 was 30% of the estimate for 1978 (Figure B56).

KLAMZ Results-NJ

The KLAMZ model for ocean quahog in the NJ area (Figure B57) fit NEFSC survey and LPUE data well (LPUE data did not affect model estimates). The CV of arithmetic scale residuals (43%) for NEFSC survey data was larger than the mean (19%) and range (14%-24%) of CV values for mean kg/tow survey data. The estimated survey scaling parameter for ESB data was Q=0.96 indicating that the model was able to match the observed ESB biomass levels on average during 1995-2008 using the catch data and trends in NEFSC survey data.

Based on KLAMZ model results, biomass of ocean quahogs in NJ declined steadily after 1978 (Figure B57). Estimated fishable biomass in NJ during 2008 was 40% of the estimate for 1978.

KLAMZ Results-LI

Preliminary KLAMZ model fits for ocean quahog in the LI area indicated that the model with constant recruitment was not able to match the apparently increasing abundance trends before 1994 and decreasing abundance trend afterwards without estimating an implausible survey scaling parameters Q=0.48 (Figure B58). A step function recruitment model with different levels of constant recruitment before and after a specified point in time was therefore used instead. A series of runs with the change in recruitment occurring at 1990 to 1999 indicated 1994 was the best change year for recruitment (Figure B59). The step function for LI allows for a higher level of recruitment prior during 1977-1993 (Figure B60) while a strong year class was recruiting to the fishery (Figures B24 and B28) and a lower level afterward.

The model (Figure B61) with step function recruitment fit the survey and LPUE data for ocean quahogs better than the model with constant recruitment (LPUE data did not affect model estimates) and the change in total likelihood indicated that the additional parameter was statistically significant. The CV of arithmetic scale residuals (25%) for NEFSC survey data was larger than the mean (18%) but within the range (14%-28%) of CV values for mean kg/tow survey data. The estimated survey scaling parameter for ESB data was Q=1.04 indicating that the model was able to match the observed ESB biomass levels on average during 1995-2008 using the catch data and trends in NEFSC survey data.

Based on KLAMZ model results (Figure B61), biomass of ocean quahogs in LI increased steadily after 1978 until 1993 when recruitment decreases and fishing mortality increased to maximum levels. Estimated fishable biomass in LI during 2008 was 89% of the estimate for 1978 and 70% of the maximum estimated biomass during 1992 (Figure B61).

KLAMZ Results-SNE

The KLAMZ model for ocean quahog in the SNE area (Figure B62) with a single recruitment parameter did not fit the apparently increasing trend in survey data prior to 1994 and decreasing trend afterwards. A step function recruitment model was therefore used instead. A series of runs with the change in recruitment occurring at 1990 to 1996 indicated 1993 was the best change year for recruitment (Figure B63). The step function for LI allows for a higher level of recruitment prior during 1977-1992 (Figure B64) while a strong year class was recruiting to the fishery (Figures B24 and B28) and a lower level afterward.

The model with step function recruitment (Figure B65) fit NEFSC survey and LPUE data better (LPUE data did not affect model estimates) and the change in total likelihood indicated that the additional parameter was statistically significant. The CV of arithmetic scale residuals (27%) for NEFSC survey data was smaller than the mean CV (35%) for mean kg/tow survey data but was within the range of observed values (18%-47%). The estimated survey scaling parameter for ESB data was Q=1.04 indicating that the model was able to match the observed ESB biomass levels on average during 1995-2008 using the catch data and trends in NEFSC survey data.

Based on KLAMZ model results, biomass of ocean quahogs in SNE increased steadily and then declined after 1992 when recruitment declined and fishing mortality increased dramatically (Figure B65). Estimated fishable biomass in SNE during 2008 was 99% of the estimate for 1978 and 78% of the maximum estimated biomass during 1994.

KLAMZ Results-GBK

The KLAMZ model for ocean quahog in the GBK area fit NEFSC survey data well although only 5 survey observations were available (Figure B66). The CV of arithmetic scale residuals (21%) for NEFSC survey data was smaller than the mean CV (18%) for mean kg/tow survey data but within the range of observed values (18%-27%). Only three ESB observations were available for GBK. The estimated survey scaling parameter for ESB data was Q=1.01 indicating that the model was able to match the observed ESB biomass levels on average during 1995-2008 and trends in NEFSC survey data to some extent. Trends in survey and ESB data were conflicting. The survey data varied without trend during 1986-2008. The shorter (and higher variance) ESB data for 1997, 2000 and 2008 showed a consistent increase.

Based on KLAMZ model results, biomass of ocean quahogs in GBK increased steadily after 1978. Estimated fishable biomass during 2008 was 13% higher than the estimate for 1978 (Figure B66).

KLAMZ Results-exploited region

The KLAMZ model for ocean quahog in the exploited stock area (Figure B67) fit NEFSC survey trends reasonably with a single recruitment pattern. However, the model with step function recruitment was significantly better based on log likelihood. A series of runs with the change in recruitment occurring at 1990 to 1996 indicated 1993 was the best change year for recruitment (Figure B68). The step function allows for a higher level of recruitment prior during 1977-1992 (Figure B69) and a lower level afterward.

The model with step function recruitment (Figure B70) fit NEFSC survey data better but fit LPUE poorly (LPUE data did not affect model estimates). Lack of fit to LPUE data was probably due to the fishery shifting its distribution across the large area modeled to maintain relatively high catch rates. The CV of arithmetic scale residuals (21%) for NEFSC survey data was larger than the mean (13%) and range (10%-14%) of CV values for mean kg/tow survey data. The estimated survey scaling parameter for ESB data was Q=1.06 indicating that the model was able to match the observed ESB biomass levels on average during 1995-2008 using the catch data and trends in NEFSC survey data.

Based on KLAMZ model results (Figure B70), biomass of ocean quahogs in entire stock area less GBK declined after 1978 and then more steeply after 1994 when recruitment declined and fishing mortality was relatively high. Estimated fishable biomass during 2008 was 62% of the estimate for 1978.

Biomass estimates from the KLAMZ model for the exploited region were similar to the sum of biomass estimates from regional KLAMZ models for DMV, NJ, LI and SNE plus VPA estimates for SVA, and to the sum of regional VPA estimates (Figure B55). Despite this high degree of consistency, 95% confidences intervals from the model for the exploited stock were wide (e.g. 1513 to 3981 thousand mt in 1978 and 1056-2195 thousand mt in 2008) indicating considerable uncertainty in estimated biomass (Figure B55).

Retrospective patterns

A retrospective analysis was carried out using the KLAMZ model for the exploited region by using 2000-2008 as the terminal year in the model (Figure B71). Estimates did not tend to change between runs unless a year with a survey (2002, 2005 or 2008) was dropped. There was no evidence of the typical retrospective pathology. Terminal years tended to be similar in all runs. Historical pre-1983 estimates changed in a random manner between runs, suggesting that recruitment during the first time period (1978-1992) was difficult to estimate.

"Best" biomass estimates

Biomass and fishing mortality estimates from regional KLAMZ models were used as the best estimates of biomass and fishing mortality for ocean quahogs in DMV, NJ, LI, SNE and GBK during 1977-2008 (Tables B21 and B22; Figures B72 through B74). VPA biomass estimates were used for SVA because a KLAMZ model was not available. Biomass estimates for the exploited stock and total stock are the sums of regional estimates. Fishing mortality rates for SVA, the exploited stock and total stock were calculated by solving the catch equation for F using observed landings, biomass and instantaneous rates of recruitment and growth for the appropriate region during the year.

. CVs for best biomass and fishing mortality estimates in DMV, NJ, LI, SNE and GBK are asymptotic estimates from KLAMZ model runs. The CVs for biomass and fishing mortality in the exploited region are from the KLAMZ model for the exploited region (regional variances were not used to avoid assumptions about independence in errors among regions during the same year). CVs for fishing mortality in the entire stock were assumed the same as for the exploited region. CVs for biomass and fishing mortality in SVA were assumed to be the same as the average CV for ESB (0.96, Table B19) in SVA.

As noted before, biomass estimates for ocean quahogs are not sensitive to choice of modeling approach (Figure B55). In addition, updated estimates for recent biomass and fishing mortality in this assessment are similar to estimates and projections in the last assessment (NEFSC 2007a, Figure B73), even for the LI and SNE models which assumed constant recruitment patterns in NEFSC (2007a) and two-step recruitment patterns in this assessment.

Biological Reference Points
(TOR-3)

Managers use biological reference points (BRPs) for fishing mortality and stock biomass in dealing with ocean quahogs and other species in the US EEZ. BRPs for management targets and management thresholds are required. Targets are BRPs that represent desirable stock conditions. Thresholds are BRPs that identify undesirable stock conditions.

BRPs for US fisheries are generally linked in policy to maximum sustained yield (MSY). In particular, the overfishing threshold is often F_{MSY}, MSY, or a proxy for either F_{MSY} or MSY. Fishing mortality levels at or higher than the F_{MSY} threshold constitute overfishing. Managers may choose any fishing mortality target level < F_{MSY} as a target for healthy stocks.

Similarly, the target reference point for biomass ("stock size") is B_{MSY}, which is the stock biomass level that produces MSY when the stock is harvested at F_{MSY}. Policy for choosing biomass thresholds is specified in the National Standard Guidelines. To the extent possible, the stock size threshold should equal whichever of the following is greater: 1) one-half the MSY stock size; or 2) the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock or stock complex were exploited at the maximum fishing mortality threshold.

Current BRPs for ocean quahog

The Atlantic Surfclam and Ocean Quahog Fishery Management Plan (FMP, Amendment 12) specifies $B_{Target} = B_{MSY}$, which is assumed be one-half of virgin biomass *for the whole stock*, and $F_{Target} = F_{0.1}$ for the *exploited region only* (whole stock less GBK) The biomass and fishing mortality thresholds are $B_{Threshold} = \frac{1}{2} B_{MSY}$ and $F_{Threshold} = F_{25\%}$ (the fishing mortality rate that reduces life time egg production for an average female to 25% of the average level with no fishing). The FMP does not specify whether the thresholds apply to the whole stock or exploited region only. Based on the last assessment, current estimates for the fishing mortality BRPs are $F_{Target} = F_{0.1} = 0.0275$ y^{-1} and $F_{Threshold} = F_{25\%} = 0.0517$ y^{-1}.

Previous assessments and reviews concluded that $F_{25\%}$ is a poor threshold reference point because it is a poor proxy for F_{MSY} in a long-lived species like ocean quahog with assumed natural mortality rate M=0.02 y^{-1} (NEFSC 2007a; 2007b). Simulation analyses in Clark (2002) indicate that long-term yield from unproductive fish stocks is maximized at fishing mortality rates of $F_{45\%}$ or lower. The same simulations show that fishing at $F_{25\%}$ would eventually result in spawning stock biomass levels less than 25% of the virgin level, which is below the B_{MSY} estimate of one-half virgin biomass. Thus, the current proxies for F_{MSY} and B_{MSY} are not compatible.

Revised and recommended fishing mortality rate reference points

Per recruit reference points (Table B23) for ocean quahogs are from a length-based per-recruit model in the NEFSC Stock Assessment Toolbox.[6] The length-based approach is better for ocean quahogs because fishery selectivity and maturity have been estimated in terms of shell length. Biological and fishery parameters (Table B24) in per recruit models were the same as in the last assessment (NEFSC 2007a).

The problem of choosing an F_{MSY} for ocean quahogs is difficult because we have relatively little experience with unproductive stocks like ocean quahogs. More importantly, MSY theory may not be applicable to ocean quahogs because low productivity may preclude economically viable

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

levels of sustained catch. Productivity is low for the stock as a whole and particularly in the south because recruitment events have been infrequent and regional, growth is slow, and there is a long lag time between spawning and recruitment to the mature or fishable stock. There is a chance that fishing on Georges Bank could be sustainable, as growth and potential recruitment rates are relatively high. It is probably not possible to maintain a sustainable fishery on the currently exploited region where recruitment and growth rates are very low. For these reasons, recommended reference points in this assessment are described as thresholds and targets but not as proxies for F_{MSY} or B_{MSY} related reference points.

Quahog specific simulation analyses were not performed for this assessment. In absence of simulations for ocean quahog, the best available information is Clark's (2002) simulation analyses of F_{MSY} proxies applicable to long lived west coast groundfish. The west coast ground fishery includes a substantial number of long-lived fishes that are managed based on Clark's (2002) simulation analyses. F_{MSY} proxies for west coast groundfish were considered at a workshop that resulted in specific recommendations for stocks with a range of life history characteristics (Appendix B7). In particular, the workshop recommended $F_{40\%}$ for relatively productive Pacific whiting and flatfish, $F_{45\%}$ for other groundfish, and $F_{50\%}$ for *Sebastes* spp. (rockfish) and *Sebastolobus* spp. (thornyheads).

The Invertebrate Subcommittee considered $F_{40\%}$ and $F_{50\%}$ as fishing mortality thresholds for ocean quahogs (Table B25). $F_{50\%}$ might be better for ocean quahogs because *Sebastes* spp. are shorter lived, grow faster and reproduce on a more regular basis than ocean quahogs. On the other hand, ocean quahogs have some characteristics that might enhance productivity to some extent (e.g. lack of fishing on Georges Bank). High quality landings and low levels of indirect and discard mortality probably enhance stock assessment information for ocean quahogs and reduce the chances for inadvertent overfishing. After discussion, the subcommittee decided to "split the difference" and recommend $F_{45\%}$ as the fishing mortality threshold which the SARC 48 then accepted.

The current $F_{Threshold}$ for ocean quahogs ($F_{25\%}$) is compared to fishing mortality rates for the exploited portion of the quahog stock (i.e. the whole stock less GBK) to determine if overfishing is occurring. This approach is the result of a policy decision taken by the Mid-Atlantic Fishery Management Council and is unique to ocean quahogs. In the absence of clear policy, the Invertebrate Subcommittee makes no recommendation regarding how fishing mortality should be calculated for comparison to the fishing mortality threshold.

MSY theory may not be applicable to ocean quahogs, as described above. However, from a technical point of view mortality rates calculated for the whole stock including Georges Bank do not describe conditions on either the exploited portion or unexploited portions of the stock (Hart 2003). In particular, fishing mortality may be higher than desired on the exploited portion (resulting in foregone yield and relatively low biomass conditions) and zero on the unexploited portion (resulting in foregone yield).

Very little simulation or other information was available for recommending biomass reference points for ocean quahog. The current proxy was therefore retained as a target reference point except that the target was defined as one-half of the fishable (fully selected) biomass during 1978 (under pre-fishery conditions) instead of one-half of virgin biomass. Fishable biomass during 1978 (pre fishery) was used in place of virgin biomass because it is the only available estimate of stock size under unfished conditions. Results in this assessment indicate that virgin biomass likely varied in long slow cycles prior to fishing as infrequent strong year classes slowly grew to fishable size.

The recommended biomass threshold of 1.432 mmt (40% of the pre-fishery biomass during

1978) is an *ad hoc* approach judged to be more realistic than the current threshold (25% of virgin biomass). It is possible that a higher threshold may be required, particularly if the stock on GBK is found to be unproductive.

The growth curve used in calculations was for the ocean quahogs in the Mid-Atlantic Bight that did not include growth data from the GBK area where growth is faster and maximum size is larger (Lewis et al., 2001). Growth and recruitment assumptions should be revisited if managers decide to apply threshold fishing mortality rates to the whole stock (including GBK) or if a fishery develops on GBK.

Uncertainty in biological reference points

Ocean quahogs (including GBK) may or may not have the potential for supporting sustainable catches in the long term. Some recruitment and growth occurs each year but at low levels. Much depends on the response of the stock on Georges Bank to fishing, where growth and potential recruitment rates are relatively high. It is probably not possible to maintain a sustainable fishery on the currently exploited region where recruitment and growth rates are very low.

It is probably constructive and technically valid to view the ocean quahog fishery and fishing on Georges Bank is as an adaptive management experiment. The stock (including Georges Bank) may or may not support a sustainable fishery, the answer should be clear after a decade or two of fishing on Georges Bank, and managers should be prepared to react in either case. Policy and management actions in the event the fishery is not sustainable should be considered carefully beforehand. One obvious option would be to discontinue fishing, for ocean quahogs, potentially for a decade or more, if stock biomass reaches its biomass threshold.

In conducting the adaptive management experiment, it is important that removal rates are low enough to provide one or two decades for increased recruitment following fishing because the lag time between spawning and recruitment to the fishery is relatively long. At high fishing mortality rates, it would be theoretically be possible to eliminate the spawning biomass before recruitment has a chance to occur.

Threshold reference points were sensitive to assumptions about natural mortality. The range of values for $F_{45\%}$ was 0.017, 0.019 and 0.027 y^{-1} at assumed natural mortality levels of M=0.015, 0.02 and 0.025 y^{-1}. Thus, there is considerable uncertainty associated with uncertainty in M. Uncertainty in biomass reference points is probably about the same as relative uncertainties in fishing mortality thresholds.

Stock Status
(TOR-4)

Ocean quahogs in the US EEZ are not overfished and overfishing is not occurring. Total fishable stock biomass (all regions) during 2008 was 2.905 million mt (Table B21), which is above the current and recommended management target of 1.790 million mt. As shown in Figure B74, there is nil probability based on model results that 2008 biomass for the entire stock was below the management target. The fishing mortality rate during 2008 for the stock in the exploited region was F= 0.01 y^{-1} (Table B22) which is below the current $F_{25\%}$ = 0.0517 y^{-1} and recommended $F_{45\%}$=0.0219 threshold reference points. As shown in figure B74, there is nil probability based on model results that fishing mortality during 2008 exceeded the current or recommended threshold values. For comparison, the fishing mortality rate for the entire fishable stock (all areas) during 2008 was 0.0055 y^{-1}.

Biological condition of the EEZ stock

The ocean quahog population is relatively unproductive. Total biomass is gradually declining and approaching the recommended biomass target (½ virgin of the unfished biomass during 1978) after about three decades of relatively low fishing mortality (Figure B74).

Based on survey data (Figure B23), LPUE data (Figure B9) and best estimates for 1977-2008 (Figure B72), declines in stock biomass have occurred in southern regions (SVA, DMV and NJ) where the fishery has been active longest and where little recruitment has occurred. During 2008, fishable stock biomass in SVA, DMV and NJ was less than half of pre-fishing (1978) levels (Figure B72). In contrast, stock biomass in northern regions LI and SNE increased after 1978 to due to recruitment and growth and then began to decrease in the mid-1990s when fishing commenced (Figure 72). Biomass in the unfished GBK region appears to have increased gradually since 1978 (Figure B72).

The LI, SNE and GBK regions in the north contained about 67% of total fishable biomass during 1978 and about 84% of the remaining fishable biomass during 2008 (Figures B75 and B76). The GBK region, which is currently not fished due to risk of PSP contamination, contained about 32% of total fishable biomass during 1978 and about 45% during 2008 (Figures B75 and B76).

Recruitment biomass is remarkably low (< 48 thousand mt during all years, Figure B77) for a stock with biomass levels in excess of 3 million mt during 1978-2008 (Figure B75). Almost all recruitment since 1978 occurred in northern regions (LI, SNE and GBK). Estimated recruitment declined during 1992-2000. Since 2000, recruitment (about 17 thousand mt per year) has occurred almost entirely on GBK (Figure B75).

Fishing effort and mortality

Fishing effort has shifted to offshore and northern grounds over time as catch rates and abundance in the south declined (Figure B6). Analysis of LPUE data for individual 10-minute squares indicates considerable fishing-down on fishing grounds that historically supplied the bulk of landings (Figure B12). There is no indication that LPUE increased on historical grounds after fishing effort was reduced.

Fishing mortality rates during 2008 are relatively low for the entire stock (F=0.0056 y^{-1}) and for the exploited stock (F=0.01 y^{-1}), which excludes GBK (Figure B64). Fishing mortality rates in southern areas declined over the last decade to low levels (F = 0.0, 0.003 and 0.0047 y^{-1} for SVA, DMV and NJ during 2008). Fishing mortality rates for LI increased abruptly during 1992 as effort increased, declined and then increased to F=0.0193 y^{-1} during 2008. Fishing mortality rates for SNE increased after 1995 to levels above 0.01 y^{-1} during 1997-2000 and then decreased to 0.0041 y^{-1} during 2008.

Survey size composition (Figures B26 and B30) and fishery data (Figure B13) indicate a strong year class in a relatively small area within SNE off the southwest coast of Cape Cod. Growth rates in this area (which is intermediate between the MAB and GBK) are uncertain but these recruits are expected to enter the fishery over the next decade. Survey data for GBK (Figures B24, B25 and B30) where growth is faster indicate a recent recruitment event that has already reached fishable sizes (Figure B73). This recruitment was not detected until 2008 because of low coverage during the 2002 and 2005 surveys.

Productivity under fishing

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

Ocean quahogs in the EEZ do not currently show a clear increase in stock productivity due to higher recruitment and increased growth rates, which would be expected as biomass declines to B_{MSY} levels. Indeed, estimated recruitment in northern regions began to decrease in about 1993 (Figure B77) as the fishery moved into the northern LI and SNE regions. Given the long periods between settlement and recruitment and slow growth once ocean quahogs reach fishable size, any increase in stock productivity may be delayed (Powell and Mann 2005).

Biological condition of ocean quahog in Maine waters
See Appendix B2.

Projections
(TOR-5)

Median stochastic projections were similar to corresponding deterministic projections (Table B26). As with the deterministic results, stochastic projections indicate that overfished (low biomass) stock conditions are not likely to occur by 2015 under any of the states of nature or management actions considered (Table B27). Overfishing relative to the true $F_{45\%}$ mortality threshold is not likely to occur under status-quo landings or at the minimum landings level specified in the FMP (Table B27). However, there is some probability of overfishing at the current quota and maximum landings level specified in the FMP, particularly if natural mortality $M \leq 0.02$ (Table B27).

Based on deterministic and stochastic projections, overfishing relative to the true $F_{45\%}$ would occur by 2015 under most of the states of nature considered. Most of these results are artifacts, however, because $F_{45\%}$ is one of the most conservative harvest policies considered and harvest at the relatively aggressive $F_{40\%}$, $F_{20\%}$, $F_{0.1}$ policies would constitute overfishing relative to $F_{45\%}$ by definition.

Projections indicate that landings levels based on $F_{45\%}$ and $F_{50\%}$ and exploited stock biomass would not result in F values for the entire stock larger than $F_{45\%}$ under any of the states of nature.

Stochastic biomass projections (Figure B79) indicate that changes in biomass are likely to be gradual under all harvest policies and states of nature considered. Projected fishing mortality estimates (Figure B80) show that some of the harvest policies considered are relatively aggressive in comparison to the status-quo catch policy.

Projection methods

Projected fishable biomass, fishing mortality and landings during 2010-2015 were calculated in two ways. The first method is a relatively simple approach used in the last assessment that has proven to be useful and reliable. The simple approach works well for ocean quahogs because stock biomass changes very slowly under current conditions. The principle advantage of the simple approach is that it provides projection information for each separate region based on regional conditions, as well as for the exploited region and total stock area. The principle disadvantage is that the uncertainty calculations for the simple approach are relatively crude.

The second approach provides stochastic projections based on the KLAMZ model for ocean quahogs in the exploited portion of the stock. This more complicated method captures uncertainty in 2008 biomass in addition to uncertainty in estimated recruitment levels. The stochastic approach is similar to the methods used for finfish in the US. Stochastic calculations for quahogs are slightly more complicated, however, because they involve interpreting projections for the stock in the exploited region (less GBK) in terms of the entire stock area.

All projections were started in 2008, the last year with best estimates from stock assessment models for ocean quahogs. At the time the projections were done, reasonable "anticipated" estimates of landings for 2009 were available. Therefore, all projections used actual landings for 2008 and anticipated landings for 2009 (17,690 mt meats = 3.9 million bu).

The range of harvest polices (management actions) used in projections (Table B28) included four constant landings policies (status quo, FMP minimum, FMP maximum, and FMP current quota) and five target fishing mortality policies ($F_{0.1}$, $F_{25\%}$, $F_{40\%}$, $F_{45\%}$ and $F_{50\%}$). As described below, the constant F policies were simulated by calculating a target landings level corresponding to the intended fishing mortality rate policy and the best estimate of 2008 biomass. Total catch impacting the stock in projections was landings plus 5% for assumed incidental mortality.

States of nature assumed in projections involved a range of possible values for natural mortality (M=0.015, 0.02 and 0.025) and a range of biomass levels. Deterministic projections used a range of possible biomass levels in 2008, while stochastic projections included uncertainty in 2008 biomass automatically based on bootstrap results.

Projections with F assumed known are unrealistic because F cannot be controlled directly by managers and is never truly known. Annual catch limits, in contrast, can be specified by managers and landings may be known. In practice, managers specify a landings level for ocean quahogs that are expected to generate a "target" or expected level of F. Therefore, projections in this assessment for ocean quahogs involving a target level of F (e.g. $F_{45\%}$) were carried out by calculating the catch in approximately the same manner as managers would do in managing the actual fishery based on the best biomass estimate for 2008. For example, projections with target $F= F_{45\%}$ were carried out using catch $C=F_{45\%}$ x B_{2008} for years 2010-2015.

Some of the possible states of nature considered in simulation analyses involve different levels of natural mortality M that imply different underlying biomass levels. However, managers are expected to use only the best estimates of biomass during 2008 (assuming M=0.02) in setting catch limits for 2010-2015. Therefore, management actions (landings and catch levels) are always calculated based on the best biomass estimates with M=0.02. Management decisions considered in projection analyses involve choices among harvest policies (e.g. maintain status quo landings/catch or harvest at the $F_{45\%}$ level), rather than choices among biomass estimates.

Reference points and states of nature

Mortality reference points used in simulations to determine the probabilities of overfishing were based on the true state of nature in the scenario tested**.** For example, scenarios with true M=0.015 used $F_{45\%}$=0.017 in comparisons while scenarios with true M=0.20 used $F_{45\%}$=0.0219 (Table B23). The true value of the $F_{45\%}$ reference point depends on the state of nature because the reference point depends on M (Table B23). Mortality reference points and the state of nature are linked in comparisons because the goal of the analysis is to evaluate the probability that fishing mortality in the ocean quahog stock will exceed the true value of the threshold reference point in 2015.

Biomass reference points were not adjusted for the assumed true value of M in deterministic projections although estimated biomass in 1978 and derived biomass reference points depend on natural mortality. The best method for simultaneously incorporating uncertainty in M, 1978 biomass and 2008 biomass was not clear and probably too complicated for simple deterministic calculations.

For stochastic projections, biomass reference points were adjusted for the assumed true value of M. In particular, the threshold biomass was 40% of the estimated biomass during 1978 based on original model runs for the exploited area and for GBK with the appropriate level of *M*.

Simple deterministic methods

In deterministic projections, bounds for true biomass in 2008 were B_{low}=1,438 and B_{high}=1,899 thousand mt meats for the exploited portion of the stock. The bounds were taken from an 80% bootstrap confidence interval (2000 iterations) analysis with the KLAMZ model for the exploited area. As described above, biomass in GBK during 2008 was assumed to be in the same proportion as the best estimates for 2008. Adjusting for the proportion of the biomass on GBK during 2008 (45%), the bounds for biomass of the entire stock are 2,633 and 3,475 thousand mt.

Deterministic projections are generally similar to the medians of results from more complicated stochastic projections (Jacobson and Cadrin 2004). Deterministic projection calculations for ocean quahog in this assessment use the following equations to represent biomass dynamics:

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

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

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

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

Instantaneous rates for recruitment and growth during 2009-2015 were assumed to be the same as in 2008 (Table B29). Proportions of total catch in each region during 2010-2015 were assumed to be the same as in 2008 (Table B27). Proportions of stock biomass in each region during 2008 were assumed to be the same as in best estimates for 2008 (Table B29).

Simple projections are probably best interpreted as medians. Some crude measures of uncertainty are, however, available. Uncertainty in deterministic projections is roughly the same as uncertainty in the best biomass estimates for 2008 because recruitment is very low and projections are short-term. Thus, CVs for best estimates of 2008 biomass (based on the variance of 2008 biomass estimates from KLAMZ models for the exploited region and for GBK) can serve as estimates of uncertainty for projected biomass in 2015. If uncertainty in biomass is lognormal, then bounds for an asymmetric 80% confidence interval can be computed approximately as the median estimate multiplied or divided by $e^{1.28\sigma}$ where $\sigma = \sqrt{\ln\left(CV^2 + 1\right)}$. If uncertainty in biomass is lognormal, and uncertainty in assumed catches is zero, then fishing mortality is also lognormal with the same CV as for biomass (Deming 1960).

CVs and standard deviations for uncertainty in projected biomass and fishing mortality from best estimates, with standard deviations (σ).

Region	Total less GBK	Total
CV	0.101	0.135
σ	0.101	0.135
$1/e^{1.28\sigma}$	0.879	1.138
$e^{1.28\sigma}$	0.841	1.189

Deterministic projections for biomass and fishing mortality levels were compared to a range of reference points. Overfishing was judged "likely" for a scenario if projected median fishing mortality exceeded the threshold reference point. Threshold reference points were compared to median fishing mortality for both the exploited portion of the stock and the entire stock area. Overfished stock status was judged likely if projected median biomass for the entire stock was lower than the biomass threshold.

Stochastic projection methods

Uncertainty in biomass and estimated recruitment from the KLAMZ model for ocean quahogs in the exploited and GBK regions was estimated by bootstrapping survey data and KLAMZ models for the two regions (2000 iterations). Projections were carried out for the exploited region using each bootstrap biomass estimates for 2008 as the starting point and assuming recruitment during 2009-2015 at the estimate from the model. See technical documentation for the KLAMZ model in Appendix B6 for detailed description of bootstrap and projection methods.

For simplicity, biomass on GBK during 2000-2015 in projections was assumed the same as in 2008 and uncertainty in GBK biomass was ignored. Thus, stochastic projection calculations for the entire stock ignore key uncertainties but hopefully provide useful (though understated) estimates of uncertainty for the stock as a whole. This is a topic for future research and projections in the next assessment should include the full range of uncertainty for the entire stock.

Distributions of projected biomass and fishing mortality in 2015 from stochastic projections were compared to a range of reference points. The range of natural mortality values considered in stochastic projections (M=0.015, 0.02 and 0.025) was the same as in deterministic projections. It was not necessary to assume a range in 2008 biomass estimates because the stochastic projection analyses include uncertainty in estimated biomass automatically via the bootstrap step. Projections under an assumed state of nature with M=0.015, for example, started with fitting KLAMZ models for the exploited portion of the stock and for GBK with M=0.015 assumed in the model. The resulting model for the stock in the exploited region was bootstrapped and then projections were carried out for each management action considered.

The separation of the exploited region and GBK necessitates additional steps in making comparisons of reference points to whole stock conditions. Biomass reference points were always calculated for the entire stock area based on KLAMZ estimates for1978 biomass for the exploited region and for Georges Bank at the appropriate level of M. Therefore projected values of 2015 biomass for the exploited stock area plus the estimated biomass in 2008 on GBK were compared to biomass reference points so that biomass comparisons were whole stock biomass to whole stock reference point.

Managers currently compare fishing mortality reference points to fishing mortality for the exploited stock area only. They may choose, however, to compare mortality reference points to fishing mortality for the whole stock. Projected fishing mortality rates for the entire stock were calculated from estimates for the exploited stock only by solving the catch equation for whole stock F using catch $C = \frac{F^x}{F^x + M} B^x \left(1 - e^{F^x + M}\right)$, whole stock biomass $B = B^x + B^{GBK}$ and the assumed true value of M. In these equations F is the fishing mortality estimate for the whole stock in 2015, F^x and B^x are projected estimates for the exploited stock in 2015, and B^{GBK} is the estimated biomass from the KLAMZ model for GBK during 2008. The estimates F^x, B^x and B_{GBK} were from KLAMZ models that used the value of M assumed true under the state of nature.

Vulnerability to overfishing

Ocean quahogs are an unproductive stock that is vulnerable to overfishing. If overfished (depleted biomass) conditions occur, one or more decades will be required to rebuild the stock. Current fishing mortality rates are roughly 0.01 y^{-1} for the exploited area and roughly 0.005 y^{-1} for the stock as a whole (Figure B73). In contrast, the recommended fishing mortality threshold is $F_{45\%}$=0.0219 y^{-1}. The recommended mortality threshold was based on simulation analyses for west coast groundfish and may not be appropriate for ocean quahogs, which are probably less productive than the longest-lived west coast groundfish. Traditional southern fishing grounds in the DMV and NJ regions declined after 1990 to less than ½ of their unfished biomass (Figure B72) while fishing mortality averaged about 0.01 y^{-1} (Figure B73).

Productivity (due to somatic growth and recruitment) is higher in the north (LI, SNE and GBK) but very low in the south (DMV and NJ). Recruitment to the stock as a whole declined from about 48 thousand mt y y^{-1} before 1993 to about 17 thousand mt y^{-1} after 1993 (Figure B77). Most of the recruitment during 2005 was on GBK where a relatively strong year class is reaching fishable size. A strong but very regional recruitment event in SNE southwest of Cape Cod is expected to reach fishable size over the next decade.

Projection analyses indicate that ocean quahog biomass will decline very slowly during 2010-2015 under most of the harvest rates considered in projections (Figure B79). However, there is appreciable probability of $F_{2015} > F_{45\%}$ in the exploited stock if landings during 2010-2015 are at the current quota or maximum quota levels specified in the FMP (Table B27). Fishing mortality rates for the entire stock in 2015 are unlikely to exceed F45% under any harvest policy (Table B27).

Research Recommendations
(TOR-6)

Recommendations from the previous assessment and recommendations for future research are described below.

Recommendations from last assessment (SAW 44)

1) The *R/V Delaware II* may not be available for use on NEFSC clam surveys after 2008, and it appears likely that the clam survey will become a cooperative effort with sampling done by a commercial vessel. Both the *R/V Delaware II* and a commercial vessel should be used during 2008 so that catch rates, efficiency and selectivity patterns for the two vessels can be compared and calibrated. Planning should commence immediately.
Completed. See cruise report from F/V Endeavor in Appendix B4.

2) Fishing mortality and biomass reference points used as proxies for *FMSY* and *BMSY* should be

reevaluated in the next assessment.
Completed. Several proxy reference points were evaluated in the present assessment.

3) Additional estimates of survey dredge efficiency from cooperative depletion studies are required.
Completed. Three additional depletion studies were conducted in 2008.

4) Develop a length (and possibly age) structured stock assessment model for ocean quahogs that makes better use of survey and fishery length composition data which may provide better estimates of recruitment trends.
Not attempted in the present assessment.

5) Conduct further experimental work to determine the relationship between dredge efficiency, depth, substrate and clam density. A comprehensive study coincident with the next NEFSC clam survey would be most useful. The experimental design should include sufficient contrast in variables that may affect dredge efficiency.
Completed. The relationships were evaluated and no obvious relationship was detected at this time.

6) Cover GBK in the next NEFSC clam survey.
Completed. A full survey was conducted in this region in 2008.

7) Investigate the survey data from GBK during the 1989 survey to determine why it is low relative to survey observations during earlier years. This may be important in determining if biomass is increasing in GBK.
This is no longer an important issue.

8) Survey strata with no tows are a particular problem in the GBK region. The current procedure for filling holes in survey data involves borrowing data from adjacent surveys. This may not be optimal for ocean quahog surveys and GBK in particular. In the next assessment, consider filling holes in the GBK survey data using a model with stratum and year effects.
Not attempted due primarily to limited time. The current approach was considered adequate for ocean quahogs that have slow population dynamics, and was continued in the present assessment. Years when borrowing was substantial (e.g. 1989, 2002 and 2005) were excluded from the KLAMZ model of GBK.

9) Evaluate possible increasing trends in biomass for ocean quahog on GBK.
Completed. This was evaluated directly in the KLAMZ model.

10) Evaluate effects and contribution of recruitment to stock productivity.
Completed. This was evaluated directly in the KLAMZ model.

11) Improve estimates of biological parameters for age, growth (particularly of small individuals), and maturity for ocean quahog in both the EEZ and in Maine waters.
Not attempted. No new estimates of the biological parameters were obtained in the present assessment.

12) Survey dredge and commercial dredge efficiency estimates should be reevaluated by field work

during the next NEFSC clam survey. The next survey may be the last opportunity to estimate survey dredge selectivity. The commercial dredge selectivity curve was used in this assessment was estimated from field studies done off Iceland (Thorarinsdottir and Jacobson, 2005) where conditions may differ. Repeat tow experiments (i.e. survey stations reoccupied by commercial vessels) may be useful for this purpose.
Completed in part. Efficiency comparisons were conducted but there were no selectivity studies for the commercial dredge for ocean quahogs.

13) In the next assessment, projection calculations should be carried out using a model that is basically the same as the primary stock assessment model used to estimate biomass and fishing mortality (e.g. delay-difference population model in KLAMZ).
Completed. The projection model uses the same equations as the KLAMZ model in addition to a simple deterministic approach.

14) Recommendations for future depletion studies:

- It was difficult to find areas with high concentrations of ocean quahog for depletion experiment sites during 2005. However, areas with lower densities of ocean quahog can be used if depletion tow distance is increased.
Completed. The 2008 survey design included areas of lower densities for the depletion studies,

- Revised estimators for survey dredge efficiency based on commercial depletion experiments and setup tows use data for relatively large ocean quahogs (i.e. 90+ mm) only. Future depletion sites should contain reasonably high densities of large individuals.
Completed. The 2008 survey design included areas of high densities of >90mm ocean quahogs.

- In the future, every effort must be made to collect and record precise location data at short time intervals during depletion studies.
Completed. Location data were collected at a time interval of <= 5 seconds in the 2008 depletion studies.

- Collect length and bushel count data from survey and depletion tows more frequently (e.g. every 1-2 tows). It might be advantageous to measure fewer individuals sampled from more tows.
This change was not implemented in the 2008 depletion studies because the existing protocol was considered adequate.

- Analyze results from previous depletion studies to determine if differences between bushel counts and length composition data from different tows in the same depletion experiment are significantly different. Use the results to modify sampling protocols as appropriate.
No detailed analyses were attempted.

- Changes in length composition during a depletion experiment might be incorporated into efficiency estimation by, for example, including selectivity parameters in the Patch model. Efficiency estimates (and commercial selectivity) might be more precise because more size groups would be included in catch data.
This was not attempted in the present assessment but it would be useful to conduct this analysis in

the future.

- It would be useful to analyze efficiency estimates in terms of season because ocean quahogs are believed to change their depth in sediments on a seasonal basis.
This was not attempted in the present assessment but it would be useful to conduct this analysis in the future

15) The next stock assessment should review the M=0.02 y^{-1} assumption for ocean quahog.
Not completed although projection and reference point calculations considered a range of M values.

16) In the next assessment, KLAMZ model runs with two recruitment parameters should be explored for LI and SNE. Survey length composition show more recruitment prior to 1994 than afterwards. Model fit was not as good for SNE as other regions.
Completed. The present assessment incorporated two recruitment parameters for these regions and for the exploited stock as a whole.

17) KLAMZ model runs for GBK should be explored further in the next assessment.
Completed.

New Recommendations (in rough order of priority)
1) The next survey should be conducted by a commercial vessel that is more efficient in sampling ocean quahogs compared to *R/V Delaware II.* The pilot program and analysis of existing cooperative survey data suggest that the data collected by a commercial vessel will be more precise and easier to interpret compared to data collected by the existing clam survey. A considerable amount of planning and preparation for this transition has already occurred. The survey should commence immediately in 2010 on a 15 days at sea per year schedule.

2) The 2011 survey should be of sufficient length, including anticipated down time, to cover all of the regions from Delmarva through Georges Bank.

3) Carry out simulations to determine optimum proxies for F_{MSY} and B_{MSY} in ocean quahogs, given their unusual biological characteristics.

4) The survey sensor package (SSP) should be modified so that y-tilt sensors are situated to better measure y-tilt at shallow angles; it is not important to measure y-tilt accurately at steep angles. Consider using a sensor not prone to vibration and resonance effects.

5) The SSP equipment should be redesigned and battery life extended for greater reliability and use on commercial dredges. Backup sensors should be improved as well and used routinely.

6) Estimate relationships between size and number of eggs produced. Determine spawning frequency if possible.

7) Additional age and growth studies are required to determine if extreme longevity (e.g. 400 y) is typical or unusual and to refine estimates of natural mortality. Similarly, additional age and growth studies over proper geographic scales could be used to investigate temporal and spatial recruitment

patterns.

8) Better information about maturity at length is required.

9) There has been progress in improving port sampling for ocean quahogs since the last assessment and efforts in this direction should continue, particularly as the distribution of the fishery shifts and if a fishery develops on Georges Bank.

10) Commercial dredge selectivity estimates should be obtained for the next assessment.

11) Improve estimates of biological parameters for age, growth (particularly of small individuals), and maturity for ocean quahog in both the EEZ and in Maine waters.

12) Additional estimates of survey dredge efficiency from cooperative depletion studies are required.

13) Develop a length (and possibly age) structured stock assessment model for ocean quahog that makes better use of survey and fishery length composition data which may provide better estimates of recruitment trends.

14) Conduct further analyses to determine the relationship between dredge efficiency, depth, substrate, and clam density.

15) Changes in length composition during a depletion experiment might be incorporated into efficiency estimation by, for example, including selectivity parameters in the Patch model. Efficiency estimates (and commercial selectivity) might be more precise because more size groups would be included in catch data.
16) It would be useful to analyze efficiency estimates in terms of season because ocean quahog are believed to change their depth in sediments on a seasonal basis.

17) Investigate model formulations that accommodate spatial heterogeneity.

18) Examine existing underwater photographs of ocean quahogs to evaluate the potential use of HABCAM or other optical surveys for surveying ocean quahogs and for measuring their habitat.

19) Further analysis of commercial vessel performance in making standardized tows would be advantageous to supplement work already completed.

20) Regions used in a future cooperative surveys should be spatially distinct (non-overlapping) and sensible with respect to fishery patterns, management requirements and the biological distribution of the animals. It is important that the spatial resolution of the catch and port sampling data are adequate for use with the new survey regions. The survey should cover the entire habitat area. It may be advisable to break SNE into two portions, one associated with biological patterns on GBK and the other associated with LI.

21) It may be advantageous to use survey strata that are appropriate for ocean quahogs and surfclams per se, rather than for all shellfish including scallops and other shellfish.

22) Presentation of results for SVA complicates the assessment and this area should be dropped or combined with DMV in the next assessment.

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TABLES

B. Stock assessment for ocean quahogs (*Arctica islandica*)

Invertebrate Subcommittee
SAW/SARC 48

October 5, 2009

Table B1. Annual landings and quotas (1000 metric tons meats) for ocean quahog from state waters (including Maine) and from the Exclusive Economic Zone (EEZ, state waters excluded). EEZ landings are from logbooks. Landings from state waters are not used in this assessment unless stated otherwise.

Year	Dealer Database	EEZ (Logbook)	State Waters (Logbook - Dealer)	Percent Landings in EEZ	EEZ Quota	EEZ Landings / Quota (%)
1967[a]	0.020		0.020			
1968	0.102		0.102			
1969	0.290		0.290			
1970	0.792		0.792			
1971	0.921		0.921			
1972	0.634		0.634			
1973	0.661		0.661			
1974	0.365		0.365			
1975	0.569		0.569			
1976	2.510	1.854	0.656	0.739		
1977	8.411	7.293	1.118	0.867		
1978	10.415	9.197	1.218	0.883		
1979	15.748	14.344	1.404	0.911	13.608	105%
1980[b,c]	11.623	13.407		1.000	15.876	84%
1981	11.202	13.101		1.000	18.144	72%
1982	16.478	14.234	2.244	0.864	18.144	78%
1983	16.200	14.586	1.614	0.900	18.144	80%
1984	17.939	17.975		1.000	18.144	99%
1985	22.035	20.726	1.309	0.941	22.226	93%
1986	20.585	18.902	1.683	0.918	27.215	69%
1987	22.709	21.514	1.195	0.947	27.215	79%
1988	21.007	20.273	0.734	0.965	27.215	74%
1989	23.147	22.359	0.787	0.966	23.587	95%
1990	21.235	20.965	0.270	0.987	24.040	87%
1991	22.119	22.064	0.055	0.998	24.040	92%
1992	22.871	22.477	0.395	0.983	24.040	93%
1993	24.843	21.876	2.967	0.881	24.494	89%
1994	21.159	20.985	0.173	0.992	24.494	86%
1995	23.253	21.108	2.145	0.908	22.226	95%
1996	21.122	20.061	1.061	0.950	20.185	99%
1997	19.930	19.628	0.301	0.985	19.581	100%
1998	18.098	17.897	0.201	0.989	18.144	99%
1999	17.557	17.381	0.175	0.990	20.412	85%

Table B1. (cont.)

Year	Dealer Database	EEZ (Logbook)	State Waters (Logbook - Dealer)	Percent Landings in EEZ	EEZ Quota	EEZ Landings / Quota (%)
2000	14.899	14.723	0.176	0.988	20.412	72%
2001	17.234	17.069	0.165	0.990	20.412	84%
2002	18.144	17.947	0.197	0.989	20.412	88%
2003	18.997	18.815	0.182	0.990	20.412	92%
2004	17.812	17.655	0.157	0.991	22.680	78%
2005	13.793	13.635	0.158	0.989	24.190	56%
2006	14.461	14.273	0.188	0.987	24.190	59%
2007	15.734	15.574	0.161	0.990	24.190	64%
2008	14.442	15.479		1.000	24.190	64%

[a] Figures for 1967-1979 are from NEFSC (1990)

[b] Figures for 1980-1993 from NEFSC (2003).

[c] For 1980-2005, "Dealer Database Total" landings are from commercial landings

[d] Dealer database total for 2008 may not be complete.

Table B2. Ocean quahog landings (mt meats) by region reported in logbooks for the US EEZ. Figures for 1978-1979 are not from logbooks may be less reliable.

YEAR	SVA	DMV	NJ	LI	SNE	GBK	MNE	UNK	Grand Total
1978		1,290	6,350					2,775	10,415
1979		5,450	6,030					4,268	15,748
1980		4,230	7,750	6				1,421	13,407
1981	56	3,637	8,402	3				1,003	13,101
1982	6	4,598	8,538					1,092	14,234
1983		5,396	8,249	21	629			291	14,586
1984	6	7,171	8,851		822			1,125	17,975
1985	160	7,200	10,676	40	693			1,956	20,726
1986		8,237	9,059	396	562			649	18,902
1987		10,540	9,070	1,180	696			27	21,514
1988	42	11,716	7,015	640	841			20	20,273
1989		6,439	14,100	605	1,196			20	22,359
1990	14	3,685	15,590	739	934		3		20,965
1991		4,839	14,575	1,674	865		110		22,064
1992		2,378	6,942	11,940	1,143		75		22,477
1993		1,953	10,205	8,642	1,020		56		21,876
1994		992	6,938	12,015	954		65	22	20,985
1995		699	5,357	9,527	5,412		114		21,108
1996		736	4,864	5,943	8,350		142	26	20,061
1997		1,072	4,229	5,141	8,968		218		19,628
1998		1,365	2,684	6,856	6,736		218	39	17,897
1999		1,090	3,039	6,329	6,618		279	27	17,381
2000		1,048	3,318	4,745	5,083	49	357	123	14,723
2001		894	4,560	5,692	4,694	13	326	889	17,069
2002		1,732	2,781	9,113	3,884		387	51	17,947
2003		896	3,683	11,626	2,177		359	73	18,815
2004		624	2,761	10,690	3,273		307		17,655
2005		910	669	9,714	2,021		301	19	13,635
2006		494	467	11,101	1,847		365		14,273
2007		100	1,566	11,290	2,311		306		15,574
2008		270	1,733	11,123	2,151		201	0	15,479

[c] All data for 1980-1993 fron NEFSC (2003), all other data from logbooks.

Table B3. Ocean quahog landings by region as reported in logbooks for the US EEZ. Landings (except for Maine) are in thousands of ITQ bushels.

YEAR	SVA	DMV	NJ	LI	SNE	GBK	MNE	MNE (Maine bushels)	UNK	Grand Total
1980		933	1,709	1					313	2,956
1981	12	802	1,852	1					221	2,888
1982	1	1,014	1,882						241	3,138
1983		1,190	1,819	5	139	64			64	3,280
1984	1	1,581	1,951		181	248			248	4,211
1985	35	1,587	2,354	9	153	431			431	5,001
1986		1,816	1,997	87	124	143			143	4,310
1987		2,324	2,000	260	153	6			6	4,749
1988	9	2,583	1,546	141	185	4			4	4,474
1989		1,420	3,108	133	264	4			4	4,934
1990	3	812	3,437	163	206		1	1		4,623
1991		1,067	3,213	369	191		24	37		4,901
1992		524	1,530	2,632	252		16	25		4,980
1993		431	2,250	1,905	225		12	19		4,841
1994		219	1,530	2,649	210	5	14	21	5	4,653
1995		154	1,181	2,100	1,193		25	38		4,691
1996		162	1,072	1,310	1,841	6	31	47	6	4,476
1997		236	932	1,133	1,977		48	73		4,400
1998		301	592	1,511	1,485	9	48	72	9	4,026
1999		240	670	1,395	1,459	6	62	93	6	3,931
2000		231	732	1,046	1,121	27	79	119	27	3,381
2001		197	1,005	1,255	1,035	196	72	109	196	4,065
2002		382	613	2,009	856	11	85	129	11	4,097
2003		198	812	2,563	480	16	79	120	16	4,284
2004		138	609	2,357	722		68	102		3,994
2005		201	148	2,142	446	4	66	100	4	3,110
2006		109	103	2,447	407		80	121		3,268
2007		22	345	2,489	510		68	102		3,535
2008		59	382	2,452	474	0	44	67	0	3,479

[c] All data for 1980-1993 are landings in NEFSC (2003) / 220.463.

Table B4. Real and nominal prices for ocean quahog based on dealer data. Average price was computed as total revenues divided by total landed meat weight during each year, rather than as annual averages of prices for individual trips, to reduce bias due to small deliveries at relatively high prices. The consumer price index (CPI) used to convert nominal dollars to 1991 equivalent dollars is for unprocessed and packaged fish, which includes shellfish and finfish (Eric Thunberg, NEFSC, pers. comm.).

Year	CPI	Excluding Maine			Maine only		
		Nominal ($/lb)	Real price (1991 $/lb)	Real price (1991 $/ITQ bu)	Nominal ($/lb)	Real price (1991 $/lb)	Real price (1991 $/Maine bu)
1982	0.67	0.31	0.46	4.58	NA	NA	NA
1983	0.71	0.31	0.43	4.33	NA	NA	NA
1984	0.75	0.31	0.41	4.06	0.78	1.03	6.83
1985	0.77	0.31	0.40	4.00	NA	NA	NA
1986	0.84	0.30	0.36	3.62	1.75	2.10	13.88
1987	0.94	0.29	0.31	3.09	2.30	2.46	16.27
1988	0.99	0.29	0.29	2.90	1.90	1.91	12.64
1989	0.96	0.29	0.31	3.06	2.72	2.85	18.86
1990	0.98	0.32	0.32	3.23	2.70	2.75	18.19
1991	1.00	0.34	0.34	3.39	4.10	4.10	27.15
1992	1.04	0.36	0.34	3.40	4.07	3.90	25.80
1993	1.05	0.40	0.38	3.82	3.58	3.42	22.62
1994	1.08	0.38	0.36	3.57	3.83	3.55	23.49
1995	1.14	0.40	0.35	3.52	3.46	3.02	20.03
1996	1.11	0.41	0.37	3.74	3.10	2.79	18.50
1997	1.19	0.42	0.35	3.49	2.62	2.20	14.58
1998	1.23	0.42	0.34	3.45	2.50	2.04	13.52
1999	1.28	0.42	0.33	3.30	2.75	2.16	14.28
2000	1.33	0.43	0.33	3.26	2.74	2.07	13.69
2001	1.28	0.55	0.43	4.32	3.23	2.53	16.77
2002	1.28	0.54	0.42	4.19	3.69	2.88	19.10
2003	1.31	0.53	0.41	4.05	3.75	2.87	19.03
2004	1.38	0.52	0.38	3.75	3.79	2.75	18.20
2005	1.49	0.51	0.34	3.41	3.60	2.42	16.02
2006	1.59	0.51	0.32	3.18	3.23	2.03	13.47
2007	1.62	0.52	0.32	3.18	3.16	1.95	12.90
2008	1.71	0.54	0.32	3.16	3.29	1.93	12.77

Table B5. Ocean quahog fishing effort (hours fished) by region in the US EEZ based on logbook data. “Sub-trips" (deliveries from the same trip to different dealers) are counted only once.

YEAR	SVA	DMV	NJ	LI	SNE	GBK	MNE	UNK	Grand Total
1983		7,131	13,937	50	1,535			56	22,709
1984	15	11,106	15,477		2,523			1,231	30,352
1985	204	10,058	17,890	87	2,066			2,955	33,260
1986		12,260	14,360	361	1,138			1,012	29,130
1987		15,818	14,698	806	1,340			49	32,711
1988	64	19,100	11,598	615	1,639			64	33,079
1989		12,124	24,262	797	2,327			50	39,560
1990	25	8,166	29,327	1,283	1,838		286		40,924
1991		12,048	30,397	1,844	1,433		17,110		62,832
1992		5,513	15,998	13,148	1,964		13,424		50,047
1993		4,622	25,457	12,883	1,783		5,720		50,465
1994		2,260	20,543	19,165	2,082		5,056	57	49,162
1995		1,621	13,598	16,015	8,561		5,731		45,526
1996		1,521	9,340	10,239	11,866		8,404	54	41,423
1997		2,742	9,382	8,295	13,515		11,734		45,669
1998		3,225	6,983	10,509	10,639		11,631	79	43,066
1999		2,595	7,623	9,132	12,258		10,821	90	42,518
2000		2,517	7,966	7,071	10,542	63	12,215	612	40,986
2001		2,170	10,844	7,813	11,404	22	13,113	1,454	46,820
2002		4,290	6,683	11,605	7,797		16,779	85	47,240
2003		2,617	10,750	16,113	4,596		17,832	108	52,016
2004		2,495	7,905	14,582	6,642		19,014		50,638
2005		3,445	1,972	12,519	4,043		16,905	45	38,928
2006		1,811	1,386	14,542	3,314		14,638		35,691
2007		346	3,719	15,618	4,286		13,821		37,791
2008		956	4,768	14,980	3,965		10,734	11	35,414

Table B6. Ocean quahog landings per unit effort (LPUE, total bushels / total hours fished) based on logbook data for all vessels operating in the US EEZ.

YEAR	DMV	NJ	LI	SNE	MNE	Total ITQ
1983	131	123	26			130.16
1984	72	120				95.16
1985	101	105				94.35
1986	97	127	13	122		112.59
1987	100	133		135		129.86
1988	83	203	14	93		313.14
1989	150	82	109	53		164.92
1990	285	68	203	84		134.90
1991	214	51	77	129		77.43
1992	257	194	10	134		111.33
1993	176	135	13	115		109.89
1994	472	156	19	92		130.29
1995	323	113	164	29		146.44
1996	283	241	186	19	0.08	157.81
1997	80	163	319	16	1.21	138.65
1998	48	169	200	112	2.16	155.79
1999	63	141	143	150	2.89	172.67
2000	94	117	160	188	3.94	187.95
2001	139	55	193	130	3.66	143.08
2002	56	100	120	187	3.67	127.55
2003	88	68	65	244	4.41	88.34
2004	79	127	86	156	3.78	108.45
2005	111	311	160	212	5.04	142.28
2006	109	586	176	145	5.41	117.81
2007	398	164	151	168	4.90	103.91
2008	210	31	143	112	6.18	85.95

Table B7. Number of quahogs measured, trips sampled, percentage of trips sampled, and the number quahogs measured per bushel landed by year and region, from port samples.

Region	Year	Quahogs sampled	Trips sampled	% of trips sampled	Samples per bushel landed
SNE	1996	30	1	0.12	0.00002
	1997	310	10	1.20	0.00016
	1998	796	25	3.88	0.00054
	1999	634	21	2.67	0.00043
	2000	822	27	4.12	0.00073
	2001	761	25	3.84	0.00074
	2002	1353	42	7.18	0.00158
	2003	606	20	6.31	0.00126
	2004	1302	43	10.39	0.00180
	2005	1280	42	14.58	0.00287
	2006	996	32	12.45	0.00245
	2007	1282	42	14.84	0.00252
	2008	2406	80	34.19	0.00507
Region	Year	Quahogs sampled	Trips sampled	% of trips sampled	Samples per bushel landed
LI	1996	30	1	0.12	0.00002
	1997	1012	32	5.02	0.00089
	1998	480	16	2.28	0.00032
	1999	1440	48	7.12	0.00103
	2000	390	13	2.63	0.00037
	2001	180	6	1.05	0.00014
	2002	150	5	0.63	0.00007
	2003	990	33	3.26	0.00039
	2004	360	12	1.37	0.00015
	2005	1866	62	9.00	0.00087
	2006	2928	98	12.68	0.00120
	2007	2099	68	8.58	0.00084
	2008	2482	81	11.81	0.00101
Region	Year	Quahogs sampled	Trips sampled	% of trips sampled	Samples per bushel landed
NJ	1996	30	1	0.14	0.00003
	1997	390	13	2.03	0.00042
	1998	420	14	3.47	0.00071
	1999	420	14	3.13	0.00063
	2000	600	20	4.13	0.00082
	2001	780	26	3.99	0.00078
	2002	510	17	4.59	0.00083
	2003	390	13	2.68	0.00048
	2004	1080	36	9.92	0.00177
	2005	90	3	3.23	0.00061
	2006	243	8	11.59	0.00236
	2007	343	11	6.04	0.00099
	2008	330	11	4.74	0.00086
Region	Year	Quahogs sampled	Trips sampled	% of trips sampled	Samples per bushel landed
DMV	1996	180	6	5.08	0.00111
	1997	570	19	10.86	0.00241
	1998	390	13	6.70	0.00130
	1999	960	32	19.39	0.00399
	2000	690	23	14.65	0.00299
	2001	660	22	18.64	0.00335
	2002	120	4	1.78	0.00031
	2003	390	13	10.66	0.00197
	2004	150	5	4.46	0.00109
	2005	511	17	12.32	0.00255
	2006	743	24	29.63	0.00683
	2007	195	6	42.86	0.00887
	2008	120	4	10.00	0.00202

Table B8. Number of random and nearly random NEFSC survey tows used to estimate trends in abundance of ocean quahog. Figures in each cell are the number of tows in calculations for each combination of stratum and cruise. Figures in plain text are the number of original tows (without borrowing). Bold and outlined figures are for cells that had zero tows originally but were filled by borrowing tows from the same strata during previous and/or subsequent cruises. Black cells are for cells with zero tows that could not be filled by borrowing. Survey/region combinations with relatively poor sampling (a relatively large number or relatively large strata) are shown in grey.

Region	Stratum	Area (nm2)	%Total Stratum Area	Survey Year											
				1982	1983	1984	1986	1989	1992	1994	1997	1999	2002	2005	2008
SVA	5	690	0.97	4	9	13	8	8	8	8	8	**16**	8	8	**8**
	6	22	0.03	1	1	1	1	1	1	1	1	**3**	2	1	**1**
DMV	9	1894	0.47	30	26	35	29	37	37	39	39	38	39	39	31
	10	190	0.05	2	2	3	3	3	3	3	3	3	3	3	2
	11	246	0.06	2	2	**4**	2	2	2	2	2	2	2	2	**2**
	13	1149	0.28	19	18	25	20	20	20	21	22	19	20	20	15
	14	205	0.05	2	2	3	3	3	3	5	3	3	3	3	**3**
	15	387	0.10	4	4	**8**	4	4	4	5	4	5	4	4	**4**
NJ	17	703	0.11	11	11	18	12	12	12	12	14	12	12	12	12
	18	240	0.04	3	3	**6**	3	3	3	3	3	3	3	3	3
	19	266	0.04	3	3	**6**	3	3	3	3	3	3	3	3	3
	21	1693	0.26	18	18	22	19	20	20	23	26	39	29	29	28
	22	305	0.05	3	3	**6**	3	3	3	5	3	3	3	3	3
	23	724	0.11	7	6	**11**	5	4	5	5	5	5	5	5	5
	25	647	0.10	9	9	13	8	9	9	9	12	8	9	9	13
	26	190	0.03	2	2	**5**	3	3	3	3	3	3	3	3	3
	27	442	0.07	4	4	**8**	4	4	4	4	4	4	4	4	4
	87	356	0.05	8	7	10	9	9	9	9	9	9	16	16	9
	88	484	0.07	15	15	24	17	20	20	20	21	22	20	20	19
	89	343	0.05	15	15	21	15	18	17	17	19	18	18	18	18
	90	117	0.02	2	2	3	2	2	2	2	2	2	2	2	1

Table B8. (cont.)

Region	Stratum	Area (nm2)	%Total Stratum Area	Survey Year											
				1982	1983	1984	1986	1989	1992	1994	1997	1999	2002	2005	2008
LI	29	1078	0.24	11	10	20	10	10	10	10	10	11	10	10	16
	30	667	0.15	7	8	14	6	6	6	6	6	7	6	6	12
	31	932	0.21	9	7	12	5	7	8	8	8	9	8	8	8
	33	361	0.08	4	4	8	4	4	4	5	4	4	4	4	10
	34	207	0.05	2	2	4	2	2	2	5	2	2	2	2	8
	35	614	0.14	4	2	4	2	5	6	6	6	6	6	6	6
	91	342	0.08	3	2	4	4	3	3	3	3	3	3	3	5
	92	165	0.04	2	2	3	2	2	2	2	2	2	2	2	5
	93	97	0.02	1	1	2	1	1	1	1	1	1	2	2	4
SNE	37	660	0.13	7	4	7	3	6	3	5	4	4	3	3	
	38	268	0.05	3	2	5	3	3	3	5	3	3	3	3	3
	39	946	0.19	6	4	6	2	5	5	5	5	5	5	5	5
	41	580	0.12	6	5	7	5	6	6	6	6	5	6	6	6
	45	407	0.08	3	7	9	4	4	4	4	4	4	3	3	4
	46	205	0.04	2	5	5	3	2	3	5	3	3	2	2	3
	47	873	0.18	4	3	4	2	2	4	5	4	3	1	1	4
	94	215	0.04	1	2	2		1	1	2	2	4	2	2	
	95	278	0.06	4	14	11	4	4	4	4	4	4	4	8	4
	96	490	0.10	12	12	13	1	1	3	2	4	4		1	1

Table B8. (cont.)

Region	Stratum	Area (nm2)	%Total Stratum Area	Survey Year											
				1982	1983	1984	1986	1989	1992	1994	1997	1999	2002	2005	2008
GBK	54	295	0.04		3	3	3	6	3	3	3	3		2	2
	55	386	0.05	3	3	3	3	1	3	3	3	2	2	4	2
	56	214	0.03								4	4	4		
	57	176	0.02			2	2	1	2	5	2	2	2	4	2
	58	303	0.04								5	5	5		
	59	512	0.07		4	5	1	2	6	5	5	4	5	9	4
	60	801	0.10			2	2	2	4	2	5	5	5	9	4
	61	588	0.08	8	1	6	5	12	7	6	6	6	6	11	5
	62	731	0.09			1	1	1	4	4	4	4	4	7	3
	65	184	0.02			3	3	5	2	2	3	4	1	1	
	67	196	0.03		5	5	5	7	7	7	7	7		2	2
	68	380	0.05	1	8	7	3	6	6	5	5	5		6	6
	69	902	0.12	2	5	11	6	6	6	7	6	7	7	4	4
	70	544	0.07	1	2	6	4	8	4	4	4	3	2	6	4
	71	168	0.02		2	2	3	1	2	3	3	1	2	3	1
	72	472	0.06	2	10	8	1	8	8	8	8	6	6	4	4
	73	526	0.07	1	1	4	3	6	6	6	6	5	6	9	3
	74	443	0.06	3	4	1	3	7	4	4	4	3	3	6	3

Table B9. Parameter estimates for the relationship between shell length (L, mm) and meat weight (W, g) in ocean quahog (same as in NEFSC 2004). The equation for the relationship is $W = e^{\alpha}L^{\beta}$.

Region	Alpha	Beta
SVA	-9.042313	2.787987
DMV	-9.042313	2.787987
NJ	-9.847183	2.94954
LI	-9.233646	2.822474
SNE	-9.124283	2.774989
GBK	-8.969073	2.767282

Table B10. Trends in survey, stock and fishable abundance and biomass for ocean quahog ≥ 50 mm SL during 1982-2008 based on NEFSC clam survey data. Figures include original plus borrowed tows. "Number Strata" for a particular year includes strata sampled by the survey during the same year plus strata sampled by tows borrowed from the previous and subsequent surveys. Survey data for 1994 should be ignored because of gear problems that artificially boosted sampling efficiency. Survey coverage was incomplete on GBK prior to 1986 and 2005.

		survey				stock				fishable						
region	year	N/tow	CV	Kg/tow	CV	N/tow	CV	Kg/tow	CV	N/tow	CV	Kg/tow	CV	tows per region	positive tows	strata surveyed in region
GBK	1986	278.06	0.19	6.99	0.18	430.11	0.23	9.66	0.19	233.54	0.19	5.99	0.18	47	21	16
GBK	1989	92.29	0.26	2.72	0.25	126.71	0.24	3.37	0.25	80.19	0.26	2.41	0.25	78	38	16
GBK	1992	346.25	0.21	10.44	0.21	485.71	0.19	12.86	0.20	302.84	0.21	9.30	0.21	74	41	16
GBK	1994	405.23	0.20	12.34	0.20	578.46	0.19	15.22	0.19	355.56	0.20	11.03	0.20	76	40	16
GBK	1997	269.76	0.19	7.99	0.19	389.38	0.19	10.08	0.18	234.25	0.19	7.11	0.19	83	44	18
GBK	1999	273.40	0.17	8.88	0.19	365.97	0.16	10.63	0.18	241.90	0.17	8.04	0.19	77	47	18
GBK	2002	328.37	0.18	10.29	0.19	478.14	0.15	12.68	0.18	288.96	0.18	9.26	0.19	61	38	15
GBK	2008	323.77	0.30	7.09	0.28	693.48	0.31	12.01	0.29	265.74	0.29	6.03	0.27	49	30	15
SNE	1982	277.61	0.27	9.41	0.25	345.84	0.28	11.07	0.26	245.46	0.27	8.47	0.25	48	30	10
SNE	1983	173.21	0.29	5.61	0.30	237.69	0.31	6.92	0.29	151.40	0.29	5.02	0.30	58	37	10
SNE	1984	188.46	0.27	6.40	0.29	234.35	0.26	7.52	0.28	166.80	0.27	5.77	0.29	69	38	10
SNE	1986	289.15	0.31	9.37	0.31	394.36	0.35	11.51	0.32	253.12	0.31	8.39	0.31	27	23	9
SNE	1989	274.66	0.19	9.03	0.18	353.18	0.21	10.83	0.19	241.36	0.19	8.09	0.18	34	29	10
SNE	1992	333.08	0.19	11.64	0.19	400.10	0.19	13.40	0.19	297.00	0.19	10.53	0.20	36	31	10
SNE	1994	529.09	0.22	18.12	0.20	670.13	0.25	21.44	0.21	467.48	0.22	16.37	0.20	43	32	10
SNE	1997	292.89	0.54	8.23	0.45	447.96	0.61	11.27	0.51	246.94	0.52	7.17	0.43	39	27	10
SNE	1999	252.43	0.54	8.31	0.48	312.91	0.56	9.84	0.51	221.84	0.53	7.42	0.47	39	30	10
SNE	2002	180.67	0.22	6.89	0.22	206.74	0.22	7.64	0.22	164.25	0.22	6.34	0.22	29	28	9
SNE	2005	157.78	0.26	4.81	0.23	333.78	0.42	6.93	0.27	137.54	0.25	4.33	0.22	40	34	10
SNE	2008	201.41	0.25	5.48	0.22	523.90	0.42	9.07	0.27	172.65	0.24	4.88	0.22	37	31	8

Table B10. (cont.)

		Survey				Stock				Fishable						
Region	**Year**	**N/tow**	**CV**	**Kg/tow**	**CV**	**N/tow**	**CV**	**Kg/tow**	**CV**	**N/tow**	**CV**	**Kg/tow**	**CV**	**N tows**	**N positive tows**	**N strata surveyed**
LI	1982	277.91	0.15	6.98	0.16	433.99	0.16	9.29	0.15	238.75	0.15	6.22	0.16	42	36	9
LI	1983	185.88	0.21	5.23	0.21	253.51	0.22	6.36	0.21	163.62	0.21	4.74	0.21	38	36	9
LI	1984	239.24	0.17	6.67	0.16	323.92	0.17	8.11	0.16	210.02	0.17	6.03	0.16	71	63	9
LI	1986	319.60	0.22	8.89	0.20	426.26	0.22	10.78	0.21	280.44	0.21	8.02	0.20	36	31	9
LI	1989	226.21	0.34	5.06	0.29	367.49	0.38	7.15	0.33	190.10	0.33	4.38	0.28	40	36	9
LI	1992	323.33	0.18	8.31	0.16	465.23	0.20	10.62	0.17	279.03	0.17	7.40	0.16	42	36	9
LI	1994	592.57	0.16	15.35	0.16	827.85	0.17	19.30	0.16	513.28	0.16	13.66	0.16	46	44	9
LI	1997	401.64	0.16	11.16	0.16	518.85	0.17	13.35	0.16	353.15	0.16	10.05	0.16	42	35	9
LI	1999	232.27	0.17	6.28	0.15	310.52	0.19	7.67	0.16	202.72	0.17	5.63	0.14	45	41	9
LI	2002	253.06	0.21	6.97	0.20	330.41	0.21	8.39	0.20	222.21	0.21	6.27	0.20	43	40	9
LI	2005	149.38	0.19	4.07	0.19	215.78	0.19	5.06	0.18	131.16	0.19	3.68	0.20	45	39	9
LI	2008	155.33	0.16	4.55	0.15	206.67	0.19	5.41	0.16	137.71	0.16	4.14	0.15	74	66	9
NJ	1982	112.34	0.20	5.09	0.20	129.33	0.20	5.61	0.20	102.55	0.20	4.73	0.20	99	50	13
NJ	1983	86.09	0.21	4.05	0.21	98.42	0.21	4.42	0.21	79.20	0.21	3.79	0.21	98	55	13
NJ	1984	147.61	0.24	6.69	0.24	170.30	0.24	7.37	0.24	134.86	0.24	6.21	0.24	151	79	13
NJ	1986	144.02	0.23	7.03	0.22	159.78	0.24	7.56	0.22	133.62	0.23	6.61	0.22	103	52	13
NJ	1989	72.24	0.22	3.10	0.21	88.60	0.22	3.51	0.21	65.22	0.22	2.85	0.21	109	52	13
NJ	1992	88.04	0.18	4.33	0.17	97.82	0.18	4.65	0.17	81.73	0.18	4.07	0.17	110	52	13
NJ	1994	235.41	0.22	10.90	0.21	269.04	0.22	11.92	0.21	216.05	0.22	10.16	0.20	115	59	13
NJ	1997	122.26	0.15	6.11	0.15	135.78	0.16	6.55	0.15	113.72	0.15	5.76	0.15	124	59	13
NJ	1999	59.48	0.15	2.89	0.14	72.27	0.15	3.18	0.14	54.89	0.15	2.72	0.14	132	61	13
NJ	2002	89.79	0.23	4.62	0.24	101.12	0.22	4.94	0.23	83.82	0.24	4.38	0.24	127	60	13
NJ	2005	47.08	0.16	2.24	0.15	62.36	0.15	2.53	0.15	43.12	0.15	2.11	0.14	103	54	13
NJ	2008	45.15	0.17	2.14	0.16	60.59	0.17	2.43	0.16	41.27	0.17	2.01	0.16	121	65	13

Table B10. (cont.)

		survey				stock				fishable						
Region	**Year**	**N/tow**	**CV**	**Kg/tow**	**CV**	**N/tow**	**CV**	**Kg/tow**	**CV**	**N/tow**	**CV**	**Kg/tow**	**CV**	**N tows**	**N positive tows**	**N strata surveyed**
DMV	1982	79.16	0.32	2.96	0.34	86.64	0.31	3.16	0.33	73.84	0.32	2.79	0.34	59	24	6
DMV	1983	86.23	0.49	2.55	0.42	106.61	0.52	2.99	0.45	76.16	0.48	2.30	0.41	54	28	6
DMV	1984	52.01	0.35	1.67	0.30	63.19	0.36	1.90	0.31	46.65	0.34	1.53	0.30	78	34	6
DMV	1986	75.68	0.23	2.53	0.22	86.74	0.24	2.80	0.22	68.94	0.23	2.34	0.22	61	28	6
DMV	1989	64.35	0.58	1.80	0.46	82.47	0.62	2.18	0.51	55.95	0.55	1.61	0.44	69	31	6
DMV	1992	71.98	0.36	2.29	0.31	85.41	0.40	2.59	0.33	64.68	0.35	2.09	0.30	69	25	6
DMV	1994	39.46	0.25	1.33	0.23	47.97	0.27	1.49	0.24	35.89	0.25	1.23	0.23	75	28	6
DMV	1997	47.74	0.21	1.67	0.21	56.44	0.22	1.85	0.21	43.72	0.21	1.56	0.21	73	28	6
DMV	1999	28.36	0.29	0.95	0.27	33.39	0.29	1.06	0.27	25.82	0.29	0.88	0.26	70	23	6
DMV	2002	31.81	0.25	1.11	0.23	38.77	0.26	1.23	0.23	29.14	0.24	1.03	0.22	71	19	6
DMV	2005	19.41	0.49	0.69	0.53	24.84	0.45	0.78	0.50	17.91	0.50	0.65	0.53	66	21	6
DMV	2008	17.76	0.54	0.62	0.59	22.61	0.49	0.70	0.56	16.34	0.55	0.58	0.59	57	16	6
SVA	1982	0.039	0.000	0.002	0.000	0.039	0.000	0.002	0.000	0.038	0.000	0.002	0.000	5	1	2
SVA	1983	1.892	0.578	0.099	0.577	1.916	0.577	0.101	0.577	1.854	0.579	0.097	0.577	10	3	2
SVA	1984	0.189	0.846	0.010	0.870	0.191	0.845	0.010	0.868	0.185	0.848	0.010	0.871	14	2	2
SVA	1986	0.285	0.000	0.013	0.000	0.294	0.000	0.013	0.000	0.275	0.000	0.012	0.000	9	1	2
SVA	1989	0.392	0.000	0.018	0.000	0.401	0.000	0.019	0.000	0.380	0.000	0.018	0.000	9	1	2
SVA	1992	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	9	0	2
SVA	1994	4.467	0.787	0.225	0.807	4.559	0.782	0.229	0.805	4.349	0.790	0.220	0.810	8	2	2
SVA	1997	0.154	0.000	0.004	0.000	0.282	0.000	0.006	0.000	0.132	0.000	0.003	0.000	9	1	2
SVA	1999	0.081	0.551	0.002	0.607	0.182	0.501	0.003	0.541	0.069	0.556	0.002	0.614	19	2	2
SVA	2002	0.045	1.000	0.001	1.000	0.133	1.000	0.002	1.000	0.037	1.000	0.001	1.000	10	1	2
SVA	2005	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	9	0	2
SVA	2008	0.000		0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	9	0	2

Table B11. Survey abundance trends for small quahogs (1-69 mm SL). Mean numbers per tow (N/Tow) are standardized to a 0.15 nm tow distance based on start and end tow position data. Figures include original plus borrowed tows. "Number Strata" for a particular year includes strata sampled by the survey during the same year plus strata sampled by tows borrowed from the previous and subsequent surveys. Survey data for 1994 should be ignored because of gear problems that artificially boosted sampling efficiency. Survey coverage was incomplete on GBK prior to 1986 and 2005.

Year	SVA		DMV		NJ		LI		SNE		GBK	
	N/tow	CV	N/tow	CV	N/tow	CV	N/tow	CV	N/tow	CV	N/tow	CV
1982	0.00		0.74	0.28	2.01	0.33	68.51	0.23	9.50	0.35	10.83	0.16
1983	0.00		1.77	0.57	2.29	0.52	22.24	0.31	22.67	0.73	12.07	0.39
1984	0.00		1.62	0.47	3.30	0.41	26.50	0.22	7.89	0.35	37.12	0.66
1986	0.00		0.54	0.58	1.99	0.59	30.82	0.28	23.76	0.70	40.73	0.59
1989	0.00		1.07	0.78	3.45	0.36	51.56	0.52	14.17	0.59	7.13	0.31
1992	0.00		0.99	0.63	1.02	0.38	42.30	0.36	5.91	0.35	31.75	0.35
1994	0.03	0.00	1.34	0.55	4.02	0.30	62.43	0.27	30.77	0.61	36.29	0.32
1997	0.04	0.00	1.47	0.53	1.50	0.26	21.81	0.29	58.00	0.80	61.97	0.35
1999	0.03	0.50	0.96	0.49	3.65	0.32	14.11	0.30	6.77	0.75	35.35	0.34
2002	0.02	1.00	1.44	0.48	2.29	0.19	16.08	0.41	2.14	0.42	39.72	0.18
2005	0.00		1.26	0.36	4.05	0.19	19.42	0.36	47.95	0.60	97.92	0.34
2008	0.00		1.10	0.40	4.57	0.20	14.15	0.50	82.74	0.55	150.58	0.37

Table B12. Linear correlations between sensor data summary statistics that dredge performance of individual successful random tows during the 2005 (top, above diagonal) and 2008 (bottom, below diagonal) NEFSC clam surveys. Performance statistics were calculated using data from periods when the dredge was potentially fishing (i.e. between the first and last seconds of each tow when smoothed y-tilt ≤ 5.16°). Sample sizes vary between surveys. However, with the exception of backup y-tilt, samples involved several hundred stations and tens of thousands of sensor measurements at 1 second intervals. Backup y-tilt data for 2008 were from only 8 tows and 2341 sensor measurements. No backup suitable y-tilt data are available for 2005. Correlations with absolute value ≥ 0.5 are shown in bold.

2008 survey (below diagonal); 2005 survey (above diagonal)

	Tow time	Proportion time fishing	X-tilt	SD X-tilt	Y-tilt	SD Y-tilt	Depth	Speed over ground	Backup y-tilt
Tow time		-0.08	0.04	-0.01	0.07	0.13	***0.65***	-0.25	NA
Proportion time fishing	***0.94***		0.18	***-0.64***	***-0.68***	***-0.49***	-0.04	-0.19	NA
X-tilt	***0.56***	0.31		0.25	-0.20	0.03	0.12	0.00	NA
SD X-tilt	0.35	0.36	0.31		0.31	***0.54***	0.03	0.08	NA
Y-tilt	***-0.87***	***-0.79***	***-0.51***	***-0.42***		0.11	0.15	0.34	NA
SD Y-tilt	***-0.63***	***-0.76***	0.07	0.13	0.26		0.14	-0.05	NA
Depth	-0.08	0.21	***-0.44***	0.12	0.17	-0.35		0.23	NA
Speed over ground	***-0.91***	***-0.85***	-0.32	-0.30	***0.82***	***0.59***	0.22		NA
Backup y-tilt	***0.87***	***0.81***	***0.54***	***0.55***	***-0.98***	-0.25	-0.05	***-0.77***	

Table B13. Summary of linear correlations for sensor data summary statistics that survey dredge performance in NEFSC clam surveys. Correlations ≥ 0.5 are marked "++". Correlations ≤ -0.5 are marked "- -". No backup y-tilt data were available in 2005.

Variable 1	Variable 2	Survey 2005	2008
Tow time	Proportion time		++
	X-tilt		++
	SD X-tilt		
	Y-tilt		--
	SD Y-tilt		--
	Depth	++	
	Speed over ground		--
	Backup y-tilt	na	++
Proportion time	X-tilt		
	SD X-tilt	--	
	Y-tilt	--	--
	SD Y-tilt	--	--
	Depth		
	Speed over ground		--
	Backup y-tilt	Na	++
X-tilt	SD X-tilt		
	Y-tilt		--
	SD Y-tilt		
	Depth		--
	Speed over ground		
	Backup y-tilt	na	++
SD X-tilt	Y-tilt		--
	SD Y-tilt	++	
	Depth		
	Speed over ground		
	Backup y-tilt	na	--
Y-tilt	SD Y-tilt		
	Depth		
	Speed over ground		++
	Backup y-tilt	na	--
SD Y-tilt	Depth		
	Speed over ground		++
	Backup y-tilt		
Depth	Speed over ground		
	Backup y-tilt		
Speed over ground	Backup y-tilt	na	--

Table B14. DE2DE2 (Delaware II-Delaware II) repeat station tow data (50+ mm SL). Catch are numbers of ocean quahogs caught adjusted to a standard area swept based on sensor tow distance data (4,557 ft^2 = 423 m^2). Stations with useful data are at the top of the table. Stations excluded from the analysis because both tows were zero or because of poor dredge performance (based on differential pressure and amperage sensors) are shown at the bottom. "HG" codes are NEFSC survey database codes that describe results of the haul and damage to the dredge based on observations by the watch chief (without using sensor data). By convention, tows with HG ≤ 36 are used in most analyses.

	Original station					Repeat station				
Stratum	Station	Catch	Cable	Pump	SHG	Station	Catch	Cable	Pump	HG
				Useful repeat stations						
6250	16	5.754	old	old	11	315	4.233	new	new	36
6250	17	1.4855	old	old	11	292	2.100	new	new	11
6250	23	3.1124	old	old	11	294	0.000	new	new	11
6250	25	0.9655	old	old	11	313	0.000	new	new	11
6930	170	2.9155	old	new	23	325	1.485	new	new	11
6930	172	21.295	old	new	34	329	284.070	new	new	35
6250	38	0.8368	old	old	11	296	0.000	new	new	11
6930	172	21.2954	old	new	34	327	7.068	new	new	11
6930	173	611.722	old	new	11	328	341.535	new	new	11
6330	174	105.004	old	new	36	328	341.535	new	new	11
6330	178	280.119	old	new	11	333	260.802	new	new	35
6930	179	19.830	old	new	11	335	13.517	new	new	11
6330	180	288.316	old	new	11	336	102.231	new	new	11
6920	181	10.588	old	new	11	337	7.724	new	new	11
6290	182	453.819	old	new	11	338	230.036	new	new	11
6290	183	359.921	old	new	11	339	121.018	new	new	11
6250	214	1.047	old	new	11	295	24.768	new	new	11
				Both catches zero						
6890	13	0.0000	old	old	11	316	0.000	new	new	11
6890	26	0.0000	old	old	11	314	0.000	new	new	11
6890	30	0.0000	old	old	11	312	0.000	new	new	11
6210	37	0.0000	old	old	11	302	0.000	new	new	36
6210	41	0.0000	old	old	11	303	0.000	new	new	11
6890	42	0.0000	old	old	11	304	0.000	new	new	11
6890	45	0.0000	old	old	35	310	0.000	new	new	34
6890	48	0.0000	old	old	35	317	0.000	new	new	11
6880	51	0.0000	old	old	11	318	0.000	new	new	11
6880	53	0.0000	old	old	11	319	0.000	new	new	48
				Poor dredge performance						
6250	22	26.069	old	old	11	293	27.008	new	new	23
6330	171	31.390	old	new	35	326	6.525	new	new	36
6300	206	327.657	old	new	11	287	420.315	new	new	11

Table B15. DE2FV (Delaware II – F/V Endurance) repeat tow data. Catches are numbers or ocean quahogs per standard area swept (4557 ft^2 = 423 m^2). "HG" codes are NEFSC survey database codes that describe results of the haul and damage to the dredge based on observations by the watch chief (without using sensor data). All of the stations shown in the table are useable based on differential pressure and amperage data from sensors. By convention, tows with HG ≤ 36 are used in most analyses.

Sequential FV tow number	DE2 station number	Pump	Electrical cable	HG code	W code	DE2 catch (N per standard tow area)	FV catch (N per standard tow area)	Summary of DE2 Configuration
76	304	New	New	11	2	0.000	0.000	New pump-New cable
77	303	New	New	11	0	0.000	0.000	New pump-New cable
79	312	New	New	11	0	0.000	0.382	New pump-New cable
80	313	New	New	11	0	0.000	0.597	New pump-New cable
81	314	New	New	11	0	0.000	0.000	New pump-New cable
82	316	New	New	11	0	0.000	0.000	New pump-New cable
84	290	New	New	11	1	93.661	286.865	New pump-New cable
84	289	New	New	11	1	81.602	286.865	New pump-New cable
85	290	New	New	11	1	93.661	305.617	New pump-New cable
85	289	New	New	11	1	81.602	305.617	New pump-New cable
102	272	New	New	11	3	71.985	263.336	New pump-New cable
103	274	New	New	36	3	0.966	30.072	New pump-New cable
104	276	New	New	11	-2	28.000	65.263	New pump-New cable
105	278	New	New	11	2	33.736	383.916	New pump-New cable
106	282	New	New	11	0	145.733	320.499	New pump-New cable
107	280	New	New	11	2	0.702	3.541	New pump-New cable
118	354	New	New	11	1	162.193	674.015	New pump-New cable
118	355	New	New	11	1	161.239	674.015	New pump-New cable
118	353	New	New	11	1	143.319	674.015	New pump-New cable
159	319	New	New	48	1	0.000	0.000	New pump-New cable
160	318	New	New	11	2	0.000	0.000	New pump-New cable
161	296	New	New	11	0	0.000	0.000	New pump-New cable
162	295	New	New	11	2	23.642	45.174	New pump-New cable
167	339	New	New	11	1	35.257	200.715	New pump-New cable
168	336	New	New	11	0	62.378	96.687	New pump-New cable
169	334	New	New	11	4	55.518	168.281	New pump-New cable
170	333	New	New	35	0	93.726	315.868	New pump-New cable
171	324	New	New	11	0	66.136	191.406	New pump-New cable
172	326	New	New	36	5	2.175	0.000	New pump-New cable
174	328	New	New	11	0	148.925	430.130	New pump-New cable
191	338	New	New	11	1	113.000	178.561	New pump-New cable

Table B15. (cont.)

Sequential FV tow number	DE2 station number	Pump	Electrical cable	HG code	W code	DE2 catch (N per standard tow area)	FV catch (N per standard tow area)	Summary of DE2 Configuration
192	293	New	New	23	2	24.847	142.024	New pump-New cable
193	294	New	New	11	0	0	7.608	New pump-New cable
194	292	New	New	11	0	1.05	9.009	New pump-New cable
195	315	New	New	36	1	3.175	5.853	New pump-New cable
196	310	New	New	34	5	0	0	New pump-New cable
101	205	New	Old	11	1	52.228	153.64	New pump-Old cable
163	201	New	Old	11	1	70.373	429.723	New pump-Old cable
164	209	New	Old	11	4	101.89	395.804	New pump-Old cable
165	207	New	Old	23	3	47.045	341.305	New pump-Old cable
166	203	New	Old	11	1	46.442	323.178	New pump-Old cable
167	183	New	Old	11	1	110.22	200.715	New pump-Old cable
168	180	New	Old	11	0	150.835	96.687	New pump-Old cable
170	178	New	Old	35	0	97.339	315.868	New pump-Old cable
174	173	New	Old	11	0	374.091	430.13	New pump-Old cable
174	176	New	Old	11	0	113.529	430.13	New pump-Old cable
174	174	New	Old	36	1	44.657	430.13	New pump-Old cable
174	177	New	Old	11	0	43.126	430.13	New pump-Old cable
191	182	New	Old	11	1	221.989	178.561	New pump-Old cable
200	199	New	Old	11	1	16.213	77.062	New pump-Old cable
78	36	Old	Old	11	1	3.435	13.902	Old pump-Old cable
169	2	Old	Old	11	4	25.028	168.281	Old pump-Old cable
171	1	Old	Old	11	0	150.771	191.406	Old pump-Old cable
197	49	Old	Old	11	0	0	0	Old pump-Old cable
198	60	Old	Old	11	1	0	0	Old pump-Old cable
199	64	Old	Old	11	0	0	0	Old pump-Old cable

Table B16. Summary of 2008 commercial depletion experiments for ocean quahog with comparisons to results of experiments during 1997-2005. Depletion experiments are identified by a sequential and field ID codes. The sequential codes are ordered by date (e.g. OQ2008-3 was the third study for ocean quahog completed during 2008). The field identification codes were used in planning and carrying out the experiments (e.g. field ID OQ08-6 for the experiment with sequential ID OQ2008-03). Sequential ID codes are used in this assessment.

