



Northeast Fisheries Science Center Reference Document 10-03

*A Report of the 49th Northeast Regional  
Stock Assessment Workshop*

**49th Northeast Regional  
Stock Assessment Workshop  
(49th SAW)  
*Assessment Report***

by the Northeast Fisheries Science Center

February 2010

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**U.S. DEPARTMENT OF COMMERCE**  
National Oceanic and Atmospheric Administration  
National Marine Fisheries Service  
Northeast Fisheries Science Center  
Woods Hole, Massachusetts

February 2010

## Northeast Fisheries Science Center Reference Documents

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**Editorial Treatment:** To distribute this report quickly, it has not undergone the normal technical and copy editing by the Northeast Fisheries Science Center's (NEFSC's) Editorial Office as have most other issues in the NOAA Technical Memorandum NMFS-NE series. Other than the four covers and first two preliminary pages, all writing and editing have been performed by the authors listed within. This report was reviewed by the Stock Assessment Review Committee, a panel of assessment experts from the Center for Independent Experts (CIE), University of Miami.

**Information Quality Act Compliance:** In accordance with section 515 of Public Law 106-554, the Northeast Fisheries Science Center completed both technical and policy reviews for this report. These predissemination reviews are on file at the NEFSC Editorial Office.

This document may be cited as:

Northeast Fisheries Science Center. 2010. 49th Northeast Regional Stock Assessment Workshop (49th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 10-03; 383 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026, or online at <http://www.nefsc.noaa.gov/nefsc/publications/>

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## Foreword

The Northeast Regional Stock Assessment Workshop (SAW) process has three parts: preparation of stock assessments by the SAW Working Groups and/or by ASMFC Technical Committees / Assessment Committees; peer review of the assessments by a panel of outside experts who judge the adequacy of the assessment as a basis for providing scientific advice to managers; and a presentation of the results and reports to the Region's fishery management bodies.

Starting with SAW-39 (June 2004), the process was revised in two fundamental ways. First, the Stock Assessment Review Committee (SARC) became smaller panel with panelists provided by the Independent System for Peer Review (Center of Independent Experts, CIE). Second, the SARC provides little management advice. Instead, Council and Commission teams (e.g., Plan Development Teams, Monitoring and Technical Committees, Science and Statistical Committee) formulate management advice, after an assessment has been accepted by the SARC. Starting with SAW-45 (June 2007) the SARC chairs were from external agencies, but not from the CIE. Starting with SAW-48 (June 2009), SARC chairs are from the Fishery Management Council's Science and Statistics Committee (SSC), and not from the CIE. Also at this time, some assessment Terms of Reference were revised to provide additional science support to the SSCs, as the SSC's are required to make annual ABC recommendations to the fishery management councils.

Reports that are produced following SAW/SARC meetings include: An *Assessment Summary Report* - a brief summary of the assessment results in a format useful to managers; this *Assessment Report* - a detailed account of the assessments for each stock; and the SARC

panelist report - a summary of the reviewer's opinions and recommendations as well as individual reports from each panelist. SAW/SARC assessment reports are available online at <http://www.nefsc.noaa.gov/nefsc/publication/series/crdlist.htm>. The CIE review reports and assessment reports can be found at <http://www.nefsc.noaa.gov/nefsc/saw/>.

The 49th SARC was convened in Woods Hole at the Northeast Fisheries Science Center, November 30 - December 3, 2009 to review two assessments Atlantic surfclam (*Spisula solidissima*), and butterfish (*Peprilus triacanthus*). CIE reviews for SARC49 were based on detailed reports produced by NEFSC Assessment Working Groups. This Introduction contains a brief summary of the SARC comments, a list of SARC panelists, the meeting agenda, and a list of attendees (Tables 1 - 3). Maps of the Atlantic coast of the USA and Canada are also provided (Figures 1 - 5).

### **Outcome of Stock Assessment Review Meeting:**

Based on the Review Panel reports (available at <http://www.nefsc.noaa.gov/nefsc/saw/> under the heading "SARC 49 Panelist Reports"), the SARC review committee concluded that the Terms of Reference (ToRs) for the Atlantic surfclam assessment were met. Commercial landings and effort data were well characterized. Two semi-independent analytical approaches were used to assess the stock, namely, efficiency corrected swept-area biomass and the KLAMZ model. The KLAMZ model was used as the primary tool for stock status determination. Estimates of whole stock biomass from 1981-2008 were fairly stable with a gradual decreasing trend in abundance since the late 1990s. Whole stock estimates of fishing mortality (F) were low and fairly stable,

while estimates of growth and recruitment showed a consistent decline over the time period of the analysis. Despite these downward trends, there was consensus that the Atlantic surfclam stock is not overfished and overfishing is not occurring. Concerns were raised about the validity of the whole stock assumption, particularly given the sedentary nature of surfclams and the potential for metapopulation dynamics.

The review panel concluded that the ToRs for the butterfish assessment were met in that the information specified by each ToR was provided; however, the review panel felt that not all of the assessment results could be used to support management. This conclusion was not a result of poor analytical procedures or any fault of the Coastal/Pelagic Working Group. It was due to the significant uncertainty associated with the input data and KLAMZ assessment model output. Commercial catch estimates were not precisely known due to a lack of precision of the discard estimates. Of the available survey data, only the NEFSC fall index appeared to be a reliable indicator of butterfish relative abundance. Estimates

of biomass and  $F$  were fairly imprecise, and the KLAMZ model struggled to capture the scale of butterfish biomass. The review panel felt that the biomass and  $F$  estimates reflect appropriate trends, but recommended that the point biomass and  $F$  estimates be interpreted with caution. The review panel did not accept the adequacy of the redefined BRPs or the BRPs used for stock status determination in the 2004 butterfish assessment. The review panel questioned the application of MSY theory to a short-lived recruitment-dominated population, particularly the use of equilibrium methods when trends in the data suggest the stock is declining even with low fishing mortality. It was agreed that overfishing was not likely occurring. The review panel concluded that the decline in the butterfish stock appears to be driven by environmental processes and low recruitment. Determination of an overfished versus not overfished condition was not resolved at the meeting, which left the overfished status of butterfish unknown.

**Table 1. 49th Stock Assessment Review Committee Panel.**

49th Northeast Regional Stock Assessment Workshop (SAW 49)  
**Stock Assessment Review Committee (SARC) Meeting**

November 30 – December 3, 2009  
Woods Hole MA

**SARC Chairman (MAFMC SSC Member):**

Dr. Robert J. Latour  
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**SARC Panelists (CIE):**

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Table 2. Agenda, 49th Stock Assessment Review Committee Meeting.

**49th Northeast Regional Stock Assessment Workshop (SAW 49)  
Stock Assessment Review Committee (SARC) Meeting**

**November 30 – December 3, 2009**

Stephen H. Clark Conference Room – Northeast Fisheries Science Center  
Woods Hole, Massachusetts

**DRAFT AGENDA\* (version: 11-23-09)**

TOPIC	PRESENTER(S)	SARC LEADER	RAPPORTEUR
<b><u>Monday, 30 Nov</u></b>			
<b>1:00 – 1:30 PM</b>			
Opening			
Welcome	<b>James Weinberg</b> , SAW Chairman		
Introduction	<b>Robert Latour</b> , SARC Chairman		
Agenda			
Conduct of Meeting			
<b>1:30 – 3:30</b>	Assessment Presentation Surfclam <b>Larry Jacobson</b>	<b>TBD</b>	<b>Toni Chute, Dan Hennen</b>
<b>3:30 – 3:45</b>	Break		
<b>3:45 – 5:30</b>	SARC Discussion of Surfclam <b>Robert Latour</b> , SARC Chairman		<b>Toni Chute, Dan Hennen</b>
<b><u>Tuesday, 1 Dec</u></b>			
<b>9:00 – 10:30 AM</b>	Assessment Presentation Butterfish <b>Tim Miller</b>	<b>TBD</b>	<b>Julie Nieland</b>
<b>10:30 – 10:45</b>	Break		
<b>10:45 – Noon</b>	SARC Discussion of Butterfish <b>Robert Latour</b> , SARC Chairman		<b>Julie Nieland</b>
<b>Noon – 1:15</b>	Lunch		
<b>1:15 – 2:15</b>	Continue SARC Discussion of Butterfish <b>Robert Latour</b> , SARC Chairman		
<b>2:15 – 3:30</b>	Revisit Surfclam Assessment with Presenters <b>Robert Latour</b> , SARC Chairman		<b>Toni Chute, Dan Hennen</b>

**3:30 – 3:45** Break

**3:45 – 5:30** Revisit Surfclam and/or Butterfish Assessments with Presenters  
**Robert Latour**, SARC Chairman

**Wednesday, 2 Dec**

**9:00 – 10:00** Revisit Butterfish Assessment with Presenters  
**Robert Latour**, SARC Chairman **Julie Nieland**

**10:00 – 10:15** Break

**10:15 - Noon** Surfclam follow up + review Assessment Summary Report  
**Robert Latour**, SARC Chairman

**Noon – 1:15 PM** Lunch

**1:15 – 3:00** Butterfish follow up + review Assessment Summary Report  
**Robert Latour**, SARC Chairman

**3:00 – 3:15** Break

**3:15 – 5:30** SARC Report writing. (closed meeting)

**Thursday, 3 Dec**

**9:00 – 2:00 PM** SARC Report writing. (closed meeting)

\*Times are approximate, and may be changed at the discretion of the SARC chair. The meeting is open to the public, except where noted.

Table 3. 49th SAW/SARC, List of Attendees

Name	Affiliation	email
Guy Simmons	Sea Watch	<a href="mailto:guy@seaclam.com">guy@seaclam.com</a>
Chris Legault	NEFSC	<a href="mailto:chris.legault@noaa.gov">chris.legault@noaa.gov</a>
Daniel Hennen	NEFSC	<a href="mailto:daniel.hennen@noaa.gov">daniel.hennen@noaa.gov</a>
Carolyn Creed	Rutgers	<a href="mailto:creed@aesop.rutgers.edu">creed@aesop.rutgers.edu</a>
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Wendy Gabriel	NEFSC	<a href="mailto:wendy.gabriel@noaa.gov">wendy.gabriel@noaa.gov</a>
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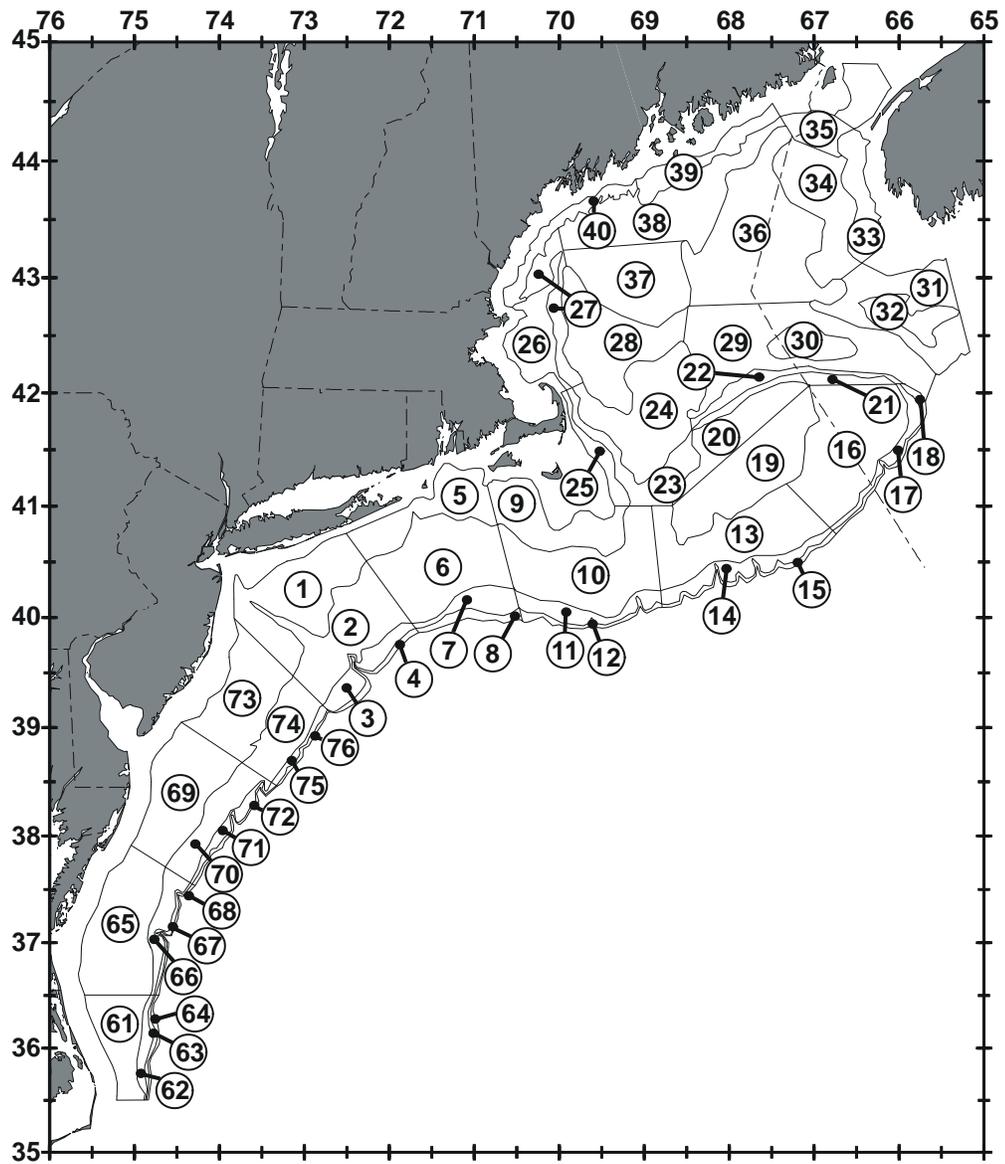


Figure 1. Offshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys.

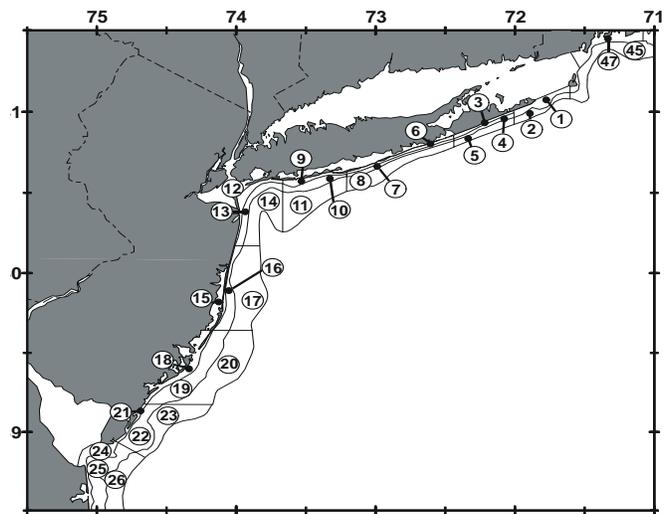
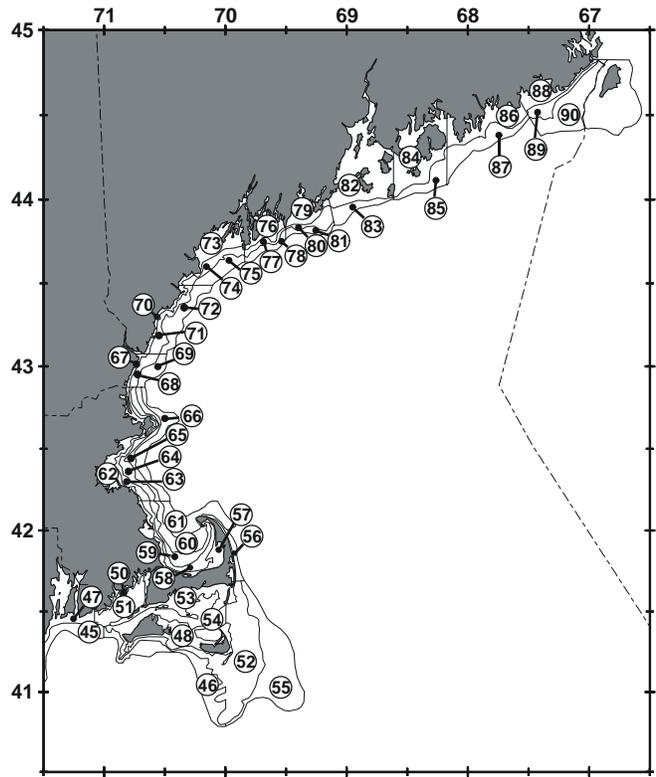
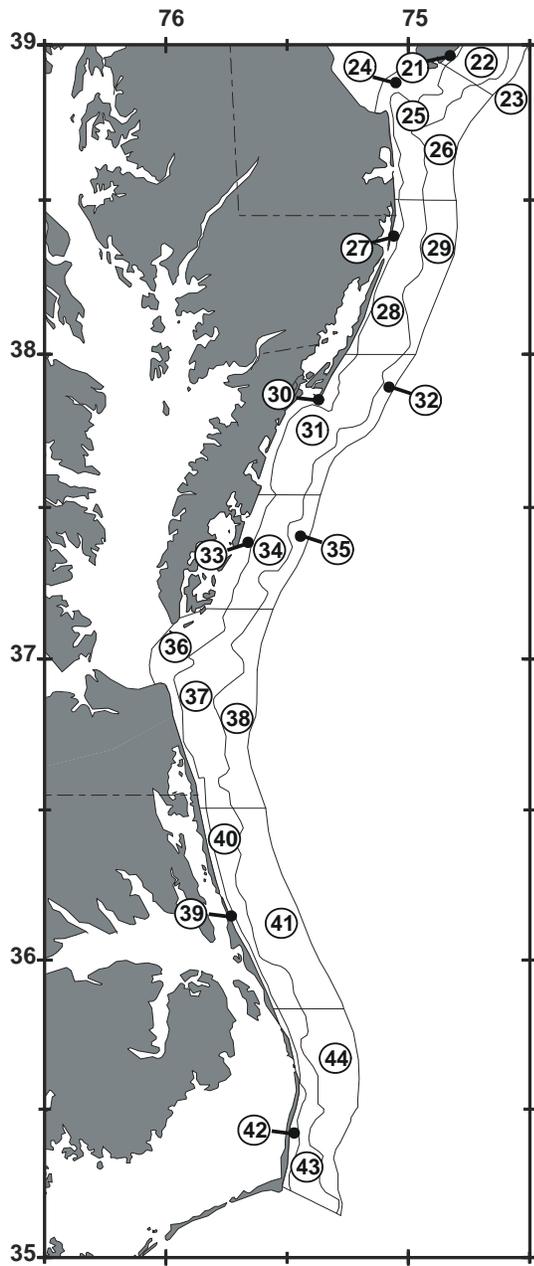


Figure 2. Inshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys.

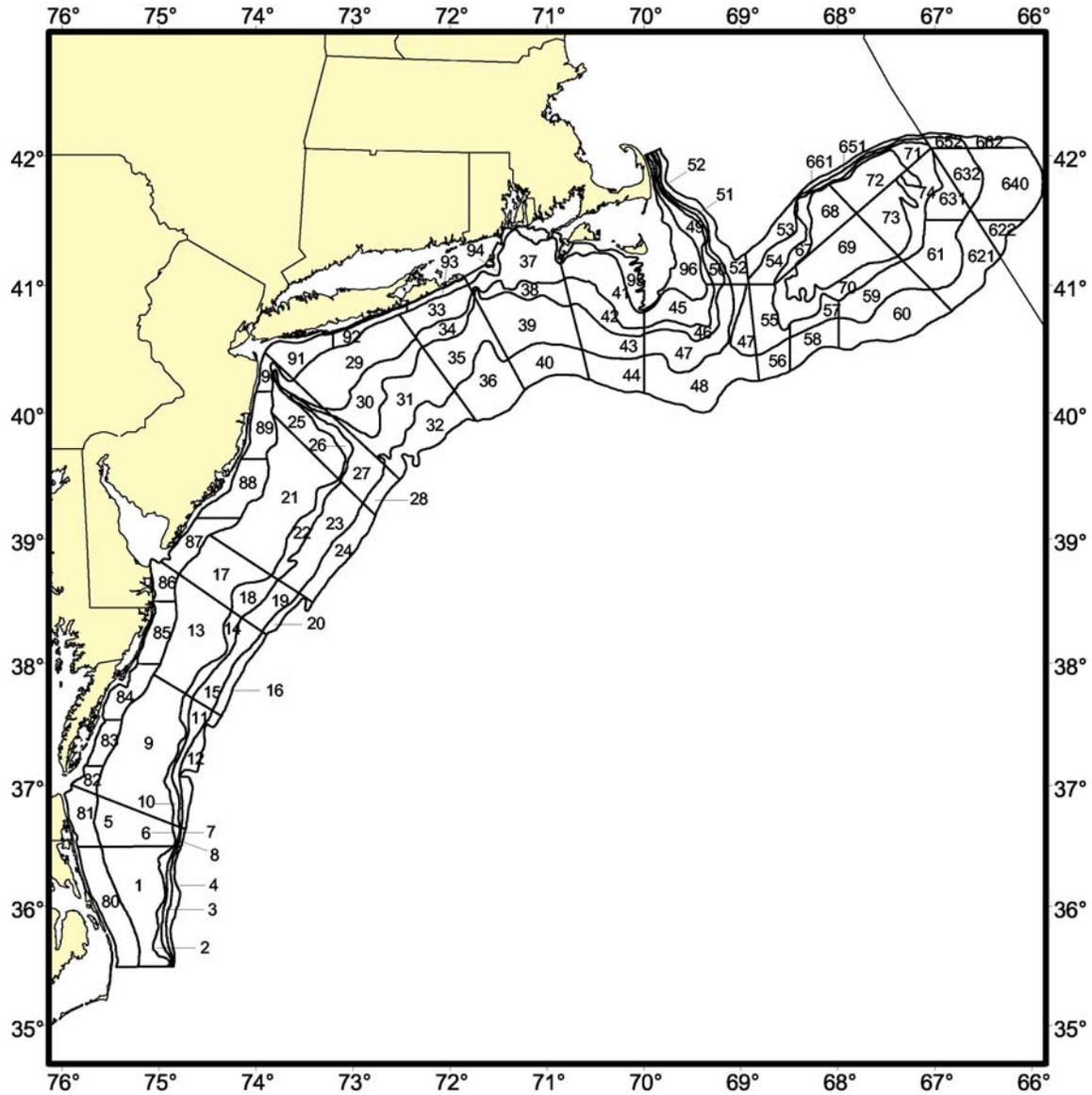


Figure 3. Depth strata sampled during Northeast Fisheries Science Center clam dredge research surveys.

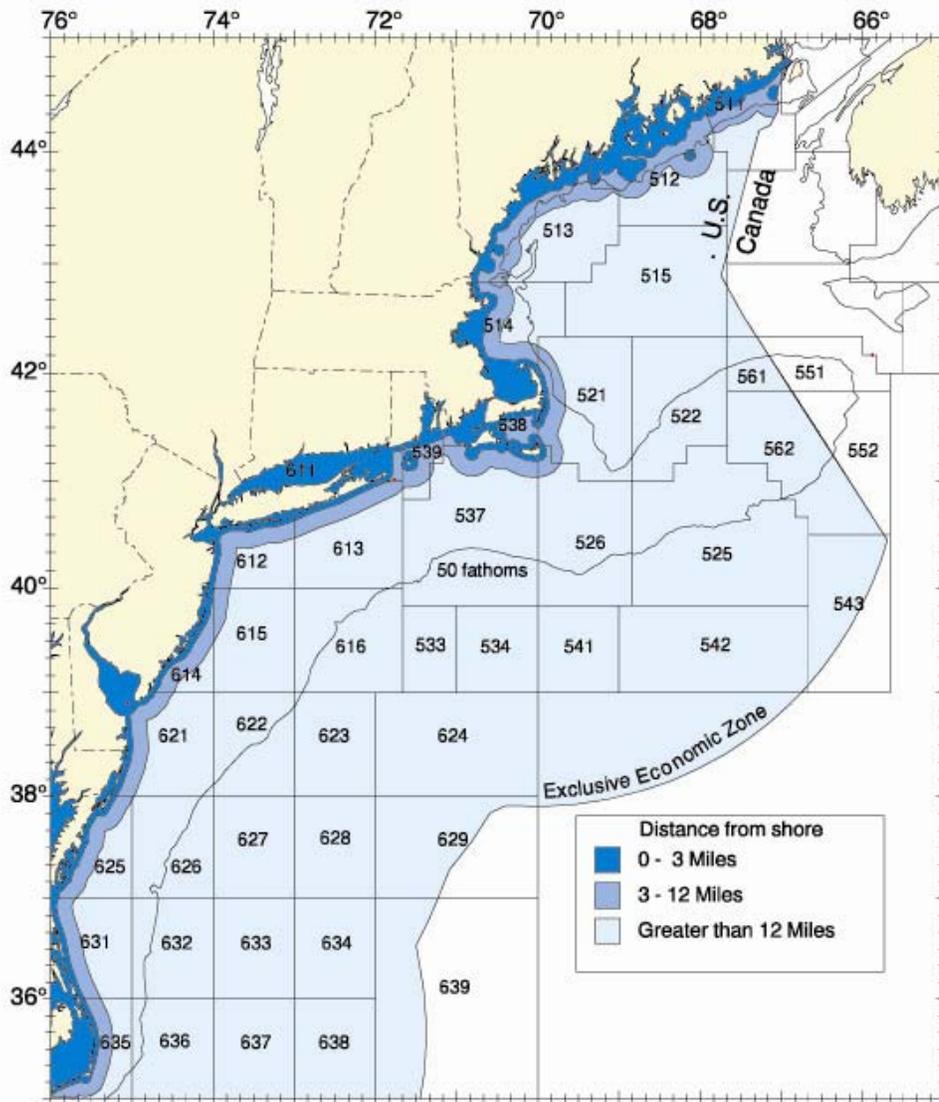


Figure 4. Statistical areas used for reporting commercial catches.

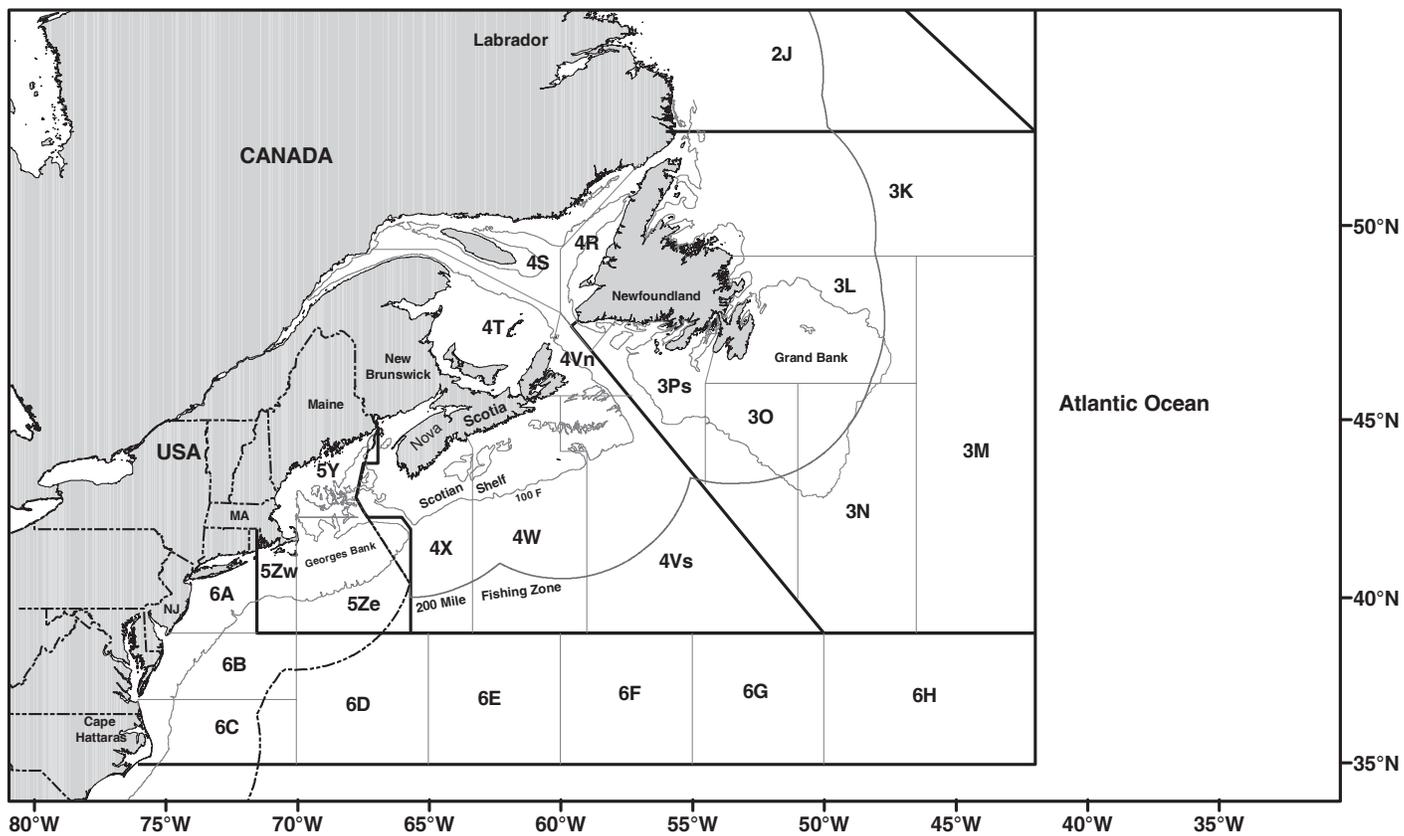


Figure 5. Catch reporting areas of the Northwest Atlantic Fisheries Organization (NAFO) for Subareas 3-6.

## A. Surfclam Assessment

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

### Terms of Reference for Atlantic surfclam

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

### Executive Summary

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

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

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

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

## Introduction

### Distribution and biology

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

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

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

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

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

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<sup>1</sup> <http://www.nefsc.noaa.gov/nefsc/publications/tm/tm142/>

## Management

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

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

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

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

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

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

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

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

## **Previous assessments**

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

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

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

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

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

## **Term of Reference 1: Commercial Catch**

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

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

Unit	Equivalent
1 cage	32 bushels
1 bushel	1.88 ft <sup>3</sup>
1 bushel	17 lbs meats
1 bushel	7.71 kg meats

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

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

### **New discard data**

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

Size limits for surfclams were intended to protect strong year classes following a large scale die-off due to hypoxia during 1976 that occurred in waters off NJ. These year classes were large, grew quickly and began to recruit to the fishery in about 1979. Discards were small during 1979 because vessels were still targeting relatively dense beds of large surfclams unaffected by the die-off. Discards increased during 1980-1981 as catch rates for large surfclams declined and vessels began to target dense beds of relatively small clams.

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

### **Age and size at recruitment to the fishery**

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

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

### **Landings, fishing effort and prices**

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

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

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

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

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

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

### **Landings per unit effort (LPUE)**

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

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

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

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

### **Spatial patterns in fishery data**

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

Figures A7-A9 show the spatial patterns in the surf clam fishery over the past 28 years. In all the years, the greatest concentration of fishing effort and landings has occurred in about 25 TMS in the NJ region, with fishing activity in other regions occurring more intermittently. For example, during the first ten-year time period, from 1981 to 1990, the highest landings and fishing effort were still concentrated off NJ, but there were relatively high levels of landings and fishing effort mostly offshore in DMV and SVA, and some fishing activity in SNE off of Martha's Vineyard (about 41°N 70°W). During 1996-2000, there were little landings or effort in SVA or SNE, reduced activity in DMV, and increased activity in NJ with expansion to offshore regions. During 2001-2005, fishing effort in DMV increased and fishing effort expanded eastward along the south shore of Long Island. During 2006-2008, some landings have come from a small offshore area in DMV, and fishing north of NJ has been mostly limited to the waters adjacent to Long Island.

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

### **Important TMS**

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

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

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

### **Fishery length composition**

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

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

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

### **Term of Reference 2: NEFSC and Cooperative clam surveys**

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

dredge instead of the deck of the vessel. The survey dredge is useful for surfclams as small as 50 mm SL (size selectivity described below). Changes in ship construction, winch design, winch speed and pump voltage that may have affected survey dredge efficiency are summarized in Table A7 of NEFSC (2004). Each of these factors has been constant since the 2002 survey.

Surveys prior to 1982 were not used in this assessment because they were carried out during different seasons, used other sampling equipment or, in the case of 1981, have not been integrated into the clam survey database (Table A7 in NEFSC 2004).

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

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

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

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

Following survey tows, all ocean quahogs and Atlantic surfclams in the survey dredge are counted and shell length is measured to the nearest mm. A few very large catches are subsampled. Mean meat weight (kg) per tow is computed with shell length-meat weight (SLMW) equations which were updated in this assessment based on fresh meat weight samples obtained during the 1997-2008 surveys (see below).

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

### **NEFSC clam survey trends and size composition**

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

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

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

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

### **NEFSC survey age composition**

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

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

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

### **Dredge efficiency**

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

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

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

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

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

#### *Variance of survey dredge efficiency $e$*

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

$$\Lambda = \Lambda_p + \Lambda_s$$

where  $\Lambda_p$  and  $\Lambda_s$  are negative log likelihoods for the depletion study data and the setup tow data. The setup tow likelihood  $\Lambda_s$  was calculated:

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

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

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

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

### **New depletion studies**

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

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

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

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

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

### **Repeat tow analysis for cable and pump effects**

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

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

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

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

## **Background**

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

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

## **De2De2 repeat stations**

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

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

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

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

$$\text{Log(Catch)} = \text{Pair effect} + \text{Pump} * \text{Cable effects}$$

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

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

### **De2Fv repeat stations**

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

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

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

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

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

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

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

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

## Size selectivity

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

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

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

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

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

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

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

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

### SELECT estimates

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

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

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

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

where shell length ( $L$ ) is in mm and  $\alpha = -8.868$  and  $\beta = 0.14391$  are parameters (Figure A45).

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

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

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

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

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

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

#### *Beta-binomial estimates*

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

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

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

and

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

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

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

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

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

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

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

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

#### *Best estimate of survey dredge selectivity*

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

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

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

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

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

#### *Unlined commercial dredge*

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

#### **Shell length-meat weight relationships**

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

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

#### **SLMW for the entire stock**

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

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

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

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

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

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

### **Growth**

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

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

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

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

### **Growth in length and weight for whole stock**

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

$$S_a = S_\infty (1 - e^{-K(a-t_0)})$$

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

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

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

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

### **Term of Reference 3: Stock biomass and fishing mortality**

#### **Efficiency corrected swept-area biomass**

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

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

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

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

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

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

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

The NEFSC surfclam database was reprogrammed to calculate the expected mean numbers per setup tow while accounting for the dome shaped selectivity pattern (i.e.,

$n_j^* = \sum_L \frac{n_{j,L}}{s_L}$ , where  $n^*$  is the catch density adjusted for dome shape selectivity from setup tow  $j$ ,

$n_{j,L}$ , is the observed (unadjusted) catch density for length  $L$ , and  $s_L$  is the selectivity. The estimate of capture efficiency using the adjusted data is  $e^* = \bar{n}^*/N \propto \bar{n}^*$  and the efficiency

corrected swept-area biomass would be  $B^* = \frac{\bar{b}^*A}{ae^*} = \frac{\bar{b}^*AN}{a\bar{n}^*} \propto \bar{b}^*/\bar{n}^*$ .

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

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

### **KLAMZ modeling**

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

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

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

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

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

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

#### *Model configuration*

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

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

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

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

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

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

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

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

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

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

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

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

#### *Results-whole stock*

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

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

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

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

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

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

#### *Basecase retrospective analysis*

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

#### *Historical retrospective analysis*

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

#### *Building a bridge*

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

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

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

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

#### *Results-DMV and NJ*

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

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

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

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

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

According to the FMP for Atlantic surfclams, overfishing occurs whenever the fishing mortality rate on the entire stock is larger than the  $F_{MSY}$  proxy. The stock is overfished if total biomass falls below  $B_{Threshold}$ , which is estimated as of the  $\frac{1}{2} B_{MSY}$  proxy. When stock biomass is less than the biomass threshold, the fishing mortality rate threshold is reduced from  $F_{MSY}$  to zero in a linear fashion.

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

Reference Point	Last assessment	Revised
$F_{MSY}$	$M=0.15 \text{ y}^{-1}$	Same
$B_{1999}$	1,460 thousand mt meats	1086 thousand mt meats
$B_{MSY} = \frac{1}{2} B_{1999}$ (target)	730 thousand mt meats	543 thousand mt meats
$B_{Threshold} = \frac{1}{2} B_{MSY}$	365 thousand mt meats	271.5 thousand mt meats

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

#### *Scientific adequacy of reference points*

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

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

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

The technical basis of the current biomass reference points for surfclam as  $B_{MSY}$  proxies ( $B_{Target} = \frac{1}{2}$  estimated  $B_{2009}$  and  $B_{Threshold} = \frac{1}{2} B_{Target}$ ) has been, at least through 2008, undermined by spatial patterns in the fishery and stock. Through 2008, the GBK region was closed to fishing because of PSP. Under these conditions and based on current reference points it would be theoretically possible to eliminate all of the surfclams in southern regions, to the detriment of the stock and fishery, without triggering an overfished stock status condition. In particular, the basecase model estimate of  $B_{2009}$  in this assessment is 1,086 thousand mt, the biomass target is 543 thousand mt, and the threshold is 272 thousand mt. Efficiency corrected swept-area biomass estimates (Table A24), indicate that the biomass on GBK in 2008 was 518 thousand mt. Thus, if all surfclams in the SVA, DMV, NJ, LI and SNE regions where the fishery took place prior to 2009 were eliminated, the surfclam stock biomass (518 thousand mt entirely on GBK) would be officially near its biomass target (543 thousand mt). In this hypothetical scenario, the stock would not be overfished ( $B < B_{Threshold}$ ) unless about half of the biomass on GBK were removed as well. These problems are in addition to technical problems in defining and estimating  $F_{MSY}$  and  $B_{MSY}$  for sessile spatially heterogeneous stocks like surfclams, ocean quahogs (NEFSC 2009) and Atlantic sea scallops (Hart 2003) with differences in biological properties (growth, SLMW, etc.), recruitment patterns and mortality.

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

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

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

Based on confidence intervals, surfclam biomass in 2008 was probably above its target level ( $B \leq B_{Target}$ ). The biomass target is 1/2 of the estimated biomass during 1999 = 543 thousand mt (CV 16%) with a 95% confidence interval of 400 to 738 thousand mt (Figure A70).

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

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

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

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

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

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

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

### **Survey data**

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

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

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

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

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

### **Growth**

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

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

### **Water temperatures**

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

### **Predator data**

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

### **Potential fishing effects**

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

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

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

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

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

### **Term of Reference 7: Projection and decision table analysis**

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

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

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

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

*Management actions used in projection analyses.*

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

**Term of Reference 7a: Forecast projections-whole stock**

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

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

*Forecast projections-DMV & NJ*

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

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

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

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

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

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

### Term of Reference 7b: Decision tables

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

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

*Qualitative prior probabilities for states of nature and their combinations.*

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

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

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

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

### **Term of Reference 8: Research recommendations**

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

- i) Consider using year-, region- or episodic natural mortality rates. *No progress. This was discussed in the working group but deferred until a later assessment.*
- ii) Develop a forward casting age-structured, numbers-based stock assessment model. *In progress. A preliminary Stock Synthesis model for surfclams is presented in an appendix to this assessment. Results appear promising and the Stock Synthesis Model is expected to be the principal model in the next assessment. In fact, a Stock Synthesis or similar model that can incorporate spatial heterogeneity in data and biological characteristics may be required because the NEFSC clam survey is expected to transition in 2011 to a cooperative survey carried out by a commercial vessel that would cover one third of the stock each year. It would be difficult using the current assessment model to estimate biomass and fishing mortality for the whole stock using non-synoptic survey data.*
- iii) Collect commercial age and length data to monitor and predict recruitment and for use in length and age structured models. *Length data but no age data are currently being collected from port samples. Age data from triennial survey are available*
- iv) Reexamine coefficients used to convert commercial catches in bushels to meat weights. *No progress.*

- v) Consider using a sensor that tracks dredge position, rather than the ships position, during surveys and depletion studies. *No progress. However, simulation results of Patch model performance indicate that uncertainty in dredge position has relatively minor effects on survey dredge efficiency estimates.*
- vi) Conduct surveys more frequently than every three years in critical areas. *No progress. The NEFSC clam survey is expected to transition in 2011 to a cooperative survey carried out by a commercial vessel that would cover one third of the stock each year, a plan that basically amounts to a triennial survey..*
- vii) Consider new technological methods that rely less heavily on estimating dredge efficiency. *No progress.*
- viii) Consider new methods to estimate variability in the spatial distribution of biomass. *This topic is an important part of ongoing research that involves simulation analyses to evaluate sensitivity of Patch model dredge efficiency estimates to spatial variability and other factors. Results to date are presented in an appendix to this assessment.*
- ix) Refine logbook data collection, focusing on spatial details. Resolve apparent problems with locations for some records. Can recent data show patterns on finer spatial scales (e.g. for 1-minute rather than 10-minute squares)? *No progress.*
- x) Improve collection and use of port sample data from the commercial fishery. *In progress. The preliminary Stock Synthesis model presented in an appendix makes full use of commercial length data.*
- xi) Characterize relationships between shell height, width and length for potential use in understanding the size selectivity of commercial and survey dredges and commercial sorting gear. *No progress. However, survey dredge size-selectivity was estimated using cooperative survey data.*
- xii) Test the Patch model for depletion experiments with simulations focusing on potential effects of uncertainty about position data and including all effects of cell size and smoothing. *In progress (see item viii above).*
- xiii) Determine the size selectivity of survey and commercial fishing equipment experimentally. *Survey dredge size-selectivity was estimated using cooperative survey data.*
- xiv) Improve procedures for filling holes in the survey data using statistical models with year and spatial effects. Determine if filling holes is preferable to borrowing data from previous and subsequent surveys. *No progress.*
- xv) Review survey age data carefully to determine if strong year classes can be used to estimate mortality rates outside of a stock assessment model (e.g. “empirical”  $Z$  estimates). *A marginal increment analysis study was carried out to show that annuli used to age surfclams are annual marks. Survey age data were used more extensively in the current assessment to identify strong year classes. The preliminary Stock Synthesis model presented in an appendix makes full use of commercial length data.*
- xvi) Devote sufficient time and resources to fully develop and improve dynamic population models. *See item ii above.*
- xvii) Review the technical basis of the current  $B_{MSY}$  proxy given new data and possible climate effects. *No progress.*
- xviii) Utilize New Jersey and New York inshore clam survey data more fully in the EEZ surfclam assessment. *Completed. This report includes an appendix containing a summary of stock conditions in state waters that was completed in cooperation with biologists employed by New Jersey, New York and a private consulting firm.*

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

- i) Continue surfclam recruitment research.
- ii) Port samples should be taken from the SNE and GBK (if fishing resumes there) regions.
- iii) Determine how much of Georges Bank is suitable habitat for surfclams, and if depletion and selectivity experiments done in the mid-Atlantic are applicable to the Georges Bank region.
- iv) Fecundity and maturity at length information is required to improve reference point calculations and predict management effects.
- v) Data on the number of clams per bushel landed at different ports over time would be useful.
- vi) Commercial length data for surfclams should be more accessible.
- vii) Determine whether the carrying capacity of surfclams has changed over time.
- viii) Estimate densities of spawning surfclams necessary for successful reproduction. Is reproduction likely to be impaired if relatively dense beds of surfclams are reduced?

## Acknowledgements:

The subcommittee would like to thank Jay Burnett, Chris Legault, Tim Miller, Maureen Taylor, Eric Thunberg (NEFSC), Adriana Picariello (Tabor Academy), Jeff Normant (New Jersey Department of Environmental Protection), Wade Carden (New York State Department of Environmental Conservation), Jason Morson (Haskins Shellfish Research Laboratory), William Burton (Versar Inc.), the captain and crew of the commercial fishing Vessel *Endeavor*, and the captain and crew of the NOAA Research Vessel *Delaware II* for all of their work which contributed to this assessment.

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## Tables

Table A1. Surfclam discard estimates from 1982 through 1994. Most of the discards are due to a minimum size regulation that was in effect from 1982 through 1990.

Year	Discard (mt meats)					Landings (mt meats)	Discards / Landings	Catch	Size limit (mm)
	NNJ	SNJ	NJ	DMV	Total				
1982	3,684	215	3,899	2,295	6,194	16,688	37%	22,882	140
1983	2,122	385	2,507	2,127	4,634	18,592	25%	23,226	140
1984	2,266	458	2,724	2,015	4,739	22,888	21%	27,627	133
1985	1,938	248	2,186	1,725	3,911	22,480	17%	26,391	127
1986	2,328	233	2,561	239	2,800	24,520	11%	27,320	127
1987	1,414	61	1,475	415	1,890	21,744	9%	23,634	127
1988	1,317	13	1,330	106	1,436	23,377	6%	24,813	127
1989	1,048	6	1,054	258	1,312	21,887	6%	23,199	127
1990	1,089	57	1,146	123	1,269	24,018	5%	25,287	127
1991	495	36	531	5	536	20,615	3%	21,151	--
1992	918	102	1,020	4	1,024	21,685	5%	22,709	--
1993	0	0	0	0	0	21,859	0%	21,859	--
1994	0	0	0	0	0	21,942	0%	21,942	--

Table A2. (Following page) Atlantic surfclam landings and EEZ surfclam quotas. All figures are meat weights in mt. Total landings for 1965-1981 are from NEFSC (2003) while figures for other years were from a dealer databases (CFDBS). EEZ landings for 1965-1982 are from NEFSC (2003) while figures from later years are from a logbook database (SFOQVR).

Landings for state waters are total landings - EEZ landings.

Year	Total (dealer data)	EEZ (logbooks)	State waters (dealer- logbooks)	Proportion from EEZ	EEZ Quota
1965	19,998	14,968	5,030	0.75	
1966	20,463	14,696	5,767	0.72	
1967	18,168	11,204	6,964	0.62	
1968	18,394	9,072	9,322	0.49	
1969	22,487	7,212	15,275	0.32	
1970	30,535	6,396	24,139	0.21	
1971	23,829	22,704	1,125	0.95	
1972	28,744	25,071	3,673	0.87	
1973	37,362	32,921	4,441	0.88	
1974	43,595	33,761	9,834	0.77	
1975	39,442	20,080	19,362	0.51	
1976	22,277	19,304	2,973	0.87	
1977	23,149	19,490	3,659	0.84	
1978	17,798	14,240	3,558	0.80	13,880
1979	15,836	13,186	2,650	0.83	13,880
1980	17,117	15,748	1,369	0.92	13,882
1981	20,910	16,947	3,963	0.81	13,882
1982	21,727	16,688	5,039	0.77	18,506
1983	23,631	18,592	5,038	0.79	18,892
1984	30,530	22,889	7,641	0.75	18,892
1985	28,316	22,480	5,835	0.79	21,205
1986	35,073	24,521	10,552	0.70	24,290
1987	27,231	21,744	5,486	0.80	24,290
1988	28,506	23,378	5,128	0.82	24,290
1989	30,081	21,888	8,194	0.73	25,184
1990	32,628	24,018	8,610	0.74	24,282
1991	30,794	20,615	10,179	0.67	21,976
1992	33,164	21,686	11,478	0.65	21,976
1993	32,878	21,859	11,019	0.66	21,976
1994	32,379	21,943	10,436	0.68	21,976
1995	30,061	19,627	10,434	0.65	19,779
1996	28,834	19,827	9,008	0.69	19,779
1997	26,311	18,612	7,700	0.71	19,779
1998	24,506	18,234	6,272	0.74	19,779
1999	26,677	19,577	7,100	0.73	19,779
2000	31,093	19,778	11,315	0.64	19,779
2001	31,237	22,017	9,220	0.70	21,976
2002	32,645	24,006	8,639	0.74	24,174
2003	31,526	25,017	6,509	0.79	25,061
2004	28,327	24,197	4,130	0.85	26,218
2005	26,883	21,163	5,720	0.79	26,218
2006	27,177	23,573	3,605	0.87	26,218
2007	30,004	24,915	5,089	0.83	26,218
2008	27,750	22,481	5,269	0.81	26,218
Min	15,836	6,396	1,125	0.21	13,880
Max	43,595	33,761	24,139	0.95	26,218
Mean	27,502	20,053	7,449	0.73	21,427

Table A3. EEZ surfclam landings (mt meats) by region and year. Landings from unknown regions were prorated to known areas based on logbook proportions of landings in known areas during the same year. Figures in the table differ slightly from those in NEFSC (2007) because proration calculations were corrected.

Year	SVA	DMV	NJ	LI	SNE	Other	Total EEZ
1979	0	11,836	1,350	0	0	0	13,186
1980	64	12,788	2,878	17	0	0	15,748
1981	568	7,472	8,820	88	0	0	16,947
1982	1,705	6,679	8,086	94	125	0	16,688
1983	2,225	7,173	8,095	264	836	0	18,592
1984	1,797	5,979	11,905	7	382	2,819	22,889
1985	741	7,856	11,246	0	452	2,185	22,480
1986	529	2,853	17,730	17	1,223	2,168	24,521
1987	378	1,303	18,017	0	1,140	907	21,744
1988	558	1,149	19,420	0	1,512	739	23,378
1989	439	3,123	16,532	0	1,361	433	21,888
1990	1,502	3,546	17,887	0	998	86	24,018
1991	0	1,634	18,913	15	33	21	20,615
1992	0	1,221	20,399	61	5	0	21,686
1993	0	3,414	18,365	62	3	14	21,859
1994	0	3,454	18,418	71	0	0	21,943
1995	0	2,752	16,497	0	378	0	19,627
1996	0	2,239	17,479	26	82	0	19,827
1997	0	1,540	16,999	73	0	0	18,612
1998	0	484	17,511	117	121	0	18,234
1999	0	648	18,755	157	16	0	19,577
2000	0	2,042	17,513	121	103	0	19,778
2001	0	3,282	17,719	935	81	0	22,017
2002	64	4,489	18,271	1,130	52	0	24,006
2003	0	1,432	21,693	1,625	267	0	25,017
2004	0	1,482	19,197	906	2,612	0	24,197
2005	0	1,668	16,850	759	1,885	0	21,163
2006	0	2,773	19,660	245	895	0	23,573
2007	0	3,073	20,268	1,117	458	0	24,915
2008	0	3,223	17,517	1,317	423	0	22,481
Min	0	484	1,350	0	0	0	13,186
Max	2,225	12,788	21,693	1,625	2,612	2,819	25,017
Mean	352	3,754	15,800	307	515	312	21,040

Table A4. EEZ fishing effort (hours fished by all vessels) for surfclams year based on logbook data, by stock assessment region and. The fraction of logbook effort from unknown areas in each year was prorated to known areas based on effort in known areas. Effort data prior to 1981 are less reliable due to restrictions on hours fished per day. Figures in the table differ slightly from those in NEFSC (2007) because proration calculations were corrected.

Year	SVA	DMV	NJ	LI	SNE	Other	Total EEZ
1991	0	1,254	17,243	21	107	293	18,918
1992	0	797	21,379	67	0	0	22,243
1993	0	2,423	18,232	57	15	5	20,732
1994	0	1,930	21,495	70	0	0	23,495
1995	0	1,560	18,625	0	1,059	0	21,244
1996	0	1,577	20,995	40	287	0	22,899
1997	0	1,098	20,383	77	0	0	21,558
1998	0	289	19,609	134	518	0	20,550
1999	0	734	18,146	151	149	0	19,179
2000	0	1,859	16,787	115	368	0	19,128
2001	0	2,536	18,462	962	148	0	22,108
2002	112	5,505	19,825	1,241	62	0	26,746
2003	0	2,367	25,048	1,833	176	0	29,424
2004	0	3,161	26,544	1,254	1,108	0	32,067
2005	0	2,660	24,285	1,206	1,364	0	29,515
2006	0	5,883	27,184	343	1,035	0	34,445
2007	0	7,065	34,665	1,579	960	0	44,269
2008	0	8,110	34,054	2,339	541	0	45,044
Min	0	289	16,787	0	0	0	18,918
Max	112	8,110	34,665	2,339	1,364	293	45,044
Mean	6	2,823	22,387	638	439	17	26,309

Table A5. Real and nominal ex-vessel prices for surfclams (ITQ and state fisheries combined) based on dealer data for 1982-2008. Average price was computed as total revenues divided by total landed meat weight during each year, rather than as averages of prices for individual trips, to reduce effects of small deliveries at relatively high prices. The consumer price index (CPI) used to convert nominal dollars to 1991 equivalent real dollars is for unprocessed and packaged fish, which includes shellfish and finfish (Eric Thunberg, NEFSC, pers. comm.).

Year	CPI	Prices (\$ / bu)		Revenue (million \$)	
		Nominal	Real (\$1991)	Nominal	Real (\$1991)
1982	0.67	8.94	13.36	25.186	37.653
1983	0.71	7.57	10.74	23.207	32.917
1984	0.75	8.37	11.11	33.156	43.982
1985	0.77	9.34	12.19	34.303	44.749
1986	0.84	9.20	11.01	41.841	50.082
1987	0.94	7.83	8.36	27.644	29.520
1988	0.99	7.80	7.84	28.826	28.981
1989	0.96	7.78	8.13	30.330	31.731
1990	0.98	7.66	7.78	32.393	32.899
1991	1.00	7.51	7.51	29.975	29.975
1992	1.04	7.40	7.09	31.832	30.486
1993	1.05	7.83	7.48	33.369	31.876
1994	1.08	9.82	9.10	41.241	38.200
1995	1.14	10.58	9.26	41.246	36.102
1996	1.11	10.24	9.22	38.275	34.491
1997	1.19	10.31	8.66	35.189	29.538
1998	1.23	9.19	7.50	29.200	23.829
1999	1.28	8.79	6.89	30.421	23.824
2000	1.33	9.43	7.12	38.025	28.696
2001	1.28	9.76	7.65	39.555	30.993
2002	1.28	9.45	7.39	39.988	31.267
2003	1.31	9.64	7.38	39.427	30.181
2004	1.38	9.58	6.95	35.209	25.515
2005	1.49	9.50	6.38	33.123	22.246
2006	1.59	10.19	6.42	35.908	22.613
2007	1.62	10.54	6.49	41.024	25.260
2008	1.71	10.96	6.42	39.440	23.114

Table A6. Nominal landings per unit effort (LPUE, bushels h<sup>-1</sup>) for surfclam fishing (all vessels) in the US EEZ from logbooks. LPUE is total landings in bushels divided by total hours fished. Landings and fishing effort from unknown areas were prorated to area before LPUE was calculated.

Year	SVA	DMV	NJ	LI	SNE	Other	All areas
1991			142	95	40	9	141
1992		199	124	119			126
1993		183	131	143	28	390	137
1994		232	111	132			121
1995		229	115		46		120
1996		184	108	85	37		112
1997		182	108	122			112
1998		217	116	114	30		115
1999		115	134	135	14		132
2000		142	135	137	36		134
2001		168	124	126	71		129
2002	74	106	120	118	108		116
2003		78	112	115	197		110
2004		61	94	94	306		98
2005		81	90	82	179		93
2006		61	94	93	112		89
2007		56	76	92	62		73
2008		52	67	73	101		65
Min	74	52	67	73	14	9	65
Max	74	232	142	143	306	390	141
Mean	74	138	111	110	91	199	112

Table A7. Numbers of commercial trips sampled and numbers of surfclams measured in port samples from landings during 1982-2008, by region. Numbers of trips during 1982-1999 were estimated assuming 30 individuals sampled per trip, as specified in port sample instructions.

Year	DMV		NJ		LI		SNE	
	Trips	Lengths	Trips	Lengths	Trips	Lengths	Trips	Lengths
1982	259	7756	249	7477			1	30
1983	197	5923	375	11253	Unk.	Unk.	1	30
1984	102	3066	425	12751			3	90
1985	61	1832	256	7674			5	150
1986	42	1260	171	5130			11	330
1987	24	730	30	900			19	569
1988	14	420	30	900			27	810
1989	29	866	31	919			15	449
1990	30	892	30	901			7	209
1991	36	1080	76	2272				
1992	39	1170	57	1710				
1993	46	1392	31	928	Unk.	Unk.		
1994	4	119	30	900				
1995	24	720	17	510				
1996	38	1154	37	1117				
1997	54	1622	32	957				
1998	52	1560	23	690				
1999	57	1720	29	856				
2000	20	600	111	3315	1	30		
2001	33	970	42	1260				
2002	7	210	37	1111				
2003	2	60	80	2455	5	150		
2004			36	1080	2	60		
2005	19	581	61	1834	11	330		
2006	50	1541	49	1482	23	690		
2007	68	2215	72	2409	16	508		
2008	57	1712	65	1950	21	632		
Min	2	60	17	510	1	30	1	30
Max	259	7,756	425	12,751	23	690	27	810
Mean	53	1,584	92	2,768	11	343	10	296

Table A8. Number of successful random tows in NEFSC clam surveys used for estimating survey trends and efficiency corrected swept-area biomass. “Holes” (unsampled survey strata in some years) were filled by borrowing from adjacent surveys (borrowed totals are negative numbers in grey-shaded boxes). Holes that could not be filled have zeros in black boxes. Survey strata are grouped by region. Survey strata not used for surfclams are not shown.

Stratum	Years											
	1982	1983	1984	1986	1989	1992	1994	1997	1999	2002	2005	2008
<i>SVA</i>												
1	-10	10	14	7	10	10	10	10	-10	0	0	0
2	0	0	0	-1	1	2	1	1	-1	0	0	0
5	4	9	13	8	8	8	7	8	-16	8	8	-8
6	1	1	1	1	1	1	1	1	-3	2	1	-1
80	-6	6	9	3	7	7	8	7	-7	0	0	0
81	-4	4	7	3	5	5	5	5	-10	5	-5	5
<i>DMV</i>												
9	30	26	35	29	37	37	38	37	37	38	37	31
10	2	2	3	3	3	3	3	3	3	3	3	2
13	19	18	25	20	20	20	21	20	19	20	18	15
14	2	2	3	3	3	3	5	3	3	3	3	-3
82	1	1	1	1	1	1	1	1	2	2	-3	1
83	2	2	2	2	2	2	2	2	2	2	2	2
84	4	3	3	4	4	4	4	4	3	4	4	4
85	5	5	4	5	5	5	5	5	5	5	5	5
86	2	2	3	3	3	2	3	3	3	3	3	3
<i>NJ</i>												
17	11	11	18	12	12	12	12	12	12	12	12	12
18	3	3	-6	3	3	3	3	3	3	3	3	3
21	18	18	22	19	20	20	20	20	33	27	20	28
22	3	3	-6	3	3	3	5	3	3	3	3	3
25	9	9	13	8	9	9	9	9	8	9	9	13
26	2	2	-5	3	3	3	3	3	3	3	3	3
87	8	7	10	9	9	9	9	9	9	16	8	9
88	15	15	24	17	20	20	20	21	21	20	17	19
89	15	15	21	15	18	17	18	19	18	18	15	18
90	2	2	3	2	2	2	2	2	2	2	2	1

Table 8. (cont.)

Stratum	Years											
	1982	1983	1984	1986	1989	1992	1994	1997	1999	2002	2005	2008
<i>LI</i>												
29	11	10	-20	10	10	10	10	10	10	10	10	16
30	7	8	-14	6	6	6	6	6	5	6	7	12
33	4	4	-8	4	4	4	5	4	4	4	4	10
34	2	2	-4	2	2	2	5	2	1	2	2	8
91	3	2	4	4	3	3	3	3	3	3	3	5
92	2	2	3	2	2	2	2	2	2	2	2	5
93	1	2	2	1	1	1	1	1	1	2	1	4
<i>SNE</i>												
37	7	4	-7	3	-6	3	5	4	4	3	-3	3
38	3	2	-5	3	3	3	5	3	3	3	2	3
41	6	5	7	5	6	6	6	6	5	6	6	6
45	3	7	9	4	4	4	4	4	4	2	4	4
46	2	5	5	3	2	3	5	3	3	2	3	3
47	4	3	4	2	2	4	4	4	3	1	7	4
94	1	2	-2	0	-1	1	2	2	-4	2	-2	2
95	4	14	11	4	4	4	4	4	4	4	-8	4
96	-12	12	-13	1	1	3	2	4	-4	0	-1	1
<i>GBK</i>												
54	0	-3	3	3	-6	3	3	3	-3	0	-2	2
55	3	-3	-3	3	1	3	3	3	2	2	-4	2
57	0	0	-2	2	1	2	5	2	2	2	-4	2
59	1	4	-5	1	2	6	5	5	4	5	-9	4
61	8	1	-6	5	-12	7	5	6	6	6	-11	5
65	0	0	-3	3	-5	2	4	3	-4	1	-1	1
67	0	-5	5	5	7	7	7	7	-7	0	-2	2
68	1	-8	7	3	6	6	5	5	-5	0	-6	6
69	2	5	-11	6	6	6	7	6	8	-8	-4	4
70	1	2	-6	4	-8	4	4	4	3	2	-6	4
71	0	-2	2	3	1	2	3	3	1	2	-3	1
72	2	-10	8	1	8	8	8	8	6	-6	-4	4
73	1	1	-4	3	6	6	6	6	5	6	-9	3
74	3	-4	1	3	-7	4	4	4	3	3	-6	3

Table A9. (On the following pages.) NEFSC clam survey data for surfclam abundance (mean numbers per tow) and biomass (mean kg per tow). Data are for three size groups: prerecruits (50-119 mm), fishable clams (120+ mm) and all clams greater than 50 mm SL. Data from 1994 are shown but difficult to interpret due to changes in the capture efficiency of the survey dredge in some regions (see text). Note that GBK was not sampled entirely in surveys prior to 1986.

Year	Prerecruits (50-119 mm SL)				Large fishable (120+ mm SL)				All surfclams 50mm and above				N Tows	Pos. Tows	N Strata	
	N/ Tow	CV	KG / Tow	CV	N / Tow	CV	KG / Tow	CV	N/ Tow	CV	KG / Tow	CV				
SVA	1982	3.53	0.88	0.12818	0.91	3.73	0.92	0.2836	0.86	7.26	0.90	0.41179	0.87	25	5	5
	1983	6.60	0.62	0.23889	0.64	5.71	0.62	0.44929	0.59	12.31	0.58	0.68818	0.57	30	9	5
	1984	7.85	0.37	0.2928	0.41	21.82	0.31	1.7998	0.29	29.66	0.30	2.09259	0.29	44	16	5
	1986	1.50	0.35	0.05593	0.42	22.20	0.75	1.7068	0.74	23.69	0.72	1.76273	0.72	23	11	6
	1989	3.11	0.75	0.07396	0.7	9.78	0.83	0.85428	0.82	12.89	0.81	0.92825	0.81	32	10	6
	1992	18.15	0.86	0.74134	0.9	12.10	0.77	0.88383	0.79	30.25	0.65	1.62517	0.64	33	17	6
	1994	43.38	0.46	0.67111	0.32	6.38	0.44	0.4678	0.37	49.76	0.40	1.13892	0.29	33	19	6
	1997	10.31	0.44	0.27186	0.47	0.49	0.46	0.03244	0.44	10.80	0.43	0.3043	0.45	32	14	6
	1999	9.32	0.41	0.21099	0.36	1.22	0.46	0.09191	0.47	10.54	0.38	0.3029	0.33	47	19	6
	2002	13.69	0.61	0.31622	0.62	5.66	0.55	0.43964	0.55	19.35	0.58	0.75586	0.56	15	5	3
	2005	3.65	0.66	0.04045	0.58	0.00	0.00	0.00	0.00	3.65	0.66	0.04045	0.58	14	4	3
2008	4.94	0.72	0.05281	0.66	0.00	0.00	0.00	0.00	4.94	0.72	0.05281	0.66	9	3	2	
DMV	1982	157.13	0.46	5.37905	0.44	21.36	0.23	2.17314	0.29	178.49	0.42	7.55219	0.38	68	37	9
	1983	30.68	0.54	1.2455	0.61	31.21	0.46	2.56435	0.35	61.88	0.49	3.80985	0.42	61	30	9
	1984	184.10	0.74	4.26795	0.61	34.91	0.28	2.87828	0.28	219.01	0.63	7.14624	0.38	79	47	9
	1986	58.77	0.43	2.53211	0.46	74.79	0.38	5.42915	0.32	133.56	0.39	7.96126	0.36	70	44	9
	1989	16.71	0.54	0.66015	0.55	31.24	0.26	2.48168	0.24	47.94	0.26	3.14182	0.23	78	37	9
	1992	13.49	0.28	0.471	0.38	28.86	0.29	2.36261	0.24	42.35	0.28	2.83361	0.26	77	52	9
	1994	68.70	0.33	2.26328	0.43	60.96	0.21	4.82485	0.2	129.67	0.23	7.08813	0.22	83	63	9
	1997	77.18	0.17	2.71729	0.2	54.53	0.24	3.99175	0.22	131.71	0.17	6.70904	0.19	82	61	9
	1999	29.61	0.28	1.25239	0.28	26.36	0.22	1.94862	0.2	55.98	0.23	3.20101	0.21	78	44	9
	2002	16.47	0.28	0.48278	0.28	20.70	0.21	1.80875	0.19	37.17	0.22	2.29153	0.19	81	50	9
	2005	6.44	0.42	0.20455	0.43	4.76	0.26	0.4109	0.28	11.19	0.27	0.61545	0.24	74	40	9
2008	9.87	0.29	0.24142	0.33	2.64	0.35	0.24522	0.35	12.50	0.28	0.48664	0.29	66	37	9	
NJ	1982	33.10	0.30	1.49319	0.31	32.78	0.22	3.39903	0.2	65.88	0.19	4.89222	0.17	85	50	10
	1983	27.78	0.51	1.35886	0.55	25.38	0.22	2.61903	0.2	53.16	0.30	3.9779	0.24	85	54	10
	1984	15.93	0.23	0.59675	0.22	29.97	0.20	3.10535	0.18	45.90	0.18	3.70211	0.17	126	68	10
	1986	10.33	0.21	0.41188	0.2	29.68	0.18	3.47088	0.18	40.01	0.17	3.88276	0.17	91	59	10
	1989	9.88	0.29	0.4085	0.31	31.53	0.15	3.46162	0.13	41.40	0.15	3.87011	0.14	99	60	10
	1992	16.46	0.33	0.70917	0.42	23.22	0.16	2.65687	0.15	39.68	0.20	3.36604	0.16	98	62	10
	1994	67.39	0.20	2.22782	0.18	82.77	0.17	9.16575	0.16	150.16	0.16	11.39357	0.16	103	84	10
	1997	17.91	0.16	0.84515	0.17	83.72	0.13	9.5209	0.12	101.63	0.13	10.36605	0.12	112	83	10
	1999	8.02	0.25	0.32494	0.28	50.58	0.21	5.74409	0.17	58.60	0.21	6.06903	0.18	120	77	10
	2002	10.68	0.16	0.38791	0.16	35.03	0.17	4.57607	0.17	45.71	0.14	4.96399	0.16	115	94	10
	2005	7.81	0.20	0.33195	0.22	19.09	0.18	2.34449	0.17	26.90	0.16	2.67644	0.16	92	60	10
2008	10.07	0.14	0.34008	0.14	17.05	0.16	2.05726	0.17	27.11	0.13	2.39734	0.15	109	88	10	

Year	Prerecruits (50-119 mm SL)				Large fishable (120+ mm SL)				All surfclams 50mm and above				N Tows	Pos. Tows	N Strata	
	N / Tow	CV	KG / Tow	CV	N / Tow	CV	KG / Tow	CV	N / Tow	CV	KG / Tow	CV				
LI	1982	0.03	1.00	0.0022	1	3.99	0.61	0.64638	0.62	4.03	0.61	0.64858	0.61	29	1	7
	1983	0.17	0.61	0.00355	0.6	0.41	0.72	0.05375	0.72	0.58	0.60	0.0573	0.69	29	3	7
	1984	0.56	0.30	0.01779	0.37	1.64	0.34	0.24819	0.34	2.20	0.22	0.26597	0.31	55	12	7
	1986	0.58	0.39	0.01781	0.4	1.72	0.61	0.28911	0.61	2.30	0.45	0.30691	0.57	29	7	7
	1989	2.24	0.87	0.07423	0.88	3.48	0.72	0.4693	0.74	5.72	0.78	0.54353	0.76	28	4	7
	1992	5.73	0.44	0.25896	0.47	2.54	0.33	0.2621	0.32	8.28	0.39	0.52106	0.37	28	9	7
	1994	4.23	0.17	0.1826	0.2	7.24	0.19	0.87859	0.22	11.48	0.17	1.06119	0.21	32	11	7
	1997	1.44	0.49	0.07067	0.54	4.17	0.64	0.55448	0.63	5.62	0.59	0.62515	0.61	28	6	7
	1999	1.61	0.64	0.03764	0.48	10.71	0.65	1.40682	0.6	12.32	0.65	1.44446	0.59	30	8	7
	2002	0.85	0.45	0.02821	0.44	1.94	0.67	0.30691	0.67	2.80	0.59	0.33511	0.65	29	7	7
	2005	1.42	0.34	0.05064	0.39	12.62	0.50	1.62469	0.47	14.04	0.47	1.67533	0.46	29	7	7
2008	1.47	0.24	0.05299	0.23	3.52	0.24	0.47737	0.23	5.00	0.21	0.53036	0.22	60	21	7	
SNE	1982	2.58	0.29	0.10604	0.36	12.40	0.41	1.98556	0.42	14.99	0.33	2.0916	0.39	42	14	9
	1983	0.84	0.40	0.03775	0.44	7.88	0.39	1.43894	0.39	8.72	0.38	1.4767	0.39	54	18	9
	1984	0.81	0.36	0.03202	0.44	10.84	0.34	1.89401	0.34	11.65	0.34	1.92603	0.34	63	18	9
	1986	1.12	0.14	0.02356	0.27	4.12	0.68	0.72633	0.69	5.24	0.54	0.7499	0.67	25	8	8
	1989	1.18	0.43	0.04058	0.44	4.57	0.33	0.77265	0.33	5.75	0.31	0.81322	0.32	29	10	9
	1992	1.15	0.56	0.02842	0.5	2.49	0.58	0.45216	0.58	3.64	0.44	0.48058	0.55	31	9	9
	1994	1.26	0.52	0.05842	0.59	1.69	0.53	0.30128	0.55	2.96	0.45	0.3597	0.5	38	10	9
	1997	2.95	0.31	0.11307	0.35	12.28	0.30	2.16823	0.3	15.23	0.25	2.28129	0.29	34	13	9
	1999	2.60	0.42	0.08181	0.48	4.30	0.66	0.83016	0.66	6.90	0.45	0.91197	0.6	34	15	9
	2002	1.01	0.69	0.05603	0.73	3.85	0.27	0.6814	0.22	4.86	0.31	0.73744	0.23	24	5	8
	2005	0.26	0.49	0.03982	0.08	1.62	0.24	0.32571	0.24	2.95	0.14	0.36554	0.21	30	6	8
2008	1.77	0.08	0.05685	0.12	5.01	0.63	0.88828	0.59	6.78	0.47	0.94513	0.56	32	7	7	
GBK	1986	20.00	0.79	0.6602	0.78	4.97	0.52	0.70549	0.56	24.97	0.68	1.36568	0.53	44	20	14
	1989	5.21	0.34	0.26761	0.43	24.86	0.73	2.95529	0.73	30.07	0.66	3.22291	0.71	75	36	14
	1992	15.54	0.40	0.65507	0.46	7.89	0.33	0.94165	0.34	23.43	0.33	1.59672	0.32	66	43	14
	1994	30.01	0.33	1.50664	0.34	45.84	0.39	5.78077	0.41	75.85	0.33	7.28741	0.37	70	47	14
	1997	58.55	0.31	2.80136	0.33	23.52	0.25	2.68139	0.25	82.07	0.28	5.48275	0.26	65	45	14
	1999	24.01	0.41	1.25708	0.41	29.59	0.31	3.31966	0.3	53.60	0.35	4.57674	0.33	59	34	14
	2002	22.09	0.52	1.08775	0.54	27.05	0.43	3.19783	0.41	49.15	0.46	4.28558	0.43	43	21	11
2008	7.45	0.28	0.41502	0.34	33.02	0.25	3.93843	0.24	40.47	0.21	4.35346	0.22	41	25	13	

Year	Prerecruits (50-119 mm SL)				Large fishable (120+ mm SL)				All surfclams 50mm and above				N Tows	Pos. Tows	N Strata	
	N / Tow	CV	KG / Tow	CV	N / Tow	CV	KG / Tow	CV	N / Tow	CV	KG / Tow	CV				
SVA-SNE	1982	47.04	0.37	1.88141	0.35	17.26	0.14	1.84999	0.15	64.30	0.28	4.28	0.22	249	137	40
	1983	15.70	0.35	0.71814	0.39	16.53	0.23	1.63938	0.18	32.23	0.26	2.73	0.22	259	144	40
	1984	49.38	0.66	1.37927	0.52	21.81	0.14	2.17245	0.13	71.19	0.46	4.07	0.21	367	201	40
	1986	17.25	0.35	0.81488	0.4	30.15	0.24	2.78912	0.2	47.40	0.27	4.17	0.23	238	155	40
	1989	7.54	0.31	0.30773	0.34	18.46	0.14	1.83318	0.13	26.00	0.15	2.48	0.13	266	158	41
	1992	11.36	0.26	0.47212	0.32	15.57	0.17	1.53978	0.15	26.93	0.17	2.33	0.15	267	168	41
	1994	41.27	0.17	1.30618	0.22	38.08	0.12	3.73868	0.12	79.35	0.13	5.82	0.12	289	193	41
	1997	25.25	0.13	1.0211	0.15	37.56	0.11	3.75914	0.1	62.81	0.10	5.54	0.1	288	190	41
	1999	11.28	0.19	0.4765	0.21	21.86	0.15	2.21838	0.13	33.15	0.14	3.13	0.13	309	186	41
	2002	8.81	0.17	0.29369	0.16	17.40	0.12	1.99415	0.12	26.21	0.11	2.67	0.11	264	181	37
	2005	4.69	0.18	0.16826	0.2	9.17	0.16	1.0314	0.15	13.86	0.13	1.40	0.14	245	145	38
2008	6.70	0.14	0.1962	0.15	7.57	0.14	0.86564	0.15	14.27	0.11	1.23	0.13	276	168	35	
SVA-GBK	1986	17.87	0.33	0.77357	0.36	24.41	0.23	2.35099	0.19	42.28	0.25	3.70	0.22	282	149	54
	1989	7.01	0.26	0.29587	0.29	19.90	0.23	2.00103	0.22	26.92	0.20	2.73	0.2	341	157	55
	1992	12.30	0.22	0.49847	0.27	13.83	0.15	1.40033	0.14	26.14	0.15	2.25	0.14	333	192	55
	1994	38.72	0.15	1.32446	0.19	39.84	0.14	4.03626	0.14	78.56	0.12	6.34	0.13	359	234	55
	1997	32.78	0.15	1.33061	0.16	34.38	0.10	3.48823	0.09	67.16	0.11	5.70	0.09	353	222	55
	1999	14.16	0.20	0.61159	0.2	23.61	0.14	2.37457	0.13	37.77	0.15	3.54	0.13	368	197	55
	2002	11.75	0.24	0.43179	0.26	19.54	0.16	2.16969	0.14	31.29	0.18	3.10	0.15	307	182	48
	2008	6.89	0.13	0.23703	0.16	14.02	0.16	1.46895	0.15	20.91	0.12	2.03	0.13	317	181	48

Table A10. Summary of Patch model estimates from commercial depletion studies and associated NEFSC survey dredge efficiency estimates. All estimates are for surfclams 150+ mm SL.

Statistic	N successful experiments	Population Density (N ft <sup>-2</sup> )	Depletion Vessel Efficiency	Neg. Binomial Parameter <i>k</i>	Setup Density (N ft <sup>-2</sup> )	NEFSC Dredge Efficiency
<b>1997</b>						
Mean		0.023	0.790	4.758	0.0061	0.317
Median		0.017	0.890	3.261	0.0069	0.270
Lower 80% CI bound	5	0.012	0.613	3.134	0.0049	0.225
Upper 80% CI bound		0.033	0.967	6.382	0.0072	0.409
SE		0.007	0.115	1.059	0.0008	0.060
CV (SE / Mean)		0.296	0.146	0.223	0.1281	0.189
<b>1999</b>						
Mean		0.035	0.652	20.534	0.0061	0.189
Median	6 commercial	0.025	0.726	12.841	0.0058	0.199
Lower 80% CI bound	depletion, 5	0.024	0.469	10.137	0.0051	0.130
Upper 80% CI bound	with setup	0.046	0.835	30.930	0.0070	0.248
SE	tows	0.007	0.124	7.044	0.0006	0.039
CV (SE / Mean)		0.211	0.190	0.343	0.1012	0.205
<b>2002</b>						
Mean		0.014	0.584	16.792	0.0070	0.516
Median		0.014	0.584	16.792	0.0070	0.516
Lower 80% CI bound	2	0.012	-0.268	-26.157	-0.0032	-0.282
Upper 80% CI bound		0.016	1.437	59.740	0.0173	1.313
SE		0.001	0.277	13.955	0.0033	0.259
CV (SE / Mean)		0.038	0.474	0.831	0.4740	0.503
<b>2004</b>						
Mean		0.024	0.736	5.939	NA	NA
Median		0.024	0.736	5.939	NA	NA
Lower 80% CI bound	2 commercial	0.004	0.517	0.220	NA	NA
Upper 80% CI bound	depletion	0.043	0.955	11.658	NA	NA
SE	experiments	0.006	0.071	1.858	NA	NA
CV (SE / Mean)		0.268	0.097	0.313	NA	NA
<b>2005</b>						
Mean		0.037	0.717	4.078	0.005	0.158
Median		0.034	0.676	4.593	0.005	0.158
Lower 80% CI bound	4	0.023	0.551	3.121	0.004	0.105
Upper 80% CI bound		0.051	0.882	5.035	0.006	0.210
SE		0.009	0.101	0.584	0.000	0.032
CV (SE / Mean)		0.234	0.141	0.143	0.084	0.203
<b>2008</b>						
Mean		0.011	0.829	5.447	0.009	0.898
Median		0.010	0.931	6.327	0.008	0.627
Lower 80% CI bound	5	0.010	0.688	3.603	0.0000	0.412
Upper 80% CI bound		0.012	0.970	7.290	0.1534	1.383
SE		0.001	0.092	1.202	0.094	0.317
CV (SE / Mean)		0.067	0.111	0.221	10.337	0.353
<b>All years</b>						
Q33%		0.015	0.645	4.314	0.005	0.213
Mean	24	0.025	0.730	9.833	0.007	0.413
Median	commercial	0.018	0.786	6.002	0.006	0.256
Q67%	depletion, 21	0.025	0.873	7.640	0.007	0.376
Lower 80% CI bound	with setup	0.021	0.665	6.717	0.006	0.285
Upper 80% CI bound	tows	0.029	0.794	12.950	0.008	0.541
SE		0.003	0.049	2.374	0.001	0.098
CV (SE / Mean)		0.131	0.067	0.241	0.112	0.236

Table A11 (Following pages). Summary of commercial depletion experiments, Patch model estimates, setup tows and survey dredge efficiency estimates for surfclams 150+ mm SL.

See next page.

Experiment and Study Area							Depletion Tows				
Experiment Name	Original Name	Region	Approx. latitude (decimal degrees)	Approx. longitude (decimal degrees)	Depth (m)	Mean Sediment Size (microns)	Depletion Study Vessel	Depletion Date	Ship Position Data (source / nominal accuracy / time interval)	Depletion tows: N used, [N with bushel count and length samples]	Depletion vessel blade width (ft)
SC1997-2	PP-1	NNJ (Pt. Pleasant)	40.05317	73.83917	26		Sherri Ann	6/9/1997	Loran / 100M / 1 Minute	39 [9]	8.33
SC1997-3	AC2-1	NNJ (Atlantic City)	39.39317	73.91033	30		Jersey Girl	6/10/1997	Loran / 100M / 1 Minute	13 [4]	10.83
SC1997-4	AC2-2	NNJ (Atlantic City)	39.39317	73.91033	30		Jersey Girl	6/10/1997	Loran / 100M / 1 Minute	31 [4]	10.83
SC1997-5	AC1-1	NNJ (Atlantic City)	31.36500	73.89833	30		Judy Marie	6/11/1997	Loran / 100M / 1 Minute	17 [4]	8.33
SC1997-6	AC1-2	NNJ (Atlantic City)	39.36500	73.89833	30		Judy Marie	6/11/1997	Loran / 100M / 1 Minute	19 [4]	8.33
SC1999-2	JG-1 (S99-5)	NNJ	39.68133	73.74667	24	0.88	Jersey Girl	9/14/1999	Loran / 100M / 1 Minute	4 [1]	10.83
SC1999-3	JG-2 (s99-5)	NNJ	39.68133	73.74667	24	0.88	Jersey Girl	9/14/1999	Loran / 100M / 1 Minute	5 [2]	10.83
SC1999-4	JG-3 (S99-6)	NNJ	39.52133	73.77867	26	0.67	Jersey Girl	9/14/1999	Loran / 100M / 1 Minute	6 [2]	10.83
SC1999-5	CH-1 (S99-DEII)	DMV	36.90200	74.97583	35	1.13	Christy	9/25/1999	Loran / 100M / 1 Minute	28 [6]	10.83
SC1999-6	MJ-1 (s99-3, NJ Inshore Site 1)	NJ	39.56333	73.91167	26	1.08	Melissa J	9/28/1999	Loran / 100M / 1 Minute	4 [1]	10.83
SC1999-7	MJ-1 (s99-3, NJ Inshore Site 2)	NJ	39.76800	73.91633	24	3.85	Melissa J	9/28/1999	Loran / 100M / 1 Minute	10 [2]	10.83
SC2002-2	SC02-2	NJ	40.10908	73.84423	38	0.43	Jersey Girl	8/20/2002	GPS-D/3M/2 sec.	16 [3]	10.83
SC2002-3	SC02-3	NJ	39.26923	73.78116	31	1.12	Jersey Girl	8/19/2002	GPS-D/3M/2 sec.	19 [see footnote]	10.83
SC2002-4	SC02-4	DMV	38.85791	74.40888	31	0.48	Jersey Girl	8/20/2002	GPS-D/3M/2 sec.	18 [4]	10.83
SC2004-1	SC04-1	NJ	39.28611	73.87778	35		Lisa Kim	4/8/2004	GPS-D/3M/2 sec.	24 [5] (see note)	10
SC2004-2	SC04-2	NJ	39.58278	74.02778	21		Lisa Kim	4/8/2004	GPS-D/3M/2 sec.	20 [4] (see note)	10
SC2004-3	SC04-3	DMV	38.27075	74.37920	38		Lisa Kim	7/3/2004	GPS-D/3M/10 sec.	20 [4] (see note)	10
SC2005-2	SC05-02	NJ	39.56383	73.90364	24	0.29	Lisa Kim	9/7/2005	GPS / 6 ft / 6 sec	17 [3]	10
SC2005-3	SC05-03	NJ	39.89733	73.90591	38	0.24	Lisa Kim	9/8/2005	GPS / 6 ft / 6 sec	20 [4]	10
SC2005-4	SC05-04	DMV	39.56972	73.54946	41	0.20	Lisa Kim	9/9/2005	GPS / 6 ft / 6 sec	20 [4]	10
SC2005-5	SC05-05	NJ	39.43615	73.37320	33	0.28	Lisa Kim	9/10/2005	GPS / 6 ft / 6 sec	17 [4]	10
SC2005-6	SC05-01	NJ	38.26530	74.37947	26	0.19	Lisa Kim	9/7/2005	GPS / 6 ft / 6 sec	20 [4]	10
SC2008-1	SC08-02	NJ	39.18136	-74.07645	21	0.36	Endeavor	9/12/2008	GPS / 6 ft / 6 sec	18 [4]	12.5
SC2008-2	SC08-01	NJ	39.30475	-74.05158	27	0.33	Endeavor	9/12/2008	GPS / 6 ft / 6 sec	13 [3]	12.5
SC2008-3	SC08-03	NJ	39.60343	-73.42194	37	0.36	Endeavor	9/13/2008	GPS / 6 ft / 6 sec	20 [5]	12.5
SC2008-4	SC08-04	NJ	39.81033	-73.91490	22	0.17	Endeavor	9/13/2008	GPS / 6 ft / 6 sec	17 [3]	12.5
SC2008-5		SNE	41.14656	-70.05056	24	0.24	Endeavor	9/17/2008	GPS / 6 ft / 6 sec	6 [1]	12.5
SC2008-6	SC08-09	NJ	39.31328	-74.05285	27	0.29	Endeavor	9/20/2008	GPS / 6 ft / 6 sec	17 [4]	12.5

Experiment Name	Original Name	Patch Model						Survey setup tows			NEFSC survey		Notes
		Cell size (ft)	Population Density ( $D$ , $\geq 150$ mm SL, $N$ ft <sup>2</sup> )	Depletion vessel efficiency ( $E$ , fully recruited, $\geq 150$ mm SL)	Negative binomial parameter ( $K$ )	Gamma (indirect effects, $\gamma$ )	Goodness of fit (-log likelihood)	Survey id, [station id] (N tows) (N tows with length data)	Catch density ( $d$ , $\geq 150$ mm SL, $N$ ft <sup>2</sup> )	CV for catch density (se / mean)	Efficiency (e, fully recruited)	CV	
SC1997-2	PP-1	16.67	0.0492	0.3540	7.5313	0.5	210.3	199703 [183-190] (8) (4)	0.0081	0.15	0.16	Forty depletion tows total but tow 1 (and samples) omitted. Setup tows during calibration survey 199703 prior to 199704 clam survey.	
SC1997-3	AC2-1	21.67	0.0172	0.7646	2.6272	0.5	66.1	199703 [169, 175-181] (8) (8)	0.0042	0.10	0.25	Setup tows during calibration survey 199703 prior to 199704 clam survey.	
SC1997-4	AC2-2	21.67	0.0157	0.9900	3.2368	0.5	95.8	Same as SC1997-2	0.0042	0.10	0.27	Setup tows during calibration survey 199703 prior to 199704 clam survey.	
SC1997-5	AC1-1	16.67	0.0137	0.9500	3.2606	0.5055	86.9	199703 [166-168, 170-174] (8) (8)	0.0069	0.12	0.50	Same as above plus -> Previous analyses at SAW-26 (NEFSC 1998) omitted depletion tow 10, which was included here	
SC1997-6	AC1-2	16.67	0.0171	0.8902	7.1339	0.5	99.2	Same as SC1997-5	0.0069	0.12	0.40	Same as above plus -> Previous analyses at SAW-26 (NEFSC 1998) omitted depletion tows 17 and 19, which were included here	
SC1999-2	JG-1 (S99-5)	21.67	0.0249	0.8453	10.2855	0.5	21.5	199903 [105-108] (4) (4)	0.0075	0.23	0.30		
SC1999-3	JG-2 (s99-5)	21.67	0.0631	0.4625	9.3468	0.5	30.0	Same as SC1999-2	0.0075	0.23	0.12		
SC1999-4	JG-3 (S99-6)	21.67	0.0251	0.9900	15.3974	0.5	31.5	199903 [112-115] (4) (4)	0.0050	0.14	0.20		
SC1999-5	CH-1 (S99-DEII)	21.67	0.0193	0.1641	5.6765	0.5	92.8	19903 [367-370] (4) (0)				No length data for setup tows	
SC1999-6	MJ-1 (s99-3, NJ Inshore Site 1)	21.67	0.0245	0.8357	32.4987	0.5	18.7	199903 [82-85] (4) (4)	0.0058	0.44	0.24	Sarc31 list Blade at 13	
SC1999-7	MJ-1 (s99-3, NJ Inshore Site 2)	21.67	0.0513	0.6164	49.9988	0.5	52.2	199903 [88-90] (3) (3)	0.0046	0.17	0.09	Sarc31 list Blade at 13	
SC2002-2	SC02-2	21.67	0.0144	0.8610	30.7464	0.5	74.1	200206 [87-91] (5) (1)	0.0037	0.28	0.26		
SC2002-3	SC02-3	21.67	0.0134	0.3071	2.8366	0.5	88.3	200206 [202-206] (5) (4)	0.0104	0.61	0.77	Depletion tows: 1) bushel count for tow 1 only (tows 2-19 had catch < 1 bu); 2) clams counted for all tows because catches were low; and 3) lengths measured for 10 for tows. Setup tows: zero clams caught at setup tow (station 206); only two clams measured at station 205	
SC2002-4	SC02-4	21.67						200206 [335-339] (5) (1)				Zero clams $\geq 150$ mm in tows 1-3, very low and variable catches in other tows.	
SC2004-1	SC04-1	20.00	0.0301241	0.8072	4.0810	0.5000	130.753					200416 Cooperative Survey (shakedown leg) stations 15-38	
SC2004-2	SC04-2	20.00	0.017376	0.6646	7.7973	0.5000	102.320					200416 Cooperative Survey (shakedown leg) stations 49-68	
SC2004-3	SC04-3	20.00										200416 Cooperative Survey stations 146-165; zero clams $\geq 150$ mm in tow 1, very low and variable catches in other tows.	
SC2005-2	SC05-02	20.00	0.0407	0.7633	4.7110	0.5	98.5	200507 [137, 377-381] (6) (5)	0.004	0.36	0.10		
SC2005-3	SC05-03	20.00	0.0590	0.5879	4.7883	0.5	120.6	200507 [21, 384-387] (5) (37)	0.006	0.30	0.10		
SC2005-4	SC05-04	20.00	0.0264	0.5341	4.4756	0.5	104.5	200507 [41, 391-393, 395] (5) (3)	0.006	0.26	0.21		
SC2005-5	SC05-05	20.00	0.0212	0.9823	2.3360	0.5	96.1	200507 [143, 397-402] (7) (5)	0.004	0.18	0.21		
SC2005-6	SC05-01	20.00						200507 [123-127, 354] (6) (6)				Low catches $\geq 150$ mm SL in setup and depletion tows (less than 6% of total).	
SC2008-1	SC08-02	25.00	0.0093	0.9900	6.3267	0.5	104.7	200808 [74-78]	0.020	0.68	2.10	0.61	Survey dredge efficiency > 1.
SC2008-2	SC08-01	25.00	0.0122	0.9900	8.5387	0.5	75.2	200808 [67-71]	0.008	0.82	0.63	0.73	
SC2008-3	SC08-03	25.00	0.0098	0.7105	3.8503	0.5	114.9	200808 [298-301]	0.0046	0.92	0.47	0.79	Depletion tow 13 omitted because of missing catch data. One setup tow had zero catch of surfclams 150+ mm.
SC2008-4	SC08-04	25.00	0.0128	0.5244	1.6884	0.5	102.3	200808 [44, 305-306]	0.005	0.36	0.36	0.29	
SC2008-5								200808 [358, 368-369]	0.013	1.07			Strong currents during depletion tows made it difficult to navigate. Not used.
SC2008-6	SC08-09	25.00	0.0097	0.9310	6.8293	0.5	97.8	200808 [67-70]	0.009	0.69	0.93	0.80	

Table A12. Delaware II-Delaware II (De2De2) repeat station tow data for surfclams (50+ mm SL) in the 2008 NEFSC clam survey. Catches are numbers of surfclams (SC) or ocean quahogs (OQ) caught in the survey dredge, adjusted to a standard area swept based on sensor tow distance data (5 ft x 0.15 nm = 4557 ft<sup>2</sup> = 423 m<sup>2</sup>). Stations with useful data are at the top of the table. Stations excluded from the analysis because surfclam catches for both tows were zero or because of poor dredge performance (based on differential pressure and amperage sensors) are shown at the bottom.

Original station						Repeat station					
Station	OQ Catch	SC catch	Cable	Pump	HG	Station	OQ Catch	SC catch	Cable	Pump	HG
<i>Useful repeat stations</i>											
1	169.359	0.688	old	old	11	324	74.810	0.000	new	new	11
13	0.000	63.610	old	old	11	316	0.000	37.623	new	new	11
16	5.754	60.833	old	old	11	315	4.233	57.151	new	new	36
17	1.486	146.325	old	old	11	292	2.100	100.778	new	new	11
23	3.112	100.376	old	old	11	294	0.000	105.844	new	new	11
25	0.966	77.240	old	old	11	313	0.000	99.657	new	new	11
26	0.000	60.142	old	old	11	314	0.000	30.489	new	new	11
30	0.000	96.674	old	old	11	312	0.000	27.551	new	new	11
37	0.000	51.172	old	old	11	302	0.000	29.068	new	new	36
38	0.837	56.900	old	old	11	296	0.000	117.536	new	new	11
39	0.000	92.336	old	old	35	297	0.000	121.142	new	new	35
41	0.000	66.101	old	old	11	303	0.000	90.476	new	new	11
42	0.000	34.171	old	old	11	304	0.000	33.665	new	new	11
48	0.000	34.617	old	old	35	317	0.000	41.730	new	new	11
51	0.000	30.731	old	old	11	318	0.000	10.907	new	new	11
170	2.915	81.633	old	new	23	325	1.485	83.876	new	new	11
172	21.295	7.453	old	new	34	327	7.068	3.534	new	new	11
178	280.119	2.163	old	new	11	333	260.802	0.000	new	new	35
179	19.830	57.508	old	new	11	335	13.517	75.309	new	new	11
180	288.316	0.786	old	new	11	336	102.231	0.000	new	new	11
181	10.589	13.614	old	new	11	337	7.724	9.655	new	new	11
182	453.819	2.187	old	new	11	338	230.036	0.000	new	new	11
214	35.610	134.060	old	new	11	295	24.768	135.096	new	new	11
<i>Surfclam catches zero in each tow</i>											
173	611.722	0.000	old	new	11	328	341.535	0.000	new	new	11
173	611.722	0.000	old	new	11	329	284.070	0.000	new	new	35
173	611.722	0.000	old	new	11	330	380.974	0.000	new	new	11
173	611.722	0.000	old	new	11	330	380.974	0.000	new	new	11
173	611.722	0.000	old	new	11	331	258.288	0.000	new	new	11
174	105.004	0.000	old	new	36	328	341.535	0.000	new	new	11
174	105.004	0.000	old	new	36	329	284.070	0.000	new	new	35
175	133.078	0.000	old	new	11	328	341.535	0.000	new	new	11
183	359.921	0.000	old	new	11	339	121.018	0.000	new	new	11
<i>Poor dredge performance by sensor or HG criteria</i>											
2	105.675	0.000	old	old	11	334	199.518	0.000	new	new	11
22	26.069	125.516	old	old	11	293	27.008	169.609	new	new	23
44	0.000	114.895	old	old	35	305	0.000	65.823	new	new	35
44	0.000	114.895	old	old	35	306	0.000	65.926	new	new	35
53	0.000	46.006	old	old	11	319	0.000	0.000	new	new	48
171	31.390	0.981	old	new	35	326	6.525	0.000	new	new	36
206	327.657	0.000	old	new	11	286	0.000	0.000	new	new	47
206	327.657	0.000	old	new	11	287	420.315	0.000	new	new	11

Table A13. *F/V Delaware II-R/V Endeavor (De2Fv)* repeat station tow data for surfclams in the 2008 NEFSC clam survey. Catches are numbers of surfclams 150+ mm adjusted to a standard area swept (423 m<sup>2</sup>) based on sensor tow distance data.

FV sequential station number	FV original station name	FV new station name	NEFSC station name	FV catch	RV catch	RV / FV ratio	Cable	Pump
3	SC08-02-Tow002	SC2008-1 tow 2	74	1188.1	148.5	8.0	old	old
3	SC08-02-Tow002	SC2008-1 tow 2	75	1188.1	241.5	4.9	old	old
3	SC08-02-Tow002	SC2008-1 tow 2	76	1188.1	333.7	3.6	old	old
3	SC08-02-Tow002	SC2008-1 tow 2	77	1188.1	83.8	14.2	old	old
23	SC08-01-Tow002	SC2008-2 tow 2	67	2891.2	117.5	24.6	old	old
23	SC08-01-Tow002	SC2008-2 tow 2	68	2891.2	105.8	27.3	old	old
23	SC08-01-Tow002	SC2008-2 tow 2	69	2891.2	37.4	77.4	old	old
23	SC08-01-Tow002	SC2008-2 tow 2	70	2891.2	18.6	155.1	old	old
23	SC08-01-Tow002	SC2008-2 tow 2	71	2891.2	13.2	218.7	old	old
76	survey 303	NA	41	5402.6	25.0	216.3	old	old
76	survey 303	NA	303	5402.6	25.3	213.6	new	new
77	survey 36	NA	36	1336.8	9.0	148.1	old	old
78	survey 312	NA	30	12541.3	58.2	215.5	old	old
78	survey 312	NA	312	12541.3	22.5	556.8	new	new
79	survey 313	NA	25	15314.7	32.0	479.1	old	old
79	survey 313	NA	313	15314.7	78.5	195.1	new	new
80	survey 304	NA	42	21061.4	16.6	1267.4	old	old
80	survey 304	NA	304	21061.4	24.6	855.9	new	new
81	survey 316	NA	13	32295.5	69.4	465.6	old	old
81	survey 316	NA	316	32295.5	29.9	1079.5	new	new
107	SC08-05-Tow002	SC2008-5 tow 2	358	1263.5	90.4	14.0	new	new
107	SC08-05-Tow002	SC2008-5 tow 2	366	1263.5	10.6	119.5	new	new
107	SC08-05-Tow002	SC2008-5 tow 2	368	1263.5	266.1	4.7	new	new
107	SC08-05-Tow002	SC2008-5 tow 2	369	1263.5	5.9	215.1	new	new
161	survey 296	NA	38	24303.2	1.3	18412.0	old	old
161	survey 296	NA	296	24303.2	17.4	1396.6	new	new
162	survey 295	NA	214	1160.0	2.4	482.4	old	new
162	survey 295	NA	295	1160.0	8.3	139.7	new	new
192	survey 293	NA	22	0.0	1.1	0.0	old	old
192	survey 293	NA	293	0.0	2.9	0.0	new	new
193	survey 294	NA	23	6390.1	27.5	232.1	old	old
193	survey 294	NA	294	6390.1	55.9	114.4	new	new
194	survey 292	NA	17	1498.3	22.4	66.9	old	old
194	survey 292	NA	292	1498.3	14.7	101.7	new	new
195	survey 315	NA	16	3886.1	16.3	238.9	old	old
195	survey 315	NA	315	3886.1	6.9	561.2	new	new
196	survey 310	NA	310	4667.0	31.0	150.5	new	new
197	survey 49	NA	49	1835.9	3.8	479.2	old	old
198	survey 60	NA	60	1739.7	22.5	77.4	old	old
199	survey 64	NA	64	702.9	21.0	33.5	old	old
999	survey 317	NA	48	0.0	14.0	0.0	old	old
999	survey 317	NA	317	0.0	26.1	0.0	new	new

Table A14. Station numbers and total numbers measured for R/V Delaware II and F/V Endeavor tows used to estimate size-selectivity for surfclams. For each type of tow, N is the number of surfclams measured. R/V selectivity data for the station /with Selectivity ID 318 (R/V stations 51 and 318) were not used because the RV and F/V tows were more than 300 m away from one another. Data from R/V station 319 was not used because the tow was not successful (database SHG code > 136).

Experiment ID	R/V survey station id	R/V survey station N	R/V repeat station id	R/V repeat station N	F/V selectivity N (lined dredge)	F/V repeat N (unlined dredge)
36	36	14			105	84
49	49	12			181	108
60	60	66			125	106
64	64	14			20	71
292	17	191	292	82	503	129
293	22	128	293	155	242	204
294	23	114	294	96	304	103
295	214	127	295	112	651	158
296	38	69	296	110	463	150
303	41	66	303	80	266	92
304	42	40	304	41	236	85
310	310	37			113	77
312	30	62	312	29	230	89
313	25	65	313	79	285	108
314	26	51	314	24	245	104
315	16	62	315	50	260	98
316	13	62	316	37	328	95
317	317	33	48	41	173	97
318	318	not used	51	not used	45	113
319	53	63	319	not used	156	105

Table A15. F/V and R/V shell height composition data used to estimate NEFSC clam survey dredge selectivity for surfclams. Numbers of positive stations (e.g. R/V n positive stations) give the number of stations at which surfclams of each shell length group were captured. For example, “F/V lined dredge N positive stations” =3 for the 20-29 mm SL group because individuals in the 20-29 mm size group were observed in F/V selectivity tows at three sites.

SL group	F/V lined dredge N measurements	F/V unlined dredge N measurements	R/V N measurements	F/V lined dredge N positive stations	F/V unlined dredge N positive stations	R/V N positive stations
20-29	3	0	0	3	0	0
30-39	27	0	1	11	0	1
40-49	109	0	6	15	0	3
50-59	180	1	29	17	1	11
60-69	219	4	83	19	4	15
70-79	217	10	128	19	6	17
80-89	250	23	157	16	12	17
90-99	226	60	135	17	16	16
100-109	221	124	139	18	16	16
110-119	332	181	181	19	20	16
120-129	422	221	278	19	18	15
130-139	464	263	282	17	19	17
140-149	524	352	335	19	20	18
150-159	612	502	285	18	19	19
160-169	432	359	126	18	17	16
170-179	130	63	38	15	16	11
180-189	24	13	7	5	6	3
190-199	2	1	2	1	1	1

Table A16. Numbers of surfclams in survey dredge selectivity experiments by length group and station. For example, “5:19” means that five surfclams of a particular length at a particular station were measured in catches by the *R/V Delaware II* and 19 surfclams were measured in catches by the *F/V Endeavor*.

SL bin	Sta 36	Sta 49	Sta 60	Sta 64	Sta 292	Sta 293	Sta 294	Sta 295	Sta 296	Sta 303
25	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	1:0	0:0
35	0:0	1:0	1:0	0:0	0:0	0:0	1:0	1:0	1:1	0:0
45	0:0	9:0	4:0	0:0	10:0	3:0	5:0	6:0	7:4	1:0
55	0:0	13:0	6:1	0:0	9:1	13:3	15:7	31:4	26:2	4:1
65	2:1	16:0	9:1	1:0	29:4	18:14	21:9	15:5	28:11	7:4
75	5:0	10:1	13:14	1:0	20:8	16:16	8:5	7:2	33:26	25:22
85	0:1	11:1	6:17	0:0	28:10	14:23	10:2	1:1	48:26	43:31
95	0:0	8:2	8:15	0:0	15:10	18:16	10:2	8:4	40:23	41:24
105	2:0	11:1	4:5	0:0	23:12	25:40	2:8	32:19	41:19	23:13
115	1:0	8:1	5:2	2:1	31:11	43:58	20:17	90:47	44:9	15:11
125	2:1	8:0	4:0	2:1	72:38	54:68	41:34	115:81	50:12	13:5
135	3:1	3:1	1:0	0:0	94:78	24:35	35:29	97:47	42:15	7:1
145	19:3	7:2	10:0	2:2	78:69	6:7	55:46	45:23	45:19	8:6
155	29:5	38:3	19:4	6:7	36:29	0:3	55:35	11:6	31:9	12:14
165	19:1	22:0	19:4	4:2	5:3	0:0	17:16	1:0	18:2	26:7
175	2:1	4:0	8:3	2:1	0:0	0:0	2:0	0:0	2:1	17:6
185	0:0	0:0	1:0	0:0	0:0	0:0	0:0	0:0	0:0	1:1
195	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0

SL bin	Sta 304	Sta 310	Sta 312	Sta 313	Sta 314	Sta 315	Sta 316	Sta 317	Sta 319	Total
25	1:0	0:0	0:0	0:0	0:0	0:0	0:0	1:0	0:0	3:0
35	3:0	6:0	0:0	0:0	2:0	0:0	4:0	4:0	3:0	27:1
45	5:1	26:1	0:0	0:0	3:0	2:0	17:0	5:0	6:0	109:6
55	5:4	17:3	5:0	3:0	6:1	1:0	13:1	10:1	3:0	180:29
65	16:8	9:9	6:2	6:3	8:0	1:0	7:3	14:7	6:2	219:83
75	10:6	6:4	3:3	8:4	8:4	1:1	19:4	17:7	7:1	217:128
85	9:11	4:2	5:5	18:4	11:6	0:1	17:7	20:9	5:0	250:157
95	4:3	2:6	6:5	10:8	20:4	3:2	15:0	12:7	6:4	226:135
105	1:1	1:1	6:3	11:3	12:4	1:1	7:3	10:6	9:0	221:139
115	5:3	8:0	4:1	13:4	12:5	3:3	11:4	8:4	9:0	332:181
125	3:1	4:0	9:4	10:8	3:6	12:5	12:12	5:0	3:2	422:278
135	7:4	3:1	14:8	28:22	13:7	65:26	27:2	1:2	0:3	464:282
145	24:12	1:1	23:16	36:34	20:9	96:58	14:6	22:8	13:14	524:335
155	58:16	8:4	60:23	78:37	33:10	37:14	43:26	27:17	31:23	612:285
165	38:9	10:3	58:15	31:17	66:11	3:1	53:17	11:6	31:12	432:126
175	8:2	3:2	9:6	8:0	13:7	1:0	43:7	0:0	8:2	130:38
185	1:0	0:0	1:0	0:0	0:1	0:0	20:5	0:0	0:0	24:7
195	0:0	0:0	0:0	0:0	0:0	0:0	2:2	0:0	0:0	2:2

Table A17. Revised shell length-meat weight parameters for surfclams based on fresh (not frozen) samples collected during 1997-2008 NEFSC clam surveys. The SLMW relationship is  $W = \exp(a)L^b$  where W is weight in kg and L is shell length in cm. Parameters used by NEFSC (2000) in the last stock assessment for SARC-44 are shown for comparison.

Source	DMV			NJ			LI		
	a	b	n	a	b	n	a	b	n
1997 (fresh samples)	-9.92060	2.96191	702	-9.41163	2.89971	149	-9.92478	2.96477	130
2002 (fresh samples)	-10.83117	3.13644	294	-9.68603	2.93156	233			
2005 (fresh samples)	-9.80927	2.95150	250	-9.77665	2.92920	338			
2008 (fresh samples)	-9.21853	2.67956	89	-9.79938	2.89804	311			
All fresh samples	-9.6465	2.8493		-9.4326	2.851				

Source	SNE			GBK		
	a	b	n	a	b	n
1997 (fresh samples)	-9.80164	2.96367	48	-8.55829	2.73074	116
2002 (fresh samples)				-10.27049	3.06418	54
2005 (fresh samples)						
2008 (fresh samples)						
All fresh samples	-9.80164	2.96367		-9.1488	2.8282	

Table A18. Regional shell length-meat weight parameter estimates from fresh material collected during NEFSC clam surveys during 1997-2008, by region with parameters from NEFSC (2000) used in the last assessment. Parameters for all fresh samples in each region were calculated by averaging the curves for each year and estimating parameters to fit the average curve.

Region	Updated		NEFSC 2000 (SARC 44)	
	a	b	a	b
DMV	-9.64650	2.84930	-9.48913	2.86018
NJ	-9.43260	2.85100	-9.31214	2.86372
LI	-9.92480	2.96480	-7.98370	2.58020
SNE	-9.80164	2.96367	-7.98370	2.58020
GBK	-9.14880	2.82820	-8.27443	2.65422
All but GBK	-9.47060	2.84300	-8.52318	2.67522
All	-9.34040	2.82300	-8.48764	2.67222

Table A19. Shell length-meat weight (SLMW) parameters for the entire stock of surfclams during years with NEFSC clam surveys. The SLMW relationship is  $W=\exp(a)L^b$  where  $W$  is weight in kg and  $L$  is shell length in cm. The parameters change over time because the proportion of the stock in each region changed over time.

Year	a	B	exp(a)	exp(b)
1982	-9.602	2.879	6.76E-05	17.80
1983	-9.566	2.867	7.01E-05	17.59
1984	-9.570	2.868	6.98E-05	17.60
1986	-9.569	2.856	6.98E-05	17.39
1989	-9.449	2.853	7.88E-05	17.34
1992	-9.516	2.855	7.37E-05	17.38
1994	-9.422	2.848	8.09E-05	17.25
1997	-9.483	2.859	7.62E-05	17.45
1999	-9.437	2.856	7.97E-05	17.40
2002	-9.413	2.851	8.16E-05	17.30
2005	-9.364	2.855	8.58E-05	17.38
2008	-9.330	2.852	8.87E-05	17.33

Table A20. Numbers of age samples for surfclams collected in the NEFSC clam survey during 1978-2008, by region. A few samples for SVA were combined with DMV. Obvious data errors were omitted.

Survey year	Region				
	DMV	NJ	LI	SNE	GBK
1978	199	289			
1980	391	452	29	61	
1981	446	641	27	38	
1982	801	927	40	123	4
1983	564	934	6	369	
1984					643
1986	812	1216	45	71	413
1989	162	566	53	42	86
1992	145	257	47	54	311
1994	299	476			
1997	626	227			50
1999	510	496	22	50	178
2002	356	779	31	20	54
2005	339	523	21	6	
2008	138	459	99	39	105

Table A21. Von Bertalanffy growth parameters and standard errors for surfclams by region estimated using nonlinear least squares. The growth equation is  $L=L_{max} (1-\exp(-k (A-t_0)))$  where  $A$  is age in years,  $L$  is length in cm and  $L_{max}$ ,  $k$  and  $t_0$  are parameters. Age data were pooled across years for individual regions or across years and regions for combined regions such as “DMV to SNE” and “Whole stock”.

Region	N shells	$L_{max}$	SE	$k$	SE	$t_0$	SE
GBK	1,844	147.10	1.379	0.253	0.010	0.041	0.085
DMV (1978-1992)	3,520	171.82	0.872	0.198	0.005	-0.739	0.081
DMV (1994-2008)	2,268	146.45	1.101	0.200	0.008	-1.012	0.132
DMV (all years)	5,788	159.95	0.736	0.206	0.005	-0.784	0.077
NJ (1978-1992)	5,282	168.64	0.670	0.236	0.005	-0.468	0.057
NJ (1999-2008)	2,960	161.73	0.866	0.193	0.006	-1.303	0.134
NJ	8,242	163.49	0.493	0.237	0.004	-0.577	0.054
LI	420	159.41	1.328	0.302	0.018	-0.050	0.160
SNE	873	165.33	1.016	0.284	0.013	0.149	0.135
GBK	1,844	147.10	1.379	0.253	0.010	0.041	0.085
DMV to SNE	13,207	163.35	0.416	0.228	0.003	-0.621	0.047
Whole stock (1986-1992)	4,280	166.93	0.899	0.200	0.005	0.086	0.074
Whole stock (1999-2008)	3,336	154.62	0.817	0.225	0.007	-0.402	0.108
Whole stock (all years)	7,616	160.27	0.605	0.213	0.004	-0.658	0.063

Table A22. Von Bertalanffy growth parameters for shell length and estimated age at recruitment to the fishery (ssumed to occur at 12 cm SL) for surfclams in the stock as a whole during years with NEFSC clam surveys. The growth equation is  $L=L_{max}*(1-\exp(-k*(a-t_0)))$  where  $a$  is age in years,  $L$  is length in cm and  $L_{max}$ ,  $k$  and  $t_0$  are parameters in the table.

Parameter	Lmax	K	t0	Age at Recruitment (12 cm SL)
1982	16.631	0.229	-0.517	5.056
1983	16.637	0.222	-0.548	5.200
1984	16.626	0.222	-0.540	5.222
1986	16.784	0.212	-0.646	5.268
1989	16.194	0.228	-0.453	5.480
1992	16.530	0.220	-0.573	5.314
1994	15.436	0.231	-0.517	5.980
1997	15.661	0.233	-0.526	5.711
1999	15.568	0.238	-0.436	5.754
2002	15.488	0.235	-0.445	5.890
2005	15.368	0.247	-0.261	5.882
2008	15.357	0.247	-0.209	5.936

Table A23. Von Bertalanffy parameters for growth in meat weight for the surfclam stock as a whole and the growth parameter  $J=W_{k-1}/W_k$ , where  $k$  is the estimated age at which a surfclam reaches 12 cm SL, and  $W_k$  is predicted meat weight at age  $k$ .

Parameter	$W_{\infty}$	K	t0	J
1982	0.223	0.178	2.108	0.718
1983	0.223	0.178	2.221	0.722
1984	0.223	0.178	2.233	0.723
1986	0.220	0.178	2.344	0.715
1989	0.224	0.178	2.169	0.757
1992	0.223	0.178	2.238	0.733
1994	0.198	0.178	2.035	0.809
1997	0.201	0.178	2.002	0.792
1999	0.205	0.178	1.974	0.797
2002	0.204	0.178	2.016	0.804
2005	0.213	0.178	1.945	0.808
2008	0.218	0.178	1.983	0.809

Table A24. Efficiency corrected swept-area biomass estimates (1000 mt) and CVs for surfclams (120+ mm SL), by region. Figures for SVA during 2005 and 2008 are the same as during 2002 because no data were available for 2005 and 2008.

INPUT: Nominal tow distance ( $d_n$ , nm) INPUT: Dredge width (nm) Area swept per standard tow ( $a$ , nm <sup>2</sup> )	Estimate	CV									
	0.15										
	0.0008225										
	1.23375E-04	10%									
<b>Area of assessment region (A, nm<sup>2</sup>) - no correction for stations with unsuitable clam habitat</b>											
S. Virginia and N. Carolina (SVA)	3,119	10%									
Delmarva (DMV)	4,660	10%									
New Jersey (NJ)	5,078	10%									
Long Island (LI)	2,917	10%									
Southern New England (SNE)	4,321	10%									
Georges Bank (GBK)	5,772	10%									
Total	25,867										
<b>INPUT: Fraction suitable habitat (u)</b>											
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)	100%	10%									
Georges Bank (GBK)	88%	10%									
<b>Habitat area in assessment region (A', nm<sup>2</sup>)</b>											
S. Virginia and N. Carolina (SVA)	3,119	14%									
Delmarva (DMV)	4,660	14%									
New Jersey (NJ)	5,078	14%									
Long Island (LI)	2,917	14%									
Southern New England (SNE)	4,321	14%									
Georges Bank (GBK)	5,079	14%									
<b>INPUT: Biomass fraction in unsurveyed deep water</b>											
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)	0%	10%									
Georges Bank (GBK)	0%	10%									
<b>INPUT: Original survey mean catch from fishable stock (kg/tow, for tows adjusted to nominal tow distance using sensors)</b>											
	Estimates for 1997		Estimates for 1999		Estimates for 2002		Estimates for 2005		Estimates for 2008		
	CV	CV	CV	CV	CV	CV	CV	CV	CV	CV	
S. Virginia and N. Carolina (SVA) 120+ mm	0.0164	43%	0.0164	43%	0.3165	60%	0.3165	60%	0.3165	60%	
Delmarva (DMV) 120+ mm	2.1372	21%	1.3123	20%	2.3604	21%	0.4013	32%	0.3335	34%	
New Jersey (NJ) 120+ mm	6.0896	11%	4.2252	15%	4.4673	17%	2.4969	16%	2.8925	17%	
Long Island (LI) 120+ mm	0.4230	63%	1.0199	45%	0.3309	64%	2.4739	34%	0.6172	26%	
Southern New England (SNE) 120+ mm	1.7579	36%	1.0445	65%	0.8043	24%	0.4093	29%	1.1185	63%	
Georges Bank (GBK) 120+ mm	1.7340	25%	2.1690	30%	2.0802	42%	3.7936	23%	4.6824	19%	
<b>Swept-area biomass without efficiency correction (B', 1000 mt):</b>											
S. Virginia and N. Carolina (SVA) 120+ mm	0.4156	47%	0.4156	47%	8.0021	63%	8.0021	63%	8.0021	63%	
Delmarva (DMV) 120+ mm	80.7250	29%	49.5673	28%	89.1540	29%	15.1586	38%	12.5978	39%	
New Jersey (NJ) 120+ mm	250.6431	23%	173.9036	25%	183.8716	26%	102.7709	26%	119.0526	26%	
Long Island (LI) 120+ mm	10.0002	66%	24.1143	49%	7.8224	67%	58.4901	39%	14.5920	33%	
Southern New England (SNE) 120+ mm	61.5661	41%	36.5815	68%	28.1678	31%	14.3340	35%	39.1729	66%	
Georges Bank (GBK) 120+ mm	71.3893	32%	89.2975	36%	85.6404	47%	156.1816	30%	192.7744	28%	
SVA to SNE	403	17%	285	19%	317	18%	199	18%	193	21%	
Total (including GBK)	475	15%	374	17%	403	17%	355	17%	386	17%	
<b>INPUT: Survey dredge efficiency (e) from Patch m</b>											
	0.256	21%	0.256	21%	0.256	21%	0.26	21%	0.256	21%	
<b>INPUT: Adjustment for domed survey selectivity</b>											
	1.453	16%	1.453	16%	1.453	16%	1.45	16%	1.453	16%	
<b>Adjusted survey dredge efficiency</b>											
	0.372	26%	0.372	26%	0.372	26%	0.37	26%	0.372	26%	
<b>Efficiency adjusted swept area fishable biomass (B, 1000 mt)</b>											
S. Virginia and N. Carolina (SVA) 120+ mm	1.117	54%	1.117	54%	21.506	68%	21.506	68%	21.506	68%	
Delmarva (DMV) 120+ mm	217	39%	133	38%	240	39%	41	46%	34	47%	
New Jersey (NJ) 120+ mm	674	35%	467	36%	494	37%	276	37%	320	37%	
Long Island (LI) 120+ mm	27	71%	65	56%	21	72%	157	47%	39	42%	
Southern New England (SNE) 120+ mm	165	49%	98	73%	76	41%	39	44%	105	71%	
Georges Bank (GBK) 120+ mm	192	41%	240	45%	230	53%	420	40%	518	38%	
SVA to SNE	1,084	31%	765	32%	852	32%	534	32%	520	34%	
Total (including GBK)	1,276	30%	1,005	31%	1,082	31%	954	31%	1,038	31%	
<b>Lower bound for 80% confidence intervals on fishable biomass (1000 mt, for lognormal distribution with no bias correction)</b>											
	Estimates for 1997	Estimates for 1999	Estimates for 2002	Estimates for 2005	Estimates for 2008						
S. Virginia and N. Carolina (SVA) 120+ mm	0.584	0.584	9.729	9.729	9.729						
Delmarva (DMV) 120+ mm	134	83	148	23	19						
New Jersey (NJ) 120+ mm	438	298	312	175	202						
Long Island (LI) 120+ mm	12	33	9	88	23						
Southern New England (SNE) 120+ mm	92	43	46	23	46						
Georges Bank (GBK) 120+ mm	115	139	121	256	324						
SVA to SNE	736	512	575	359	341						
Total (including GBK)	875	682	733	647	701						
<b>Upperbound for 80% confidence intervals on fishable biomass (1000 mt, for lognormal distribution with no bias correction)</b>											
S. Virginia and N. Carolina (SVA) 120+ mm	2.137	2.137	47.537	47.537	47.537						
Delmarva (DMV) 120+ mm	351	214	388	71	141						
New Jersey (NJ) 120+ mm	1,037	732	782	435	2,293						
Long Island (LI) 120+ mm	61	126	48	279	172						
Southern New England (SNE) 120+ mm	299	227	125	66	590						
Georges Bank (GBK) 120+ mm	319	414	437	688	4,388						
SVA to SNE	1,597	1,143	1,263	795	4,085						
Total (including GBK)	1,860	1,480	1,598	1,407	9,829						

Table A25. Fishing mortality estimates for surfclams based on catch and efficiency corrected swept-area biomass estimates.

INPUT: Incidental mortality allowance	12%									
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)	0.000	0.000	0.064	0.000	0.000					
Delmarva (DMV)	1.540	0.648	4.489	1.668	3.223					
New Jersey (NJ)	16.998	18.749	18.271	16.850	17.517					
Long Island (LI)	0.073	0.157	1.130	0.759	1.317					
Southern New England (SNE)	0.000	0.016	0.052	1.885	0.423					
Georges Bank (GBK)	0.000	0.000	0.000	0.000	0.000					
Total	18.611	19.570	24.006	21.163	22.481					
Catch (1000 mt, landings + upper bound incidental mortality allowance)	0.000	0.000	0.072	0.000	0.000					
S. Virginia and N. Carolina (SVA)	1.725	0.726	5.028	1.868	3.610					
Delmarva (DMV)	19.038	20.999	20.463	18.872	19.619					
New Jersey (NJ)	0.081	0.176	1.265	0.850	1.475					
Long Island (LI)	0.000	0.018	0.058	2.112	0.474					
Southern New England (SNE)	0.000	0.000	0.000	0.000	0.000					
Georges Bank (GBK)	0.000	0.000	0.000	0.000	0.000					
Total	20.844	21.919	26.886	23.702	25.178					
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) 120+ mm	1	54%	1	54%	22	68%	22	68%	22	68%
Delmarva (DMV) 120+ mm	217	39%	133	38%	240	39%	41	46%	34	47%
New Jersey (NJ) 120+ mm	674	35%	467	36%	494	37%	276	37%	320	37%
Long Island (LI) 120+ mm	27	71%	65	56%	21	72%	157	47%	39	42%
Southern New England (SNE) 120+ mm	165	49%	98	73%	76	41%	39	44%	105	71%
Georges Bank (GBK) 120+ mm	192	41%	240	45%	230	53%	420	40%	518	38%
SVA to SNE	1,084	31%	765	32%	852	32%	534	32%	520	34%
Total (including GBK)	1,276	30%	1,005	31%	1,082	31%	954	31%	1,038	31%
Fishing mortality ( $y^{-1}$ )	0.0000	NA	0.0000	NA	0.0034	69%	0.0000	NA	0.0000	NA
S. Virginia and N. Carolina (SVA) 120+ mm	0.0080	40%	0.0054	40%	0.0210	40%	0.0459	47%	0.1066	48%
Delmarva (DMV) 120+ mm	0.0283	36%	0.0449	38%	0.0414	38%	0.0683	38%	0.0613	38%
New Jersey (NJ) 120+ mm	0.0030	72%	0.0027	57%	0.0602	73%	0.0054	48%	0.0376	43%
Long Island (LI) 120+ mm	0.0000	50%	0.0002	74%	0.0008	42%	0.0548	45%	0.0045	72%
Southern New England (SNE) 120+ mm	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA
Georges Bank (GBK) 120+ mm	0.0192	33%	0.0287	34%	0.0316	33%	0.0444	33%	0.0484	35%
SVA to SNE	0.0163	32%	0.0218	33%	0.0248	33%	0.0248	33%	0.0243	33%
Total (including GBK)										
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) 120+ mm	NA	NA	0.0015	NA	NA					
Delmarva (DMV) 120+ mm	0.0048	0.0033	0.0128	0.0259	0.0593					
New Jersey (NJ) 120+ mm	0.0181	0.0282	0.0258	0.0427	0.0382					
Long Island (LI) 120+ mm	0.0013	0.0014	0.0262	0.0030	0.0222					
Southern New England (SNE) 120+ mm	NA	0.0001	0.0005	0.0316	0.0020					
Georges Bank (GBK) 120+ mm	NA	NA	NA	NA	NA					
SVA to SNE	0.0128	0.0188	0.0209	0.0293	66.6881					
Total (including GBK)	0.0110	0.0145	0.0165	0.0165	160.5256					
Upper bound for 80% confidence intervals for fishing mortality ( $y^{-1}$ , for lognormal distribution with no bias correction)	NA	NA	0.0075	NA	NA					
S. Virginia and N. Carolina (SVA) 120+ mm	0.0131	0.0089	0.0345	0.0812	0.1917					
Delmarva (DMV) 120+ mm	0.0442	0.0715	0.0665	0.1092	0.0985					
New Jersey (NJ) 120+ mm	0.0069	0.0053	0.1385	0.0097	0.0638					
Long Island (LI) 120+ mm	NA	0.0004	0.0013	0.0950	0.0103					
Southern New England (SNE) 120+ mm	NA	NA	NA	NA	NA					
Georges Bank (GBK) 120+ mm	0.0289	0.0436	0.0477	0.0673	0.0750					
SVA to SNE	0.0243	0.0327	0.0374	0.0373	0.0366					
Total (including GBK)										

Table A26. Building a bridge--effects of changes in criteria for omitting "bad" tows (step 1), borrowing from the 2008 survey (step 2), new shell length-meat weight (SLMW) relationships (step 3), new survey dredge selectivity estimates (step 4), and the new survey dredge selectivity curve (step 5) on efficiency corrected swept-area biomass for surfclams during 2005.

Region	NEFSC (2007)	Change criteria for "bad" tows - step 1	Borrow from 2008 survey - step 2	New SLMW - step 3	Survey data adjusted for domed selectivity - step 4	New efficiency - step 5	Percent change (New-Old)/Old
SVA	29	30	30	33	31	22	-26%
DMV	68	67	68	55	59	41	-40%
NJ	397	396	397	330	401	276	-30%
LI	206	205	206	202	228	157	-24%
SNE	29	35	28	33	56	39	33%
GBK	337	344	615	606	609	420	25%
Total	1,066	1,078	1,343	1,258	1,385	954	-11%

Table A27. Efficiency corrected swept-area biomass estimates in this assessment, compared to estimates from the last four surfclam stock assessments.

Year	SARC-26 All		SARC-30 All		SARC-37 110+ and 120+		SARC-44 120+ mm		New assessment 120+ mm	
	Biomass (1000 mt)	Survey efficiency (e)	Biomass (1000 mt)	Survey efficiency (e)	Biomass (1000 mt)	Survey efficiency (e)	Biomass (1000 mt)	Survey efficiency (e)	Biomass (1000 mt)	Survey efficiency (e)
1997	1,130	0.897	1,106	0.588	1,146	0.460	1,913	0.226	1,472	0.256
1999			1,596	0.276	1,460	0.276	1,503	0.226	1,176	0.256
2002					803	0.389	1,479	0.226	1,153	0.256
2005							1,066	0.226	1,110	0.256
2008									1,170	0.256

Table A28. Fishing mortality estimates based on catch and efficiency corrected swept-area biomass in this assessment, compared to estimates from the last four surfclam stock assessments.

Year	SARC-26 All		SARC-30 All		SARC-37 110+ and 120+		SARC-44 120+ mm		New assessment 120+ mm	
	Fishing mortality	Survey efficiency (e)	Fishing mortality	Survey efficiency (e)	Fishing mortality	Survey efficiency (e)	Fishing mortality	Survey efficiency (e)	Fishing mortality	Survey efficiency (e)
1997	0.0181	0.897	0.0188	0.588	0.0180	0.460	0.0109	0.226	0.0142	0.256
1999			0.0137	0.276	0.0150	0.276	0.0146	0.226	0.0186	0.256
2002					0.0330	0.389	0.0182	0.226	0.0233	0.256
2005							0.0222	0.226	0.0214	0.256
2008									0.0215	0.256

Table A29. Calculations to predict changes in estimated survey dredge efficiency due to dome shaped selectivity for surfclams 150+ mm SL based on all 21 actual surfclam commercial depletion experiments with set up tows by the *R/V Delaware II*. Set up tow details are given for use elsewhere.

Experiment Name	NEFSC cruise number	Station numbers for setup tows	Adjust for survey for hypothetical dome-shaped dredge selectivity?	Survey set up tow density (N per standard tow) 150+ mm SL										Ratio survey dredge efficiency with and without assuming dome shaped selectivity
				Tow 1	Tow 2	Tow 3	Tow 4	Tow 5	Tow 6	Tow 7	Tow 8	Mean setup density (n or n*)	CV	
SC1997-2	199703	183-190	No	0.000	0.000	0.542	0.000	0.000	0.997	0.000	4.109	0.706	2.02	1.320
			Yes	0.000	0.000	0.730	0.000	0.000	1.186	0.000	5.537	0.932	2.05	
SC1997-3	199703	169, 175-181	No	0.000	0.000	0.000	0.000	0.000	1.954	0.000	1.572	0.441	1.87	1.151
			Yes	0.000	0.000	0.000	0.000	0.000	2.302	0.000	1.756	0.507	1.87	
SC1997-5	199703	166-168, 170-174	No	4.317	1.535	0.000	0.000	0.000	1.175	0.000	0.000	0.878	1.73	1.386
			Yes	5.179	3.092	0.000	0.000	0.000	1.467	0.000	0.000	1.217	1.60	
SC1999-2	199903	105-108	No	49.237	19.388	45.632	22.167					34.106	0.45	1.818
			Yes	89.869	37.235	79.487	41.454						62.011	
SC1999-4	199903	112-115	No	29.371	14.262	22.280	24.975					22.722	0.28	1.455
			Yes	43.733	19.719	31.918	36.832						33.050	
SC1999-6	199903	82-85	No	32.776	56.478	10.759	6.020					26.508	0.87	1.397
			Yes	43.145	79.329	17.114	8.493						37.020	
SC1999-7	199903	88-90	No	27.350	14.881	20.057						20.763	0.30	1.424
			Yes	38.132	22.285	28.308							29.575	
SC2002-2	200206	87-91	No	33.635	0.000	0.000	0.000	0.000				6.727	2.24	1.420
			Yes	47.777	0.000	0.000	0.000	0.000					9.555	
SC2002-3	200206	202-206	No	71.064	12.849	150.440	1.039	0.000				47.078	1.38	1.941
			Yes	139.838	24.244	291.421	1.474	0.000					91.395	
SC2002-4	200206	335-339	No	1.017	0.000	0.000	0.000	0.000				0.203	2.24	1.231
			Yes	1.252	0.000	0.000	0.000	0.000					0.250	
SC2005-2	200507	137, 377-381	No	2.789	17.423	12.392	3.087	0.000	47.352			13.841	1.28	1.540
			Yes	5.142	26.205	18.544	5.729	0.000	72.236				21.309	
SC2005-3	200507	21, 384-387	No	33.017	0.000	27.587	0.000	19.024				15.925	0.97	1.725
			Yes	58.028	0.000	50.517	0.000	28.841					27.477	
SC2005-4	200507	41, 391-393, 395	No	20.743	50.243	0.000	16.476	0.000				17.492	1.18	1.401
			Yes	29.271	70.438	0.000	22.860	0.000					24.514	
SC2005-5	200507	143, 397-402	No	20.357	31.442	17.148	0.000	29.382	0.000			16.388	0.84	1.451
			Yes	30.035	45.498	24.347	0.000	42.761	0.000				23.773	
SC2005-6	200507	123-127, 354	No	3.269	3.963	6.978	2.020	4.690	3.826			4.124	0.40	1.385
			Yes	4.442	4.964	10.840	2.557	5.876	5.590				5.711	
SC2008-1	200808	74-78	No	77.758	125.312	174.265	43.610	25.195				89.228	0.68	1.912
			Yes	148.519	241.463	333.695	83.850	45.609					170.627	
SC2008-2	200808	67-71	No	68.850	62.099	24.765	9.882	9.279				34.975	0.82	1.673
			Yes	117.492	105.797	37.361	18.642	13.222					58.503	
SC2008-3	200808	298-301	No	3.191	0.000	3.088	0.789					1.767	0.92	1.823
			Yes	5.023	0.000	6.803	1.063						3.222	
SC2008-4	200808	44, 305-306	No	28.965	19.631	14.127						20.908	0.36	1.728
			Yes	47.944	35.336	25.083							36.121	
SC2008-5	200808	358, 368-369	No	47.832	130.638	3.028						60.499	1.07	1.996
			Yes	90.361	266.091	5.874							120.776	
SC2008-6	200808	67-70	No	68.850	62.099	24.765	9.882					41.399	0.69	1.687
			Yes	117.492	105.797	37.361	18.642						69.823	
Mean											29.638	1.077	1.565	

Table A30. Calculations to predict effects of dome shaped survey selectivity on efficiency corrected swept-area biomass estimates for surfclams 120+ mm SL based on all 21 actual commercial depletion experiments with set up tows by the *R/V Delaware II*. Set up tow details are given for use elsewhere. Information from Table A29 is used in these calculations.

Experiment Name	Survey set up biomass density (kg per standard tow) 120+ mm SL										Ratio efficiency corrected swept area biomass with and without assuming dome shaped selectivity
	Tow 1	Tow 2	Tow 3	Tow 4	Tow 5	Tow 6	Tow 7	Tow 8	Mean biomass density (b or b*)	CV	
SC1997-2	1.17485	2.81794	1.2596	1.58652	0.79793	2.26561	5.99174	2.89293	2.348	0.708	0.772
	1.19017	2.84189	1.28994	1.59123	0.79838	2.31165	5.99719	3.11482	2.392	0.699	
SC1997-3	0	0.86331	0.09428	0.14413	3.1936	1.48921	7.67058	4.11179	2.196	1.222	0.878
	0	0.86341	0.09458	0.14414	3.23642	1.55237	7.67638	4.17731	2.218	1.213	
SC1997-5	4.36841	0.29387	0	0	0	1.19392	1.02917	4.03984	1.366	1.329	0.757
	4.5133	0.61727	0	0	0	1.24603	1.04511	4.04435	1.433	1.273	
SC1999-2	9.32059	4.43466	9.49393	4.53104					6.945	0.410	0.914
	16.00883	7.42478	15.01543	7.71542					11.541	0.399	
SC1999-4	9.94403	5.01466	5.4824	10.12495					7.642	0.363	0.833
	12.22628	5.89088	6.91095	12.00189					9.258	0.359	
SC1999-6	9.67779	13.75515	3.01192	1.44464					6.972	0.826	0.880
	11.2486	17.21284	4.00893	1.80316					8.568	0.821	
SC1999-7	9.74365	3.58978	4.94414						6.093	0.531	0.856
	11.40007	4.70924	6.1844						7.431	0.473	
SC2002-2	15.24823	0	0	0	0				3.050	2.236	0.813
	17.60645	0	0	0	0				3.521	2.236	
SC2002-3	11.85864	1.98236	25.5799	0.14174	0				7.913	1.393	1.001
	23.54212	3.7987	49.35318	0.20095	0				15.379	1.388	
SC2002-4	14.75331	0	0	0	0				2.951	2.236	0.817
	14.84429	0	0	0	0				2.969	2.236	
SC2005-2	0.57474	4.79954	2.71874	0.79511	0	10.204			3.182	1.215	0.887
	0.95286	6.19493	3.66591	1.21376	0	14.03358			4.344	1.209	
SC2005-3	6.42795	0	5.12432	0	3.95586				3.102	0.955	0.935
	10.48768	0	8.96175	0	5.56445				5.003	0.980	
SC2005-4	5.76815	18.16377	0	5.74365	0				5.935	1.250	0.846
	7.09408	21.36932	0	6.72525	0				7.038	1.240	
SC2005-5	6.01691	8.87164	3.92568	0	6.75585	0			4.262	0.859	0.870
	7.52467	11.01364	4.97556	0	8.76345	0			5.380	0.855	
SC2005-6	5.55319	6.18964	6.64017	4.62904	6.27213	4.91524			5.700	0.141	0.756
	5.75765	6.36886	7.27015	4.73744	6.46804	5.20181			5.967	0.155	
SC2008-1	14.74444	23.61123	34.94362	9.45938	4.40948				17.434	0.694	0.932
	26.72091	43.077	61.61151	16.18006	7.7019				31.058	0.695	
SC2008-2	14.83423	13.65604	5.91768	2.26072	1.98458				7.731	0.797	0.885
	22.5226	20.48331	7.90685	3.72814	2.56615				11.441	0.824	
SC2008-3	0.94432	0.13917	1.26496	1.03247					0.845	0.579	0.711
	1.22719	0.13949	1.91408	1.1028					1.096	0.667	
SC2008-4	6.07713	4.69383	3.05753						4.609	0.328	0.893
	9.12357	7.28332	4.91975						7.109	0.296	
SC2008-5	8.28371	23.31151	0.50443						10.700	1.084	0.988
	15.30413	46.97563	1.00714						21.096	1.115	
SC2008-6	14.83423	13.65604	5.91768	2.26072					9.167	0.662	0.884
	22.5226	20.48331	7.90685	3.72814					13.660	0.677	
									mean		0.862

Table A31. Basecase KLAMZ model estimates for the entire surfclam stock. CVs were estimated using the delta method).

Year	Biomass (1000 mt)	CV	Recruitment (1000 mt)	CV	Fishing mortality ( $y^{-1}$ )	CV
1981	831	0.10	NA	NA	0.0263	0.10
1982	862	0.08	103	0.15	0.0278	0.08
1983	889	0.08	101	0.15	0.0273	0.08
1984	916	0.08	104	0.15	0.0316	0.08
1985	935	0.08	102	0.15	0.0296	0.08
1986	954	0.09	104	0.14	0.0301	0.09
1987	973	0.10	106	0.14	0.0255	0.10
1988	988	0.11	102	0.14	0.0263	0.11
1989	1,003	0.11	105	0.14	0.0243	0.12
1990	1,021	0.12	109	0.14	0.0260	0.12
1991	1,029	0.13	104	0.14	0.0216	0.13
1992	1,045	0.13	109	0.14	0.0228	0.13
1993	1,059	0.13	112	0.14	0.0217	0.14
1994	1,070	0.14	109	0.14	0.0215	0.14
1995	1,082	0.14	112	0.13	0.0190	0.14
1996	1,088	0.14	107	0.13	0.0191	0.14
1997	1,090	0.14	105	0.13	0.0179	0.14
1998	1,092	0.14	106	0.13	0.0176	0.15
1999	1,086	0.15	98	0.13	0.0190	0.15
2000	1,074	0.15	95	0.13	0.0194	0.15
2001	1,059	0.15	94	0.13	0.0220	0.15
2002	1,037	0.15	89	0.13	0.0245	0.15
2003	1,012	0.15	87	0.13	0.0262	0.15
2004	984	0.15	84	0.13	0.0261	0.15
2005	955	0.15	82	0.13	0.0235	0.16
2006	931	0.15	82	0.13	0.0269	0.16
2007	905	0.16	81	0.13	0.0293	0.16
2008	878	0.16	80	0.13	0.0272	0.16
Min	831	0.08	80	0.13	0.0176	0.08
Median	1,007	0.14	103	0.13	0.0250	0.14
Mean	995	0.13	99	0.14	0.0243	0.13
Max	1,092	0.16	112	0.15	0.0316	0.16

Table A32. Changes in KLAMZ model data and configuration (“Steps”) responsible for differences between basecase biomass estimates and biomass estimates in the last assessment (NEFSC 2007).

Year	NEFSC (2007)	Updated model old data (step 1)	"Bad" tows and borrow from 2008 (steps 2&3)	New SLMWT (step 4)	New efficiency (step 5)	Logistic survey selectivity (step 6)	One new growth curve for all years (step 7)	Two new growth curves before/after 1994 (step 8)	Data through 2008 (step 9)	Smooth growth parameters (step 10)	Dome shaped survey selectivity (step 11)	Basecase (step 12)
1981	1,020	1,020	997	911	824	824	1,454	795	809	789	817	831
1982	1,036	1,036	1,013	928	840	840	1,479	808	852	837	844	862
1983	1,059	1,059	1,037	954	866	866	1,441	830	891	881	867	889
1984	1,083	1,083	1,066	980	892	892	1,402	852	929	925	889	916
1985	1,141	1,141	1,122	1,034	946	946	1,391	902	965	965	908	935
1986	1,225	1,225	1,208	1,116	1,026	1,026	1,408	977	1,003	1,006	930	954
1987	1,271	1,271	1,251	1,157	1,070	1,070	1,384	1,007	1,038	1,044	949	973
1988	1,290	1,290	1,268	1,175	1,089	1,089	1,340	1,014	1,075	1,082	972	988
1989	1,289	1,289	1,266	1,173	1,089	1,089	1,284	1,005	1,108	1,115	992	1,003
1990	1,285	1,285	1,260	1,168	1,086	1,086	1,232	992	1,146	1,152	1,016	1,021
1991	1,283	1,283	1,254	1,162	1,083	1,083	1,186	980	1,185	1,188	1,041	1,029
1992	1,290	1,290	1,261	1,169	1,089	1,089	1,159	985	1,232	1,229	1,071	1,045
1993	1,476	1,476	1,466	1,365	1,266	1,266	1,317	1,183	1,286	1,277	1,106	1,059
1994	1,613	1,613	1,620	1,506	1,396	1,396	1,429	1,309	1,346	1,331	1,145	1,070
1995	1,709	1,709	1,716	1,595	1,472	1,472	1,487	1,392	1,392	1,373	1,177	1,082
1996	1,780	1,780	1,784	1,659	1,525	1,525	1,526	1,450	1,427	1,407	1,203	1,088
1997	1,842	1,842	1,853	1,721	1,581	1,581	1,574	1,505	1,448	1,430	1,220	1,090
1998	1,824	1,824	1,833	1,703	1,564	1,564	1,541	1,483	1,449	1,432	1,224	1,092
1999	1,799	1,799	1,809	1,682	1,544	1,544	1,510	1,460	1,434	1,420	1,215	1,086
2000	1,723	1,723	1,735	1,613	1,479	1,479	1,434	1,393	1,402	1,390	1,193	1,074
2001	1,628	1,628	1,642	1,527	1,399	1,399	1,345	1,311	1,358	1,349	1,162	1,059
2002	1,531	1,531	1,550	1,440	1,318	1,318	1,261	1,231	1,304	1,297	1,121	1,037
2003	1,415	1,415	1,445	1,343	1,227	1,227	1,168	1,141	1,244	1,239	1,074	1,012
2004	1,292	1,292	1,342	1,246	1,136	1,136	1,080	1,051	1,181	1,177	1,024	984
2005	1,170	1,170	1,243	1,156	1,054	1,054	995	972	1,119	1,115	973	955
2006									1,063	1,059	927	931
2007									1,008	1,004	881	905
2008									956	951	837	878
Min	1,020	1,020	997	911	824	824	995	795	809	789	817	831
Average	1,403	1,403	1,402	1,299	1,194	1,195	1,353	1,121	1,166	1,159	1,028	995
Median	1,290	1,290	1,268	1,175	1,089	1,089	1,391	1,014	1,163	1,164	1,020	1,007
Max	1,842	1,842	1,853	1,721	1,581	1,581	1,574	1,505	1,449	1,432	1,224	1,092

Table A33. Decision table analysis showing probabilities of a simulated surfclam stock with total biomass (120+ mm) at or lower than the target level ( $B_{Target}=B_{1999}/2$ ), at or lower than the threshold level ( $B_{Threshold}=B_{Target}/2$ ), and with fishing mortality rates at or higher than the threshold level ( $F_{Threshold}=M$ ) during 2015, assuming nine states of nature and four possible management approaches. States of nature considered are ranked in order of probability as least, less and most likely. The column “Pattern ID for catchability” is to help make comparisons at the same survey dredge catchability over the range of natural mortality rates. For example, the pattern with horizontal bars identifies scenarios with low survey catchability at all natural mortality levels.

States of nature			Management actions				Pattern ID for dredge catchability
Natural mortality	Survey dredge catchability	Probability for state of nature	FMP minimum	Industry estimate	FMP maximum	Fmsy proxy	
<i>Probability of stock biomass below <math>B_{MSY}</math> proxy target level in 2015</i>							
Low	Low	Least	0	0	0	0.612	
Low	Medium	Less	0	0	0	0.982	
Low	High	Least	0	0	0.004	1	
Medium	Low	Less	0	0	0	0.91	
Medium	Medium	Most	0	0	0.002	0.952	
Medium	High	Less	0.006	0.012	0.014	0.998	
High	Low	Least	0	0	0	0.618	
High	Medium	Less	0	0.002	0.002	0.924	
High	High	Least	0	0.002	0.018	0.984	
<i>Probability of stock biomass below <math>B_{Threshold}</math> level in 2015</i>							
Low	Low	Least	0	0	0	0	
Low	Medium	Less	0	0	0	0	
Low	High	Least	0	0	0	0.894	
Medium	Low	Less	0	0	0	0	
Medium	Medium	Most	0	0	0	0.002	
Medium	High	Less	0	0	0	0.268	
High	Low	Least	0	0	0	0	
High	Medium	Less	0	0	0	0	
High	High	Least	0	0	0	0.294	
<i>Probability of overfishing in 2015</i>							
Low	Low	Least	0	0	0	0.908	
Low	Medium	Less	0	0	0	1	
Low	High	Least	0	0	0	1	
Medium	Low	Less	0	0	0	0.312	
Medium	Medium	Most	0	0	0	0.948	
Medium	High	Less	0	0	0	1	
High	Low	Least	0	0	0	0.002	
High	Medium	Less	0	0	0	0.196	
High	High	Least	0	0	0	0.996	

## Figures

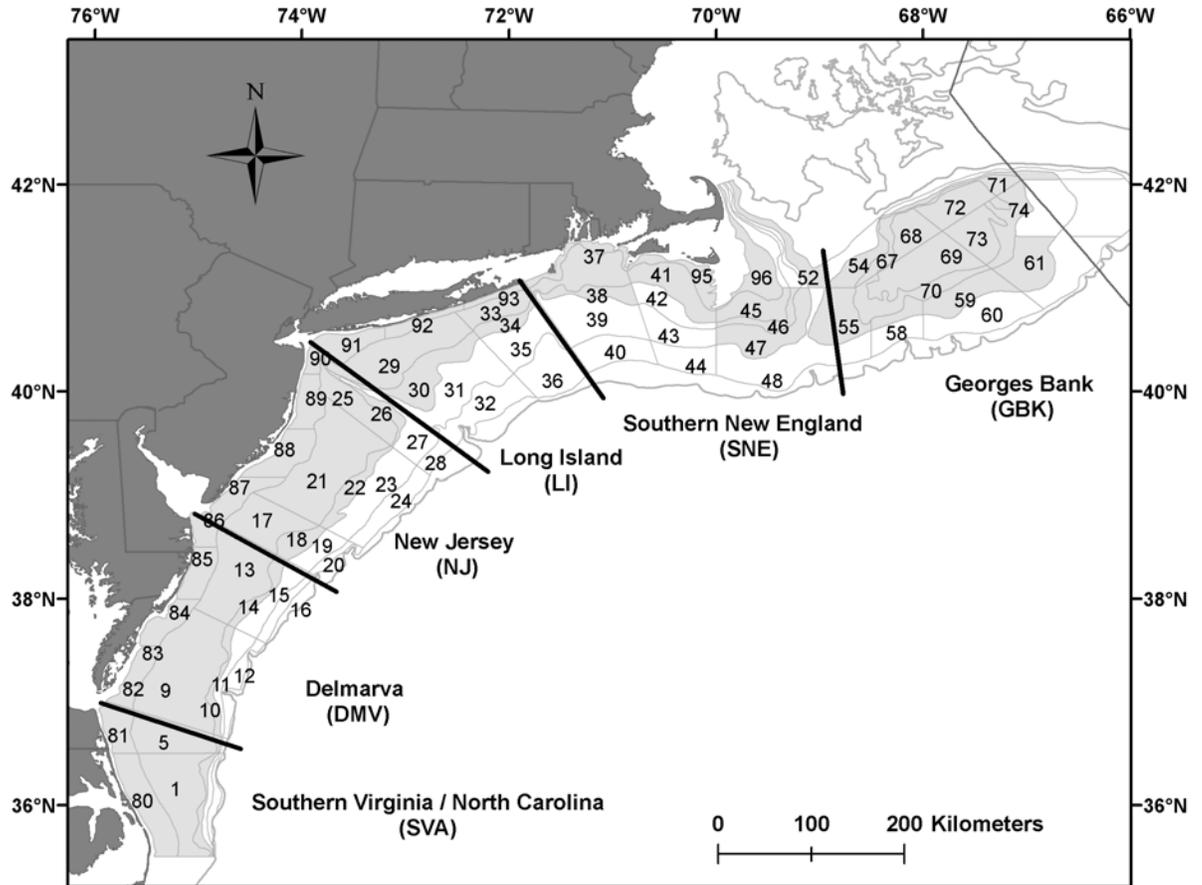


Figure A1. Surfclam stock assessment regions and NEFSC shellfish survey strata. The shaded strata are where surfclams are found.