Depletion experiment ID (Field ID)	**Commercial dredge efficiency estimate**	**Population density estimate (N/ft^2)**	**Negative binomial k estimate**	**Setup tow station numbers**	**Setup Configuration**	**Setup Density (N/tow)**	**Setup Density (N/ft^2)**	**Setup Density CV**	**Survey dredge efficiency**	**Comment**
OQ2008-01 (OQ08-1)	1.000	0.068	7.55	173, 174, 176, 177	Old cable; new pump	143.851	0.032	0.546	0.467	Poor Patch model fit, note high CV for stock density from Patch model and setup tow density
OQ2008-02 (OQ08-2)	0.780	0.086	14.55	289	New cable; new pump	81.602	0.018	NA	0.207	Good Patch model fit; only 1setup tow
OQ2008-03 (OQ08-6)	1.000	0.120	5.95	353, 354, 355	New cable; new pump	155.584	0.034	0.039	0.285	Good Patch model fit
Mean OQ-08 (N=3)	0.927	0.091	9.349	NA	NA	127.012	0.028	NA	0.320	2008 commercial efficiency estimates higher than average from previous studies; 2008 population density estimates about the same as average from previous studies; survey dredge efficiencies 25% higher than average of previous estimates
All 1997-2005 (N=17)	0.596 (95% CI 0.469 to 0.723)	0.097 (95% CI 0.032 to 0.162)		NA	NA	NA	NA	NA	0.248	

Table B17. Patch model estimates for ocean quahogs 90+ mm SL in commercial and NEFSC survey clam dredges based on depletion experiments during 1997-2008. "NA" means not available. The sequential codes are ordered by date (e.g. OQ2008-3 was the third study for ocean quahog completed during 2008). The field identification codes were used in planning and carrying out the experiments (e.g. field ID OQ08-6 for the experiment with sequential ID OQ2008-03). Sequential ID codes are used in this assessment. Footnotes are on the page following the table.

Study area						Depletion Tows						Patch Model							Setup Tows (if applicable)				
Experiment	Region	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth (m)	Mean Sediment Size (microns)	Depletion Vessel	Date	Ship Position Data (source / nominal accuracy / time interval)	N tows used	N Bushel Counts / Length samples	Depletion Vessel Blade Width (ft)	Cell Size (ft)	Density (N ft^{-2})	Depletion Vessel Efficiency	Neg. binomial *k*	Gamma γ	Neg. Log likelihood	Fit to Catch Data (R2s)	Setup Date	RV stations	Setup or RV Density (N ft^{-2})	NEFSC Survey Dredge Efficiency	Foot-notes
OQ2008-01 (OQ08-1)	LI	-72.04765	40.93762	27	530	F/V Endurance	2-Sep	GPS / 6 ft / 6 sec	17	4 / 4	12.5	25	0.068	1.000	7.55	0.50	118.5	Poor	16-Jul	173-174, 176, 177	0.032	0.467	19
OQ2008-02 (OQ08-2)	LI	-72.84397	40.27445	49	258	F/V Endurance	16-Sep	GPS / 6 ft / 6 sec	17	4 / 4	12.5	25	0.086	0.781	14.55	0.50	115.0	Ok	22-Jul	289	0.018	0.207	19
OQ2008-03 (OQ08-6)	SNE	-70.85472	41.02307	46	357	F/V Endurance	18-Sep	GPS / 6 ft / 6 sec	17	4 / 4	12.5	25	0.120	1.000	*5.95*	0.50	127.5	Ok	30-Jul	353-355	0.034	0.285	19
Mean				*41*	*382*								*0.091*	*0.927*	*9.350*						*0.0279*	*0.320*	
CV for Mean				*17%*	*21%*								*17%*	*8%*	*28%*						*18%*	*0.241*	
OQ2005-1	LI	40.51903	72.07617	57	536	F/V Lisa Kim	5-Sep	GPS / 6 ft / 6 sec	20	4 / 4	10	20	0.073	0.183	1.97	0.50	127.0	Ok	Jun-05	165, 231-234	0.0120	0.165	1
OQ2005-2	LI	40.38957	72.38950	53	438	F/V Lisa Kim	5-Sep	GPS / 6 ft / 6 sec	21	4 / 4	10	20	0.047	0.402	8.57	0.50	131.8	Ok	Jun-05	162, 235-238	0.0080	0.169	1
OQ2005-3	LI	40.64220	72.65170	35	267	F/V Lisa Kim	5-Sep	GPS / 6 ft / 6 sec	20	4 / 4	10	20	0.085	0.733	9.57	0.50	125.9	Ok	Jun-05	3, 239-242	0.0101	0.119	1
OQ2005-4	LI	40.68817	72.18147	46	308	F/V Lisa Kim	5-Sep	GPS / 6 ft / 6 sec	17	4 / 4	10	20	0.027	0.815	12.31	0.50	89.4	Ok	Jun-05	168, 243-246	0.0042	0.154	1
OQ2005-6	LI	40.05550	72.41673	65	554	F/V Lisa Kim	5-Sep	GPS / 6 ft / 6 sec	20	4 / 4	10	20	0.137	0.660	2.55	0.50	146.3	Ok	Jun-05	252-256	0.0210	0.153	1
Mean				*51*	*421*								*0.074*	*0.559*	*6.99*						*0.0110*	*0.152*	
CV for Mean				*10%*	*14%*								*25%*	*21%*	*29%*						*25%*	*0.058*	
OQ2002-1 (LK-1)	LI	40.72762	71.73730	60	331	F/V Lisa Kim	5-Mar	GPS / 1 ft / 6 sec	24	5 / 5	10	20	0.295	0.489	6.56	0.50	173.1	Ok	Jun-02	5 - 9	0.0290	0.098	1, 2, 5
OQ2002-2 (LK-2)	LI	40.10312	73.19108	48	277	F/V Lisa Kim	5-Mar	GPS / 1 ft / 6 sec	22	4 / 4	10	20	0.165	0.785	10.57	0.50	149.7	Ok	Jun-02	25- 29	0.0245	0.149	1, 2
OQ2002-3 (LK-3)	NJ	38.81491	73.81335	50	195	F/V Lisa Kim	5-Mar	GPS / 1 ft / 6 sec	20	4 / 4	10	20	0.081	0.777	11.57	0.50	133.4	Ok	Jun-02	213 - 217	0.0239	0.297	1, 2
OQ2002-4 (LK-4)	DMV	37.88755	74.64486	48	135	F/V Lisa Kim	4-Mar	GPS / 1 ft / 6 sec	24	5 / 5	10	20	0.073	0.254	12.46	0.50	136.0	Ok	Jun-02	272 - 276	0.0210	0.287	1, 2,9, 16
Mean		*39.38330*	*73.34665*	*52*	*235*								*0.153*	*0.576*	*10.29*						*0.0246*	*0.208*	
CV for Mean				*6%*	*18%*								*34%*	*22%*	*13%*						*7%*	*0.239*	
OQ2000-1 (JN-1)	LI	40.60217	71.98750	58	N/A	F/V John N	1-Mar	GPS / 1 ft / 30 sec	22	5 / 5	12.5	25	0.100	0.730	5.55	0.50	157.4	Ok	Jun-99	194 - 199	NA	NA	1, 2,6
OQ2000-2 (JN-2)	LI	40.39450	72.54300	48	N/A	F/V John N	1-Mar	GPS / 1 ft / 30 sec	16	4 / 3	12.5	25	0.062	0.554	15.10	0.50	98.1	Ok	Jun-99	178 - 180	0.0145	0.234	1, 2,7,11,12, 17
OQ2000-3 (DM-1)	LI	40.58300	72.79683	40	N/A	F/V Danielle Maria	1-May	GPS / 1 ft / 30 sec	27	6 / 6	10	20	0.089	0.560	4.57	0.50	184.2	Ok	Jun-99	3 - 8	0.0147	0.165	1, 2,8,10,12, 18
Mean		*40.52656*	*72.44244*	*49*									*0.084*	*0.615*	*8.405*						*0.0146*	*0.199*	
CV for Mean				*11%*									*14%*	*9%*	*40%*						*1%*	*0.175*	
OQ1999-01 DE2	LI	40.60227	71.98483	57	N/A	R/V Delaware II	1-Jun	GPS / 36 ft / 1 sec	60	8 / 8	5	10	0.007	0.990	4.05	0.25	253.1	Poor		N/A		0.990	14, 15
OQ1998-1 (SH-3)	LI (Shinnecock)	40.76650	72.17950	41	N/A	F/V Cape Fear	1-Mar	Loran / 40 ft / 30 sec.	14	3 / 3	10	20	0.017	1.000	3.48	0.50	76.5	Poor					1, 13
OQ1998-2 (SH-2)	LI (Shinnecock)	40.72200	72.00750	45	N/A	F/V Cape Fear	1-Mar	Loran / 40 ft / 30 sec.	23	5 / 5	10	20	0.067	0.869	10.57	0.50	140.3	Ok		NA		NA	15
OQ1998-3 (NS-1)	SNE (Nantucket Shoals)	40.46700	69.48300	63	N/A	F/V Cape Fear	1-Apr	Loran / 40 ft / 30 sec.	24	5 / 5	10	20	0.255	0.710	7.56	0.50	195.5	Ok					15
Mean		*40.65183*	*71.22333*	*50*									*0.113*	*0.860*	*7.204*								
CV for Mean				*14%*									*64%*	*10%*	*29%*								
OQ1997-1 (SH-1)	LI (Shinnecock)	40.26950	72.29850	58	N/A	F/V Laura Ann	1-Jul	Loran / 40 ft / 30 sec.	28	7 / 7	7.75	20	0.083	0.458	10.57	0.39	164.2	Ok					1,3
OQ1997-2 (WW-1)	NJ (Wildwood)	38.50950	74.11150	49	N/A	F/V Agitator	1-Aug	Loran / 40 ft / 30 sec.	28	13 / 6	10	20	0.084	0.150	2.37	0.50	176.0	Ok		NA		NA	1,4
Mean		*39.38950*	*73.20500*	*54*									*0.083*	*0.304*	*6.47*								
CV for Mean				*8%*									*0%*	*51%*	*63%*								

Footnotes for Table B17

[1] NA
[2] NA
[3] Depletion tows 1, 2, 12 & 18 omitted per NEFSC 1998, Figure E18
[4] Depletion tows 1, 19, 23 & 27 omitted per NEFSC 1998, Figure E21
[5] Setup station 5 dropped because sensor tow distance < 0.04 nm
[6] Length composition data collected at setup tow 194 only for OQ2000-1 (indicated 6% of catch >= 90 mm SL), setup data not useable.
[7] Length composition data collected at setup tow 178 only for OQ2000-2 (indicated 28% of catch >= 90 mm SL), used for all setup tows.
[8] Length composition data collected at setup tows 3 and 6 only for OQ2000-3 (average 33% and 28% of catch >= 90 mm SL), used for all setup tows.
[9] Length composition data collected at setup tow 272 only for OQ2000-4 (33% of catch >= 90 mm SL), used for all setup tows.
[10] Sensor tow distance missing for setup station 4, average tow distance at stations 3, 5, 6, 7, 8 used instead.
[11] Depletion tow 1 omitted because it was outside the study area.
[12] Adjustments for apparent trends in numbers per bushel during depletion experiment.
[13] Original estimates appear to have used incorrect mean number per bushel in depletion tows
[14] Missing GPS location data at survey stations 198 and 216 (depletion tows 5 and 23) replaced by approximate start/stop locations and interpolation.
[15] Anomalously high bushel count and length data at station 200 were not used.
[16] One setup tow with length data for OQ2002-4.
[17] One setup tow with length data for OQ2000-2.
[18] Two setup tows with length data for OQ2000-3.
[19] Used backup GPS and backup depth sensor data in place of SSP sensor data for depletion tows. Setup tows used SSP data.

Table B18. Summary of density, commercial dredge efficiency, and NEFSC dredge efficiency estimates for ocean quahog 90+ mm SL from the Patch model. The 90% confidence interval calculated by bootstrapping the fifteen survey efficiency estimates (15,000 iterations) ranged from 0.154 to 0.285.

Statistic	Density ($N\ ft^{-2}$)	Commercial Vessel Efficiency	NEFSC Survey Dredge Efficiency
N experiments	21	20	15
Minimum	0.007	0.150	0.098
Maximum	0.295	1.000	0.990
Median	0.083	0.720	0.169
Mean	0.096	0.646	0.263
Distribution of point estimates[1]			
Standard deviation	0.070	0.259	0.222
CV (sd/mean)	0.728	0.402	0.845
Lo 95%	0.000	0.137	0.000
Hi 95%	0.233	1.000	0.697
Distribution of average estimates[1]			
Standard error	0.015	0.058	0.057
CV (se/mean)	0.159	0.090	0.218
Lo 95%	0.066	0.532	0.150
Hi 95%	0.126	0.759	0.375

Table B19. Efficiency corrected swept-area fishable biomass estimates (1,000 mt meats) and CVs for ocean quahog during 1997, 2000, 2002, 2005 and 2008 (years with NEFSC clam surveys), by region. Figures for SVA and GBK during 2005 are, in effect, averages of figures for 2002 and 2008 because little data were available for 2005.

Area of assessment region (*A* , nm^2) - no correction for stations with unsuitable clam habitat

S. Virginia and N. Carolina (SVA)	712	10%
Delmarva (DMV)	4,071	10%
New Jersey (NJ)	6,510	10%
Long Island (LI)	4,463	10%
Southern New England (SNE)	4,922	10%
Georges Bank (GBK)	7,821	10%
Total	28,499	

INPUT: Fraction suitable habitat (*u*)

S. Virginia and N. Carolina (SVA)	100%	10%
Delmarva (DMV)	100%	10%
New Jersey (NJ)	100%	10%
Long Island (LI)	100%	10%
Southern New England (SNE)	96%	10%
Georges Bank (GBK)	90%	10%

Habitat area in assessment region (*A'* , nm2)

S. Virginia and N. Carolina (SVA)	712	14%
Delmarva (DMV)	4,071	14%
New Jersey (NJ)	6,510	14%
Long Island (LI)	4,463	14%
Southern New England (SNE)	4,714	14%
Georges Bank (GBK)	7,039	14%

INPUT: Biomass fraction in unsurveyd deep water

S. Virginia and N. Carolina (SVA)	0%	10%
Delmarva (DMV)	0%	10%
New Jersey (NJ)	0%	10%
Long Island (LI)	0%	10%
Southern New England (SNE)	2%	10%
Georges Bank (GBK)	13%	10%

INPUT: Original survey mean catch from fishable stock (kg/tow, for tows adjusted to nominal tow distance using sensors)

	Estimates for 1997	CV	Estimates for 1999	CV	Estimates for 2002	CV	Estimates for 2005	CV	Estimates for 2008	CV
S. Virginia and N. Carolina (SVA)	0.0013	100%	0.0007	55%	0.0004	100%	0.0004	100%	0.0004	100%
Delmarva (DMV)	0.6528	23%	0.4449	26%	0.6879	24%	0.4221	48%	0.3908	52%
New Jersey (NJ)	1.7341	15%	0.9728	14%	1.8752	23%	1.0553	14%	1.2071	19%
Long Island (LI)	4.5648	17%	3.0065	14%	3.5561	18%	2.1791	16%	3.4396	15%
Southern New England (SNE)	2.2252	37%	2.6964	45%	3.2654	26%	2.0689	22%	2.8049	22%
Georges Bank (GBK)	2.6710	16%	3.1454	18%	3.8760	17%	4.3336	20%	4.7733	27%

Swept-area biomass without efficiency correction (B', 1000 mt):

S. Virginia and N. Carolina (SVA)	0.008	102%	0.004	59%	0.002	102%	0.002	102%	0.002	102%
Delmarva (DMV)	22	30%	15	33%	23	31%	14	52%	13	56%
New Jersey (NJ)	91	25%	51	24%	99	30%	56	24%	64	28%
Long Island (LI)	165	26%	109	24%	129	27%	79	26%	124	25%
Southern New England (SNE)	87	42%	105	49%	127	33%	81	30%	109	30%
Georges Bank (GBK)	172	26%	203	27%	250	26%	279	28%	308	34%
Total fishable biomass less GBK	365	17%	280	21%	378	17%	229	15%	310	16%
Total fishable biomass	537	14%	483	17%	627	14%	508	17%	618	19%

INPUT: Survey dredge efficiency (e)	0.169	21%	0.169	21%	0.169	21%	0.169	21%	0.169	21%

Efficiency adjusted swept area fishable biomass (B, 1000 mt)

S. Virginia and N. Carolina (SVA)	0.045	104%	0.024	62%	0.013	104%	0.013	104%	0.013	104%
Delmarva (DMV)	127	37%	87	39%	134	38%	82	56%	76	60%
New Jersey (NJ)	541	33%	304	32%	585	37%	329	32%	377	35%
Long Island (LI)	977	34%	644	32%	761	34%	466	33%	736	33%
Southern New England (SNE)	513	47%	622	54%	753	39%	477	36%	647	36%
Georges Bank (GBK)	1,019	33%	1,200	34%	1,479	34%	1,653	35%	1,821	40%
Total fishable biomass less GBK	2,159	27%	1,656	30%	2,234	27%	1,355	26%	1,836	26%
Total fishable biomass	3,178	25%	2,856	27%	3,713	25%	3,009	27%	3,657	28%

Lower bound for 80% confidence intervals on fishable biomass (1000 mt, for lognormal distribution with no bias correction)

	Estimates for 1997	Estimates for 1999	Estimates for 2002	Estimates for 2005	Estimates for 2008
S. Virginia and N. Carolina (SVA)	0.015	0.011	0.004	0.004	0.004
Delmarva (DMV)	81	54	84	42	38
New Jersey (NJ)	360	203	370	220	245
Long Island (LI)	643	430	498	309	490
Southern New England (SNE)	290	327	465	304	412
Georges Bank (GBK)	674	785	973	1,067	1,117
Total fishable biomass less GBK	1,539	1,138	1,596	978	1,320
Total fishable biomass	2,311	2,037	2,693	2,142	2,573

Upperbound for 80% confidence intervals on fishable biomass (1000 mt, for lognormal distribution with no bias correction)

S. Virginia and N. Carolina (SVA)	0.134	0.049	0.039	0.039	0.039
Delmarva (DMV)	202	141	214	161	154
New Jersey (NJ)	814	454	926	493	580
Long Island (LI)	1,485	962	1,164	705	1,106
Southern New England (SNE)	909	1,182	1,218	749	1,016
Georges Bank (GBK)	1,540	1,835	2,248	2,561	2,969
Total fishable biomass less GBK	3,029	2,409	3,127	1,879	2,555
Total fishable biomass	4,371	4,004	5,118	4,226	5,198

Table B20. Ocean quahog fishing mortality estimates based on catch and efficiency corrected swept-area biomass for fishable ocean quahog during 1997, 1999, 2002, 2005 and 2008 with NEFSC clam surveys. CVs are based on analytical variance calculations assuming log normality, and include uncertainty in catch, survey data, swept-area, amount of suitable habitat, and survey dredge efficiency.

INPUT: Upper bound incidental mortality allowance	5%
INPUT: Assumed CV for catch	10%

INPUT: Landings (1000 mt, discard ~ 0)	**Estimates for 1997**	**Estimates for 1999**	**Estimates for 2002**	**Estimates for 2005**	**Estimates for 2008**
S. Virginia and N. Carolina (SVA)	0	0.000	0.000	0.000	0.000
Delmarva (DMV)	1.072	1.092	1.737	0.912	0.270
New Jersey (NJ)	4.229	3.043	2.789	0.670	1.733
Long Island (LI)	5.141	6.339	9.140	9.728	11.123
Southern New England (SNE)	8.968	6.628	3.895	2.024	2.151
Georges Bank (GBK)	0.000	0.000	0.000	0.000	0.000
Total	19.410	17.102	17.561	13.334	15.278

Catch (1000 mt, landings + upper bound incidental mortality allowance)					
S. Virginia and N. Carolina (SVA)	0.000	0.000	0.000	0.000	0.000
Delmarva (DMV)	1.126	1.146	1.824	0.957	0.283
New Jersey (NJ)	4.441	3.195	2.928	0.704	1.820
Long Island (LI)	5.398	6.656	9.597	10.215	11.679
Southern New England (SNE)	9.416	6.960	4.090	2.125	2.259
Georges Bank (GBK)	0.000	0.000	0.000	0.000	0.000
Total	20.380	17.957	18.439	14.001	16.042

INPUT: Efficiency Corrected Swept Area Biomass for Fishable Stock (1000 mt)	**Estimates for 1997**	**CV**	**Estimates for 1999**	**CV**	**Estimates for 2002**	**CV**	**Estimates for 2005**	**CV**	**Estimates for 2008**	**CV**
S. Virginia and N. Carolina (SVA)	0	104%	0	62%	0	104%	0	104%	0	104%
Delmarva (DMV)	127	37%	87	39%	134	38%	82	56%	76	60%
New Jersey (NJ)	541	33%	304	32%	585	37%	329	32%	377	35%
Long Island (LI)	977	34%	644	32%	761	34%	466	33%	736	33%
Southern New England (SNE)	513	47%	622	54%	753	39%	477	36%	647	36%
Georges Bank (GBK)	1,019	33%	1,200	34%	1,479	34%	1,653	35%	1,821	40%
Total fishable biomass less GBK	2,159	27%	1,656	30%	2,234	27%	1,355	26%	1,836	26%
Total fishable biomass	3,178	25%	2,856	27%	3,713	25%	3,009	27%	3,657	28%

Fishing mortality (y^{-1})										
S. Virginia and N. Carolina (SVA)	0.000	105%	0.000	63%	0.000	105%	0.000	105%	0.000	105%
Delmarva (DMV)	0.009	38%	0.013	40%	0.014	39%	0.012	57%	0.004	60%
New Jersey (NJ)	0.008	34%	0.011	34%	0.005	38%	0.002	34%	0.005	36%
Long Island (LI)	0.006	NA	0.010	NA	0.013	36%	0.022	35%	0.016	34%
Southern New England (SNE)	0.018	48%	0.011	54%	0.005	40%	0.004	38%	0.003	38%
Georges Bank (GBK)	0.000	NA	0.000	NA	0.000	NA	0.000	0%	0.000	0%
Total fishable biomass less GBK	0.009	29%	0.011	32%	0.008	29%	0.010	28%	0.009	28%
Total fishable biomass	0.006	27%	0.006	29%	0.005	27%	0.005	29%	0.004	30%

Lower bound for 80% confidence intervals for fishing mortality (y^{-1}, for lognormal distribution with no bias correction)	**Estimates for 1997**	**Estimates for 1999**	**Estimates for 2002**	**Estimates for 2005**	**Estimates for 2008**
S. Virginia and N. Carolina (SVA)	NA	NA	NA	NA	NA
Delmarva (DMV)	0.005	0.008	0.008	0.006	0.002
New Jersey (NJ)	0.005	0.007	0.003	0.001	0.003
Long Island (LI)	NA	NA	0.008	0.014	0.010
Southern New England (SNE)	0.010	0.006	0.003	0.003	0.002
Georges Bank (GBK)	NA	NA	NA	NA	NA
Total fishable biomass less GBK	0.007	0.007	0.006	0.007	0.006
Total fishable biomass	0.005	0.004	0.004	0.003	0.003

Upper bound for 80% confidence intervals for fishing mortality (y^{-1}, for lognormal distribution with no bias correction)					
S. Virginia and N. Carolina (SVA)	NA	NA	NA	NA	NA
Delmarva (DMV)	0.014	0.022	0.022	0.023	0.008
New Jersey (NJ)	0.013	0.016	0.008	0.003	0.008
Long Island (LI)	NA	NA	0.020	0.034	0.024
Southern New England (SNE)	0.033	0.021	0.009	0.007	0.006
Georges Bank (GBK)	NA	NA	NA	NA	NA
Total fishable biomass less GBK	0.014	0.016	0.012	0.015	0.012
Total fishable biomass	0.009	0.009	0.007	0.007	0.006

Table B21. “Best” biomass estimates for ocean quahogs during 1978-2008. SVA estimates are from "VPA" and other regional estimates are from KLAMZ models. Whole stock and exploited stock biomass are sums of regional estimates. "KLAMZ (1R)" means from a KLAMZ model that has constant recruitment in each year. "KLAMZ (2R)" means from a KLAMZ model assuming two periods of constant recruitment. "*Q* for ESB" is the estimated (KLAMZ model) or assumed (VPA) survey scaling parameter for efficiency corrected swept area biomass. *Q* values are a diagnostic for KLAMZ model fits and expected to be near one.

Biomass *Q* for ESB	VPA 1.00		KLAMZ (1R) 0.96		KLAMZ (1R) 0.96		KLAMZ (2R) 1.04		KLAMZ (2R) 1.04		KLAMZ (1R) 0.98		Sum of best regional estimates			
Year	SVA	CV	DMV	CV	NJ	CV	LI	CV	SNE	CV	GBK	CV	Exploitable stock	CV	Whole Stock	CV
1978	0.3344	0.96	298	0.14	897	0.13	663	0.28	553	0.38	1,169	0.41	2,412	0.24	3,580	0.21
1979	0.3344	0.96	290	0.15	872	0.13	676	0.26	564	0.36	1,175	0.39	2,403	0.24	3,577	0.21
1980	0.3344	0.96	277	0.15	848	0.13	689	0.25	575	0.34	1,181	0.37	2,389	0.23	3,570	0.20
1981	0.3344	0.96	267	0.15	824	0.14	702	0.24	586	0.32	1,186	0.36	2,378	0.22	3,564	0.19
1982	0.2708	0.96	257	0.15	800	0.14	714	0.23	596	0.30	1,192	0.34	2,368	0.22	3,560	0.19
1983	0.2639	0.96	247	0.16	776	0.14	727	0.22	607	0.28	1,198	0.32	2,358	0.21	3,555	0.18
1984	0.2639	0.96	237	0.16	754	0.14	740	0.21	616	0.26	1,203	0.31	2,347	0.21	3,550	0.17
1985	0.2571	0.96	225	0.17	731	0.14	752	0.20	626	0.24	1,209	0.29	2,334	0.20	3,542	0.17
1986	0.0712	0.96	212	0.17	706	0.14	764	0.19	635	0.23	1,214	0.28	2,318	0.20	3,532	0.16
1987	0.0712	0.96	200	0.18	684	0.15	776	0.19	645	0.22	1,220	0.27	2,305	0.19	3,524	0.16
1988	0.0712	0.96	185	0.19	662	0.15	787	0.18	654	0.21	1,225	0.25	2,289	0.19	3,514	0.15
1989	0.0272	0.96	170	0.20	643	0.15	798	0.17	663	0.20	1,231	0.24	2,275	0.19	3,506	0.15
1990	0.0272	0.96	160	0.21	618	0.15	810	0.17	672	0.19	1,236	0.23	2,260	0.18	3,496	0.14
1991	0.0130	0.96	154	0.22	591	0.16	821	0.17	681	0.18	1,241	0.22	2,247	0.18	3,488	0.14
1992	0.0130	0.96	146	0.22	566	0.16	831	0.16	690	0.17	1,246	0.21	2,233	0.18	3,479	0.14
1993	0.0130	0.96	140	0.23	549	0.16	813	0.16	684	0.17	1,251	0.20	2,187	0.18	3,438	0.13
1994	0.0130	0.96	136	0.23	529	0.16	799	0.17	678	0.17	1,256	0.20	2,142	0.18	3,398	0.13
1995	0.0130	0.96	132	0.23	513	0.17	781	0.17	672	0.17	1,261	0.19	2,098	0.18	3,359	0.13
1996	0.0130	0.96	129	0.23	499	0.17	765	0.17	661	0.17	1,266	0.19	2,054	0.18	3,320	0.13
1997	0.0130	0.96	125	0.24	485	0.17	753	0.17	647	0.17	1,271	0.18	2,011	0.18	3,282	0.13
1998	0.0130	0.96	122	0.24	472	0.17	742	0.17	633	0.17	1,276	0.18	1,969	0.18	3,245	0.13
1999	0.0130	0.96	118	0.24	461	0.17	728	0.17	621	0.18	1,280	0.18	1,928	0.18	3,209	0.13
2000	0.0130	0.96	115	0.24	450	0.17	715	0.17	608	0.18	1,285	0.18	1,888	0.18	3,173	0.13
2001	0.0130	0.96	111	0.25	439	0.17	704	0.17	597	0.18	1,290	0.18	1,852	0.18	3,141	0.13
2002	0.0130	0.96	108	0.25	426	0.17	691	0.17	587	0.18	1,294	0.18	1,813	0.18	3,107	0.13
2003	0.0130	0.96	104	0.25	416	0.18	675	0.18	577	0.18	1,298	0.18	1,773	0.18	3,071	0.13
2004	0.0130	0.96	101	0.25	405	0.18	657	0.18	569	0.18	1,303	0.18	1,732	0.18	3,035	0.13
2005	0.0130	0.96	99	0.26	396	0.18	639	0.18	559	0.18	1,307	0.18	1,693	0.19	3,000	0.13
2006	0.0130	0.96	96	0.26	388	0.18	623	0.18	551	0.18	1,311	0.19	1,658	0.19	2,969	0.13
2007	0.0130	0.96	94	0.26	381	0.18	605	0.19	544	0.18	1,315	0.19	1,623	0.19	2,938	0.13
2008	0.0130	0.96	92	0.26	373	0.18	587	0.19	535	0.18	1,319	0.20	1,586	0.19	2,905	0.13
Min	0.0130	0.96	92	0.145	373	0.132	587	0.163	535	0.171	1,169	0.176	1,586	0.176	2,905	0.127
Median	0.0130	0.96	140	0.226	549	0.160	728	0.178	616	0.182	1,251	0.209	2,187	0.185	3,438	0.135
Mean	0.0934	0.96	166	0.210	586	0.157	727	0.191	616	0.217	1,249	0.242	2,094	0.193	3,343	0.150
Max	0.3344	0.96	298	0.260	897	0.178	831	0.278	690	0.383	1,319	0.407	2,412	0.244	3,580	0.213

Table B22. Best fishing mortality estimates for ocean quahogs during 1978-2008. . Whole stock, exploited region, and SVA estimates are from solving the catch equation for catch given best biomass estimates and instantaneous rates for growth and recruitment. Other regional estimates are from KLAMZ models that provided the best biomass estimates.

Year	SVA	CV	DMV	CV	NJ	CV	LI	CV	SNE	CV	GBK	CV	Exploitable stock	CV	Whole Stock	CV
1978	0.0000	0.00	0.0060	0.15	0.0098	0.13	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0045	0.24	0.0031	0.24
1979	0.0000	0.00	0.0264	0.15	0.0096	0.13	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0069	0.24	0.0046	0.24
1980	0.0000	0.96	0.0174	0.15	0.0104	0.14	0.0000	0.25	0.0000	0.00	0.0000	0.00	0.0059	0.23	0.0039	0.23
1981	0.2135	0.96	0.0150	0.15	0.0112	0.14	0.0000	0.24	0.0000	0.00	0.0000	0.00	0.0058	0.23	0.0039	0.23
1982	0.0258	0.00	0.0197	0.16	0.0117	0.14	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0063	0.22	0.0042	0.22
1983	0.0000	0.96	0.0227	0.16	0.0110	0.14	0.0000	0.22	0.0011	0.28	0.0000	0.00	0.0065	0.21	0.0043	0.21
1984	0.0264	0.96	0.0331	0.16	0.0127	0.14	0.0000	0.00	0.0014	0.26	0.0000	0.00	0.0081	0.21	0.0053	0.21
1985	1.3050	0.00	0.0364	0.17	0.0164	0.14	0.0001	0.20	0.0012	0.24	0.0000	0.00	0.0094	0.20	0.0062	0.20
1986	0.0000	0.00	0.0414	0.18	0.0135	0.14	0.0005	0.19	0.0009	0.23	0.0000	0.00	0.0086	0.20	0.0056	0.20
1987	0.0000	0.96	0.0548	0.19	0.0135	0.15	0.0015	0.19	0.0011	0.22	0.0000	0.00	0.0098	0.19	0.0064	0.19
1988	0.9770	0.00	0.0660	0.20	0.0108	0.15	0.0008	0.18	0.0013	0.21	0.0000	0.00	0.0093	0.19	0.0061	0.19
1989	0.0000	0.96	0.0390	0.21	0.0224	0.15	0.0008	0.17	0.0018	0.20	0.0000	0.00	0.0104	0.19	0.0067	0.19
1990	0.7487	0.00	0.0235	0.21	0.0258	0.15	0.0009	0.17	0.0014	0.19	0.0000	0.00	0.0098	0.18	0.0063	0.18
1991	0.0000	0.00	0.0324	0.22	0.0252	0.16	0.0020	0.17	0.0013	0.18	0.0000	0.00	0.0103	0.18	0.0066	0.18
1992	0.0000	0.00	0.0166	0.23	0.0125	0.16	0.0145	0.16	0.0017	0.17	0.0000	0.00	0.0106	0.18	0.0068	0.18
1993	0.0000	0.00	0.0141	0.23	0.0189	0.16	0.0107	0.17	0.0015	0.17	0.0000	0.00	0.0106	0.18	0.0067	0.18
1994	0.0000	0.00	0.0074	0.23	0.0133	0.16	0.0152	0.17	0.0014	0.17	0.0000	0.00	0.0103	0.18	0.0065	0.18
1995	0.0000	0.00	0.0054	0.23	0.0106	0.17	0.0123	0.17	0.0081	0.17	0.0000	0.00	0.0106	0.18	0.0066	0.18
1996	0.0000	0.00	0.0058	0.24	0.0099	0.17	0.0078	0.17	0.0128	0.17	0.0000	0.00	0.0103	0.18	0.0063	0.18
1997	0.0000	0.00	0.0087	0.24	0.0088	0.17	0.0069	0.17	0.0140	0.17	0.0000	0.00	0.0102	0.18	0.0062	0.18
1998	0.0000	0.00	0.0114	0.24	0.0058	0.17	0.0093	0.17	0.0108	0.18	0.0000	0.00	0.0095	0.18	0.0058	0.18
1999	0.0000	0.00	0.0094	0.24	0.0067	0.17	0.0088	0.17	0.0108	0.18	0.0000	0.00	0.0094	0.18	0.0056	0.18
2000	0.0000	0.00	0.0093	0.24	0.0075	0.17	0.0067	0.17	0.0085	0.18	0.0000	0.00	0.0081	0.18	0.0048	0.18
2001	0.0000	0.00	0.0086	0.25	0.0111	0.17	0.0082	0.17	0.0084	0.18	0.0000	0.00	0.0096	0.18	0.0056	0.18
2002	0.0000	0.00	0.0163	0.25	0.0066	0.17	0.0133	0.18	0.0067	0.18	0.0000	0.00	0.0103	0.18	0.0060	0.18
2003	0.0000	0.00	0.0087	0.25	0.0090	0.18	0.0175	0.18	0.0038	0.18	0.0000	0.00	0.0110	0.18	0.0063	0.18
2004	0.0000	0.00	0.0062	0.25	0.0069	0.18	0.0165	0.18	0.0058	0.18	0.0000	0.00	0.0106	0.18	0.0060	0.18
2005	0.0000	0.00	0.0094	0.26	0.0017	0.18	0.0154	0.18	0.0036	0.18	0.0000	0.00	0.0083	0.19	0.0047	0.19
2006	0.0000	0.00	0.0052	0.26	0.0012	0.18	0.0181	0.19	0.0034	0.18	0.0000	0.00	0.0089	0.19	0.0049	0.19
2007	0.0000	0.00	0.0011	0.26	0.0042	0.18	0.0190	0.19	0.0043	0.18	0.0000	0.00	0.0100	0.19	0.0055	0.19
2008	0.0000	0.00	0.0030	0.26	0.0047	0.18	0.0193	0.19	0.0041	0.18	0.0000	0.00	0.0102	0.19	0.0056	0.19
Min	0.0000	0.00	0.0011	0.15	0.0012	0.13	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0045	0.18	0.0031	0.18
Median	0.0000	0.00	0.0146	0.23	0.0107	0.16	0.0068	0.17	0.0016	0.18	0.0000	0.00	0.0095	0.19	0.0059	0.19
Mean	0.1099	0.19	0.0193	0.21	0.0113	0.16	0.0069	0.16	0.0039	0.16	0.0000	0.00	0.0090	0.19	0.0056	0.19
Max	1.3050	0.96	0.0660	0.26	0.0258	0.18	0.0190	0.25	0.0140	0.28	0.0000	0.00	0.0110	0.24	0.0068	0.24

Table B23. Biological reference points from per recruit models for ocean quahogs. Reference points from model runs with natural mortality M=0.02 y^{-1} are for potential use by managers. Results with M=0.015 and 0.025 are for sensitivity analyses.

Policy	Fishing mortality rate (F)	Yield per recruit (g)	Spawning biomass per recruit (g)	Total biomass per recruit (g)
***M*=0.015**				
F=0	0.0000	0.00	1124	1341
F_{MAX}	0.0540	9.54	215	346
$F_{0.1}$	0.0220	8.53	431	592
$F_{25\%}$	0.0390	9.41	282	425
$F_{40\%}$	0.0200	8.31	459	623
$F_{45\%}$	0.0170	7.89	507	676
$F_{50\%}$	0.0140	7.32	566	740
$F_{55\%}$	0.0110	6.56	638	819
$F_{60\%}$	0.0090	5.89	696	882
***M*=0.02**				
F=0	0.0000	0.00	704	877
F_{MAX}	0.0759	7.52	129	234
$F_{0.1}$	0.0277	6.59	275	407
$F_{25\%}$	0.0517	7.39	176	292
$F_{40\%}$	0.0266	6.51	282	415
$F_{45\%}$	0.0219	6.11	317	454
$F_{50\%}$	0.0180	5.67	353	495
$F_{55\%}$	0.014	5.05	399	545
$F_{60\%}$	0.0120	4.66	426	575
***M*=0.025**				
F=0	0.0000	0.00	466	608
F_{MAX}	0.1030	6.11	82	169
$F_{0.1}$	0.0360	5.34	179	289
$F_{25\%}$	0.0660	5.98	117	214
$F_{40\%}$	0.0330	5.21	189	300
$F_{45\%}$	0.0270	4.87	212	327
$F_{50\%}$	0.0220	4.49	237	355
$F_{55\%}$	0.0180	4.09	261	382
$F_{60\%}$	0.015	3.72	282	406

Table B24. Input parameters for length based per recruit models used to estimate biological reference points for ocean quahog. The shell height-meat weight relationship is $W = e^{\alpha + \beta \ln L}$ where W is meat weight in grams and L is shell height (mm). Meat weights are in grams. Logistic functions for maturity and fishery selectivity at length were $p_L = 1 \Big/ \left[1 + e^{-(\alpha + \beta L)}\right]$ where L is shell height in mm and p_L is the corresponding proportion.

Parameter	Value
von Bertalanffy growth curve	
L_∞	97.28
K	0.0311
Shell height-meat weight relationship	
ln(α)	-9.258
β	2.825
Natural mortality (*M*)	0.02
Logistic fishery selectivity at size	
α	-7.63
β	0.105
Logistic maturity at size	
α	-5.92
β	0.0927

Table B25. Factors considered in choosing an F_{MSY} proxy for ocean quahogs between $F_{40\%}$ and $F_{50\%}$.

Factors affecting MSY estimates for fishable quahogs	Groundfish proxy ($F_{40\%}$)	Less resilient than groundfish proxy ($F_{50\%}$)
Temporal recruitment pattern (regularity)		x
Accurate catch data	x	
Low bycatch mortality	x	
Long time lags between spawning and recruitment to the fishery and spawning stock		x
Heterogeneous fishing patterns	x	x
Longevity		x
Mature before entering the fishery	x	
Slow growth		x
Time to fix errors if we are wrong	x	

Table B26. Stochastic projection results for ocean quahogs in 2015 with natural mortality M=0.02 under various constant quotas. Starting biomass levels in 2008 are from a bootstrap analysis (1673 iterations) with the KLAMZ model ocean quahogs in the exploited area. Biomass on GBK was assumed constant at the 2008 estimate. Actual landings were used in simulations for 2008 and expected landings (3.8 million bushels or 17.2 mt meats) were used for 2009. For 2010-2015, simulated managers specified a constant level of annual landings (quota) based on a harvest policy. Quotas are calculated by multiplying the target fishing mortality times the current best estimate of biomass during 2008, where the biomass estimate is for either the exploited or entire stock area. Simulated catches were equal to the quota plus 5% to account for incidental mortality. Probabilities of overfished stock conditions ($B_{2015} \leq B_{Threshold}$) and probabilities of overfishing ($F_{2015} \geq F_{45\%}$) in 2015 are shown in the last three columns. The probability of overfishing is for either the exploited stock (F_{2015} for exploited stock $\geq F_{45\%}$) or the entire stock (F_{2015} for entire stock $\geq F_{45\%}$).

How are the landings calculated? (alternative management actions, under constant annual removal)	Annual landings 2010-2015 (million bushels)	Annual landings 2010-2015 (1000 mt meats)	Probability overfished in 2015 ($B_{2015} \leq B_{Threshold}$)	Probability of overfishing for exploited stock in 2015 (F_{2015} for exploited stock $\geq F_{45\%}$)	Probability of overfishing for entire stock in 2015 (F_{2015} for entire stock $\geq F_{45\%}$)
Status quo landings	3.8	17.2	0	0.00	0.00
Current quota	5.3	24.2	0	0.19	0.00
FMP min landings	4.0	18.1	0	0.00	0.00
FMP max landings	6.0	27.2	0	0.54	0.00
Recommended *F* threshold ($F_{45\%}$) x 2008 biomass in exploited area	7.7	34.8	0	0.90	0.00
Current *F* target ($F_{0.1}$) x 2008 biomass in exploited area	9.7	44.0	0	0.99	0.00
Current *F* threshold ($F_{25\%}$) x 2008 biomass in exploited area	18.1	82.2	0	1.00	1.00
Recommended *F* threshold ($F_{45\%}$) x biomass in entire area	14.0	63.7	0	1.00	0.97
Current *F* target ($F_{0.1}$) x biomass in entire area	17.8	80.6	0	1.00	1.00
Current *F* threshold ($F_{25\%}$) x biomass in entire area	33.1	150.4	0	1.00	1.00

Table B27. Probabilities of overfishing and overfished stock status by 2015 for ocean quahogs under various harvest policies and three states of nature (M=0.015, 0.02 and 0.025) based on stochastic projection analyses for 2008-2015. Actual landings were used for 2008 and expected landings were used for 2009. For 2010-2015, simulated managers specify annual landings in terms of a constant landings policy (e.g. status-quo landings) or by multiplying an F based reference point (e.g. F20%) times the best estimate of stock biomass in 2008, where the biomass estimate may be for either the whole stock or the exploited stock only. The specified level of annual landings (+ 5% for incidental mortality) is then extracted from the simulated population during 2010-2015. Figures on the left side of the figure describe management actions (harvest policies) and calculation of annual landings during 2010-2015. Figures on the right hand side of the figure give the probability of overfishing for the exploited stock and the entire stock relative to the true mortality threshold $F_{45\%}$, as well as the probability of overfished stock conditions for the whole stock relative to the assumed true biomass threshold $B_{threshold} = 0.4B_{1978}$. The mortality and biomass thresholds depend on the state of nature because $F_{45\%}$ and B_{1978} depend on M. Probabilities equal zero are not shown to enhance the readability of the table. Figures above the dash line are for constant landings policies. Figures below the dashed line are for F based harvest policies.

Harvest policies (management actions)							States of nature M=0.015			M=0.02			M=0.025		
Policy	Reference point F	Stock area for target landings	Best estimate 2008 biomass for catch calculations	Landings (million bushels)	Landings (1000 mt meats)	Landings + indicidental mortality (1000 mt meats)	Biomass	F for exploit. stock	F whole stock	Biomass	F for exploit. stock	F whole stock	Biomass	F for exploit. stock	F whole stock
Current quota		NA	NA	5.33	1.175	1.234	0.00	0.68	0.00	0.00	0.19	0.00	0.00	0.01	0.00
FMP max landings	NA	NA	NA	6.00	1.323	1.389	0.00	0.86	0.00	0.00	0.54	0.00	0.00	0.12	0.00
FMP min landings	NA	NA	NA	4.00	0.882	0.926	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Status quo landings	NA	NA	NA	3.80	0.838	0.880	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F0.1	0.0277	Whole	2,908	17.76	80.557	84.584	0.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00	1.00
F25%	0.0517	Whole	2,908	33.15	150.353	157.871	0.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00	1.00
F40%	0.0266	Whole	2,908	17.05	77.358	81.226	0.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00	0.99
F45%	0.0219	Whole	2,908	14.04	63.689	66.874	0.00	1.00	1.00	0.00	1.00	0.97	0.00	1.00	0.70
F50%	0.0180	Whole	2,908	11.54	52.347	54.965	0.00	1.00	0.98	0.00	1.00	0.60	0.00	1.00	0.00
F0.1	0.0277	Exploitable	1,589	9.70	44.015	46.216	0.00	1.00	1.00	0.00	0.99	0.00	0.00	0.96	0.00
F25%	0.0517	Exploitable	1,589	18.11	82.151	86.259	0.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00	1.00
F40%	0.0266	Exploitable	1,589	9.32	42.267	44.381	0.00	1.00	1.00	0.00	0.99	0.00	0.00	0.93	0.00
F45%	0.0219	Exploitable	1,589	7.67	34.799	36.539	0.00	0.99	0.01	0.00	0.90	0.00	0.00	0.73	0.00
F50%	0.0180	Exploitable	1,589	6.31	28.602	30.032	0.00	0.90	0.00	0.00	0.65	0.00	0.00	0.24	0.00

Table B28. Harvest policies (management actions) considered in projection analyses for ocean quahogs. Constant landings policies are shown with the corresponding approximate true F for the whole and exploited stock components. Constant F policies are shown with the corresponding landings level determined by multiplying the target *F* by the biomass for the whole stock in 2008.

Whole stock 2008 biomass (1000 mt meats)		2,908		
Constant landings policies				
Policy (management action)	F (whole stock)	Landings Million bu	Landings Thousand mt meats	F exploited stock (for comparison)
Status quo landings	0.006	3.80	17.24	0.011
FMP maximum landings	0.009	6.00	27.22	0.017
FMP minimum landings	0.006	4.00	18.14	0.012
FMP current landings quota	0.008	5.33	24.18	0.015
Constant F policies				
F0.1 (current target)	0.028	17.76	80.56	0.052
F25% (current threshold)	0.052	33.15	150.35	0.100
F40%	0.027	17.05	77.36	0.050
F45% (recommended target)	0.022	14.04	63.69	0.041
F50%	0.018	11.54	52.35	0.034

Table B29. Input data used in simple projection analyses for ocean during 2009-2015.

Year	SVA	DMV	NJ	LI	SNE	GBK	Total Less GBK	Total
Somatic growth rate (G y^{-1})								
2008	1.05011E-07	1.05011E-07	0.00122	0.00792	0.00841	0.01116	0.00588	0.00837
Recruitment rate (r = Recruitment / Average Biomass in 2005 y^{-1})								
2008	0	1.0686E-08	0.00142	0.00002	0.00002	0.01182	0.00035	0.00548
Natural mortality (M y^{-1})								
2008	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Initial biomass proportions by region								
2008	4.46199E-06	0.03151	0.12819	0.20270	0.18399	0.45361	0.54639	1.00000
Proportions landings and catch by region								
2008	0	0.01766	0.11345	0.72807	0.14081	0.00000	1.00000	1.00000

FIGURES

B. Stock assessment for ocean quahogs (*Arctica islandica*)

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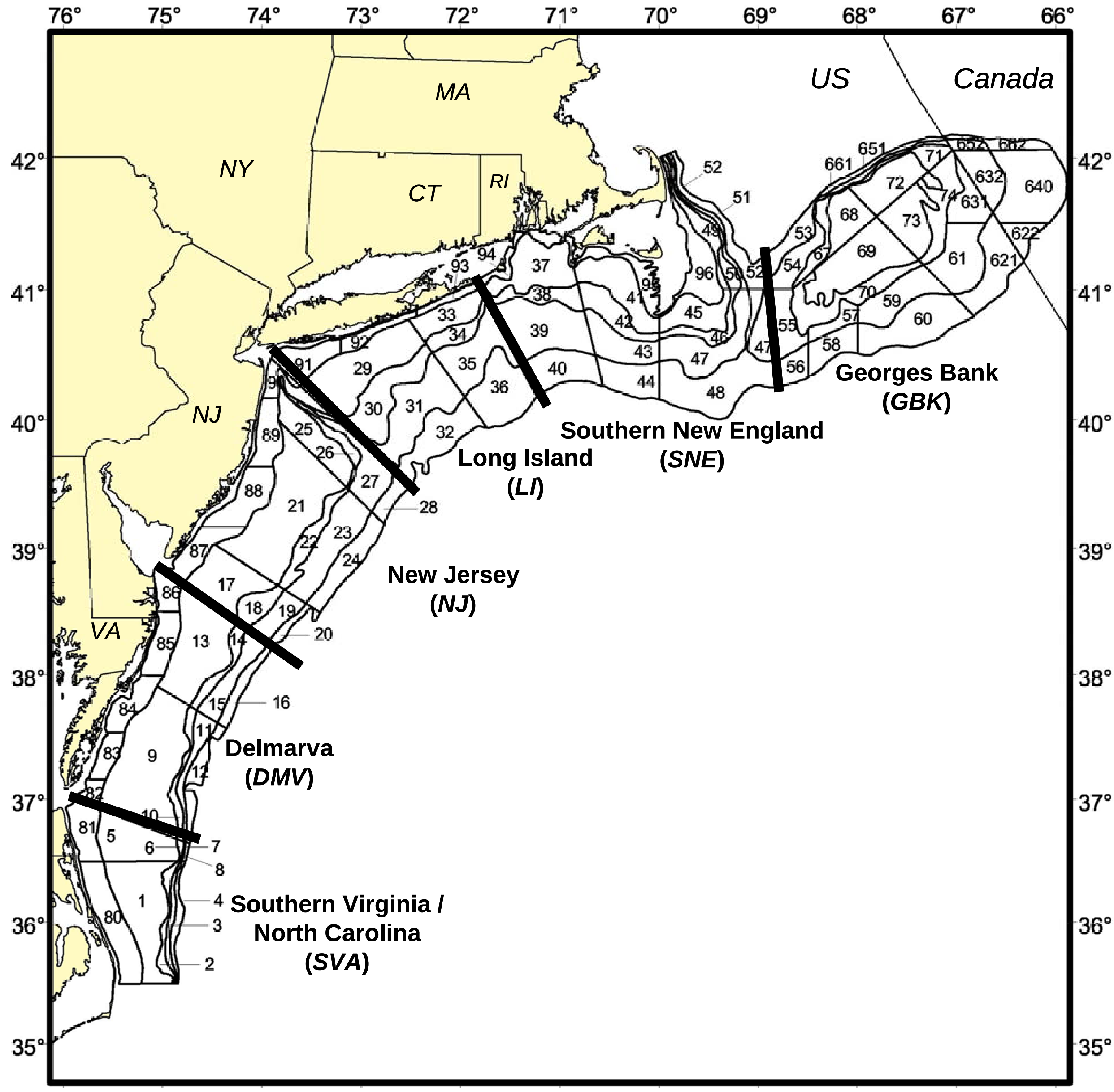


Figure B1. Stock assessment regions for ocean quahog in the US EEZ, with NEFSC shellfish survey strata boundaries.

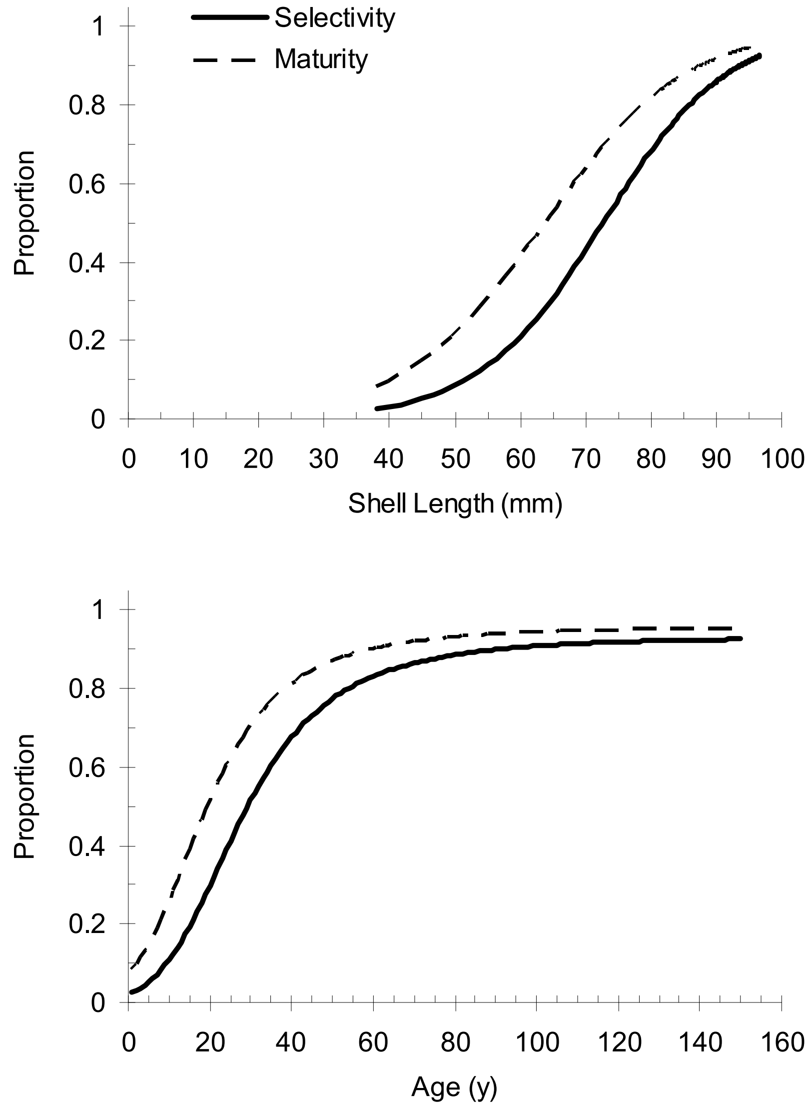


Figure B2. Commercial size-selectivity and maturity by length (*top panel*) and by age (*bottom panel*) assuming the von Bertalanffy growth curve for ocean quahogs in MAB (exploited region). Estimates in upper panel are from Thorarinsdottir and Jacobson, 1995).

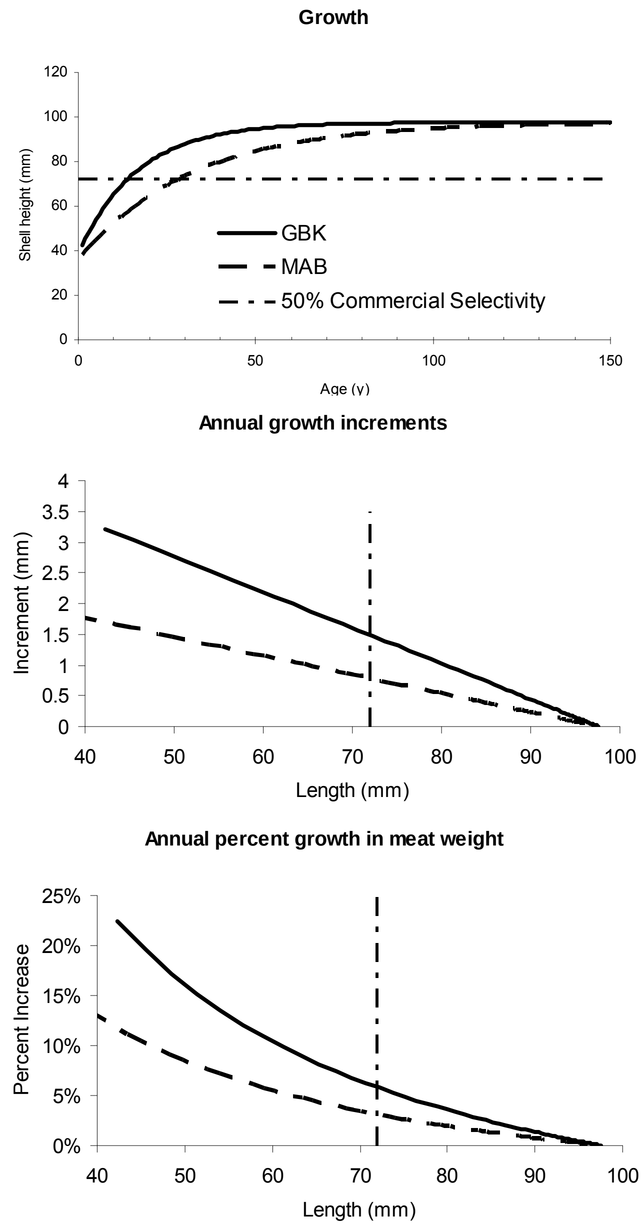


Figure B3. Growth, annual growth increments and percent annual change in meat weights for ocean quahog in GBK and in the Mid-Atlantic Bight (MAB) based on von Bertalanffy growth curves (Lewis et al., 2001) and shell length-meat weight relationships. The growth curve for MAB is used in this assessment for the exploited ocean quahog stock (which excludes GBK).

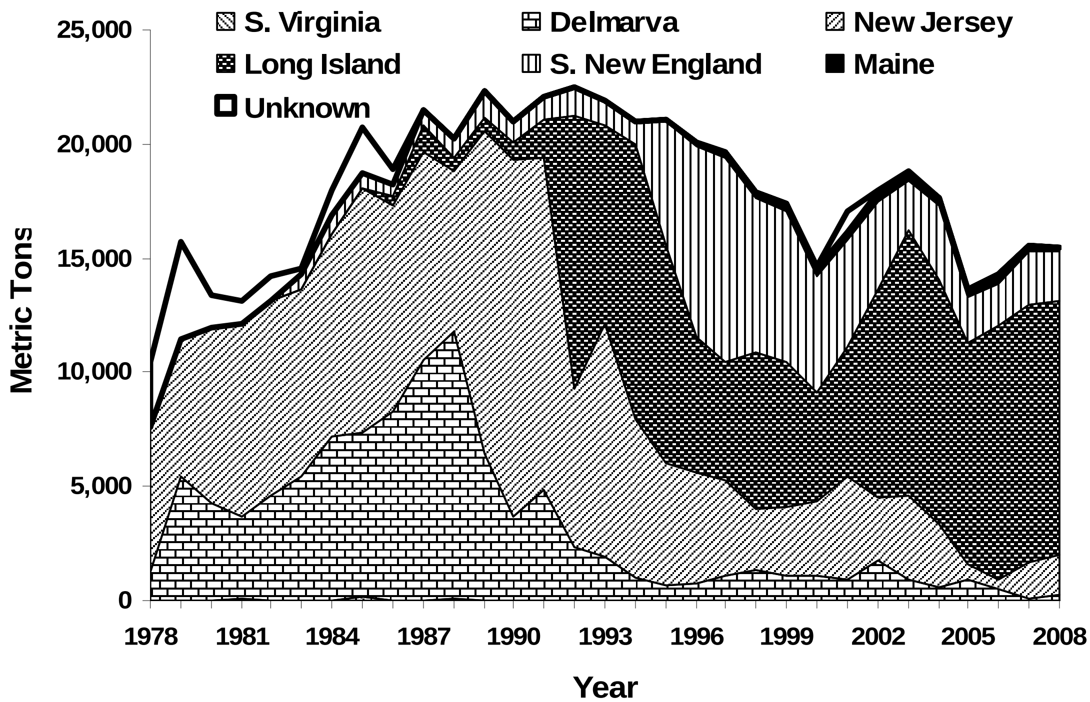
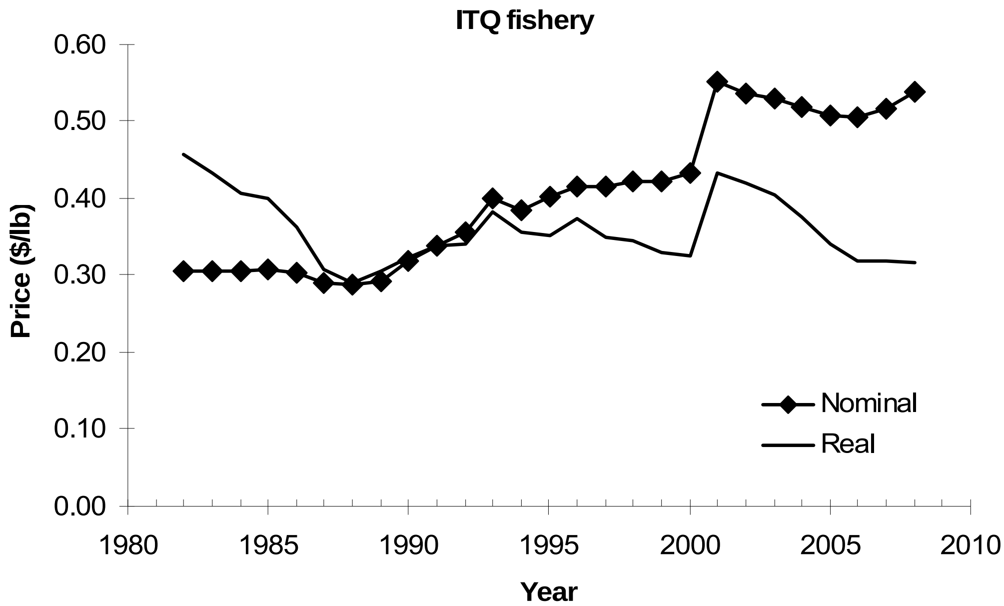


Figure B4. Ocean quahog commercial landings (in metric tons meat weights) from the US EEZ during 1978-2008. Landings in the SVA (S. Virginia) area are too small to be visible in the figure.



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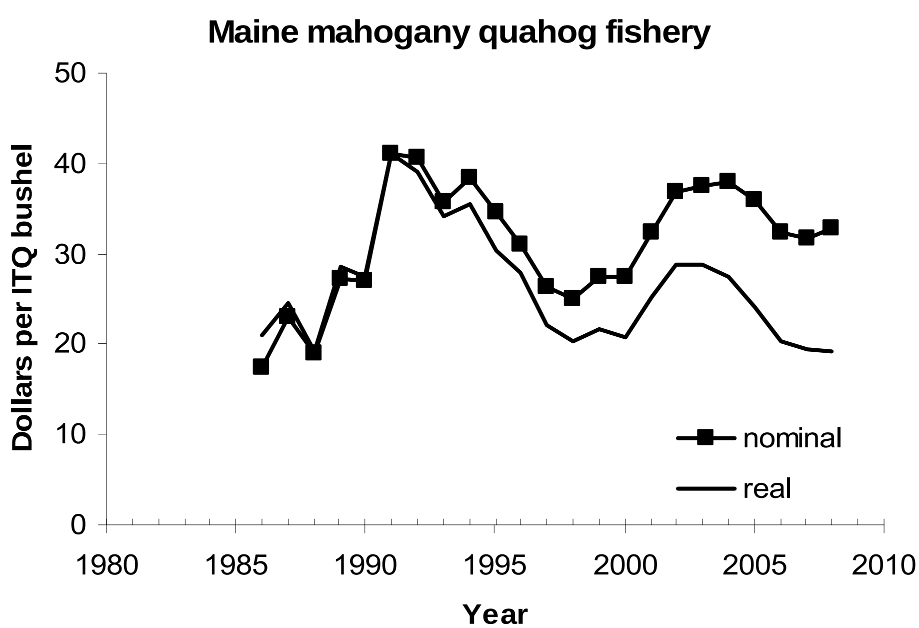


Figure B5. Real and nominal ex-vessel prices (total revenue/total landings) for the ITQ and Maine ocean quahog fisheries. Real prices are 1991 dollars.

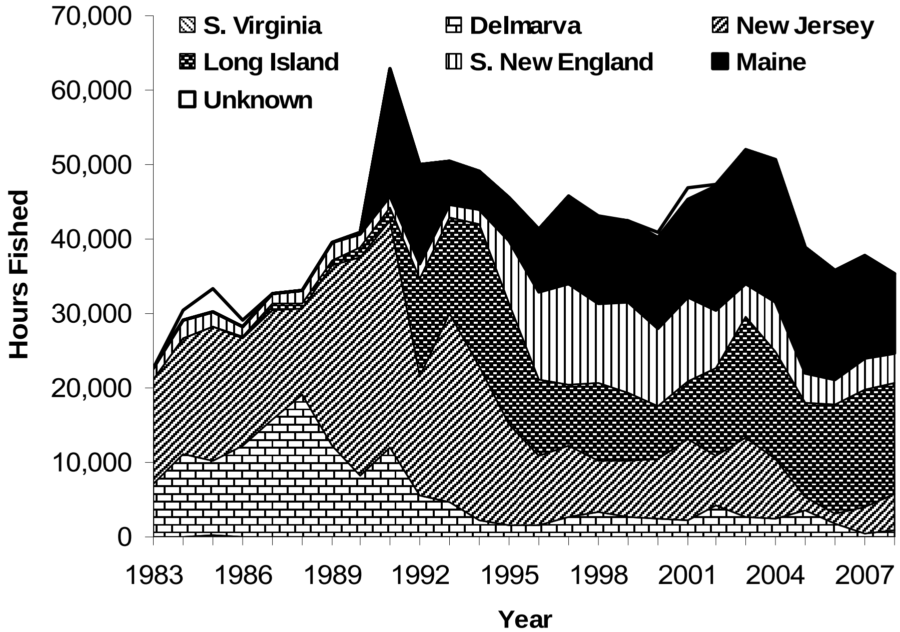


Figure B6. Hours fished for ocean quahog in the US EEZ during 1983-2008 based on logbook records. Hours fished in the SVA (S. Virginia) area are too small to be visible in the figure.

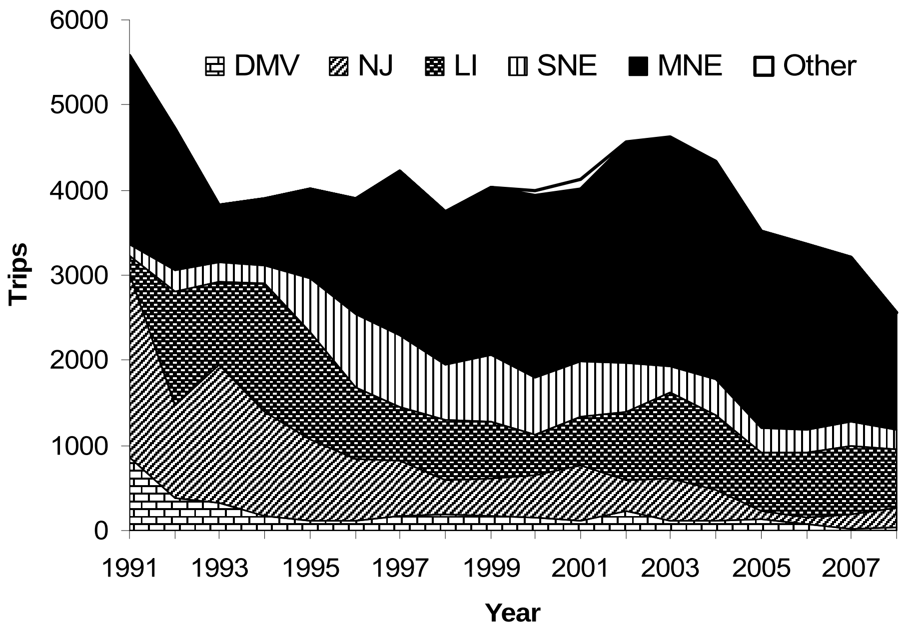


Figure B7. Number of trips for ocean quahog in the US EEZ during 1991-2008 based on logbook records.

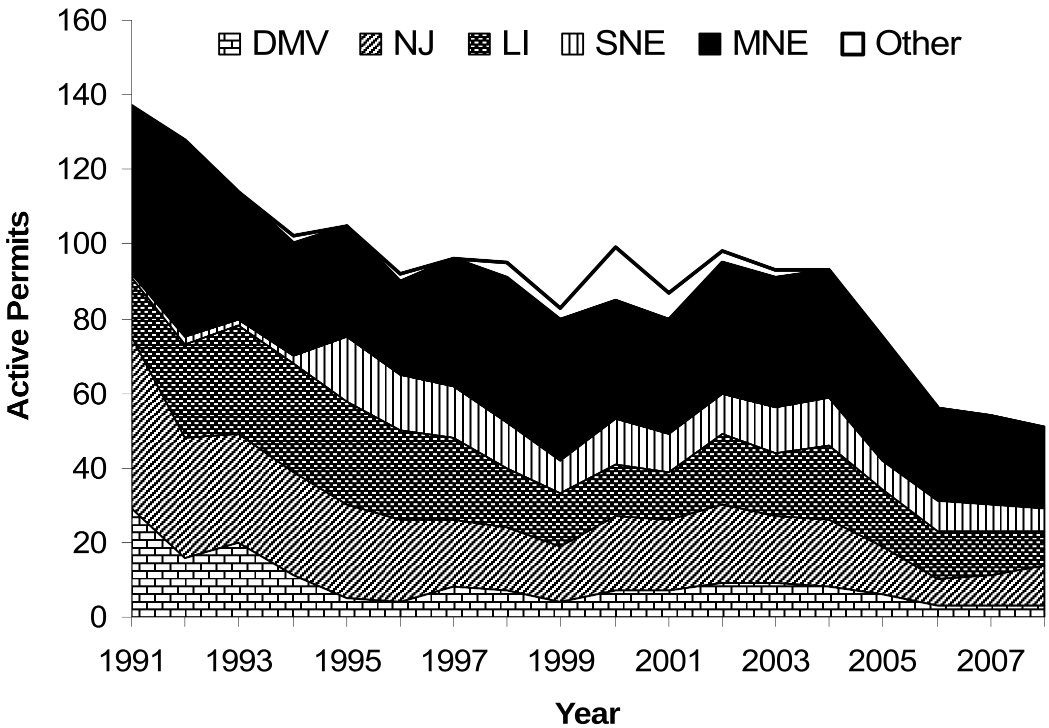


Figure B8. Number of active permits (fishing vessels) for ocean quahog in the US EEZ during 1991-2008 based on logbook records. The total number of permits in the graph for any year may exceed the total number of active permits in the fishery because some vessels fished in more than one area.

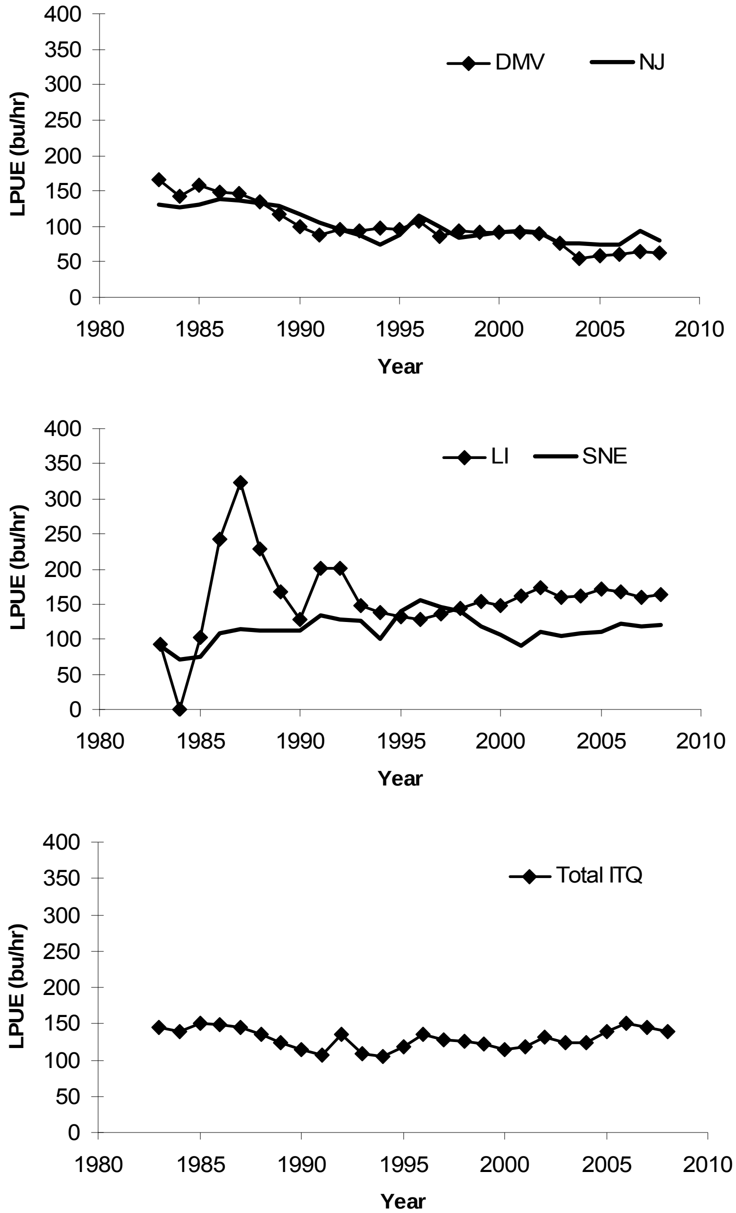


Figure B9. Trends in nominal LPUE for ocean quahog during 1980-2008 by region.

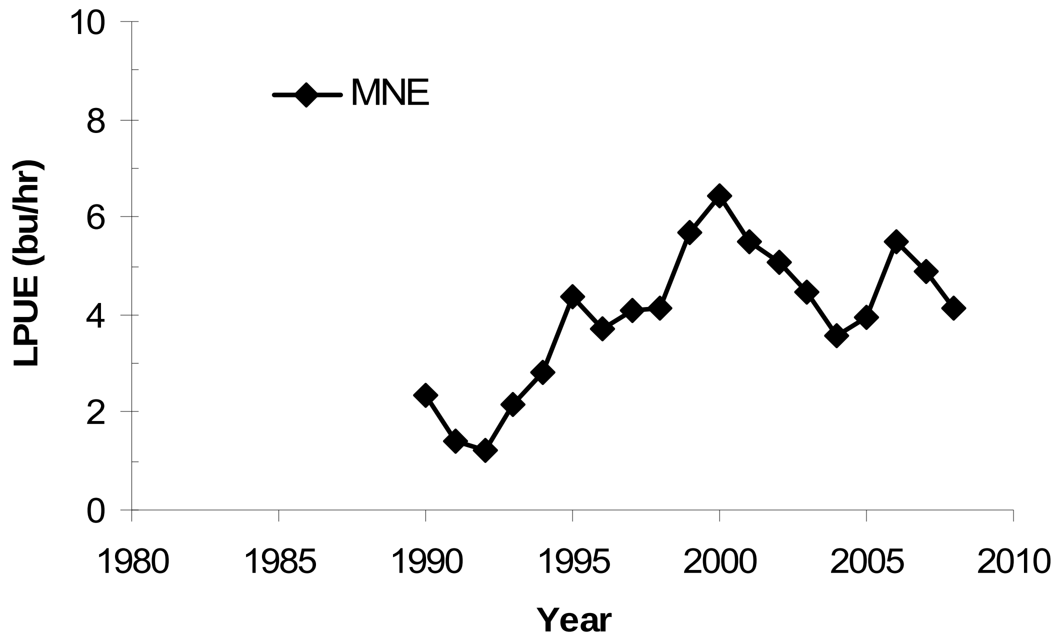


Figure B10. Nominal LPUE (ITQ bushels per hour) in the Maine ocean quahog fishery.

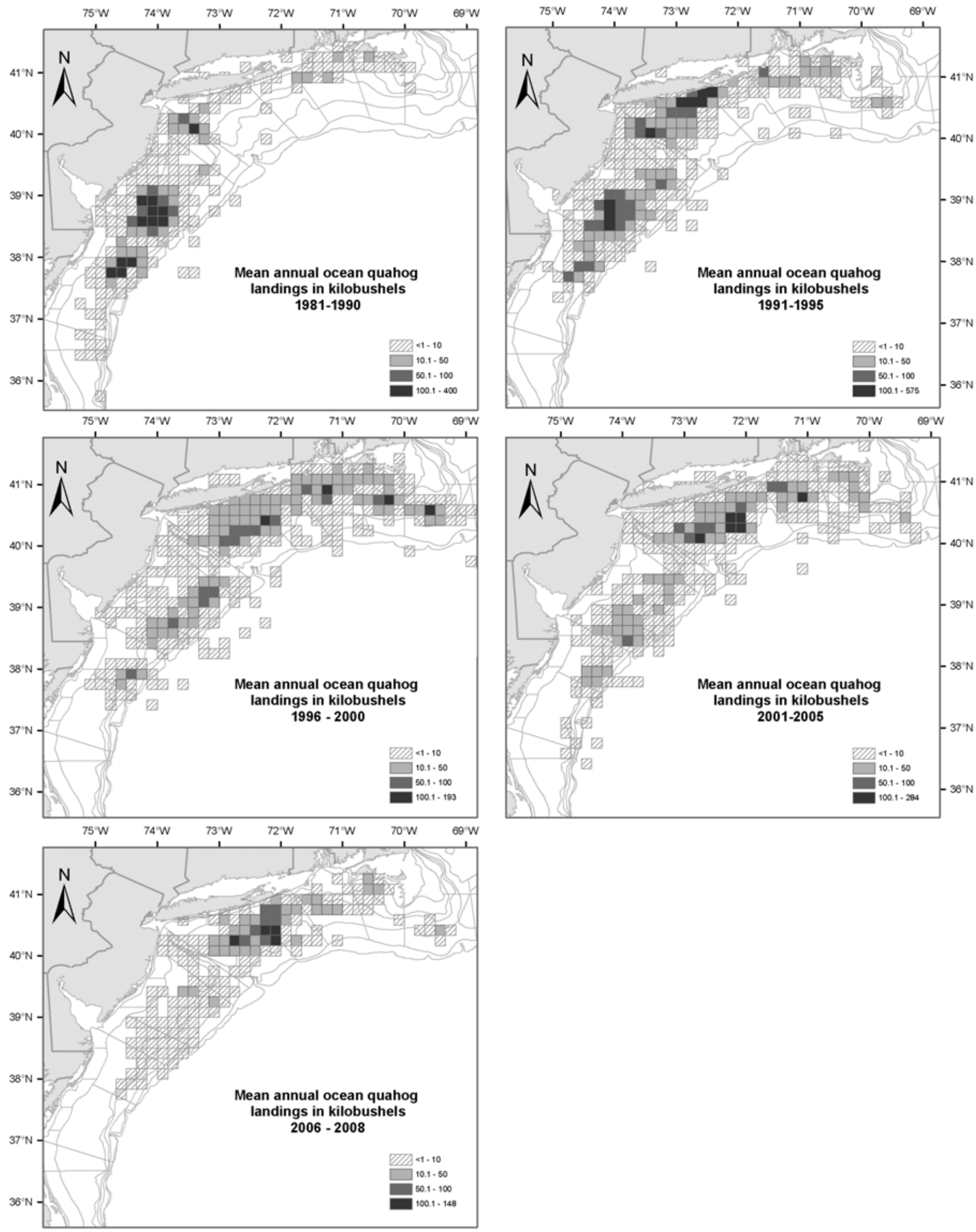


Figure B11. Spatial patterns in average annual landings (1000 ITQ bushels per year) for ocean quahog from logbook records. Data in TNMS far offshore reflect errors in logbook data.

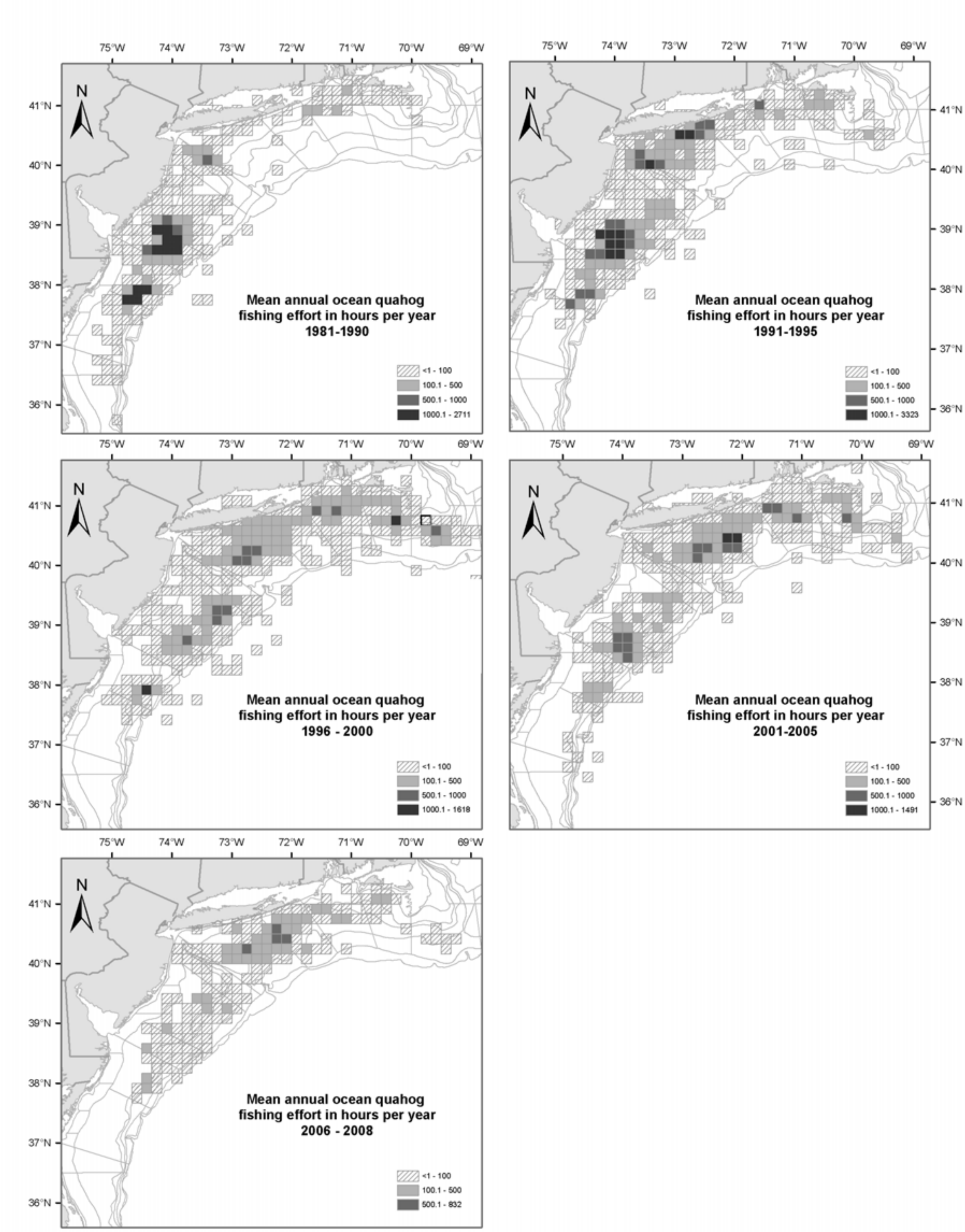


Figure B12. Spatial patterns in average annual fishing effort (hours fished per year) for ocean quahog from logbook records. Data in TNMS far offshore reflect errors in logbook data.

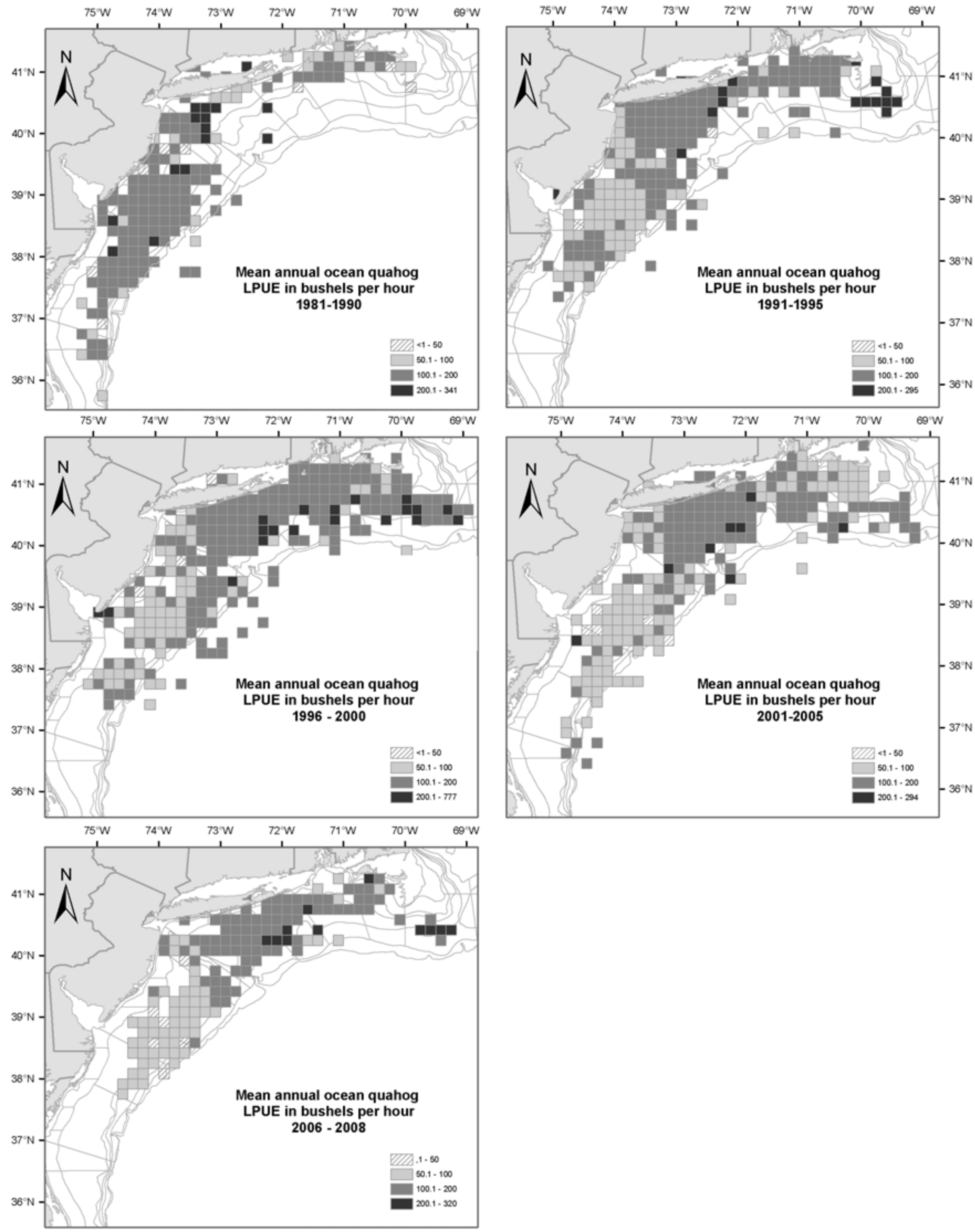


Figure B13. Spatial patterns in average LPUE (ITQ bushels per hours fished) for ocean quahog from logbook records. Data in TNMS far offshore reflect errors in logbook data.