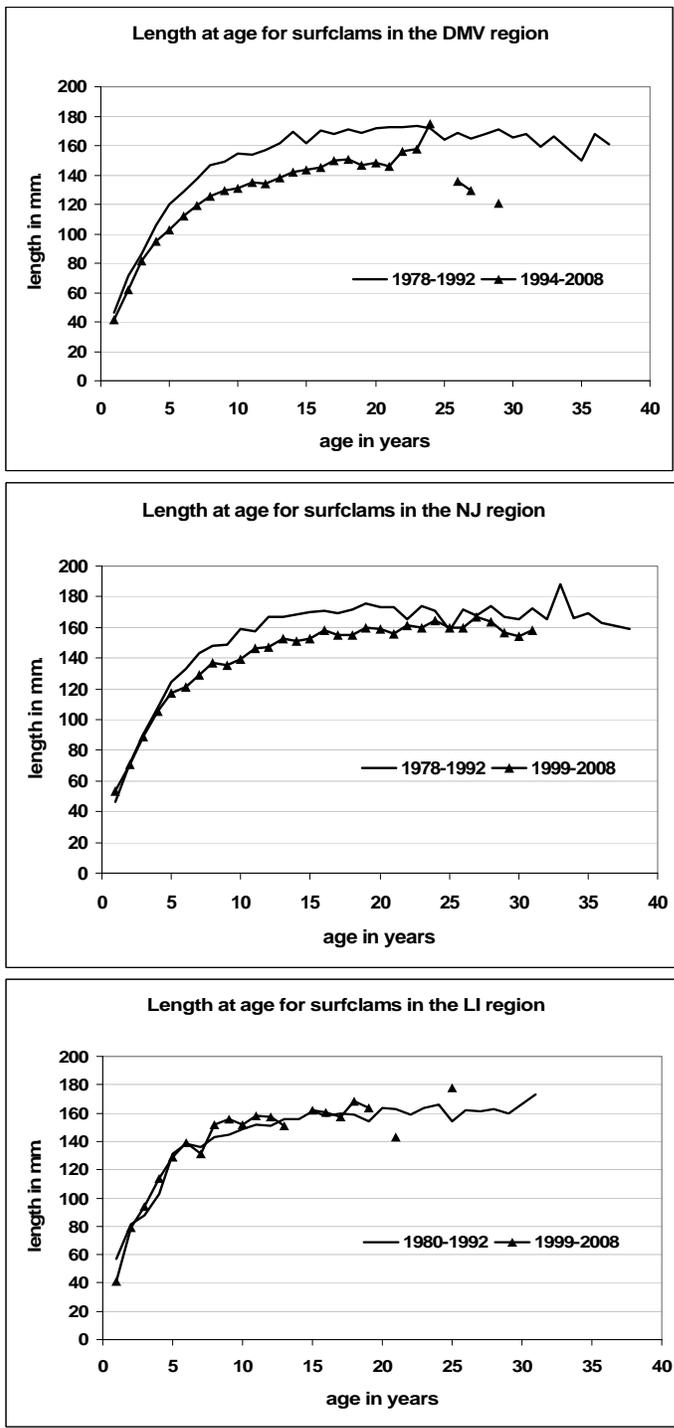


Figure A2. Length at age for surfclams in the DMV, NJ and LI regions, based on NEFSC clam survey data.

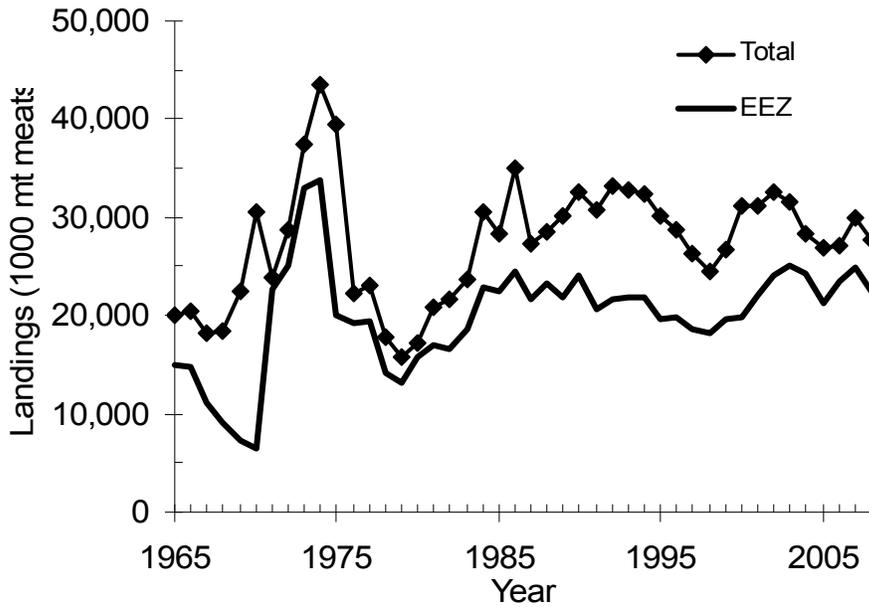


Figure A3. Surfclam landings (total and EEZ) during 1965-2008. Landings from fishing state waters (primarily NJ and NY) account for the difference between total and EEZ landings.

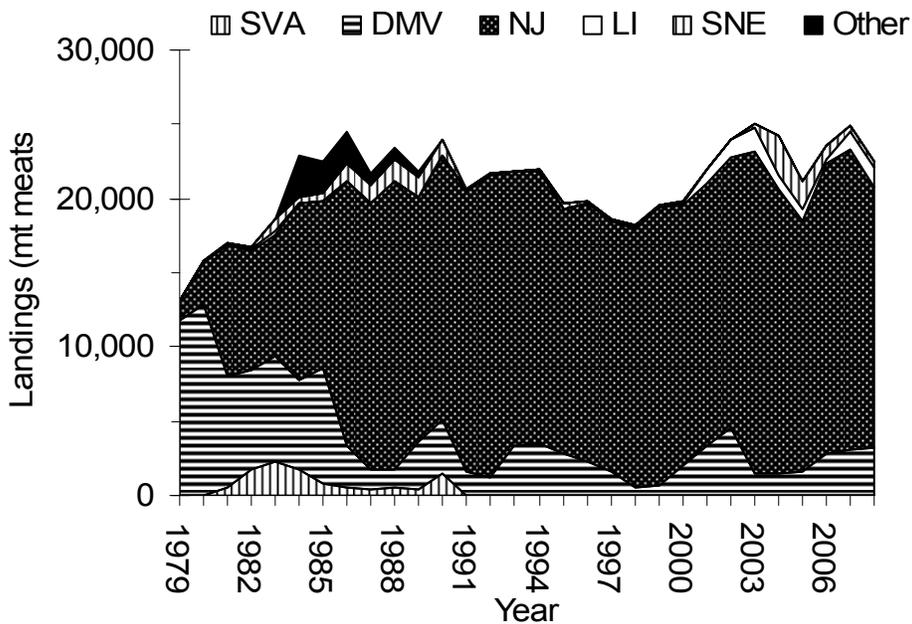


Figure A4. Surfclam landings from the US EEZ during 1979-2008, by stock assessment region.

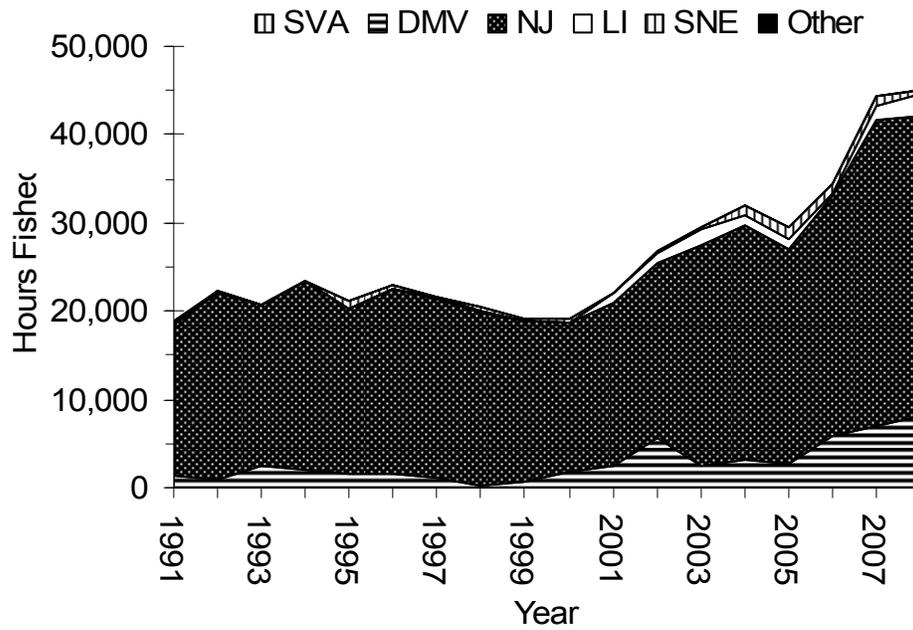


Figure A5. Total fishing effort (hours fished during all trips by all vessels) for surfclams during 1991-2008 in the US EEZ, by stock assessment region.

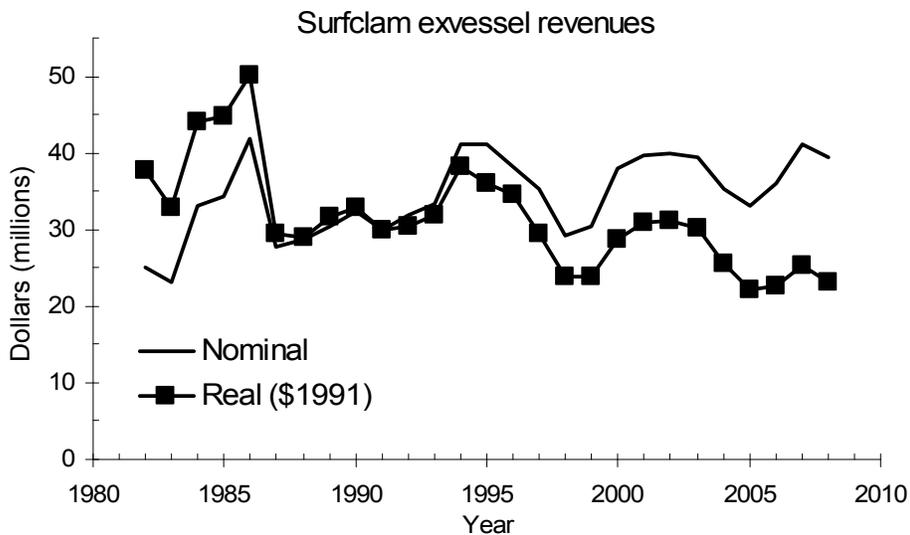
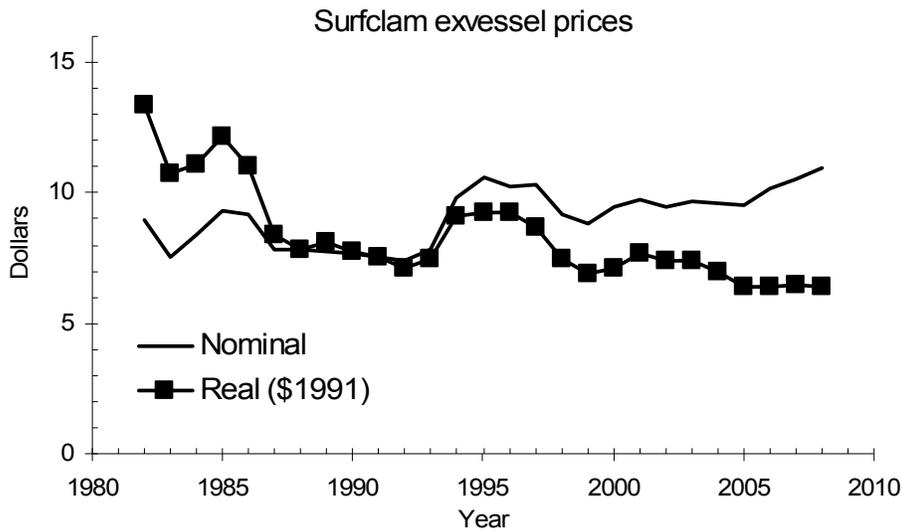


Figure A6. Real and nominal exvessel prices and revenues for surfclams based on dealer data. Average price was computed as total revenues (state waters and EEZ) divided by total landed meat weight during each year, rather than as annual averages of prices for individual trips, to reduce effects of small 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.)

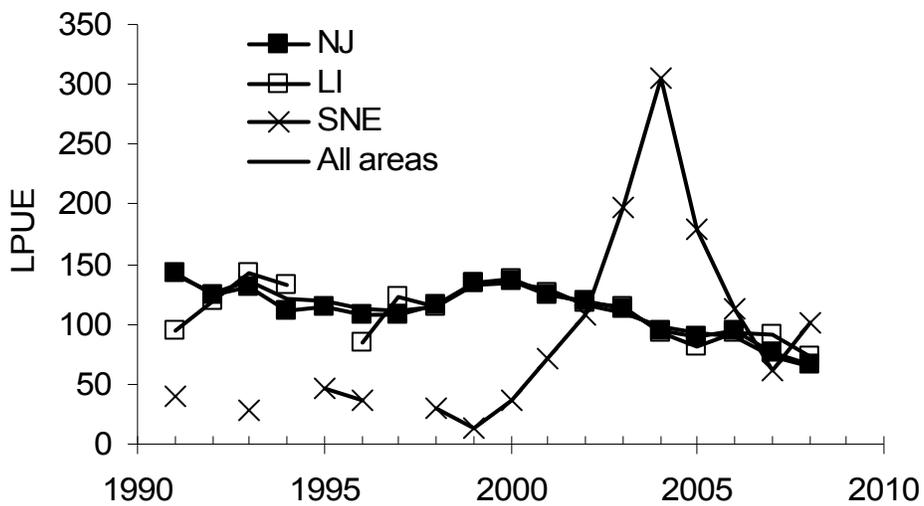
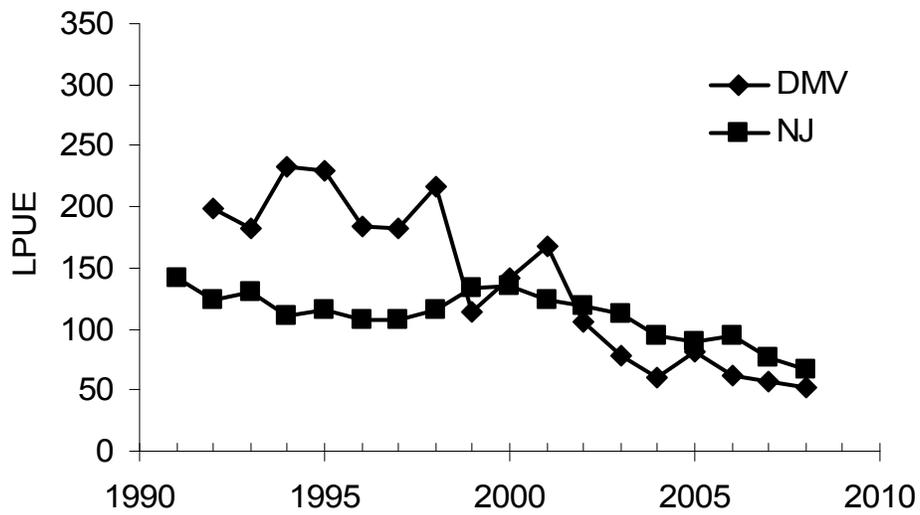


Figure A7. Nominal landings per unit effort (LPUE in bushels landed per hour fished) for surfclams, by region. NJ is shown in both panels to facilitate comparison of northern and southern regions. LPUE is total landings in bushels divided by total fishing effort.

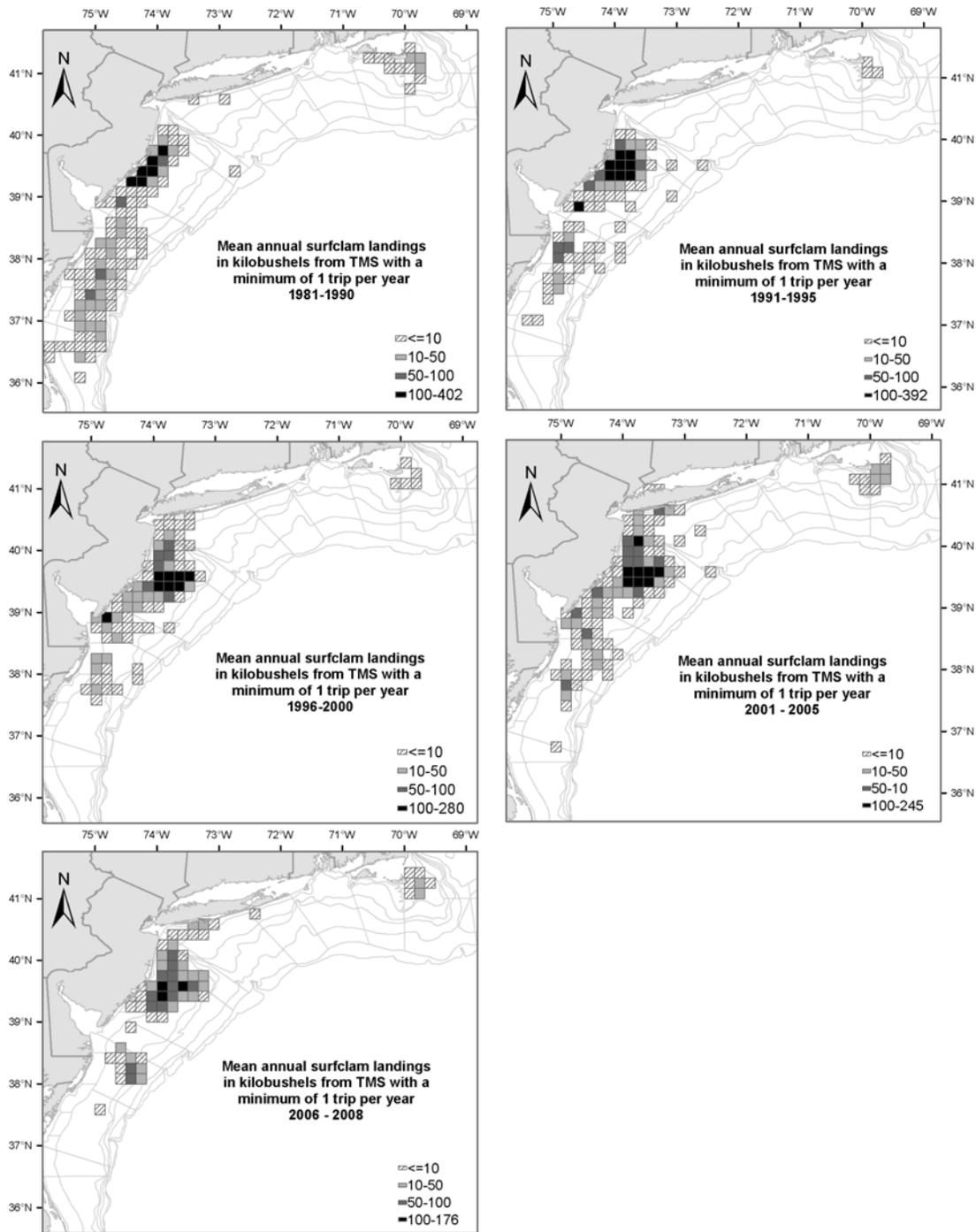


Figure A8. Spatial patterns in surfclam landings (1000 bu) in the US EEZ from logbooks. Spatial blocks are ten minute squares (TMS) shaded to reflect average landings per year.

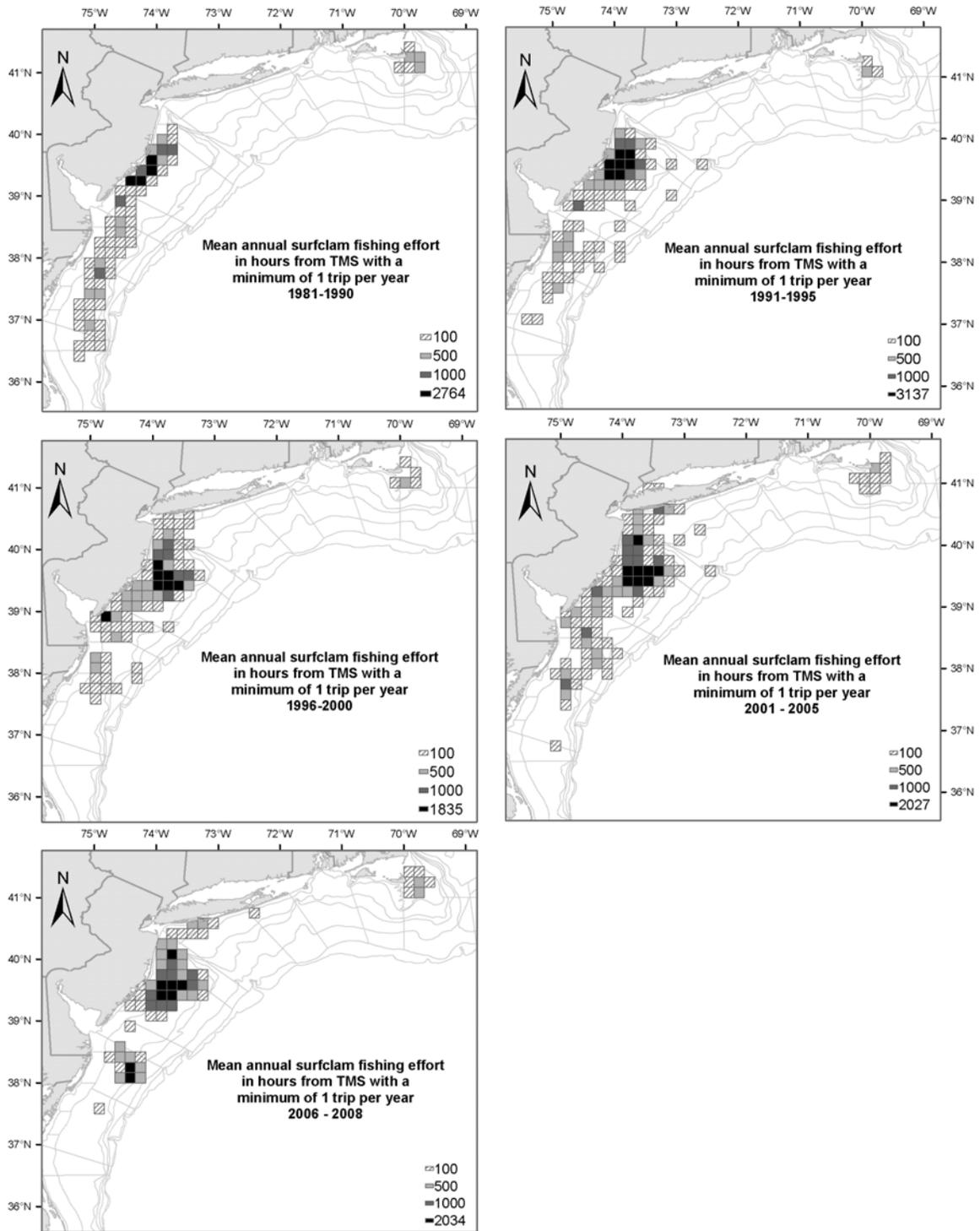


Figure A9. Spatial patterns in fishing effort (hours fished) in the US EEZ from logbooks. Spatial blocks are ten minute squares (TMS) shaded to reflect average fishing effort per year.

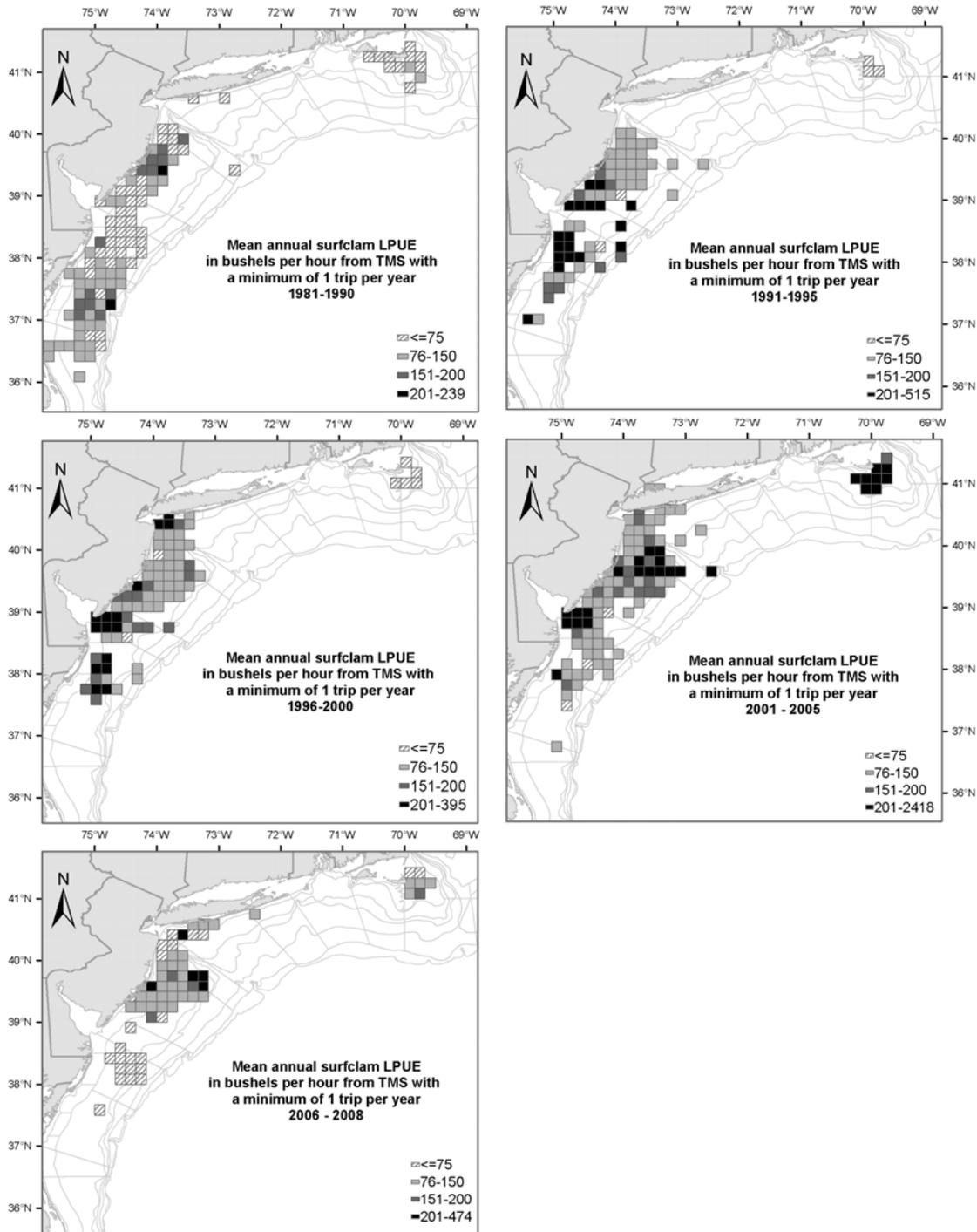


Figure A10. Spatial patterns in surfclam landings per unit fishing effort (LPUE, bushels landed per hour fished) in the US EEZ from logbooks. Spatial blocks are ten minute squares (TMS) shaded to reflect average LPUE per year.

# Surfclam Landings

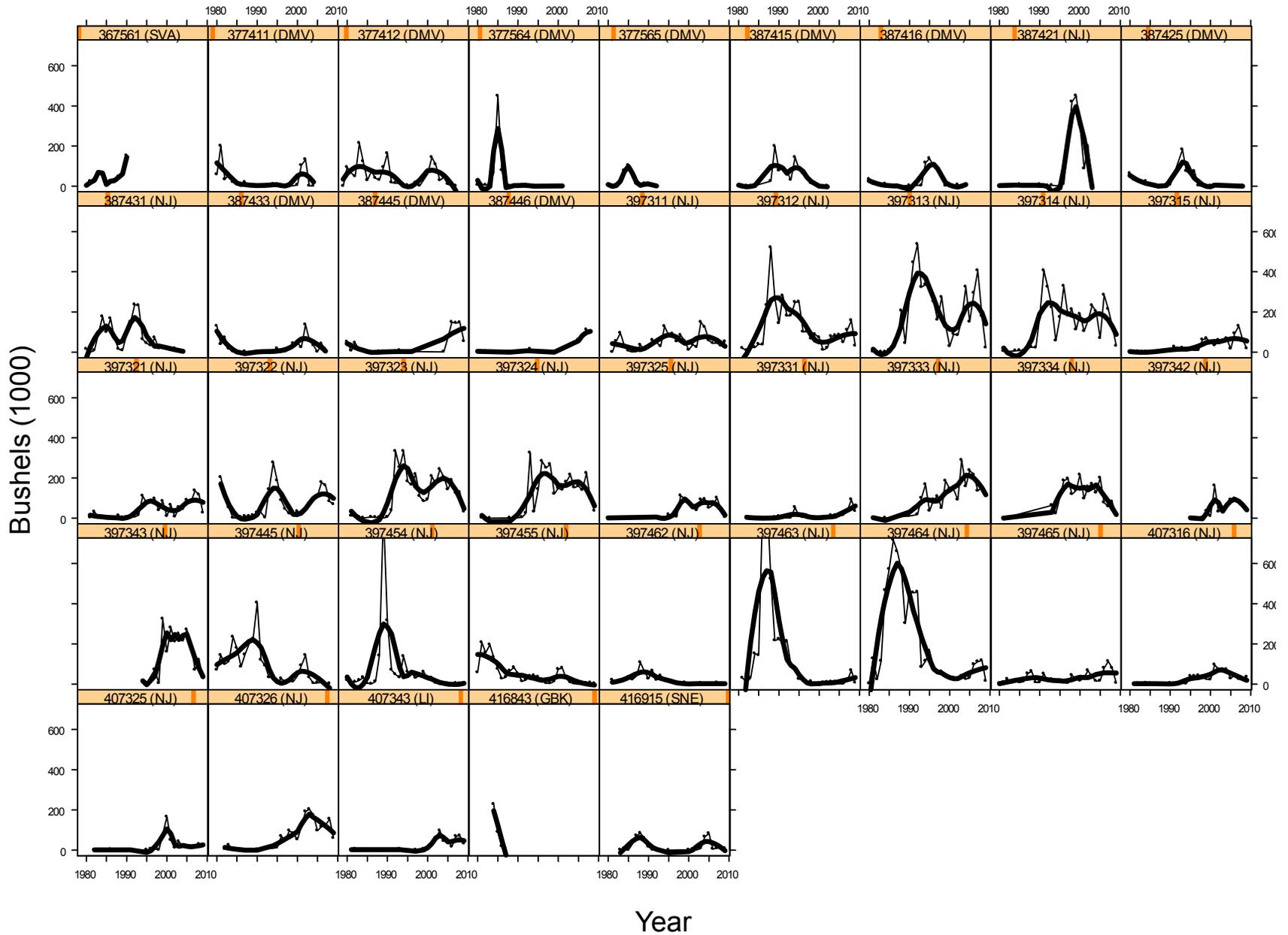


Figure A11. Annual surfclam landings (kilobushels per year) for important ten-minute squares during 1980-2008 based on logbook data. The smooth dark line is a spline intended to show trends.

# Surfclam Fishing Effort

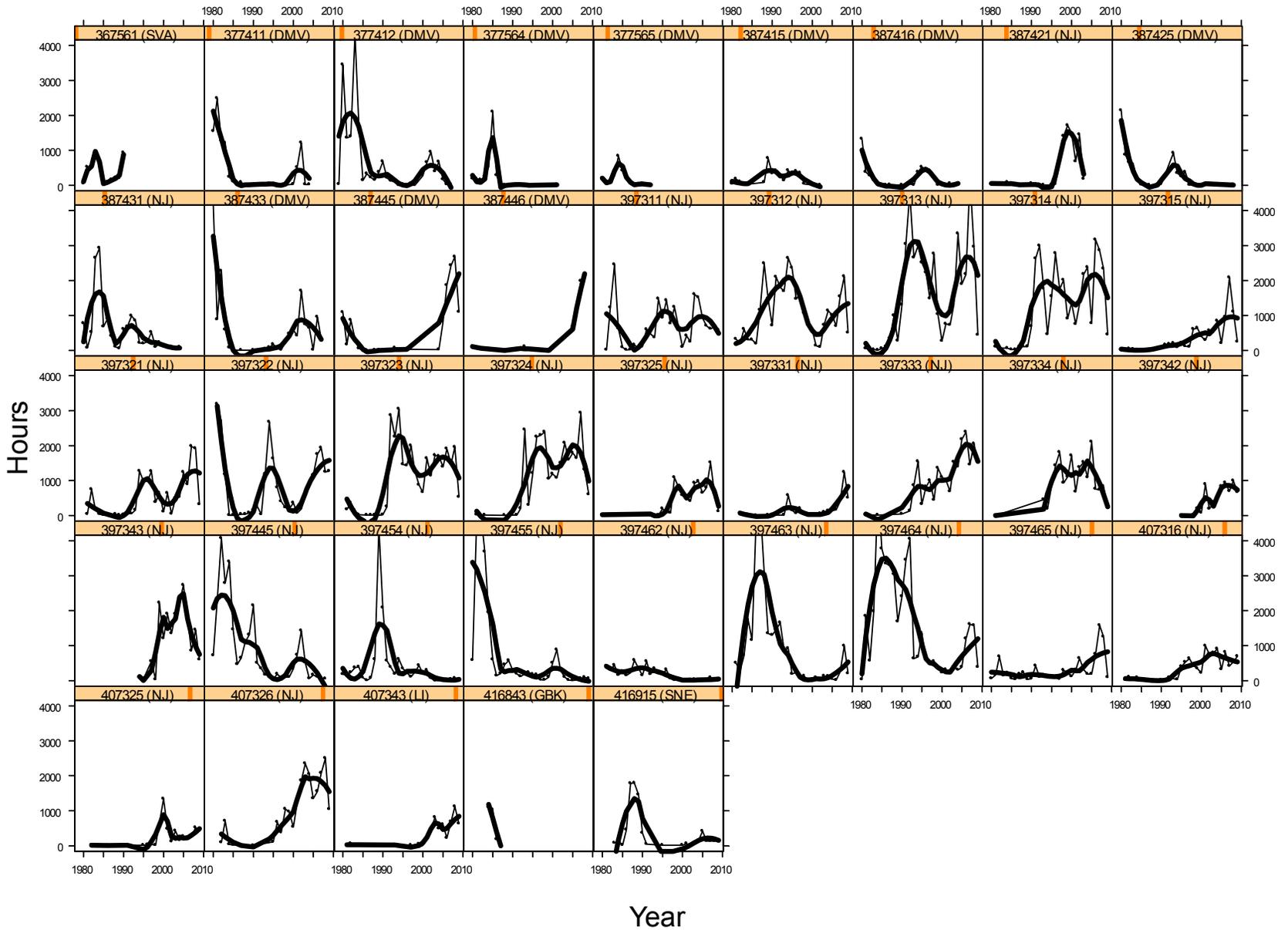


Figure A12. Annual surfclam fishing effort (hours per year) for important ten-minute squares during 1980-2008 based on logbook data. The smooth dark line is a spline intended to show trends.

## Surfclam LPUE

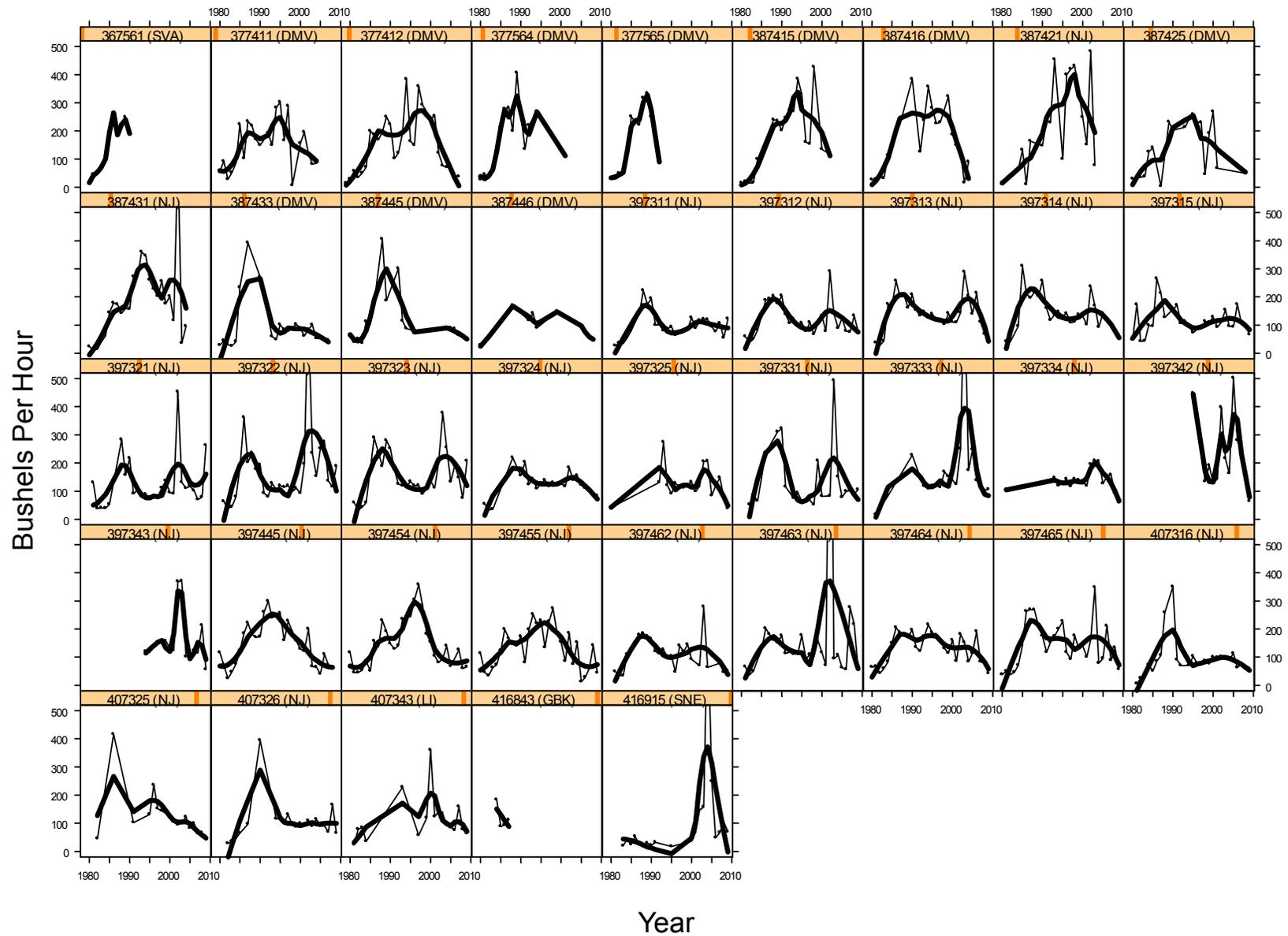


Figure A13. Annual surfclam LPUE (bushels per hour fished) for important ten-minute squares during 1980-2008 based on logbook data. The smooth dark line is a spline intended to show trends.

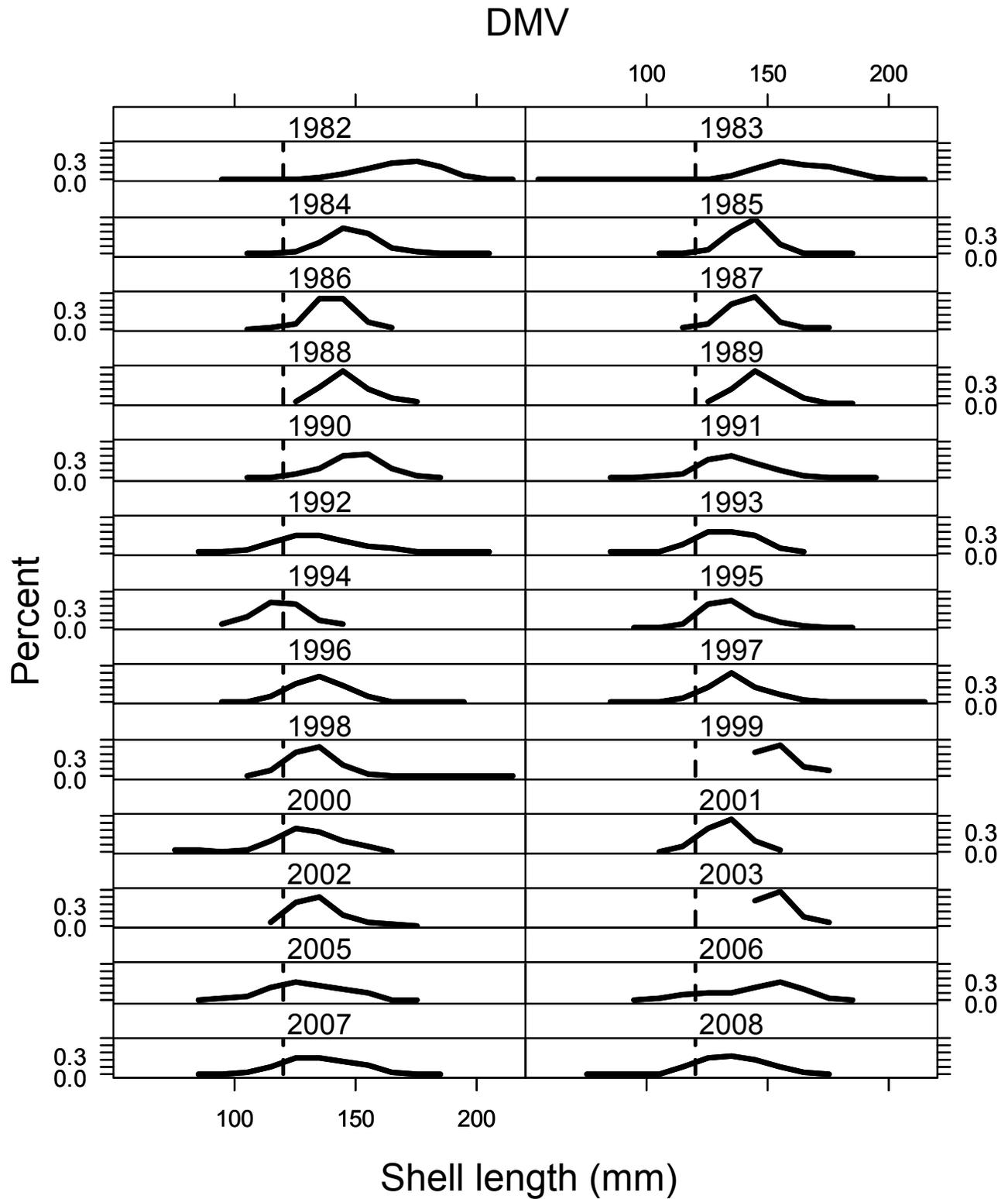


Figure A14. Port sample length composition data for surfclams from the DMV region.

# NJ

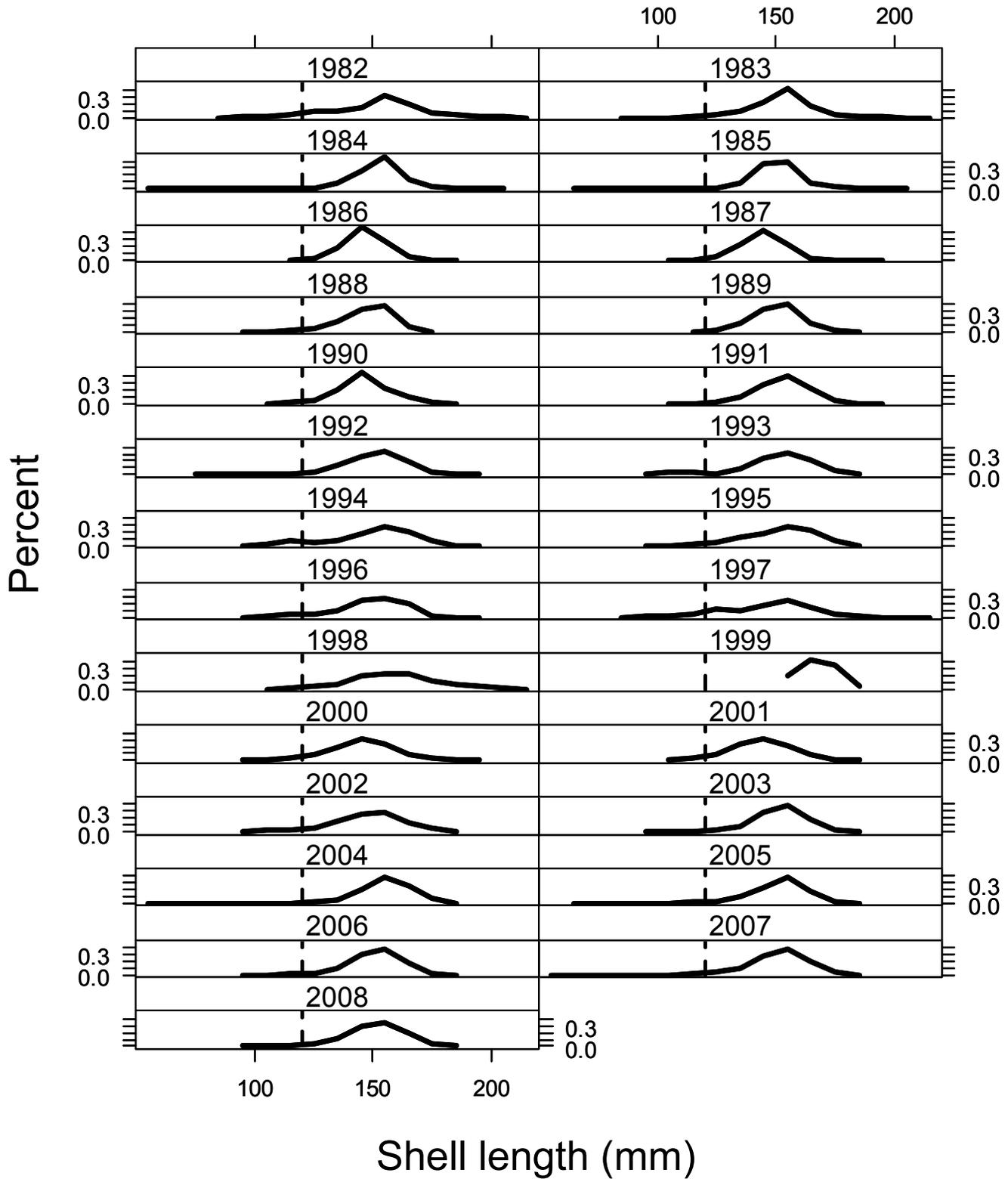


Figure A15. Length Port sample length composition data for surfclams from the NJ region.

# LI

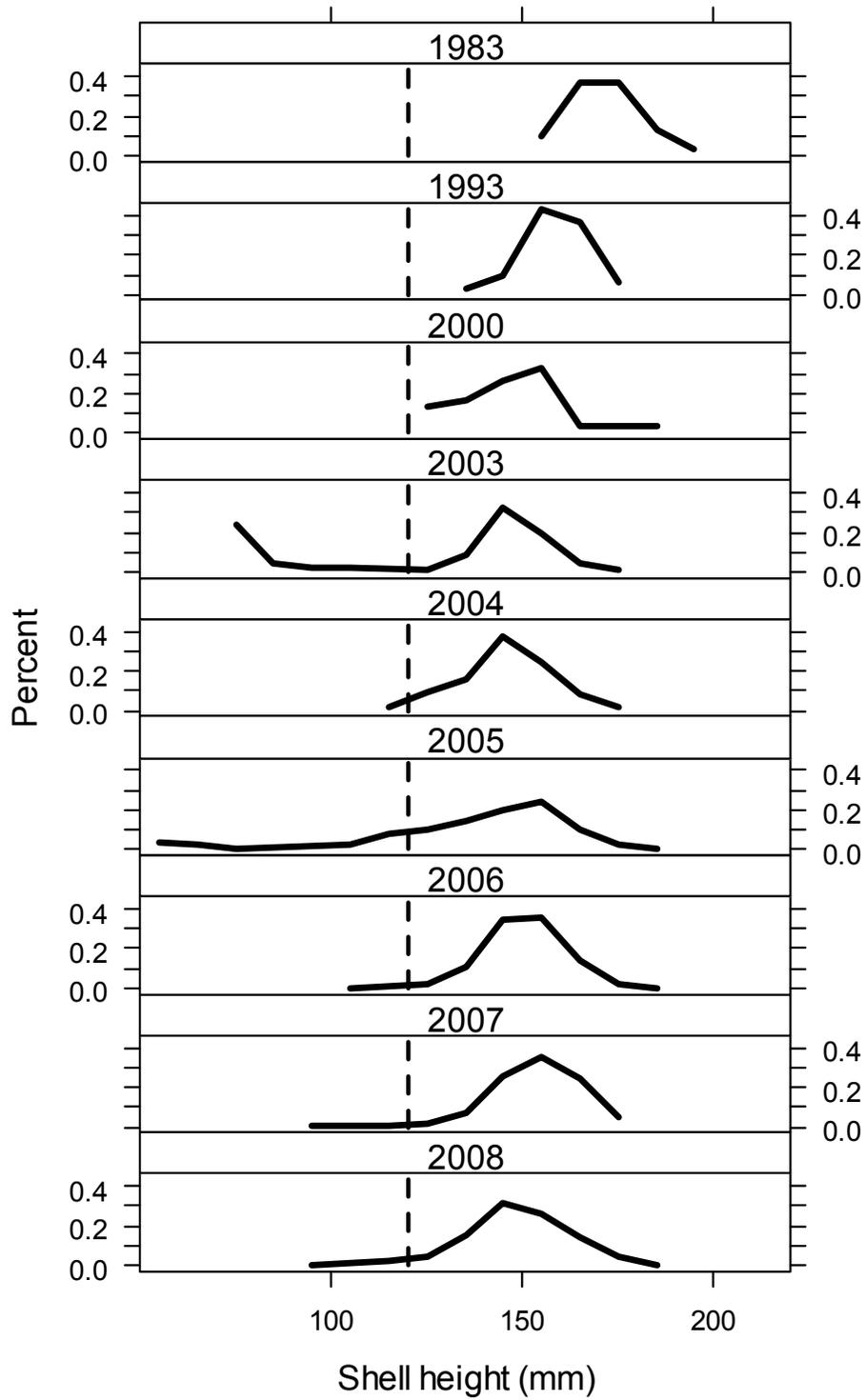


Figure A16. Port sample length composition data for surfclams from the LI region. Data from 1983 and 1993 may be because the number of trips sampled is unknown.

# SNE

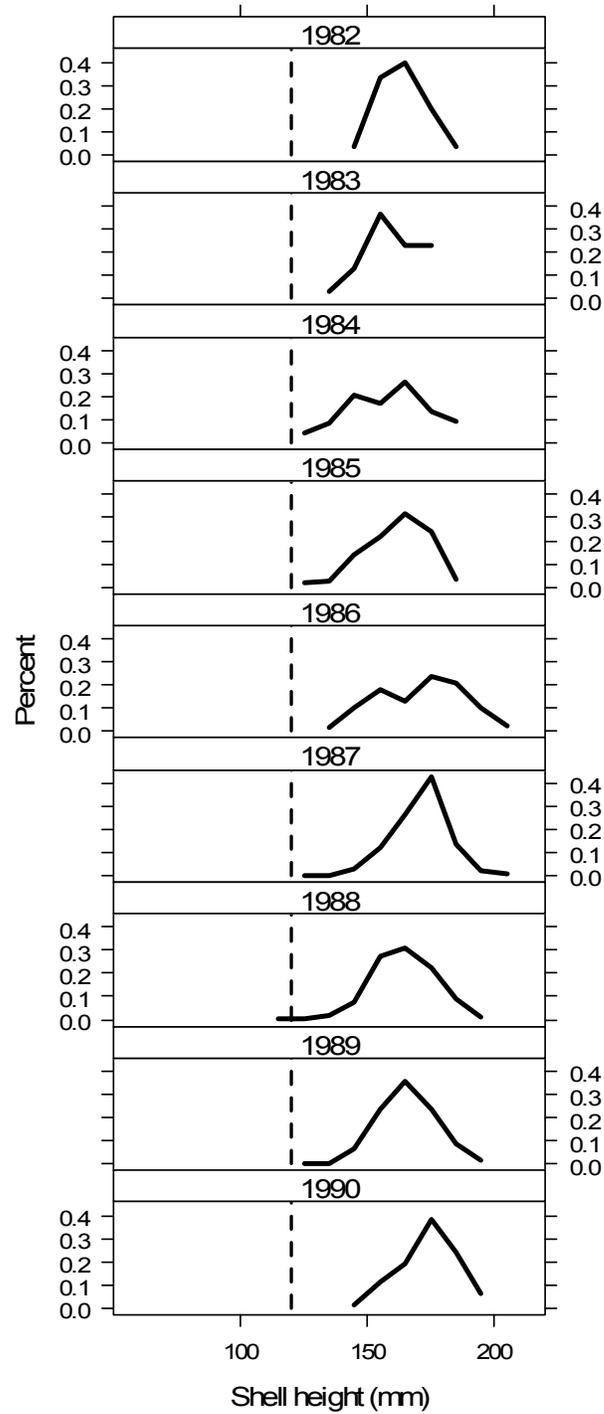


Figure A17. Port sample length composition data for surfclams from the SNE region.

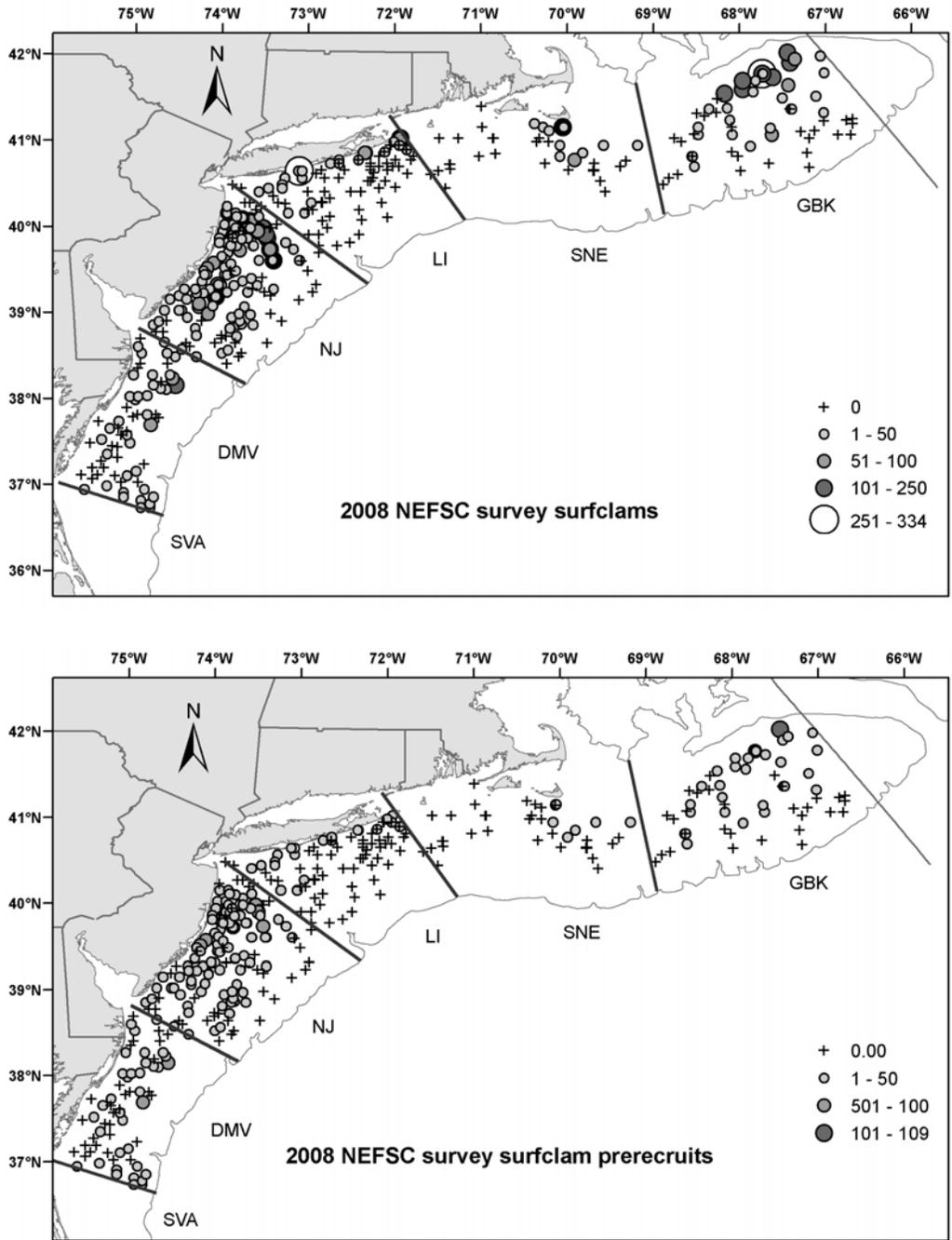
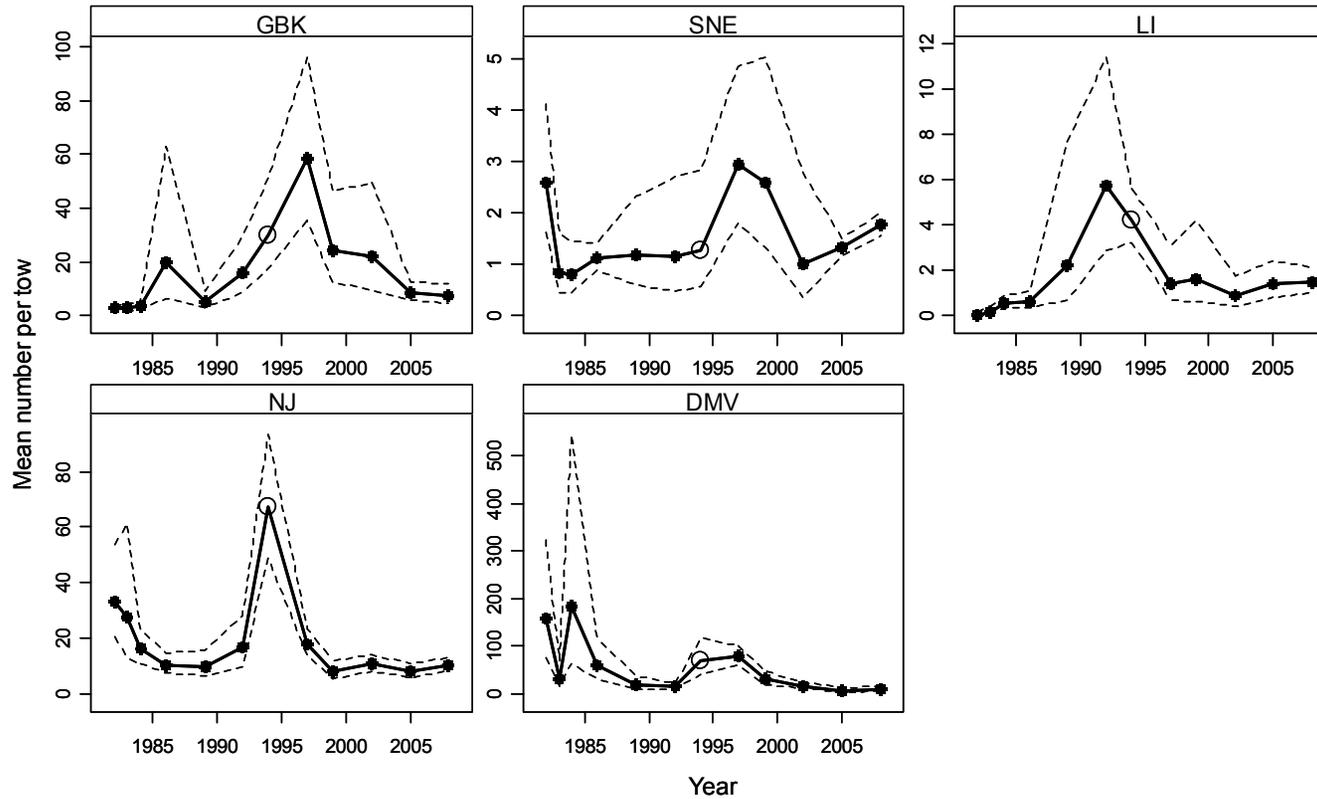


Figure A18. 2008 NEFSC survey catches per tow of all surfclams at top and surfclam prerecruits (less than 120mm SL) at bottom.

**NEFSC clam survey trends for small surfclams (50-119 mm SL), 1982-2008**



**Confidence intervals have 80% coverage**

Figure A19. Trends in mean number of small (50-119 mm SL) surfclams in the NEFSC clam survey during 1982-2008 by region with approximate 80% confidence intervals (data not adjusted for survey dredge selectivity). Data for 1994 (open circle) may not be comparable to other years because of a problem with pump voltage that increased capture efficiency in some regions. These data are shown without confidence intervals and excluding 1994 in the next figure.

**NEFSC clam survey trends for small surfclams (50-119 mm SL), 1982-2008**

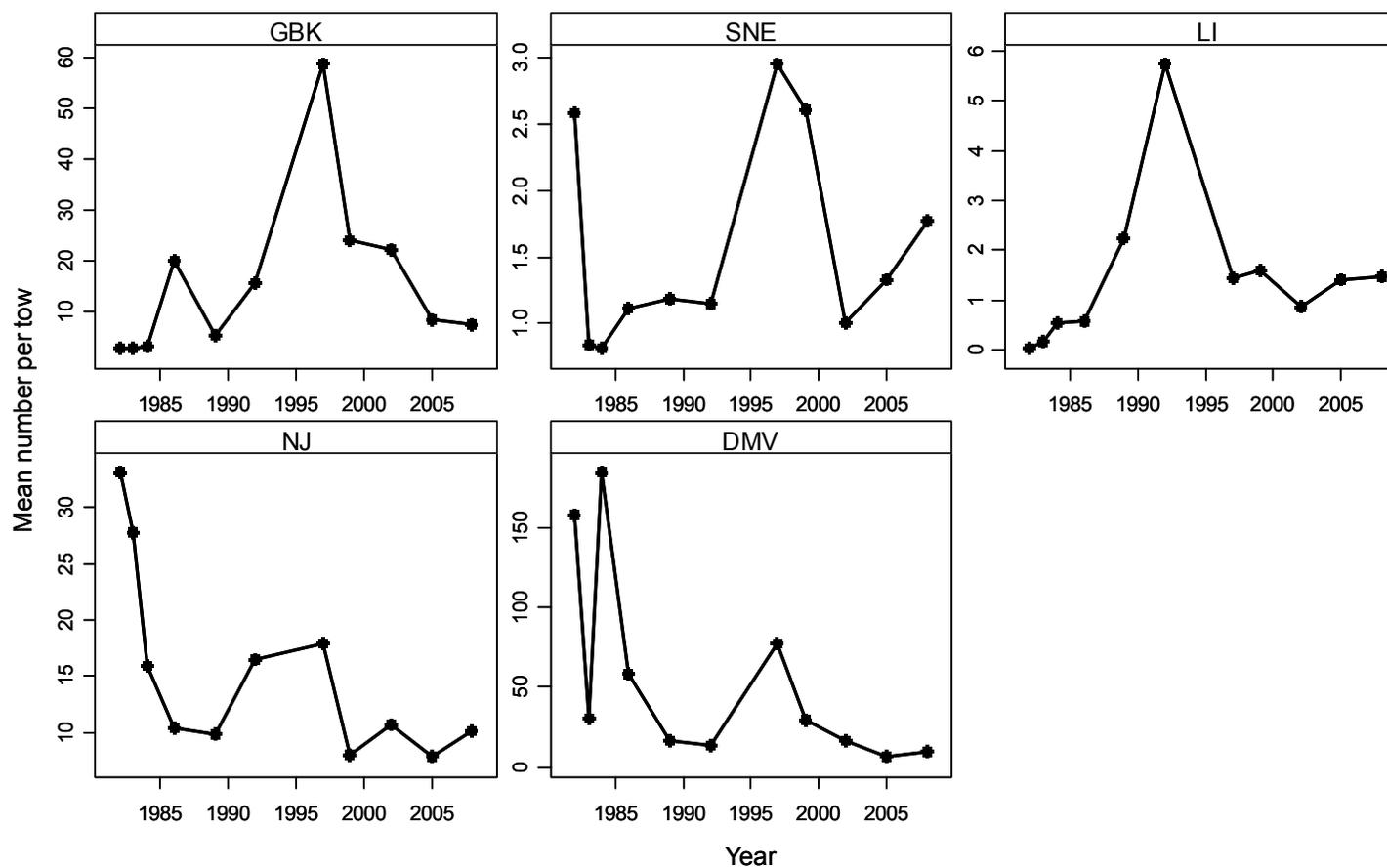


Figure A20. Trends in mean number of small (50-119 mm SL) surfclams in the NEFSC clam survey during 1982-2008 by region, excluding 1994 and without confidence intervals to facilitate comparison of trends in recruitment.

**NEFSC clam survey trends for large surfclams (120+ mm SL), 1982-2008**

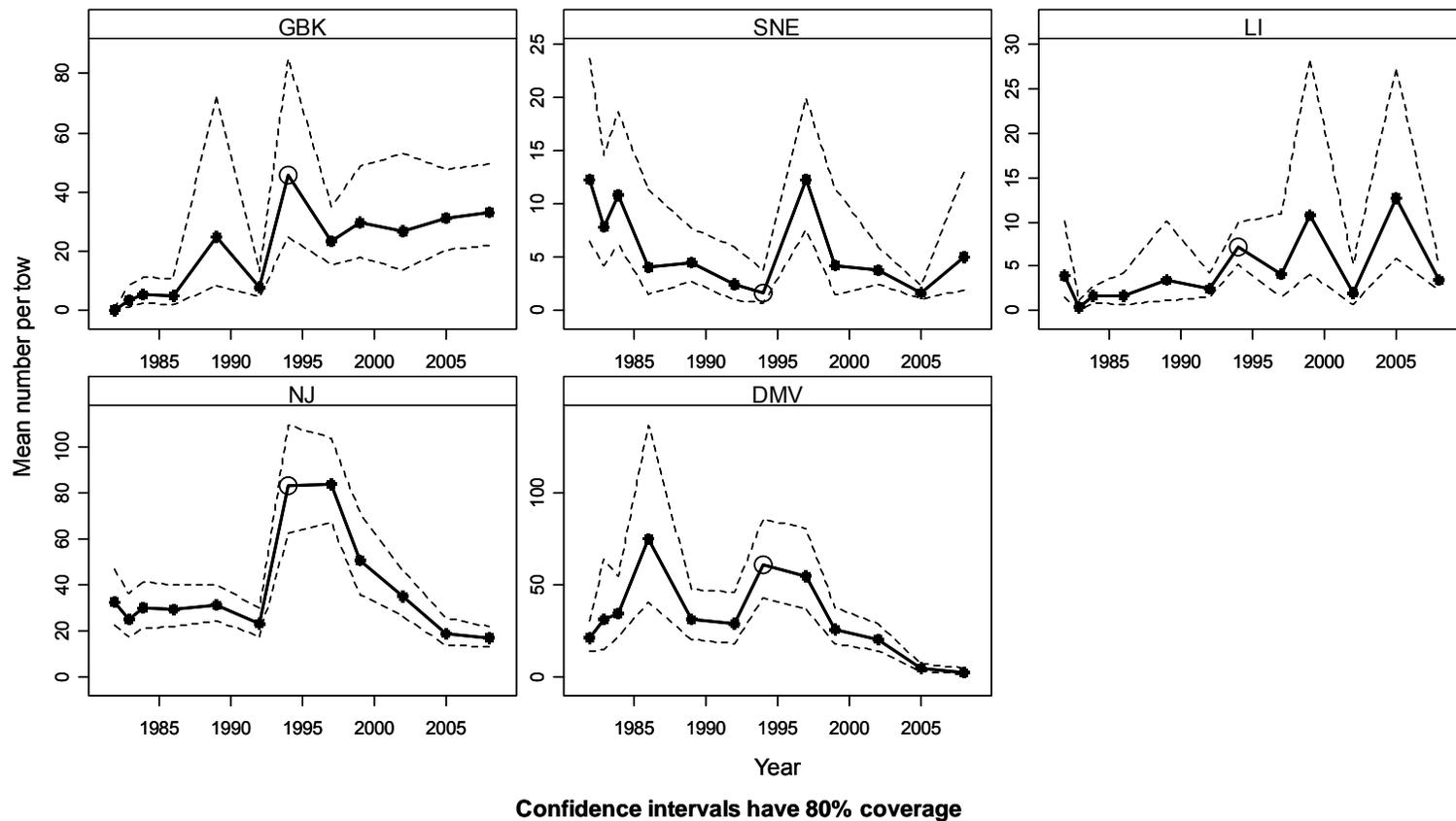


Figure A21. Trends in mean number of large (120+ mm SL) surfclams in the NEFSC clam survey during 1982-2008 by region, with approximate 80% confidence intervals (data not adjusted for survey dredge selectivity). Data for 1994 (open circle) may not be comparable to other years because of a problem with pump voltage that increased capture efficiency in some regions. These data are shown without confidence intervals and excluding 1994 in the next figure.

**NEFSC clam survey trends for large surfclams (120+ mm SL), 1982-2008**

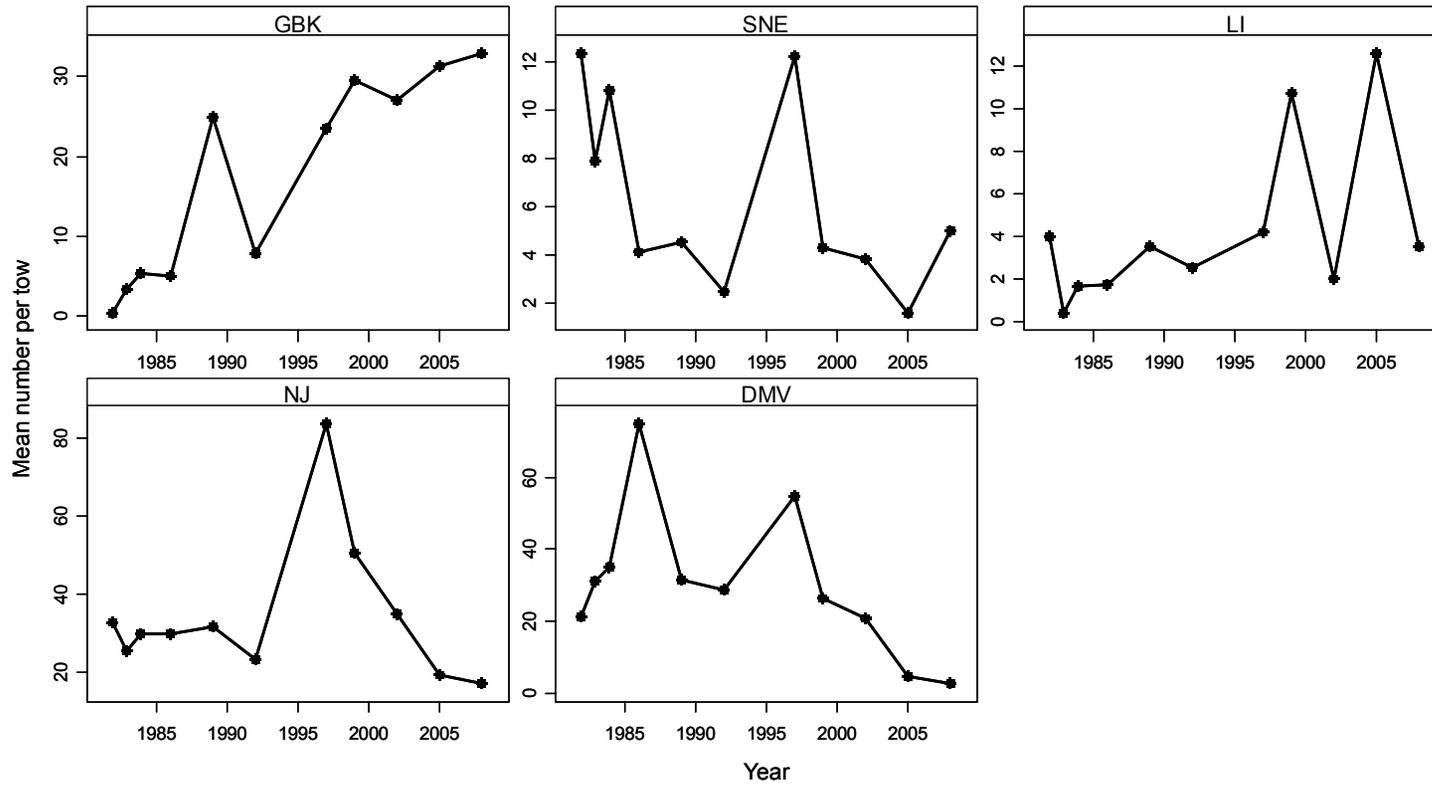


Figure A22. Trends in mean number of large (120+ mm SL) surfclams in the NEFSC clam survey during 1982-2008 by region, excluding 1994 and without confidence intervals to facilitate comparison of trends.

**NEFSC clam survey trends for small surfclams in DMV to GBK (50-119 mm SL), 1982-2008**

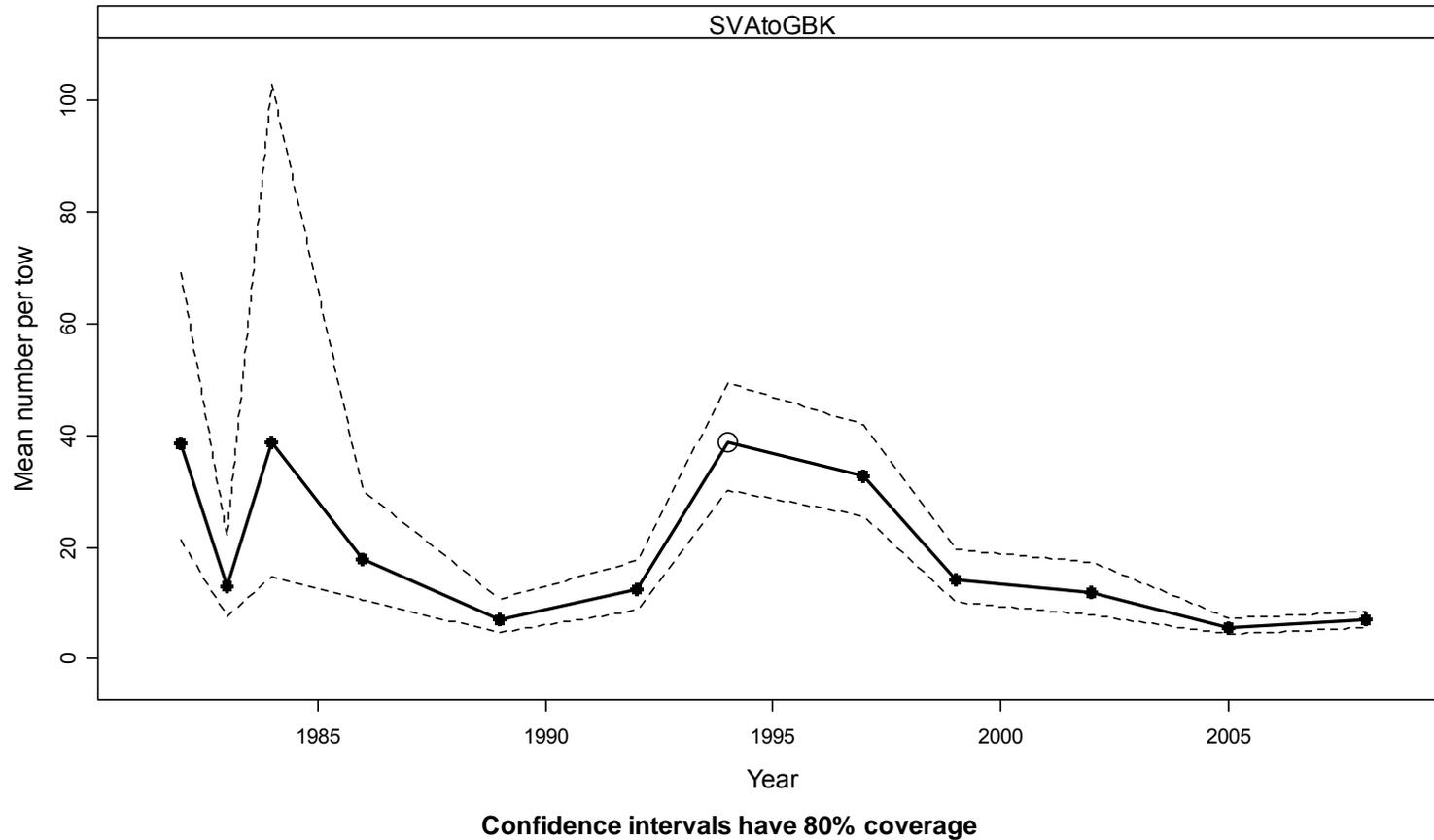


Figure A23. Trends in mean number of small (50-119 mm SL) surfclams in the NEFSC clam survey during 1982-2008 for the entire stock area with approximate 80% confidence intervals (data not adjusted for survey dredge selectivity). Data for 1994 (open circle) may not be comparable to other years because of a problem with pump voltage that increased capture efficiency in some regions.

**NEFSC clam survey trends for large surfclams in DMV to GBK (120+ mm SL), 1982-2008**

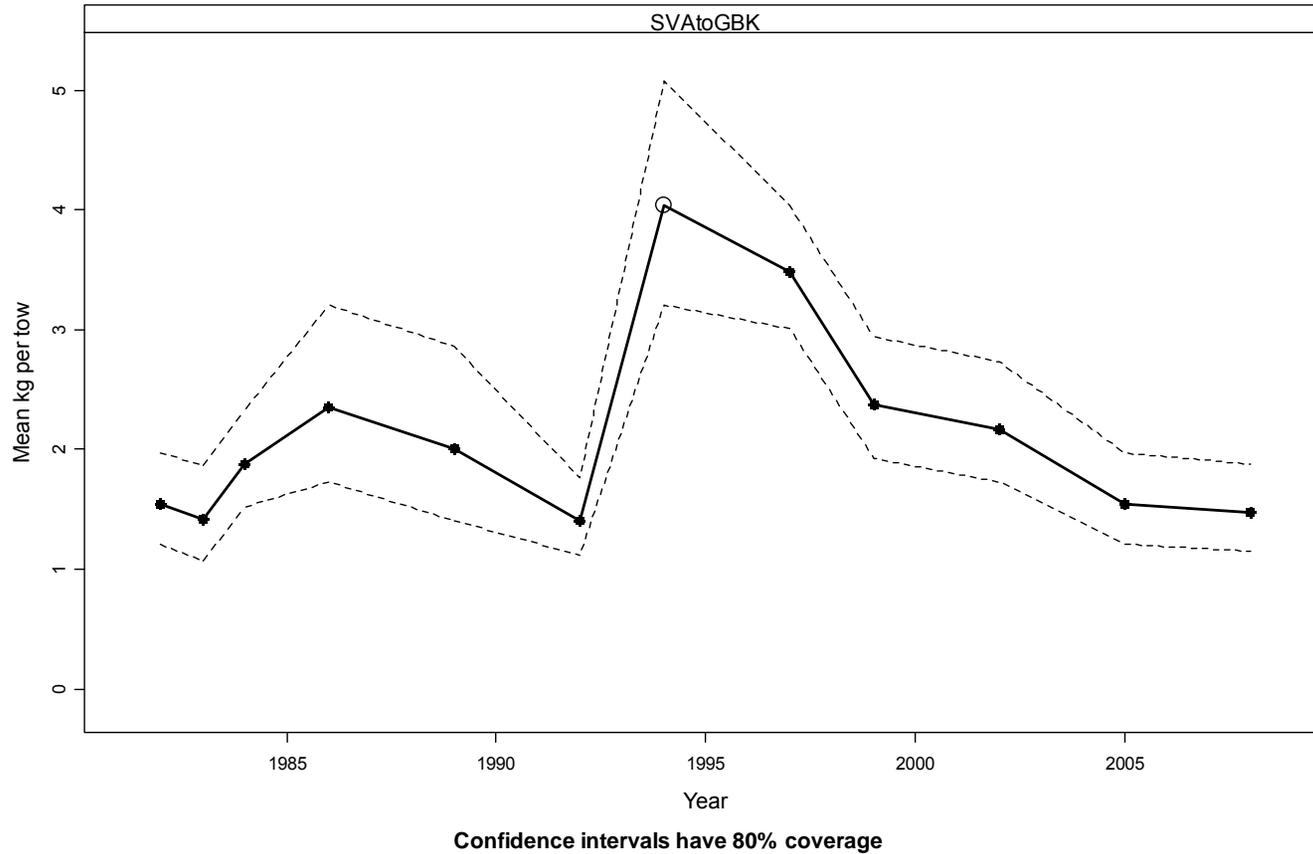


Figure A24. Trends in mean biomass of large (120+ mm SL) surfclams in the NEFSC clam survey during 1982-2008 for the entire stock area with approximate 80% confidence intervals (data not adjusted for survey dredge selectivity). Data for 1994 (open circle) may not be comparable to other years because of a problem with pump voltage that increased capture efficiency in some regions.

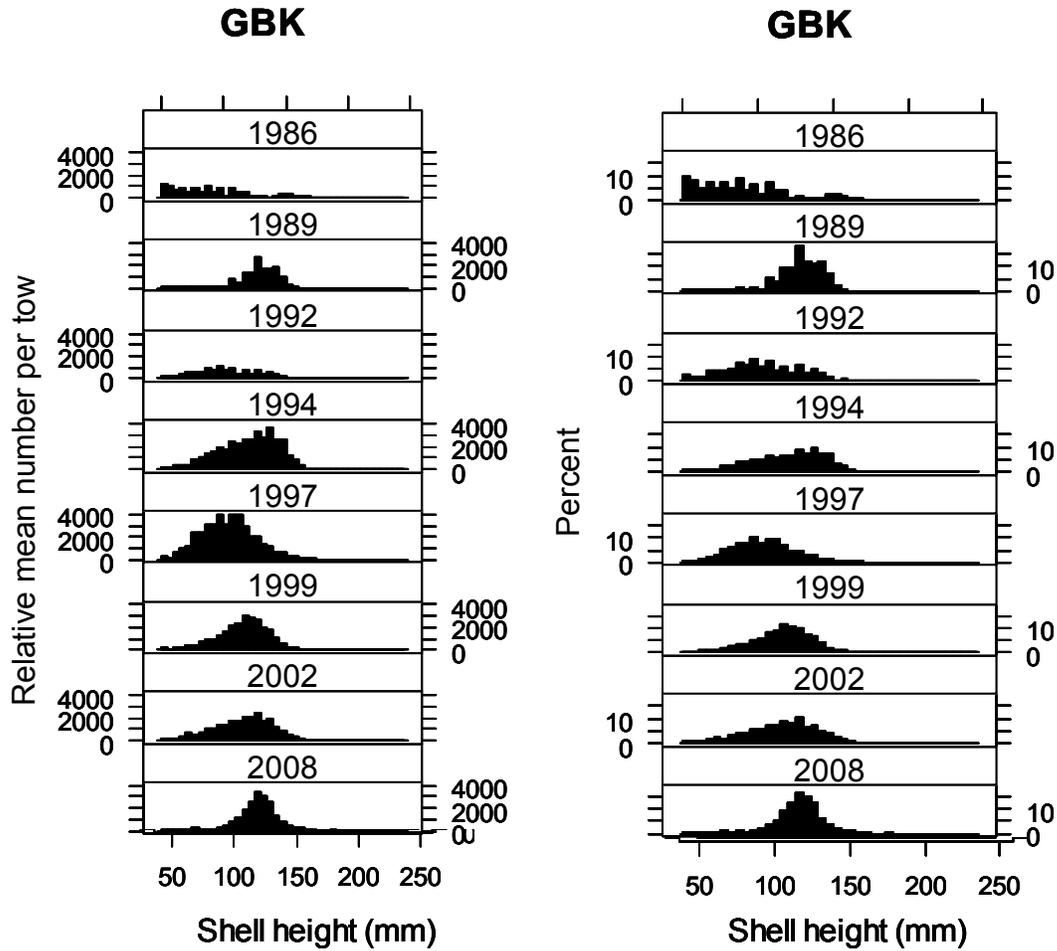


Figure A25. NEFSC survey length composition data for surfclams in the GBK region. The y-axes for graphs on the left are relative numbers per tow that can be compared between shell length bins and years. The y-axes for graphs on the right are standardized as percentages to clearly show relative frequencies in the same year.

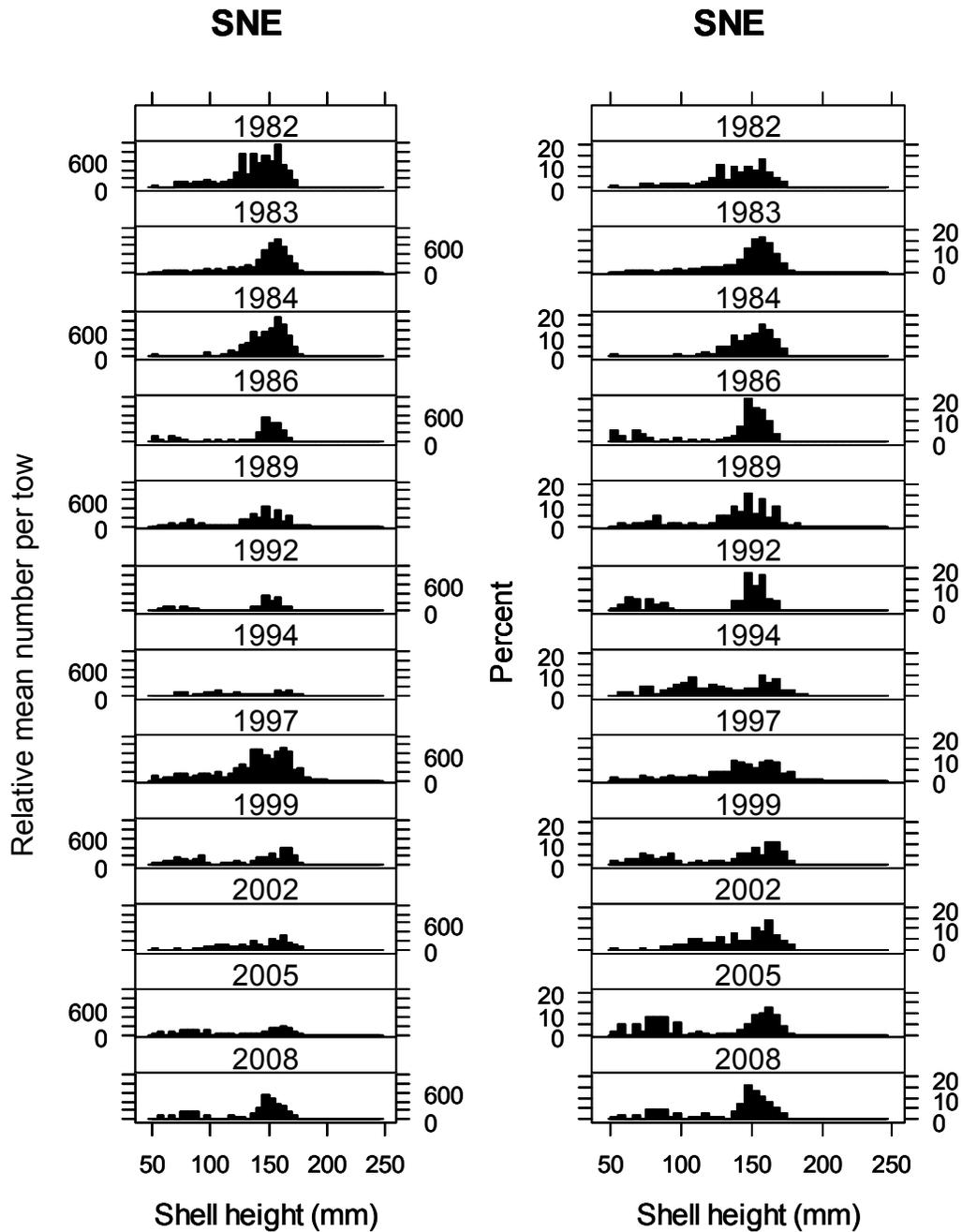


Figure A26. NEFSC survey length composition data for surfclams in the SNE region. The y-axes for graphs on the left are relative numbers per tow that can be compared between shell length bins and years. The y-axes for graphs on the right are standardized as percentages to clearly show relative frequencies in the same year.

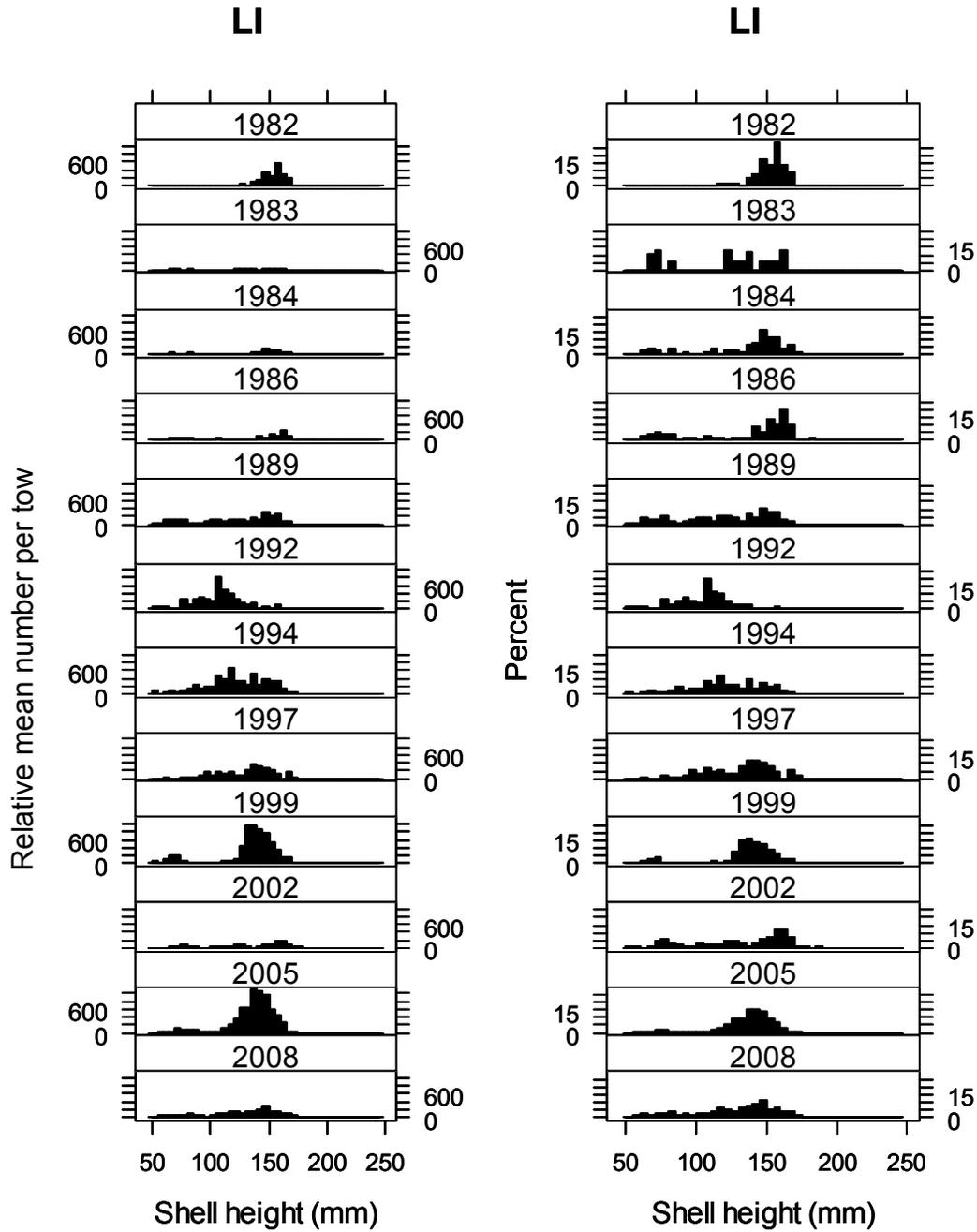


Figure A27. NEFSC survey length composition data for surfclams in the LI region. The y-axis for graphs on the left is relative numbers per tow that can be compared between shell length bins and years. The y-axes for graphs on the right are standardized as percentages to clearly show relative frequencies in the same year.

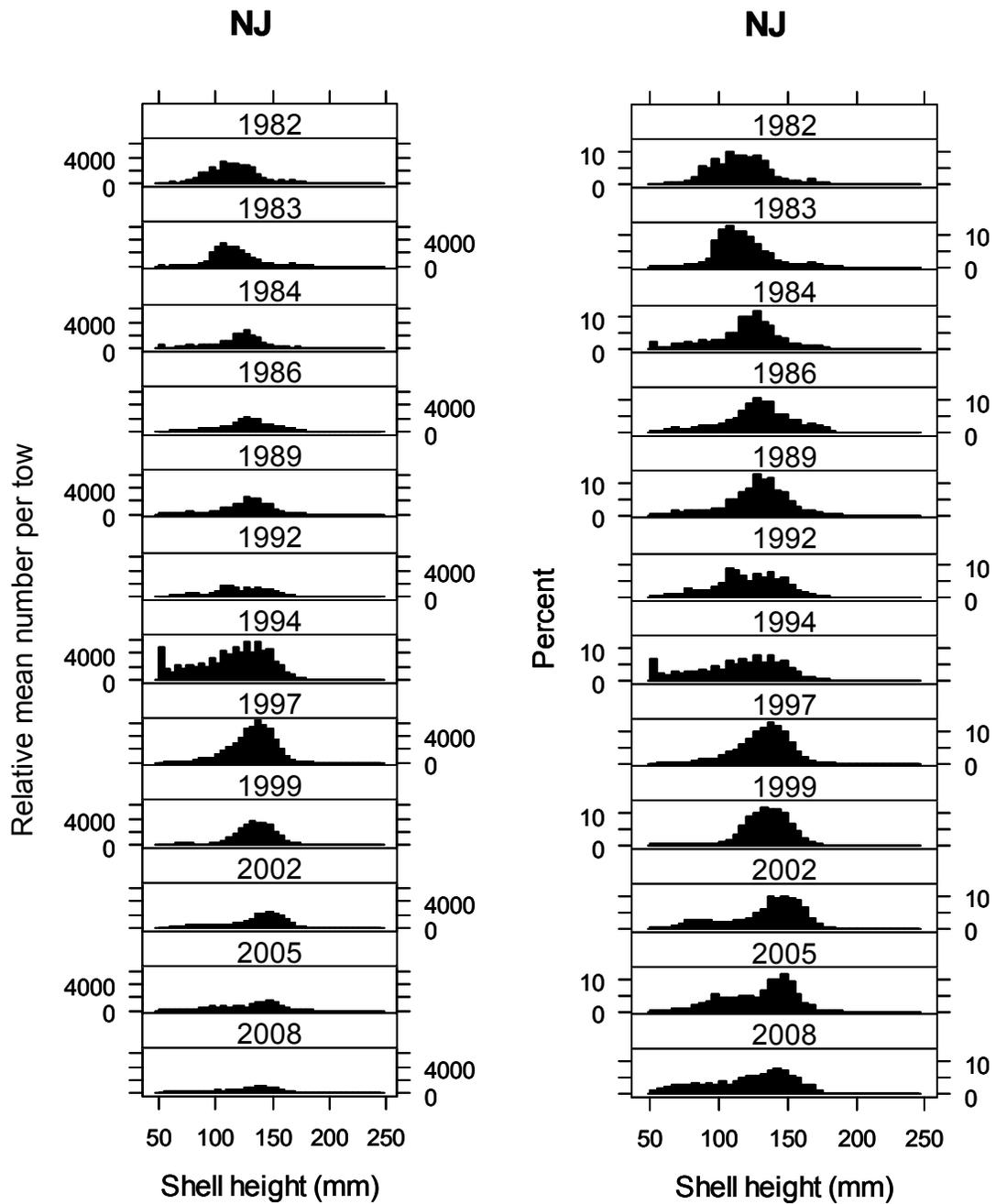


Figure A28. NEFSC survey length composition data for surfclams in the NJ region. The y-axes for graphs on the left are relative numbers per tow that can be compared between shell length bins and years. The y-axes for graphs on the right are standardized as percentages to clearly show relative frequencies in the same year.

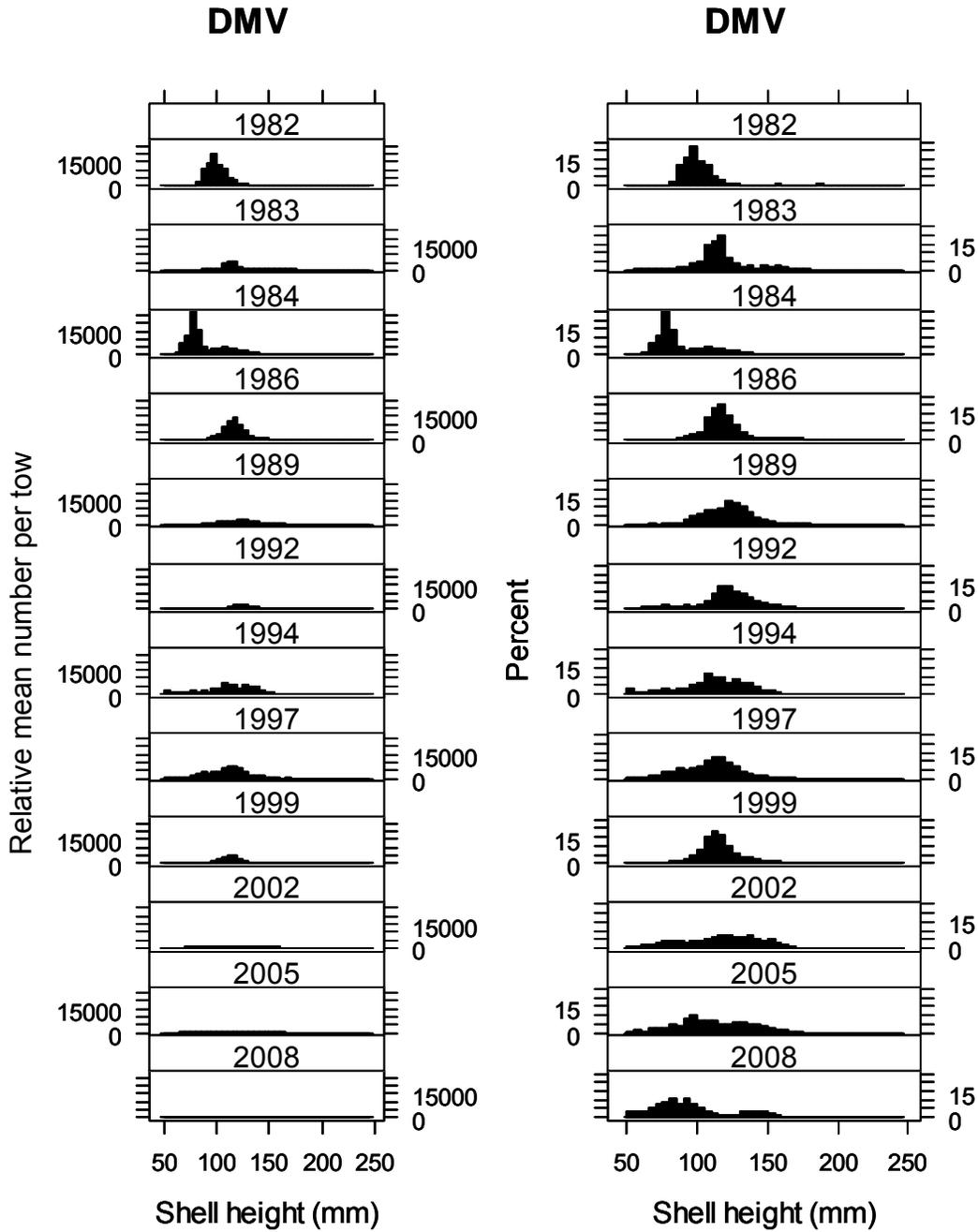


Figure A29. NEFSC survey length composition data for surfclams in the DMV region. The y-axes for graphs on the left are relative numbers per tow that can be compared between shell length bins and years. The y-axes for graphs on the right are standardized as percentages to clearly show relative frequencies in the same year.

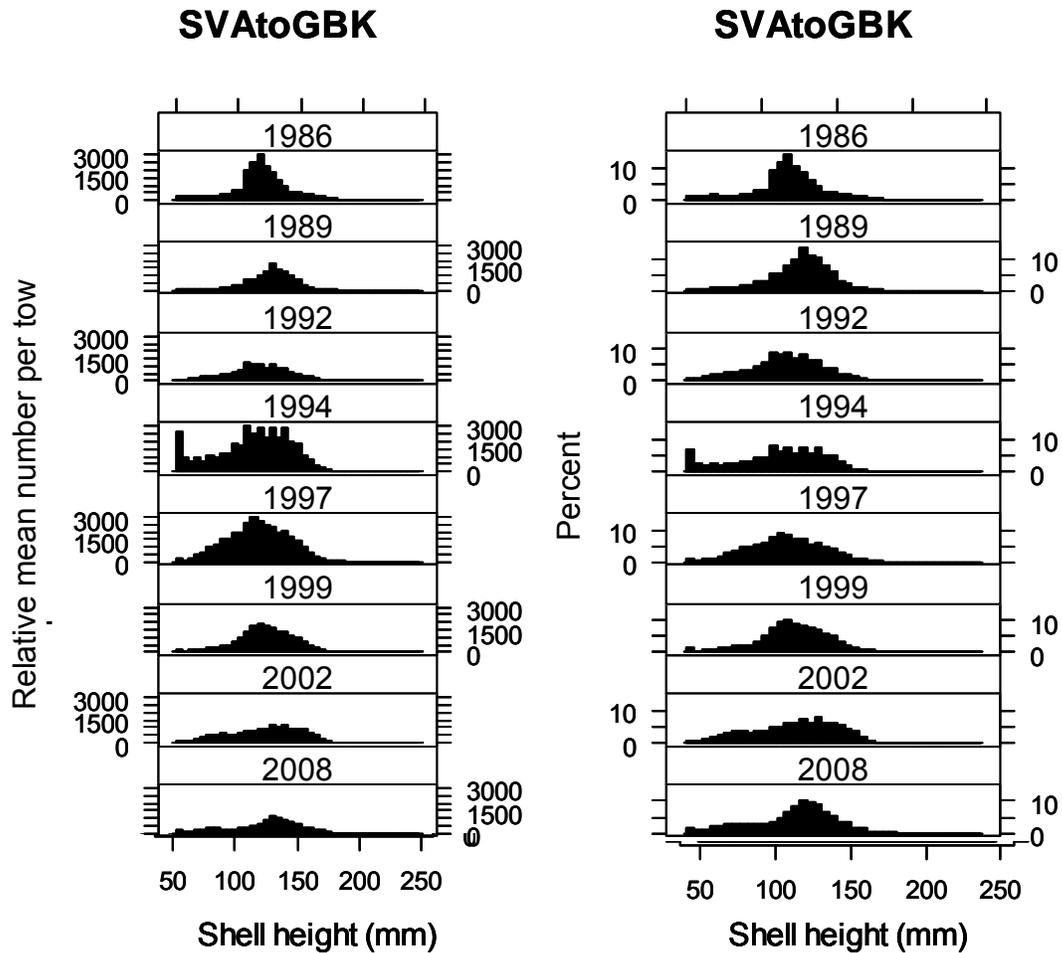


Figure A30. NEFSC survey length composition data for surfclams in the entire stock region (SVA to GBK). The y-axes for graphs on the left are relative numbers per tow that can be compared between shell length bins and years. The y-axes for graphs on the right are standardized as percentages to clearly show relative frequencies in the same year.

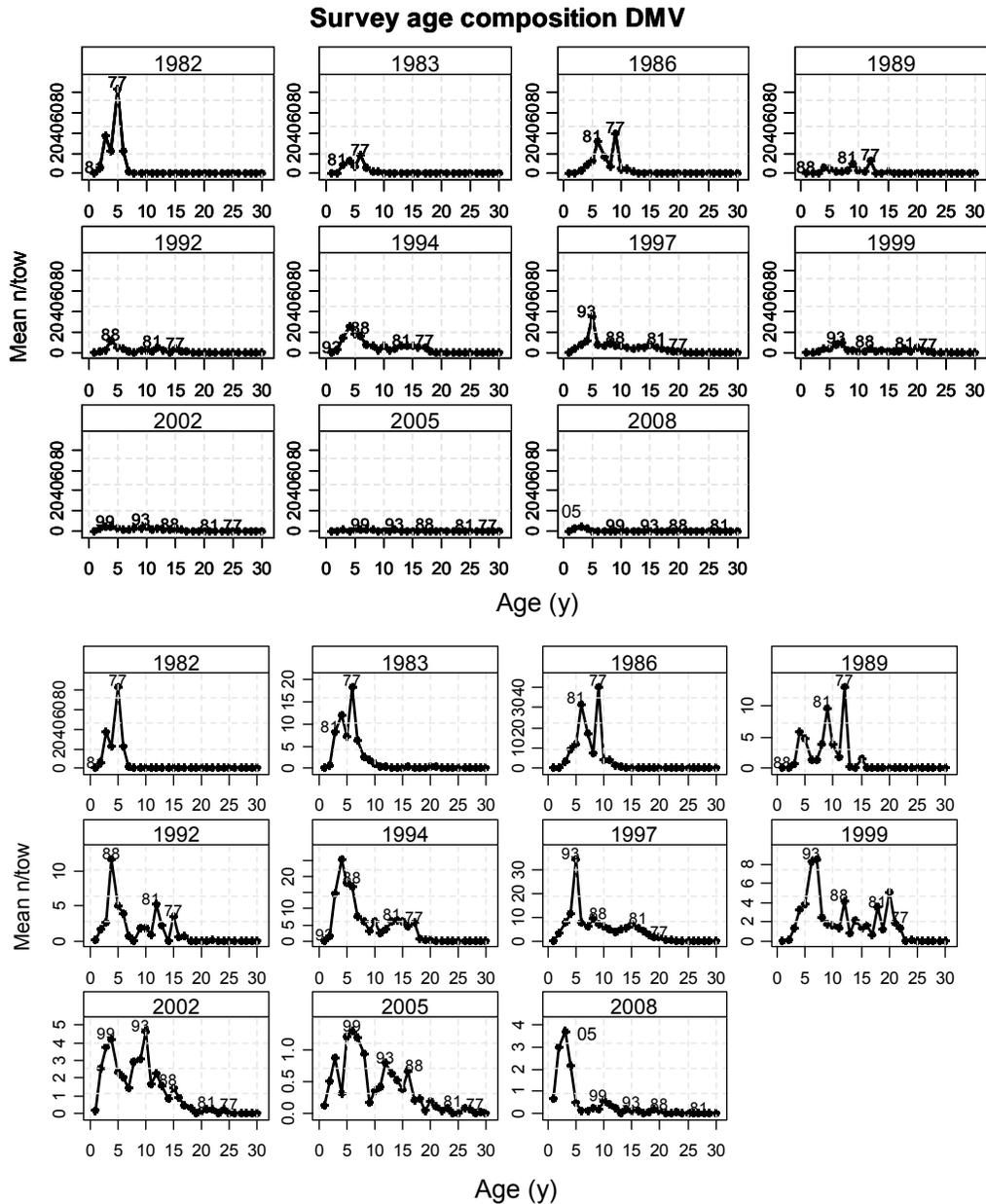


Figure A31. Mean numbers per tow at age for surfclams in DMV from survey data (no adjustment for survey dredge selectivity) with recognizable and strong year classes identified. The scale of the y-axis is the same in for all graphs in the top panel to enhance comparability across surveys. The scale varies by year in the bottom panel to facilitate comparisons of age groups during the same survey.

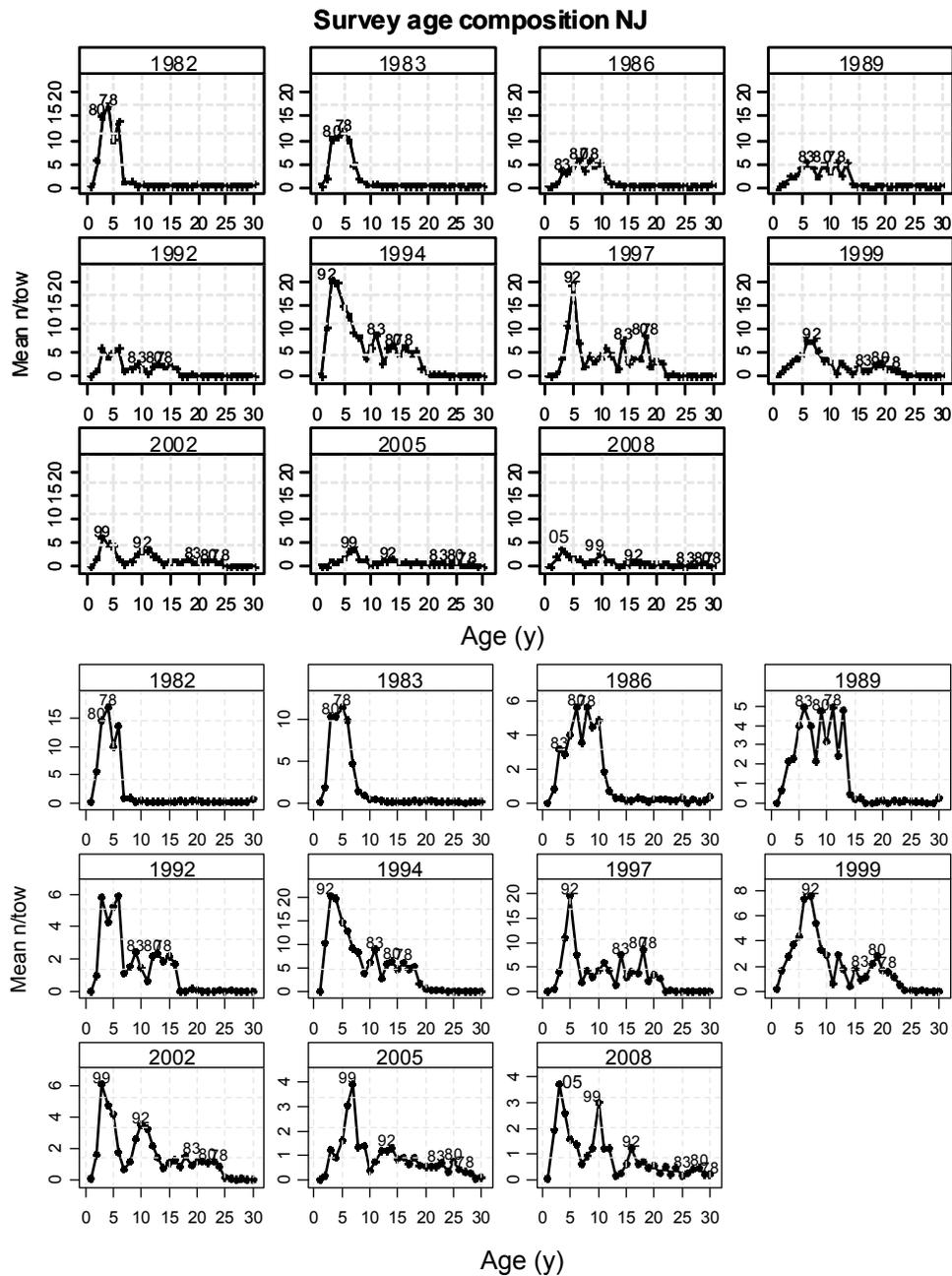


Figure A32. Mean numbers per tow at age for surfclams in NJ from survey data (no adjustment for survey dredge selectivity) with recognizable and strong year classes identified. The scale of the y-axis is the same in for all graphs in the top panel to enhance comparability across surveys. The scale varies by year in the bottom panel to facilitate comparisons of age groups during the same survey.

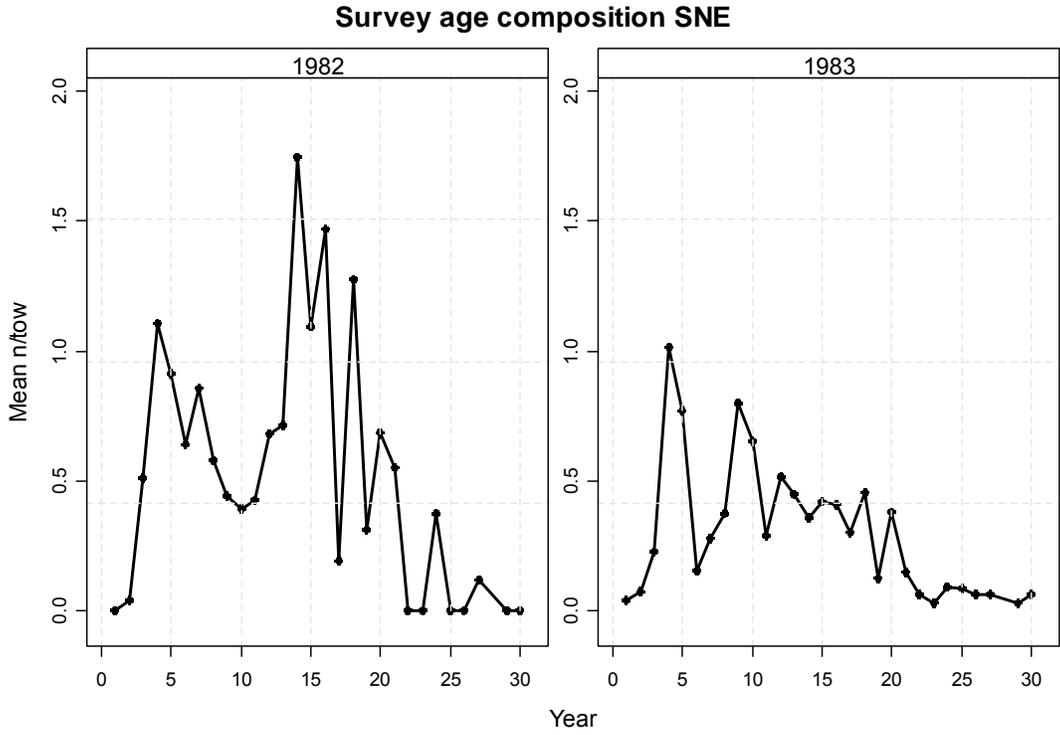


Figure A33. Mean numbers per tow at age for surfclams in SNE from survey data (no adjustment for survey dredge selectivity).

### Survey age composition GBK

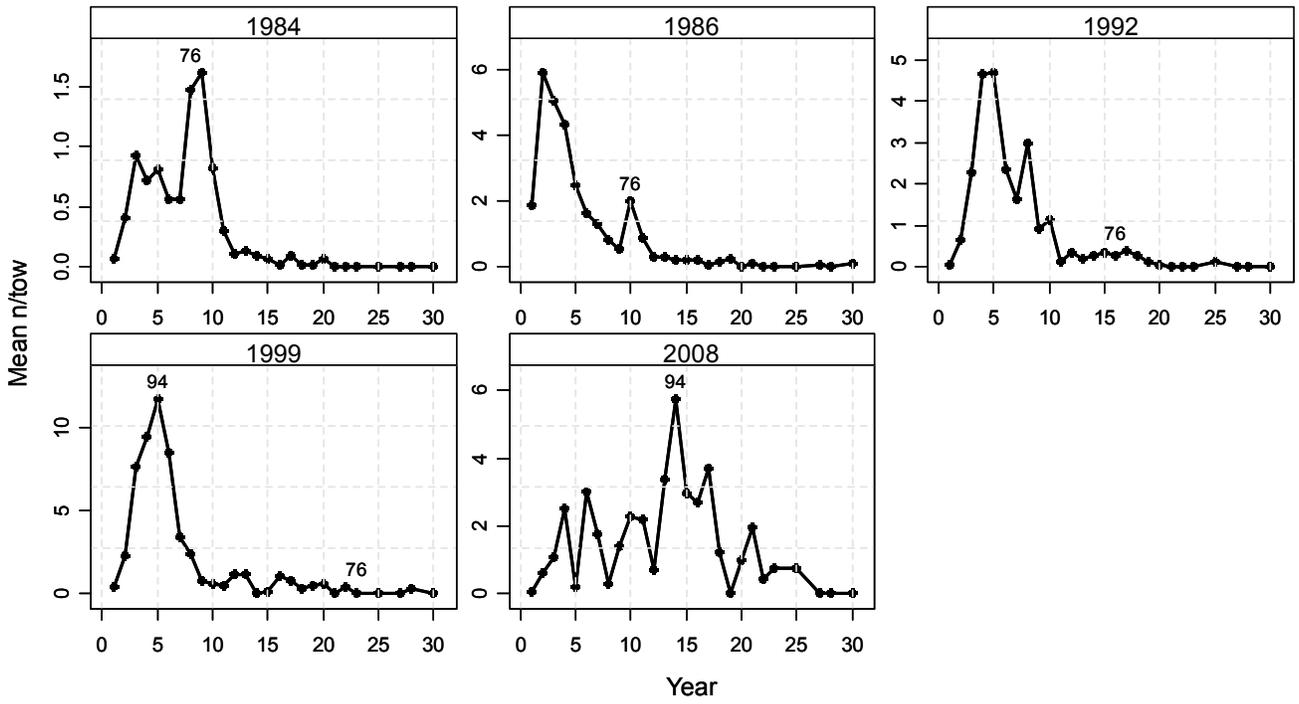


Figure A34. Mean numbers per tow at age for surfclams in the GBK region from survey data (no adjustment for survey dredge selectivity) with strong year classes identified.

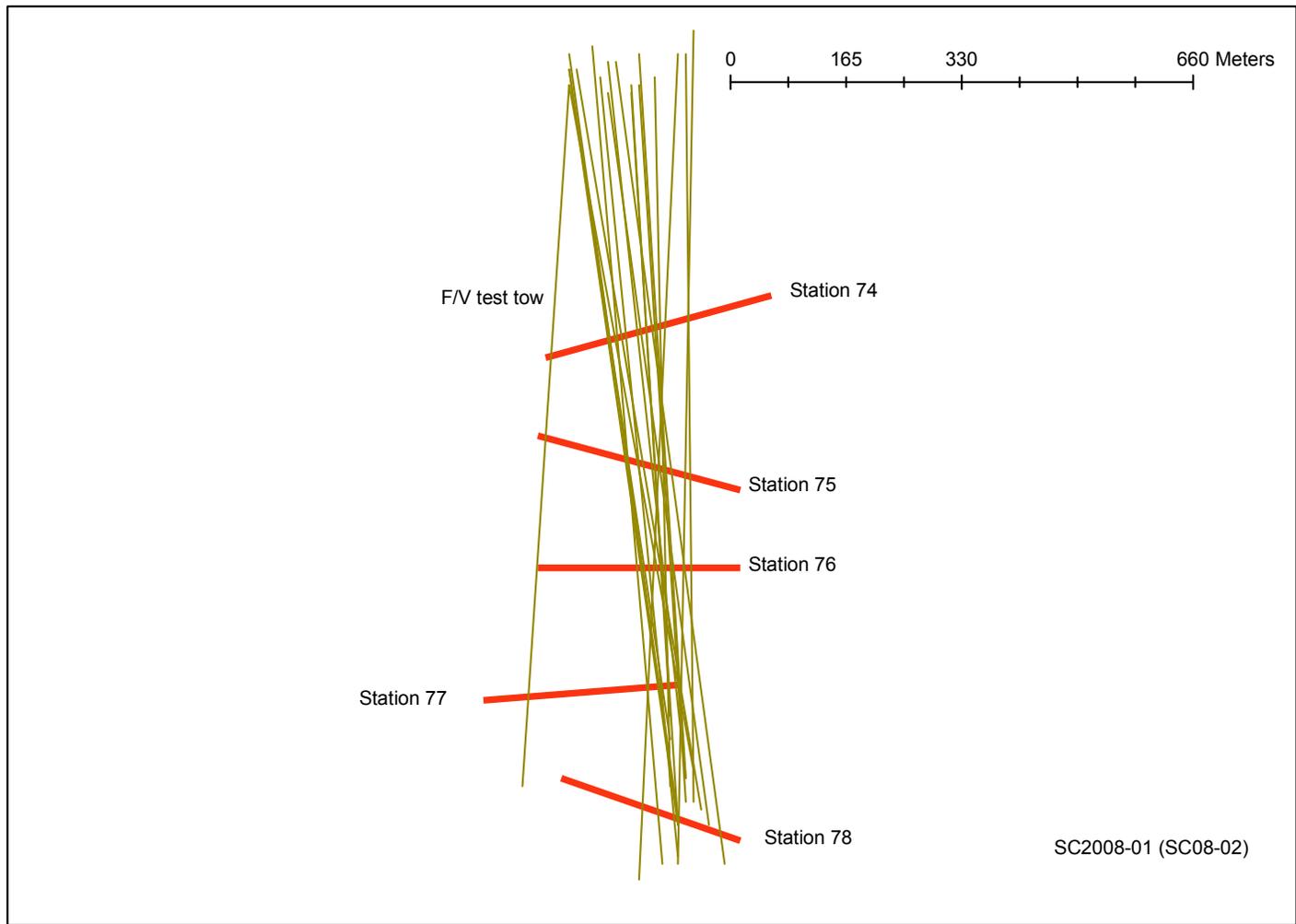


Figure A35. Depletion, setup and test tows for the SC2008-1(originally SC08-02) commercial depletion experiment for surfclams.

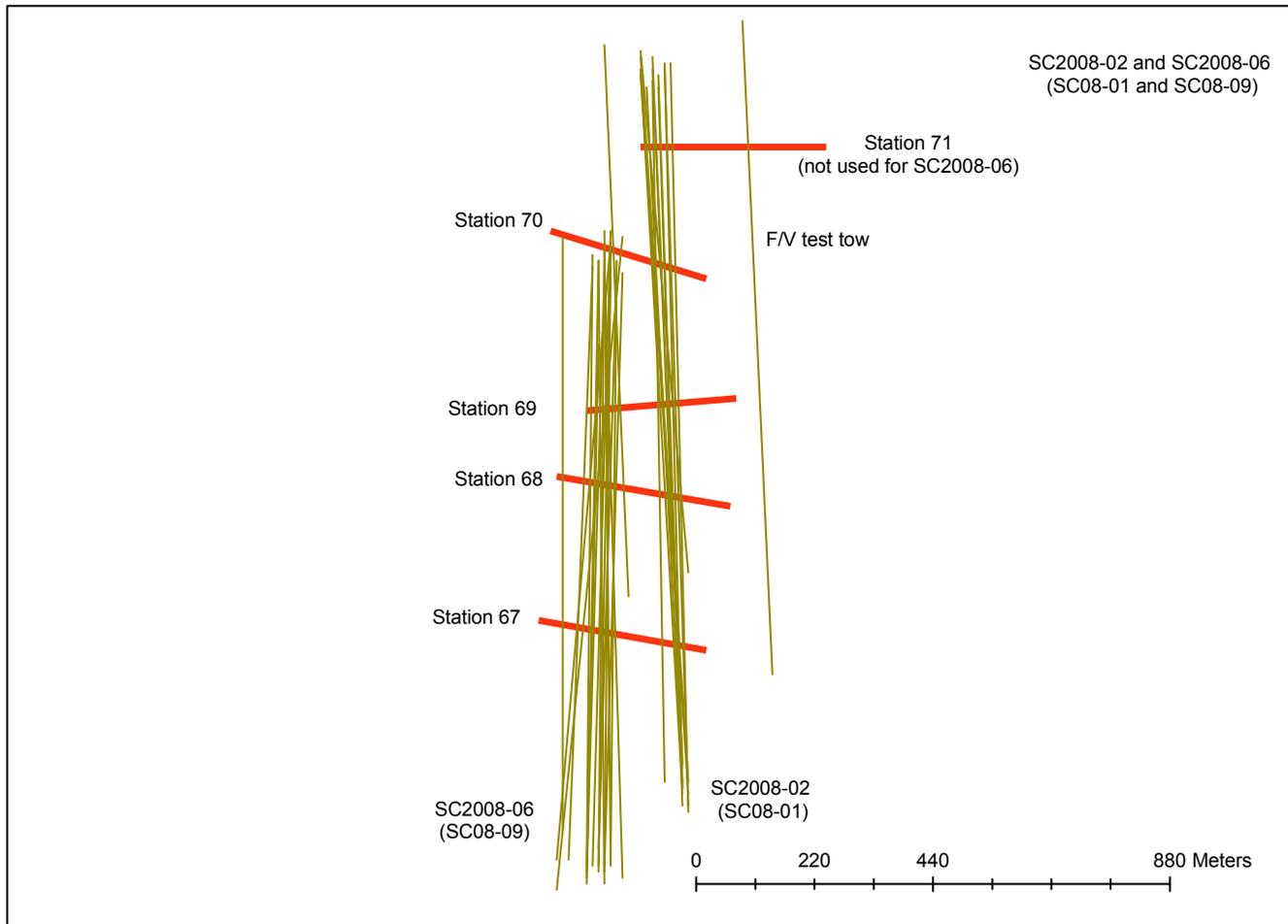


Figure A36. Depletion, setup and test tows for the SC2008-2 and SC2008-6 (originally SC08-01 and SC08-9) commercial depletion experiments for surfclams.

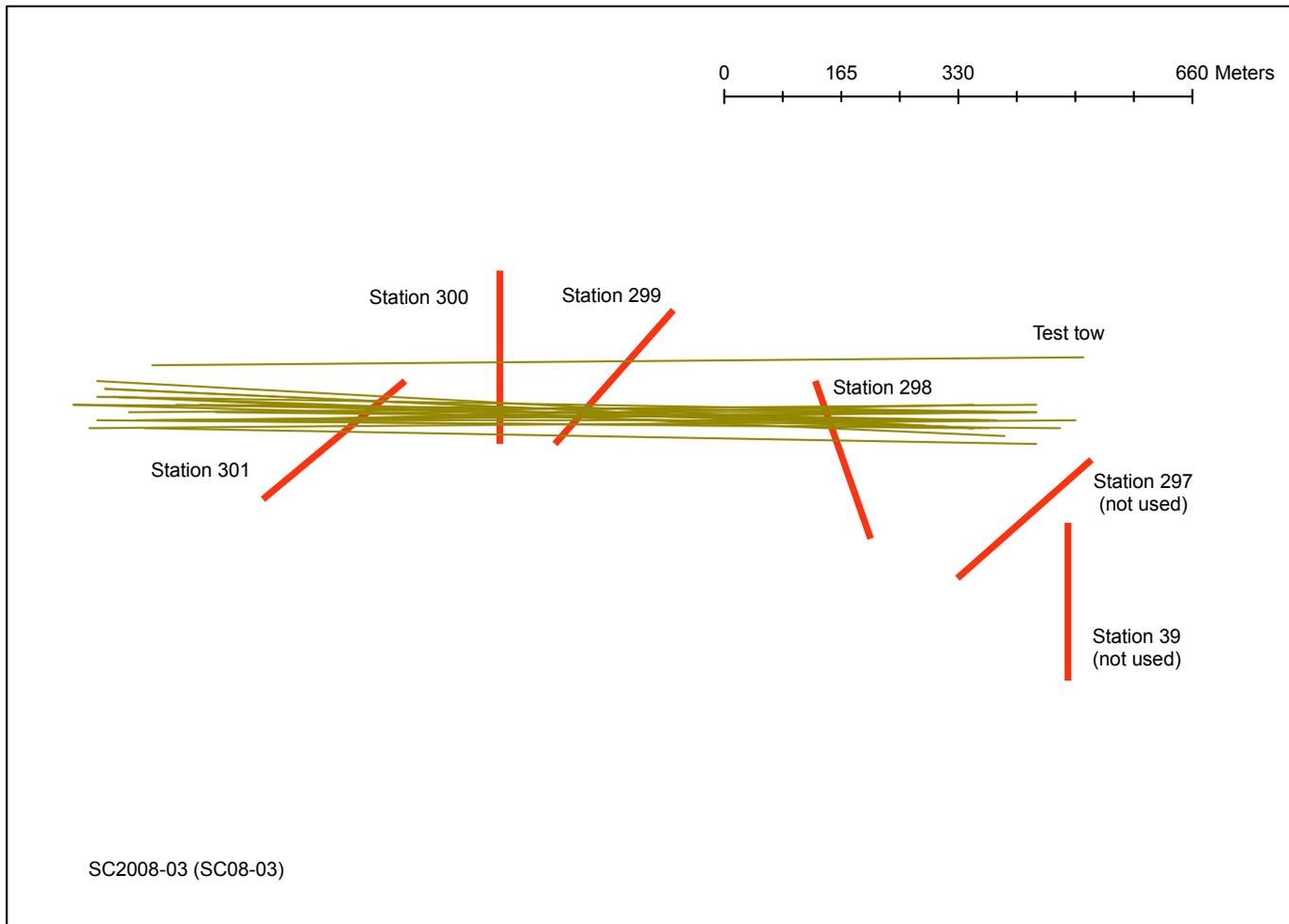


Figure A37. Depletion, setup and test tows for the SC2008-03 (originally SC08-03) commercial depletion experiment for surfclams.

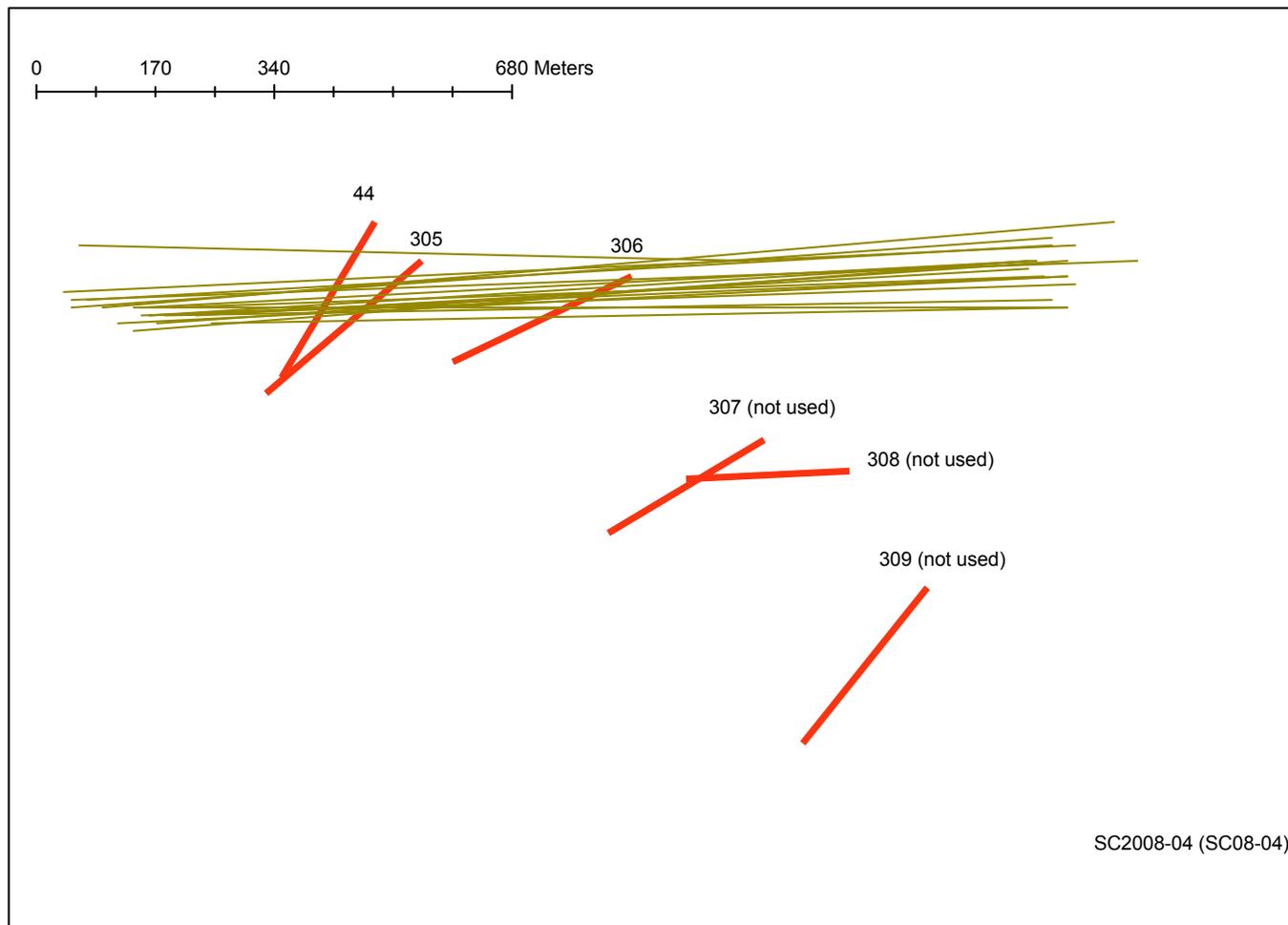


Figure A38. Depletion, setup and test tows for the SC2008-4 (originally SC08-04) commercial depletion experiment for surfclams.

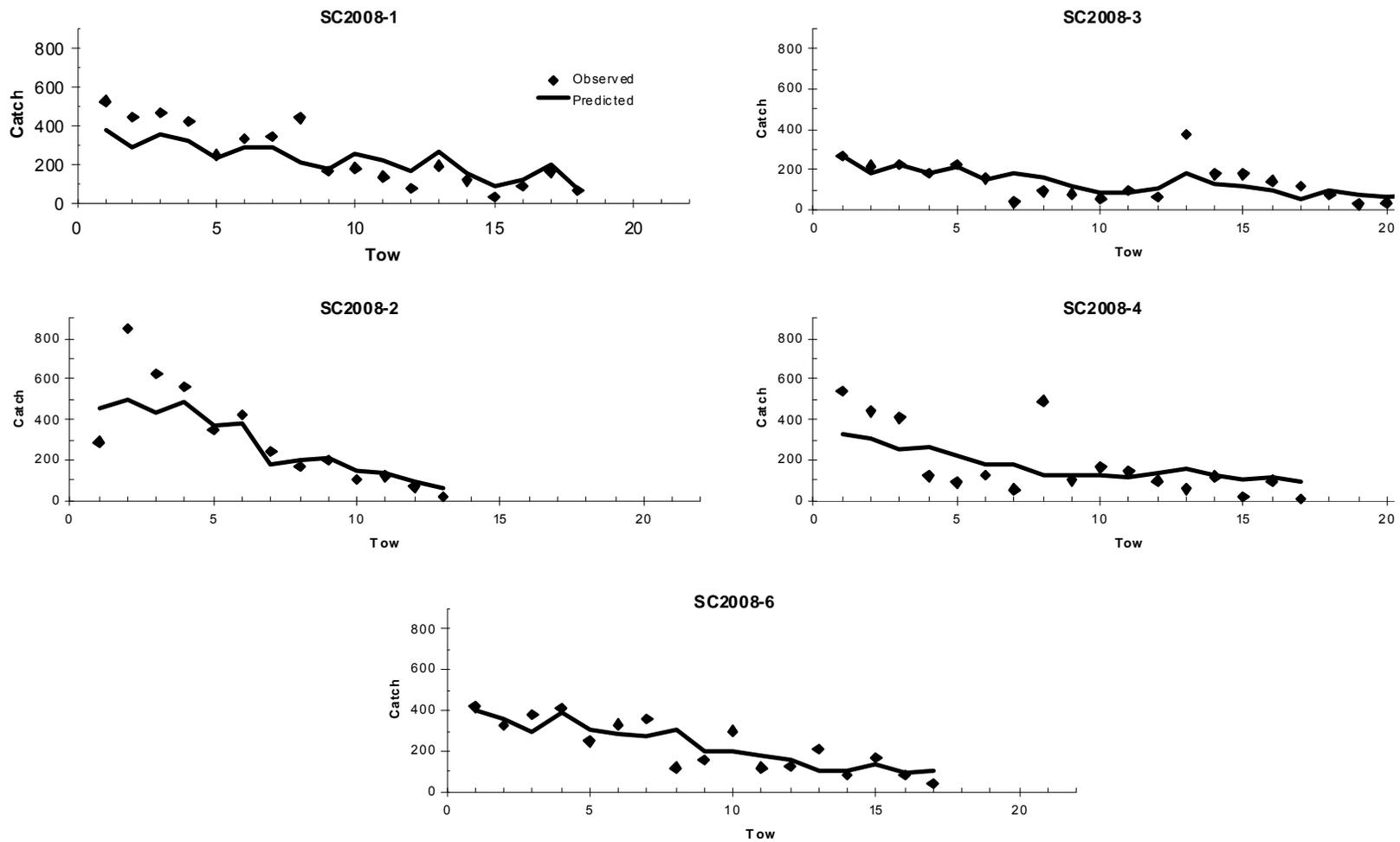


Figure A39. Observed and predicted catch by tow for surfclams in 2008 commercial depletion studies.

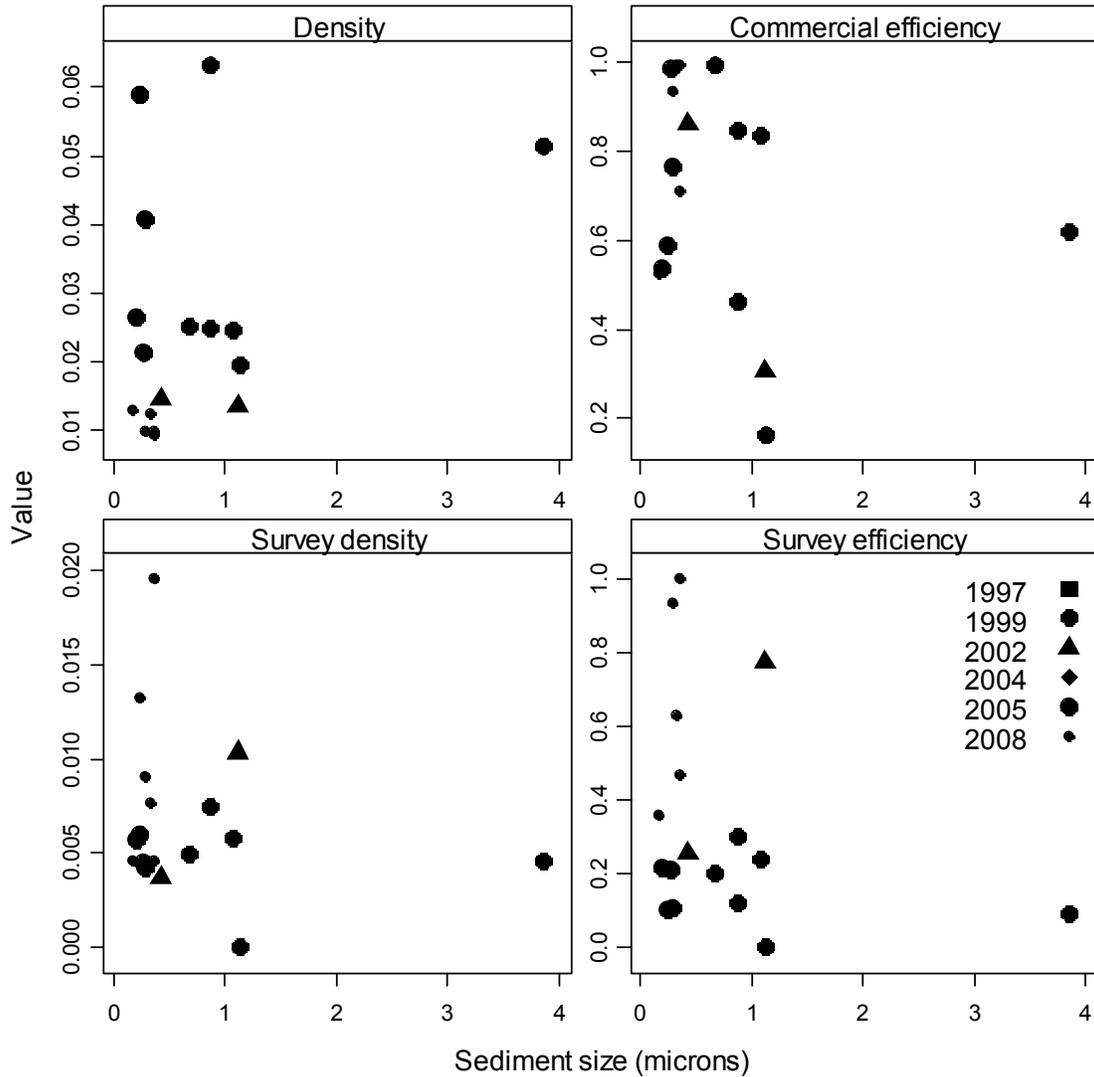


Figure A40. Relationships between efficiency estimates and sediment size in millimeters in depletion experiments for surfclams. The variable plotted on the y-axis is identified in the strip at the top of each panel. Sediment size data are not available for depletion experiments during 1997 and 2004.

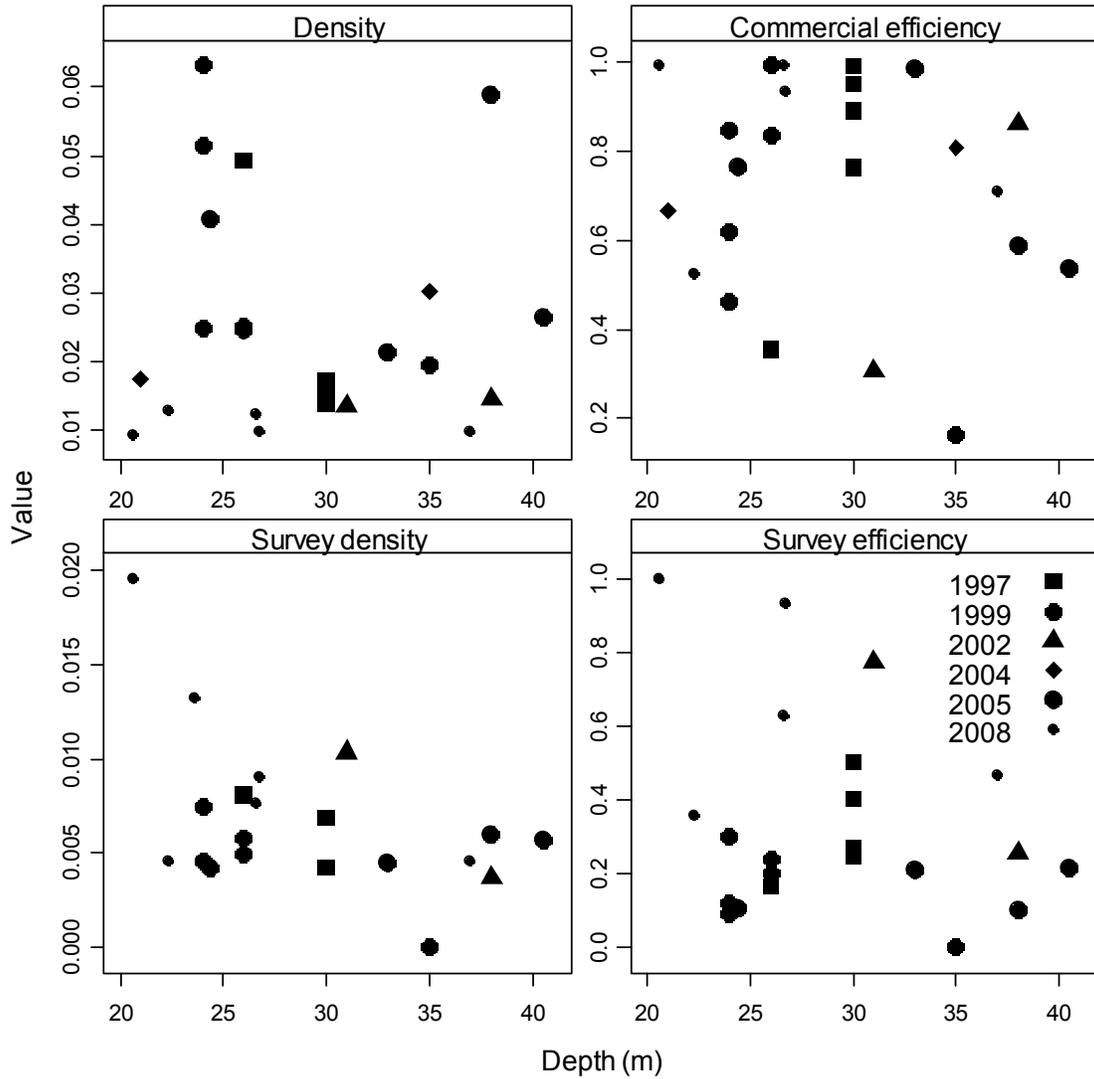


Figure A41. Relationships between efficiency estimates and environmental variables in depletion experiments for surfclams. The variable plotted on the y-axis is identified in the strip at the top of each panel.