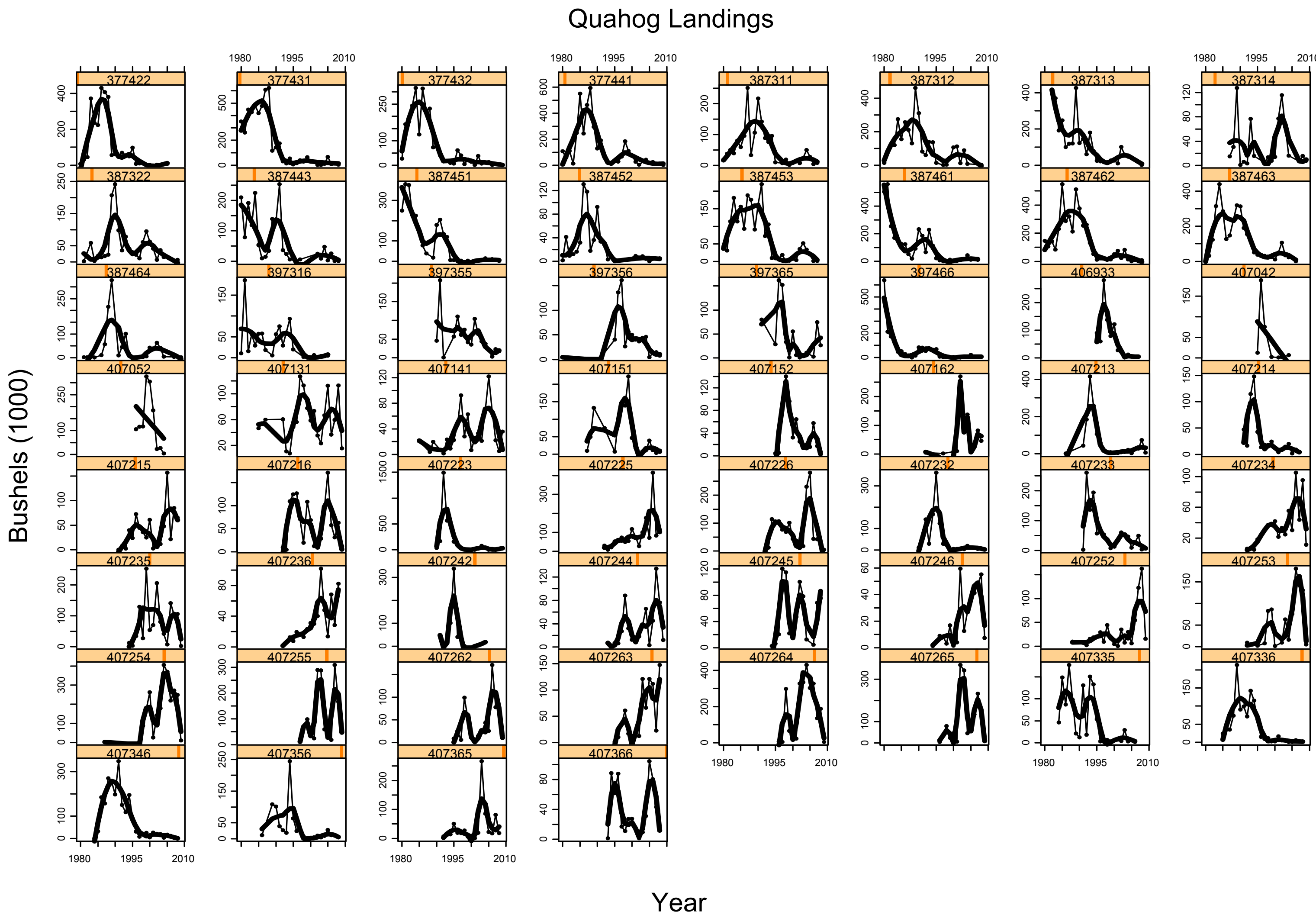


Figure B14. Trends in total annual landings (ITQ bu per year, vessel ton class 3-4) for ocean quahog in important TNMS during 1980-2008.

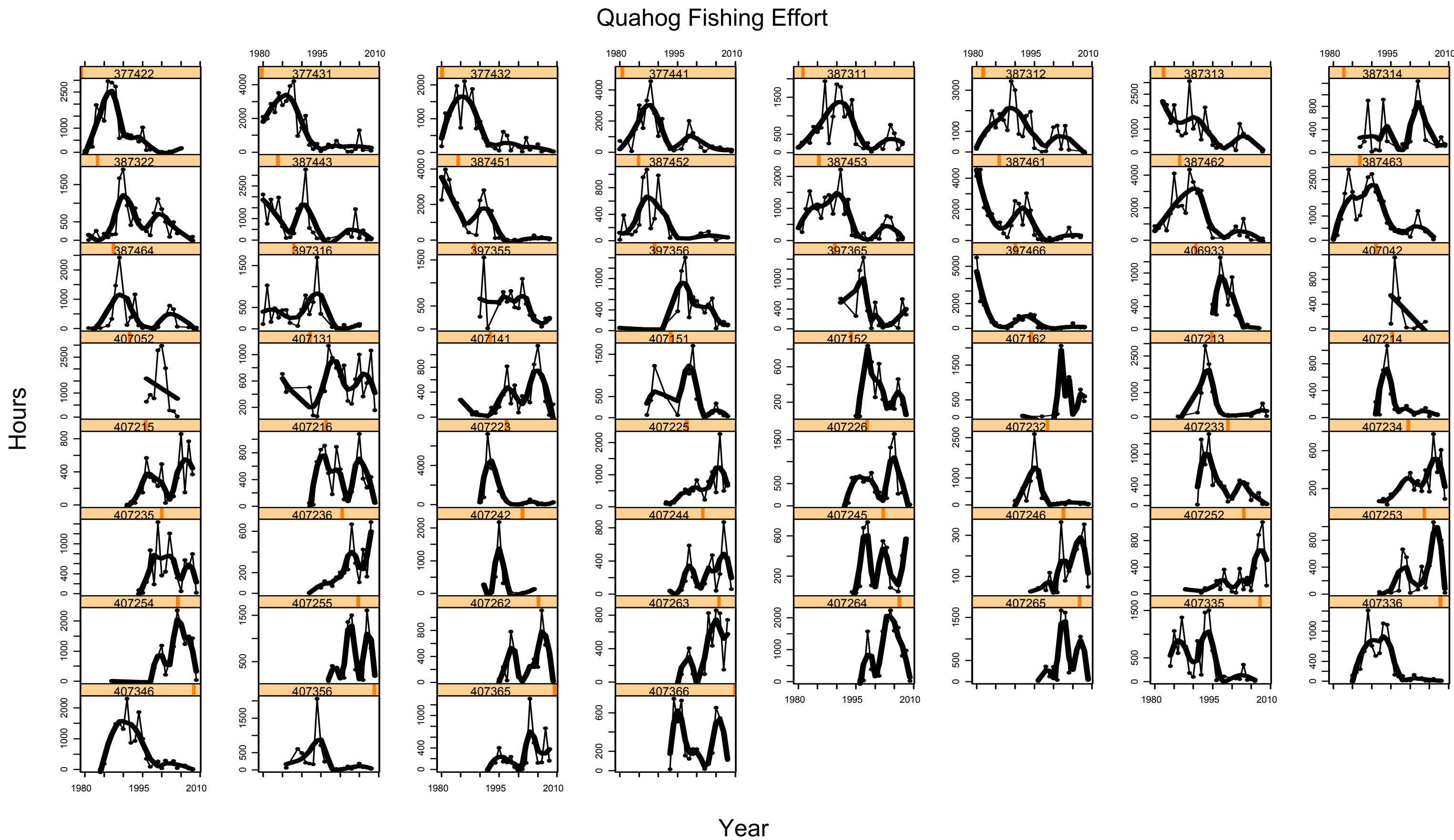


Figure B15. Trends in total annual fishing effort (hours fished per year, vessel ton class 3-4) for ocean quahog in important TNMS during 1980-2008.

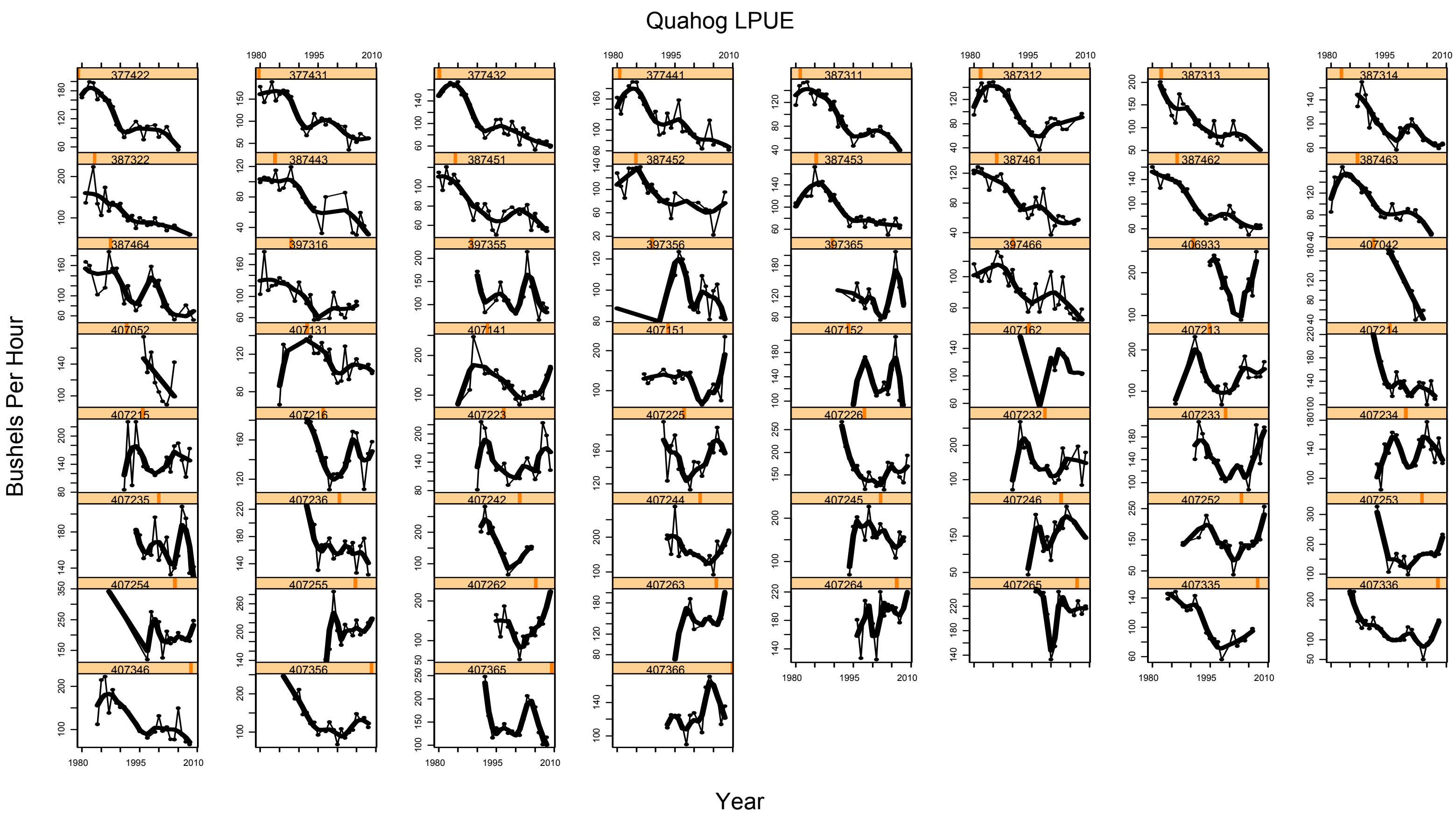


Figure B16. Trends in annual LPUE (ITQ bu h^{-1}, total landings/total hours fished) for ocean quahog in important TNMS during 1980-2008.

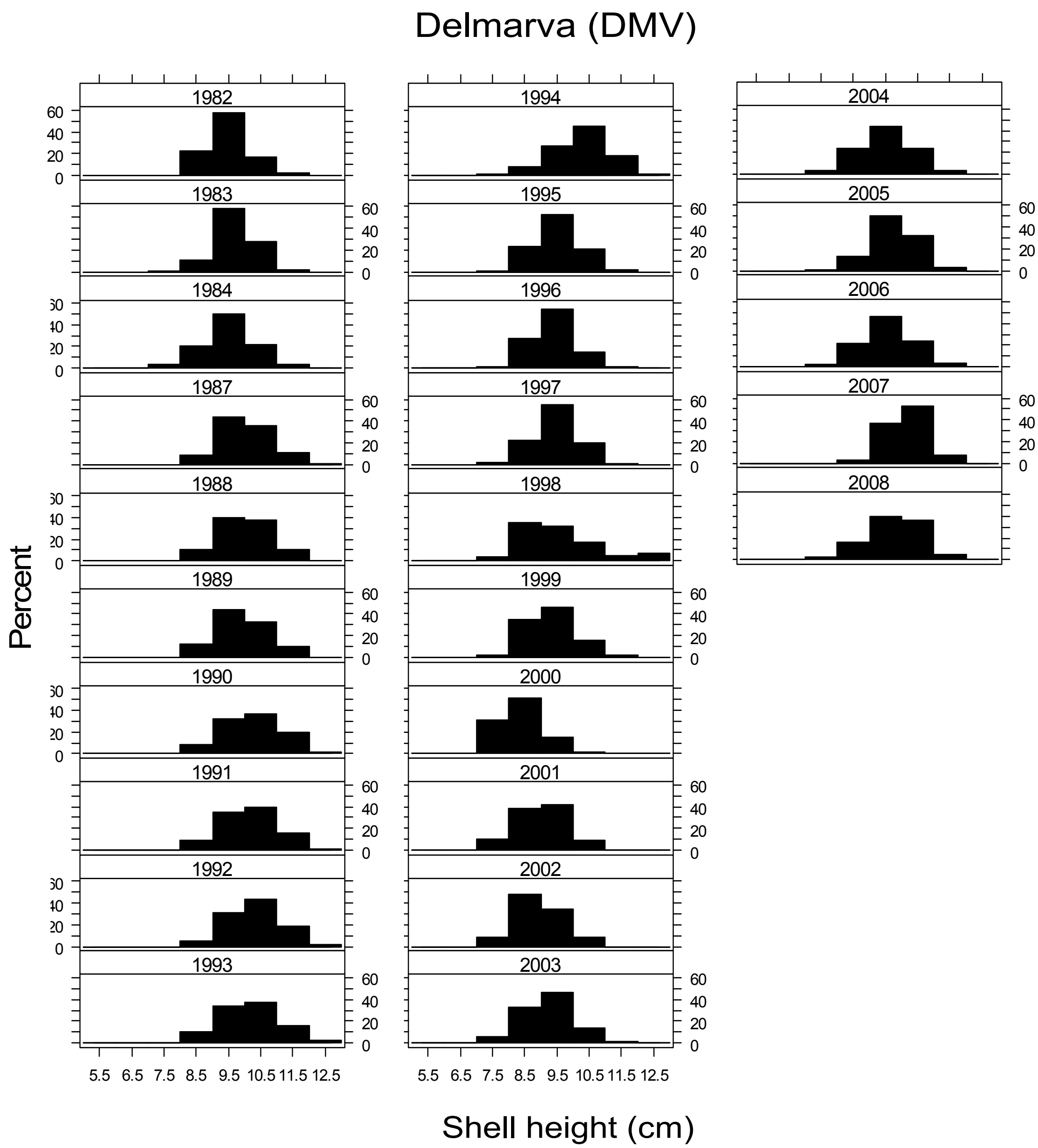


Figure B17. Commercial length composition data for ocean quahogs landed in the DMV region.

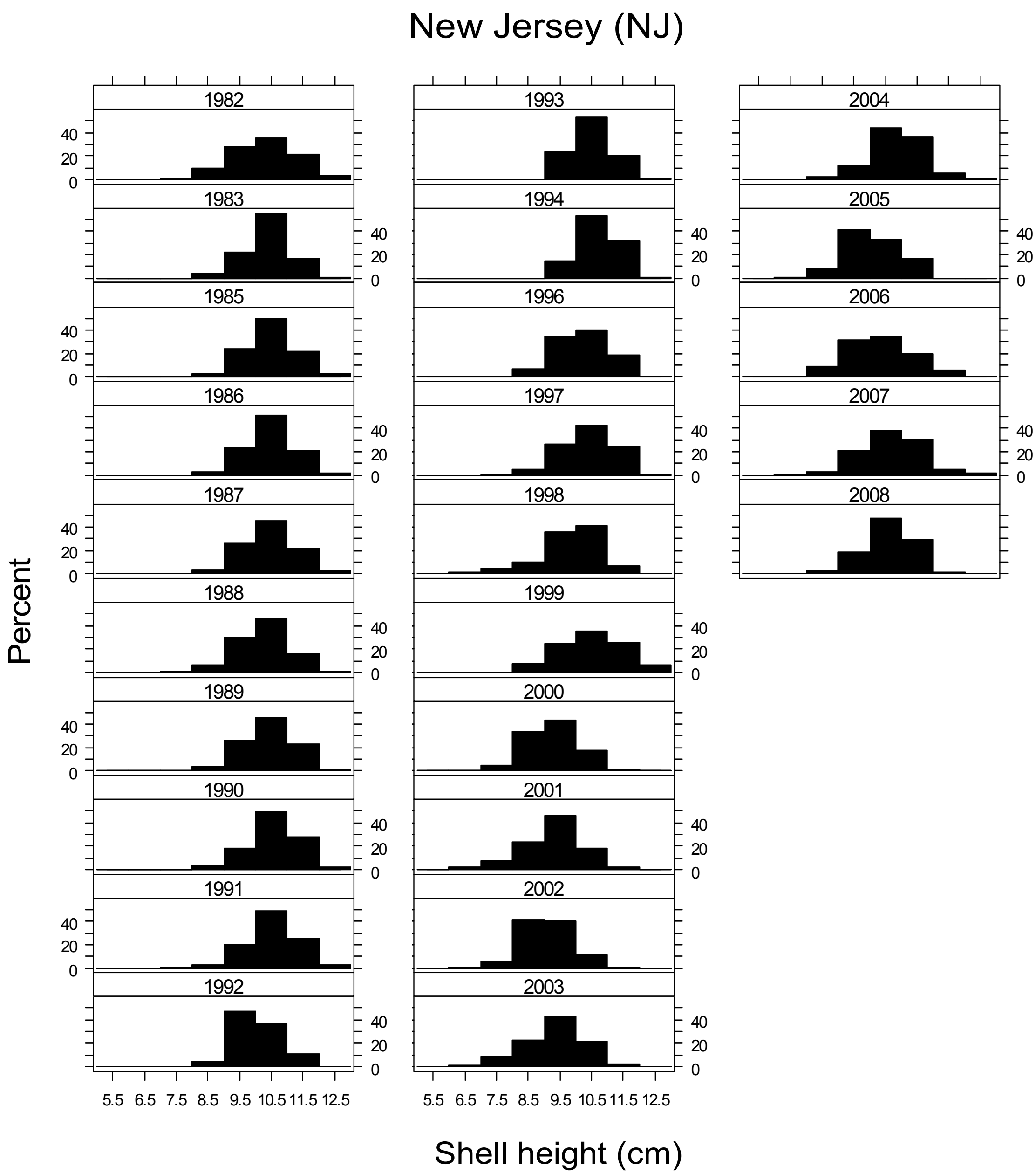


Figure B18. Commercial length composition data for ocean quahogs landed in the NJ region.

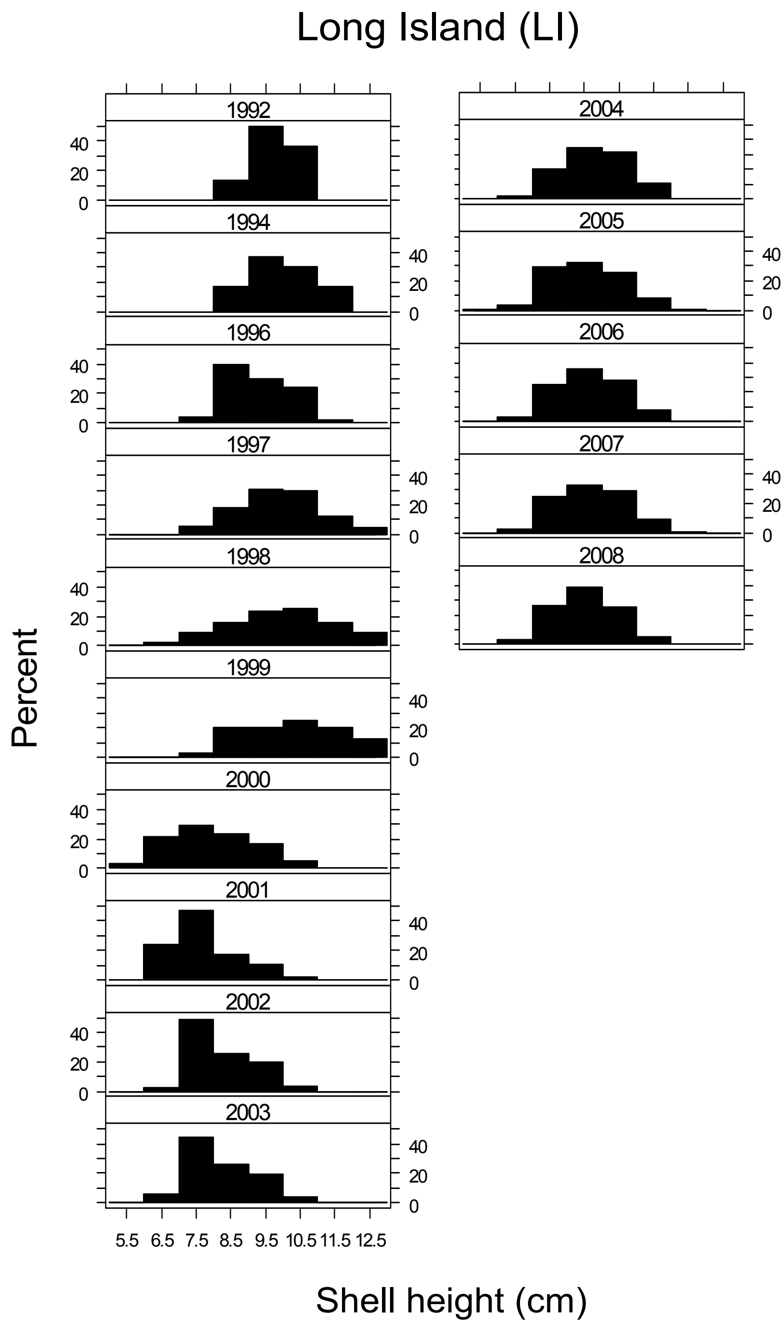


Figure B19. Commercial length composition data for ocean quahog landed in the LI region.

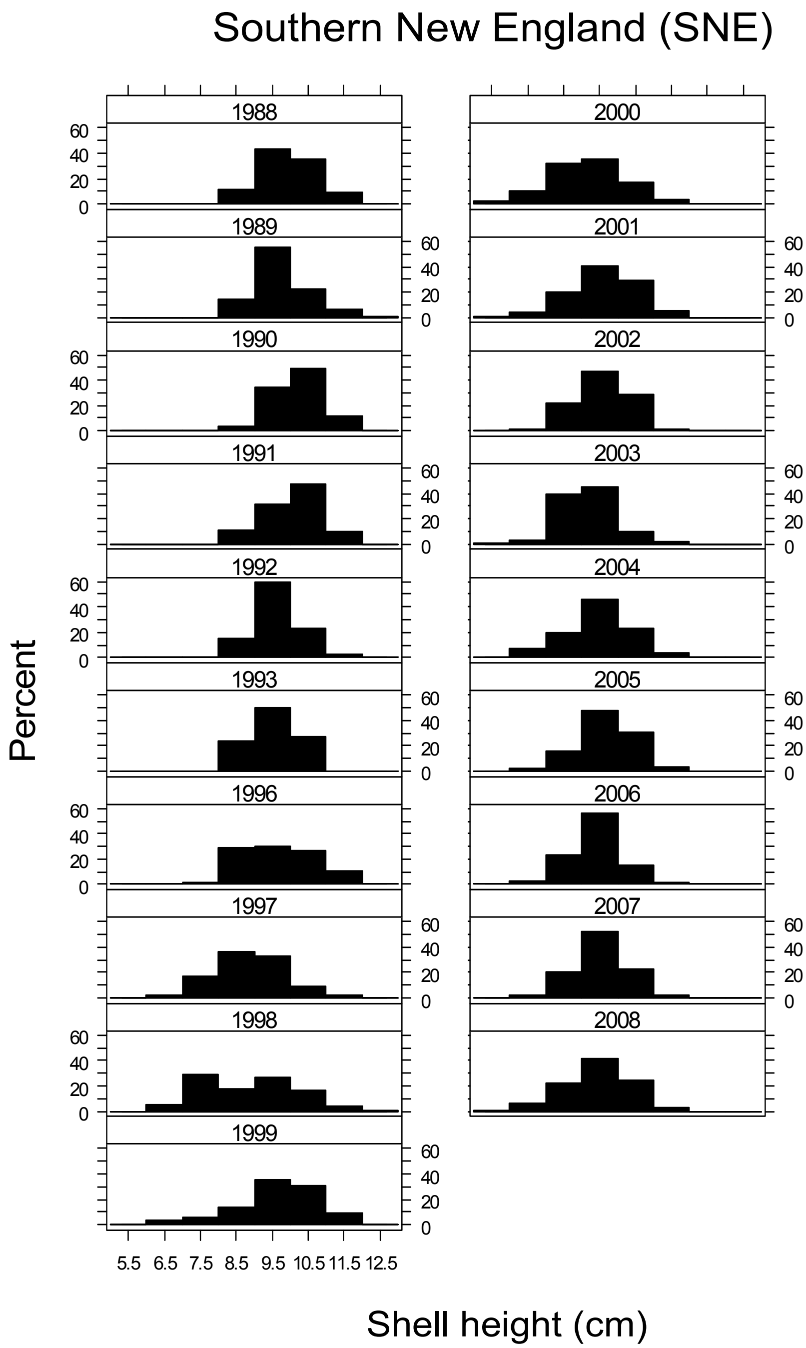


Figure B20. Commercial length composition data for ocean quahog landed in the SNE region.

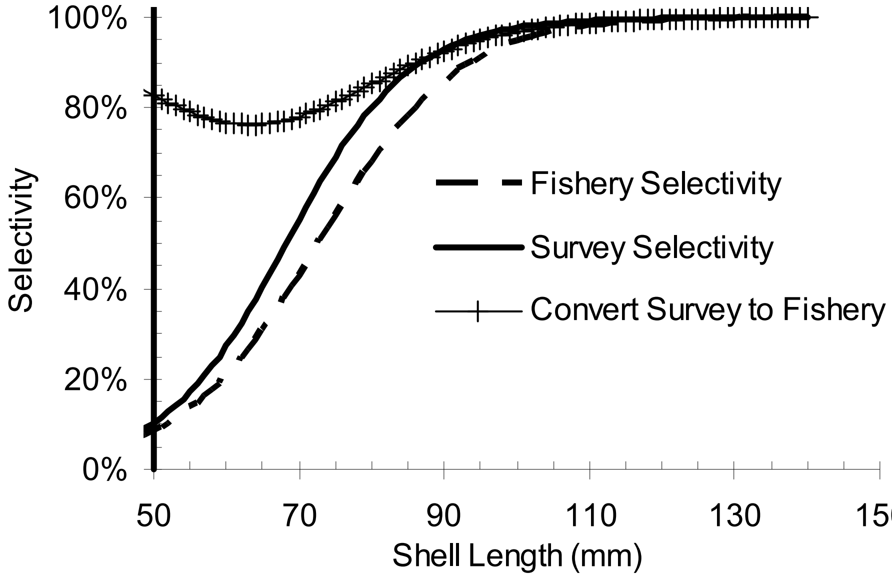


Figure B21. Fishery and survey selectivity curves for ocean quahog from NEFSC (2007a). The ratio of the fishery and survey selectivity curves, which can be used to convert survey abundance at size directly to fishable abundance at size, is also shown.

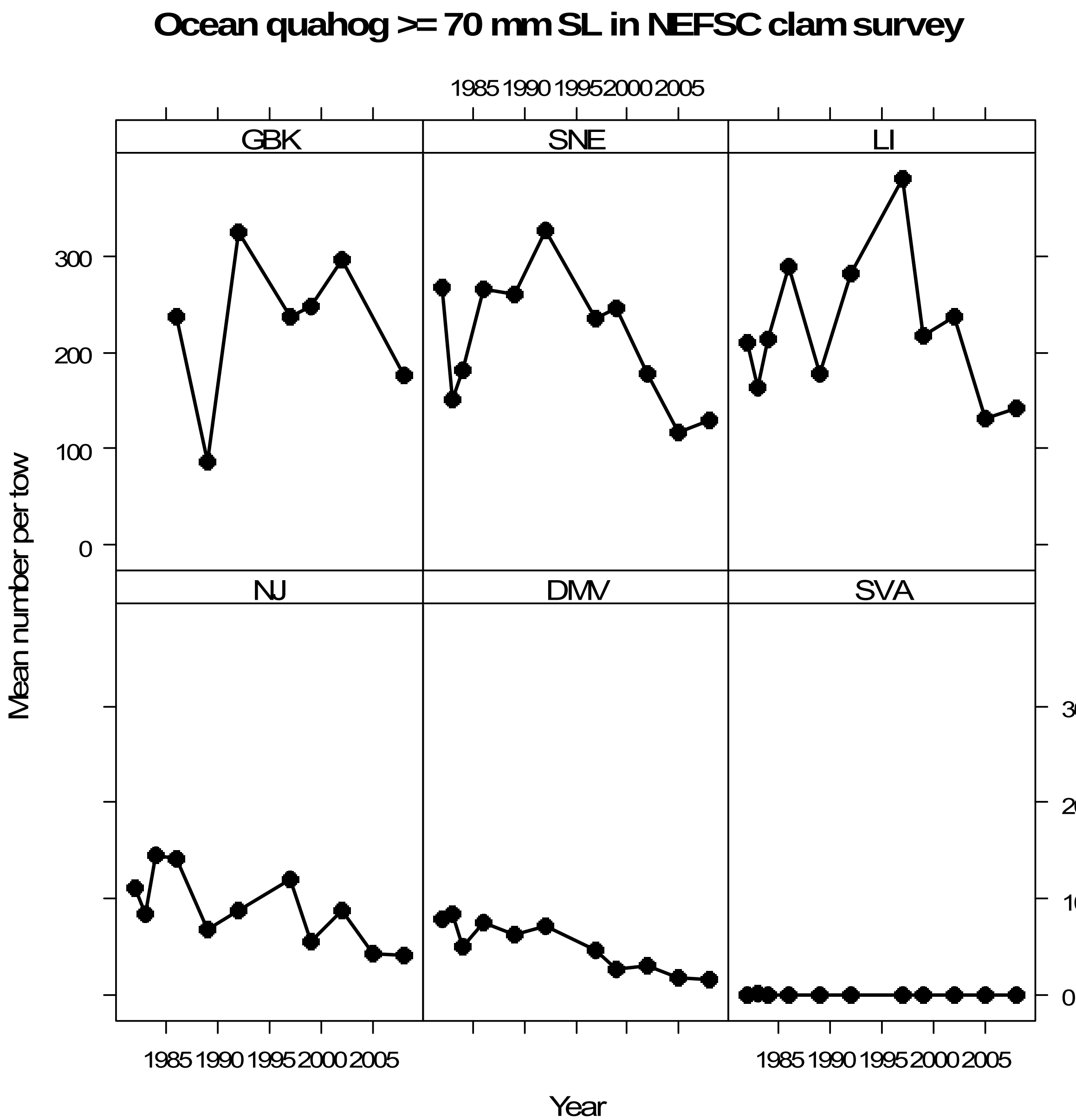


Figure B22. Long-term trends in survey abundance (mean number per tow) for large (≥70 mm SH) ocean quahogs during 1982-2008. Data from the 1994 survey are not shown because of voltage problems that affected catchability of the survey dredge. Sampling was relatively poor and figures are less unreliable for GBK during 1982-1984, 1989, 2002 and 2005; SNE during 1984 and 2005; LI during 1984; NJ during 1984; DMV during 2008; and in SVA during 1999 and 2008 (Table B8).

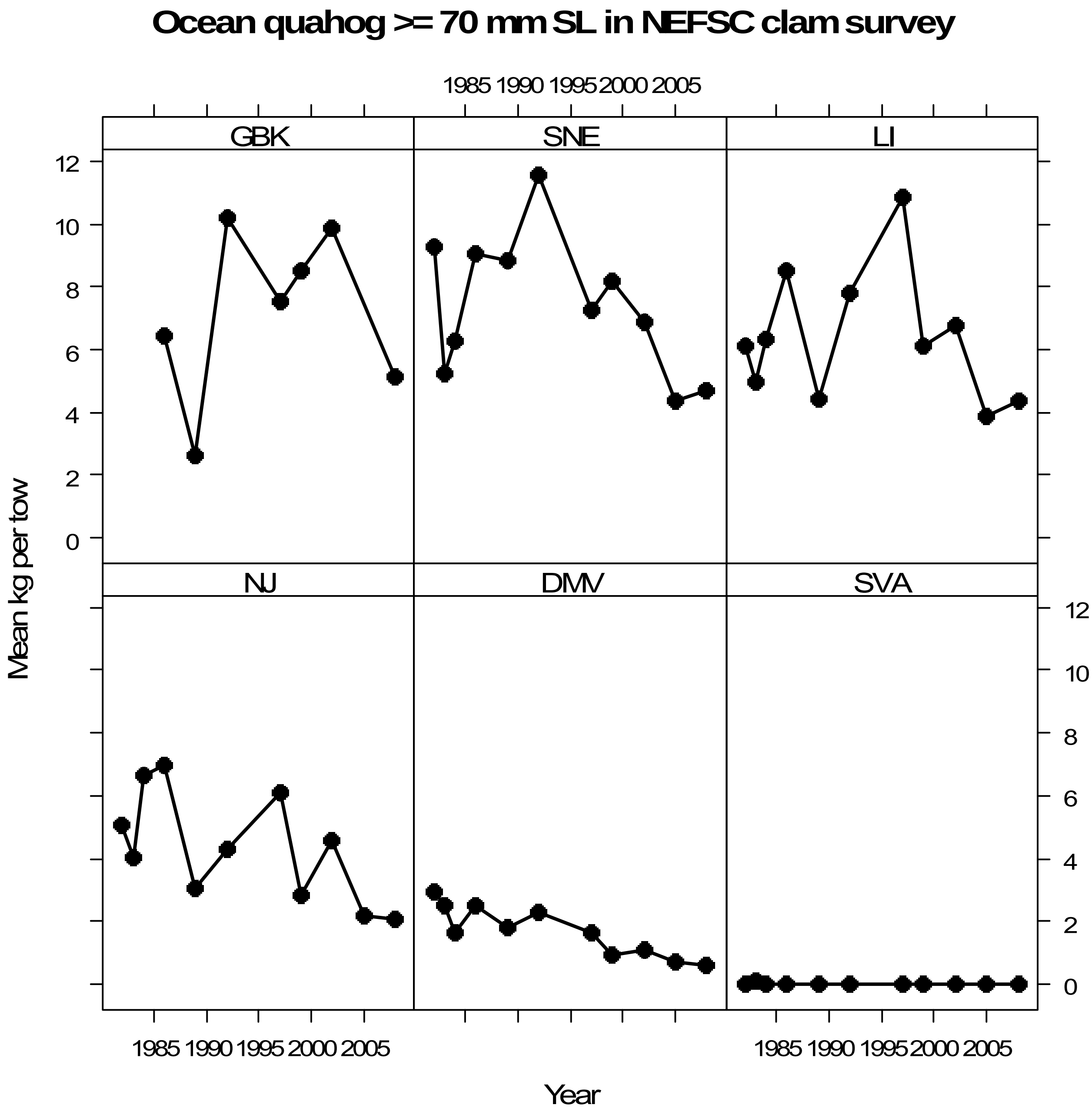


Figure B23. Long-term trends in survey mean biomass per tow for large (≥70 mm SH) ocean quahogs during 1982-2008. Data from the 1994 survey are not shown because of voltage problems that affected catchability of the survey dredge. Data for GBK from the 1982, 1983, 1984 and 2005 surveys are not shown because GBK was poorly sampled during those years (Table B8).

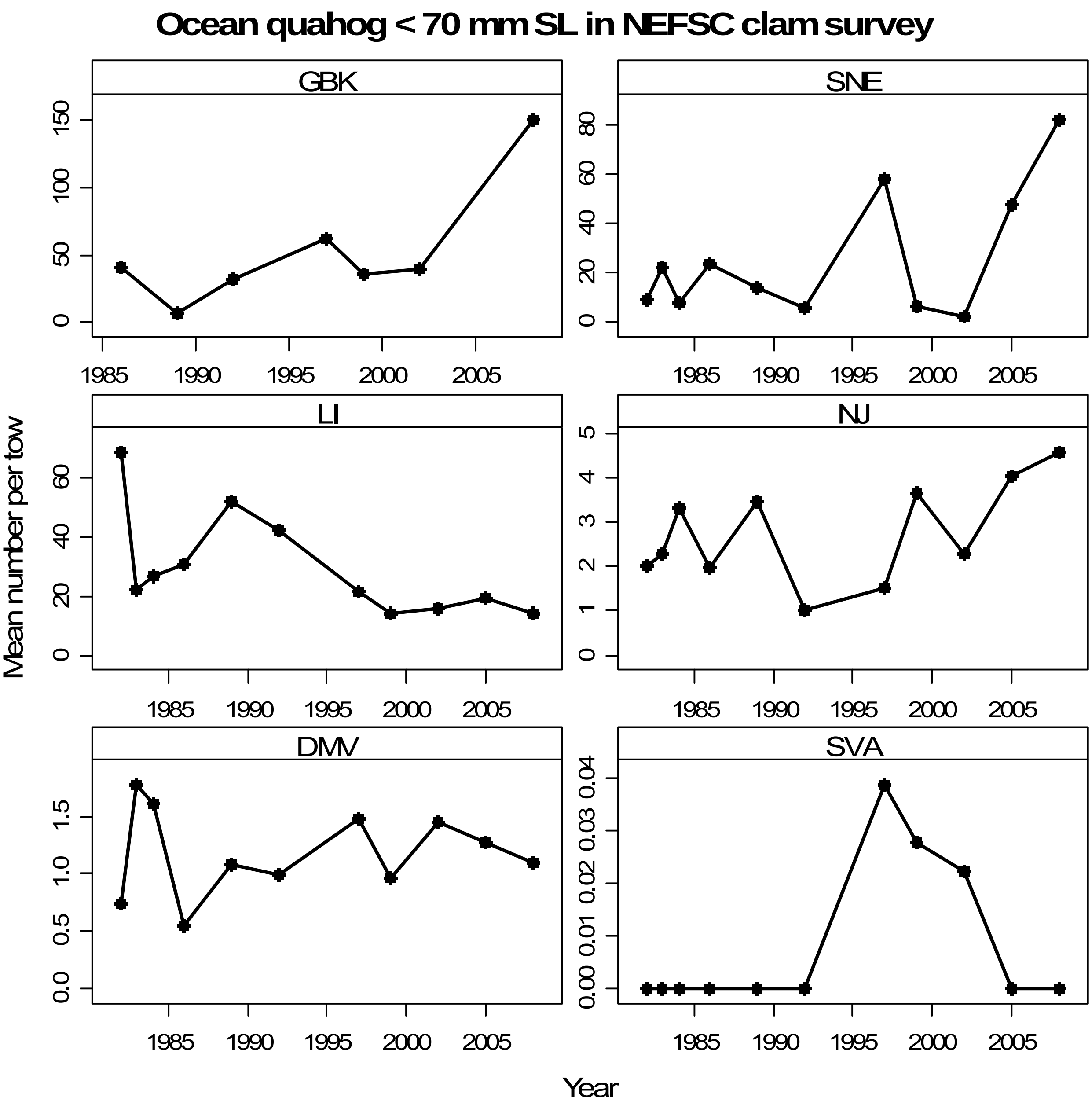


Figure B24. Long-term trends in abundance of small (<70 mm SH) ocean quahogs during 1982-2008. Data from the 1994 survey are not shown because of voltage problems that affected catchability of the survey dredge. Data for GBK from the 1982, 1983, 1984 and 2005 surveys are not shown because GBK was poorly sampled during those years (Table B8).

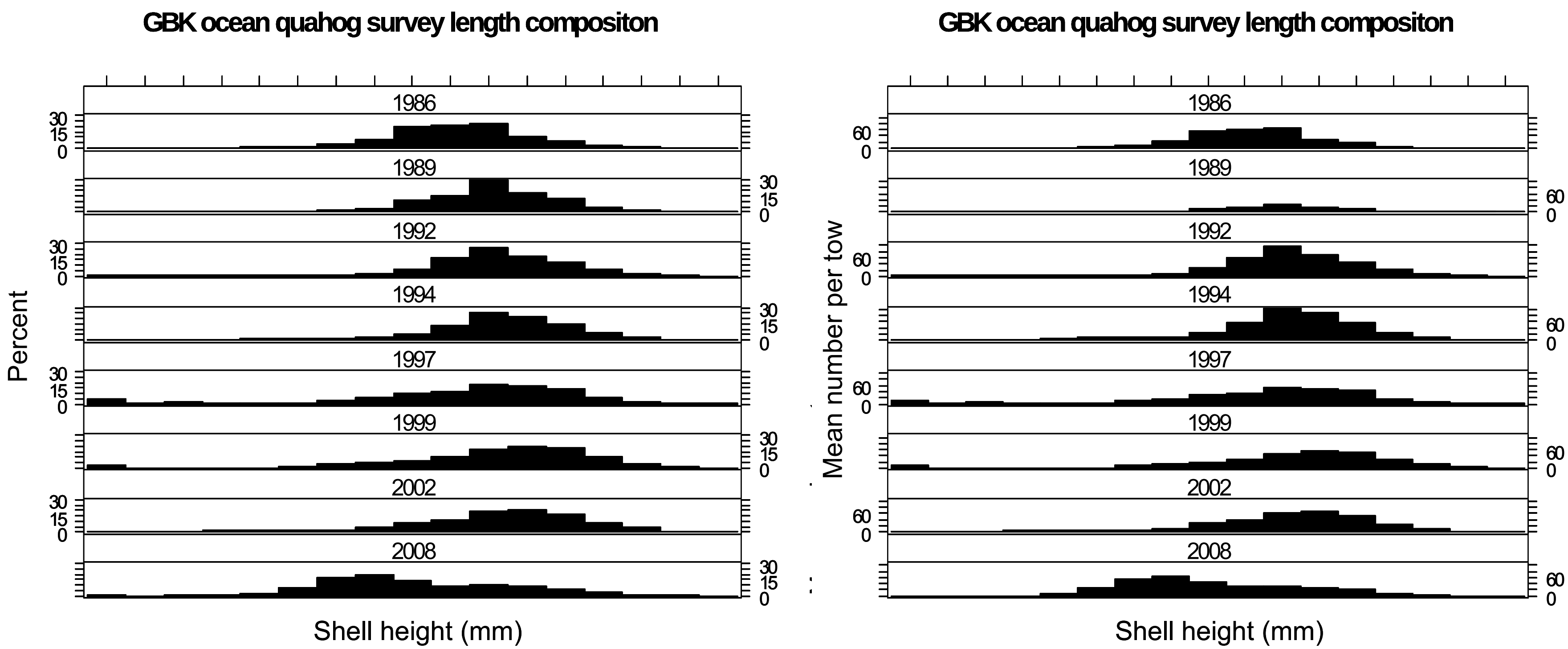
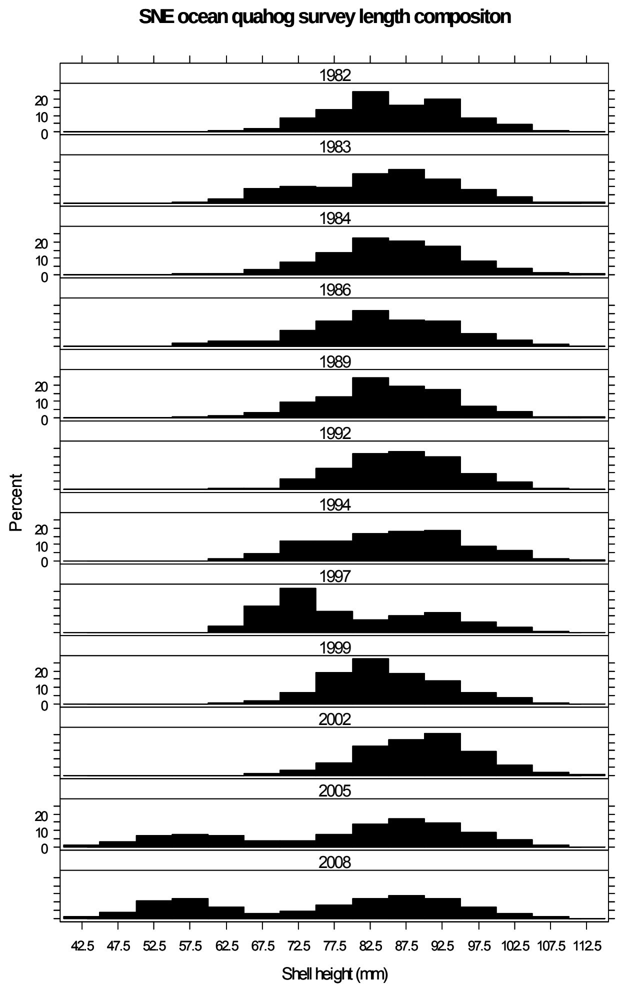


Figure B25. Survey length composition for ocean quahog in NEFSC clam surveys in the GBK region. The plots on the left show proportions of total mean number per tow in each year. The plots on the right show mean numbers per tow. All figures are without adjustment for survey dredge selectivity.



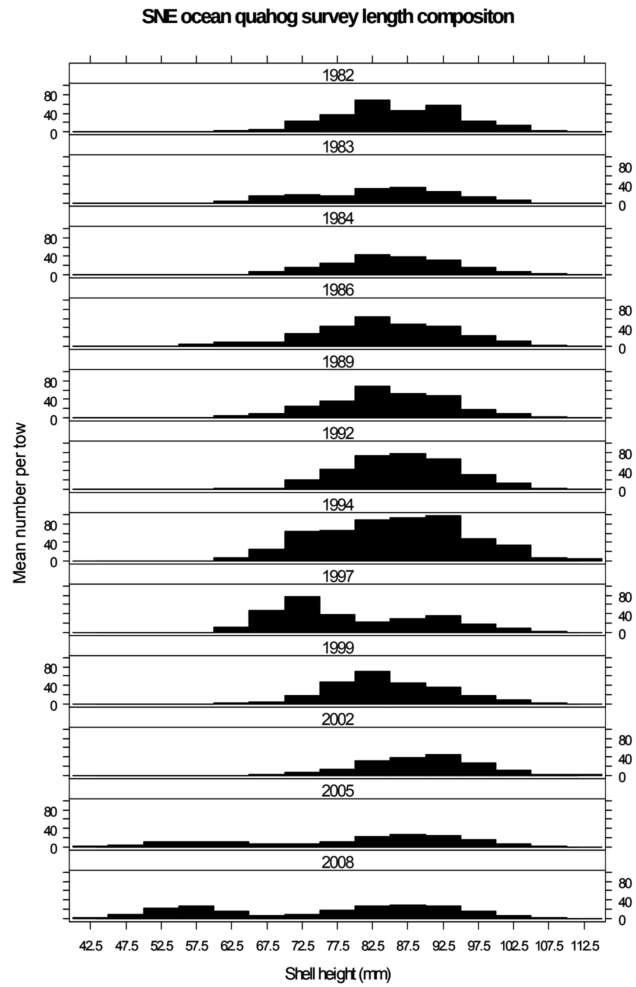


Figure B26. Survey length composition for ocean quahog in NEFSC clam surveys in the SNE region. The plots on the left show proportions of total mean number per tow in each year. The plots on the right show mean numbers per tow. All figures are without adjustment for survey dredge selectivity. Sampling was relatively poor and figures are less unreliable for SNE during 1984 (Table B8).

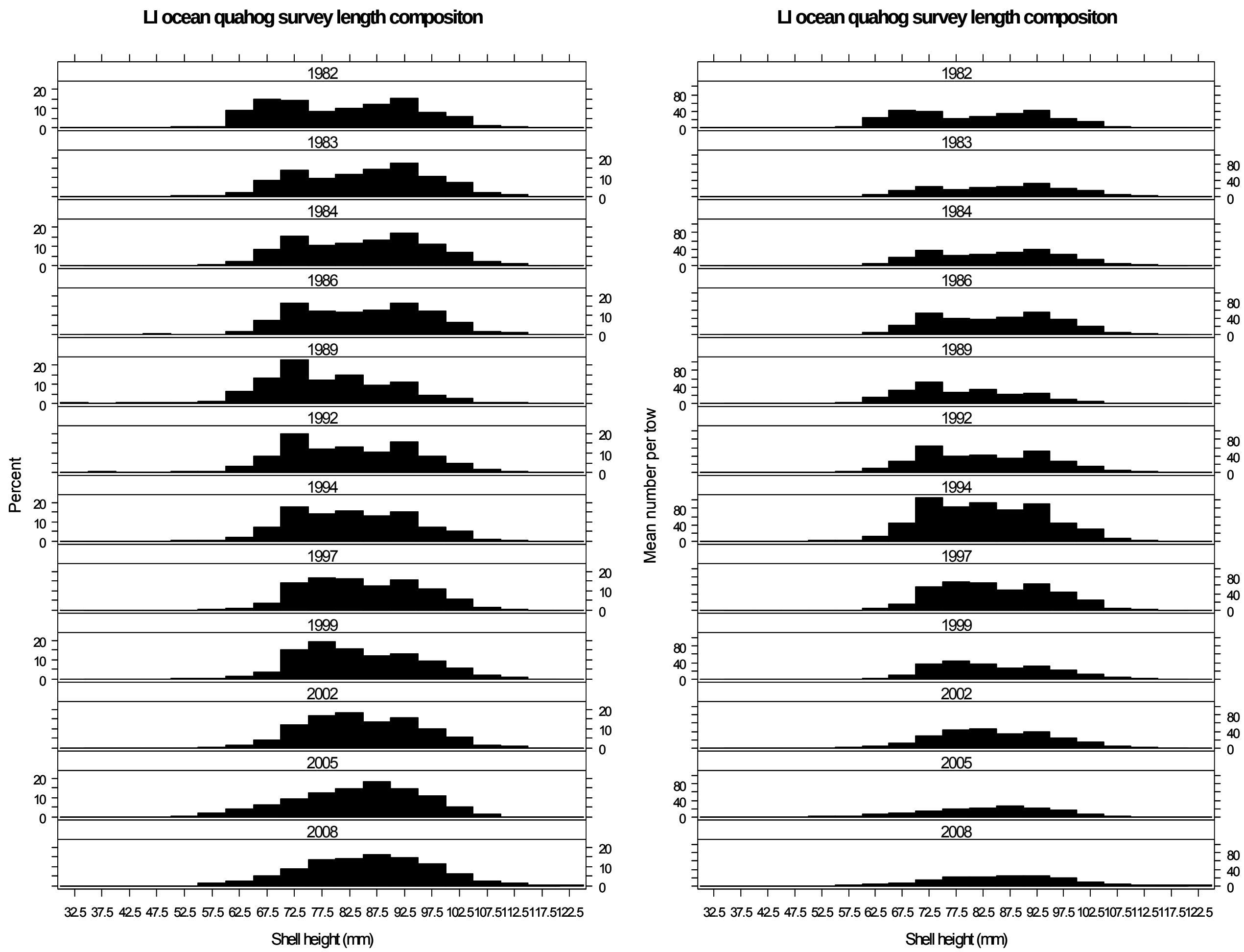


Figure B27. Survey length composition for ocean quahog in NEFSC clam surveys in the LI region. The plots on the left show proportions of total mean number per tow in each year. The plots on the right show mean numbers per tow. All figures are without adjustment for survey dredge selectivity. Sampling was relatively poor and figures are less unreliable for LI during 1984 (Table B8).

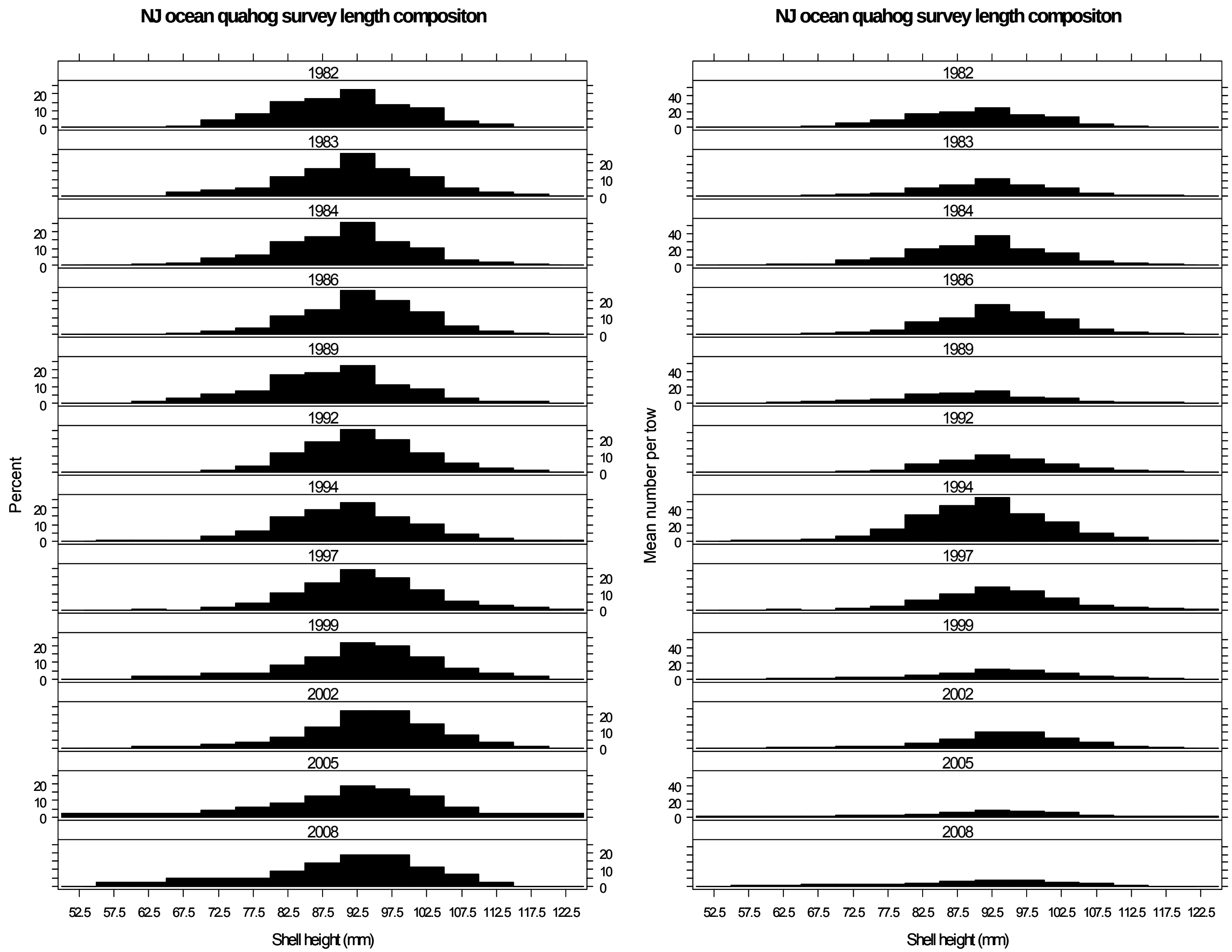


Figure B28. Survey length composition for ocean quahog in NEFSC clam surveys in the NJ region. The plots on the left show proportions of total mean number per tow in each year. The plots on the right show mean numbers per tow. All figures are without adjustment for survey dredge selectivity. Sampling was relatively poor and figures are less unreliable for NJ during 1984 (Table B8).

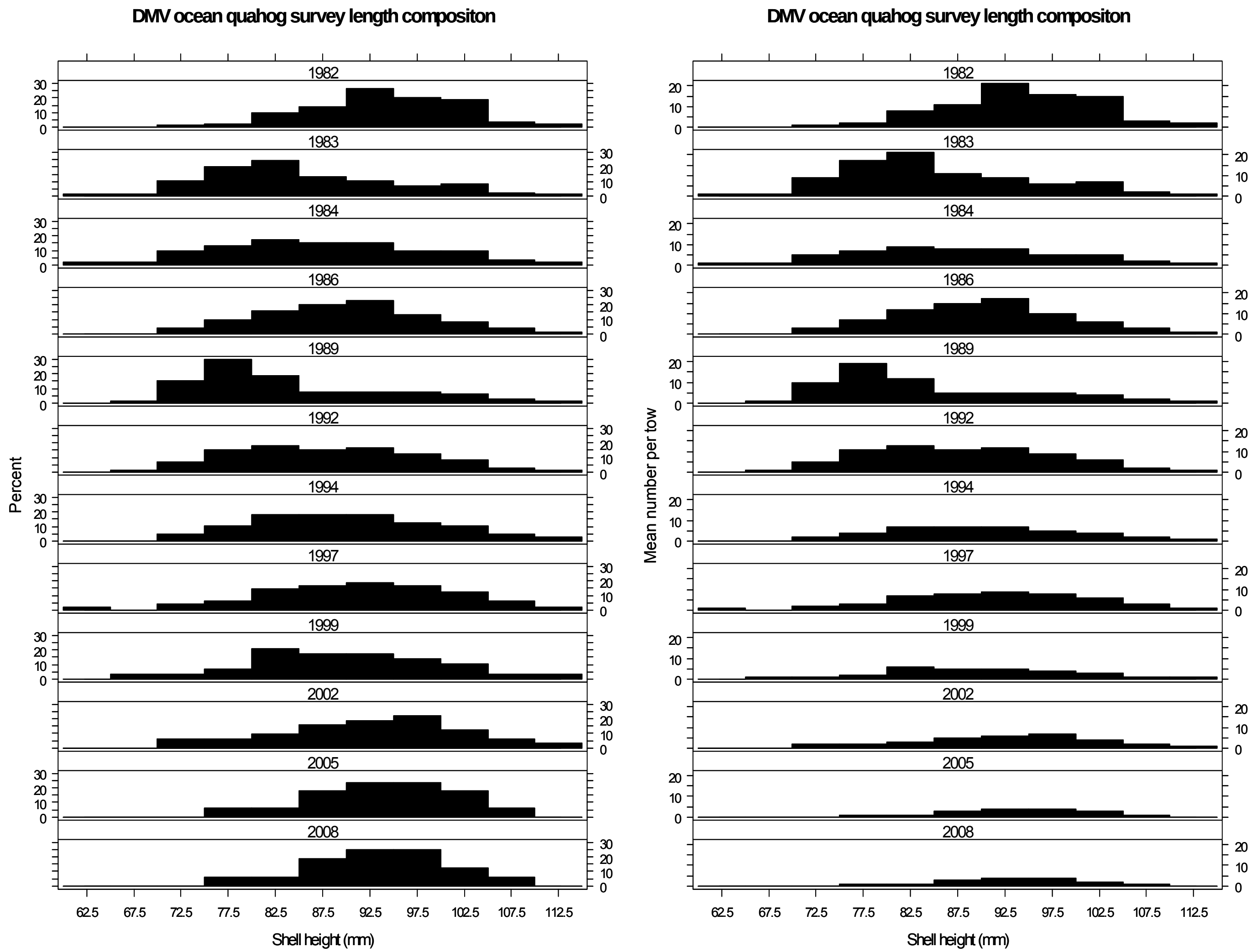


Figure B29. Survey length composition for ocean quahog in NEFSC clam surveys in the DMV region. The plots on the left show proportions of total mean number per tow in each year. The plots on the right show mean numbers per tow. All figures are without adjustment for survey dredge selectivity. Sampling was relatively poor and figures are less unreliable for DMV during 2008 (Table B8).

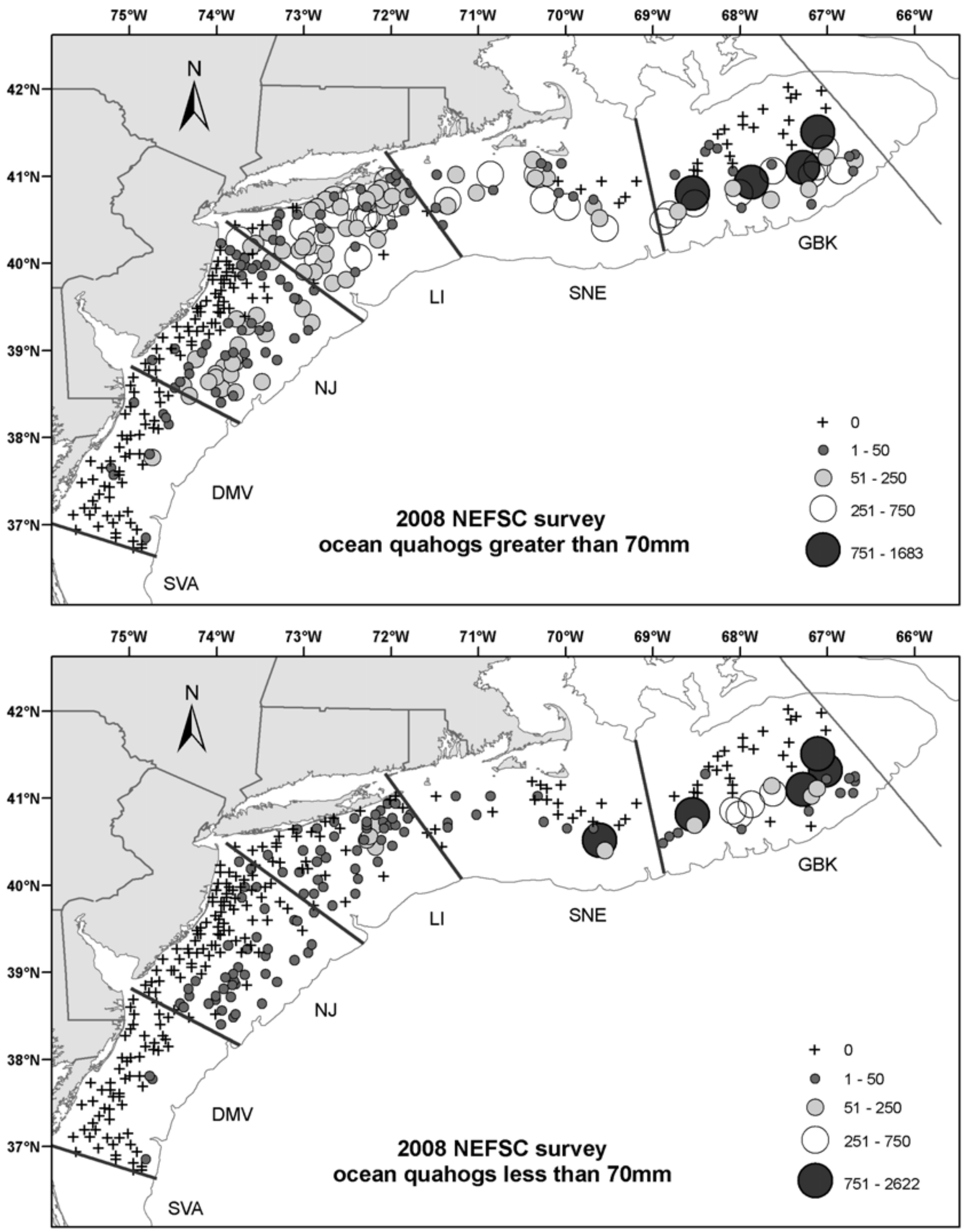


Figure B30. Location of tows and catch of large (≥70 SL) and small (<70 mm) ocean quahogs in 2008 clam survey. See Appendix B5 for other years.

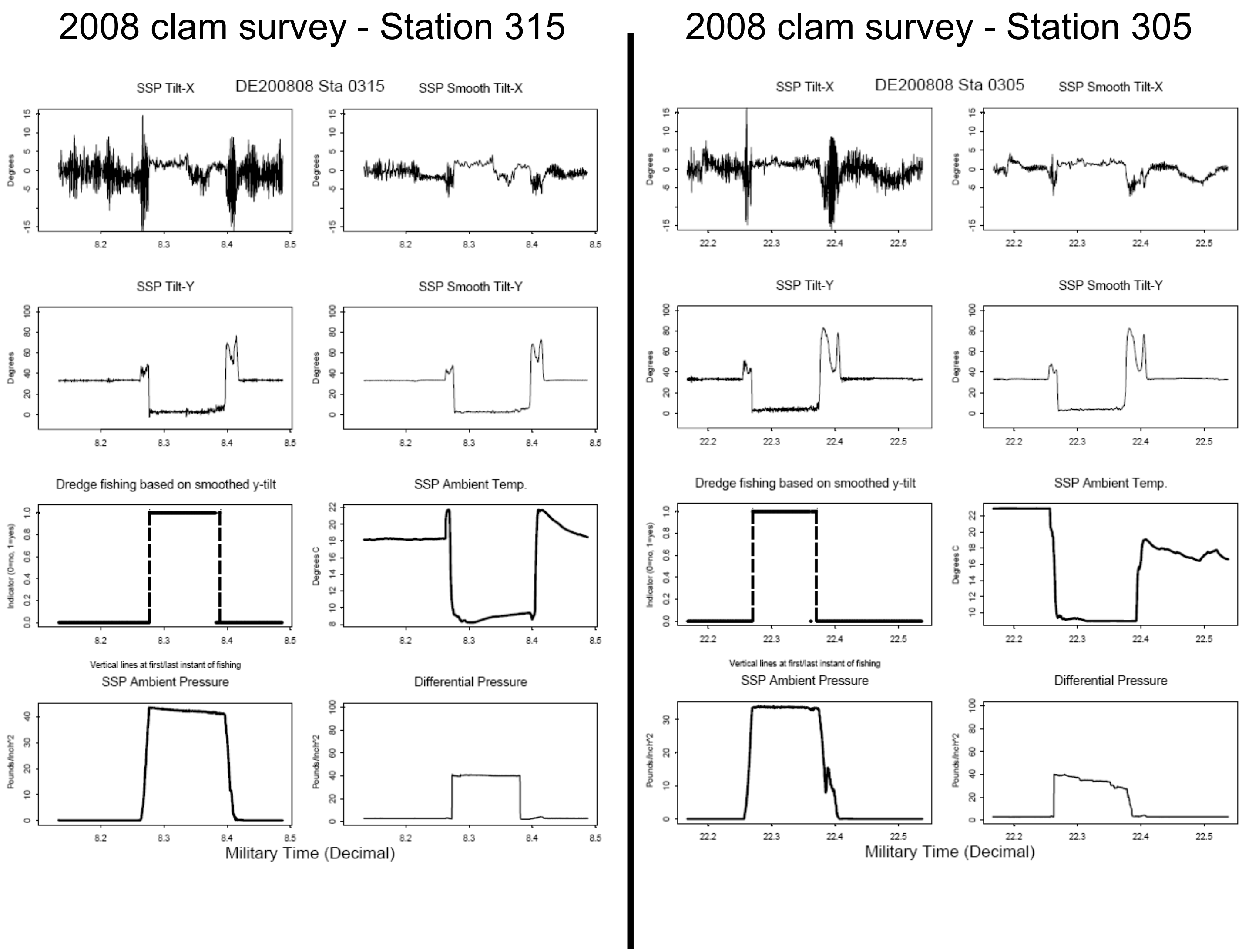
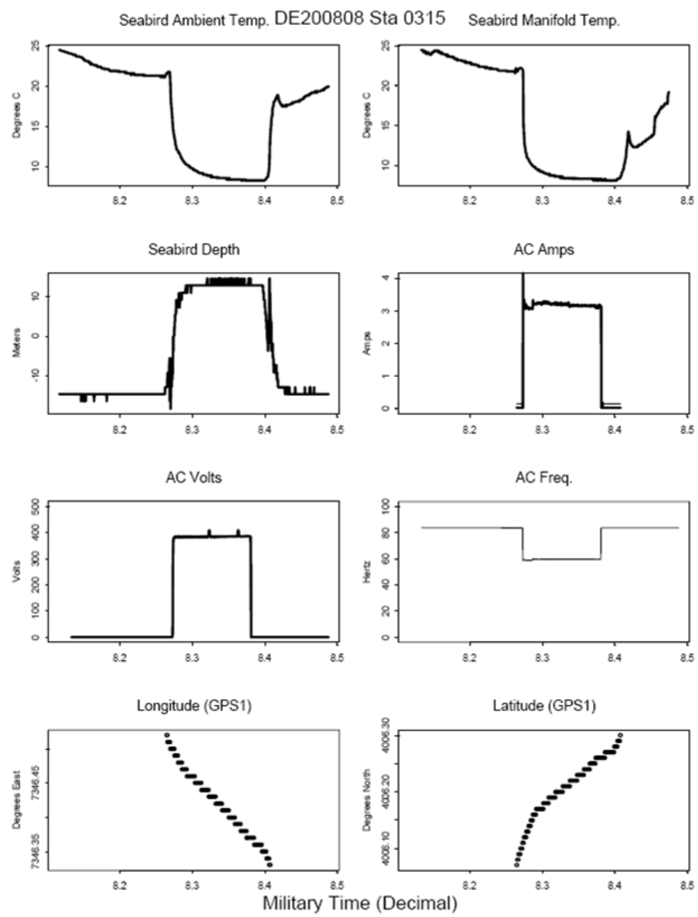


Figure B31. Sensor data from stations 315 (left) and 305 (right) in the 2008 NEFSC clam survey. Based on amperage and differential pressure, dredge performance was better at station 315.

2008 clam survey - Station 315



2008 clam survey - Station 305

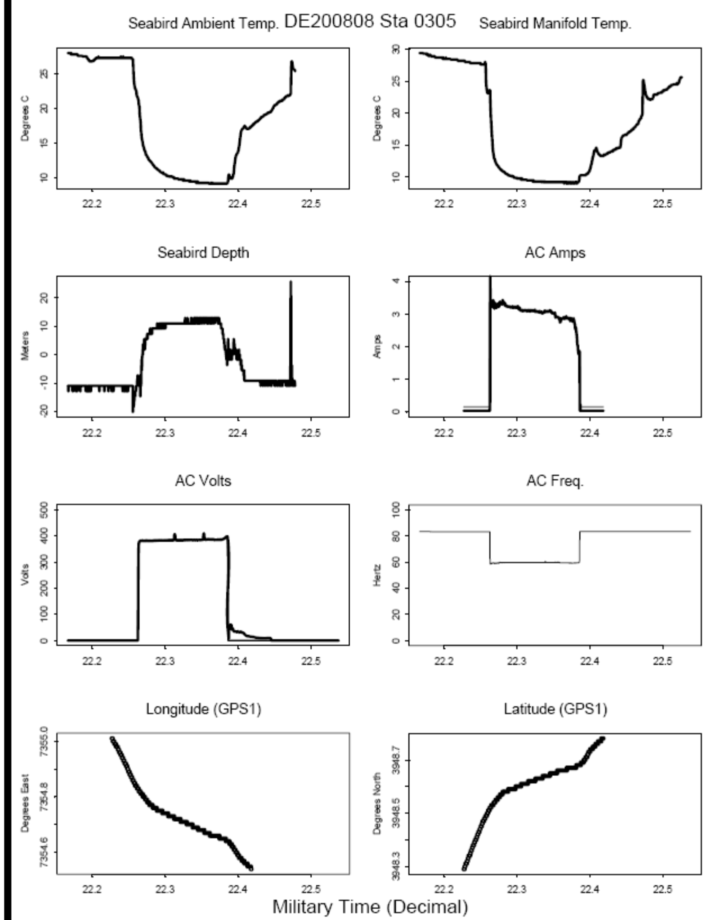
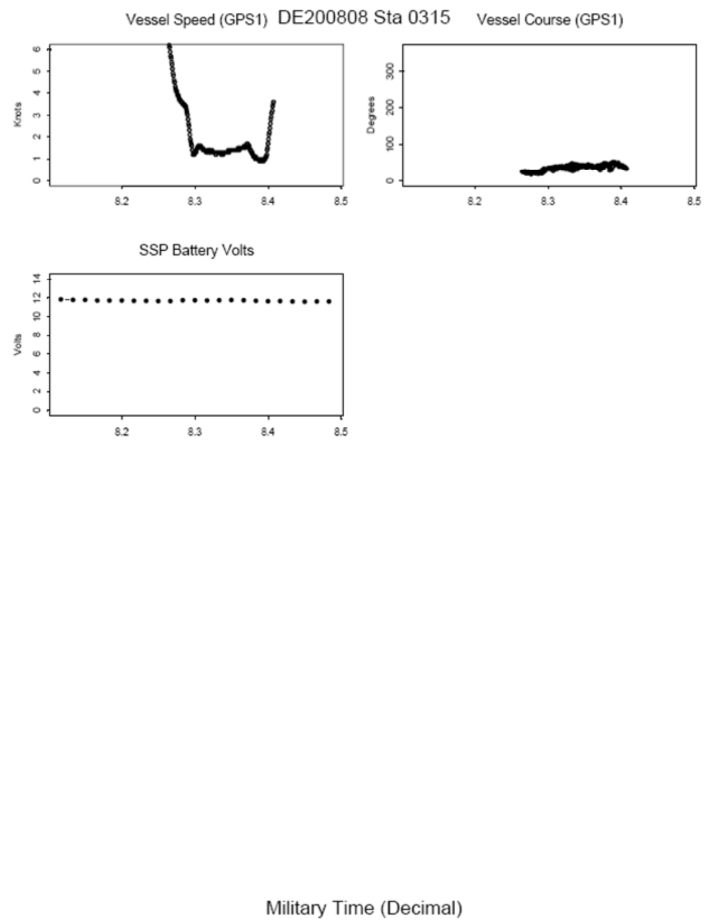


Figure B31 (cont.)

2008 clam survey - Station 315



2008 clam survey - Station 305

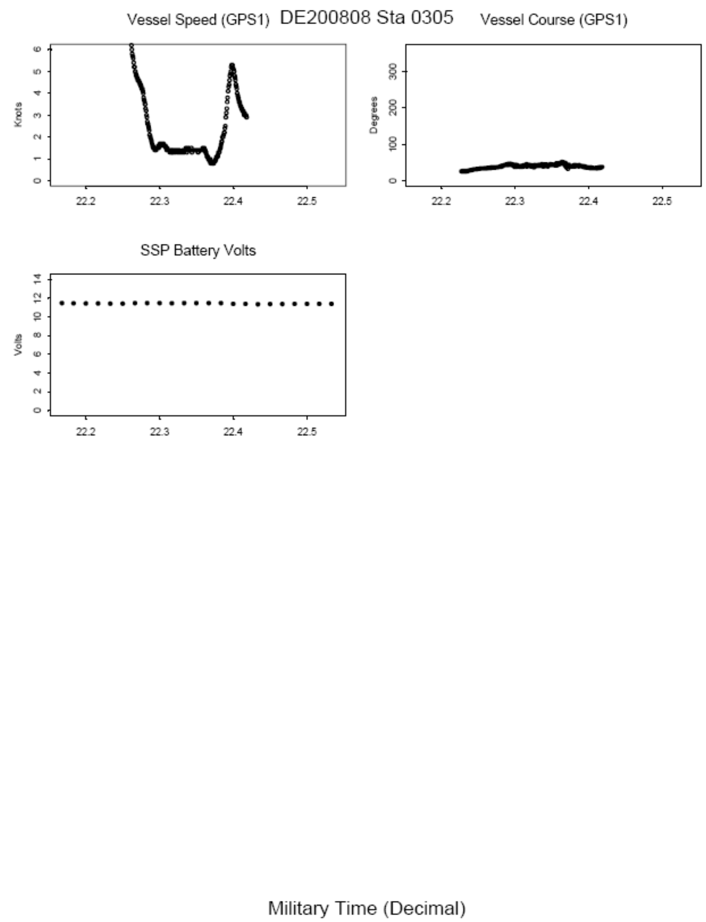


Figure B31 (cont.)

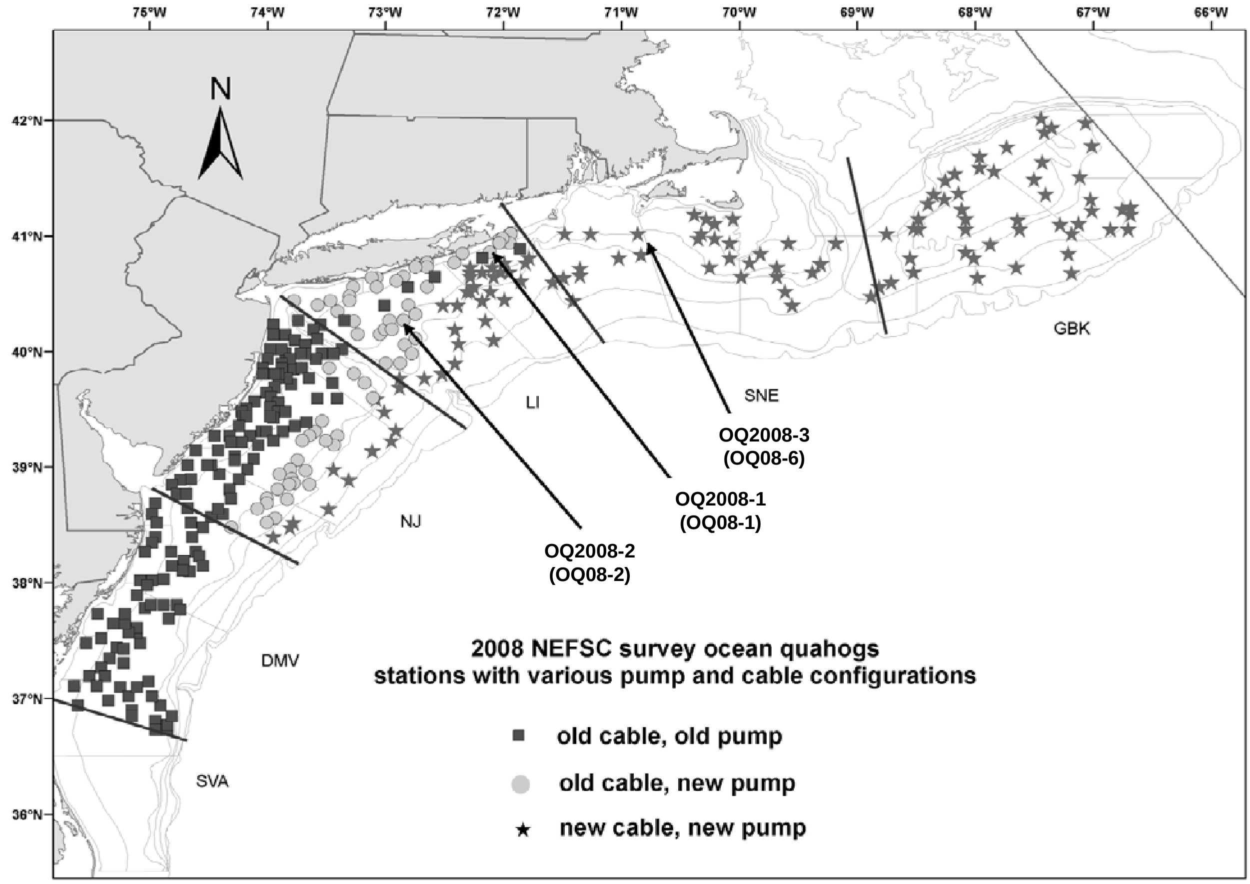


Figure B32. Map showing the locations of random tows done during the 2008 NEFSC clam survey. The different symbols represent different configurations of the electrical cable and dredge pump, which were both replaced during the survey. Arrows point to the areas where the depletion experiments were conducted.

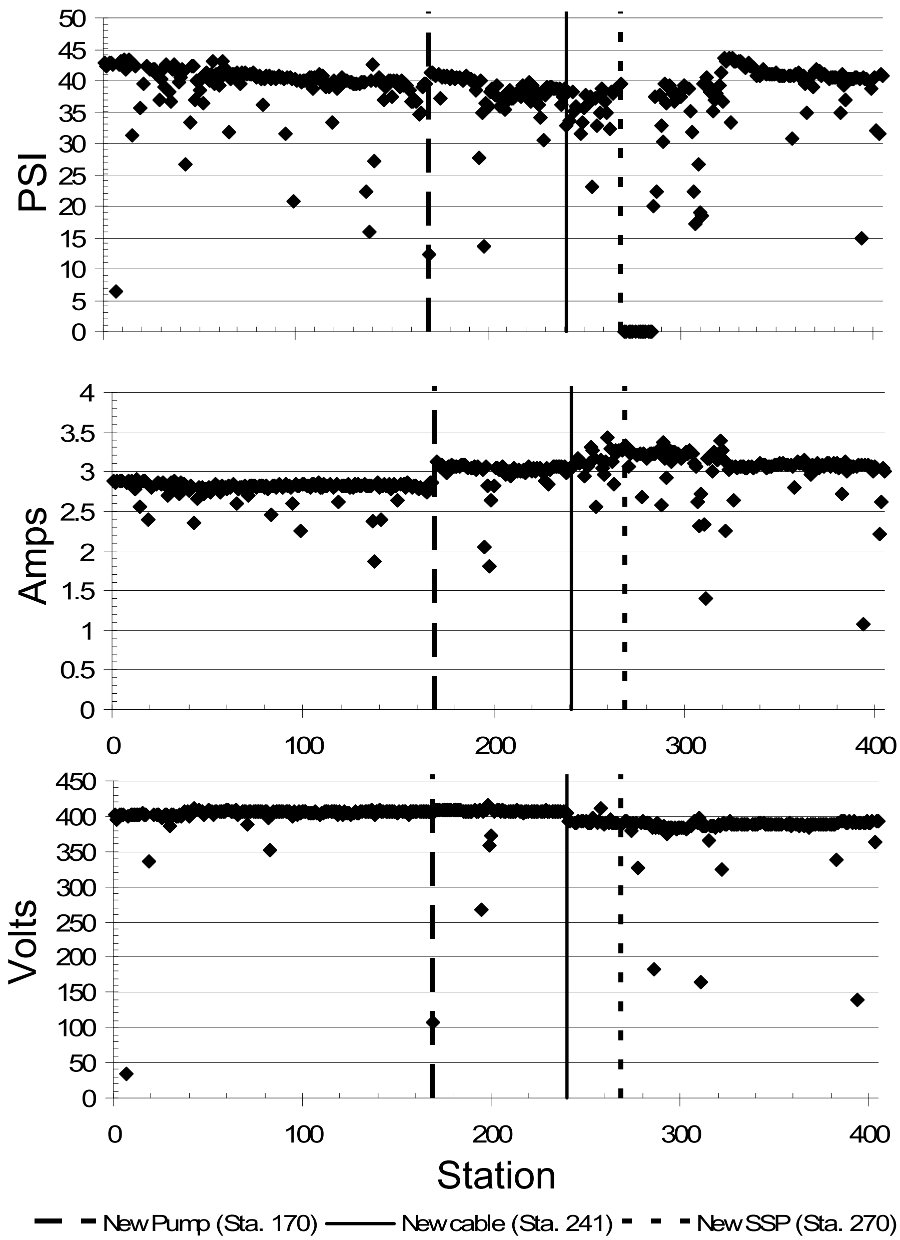


Figure B33. Mean SSP sensor data during periods when the dredge was fishing effectively, for stations 1-405.

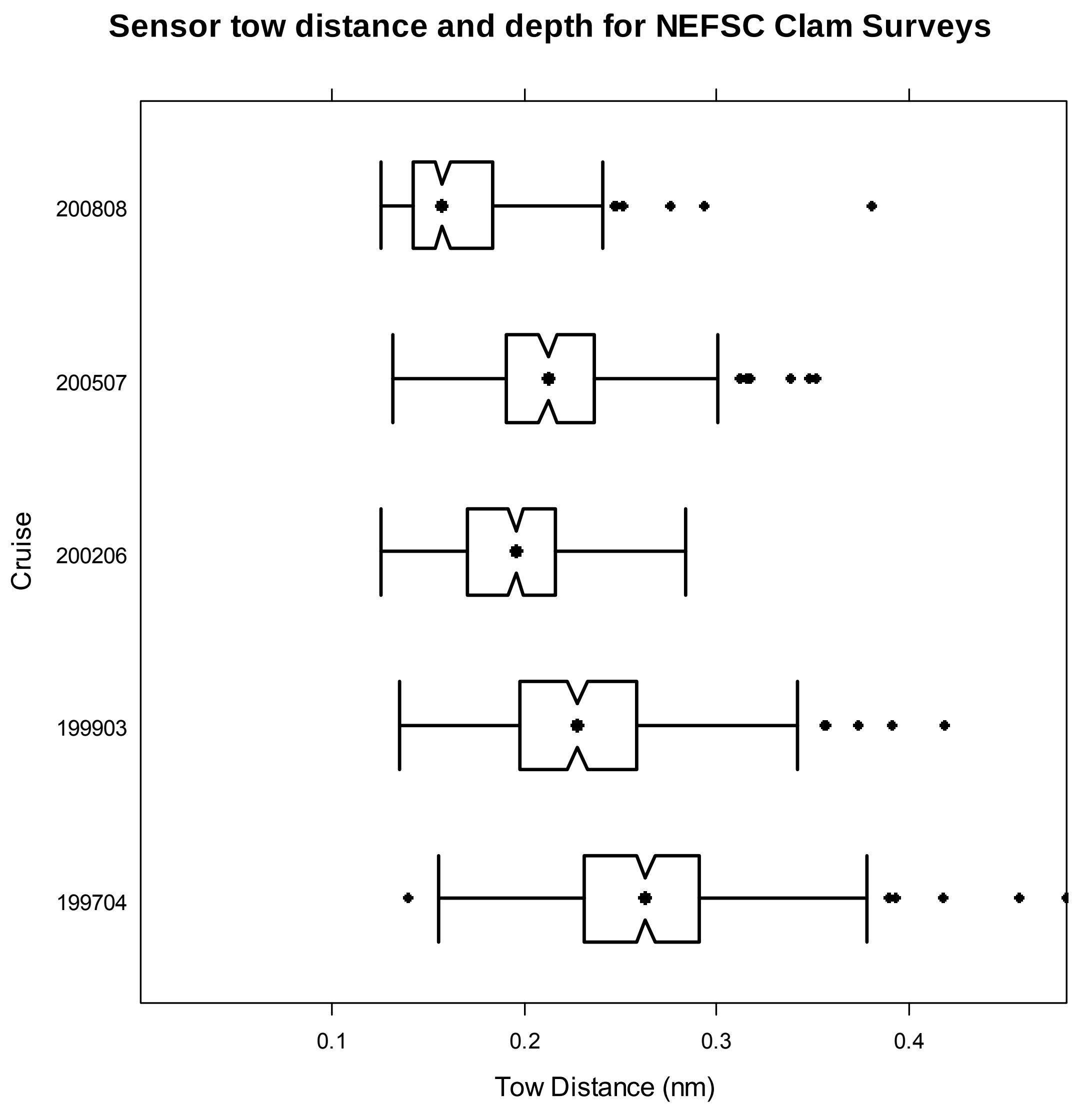


Figure B34. Distribution of sensor based tow distances for all tows in the 1997-2008 surveys with useable y-tilt data.

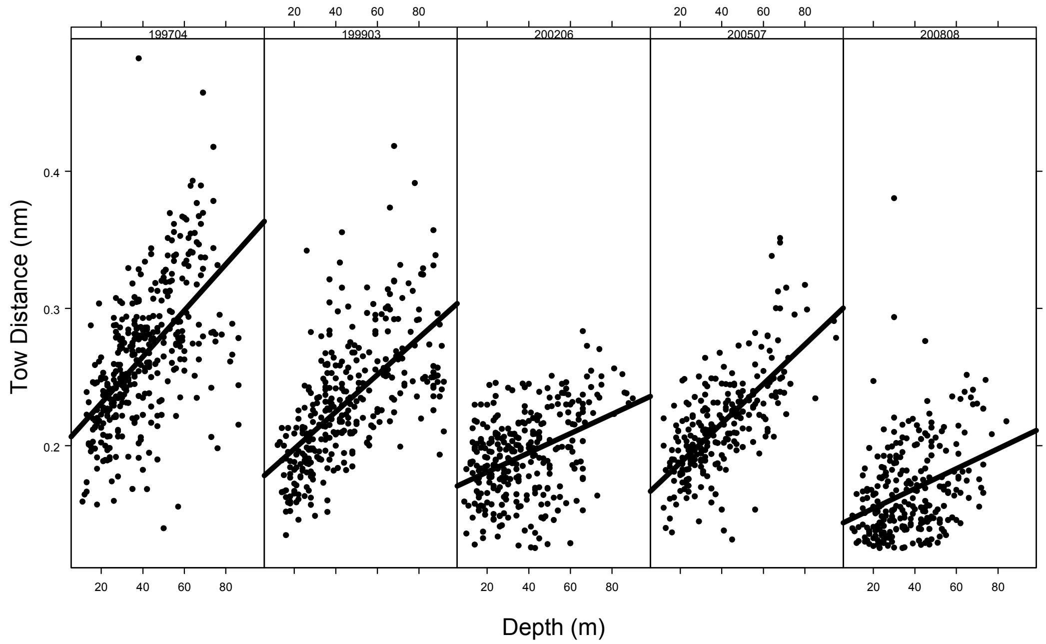


Figure B35. Survey specific linear regression models for relationships between tow distance (based on sensor data) and depth. Data are for successful random tows only.