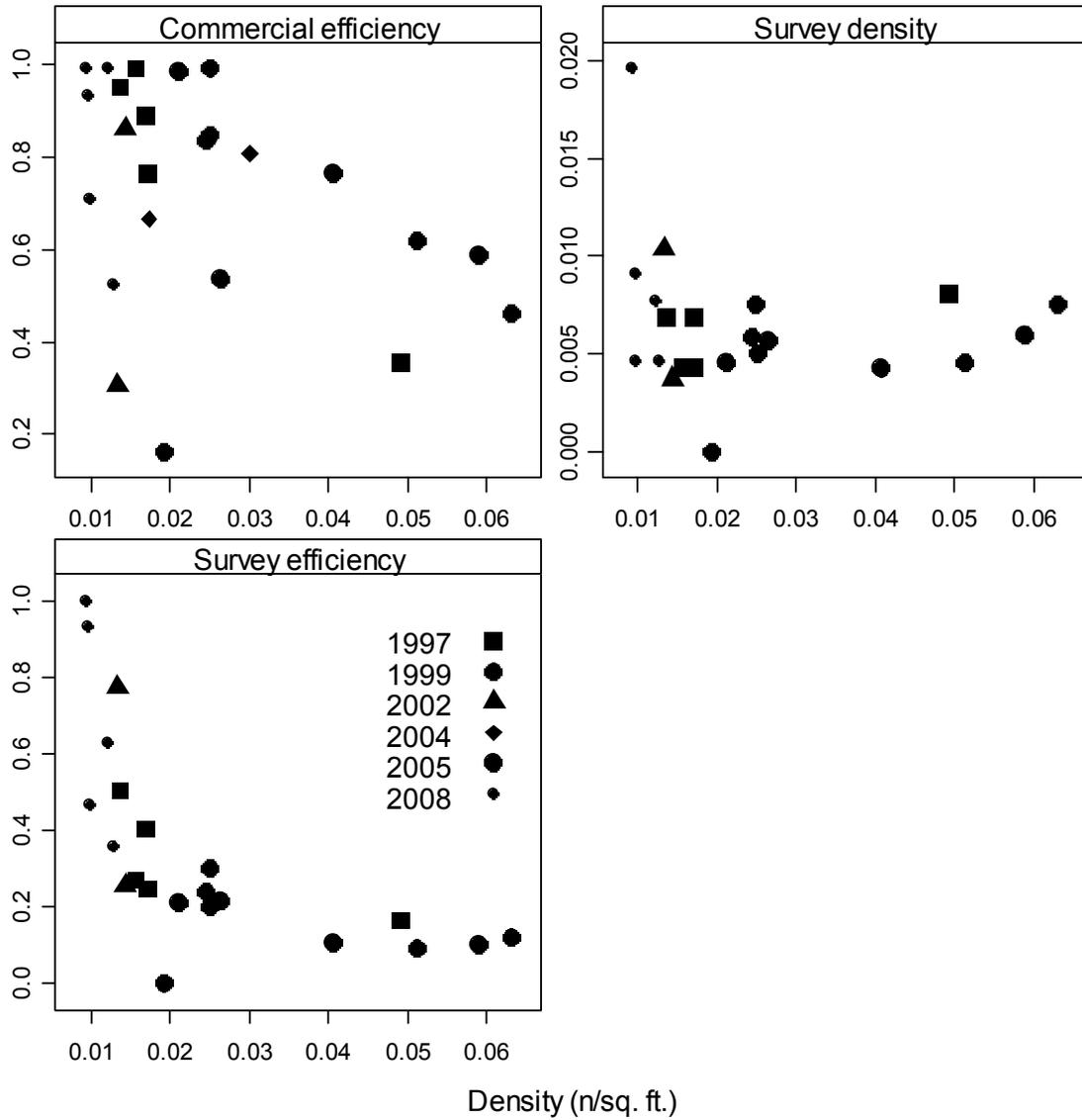


Figure A41. (cont.)

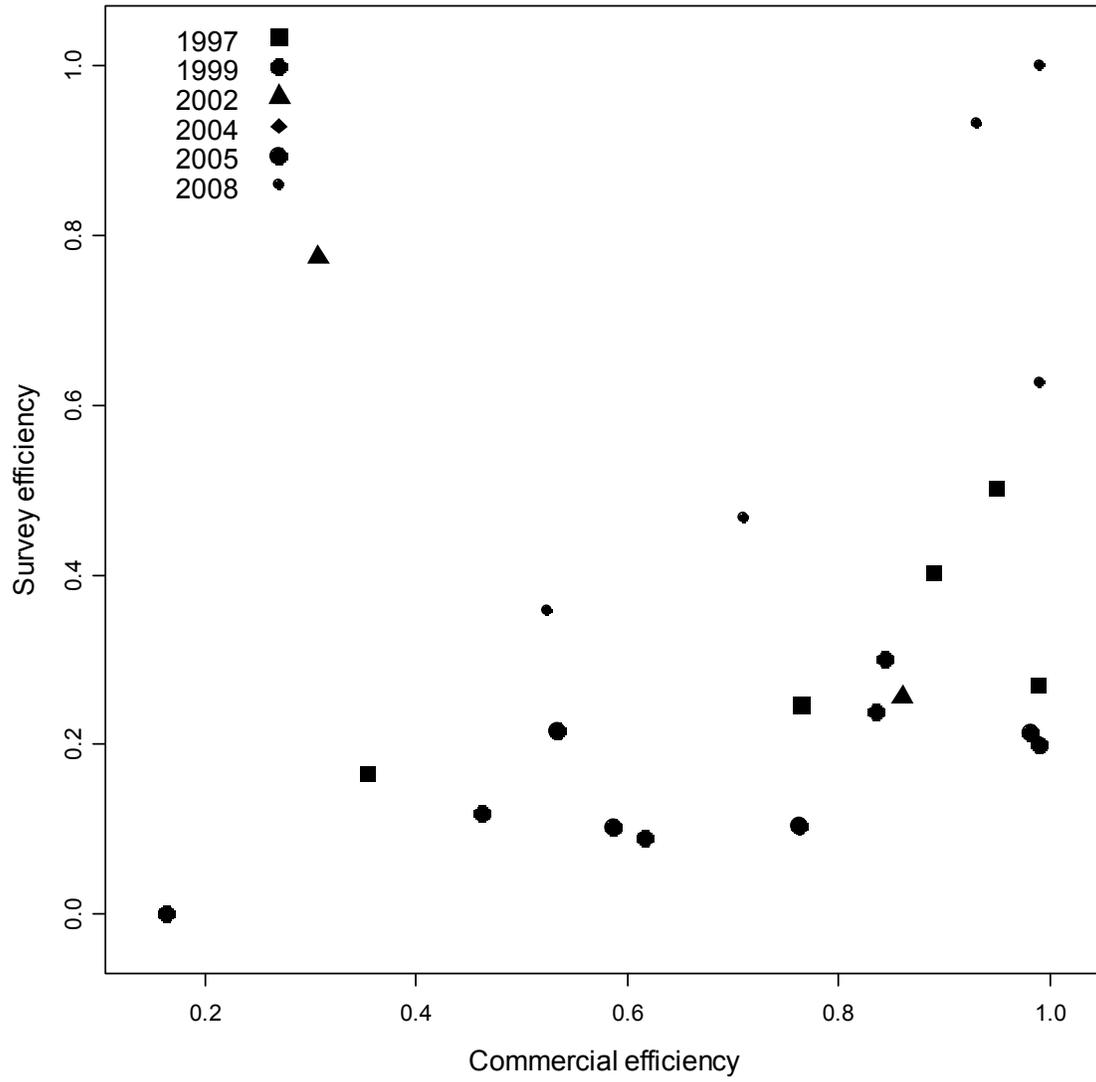


Figure A41. (cont.)

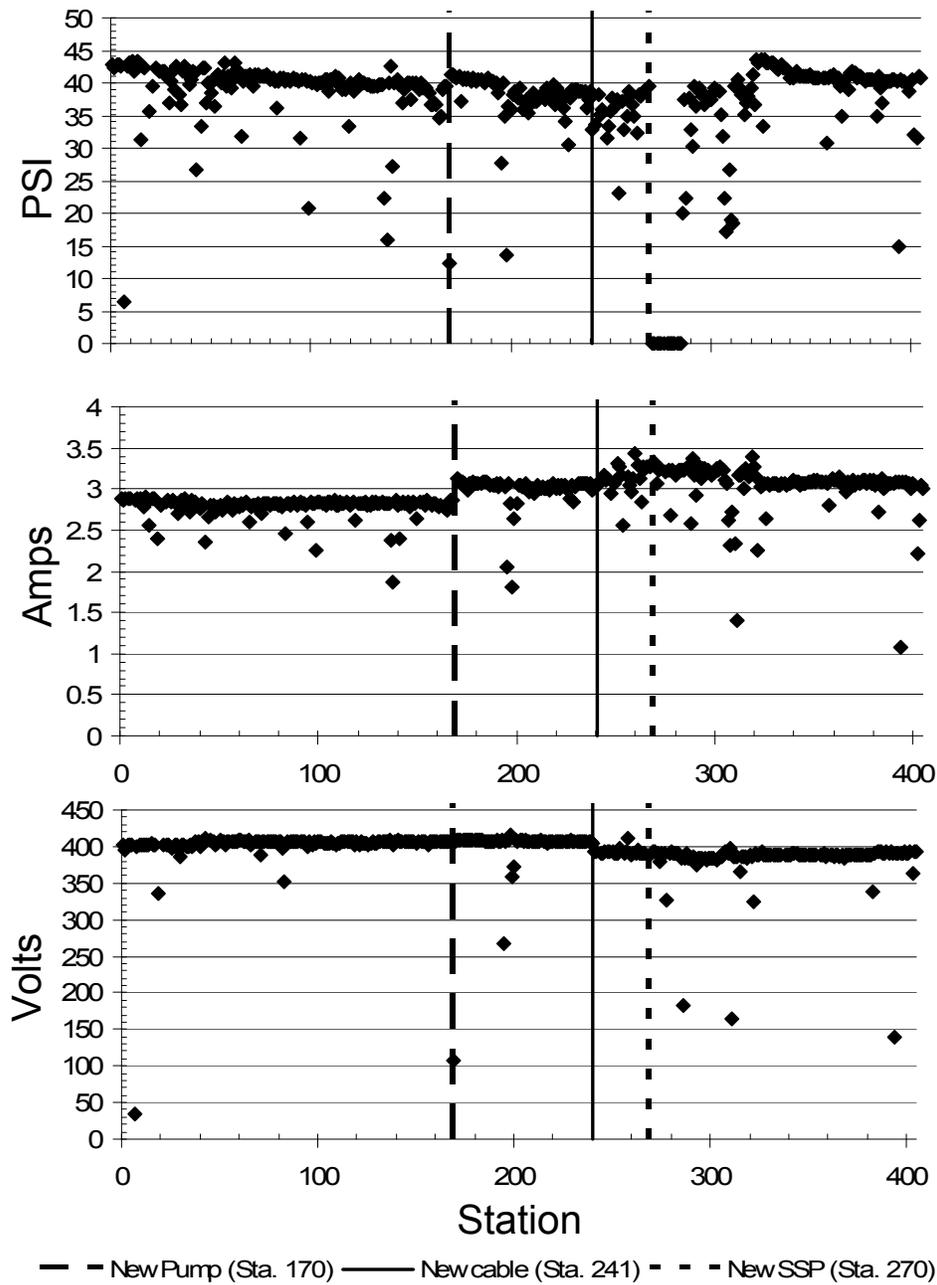


Figure A42. Mean survey dredge sensor data during periods when the dredge was fishing based on y-tilt sensor data, for stations 1-405 in the 2008 NEFSC clam survey.

### De2De2 surfclam repeat stations

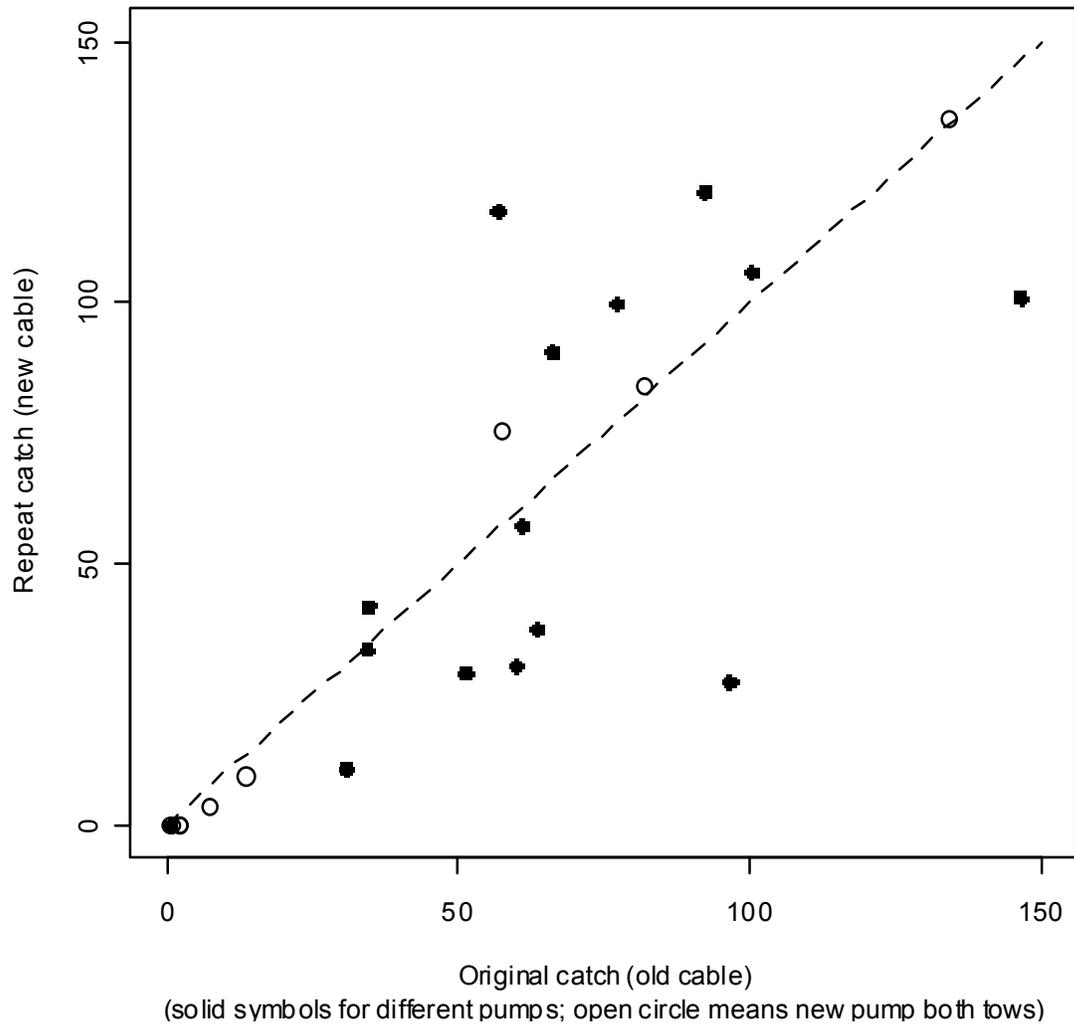


Figure A43. Delaware II-Delaware II (De2De2) repeat station results for surfclam in the 2008 NEFSC clam survey. Solid circles indicate that the original tow used the old pump while the repeat tow used the new pump. Open circles indicate that both the original and repeat tows used the new pump. All repeat stations used the new cable and all original stations used the old cable.

### De2Fv surfclam repeat stations

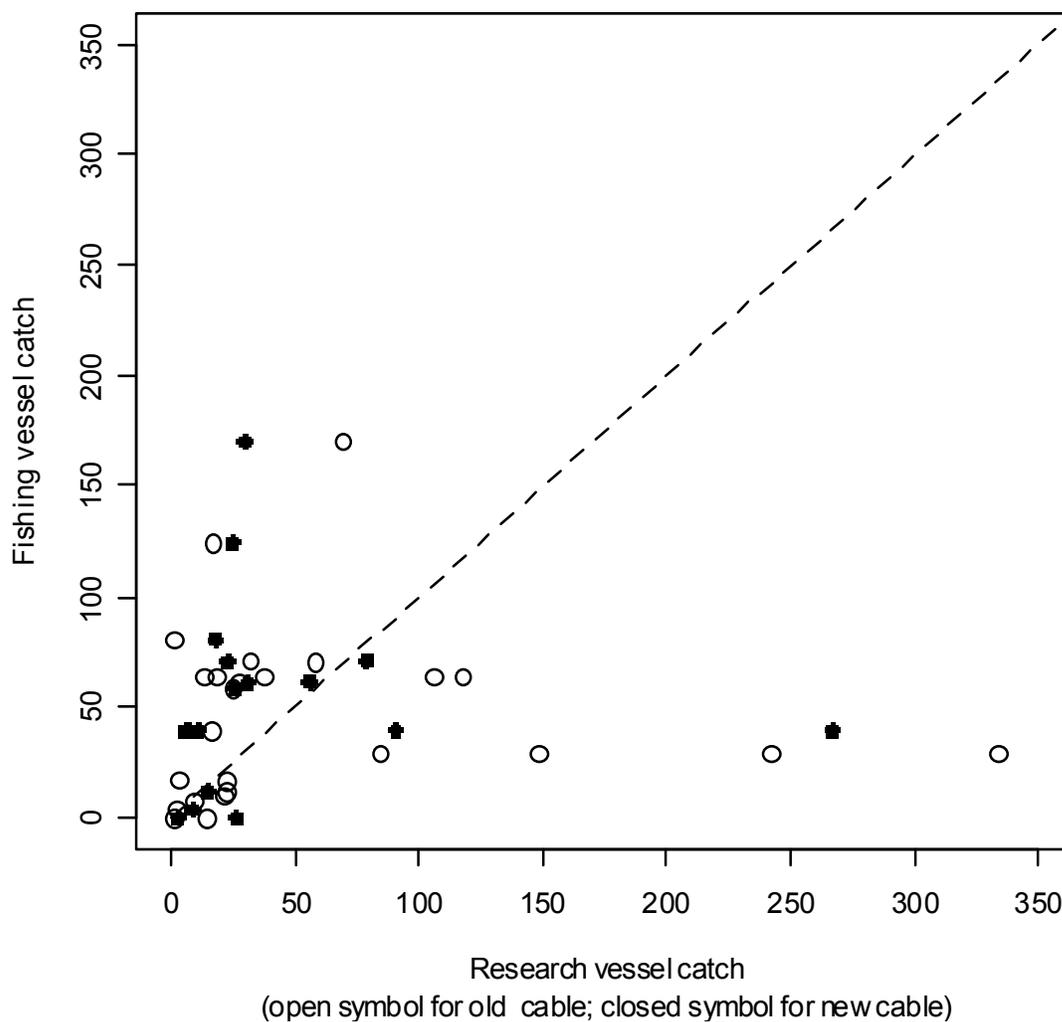


Figure A44. *R/V Delaware II-F/V Endeavor* (De2Fv) repeat station experiment results for surfclam in the 2008 NEFSC clam survey. Open circles indicate that the *R/V Delaware II* original tow used the old pump and closed circles indicate that the *R/V Delaware II* used the new cable. The dashed line is  $y=x$ , where the original and repeat catches are identical.

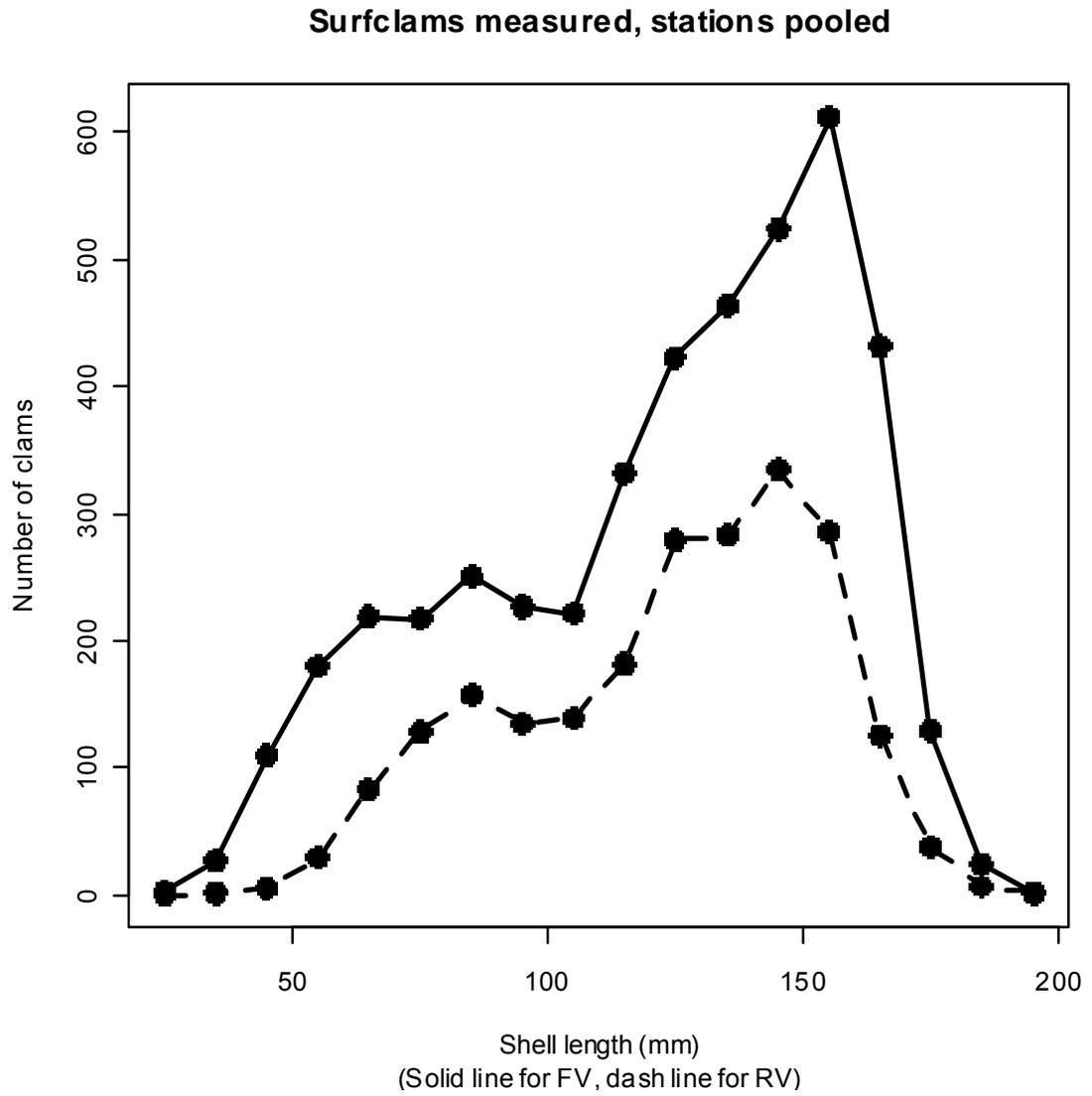


Figure A45. Surfclam shell height composition data used to estimate selectivity of the NEFSC survey clam dredge.

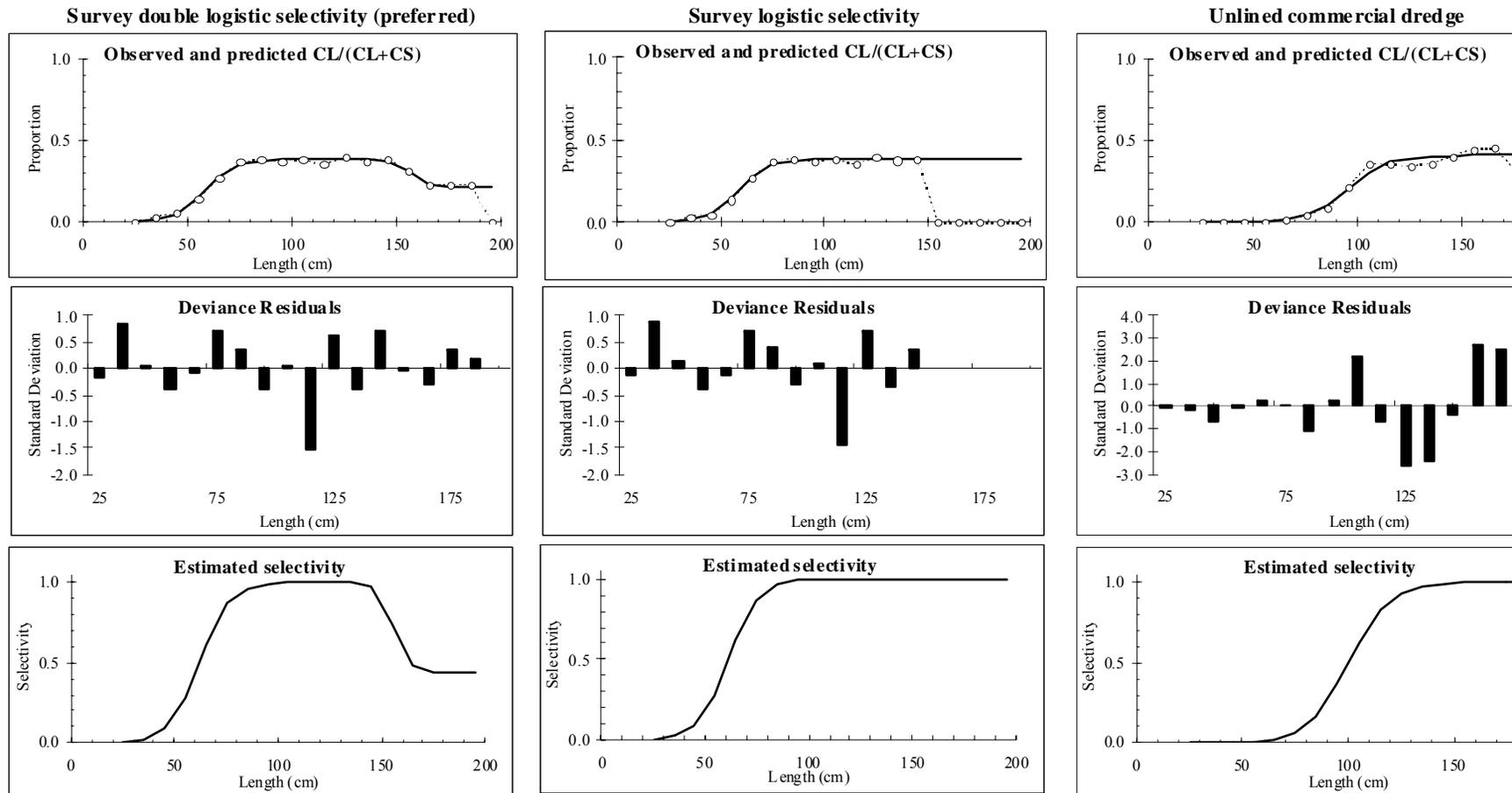


Figure A46. Data, diagnostics and estimated selectivity curves for surfclams in the NEFSC clam survey dredge. The unlined commercial dredge was configured for survey work and not representative of dredges used during commercial fishing.

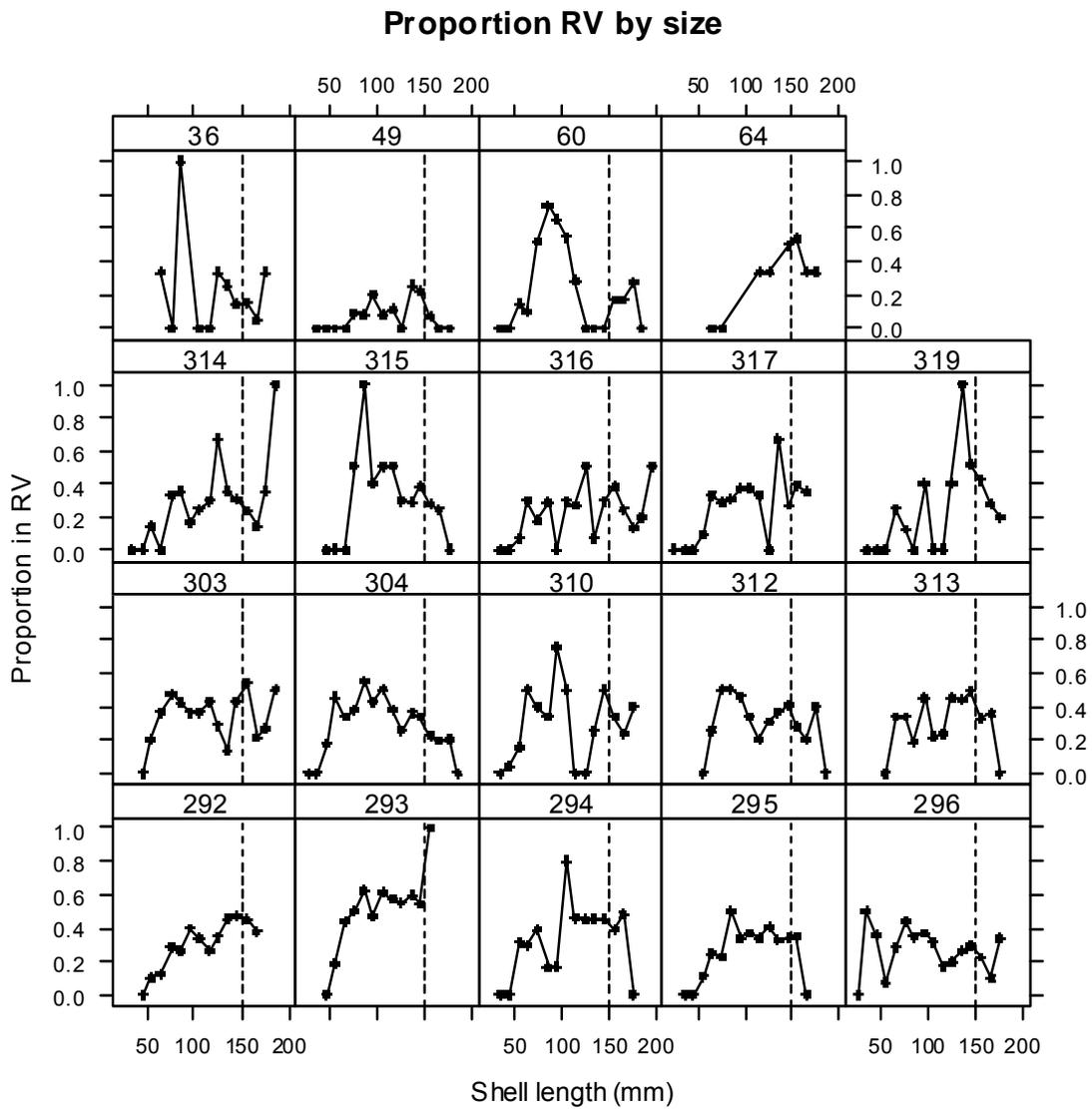


Figure A47. Ratios of R/V over total catch ( $R/V + F/V$ ) for selectivity experiments during 2008 (labels at the top of each panel are selectivity experiment IDs). The dashed vertical line is at 150 mm SL.

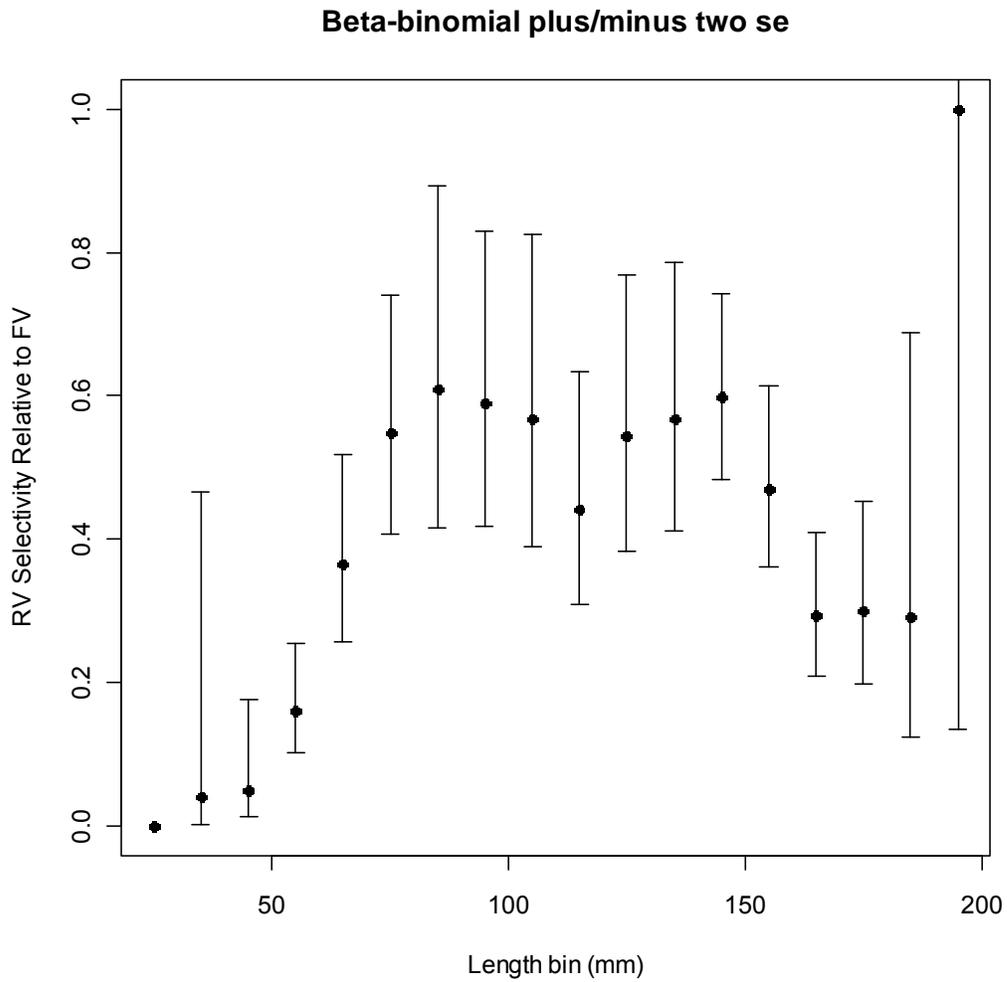
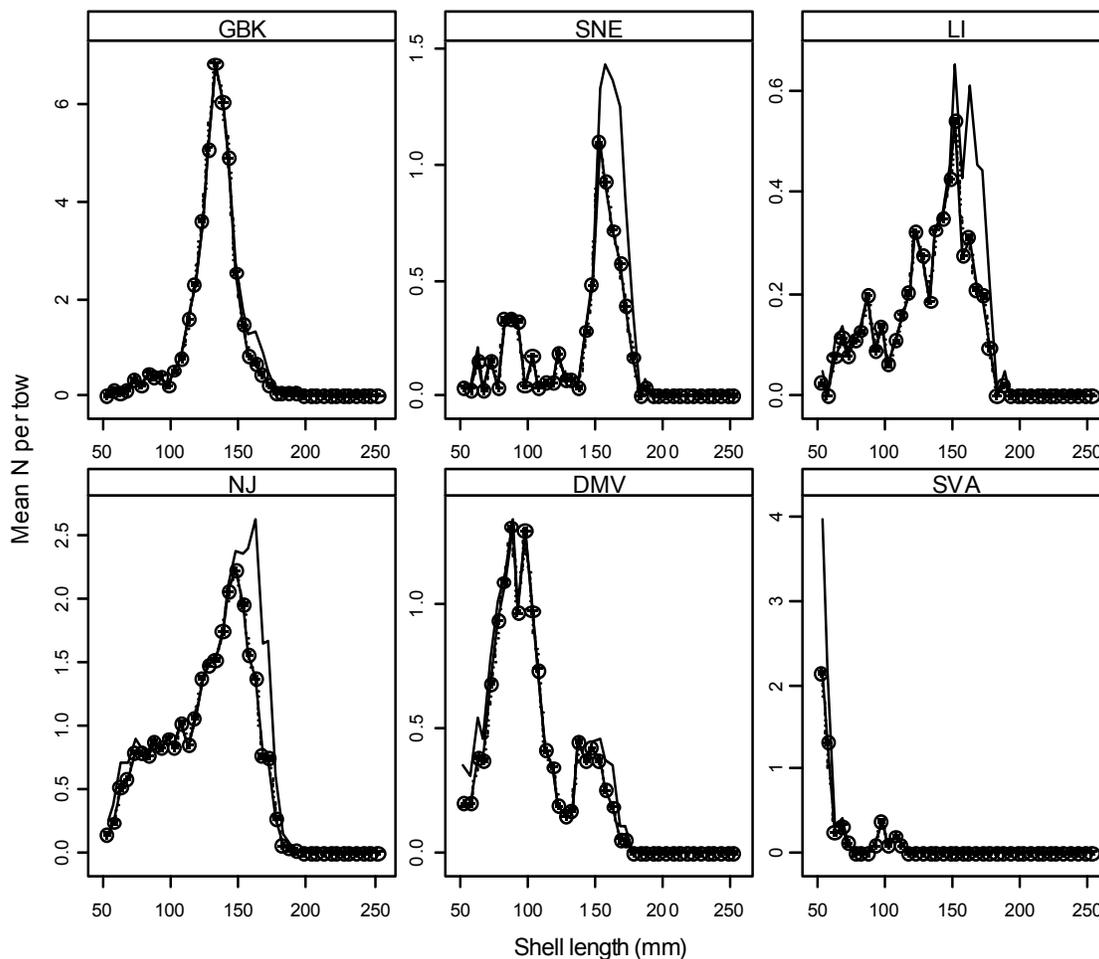


Figure A48. Beta-binomial estimates for selectivity of the NEFSC clam survey dredge, with 95% confidence interval, by shell size group.

NEFSC clam survey length data for surfclam in 2008



(solid line corrected for selectivity, symbols not corrected)

Figure A49. NEFSC survey length composition for surfclams in the 2008 survey with (solid line) and without (symbols) correction for dome shaped survey dredge selectivity.

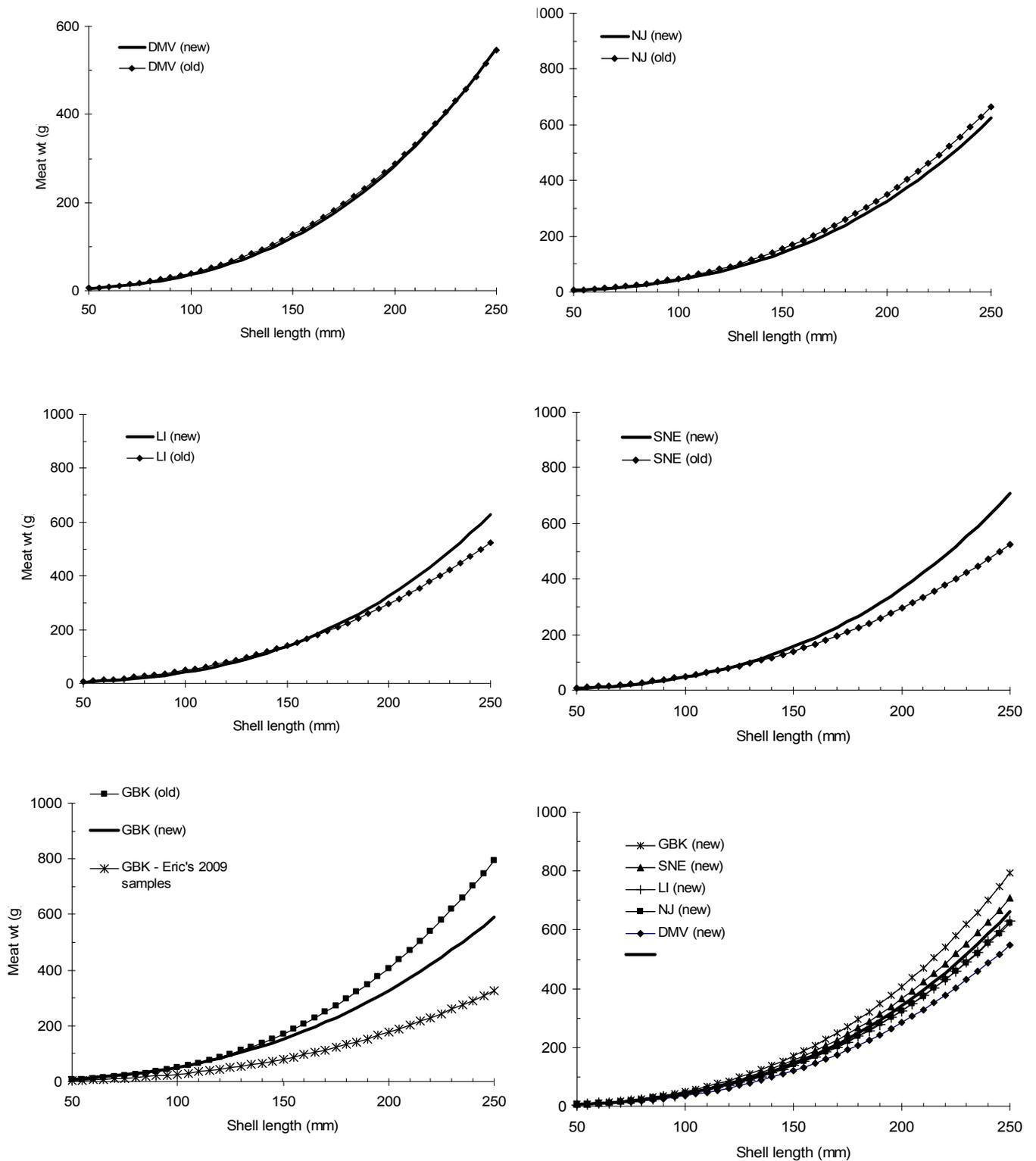


Figure A50. Updated and original shell length/ meat weight relationships by region.

### NEFSC clam survey age and shell length data for DMV

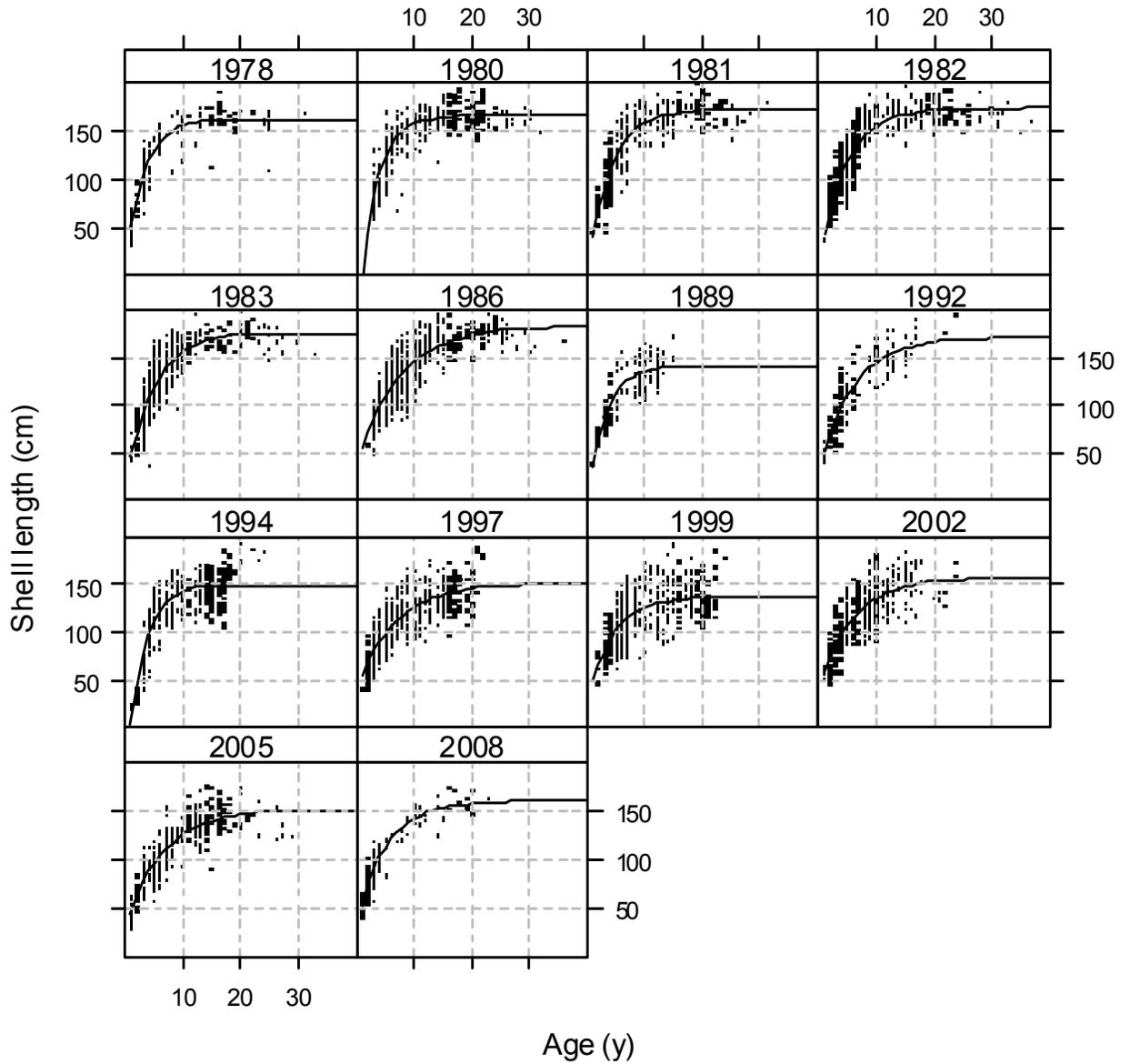


Figure A51. NEFSC surfclam size at age data for the DMV region with von Bertalanffy growth curves fit using nonlinear regression, by year.

# NEFSC clam survey age and shell length data for NJ

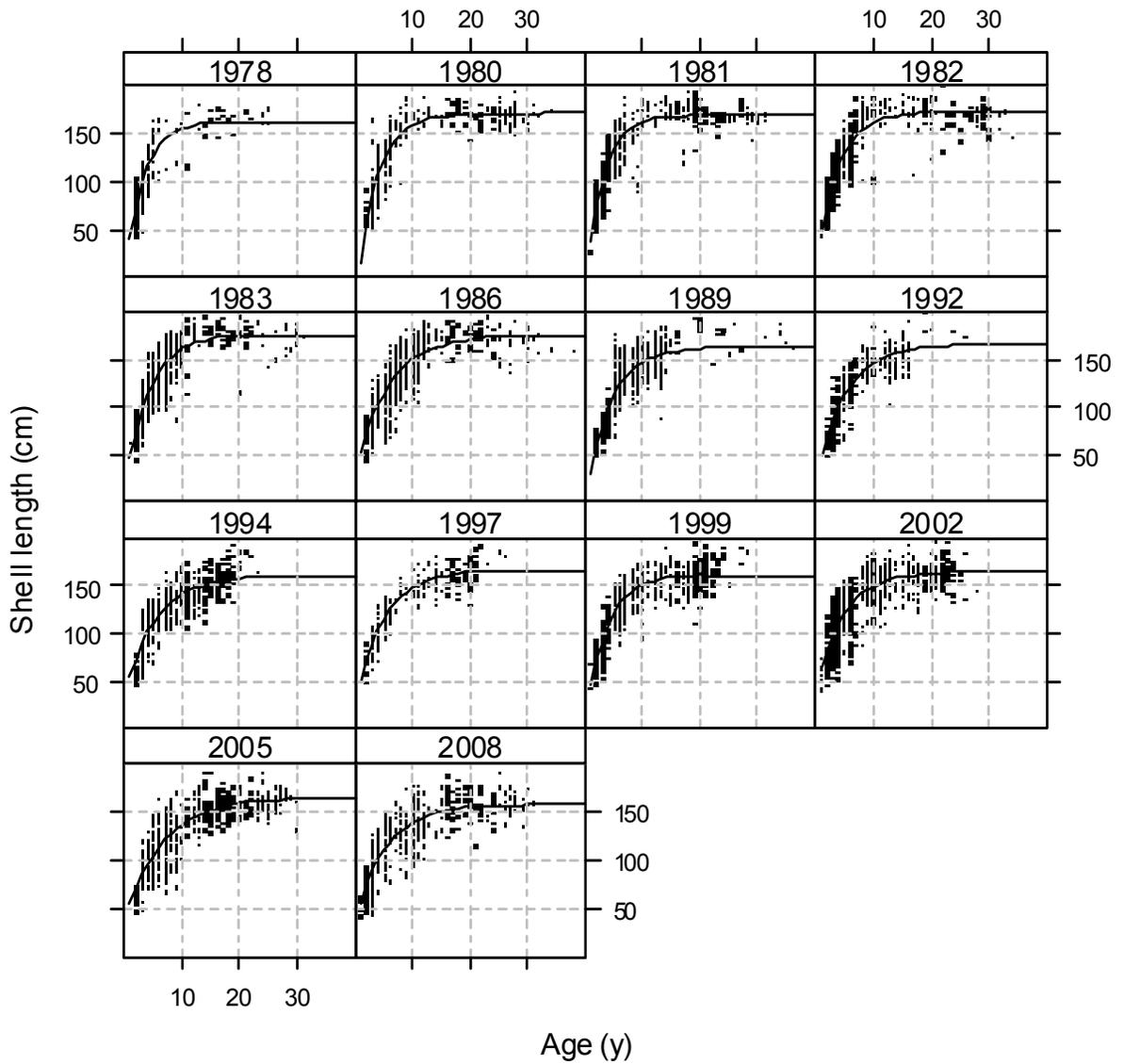


Figure A52. NEFSC surfclam size at age data for the NJ region with von Bertalanffy growth curves fit using nonlinear regression, by year.

### NEFSC clam survey age and shell length data for LI

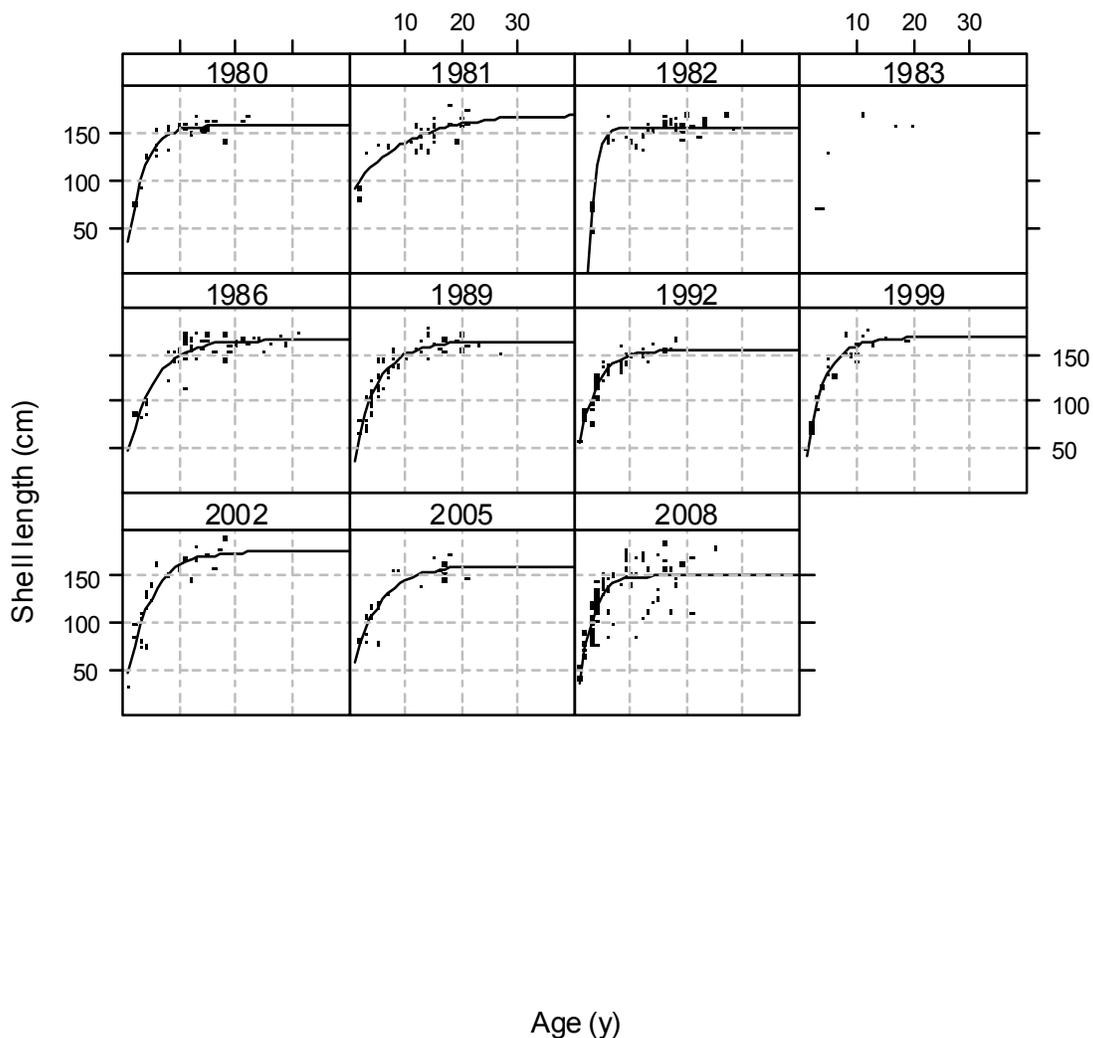


Figure A53. NEFSC surfclam size at age data for the LI region with von Bertalanffy growth curves fit using nonlinear regression, by year. There was not enough data for 1983 to draw a curve.

### NEFSC clam survey age and shell length data for SNE

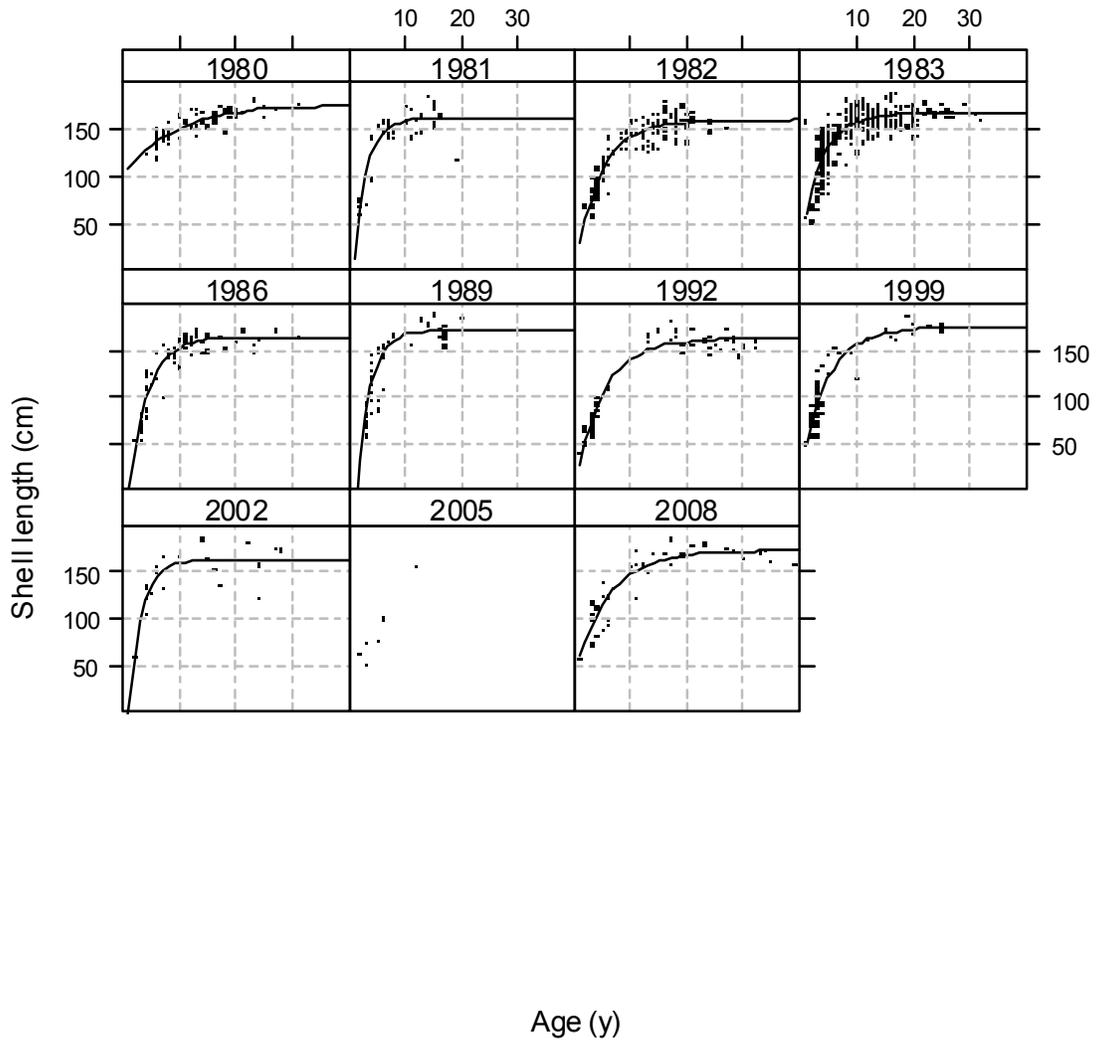


Figure A54. NEFSC surfclam size at age data for the SNE region with von Bertalanffy growth curves fit using nonlinear regression, by year. There was not enough data from 2005 to draw a curve.

### NEFSC clam survey age and shell length data for GBK

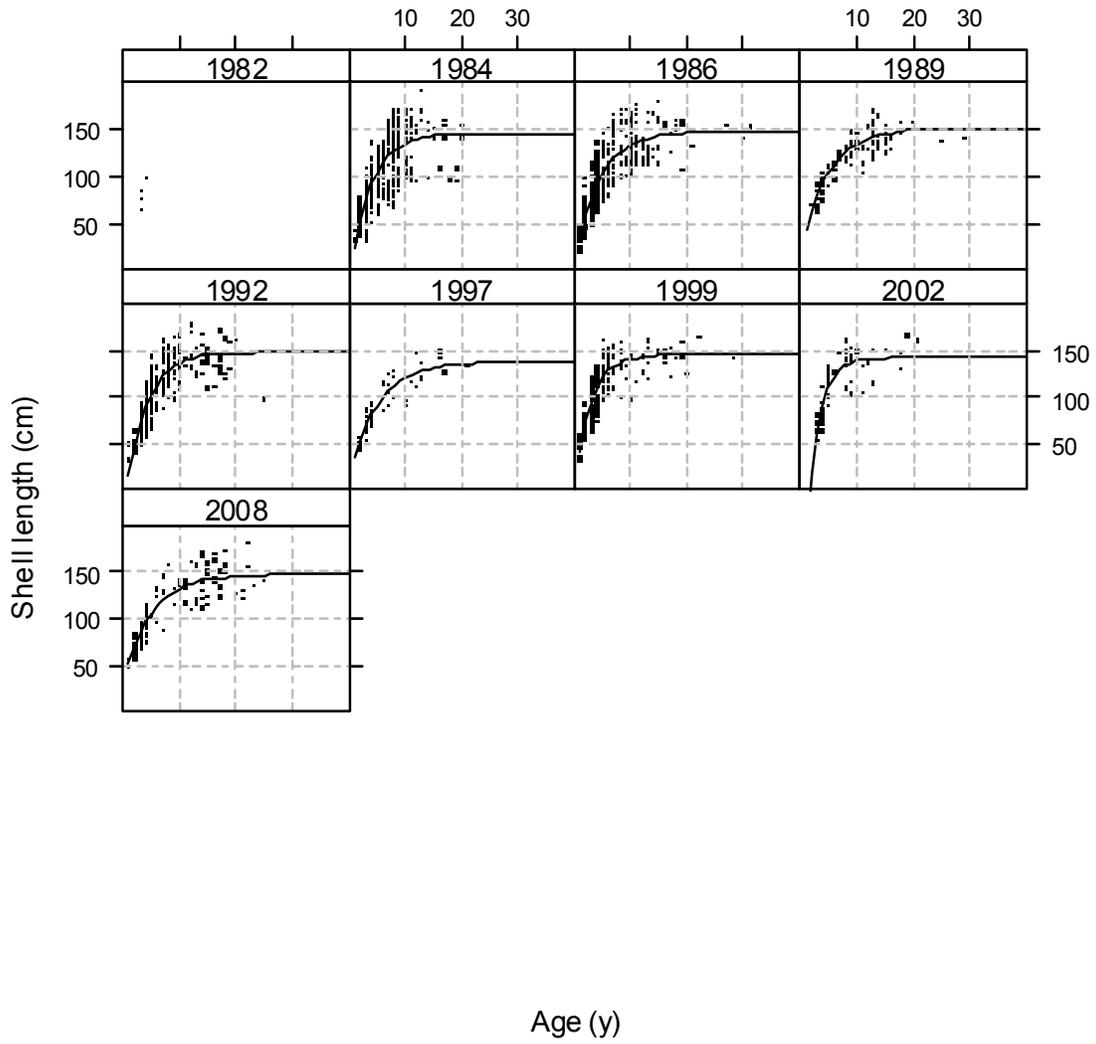


Figure A55. NEFSC surfclam size at age data for the GBK region with von Bertalanffy growth curves fit using nonlinear regression, by year. There was not enough data from 1982 to draw a curve.

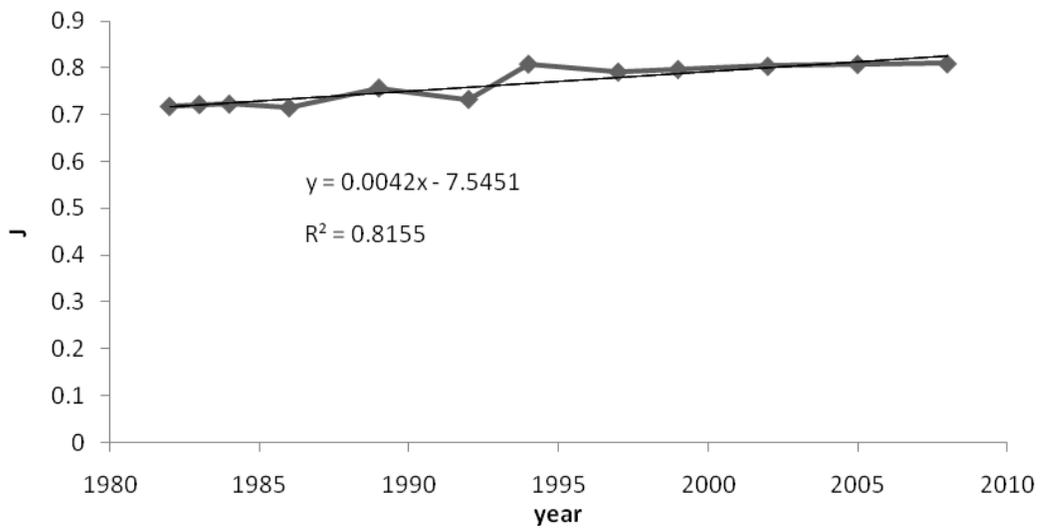


Figure A56. Annual estimates and linear regression analysis for the growth parameter  $J$ , which is used in the KLAMZ model for the entire surfclam stock.

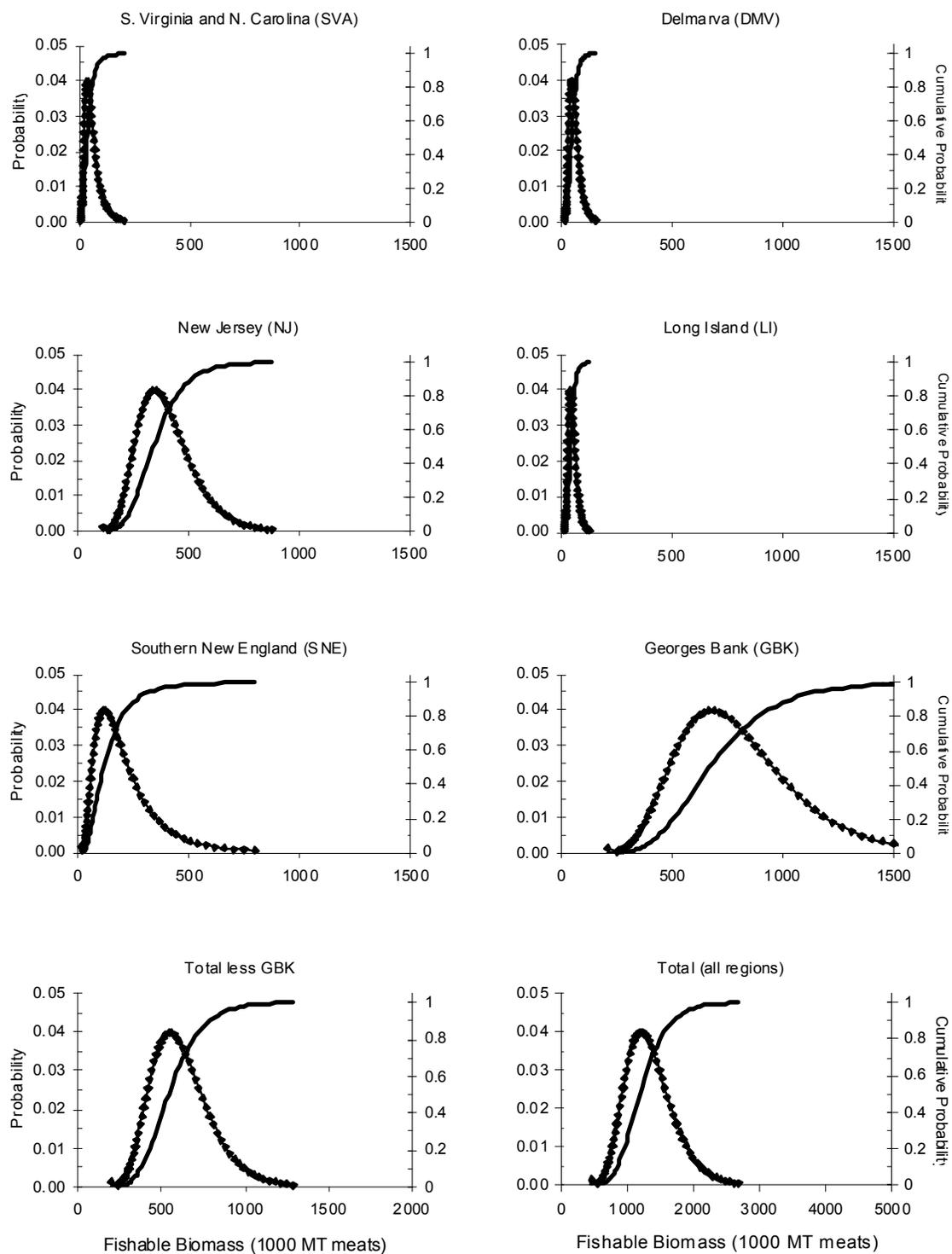


Figure A57. Uncertainty in efficiency corrected swept-area biomass estimates for surfclams.

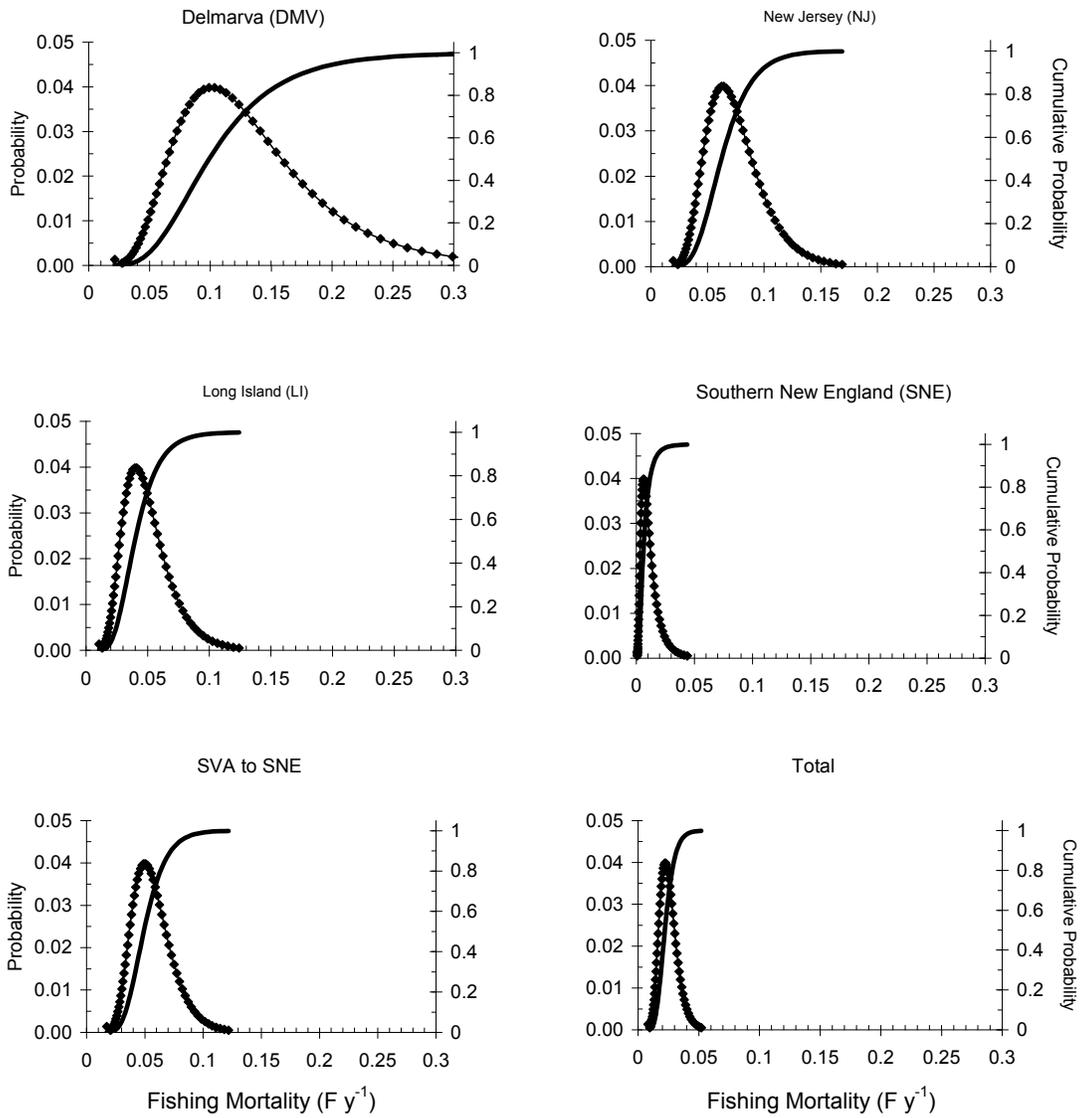


Figure A58. Uncertainty in fishing mortality estimates for surfclams based on catch and efficiency corrected swept-area biomass estimates.