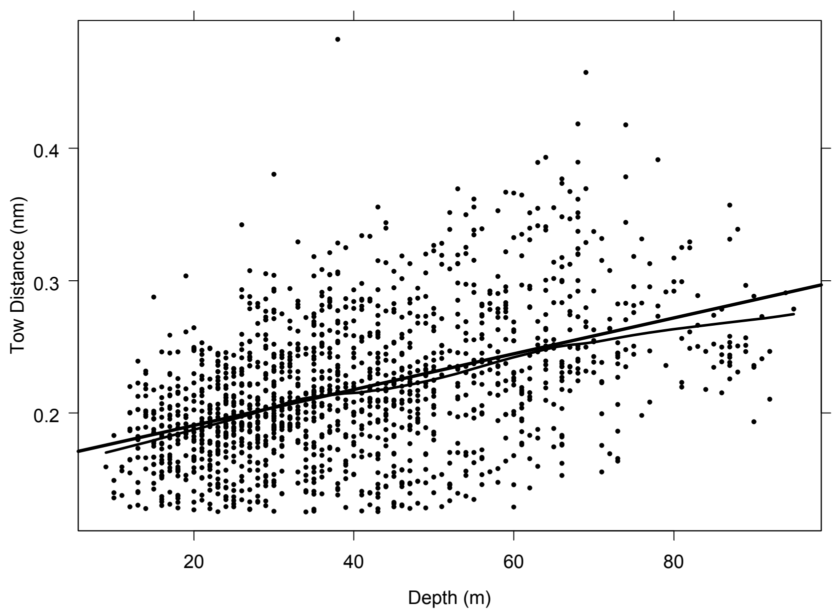


Figure B36. Relationship between tow distance (based on sensor data) and depth for successful random tows in surveys with sensor data conducted between 1997 and 2009. The straight line shows the linear regression model Distance=0.1635+0.0014 x Depth. The nonlinear line is a spline meant to show underlying, potentially nonlinear, trends.

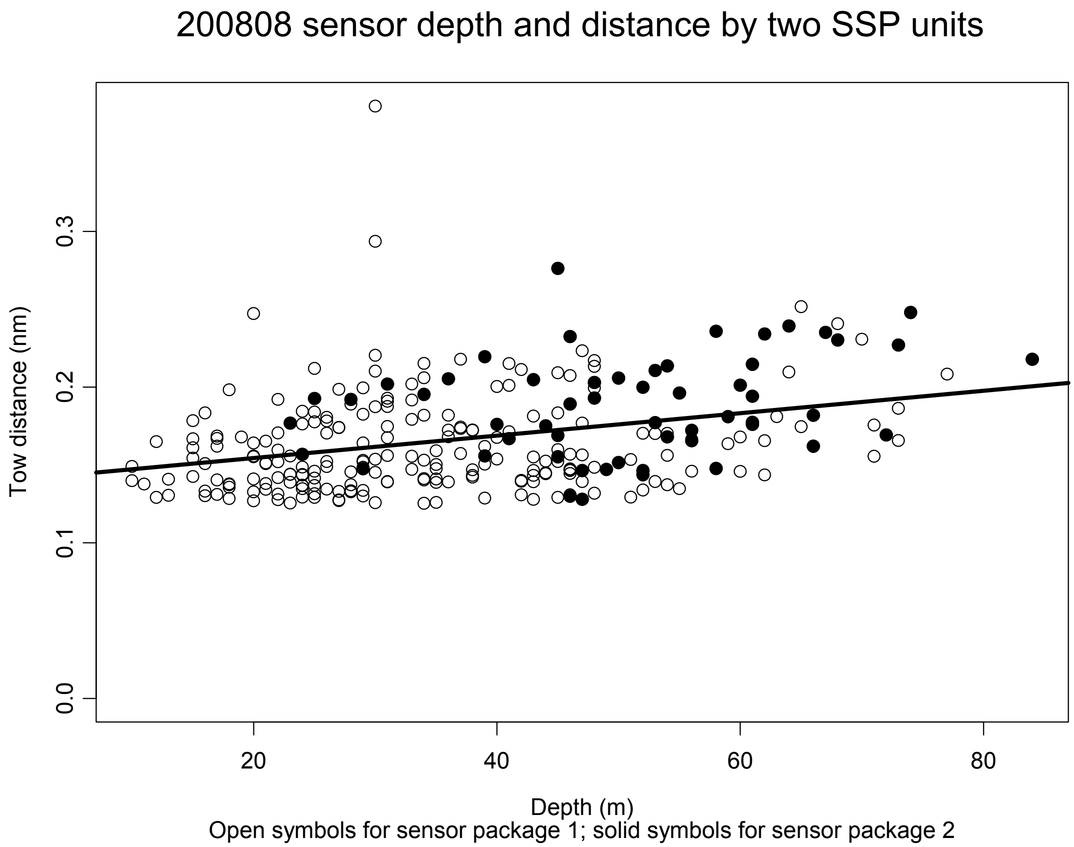


Figure B37. Relationship between tow distance and depth during the 2008 clam survey estimated using y-tilt data from the original (open symbols, stations 1-269) and replacement (dark symbols, stations 270-401) SSP units.

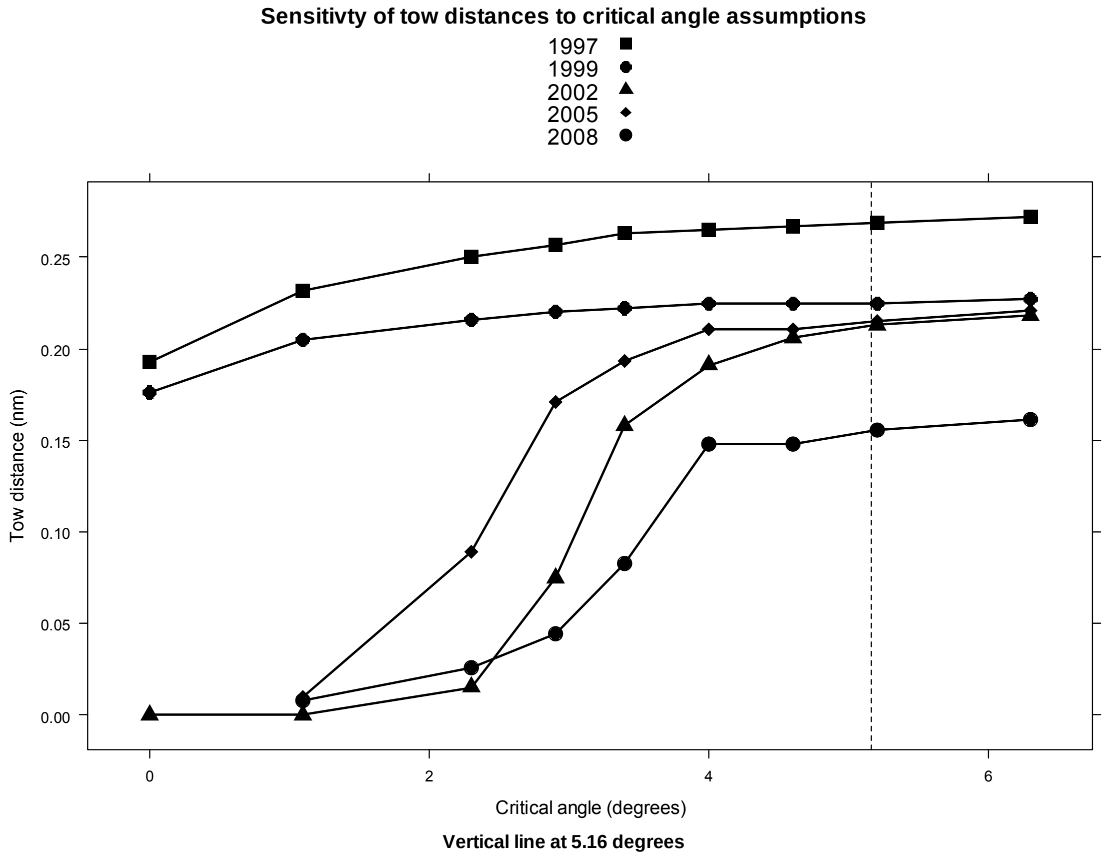


Figure B38. Sensitivity of median survey tow distance to assumptions about the critical angle at which the survey dredge fishes effectively. Median tow distances are for all successful random survey tows with y-tilt data during the 1997-2008 surveys. Surveys during 1997 and 1999 surveys used an inclinometers attached to the dredge. Surveys during 2002, 2005 and 2008 used integrated SSP (survey sensor package) sensors. Over the range of dredge angles shown in the figure, D = 0.731*A -7.947, where D is the blade depth (inches) and A is the critical angle in degrees. This analysis updates Figure C21 in NEFSC (2003).

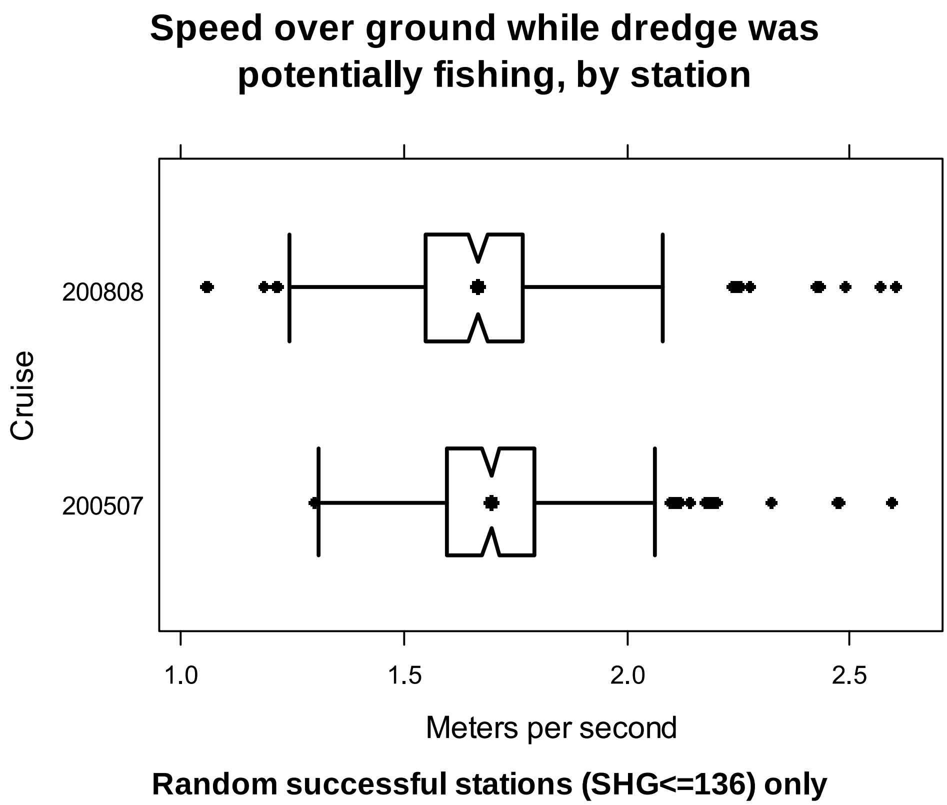
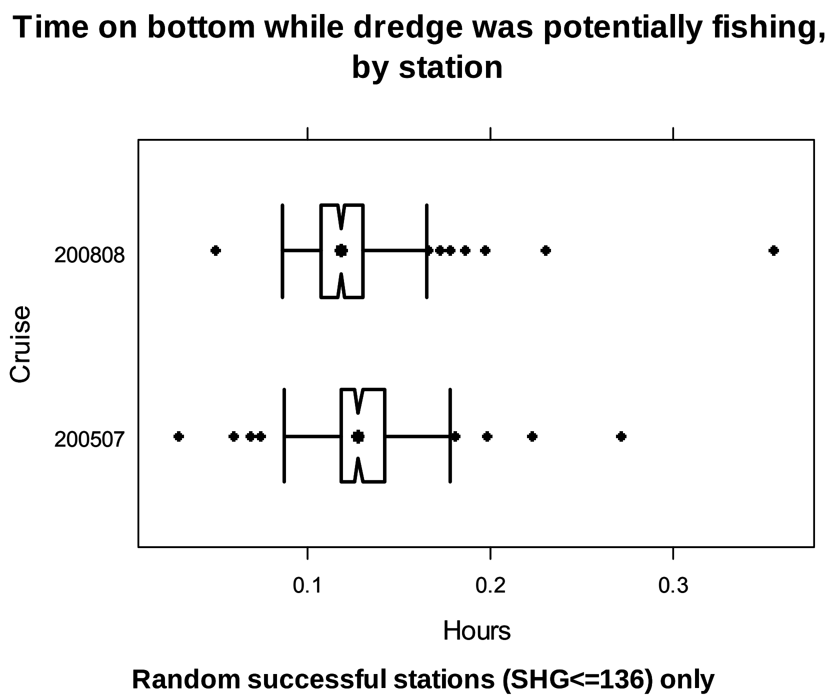


Figure B39. Box plots showing distributions of dredge performance variables from sensor data for successful random tows during the 2005 and 2008 NEFSC clam survey. For some variables that are highly skewed, two boxplots are presented with the plot at the top showing the distribution of all of the data and the plot at the bottom rescaled to exclude outliers and to better depict the relative distributions of most of the data.



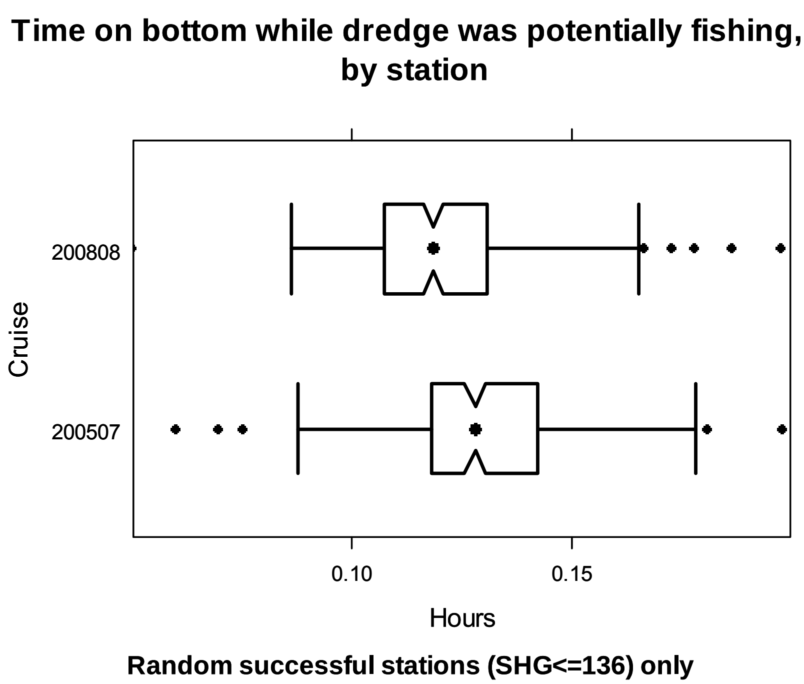
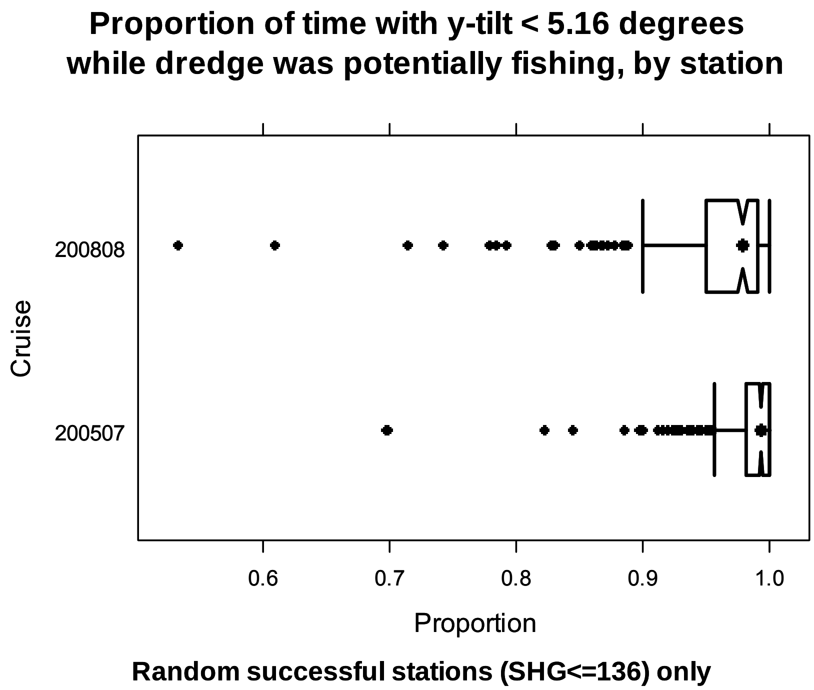


Figure B39. (cont.)



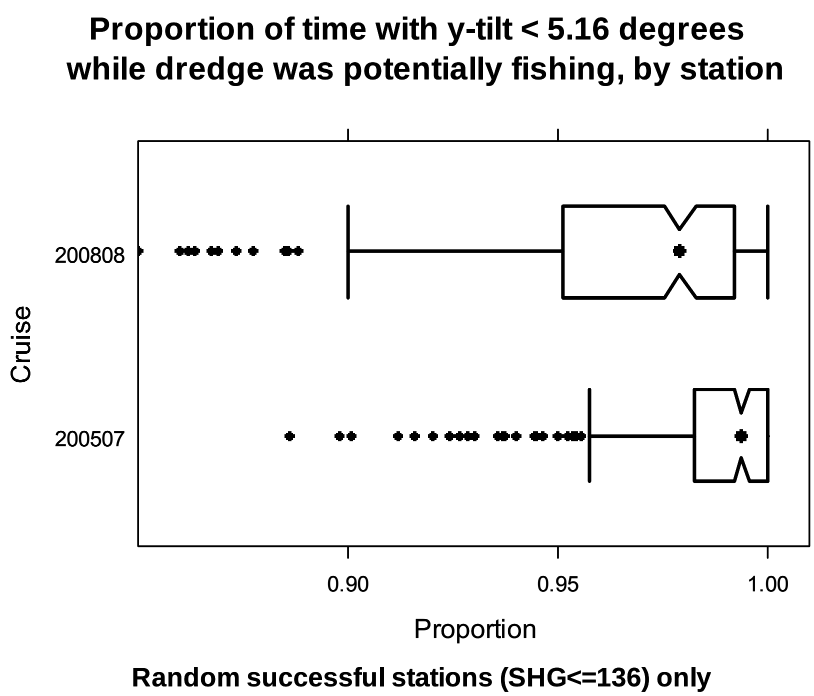
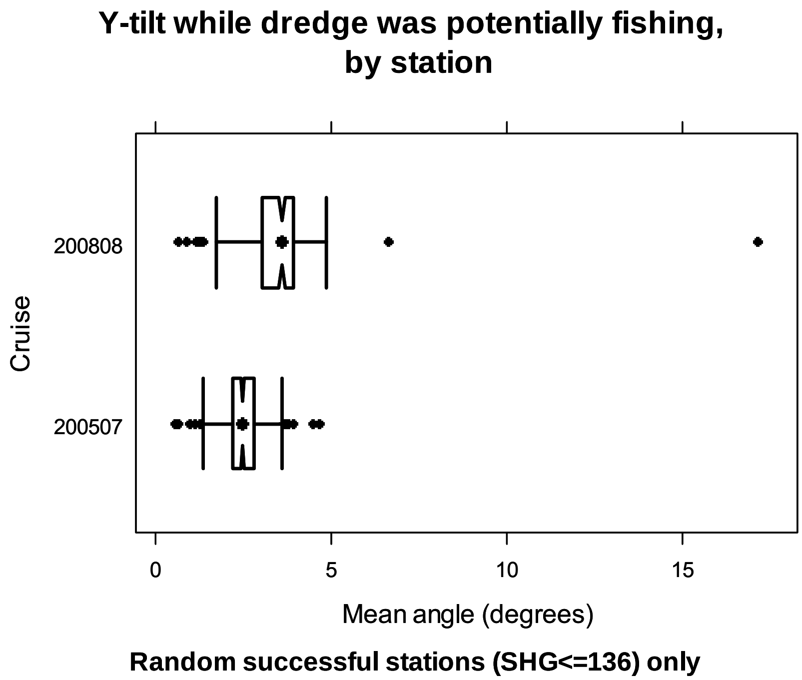


Figure B39. (cont.)



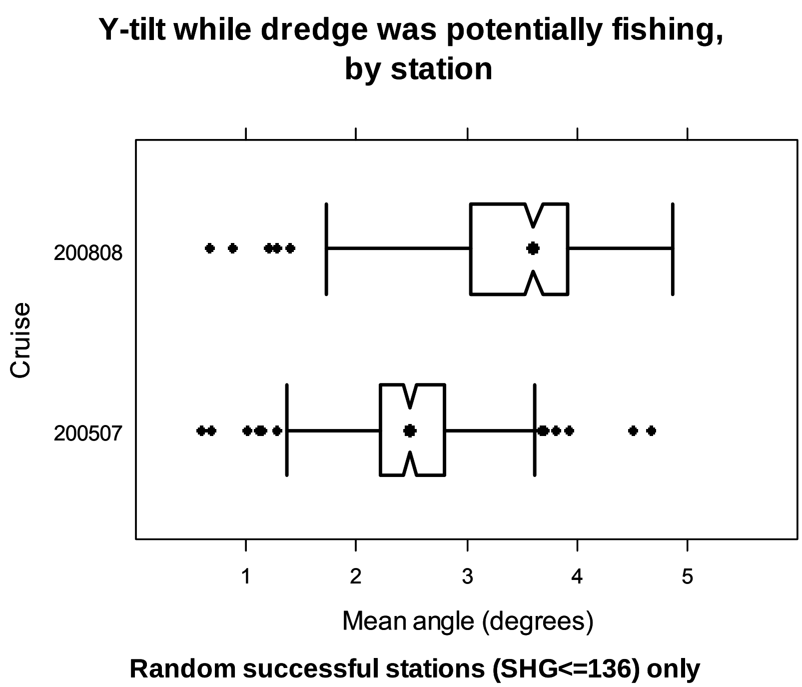
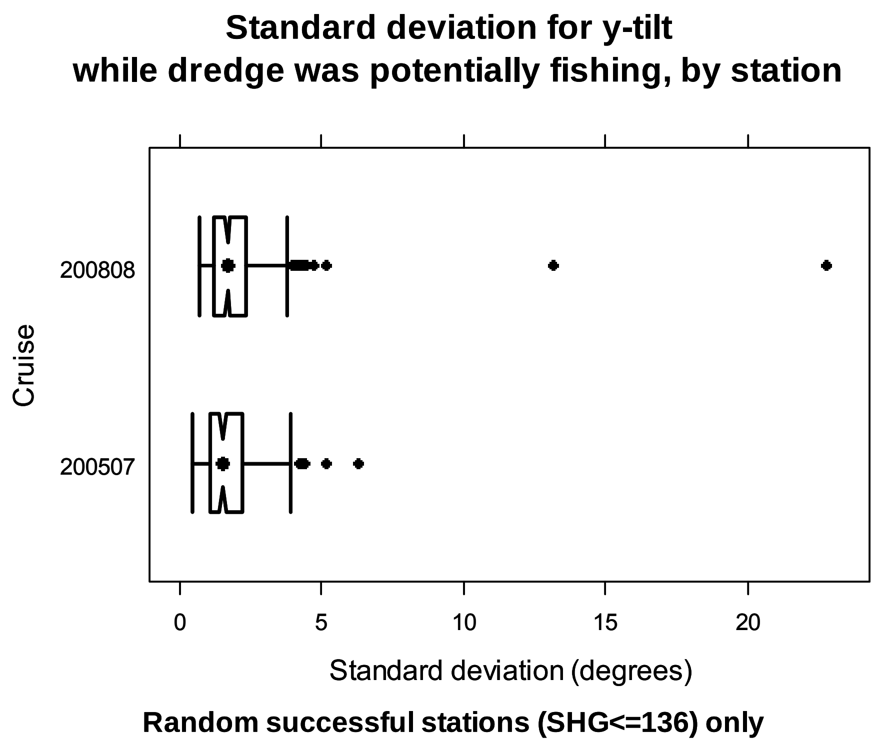


Figure B39. (cont.)



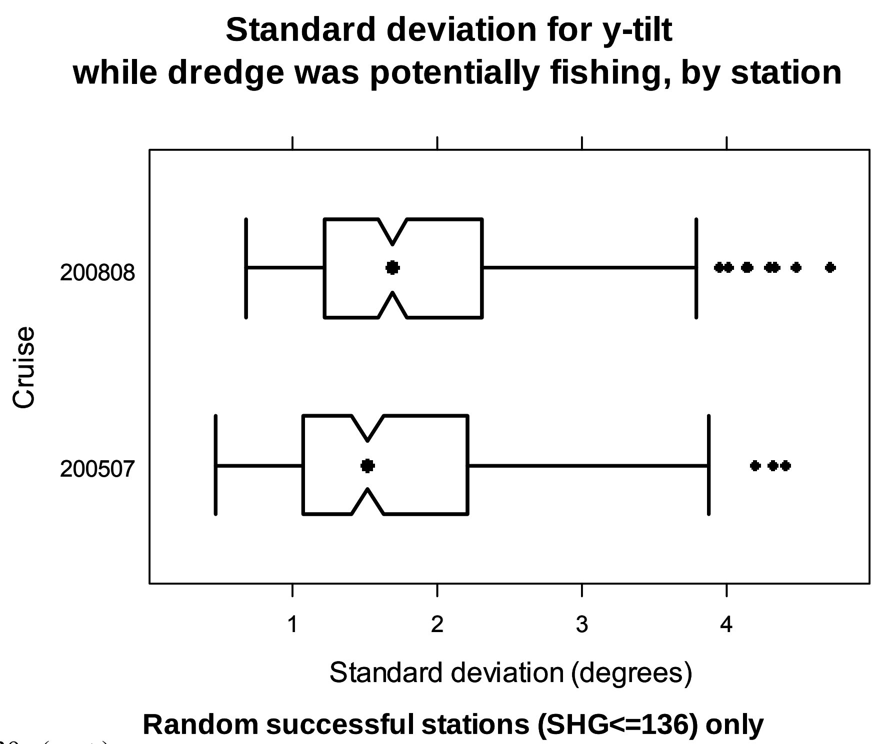
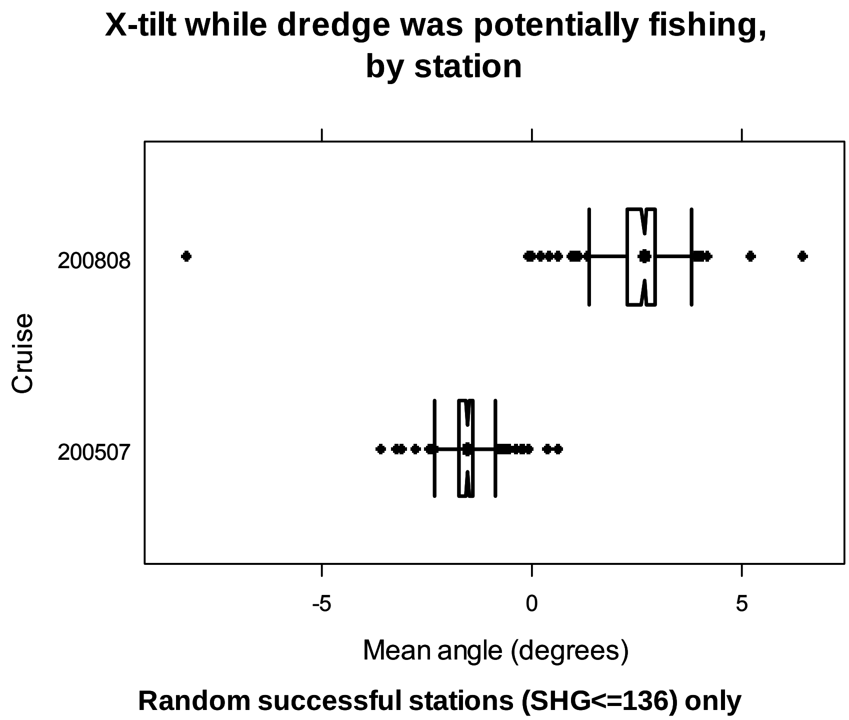


Figure B39. (cont.)



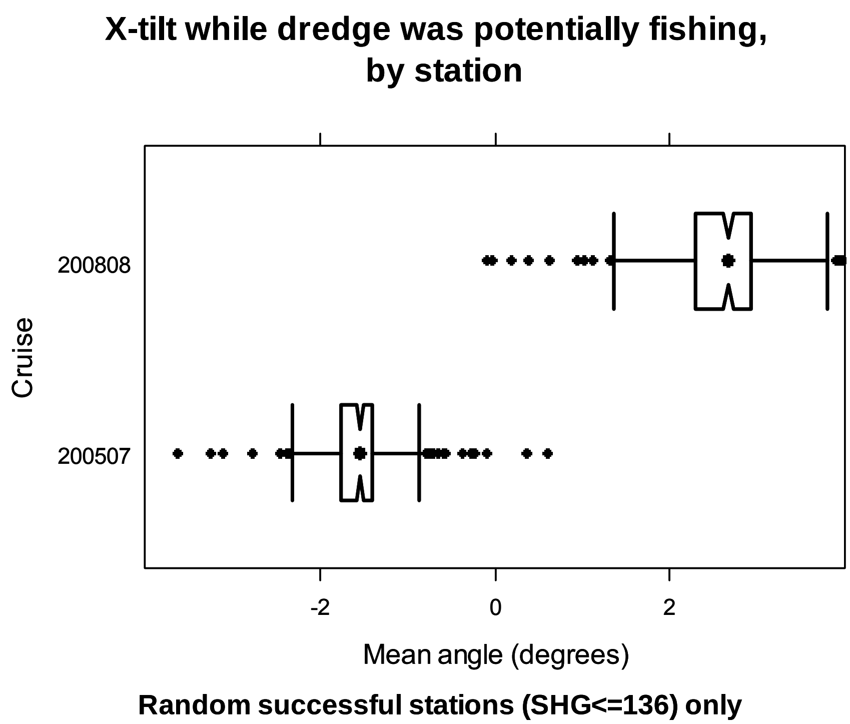
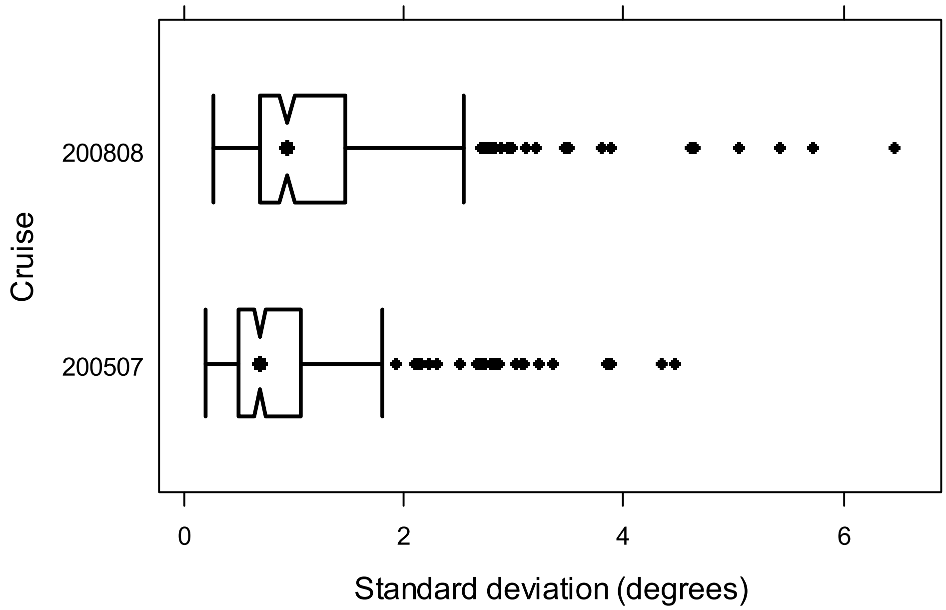


Figure B39. (cont.)

Standard deviation for x-tilt while dredge was potentially fishing, by station



Random successful stations (SHG<=136) only

Figure B39. (cont.)

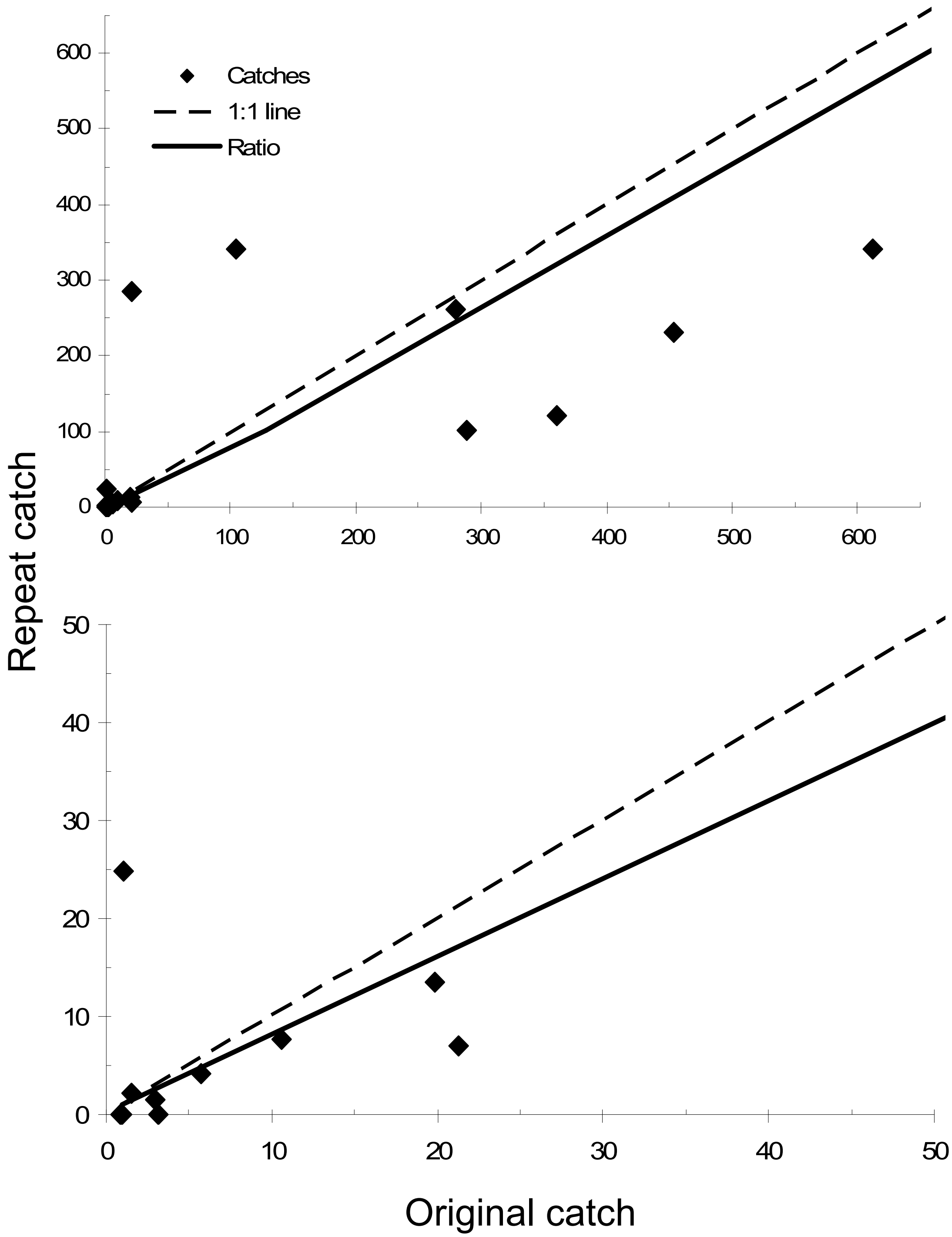


Figure B40. *Delaware II-Delaware II* (De2-De2) repeat station results. *Top*: all data. *Bottom*: showing observations near the origin that are hard to see in the upper panel.

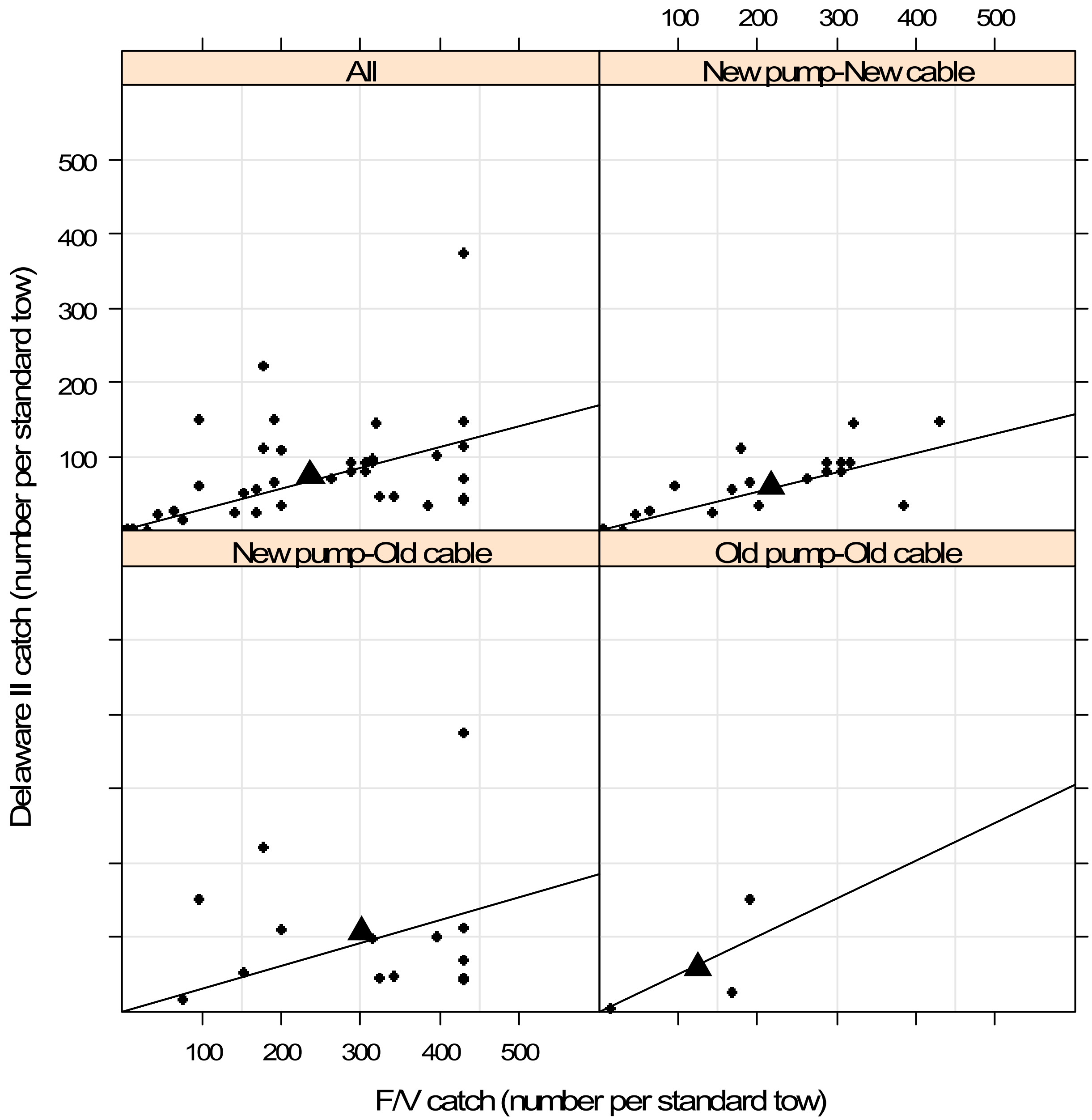


Figure B41. Catch per standard tow in DE2FV (Delaware II – F/V Endurance) repeat tows. The solid line in each panel is a regression line forced through the origin. The dark triangle in each plot shows the mean catch by both vessels.

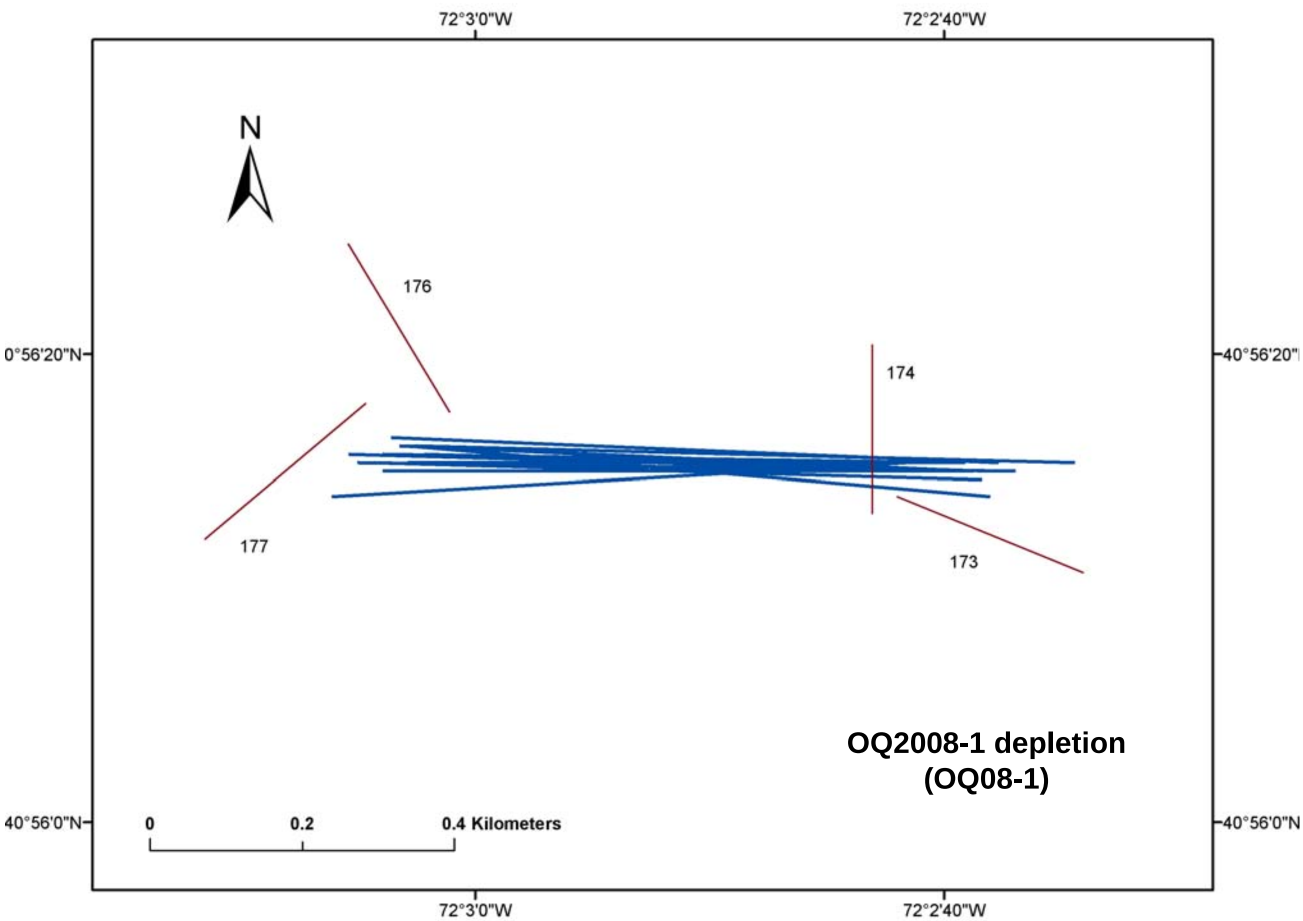


Figure B42. Depletion and setup tows for the OQ2008-1 commercial depletion experiments.

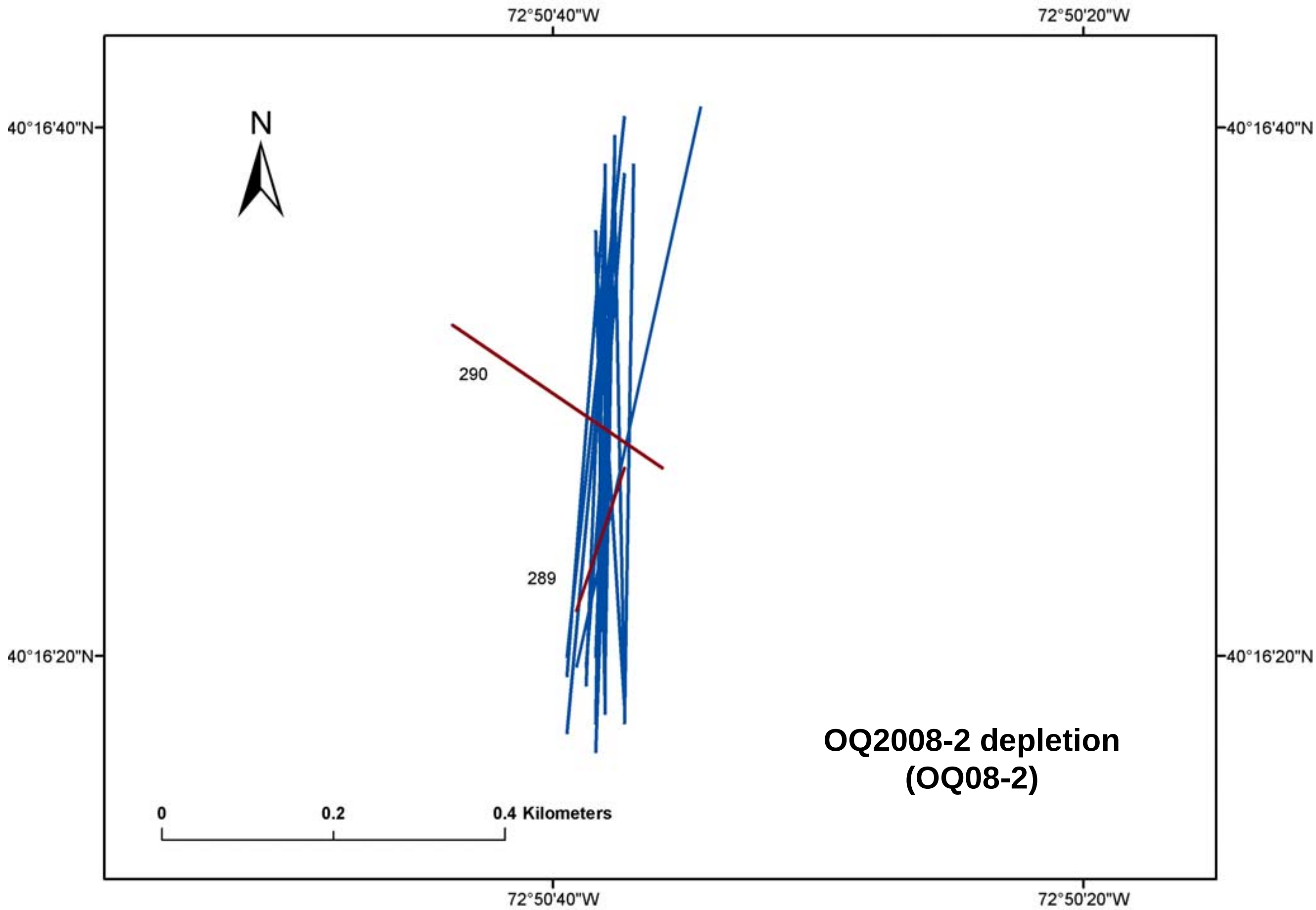


Figure B43. Depletion and setup tows for the OQ2008-2 commercial depletion experiments. The setup tow at station 289 is located under the depletion tows and may not be visible.

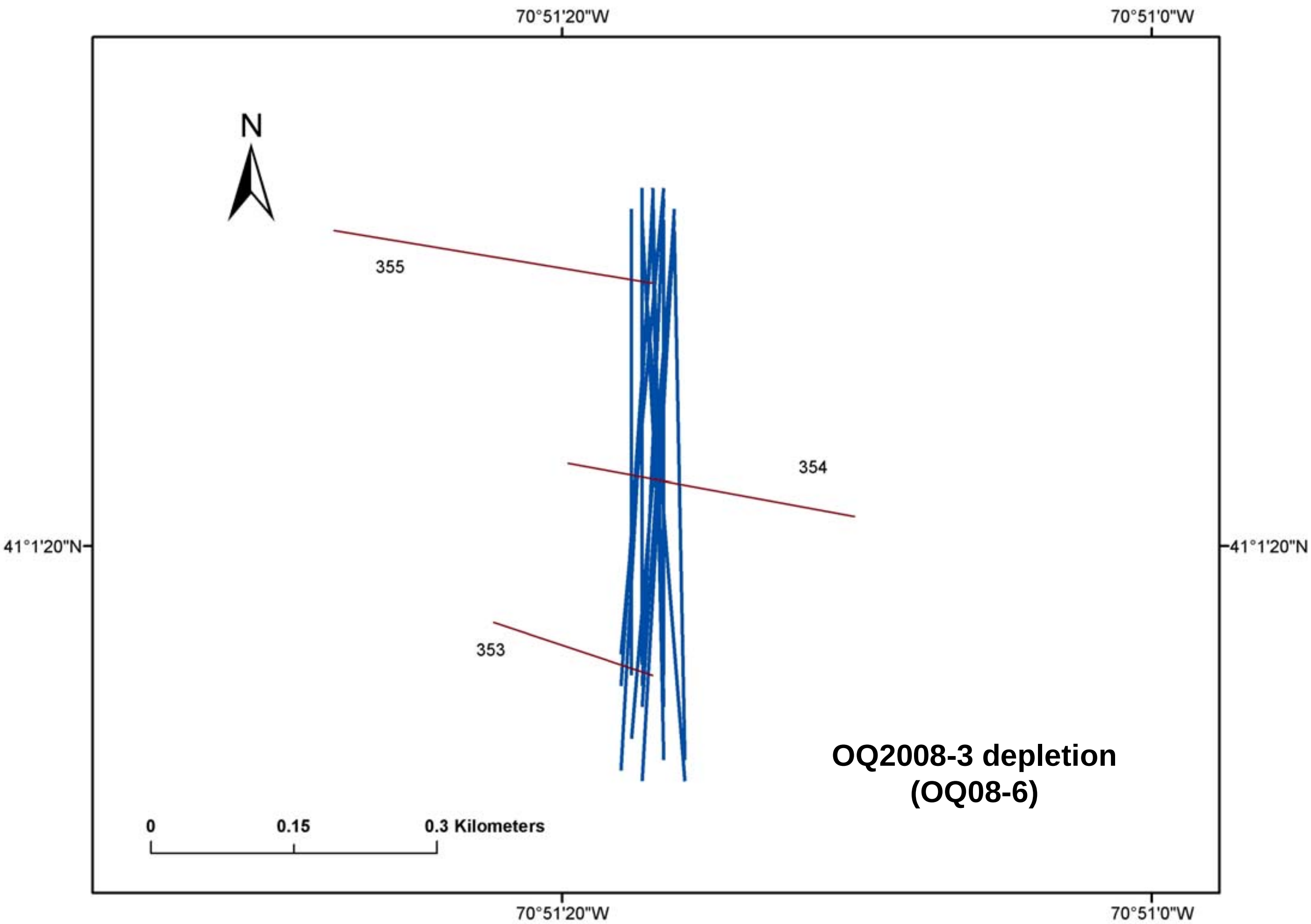


Figure B44. Depletion and setup tows for the OQ2005-3 commercial depletion experiments.

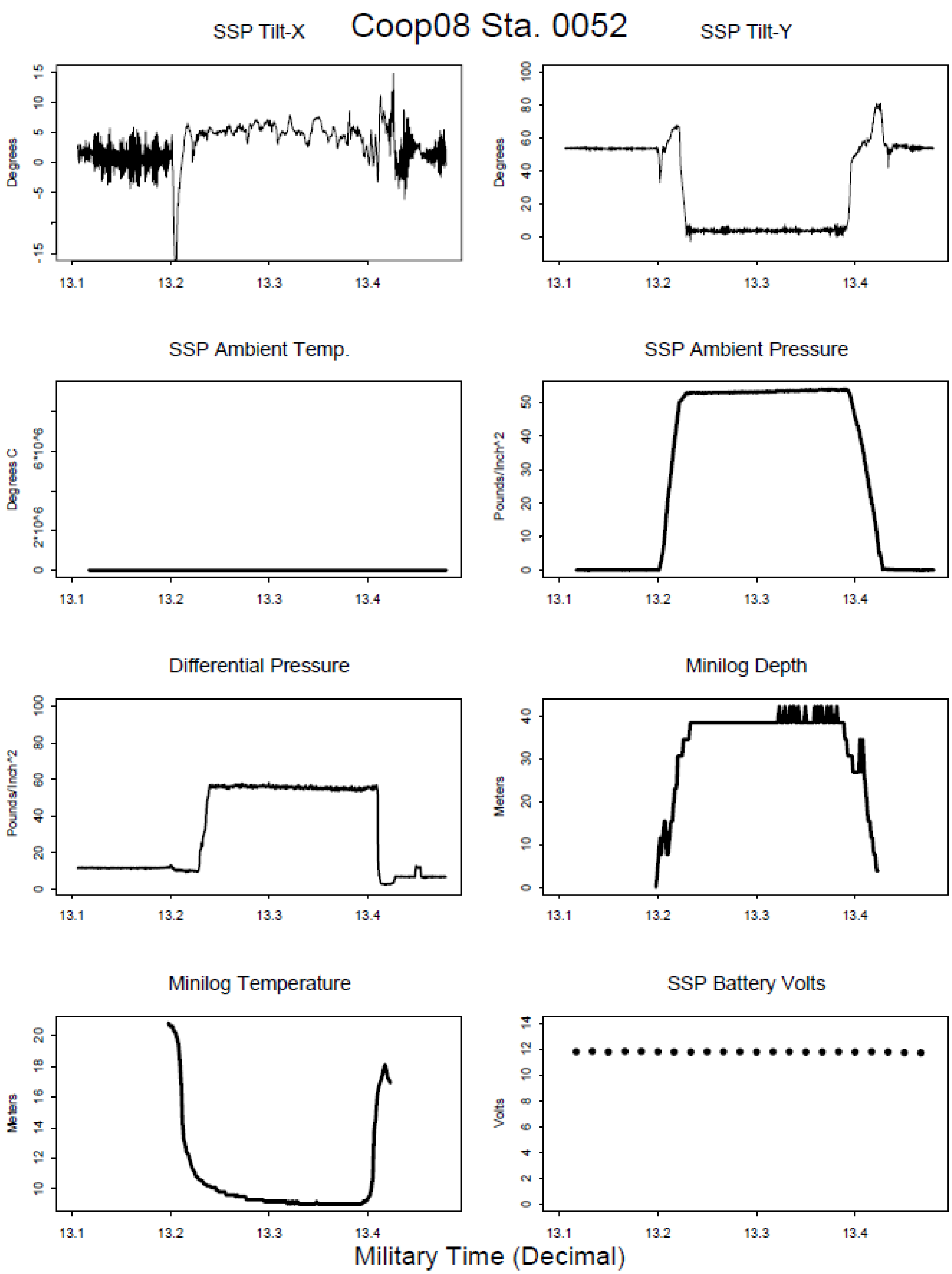


Figure B45. SSP sensor data for a tow by the F/V Endeavor during the 2008 cooperative clam survey.

Original and smoothed Position Data OQ2008-1

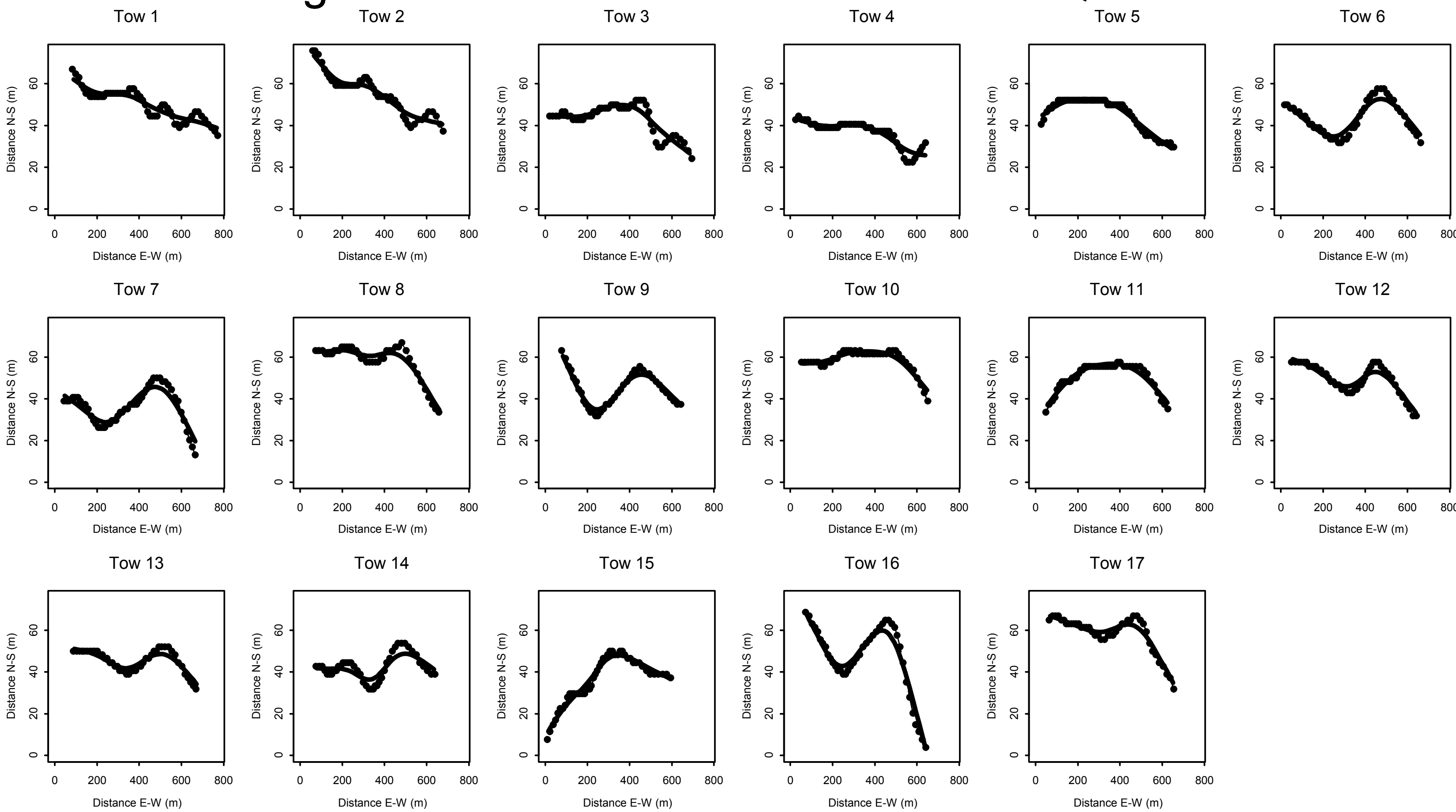


Figure B46. Original and smoothed position data for the OQ2008-1 commercial depletion study.

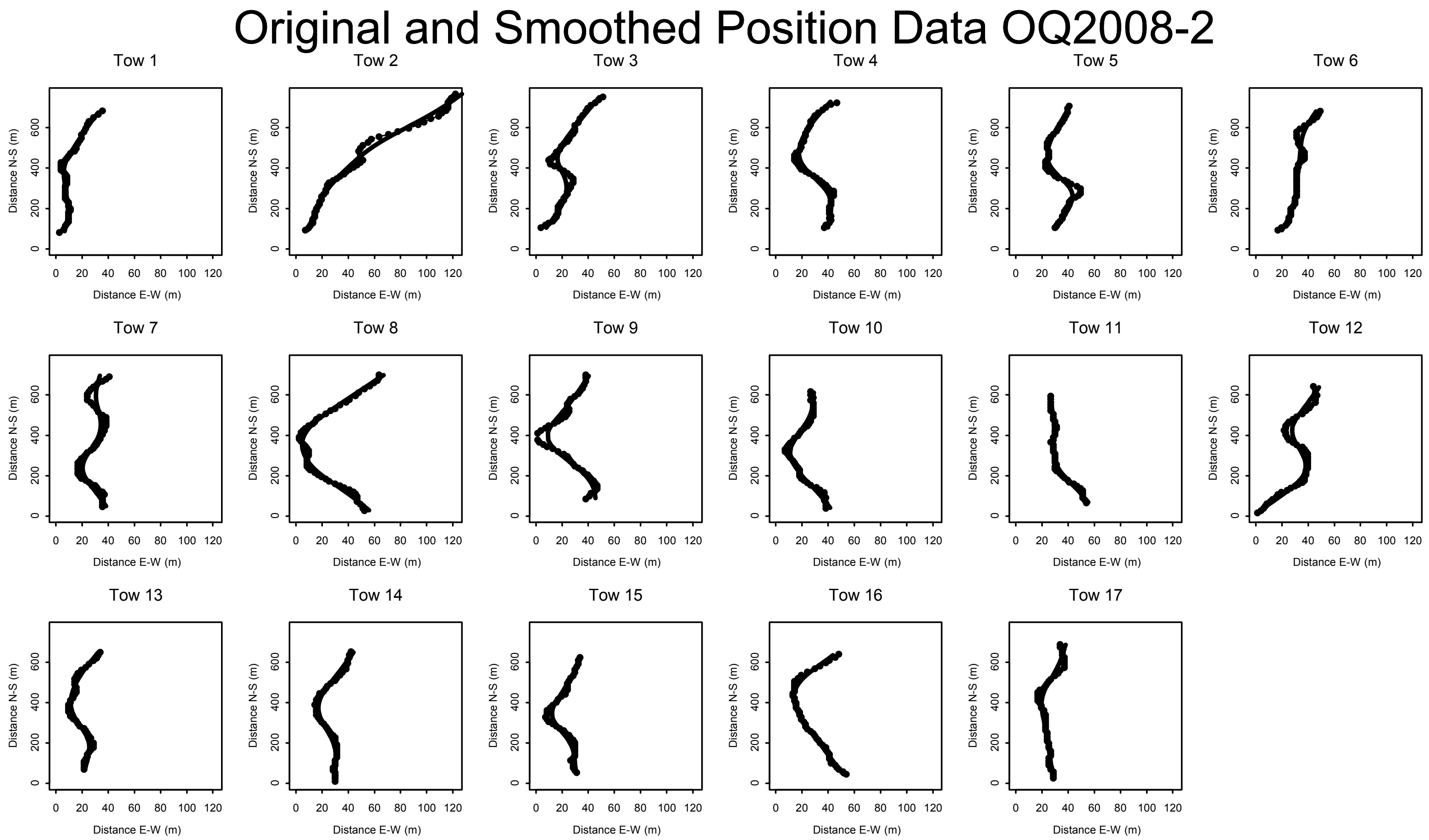


Figure B47. Original and smoothed position data for the OQ2008-2 commercial depletion study.

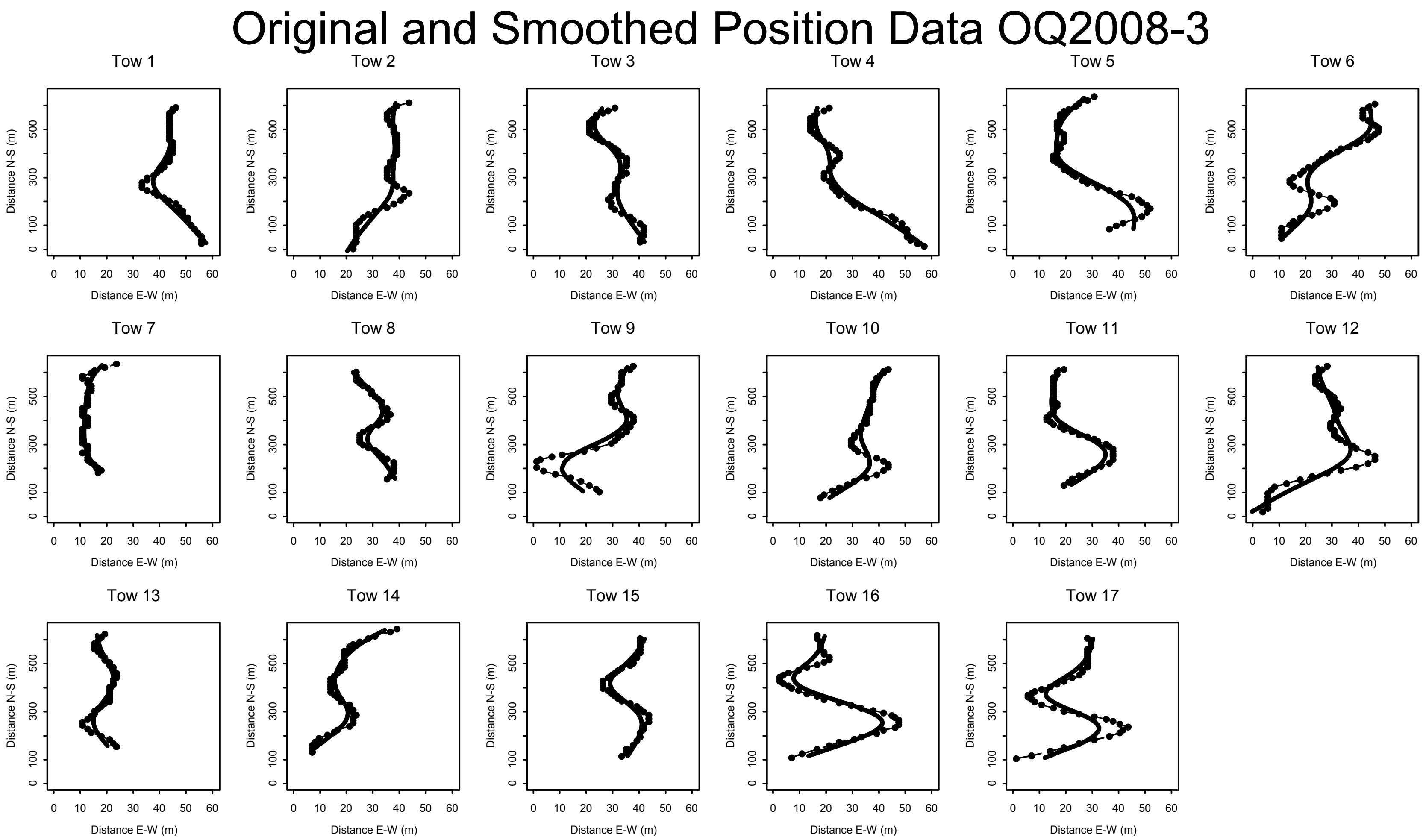


Figure B48. Original and smoothed position data for the OQ2008-3 commercial depletion study.

OQ2008-1 Patch model estimates, goodness of fit and likelihood profiles.

Density	0.0676
Efficiency	0.99994
K	7.54808
Gamma	0.50001
NLL	118.47

Note: estimates for ocean quahogs 90+ mm SL.

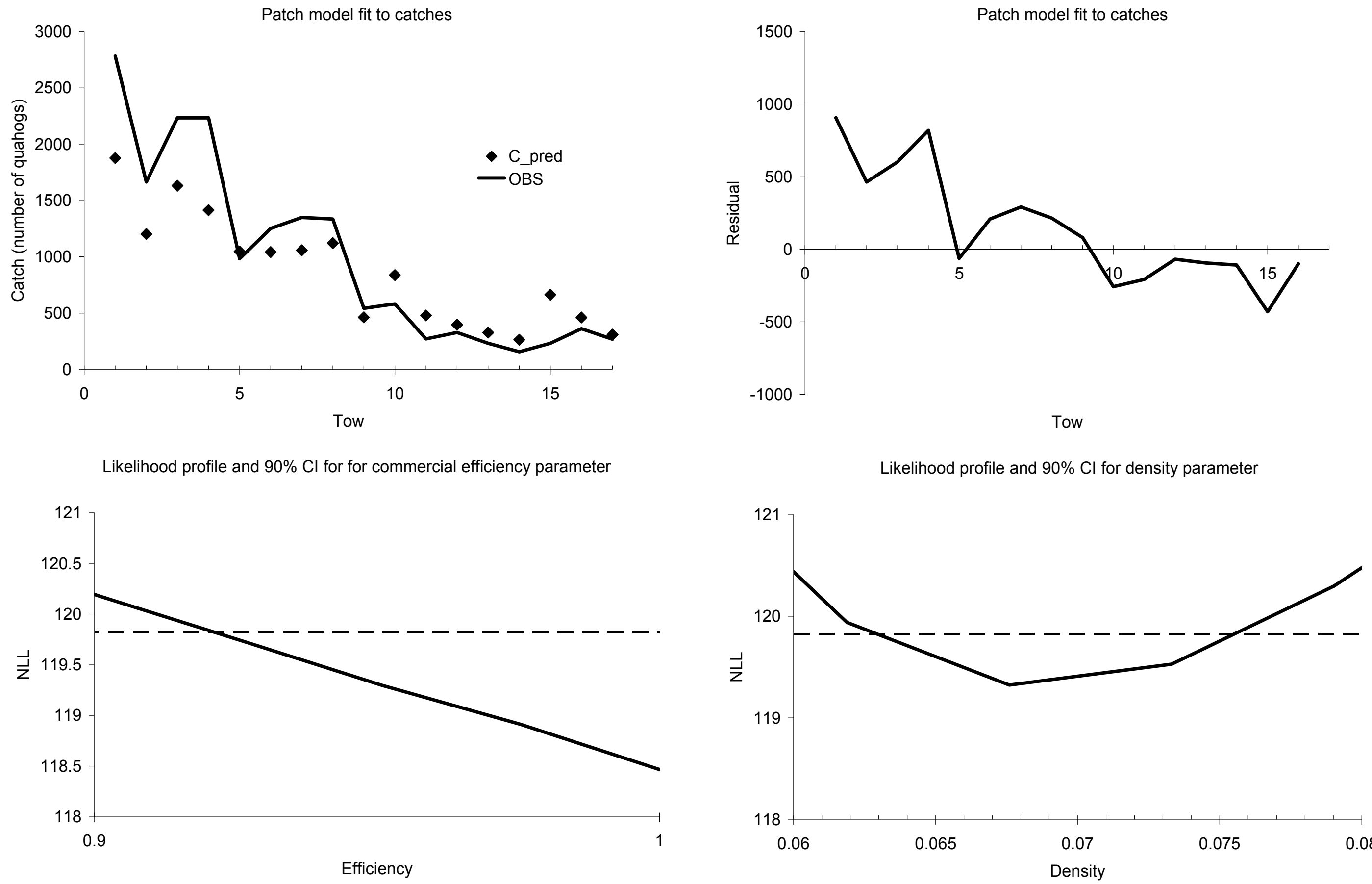
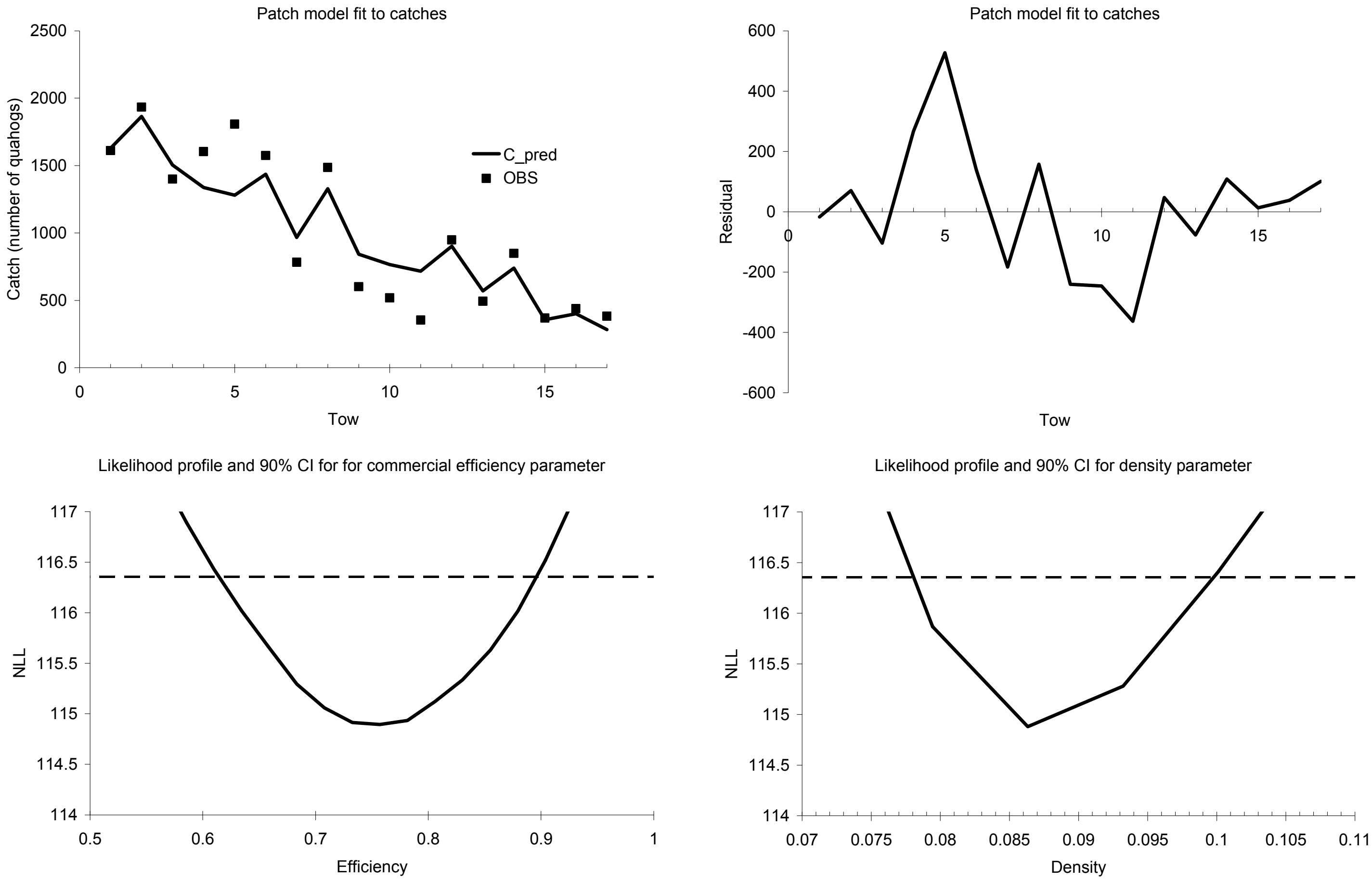


Figure B49. Goodness of fit and likelihood profile confidence intervals for the Patch model estimates for the OQ2008-1 commercial depletion study.

OQ2008-2 Patch model estimates, goodness of fit and likelihood profiles.

Density	0.08633
Efficiency	0.78149
K	14.5478
Gamma	0.50001
NLL	115.002

Note: estimates for ocean quahogs 90+ mm SL.



FigureB50. Goodness of fit and likelihood profile confidence intervals for the Patch model estimates for the OQ2008-2 commercial depletion study.

OQ2008-3 Patch model estimates, goodness of fit and likelihood profiles.

Density	0.11981	
Efficiency	1	
K	5.95464	Note: estimates for ocean quahogs 90+ mm SL.
Gamma	0.50001	
NLL	127.49	

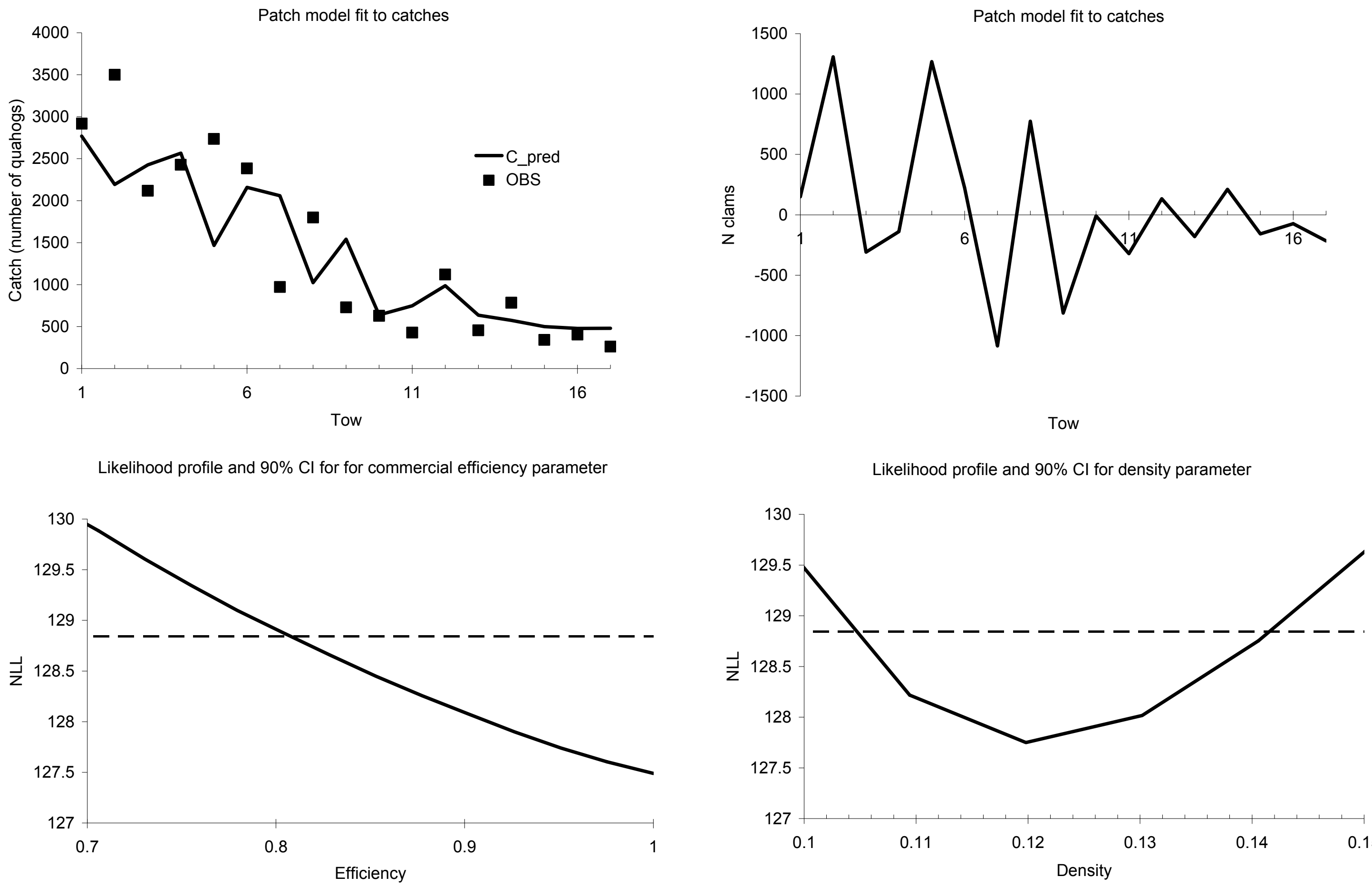


Figure B51. Goodness of fit and likelihood profile confidence intervals for the Patch model estimates for the OQ2008-3 commercial depletion study.

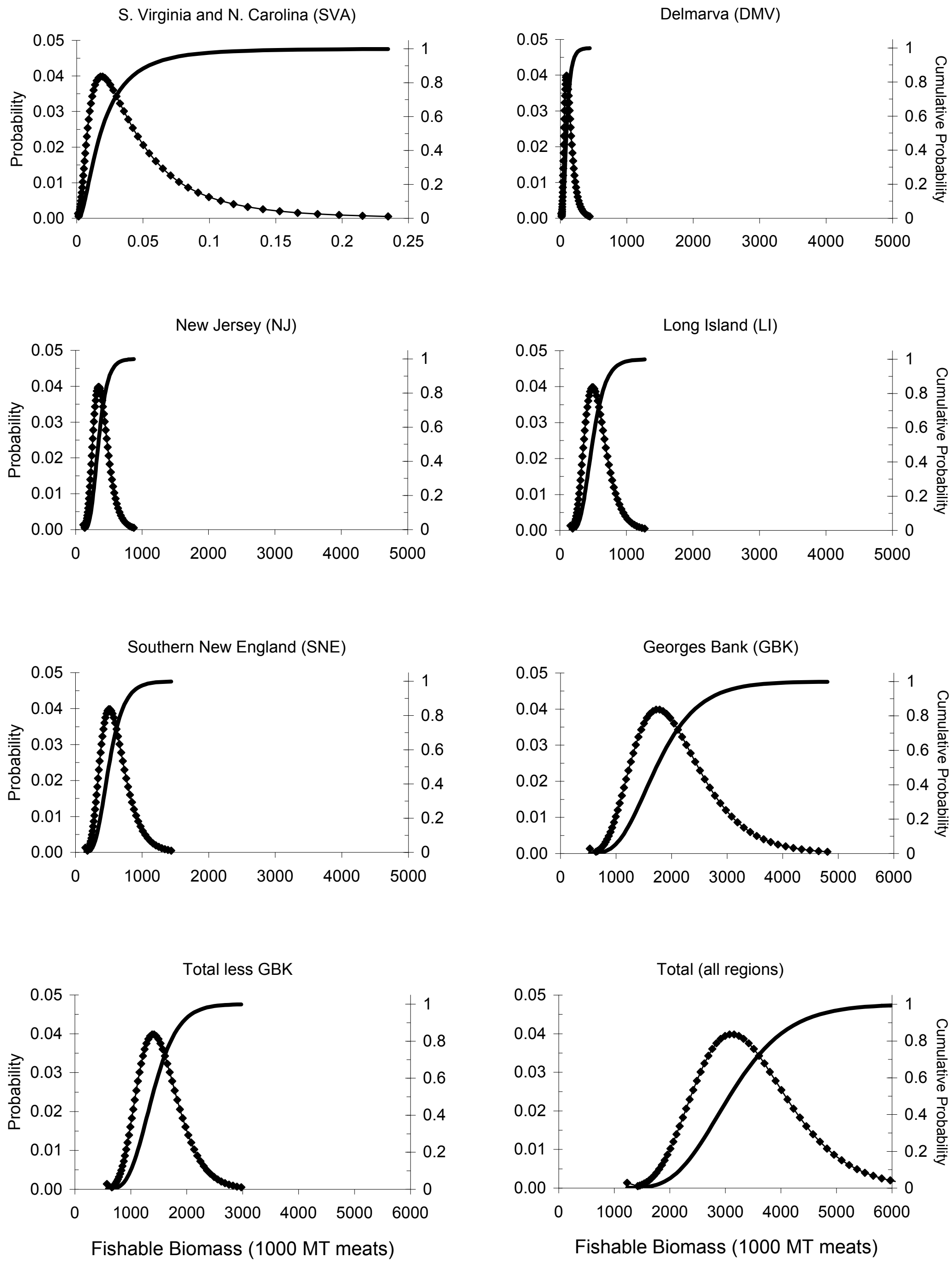


Figure B52. Uncertainty in efficiency corrected swept area biomass ESB) estimates for fishable ocean quahog during 2008. Note that the x-axis differs in the panel for SVA but is the same in all other panels to facilitate comparisons.

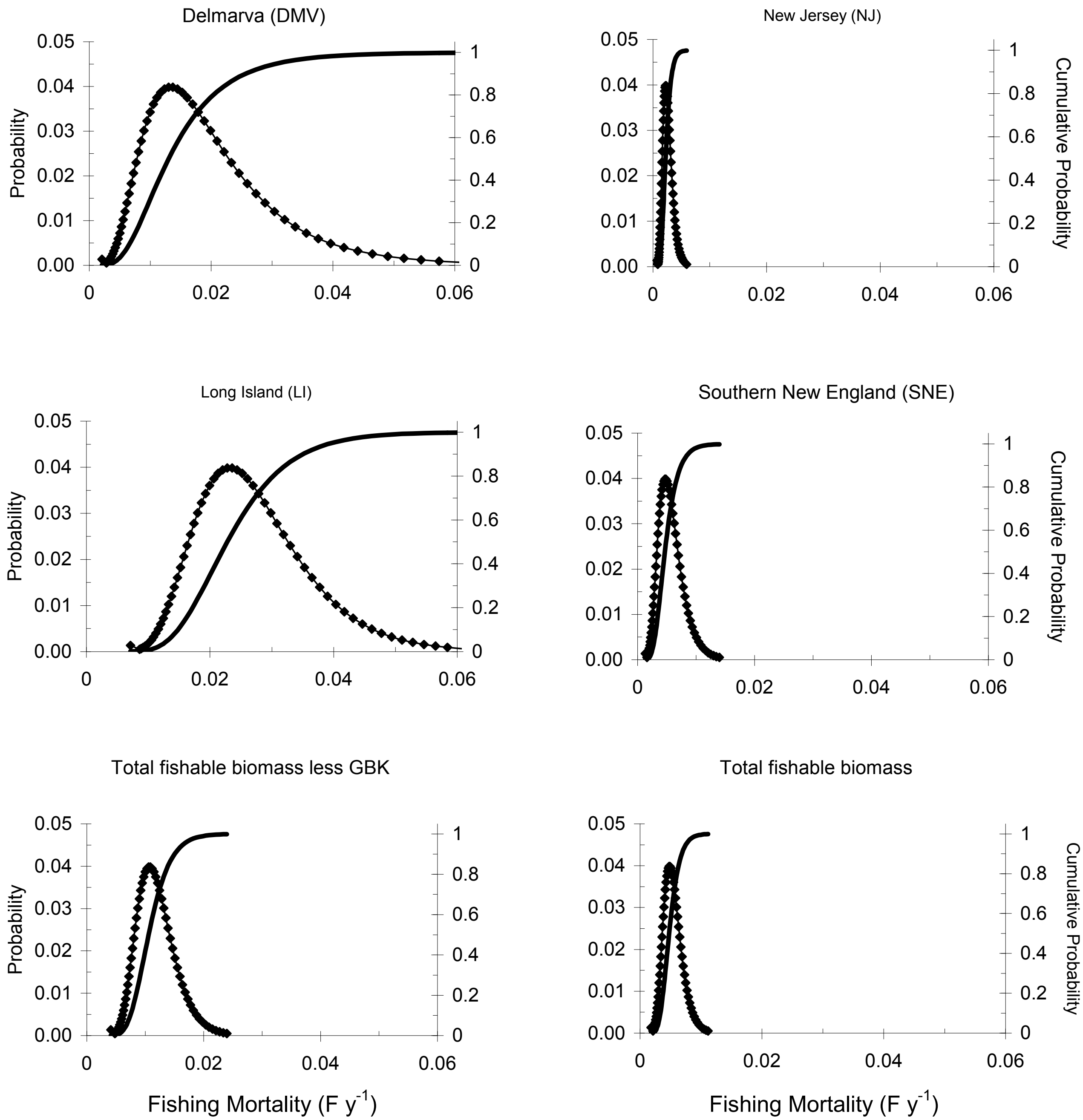


Figure B53. Uncertainty in fishing mortality estimates for ocean quahog during 2008 based on catch data and efficiency corrected swept-area biomass. X-axes are scaled to the same maximum to facilitate comparisons.

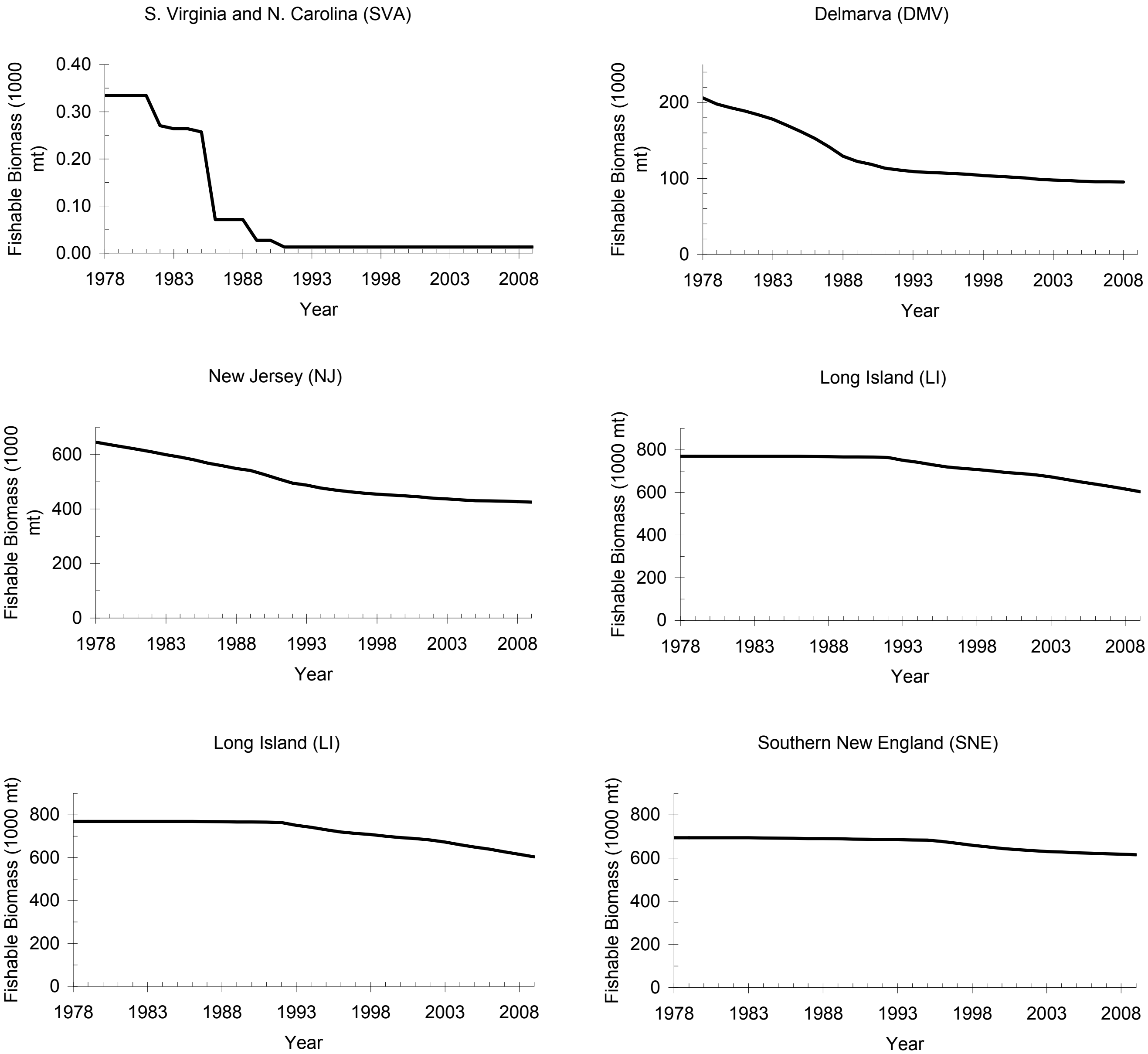


Figure B54. Trends in fishable biomass for ocean quahog from the "VPA" method during 1978-2009, by region. The VPA estimate for GBK is the mean of ESB estimates for 2002, 2005 and 2008 because no catch occurs in GBK.

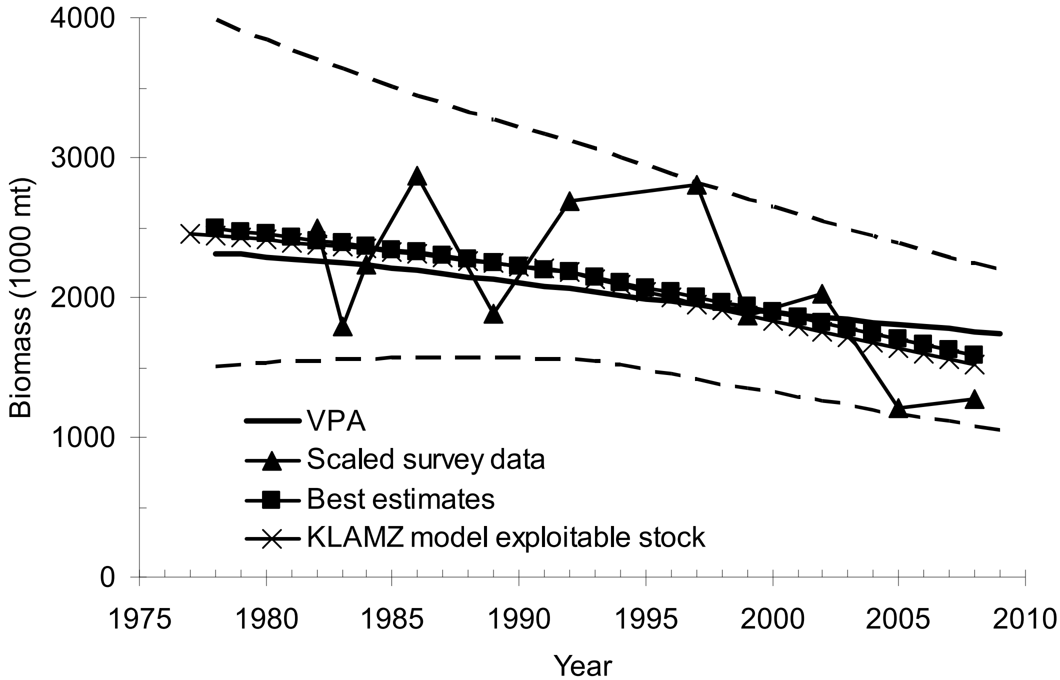


Figure B55. Biomass estimates for ocean quahogs in the exploited region with survey trend data adjusted to the same scale. Estimates are from: i) the sum of best estimates in this assessment (VPA model for SVA and regional KLAMZ models for other areas); ii) VPA (sum of regional VPA estimates); and a KLAMZ model fit to the entire exploited region. The dashed lines show an asymmetric confidence interval for the KLAMZ model fit to the entire exploited region.

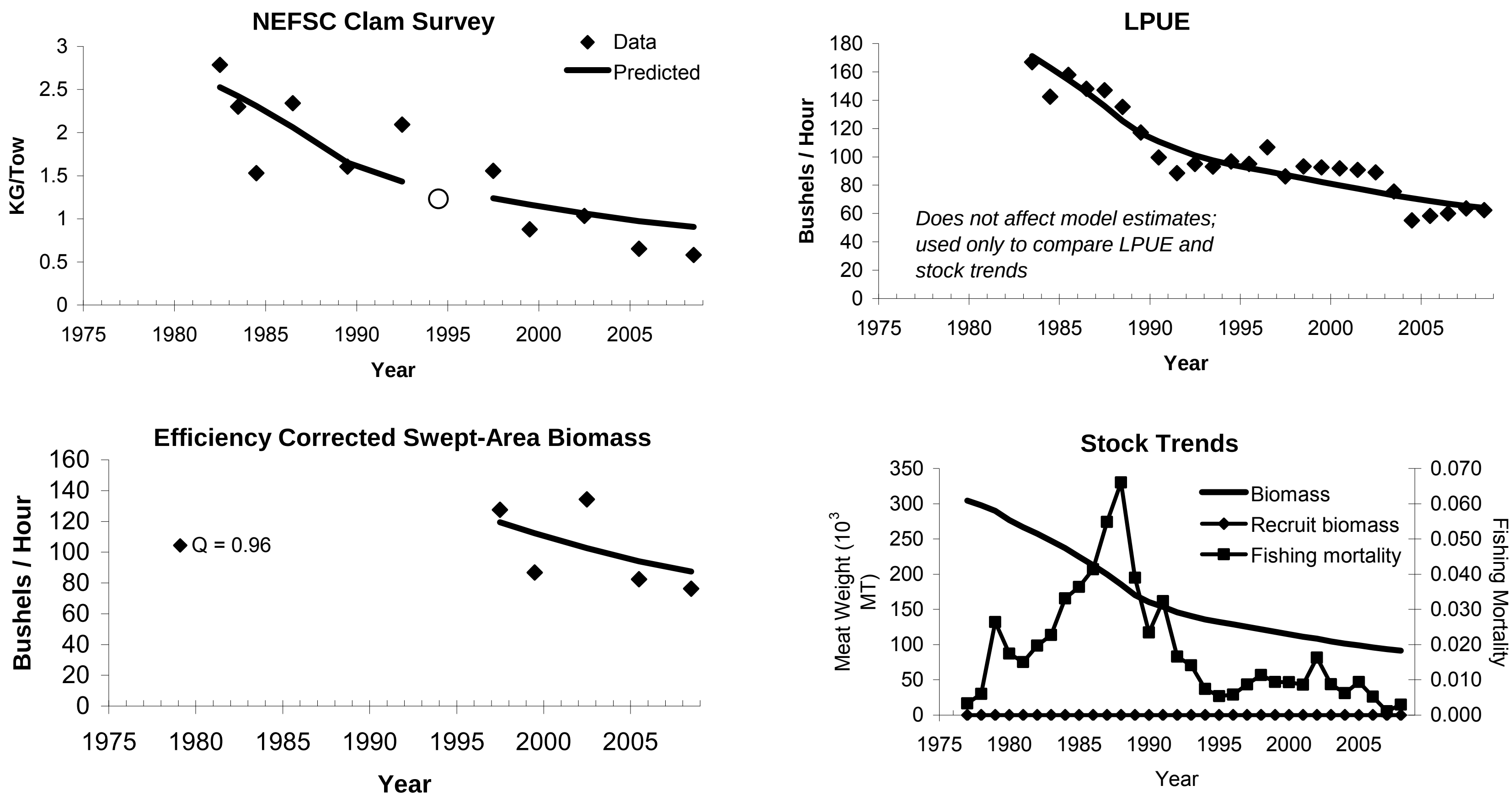


Figure B56. KLAMZ model results for ocean quahog in the DMV stock assessment region during 1977-2008. The bottom right panel shows population estimates. Other panels show goodness of fit to survey, LPUE and swept area biomass trend data. Results are for a KLAMZ model run with M=0.02 y-1 and recruitment biomass fixed near zero. The survey scaling parameter estimate for ESB data is shown in the bottom left panel. The 1994 clam survey observation (open circle) was not used in fitting the model.

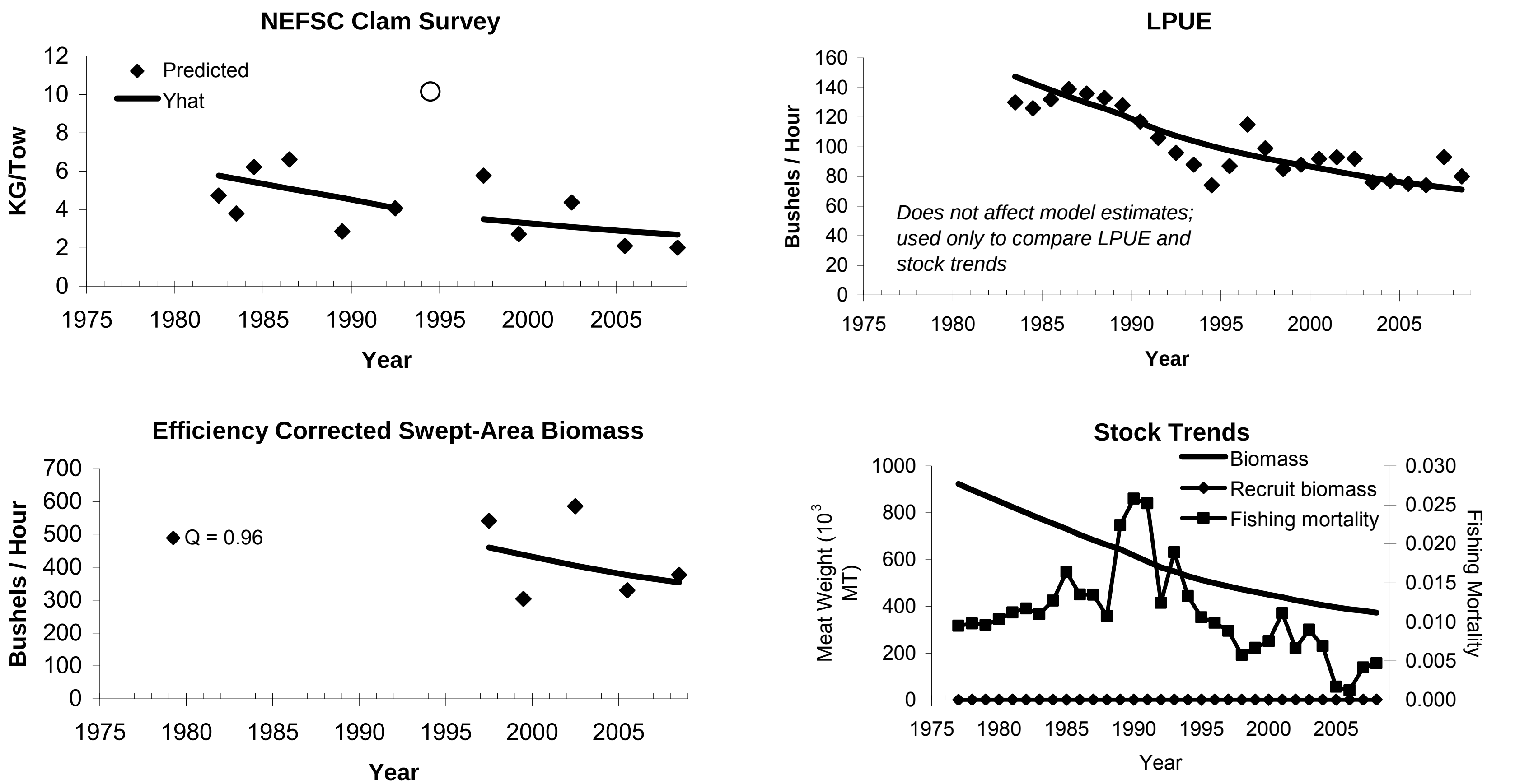


Figure B57. KLAMZ model results for ocean quahog in the NJ stock assessment region during 1977-2008. The bottom right panel shows population estimates. Other panels show goodness of fit to survey, LPUE and swept area biomass trend data. Results are for a KLAMZ model run with M=0.02 y-1 and recruitment biomass estimated at a relatively low level. The survey scaling parameter estimate for ESB data is shown in the bottom left panel. The 1994 clam survey observation (open circle) was not used in fitting the model.

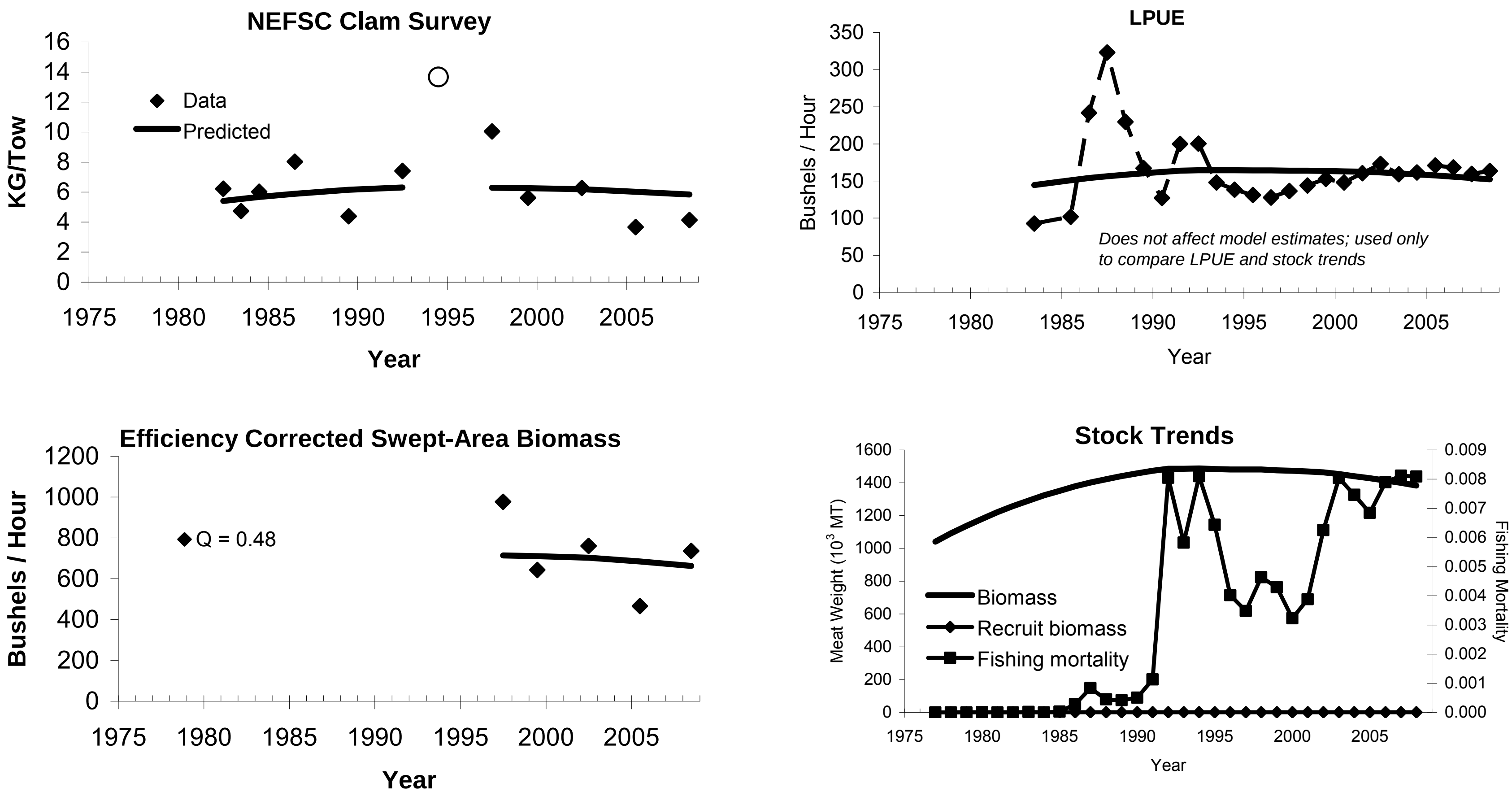


Figure B58. Preliminary results from a KLAMZ model with constant recruitment for ocean quahog in the LI stock assessment region during 1977-2008. Note the slight lack of fit to recent survey data (top left panel) and the anomalous survey scaling coefficient value (*Q*=0.48) for efficiency corrected swept area biomass (bottom left panel).

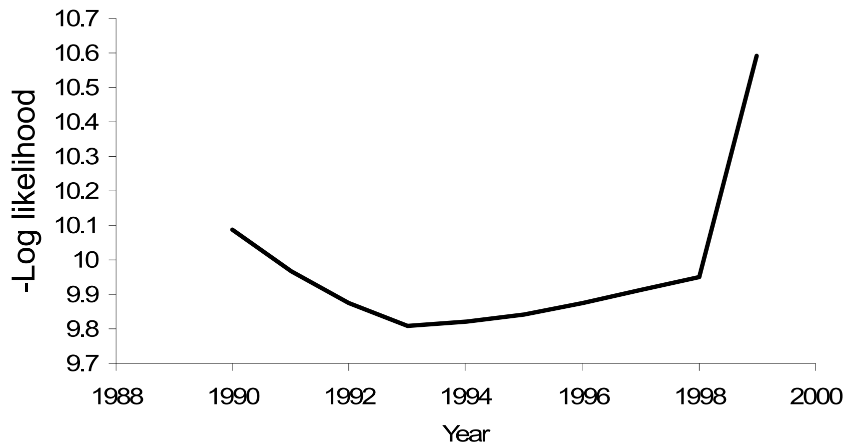


Figure B59. Profile likelihood analysis to determine the change year for the step recruitment function in the KLAMZ model for LI.

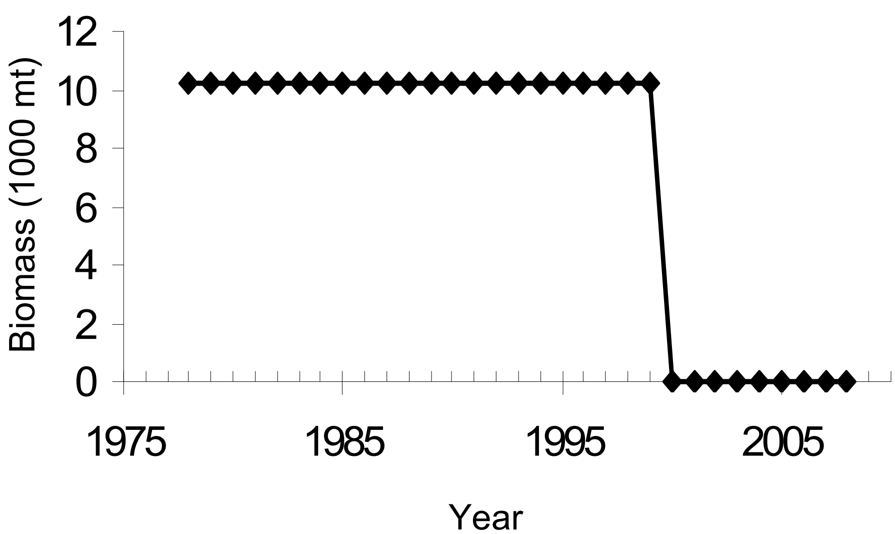


Figure B60. Step function recruitment estimates from the KLAMZ model for LI.

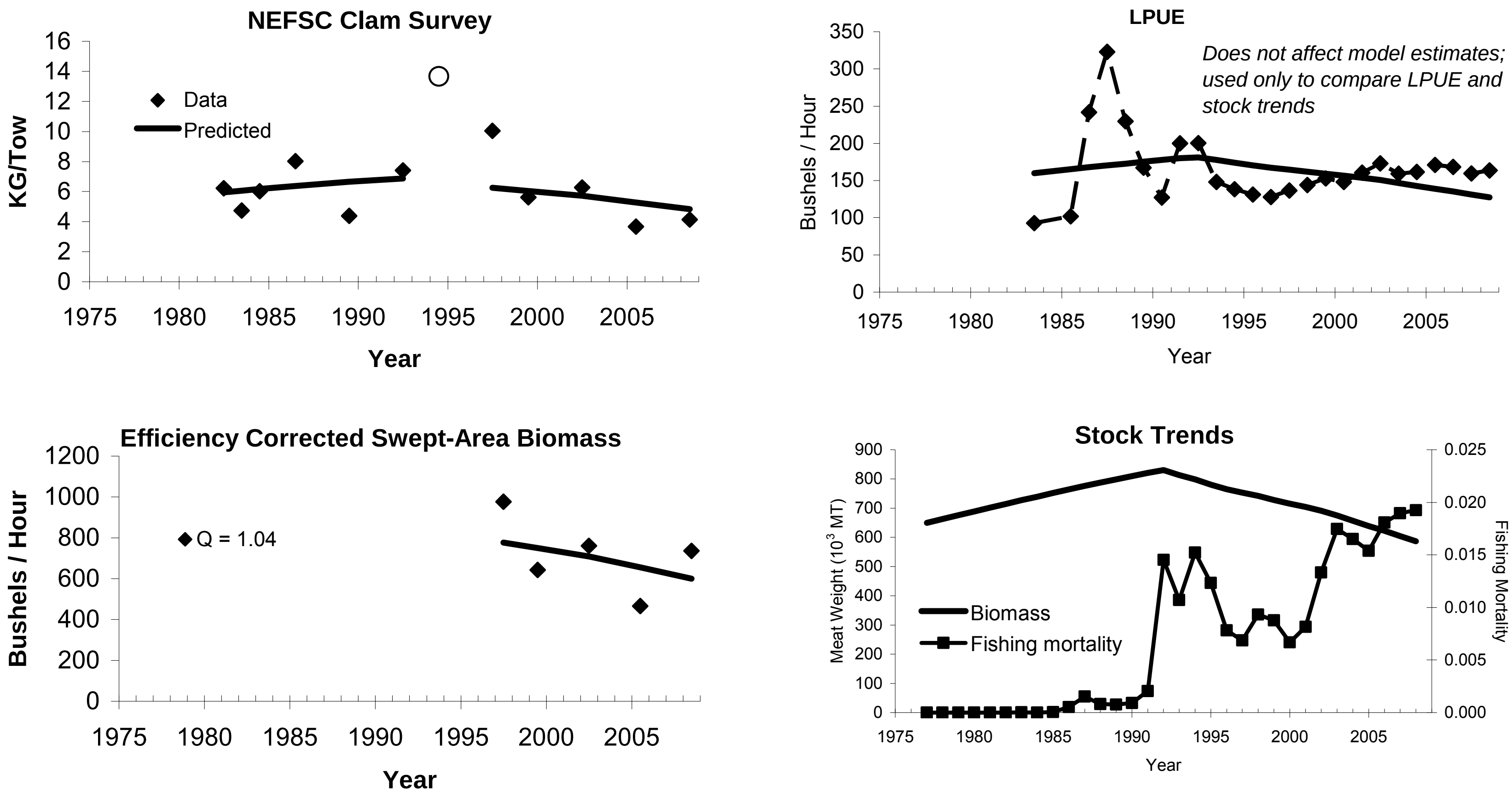


Figure B61. KLAMZ model results for ocean quahog in the LI stock assessment region during 1977-2008. The bottom right panel shows population estimates. Other panels show goodness of fit to survey, LPUE and swept area biomass trend data. Results are for a KLAMZ model run with M=0.02 y-1 and recruitment biomass estimated using a step function with the second period starting in 1994 (Figure K5). The survey scaling parameter estimate for ESB data is shown in the bottom left panel. The 1994 clam survey observation (open circle) was not used in fitting the model.

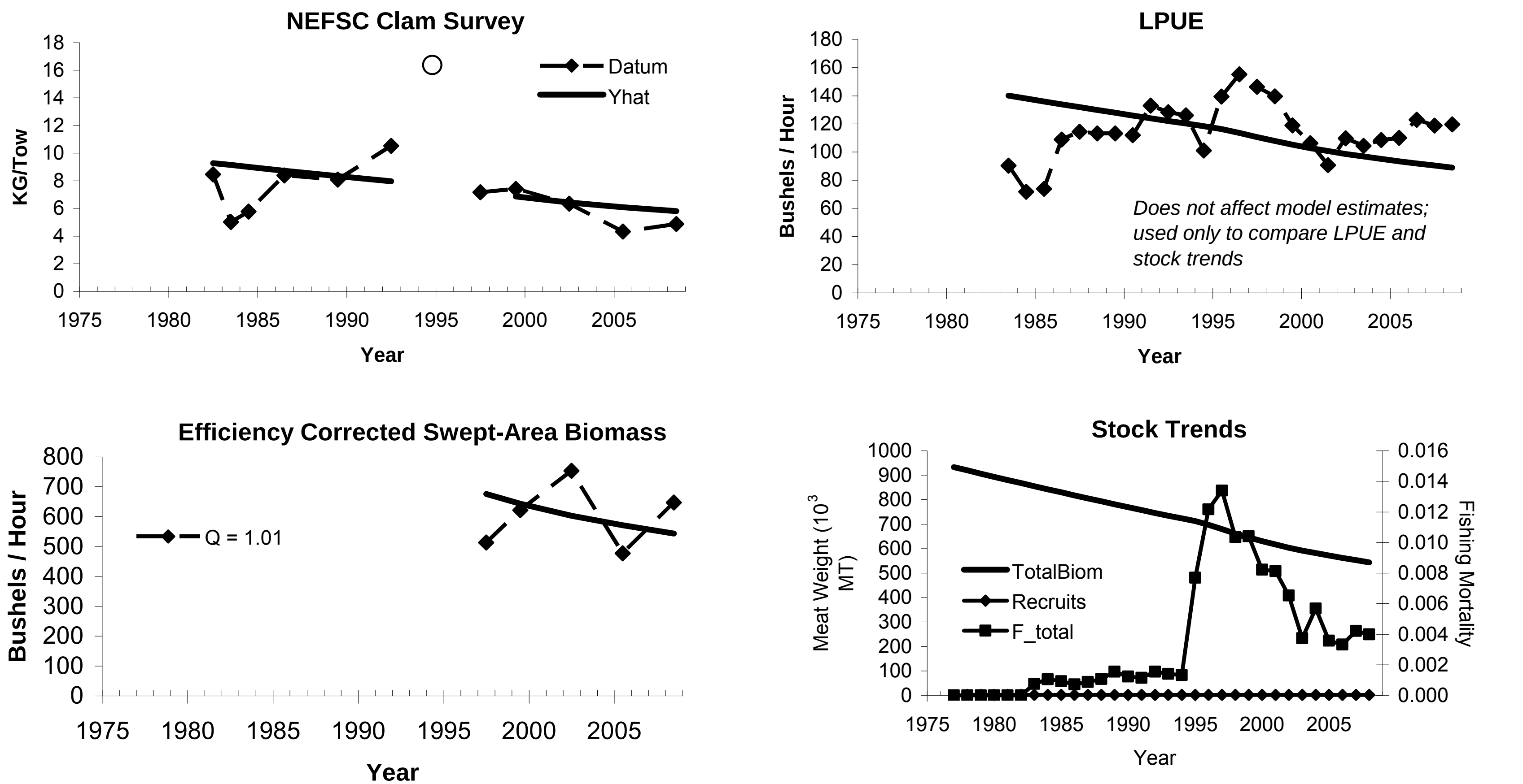


Figure B62. Preliminary results from a KLAMZ model with constant recruitment for ocean quahog in the SNE stock assessment region during 1977-2008. Note lack of fit to survey data (top left panel).

Figure B63. Profile likelihood analysis to determine the change year for the step recruitment function in the KLAMZ model for SNE.

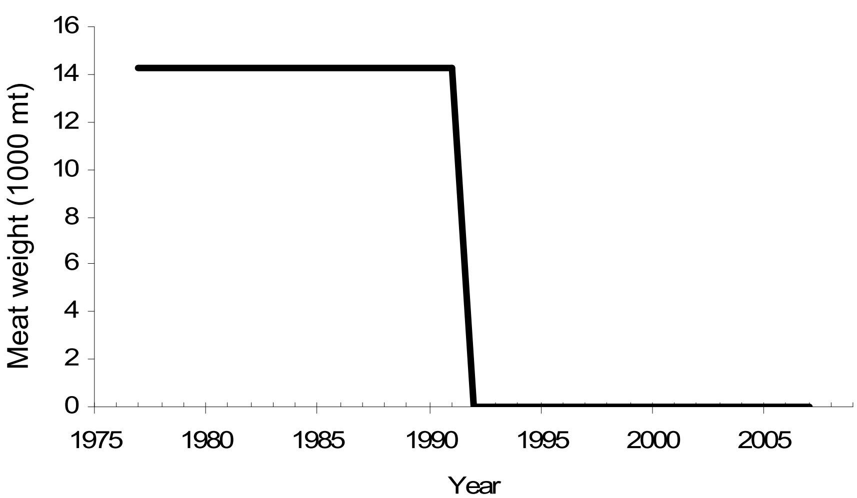


Figure B64. Step function recruitment estimates from the KLAMZ model for SNE.

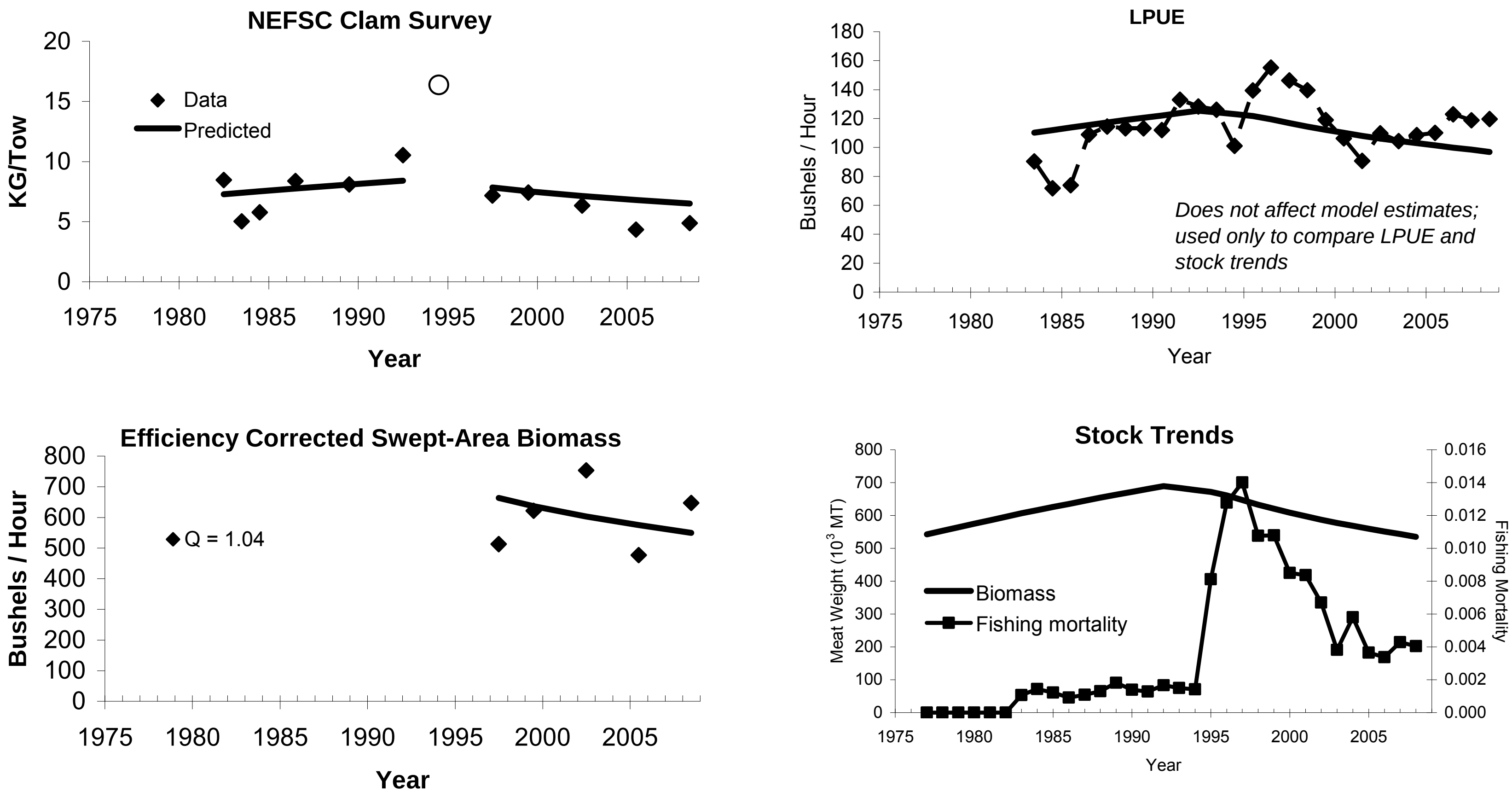


Figure B65. KLAMZ model results for ocean quahog in the SNE stock assessment region during 1977-2008. The bottom right panel shows population estimates. Other panels show goodness of fit to survey, LPUE and swept area biomass trend data. Results are for a KLAMZ model run with M=0.02 y-1 and recruitment biomass estimated using a step function with the second period starting in 1994 (Figure K5). The survey scaling parameter estimate for ESB data is shown in the bottom left panel. The 1994 clam survey observation (open circle) was not used in fitting the model.

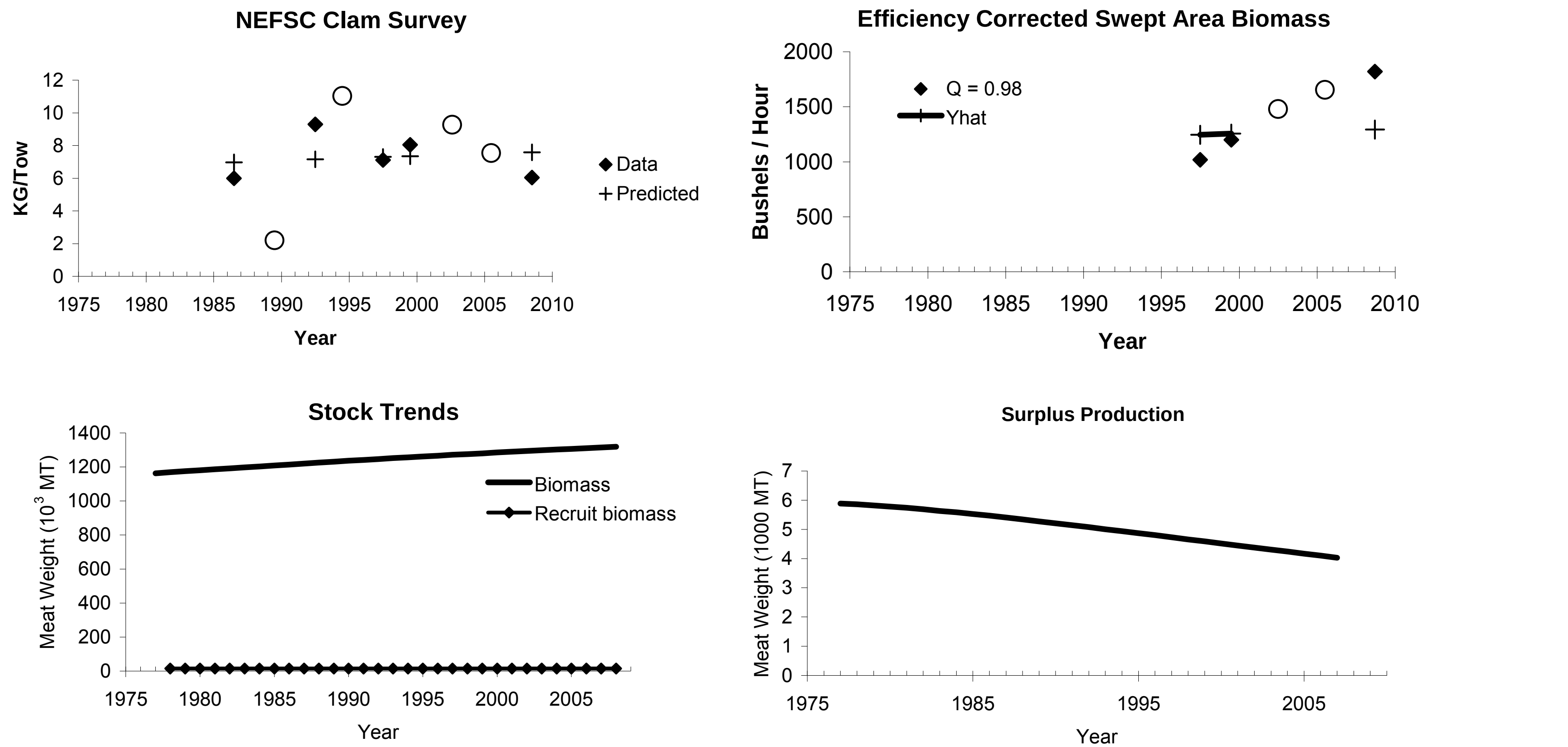


Figure B66. KLAMZ model results for ocean quahog in the GBK stock assessment region during 1977-2008. The bottom two panels show population estimates. Other panels show goodness of fit to survey and swept area biomass trend data. Results are for a KLAMZ model run with M=0.02 y-1 and recruitment biomass estimated at a relatively low level. The survey scaling parameter estimate for ESB data is shown in the bottom left panel. Survey and swept area biomass data for 1989, 1994, 2002 and 2005 (open circles) were not used in fitting the model due to voltage problems in 1994 and poor sampling in other years.

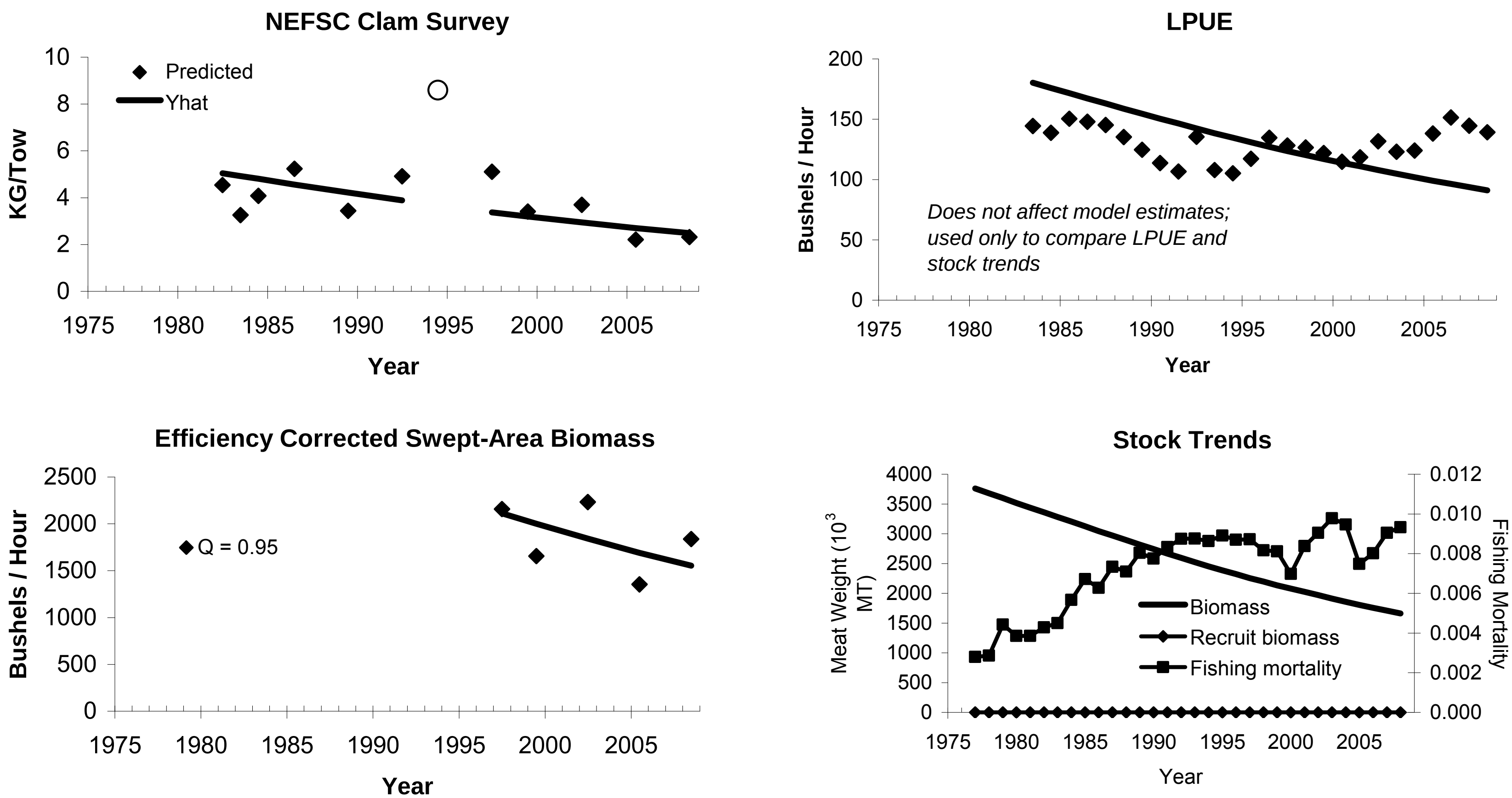


Figure B67. Preliminary results from a KLAMZ model with constant recruitment for ocean quahog in the exploited stock area during 1977-2008. Note lack of fit to survey data (top left panel).

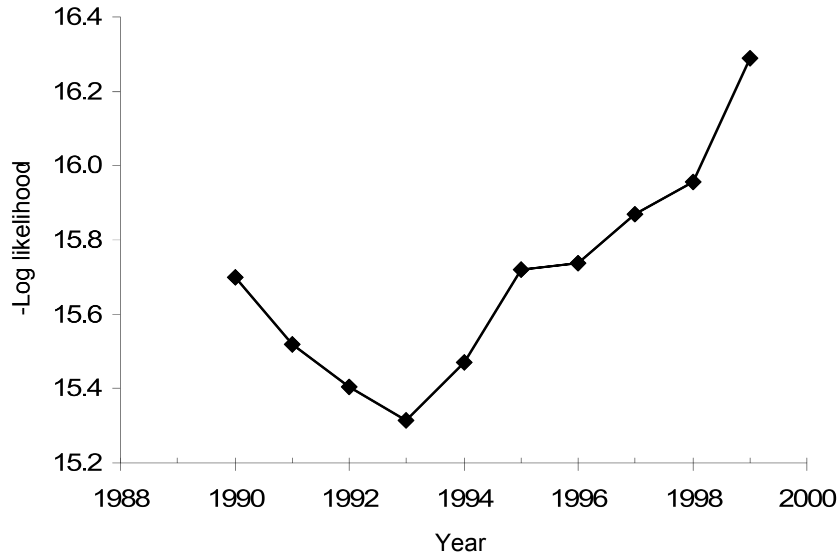


Figure B68. Profile likelihood analysis to determine the change year for the step recruitment function in the KLAMZ model for the exploited stock region.

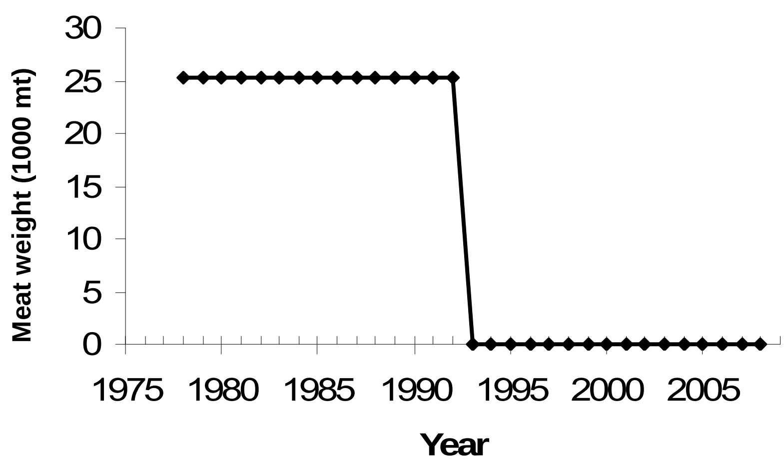


Figure B69. Step function recruitment estimates from the KLAMZ model for ocean quahogs in the exploited stock region.

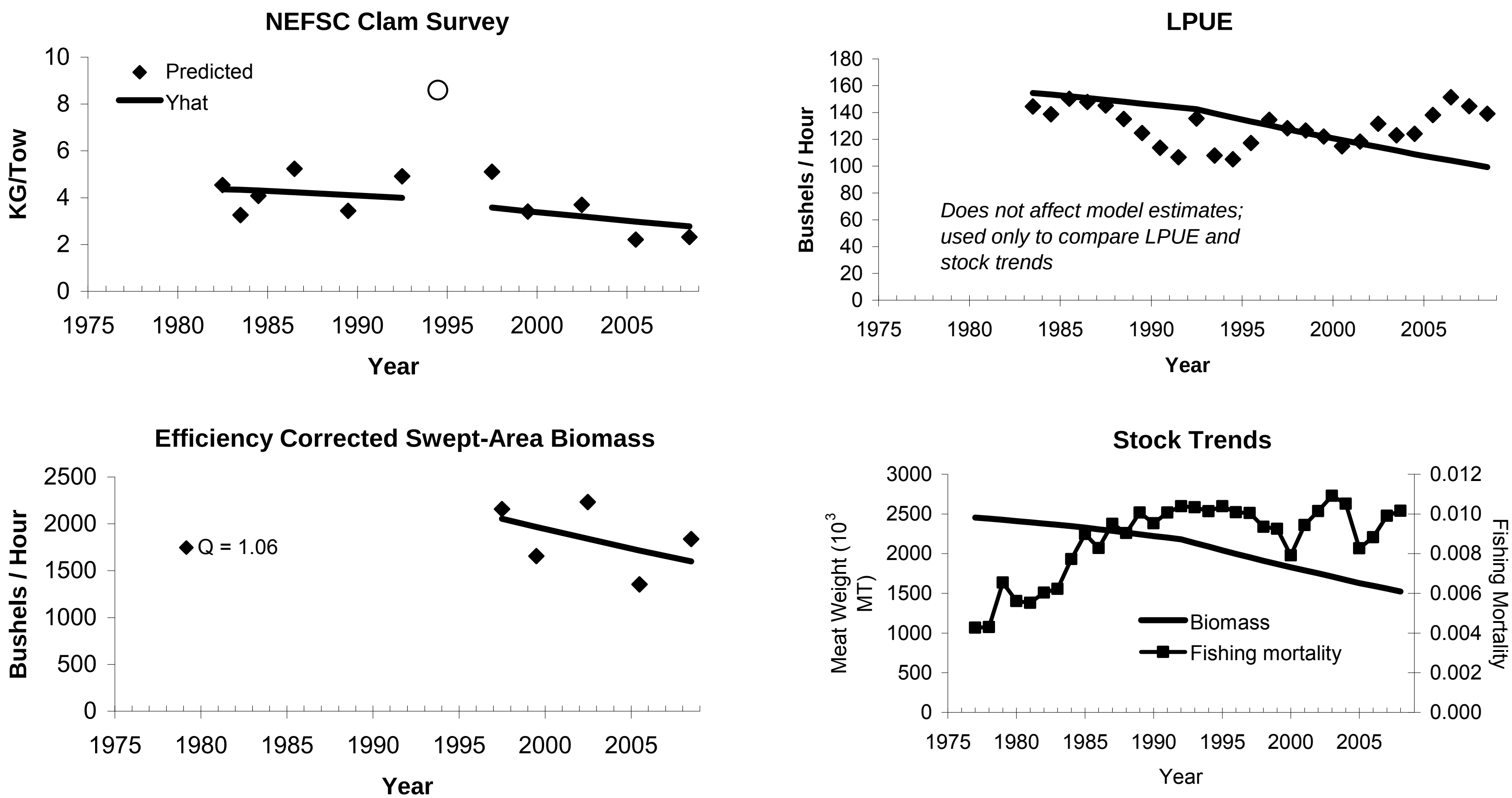


Figure B70. KLAMZ model results for ocean quahog in the LI stock assessment region during 1977-2008. The bottom right panel shows population estimates. Other panels show goodness of fit to survey, LPUE and swept area biomass trend data. Results are for a KLAMZ model run with M=0.02 y-1 and recruitment biomass estimated using a step function with the second period starting in 1994 (Figure B69). The survey scaling parameter estimate for ESB data is shown in the bottom left panel. The 1994 clam survey observation (open circle) was not used in fitting the model.

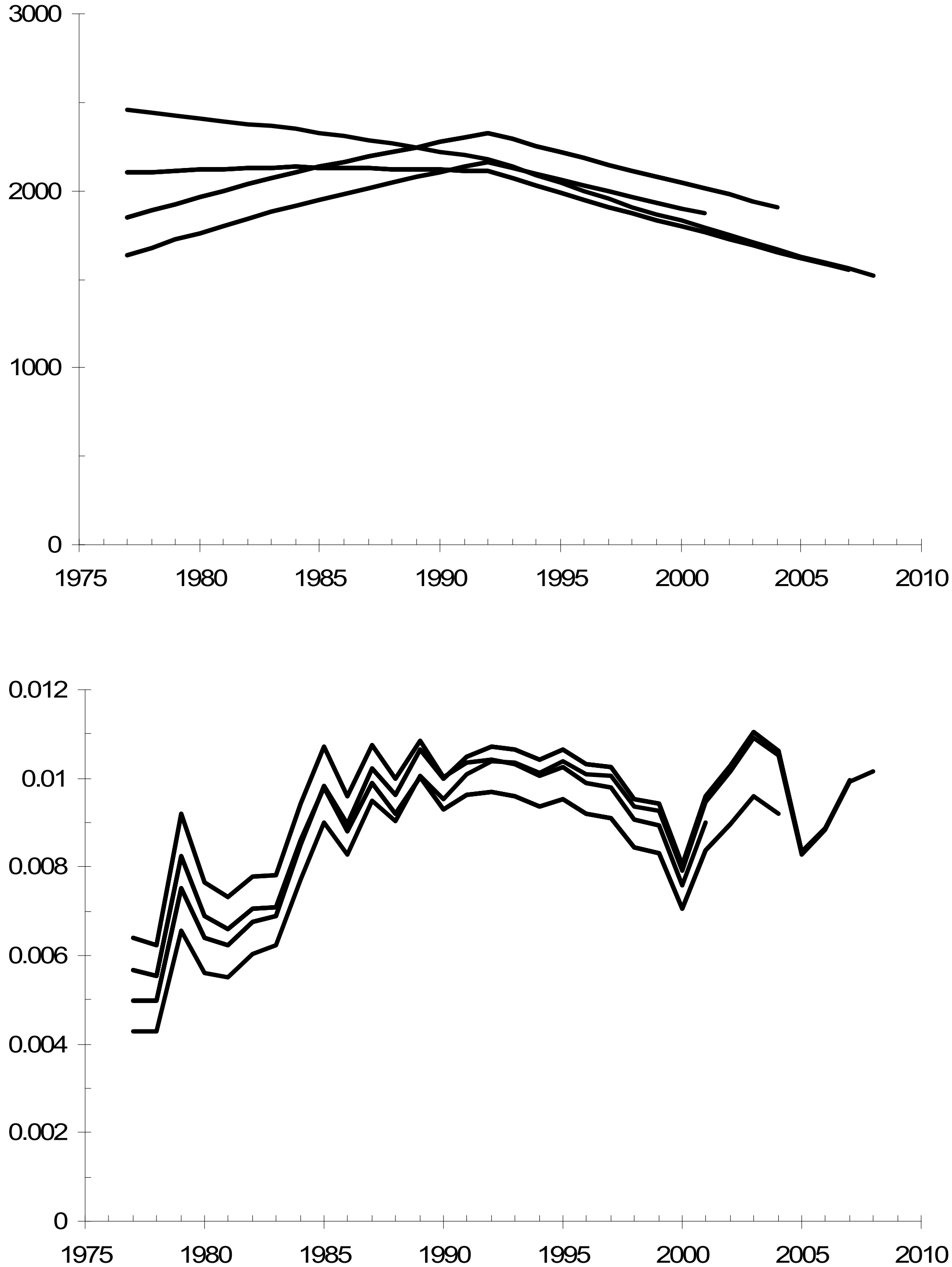


Figure B71. Retrospective analysis with the KLAMZ model for ocean quahogs in the exploited region with 2000-2008 as the terminal year. Results for some terminal years are not visible because the estimates were exactly the same as in an adjacent run (estimates may not change unless a year with survey data is omitted).

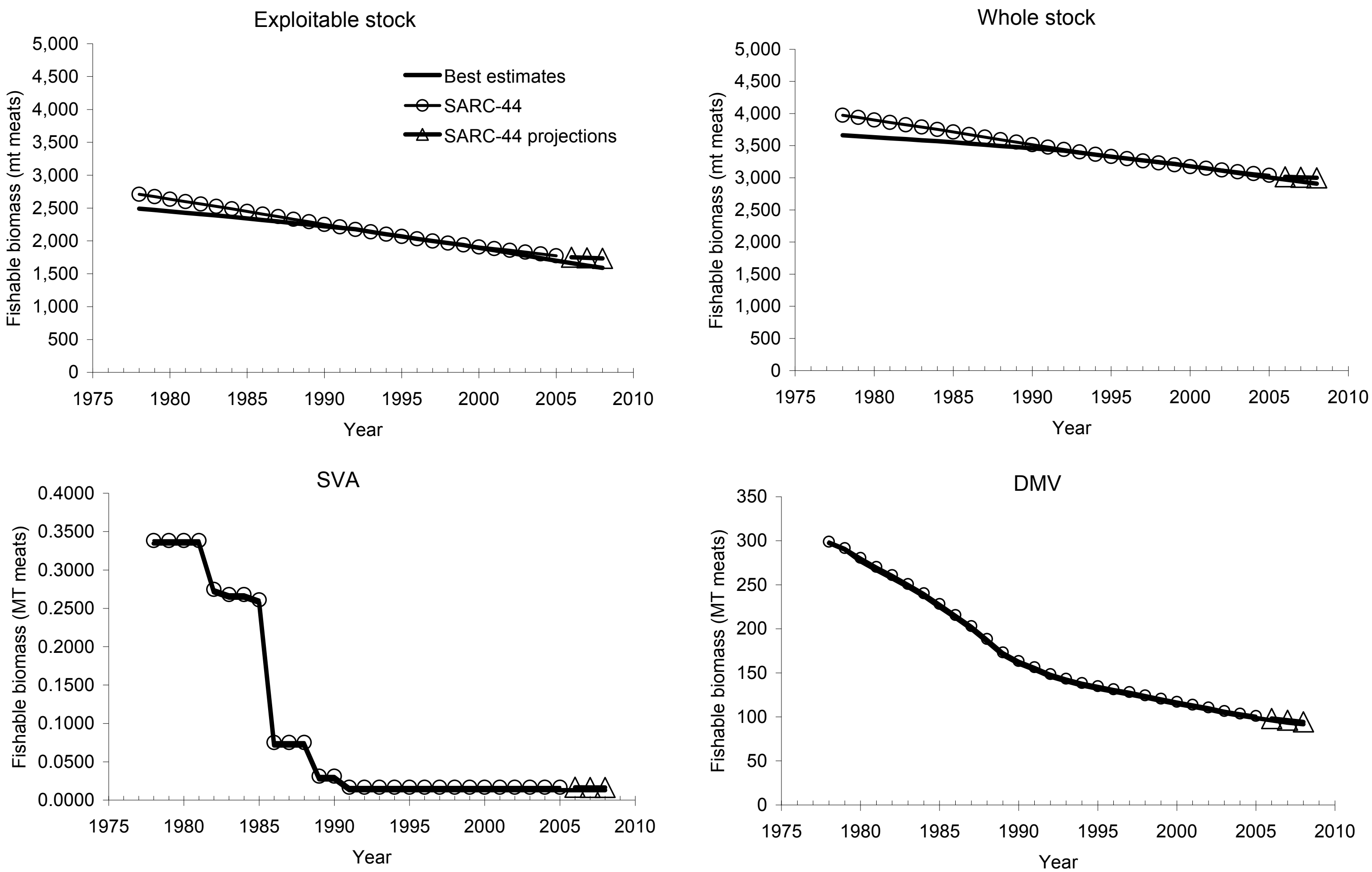


Figure B72. Best biomass estimates for ocean quahogs during 1978-2008, with estimates for 1978-2005 and projections for 2006-2008 from the last assessment (NEFSC 2007a). The report for the previous assessment did not include projections with status-quo catches so the projections for 2006-2008 were rerun starting from the 2005 biomass estimate in the previous assessment and using actual catches during 2006-2008.

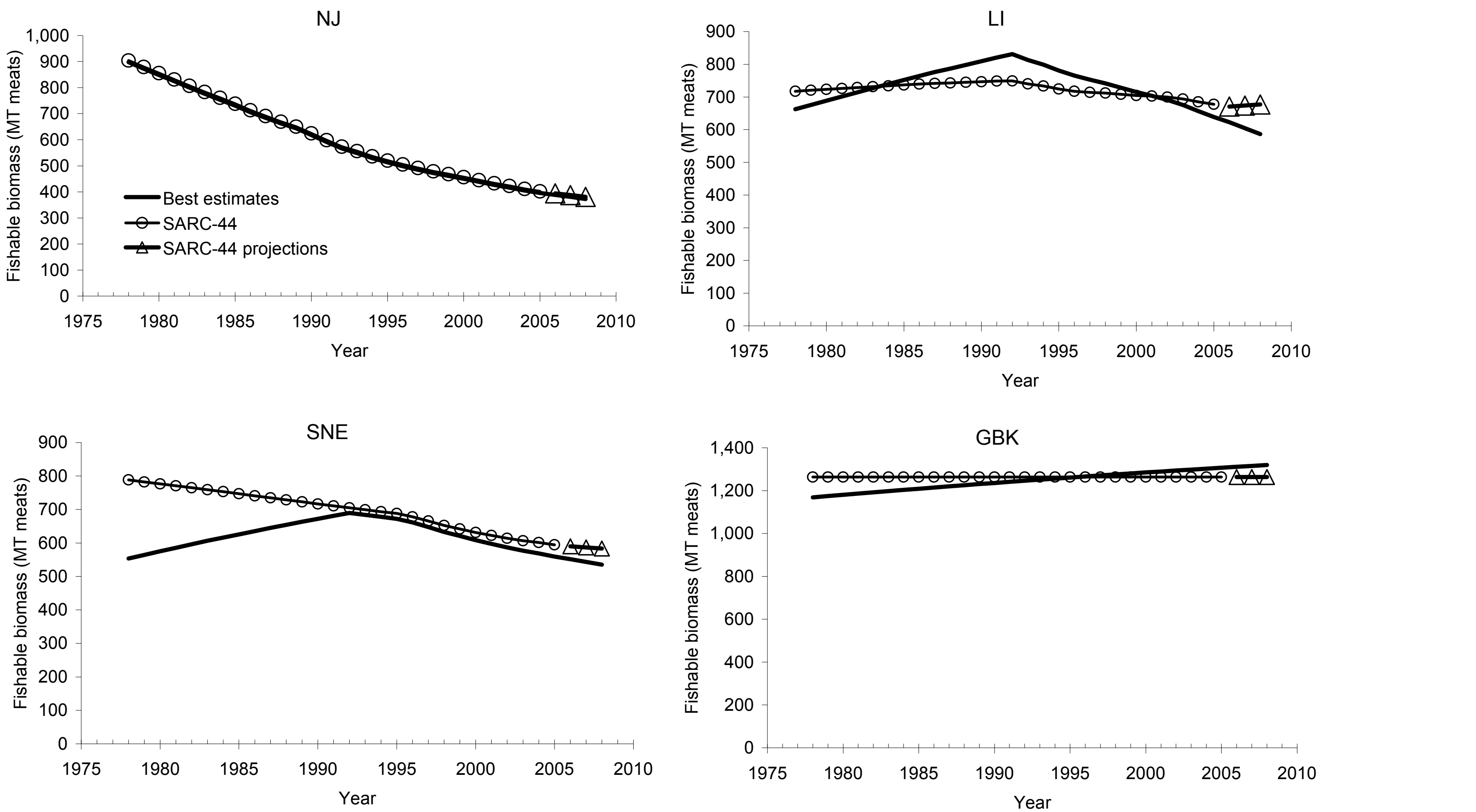


Figure B72. (cont.)

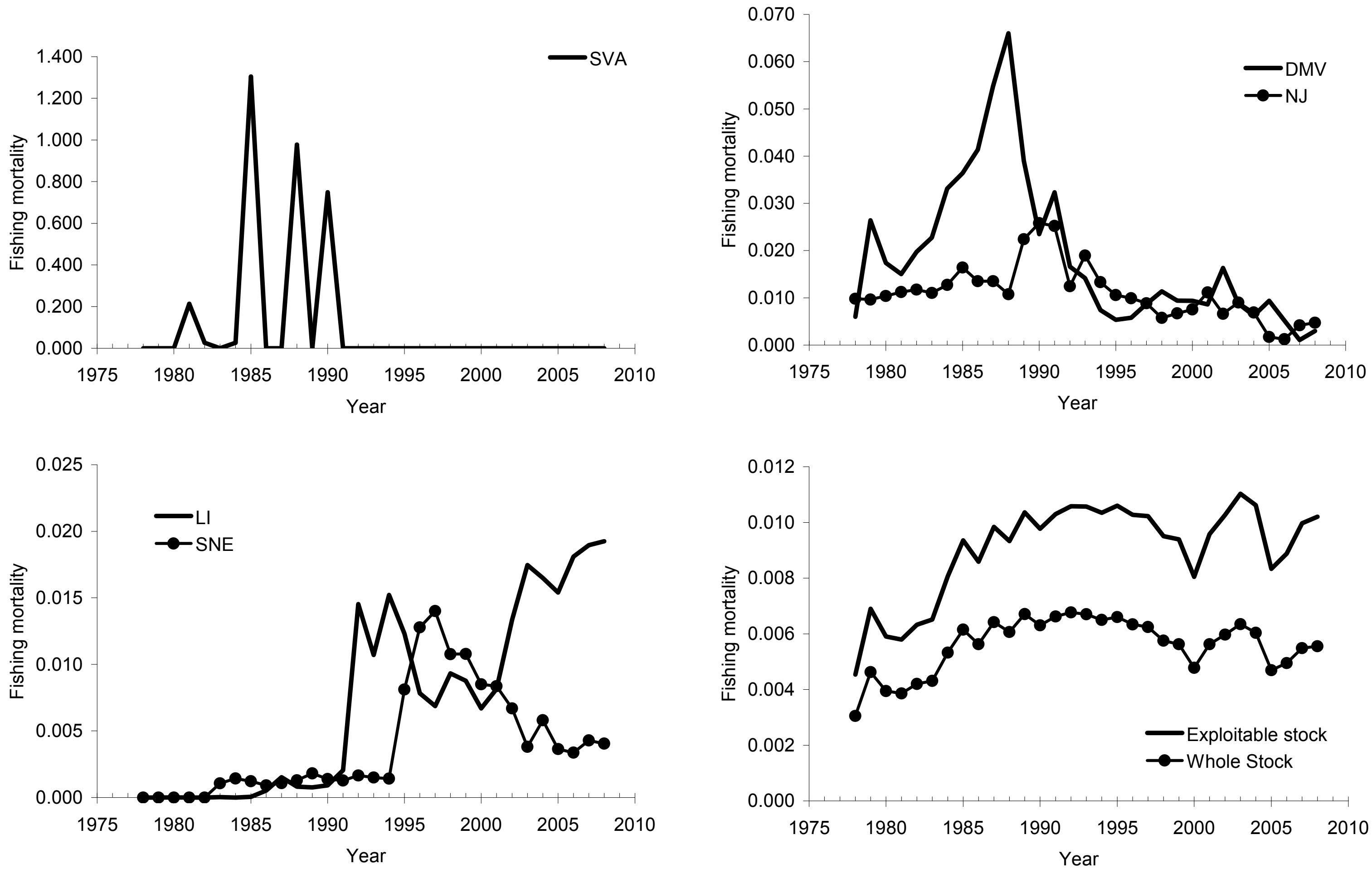


Figure B73. Best estimates of fishing mortality for ocean quahogs during 1978-2008.

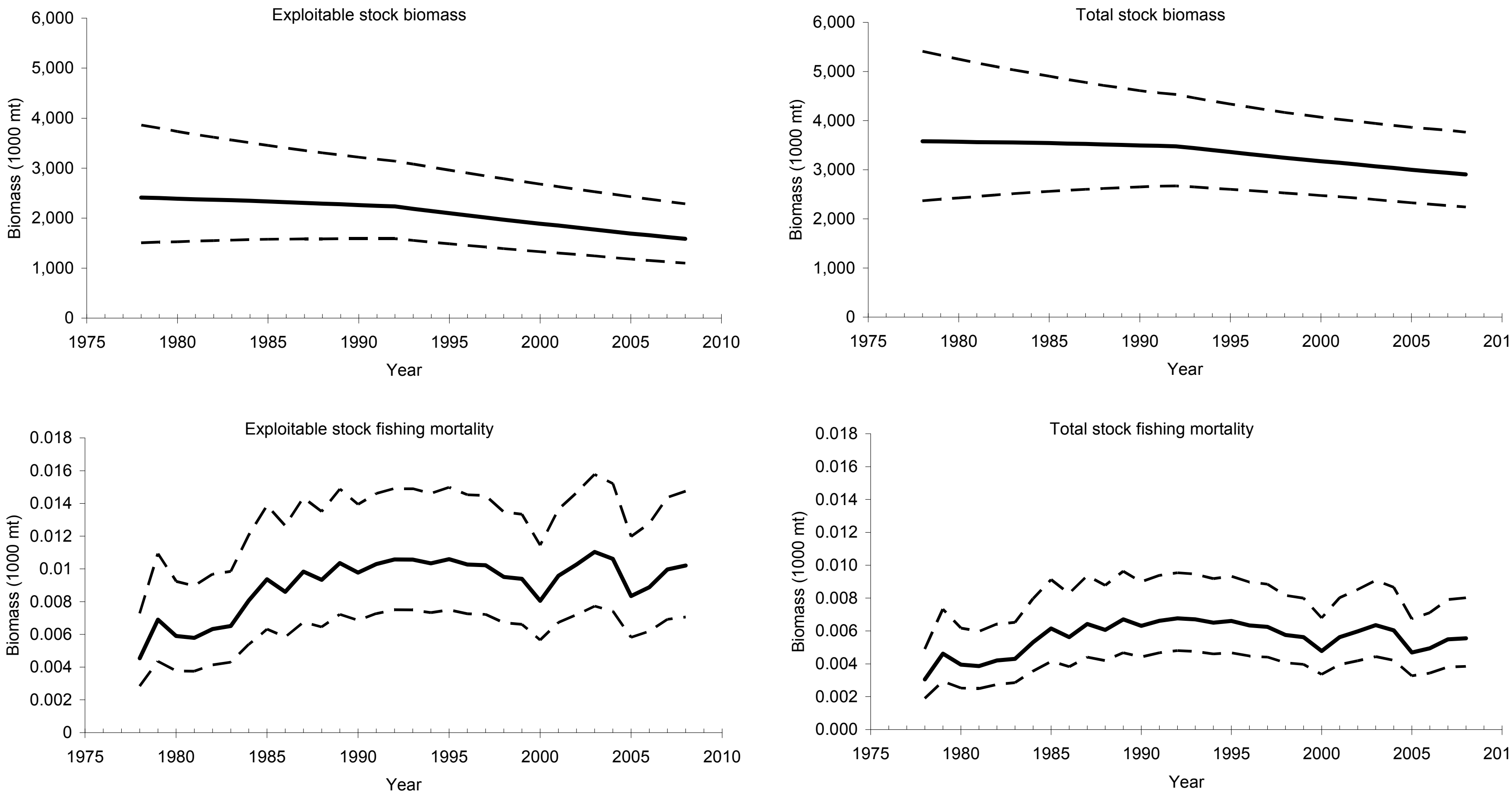


Figure B74. Approximate asymmetric 95% confidence intervals for best biomass and fishing mortality estimates for ocean quahogs in the exploited and total stock regions.

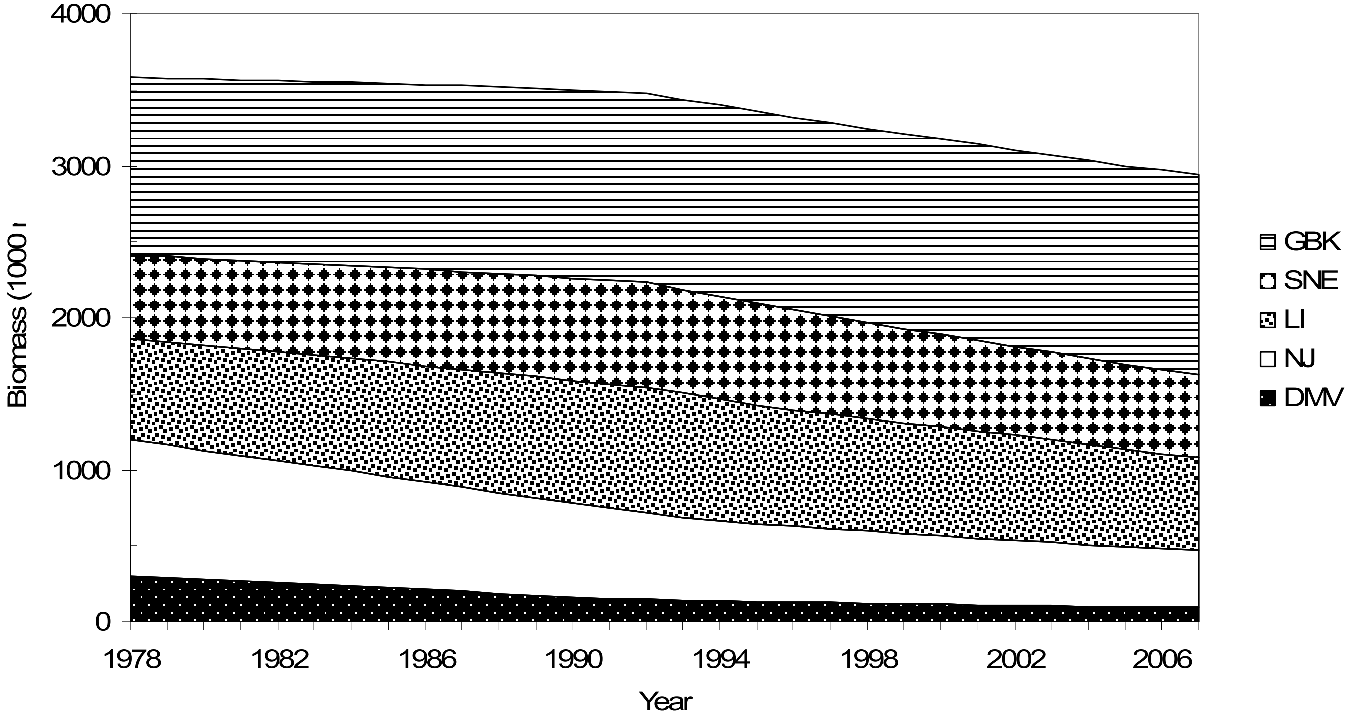


Figure B75. Trends in ocean quahog biomass during 1978-2008, by region based on best estimates. SVA is excluded because biomass is negligible there.

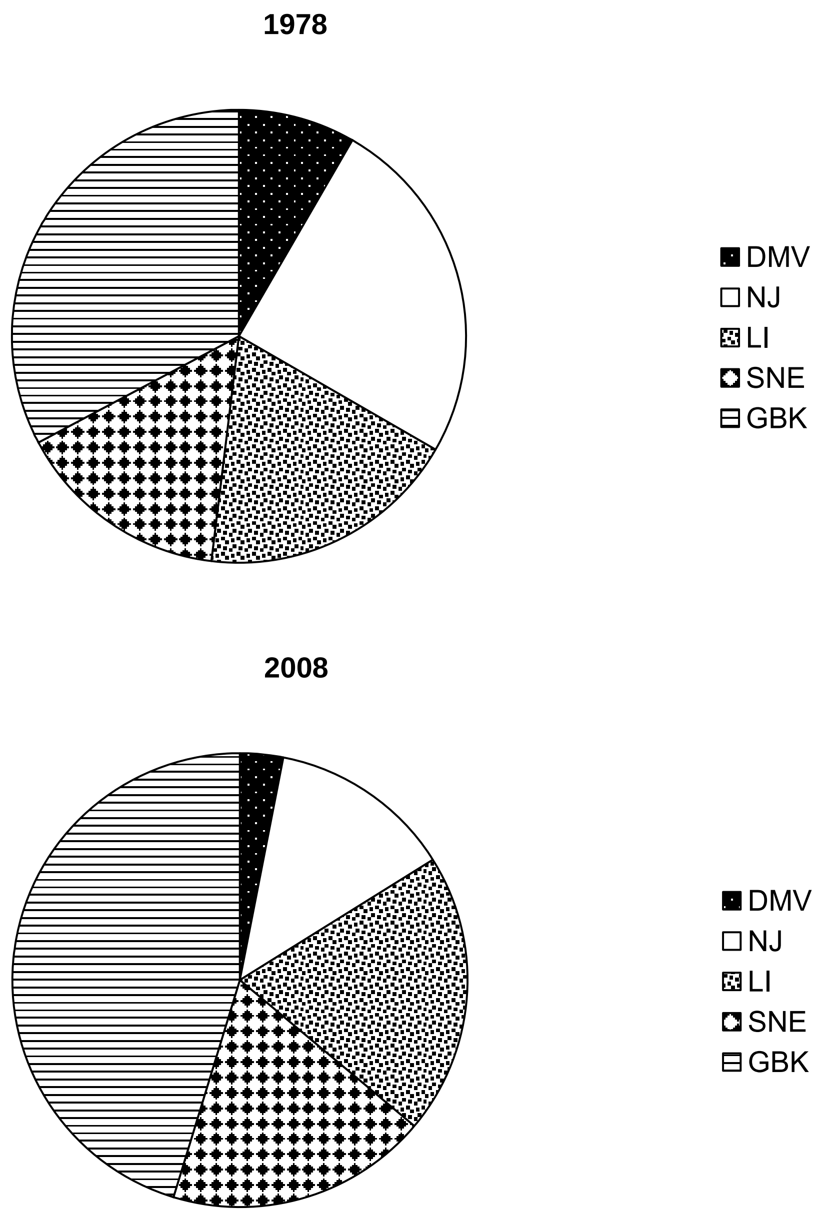


Figure B76. Proportion of ocean quahog biomass by region during 1978 and 2008, based on best estimates. SVA is excluded because it contains negligible biomass.

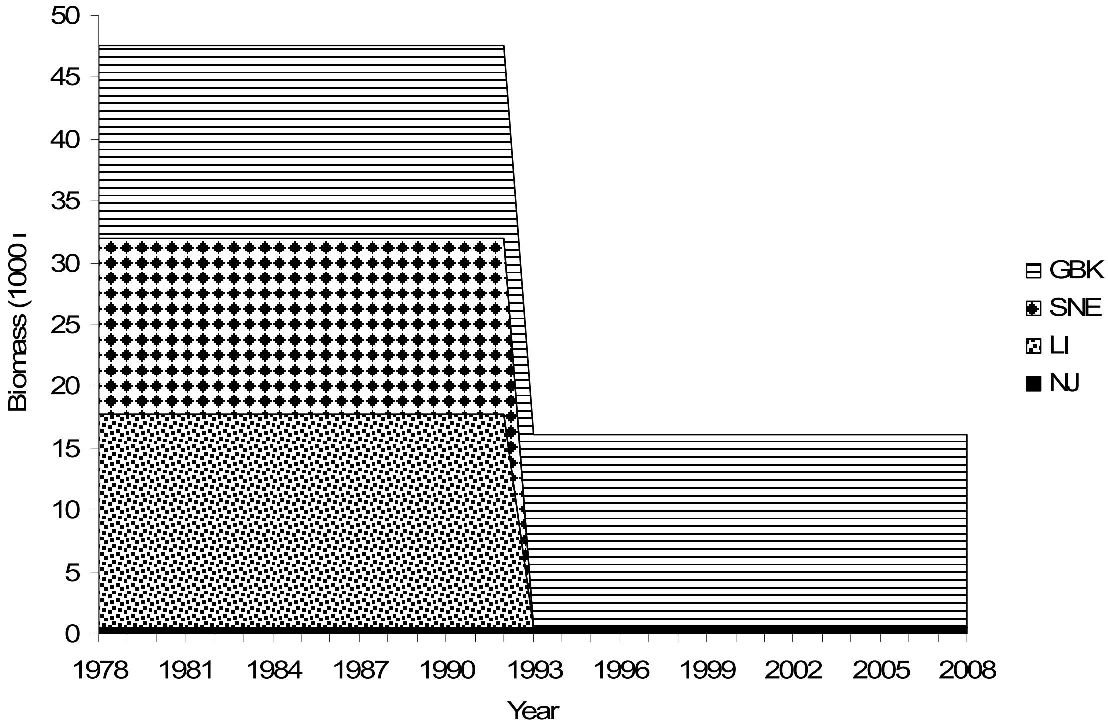


Figure B77. Estimated ocean quahog recruitment during 1978-2008, based on best regional models. Recruitment trends follow a stair step pattern because KLAMZ models for SNE and LI assumed two periods of constant recruitment with changes in level after 1992. SVA and DMV are not shown because recruitment is negligible there.

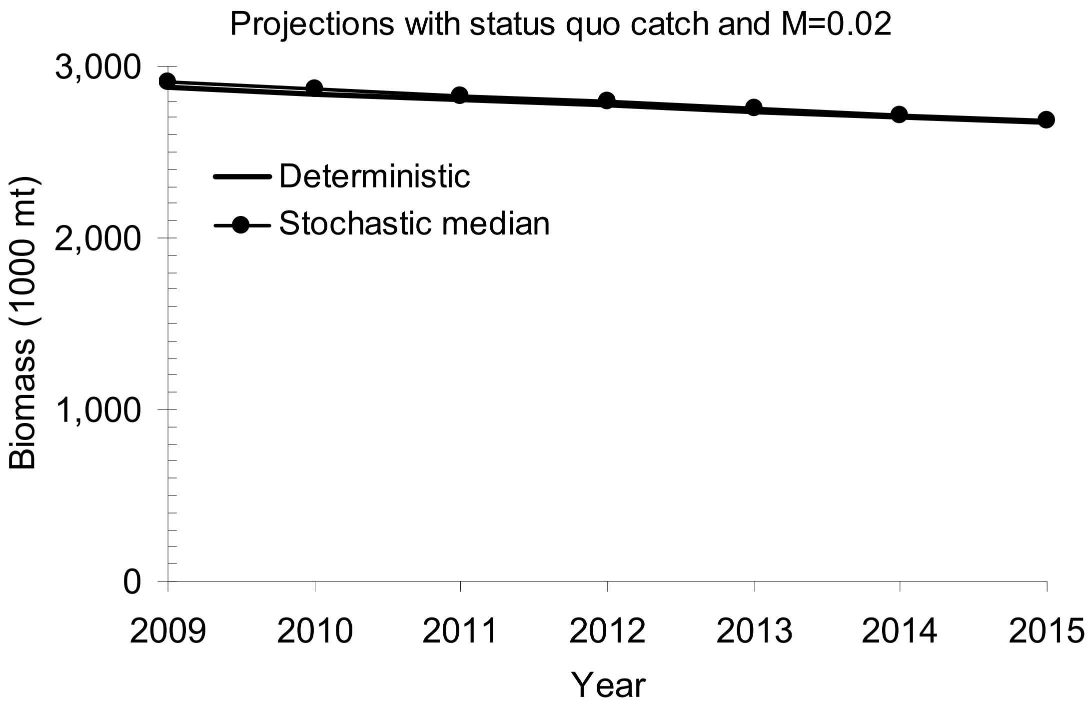


Figure B78. Deterministic and median stochastic projected biomass with M=0.02 and the determinist projection starting at the best estimates for 2008.

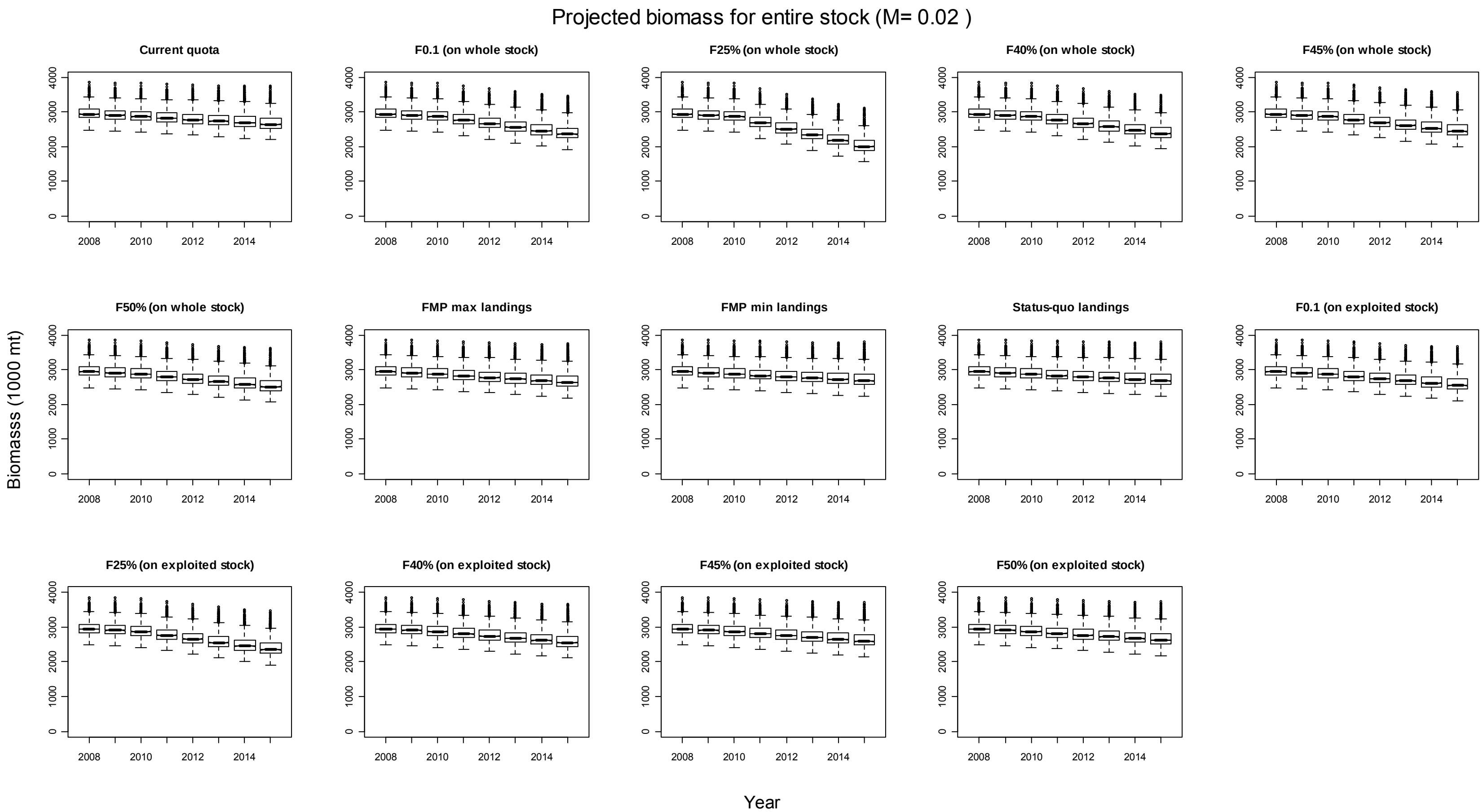


Figure B79. Projected estimates of whole stock biomass for ocean quahogs during 2010-2015 under various harvest policies assuming the true state of nature is *M*=0.02.

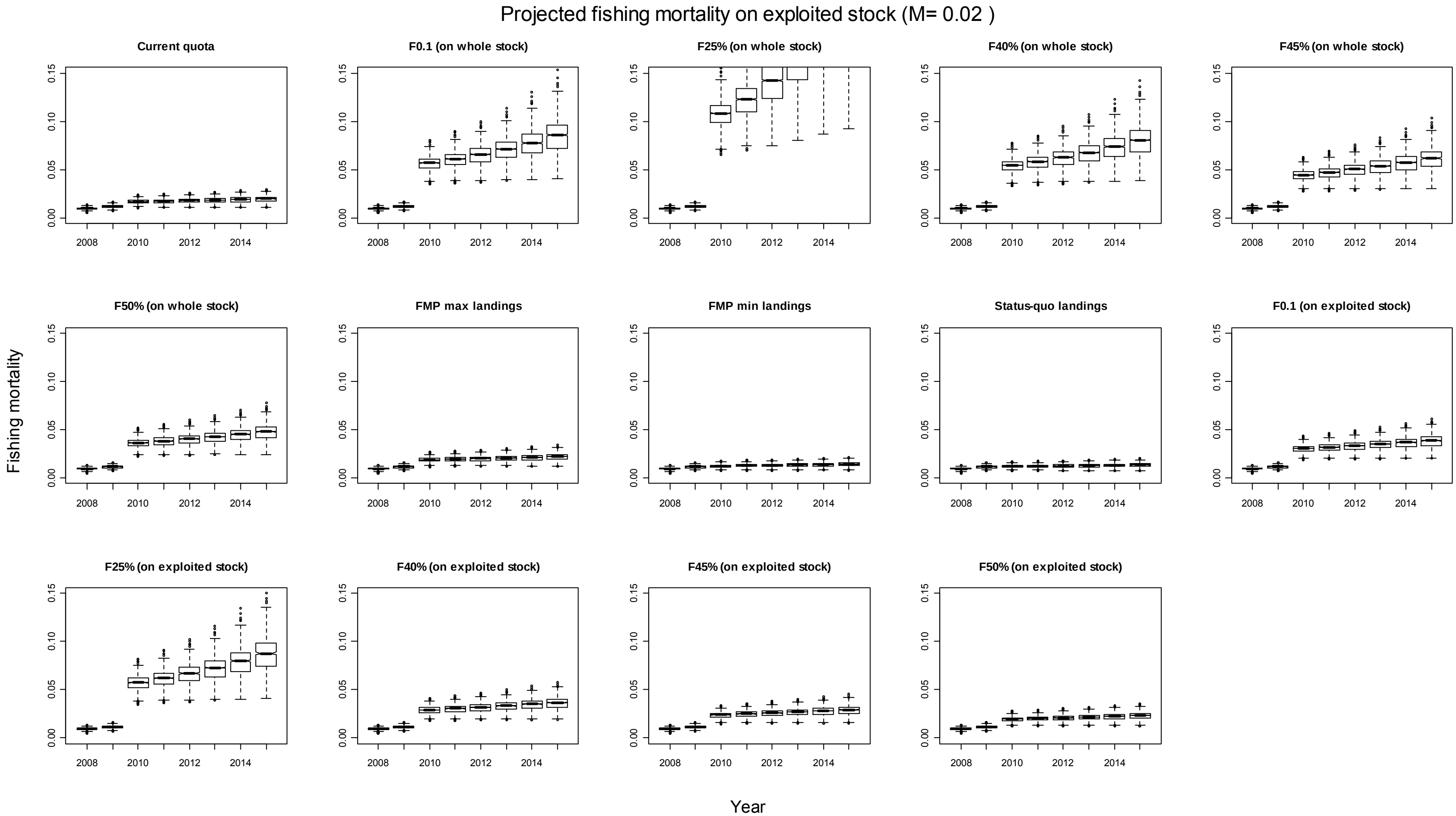


Figure B80. Projected estimates of fishing mortality for ocean quahogs in the exploited region during 2010-2015 under various harvest policies and assuming the true state of nature is *M*=0.02

APPENDIX B1: List of invertebrate working group participants:

Larry Jacobson, NEFSC
Paul Rago, NEFSC
Dvora Hart, NEFSC
Toni Chute, NEFSC
Ralph Mayo, NEFSC
Jiashen Tang, NEFSC
Eric Powell, Haskin Shellfish Research Laboratory
Roger Mann, Virginia Institute of Marine Science
Dave Wallace, Wallace and Associates, Ltd.
Tom Alspach, Sea Watch International
John Womack, Wallace and Associates, Ltd.
Tom Hoff, MAFMC
Robert Russell, Maine DMF
Ed Houde, Chesapeake Biological Laboratory
Bonnie McCay, Rutgers University

APPENDIX B2: Report on the ocean quahog resource in Maine waters.