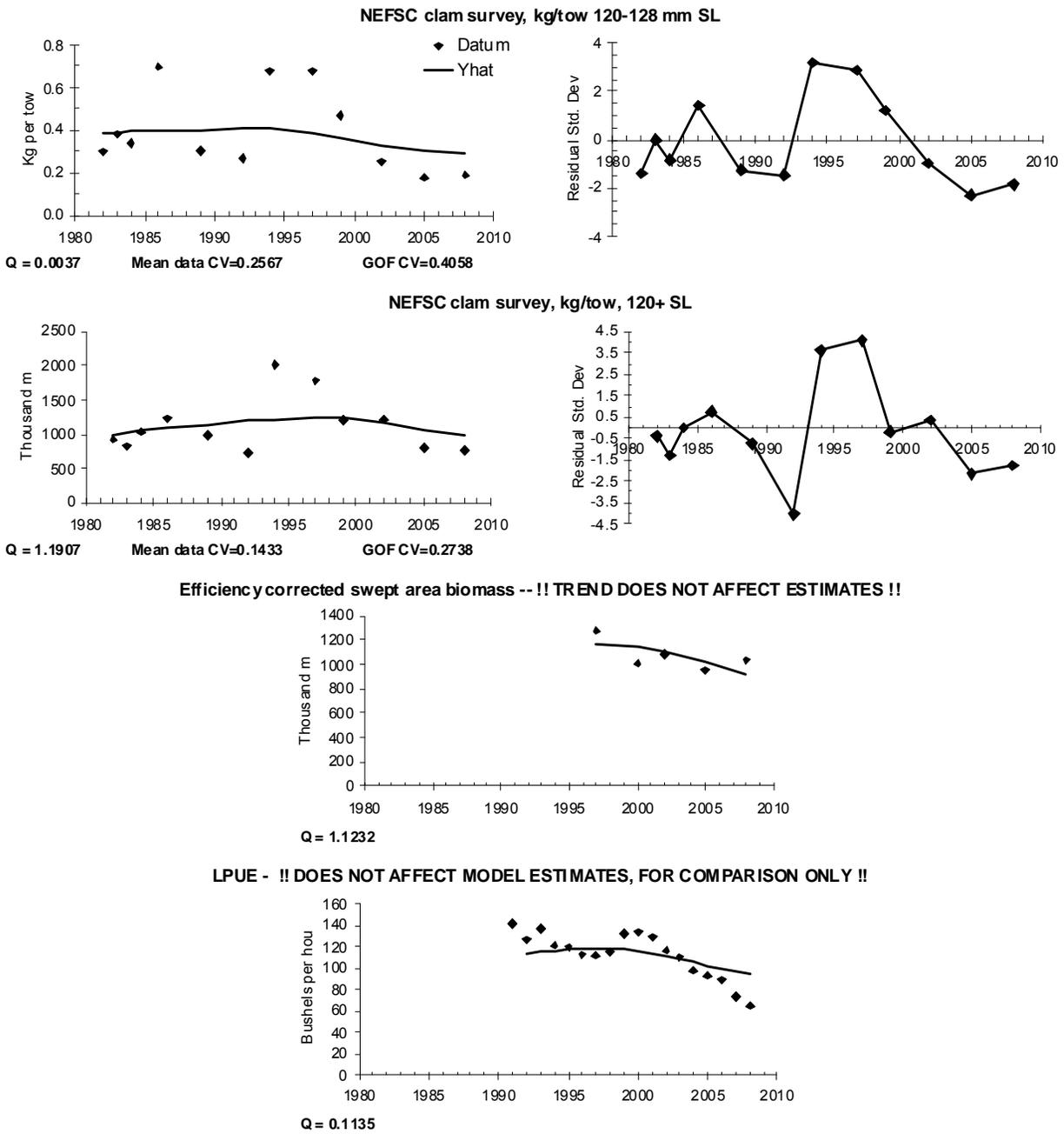


Figure A59. Goodness of fit to biomass trend data for the entire stock of surfclams in the basecase KLAMZ model.

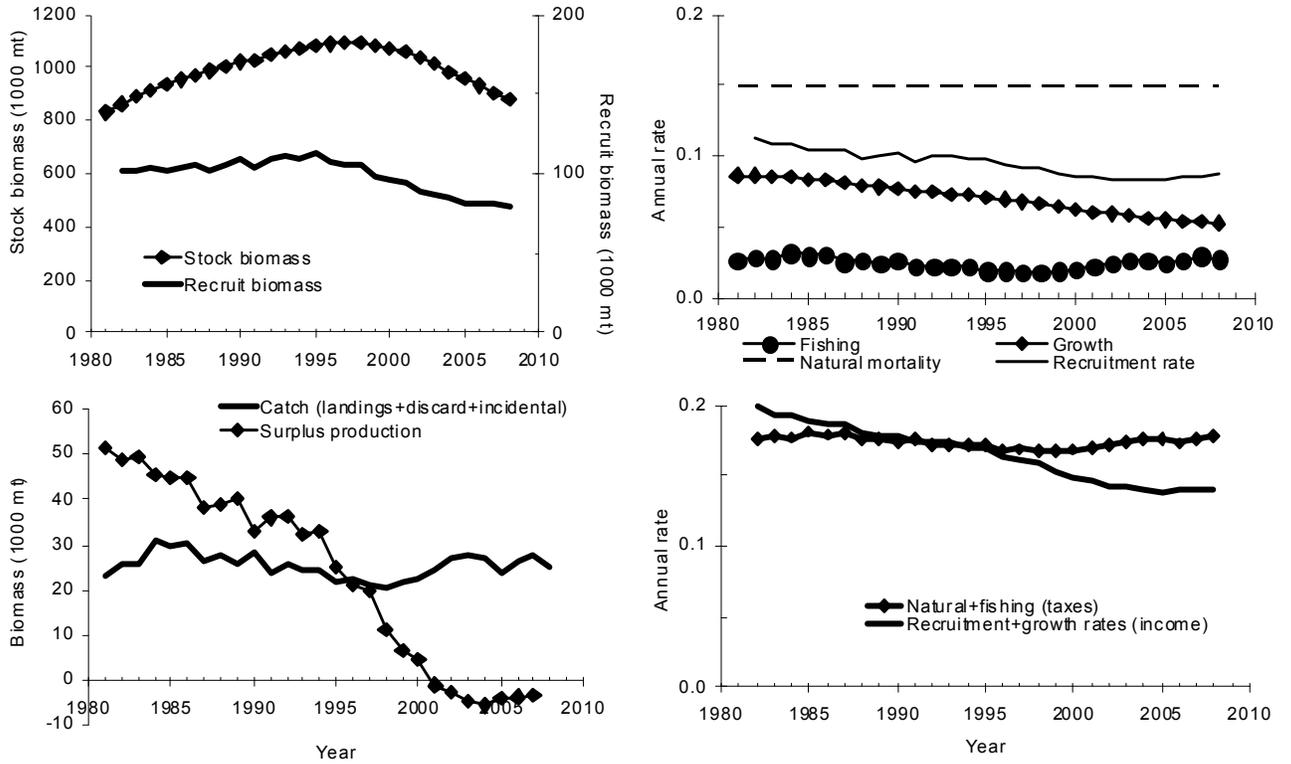


Figure A60. Population dynamics for the entire stock of surfclams estimated in the basecase KLAMZ model, including stock and recruitment biomass (top left), catch and surplus production (bottom left), instantaneous annual rates for fishing mortality, somatic growth, natural mortality and recruitment (top right). The bottom right panel shows combined natural and fishing mortality rates (which decrease stock biomass) with combined recruitment and growth rates (which increase stock biomass).

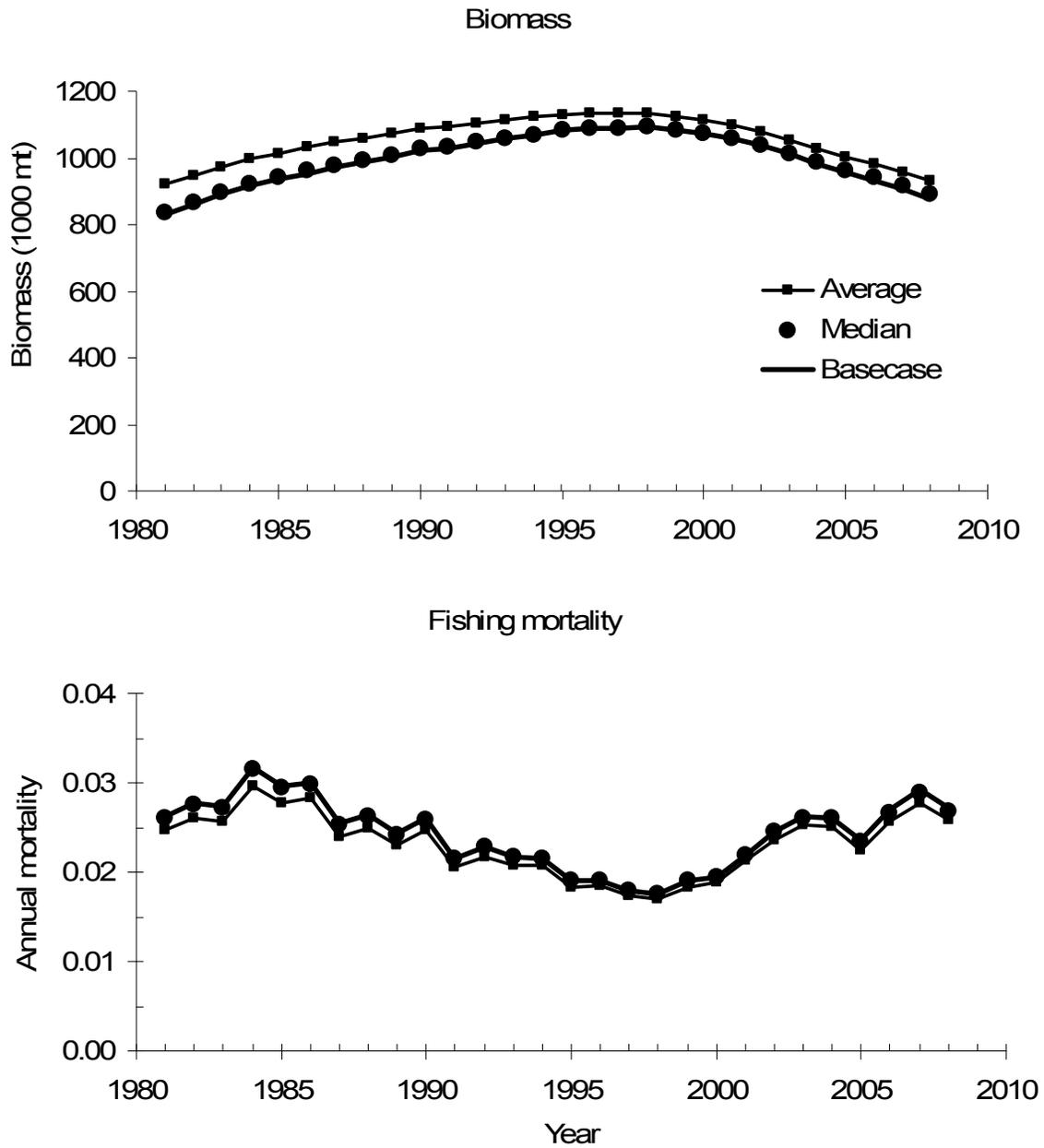


Figure A61. Basecase biomass and fishing mortality estimates compared to the means and median of 2000 bootstrap estimates.

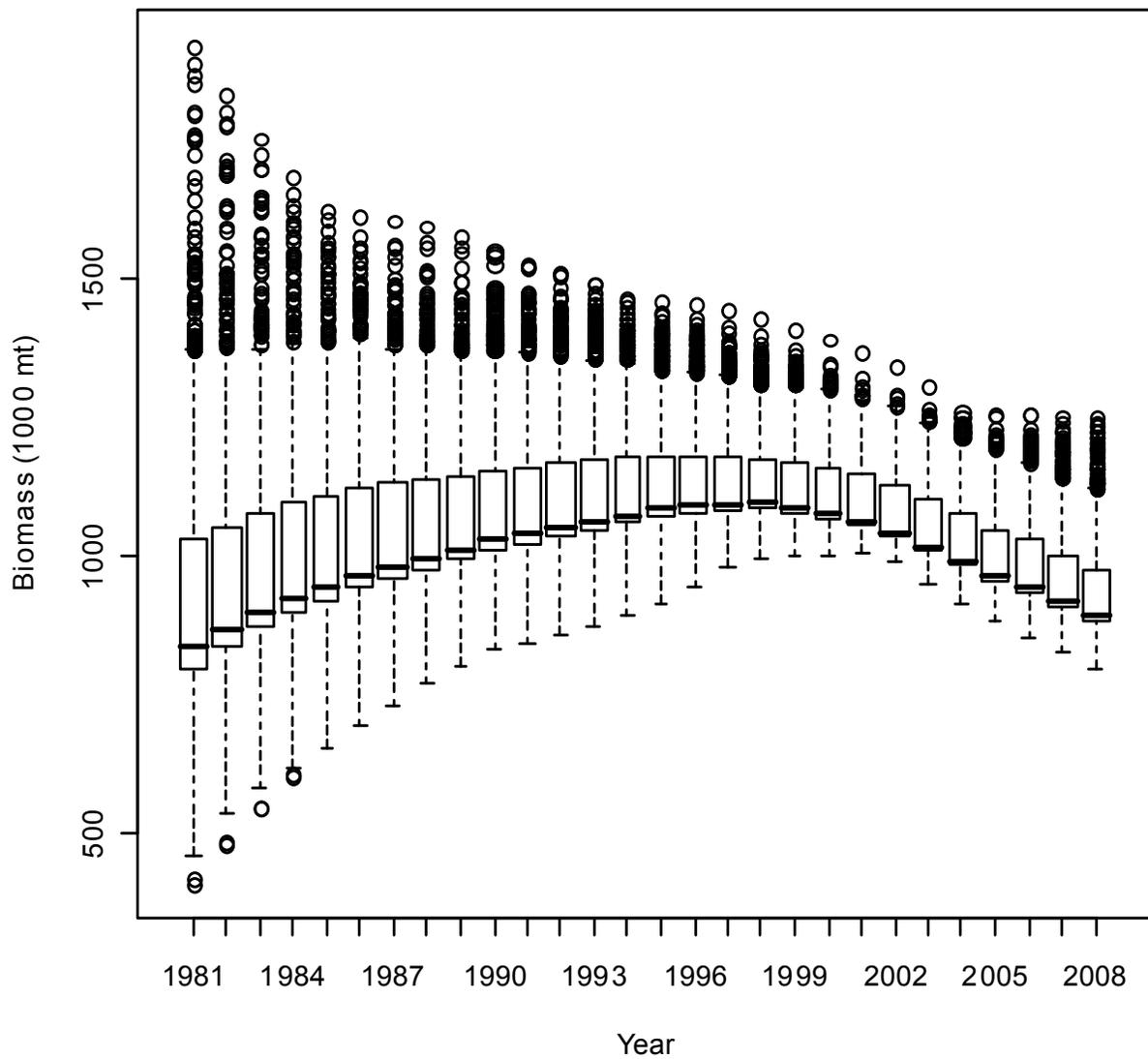


Figure A62. Boxplots showing the distribution of bootstrap biomass estimates for surfclams from for the basecase KLAMZ model.

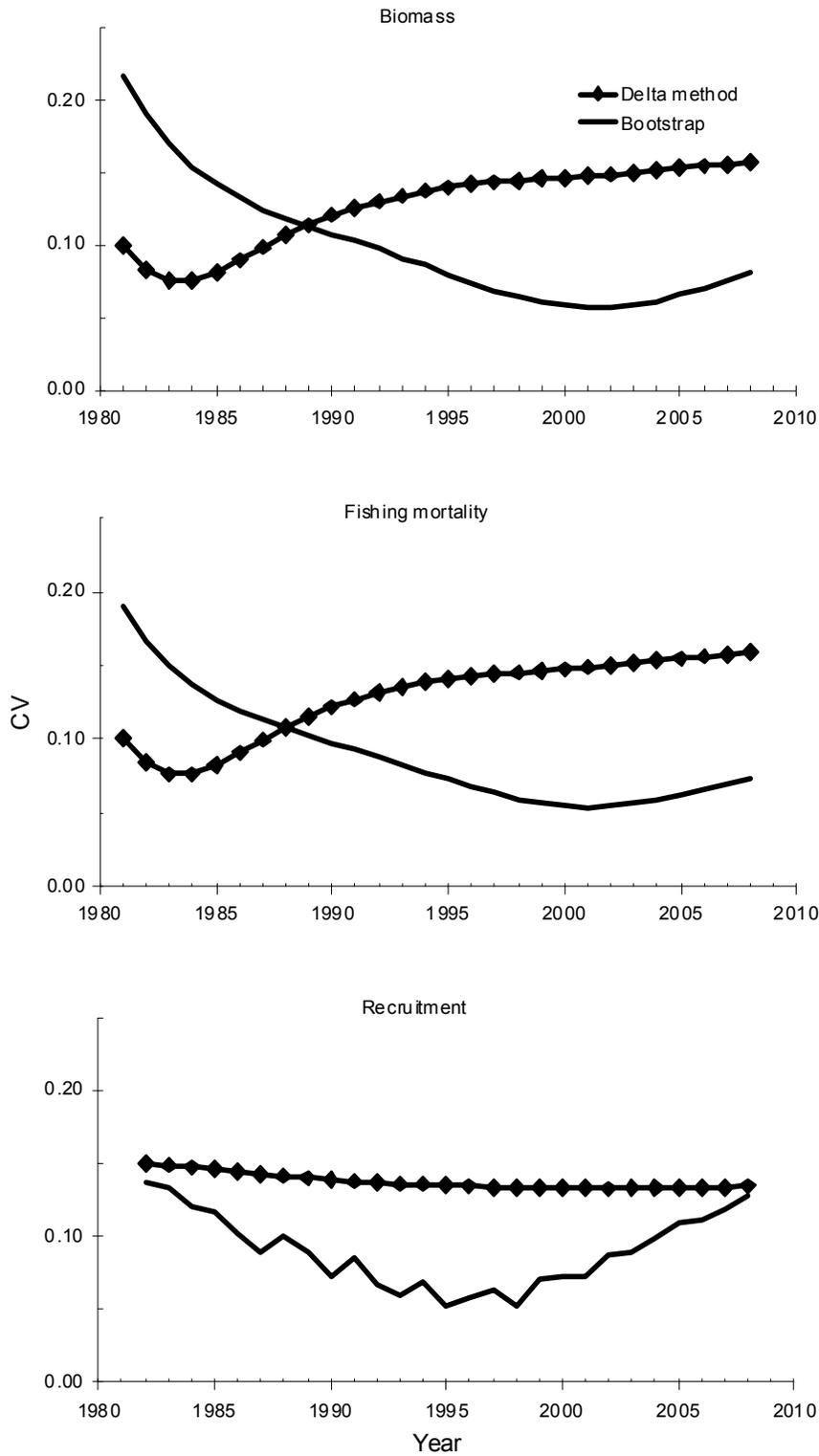


Figure A63. CVs for biomass, fishing mortality and recruitment estimates for the entire surfclam stock from the basecase KLAMZ model, calculated by two methods.

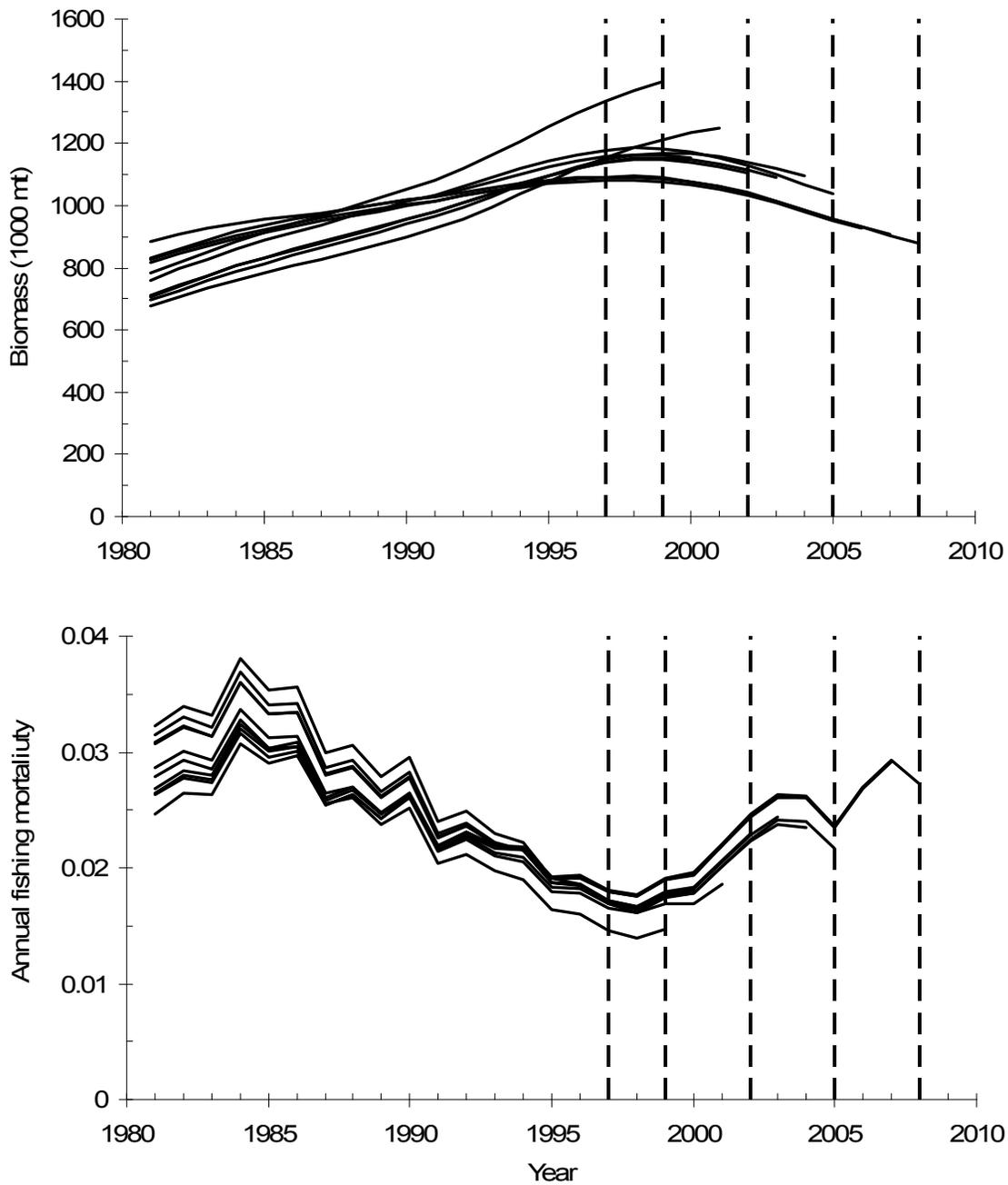


Figure B64. Retrospective analysis with the basecase KLAMZ model for surfclams. The vertical dashed lines show the timing of NEFSC clam surveys.

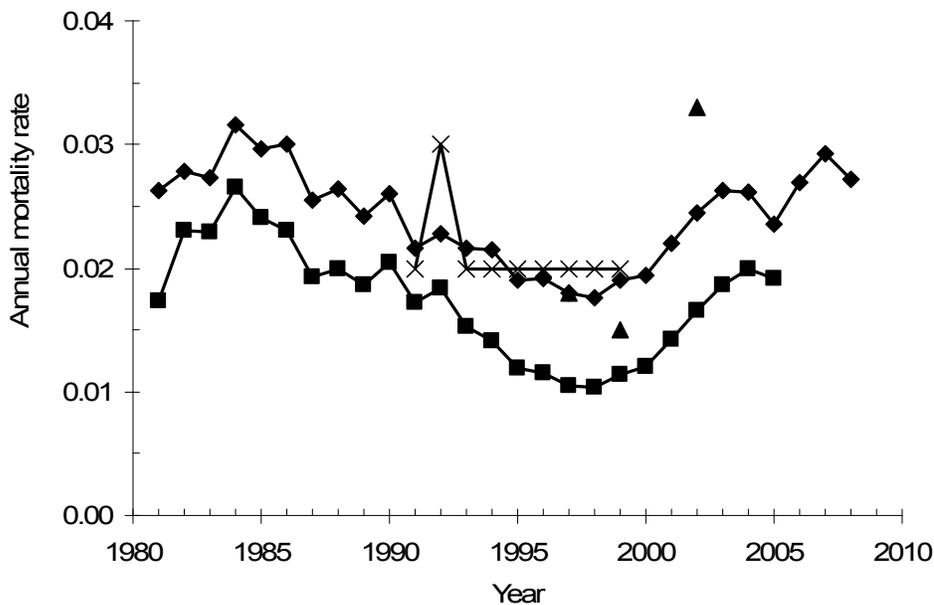
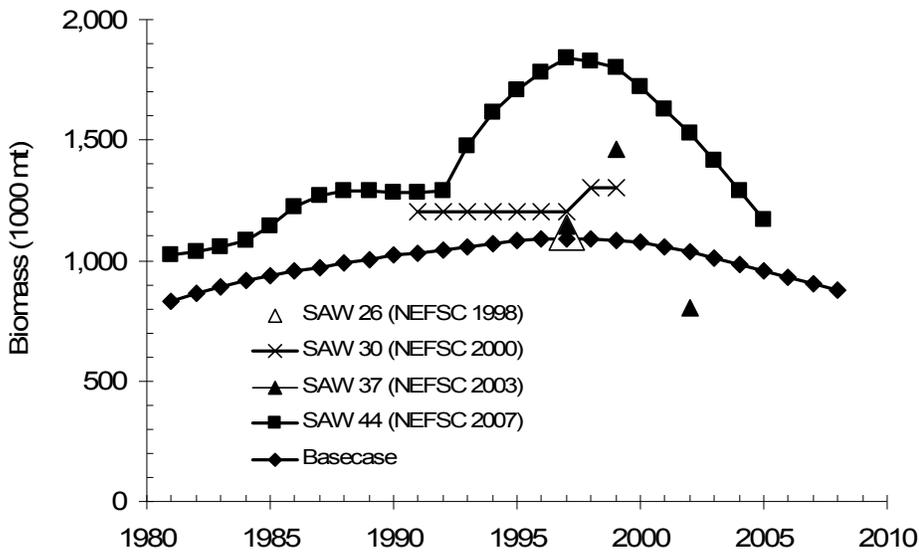


Figure A65. Historical retrospective analyses for biomass (top) and fishing mortality (bottom) estimates from surfclam stock assessments carried out during 1998-present. Estimates in the basecase model (this assessment) and from SAW 44 are from KLAMZ models for surfclams 120+ mm SL. Estimates from SAW 30 (KLAMZ model) and SAW 37 (efficiency corrected swept-area biomass) are for surfclams 120+ mm SL in NJ and 100+ mm SL elsewhere. The estimate from SAW 26 (efficiency corrected swept-area biomass) is for all sizes.

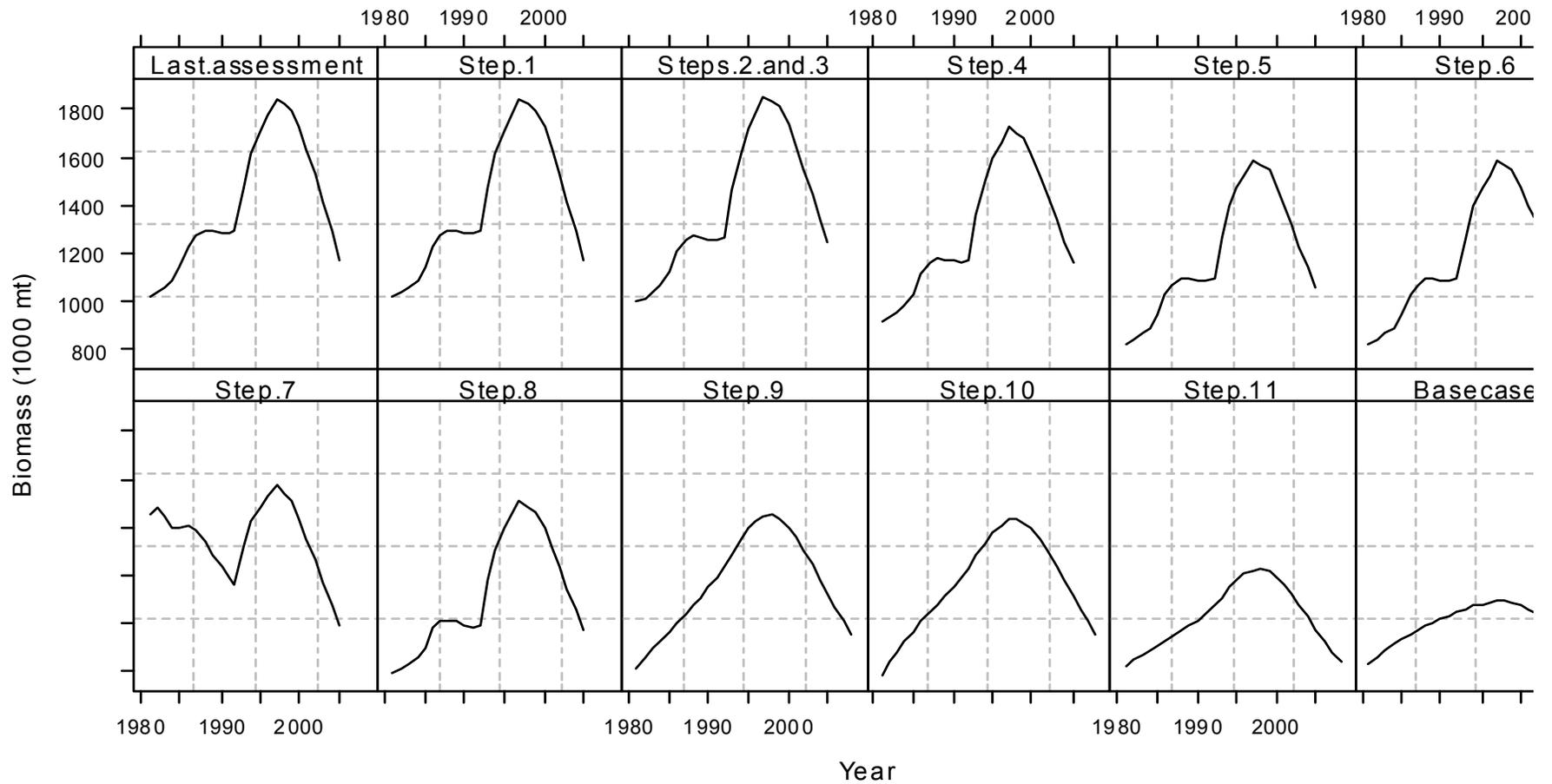


Figure A66. Changes in KLAMZ model data and configuration (“Steps”) responsible for differences between basecase biomass estimates and biomass estimates in the last assessment (NEFSC 2007). See table KLAMZ-2 for details.

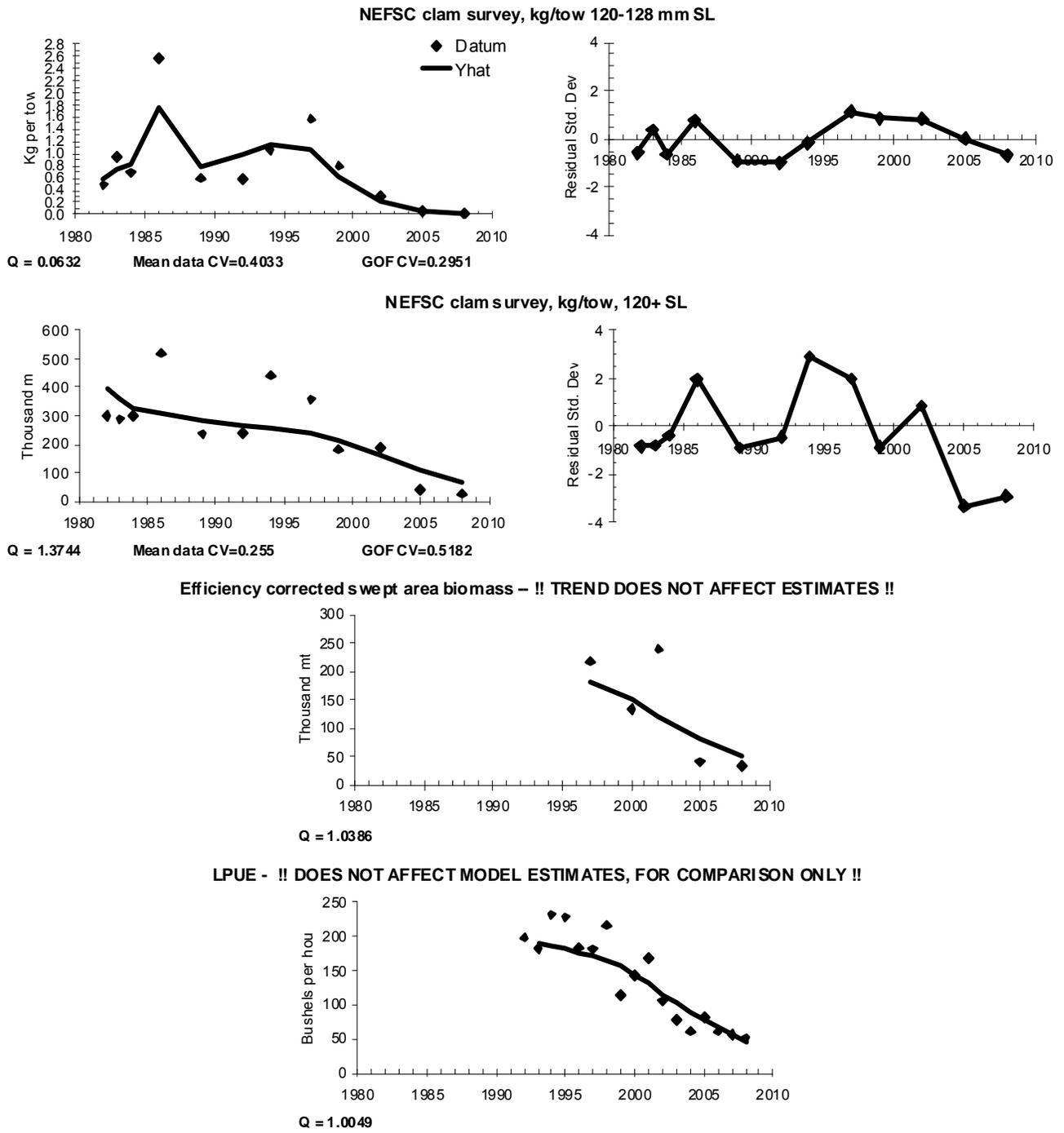


Figure A67. Goodness of fit to biomass trend data for the surfclams in the DMV region.

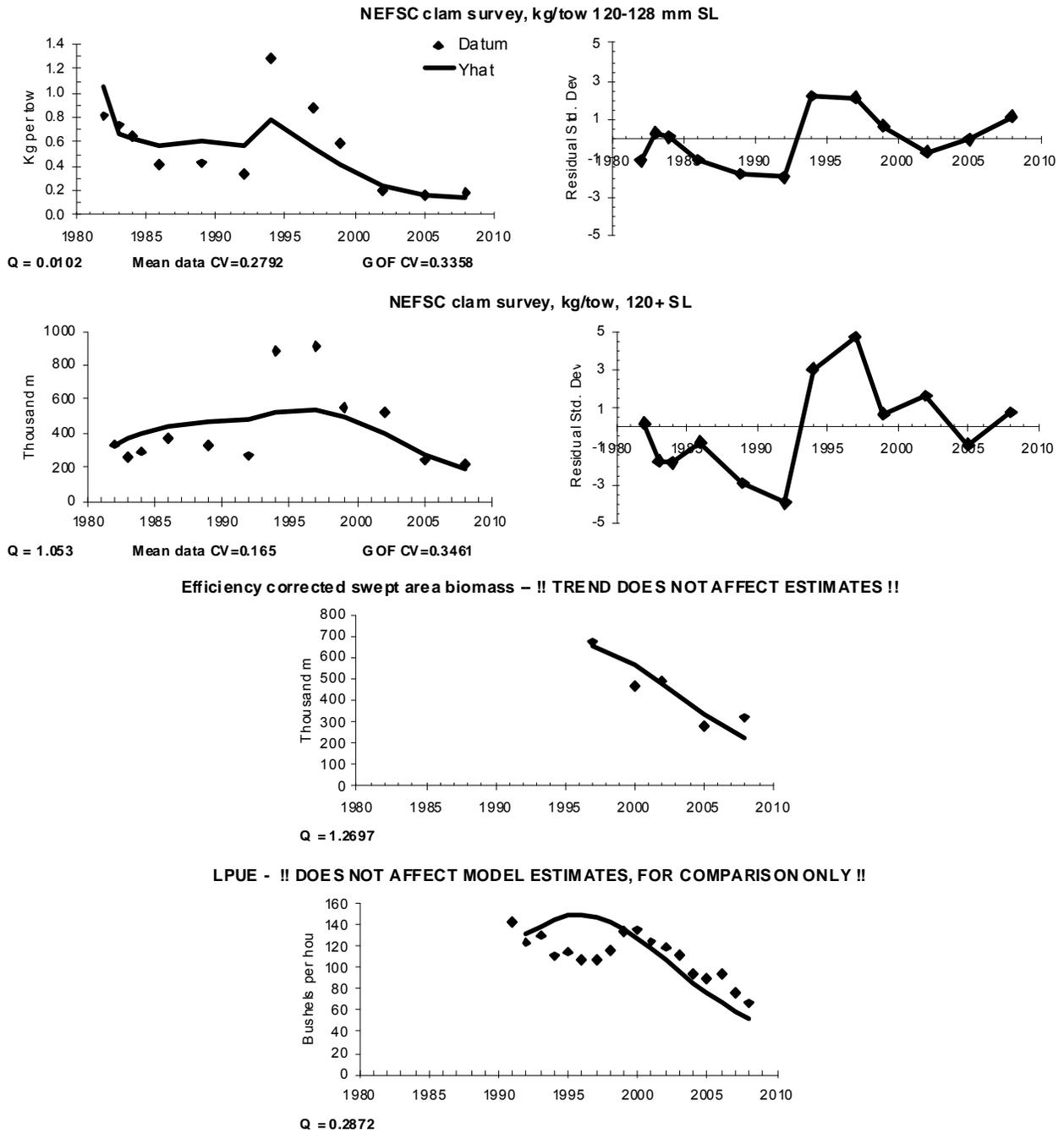


Figure A68. Goodness of fit to biomass trend data for the surfclams in the NJ region.

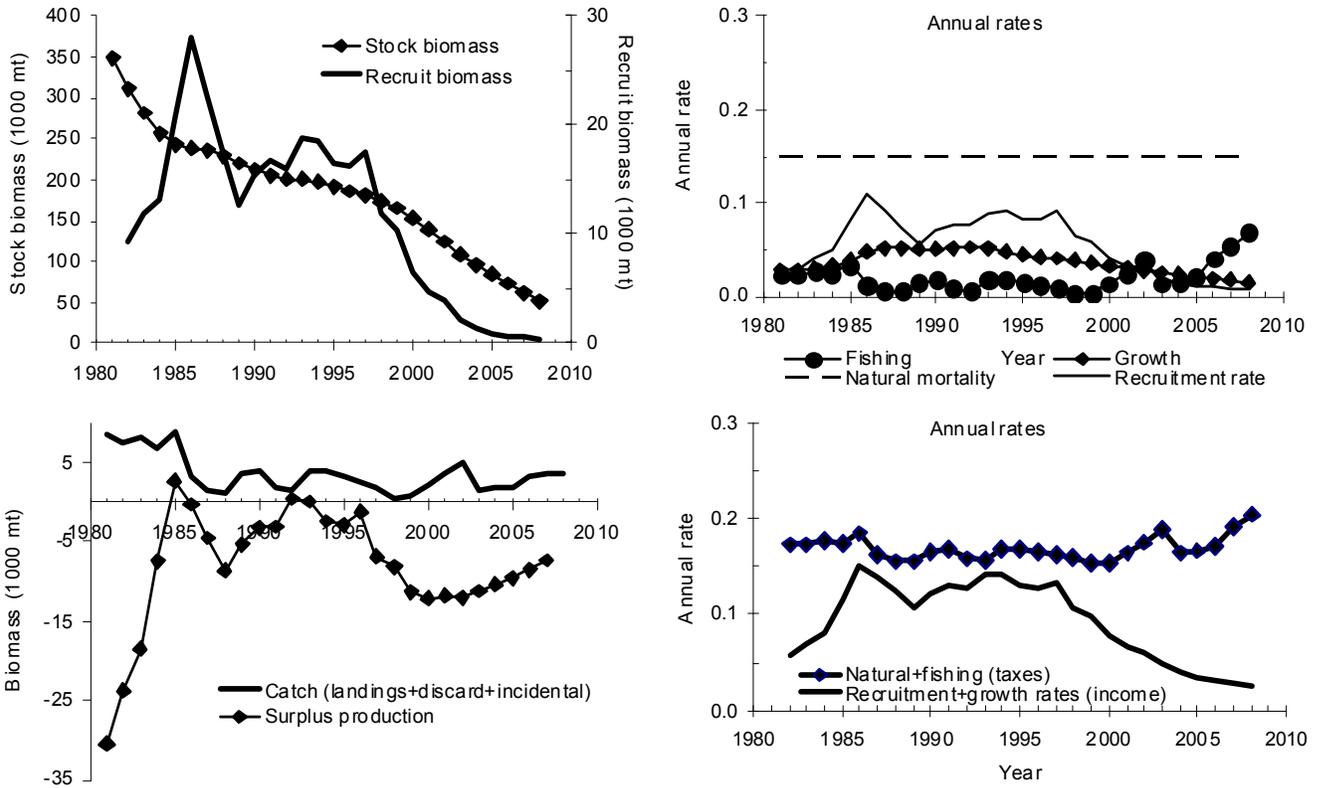


Figure 69. Population dynamic estimates from the KLAMZ model for surfclams in the DMV region. Estimates include stock and recruitment biomass (top left), catch and surplus production (bottom left), instantaneous annual rates for fishing mortality, somatic growth, natural mortality and recruitment (top right). The bottom right panel shows combined natural and fishing mortality rates (which decrease stock biomass) with combined recruitment and growth rates (which increase stock biomass).

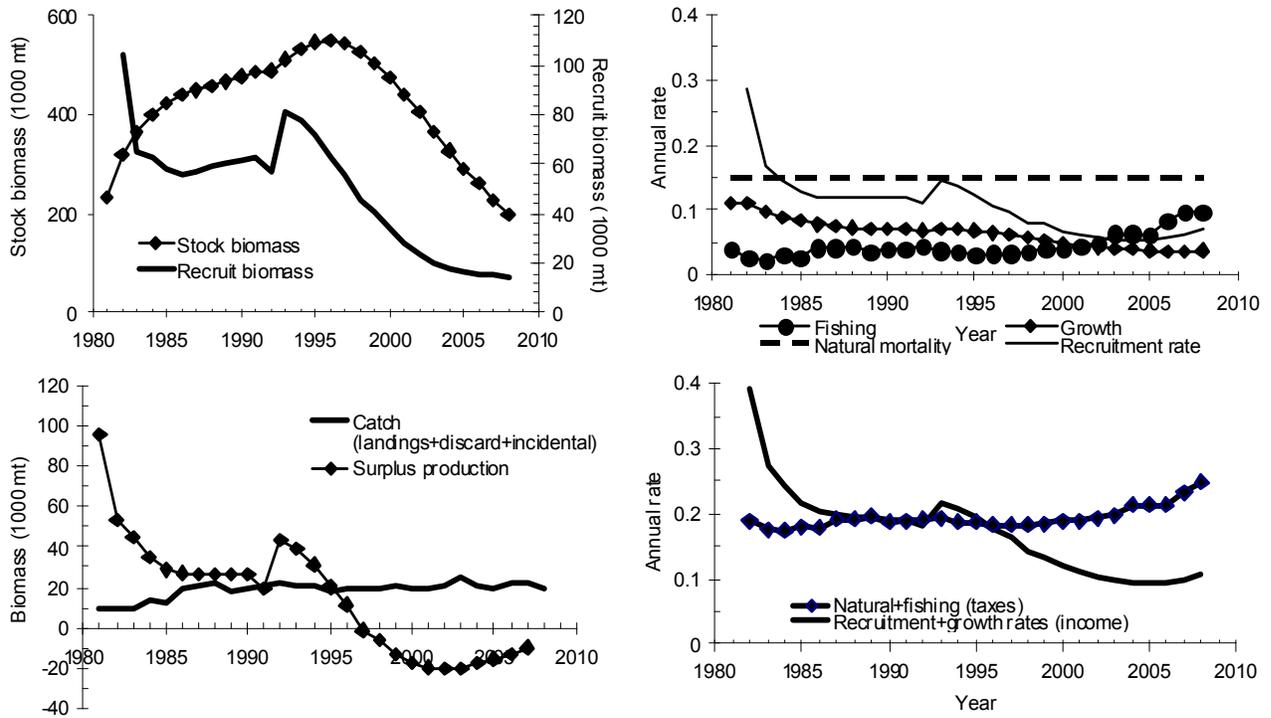


Figure A70. Population dynamic estimates from the KLAMZ model for surfclams in the NJ region. Estimates include stock and recruitment biomass (top left), catch and surplus production (bottom left), instantaneous annual rates for fishing mortality, somatic growth, natural mortality and recruitment (top right). The bottom right panel shows combined natural and fishing mortality rates (which decrease stock biomass) with combined recruitment and growth rates (which increase stock biomass).

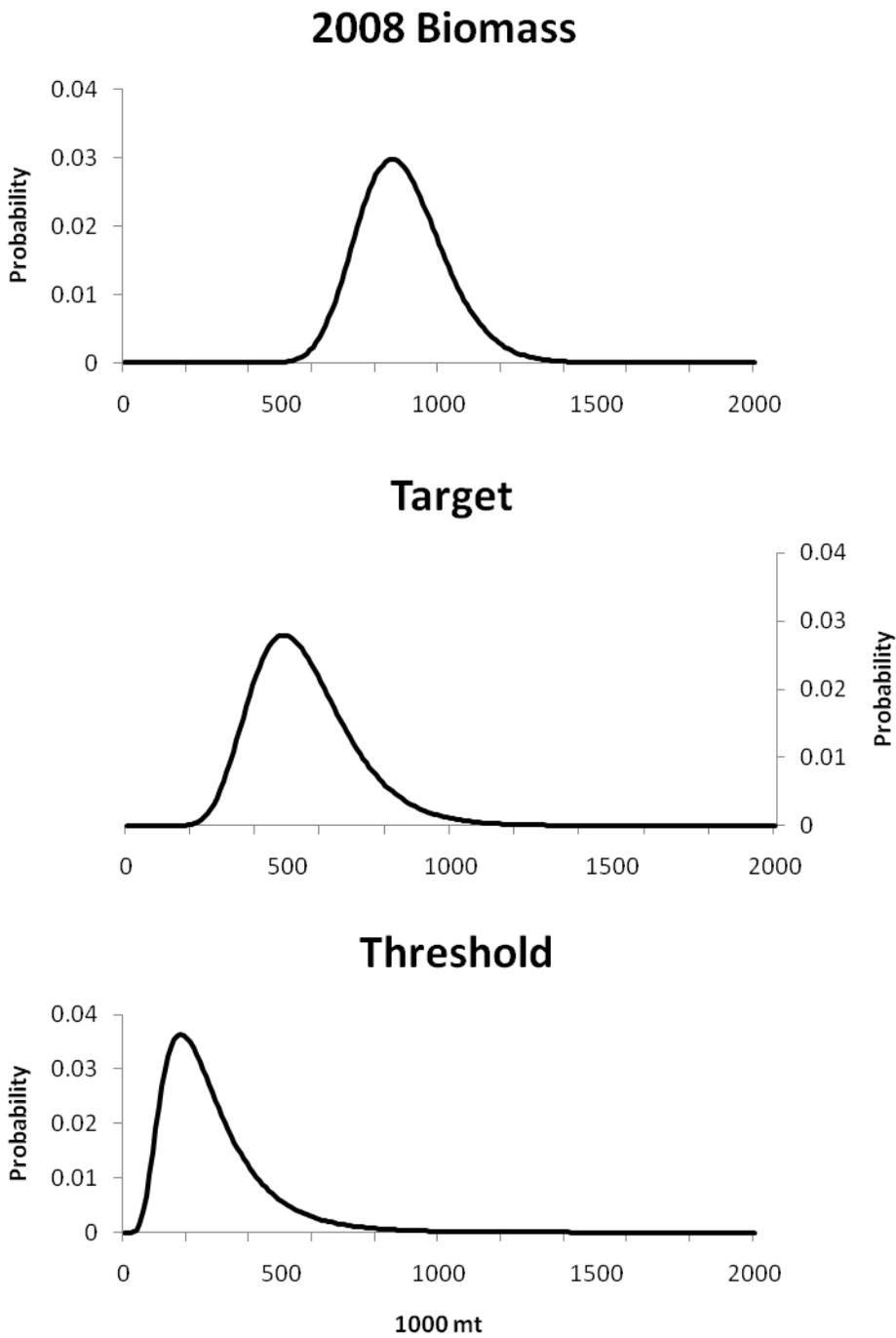


Figure A71. Probability distributions for basecase KLAMZ model estimates of surfclam biomass in 2008, the biomass target ( $B_{1999}/2$ ) and the biomass threshold ( $B_{1999}/4$ ).

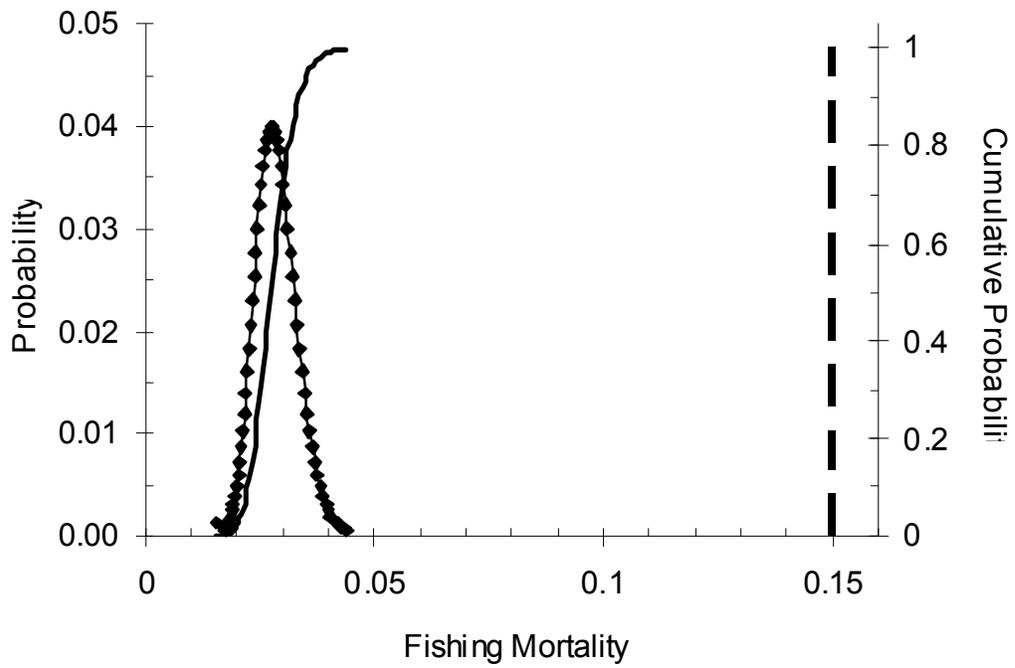


Figure A72. Probability and cumulative probability density functions for estimated fishing mortality during 2008 from the KLAMZ model. The vertical dashed line is the  $F_{MSY}$  threshold reference point.

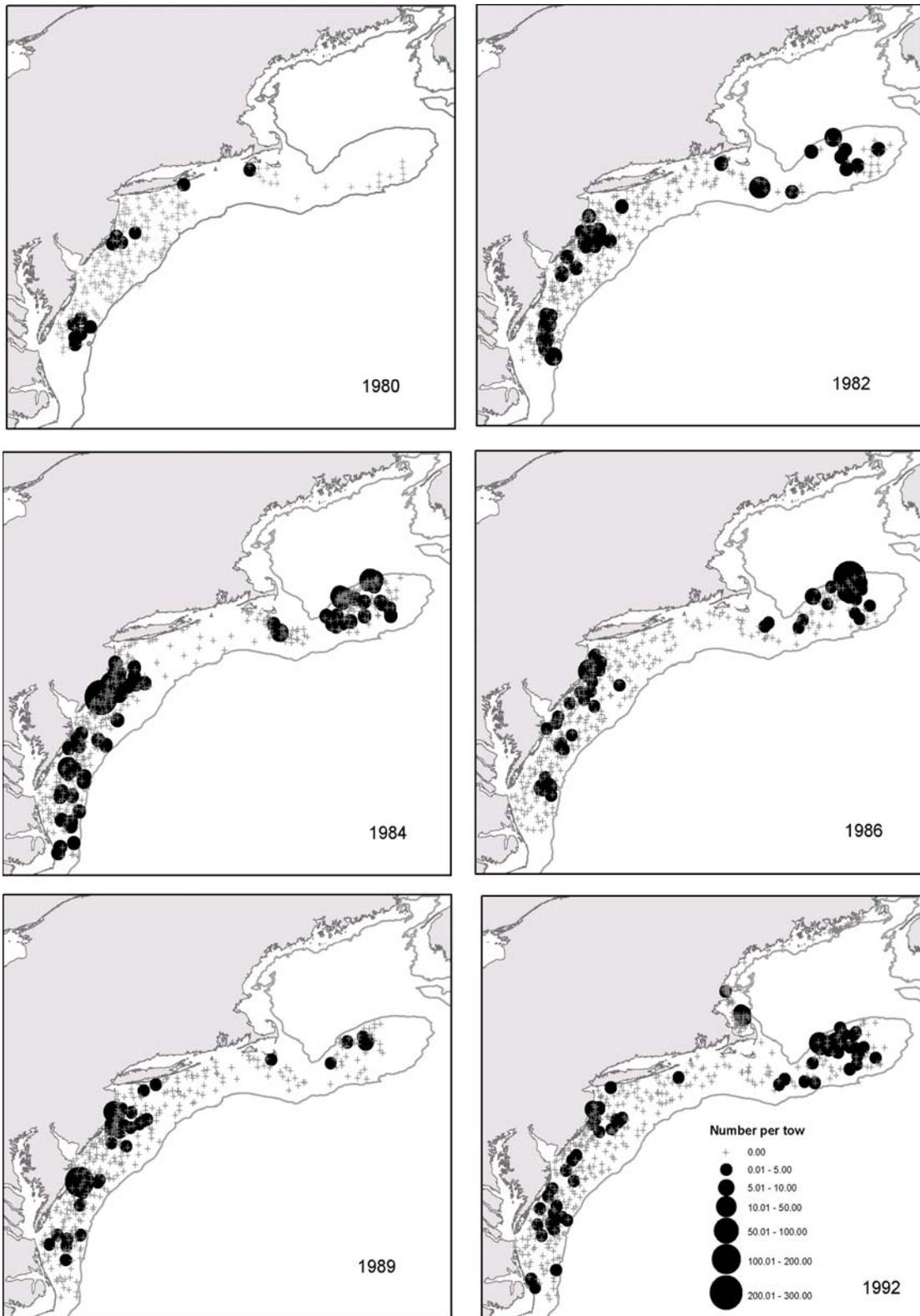


Figure A73. Mean numbers per tow for very small surfclams ( $\leq 60$  mm SL) taken in NEFSC clam surveys during 1980-2008. Not all regions were surveyed in each year.

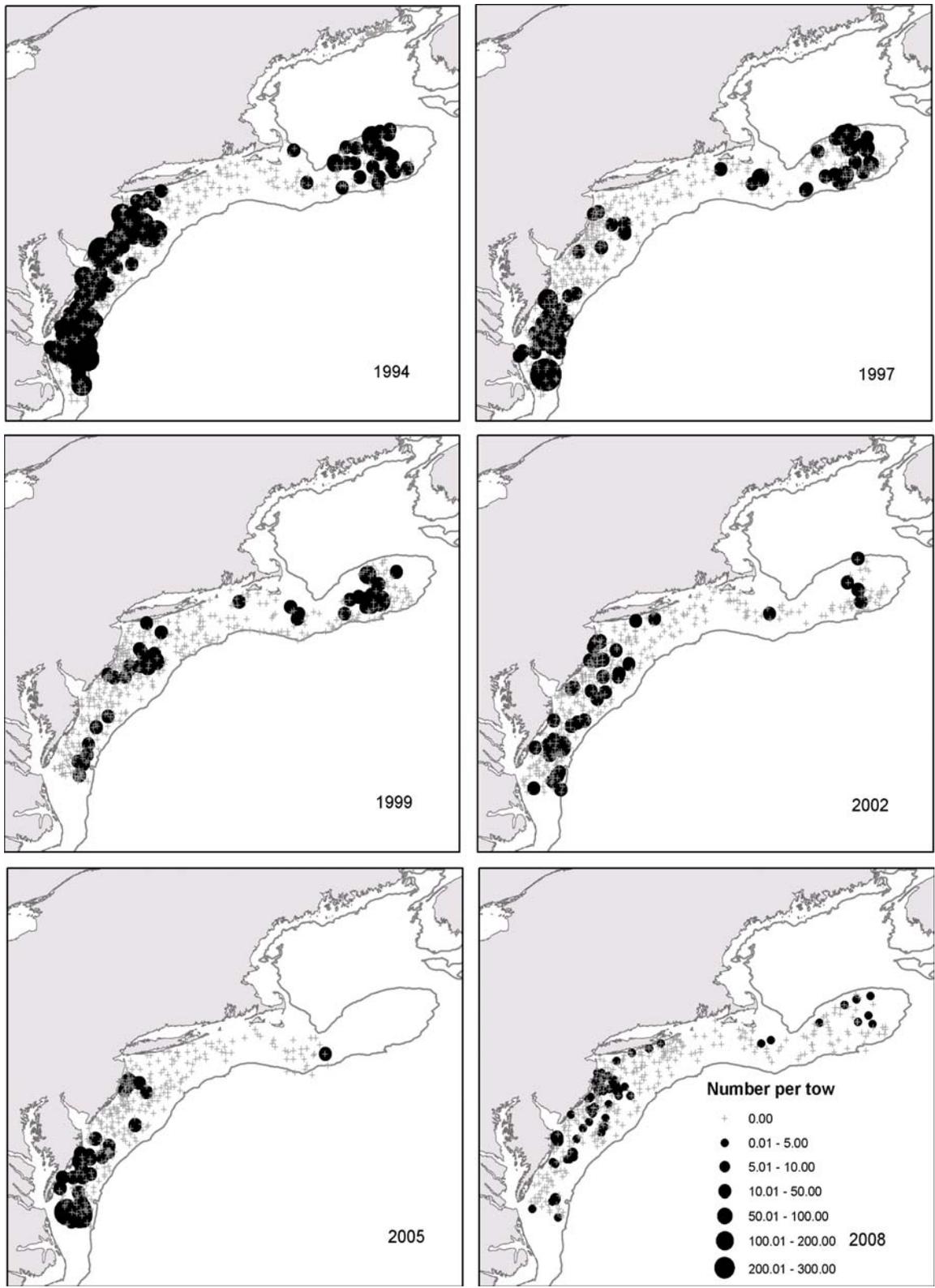


Figure A73. (continued)

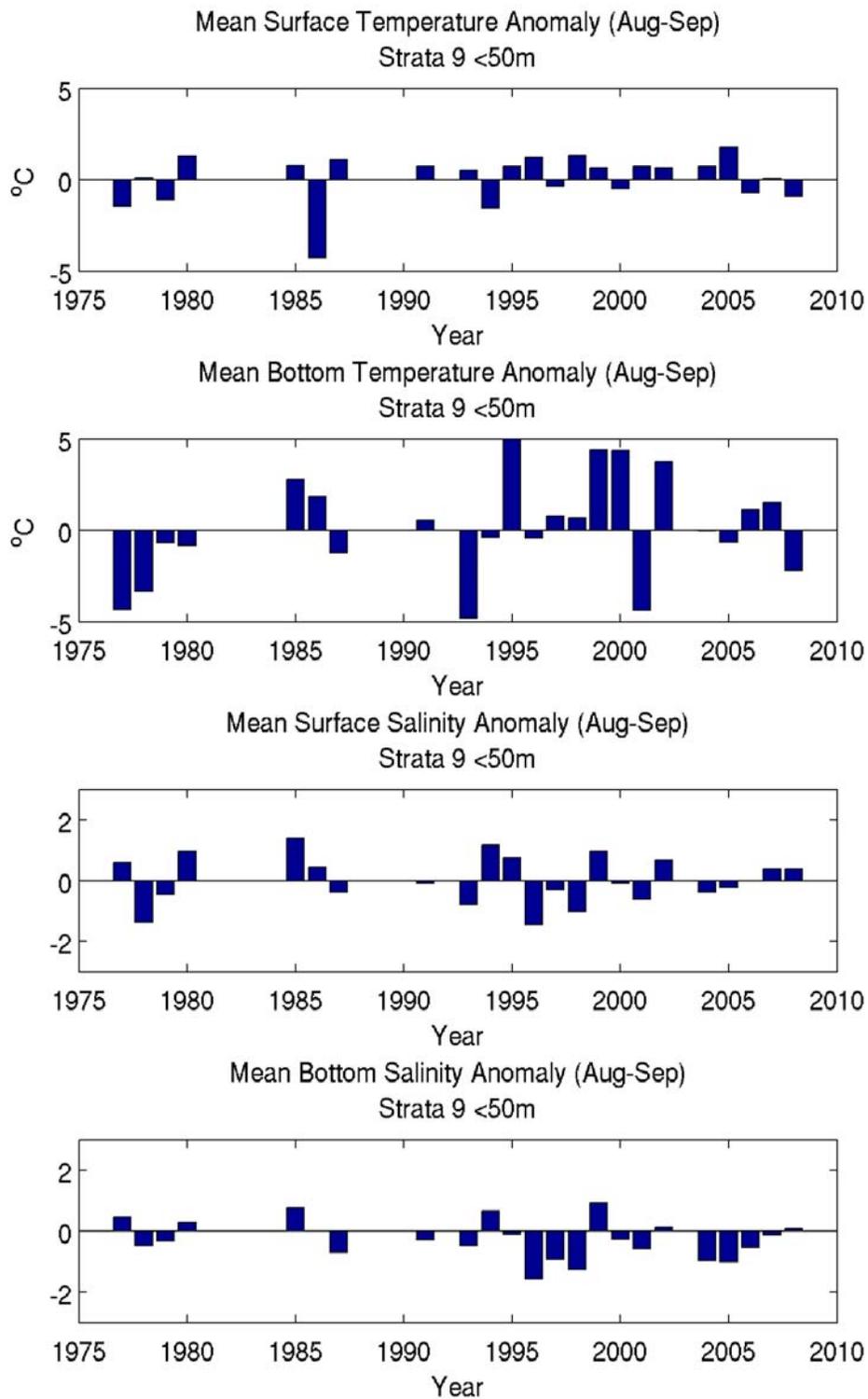


Figure A74. Summer (August-September) temperature and salinity anomalies for NEFSC shellfish stratum 9 (DMV region) at depths  $\leq 50$  m, during 1976-2009, based on data collected during NEFSC surveys.

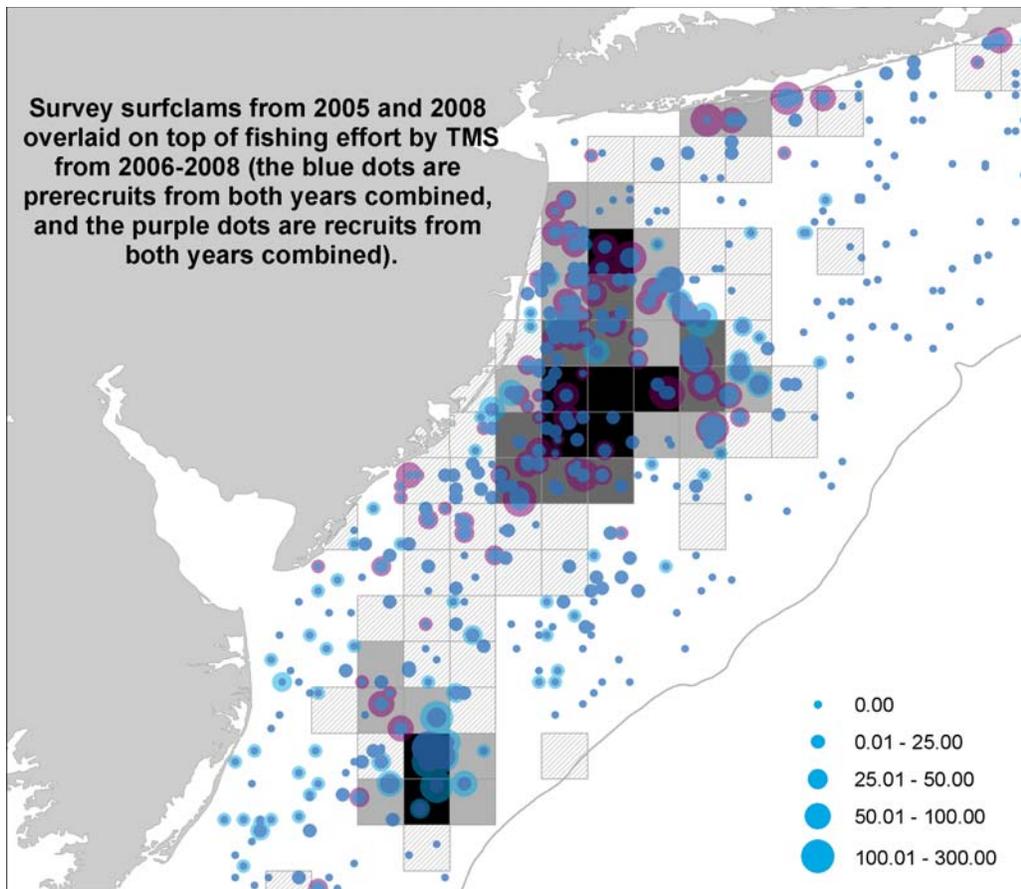


Figure A75. Locations of NEFSC survey catches for surfclams 50-119 mm SL in the 2005 and 2008 NEFSC clam surveys and fishing effort during 2006-2008 based on logbook data. Note that most of the DMV region south of Hudson Canyon was not sampled during 2008.

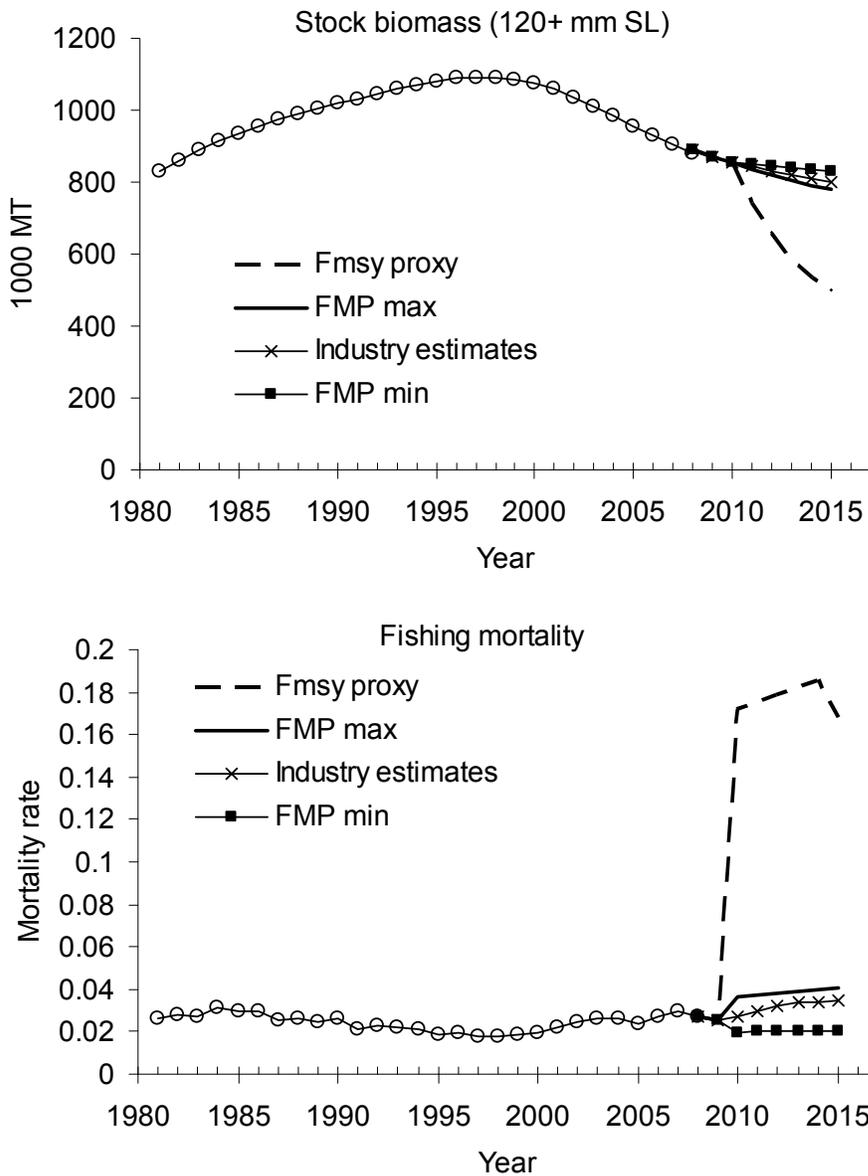


Figure A76. Stock biomass and fishing mortality forecast results for surfclams during 2010-2015 (medians from 2000 iterations), using the basecase KLAMZ model and assuming landings during 2010-2015 that correspond to four different management strategies.

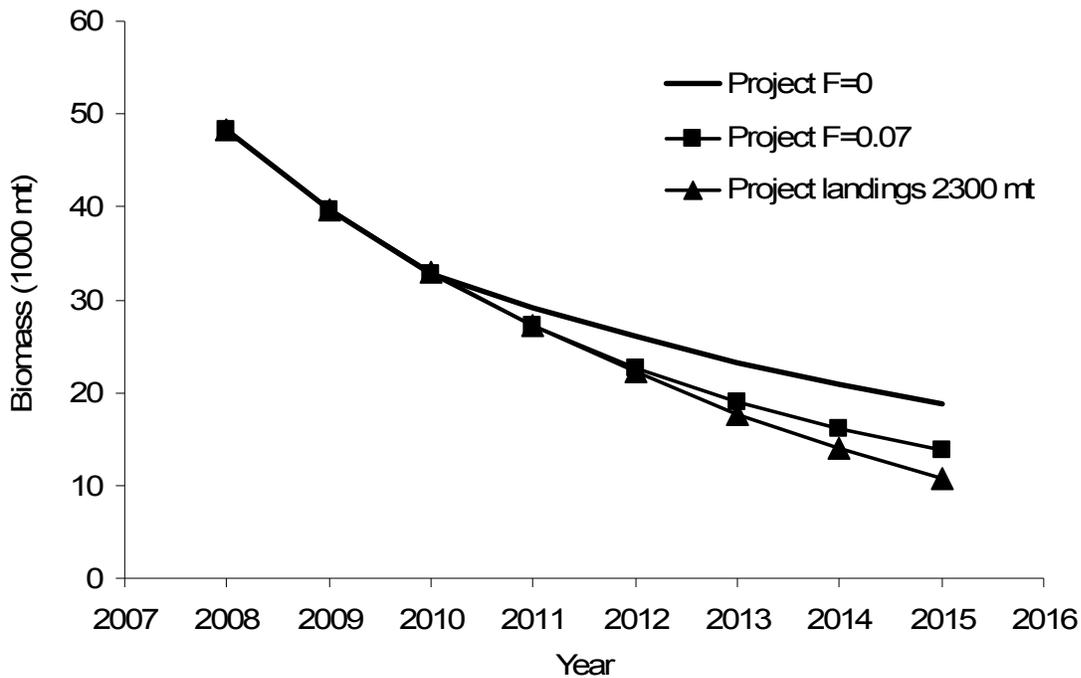
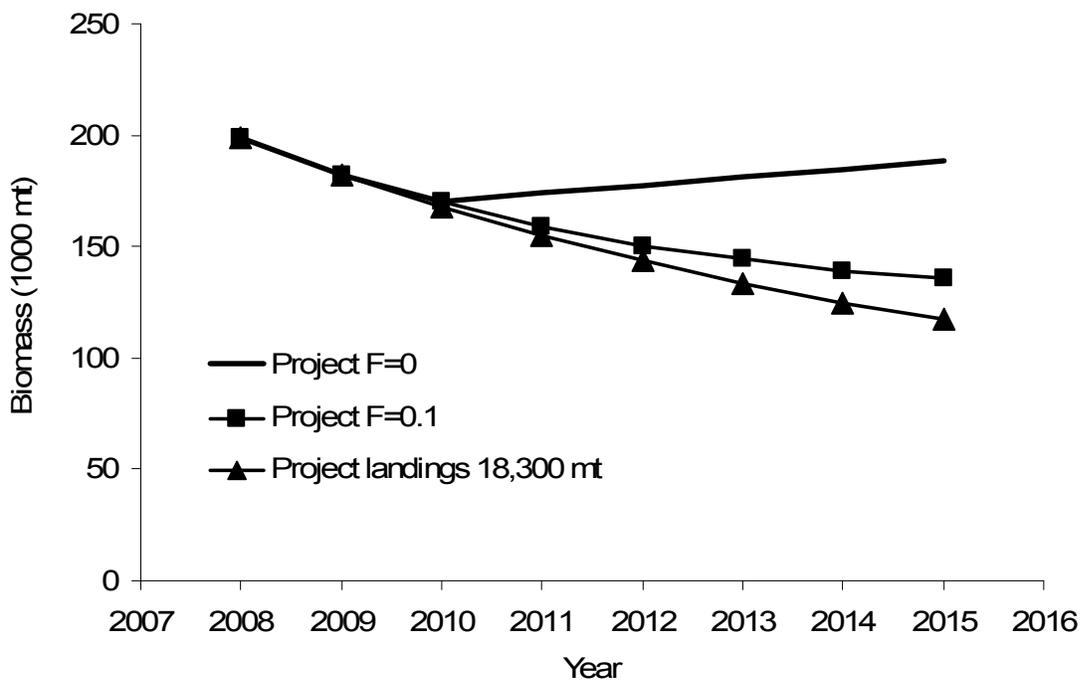


Figure A77. Forecast projection results for DMV under three harvest scenarios.



A78. Forecast projection results for NJ under three harvest scenarios.

## **Appendix A1: Invertebrate Subcommittee**

Persons who attended Invertebrate Subcommittee meetings and contributed to this report are:

Larry Jacobson (NEFSC, Chair, assessment lead)  
Bonnie McCay (Rutgers University)  
Carolyn Creed (Rutgers University)  
Chris Legault (NEFSC)  
Dan Hennen (NEFSC)  
David Wallace (Wallace & Associates, Inc.)  
Eric Powell (Rutgers University)  
Fred Serchuk (NEFSC)  
Jiashen Tang (NEFSC)  
Jeff Normant (NJ Division of Fish and Wildlife)  
Josef Idoine (NEFSC)  
John Womack (Wallace & Associates, Inc.)  
Mark Terciero (NEFSC)  
Paul Rago (NEFSC)  
Roger Mann (VIMS)  
Tom Alspach (Sea Watch International, Inc.)  
Tom Hoff (MAFMC)  
Toni Chute (NEFSC)  
Wade Carden (NYSDEC)  
Wendy Gabriel (NEFSC)

## Appendix A2: Simulation analysis of Patch model estimates

The Patch model (Rago et al. 1996) was tested using simulated data for ocean quahogs and surfclams using the R statistical programming language. The purpose of the simulations was to evaluate model performance under “nominal” conditions (i.e. under the conditions assumed in developing the model), effects of measurement error in position data, assumptions about the spatial distribution of clams, and the size of spatial grids assumed in tabulating position data prior to fitting the Patch model. The simulation analysis involved depicting depletion sites in terms of “cells” (generally 0.25 x 0.25 m) that were small relative to a commercial clam dredge (e.g. 3 m) and the grids that are used in fitting the Patch model (e.g. 6 m). Small cells were used to minimize approximations in simulating the process of a dredge catching clams. Conversion of commercial depletion study results to estimates of survey dredge efficiency was not considered here although it is an important topic for future simulation work.

In the context of the simulations, the most important differences among simulated depletion experiments were the number and spatial pattern of the depletion tows and the species involved. The simulated depletion experiments were based directly on the actual depletion experiments carried out prior to 2008 (17 depletion experiments for ocean quahogs and 22 for surfclams, Table A11-A12 in NEFSC 2008a and Table C13-C14 in NEFSC 2008b). All of the experiments were “commercial” depletion experiments carried out using commercial clam dredges of various widths. Dredge widths assumed in simulations were the same as in the actual experiments.

Simulated depletion study sites were bounded by a rectangle with sides running north-south and east-west (Fig. Sims-1). The simulated study sites were as small as possible with width and length in even multiples the cell size and with a buffer included around the edge of the site that was at least as wide as the dredge. Smaller cells make calculation of simulated catches more accurate but require more computer memory. A cell size of 0.25 m was used in most simulations unless a larger cell size (e.g. 0.5 m) was required to conserve computer memory.

Position data for simulations were the same as smoothed data actually used in the Patch model (NEFSC 2008a, b). There are differences in position data among real depletion experiments that affect accuracy of the actual data but these differences had no impact on simulation results. In particular, there were differences in recording interval, data recording method, and the instruments used to measure position (e.g. various GPS, and Loran-C devices). Similarly, there were differences between experiments in crew, vessels and dredge width, although differences in dredge width were incorporated into the simulations and the Patch model. In general, depletion experiments made during the same year were more similar than depletion experiments made in different years, as the same vessels, commercial dredge and crew were usually used for most or all experiments in any one year. The chief scientists’ approach to choosing tow paths was similar for all experiments during any one year but generally changed over time.

In most simulations, surfclams and ocean quahogs were assumed to be distributed across the bottom of the experimental site according to a negative binomial distribution  $NB(\mu, k)$  with parameter  $\mu$  measuring the mean density and dispersion parameter  $k$  measuring contagion or “clumpiness”. The dispersion parameter  $k$  is negatively correlated with variance,  $\sigma^2 = \mu + \frac{\mu^2}{k}$ . As  $k \rightarrow \infty$ , the negative binomial distribution approaches the Poisson distribution with mean and variance  $\mu$ . The negative binomial distribution has a useful property (pointed out by Jiashen T.)

that is used in the simulations. In particular, if  $X_i \sim \text{NB}(\mu, k)$  then  $Y = x_1 + x_2 + x_3 + \dots + x_n \sim \text{NB}(n\mu, nk)$ .

We simulated the distribution of clams in depletion experiments using negative binomial distributions with parameters on a per unit area basis (Appendix Table 2-1). Ocean quahogs had a higher density and dispersion parameter (lower variance) than surfclams. The per unit area parameters were based on the median density and dispersion parameter estimates from the real depletion experiments for ocean quahogs and surfclams. For example,  $\mu$  per unit area was the mean density estimate for all of the ocean quahog experiments. The per unit area dispersion parameter for ocean quahogs for experiment  $j$  was  $\frac{k}{\bar{a}_j}$ , where  $k$  was the median dispersion parameter for ocean quahog depletion experiments, and  $\bar{a}_j$  was the mean area swept by all tows in the experiment. If the spatial cells used in the simulation were  $0.25 \times 0.25 = 0.0625 \text{ m}^2$ , for example, then the negative binomial distribution used to populate the cells was  $\text{NB}(0.0625 \mu, 0.0625 k)$ .

In simulations and recent assessments, position data were assumed to track the center of the dredge. The assessment algorithm calculates catch assuming that all model grids are hit by the dredge if they intersect straight lines drawn between adjacent position observations. The simulation algorithm is potentially more accurate because it is based on smaller population cells and because the width of the dredge is included in calculating catch. The assessment and simulation algorithms both assume the clams in each grid and cell are mixed randomly prior to each tow.

The path of each tow in simulations was represented as a series of segments composed of rectangles and triangles centered on the straight lines between sequential position observations. The rectangle for each segment was as wide as the simulated dredge and as long as the distance between the position observations. Overlap of sequential rectangles and additional area swept when the dredge changed direction between segments were modeled as triangles and included in calculations (Appendix Figure A2-1).

The simulation was similar to an individual-based approach because catch from each population cell contacted by the dredge was determined by a random number for each resident clam and the assumed dredge efficiency. The simulation algorithm assumes that all of the clams in cells wholly within a rectangle are vulnerable to fishing. Rectangles partially covered by the dredge have a reduced probability  $f$  of capture, where  $f$  is the fraction of the cell covered by the dredge. Thus, the probability of capture for a clam in a cell contacted by the dredge is  $p = ef$ , where  $e$  is the assumed capture efficiency for the simulated dredge and  $f = 1$  for cells completely within the dredge path. To simulate the catch process, a uniform random number  $r \sim U(0,1)$  was drawn for each clam in cells contacted by the simulated dredge. A clam was added to the catch and removed from the simulated population if  $r \leq p$ . The number of clams in a population cell was always an integer greater than zero. All clams remaining in a cell after a dredge passed through were assumed to be randomly mixed and equally available for capture in a subsequent tow.

Procedures used to prepare data and fit the Patch model were basically the same as in the previous assessment NEFSC (2008a,b). The simulation software estimated transformed parameters  $\log(D)$ ,  $\text{logit}(e)$  and  $\text{logit}(k/k_{\max})$  where  $k_{\max} = 15$  is an upper bound on  $k$ . Rago et al. (1996) estimated arithmetic scale parameters. Following NEFSC (2006a,b) the Patch model parameter  $\gamma$  was omitted from the model. Rago et al. (2006) used  $\gamma$  to measure “indirect” effects on catches but the parameter has proven difficult to estimate in practice.

Software used for assessments determined intersections between tow lines and model grids by examining each individual interpolated position value, while the simulation used a geometric approach. However, this difference had little effect on results because the interpolation involves narrowly spaced points. Tests showed that simulation software and assessment software gave the same answers when applied to the same data.

Each simulation was run for each site using the actual tow paths recorded for each survey. A survey run involved calculating the number of clams caught by each tow in a survey, and supplying the patch model with the resulting catch totals and a matrix of the number of grid cells that were fished multiple times on successive tows (the hit matrix).

### *Scenarios and results*

Simulation scenarios tested the affects of several variables on the patch model's ability to estimate parameters with known values. We tested three different grid sizes: grid size 1x was equal to the width of the dredge, 2x was equal to twice the width of the dredge and 3x was equal to three times the width of the dredge. We considered two spatial manipulations to the clam distribution over the site: "cross" and "parallel". Each moved 50% of the clams from one side of the site to the other, in a direction that was across the main trajectory of the tow paths or along it, respectively. This created an uneven spatial distribution of clams in the study site where the density on one side was approximately twice as high as on the other. Finally, we considered a position error by adding a sinusoidal error term to each recorded position in each tow. This was thought to mimic the error produced by a GPS unit placed high on a ship that is rolling in the waves.

Increasing the grid size had a moderate effect on the performance of the patch model. The spatial manipulations had a more substantial effect, particularly in the case of the parallel permutation. Adding positional errors had no discernable effect on the performance of the patch model (Appendix Figures A2-2 and A2-3). Absolute relative median errors in density and efficiency showed the same general patterns (Appendix Tables 2-2). That is, a small affect of increasing the grid size, a moderate affect due to the spatial permutations in clam distribution and virtually no affect due to the inclusion of positional errors.

### *Discussion*

The patch model performed well in the scenarios explored here. Performance was generally better for ocean quahogs than surfclams, but that may have been due to the inclusion of a few surveys that had particularly poor accuracy in the surfclam dataset. These generally resulted from surveys in which very few (< 10) tows were made. We can think of no other *a-priori* reason for differences in performance along species lines, unless there is an interaction between the starting parameter values for density and dispersion, and the patch models ability to estimate those parameters. We will continue to investigate this question in the next iteration of this study.

Increasing grid size tended to increase the magnitude of the error in the density and efficiency estimates from the patch model. The increase was slight and expected. The patch model assumes that each animal within a grid cell undergoes random redistribution after the fishing apparatus passes through. This assumption grows less realistic for clams as the grid cell size increases. Our simulation uses cells, rather than grids to place clams and then remove them as a result of fishing. Cells are small relative to grids and a random mixing of animals within a cell is probably closer to what occurs in nature. Thus the poor performance of the patch model at

larger grid sizes is likely a reflection of the extent to which the assumption of random mixing fails to describe the underlying process for generating catches.

The patch model performed better when tows were taken across patches of clams rather than along them. This orientation would tend to provide tows with consistent catch sizes (if they were taken through equally un-fished grids), while tows taken parallel to the clam bed would provide more variable catches (high when taken through the clam patch and low when taken outside the patch).

Positional errors had nugatory effects on patch performance. This result was somewhat surprising and may be due to the fact that our error term was not random with respect to position, as the error was always zero at the start of a tow. Tows typically started at (approximately) the same place in a survey site and thus our error term may have had merely displaced the tow paths more or less uniformly, which would have little effect on the hit matrix and thus little effect on patch model performance. Additional work on this topic will be done in the next iteration of this study.

This analysis shows that the patch model will probably perform better when survey tows can be oriented across a patch of clams rather than along it. This result has limited practical value unless the dimensions of a clam patch can be described before a survey tow begins. There may be a way to do this using a camera, or set up tows, or it may be financially impractical. Investigation on this topic would be useful. It is also clear that more than 10 tows are required to achieve decent results using the patch model for these species. More work will be done to find an optimal sample size given certain starting conditions in the next iteration of this analysis.

### *Conclusion*

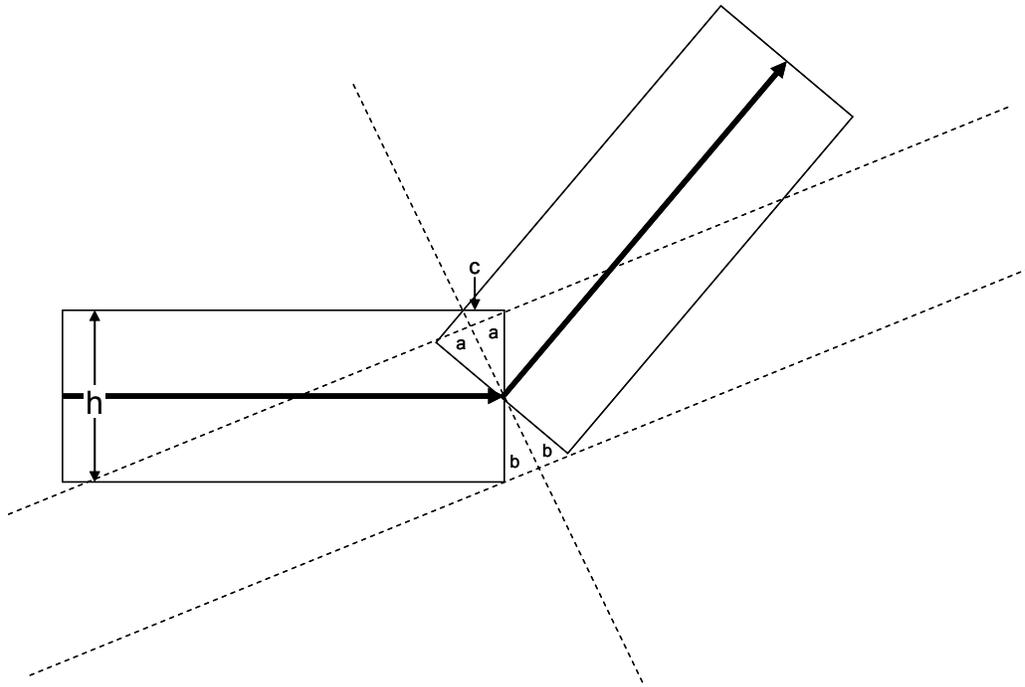
The patch model performed well under the conditions we tested in simulation. There are several interesting results that need to be investigated further and we intend to continue this work through a second iteration which will focus on developing a more realistic spatial distribution of clams and investigating the affects of tow order and orientation as well as finding an optimum number of tows given various starting conditions. We will also continue to examine the affects of positional errors. Thus far, we have found no reason to believe that the patch model is introducing consistent bias, or unacceptably inaccurate estimates of survey density and efficiency into the stock assessment process.

Appendix Table 2-1. Summary of Patch model estimates from all ocean quahog and surfclam depletion experiments conducted during 1997-2005 (Table A11 in NEFSC 2008a; Table C14 in NEFSC 2008b). The negative binomial parameter  $k$  measures variance (higher values of  $k$  indicate less variability and *vice-versa*).

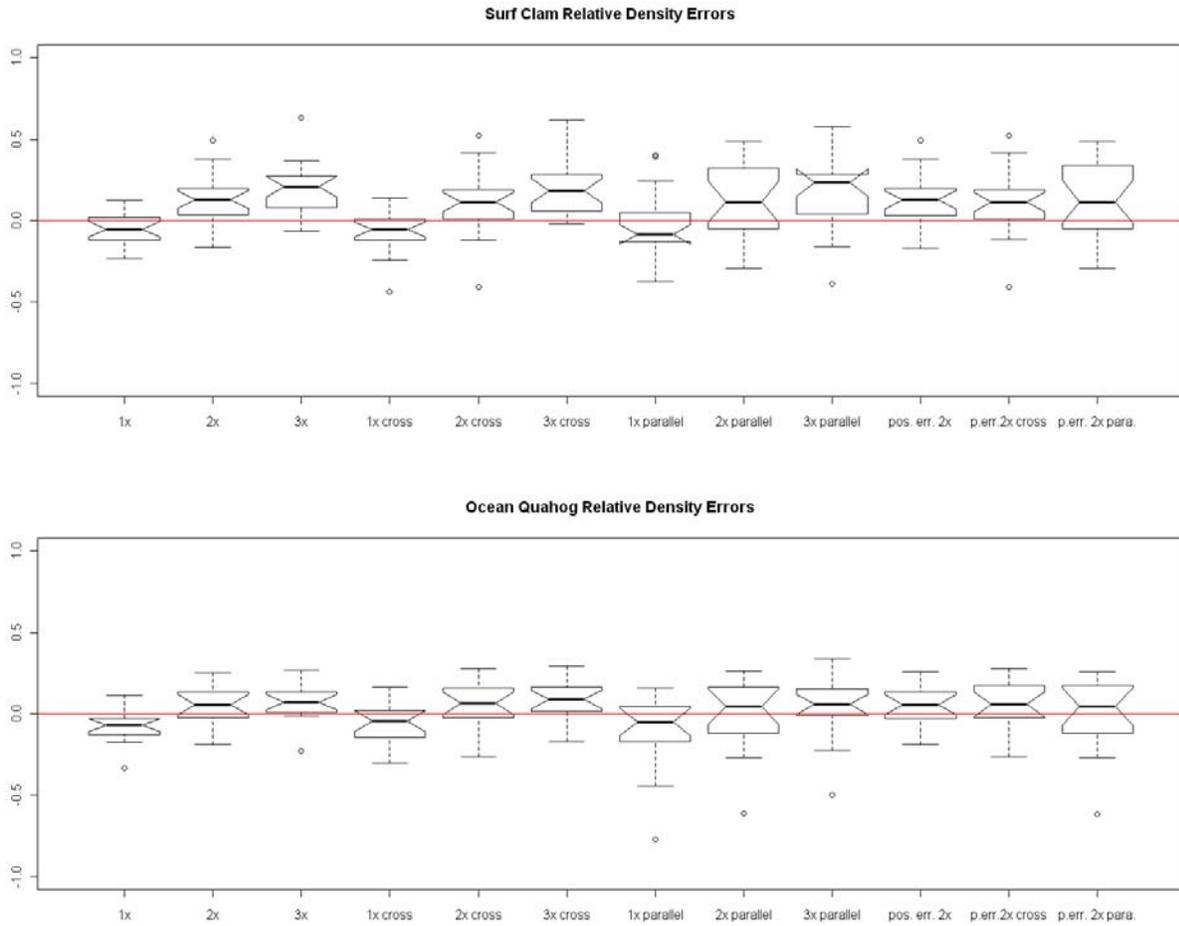
Species	N depletion experiments	Median density ( $D$ , n/m <sup>2</sup> )	Median efficiency ( $e$ )	Median $k$ for tows ( $k$ )
Ocean quahog	18	0.883	0.660	8.065
Surfclams	19	0.269	0.765	5.676

Appendix Table 2-2. Absolute estimated relative density for surfclams and ocean Quahogs, by simulation type. An absolute estimated relative density of zero would represent perfect replication of the “true” parameter values used to populate the simulated survey site.

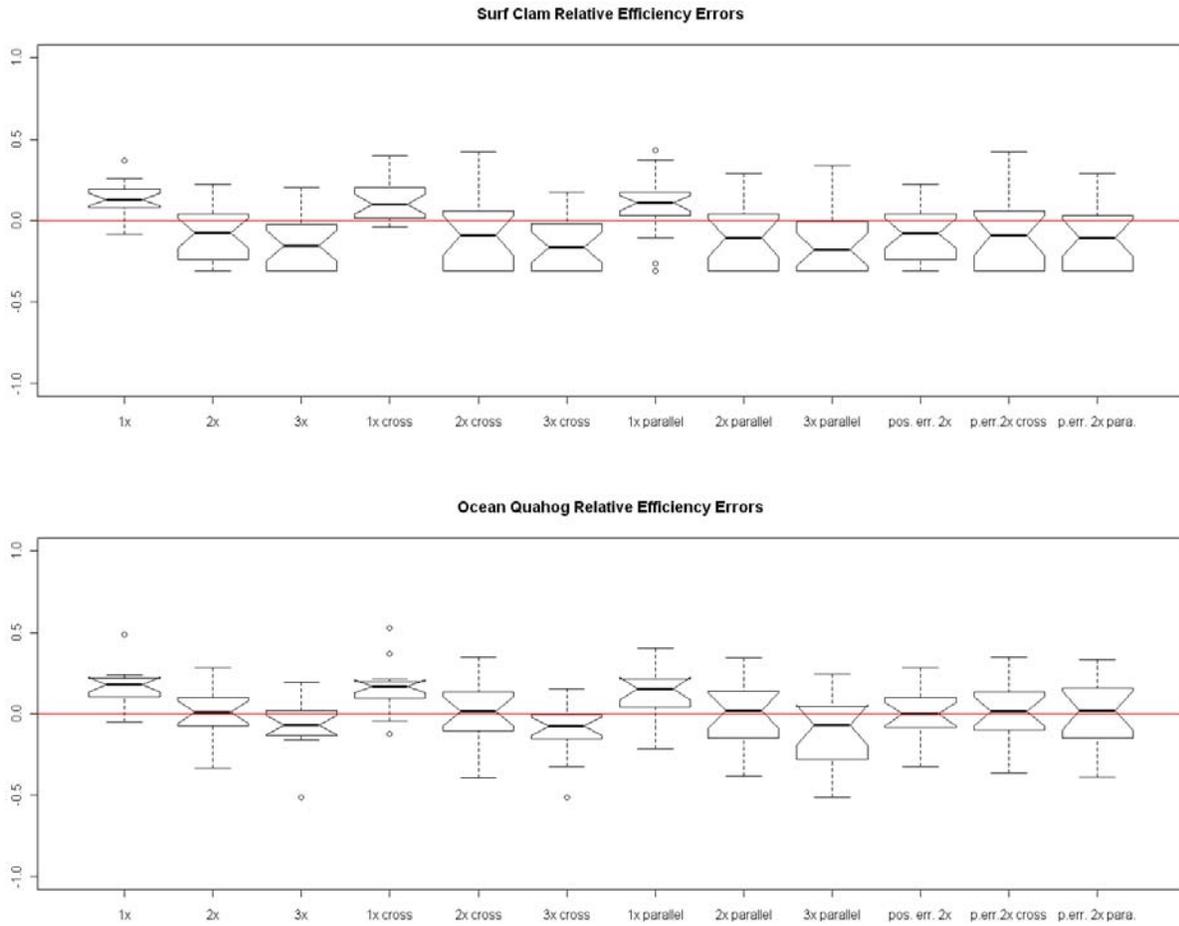
Permutation	Surf Clam	Ocean Quahog
	Absolute Relative Median Dens. Error	Absolute Relative Median Dens. Error
Grid size = dredge width	0.0703	0.0929
Grid size = 2*dredge width	0.1446	0.0873
Grid size = 3*dredge width	0.2105	0.0914
cross 1x	0.0707	0.0944
cross 2x	0.1325	0.1352
cross 3x	0.1842	0.1415
parallel 1x	0.1095	0.1402
parallel 2x	0.1832	0.1585
parallel 3x	0.2489	0.1543
position errors 2x	0.1446	0.0890
position errors 2x + cross	0.1319	0.1262
position errors 2x + parallel	0.1829	0.1605



Appendix Figure A2-1. Mathematical representation of the area swept by a simulated dredge between three position observations (heads and tails of dark arrows). The dark arrows are the center of the dredge. The large rectangles with are as wide as the dredge ( $h$ ). The areas of the triangles marked  $a$  and  $b$  where the dredge pivots cancel. The area swept is the area of the large rectangles, less the area of the triangles marked  $c$ . The additional area in the arc that can be drawn between the lower vertices of the two triangles marked  $b$  is ignored. Clams are caught with probability equal to dredge efficiency if their spatial cell intersects the rectangles and triangles that mark the simulated dredge path/.



Appendix Figure A2-2. Estimated relative density for surfclams and ocean Quahogs, by simulation type. The boxes are drawn from the first quartile to the third quartile and centered on the median. The whiskers are drawn to 1.5 times the inter-quartile (first to third quartile) distance. An estimated relative density of zero would represent perfect replication of the “true” parameter values used to populate the simulated survey site.



Appendix Figure A2-3. Estimated relative efficiency for surfclams and ocean Quahogs, by simulation type. The boxes are drawn from the first quartile to the third quartile and centered on the median. The whiskers are drawn to 1.5 times the inter-quartile (first to third quartile) distance. An estimated relative efficiency of zero would represent perfect replication of the “true” parameter values used to populate the simulated survey site.

### **Appendix A3: Surfclams in New York and New Jersey state waters**

The states of New York and New Jersey support surfclam fisheries in their territorial waters ( $\leq 3$  nmi from shore), and have had surfclam surveys since 1992 and 1988, respectively, that are carried out using commercial clam gear (Appendix Figures A3-1 to A3-3). These state surveys provide are important because the NEFSC clam survey does not cover state waters. New York and New Jersey state waters contain excellent habitat for surfclams and have provided as much as 35% of total surfclam landings in some years. However, stock biomass and recruitment have declined along the coasts of both states to low levels. The percentage of landings harvested from state waters has been falling since 2001 (Appendix Figure A3-4).

#### **The New York and New Jersey state surveys**

The New Jersey State survey is conducted annually by the New Jersey Department of Environmental Protection from a commercial clam vessel with a hydraulic dredge, most recently the F/V Ocean Girl (Appendix Figure A3-3). The survey has been conducted since 1988, and has followed a stratified random sampling protocol since 1994. The survey area is divided into regions covering the whole New Jersey coast, and each region has 3 strata one mile wide and parallel to the coast covering surfclam habitat out to the 3-mile limit (Appendix Figure A3-1). Each survey does between 250 and 330 5-minute tows, measuring the catch volume in bushels, then counting and measuring a known volume of surfclams for population estimates and length frequencies. Grab samples of the sediment are also taken.

Data available for this appendix from the State of New Jersey surfclam surveys includes catch data since 1994, length frequencies, surfclam densities, commercial landings and grab sample data.

The New York surfclam survey is conducted by the New York Department of Environmental Conservation more or less every three years. They use a commercial clam vessel, most recently the F/V Ocean Girl, with a hydraulic dredge. The survey area is divided into four regions which span the southern shore of Long Island. The three westernmost regions have three strata each within them, each a mile wide moving offshore to the three-mile limit (Appendix Figure A3-2). The last four surveys have occurred in the summer or fall, had an average of 236 stations, and used a random stratified sampling technique. Tows are three minutes long, the total volume of each tow is measured in bushels, and half a bushel of surfclams from each tow is measured and counted for population estimates and length frequencies. A picture of the dredge used is shown in Appendix Figure A3-3.

Data from New York State available for this appendix is from the 2002, 2005 and 2006 surfclam surveys, with some preliminary data from the 2008 survey. The available information includes catch data, average length frequencies, and lengths and ages of all the surfclams that were aged. Commercial landings data for state waters through 2006 were also available.

#### **Results**

Both states have seen a substantial decrease in the population of surfclams (Appendix Figure A3-5). The peak population of surfclams in New Jersey in recent years occurred in 1996, a few years before the peak in biomass of surfclams in the EEZ in 1998-1999. The data available to us from New York do not go back far enough to reflect peak abundance levels.

Despite the decline in numbers of clams since 2002, landings in New York stayed fairly high through 2006 (Appendix Figure A3-6). There was a very large harvest limit set in 2004

(930,000 bushels) and it was almost reached, making the landings from New York from that year almost double what they had been in years before. The high harvest in 2002 was followed by a substantial reduction in stock biomass.

The length composition of surfclams in New Jersey became more narrow and composed of larger surfclams each year from 2000 to 2006 (Appendix Figure A3-7), as clams were growing larger and not being replaced by new recruits. However, the years 2007-2009 show a small number of recruits entering the survey. Surfclams from the New York surveys conducted in 2005 and 2006 were larger on average than those collected in 2002 (Appendix Figure A3-8). The effect of the lack of recruitment of smaller clams into the population is shown dramatically in Appendix Figure A3-9, which shows the mean shell length of surfclams collected during the New Jersey survey from 1991 through 2009.

Appendix Figure A3-10 shows surfclam density for New Jersey State waters compared to the densities calculated for the fished areas of the EEZ (all regions except Georges Bank) in recent years from the NEFSC clam survey data. Densities have always been higher in the inshore New Jersey State strata (Appendix Figure A3-11), but recently they appear to be falling to or towards levels typical of more unproductive offshore areas.

For some reason, surfclams in New York and New Jersey have been unable to resupply their aging, and constantly harvested, populations with new recruits. This could be happening because there is not enough successful spawning occurring and the supply of larvae is not there, or because smaller surfclams are dying before they are available to a survey or commercial dredge.

In New Jersey, annual grab sample data collected since 1994 from the area of the survey show that juvenile surfclams are settling successfully out of the plankton (Appendix Figure A3-12). Some years have been better than others with occasional larger sets such as the ones seen in 2005 and 2009. This data do not show a downward trend in juvenile surfclams that might explain the decline in older surfclams of fishable size.

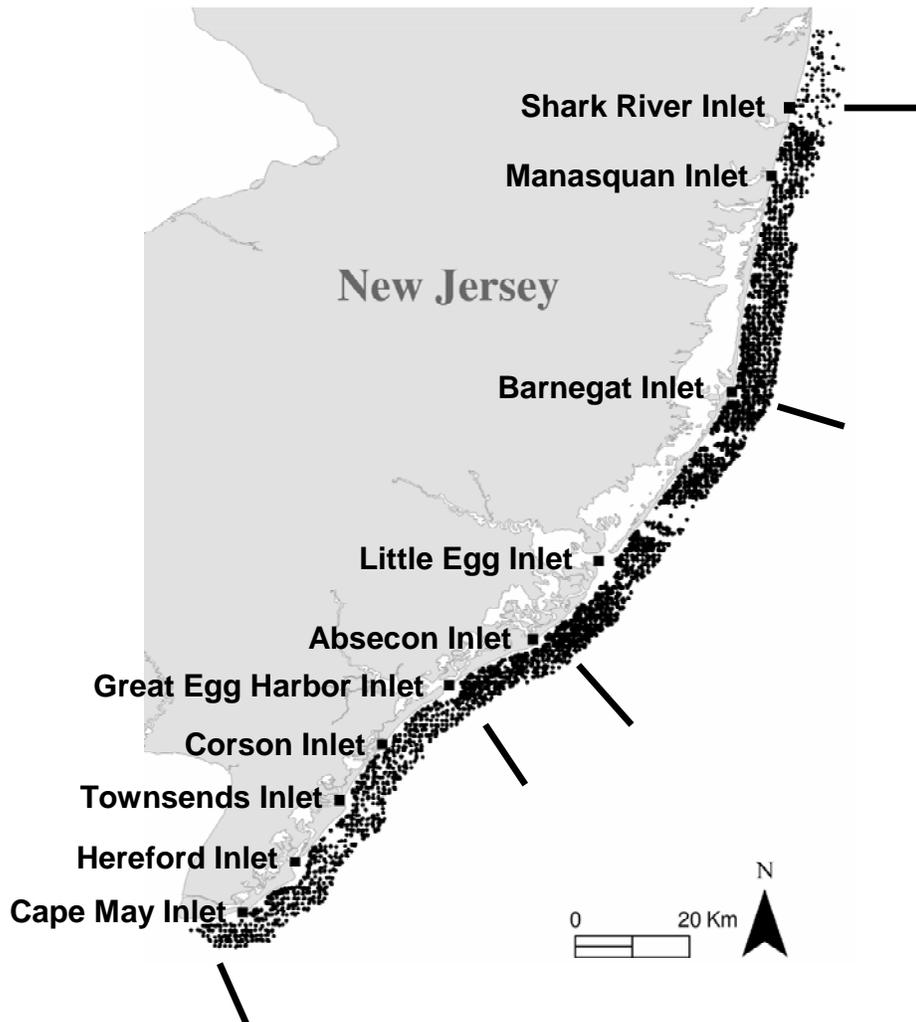
Age frequencies from the New York surveys in 2002, 2005 and 2006 (Appendix Figure A3-13) show that surfclams of all ages, although there were very few older than 20 y. There seem to be recognizable ~1996, ~1991 and ~1988 year classes which can be followed over the three NY surveys. Age data from the Long Island region of the NEFSC survey are not available, but recognizable year classes in NEFSC survey data for the New Jersey region included one in 1992.

Length-at-age data from the New York surveys (Appendix Figure A3-14) indicate there was no significant change in growth rate from 2002 through 2006, but all regions and strata were lumped together so spatial changes may be masked.

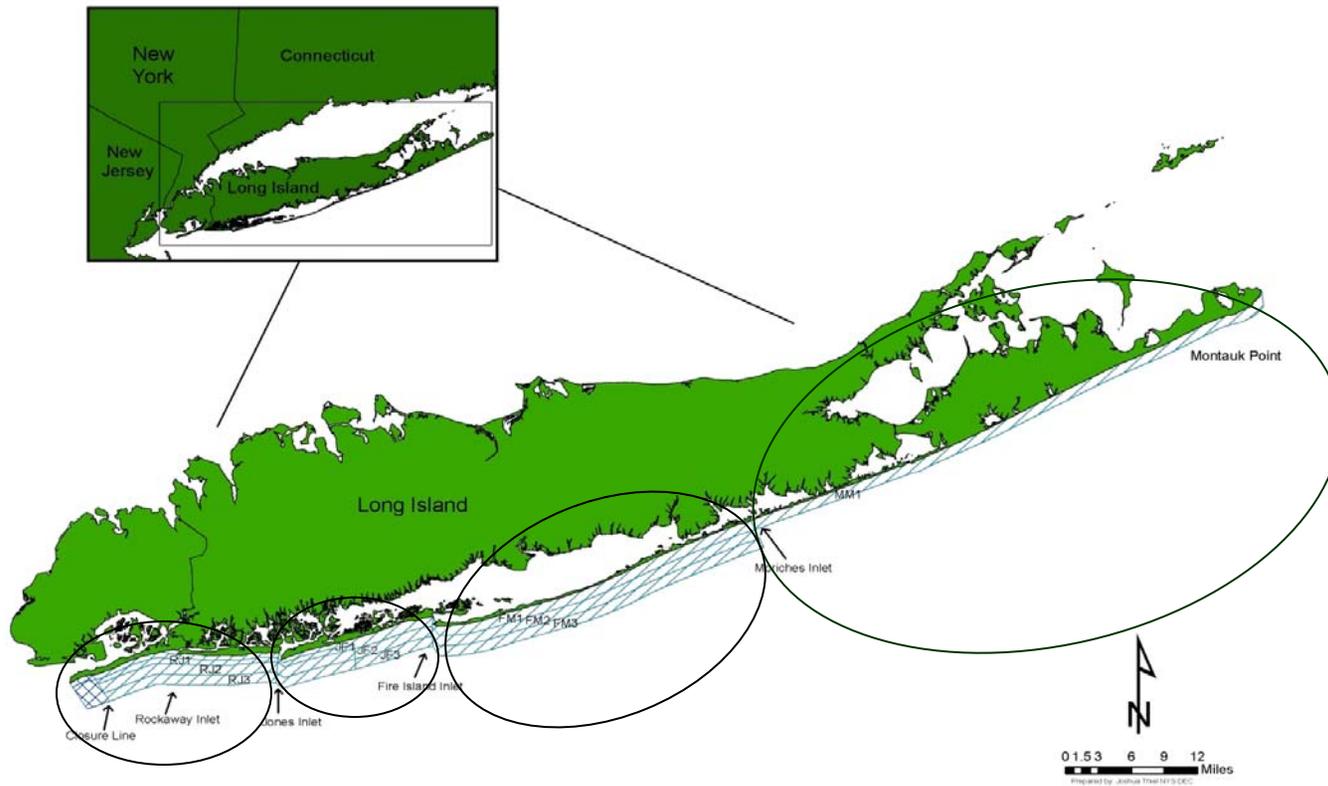
Exploitation rates (landings for human consumption / survey abundance data) were calculated for surfclams in both NJ and NY state waters (Appendix Figure A3-15). The data suggest that exploitation rates in NJ waters decreased from about 4% in 1996 to 2% in 1997-1998 then increased to about 6% in 2002 before falling to zero by 2005 as the fishery for human consumption was closed. The limited data for NY indicate that exploitation rates increased from 2.5% in 2002 to about 4.25% in 2006 (landings data were not available for NY in 2008)

The simple exploitation rates in Appendix Figure A3-15 provide useful information about trends in fishing mortality. However, these calculations assume that 100% of the surfclams in the path of the survey dredge are captured. For example, the median capture efficiency of commercial dredges in surfclam depletion experiments conducted offshore is 0.79 (Table Efficiency-1). If the capture efficiency of the survey dredge is 0.79 then the exploitation rates

calculated here for surfclams in state waters are too high and should be multiplied by 0.79. In addition, NJ landings for use as bait were excluded because surfclams for bait are harvested in contaminated areas outside of the survey region.



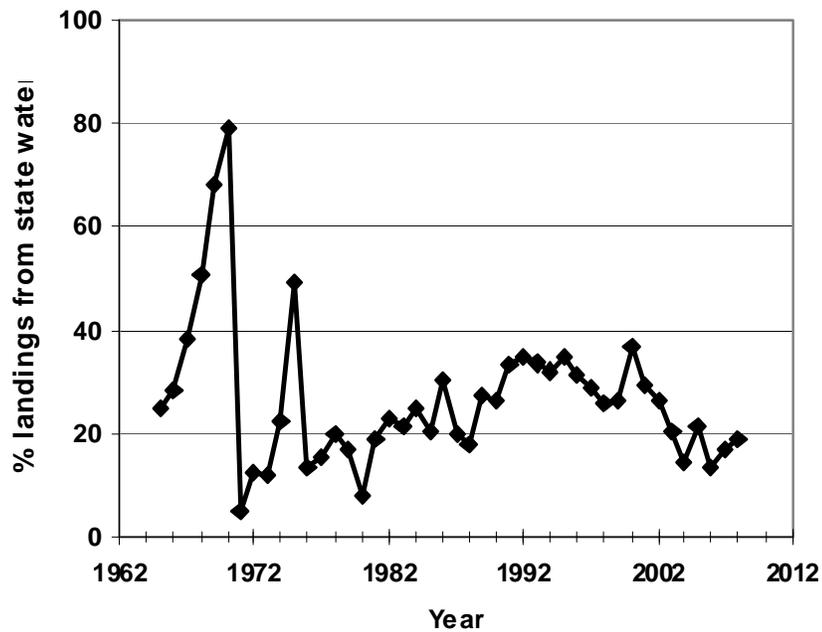
Appendix Figure A3-1. Map showing the sampling regions for the NJ state survey, and all station locations since 1988. Within each region there are three depth strata one mile wide. Map courtesy of Jeff Normant, NJDEP.



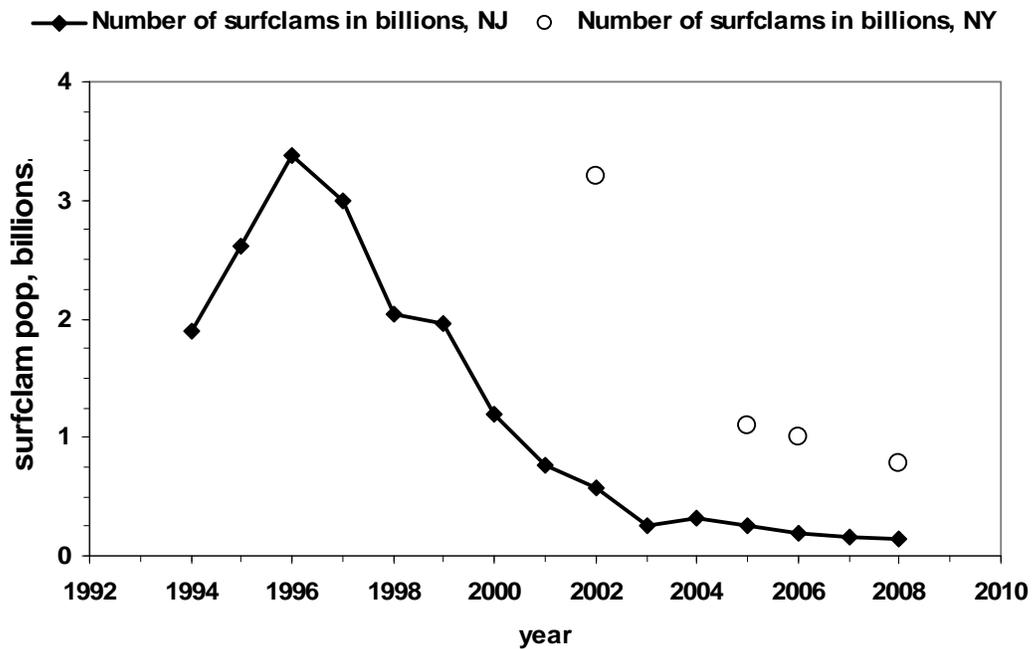
Appendix Figure A3-2. Map showing NY clam survey sampling regions from west to east. Regions RJ, JF and FM each have 3 depth strata, while region MM which has one depth stratum. Map courtesy of Wade Carden, NYSDEC.



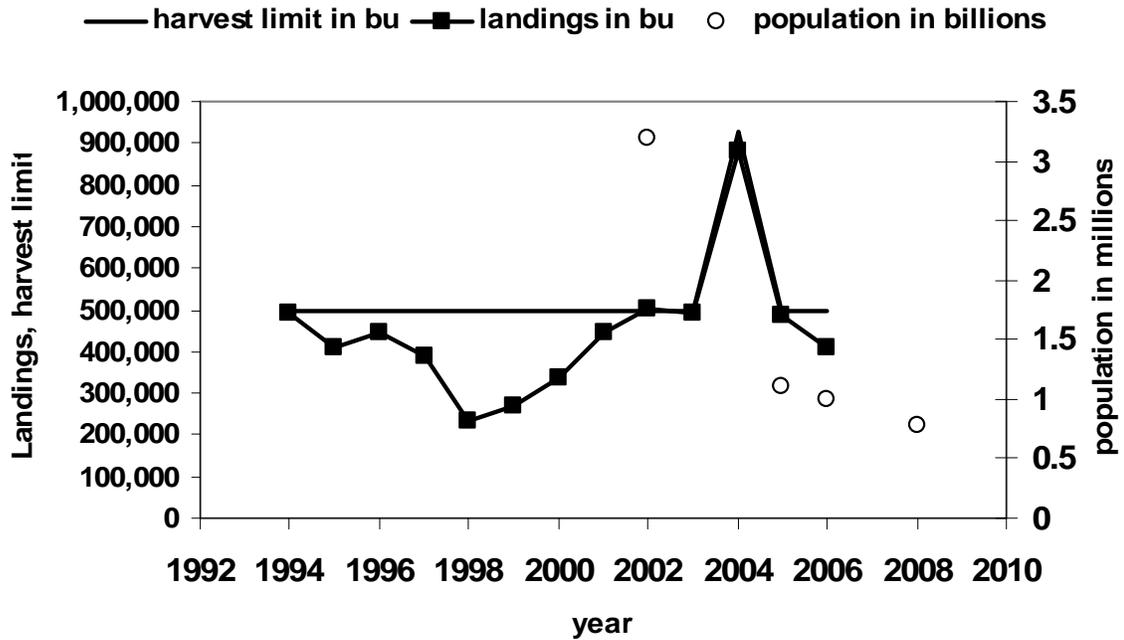
Appendix Figure A3-3. The inshore commercial clam dredge used for recent state surfclam surveys. Photo courtesy of Jeff Normant, NJDEP; William Burton, Versar, Inc.; and Beth Brandreth, USACE.



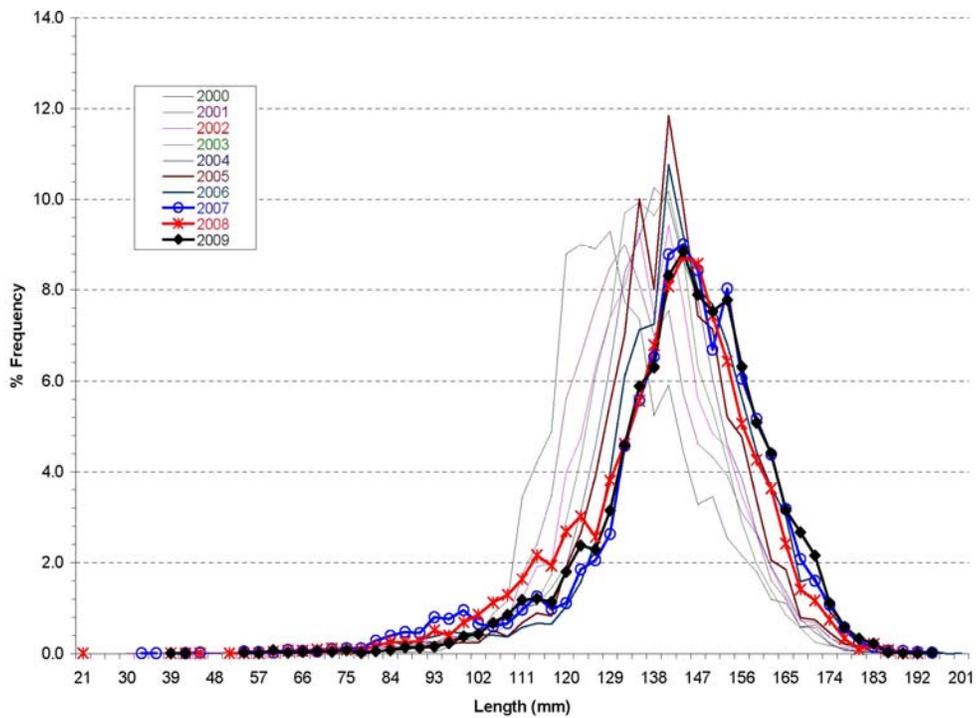
Appendix Figure A3-4. Percentage of total surfclam landings from state waters. State landings are mostly from New Jersey and New York with small amounts from Southern New England.



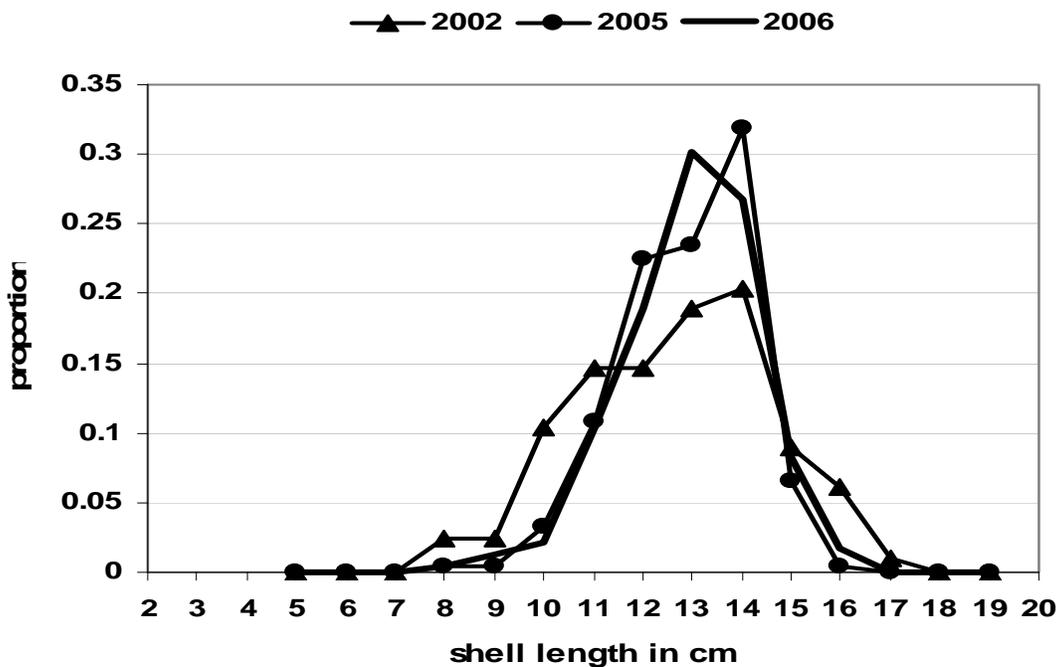
Appendix Figure A3-5. Survey-based population estimates for surfclams in New Jersey and New York for years with random stratified survey design.



Appendix Figure A3-6. Landings, harvest limit and population abundance for surfclams in New York state waters. Landings and harvest limit are scaled to the left axis and population is scaled to the right axis. The harvest limit was raised to 890,000 bushels in 2004.

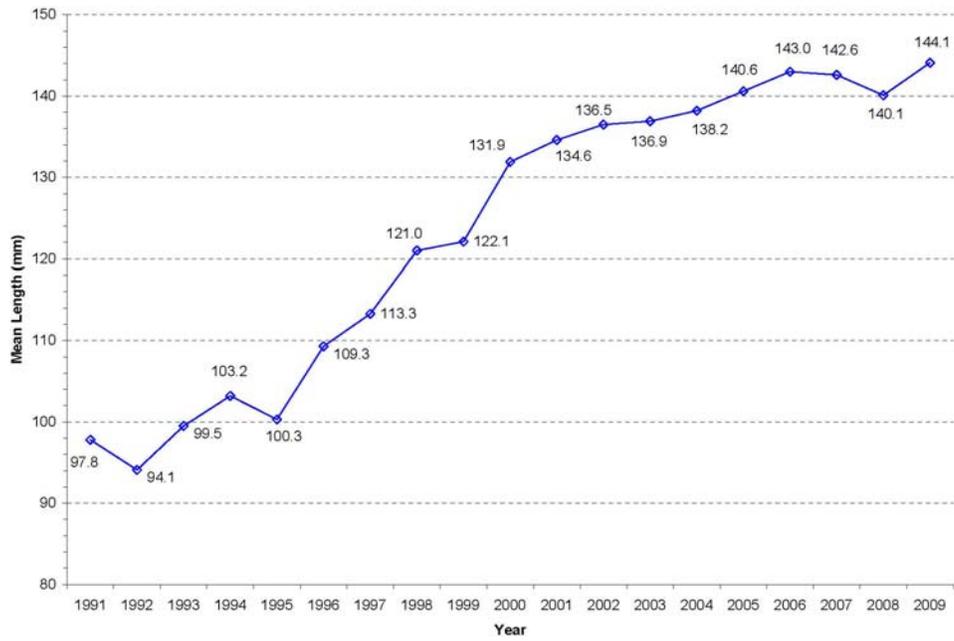


Appendix Figure A3-7. New Jersey state surfclam survey shell length composition data by year during 2000-2008. Figure courtesy of Jeff Normant, NJDEP.

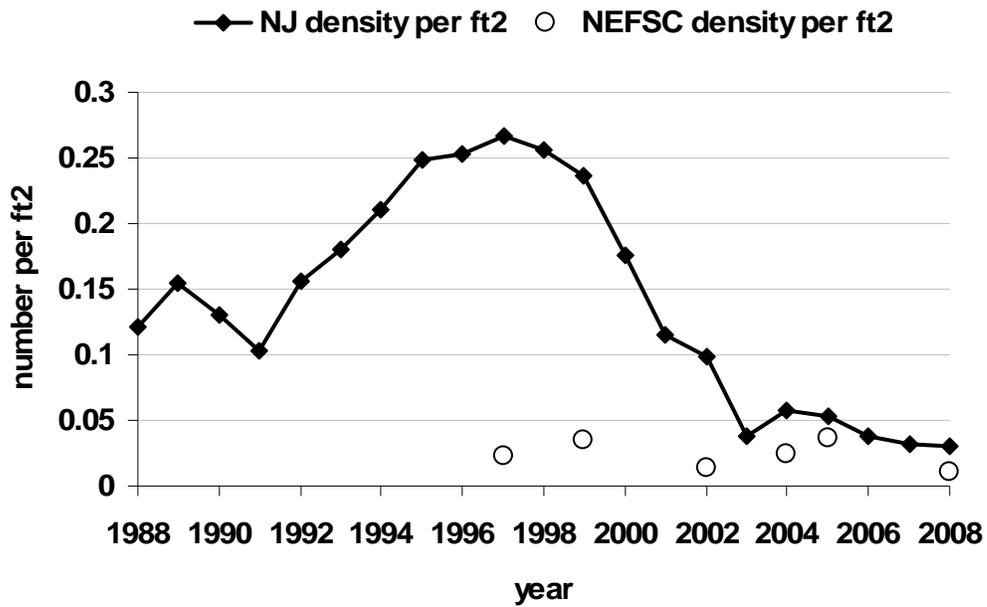


Appendix Figure A3-8. New York state surfclam survey shell length composition data during 2002, 2005 and 2006.

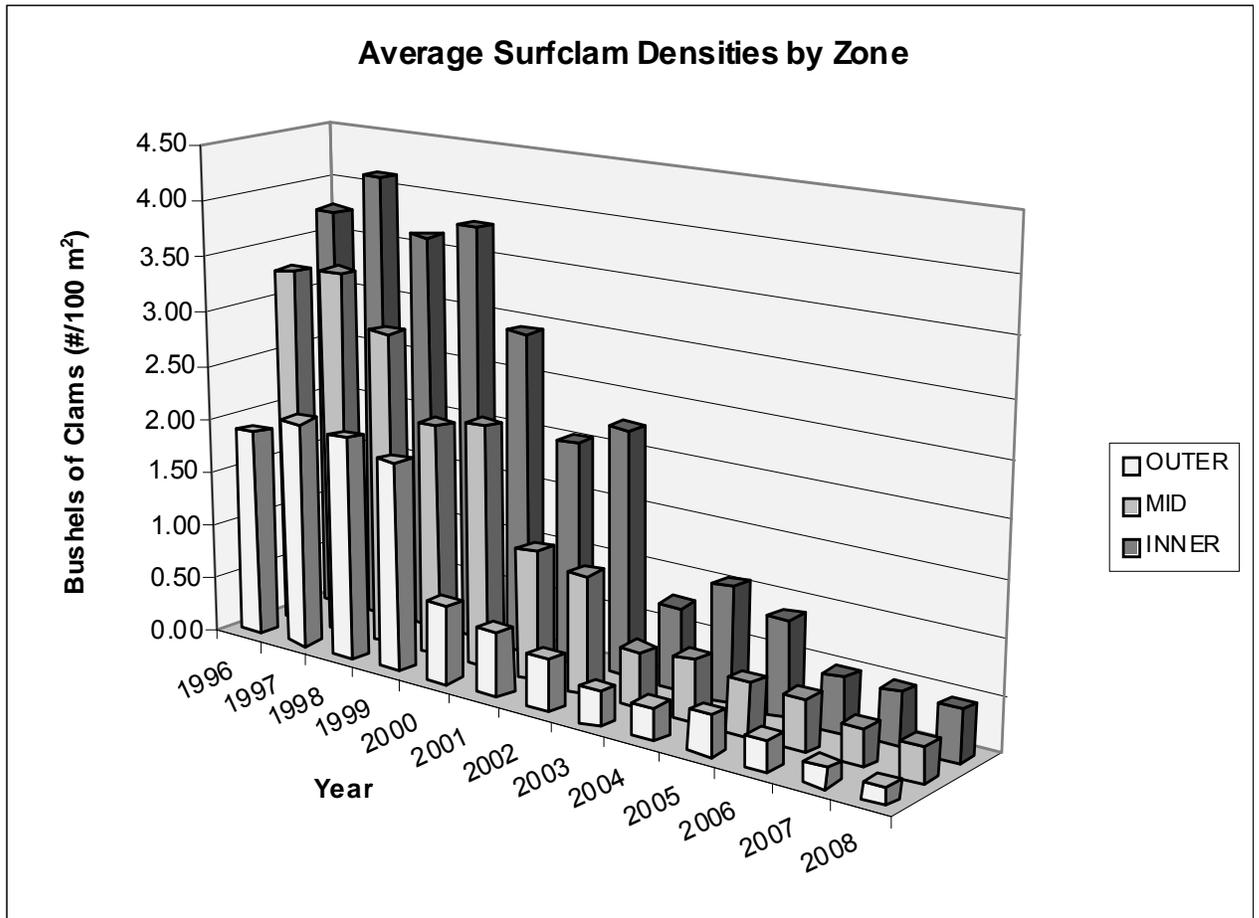
Figure 3. Mean Lengths of Surf Clams Collected by the Dredge from 1991 to 2009, New Jersey Surf Clam Inventory



Appendix Figure A3-9. Mean shell length of surfclams caught during the New Jersey state survey by year. Figure courtesy of Jeff Normant, NJDEP.

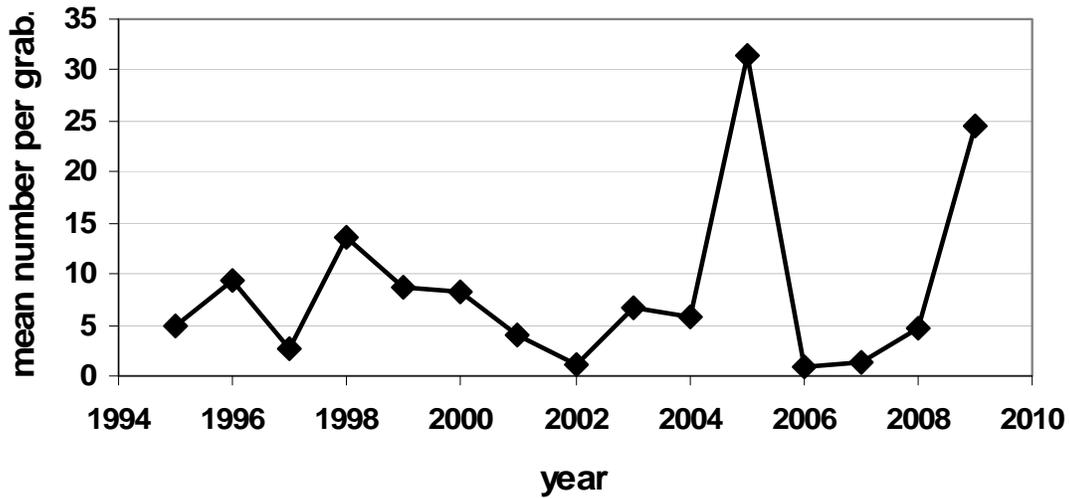


Appendix Figure A3-10. A rough comparison of density estimates from the NJ State and NEFSC surveys. However, the density estimates from the NEFSC surveys are for clams larger than 150mm, whereas the estimates for NJ are for all clams.

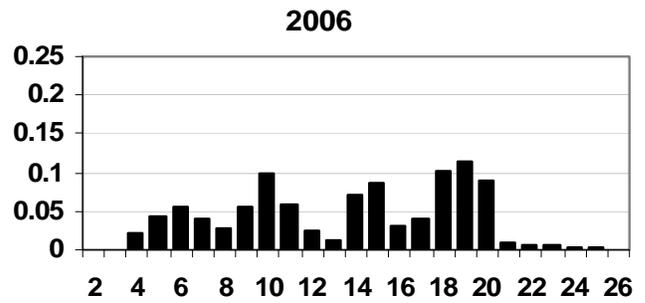
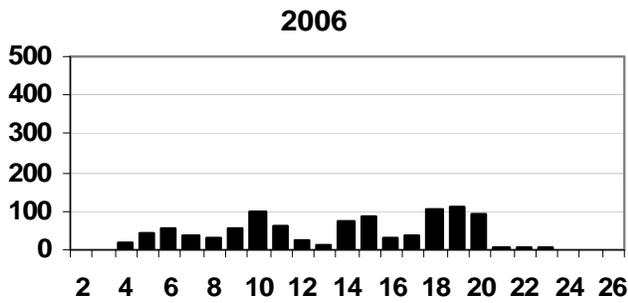
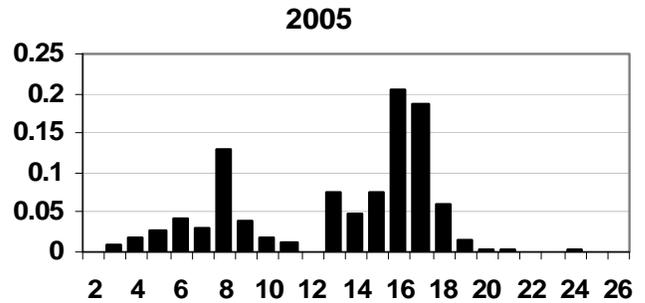
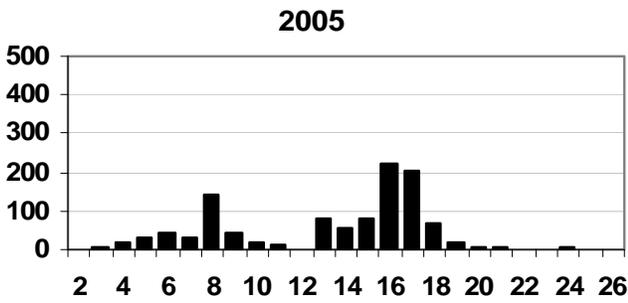
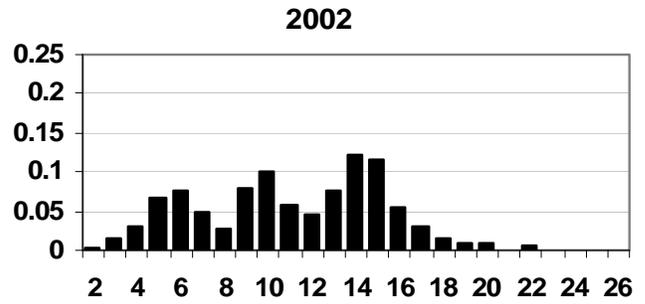
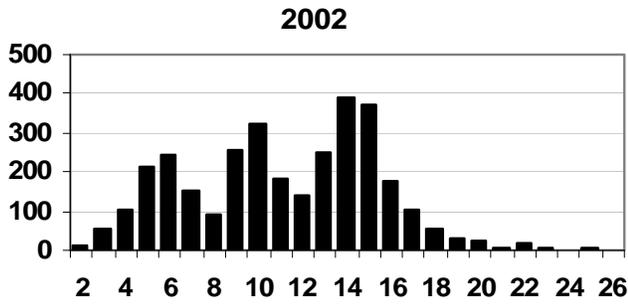


Appendix Figure A3-11. Summary of yearly surfclam densities (bushels per 100 m<sup>2</sup>) estimated for New Jersey coastal waters from 1996 through 2008 by inshore to offshore zones. Figure courtesy of Jeff Normant.

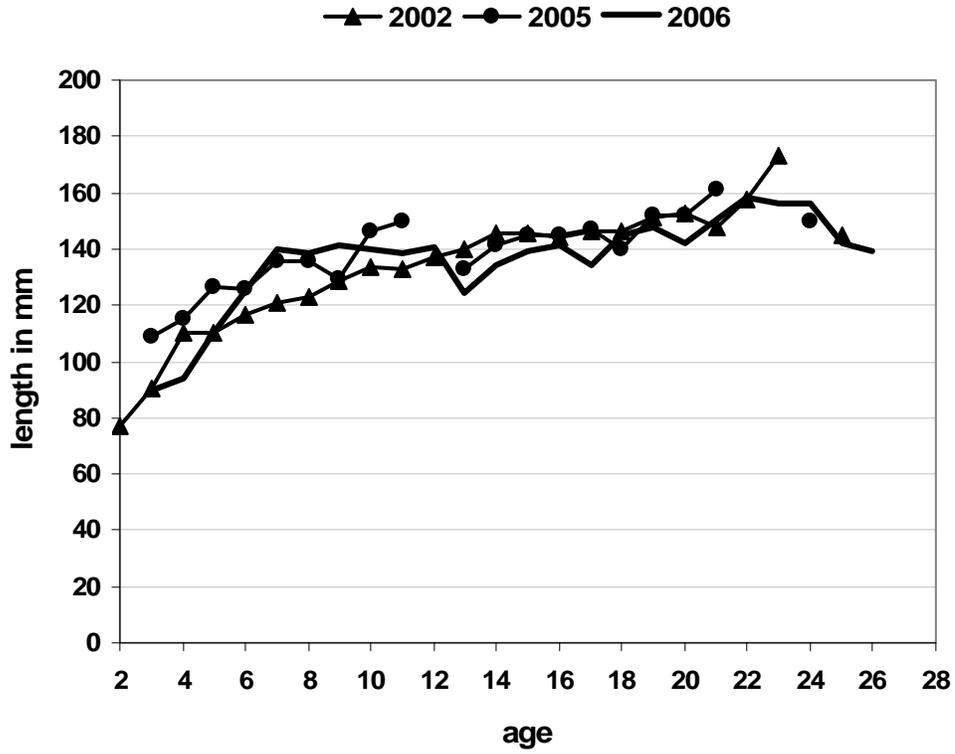
### Juvenile surfclams per grab sample



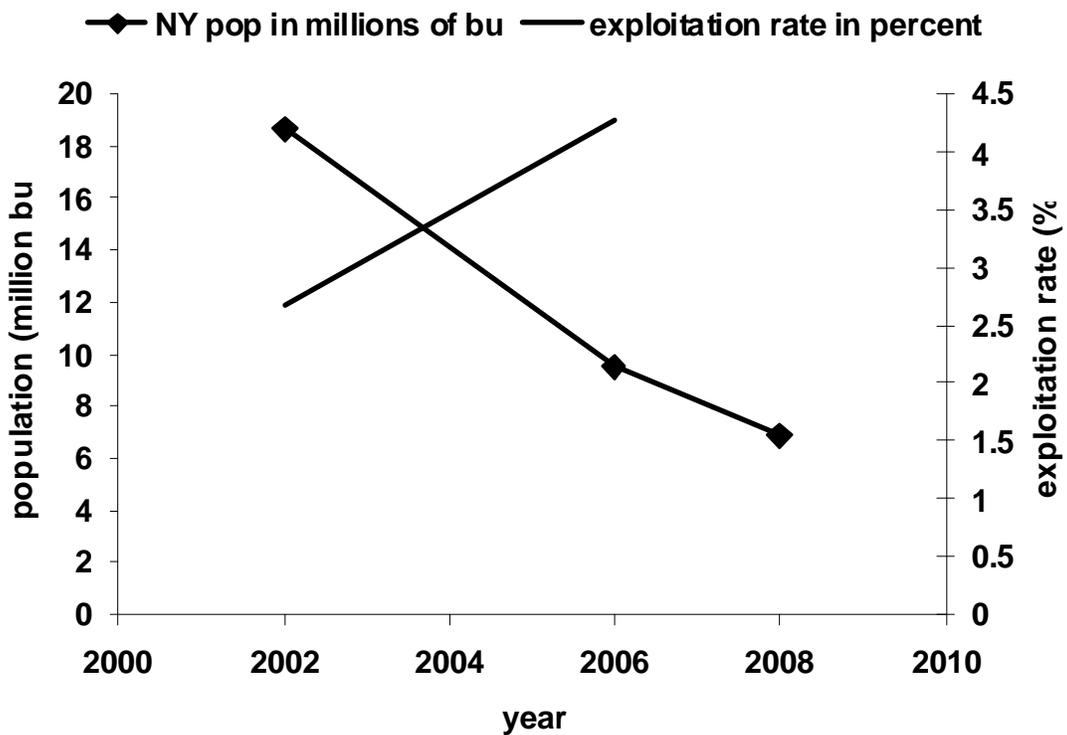
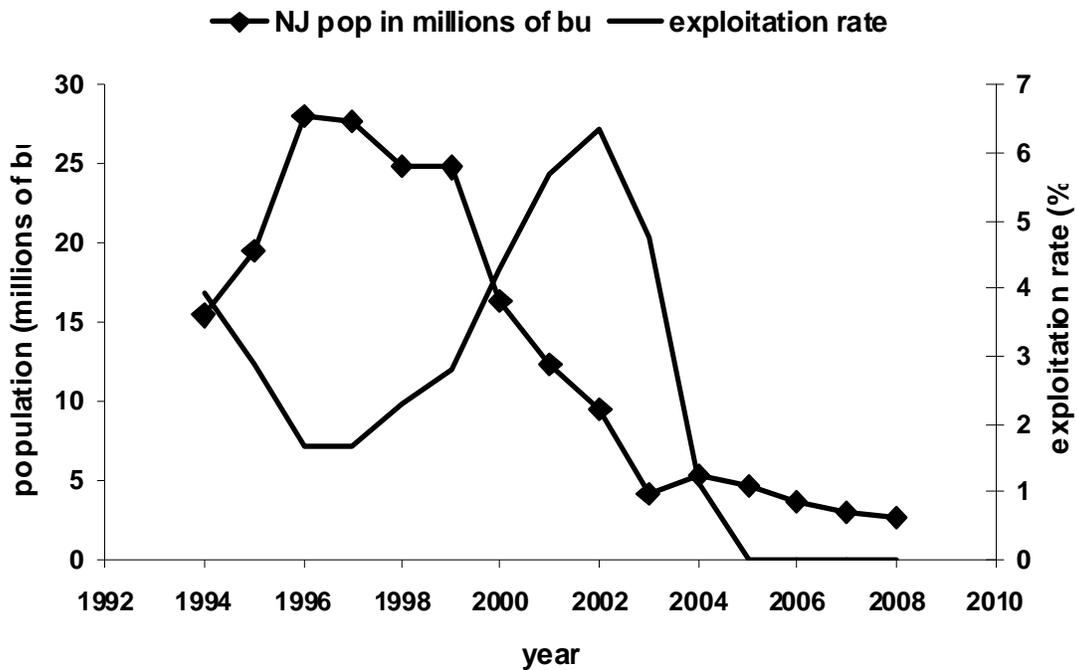
Appendix Figure A3-12. As part of the annual survey, the state of New Jersey takes sediment grab samples, which contain recently settled juvenile surfclams. The clams are generally under 10 mm SL. An average of 311 grabs are taken every survey.



Appendix Figure A3-13. Age composition data for surfclams during 2002, 2005 and 2006 from York state surfclam surveys. The graphs on the left are numbers at age in millions, and the graphs on the right are proportions at age.



Appendix Figure A3-14. Length at age for surfclams from the 2002, 2005 and 2006 New York state surveys.



Appendix Figure A3-15. Swept-area abundance and exploitation rate (landings divided by estimated abundance) for state surveys. For NJ, exploitation rates were calculated using landings from the fishing season after the survey was conducted. For NY, the landings during the same year as the survey were used.

## Appendix A4: 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.<sup>2</sup> 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  $k$ ).<sup>3</sup> 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<sup>4</sup> libraries. The AD Model Builder version is faster, more reliable and probably better for producing

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<sup>2</sup> In applications, assumptions about knife-edge selectivity can be relaxed by assuming the model tracks “fishable”, rather than 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  $\Pi_{t-a}$  is the number or biomass of fish age  $k-a$  during year  $t$ ).

<sup>3</sup> 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).

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“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:

$$B_{t+1} = (1 + \rho) \tau_t B_t - \rho \tau_t \tau_{t-1} B_{t-1} + R_{t+1} - \rho \tau_t J_t R_t$$

where  $B_t$  is total biomass of individuals at the beginning of year  $t$ ;  $\rho$  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:

$$B_{t+1} = (1 + \rho) \tau_t B_t - \rho \tau_t \tau_{t-1} B_{t-1} + w_{t+1,k} N_{t+1} - \rho \tau_t w_{t-1,k-1} N_t$$

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  $\rho=0$  in the delay difference equation, and use  $N_t$  (for numbers) in place of  $B_t$  to get:

$$N_{t+1} = \tau_t N_t + R_{t+1}$$

Mathematically, the assumption  $J_t=1$  means that no growth occurs the assumption  $\rho=0$  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  $\rho$  is constant. Use of time-variable  $J_t$  values with  $\rho$  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  $G_t^{Old} = \ln(S_t^*/S_t)$ . 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  $\Omega_t$  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 ( $\mu$ ,  $\iota$ ), and a set of annual log scale deviation parameters ( $\omega_t$ ):

$$\Omega_t = \mu + \iota + \omega_t$$

The parameter  $\iota$  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  $\omega_t$  are constrained to average zero.<sup>5</sup> With the constraint, for example, estimation of  $\mu$  and the set of  $\omega_t$  values ( $1+n$  years parameters) is equivalent to estimation of the smaller set ( $n$  years) of  $\Omega_t$  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:

$$M_t = m e^{\varpi_t}$$

where  $m = \exp(\pi)$  is the geometric mean natural mortality rate,  $\pi$  is a model parameter that may be estimated (in principal but not in practical terms), and  $\varpi_t$  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 auto correlated or independent process errors, or may be based on a covariate.<sup>6</sup> Model scenarios with zero recruitment may be initializing the parameter  $\pi$  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:

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

<sup>5</sup> The constraint is implemented by adding  $L = \lambda \bar{\omega}^2$  (where  $\bar{\omega}$  is the average deviation) to the objective function, generally with a high weighting factor ( $\lambda = 1000$ ) so that the constraint is binding.

<sup>6</sup> 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”).

where  $\kappa_t$  is the standardized covariate,  $K_t$  is the original value, and  $\bar{K}$  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:

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

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:

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

where  $\hat{C}_t$  is predicted catch weight (landings plus discard) and  $\bar{B}_t$  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.<sup>7</sup> If the rates for growth and mortality are equal, then  $X_t = 0$ ,  $\bar{B}_t = B_t$  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:

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

When  $X_t \neq 0$ , the expression for  $\bar{B}_t$  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.<sup>8</sup> 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  $G_t$ .