2009 Maine Ocean Quahog Assessment

Introduction

The Maine fishery for Ocean quahogs, although harvesting the same species (*Artica islandica*), is persecuted in a different way and fills a different sector of the shellfish market than the rest of the EEZ fishery. The Maine "mahogany" quahog is harvested at a smaller size (38-64 mm or 1.5-2.5 in shell length, SL) than elsewhere in the EEZ fishery where ocean quahogs are harvested at 89-140 mm (3.5-5.5 in) SL.

Ocean quahog from Maine waters are marketed as a less expensive alternative for *Mercenaria mercenaria* (Maine DMR 2003). Harvesting takes place year round with the highest market demand during the summer holidays (Memorial Day through Labor Day). During this peak harvest period 20-30 out of a total of 57 license holders may land some volume of product.

The majority of the vessels in the Maine fleet is between 10.7-13.7 m (35-45 ft) and classified as "under-tonnage" or "small" in issuing permits. All of the vessels use a "dry" dredge (with no hydraulic jets to loosen the sediments) with a cutter bar set by regulation at no more than 0.91 m (36 in). There are no restrictions on any other dimension of the dredge.

Quahog Fishing in Maine takes place in relatively few locations along the coast north of 43 degree 50 minute latitude. Historically the bulk of fishing activity has taken place between Mt. Desert Rock and Cross Island with two significant quahog beds south of Addison and Great Wass Island covering an area of approximately 60 square nautical miles.

The Maine fishery began to expand into Federal waters in the 1980's due in part to PSP closures within state waters. In 1990 it was determined that this fishing activity conflicted with the Magnuson-Stevens Fishery Management Conservation Act which calls for a stock to be managed as a unit throughout its range. The Maine fishery was granted "experimental" status from 1990-1997.

In 1998, the Maine fishery was fully incorporated under Amendment 10 of the FMP and given an initial annual quota of 100,000 bushels based on historical landings data. There was no independent assessment of the resource available at that time. The State of Maine is responsible under Amendment 10 to certify harvest areas free of PSP and to conduct stock assessments.

In 2002 the State of Maine conducted a pilot survey to assess the distribution and abundance of quahogs along the Maine coast. This survey was a critical first step in establishing distribution, size composition and relative abundance information for the Maine fishery and for directing the design of the current survey work. While this initial survey provided valuable information it did not have the resources to estimate dredge efficiency and therefore was not able to estimate total biomass or biological reference points. The survey conducted in 2005 was focused on estimating dredge efficiency and to map quahog density on the commercial fishing grounds.

Estimates of biomass and mortality presented in this report are only for the commercial beds south of Addison and Jonesport/Great Wass Maine. This approach was chosen due to available resources and because it was conservative. Other quahog beds are known to exist along many parts of the Maine coast. If mortality targets could be met using the estimates from the primary fishing grounds then biomass outside the survey area can act as a *de facto* preserve.

Fishery Data

Data through out this report is presented in metric units. In some cases there are specialized terms and conversion factors which are listed below.

"Mid Atlantic" bushels of Ocean Quahogs x 10	=	lbs meat.
"Mid Atlantic" bushels of ocean quahogs x 4.5359	=	kg meat
1 "Mid Atlantic" (= "industry") bushel	=	1.88cubic feet
1 "Maine" (= "US Standard") bushel	=	1.2448 cubic feet
"Under-tonnage" vessel	=	1-4.9 GRT
"Small" vessel	=	5-49.9 GRT
1 "Maine" bushel	=	0.00303 metric tons meat weight

There are 57 ocean quahog licenses in the state of Maine. Since 2004 the number of licenses reporting landings has declined from 36 to 24.

Landings have trended downwards since 2002 (Table 1). The exception to this trend is in 2006 when landings increased to 124,839 bushels. This increase is most likely due to the reopening of a highly productive portion of the fishing grounds that had been closed in previous years from PSP. After the initial boost to landings from additional fishing ground, landings again began to decline. By the end of 2008 only 67,698 bushels out of a 100,000 bushel quota had been landed. LPUE has tracked landings closely over recent years. For 2008 LPUE was at a level 6.21 bushels/hour (Figure 1).

Incidental mortality in the ocean quahog stock off Maine is an important topic for future research. Maine has a very high level of fishing activity relative to the size of the fleet. Approximately 10,776 hours of fishing took place during 2008 representing over 64,000 tows at 10 min per tow. Using standard industry dredge dimensions and tow speeds this level of fishing activity represents 31.42 nautical miles^2 of bottom swept by commercial dredges.

Research Surveys

With the limited funds dedicated for survey work on quahogs, it was decided to focus all of the survey efforts in 2005, 2006 and 2008 on the primary commercial fishing grounds south of Addison and Great Wass Is. This decision is important in the interpretation of all following data as results because estimates pertain only to these two beds and not to the coast of Maine as a whole. Vessel logbooks and the 2002 independent survey abundance indices show that the majority of fishing activity and a sizable portion of the resource was in this region (Figure 2).

The first step in designing the 2005 survey was to establish a 1 km^2 grid overlay using Arcveiw 3.2 over the known commercial beds. Based on number of days at sea, 260 sites (tows) could be completed. The centers of the 260 1 km^2 grids covering the commercial beds were selected as start points for survey tows. These points were transferred to The Cap'n Voyager Software for use on board the survey vessel.

As of 2005 the quahog bed south of Addison, (referred to as "western") had been the only open fishing grounds for 3 years due to PSP issues in other beds. The quahog bed south of Great Wass Island, (referred to as "eastern") had been unfished for 3 years but had previously been one of the most productive fishing grounds. The 2006 survey took place 9 months after the "eastern" bed had been reopened. All areas were open during the 2008 survey.

Survey gear and procedures

The original survey in 2005 was conducted using the commercial vessel F/V Promise Land. It was a 12.8 m (42 ft) Novi Style dragger piloted by Capt. Michael Danforth and was contracted to perform all the survey drag operations in 2005 and 2006. All survey tows during these two years were conducted using the same dredge with dimensions: cutter bar 0.91 m (36 in), 2.44 m (8 ft) long x 1.83 m (6 ft) wide x 1.22 m (4 ft) high, overall weight 1,361 kg (3,000 lbs), bar spacing all grills 19.05 mm (¾ in). The survey dredge was the same dredge used by the F/V Promise Land during normal fishing activity. Prior to the 2008 survey The F/V Promise Land was sold and the captain left the fishery. To conduct the survey we had to contract a new vessel and captain which also meant the drag used was different than the two previous surveys. The new vessel, The F/V Allyson J4, had nearly identical specifications to the F/V Promise Land. Captain of the F/V Allyson J4, Bruce Porter, has been a quahog fisherman for 24 years. The dredge used for the 2008 survey had been built to nearly the same specifications as the original with the difference that the catch box on the original had extensions added to allow it to hold more sediment during longer commercial tows (Figure 3). These extensions meant the original dredge was roughly 400lbs heavier than the current dredge. During tow operations it was noted that the teeth on the cutter bar of the new dredge shined to depth of 3 inches just as they had in the original dredge. From this we assumed that the new dredge was cutting to the same depth as the original. It was also felt that since the survey tows were short (2 min) in order to avoid any overfilling and subsequent material loss that the additional catch box capacity of the original dredge would not give it any advantage over the current dredge.

For the initial survey in 2005 as the vessel approached the center of one of the 260 selected tow grids, bottom type and the feasibility of conducting a tow were assessed. If suitable bottom was not immediately present at the predetermined start point, the vessel would start crossing runs within the grid. If after 5 to 6 crosses no towable bottom or a tow path free of fixed lobster gear could not be found, then the grid location was deemed untowable, a note was made, and the captain continued on to the next site. When a suitable tow path was found within a grid the dredge was lowered to the bottom by free-spooling until the ratio of cable length to depth was 3:1. Once the desired cable length was reached the drum was locked, a two minute timer was started and a GPS point was taken.

Tows were made into the current at approximately 6.48 km/hr (3.5 knots) speed over ground (average tow 188 m). After two minutes elapsed, a second GPS point was taken and the dredge was brought to the surface.

Tow distances calculated using the start and stop GPS points are good estimates of the distance actually traveled by the dredge. The manner in which the dredge is set and retrieved does not create a situation in which the dredge continues to fish as it is retrieved or before the drum is locked. In particular, the weight of the dredge keeps it in place on the bottom when the drum is unlocked at the end of the tow. In addition, the practice of backing the vessel toward the stopping point at the end of each tow means that the dredge was unlikely to travel very far at the end of the tow as it is lifted into the water column.

After the dredge was retrieved and before it was brought onboard the vessel, excess mud was cleaned from the dredge by steaming in tight circles with the dredge in the vessel's prop wash (Figure 4). Once on board, the dredge was emptied and photographed with a digital camera (Figure 5). The contents were placed on a shaker table (Figure 6), bycatch was noted and then all live quahogs were sorted out from the catch. From each tow a 5 L subsample of quahogs was taken at random (the entire catch was taken if catch was less than 5 L). The subsample was used to estimate tow counts, volume, and size frequency of the catch. The remainder of the catch was placed in calibrated buckets to determine total catch volume.

All data collected on board during operations were entered into a Juniper Systems handheld Allegro field computer running Data Plus Professional Software. All GPS data were collected using a pair of Garmin Etrex handheld units and transmitted in real time to the Allegro and a laptop running Cap'n Voyager Software. Data entry screens on the Allegro for the abundance survey consisted of: 1) trip information (date, time out, weather, sea state, time in, and comments); 2) site information (depth, bottom type, start tow GPS position, speed, end tow GPS position, and comments); 3) catch information (sample portion 5 L or all, volume, weight, count, photo id, size frequency 5 L or all, and comments); and 4) bycatch information (species, abundance).

The lengths (longest dimension) of all subsampled quahogs were measured to the nearest 0.01 mm and entered into the Allegro handheld using a Fowler Ultra-Cal IV digital caliper with an RS232 port. Estimated counts of quahogs were made by counting the number of clams in the 5 L sample and then expanding that value using the total volume of the catch. All data were analyzed using Excel with variances calculated using a bootstrap program (10,000 iterations) written by Dr. Yong Chen at the University of Maine, Orono.

Tow distances were determined by The Cap'n Software and were checked using ESRI ArcInfo software. All data from the tows were standardized to a 200 m tow prior to further analysis. For the 2006 and 2008 surveys only the 183 stations deemed towable during the initial survey were revisited. Due to vessel availability the 2006 survey needed to be conducted in the fall when there is a large amount of fixed lobster gear in the tow area. As a consequence only 130 tows could be completed.

Dredge efficiency

The Maine dry dredge is much less efficient (2-17%, ME DMR 2003) than hydraulic dredges used in the rest of the EEZ which can be up to 95% efficient (Medcolf and Caddy, 1971). A reliable estimate of dredge efficiency is needed to convert survey densities to a biomass estimate (NEFSC 2004).

One method of estimating dredge efficiency is through depletion experiments which are used to measure survey dredge efficiency for NEFSC clam surveys in Federal waters. Depletion studies for ocean quahog involve sensor and data processing equipment that were not readily available in

2005. The dry dredge used in the Maine survey is also relatively small compared to the depth of fishing. We hypothesized that it would be difficult to control the dredge precisely given the depth, size of dredge and strong currents in this region off Maine.

For the conditions off Maine is was determined that the best approach to estimating dredge efficiency would be through the use of box core samples (to directly estimate quahog density) followed by survey tows in the same area. Considering only ocean quahogs available to the fishery, the ratio of density measured by "follow on" dredge tows divided by boxcore density is an estimate of survey dredge efficiency (Thorarinsdottir and Jacobson 2005).

The *F/V Promise Land* with its large A frame and winches was able to deploy the 544 kg (1,200 lb) Ocean Instruments 610 box core with a core capacity of 0.062 m^2 and maximum penetration up to 60 cm (Figure 7). Follow on tows were conducted using the same gear used during all previous portions of the survey.

Box core work was conducted at three locations during three separate trips, one in August of 2005, one in January of 2006 and the last in April 2006. In all three experiments, follow on survey tows were made the day after the cores had been taken. The locations sampled were in the eastern quahog bed in an area of relatively high abundance. This area was also selected because it was a closed fishing ground during the August 2005 trip which would eliminate the possibility of the box core sites being commercially towed before follow on tows could be made. In January and April 2006 the region had been reopened to commercial fishing. However, VHF radio announcements describing the type of work underway were broadcast to local fisherman who were very cooperative and stayed well away from the experimental areas until all follow on tows could be completed the next day. Data entered into the Juniper Systems Allegro field computer included information about: 1) the trip (date, start tow, end tow), core (core #, core length, count, volume, weight, count of newly settled).

Each experiment began by establishing a single long towpath. To do this, the vessel was slowed to the standard tow speed of 3.5 kts and a GPS point was taken and plotted. After 2 min steaming along a fixed heading, a second GPS point was taken and plotted. These waypoints determined the endpoints for the follow on commercial tows and the path for boxcore sampling. Cores were then taken haphazardly along the tow path (60 for the August 2005 trip, 34 on the January 2006 trip and 30 on the April 2006 trip).

Once a core was brought on board it was measured for overall length and sieved through a large screen (1cm^2 mesh size). All quahogs were counted and their total volume and weight were measured.

During coring operations, it was noted that the upper 1-2 cm of very soft sediment contained recently settled quahogs (< 5mm length). The number of quahogs in this size range were recorded separately for all further cores and newly settled quahogs were retained to be preserved. During the January and April 2006 trips the top 5 cm of each core was removed and washed separately through a 300 μ sieve and all quahogs <5mm SL were preserved.

It was noted during boxcore sampling during the August 2005 boxcore trip that there was a change in sediment type beginning around 12-15 cm from the surface of each core. At this transition the sediment turned to a matrix of solid clay and old quahog shell. None of the live quahogs found in the cores in 2005 were below this transition. To assess this, the maximum depth within the core of live quahogs was measured during the 2006 trips.

After the maximum number of cores had been completed for a given trip the commercial dredge was deployed at one of the endpoints of the established tow path. Standard commercial towing was conducted for 2 min along the same path as the cores had been taken allowing the dredge to tow from one endpoint to the next. After each round of coring, 6 tows were made along the same path, three in one direction and 3 opposing to help mitigate any effect from tide.

Dredge survey results

The original 2005 survey visited 259 potential tow grids. Out of the 259 there were 183 (121 in the western bed and 62 in the eastern bed) or 70.7% that were towable. Only two stations were untowable due to fixed lobster gear or other known obstructions. The remainder of the untowable sites were due to inappropriate substrate.

Tow distance, catch volume and counts were all standardized to a 200m tow. For the 2006 and 2008 surveys only the 183 towable grids were revisited. In 2006 130 of the 183 tows were completed. In 2008 181 of the 183 tows were completed.

For all surveys the highest concentration of biomass was in the eastern bed. The eastern section has had the most variable open and close status due to PSP. Substrate data (Figure 8) from Kelly et al. (1998) show the complexity of the substrate in the eastern section with highest quahog densities found near the boundary of hard rocky substrate with gravels, sands or mud. Substrate data collected independently using sidescan imaging showed that Kelly et al.'s (1998) substrate information was relatively accurate. However, in some cases substrate labeled as "sand" or "gravel-sand mix" near our most productive tows may have been shell hash from old quahog beds that was seen in box cores from the same area.

Size frequencies for all subsampled quahogs (n=20,737 in 2005, n=2,014 in 2006 and n=4,055 in 2008) Show a difference in size structure between the western and eastern beds. The quahogs in the eastern bed were larger (mean SL of 56mm $\pm$ 5for 2008) than the western bed (mean SL 52mm $\pm$ 4.9 for 2008). Cumulative size frequency distributions and a Kolmogorov-Smirnov test were used to test the null hypothesis that the size frequency distributions in the eastern and western areas were the same (Zar 1999). The null hypothesis was rejected (p=0.001). It should also be noted that in the 3 years since the initial survey the mean size for both western and eastern beds has increased by 5.03mm and 4.45mm respectively(Figure 9). Given the growth data available for this stock these size increases should take between 8 and 14 years. This may suggest that harvesting in Maine which targets smaller sizes may be altering the stock towards a larger and older quahog.

Because the two beds have differing size compositions and abundance levels, it was decided to calculate abundance for the two beds separately before estimating combined abundance for the entire survey area. Abundance estimates (see below) include a dredge efficiency that was estimated by applying 10,000 bootstrapped efficiency estimates from the three boxcore trips to 10,000 average abundance estimates from the surveys.

To estimate the total biomass in each year for the commercial fishing grounds the size frequency distributions were converted to proportion of the population in each 1 mm size bin. Shell length (*L*) was converted to meat wet weight (*W*) using W=4.97x10-6 x $L^{3.5696}$ (Maine DMR 2003).

year	bed	Median Abundance Estimate	Median mt Meat Weight	CV
2005	west	1.729E+09	8,653	39%
	east	2.404E+09	17,208	40%
	combined	4.134E+09	25,862	39%

2006	west	1.996E+09	10,166	41%
	east	1.225E+09	8,846	41%
	combined	3.221E+09	19,012	41%
2008	west	7.111E+08	5,471	40%
	east	1.094E+09	11,103	41%
	combined	1.805E+09	16,574	40%

Box core results

Efficiency estimates from box core experiments are presented based on sizes taken in the commercial fishery (35mm SL and greater). The estimated dredge efficiency was 17.91% with a 95% bootstrap confidence interval of 8.0%-34.4%.

Another important result from the boxcore work was that the average depth of live quahogs in the region sampled was no deeper than 9.55 cm (CV 20%). The standard commercial dry dredge has cutting teeth that are set to a depth of 7.62cm. We did not see evidence of anaerobic quahogs located deep in the sediments as has been reported elsewhere (Chenowith and Dennison,1993; Taylor 1976). Based on these results, it would seem that the majority of quahogs in this region would be impacted after one pass of a dredge.

Per recruit modeling

Biological and fishery parameters from a variety of sources were used to carry out a per recruit analysis for ocean quahog in Maine waters. Age at length and growth information was taken from Kraus et al. (1992). Von Bertalanffy growth parameters estimated from a sample of 663 quahogs from Machias Bay were: $L_{inf} = 59.470 \pm 2.089$, $K = 0.055 \pm 0.006$, and $t_o = -0.235 \pm 0.483$. The growth curve from Maine shows relatively fast growth the first few years of life in comparison to curves for other areas (Figure 19). Length-weight parameters were from the 2002 Maine Quahog survey: $W = 4.97 \times 10^{-6} * L^{3.5696}$. Length-weight curves for the Maine ocean quahogs and the rest of the EEZ stock were similar (Figure 10). Size at maturity data estimates were based on Rowell et al. (1990) who found that females became fully mature at an average size of 49.2mm for a quahog stock in Nova Scotia, Canada.

Fishery selectivity was modeled as a linear ramp function that was zero at 37 mm SL and one at 47mm. Following surveys, quahog of various sizes were pushed through the grates on the commercial dredge (19.05 mm, 3/4 in. bar spacing) to see what sizes might be retained. Clams from 34mm to 38mm generally passed through the grate with some getting caught. After 41mm almost all clams were thick enough to be retained. The regression model for shell depth and shell length in Feindel (2003) shows that a 19.05 mm (¾ in) bar spacing is the thickness of an ocean quahog with 38.7 mm SL.

The per recruit model used in this analysis was a length based approach which can be downloaded from the Northeast Fisheries Science Center as part of the NMFS Stock Assessment Toolbox.[7] The length based per recruit model was also used by Thorarinsdottir and Jacobson (2005). The biological reference points estimated in per recruit modeling for ocean quahog were F_{max} =0.0561, $F_{0.1}$=0.0247 and $F_{50\%}$ =0.013 y^{-1} (Figure 11).

Sensitivity analysis shows biological reference points from the per recruit model for ocean quahog are most sensitive to fishery selectivity parameters and, in particular, the length at which

7 Contact Alan.Seaver@noaa.gov for information about the NMFS Stock Assessment Toolbox.

ocean quahog in Maine waters become fully recruited to the fishery. Commercial port sampling conducted in 2009 confirms the size selectivity estimates used in the modeling (Figure 12).

Fishing mortality rate

For this report fishing mortality is estimated as the catch in biomass/average biomass. The surveys each take place over a period of 1 month, but mortality rates are relatively low so that survey biomass is a good proxy for average biomass. Following NEFSC (2004), the catch for each year used in fishing mortality estimation was landings plus a 5% allowance for incidental mortality to account for clams that are killed during fishing activity but not harvested. Catches for 2005, 2006 and 2008 including the 5% for incidental mortality were 528mt , 642mt and 348 mt of meat weight respectively. Biomass estimates for the same years were 25,862mt, 19,012mt and 16,574mt of meat weight respectively(Table 2). F=0.020 y^{-1} for 2005, F=0.033 y^{-1} for 2006 and F=0.021 y^{-1} for 2008. Thus for 2005 and 2008 F is roughly equal to $F_{0.1}$ but higher than $F_{50\%}$.

Stock Status

It is not necessary to evaluate stock status of ocean quahog in Maine waters because the stock component off Maine is a relatively small part of the EEZ stock as a whole. Ocean quahog biomass in Maine waters represented less than 1% of the biomass for the EEZ stock as a whole during 2005. Overfishing definitions apply to the EEZ stock as a whole.

It was not possible to compare or evaluate current biomass levels relative to biological reference points associated with maximum productivity, depleted stock or historical levels because no appropriate biological reference points or historical biomass estimates are available.

The fishing mortality rates during all three surveys has been almost equal to $F_{0.1}$=0.0247 and the assumed natural mortality rate M=0.02 y^{-1} but almost double $F_{50\%}$ =0.013 y^{-1}. $F_{0.1}$ might be a reasonable reference point for managers if the goal is to maximize yield per recruit while preserving some spawning stock. Simulation analysis (Clark 2002) indicates that $F_{50\%}$ (1.3% per year) might be a reasonable reference point for managers if the goal was to preserve enough spawning potential to maintain the resource in the long term. However, preservation of spawning potential may not be necessary if recruitment originates mostly outside of Maine waters.

There is evidence or recent recruitment (newly settled ocean quahog < 5 mm SL) in one of the beds that were surveyed. However, although growth is relatively rapid in Maine waters, it may be 3 decades or longer before these recruits become large enough to enter the fishery.

Stock assessment advice concerning ocean quahog in Maine waters would be easier to provide if management goals were formulated and if biological reference points for biomass and fishing mortality were defined.

Research Recommendations

1. Impact on habitat and substrate should be investigated for the Maine Dredge along with good estimates of area swept by fishing activity,
2. More work needs to be done to determine age, growth rates and size/age at maturity for Maine ocean quahogs. New digitized methods may help in this process.

Acknowledgements

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the NEFSC Invertebrate (Clam) working group.

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Table 1. Landings from vessel logbooks.

year	Landings (Maine bushels) all vessel classes combined	Landings (only records with both effort and catch>0)	Effort (hrs fished)	Nominal LPUE (ME bushel/hr)
1990	1018	1018	286	3.56
1991	36679	34360	17163	2.00
1992	24839	24519	13469	1.82
1993	17144	17144	5748	2.98
1994	21672	21672	5106	4.24
1995	37912	37912	5747	6.60
1996	47025	47025	8483	5.54
1997	72706	72706	11829	6.15
1998	72466	72152	11745	6.14
1999	93015	92285	11151	8.28
2000	121274	119103	12739	9.35
2001	110272	110272	13511	8.16
2002	147191	147191	19681	7.48
2003	119675	119675	17853	6.70
2004	102187	102187	19022	5.37
2005	100115	100115	17063	5.87
2006	121373	121373	14902	8.14
2007	102006	102006	14018	7.28
2008	66926	66926	10776	6.21

Table 2. Commercial landings from Dealer Logbooks converted to mt meat weight for estimates of *F*.

year	landings from dealer logs (bushels)	metric tons meat landed w/ 5% incidental mortality	*F*
2005	102,671	528	0.020
2006	124,839	642	0.033
2008	67,698	348	0.021

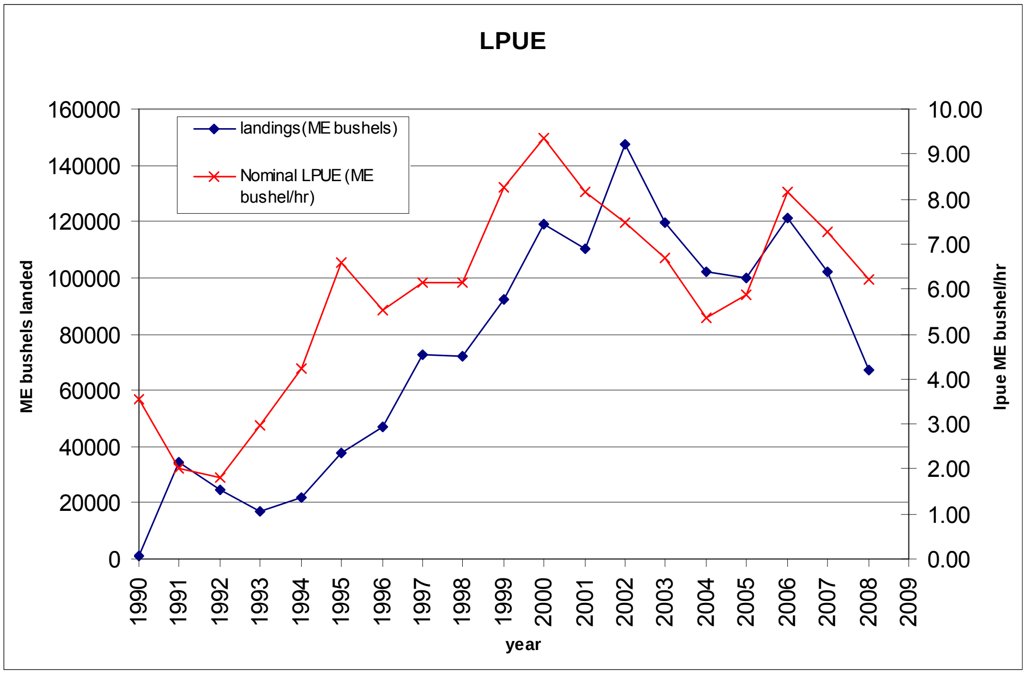

Fig 1. Commercial LPUE and Landings from vessel trip reports.

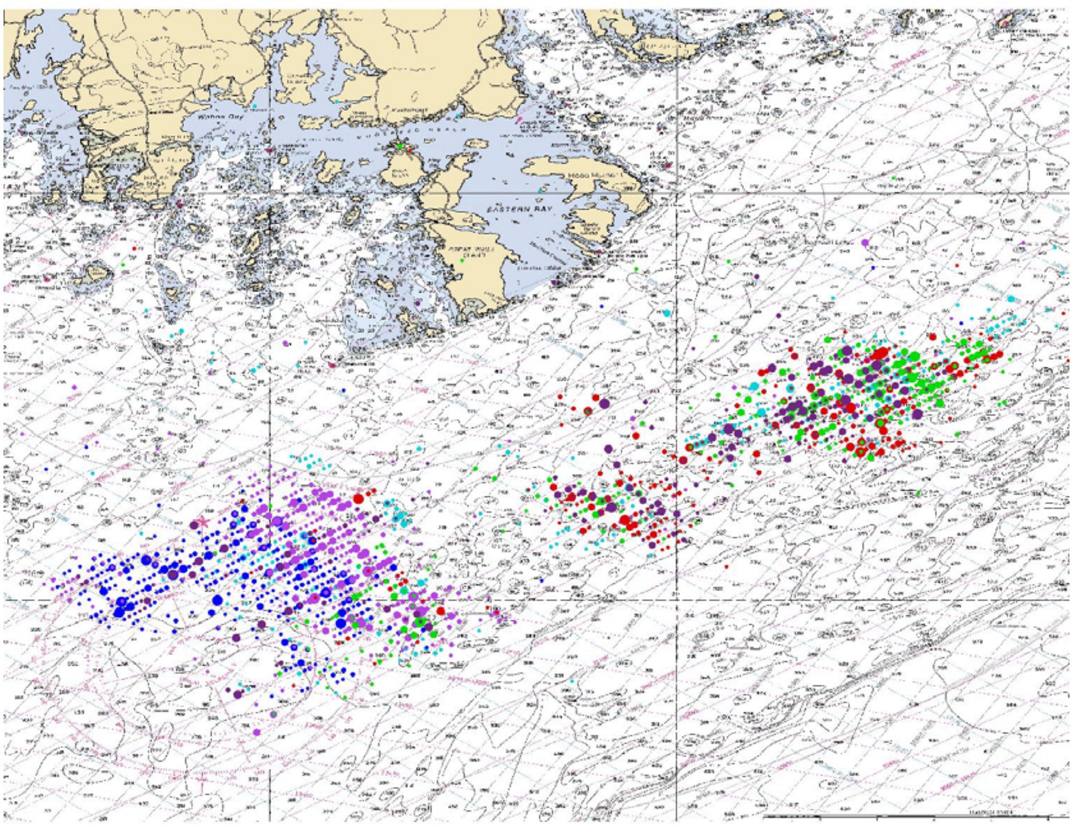

Figure 2. Combined locations of all reported commercial landings 2003-2008.

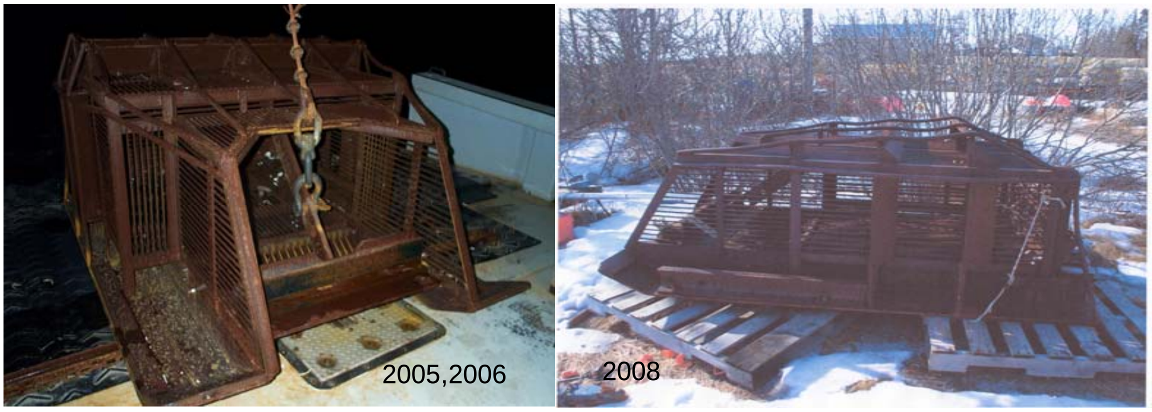

Figure 3. On left, Commercial dredge used in 2005, 2006 operations roughly 3,000lbs. On right commercial dredge used in 2008 roughly 2,600lbs.

Figure 4. Washing the catch in vessel prop wash.

Figure 5. Typical 2 min tow. Note very low bycatch and uniform size of clams.

Figure 6. Processing the catch on shaker table, used to remove shell fragments and mud. This step is performed in commercial operations as well.

Figure 7. Ocean Instruments box corer used during survey.

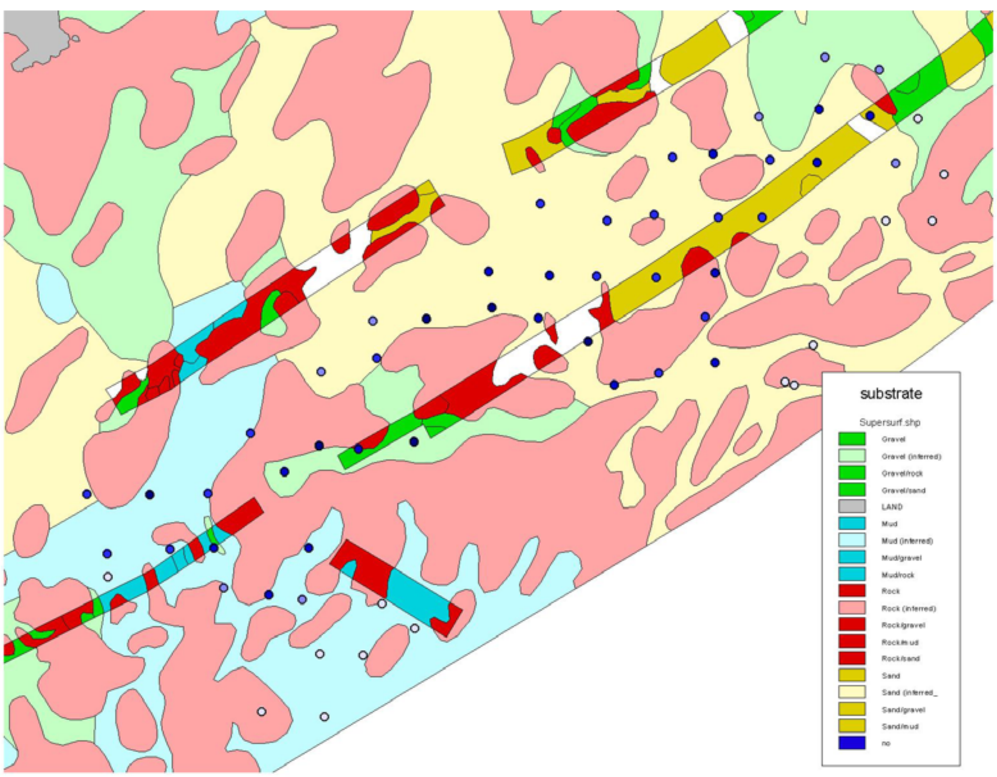

Figure 8. Substrate information from Kelly et al. Showing coincidence of hard bottom edges with high density quahog tows from eastern bed.

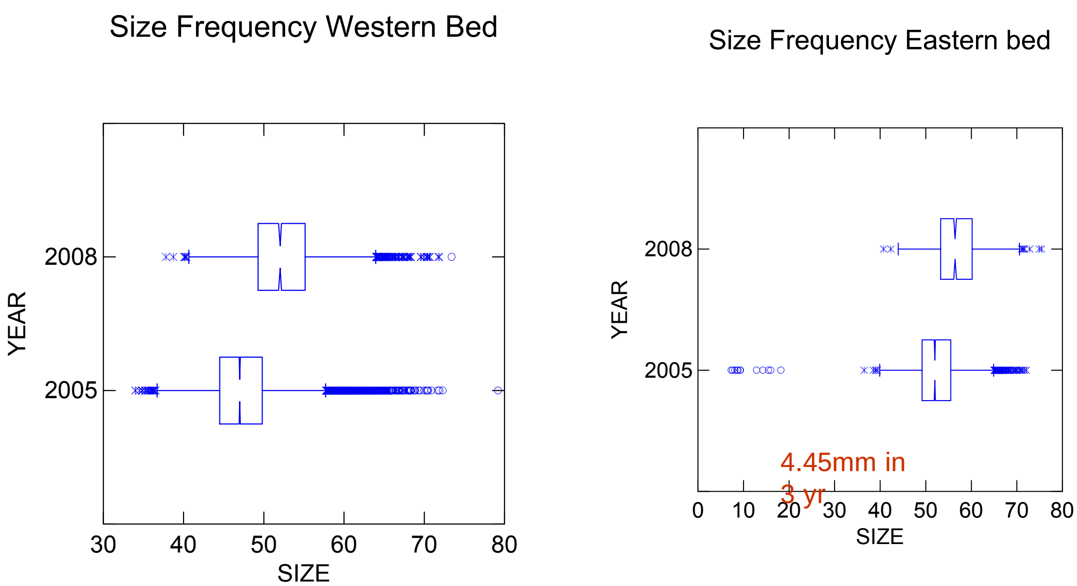

Figure 9. Growth in quahogs between 2005 and 2008 surveys. Based on Maine growth data an increase of 5mm in the western bed should have taken 8 years and the 4.45mm increase in the eastern bed should have taken 14 years.

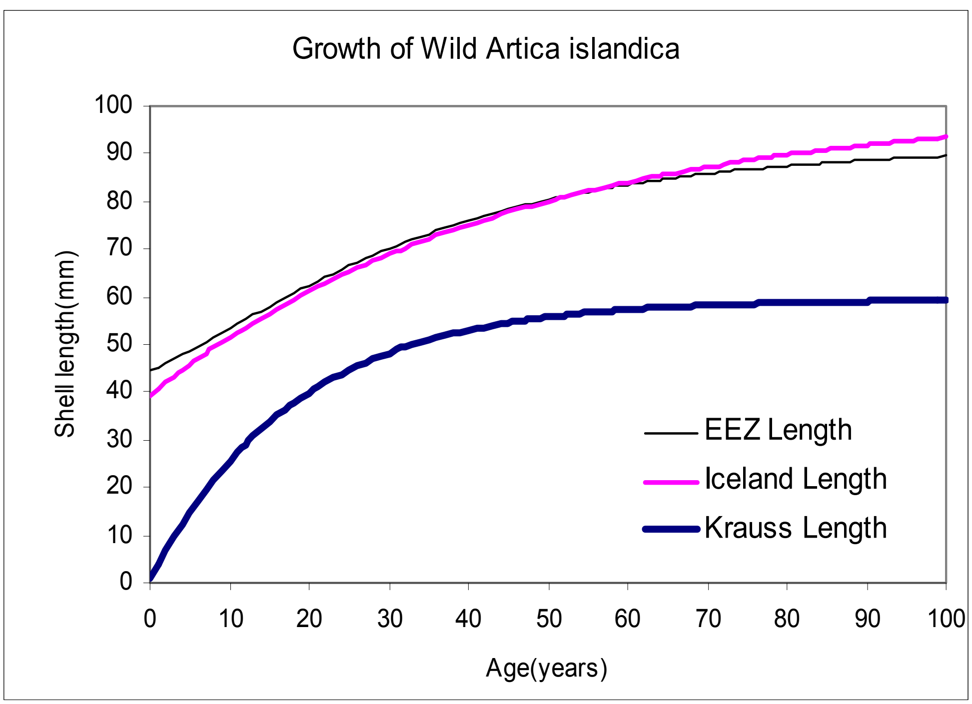

Figure 10. Growth curves for various quahog stocks. Maine (Krauss) shows rapid initial growth with much lower maximum size.

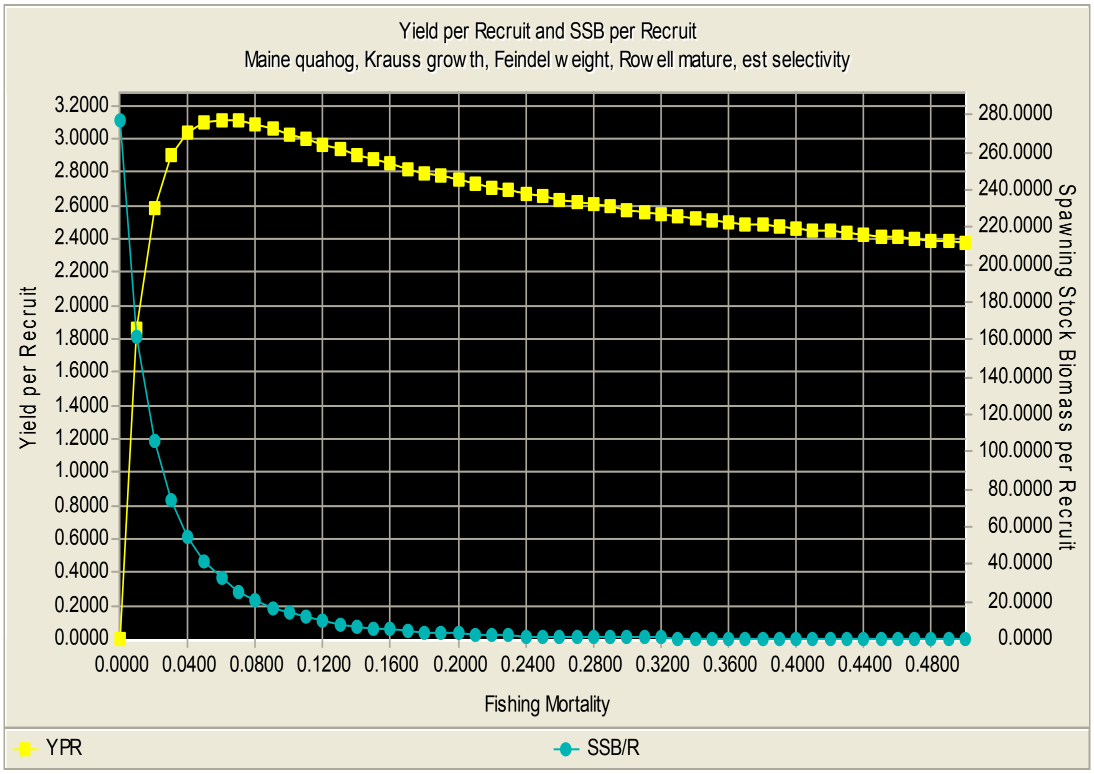

Figure 11. YPR analysis run in 2005. No new information was available to modify these results.

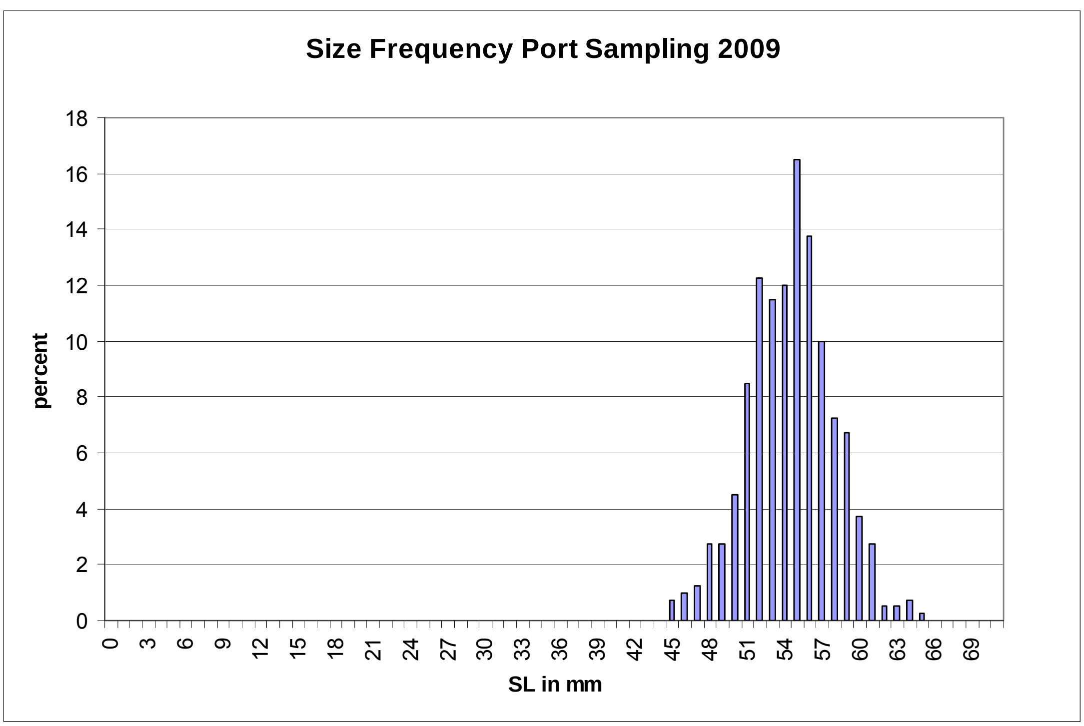

Figure 12. Size frequency for port samples collected in Jan- March 2009 from 6 different vessels. These sizes concur with ramp function used in YPR analysis

APPENDIX B3: Report on dredge performance from SSP (survey sensor package) data.

2008 Survey NOAA Clam Dredge Performance Review

April 23, 2009

Summary

The review of the 2008 NOAA clam survey tows described below accomplished the following tasks.

1) Grade the tows based on the previously developed manifold pressure "good"/"bad" criteria. For the 2008 survey this required development of a manifold pressure proxy based on pump amps due to a SSP failure towards the end of the survey. A total of 67 stations out of 453 were determined to be "bad" by the criteria.
2) Grade the tows based on the previously developed Y Tilt (dredge fore/aft angle) "good"/"bad" criteria. For the 2008 survey it was determined that sensor issues were likely creating false excessive Y tilt motions and the Y Tilt criteria should not be used. Based on this decision, the 2005 NOAA survey tows were re-reviewed for Y tilt issues and a similar determination was made. This resulted in one station, #218, previously labeled bad for Y tilt being included in a re-analysis of the 2005 survey data.
3) Evaluate the effect of changing the dredge pump, pump power cable, and SSP during the survey on the dredge's performance. The end conclusion is there was no noticeable effect on the survey results.
4) Investigate several SSP data anomalies, particularly fluctuations in frequency recorded and minor variations in pump amps and manifold pressure trends that occurred during the survey. It was determined that these anomalies were likely sensor issues or a minor pump problem that had no noticeable effect on the survey results.

Review of Survey Dredge Pump Performance Relationships

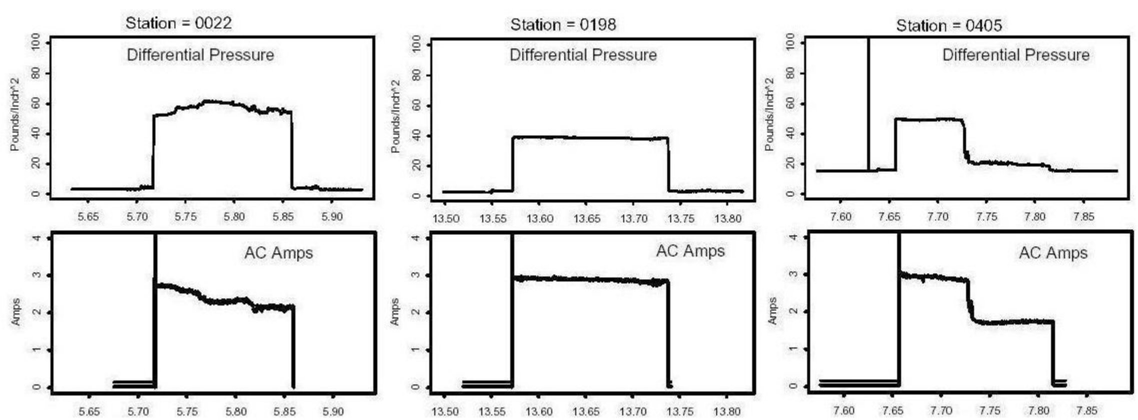

Figure 1 - Blocked Manifold Good Pressure Blocked Intake

In evaluating the performance of the NOAA clam survey, several key pieces of data are used, pump manifold pressure and pump electrical operating parameters. The key data is the manifold pressure with the electrical data serving as a backup to missing manifold pressure data and to verify the pump was seeing a consistent electrical supply.

Figure 1 shows the two dredge pump pressure problems, a blocked pump discharge manifold (pressure increase) or a blocked pump intake (pressure decrease). For a centrifugal pump such as used on the survey dredge, in both blockage cases the pump amps will fall in proportion the increase or decrease in manifold pressure. Thus with a suitable proxy, missing manifold pressures can be recreated using the amps data recorded.

The frequency and voltage data, along with the amps data, is primary used to verify a consistent electrical supply to the dredge pump motor. For the NOAA survey dredge the frequency should be 60 hertz and the voltage should be a relatively consistent value. The frequency is set by the rpm's of the generator which is governed to between 59.5 and 60.5 hertz depending on load. The voltage recorded is the voltage at the dredge pump and typically runs around 400 volts depending on power cable length.

Introduction

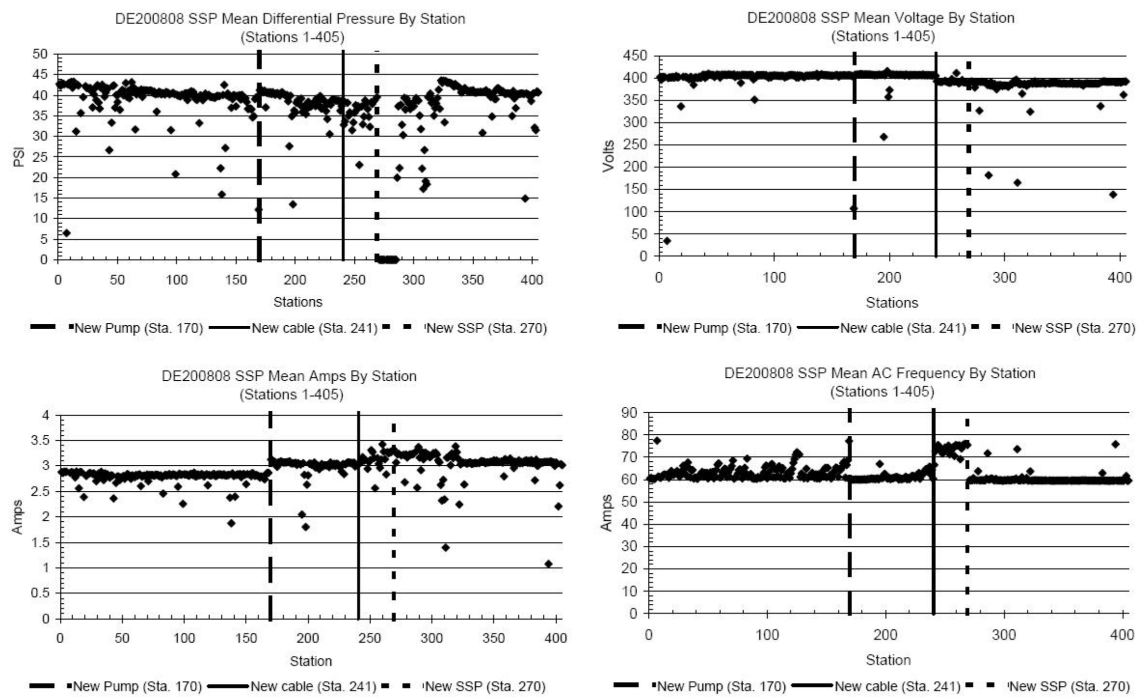

Figure 2 - SSP Mean Values for Differential Pressure, Amps, Volts, Frequency

A review of the Survey Sensor Pack (SSP) data from the 2008 NOAA clam survey was undertaken to evaluate the performance of the dredge for each of the survey tows. The SSP's mean Manifold Differential Pressure, Pump Amps Draw, Pump Voltage, and Frequency for tows 1 to 405 are plotted in Figure 2. Tows 406 to 453 are not plotted due to a failure of the SSP package. For reference survey leg 1 was stations 1 to 169, survey leg 2 was stations 170 to 319, and survey leg 3 was stations 320to 453.

For the 2008 clam survey, (4) onboard events happened.

1) The dredge pump failed during station 169 tow and was replaced with the backup unit for tows 170 till the survey end.
2) The pump power cable was replaced at station 241 with a longer cable to allow tows in deeper waters. The longer cable remained for the rest of the tows.

3) The primary SSP package failed towards station 269 and was replaced with the backup SSP for station 270 on.
4) The backup SSP failed from station 406 till the end of the survey.

A visual review of the SSP data showed the following issues of concern.
1) There were large number of tows with significant drops in the manifold differential pressure and pump amps. (Same as occurred during 2005 survey)
2) There was modest, about 3 to 5 psi, jump in the manifold differential pressure for the last third of the survey.
3) The frequency recorded from station 1 to 169 varied from 60 to 70 hertz. The frequency then stabilized at 60 hertz till about station 220 when it started a slow rise followed by a jump to over 70 hertz at station 241. The frequency then stabilized at 60 hertz till the end of the survey.
4) The dredge Y tilt (fore/aft) and X tilt (side/side) seemed to have greater fluctuations than previous surveys.

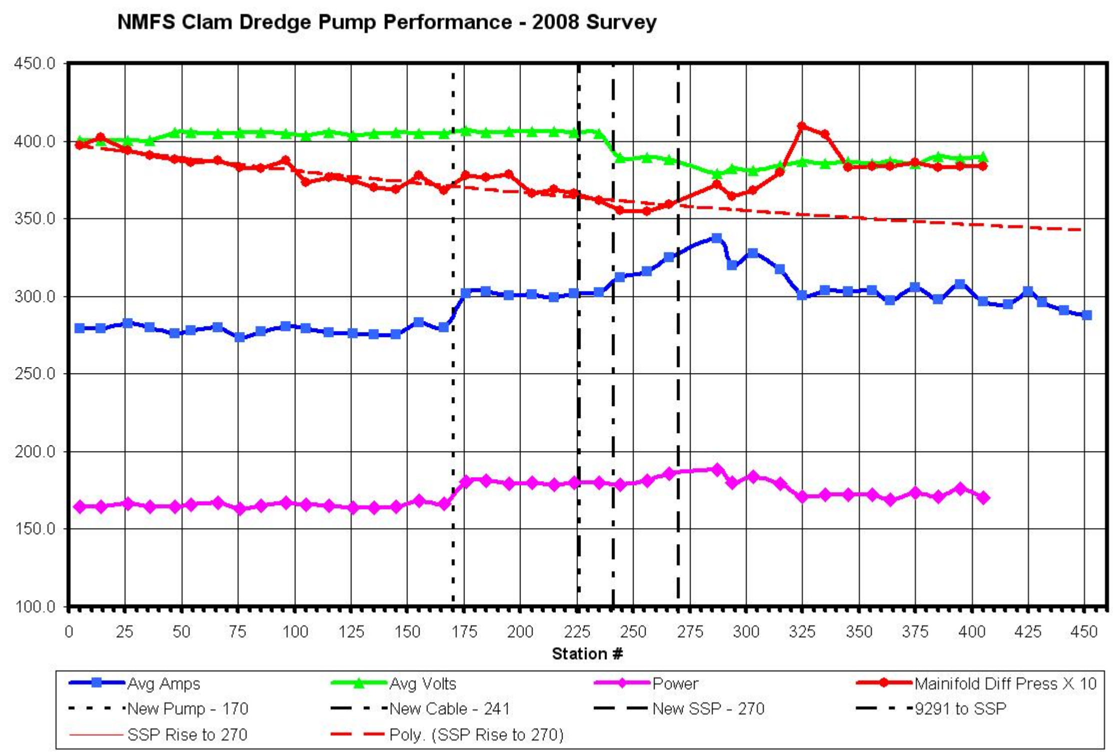

Figure 3 - Clam Dredge Pump Performance - 2008 NOAA Survey

To help evaluate the effect of the onboard events and SSP data concerns a plot of the dredge pump's general operating performance, Figure 3, was done to see trends over the entire survey. This plot was done using stations ending in (5) or if that station had problems, such as a clogged manifold, the next nearest good station was used. Note the manifold pressure, red line, is plotted at a 10 times scale.

Effect of Dredge Pump Replacement at Station 170

The dredge's pump was replaced at station 170 and is shown on figure 3 with the black short dashed line. When the new second pump was installed the manifold pressure jumped up roughly 1 psi to about 38.5 psi (red line figure 3). The pressure increase would be expected over the first pump's now worn condition, but did not increase to the first pump's "new" pressure of about 40 psi.

This is likely due to the fact that the second pump appears to have more internal running resistance than the first pump by the jump in amps draw (blue line figure 3) and power (magenta line figure 3) from about 275 amps, 160 VA, for the first pump to 300 amps, 180 VA, for the second pump. The increase in internal resistance could be from tighter bearings, shaft seals, or running clearances and would cause the second pump to run slightly slower than the first pump which would produce less manifold pressure.

Also interestingly the fluctuation in recorded frequency up to replacement of the pump disappeared and a steady 60 hertz was now being recorded (see figure 2). The variation in frequency from 60 to 70 hertz is not possible as this is a direct function of the ship's generator rpm's which are governed to 59.5 to 60.5 hertz depending on load. Variations of the size recorded would be easily noticed by ship's engineer and at 70 hertz would have likely tripped automatic over-speed safety shutdowns. In addition the higher frequencies, if they did occur, would have caused the dredge pump to run at significantly higher speeds which would have boosted the manifold pressure and raised the amps draw, neither of which occurred. The frequency variations could have been due to problems in the first pump which eventually caused the pump motor failure.

Based on the above the change in dredge pumps would have had no noticeable effect on the performance of the survey dredge as the key manifold pressure remained within the normal operating band of 35 to 40 psi.

Effect of Dredge Pump Power Cable Replacement at Station 241

The dredge pump's power cable was replaced at station 241 with a longer cable to allow sampling in deeper water and is shown on figure 3 with the black long/short dashed line. When the new longer cable was installed there was a drop in voltage (green line figure 3) at the pump from about 405 volts to 390 volts which would be expected from the higher resistance of the longer cable. There was a corresponding increase in the amps draw (blue line figure 3) from 300 amps to 315 which would also be expected as the dredge pump power draw (magenta line figure 3) remained the same.

Most importantly the key manifold pressure (red line figure 3) over the power cable change followed the general small downward typical of a survey pump wearing normally over the course of a survey. Based on this the change in dredge pump's power cable would have had no noticeable effect on the performance of the survey dredge as the key manifold pressure remained within the normal operating band of 35 to 40 psi.

Replacement of Primary SSP at Station 270

The primary SSP was replaced at station 270 due to onboard data review which was indicating a SSP failure. The frequency recorded had started to rise after station 220 and then jumped to a completely impossible 74/75 hertz (see above discussion). In addition station 268 had no SSP differential pressure and station 270 recorded no SSP data at all. These failures had followed a string of stations with low recorded manifold pressures.

The frequency data recorded by the second SSP after station 271 did return to an expected steady value of 60 hertz. In addition the voltages recorded at the pump remained steady at around 390 volts between the first and 2nd SSP's. Both of these indicate a correctly functioning second SSP.

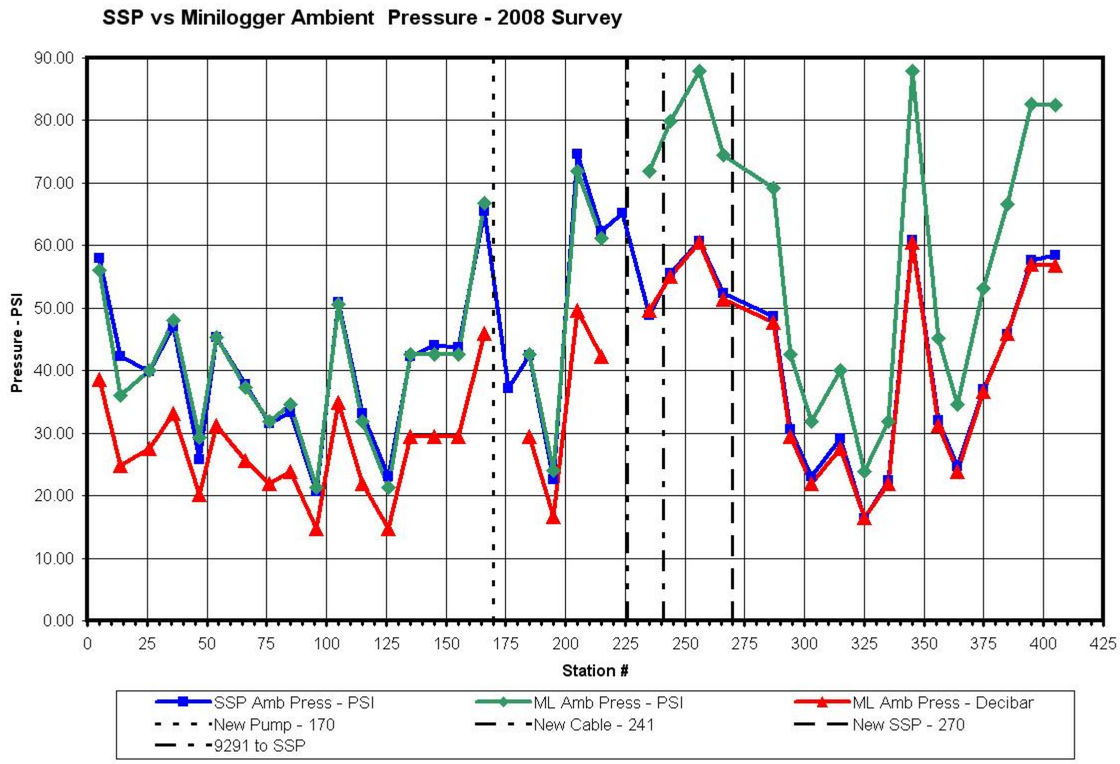

Figure 4 - SSP vs Mini-Logger Ambient Pressure - 2008 NOAA Survey

A further check was done by comparing the SSP recorded ambient pressure to the ambient pressure recorded by the mini-loggers (see figure 4). The SSP ambient pressure (blue line figure 4) tracks the mini-logger pressure (green and red lines figure 4) very closely both before and after the change in SSP's. Note the SSP value changed from psi to decibars at station 226/227 which will be discussed later. This change in units did not affect any of the review work undertaken.

The average dredge running angle recorded by the SSP's inclinometer was also compared between the first and second SSP units. (Note stations used were the good stations used to develop dredge pump performance plot in figure 3.)

	Y Tilt	X Tilt
First SSP Stations 1 to 269	3.39	2.72
Second SSP Stations 270 to 405	2.76	2.63

Both the Y (fore/aft) and X (side/side) tilt angles are within the at sea calibration errors that were done to set up the second SSP.

A review of the pump voltage, recorded by the SSP's, and pump amps, recorded independently of the SSP's, was also done to compare first and second SSP functionality. The amps (blue line figure 3) and voltages (green line figure 3) are steady from station 1 to about station 260 as would be expected. From station 260 to about station 285 though, the amps increased significantly then declined to "normal" values at station 325 and remained steady for the rest of the survey.

This increase in pump amps could only be caused by increased running resistance in the pump such as shell hash binding the pump impeller. An increase in manifold pressure would not cause this increase in amps. Whatever was causing the binding eventually wore away and the running resistance eventually returned to normal conditions. The corresponding dip and rise in voltage and increase then drop in power demand (magenta line figure 3) supports this theory.

The manifold pressure though should have dipped slightly during this episode as the added running resistance would have slowed the pump rpm's down. This did not occur though as the manifold pressure (red line figure 3) was recorded to be steadily rising and continued do so well past when this anomaly in amps draw was over. From the following discussions it appears the manifold pressure was likely having sensor issues and coupled with the fact that the amps anomaly occurred over the change in SSP's suggests the change in SSP's was not a factor.

The manifold pressure (red line figure 3) on the other hand was not recorded by the second SSP for stations 270 to 285 and then started recording till the complete failure of the second SSP at station 406. When the manifold pressure started recording at station 286 it had jumped slightly about 1 psi above the first SSP's last values, and then showed a sharp rise from about 36 psi to about 41 psi around station 325. The manifold pressure then dropped to a steady value of about 39 psi at station 345 and remained steady there after to the failure of the second SSP at station 405.

The small initial jump in pressure is within calibration errors from the first SSP to the second SSP. However from past surveys the manifold pressure should have followed a steady small downward trend due to pump wear (red dashed line figure 3). The rise in and fall in manifold pressure could be indicating a slightly plugged manifold but the pump amps, recorded independent of the SSPs, (blue line figure 3) did not drop/rise in agreement.

From the analysis of the 2005 NOAA clam survey, an unknown drift in the manifold pressure sensor readings before the pump was started (blue line figure 5b) occurred which created a false rise in the recorded manifold pressure (green line figure 5b). A possible sensor drift was also investigated for the 2008 survey, but as shown in figure 5a the same drift did not occur. Unlike the 2005 survey, the 2008 survey manifold pressure before pump start (blue line figure 5a) staid steady throughout the survey.

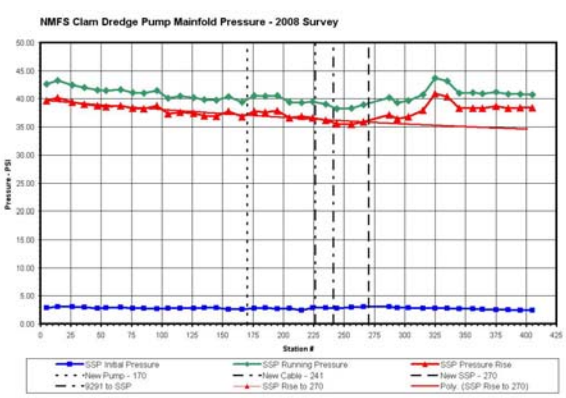

Figure 5a - 2008 Dredge Manifold Pressure

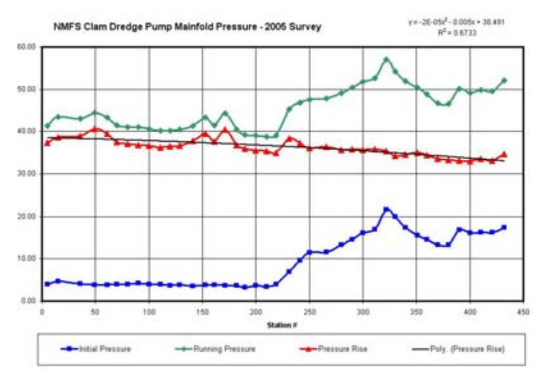

Figure 5b - 2005 Dredge Manifold Pressure

The SSP differential pressure sensor was changed from the 2005 survey's Trans Metric P022 unit to a Stellar Technology DT1900 unit for the 2008 survey which could explain the difference between 2005 and 2008 surveys. Neither manufacture was able to provide any insight into the sensor's performance.

Based on the above, no definitive judgment can be passed on the performance of the second SSP unit or the effect of the data recorded on the survey. However the second SSP's frequency values were steady at 60 hertz, voltage remained the same between the two SSP's, and the SSP ambient pressure matched the mini-logger values, all indicating consistent SSP operation.

The change in manifold pressure, the key dredge performance measuring criteria, however is a concern about the second SSP unit. The change in manifold pressures though is fairly small and the value stays within the accepted 40 to 35 psi normal range. Further the stations with pump problems shown by the second SSP (station 402 figure 6) data have amp readings, recorded independently of the SSP, that are consistent and follow the patterns as occurred with the first SSP data (station 045 figure 6) and previous surveys (station 262 figure 6). Because of this the good/bad manifold pressure criteria is still valid for stations recorded by the second SSP.

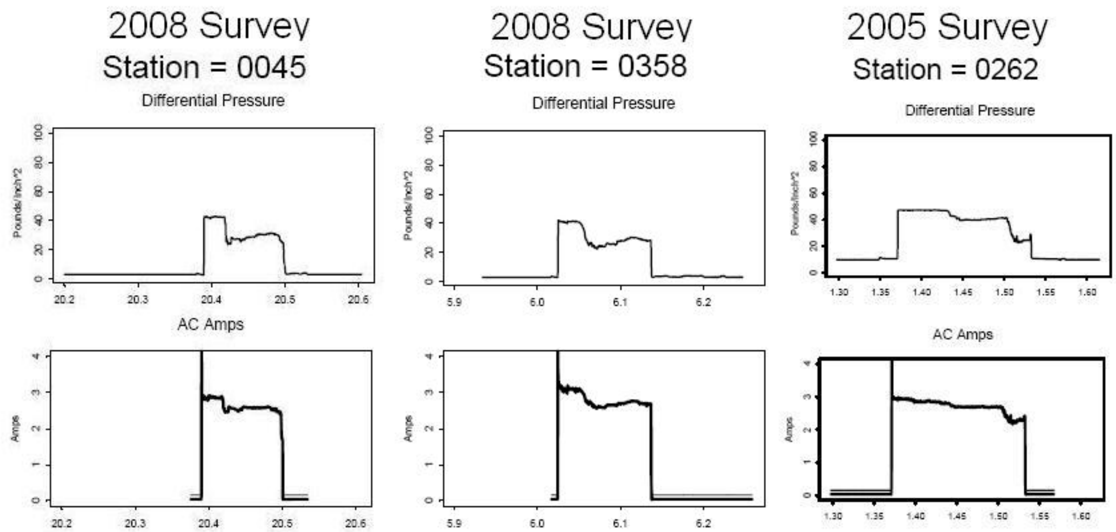

Figure 6 - 2008 & 2005 Survey 1st and 2nd SSP Manifold Pressure vs. Amps

Survey Dredge Y Tilt and X Tilt Fluctuations

From the visual inspection of the survey tow data plots the dredge Y tilt (fore/aft) and X tilt (side/side) seemed to have greater fluctuations than previous surveys. Several examples of tow Y and X tilt are shown in figure 7, with station 187 being typical of a "good" station for Y and X data. (Note different Y and X scales for degrees)

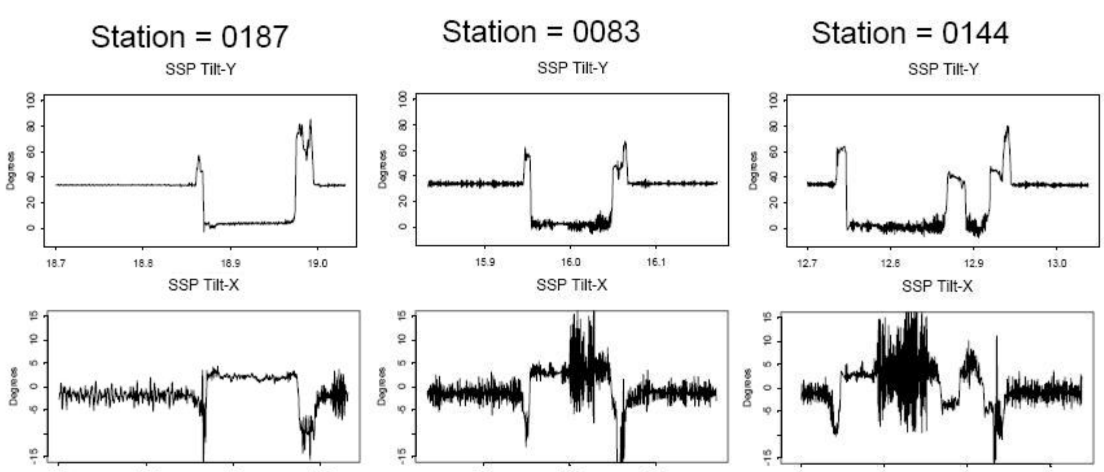

Figure 7 - NOAA Dredge 2008 Survey Y/X Tilt SSP Data Plot Examples

The SSP uses a 2 axis conductive liquid inclinometer to measure the Y and X tilt angles. This type of inclinometer measures the angle by sensing the level of a conductive fluid using (5) probes. Based on discussions with the clinometers' manufacture, the liquid used in the SSP's inclinometer has a viscosity about the same as water. Because of this the clinometers' liquid would be suspect to several error producing situations.

1) The liquid can slosh from sharp impacts or jolts.
2) The liquid can go into harmonic resonance at about 10 hertz (10 times per second).

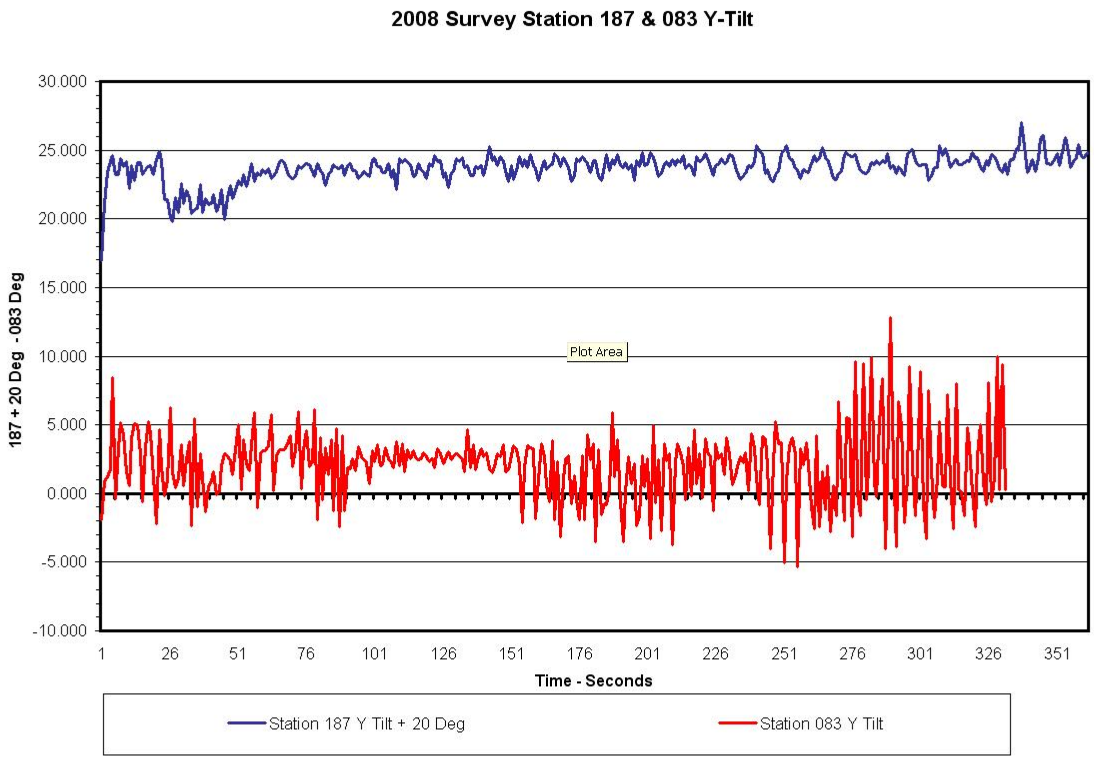

Figure 8 - 2008 Station 187 and 083 Comparison of SSP Y Tilt Plots

The sloshing of the clinometers liquid from sharp fore and aft jolting movements as the dredge jerks horizontally over the bottom can appear as a vertical Y tilting of the dredge. The rapid large vertical swings of station 083 tow (red line figure 8) are most likely from sloshing of the clinometers' conductive liquid due to the dredge jerking fore/aft horizontally through the bottom, not actual dredge vertical movement. The large 10 degree vertical swings at the end the tow are most likely from the clinometers' conductive liquid sloshing in resonance. (Good station 187 Y tilt, blue line, is plotted as a comparison.)

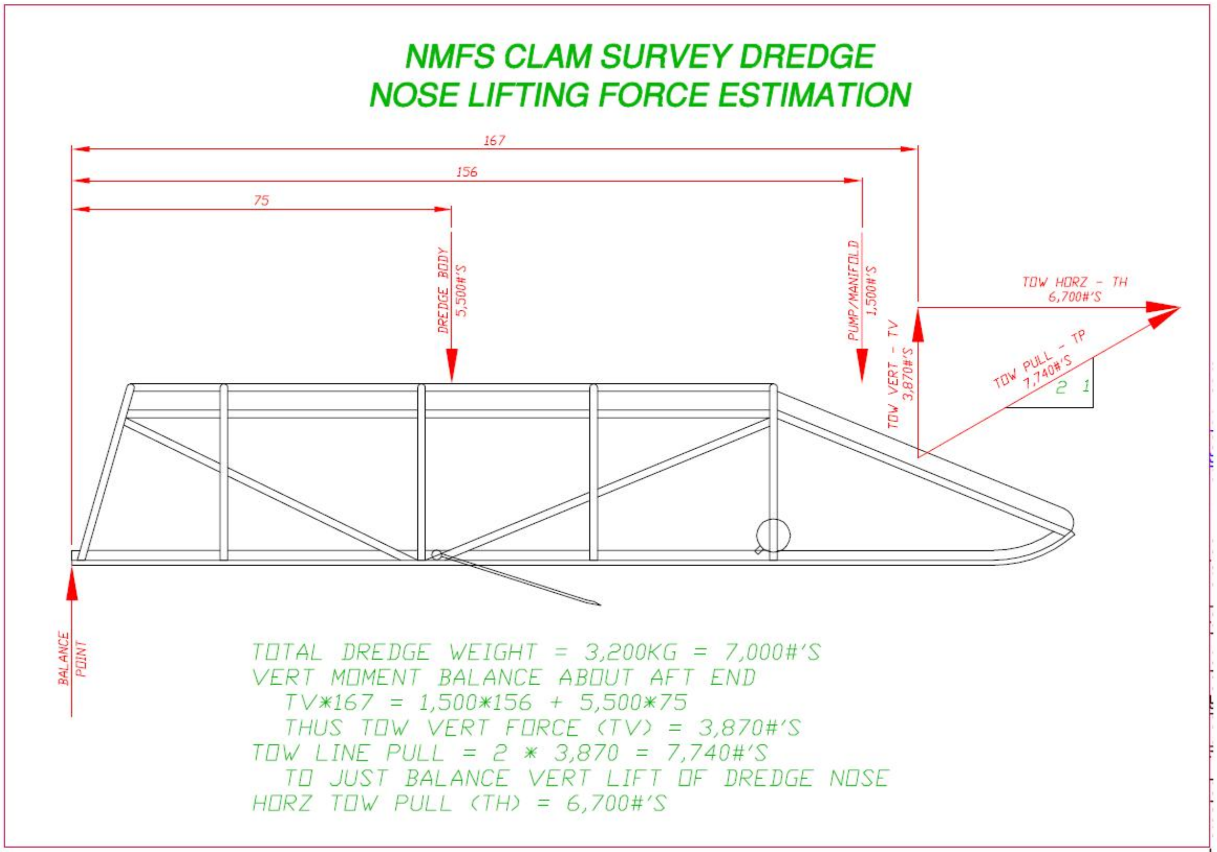

Figure 9 - NOAA Clam Dredge Nose Lifting Force Calculation

Further evidence the large Y tilt swings are from the inclinometer sloshing is the large towline pull that would be required to lift the nose of the dredge off the bottom. Figure 9 is an estimation of the towline pull that would be required to lift the nose of the dredge off the bottom. From a moment balance calculation, approximately 7,700 #'s of towline pull would be required to just balance the dredge on the aft end of the runners. But this 7,700 # towline pull also creates a horizontal pulling force of 6,700 #'s, more than ample to pull the dredge forward, particularly after the dredge's knife is completely above the bottom at a Y angle rise of about 4.4 degrees.

The last evidence the large Y tilt swings are from the inclinometer sloshing is the physical fact that it is not possible for the dredge's large flat runners to bury in the bottom as the plots would suggest. For station 083 shown, its normal running angle appears to be about 3 degrees (time 100 to 150 red line figure 8). Yet from the plots the dredge and its runners are burying 5 to 10 degrees on 1 second intervals in to the bottom, not a realistic situation. The 1 to 2 degree bounces on roughly 5 second intervals for station 187 (blue line figure 8) are realistic.

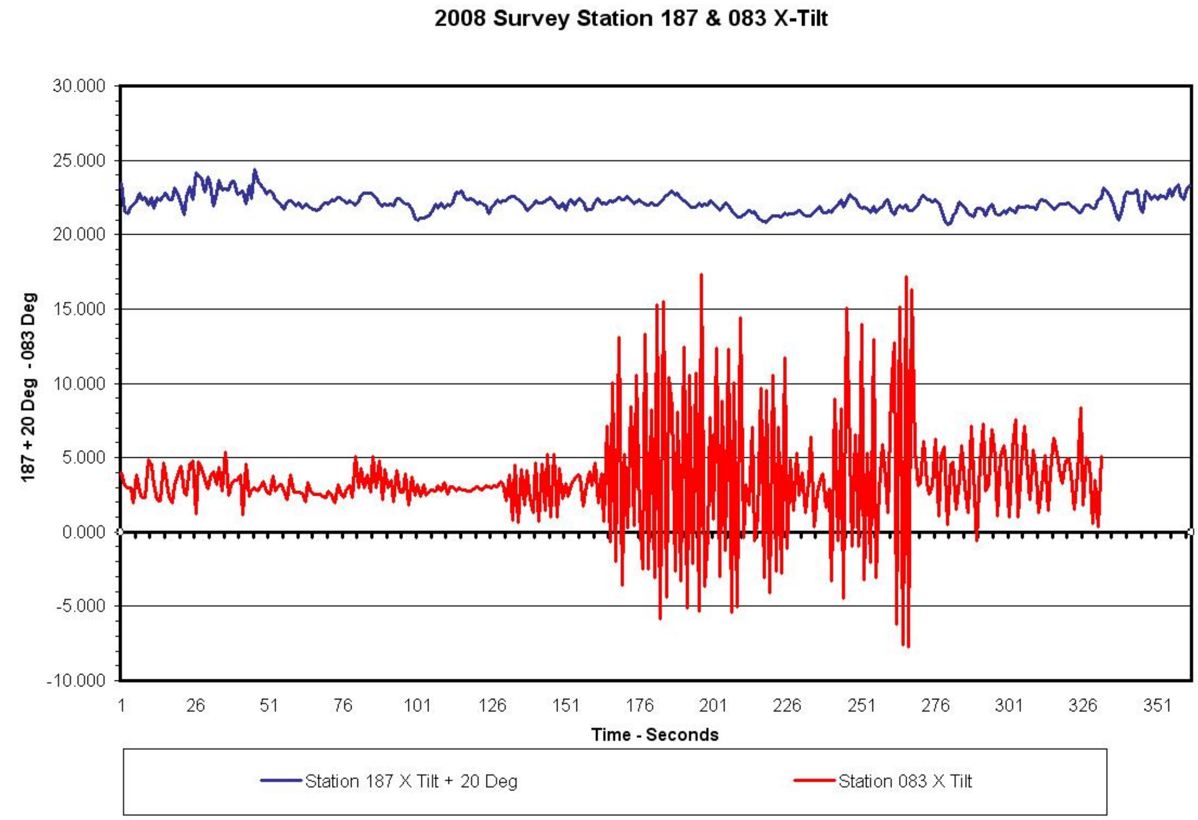

Figure 10 - 2008 Station 187 and 083 Comparison of SSP X Tilt Plots

As with Y tilt, sharp sideways jolting movements of the dredge can appear as an excessive side X tilting of the dredge. The rapid large X swings of station 083 tow (red line figure 10) are again most likely from sloshing of the clinometers' conductive liquid, probably in resonance during the 20 degree plus swings. (Good station 187 Y tilt, blue line, is plotted as a comparison.)

Because these rapid Y and X tilt fluctuations are likely due to a SSP sensor problem, and are not the actual movement of the dredge, these fluctuations can be ignored in evaluating the dredge's performance. Extreme problems in the dredge's running angle such as shown by the station 144 plots in figure 7 will not be ignored by this assumption. In this case the dredge jumped up about 40 degrees for a brief period in the latter part of the tow due to a sudden very large 5 knot increase in vessel speed. This non fishing period though will be compensated for in the tow length calculations and thus be correctly accounted for in the survey results. As such the Y-Tilt Criteria developed for the 2005 survey is no longer applicable and was not applied to the 2008 survey.

Based on the above, the 2005 NOAA survey Y and X tilt plots were re-evaluated and similar Y and X fluctuations were noted, though with a significant lesser number of occurrences than the 2008 survey. Typical examples of stations from the 2005 NOAA survey are shown in figure 11. Station 137 is a typical good station for smooth Y and X tilt plots. Station shows similar Y and X tilt fluctuations to the 2008 survey discussed above. The one 2005 survey station that was flagged as "bad" by the Y-Tilt criteria was station 218 shown in figure 11. As discussed above the Y tilt spike in the middle of the tow will be accounted for in the tow length calculations and thus station 218 can be placed back into the survey calculations.

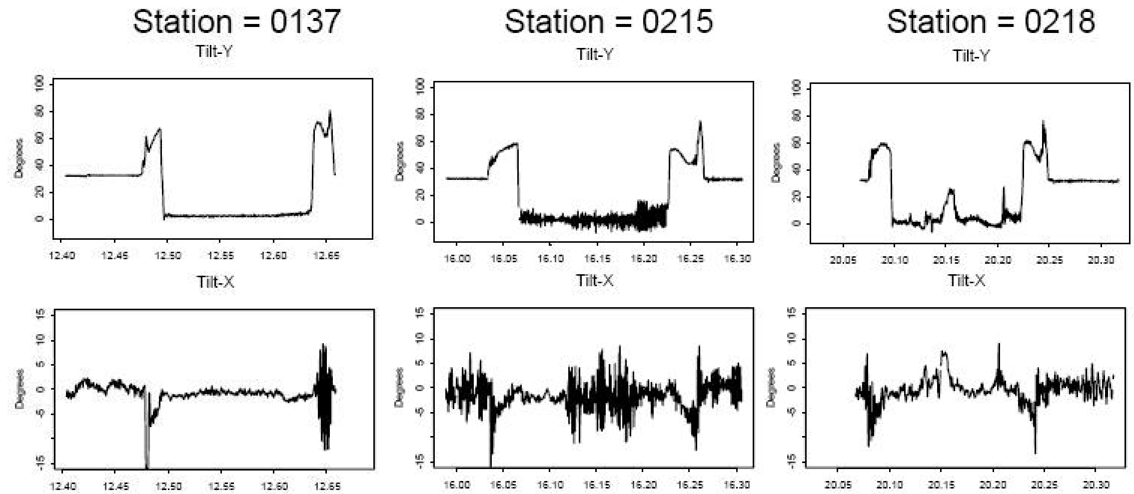

Figure 11 - NOAA Dredge 2005 Survey Y/X Tilt SSP Data Plot Examples

SSP vs Mini-Logger Ambient Pressure Comparison

From figure 4 there was an interesting anomaly in the SSP ambient pressure recorded in the data files. The SSP ambient pressure (blue line figure 4) tracks the mini-logger ambient pressure in psi (green line figure 4) up to station 226. At station 227 the SSP ambient pressure now tracks the mini-logger ambient pressure in decibars (red line figure 4) till the SSP data ends at station 405. In the excel data files the column header for SSP ambient pressure is “PRESS.AM9291” up to station 226, then switches to “PRESS.AM.SSP” for the remainder of the survey tows. This switch in header labels also occurred for SSP ambient temperature, tilt X, and tilt Y.

This unit jump appears to only have occurred in the SSP ambient pressure data. The SSP ambient temperature tracked the mini-logger ambient temperature across the full survey (see figure 12). The average Y tilt and X tilt before and after stations 226/227 was also calculated to see if a problem occurred. The Y and X tilt was stopped at station 269 when the SSP was replaced and there is a minor calibration difference between the two SSP units as discussed previously. Again from the data below it dose not appear if there was any change in the X or Y before to after station 226/227. (Note stations used in these comparisons were the good stations used to develop dredge pump performance plot in figure 3.)

	Y Tilt	X Tilt
First SSP Stations 1 to 226	3.39	2.71
First SSP Stations 227 to 269	3.38	2.75

Based on the above, this unit switch did not affect any of the 2008 survey tow review.

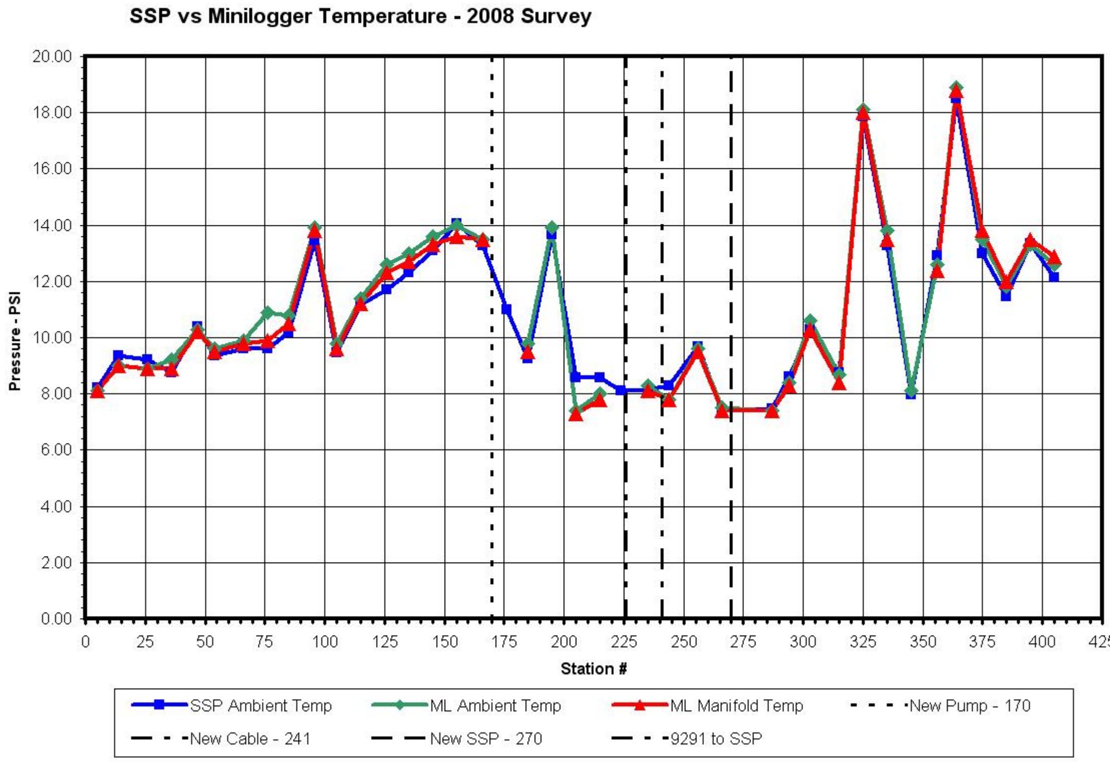

Figure 12 - SSP vs. Mini-Logger Ambient Temperature - 2008 NOAA Survey

Application of Manifold Pressure Good/Bad Tow Criteria to 2008 Survey

As with the 2005 NOAA clam survey, there were numerous stations that experienced manifold pressure problems during the 2008 survey. These suspect stations were evaluated using the good/bad manifold pressure criteria that was developed for the 2005 survey. In summary the criteria compares the time the manifold pressure was in the "normal" operating range of 35 to 40 psi with the time it was outside of that range. If the time outside of the range exceeded the time within the normal range by more than 25%, the tow is labeled a "bad" tow.

The 2008 survey did present one problem in using the good/bad manifold pressure criteria, the lack off SSP manifold pressure data after station 405. Fortunately the dredge pump's amp draw is recorded independent of the SSP's and was available for use in these latter stations. Figure 13 is a plot of several stations that experienced pressure problems were both SSP manifold pressure and amps were available. This plot was used to develop a manifold pressure from amps proxy that would allow use of the good/bad manifold pressure criteria for stations after 405.

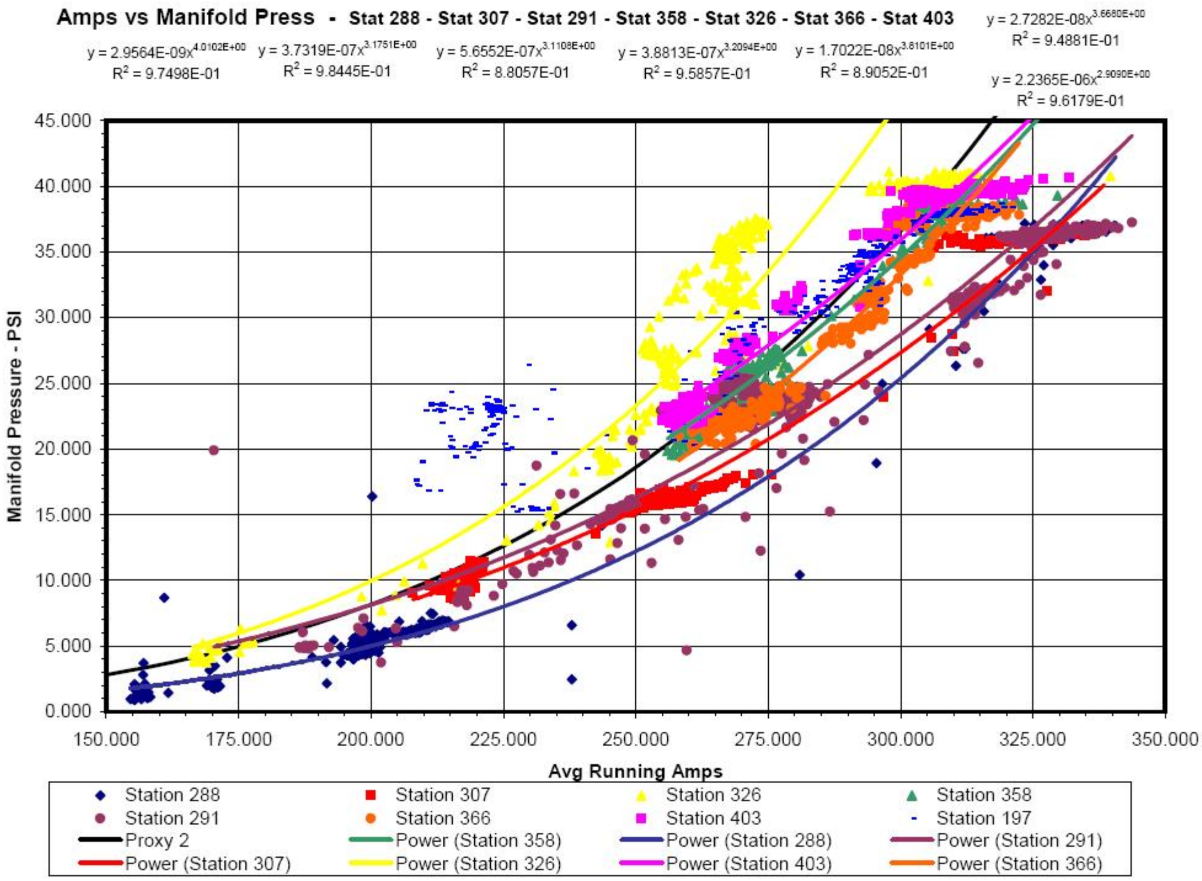

Figure 13 - Manifold Pressure vs. Pump Amps Proxy

The selected proxy is the black line in figure 13. This proxy was set by visual trial and error to best match stations 403, 358, and 366. These stations were selected as they occurred towards the end of the SSP available data and best matched the amps/pressure relationship of a normally operating pump in the latter tows.

The list on the following page are the stations determined to be "bad" by the manifold pressure criteria.

NOAA Clam Survey Station 1 to 405 Manifold Pressure Good/Bad Tow Criteria - All Bad Tows

Station #	Weighted Time < 35 PSI	Weighted Time 35-40 PSI	Weighted Time > 40 PSI	%Time Under	%Time Over	25% Good Bad	Womack #	Other Issues
15	151.95	70.00	0.01	217%	0%	Bad	5	
29	91.34	242.00	0.01	38%	0%	Bad	5	
35	70.37	205.00	0.00	34%	0%	Bad	5	
43	246.60	170.00	0.00	145%	0%	Bad	5	
45	79.92	4.00	11.55	1998%	289%	Bad	5	
48	60.77	160.00	0.00	38%	0%	Bad	4	
52	56.30	137.00	0.00	41%	0%	Bad	5	
65	129.17	119.00	0.00	109%	0%	Bad	5	
95	148.77	39.00	0.00	381%	0%	Bad	5	
99	341.51	47.00	0.00	727%	0%	Bad	5	
119	126.18	87.00	0.00	145%	0%	Bad	5	
137	304.97	54.00	0.00	565%	0%	Bad	5	
138	949.11	232.00	0.00	409%	0%	Bad	5	
141	249.06	217.00	0.00	115%	0%	Bad	5	
150	74.99	278.00	0.12	27%	0%	Bad	3	
164	71.39	88.00	0.00	81%	0%	Bad	3	
165	67.19	165.00	0.00	41%	0%	Bad	3	
169	235.57	39.00	0.00	604%	0%	Bad	5	
175	91.08	338.00	0.00	27%	0%	Bad	4	
197	104.26	183.00	0.00	57%	0%	Bad	4	
198	554.15	63.00	0.00	880%	0%	Bad	5	
206	91.58	269.00	0.00	34%	0%	Bad	4	
209	72.08	195.00	0.00	37%	0%	Bad	4	
226	41.14	112.00	0.00	37%	0%	Bad	3	
227	83.24	169.00	0.00	49%	0%	Bad	5	
229	153.22	137.00	0.00	112%	0%	Bad	5	
241	122.53	144.00	0.00	85%	0%	Bad	5	
242	92.20	96.00	0.00	96%	0%	Bad	5	
245	78.76	13.00	0.00	606%	0%	Bad	5	
246	75.65	0.00	0.00	########	0%	Bad	3	
248	179.34	51.00	0.00	352%	0%	Bad	5	
249	120.82	80.00	0.00	151%	0%	Bad	5	
250	69.02	15.00	0.00	460%	0%	Bad	4	
252	52.64	135.00	0.00	39%	0%	Bad	3	
254	582.83	166.00	0.00	351%	0%	Bad	5	
257	162.74	71.00	0.00	229%	0%	Bad	5	
258	107.49	127.00	0.00	85%	0%	Bad	5	
262	92.52	229.00	0.00	40%	0%	Bad	5	
263	160.98	196.00	0.03	82%	0%	Bad	5	
288	510.08	160.00	0.00	319%	0%	Bad	5	
290	169.52	272.00	0.00	62%	0%	Bad	5	
291	223.76	141.00	0.00	159%	0%	Bad	5	
293	71.66	230.00	0.00	31%	0%	Bad	2	
305	63.43	88.00	0.00	72%	0%	Bad	4	
306	117.97	97.00	0.00	122%	0%	Bad	5	
307	309.04	76.00	0.00	407%	0%	Bad	5	
308	389.37	54.00	0.00	721%	0%	Bad	5	
309	239.78	141.00	0.00	170%	0%	Bad	5	
310	398.91	117.00	0.00	341%	0%	Bad	5	
317	58.74	89.00	0.00	66%	0%	Bad	3	
326	119.05	134.00	1.59	89%	1%	Bad	5	
358	144.09	92.00	0.00	157%	0%	Bad	5	
366	94.22	109.00	0.00	86%	0%	Bad	5	
394	499.73	453.00	0.00	110%	0%	Bad	5	
402	150.58	175.00	0.01	86%	0%	Bad	5	
403	342.60	209.00	0.00	164%	0%	Bad	5	
424	583.83	35.00	3.96	1668%	11%	Bad	5	Manifold Press Amps Proxy
430	354.42	45.00	11.91	788%	26%	Bad	5	Manifold Press Amps Proxy
433	132.47	251.00	0.14	53%	0%	Bad		Manifold Press Amps Proxy
434	508.41	4.00	0.00	12710%	0%	Bad	5	Manifold Press Amps Proxy
435	428.23	2.00	0.00	21412%	0%	Bad	5	Manifold Press Amps Proxy
436	353.87	1.00	0.00	35387%	0%	Bad		Manifold Press Amps Proxy
437	343.27	17.00	0.00	2019%	0%	Bad	5	Manifold Press Amps Proxy
438	325.45	16.00	0.05	2034%	0%	Bad	5	Manifold Press Amps Proxy
448	236.08	21.00	0.00	1124%	0%	Bad	5	Manifold Press Amps Proxy
452	445.80	20.00	0.01	2229%	0%	Bad	5	Manifold Press Amps Proxy
453	135.09	92.00	0.61	147%	1%	Bad	5	Manifold Press Amps Proxy

APPENDIX B4: Cooperative survey report from F/V Endeavor.

2008 Cooperative Industry Surf Clam/Ocean Quahog Survey Cruise Report *F/V Endeavor*

SUMMARY

The 2008 Cooperative Surf Clam/Ocean Quahog Survey took place from September 10-23, 2008 following the 2008 NEFSC clam survey during June. The *F/V Endeavor*, based in Atlantic City, NJ was the commercial vessel used in the cooperative survey while the NEFSC survey used the NOAA Fishing Vessel R/V Delaware II. Leg 1 of the cooperative survey took place during September 11-15, leg 2 during 15-19th; and leg 3 during September 20-23rd, 2009. The cooperative survey was a joint effort by the National Fisheries Institute Clam Committee, Rutgers University, Virginia Institute of Marine Science, and the Northeast Fisheries Science Center.

Principal objectives of the survey were to: (1) further evaluate the feasibility of a cooperative clam survey using commercial vessels; 2) augment the NEFSC clam survey by repeating stations already sampled by the R/V Delaware II using the NEFSC clam survey dredge; (3) estimate efficiency of the NEFSC survey and commercial dredges by conducting depletion experiments; and (4) collect data for use in estimating size-selectivity for surfclams in the commercial and NEFSC survey dredges.

VESSEL, GEAR, and CREW INFORMATION

The *F/V Endeavor* is a 165-foot fishing vessel with a 42-foot beam, a 14,000-gallon fuel tank, and a 12,000-gallon fresh water tank. It has two 12.5-foot wide dredges, deployed by hydraulic power-out winches. The vessel was specifically outfitted with dredges that had bars with spacing reduced to 0.75 inches to retain small ocean quahogs and surfclams. The starboard dredge was lined with 1-inch hexagonal chicken wire for size selectivity studies. The dredge knives were set at 5.25 inches for surf clam sites and at 4.25 inches for quahog sites.

Two small belts ran the catch from the port and starboard hoppers onto a larger, centralized belt that transported the catch across a shaker table and onto a sorting belt. The large belt before the shaker table was about 4 feet wide and 10 feet long. Alongside the belt was a large, metal stand where workers could access the catch before it reached the shaker table, where the catch was mechanically sorted. The average spacing between the rolling bars on the shaker table was 0.73 (+/- 0.10) inches.

A NEFSC Survey Sensor Package (SSP) that records latitude, longitude, angle of the dredge (fore/aft and port/starboard), temperature, depth, and internal manifold pressure every second was carried inside the port dredge and was operational for parts of legs 1 and 2. Two Vemco mini-loggers (which record ambient temperature and pressure/depth) were fastened to each dredge on a metal rod welded to the top near the manifold. The mini-logger sensors were operational during all three survey legs.

The crew was split into two, 12-hour shifts so that operations could take place around the clock. Each shift was made up of seven people, including the captain or mate, four scientists, and two crew members. On-deck responsibilities, including sorting and measuring the catch, were shared by all four scientists on shift. In addition, one scientist was responsible for interacting with the captain to execute the cruise plan and one scientist (from NEFSC) was responsible for operating the SSP software package. Having seven people on each shift worked well and allowed the catch to be processed in a timely fashion while steaming between sites.

SITE DESCRIPTIONS AND METHODS

A. Surf Clam Size Selectivity Sites

Experiments were done at these sites to determine the size-selectivity of the commercial dredge and the NEFSC survey dredge by comparing catches from a lined commercial dredge, an unlined commercial dredge and a NEFSC survey dredge at the same site. Selectivity experiment sites were chosen based on location, and the size and species composition of the NEFSC survey dredge catches in 2008.

Experimental protocol was to first tow 5-minutes with the port (unlined) dredge. The catch was allowed to run over the shaker table and onto the sorting belt in the normal fashion in order to capture effects of both the dredge and shaker table on size selectivity. The shaker table had been pre-configured to increase selectivity of the commercial equipment as a whole for small quahogs. Thus, size selectivity for small ocean quahogs may be higher than during normal commercial operations. The total number of bushels in addition to the number of clams in any partial bushel was counted along with the number of clams in two full bushels to permit conversion of bushel counts to numbers of animals. Clams in two full bushels were also measured to the nearest mm.

The site was then towed for 30 seconds along an adjacent track using the starboard (lined) dredge. This time the catch was sorted before going over the shaker table so that the entire catch was sampled, until at least 6 full bushels of clams had been collected. All clams in the six full bushel samples were measured, regardless of size. The remainder of the catch was discarded. The volume of the catch was too large to sort the entire catch or accurately measure its volume. However, size composition data for surf clams in both tows at the site are directly comparable. Sorting the catches from the lined dredge generally took between one and three hours.

C. Surf Clam and Ocean Quahog Depletion Experiment

Depletion experiments were conducted to estimate capture efficiency of the commercial and NMFS survey dredge. The R/V Delaware II completed five “setup” tows at a predetermined site prior to the arrival of the commercial vessel. The setup tows were generally parallel and oriented either north-south or east-west.

After arriving at the site, the chief scientist aboard the F/V Endeavor selected a rectangular area near as many of the five setup tows as possible. The rectangle was oriented perpendicular to the setup tows to the extent possible with a target width of about 10 times the width of the dredge (125 feet). The length of the site was chosen so that initial catches were at least 10 bushels per tow (typically 1200 to 2400 feet) based on trial tows near the edge and parallel to depletion site.

After the size of the site was defined, depletion tows were carried out repeatedly (typically 17-22 tows per site) by the F/V Endeavor using the port dredge until the site showed substantial depletion and catch per tow declined significantly. Tow paths were adjusted based on GPS data to tow sufficiently over the entire rectangle to see a significant decline in catch per tow in all areas of the rectangle. In most cases, this took place after the entire area of the rectangle was covered at least twice with the dredge –usually between 17 and 22 tows. Each tow was approximately 5-minutes in duration. Ship positions were recorded during maximally every 5 seconds, after which the catch was allowed to run over the shaker table and onto the sorting belt. On every tow the number of clam bushels was counted and the partial bushel estimated. On every fifth tow, starting with tow two, one full bushel was measured and a second counted. Depletion experiments took anywhere between 9 and 16 hours to complete depending on the conditions at the site and the number of animals in the selected rectangular grid.

D. Surfclam and Ocean Quahog Repeat Stations

About halfway through the 2008 NEFSC clam survey with the Delaware II, an electrical cable used to power the pump on the survey dredge was replaced with a longer cable. Similarly, the pump on the NEFSC survey dredge was replaced after the original pump failed after about a third of the survey. The *F/V Endeavor* reoccupied some stations originally towed by the Delaware II which was using various configurations of old and new equipment to help quantify potential changes in survey dredge efficiency due to changing equipment. In some cases, these repeat station experiments were combined with or carried out at the same location as surfclam size selectivity and depletion experiments.

These sites had already been occupied either once or twice by the Delaware II during 2008 using the NEFSC survey dredge and the old and/or new cable and pump. At these sites the *F/V Endeavor* towed the port dredge for 5-minutes. The catch was run over the shaker table and onto the sorting belt. The total number of bushels was counted. The number of clams in the partial bushel and in two full bushels was counted, and all clams in the two full bushels were measured to the nearest mm.

Results

See Table 1 and Figure 1, which list the location and type of all cooperative stations, along with station numbers from the NEFSC clam survey for repeat stations.

The length frequency of all ocean quahogs measured on the survey can be found in Figure 2. The length frequency of all surf clams measured from 5-minute, unlined tows (size-selectivity experiments and depletion experiments) can be found in Figure 3. The length frequency of all surf clams measured from 30-second, lined tows can be found in Figure 4.

Sensor data and area swept

Sensor data was used to determine when the dredge was on/off bottom. Times on/off bottom were then matched to a GPS record of the ship's position to estimate area swept by the dredge. The NEFSC Survey Sensor Package used during the cooperative survey records latitude, longitude, angle of the dredge (fore/aft and port/starboard), temperature, depth, and internal manifold pressure every second. The frequency and resolution of the output data make it easy to determine when the dredge is on bottom and fishing. SSP data were not collected for some tows during Legs I and II because the battery could not be not fully charged due to lack of time between stations. Also, the SSP was not operational during Leg III due to lack of trained scientific staff. Therefore, SSP sensor data were available for less than half of the sites occupied. Fortunately, backup GPS and sensor data including ambient temperature and pressure (depth) from backup sensors are available for every tow.

The backup GPS and sensors were used to determine time on-bottom and area swept for tows with no SSP data. Backup sensors record depth at a lower resolution (accuracy approximately 5 meters) and at a lower frequency (5 second intervals) than the SSP. It was therefore necessary to use SSP data where available to develop procedures for estimating time on/off bottom and area swept using backup sensor data. The following steps were taken to determine when the dredge was fishing and subsequently estimate the area swept using these sensors for tows where SSP data was not available:

1. The backup pressure (depth) data for each station was used to estimate times the dredge was on or off bottom. The resolution of the backup pressure data is 5 meters and the apparent trajectory of the dredge during the tow is noisy. In particular, a small change in depth can appear to be a large change. This adds uncertainty to the estimates of time on/off bottom.

2. Initial time on/off bottom estimates based on backup sensor data were compared to estimates from SSP data for 51 surfclam stations with SSP data. In comparing time on/off bottom estimates made using backup sensor and SSP data, it was noted that estimates based on backup sensors lagged SSP estimates by about 15 seconds. Estimates based on backup sensors were therefore corrected by subtraction of 15 seconds. After this adjustment, times on/off bottom differed, on average, by only 1 second (Table 2). Furthermore, after applying this correction, the chance of the backup sensor estimate being ahead of the SSP estimate and the chance of the backup sensor estimate being behind the SSP annotation were equal. The lag method was applied to all tows for which SSP data were lacking.

3. The initial time on/off bottom estimates based on backup sensor data were compared to estimates from SSP data for 34 ocean quahog tows from depletion experiments OQ0801 and OQ0802. Backup sensor estimates of time off bottom matched well with the SSP estimates. However, the backup sensor estimate of time on bottom averaged 15 seconds ahead of the estimates based on SSP data. With the adjustment for a 15 seconds lag described above, the backup sensor estimates differed from the SSP annotations by an average of four seconds. Furthermore, after applying this correction, the chance of the backup sensor estimate being ahead of the SSP estimate and the chance of the backup sensor estimate being behind the SSP annotation were equal. Therefore, the 15 second adjustment was used for all Vemco files across all tows and all experiments for which SSP data were lacking.

4. The SSP and adjusted backup sensor estimates of time on/off bottom were used to determine the area swept.

COMMENTS

Having primary (SSP) and backup GPS and sensor data for each tow is critical. Efforts should be made to increase the reliability of the SSP on commercial vessels and to increase the resolution and the recording frequency of backup sensors.

The ambient pressure sensor on the SSP malfunctioned unexpectedly because the tubing connecting it to the dredge had a tendency to plug up. A different approach to mounting the pressure sensor should be used next time.

Backup sensors should include an inclinometer to measure the fore/aft angle of the dredge, which are useful data in determining time on/off bottom.

Power out winches made it difficult to drop the dredge within a specific rectangular area during depletion experiments, and increased difficulties in interpreting time on/off bottom from backup sensor data. Boat operators were able to adjust towing procedures and to drop the dredge reliably in the rectangular area. However, the number of unsuccessful attempted tows increased over the previous years, adding time to the total time required to conduct the experiments. In the future an effort should be made to use free-fall winches.

The chicken wire liner proved to be sturdy and reliable. No repair was needed except at the leading edge behind the knife. Welding a bar across this leading edge in the future would eliminate this one weak point and permit long-term use of a lined dredge for improved estimates of smaller clams.

SCIENTIFIC CREW

Below is a list of names and email addresses for the scientific crew that participated in the survey. In addition to the science crew, aboard the vessel for all three legs were the captain, first mate, four crew members, and a cook (16 persons in total on each leg).

Legs 1 and 2:

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Table 1. 2008 Cooperative Industry Surf Clam/Ocean Quahog Survey station list. "Shape on Map" refers to the map in Figure 1 where all stations are plotted using specific shapes to identify the purpose of the station.

NMFS Site #	NMFS Depletion #	Shape on Map	Site Type	Lat	Long	# of Surf Clam Bushels (Depletion Sites, Tow 1 Only)	# of Quahog Bushels (Depletion Sites, Tow 1 Only)	Comments
36	N/A	STAR	Surf Clam Size Selectivity	39.8597	73.7122	4	1.33	
49	N/A	STAR	Surf Clam Size Selectivity	39.6523	74.0078	6	0	
60	N/A	STAR	Surf Clam Size Selectivity	39.5688	74.1133	5.5	0	
64	N/A	STAR	Surf Clam Size Selectivity	39.4385	74.1782	3	0	
292	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	40.0633	73.6757	22.33	0.67	
293	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	39.9765	73.5343	22	8.25	
294	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	39.9427	73.588	22	0.67	
295	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	39.8575	73.4783	22	3	

296	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	39.7323	73.4477	29.75	0	
303	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	39.7213	73.8003	11	0	
304	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	39.7723	73.844	22.25	0	
310	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	39.8118	73.9473	17.75	0	
312	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	39.939	73.814	17	0.01	
313	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	39.9788	73.7162	19.5	0.25	
314	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	39.9832	73.8482	9	0	
315	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	40.1027	73.7745	22	0.33	
316	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	40.1465	73.945	28	0	

318	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	39.5633	73.9113	9.5	0	
319	N/A	CROSS	Repeat Surf Clam / Surf Clam Size Selectivity	39.4768	73.911	11	0	
67	SC08-01	CIRCLE	Surf Clam Depletion	39.3073	74.054	6.5	0	
74	SC08-02	CIRCLE	Surf Clam Depletion	39.188	74.0753	16.67	0	
297	SC08-03	CIRCLE	Surf Clam Depletion	39.6028	73.41	16	0	
305	SC08-04	CIRCLE	Surf Clam Depletion	39.8093	73.9132	11	0	
358	SC08-05	CIRCLE	Surf Clam Depletion	41.1457	70.047	14	0	The running tide, wind, and waves made it impossible to stay inside the rectangle at this location. Therefore, this site was terminated after 6 tows.
N/A	N/A (SC08-09)	CIRCLE	Surf Clam Depletion	39.3117	74.0537	14	0	We picked this site as an additional depletion site because SC08-05 was untowable.
324	N/A	SQUARE	Repeat Quahog	40.8915	71.859	0	14.5	

326	N/A	SQUARE	Repeat Quahog	40.9422	71.9528	0	0	No catch here. This tow was not run through the hopper because the dredge was filled with large rocks.
333	N/A	SQUARE	Repeat Quahog	40.8555	72.12	0	43.33	
334	N/A	SQUARE	Repeat Quahog	40.8138	72.1755	0	20.25	
336	N/A	SQUARE	Repeat Quahog	40.773	72.4152	0	13	
338	N/A	SQUARE	Repeat Quahog	40.726	72.6485	0	14	
339	N/A	SQUARE	Repeat Quahog	40.558	72.6467	0	28	
199	N/A	INV. TRIANGLE	Quahog Old Wire	40.2568	73.2653	0	6	
201	N/A	INV. TRIANGLE	Quahog Old Wire	40.1497	73.0467	0	29.25	
203	N/A	INV. TRIANGLE	Quahog Old Wire	40.2747	72.9737	0	27	
205	N/A	INV. TRIANGLE	Quahog Old Wire	40.3165	72.7473	0	18.5	
207	N/A	INV. TRIANGLE	Quahog Old Wire	40.187	72.9453	0	35.75	
209	N/A	INV. TRIANGLE	Quahog Old Wire	40.0577	72.8393	0	37.5	
272	N/A	TRIANGLE	Quahog New Wire	40.5608	72.2457	0	22.75	
274	N/A	TRIANGLE	Quahog New Wire	40.6503	72.278	0	6.5	
276	N/A	TRIANGLE	Quahog New Wire	40.7298	72.2808	0	5.25	
278	N/A	TRIANGLE	Quahog New Wire	40.7298	72.086	0	64.5	
280	N/A	TRIANGLE	Quahog New Wire	40.8082	71.7798	0	0.67	
282	N/A	TRIANGLE	Quahog New Wire	40.6865	71.948	0	24.67	

173	OQ08-01	DIAMOND	Quahog Depletion	40.9363	72.0428	0	31.33	
287	OQ08-02	DIAMOND	Quahog Depletion	40.2702	72.8483	0	30	
344	OQ08-05	DIAMOND	Quahog Depletion	40.721	71.3465	0	4	This site was untowable.
351	OQ08-06	DIAMOND	Quahog Depletion	41.0172	70.8558	0	34	
N/A	N/A (OQ08-09)	DIAMOND	Quahog Depletion	41.0187	70.8559	0	24	We picked this site as an extra one because OQ08-05 was untowable, however, we needed to leave this site after 6 tows to bring in a sick crew member.

Table 2. (On following pages): 15-second adjustments made to Vemco sensor on-bottom and off-bottom records to more closely match SSP on-bottom and off-bottom records. Columns 1 and 2, Depletion and Tow or Site #, identify the site. Column 3 and 5, On-Bottom-VEMCO and Off-Bottom-VEMCO, are the times the dredge was on the bottom and fishing and then off bottom, respectively, according to VEMCO sensor annotations. Adjusted + 15 seconds in columns 4 and 6 are the same times, but with a 15-second, or three reading adjustment. Columns 7 and 8, On-Bottom SSP and Off- Bottom SSP, are the times the dredge was on the bottom and fishing and then off bottom, respectively, according to SSP sensor annotations. The last four columns calculate the difference in seconds between the SSP data and the Vemco sensor data annotations before and after the 15-second adjustment was made.

Depletion Station	Tow or Site #	On Bottom - VEMCO	Adjusted: + 15 seconds	Off Bottom- VEMCO	Adjusted: + 15 seconds	On Bottom- SSP	Off Bottom- SSP	On Bottom Difference: Un-adjusted	Off Bottom Difference: Un-adjusted	On Bottom Difference: adjusted	Off Bottom Difference: adjusted
SC08-01	2	14:00:22	14:00:38	14:12:42	14:12:57	14:00:50	14:12:56	0:00:28	0:00:14	0:00:12	-0:00:01
SC08-01	3	14:49:15	14:49:30	15:01:15	15:01:30	14:49:25	15:01:27	0:00:10	0:00:12	-0:00:05	-0:00:03
SC08-01	5	16:16:25	16:16:40	16:28:35	16:28:50	16:16:44	16:28:57	0:00:19	0:00:22	0:00:04	0:00:07
SC08-01	6	16:50:35	16:50:50	17:03:25	17:03:40	16:50:27	17:03:50	-0:00:08	0:00:25	-0:00:23	0:00:10
SC08-01	10	18:57:36	18:57:51	19:10:11	19:10:26	18:58:00	19:10:25	0:00:24	0:00:14	0:00:09	-0:00:01
SC08-01	13	20:39:31	20:39:46	20:51:51	20:52:06	20:39:48	20:52:05	0:00:17	0:00:14	0:00:02	-0:00:01
SC08-02	2	2:41:32	2:41:47	2:51:37	2:51:52	2:41:55	2:51:37	0:00:23	0:00:00	0:00:08	-0:00:15
SC08-02	3	3:23:21	3:23:36	3:33:06	3:33:21	3:23:45	3:33:07	0:00:24	0:00:01	0:00:09	-0:00:14
SC08-02	4	3:50:16	3:50:31	3:59:56	4:00:11	3:50:36	4:00:01	0:00:20	0:00:05	0:00:05	-0:00:10
SC08-02	5	4:17:01	4:17:16	4:27:06	4:27:21	4:17:27	4:27:11	0:00:26	0:00:05	0:00:11	-0:00:10
SC08-02	6	4:41:41	4:41:56	4:51:41	4:51:56	4:42:04	4:52:01	0:00:23	0:00:20	0:00:08	0:00:05
SC08-03	1	2:08:29	2:08:44	2:16:59	2:17:14	2:08:55	2:17:22	0:00:26	0:00:23	0:00:11	0:00:08
SC08-03	2	2:37:24	2:37:39	2:46:04	2:46:19	2:37:46	2:46:26	0:00:22	0:00:22	0:00:07	0:00:07
SC08-03	4	3:48:42	3:48:57	3:57:17	3:57:33	3:49:04	3:57:38	0:00:22	0:00:21	0:00:07	0:00:05
SC08-03	5	4:13:22	4:13:38	4:21:22	4:21:37	4:13:30	4:21:38	0:00:08	0:00:16	-0:00:08	0:00:01
SC08-03	7	5:01:52	5:02:07	5:10:32	5:10:47	5:02:14	5:10:55	0:00:22	0:00:23	0:00:07	0:00:08
SC08-03	9	6:00:42	6:00:57	6:08:12	6:08:27	6:01:08	6:08:36	0:00:26	0:00:24	0:00:11	0:00:09
SC08-03	12	7:19:27	7:19:42	7:28:27	7:28:42	7:19:56	7:28:47	0:00:29	0:00:20	0:00:14	0:00:05
SC08-03	13	8:02:05	8:02:20	8:09:45	8:10:00	8:02:29	8:10:00	0:00:24	0:00:15	0:00:09	0:00:00
SC08-03	14	12:00:45	12:01:00	12:10:00	12:10:15	12:00:49	12:10:02	0:00:04	0:00:02	-0:00:11	-0:00:13
SC08-03	15	13:13:33	13:13:48	13:23:28	13:23:43	13:13:42	13:23:34	0:00:09	0:00:06	-0:00:06	-0:00:09
SC08-03	16	13:44:38	13:44:53	13:54:38	13:54:53	13:44:51	13:54:43	0:00:13	0:00:05	-0:00:02	-0:00:10
SC08-03	17	14:18:08	14:18:23	14:27:23	14:27:38	14:18:27	14:27:40	0:00:19	0:00:17	0:00:04	0:00:02
SC08-03	18	15:00:21	15:00:36	15:09:21	15:09:36	15:00:41	15:09:49	0:00:20	0:00:28	0:00:05	0:00:13
SC08-03	19	15:30:06	15:30:21	15:39:26	15:39:41	15:30:16	15:39:53	0:00:10	0:00:27	-0:00:05	0:00:12
SC08-03	21	16:51:16	16:51:31	17:00:11	17:00:26	16:51:36	17:00:32	0:00:20	0:00:21	0:00:05	0:00:06
SC08-03	22	17:17:36	17:17:51	17:27:51	17:28:06	17:17:58	17:28:10	0:00:22	0:00:19	0:00:07	0:00:04
SC08-04	2	22:44:17	22:44:32	22:55:02	22:55:17	22:44:26	22:55:04	0:00:09	0:00:02	-0:00:06	-0:00:13
SC08-04	3	23:23:41	23:23:56	23:34:51	23:35:06	23:23:56	23:35:12	0:00:15	0:00:21	0:00:00	0:00:06

SC08-04	5	0:50:31	0:50:46	1:01:56	1:02:11	0:50:48	1:02:08	0:00:17	0:00:12	0:00:02	-0:00:03
SC08-04	7	2:36:21	2:36:36	2:45:31	2:45:46	2:36:44	2:45:46	0:00:23	0:00:15	0:00:08	0:00:00
SC08-04	8	3:10:44	3:10:59	3:19:49	3:20:04	3:10:55	3:20:10	0:00:11	0:00:21	-0:00:04	0:00:06
SC08-04	9	3:43:39	3:43:54	3:52:44	3:52:59	3:43:51	3:53:07	0:00:12	0:00:23	-0:00:03	0:00:08
SC08-04	10	4:13:49	4:14:04	4:22:59	4:23:14	4:13:55	4:23:19	0:00:06	0:00:20	-0:00:09	0:00:05
SC08-04	11	4:50:09	4:50:24	4:59:19	4:59:34	4:50:16	4:59:42	0:00:07	0:00:23	-0:00:08	0:00:08
SC08-04	12	5:23:24	5:23:39	5:32:29	5:32:44	5:23:40	5:32:49	0:00:16	0:00:20	0:00:01	0:00:05
SC08-04	13	6:28:58	6:29:13	6:38:18	6:38:33	6:29:09	6:38:36	0:00:11	0:00:18	-0:00:04	0:00:03
SC08-04	14	7:00:43	7:00:58	7:10:13	7:10:28	7:00:59	7:10:30	0:00:16	0:00:17	0:00:01	0:00:02
SC08-04	15	7:33:53	7:34:07	7:43:08	7:43:23	7:34:05	7:43:30	0:00:12	0:00:22	-0:00:02	0:00:07
SC08-04	16	8:01:03	8:01:18	8:10:08	8:10:23	8:01:09	8:10:28	0:00:06	0:00:20	-0:00:09	0:00:05
SC08-05	1	16:51:06	16:51:21	16:57:06	16:57:31	16:51:28	16:57:20	0:00:22	0:00:14	0:00:07	-0:00:11
SC08-05	2	17:13:26	17:13:41	17:19:31	17:19:46	17:13:34	17:19:51	0:00:08	0:00:20	-0:00:07	0:00:05
SC08-05	3	19:08:53	19:09:08	19:14:28	19:14:43	19:09:20	19:14:43	0:00:27	0:00:15	0:00:12	0:00:00
SC08-05	6	21:04:18	21:04:33	21:10:48	21:11:03	21:04:43	21:11:01	0:00:25	0:00:13	0:00:10	-0:00:02
	304	9:37:14	9:37:29	9:43:54	9:44:09	9:37:34	9:44:10	0:00:20	0:00:16	0:00:05	0:00:01
	303	14:17:59	14:18:14	14:24:14	14:24:29	14:18:14	14:24:37	0:00:15	0:00:23	0:00:00	0:00:08
	36	17:10:13	17:10:28	17:16:43	17:16:58	17:10:32	17:16:57	0:00:19	0:00:14	0:00:04	-0:00:01
	312	18:43:43	18:43:58	18:51:28	18:51:43	18:44:05	18:51:41	0:00:22	0:00:13	0:00:07	-0:00:02
	313	21:46:33	21:46:48	21:54:28	21:54:43	21:46:46	21:54:39	0:00:13	0:00:11	-0:00:02	-0:00:04
	314	0:22:38	0:22:53	0:30:13	0:30:28	0:22:42	0:30:13	0:00:04	0:00:00	-0:00:11	-0:00:15
	316	2:48:28	2:48:43	2:55:08	2:55:33	2:48:28	2:55:48	0:00:00	0:00:40	-0:00:15	0:00:15
							Average Difference:	**0:00:16**	**0:00:16**	**0:00:01**	**0:00:01**

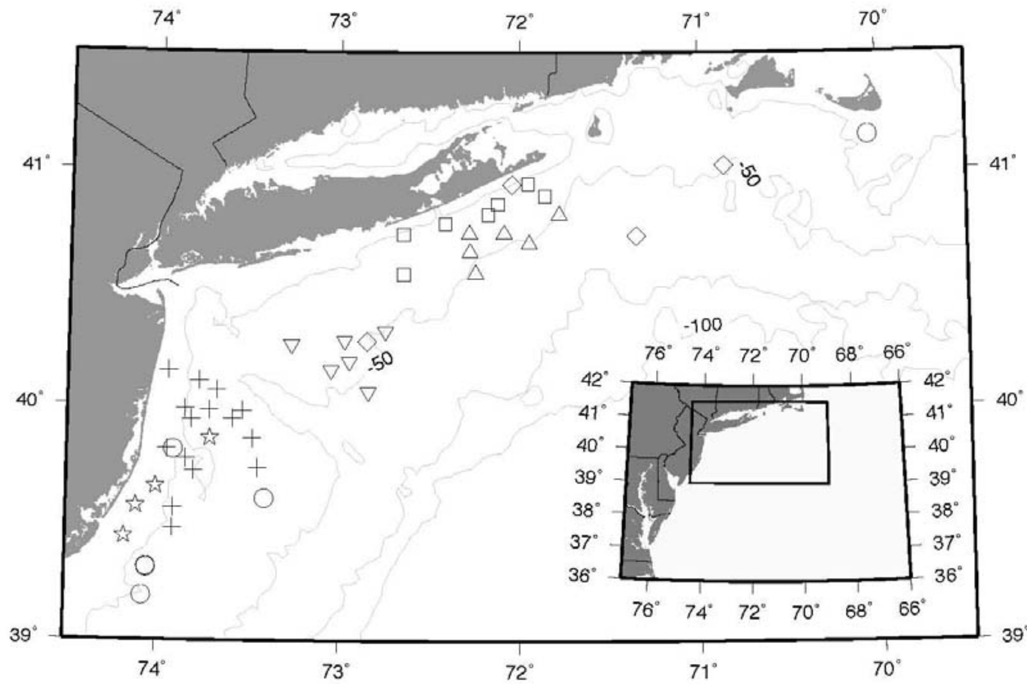


Figure 1. Map of site locations from the 2008 Cooperative Industry Surf Clam/Ocean Quahog Survey. Shapes indicate the type of site. See Table 1 for which tows are represented by which shape.

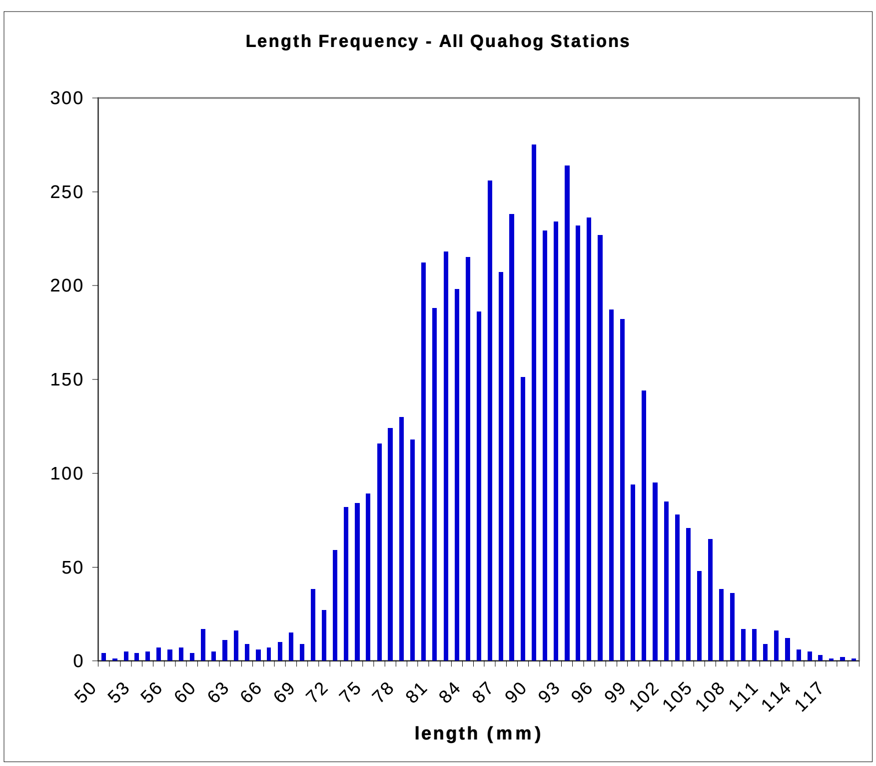


Figure 2. The length frequency of all ocean quahogs measured on 2008 Cooperative Industry Surf Clam/Ocean Quahog Survey

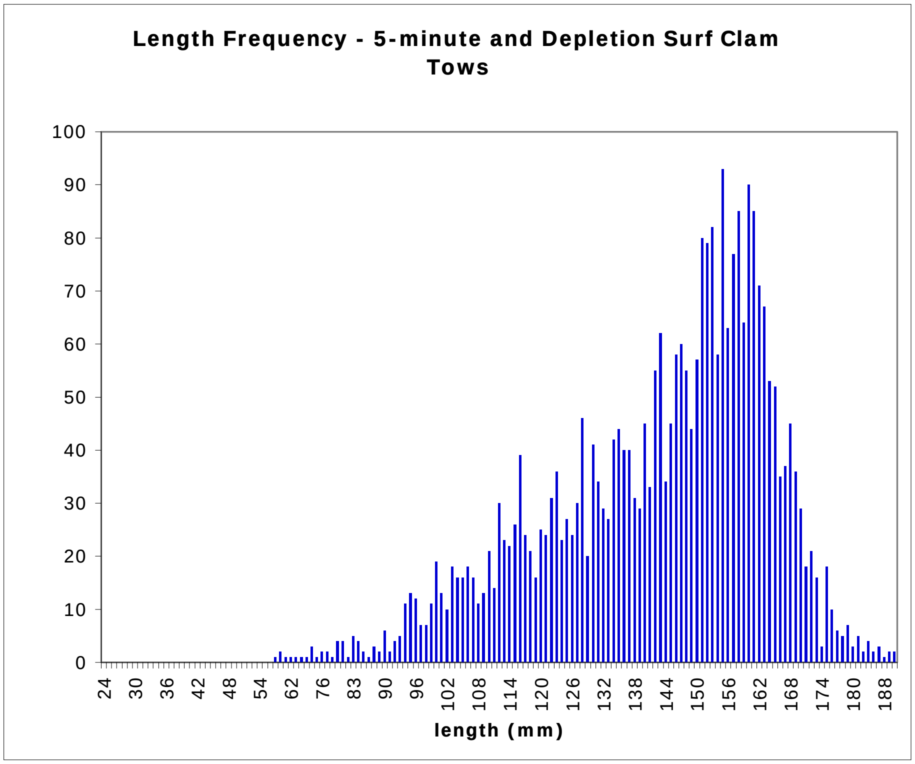


Figure 3. The length frequency of all surf clams measured from 5-minute, unlined tows (size-selectivity experiments and depletion experiments) on 2008 Cooperative Industry Surf Clam/Ocean Quahog Survey

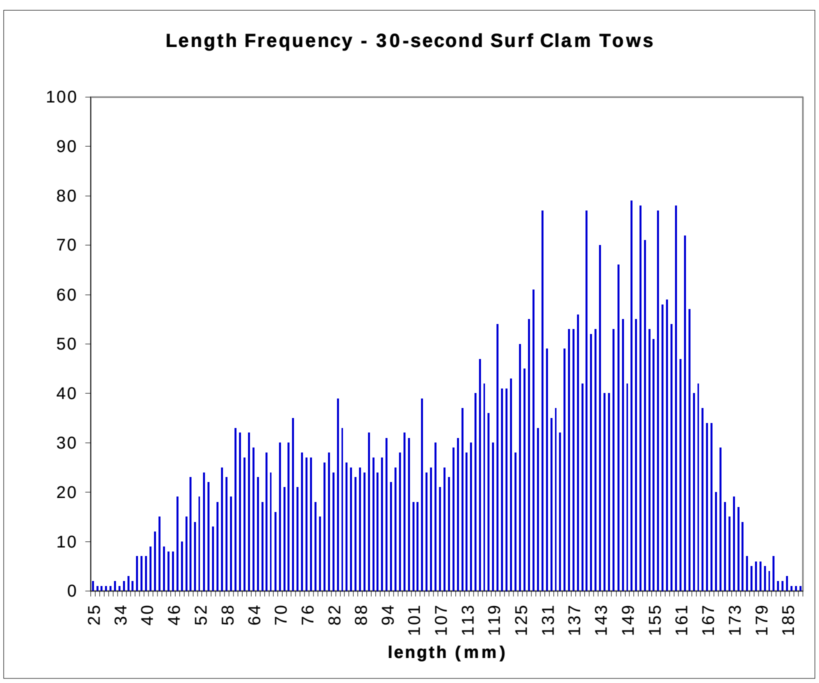


Figure 4. The length frequency of all surf clams measured from 30-second, lined tows on 2008 Cooperative Industry Surf Clam/Ocean Quahog Survey

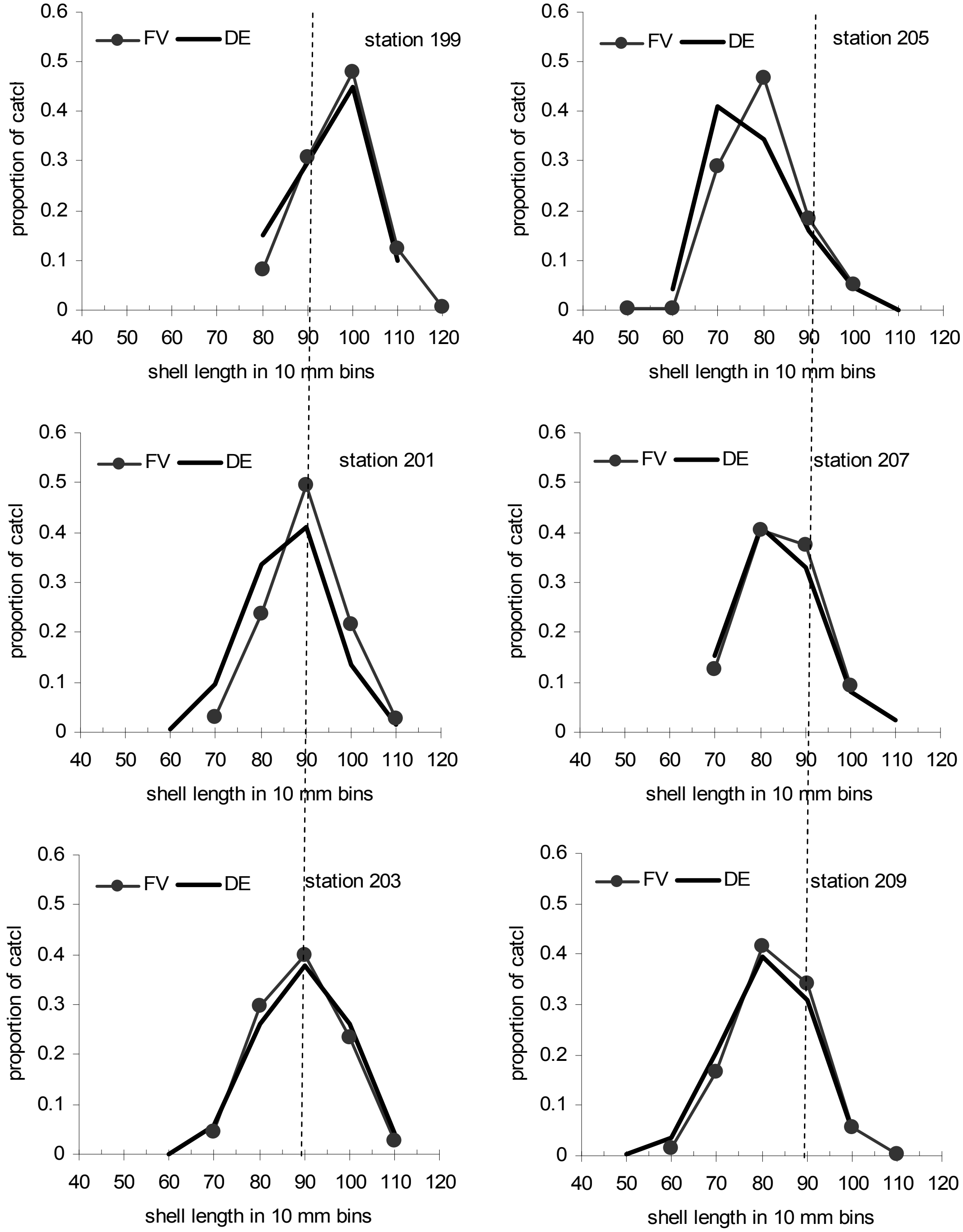


Figure 5. Length composition data for DE2FV repeat tows. For example, 70 mm on the x-axis refers to the 70-79 mm SL bin. Values on the y-axis are proportions of the total.

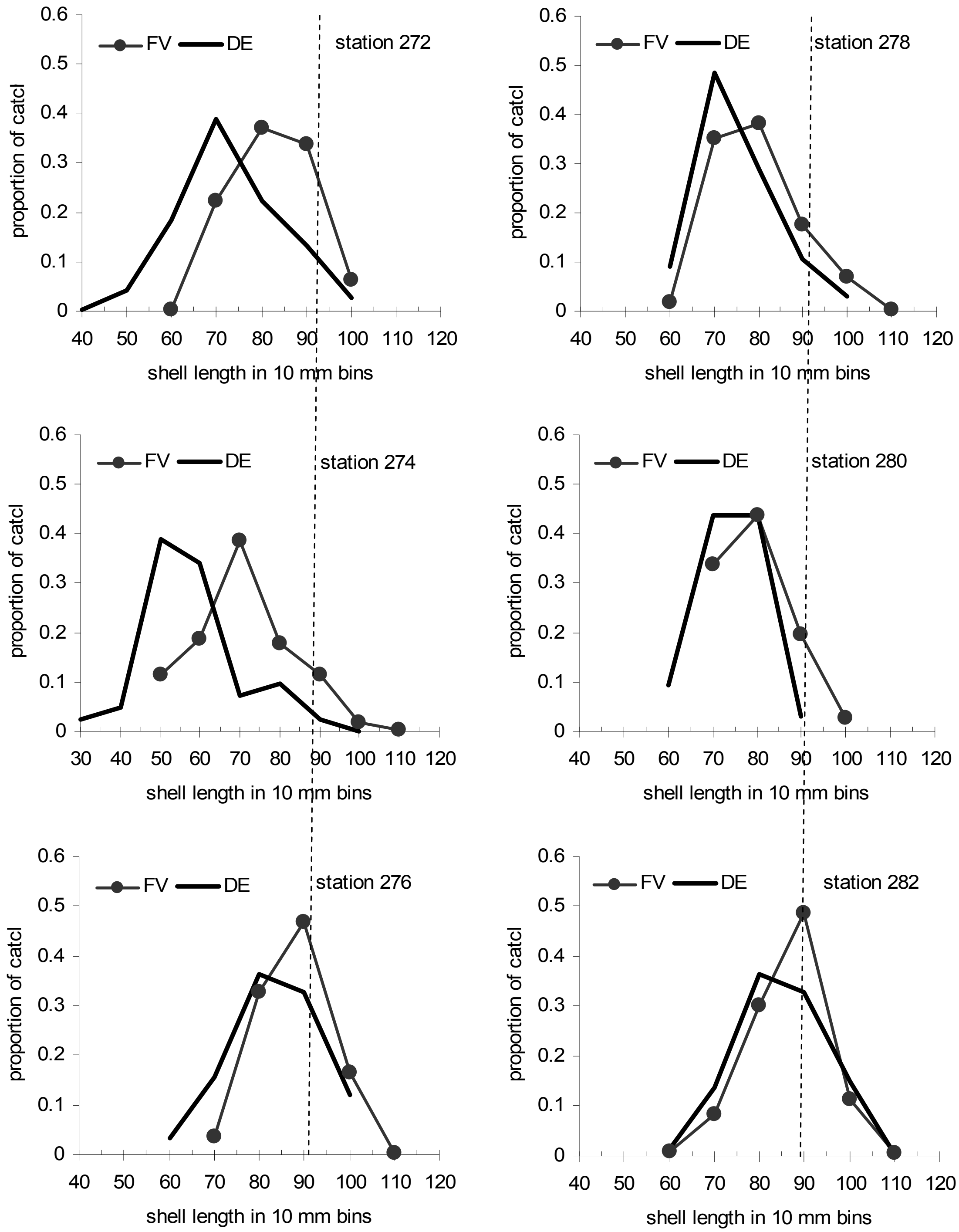
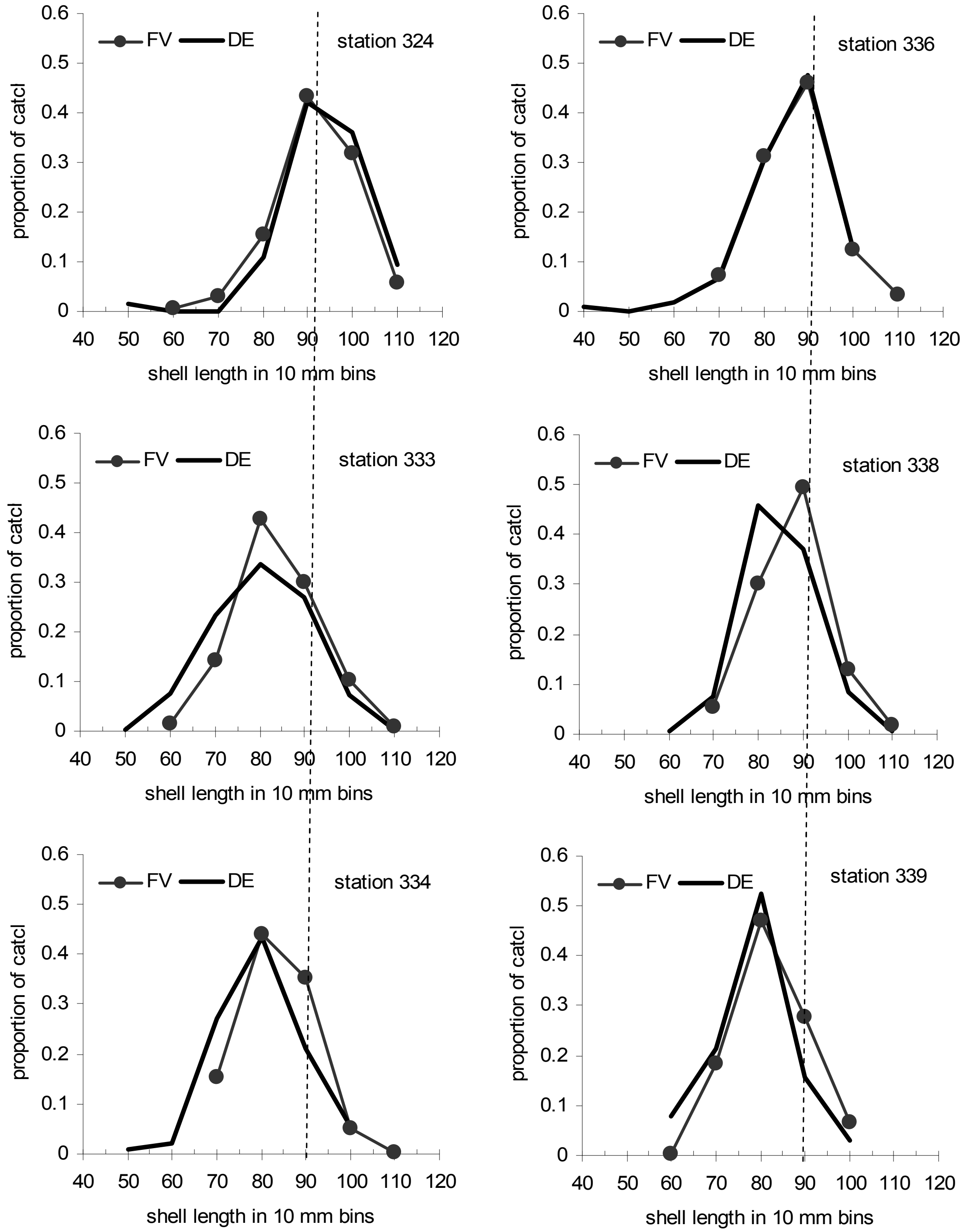
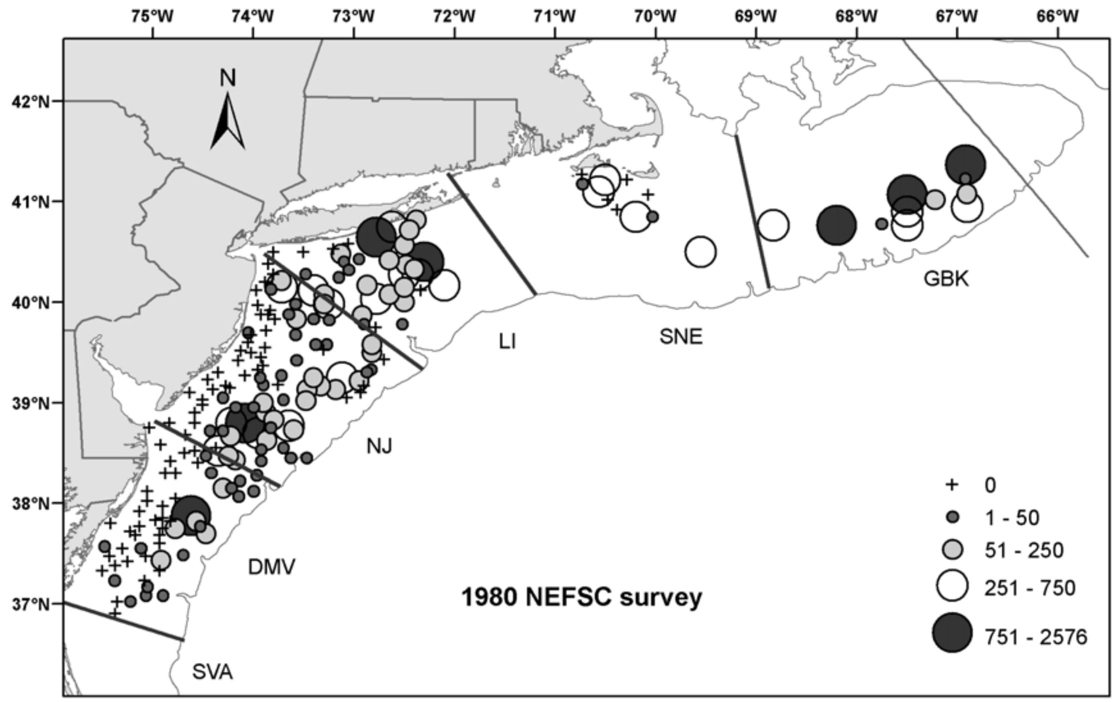
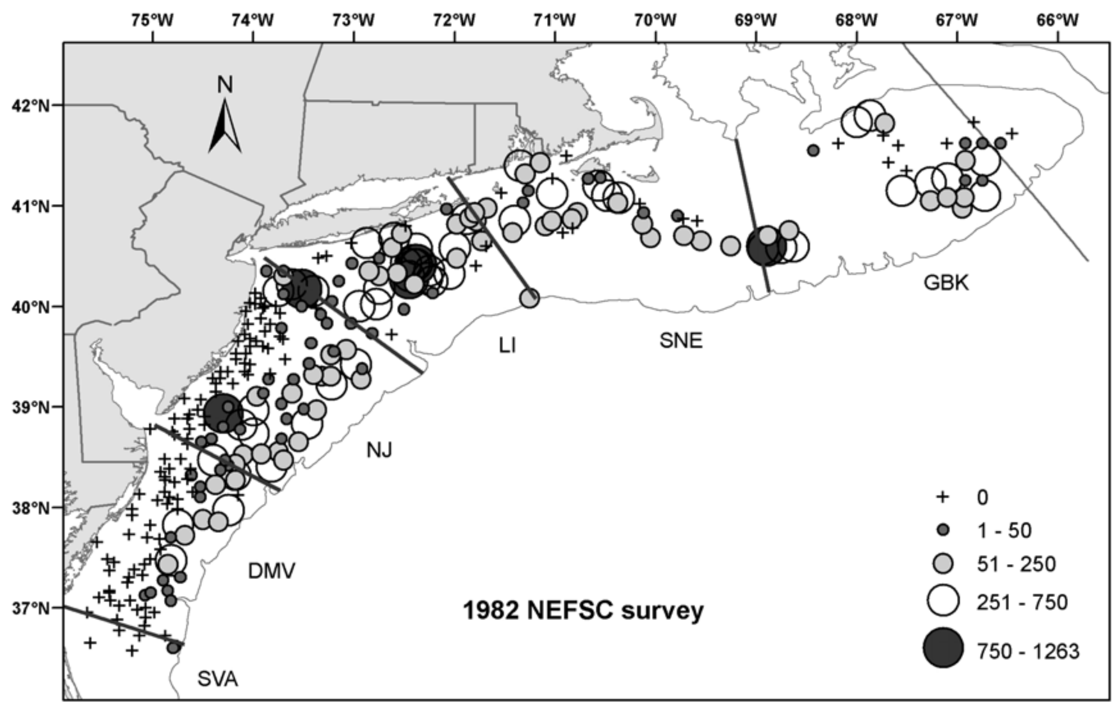


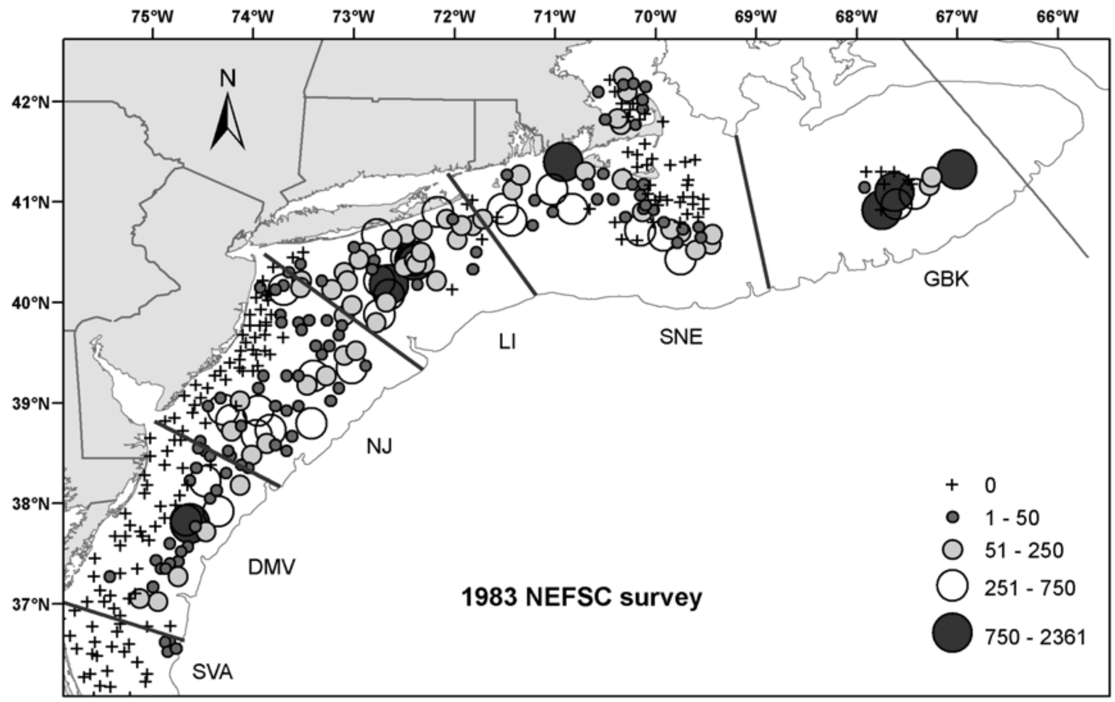
Figure 5. (cont.)


FV
DE
station 324
station 336
station 333
station 338
station 334
station 339
proportion of catcl
shell length in 10 mm bins

Appendix B5: Maps of NEFSC clam survey catches 1980-2008.






75°W
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68°W
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66°W
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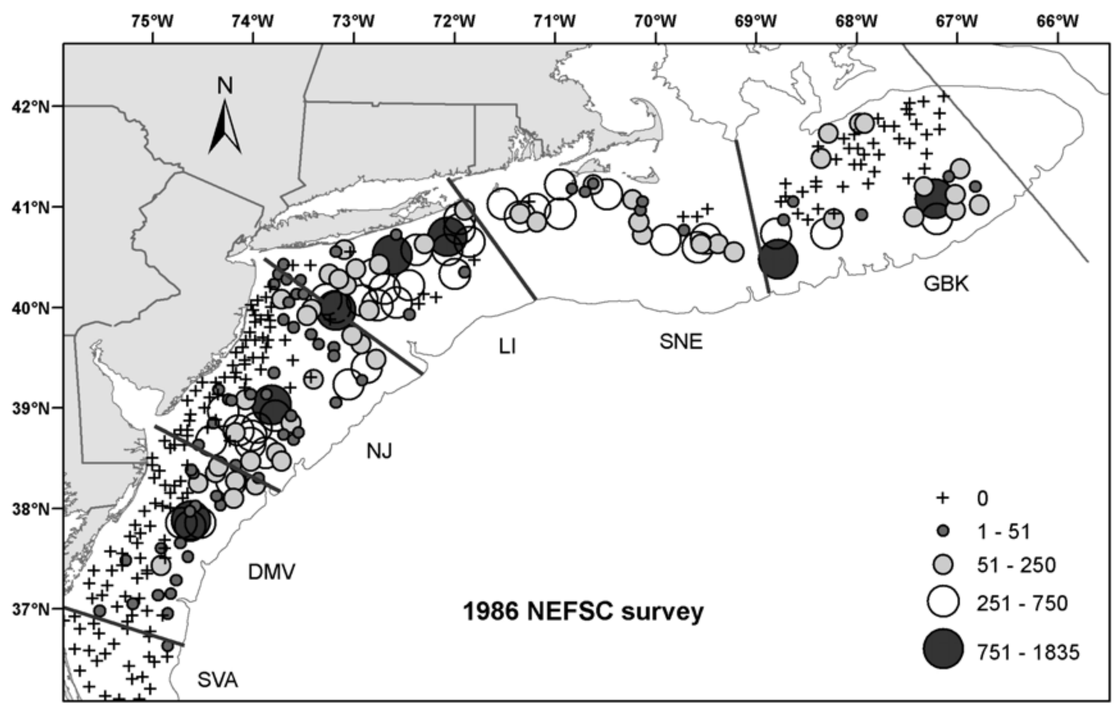
41°N
40°N
39°N
38°N
37°N
N
LI
SNE
GBK
NJ
DMV
SVA
0
1 - 50
51 - 250
251 - 750
750 - 2361
1983 NEFSC survey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38°N
37°N
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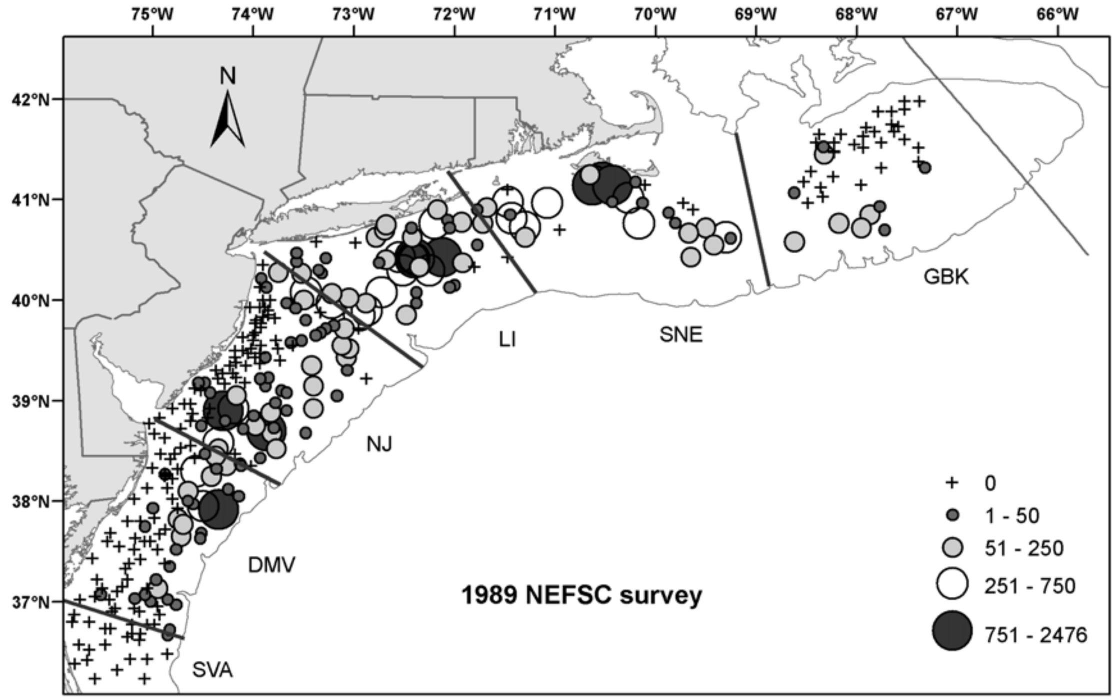
SNE
GBK
NJ
DMV
SVA
0
1 - 51
51 - 250
251 - 750
751 - 1835
1986 NEFSC survey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38°N
37°N
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NJ
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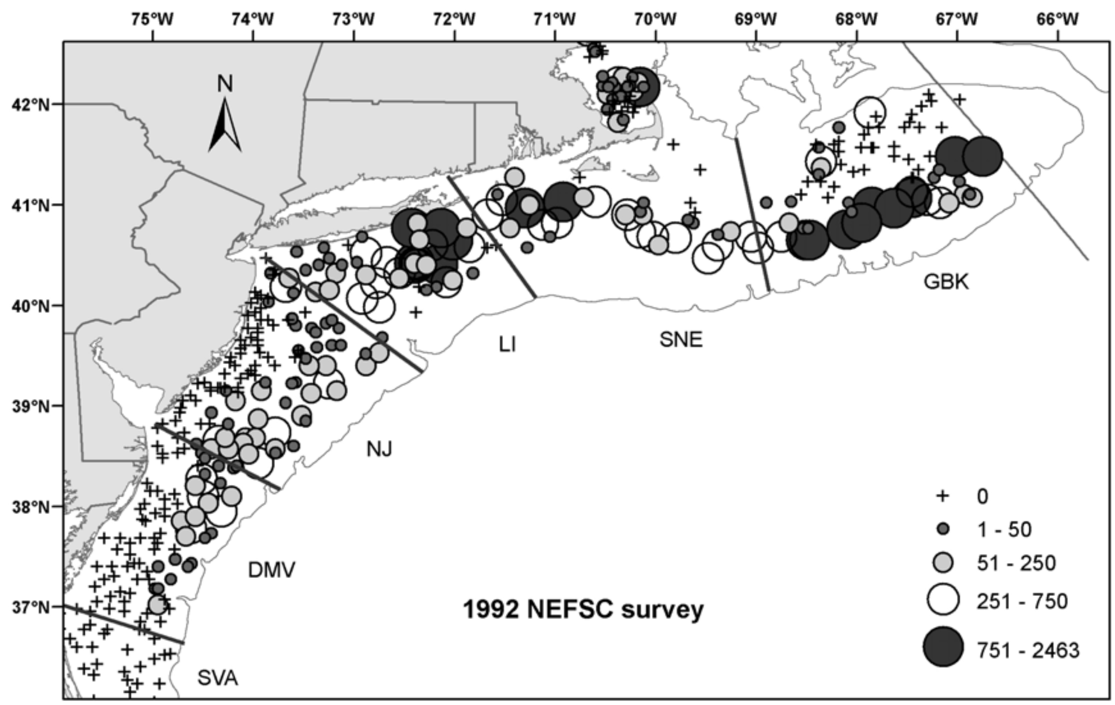
SVA
0
1 - 50
51 - 250
251 - 750
751 - 2476
1989 NEFSC survey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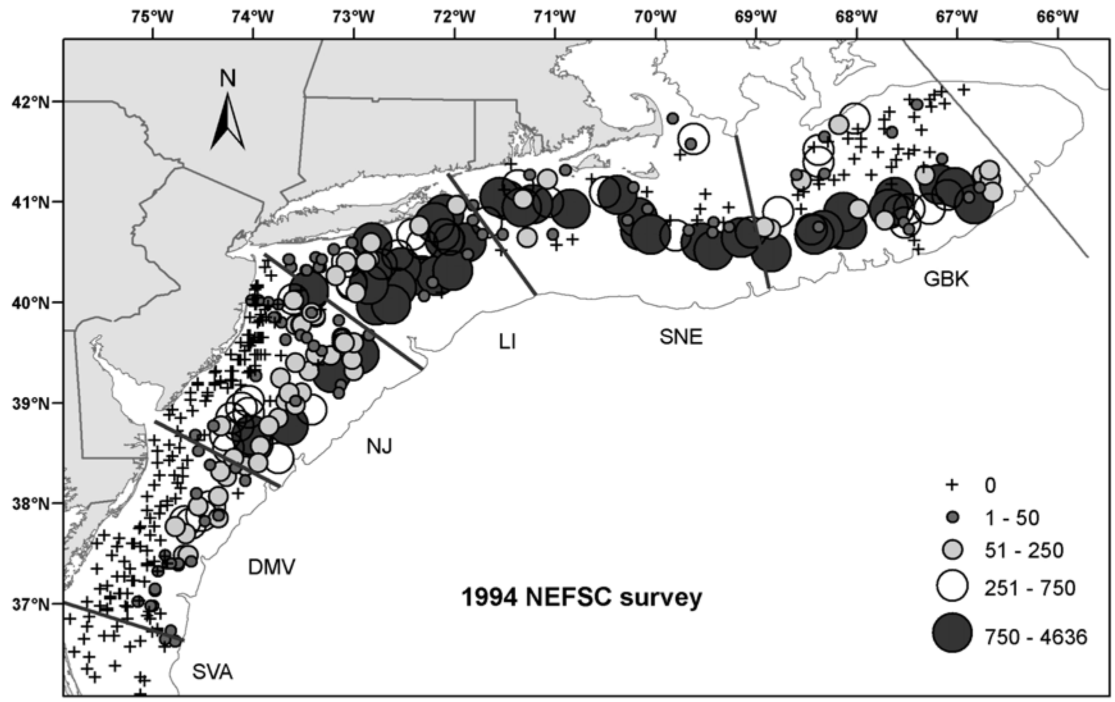
0
1 - 50
51 - 250
251 - 750
751 - 2463
1992 NEFSC survey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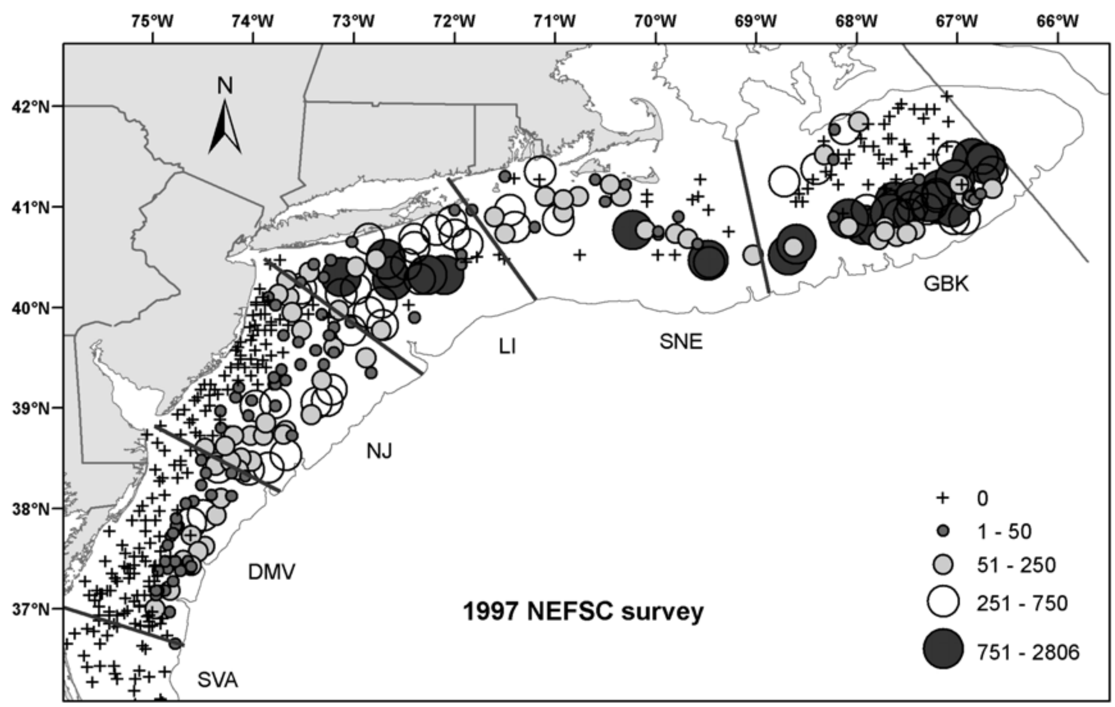
38°N
37°N
N
GBK
LI
SNE
NJ
DMV
SVA
1994 NEFSC survey
0
1 - 50
51 - 250
251 - 750
750 - 4636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NJ
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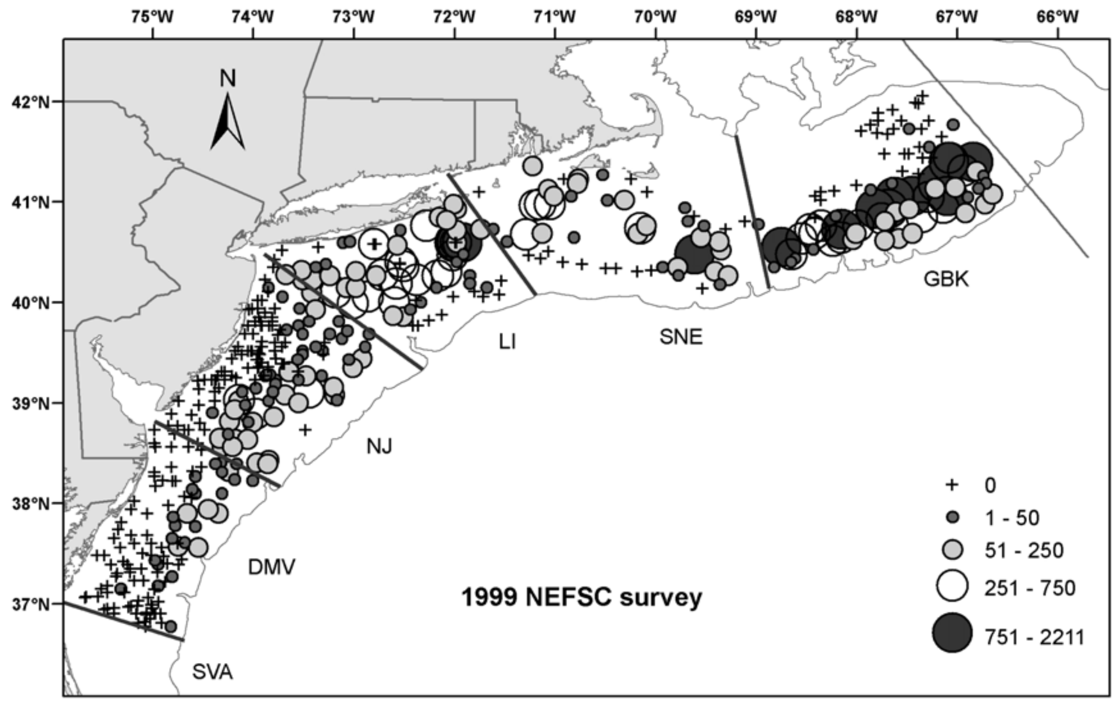
SVA
1997 NEFSC survey
0
1 - 50
51 - 250
251 - 750
751 - 2806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DMV
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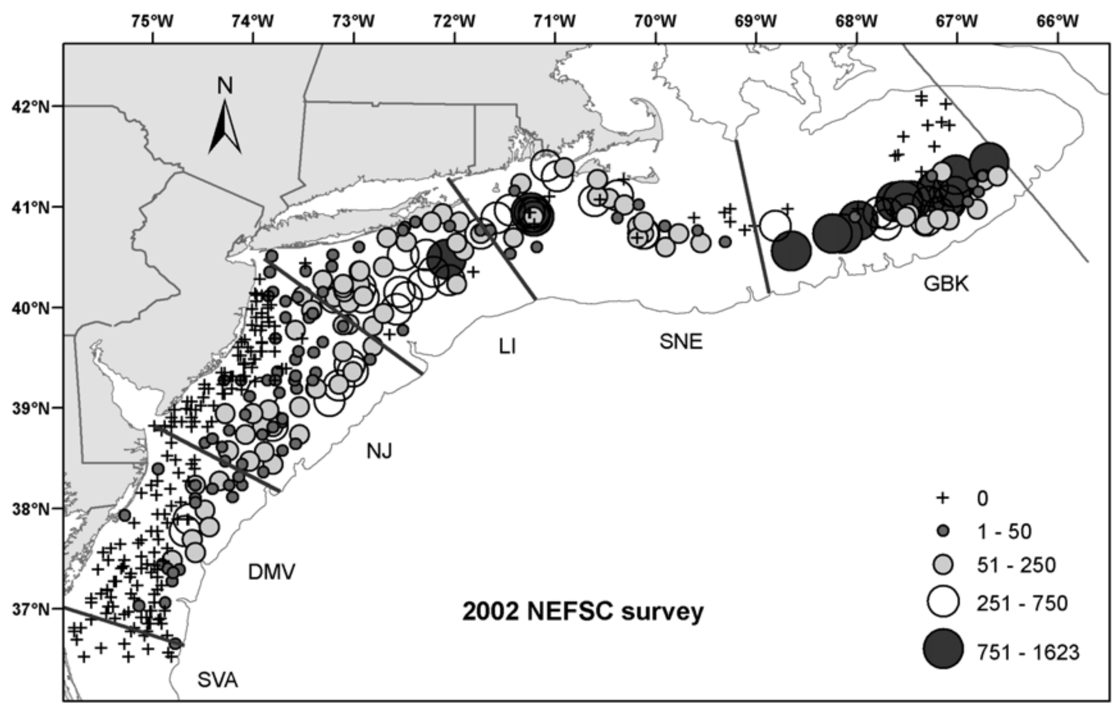
0
1 - 50
51 - 250
251 - 750
751 - 2211
1999 NEFSC survey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37°N
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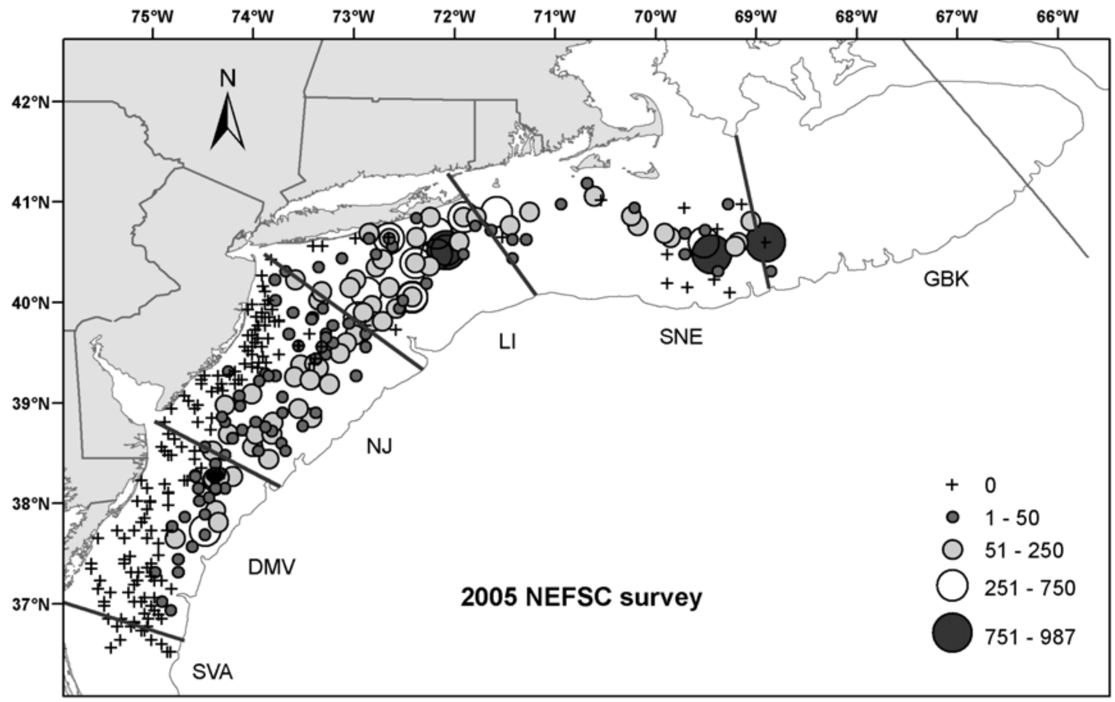
SNE
GBK
NJ
DMV
SVA
0
1 - 50
51 - 250
251 - 750
751 - 1623
2002 NEFSC survey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38°N
37°N
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SNE
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DMV
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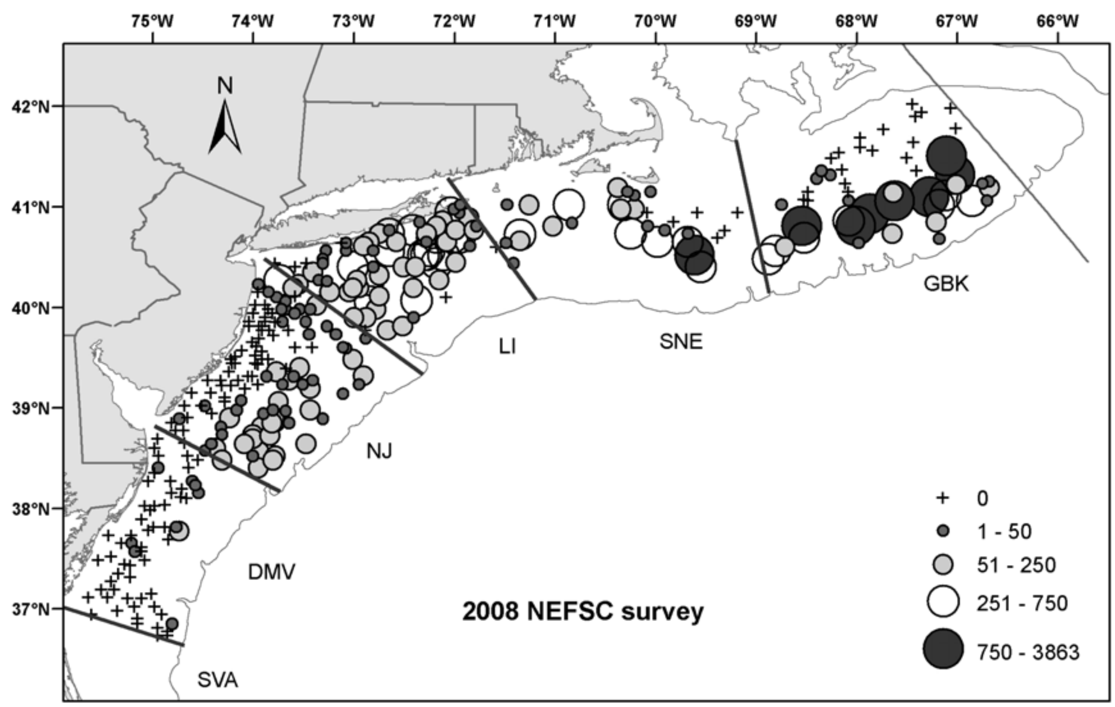
0
1 - 50
51 - 250
251 - 750
751 - 987
2005 NEFSC survey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39°N
38°N
37°N
N
LI
SNE
GBK
NJ
DMV
SVA
0
1 - 50
51 - 250
251 - 750
750 - 3863
2008 NEFSC survey

APPENDIX B6: KLAMZ model details.

KLAMZ Assessment Model – Technical Documentation

The KLAMZ assessment model is based on the Deriso-Schnute delay-difference equation (Deriso 1980; Schnute 1985; Quinn and Deriso 1999). The delay-difference equation is a relatively simple and implicitly age structured approach to counting fish in either numerical or biomass units. 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. Knife-edge selectivity means that all individuals alive in the model during the same year experience the same fishing mortality rate.[8] Natural and fishing mortality rates, growth parameters and recruitment may change from year to year, but delay-difference calculations assume that all individuals share the same mortality and growth parameters within each year. The KLAMZ model includes simple numerical models (e.g. Conser 1995) as special cases because growth can be turned off so that all calculations are in numerical units (see below).

As in many other simple models, the delay difference equation explicitly distinguishes between two age groups. In KLAMZ, the two age groups are called "new" recruits (R_t in biomass or numerical units at the beginning of year t) and "old" recruits (S_t) that together comprise the whole stock (B_t). New recruits are individuals that recruited at the beginning of the current year (at nominal age k).[9] Old recruits are all older individuals in the stock (nominal ages k+1 and older, survivors from the previous year). As described above, KLAMZ assumes that new and old recruits are fully vulnerable to the fishery. The most important differences between the delay-difference and other simple models (e.g. Prager 1994; Conser 1995; Jacobson et al. 1994) are that von Bertalanffy growth is used to calculate biomass dynamics and that the delay-difference model captures transient age structure effects due to variation in recruitment, growth and mortality exactly. Transient effects on population dynamics are captured exactly because, as described above, the delay-difference equation is algebraically equivalent to an explicitly age-structured model with von Bertalanffy growth.

The KLAMZ model incorporates a few extensions to Schnute's (1985) revision of Deriso's (1980) original delay difference model. Most of the extensions facilitate tuning to a wider variety of data that anticipated in Schnute (1985). The KLAMZ model is programmed in both Excel and in C++ using AD Model Builder[10] libraries. The AD Model Builder version is faster, more reliable

---

8 In applications, assumptions about knife-edge selectivity can be relaxed by assuming the model tracks "fishable", rather that total, biomass (NEFSC 2000a; 2000b). An analogous approach assigns pseudo-ages based on recruitment to the fishery so that new recruits in the model are all pseudo-age k. The synthetic cohort of fish pseudo-age k may consist of more than one biological cohort. The first pseudo-age (k) can be the predicted age at first, 50% or full recruitment based a von Bertalanffy curve and size composition data (Butler et al. 2002). The "incomplete recruitment" approach (Deriso 1980) calculates recruitment to the model in each year R_t as the weighted sum of contributions from two or more biological cohorts (year-classes) from spawning during successive years (i.e. $R_t = \sum_{a=1}^{k} r_a \Pi_{t-a}$ where k is the age at full recruitment to the fishery, r_a is the contribution of fish age k-a to the fishable stock, and Π_{t-a} is the number or biomass of fish age k-a during year t).

9 In some applications, and more generally, new recruits might be defined as individuals recruiting at the beginning or at any time during the current time step (e.g. NEFSC 1996).

10 Otter Research Ltd., Box 2040, Sydney, BC, Canada V8L 3S3 (otter@otter-rsch.com).

and probably better for producing "official" stock assessment results. The Excel version is slower and implements fewer features, but the Excel version remains useful in developing prototype assessment models, teaching and for checking calculations.

The most significant disadvantage in using the KLAMZ model and other delay-difference approaches, beyond the assumption of knife-edge selectivity, is that age and length composition data are not used in tuning. However, one can argue that age composition data are used indirectly to the extent they are used to estimate growth parameters or if survey survival ratios (e.g. based on the Heinke method) are used in tuning (see below).

Population dynamics

The assumed birth date and first day of the year are assumed the same in derivation of the delay-difference equation. It is therefore natural (but not strictly necessary) to tabulate catch and other data using annual accounting periods that start on the assumed biological birthday of cohorts.

Biomass dynamics

As implemented in the KLAMZ model, Schnute's (1985) delay-difference equation is:

$$\mathrm{B}_{t+1} = (1+\rho)\,\tau_t\,\mathrm{B}_t - \rho\,\tau_t\,\tau_{t-1}\,\mathrm{B}_{t-1} + \mathrm{R}_{t+1} - \rho\,\tau_t\,\mathrm{J}_t\,\mathrm{R}_t$$

where B_t is total biomass of individuals at the beginning of year t; ρ is Ford's growth coefficient (see below); $\tau_t=exp(-Z_t)=exp[-(F_t+M_t)]$ is the fraction of the stock that survived in year t, Z_t, F_t, and M_t are instantaneous rates for total, fishing and natural mortality; and R_t is the biomass of new recruits (at age k) at the beginning of the year. The natural mortality rate M_t may vary over time. Instantaneous mortality rates in KLAMZ model calculations are biomass-weighted averages if von Bertalanffy growth is turned on in the model. However, biomass-weighted mortality estimates in KLAMZ are the same as rates for numerical estimates under the assumption of knife-edge selectivity because all individuals are fully recruited. The growth parameter $J_t = w_{t-1,k-1} / w_{t,k}$ is the ratio of mean weight one year before recruitment (age k-1 in year t-1) and mean weight at recruitment (age k in year t).

It is not necessary to specify body weights at and prior to recruitment in the KLAMZ model (parameters v_{t-1} and V_t in Schnute 1985) because the ratio J_t and recruitment biomass contain the same information. Schnute's (1985) original delay difference equation is:

$$\mathrm{B}_{t+1} = (1+\rho)\,\tau_t\,\mathrm{B}_t - \rho\,\tau_t\tau_{t-1}\,\mathrm{B}_{t-1} + w_{t+1,k}\mathrm{N}_{t+1} - \rho\tau_t w_{t-1,k-1}\,\mathrm{N}_t$$

To derive the equation used in KLAMZ, substitute recruitment biomass R_{t+1} for the product $w_{t+1,k}$ $N_{t+1,k}$ and adjusted recruitment biomass $J_t R_t = (w_{t-1,k-1}/w_{t,k})\, w_{t,k}\, N_{t,k} =$ $w_{t-1,k-1}\; N_t$ in the last term on the right hand side. The advantage in using the alternate parameterization for biomass dynamic calculations in KLAMZ is that recruitment is estimated directly in units of biomass and the number of growth parameters is reduced. The disadvantage is that numbers of recruits are not estimated directly by the model. When required, numerical recruitments must be calculated externally as the ratio of estimated recruitment biomass and the average body weight for new recruits.

Numerical population dynamics

Growth can be turned on off so that abundance, rather than biomass, is tracked in the KLAMZ model. Set J_t=1 and ρ=0 in the delay difference equation, and use N_t (for numbers) in place of B_t to get:

$$\mathrm{N}_{t+1} = \tau_t\,\mathrm{N}_t + \mathrm{R}_{t+1}$$

Mathematically, the assumption J_t=1 means that no growth occurs the assumption ρ=0 means that the von Bertalanffy K parameter is infinitely large (Schnute 1985). All tuning and population dynamics calculations in KLAMZ for biomass dynamics are also valid for numerical dynamics.

Growth

As described in Schnute (1985), biomass calculations in the KLAMZ model are based on Schnute and Fournier's (1980) re-parameterization of the von Bertalanffy growth model:

$$w_a = w_{k-1} + (w_k - w_{k-1})(1 + \rho^{1+a-k}) / (1 - \rho)$$

where w_k=V and w_{k-1}=v. Schnute and Fournier's (1980) growth model is the same as the traditional von Bertalanffy growth model {W_a= W_{max} $[1 - exp(-K(a-t_{zero})]$ where W_{max}, K and t_{zero} are parameters}. The two growth models are the same because $W_{max} = (w_k - \rho\, w_{k-1})/(1-\rho)$, $K = -ln(\rho)$ and $t_{zero} = ln[(w_k - w_{k-1})/(w_k - \rho\, w_{k-1})] / ln(\rho)$.

In the KLAMZ model, the growth parameters J_t can vary with time but ρ is constant. Use of time-variable J_t values with ρ is constant is the same as assuming that the von Bertalanffy parameters W_{max} and t_{zero} change over time. Many growth patterns can be mimicked by changing W_{max} and t_{zero} (Overholtz et al., 2003). K is a parameter in the C++ version and, in principal, estimable. However, in most cases it is necessary to use external estimates of growth parameters as constants in KLAMZ.

Instantaneous growth rates

Instantaneous growth rate (IGR) calculations in the KLAMZ model are an extension to the original Deriso-Schnute delay difference model. IGRs are used extensively in KLAMZ for calculating catch biomass and projecting stock biomass forward to the time at which surveys occur. The IGR for new recruits depends only on growth parameters:

$$G_t^{New} = \ln\left(\frac{w_{k+1,t+1}}{w_{k,t}}\right) = \ln(1 + \rho - \rho J_t)$$

IGR for old recruits is a biomass-weighted average that depends on the current age structure and growth parameters. It can be calculated easily by projecting biomass of old recruits S_t=B_t-R_t (escapement) forward one year with no mortality:

$$S_t^* = (1+\rho)S_t - \rho\tau_{t-1}B_{t-1}$$

where the asterisk (*) means just prior to the start of the subsequent year t+1. By definition, the IGR for old recruits in year t is $G_t^{Old} = \ln\left(S_t^*/S_t\right)$. Dividing by S_t gives:

$$G_t^{Old} = \ln\left[(1+\rho) - \rho\tau_{t-1}\frac{B_{t-1}}{S_t}\right]$$

IGR for the entire stock is the biomass weighted average of the IGR values for new and old recruits:

$$G_t = \frac{R_t G_t^{New} + S_t G_t^{Old}}{B_t}$$

All IGR values are zero if growth is turned off.

Recruitment

In the Excel version of the KLAMZ model, annual recruitments are calculated

$R_t = e^{\Omega_t}$ where Ω_t is a log transformed annual recruitment parameter, which is estimated in the model. In the C++ version, recruitments are calculated based on two log geometric mean recruitment parameters (μ, ι_t), and a set of annual log scale deviation parameters (ω_t):

$$\Omega_t = \mu + \iota_t + \omega_t$$

The parameter ι_t is an offset for a step function that may be zero for all years or zero for years up to a user-specified "change year" and any value (usually estimated) afterward. The user must specify the change year, which cannot be estimated. The change year might be chosen based on auxiliary information outside the model, preliminary model fits or by carrying out a set of runs using sequential change year values and to choosing the change year that provides the best fit to the data.

The deviations ω_t are constrained to average zero.[11] With the constraint, for example, estimation of μ and the set of ω_t values (1+ *n* years parameters) is equivalent to estimation of the smaller set (*n* years) of Ω_t values.

Natural mortality

Natural mortality rates (M_t) are assumed constant in the Excel version of the KLAMZ model. In the C++ version, natural mortality rates may be estimated as a constant value or as a set of values that vary with time. In the model:

$$M_t = me^{\varpi_t}$$

where $m=exp(\pi)$ is the geometric mean natural mortality rate, π is a model parameter that may be estimated (in principal but not in practical terms), and ϖ_t is the log scale year-specific deviation. Deviations may be zero (turned off) so that M_t is constant, may vary in a random fashion due to autocorrelated or independent process errors, or may based on a covariate.[12] Model scenarios with zero recruitment may be initializing the parameter π to a small value (e.g. 10^{-16}) and not estimating it.

Random natural mortality process errors are effects due to predation, disease, parasitism, ocean conditions or other factors that may vary over time but are not included in the model. Calculations are basically the same as for survey process errors (see below).

Natural mortality rate covariate calculations are similar to survey covariate calculations (see below) except that the *user should standardized covariates to average zero over the time period included in the model*:

$$\kappa_t = K_t - \overline{K}$$

where κ_t is the standardized covariate, K_t is the original value, and $\overline{K}$ is the mean of the original covariate for the years in the model. *Standardization to mean zero is important because otherwise m is not the geometric mean natural mortality rate* (the convention is important in some calculations, see text).

Log scale deviations that represent variability around the geometric mean are calculated:

11 The constraint is implemented by adding $L = \lambda \overline{\varpi}^2$ (where $\overline{\varpi}$ is the average deviation) to the objective function, generally with a high weighting factor (λ = 1000) so that the constraint is binding.

12 Another approach to using time dependent natural mortality rates is to treat estimates of predator consumption as discarded catch (see "Predator consumption as discard data"). In addition, estimates of predator abundance can be used in fishing effort calculations (see "Predator data as fishing effort").

$$\varpi_t = \sum_{j=1}^{n} p_j \kappa_t$$

where n is the number of covariates and p_j is the parameter for covariate j. These conventions mean that the units for the covariate parameter p_j are 1/units of the original covariate, the parameter p_j measures the log scale effect of changing the covariate by one unit, and the parameter m is the log scale geometric mean.

Fishing mortality and catch

Fishing mortality rates (F_t) are calculated so that predicted and observed catch data (landings plus estimated discards in units of weight) "agree" to the extent specified by the user. It is not necessary, however, to assume that catches are measured accurately (see "Observed and predicted catch").

Fishing mortality rate calculations in Schnute (1985) are exact but relating fishing mortality to catch in weight is complicated by continuous somatic growth throughout the year as fishing occurs. The KLAMZ model uses a generalized catch equation that incorporates continuous growth through the fishing season. By the definition of instantaneous rates, the catch equation expresses catch as the product:

$$\hat{C}_t = F_t \overline{B}_t$$

where $\hat{C}_t$ is predicted catch weight (landings plus discard) and $\overline{B}_t$ is average biomass.

Following Chapman (1971) and Zhang and Sullivan (1988), let $X_t=G_t-F_t-M_t$ be the net instantaneous rate of change for biomass.[13] If the rates for growth and mortality are equal, then $X_t=0$, $\overline{B}_t = B_t$ and $C_t = F_t B_t$. If the growth rate G_t exceeds the combined rates of natural and fishing mortality ($F_t + M_t$), then $X_t > 0$. If mortality exceeds growth, then $X_t < 0$. In either case, with $X_t \neq 0$, average biomass is computed:

$$\overline{B}_t \approx -\frac{\left(1 - e^{X_t}\right) B_t}{X_t}$$

When $X_t \neq 0$, the expression for $\overline{B}_t$ is an approximation because G_t approximates the rate of change in mean body weight due to von Bertalanffy growth. However, the approximation is reasonably accurate and preferable to calculating catch biomass in the delay-difference model with the traditional catch equation that ignores growth during the fishing season.[14] Average biomass can be calculated for new recruits, old recruits or for the whole stock by using either G_t^{New}, G_t^{Old} or G_t.

In the KLAMZ model, the modified catch equation may be solved analytically for F_t given C_t, B_t, G_t and M_t (see the "Calculating F_t" section below). Alternatively, fishing mortality rates can be calculated using a log geometric mean parameter (Φ) and a set of annual log scale deviation parameters (ψ_t):

$$F_t = e^{\Phi + \psi_t}$$

where the deviations ψ_t are constrained to average zero. When the catch equation is solved

13 By convention, the instantaneous rates G_t, F_t and M_t are always expressed as numbers $\geq$ 0.

14 The traditional catch equation $C_t = F_t(1 - e^{-Z_t}) B_t / Z_t$ where $Z_t=F_t+M_t$ underestimates catch biomass for a given level of fishing mortality F_t and overestimates F_t for a given level of catch biomass. The errors can be substantial for fast growing fish, particularly if recent recruitments were strong.

analytically, catches must be assumed known without error but the analytical option is useful when catch is zero or very near zero, or the range of fishing mortality rates is so large (e.g. minimum F=0.000001 to maximum F=3) that numerical problems occur with the alternative approach. The analytical approach is also useful if the user wants to reduce the number of parameters estimated by nonlinear optimization. In any case, the two methods should give the same results for catches known without error.

Surplus production

Annual surplus production is calculated "exactly" by projecting biomass at the beginning of each year forward with no fishing mortality:

$$B_t^* = (1+\rho)\, e^{-M}\, B_t - \rho\, e^{-M}\, L_{t-1}\, B_{t-1} - \rho\, e^{-M}\, J_t\, R_t$$

By definition, surplus production $P_t = B^*_t - B_t$ (Jacobson et al. 2002).

Per recruit modeling

Per recruit model calculations in the Excel version of the KLAMZ simulate the life of a hypothetical cohort of arbitrary size (e.g. R=1000) starting at age k with constant M_t, F (survival) and growth (ρ and J) in a population initially at zero biomass. In the first year:

$$B_1 = R$$

In the second year:

$$B_2 = (1+\rho)\,\tau\, B_1 - \rho\,\tau\, J\, R_1$$

In the third and subsequent years:

$$B_{t+1} = (1+\rho)\,\tau\, B_t - \rho\,\tau^2\, B_{t-1}$$

This iterative calculation is carried out until the sum of lifetime cohort biomass from one iteration to the next changes by less than a small amount (0.0001). Total lifetime biomass, spawning biomass and yield in weight are calculated by summing biomass, spawning biomass and yield over the lifetime of the cohort. Lifetime biomass, spawning biomass and yield per recruit are calculated by dividing totals by initial recruitment (R).

Status determination variables

The user may specify a range of years (e.g. the last three years) to use in calculating recent average fishing mortality $\overline{F}_{\mathrm{Re}cent}$ and biomass $\overline{B}_{\mathrm{Re}cent}$ levels. These status determination variables are used in calculation of status ratios such as $\overline{F}_{\mathrm{Re}cent} / F_{MSY}$ and $\overline{B}_{\mathrm{Re}cent}/\mathrm{B_{MSY}}$.

Goodness of Fit and Parameter Estimation

Parameters estimated in the KLAMZ model are chosen to minimize an objective function based on a sum of weighted negative log likelihood (NLL) components:

$$\Xi = \sum_{v=1}^{N_\Xi} \lambda_v L_v$$

where N_Ξ is the number of NLL components (L_v) and the λ_v are emphasis factors used as weights.

The objective function Ξ may be viewed as a NLL or a negative log posterior (NLP) distribution, depending on the nature of the individual L_v components and modeling approach. Except during sensitivity analyses, weighting factors for objective function components (λ_v) are usually set to one. An arbitrarily large weighting factor (e.g. λ_v =1000) is used for "hard" constraints that must be satisfied in the model. Arbitrarily small weighting factors (e.g. λ_v =0.0001) can be used for "soft" model-based constraints. For example, an internally estimated spawner-recruit curve or surplus production curve might be estimated with a small weighting factor to summarize stock-recruit or surplus production results with minimal influence on biomass, fishing mortality and other estimates from the model. Use of a small weighting factor for an internally estimated surplus production or stock-recruit curve is equivalent to fitting a curve to model estimates of biomass and recruitment or surplus production in the output file, after the model is fit (Jacobson et al. 2002).

Likelihood component weights vs. observation-specific weights

Likelihood component weights (λ_v) apply to entire NLL components. Entire components are often computed as the sum of a number of individual NLL terms. The NLL for an entire survey, for example, is composed of NLL terms for each of the annual survey observations. In KLAMZ, observation-specific (for data) or instance-specific (for constraints or prior information) weights (usually w_j for observation or instance j) can be specified as well. Observation-specific weights for a survey, for example, might be use to increase or decrease the importance of one or more observations in calculating goodness of fit.

NLL kernels

NLL components in KLAMZ are generally programmed as "concentrated likelihoods" to avoid calculation of values that do not affect derivatives of the objective function.[15] For x~N(μ,σ^2), the complete NLL for one observation is:

$$L = \ln(\sigma) + \ln\left(\sqrt{2\pi}\right) + 0.5\left(\frac{x-u}{\sigma}\right)^2$$

The constant $\ln\left(\sqrt{2\pi}\right)$ can always be omitted because it does not affect derivatives. If the standard deviation is known or assumed known, then ln(σ) can be omitted as well because it is a constant that does not affect derivatives. In such cases, the concentrated negative log likelihood is:

$$L = 0.5\left(\frac{x-\mu}{\sigma}\right)^2$$

If there are N observations with possible different variances (known or assumed known) and possibly different expected values:

$$L = 0.5\sum_{i=1}^{N}\left(\frac{x_i-\mu_i}{\sigma_i}\right)^2$$

If the standard deviation for a normally distributed quantity is not known and is (in effect) estimated by the model, then one of two equivalent calculations is used. Both approaches assume

15 Unfortunately, concentrated likelihood calculations cannot be used with MCMC and other Bayesian approaches to characterizing posterior distributions. Therefore, in the near future, concentrated NLL calculations will be replaced by calculations for the entire NLL. At present, MCMC calculations in KLAMZ are not useful.

that all observations have the same variance and standard deviation. The first approach is used when all observations have the same weight in the likelihood:

$$L = 0.5N \ln\left[\sum_{i=1}^{N}(x_i - u)^2\right]$$

where N is the number of observations. The second approach is equivalent but used when the weights for each observation (w_i) may differ:

$$L = \sum_{i=1}^{N} w_i \left[\ln(\sigma) + 0.5\left(\frac{x_i - u}{\sigma}\right)^2\right]$$

In the latter case, the maximum likelihood estimator:

$$\hat{\sigma} = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \hat{x})^2}{N}}$$

(where $\hat{x}$ is the average or predicted value from the model) is used for σ. The maximum likelihood estimator is biased by $N/(N\text{-}d_f)$ where d_f is degrees of freedom for the model. The bias may be significant for small sample sizes but d_f is usually unknown.

Landings, discards, catch

Discards are from external estimates (d_t) supplied by the user. If $d_t \geq 0$, then the data are used as the ratio of discard to landed catch so that:

$$D_t = L_t \Delta_t$$

where $\Delta_t = D_t/L_t$ is the discard ratio. If $d_t < 0$ then the data are treated as discard in units of weight: $D_t = abs(d_t)$.

In either case, total catch is the sum of discards and landed catch ($C_t = L_t + D_t$). It is possible to use discards in weight $d_t < 0$ for some years and discard as proportions $d_t > 0$ for other years in the same model run. If catches are estimated (see below) so that the estimated catch $\hat{C}_t$ does not necessarily equal observed landings plus discard, then estimated landings are computed:

$$\hat{L}_t = \frac{\hat{C}_t}{1 + \Delta_t}$$

and estimated discards are: $\hat{D}_t = \Delta_t \hat{L}_t$.

Calculating F_t

As described above, fishing mortality rates may be estimated based on the parameters Φ and ψ_t to satisfy a NLL for observed and predicted catches:

$$L = 0.5\sum_{t=0}^{N} w_t \left(\frac{\hat{C}_t - C_t}{\kappa_t}\right)^2$$

where the standard error $\kappa_t = CV_{catch}\hat{C}_t$ with CV_{catch} and weights are w_t supplied by the user. The weights can be used, for example, if catch data in some years are less precise than in others. Using observation specific weights, any or every catch in the time series can potentially be estimated.

The other approach to calculating F_t values is by solving the generalized catch equation (see above) iteratively. Subtracting predicted catch from the generalized catch equation gives:

$$g(F_t) = C_t + \frac{F_t\left(1 - e^{X_t}\right)}{X_t} B_t = 0$$

where X_t=G_t-M_t-F_t. If X_t=0, then $\overline{B}_t = B_t$ and F_t=C_t/B_t.

If $X_t \neq 0$, then the Newton-Raphson algorithm is used to solve for F_t (Kennedy and Gentle 1980). At each iteration of the algorithm, the current estimate F_t^i is updated using:

$$F_t^{i+1} = F_t^i - \frac{g\left(F_t^i\right)}{g'\left(F_t^i\right)}$$

where $g'\left(F_t^i\right)$ is the derivative F_t^i. Omitting subscripts, the derivative is:

$$g'(F) = -\frac{Be^{-F}\left[\left(e^F - e^\gamma\right)\gamma + e^\gamma F\gamma - e^\gamma F^2\right]}{X^2}$$

where γ=G-M_t. Iterations continue until $g\left(F_t^i\right)$ and $abs\left[g\left(F_t^{i+1}\right) - g\left(F_t^{i+1}\right)\right]$ are both less than a small number (e.g. ≤ 0.00001).

Initial values are important in algorithms that solve the catch equation numerically (Sims 1982). If M_t+F_t > G_t so that $X_t < 0$, then the initial value F_t^0 is calculated according to Sims (1982). If M_t+F_t < G_t so that X_t > 0, then initial values are calculated based on a generalized version of Pope's cohort analysis (Zhang and Sullivan 1988):

$$F_t^0 = \gamma_t - \ln\left[\frac{\left(B_t e^{0.5\gamma_t} - C_t\right)e^{0.5\gamma_t}}{B_t}\right]$$

F for landings versus F for discards

The total fishing mortality rate for each year can be partitioned into a component due to landed catch ${}^{L}F_t = \frac{D_t}{C_t} F_t$, and a component due to discard ${}^{D}F_t = \frac{L_t}{C_t} F_t$.

Predator consumption as discard data

In modeling population dynamics of prey species, estimates of predator consumption can be treated like discard in the KLAMZ model as a means for introducing time dependent natural mortality. Consider a hypothetical example with consumption data (mt y^{-1}) for three important predators. If the aggregate consumption data are included in the model as "discards", then the fishing mortality rate for discards ${}^{d}F_t$ (see above) would be an estimate of the component of natural mortality due to the three predators. In using this approach, the average level of natural mortality m would normally be reduced (e.g. so that $m_{new} + {}^{d}\overline{F} = m_{old}$) or estimated to account for the portion of natural mortality attributed to bycatch.

Surplus production calculations are harder to interpret if predator consumption is treated as discard data because surplus production calculations assume that F_t=0 (see above) and because surplus production is defined as the change in biomass from one year to the next in the absence of fishing (i.e. no landings or bycatch). However, it may be useful to compare surplus production at a given level of biomass from runs with and without consumption data as a means of estimating maximum changes in potential fishery yield if the selected predators were eliminated (assuming no change in disease, growth rates, predation by other predators, etc.).

Effort calculations

Fishing mortality rates can be tuned to fishing effort data for the “landed” catch (i.e. excluding discards). Years with non-zero fishing effort used in the model must also have landings greater than zero. Assuming that effort data are lognormally distributed, the NLL for fishing effort is:

$$NLL = 0.5\sum_{y=1}^{n_{eff}} w_y \left[\frac{\ln\left(E_y/\hat{E}_y\right)}{\sigma}\right]^2$$

where w_y is an observation-specific weight, n_{eff} is the number of active effort observations (i.e. with $w_y > 0$), E_y and $\overline{E}_y$ are observed and predicted fishing effort data, and the log scale variance σ is a constant calculated from a user-specified CV.

Predicted fishing effort data are calculated:

$$\hat{E}_y = \zeta F_y^{\vartheta}$$

where $\zeta = e^u$, $\vartheta = e^b$, and u and b are parameters estimated by the model. If the parameter b is not estimated, then $\vartheta=1$ so that the relationship between fishing effort and fishing mortality is linear. If the parameter b is estimated, then $\vartheta\neq1$ and the relationship is a power function.

Predator data as fishing effort

As described under “Predator consumption as discard data”, predator consumption data can be treated as discard. If predator abundance data are available as well, and assuming that mortality due predators is a linear function of the predator-prey ratio, then both types of data may be used together to estimate natural mortality. The trick is to: 1) enter the predator abundance data as fishing effort; 2) enter the actual fishery landings as “discard”; 3) enter predator consumption estimates of the prey species as “landings” so that the fishing effort data in the refer to the predator consumption data; 4) use an option in the model to calculate the predator-prey ratio for use in place of the original predator abundance “fishing effort” data; and 5) tune fishing mortality rates for landings (a.k.a. predator consumption) to fishing effort (a.k.a. predator-prey ratio).

Given the predator abundance data κ_y, the model calculates the predator-prey ratio used in place of fishing effort data (E_y) as:

where B_y is the model’s current estimate of total (a.k.a “prey”) biomass. Subsequent calculations with E_y and the model’s estimates of “fishing mortality” (F_y, really a measure of natural mortality) are exactly as described above for effort data. In using this approach, it is probably advisable to reduce m (the estimate of average mortality in the model) to account for the proportion of natural mortality due to predators included in the calculation. Based on experience to date, natural mortality due to consumption by the suite of predators can be estimated but only if m is assumed known.

Initial population age structure

In the KLAMZ model, old and new recruit biomass during the first year (R_1 and $S_1 = B_1 - R_1$) and biomass prior to the first year (B_0) are estimated as log scale parameters. Survival in the year prior to the first year ("year 0") is $\tau_0 = e^{-F_0 - M_1}$ with F_0 chosen to obtain catch C_0 (specified as data) from the estimated biomass B_0. IGRs during year 0 and year 1 are assumed equal (G_0=G_1) in catch calculations.

Biomass in the second year of as series of delay-difference calculations depends on biomass (B_0) and survival (τ_0) in year 0:

$$\mathrm{B}_2 = (1+\rho)\,\tau_1\,\mathrm{B}_1 - \rho\,\tau_1\,\tau_0\,\mathrm{B}_0 + \mathrm{R}_2 - \rho\,\tau_1\,\mathrm{J}_1\,\mathrm{R}_1$$

There is, however, there is no direct linkage between B_0 and escapement biomass (S_1=B_1-R_1) at the beginning of the first year.

The missing link between B_0, S_1 and B_1 means that the parameter for B_0 tends to be relatively free and unconstrained by the underlying population dynamics model. In some cases, B_0 can be estimated to give good fit to survey and other data, while implying unreasonable initial age composition and surplus production levels. In other cases, B_0 estimates can be unrealistically high or low implying, for example, unreasonably high or low recruitment in the first year of the model (R_1). Problems arise because many different combinations of values for R_1, S_1 and B_0 give similar results in terms of goodness of fit. This issue is common in stock assessment models that use forward simulation calculations because initial age composition is difficult to estimate. It may be exacerbated in delay-difference models because age composition data are not used.

The KLAMZ model uses two constraints to help estimate initial population biomass and initial age structure.[16] The first constraint links IGRs for escapement (G^{Old}) in the first years to a subsequent value. The purpose of the constraint is to ensure consistency in average growth rates (and implicit age structure) during the first few years. For example, if IGRs for the first n_G years are constrained[17], then the NLL for the penalty is:

$$L_G = 0.5\sum_{t=1}^{n_G}\left[\frac{\ln\left(G_t^{Old} \big/ G_{n_G+1}^{Old}\right)}{\sigma_G}\right]^2$$

where the standard deviation σ_G is supplied by the user. It is usually possible to use the standard deviation of Q_t^{Old} for later years from a preliminary run to estimate σ_G for the first few years. The constraint on initial IGRs should probably be "soft" and non-binding ($\lambda \approx 1$) because there is substantial natural variation in somatic growth rates due to variation in age composition.

The second constraint links B_0 to S_1 and ensures conservation of mass in population dynamics between years 0 and 1. In other words, the parameter for escapement biomass in year 1 is constrained to match an approximate projection of the biomass in year 0, accounting for growth, and natural and fishing mortality. The constraint is intended to be binding and satisfied exactly (e.g. λ=1000) because incompatible values of S_1 and B_0 are biologically impossible. In calculations:

$$S_1^p = B_0 e^{G_1 - F_0 - M_1}$$

where S_1^p is the projected escapement in year 1 and B_0 is the model's estimate of total biomass in year 0. The instantaneous rates for growth and natural mortality from year 1 (G_1 and M_1) are used in place of G_0 and M_0 because the latter are unavailable. The NLL for the constraint:

$$L = \left[\ln\left(\frac{S_1^p}{S_1}\right)^2\right]^2 + \left(S_1^p - S_1\right)^2$$

16 Quinn and Deriso (1999) describe another approach attributed to a manuscript by C. Walters.

17 Normally, $n_G \leq 2$.

uses a log scale sum of squares and an arithmetic sum of squares. The former is effective when S_I is small while the latter is effective when S_I is large. Constants and details in calculation of NLL for the constraint are not important because the constraint is binding (e.g. λ=1000).

Equilibrium pristine biomass

It may be useful to constrain the biomass estimate for the first year in a model run towards an estimate of equilibrium pristine biomass if, for example, stock dynamics tend to be stable and catch data are available for the first years of the fishery, or as an alternative to the approach described above for initializing the age structure of the simulated population in the model. Equilibrium pristine biomass $\widetilde{B}_0$ is calculated based on the model's estimate of average recruitment and with no fishing mortality (calculations are similar to those described under "Per-recruit modeling" except that average recruitment is assumed in each year).[18] The NLL term for the constraint is:

$$L = \ln\left(\frac{\widetilde{B}_0}{B_0}\right)^2$$

Pristine equilibrium biomass is used as a hard constraint with a high emphasis factor (λ) so that the variance and constants normally used in NLL calculations are not important.

Estimating natural mortality

As described above, natural mortality calculations involve a parameter for the geometric mean value (m) and time dependent deviations (ϖ_t, which may or may not be turned on). Constraints on natural mortality process errors and natural mortality covariates can be used to help estimate the time dependent deviations and overall trend. The geometric mean natural mortality rate is usually difficult to estimate and best treated as a known constant. However, in the C++ version of the KLAMZ model, $m=e^{\pi}$ (where π is an estimable parameter in the model) and estimates of m can be conditioned on the constraint:

$$L = 0.5\left[\frac{\ln\left(w/w_{Target}\right)}{\sigma_{\varpi}}\right]^2$$

where w_{Target} is a user supplied mean or target value and σ_{ϖ} is a log scale standard deviation. The standard deviation is calculated from an arithmetic scale CV supplied by the user. Upper and lower bounds for m may be specified as well.

Goodness of fit for trend data

Assuming lognormal errors[19], the NLL used to measure goodness-of-fit to "survey" data that measure trends in abundance or biomass (or survival, see below) is:

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18 Future versions of the KLAMZ model will allow equilibrium initial biomass to be calculated based on other recruitment values and for a user-specified level of F (Butler et al. 2003).

19 Abundance indices with statistical distributions other than log normal may be used as well, but are not currently programmed in the KLAMZ model. For example, Butler et al. (2003) used abundance indices with binomial distributions in a delay-difference model for cowcod rockfish. The next version of KLAMZ will accommodate presence-absence data with binomial distributions.

$$L = 0.5 \sum_{j=1}^{N_v} \left[\frac{\ln\left(I_{v,j} \big/ \hat{I}_{v,j} \right)}{\sigma_{v,j}} \right]^2$$

where $I_{v,t}$ is an index datum from survey v, hats "^" denote model estimates, $\sigma_{v,j}$ is a log scale standard error (see below), and N_v is the number of observations. There are two approaches to calculating standard errors for log normal abundance index data in KLAMZ and it is possible to use different approaches for different types of abundance index data in the same model (see below).

Standard errors for goodness of fit

In the first approach, all observations for one type of abundance index share the same standard error, which is calculated based on overall goodness of fit. This approach implicitly estimates the standard error based on goodness of fit, along with the rest of the parameters in the model (see "NLL kernels" above).

In the second approach, each observation has a potentially unique standard error that is calculated based on its CV. The second approach calculates log scale standard errors from arithmetic CVs supplied as data by the user (Jacobson et al. 1994):

$$\sigma_{v,t} = \sqrt{\ln\left(1 + CV_{v,t}^2\right)}$$

Arithmetic CV's are usually available for abundance data. It may be convenient to use $CV_{v,t}$=1.31 to get $\sigma_{v,t}$=1.

There are advantages and disadvantages to both approaches. CV's carry information about the relative precision of abundance index observations. However, CV's usually overstate the precision of data as a measure of fish abundance[20] and may be misleading in comparing the precision of one sort of data to another as a measure of trends in abundance (e.g. in contrasting standardized LPUE that measure fishing success, but not abundance, precisely with survey data that measure trends in fish abundance directly, but not precisely). Standard errors estimated implicitly are often larger and more realistic, but assume that all observations in the same survey are equally reliable.

Predicted values for abundance indices

Predicted values for abundance indices are calculated:

$$\hat{I}_{v,t} = Q_v A_{v,t}$$

where Q_v is a survey scaling parameter (constant here but see below) that converts units of biomass to units of the abundance index. $A_{v,t}$ is available biomass at the time of the survey.

In the simplest case, available biomass is:

$$A_{v,t} = s_{v,New} R_t e^{-X_t^{New} \Delta_{v,t}} + s_{v,Old} S_t e^{-X_t^{Old} \Delta_{v,t}}$$

where $s_{v,New}$ and $s_{v,Old}$ are survey selectivity parameters for new recruits (R_t) and old recruits (S_t);

20 The relationship between data and fish populations is affected by factors (process errors) that are not accounted for in CV calculations.

$X_t^{New} = G_t^{New} - F_t - M_t$ and $X_t^{Old} = G_t^{Old} - F_t - M_t$; $j_{v,t}$ is the Julian date at the time of the survey, and $\Delta_{v,t}=j_{v,t}/365$ is the fraction of the year elapsed at the time of the survey.

Survey selectivity parameter values ($s_{v,New}$ and $s_{v,Old}$) are specified by the user and must be set between zero and one. For example, a survey for new recruits would have $s_{v,New}$=1 and $s_{v,Old}$=0. A survey that measured abundance of the entire stock would have $s_{v,New}$=1 and $s_{v,Old}$=1.

Terms involving $\Delta_{v,t}$ are used to project beginning of year biomass forward to the time of the survey, making adjustments for mortality and somatic growth.[21] As described below, available biomass $A_{v,t}$ is adjusted further for nonlinear surveys, surveys with covariates and surveys with time variable $Q_{v,t}$.

Scaling parameters (Q) for log normal abundance data

Scaling parameters for surveys with lognormal statistical errors were computed using the maximum likelihood estimator:

$$Q_v = e^{\frac{\sum_{i=1}^{N_v}\left[\ln\left(\frac{I_{v,i}}{A_{v,i}}\right)\Big/\sigma_{v,j}^2\right]}{\sum_{j=1}^{N_j}\left(1/\sigma_{v,j}^2\right)}}$$

where N_v is the number of observations with individual weights greater than zero. The closed form maximum likelihood estimator gives the same answer as if scaling parameters are estimated as free parameters in the assessment model assuming lognormal survey measurement errors.

Survey covariates

Survey scaling parameters may vary over time based on covariates in the KLAMZ model. The survey scaling parameter that measures the relationship between available biomass and survey data becomes time dependent:

$$\hat{I}_{v,t} = Q_{v,t} A_{v,t}$$

and

$$Q_{v,t} = Q_v e^{\sum_{r=1}^{n_v} d_{r,t}\theta_r}$$

with n_v covariates for the survey and parameters θ_r estimated in the model. Covariate effects and available biomass are multiplied to compute an adjusted available biomass:

$$A'_{v,t} = A_{v,t} e^{\sum_{r=1}^{n_v} d_{r,t}\theta_r}$$

The adjusted available biomass $A'_{v,t}$ is used instead of the original value $A_{v,t}$ in the closed form maximum likelihood estimator described above.

21 It may be important to project biomass forward if an absolute estimate of biomass is available (e.g. from a hydroacoustic or daily egg production survey), if fishing mortality rates or high or if the timing of the survey varies considerably from year to year.

Covariates might include, for example, a dummy variable that represents changes in survey bottom trawl doors or a continuous variable like average temperature data if environmental factors affect distribution and catchability of fish schools. Dummy variables are usually either 0 or 1, depending on whether the effect is present in a particular year. With dummy variables, Q_v is the value of the survey scaling parameter with no intervention ($d_{r,t}$=0).

For ease in interpretation of parameter estimates for continuous covariates (e.g. temperature data), it is useful to center covariate data around the mean:

$$d_{r,t} = d'_{r,t} - \overline{d'_r}$$

where $d'_{r,t}$ is the original covariate. When covariates are continuous and mean-centered, Q_v is the value of the survey scaling parameter under average conditions ($d_{r,t}$=0) and units for the covariate parameter are easy to interpret (for example, units for the parameter are 1/°C if the covariate is mean centered temperature in °C).

It is possible to use a survey covariate to adjust for differences in relative stock size from year to year due to changes in the timing of a survey. However, this adjustment may be made more precisely by letting the model calculate $\Delta_{v,t}$ as described above, based on the actual timing data for the survey during each year.

Nonlinear abundance indices

With nonlinear abundance indices, and following Methot (1990), the survey scaling parameter is a function of available biomass:

$$Q_{v,t} = Q_v A_{v,t}^{\Gamma}$$

so that:

$$\hat{I}_{v,t} = \left(Q_v A_{v,t}^{\Gamma}\right) A_{v,t}$$

Substituting $e^{\gamma}=\Gamma+1$ gives the equivalent expression:

$$\hat{I}_{v,t} = Q_v A_{v,t}^{e^{\gamma}}$$

where γ is a parameter estimated by the model and the survey scaling parameter is no longer time dependent. In calculations with nonlinear abundance indices, the adjusted available biomass:

$$A'_{v,t} = A_{v,t}^{e^{\gamma}}$$

is computed first and used in the closed form maximum likelihood estimator described above to calculate the survey scaling parameter. In cases where survey covariates are also applied to a nonlinear index, the adjustment for nonlinearity is carried out first.

Survey Q process errors

The C++ version of the KLAMZ model can be used to allow survey scaling parameters to change in a controlled fashion from year to year (NEFSC 2002):

$$Q_{v,t} = Q_v e^{\varepsilon_{v,t}}$$

where the deviations $\varepsilon_{v,t}$ are constrained to average zero. Variation in survey Q values is controlled by the NLL penalty:

$$L = 0.5 \sum_{j=1}^{N_v} \left[\frac{\varepsilon_{v,j}}{\sigma_v} \right]^2$$

where the log scale standard deviation σ_v based on an arithmetic CV supplied by the user (e.g. see NEFSC 2002). In practice, the user increases or decreases the amount of variability in Q by decreasing or increasing the assumed CV.

Survival ratios as surveys

In the C++ version of KLAMZ, it is possible to use time series of survival data as "surveys". For example, an index of survival might be calculated using survey data and the Heinke method (Ricker 1975) as:

$$A_t = \frac{I_{k+1,t+1}}{I_{k,t}}$$

so that the time series of A_t estimates are data that may potentially contain information about scale or trends in survival. Predicted values for an a survival index are calculated:

$$\hat{A}_t = e^{-Z_t}$$

After predicted values are calculated, survival ratio data are treated in the same way as abundance data (in particular, measurement errors are assumed to be lognormal). Selectivity parameters are ignored for survival data but all other features (e.g. covariates, nonlinear scaling relationships and constraints on *Q*) are available.

Recruitment models

Recruitment parameters in KLAMZ may be freely estimated or estimated around an internal recruitment model, possibly involving spawning biomass. An internally estimated recruitment model can be used to reduce variability in recruitment estimates (often necessary if data are limited), to summarize stock-recruit relationships, or to make use of information about recruitment in similar stocks. There are four types of internally estimated recruitment models in KLAMZ: 1) random (white noise) variation around a constant or time dependent mean modeled as a step function; 2) random walk (autocorrelated) variation around a constant or time dependent mean modeled as a step function; 3) random variation around a Beverton-Holt recruitment model; and 4) random variation around a Ricker recruitment model. The user must specify a type of recruitment model but the model is not active unless the likelihood component for the recruitment model is turned on ($\lambda > 0$).

The first step in recruit modeling is to calculate the expected log recruitment level $E[ln(R_t)]$ given the recruitment model. For random variation around a constant mean, the expected log recruitment level is the log geometric mean recruitment:

$$E[\ln(R_t)] = \sum_{j=1}^{N} \ln(R_j) \Big/ N$$

For a random walk around a constant mean recruitment, the expected log recruitment level is the logarithm of recruitment during the previous year:

$$E[\ln(R_t)] = \ln(R_{t-1})$$

with no constraint on recruitment during the first year R_1.

For the Beverton-Holt recruitment model, the expected log recruitment level is:

$$E[\ln(R_t)] = \ln\left[e^a T_{t-\ell} / \left(e^b + T_{t-\ell}\right)\right]$$

where $a=e^{\alpha}$ and $b=e^{\beta}$, the parameters α and β are estimated in the model, T_t is spawning biomass, and { is the lag between spawning and recruitment. Spawner-recruit parameters are estimated as log transformed values (e^{α} and e^{β}) to enhance model stability and ensure the correct sign of values used in calculations. Spawning biomass is:

$$T_t = m_{new} R_t + m_{old} S_t$$

where m_{new} and m_{old} are maturity parameters for new and old recruits specified by the user. For the Ricker recruitment model, the expected log recruitment level is:

$$E[\ln(R_t)] = \ln\left(S_{t-\ell} e^{a-bS_{t-\ell}}\right)$$

where $a=e^{\alpha}$ and $b=e^{\beta}$, and the parameters α and β are estimated in the model.

Given the expected log recruitment level, log scale residuals for the recruitment model are calculated:

$$r_t = \ln(R_t) - E[\ln(R_t)]$$

Assuming that residuals are log normal, the NLL for recruitment residuals is:

$$L = \sum_{t=t_{first}}^{N} w_t \left[\ln(\sigma_r) + 0.5\left(r_t / \sigma_r \right)^2 \right]$$

where λ_t is an instance-specific weight usually set equal one. The additional term in the NLL [$ln(\sigma_r)$] is necessary because the variance σ_r^2 is estimated internally, rather than specified by the user.

The log scale variance for residuals is calculated using the maximum likelihood estimator:

$$\sigma_r^2 = \frac{\sum_{j=t_{first}}^{N} r_j}{N}$$

where N is the number of residuals. For the recruitment model with constant variation around a mean value, t_{first}=1. For the random walk recruitment model, t_{first}=2. For the Beverton-Holt and Ricker models, $t_{first}=\ell+1$ and the recruit model imposes no constraint on variability of recruitment during years 1 to ℓ (see below). The biased maximum likelihood estimate for σ^2 (with N in the divisor instead of the degrees of freedom) is used because actual degrees of freedom are unknown. The variance term σ^2 is calculated explicitly and stored because it is used below.

Constraining the first few recruitments

It may be useful to constrain the first { years of recruitments when using either the Beverton-Holt or Ricker models if the unconstrained estimates for early years are erratic. In the KLAMZ model, this constraint is calculated:

$$NLL = \sum_{t=1}^{t_{first}-1} w_t \left\{ \ln(\sigma_r + 0.5\left[\frac{\ln\left(R_t / E\left(R_{t_{first}}\right)\right)}{\sigma_r} \right]^2 \right\}$$

where t_{first} is the first year for which expected recruitment $E(R_l)$ can be calculated with the spawner-recruit model. In effect, recruitments that not included in spawner-recruit calculations are constrained towards the first spawner-recruit prediction. The standard deviation is the same as used in calculating the NLL for the recruitment model.

Prior information about the absolute value abundance index scaling parameters (Q)

A constraint on the absolute value one or more scaling parameters (Q_v) for abundance or survival indices may be useful if prior information is available (e.g. NEFSC 2000; NEFSC 2001; NEFSC 2002). In the Excel version, it is easy to program these (and other) constraints in an *ad-hoc* fashion as they are needed. In the AD Model Builder version, log normal and beta distributions are preprogrammed for use in specifying prior information about Q_v for any abundance or survival index.

The user must specify which surveys have prior distributions, minimum and maximum legal bounds (q_{min} and q_{max}), the arithmetic mean $(\bar{q})$ and the arithmetic CV for the prior the distribution. Goodness of fit for Q_v values outside the bounds (q_{min}, q_{max}) are calculated:

$$L = \left| \begin{array}{l} 10000\left(Q_v - q_{\max}\right)^2 \; if \; Q_v \geq q_{\max} \\ 10000\left(q_{\min} - Q_v\right)^2 \; if \; Q_v \leq q_{\min} \end{array} \right.$$

Goodness of fit for Q_v values inside the legal bounds depend on whether the distribution of potential values is log normal or follows a beta distribution.

Lognormal case

Goodness of fit for lognormal Q_v values within legal bounds is:

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

where the log scale standard deviation $\varphi = \sqrt{\ln(1 + CV)}$ and $\tau = \ln(\bar{q}) - \frac{\varphi^2}{2}$ is the mean of the corresponding log normal distribution.

Beta distribution case

The first step in calculation goodness of fit for Q_v values with beta distributions is to calculate the mean and variance of the corresponding "standardized" beta distribution:

$$\bar{q}' = \frac{\bar{q} - q_{\min}}{D}$$

and

$$Var(q') = \left(\frac{\bar{q}\; CV}{D}\right)^2$$

where the range of the standardized beta distribution is $D=q_{max}-q_{min}$. Equating the mean and variance to the estimators for the mean and variance for the standardized beta distribution (the "method of moments") gives the simultaneous equations:

$$\bar{q}' = \frac{a}{a + b}$$

and

$$Var(q') = \frac{ab}{(a + b)^2 (a + b + 1)}$$

where a and b are parameters of the standardized beta distribution.[22] Solving the simultaneous equations gives:

$$b = \frac{(\bar{q}' - 1)[Var(q') + (\bar{q}' - 1)\bar{q}']}{Var(q')}$$

and:

$$a = \frac{b\bar{q}'}{1 - \bar{q}'}$$

Goodness of fit for beta Q_v values within legal bounds is calculated with the NLL:

$$L = (a-1)\ln(Q'_v) + (b-1)\ln(1 - Q'_v)$$

where $Q'_v = Q_v / (Q_v - q_{\min})$ is the standardized value of the survey scaling parameter Q_v.

Prior information about relative abundance index scaling parameters (Q-ratios)

Constraints on "Q-ratios" can be used in fitting models if some information about the relative values of scaling parameters for two abundance indices is available. For example, ASMFC (2001, p. 46-47) assumed that the relative scaling parameters for recruit and post-recruit lobsters taken in the same survey was either 0.5 or 1. If both indices are from the same survey cruise (e.g. one index for new recruits and one index for old recruits in the same survey), then assumptions about q-ratios are analogous to assumptions about the average selectivity of the survey of the survey for new and old recruits.

Q-ratio constraints tend to stabilize and have strong effects on model estimates. ASMFC (2001, p. 274) found, for example, that goodness of fit to survey data, abundance and fishing mortality estimates for lobster changed dramatically over a range of assumed q-ratio values.

To use q-ratio information in the KLAMZ model, the user must identify two surveys, a target value for the ratio of their Q values, and a CV for differences between the models estimated q-ratio and the target value. For example, if the user believes that the scaling parameters for abundance index 1 and abundance index 3 is 0.5, with a CV=0.25 for uncertainty in the prior information then the model's estimate of the q-ratio is $\rho = Q_1/Q_3$. The goodness of fit calculation is:

$$L = 0.5\left(\frac{\ln(\rho/\tau)}{\sigma}\right)^2$$

where τ is the target value and the log scale standard deviation σ is calculated from the arithmetic CV supplied by the user.

Normally, a single q-ratio constraint would be used for the ratio of new and old recruits taken during the same survey operation. However, in KLAMZ any number of q-ratio constraints can be used simultaneously and the scaling parameters can be for any two indices in the model.

Surplus production modeling

Surplus production models can be fit internally to biomass and surplus production estimates in the model (Jacobson et al. 2002). Models fit internally can be used to constrain estimates of biomass and recruitment, to summarize results in terms of surplus production, or as a source of

22 If x has a standardized beta distribution with parameters a and b, then the probability of x is

$$P(x) = \frac{x^{a-1}(1-x)^{b-1}}{\Gamma(a,b)}.$$

information in tuning the model. The NLL for goodness of fit assumes normally distributed process errors in the surplus production process:

$$L = 0.5 \sum_{j=1}^{N_P} \left(\frac{\tilde{P}_j - P_j}{\sigma} \right)^2$$

where N_p is the number of surplus production estimates (number of years less one), $\tilde{P}_t$ is a predicted value from the surplus production curve, P_t is the assessment model estimate, and the standard deviation σ is supplied by the user based, for example, on preliminary variances for surplus production estimates.[23] Either the symmetrical Schaefer (1957) or asymmetric Fox (1970) surplus production curve may be used to calculate $\tilde{P}_t$ (Quinn and Deriso 1999).

It may be important to use a surplus production curve that is compatible with recruitment patterns or assumptions about the underlying spawner-recruit relationship. More research is required, but the asymmetric shape of the Fox surplus production curve appears reasonably compatible with the assumption that recruitment follows a Beverton-Holt spawner-recruit curve (Mohn and Black 1998). In contrast, the symmetric Schaefer surplus production model appears reasonably compatible with the assumption that recruitment follows a Ricker spawner-recruit curve.

The Schaefer model has two log transformed parameters that are estimated in KLAMZ:

$$\tilde{P}_t = e^{\alpha} B_t - e^{\beta} B_t^2$$

The Fox model also has two log transformed parameters:

$$\tilde{P}_t = -e\left(e^{e^{\alpha}}\right) \frac{B_t}{e^{\beta}} \log\left(\frac{B_t}{e^{\beta}} \right)$$

See Quinn and Deriso (1999) for formulas used to calculate reference points (F_{MSY}, B_{MSY}, MSY, and K) for both surplus production models.

Catch/biomass

Forward simulation models like KLAMZ may tend to estimate absurdly high fishing mortality rates, particularly if data are limited. The likelihood constraint used to prevent this potential problem is:

$$L = 0.5 \sum_{t=0}^{N} \left(d_t^2 + q^2 \right)$$

where:

$$d_t = \left| \begin{array}{l} Ft - \Phi \ if \ Ft > \Phi \\ 0 \ otherwise \end{array} \right.$$

and

with the threshold value κ normally set by the user to about 0.95. Values for κ can be linked to

23 Variances in NLL for surplus production-biomass models are a subject of ongoing research. The advantage in assuming normal errors is that negative production values (which occur in many stocks, e.g. Jacobson et al. 2001) are accommodated. In addition, production models can be fit easily by linear regression of P_t on B_t and B_t^2 with no intercept term. However, variance of production estimate residuals increases with predicted surplus production. Therefore, the current approach to fitting production curves in KLAMZ is not completely satisfactory.

maximum F values using the modified catch equation described above. For example, to use a maximum fishing mortality rate of about $F \approx 4$ with M=0.2 and G=0.1 (maximum X=4+0.2-0.1=4.1), set $\kappa \approx F/X(1-e^{-X})$=4 / 4.1 (1-e^{-4})=0.96.

Uncertainty

The AD Model Builder version of the KLAMZ model automatically calculates variances for parameters and quantities of interest (e.g. R_t, F_t, B_t, F_{MSY}, B_{MSY}, $\overline{F}_{\mathrm{Re}cent}$, $\overline{B}_{\mathrm{Re}cent}$, $\overline{F}_{\mathrm{Re}cent} / F_{MSY}$, $\overline{B}_{\mathrm{Re}cent} / B_{MSY}$, etc.) by the delta method using exact derivatives. If the objective function is the log of a proper posterior distribution, then Markov Chain Monte Carlo (MCMC) techniques implemented in AD Model Builder libraries can be used estimate posterior distributions representing uncertainty in the same parameters and quantities.[24]

Bootstrapping

A FORTRAN program called BootADM can be used to bootstrap survey and survival index data in the KLAMZ model. Based on output files from a "basecase" model run, BootADM extracts standardized residuals:

$$r_{v,j} = \frac{\ln\left(I_{v,j} \Big/ \hat{I}_{v,j} \right)}{\sigma_{v,j}}$$

along with log scale standard deviations ($\sigma_{v,j}$, originally from survey CV's or estimated from goodness of fit), and predicted values $\left(\hat{I}_{v,j}\right)$ for all active abundance and survival observations. The original standardized residuals are pooled and then resampled (with replacement) to form new sets of bootstrapped survey "data":

$$^{x}I_{v,j} = \hat{I}_{v,j} e^{r\sigma_{v,j}}$$

where r is a resampled residual. Residuals for abundance and survival data are combined in bootstrap calculations. BootADM builds new KLAMZ data files and runs the KLAMZ model repetitively, collecting the bootstrapped parameter and other estimates at each iteration and writing them to a comma separated text file that can be processed in Excel to calculate bootstrap variances, confidence intervals, bias estimates, etc. for all parameters and quantities of interest (Efron 1982).

Projections

Stochastic projections can be carried out using another FORTRAN program called SPROJDDF based on bootstrap output from BootADM. Basically, bootstrap estimates of biomass, recruitment, spawning biomass, natural and fishing mortality during the terminal years are used with recruit model parameters from each bootstrap run to start and carryout projections.[25] Given a user-specified level of catch or fishing mortality, the delay-difference equation is used to project stock status for a user-specified number of years. Recruitment during each projected year is based on

24 MCMC calculations are not available in the current version because objective function calculations use concentrated likelihood formulas. However, the C++ version of KLAMZ is programmed in other respects to accommodate Bayesian estimation.

25 At present, only Beverton-Holt recruitment calculations are available in SPROJDDF.

simulated spawning biomass, log normal random numbers, and spawner-recruit parameters (including the residual variance) estimated in the bootstrap run. This approach is similar to carrying out projections based on parameters and state variables sampled from a posterior distribution for the basecase model fit. It differs from most current approaches because the spawner-recruit parameters vary from projection to projection.

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APPENDIX B7: "West coast groundfish harvest rate policy workshop report", provided courtesy of the Pacific Fishery Management Council.

West Coast Groundfish Harvest Rate Policy Workshop
Alaska Fisheries Science Center, Seattle, Washington: March 20-23, 2000
Sponsored by the Scientific & Statistical Committee of
the Pacific Fishery Management Council

Panel Report

Stephen Ralston (chairman), James R. Bence, William G. Clark,
Ramon J. Conser, Thomas Jagielo, and Terrance J. Quinn II.

Scientific and Management Background

Through 1998 the policy of the Pacific Fishery Management Council (PFMC) was to set the Allowable Biological Catch (ABC) of a stock by applying the fishing mortality rate that produces Maximum Sustainable Yield (F_{MSY}) to an estimate of exploitable stock biomass. Policies of this kind are termed constant rate policies because, once the estimate of F_{MSY} is determined, the annual ABC is strictly proportional to estimates of exploitable biomass. However, owing to short data series and other technical issues, it generally has not been possible to directly estimate F_{MSY} reliably for any stock. Consequently, during the 1980s and into the early 1990s, one of several common surrogate or proxy estimates of F_{MSY} was used (e.g., $F_{0.1}$ or F=M).

Clark (1991) proposed the $F_{35\%}$ harvest rate as a more general and rational surrogate rate. $F_{35\%}$ is the fishing mortality rate that reduces the spawning potential *per recruit* to 35% of the unfished level. By reasonably assuming that fecundity is proportional to average weight, it is the rate of fishing that reduces the spawning biomass *per recruit* to 35% of what would exist if there were no fishing. Clark showed that this rate would produce a yield close to MSY for a range of life history parameters and productivity relationships that were intended to cover the great majority of well-studied groundfish stocks with long histories of exploitation (most of which were Atlantic stocks). He also showed that $F_{35\%}$ was very close to both $F_{0.1}$ and F=M when the schedules of recruitment and maturity coincided, and were sensibly higher or lower when they differed. However, a later paper extended the original analysis to cases with random and serially correlated recruitment variation (Clark 1993), and concluded that $F_{40\%}$ would be a better choice overall than $F_{35\%}$. Mace (1994) also recommended $F_{40\%}$ on the basis of deterministic calculations. The current scientific consensus now indicates that $F_{40\%}$ is an appropriate default harvest rate for stocks with unknown productivity parameters.

The PFMC adopted $F_{35\%}$ as its standard surrogate in 1992, and switched to $F_{40\%}$ for *Sebastes* only in 1997, based principally on the conclusions of Clark (1993) and Mace (1994). In 1998 it then adopted the so-called "40-10" rule under Amendment 11 to the groundfish FMP. The 40-10 rule represented a departure from prior constant rate harvest policies, wherein the target fishing mortality rate is reduced for stocks whose biomass is below 40% of the estimated unfished biomass (B_0).

Common Confusion Over Relative Biomass and Relative Biomass per Recruit

In addition to recommending the $F_{35\%}$ strategy, Clark (1991) suggested a more robust biomass-based strategy that consists of simply maintaining spawning biomass at around 40% of the estimated unfished level. Perhaps partly because of the shared "40%" level, it is often supposed that the $F_{40\%}$ harvest rate will reduce spawning biomass to 40% of unfished biomass, but that is only true for stocks with highly resilient spawner-recruit relationships. For less resilient stocks, $F_{40\%}$ will reduce biomass to a lower level, possibly much lower, while still providing a yield near MSY. That is possible because yield is not very sensitive to equilibrium biomass over a wide range of biomass levels, so a yield near MSY can be obtained even when biomass is well below B_{MSY}. It is this feature of yield curves that makes it possible for a rate like $F_{40\%}$ to perform well in terms of yield over a wide range of spawner-recruit productivity curves. For some curves $F_{40\%}$ is well above F_{MSY} and for some of the curves it is well below, but in none of the cases considered is it so far above or below F_{MSY} that yield is much lower than MSY.

For the most likely sort of groundfish spawner-recruit relationships (i.e., asymptotic curves such as the Beverton-Holt model), and if other forms of stock compensation are negligible, B_{MSY} is likely to lie in the range of 25-40% of unfished biomass. Therefore, even if F_{MSY} was known and was implemented for a stock, the resulting biomass level would generally be less than 40% of B_0 on average. For some stocks, recruitment variations alone might then result in biomass levels falling below 25% of the unfished level, which is the overfished threshold as implemented in Amendment 11 to the groundfish FMP. Thus, fishing at $F_{40\%}$, which can be well above (or below) F_{MSY}, can be expected to result in biomass levels that are occasionally or on average very low for some stocks. Thus, given the new requirement of biomass-based overfished thresholds (Department of Commerce 1998), the relationship between harvest rates and biomass levels becomes more critical.

Declines of Pacific Coast Stocks Fished at $F_{35\text{-}40\%}$

Ralston (1998) showed that a number of Pacific coast rockfish stocks declined to low levels during the last two decades, contributing to concerns about the wisdom of the $F_{35\%}$ policy. His findings, as well as analyses conducted by the GMT during the preparation of Amendment 11, led to a series of workshops, including this latest review. This panel received a number of papers dealing with the productivity of the stocks in question and considered arguments for and against retaining the $F_{35\%}/F_{40\%}$ rate (in conjunction with the 40-10 rule) for all stocks.

We believe there are at least three possible factors that are responsible for the observed declines in groundfish stocks:

1. *Normal operation of the $F_{35\%}/F_{40\%}$ strategy.*

As explained above, either an $F_{35\%}$ or $F_{40\%}$ harvest rate will often lead to biomass levels that are well below what many people commonly expect, even when the rate is no larger than F_{MSY}. When it is larger, as will happen for some stocks, resulting biomasses can be very low. The important point is that both F_{MSY} and the proxy rate are calculated to achieve a certain level of yield, not biomass. In addition, harvesting at $F_{35\%}/F_{40\%}$ should be viewed as a risk-neutral policy in that, being a compromise intermediate rate, some stocks will be over-exploited and some stocks will be under-exploited, with no penalty imposed for over-exploitation.

2. *Higher than intended harvest rates.*

Recent assessments show that in many cases, actual fishing mortality rates were well above $F_{35\%}$. This can happen in any fishery when quotas are set on the basis of current biomass estimates, which are subsequently revised downward in a later assessment.

3. *Apparently low productivity of Pacific coast stocks.*

The spawner-recruit estimates that have accumulated over the last twenty years on Pacific coast groundfish stocks indicate very low resiliency in the spawner-recruit relationships — at or below the lowest values estimated for well-studied stocks elsewhere in the world (Myers *et al.* 1999). It is not surprising then, that the estimated productivity of these stocks is in many instances lower than the range of values considered plausible by Clark (1991) in his derivation of the $F_{35\%}$ strategy.

Because these low productivity estimates are so common among Pacific coast groundfish stocks, and so uncommon elsewhere, there is some suspicion that they result from some unrecognized flaw common to all of the Pacific coast groundfish assessments. However, with the exception of discards (see below), the panel has no reason to doubt the accuracy of west coast groundfish stock assessments. The same methods and models have produced estimates of higher productivity elsewhere (e.g., in Alaska). For the time being, therefore, we believe that all of the assessment results should be taken at face value, and that the Council's harvest strategy should be reconsidered in light of the apparently low productivity of many of the stocks.

The reason for anomalously low productivity in this region is not certain, but it may well be linked to the climatic regime shift that occurred in the eastern Pacific ocean around 1977-78. Since then, ocean conditions have been generally more favorable for many Alaskan stocks and have been less favorable for many Pacific coast stocks. Sometime in the future conditions on the west coast are likely to change again. Still, there is no assurance that this will occur in the near future and so, in the interim, the PFMC should manage groundfish stocks according to their current productive capacity.

The panel reviewed results presented by Williams (see Appendix A), which suggest that discards of small fish could contribute to the perception of low groundfish productivity. To the extent that this occurs, its effect is to reduce apparent recruitments and therefore to make ground-fish stocks appear to be less resilient. This scenario depends on: (1) an increasing exploitation rate over time and (2) substantial unaccounted for discarding of the smallest fish captured. While groundfish exploitation rates have certainly risen, and substantial unaccounted for discards of small fish is likely in some fisheries, discards are generally not documented for these stock and cannot be quantified at present. Clearly more research on this issue is desirable and, in general,

the panel stresses that a full accounting of total catch is necessary for the PFMC to adequately manage any of the resources under its authority.

Panel Recommendations for Default Groundfish Harvest Rates

The panel reviewed the information presented by each presenter (see Appendix A), as well as other recently published material (e.g., Myers *et al.* 1999). Of particular importance were the works of Brodziak, Dorn, MacCall, and Parrish because each of these studies broadly re-analyzed the information presented in historical PFMC stock assessments in an attempt to estimate F_{MSY} for each stock and their F_{spr} equivalents (i.e., the spawning potential per recuit fishing mortality rate). Significantly, each of these studies indicated that in many instances groundfish productivity, as estimated from the results of stock assessments, is insufficient to support harvests at the $F_{35\%}$ or even $F_{40\%}$ rates.

With respect to the rockfishes (*Sebastes* spp.) the panel found the work of Dorn to be very compelling. His results showed that, when the genus is examined as a whole through the use of meta-analysis, west coast rockfish stocks (exclusive of Pacific ocean perch) have F_{MSY} rates that range between $F_{45\%} - F_{67\%}$ for risk-neutral models, assuming either the Beverton-Holt or Ricker models with lognormal or gamma errors (four cases). However, gamma error models fit the data more poorly than models with a lognormal error structure and, as a consequence, the panel supported the use of Dorn's lognormal analysis only. For that subset of cases, the estimated F_{MSY} rates ranged $F_{45\%} - F_{54\%}$ over the two recruitment models. The panel then adopted $F_{50\%}$ as a midpoint, risk-neutral, proxy for rockfish F_{MSY}. In addition, the panel recommends including the thorneyheads (genus *Sebastolobus*) with the rockfish in the setting of default harvest rate proxies.

The panel discussed results for Pacific whiting and concluded that the information base for that species was the best available for any west coast groundfish. Harvests are currently determined using the 40-10 policy in association with a fishing mortality rate equal to $F_{40\%}$. This rate is based on a separate and distinct meta-analysis of worldwide *Merluccius* productivity that was conducted as part of the last stock assessment (Dorn *et al.* 1999) and seems appropriate as a risk-neutral harvest policy. Consequently, the panel does not recommend any changes in harvest rate for Pacific whiting.

For flatfishes (including Dover sole), the panel concluded that resiliency is typically higher than in other taxa (e.g., Brodziak *et al.* 1997, Mace and Sissenwine 1993, Myers *et al.* 1999). As a consequence, the panel recommends using a default rate of $F_{40\%}$ for all flatfish species in the groundfish FMP. This rate is consistent with the general findings of Clark (1993) and Mace (1994).

For all other species in the groundfish FMP (including sablefish and lingcod) the panel recommends an intermediate harvest rate of $F_{45\%}$. This intermediate rate was selected as a sensible risk-neutral alternative that would afford increased protection to all the remaining groundfish stocks. However, the level of certainty in setting this default rate is very low. Consequently, the panel makes two recommendations with respect to the estimation of groundfish productivity, i.e.,

(1) Assessment authors are encouraged to evaluate the resiliency of the specific stocks they model. When such analysis produces scientifically credible estimates of productivity, the analyst is encouraged to present those findings as part of their stock assessment. However, any productivity analysis should always include a measure of the uncertainty in the point estimates of management reference points (e.g., F_{MSY}, B_{MSY}, and B_0).

(2) A proper consideration of risk is essential in the setting of optimum yields for west coast groundfish stocks. Utilization of a risk-neutral harvest rate proxy (e.g., $F_{50\%}$ for *Sebastes* and *Sebastolobus*) implies that some stocks within the group are quite likely to be over-exploited. Similarly, calculation of an ABC using an unbiased stock-specific point estimate of F_{MSY} will result in overfishing if the estimate is, by chance, too high. It is the PFMC's responsibility to account for these risks of overfishing through the use of a precautionary approach in the establishment of optimum yields. In addition, the NMFS Guidelines specify that status determination criteria must specify a maximum fishing mortality rate threshold that is less than or equal to F_{MSY} (Department of Commerce 1998). While this issue is not specifically addressed in this report, the choice of the threshold should depend on the level of uncertainty associated with the estimate of F_{MSY} or its proxy.

In summary, panel recommendations with respect to risk-neutral default harvest rate F_{MSY} proxies for west coast groundfish are:

Pacific whiting	$F_{40\%}$
Sebastes & *Sebastolobus*	$F_{50\%}$
Flatfish	$F_{40\%}$
Other groundfish	$F_{45\%}$

Due to a lack of detailed life history and stock status information, it will not be possible to implement these recommendations for many stocks. In particular, the "remaining rockfish" management unit (PFMC 1999) includes a number of species for which the ABC has been set using the F=M harvest rate proxy (Rogers *et al.* 1996). Currently, the optimum yield (OY) of those species is reduced by 25% as a "precautionary adjustment" (PFMC 1999), amounting to an F=0.75M policy. The panel discussed the remaining rockfish category in light of results presented in MacCall's production model analysis (Appendix A), which indicated that 0.40M may be a better proxy for an optimal exploitation rate. However, due to the review panel's unwillingness to fully endorse production modeling as a viable means of estimating groundfish productivity (see below), the panel recommended that the PFMC establish F=0.75M as the default, risk-neutral policy for the remaining rockfish management category. This determination was consistent with results presented for Pacific ocean perch, for which F_{MSY}=0.80M. Even so, concern was expressed within the panel that a more conservative harvest rate might be warranted, such as that used by the North Pacific Fishery Management Council, which in similar swept-area applications assumes that q=1.0. In either case, given the high degree of uncertainty underlying the technical basis of this recommendation, and the real possibility that MacCall's findings are accurate, precautionary adjustments in setting the OY of the remaining rockfish are recommended.

The panel discussed the hardship to the fishing industry that the immediate application of these new, more restrictive, rates will cause. The National Standard Guidelines for implementa-tion of the Magnuson-Stevens Act specify (Department of Commerce 1998): "Overfishing occurs whenever a stock of stock complex is subjected to a rate or level of fishing mortality that jeopardizes the capacity of a stock or stock complex to produce MSY on a continuing basis." The PFMC may, therefore, wish to consider the propriety and legality of a short-term phase-in of these new rates to ameliorate the immediate impact to the groundfish industry.

Surplus Production Models

During the workshop, methods considering an examination of the relationship between surplus production and stock biomass were discussed as potential alternatives to methods based on stock-recruit models for determining appropriate exploitation rates. The panel generally agreed that an examination of estimates of surplus production and their relationship with estimates of biomass or other variables is useful. However, the panel does not endorse the general replacement of a stock-recruitment based approach at this time, nor the requirement of using a biomass-based surplus production model as one approach for estimating MSY, F_{MSY} and B_{MSY} for all assessed stocks. The panel concluded that this is an area that could benefit from additional research.

There were three presentations dealing with biomass-based production model approaches on the agenda (Jacobson *et al*, MacCall, and Parrish; see Appendix A). The fundamental premise of these approaches was to use the output from a detailed age-structured model as an accurate representation of exploitable stock biomass (i.e., assume q = 1.0) and to estimate the relationship between catches and changes in biomass to determine production. Most of the panel concluded that this kind of approach has potential application when applied to estimates generated from age-structured or delay-difference assessments. This is possible because absolute stock biomass estimates are generally available from the assessment models and, by definition, estimated surplus production can be calculated from the time series of catch and estimated biomass. The disadvantage of this approach, however, is that the various biological processes underlying stock compensation are not directly addressed, whereas in age-structured approaches these processes can be treated explicitly. Whether surplus production is estimated internally within the model (e.g., Jacobson *et al.*) or externally after the fact (MacCall, Parrish), is an issue deserving of more study (see also results from Ianelli).

Although the full panel saw benefits to explicit consideration of biomass production implied by assessments, some panelists expressed significant reservations regarding the use of production models to determine F_{MSY} and related quantities. These reservations were largely based on the view that this approach discards important information contained in the original age-structured model results. For example, age-structure can influence production because young fish generally have higher weight-specific growth rates than older fish. As a result, the same biomass can lead to different levels of production, depending upon the age composition of the population. Likewise, changes in selectivity over time will change the amount of surplus production at a given biomass. Although such variation in surplus production could be dealt with as correlated process error (Jacobson *et al.*) this converts variation explained by the age-structured model into additional error. In any event, age-structured analyses can provide specific information on the nature of compensation (e.g., in individual growth, maturation, or recruitment), which is not possible from an examination of the aggregate surplus production-biomass relationship alone.

Other panelists argued that estimates of F_{MSY} from surplus production models might be more robust than those that depend upon solely on stock-recruitment relationships. The idea here is that (1) error in assessment model estimates of biomass may cancel-out because production estimates involve differencing model biomass estimates, and (2) potentially biased estimates of recruitment (e.g., discards of small fish) play a less critical role in the analysis. Simulations presented by MacCall at the second Groundfish Productivity Workshop in Monterey, CA suggested this was the case. However, given the few number of replicate simulations and the limited suite of scenarios in that paper, the panel did not view this work as definitive.

Estimation of B_0, B_{40} and Related Problems

Although variable rate biomass-based harvest policies were not the primary focus of the workshop, the newly implemented 40-10 harvest policy was, nonetheless, the subject of much discussion. While in practice it is possible to consider F_{MSY} proxies in isolation from biomass targets and thresholds, in principle these two subjects are inextricably linked.

The main concern about the 40-10 harvest policy is that it involves the calculation of two biomass reference points, i.e., the virgin biomass that would exist in the absence of fishing (B_0) and the exploited biomass that is 40% of that pristine level ($B_{40\%}$). Within the PFMC, it appears that parameter B_0 is usually obtained from a stock assessment model and estimates of what biomass may have been in the far past.

A number of problems are likely to occur in the estimation of this parameter. First, its estimated value may be far larger than any historical observed biomass due to vagaries of parameter estimation and the age composition of the population at the start of the data series (e.g., Pacific ocean perch; see Ianelli in Appendix A). In some cases, it may be justifiable to constrain the value of B_0 to be near the historical maximum or some other value, as long as a clear rationale is provided and the sensitivity of the constraint is examined.

A second problem is that models are frequently configured to assume that the age composition is at equilibrium at the start of the modeled period. If this assumption fails, then the estimate of parameter B_0 may be biased. Third, there is no guarantee that under any fishing mortality regime, including zero fishing, that the population will rebuild to this level. The reason for this is that the amount of recruitment needed to produce historical levels of spawning biomass may not occur in the future. Given that many West Coast stocks have been on a "one-way trip" downward, a sensible harvest policy would first reverse the decline, and then rebuild to a level that could be expected based on current and expected future conditions. Once that level of rebuilding is accomplished, it may then be possible to rebuild toward a level consistent with historical patterns.

Therefore, some alternatives for calculating B_0 that look toward the future instead of the past should probably be considered. Two clear alternatives involve determining: (1) whether a spawner-recruit model is used to project the population forward and (2) if not, what exact values of the recruitment time series are to be used in forecasting future biomass. If a spawner-recruit model is used, then it should be possible to determine pristine biomass and B_{MSY} as reference points automatically. These points can then be implemented in the harvest policy, as is done by the North Pacific Fishery Management Council. However, it is often quite difficult to assert that a reliable spawner-recruit relationship is known, so typically such a relationship would not be invoked. Nevertheless, it is often wise to provide for reduced recruitment at low spawning biomass levels, particularly if the stock has been fished down to a point where recruitment is believed to have been impacted. Some recent modeling efforts with ADMB and Bayesian considerations (e.g., Pacific hake) lend hope to better determining MSY parameters.

If a spawner-recruit relationship is not used, then a projection of future unfished equilibrium biomass can be made by multiplying contemporary recruitment values by the corresponding spawner biomass per recruit (SPR) function. For example, the average recruitment over the time series might be used with an SPR function at a fishing mortality of 0 to arrive at the expected equilibrium unfished biomass in the future, to be used as B_0. From this information $B_{40\%}$ could be obtained. This type of approach is especially appropriate if it is known there has been a change in stock productivity. A caveat to doing this, however, is that it can be very difficult to detect a change in productivity, so the rationale for restricting the time period must be carefully considered.

Whichever approach is used, it should be documented carefully and properly justified. The same methodology should be used for all biomass reference points and it should be clearly stated whether a reference point is based on SPR calculations that are fully independent of spawning biomass, or whether recruitments have been adjusted downward by a spawner-recruit relationship. We think justification for the calculation of biomass reference points should address consistency between the assumptions used in their derivation and those underlying F_{MSY} estimates or proxies.

We note that another type of calculation is required by the NMFS overfishing guidelines, which could lead to further confusion. Namely, a threshold level that provides for a 10-year rebuilding to a target level such as B_{MSY} must be found (Department of Commerce 1998). This level is also a function of the recruitment series used and depends on whether a spawner-recruit relation exists. Consequently, for consistency the same process that is used for determining other reference points should be used here. The PFMC has apparently been allowed to use $B_{25\%}$ for this threshold, but it is unclear how rebuilding plans, which are triggered when biomass drops below this value, will interface with the 40-10 rule, which in itself, is an automatic rebuilding plan. Other Councils are currently experiencing this confusion as well, so hopefully there will be more flexibility and clarity in the NMFS overfishing guidelines in the future.

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APPENDIX B8: **Updated shell length/ meat weight relationships for use in the next assessment.**

For each ocean quahog assessment, biomass of meats per tow is calculated using a shell length/meat weight relationship for quahogs of any given length ($MW = e^aL^b$). Each of the assessment regions has its own set of alpha and beta parameters as meat weight at length varies by region. For the last several assessments (2000, 2004, 2007 and current), biomass of meats per tow for DMV and NJ has been calculated using SL/MW relationships from Murawski and Serchuk (1979). The clams they used were measured at sea and their meats were frozen for later weighing ashore.

During the 1997 NEFSC clam survey, quahogs from LI and GBK were measured and the meats weighed fresh on board the DEII to derive SL/MW relationships for those two areas. This new 1997 GBK relationship was used starting with the 2000 assessment. For the 2000 assessment, the parameters for LI were an average of the parameters derived from the fresh meats samples on the 1997 survey and those derived by Murawski and Serchuk (1979) from frozen meats (Table 1).

Since the 1997 NEFSC clam survey, fresh meat weights have also been collected during the 2002, 2005 and 2008 NEFSC clam surveys. We used only the lengths and fresh meat weights from these surveys to derive new SL/MW parameters for NJ, LI, SNE and GBK. Data was not collected from all regions every year, and no data was collected from SVA or DMV during any of those four surveys. We fit curves for each year the data was collected for each region, and then created an average curve for each region. These new relationships should give a more accurate and current estimate of biomass for the next assessment.

Table 1. Alpha and beta parameters for various SL/MW relationships by region and source. The years 1997, 2002, 2005 and 2005 are the years fresh meats were collected during the NEFSC clam survey, N refers to how many samples (clams) were used to fit the curve.

	SVA			DMV			NJ		
	alpha	beta	N	alpha	beta	N	alpha	beta	N
Murawski and Serchuk (1979)	-9.0423	2.7880		-9.0423	2.7880		-9.8472	2.9495	
1997									
2002							-9.4091	2.9320	117
2005							-10.0110	3.1144	155
2008							-9.6618	2.9689	324
average curves (data 1997+)							-9.6634	2.9927	
previous SARCs (2004,2007)	-9.0423	2.7880		-9.0423	2.7880		-9.8472	2.9495	

	LI			SNE			GBK		
	alpha	beta	N	alpha	beta	N	alpha	beta	N
Murawski and Serchuk (1979)	-9.1243	2.7750							
1997	-9.3102	2.8605	151				-8.8338	2.7611	72
2002				-9.0439	2.8238	158	-9.6670	2.9522	268
2005	-10.0380	3.1627	92	-9.6041	2.9108	71			
2008	-8.7270	2.5520	460	-9.5091	2.9104	243	-9.0576	2.7328	308
average curves (data 1997+)	-9.1962	2.7790		-9.3541	2.8729		-9.1276	2.7952	
previous SARCs (2000, 2004,2007)	-9.2336	2.8225		-9.1243	2.7750		-8.9691	2.7673	

The surveys in 1997, 2002, 2005 and 2008 collected SLMW data from freshly shucked meats.

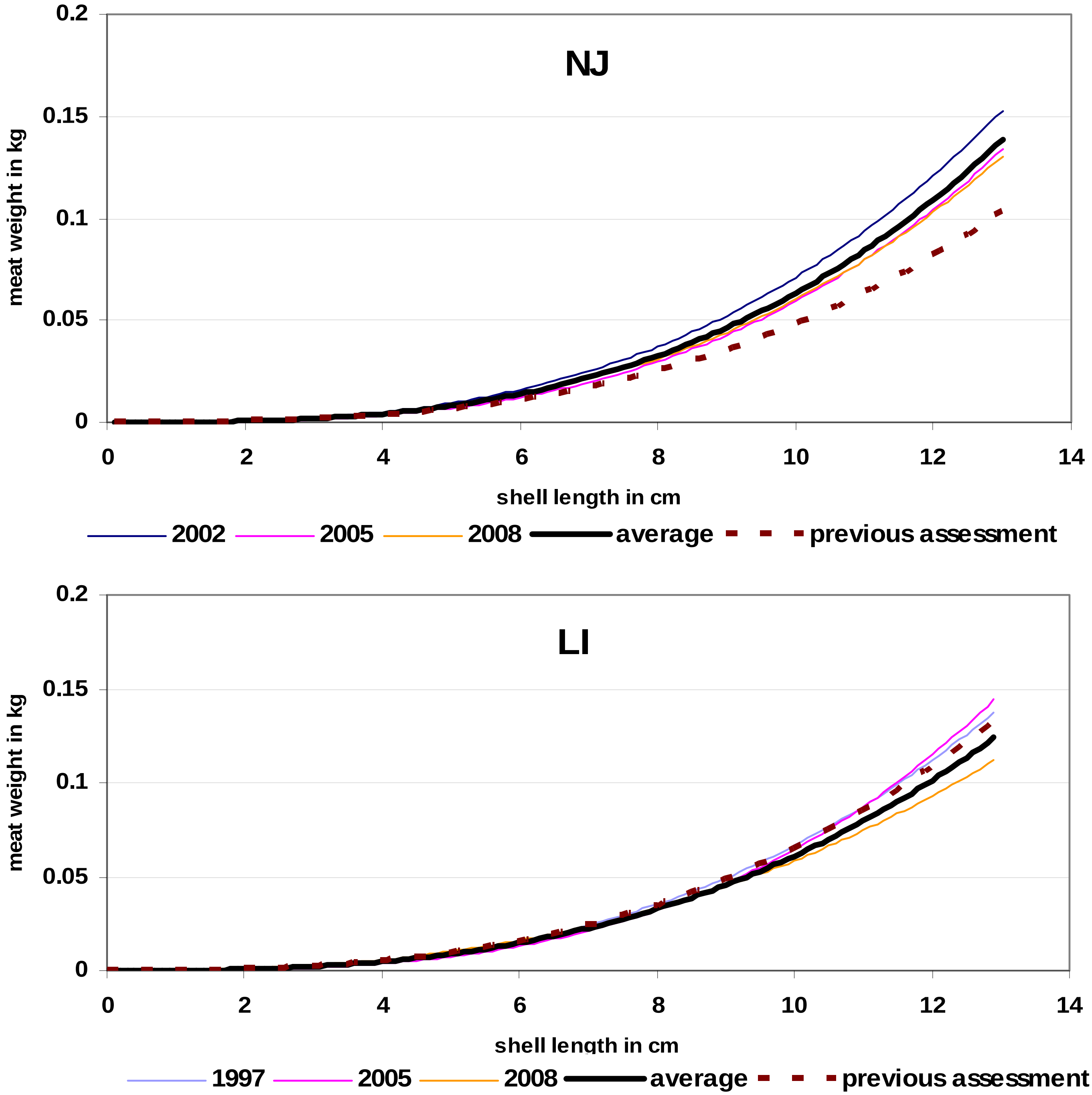

Figure 1. Shell length/ meat weight relationships for the NJ and LI assessment regions.

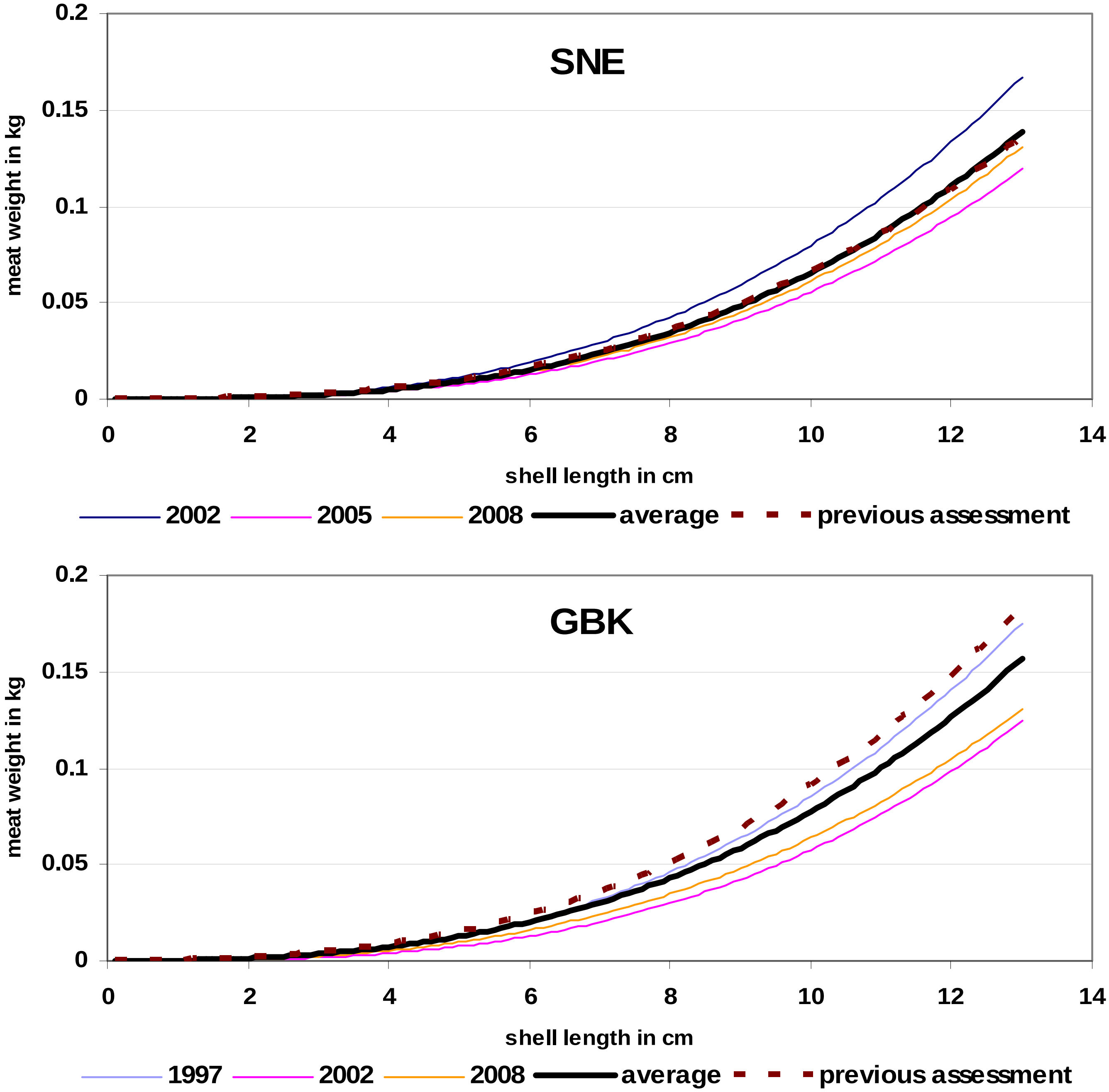

Figure 2. Shell length/ meat weight relationships for the SNE and GBK assessment regions