<sup>7</sup> By convention, the instantaneous rates  $G_t$ ,  $F_t$  and  $M_t$  are always expressed as numbers  $\geq 0$ .

<sup>8</sup> 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.

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 ( $\Phi$ ) and a set of annual log scale deviation parameters ( $\psi_t$ ):

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

where the deviations  $\psi_t$  are constrained to average zero. When the catch equation is solved 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 ( $\rho$  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  $\bar{F}_{Recent}$  and biomass  $\bar{B}_{Recent}$  levels. These status determination variables are used in calculation of status ratios such as  $\bar{F}_{Recent} / F_{MSY}$  and  $\bar{B}_{Recent} / B_{MSY}$ .

### 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  $N_{\Xi}$  is the number of NLL components ( $L_v$ ) and the  $\lambda_v$  are emphasis factors used as weights. The objective function  $\Xi$  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 ( $\lambda_v$ ) are usually set to one. An arbitrarily large weighting factor (e.g.  $\lambda_v=1000$ ) is used for “hard” constraints that must be satisfied in the model. Arbitrarily small weighting factors (e.g.  $\lambda_v=0.0001$ ) 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 ( $\lambda_v$ ) 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 used 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.<sup>9</sup> For  $x \sim N(\mu, \sigma^2)$ , the complete NLL for one observation is:

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

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

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

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<sup>9</sup> 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.

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 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  $\sigma$ . The maximum likelihood estimator is biased by  $N/(N-d_f)$  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:

$$D_t = \text{abs}(d_t).$$

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  $\Phi$  and  $\psi_t$  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:

$$g(F_t) = C_t + \frac{F_t(1 - e^{X_t})}{X_t} B_t = 0$$

where  $X_t = G_t - M_t - F_t$ . If  $X_t = 0$ , then  $\bar{B}_t = B_t$  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:

$$F_t^{i+1} = F_t^i - \frac{g(F_t^i)}{g'(F_t^i)}$$

where  $g'(F_t^i)$  is the derivative  $F_t^i$ . Omitting subscripts, the derivative is:

$$g'(F) = - \frac{B e^{-F} [(e^F - e^\gamma) \gamma + e^\gamma F \gamma - e^\gamma F^2]}{X^2}$$

where  $\gamma = G - M_t$ . Iterations continue until  $g(F_t^i)$  and  $abs[g(F_t^{i+1}) - g(F_t^i)]$  are both less than a small number (e.g.  $\leq 0.00001$ ).

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):

$$F_t^0 = \gamma_t - \ln \left[ \frac{(B_t e^{0.5\gamma_t} - C_t) e^{0.5\gamma_t}}{B_t} \right]$$

### $F$ 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<sup>-1</sup>) for three important predators. If the aggregate consumption data are included in the model as “discards”, then the fishing mortality rate for discards  ${}^dF_t$  (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  $m_{new} + {}^d\bar{F} = m_{old}$ ) 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:

$$NLL = 0.5 \sum_{y=1}^{n_{eff}} w_y \left[ \frac{\ln(E_y / \hat{E}_y)}{\sigma} \right]^2$$

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  $\hat{E}_y$  are observed and predicted fishing effort data, and the log scale variance  $\sigma$  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  $\vartheta \neq 1$  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  $\kappa_y$ , the model calculates the predator-prey ratio used in place of fishing effort data ( $E_y$ ) as:

$$E_y = \frac{\kappa_y}{B_y}$$

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 a series of delay-difference calculations depends on biomass ( $B_0$ ) and survival ( $\tau_0$ ) in year 0:

$$B_2 = (1 + \rho) \tau_1 B_1 - \rho \tau_1 \tau_0 B_0 + R_2 - \rho \tau_1 J_1 R_1$$

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.<sup>10</sup> 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<sup>11</sup>, then the NLL for the penalty is:

$$L_G = 0.5 \sum_{t=1}^{n_G} \left[ \frac{\ln(G_t^{Old} / G_{n_G+1}^{Old})}{\sigma_G} \right]^2$$

where the standard deviation  $\sigma_G$  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  $\sigma_G$  for the

<sup>10</sup> Quinn and Deriso (1999) describe another approach attributed to a manuscript by C. Walters.

<sup>11</sup> Normally,  $n_G \leq 2$ .

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.  $\lambda = 1000$ ) 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:

$$L = \left[ \ln \left( \frac{S_1^p}{S_1} \right) \right]^2 + (S_1^p - S_1)^2$$

uses a log scale sum of squares and an arithmetic sum of squares. The former is effective when  $S_1$  is small while the latter is effective when  $S_1$  is large. Constants and details in calculation of NLL for the constraint are not important because the constraint is binding (e.g.  $\lambda = 1000$ ).

#### *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  $\tilde{B}_0$  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).<sup>12</sup> The NLL term for the constraint is:

$$L = \ln \left( \frac{\tilde{B}_0}{B_0} \right)^2$$

Pristine equilibrium biomass is used as a hard constraint with a high emphasis factor ( $\lambda$ ) 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 ( $\omega_t$ , 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

<sup>12</sup> 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).

as a known constant. However, in the C++ version of the KLAMZ model,  $m=e^\pi$  (where  $\pi$  is an estimable parameter in the model) and estimates of  $m$  can be conditioned on the constraint:

$$L = 0.5 \left[ \frac{\ln(w/w_{Target})}{\sigma_\pi} \right]^2$$

where  $w_{Target}$  is a user supplied mean or target value and  $\sigma_\pi$  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<sup>13</sup>, the NLL used to measure goodness-of-fit to “survey” data that measure trends in abundance or biomass (or survival, see below) is:

$$L = 0.5 \sum_{j=1}^{N_v} \left[ \frac{\ln \left( I_{v,j} / \hat{I}_{v,j} \right)}{\sigma_{v,j}} \right]^2$$

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):

$$\sigma_{v,t} = \sqrt{\ln(1 + CV_{v,t}^2)}$$

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<sup>14</sup> 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,

<sup>13</sup> 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.

<sup>14</sup> The relationship between data and fish populations is affected by factors (process errors) that are not accounted for in CV calculations.

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 ( $S_t$ );  $X_t^{New} = G_t^{New} - F_t - M_t$  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.<sup>15</sup> 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:

$$Q_v = e^{\frac{\sum_{i=1}^{N_v} \left[ \ln \left( \frac{I_{v,i}}{A_{v,i}} \right) \right]^2 / \sigma_{v,i}^2}{\sum_{j=1}^{N_j} \left( \frac{1}{\sigma_{v,j}^2} \right)}}$$

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.

<sup>15</sup> 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 are high or if the timing of the survey varies considerably from year to year.

### 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  $\theta_r$  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.

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:

$$d'_{r,t} = d_{r,t} - \bar{d}_r$$

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  $1/^\circ\text{C}$  if the covariate is mean centered temperature in  $^\circ\text{C}$ ).

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:

$$\hat{I}_{v,t} = (Q_v A_{v,t}^\Gamma) A_{v,t}$$

Substituting  $e^\gamma = \Gamma + 1$  gives the equivalent expression:

$$\hat{I}_{v,t} = Q_v A_{v,t}^{e^\gamma}$$

where  $\gamma$  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:

$$L = 0.5 \sum_{j=1}^N \left[ \frac{\varepsilon_{v,j}}{\sigma_v} \right]^2$$

where the log scale standard deviation  $\sigma_v$  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:

$$E[\ln(R_t)] = \sum_{j=1}^N \ln(R_j) / N$$

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:

$$E[\ln(R_t)] = \ln[e^a T_{t-\ell} / (e^b + T_{t-\ell})]$$

where  $a=e^\alpha$  and  $b=e^\beta$ , the parameters  $\alpha$  and  $\beta$  are estimated in the model,  $T_t$  is spawning biomass, and  $\ell$  is the lag between spawning and recruitment. Spawner-recruit parameters are estimated as log transformed values ( $e^\alpha$  and  $e^\beta$ ) 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:

$$E[\ln(R_t)] = \ln(S_{t-\ell} e^{a-bS_{t-\ell}})$$

where  $a=e^\alpha$  and  $b=e^\beta$ , and the parameters  $\alpha$  and  $\beta$  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:

$$L = \sum_{t=t_{first}}^N w_t \left[ \ln(\sigma_r) + 0.5 \left( \frac{r_t}{\sigma_r} \right)^2 \right]$$

where  $\lambda_t$  is an instance-specific weight usually set equal one. The additional term in the NLL  $[\ln(\sigma_r)]$  is necessary because the variance  $\sigma_r^2$  is estimated internally, rather than specified by the user.

The log scale variance for residuals is calculated using the maximum likelihood estimator:

$$\sigma_r^2 = \frac{\sum_{j=t_{first}}^N r_j^2}{N}$$

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  $\ell$  (see below). The biased maximum likelihood estimate for  $\sigma^2$  (with  $N$  in the divisor instead of the degrees of freedom) is used

because actual degrees of freedom are unknown. The variance term  $\sigma^2$  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:

$$NLL = \sum_{t=1}^{t_{first}-1} w_t \left\{ \ln \left( \sigma_r + 0.5 \left[ \frac{\ln(R_t / E(R_{t_{first}}))}{\sigma_r} \right]^2 \right) \right\}$$

where  $t_{first}$  is the first year for which expected recruitment  $E(R_t)$  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:

$$L = \begin{cases} 10000 (Q_v - q_{max})^2 & \text{if } Q_v \geq q_{max} \\ 10000 (q_{min} - Q_v)^2 & \text{if } Q_v \leq q_{min} \end{cases}$$

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:

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

where the log scale standard deviation  $\phi = \sqrt{\ln(1 + CV)}$  and  $\tau = \ln(\bar{q}) - \frac{\phi^2}{2}$  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.<sup>16</sup> 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:

<sup>16</sup> If  $x$  has a standardized beta distribution with parameters  $a$  and  $b$ , then the probability of  $x$  is

$$P(x) = \frac{x^{a-1}(1-x)^{b-1}}{\Gamma(a,b)}$$

$$L = 0.5 \left( \frac{\ln(\rho/\tau)}{\sigma} \right)^2$$

where  $\tau$  is the target value and the log scale standard deviation  $\sigma$  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 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  $\sigma$  is supplied by the user based, for example, on preliminary variances for surplus production estimates.<sup>17</sup> 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.

<sup>17</sup> 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.

### 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:

$$L = 0.5 \sum_{t=0}^N (d_t^2 + q^2)$$

where:

$$d_t = \begin{cases} Ft - \Phi & \text{if } Ft > \Phi \\ 0 & \text{otherwise} \end{cases}$$

and

with the threshold value  $\kappa$  normally set by the user to about 0.95. Values for  $\kappa$  can be linked to 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.  $R_t$ ,  $F_t$ ,  $B_t$ ,  $F_{MSY}$ ,  $B_{MSY}$ ,  $\bar{F}_{Recent}$ ,  $\bar{B}_{Recent}$ ,  $\bar{F}_{Recent} / F_{MSY}$ ,  $\bar{B}_{Recent} / B_{MSY}$ , 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.<sup>18</sup>

### 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:

$$r_{v,j} = \frac{\ln \left( I_{v,j} / \hat{I}_{v,j} \right)}{\sigma_{v,j}}$$

along with log scale standard deviations ( $\sigma_{v,j}$ , originally from survey CV’s or estimated from goodness of fit), and predicted values ( $\hat{I}_{v,j}$ ) 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

<sup>18</sup> 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.

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.<sup>19</sup> 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 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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<sup>19</sup> At present, only Beverton-Holt recruitment calculations are available in SPROJDDF.

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## **Appendix A5: Preliminary stock synthesis models for surfclams.**

This appendix presents a preliminary evaluation of the Stock Synthesis Model (Version 3) for potential use in surfclam assessments. These materials are not to be used by managers in making decisions about the surfclam resource because the data and model are preliminary and may contain errors.

Although the KLAMZ model has performed well in recent assessments, it will not be used as the primary model in the next assessment due to expected changes in survey data. Further testing is required but the Invertebrate Subcommittee plans to replace KLAMZ with the Stock Synthesis model (Version 3). SS3 makes better use of available age and length data, is more flexible and better accommodates regional differences in biological parameters and surveys. A wider range of potential biological reference points are available with SS3. Moreover, SS3 can be configured to resemble the current KLAMZ model if required.

As shown below, biomass and exploitation rate estimates from SS3 and KLAMZ were similar when the two models were configured in approximately the same way with approximately the same data and number of parameters. Recruitment estimates from SS3 were more variable and probably more realistic than recruitment estimates from KLAMZ. The two models use measured fishing mortality using different metrics. The two mortality metrics were similar in trend but different in magnitude. Therefore, fishing mortality rates from the two models should not be compared. Simple exploitation rates (catch/biomass) from the SS3 and KLAMZ models are comparable and were quite similar.

### **Background**

The current stock assessment model for surfclams and ocean quahogs (KLAMZ) is relatively simple, has proven stable, shows little or no retrospective patterns and projections from previous assessments have been similar to updated biomass estimates. However, it will be difficult to use in the next assessment if the current triennial synoptic NEFSC clam survey is replaced, as expected, with a cooperative clam survey using an industry vessel that would cover 1/3 of the stock each year. Anticipating these developments, the Invertebrate Subcommittee is developing a Stock Synthesis model (SS3) for surfclams. The most important potential benefits in using SS3 for surfclams stem from the ability to model regions independently using separate data streams and assuming different biological properties (growth, natural mortality, etc.).

The cooperative survey using a commercial vessel is expected to start in 2010 and will cover 1/3 of the stock each year. If a stock assessment were done in 2013, after cooperative surveys during 2010, 2011 and 2012, then the three regions will have survey data collected during different years and it would be difficult to combine the survey results to obtain a single index for the entire stock in a single year. It is possible, however, to use SS3 to estimate biomass for the area surveyed in 2010 based on survey and fishery data up to 2010, and project stock biomass forward based on fishery data up to 2012 precisely enough for use by managers (and so on for other regions). The estimation and projection calculations for each region would be carried out in a single model run. Whole stock biomass estimates for the terminal year, for example, would amount to the sum of the estimated and projected values for each region. The bookkeeping involved in combining regional estimates is handled automatically in SS3 and it is possible to use data for the whole stock, in addition to regional data. The community of users for SS3 is large relative to most other stock assessment models and a

variety of related tools (e.g. for graphical display of assessment results) are available and constantly being updated. In contrast, the KLAMZ model has a small pool of users and fewer available tools.

It would be possible but impractical to estimate stock biomass in 2012 by running three KLAMZ model runs for the three regions and using regional survey data. Whole stock biomass estimates could be produced for 2012 as in SS3 (by combining projection results and estimates from the regional models for each region). However, a substantial amount of programming effort would be required to avoid manual (and error prone) calculations, variance estimates might become unwieldy, and there are a number of potential sources of error to contend with. SS3, in contrast, is widely used, well tested, appears suitable and is generally modified quickly when a user needs an additional feature.

Like all models (including SS3), KLAMZ has a number of shortcomings related to use of available data, realism of biological assumptions, and circumstances in the fishery. In particular, KLAMZ does not make full use of all the available shell length or age data from surveys or shell length data from the fishery, which contain useful information about recruitment. KLAMZ assumes knife edge selection (fish of the same age or size recruit to the fishery and the model at the beginning of the year). In reality, surfclams begin to recruit to the commercial fishery at roughly 10 cm and are almost fully recruited at about 15 cm, with variability among regions and over time. KLAMZ assumes that all individuals are the same size at each age even though growth data show considerable variability in size among surfclams of the same size. KLAMZ is divided up into two “age” groups (new and old recruits) with the latter representing survivors from previous years. In KLAMZ all of the old recruits have the same survey selectivity, even though the actual survey selectivity pattern is dome shaped for surfclams. KLAMZ is mathematically identical to an age structured model with knife edge recruitment and von Bertalanffy growth. It is expressed in terms of a single equation that is opaque and not easy to understand. Age structure details are implicit in the model but not available to the user. An age based model with conventional bookkeeping (numbers at age in each year) would be more useful to constituents. The KLAMZ model can be approximated in SS3, which is a very general modeling approach.

## **Methods**

To facilitate comparison of results, the SS3 model was configured in a manner similar to the current KLAMZ model for comparison of results. Due to time limitations, the preliminary model described in this appendix does not make use of regional modeling features in SS3.

### *Model configuration*

The entire stock of surfclams (age groups 0-40+ y) during 1965-2008 was modeled in SS3 as one sex in a single region. In contrast, the KLAMZ model (one sex and one region) was for the stock of surfclams 120+ mm SL (approximately age 5-7 y). Sexual dimorphism is not thought important for surfclams, although SS3 can model male and female dynamics after recruitment independently. The basecase KLAMZ model in this assessment was for 1982-2008 but it was rerun starting in 1965 for comparison to SS3 estimates in this appendix. As stated above, the KLAMZ model starting in 1965 is preliminary, for comparative purposes only and not for use by managers.

The SS3 model assumed a Beverton-Holt spawner-recruit relationship with the steepness parameter fixed at 0.95. In effect, the SS3 model assumed that recruitments were randomly distributed around a constant mean. Mean recruitment, recruit variance and annual deviations in recruitment were parameters estimated in the model. The KLAMZ model used an auto correlated random walk recruitment model with a specified variance for annual changes in recruitment.

The SS3 model for surfclam estimates initial age composition and abundance based on recruitment and a user supplied estimate of average historical catch (an equilibrium approach). Equilibrium estimates for young age groups in the first year can be replaced with direct estimates to the extent that age, size and other data contain information about recruitment prior to the first year in the model. For surfclams, the average catch during 1965-1969 (12,802 mt per year) was used as the historical catch level and the first year with an estimated recruitment parameter was 1975. The KLAMZ model estimates a parameter that defines the initial age structure (given other parameters, data and assumptions in the model) without making an equilibrium assumption.

The last year with an estimated recruitment pattern in the SS3 model was 2004 and average recruitment was assumed for 2005-2009. The data were insufficient to estimate recruitments during the latter period, probably because GBK was not sampled during the 2005 survey and survey age and length data for 2005 were not available for the stock as a whole.

SS3 assumed a single von Bertalanffy curve for growth in length and a single shell length-meat weight (SLMW) relationship. Due to time limitations, temporal variation in growth and SLMW parameters were ignored and relationships for different regions were combined using relatively crude procedures (e.g. by pooling all of the data). The KLAMZ model used time varying von Bertalanffy curves for growth in meat weight, which were carefully adjusted for the regional differences in growth and SHMW.

Variation in size at age is important in interpretation of shell length data, modeling mortality and in other SS3 calculations. The SS3 model for surfclams assumed variability in size at age with a constant CV at ages 0-1 y and a different constant CV at ages 30+ y. CVs for ages 1-36 y were interpolated. Survey age data show that CVs for shell length decline with age (Figure A5-1). Based on a regression model ( $C_A = 0.1932 - 0.004190A$ , where  $C_A$  is the CV at age  $A$ ), the CV for size at age 1 was 0.189 and the CV for size age 30 was 0.0655. These estimates were used as initial parameter values in the SS3 model.

Surfclam survey age data were assumed to be unbiased and relatively precise in SS3 (Table A5-1 and Figure A5-1). One age reader carried out repeat age reading experiments to measure ageing precision following the 2005, 2007 and 2009 surveys. The total sample size (number of chondrophore sections read twice) was  $N=850$ . The best age for each chondrophore was the average of the two age readings and the data were binned by best age. Sample size declined with age but there were at least 10 chondrophores for most ages between 2 and 24 y (Figure A5-1). Exploratory analysis showed a slight but clear tendency for the standard deviation of age readings to increase with age (Figure A5-1). There were some young and old age groups with standard deviations of zero, although the sample size was usually less than 10 in these cases. A robust linear regression model was fit to the estimates for each age after excluding the zero cases ( $S_A = 0.2919 + 0.0102A$ , where  $S_A$  is the standard deviation for age  $A$ ). Predicted values from the model were used as estimates of ageing precision for SS3 modeling. This procedure may bias estimates of ageing precision because ages with no

ageing imprecision in the experimental data were omitted. The KLAMZ model for surfclams does not require estimates of ageing precision because age data are not used.

Based on previous assessments, SS3 model runs assumed that 50% of age zero and 100% of older individuals were sexually mature. Common biological reference points based on egg production or mature spawning biomass are calculated in SS3 but not useful for surfclam at this time because of uncertainty about maturity and egg production as a function of shell length. The KLAMZ model does not estimate spawning biomass or related reference points so no assumptions about maturity are necessary.

SS3 was configured to estimate a one logistic size-selectivity curve for the commercial fishery during all years. The KLAMZ model assumes implicitly that all surfclams in the model are fully selected by the fishery. Age based fishery selectivity estimates were not required in SS3 because there were no age data available from the fishery.

Size- and age based selectivity curves were required in the SS3 model for surfclam because both shell length and age composition data are available from the NEFSC clam survey. The dome shaped size selectivity pattern for surfclams in NEFSC clam surveys was parameterized as the double normal selectivity function recommended for use in SS3 (Figure A5-2). An age based selectivity pattern for surfclams was estimated by converting shell lengths (0 to 160 mm in steps of 5 mm) to predicted ages based on the inverted von Bertalanffy growth curve. Selectivity was assumed to be zero at age zero. This resulted in an age based survey selectivity curve that was equivalent to the size based curve, but the ages were not integers. Selectivity values at integer ages 0-30 y were calculated by interpolation. Selectivity at 30-40 y was assumed constant. The result was a dome shaped curve with a right hand limb that declined starting at about age 9 y (Figure A5-2). Survey selectivity parameters were difficult to estimate for surfclam in SS3 so the size- and age based survey selectivity curves were fixed (not estimated) in the SS3 model. This is a topic for future research.

The SS3 model used Pope's approximation to calculate fishing mortality in order to speed up calculations. KLAMZ solves the catch equation exactly. However, at typical surfclam fishing mortality rates ( $F < 0.05$ ), the approximation in SS3 is accurate.

## Data

Data used in SS3 included commercial catch weights (landings plus discard with incidental mortality assumed to be 15% of landings).<sup>20</sup> Landings were assumed to be accurate in both models. NEFSC clam survey trends in abundance (mean numbers per tow for surfclams 30+ mm SL) were for all surveys during 1982-2008 without adjustment for survey dredge selectivity.<sup>21</sup> The KLAMZ model used survey biomass trends (mean kg per tow, adjusted for survey dredge selectivity prior to modeling) for surfclams 120+

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<sup>20</sup> We initially modeled landings and stock abundance in SS3 as bushels (the units in which landings are reported). Later runs used meat weights instead to enhance comparison to KLAMZ model results and because predicted values for catch meat weight in SS3 account for the size of clams taken in the fishery (a bushel of large clams contains fewer individuals and represents less mortality than a bushel of small clams). The conversion from bushels to meat weight is based on a single crude conversion coefficient so bushels and meat weight of catch are proportional. This is an area for additional research. Additional port sampling to characterize annual mean numbers of surfclams per bushel may be desirable.

<sup>21</sup> Survey indices for all years with survey include holes (strata not sampled in some surveys) that are filled by borrowing from adjacent surveys (Table A8). Borrowing (or imputation of missing data) will be almost unnecessary when SS3 models are broken into regions because survey data for region/year combinations with substantial missing data will be simply omitted from the regional SS3 model.

SL to track trends in the stock as a whole and biomass trends for surfclams 120-128 mm SL as an index of recruitment. Both models assumed lognormal errors in survey trend data and both models used stratified random CVs in calculating the log likelihood. However, in SS3 the CV were “tuned” based on preliminary runs so that adjusted CVs and CVs implied by goodness of fit were similar.

Data for SS3 included efficiency corrected swept area survey abundance estimates (without adjustments for survey selectivity) for surfclams 30+ mm SL during 1997-2008, which are roughly analogous to the efficiency corrected swept area biomass estimates (adjusted for survey selectivity) for surfclams 120+ mm SL used in the KLAMZ model. The size selectivity pattern used in the SS3 model for efficiency corrected swept area abundance was the same as for NEFSC survey trend data. The data used in SS3 were not adjusted for selectivity *a priori* because the calculation is done in the model. SS3 used swept area abundance instead of biomass because the original survey data were collected in units of abundance and because the conversion from numbers at size to biomass is handled in the model.

The KLAMZ model for surfclams used swept area biomass data to estimate trend but not scale (the overall magnitude of stock biomass) to avoid “double dipping” (survey trend data for in the model for 1997-2005 is also used in calculating swept area biomass). Swept-area abundance data were used to estimate trends in SS3 because it was not possible to clearly separate the two types of information. In preliminary SS3 models, the likelihood weight for swept area biomass trends was reduced substantially but this approach seemed to degrade estimation of the catchability parameter for swept area abundance, which provides crucial information about scale (the overall biomass level).

SS3 was configured to use prior information about the catchability coefficient for efficiency corrected swept area abundance in a manner similar to the way KLAMZ uses prior information about the catchability coefficient for efficiency corrected swept area biomass. The prior information is important in scaling biomass estimates from both models. Unfortunately, selectivity and catchability are confounded to some extent in selectivity and capture efficiency estimates for surfclams. Based on estimates in this assessment, survey capture efficiency  $e=0.256$  for surfclams 150+ mm SL. Size selectivity ranges 0.74 to 0.43 for surfclams 150 to 179 mm SL and is constant for larger sizes (Figure A5-3 and see below). For lack of a better approach, the average size selectivity for surfclams 150+ mm was assumed to be about 0.523 (the simple average of the selectivity values in the table below). Based on this assumption, capture efficiency for fully selected size groups in the NEFSC survey should be about  $0.256/0.523=0.489$ . The efficiency corrected swept area abundance estimates used as data in the SS3 model were therefore calculated without adjustment for selectivity assuming a capture efficiency of 0.489 so that the catchability coefficient for swept area abundance estimated in the SS3 model would be about 1.0.

Middle of shell length bin	Survey dredge selectivity
155	0.74
165	0.48
175	0.44
185 to 245	0.43

In SS3, a lognormal distribution with a mean of one and CV=0.14 was used as a prior for the swept area abundance catchability parameter. The same distribution was used in KLAMZ for swept area biomass.

Survey shell length composition data (30-250 mm SL in 5 mm bins) was used in SS3 for all years with surveys. In addition, NEFSC clam survey age composition data (from age length keys) were included for years with age samples from each region (Table A20).<sup>22,23</sup> The KLAMZ model uses survey size or age data to distinguish new and old recruits only.

## Results

Estimates from the final demonstration SS3 and KLAMZ models were similar but direct comparisons must be made with care because of differences between the models. In particular, KLAMZ calculates the biomass of surfclams 120+ mm SL while “summary biomass” output from SS3 was for surfclams age 5+.

The number of parameters estimated in the final preliminary demonstration models were similar for SS3 (42 parameters, Table A5-2) and KLAMZ (47 parameters, Table A5-3). Direct comparisons are difficult because, for example, SS3 estimates survey catchability values using two formal parameters while KLAMZ estimates catchability using closed form maximum likelihood estimates not counted as parameters. Similarly, the KLAMZ model constrains recruitment deviations to a greater extent than SS3 (using fewer degrees of freedom).

Annual recruitment parameters were the most difficult parameters to estimate in both models (note large CVs for some recruitment parameters in the SS3 output in Table A5-2). The KLAMZ model did not fully converge because the Hessian could not be inverted. Experience indicates that the problem was likely due to at least one weak recruitment parameter estimate.<sup>24</sup> Routine diagnostic plots (Figures A5-4 to A5-8a) indicate that the SS3 model fit the data for surfclam reasonably well. The estimated selectivity pattern from SS3 for the commercial fishery (Figure A5-8b) and estimated variance around the assumed growth curve were plausible (Figure A5-8c).

Biomass estimates from the two models were similar in scale and both suggest declining trends in recent years (Figure A5-9). Biomass trends for years prior to 1965 differed. The biomass estimates from KLAMZ were smoother because the lack of information about recruitment necessitated a very smooth recruitment pattern in KLAMZ compared to SS3 (Figure A5-10). The effects of more variable recruitment in the SS3 model are evident in estimates of numbers at age during each year, which suggest periodic pulses of strong recruitment over several years are important to the surfclam stock (Figure A5-11).

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<sup>22</sup> Once the SS3 model is broken into regions, age data for all regions/years with samples will be used because synoptic sampling across the entire stock is not required.

<sup>23</sup> “Conditional age at length” data (records of length and age) are the current preferred approach for using survey age data in SS3. However, the survey age data collection protocol is stratified based on stratum and shell length. The stratified approach precludes using conditional age at length data for the entire stock because unweighted samples are not representative of the stock as a whole. Weighting age by survey catch to obtain representative samples is an area for future research. Once the SS3 model is broken into regions, it should be easier to use conditional age at length data.

<sup>24</sup> If additional time were available, the weak recruitment estimates from the KLAMZ model could probably be identified and strengthened by minor changes to annual recruit parameter weights.

Based on delta method variance calculations for spawning biomass and recruitment estimates, population estimates from the SS3 model are relatively uncertain, as might be expected given data limitations that were exasperated by the one stock approach (Figures A5-12 and A5-13). CVs for the basecase KLAMZ model in this assessment were smaller due to the highly constrained recruitment estimates.

Simple exploitation rates (catch / estimated biomass) from the SS3 and KLAMZ models were similar in trend and magnitude. However, the most typical measures of fishing mortality (fully recruited  $F$  in SS3 and total  $F$  in KLAMZ) were similar in trend but different in magnitude (Figure A5-14). SS3 uses a number of metrics to measure fishing mortality that may be quite different than the metric used in KLAMZ. Trends may be comparable but the magnitude of fishing mortality estimates from SS3 and KLAMZ models should not be compared. Simpler exploitation rates (catch/biomass) are much easier to compare and interpret. For similar reasons, reference points computed in one model should never be compared to biomass or fishing estimates from the other model.

Table A5-1. Ageing precision data and estimates for surfclams from NEFSC clam surveys during 2005-2008.

Age bin	N	Minimum age	Maximum age	Standard deviation (mm)	CV	Fitted standard deviation (mm)
1	7	1	1	0.000	0.000	NA
2	55	1	3	0.354	0.177	0.312
3	145	3	3	0.000	0.000	NA
4	114	3	5	0.311	0.078	0.333
5	49	5	5	0.000	0.000	NA
6	56	4	8	0.484	0.081	0.353
7	21	6	8	0.312	0.045	0.363
8	41	7	9	0.458	0.057	0.374
9	26	9	9	0.000	0.000	NA
10	51	9	11	0.281	0.028	0.394
11	22	10	12	0.374	0.034	0.404
12	29	11	13	0.439	0.037	0.414
13	19	12	14	0.232	0.018	0.425
14	22	13	15	0.457	0.033	0.435
15	9	14	16	0.343	0.023	0.445
16	32	14	18	0.617	0.039	0.455
17	11	16	18	0.436	0.026	0.465
18	24	17	19	0.565	0.031	0.476
19	14	18	20	0.385	0.020	0.486
20	17	19	21	0.500	0.025	0.496
21	12	21	21	0.000	0.000	NA
22	27	21	23	0.532	0.024	0.516
23	11	22	24	0.309	0.013	0.527
24	21	23	26	0.656	0.027	0.537
25	1	25	25	0.000	0.000	NA
26	2	26	26	0.000	0.000	NA
27	2	27	27	0.000	0.000	NA
28	9	27	29	0.639	0.023	0.578
29	1	29	29	0.000	0.000	NA

Table A5-2. Descriptions, estimates, standard errors and CVs for parameters in the SS3 model.

Index	Description	Estimate	SD	CV
1	Predicted length at age 30	15.384	0.088	0.01
2	von Bertalanffy K	0.259	0.009	0.04
3	CV for size at age 1	0.145	0.011	0.08
4	CV for size at age 30	0.051	0.009	0.17
5	Beverton-Holt maximum recruitment	14.072	0.250	0.02
6	Recruitment standard deviation	0.569	0.074	0.13
7	Recruitment offset parameter	0.023	0.059	2.55
8	Recruitment deviation 1975	-0.663	0.409	0.62
9	Recruitment deviation 1976	0.147	0.392	2.67
10	Recruitment deviation 1977	1.390	0.310	0.22
11	Recruitment deviation 1978	1.307	0.272	0.21
12	Recruitment deviation 1979	-0.386	0.375	0.97
13	Recruitment deviation 1980	0.830	0.212	0.26
14	Recruitment deviation 1981	0.339	0.278	0.82
15	Recruitment deviation 1982	-0.084	0.258	3.07
16	Recruitment deviation 1983	-0.206	0.239	1.16
17	Recruitment deviation 1984	0.373	0.190	0.51
18	Recruitment deviation 1985	-0.556	0.302	0.54
19	Recruitment deviation 1986	-0.361	0.265	0.73
20	Recruitment deviation 1987	0.669	0.231	0.35
21	Recruitment deviation 1988	0.621	0.257	0.41
22	Recruitment deviation 1989	-0.013	0.269	21.46
23	Recruitment deviation 1990	0.300	0.253	0.84
24	Recruitment deviation 1991	0.027	0.324	11.93
25	Recruitment deviation 1992	1.445	0.142	0.10
26	Recruitment deviation 1993	0.335	0.279	0.83
27	Recruitment deviation 1994	-0.208	0.272	1.31
28	Recruitment deviation 1995	-0.436	0.247	0.57
29	Recruitment deviation 1996	-0.765	0.258	0.34
30	Recruitment deviation 1997	-0.593	0.267	0.45
31	Recruitment deviation 1998	-0.165	0.241	1.46
32	Recruitment deviation 1999	-0.042	0.209	4.94
33	Recruitment deviation 2000	-0.498	0.315	0.63
34	Recruitment deviation 2001	-0.675	0.393	0.58
35	Recruitment deviation 2002	-0.541	0.334	0.62
36	Recruitment deviation 2003	-0.758	0.330	0.44
37	Recruitment deviation 2004	-0.831	0.292	0.35
38	Fishing mortality rate prior to 1965	0.018	0.005	0.28
39	Catchability clam survey	-5.743	0.286	0.05
40	Catchability swept area abundance	0.458	0.312	0.68
41	Commercial size selectivity parameter	13.213	0.287	0.02
42	Commercial size selectivity parameter	3.830	0.384	0.10

Table A5-3. Descriptions and estimates for parameters in the KLAMZ model. Standard errors and CVs are not available because the model did not fully converge.

Index	Description	Estimate
1	Log old recruits 1965	6.66362
2	Log total biomass 1964	6.75012
3	Log mean recruitment	4.58878
4	Recruitment deviation 1965	0.00277
5	Recruitment deviation 1966	0.00270
6	Recruitment deviation 1967	0.00248
7	Recruitment deviation 1968	0.00277
8	Recruitment deviation 1969	0.00322
9	Recruitment deviation 1970	0.00296
10	Recruitment deviation 1971	0.00270
11	Recruitment deviation 1972	0.00291
12	Recruitment deviation 1973	0.00303
13	Recruitment deviation 1974	0.00296
14	Recruitment deviation 1975	0.00244
15	Recruitment deviation 1976	0.00245
16	Recruitment deviation 1977	0.00258
17	Recruitment deviation 1978	0.00405
18	Recruitment deviation 1979	0.00521
19	Recruitment deviation 1980	0.00482
20	Recruitment deviation 1981	0.00566
21	Recruitment deviation 1982	0.00631
22	Recruitment deviation 1983	0.00864
23	Recruitment deviation 1984	0.01000
24	Recruitment deviation 1985	0.01024
25	Recruitment deviation 1986	0.00909
26	Recruitment deviation 1987	0.01095
27	Recruitment deviation 1988	0.01058
28	Recruitment deviation 1989	0.01064
29	Recruitment deviation 1990	0.01119
30	Recruitment deviation 1991	0.01079
31	Recruitment deviation 1992	0.00966
32	Recruitment deviation 1993	0.00982
33	Recruitment deviation 1994	0.00877
34	Recruitment deviation 1995	0.00529
35	Recruitment deviation 1996	0.00355
36	Recruitment deviation 1997	0.00239
37	Recruitment deviation 1998	-0.00104
38	Recruitment deviation 1999	-0.00601
39	Recruitment deviation 2000	-0.00738
40	Recruitment deviation 2001	-0.01015
41	Recruitment deviation 2002	-0.01409
42	Recruitment deviation 2003	-0.01721
43	Recruitment deviation 2004	-0.01899
44	Recruitment deviation 2005	-0.02076
45	Recruitment deviation 2006	-0.02246
46	Recruitment deviation 2007	-0.02480
47	Recruitment deviation 2008	-0.02593

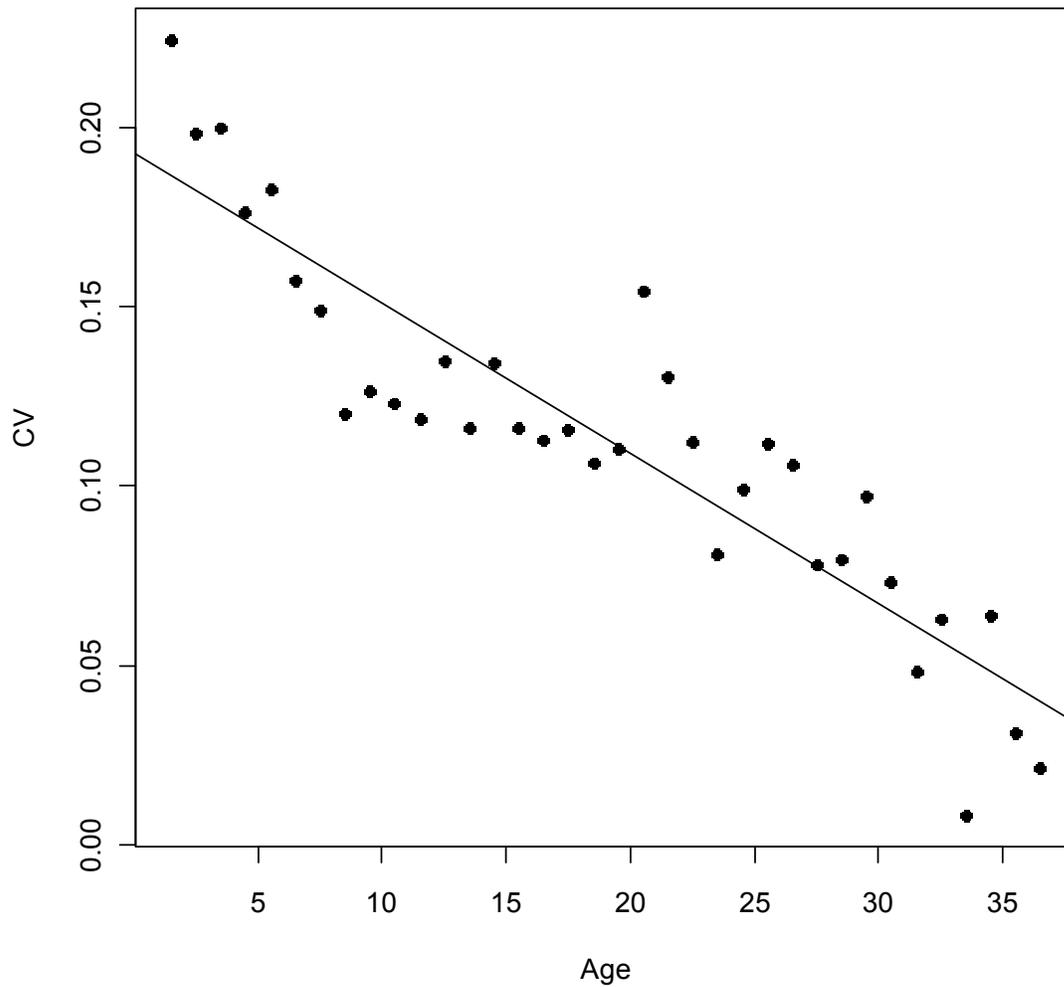


Figure A5-1. CVs for size at age 1-36 y for surfclams. The line was fit by linear regression using the sample size at each age as weights.

Surfclam age precision data

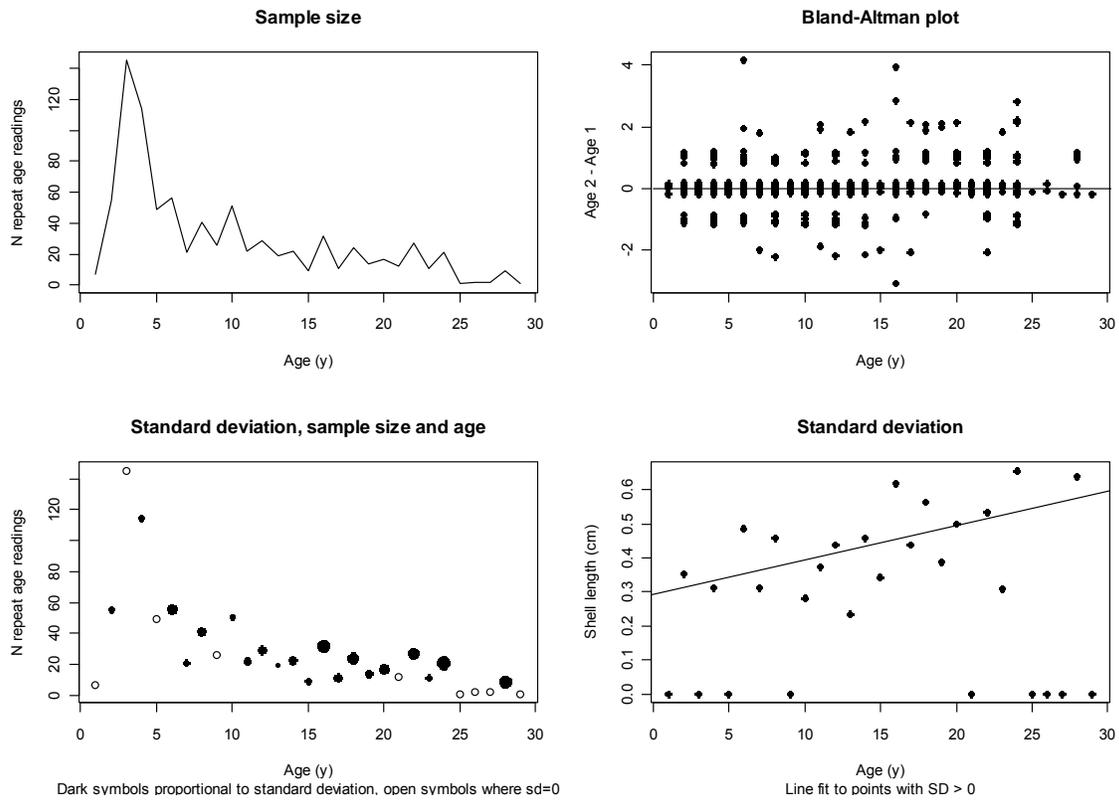


Figure A5-2. Surfclam age reader precision data from NEFSC clam surveys during 2005-2008. Data in the Bland-Altman plot (upper right) have been jittered to enhance visibility.

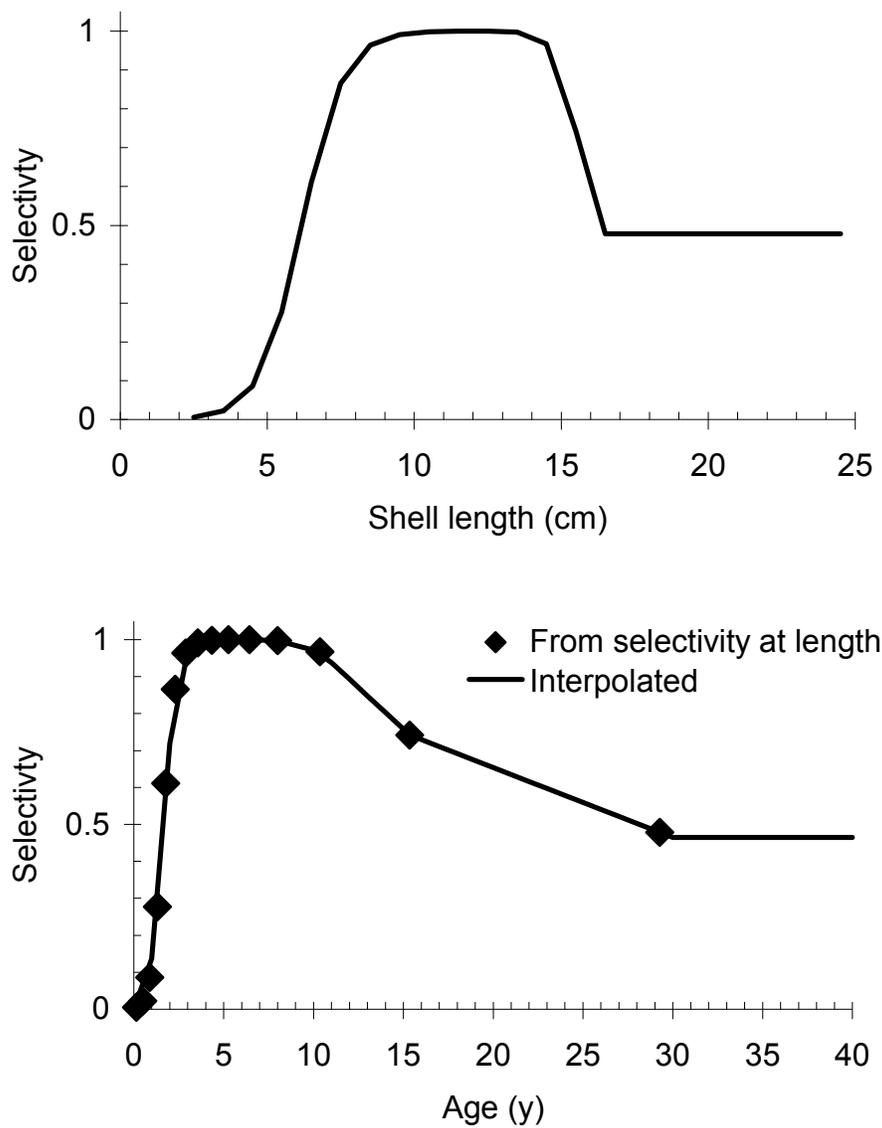


Figure A5-3. Selectivity at length and age for the NEFSC clam survey in preliminary SS3 models for surfclams.

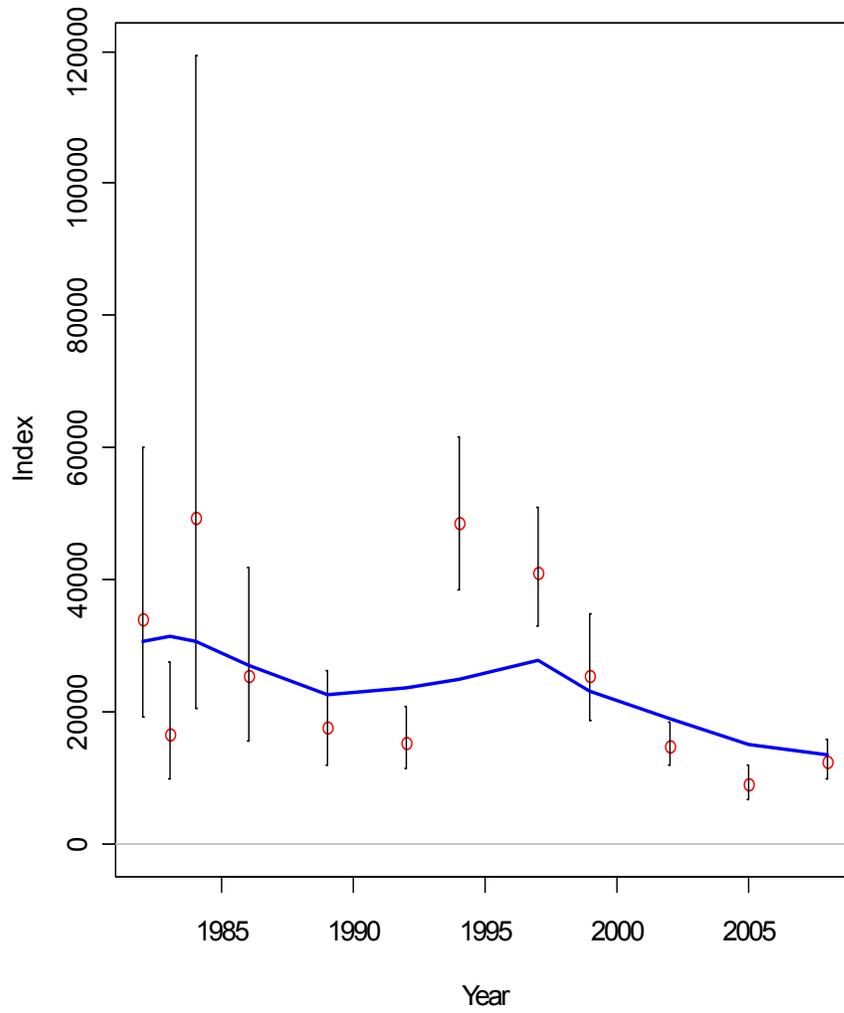


Figure A5-4. Observed and predicted values for NEFSC clam survey abundance data (mean number per tow) for surfclams 30+ mm SL from the SS3 model

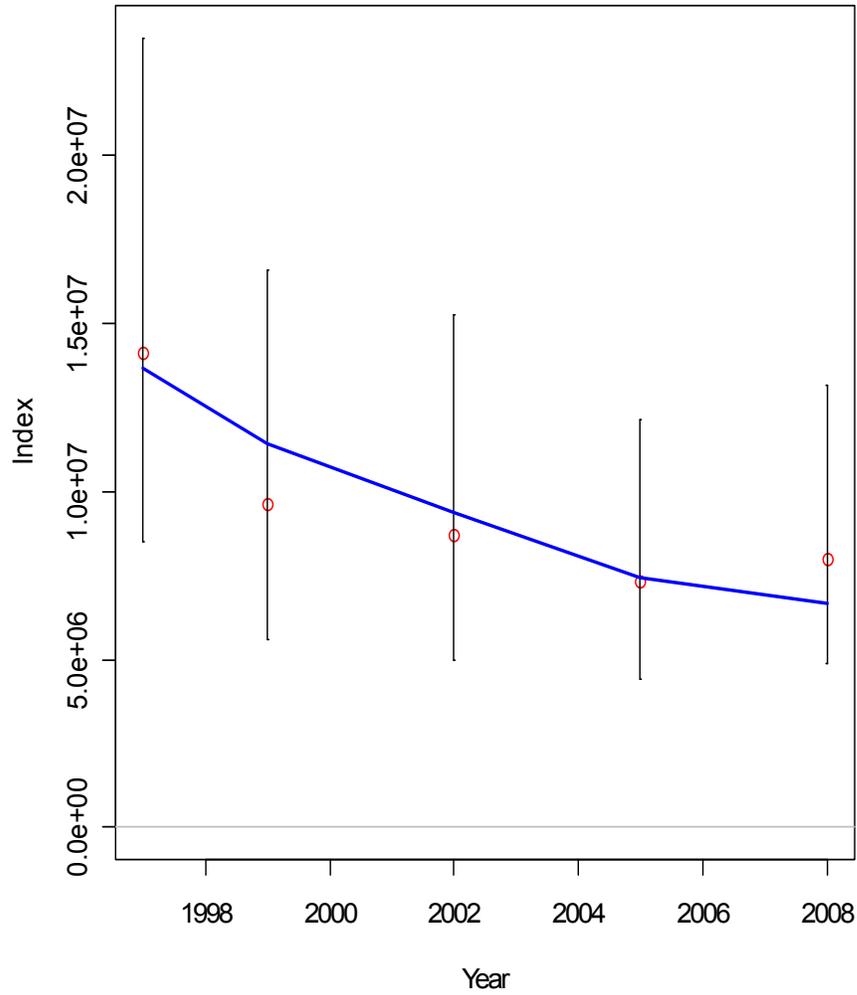


Figure A5-5. Observed and predicted values for efficiency corrected swept area abundance data for surfclams 30+ mm SL from the SS3 model.

## Commercial shell length composition

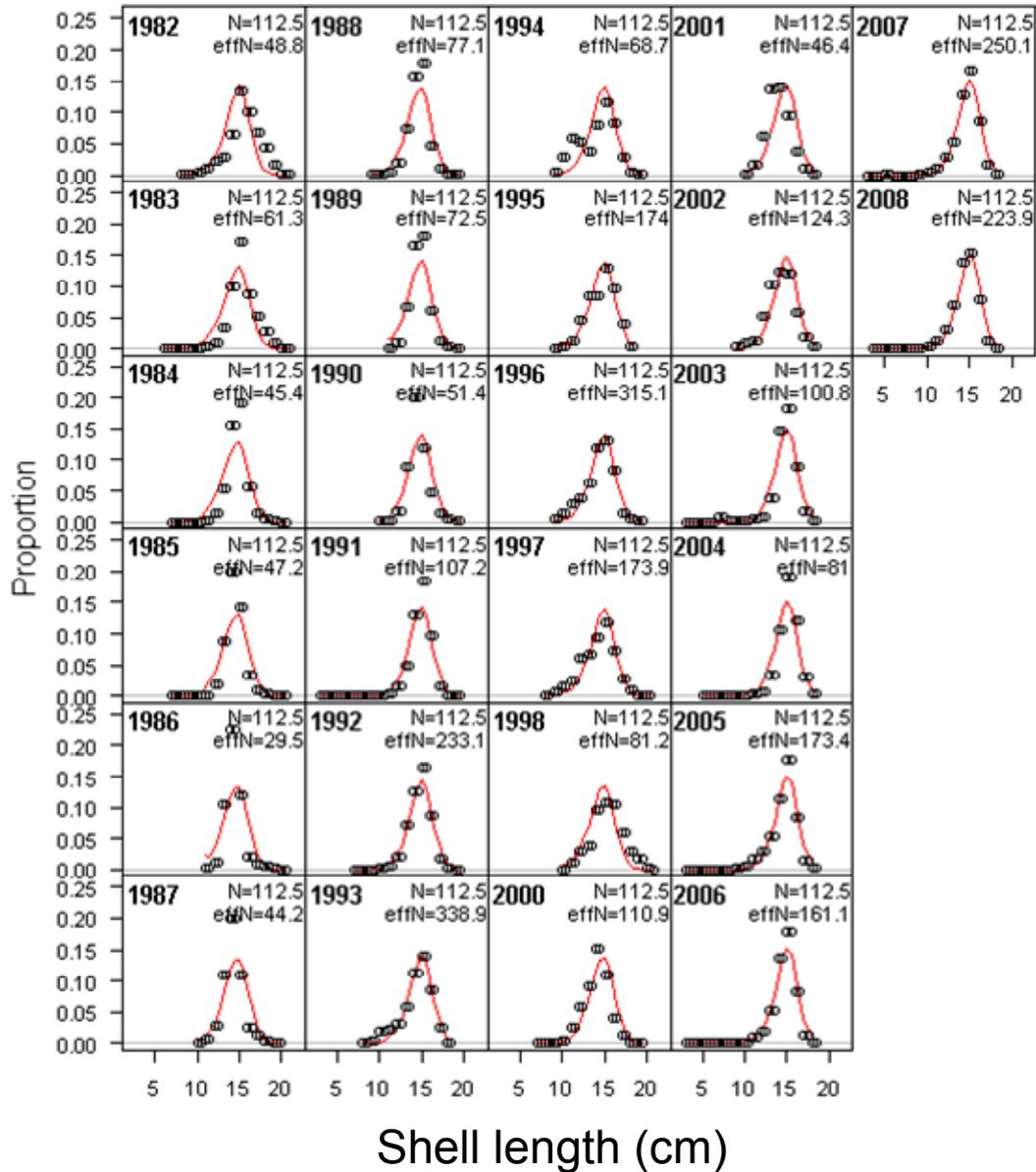


Figure A5-6. Observed and predicted fishery length composition data for surfclams from the SS3 model.

# Clam survey shell length composition

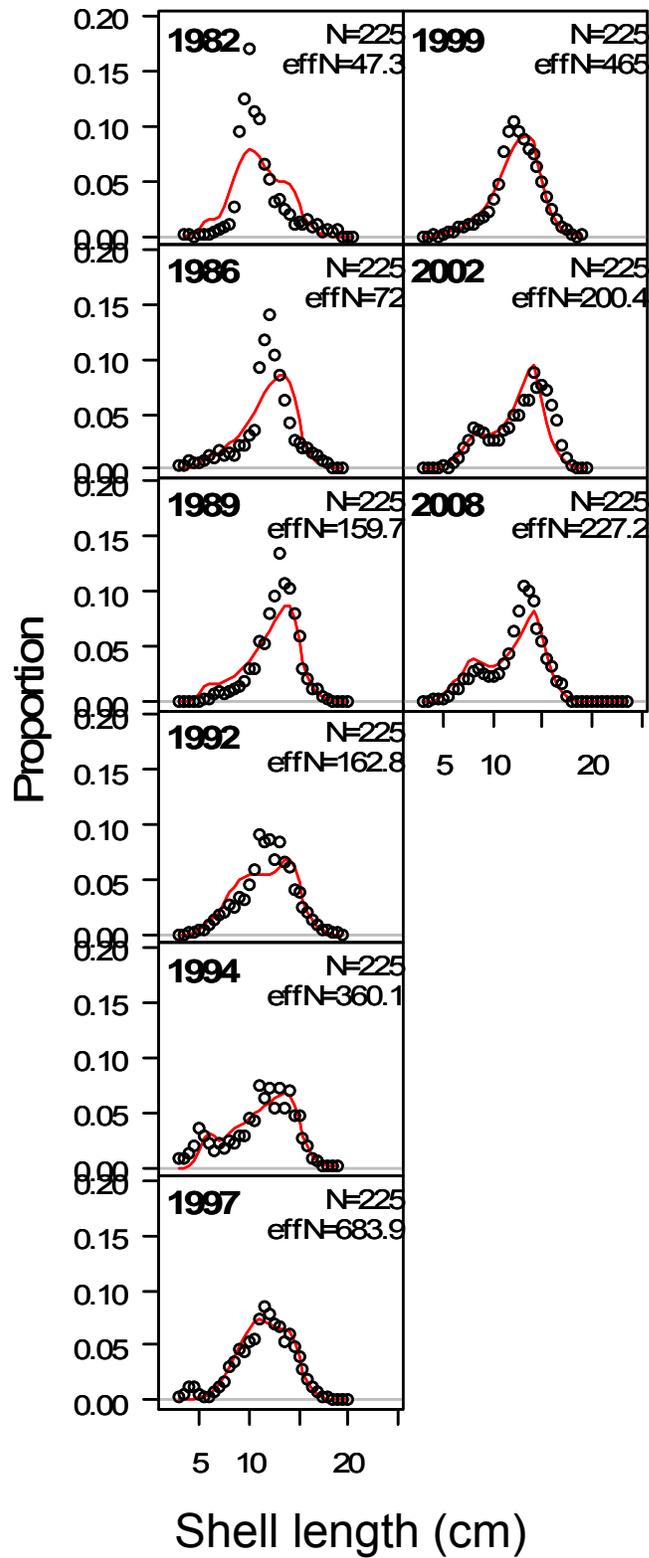


Figure A5-7. Observed and predicted NEFSC clam survey length composition data for surfclams from the SS3 model.

# Clam survey age composition

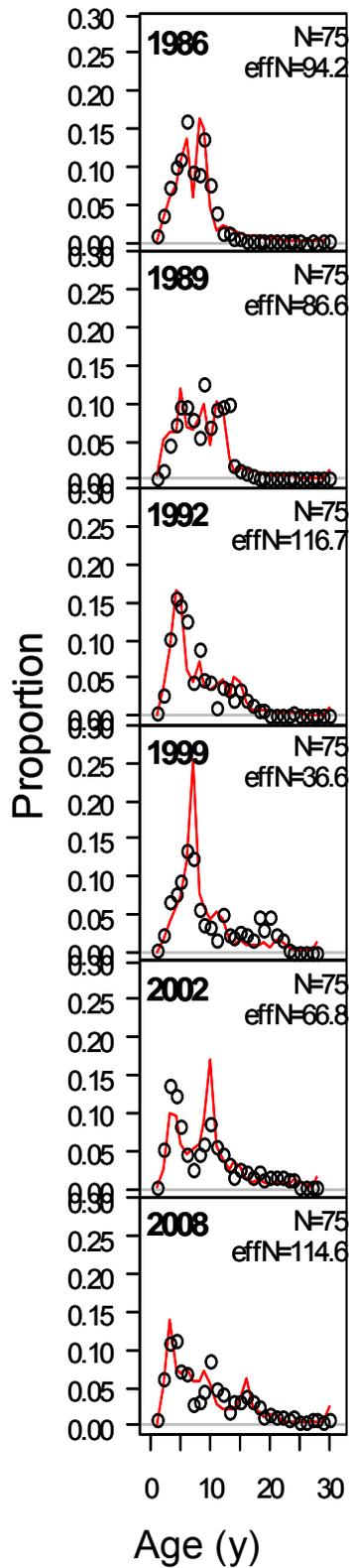


Figure A5-8a. Observed and predicted NEFSC clam survey age composition data for surfclams from the SS3 model.

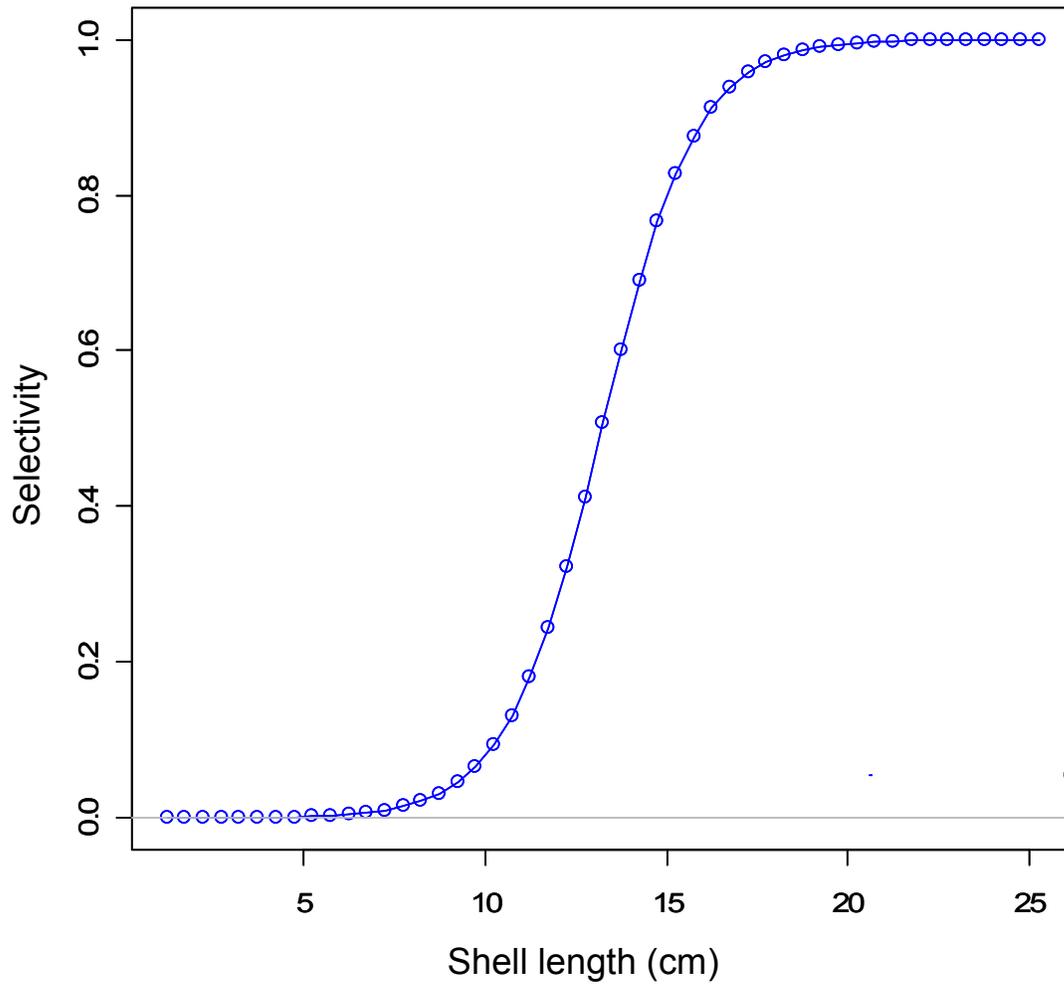


Figure A5-8b. Commercial fishery size selectivity curve for surfclams estimated in the SS3 model.

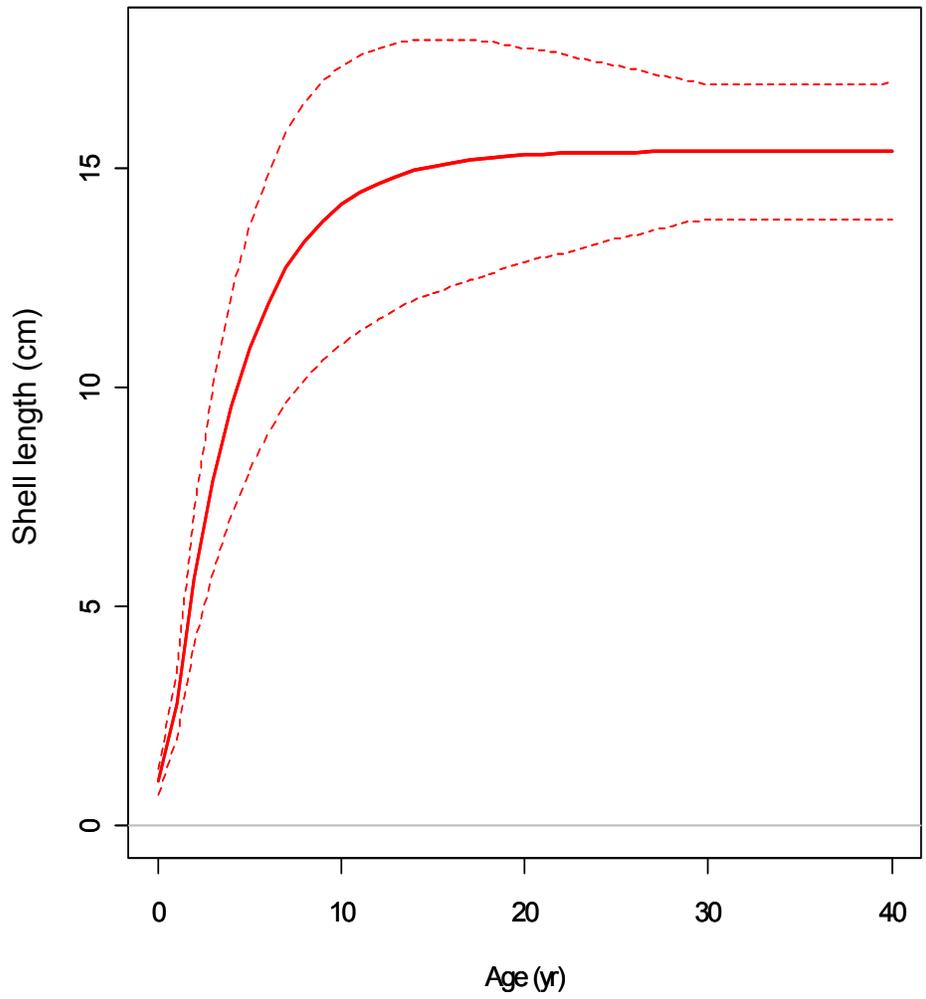


Figure A5-8c. The assumed growth curve and estimated distribution in size at age in the SS3 model for surfclams.

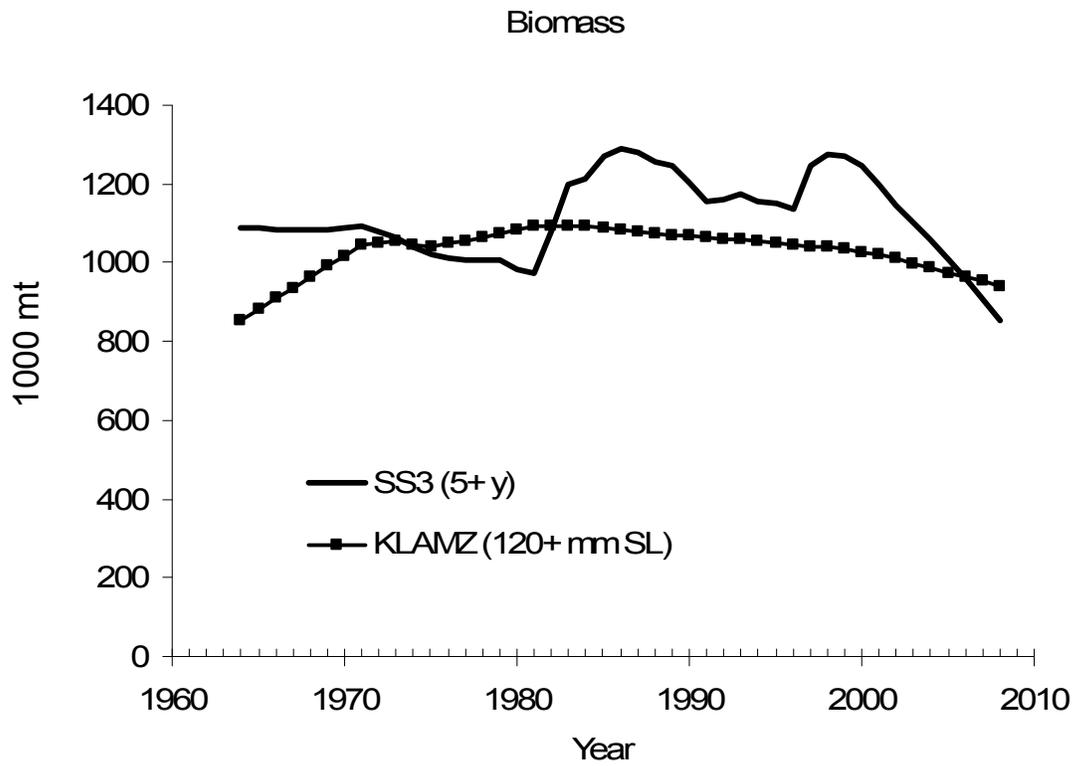


Figure A5-9. Biomass estimates from the SS3 and KLAMZ models. Note that estimates from SS3 are for surfclams ages 5+ while estimates from KLAMZ are for surfclams 120+ mm SL.

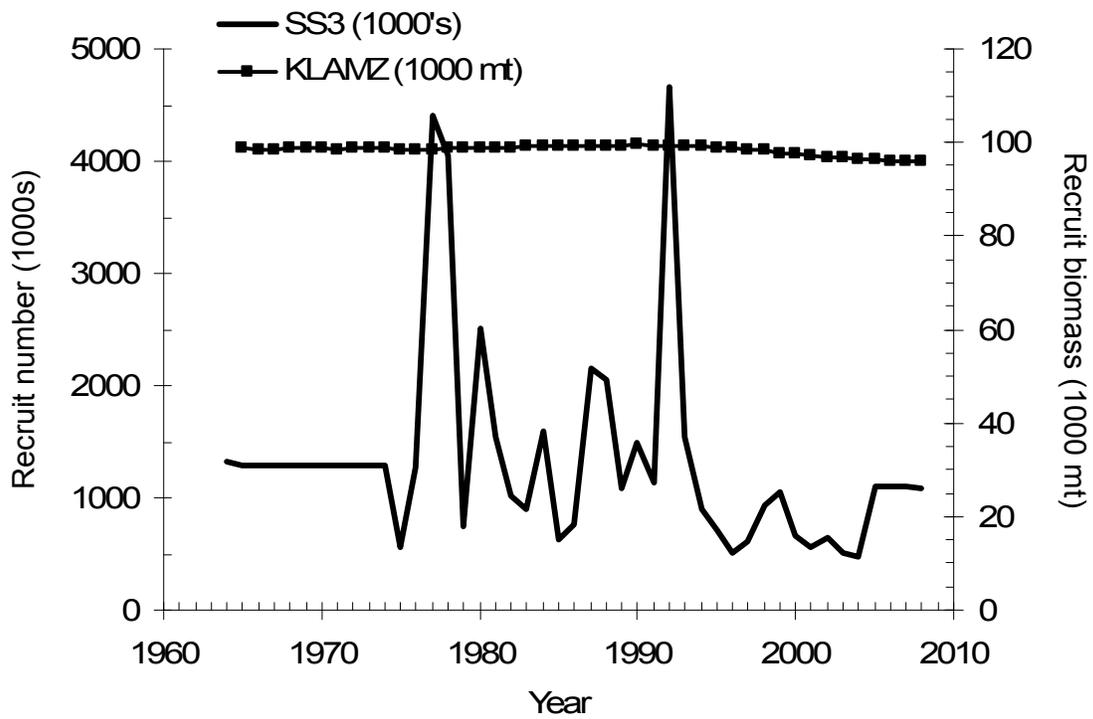


Figure A5-10. Recruitment estimates from the SS3 and KLAMZ models. Note that estimates from SS3 are for surfclams at age zero while estimates from KLAMZ are for surfclams approximately 120-128 mm SL and 5-7 y in age.

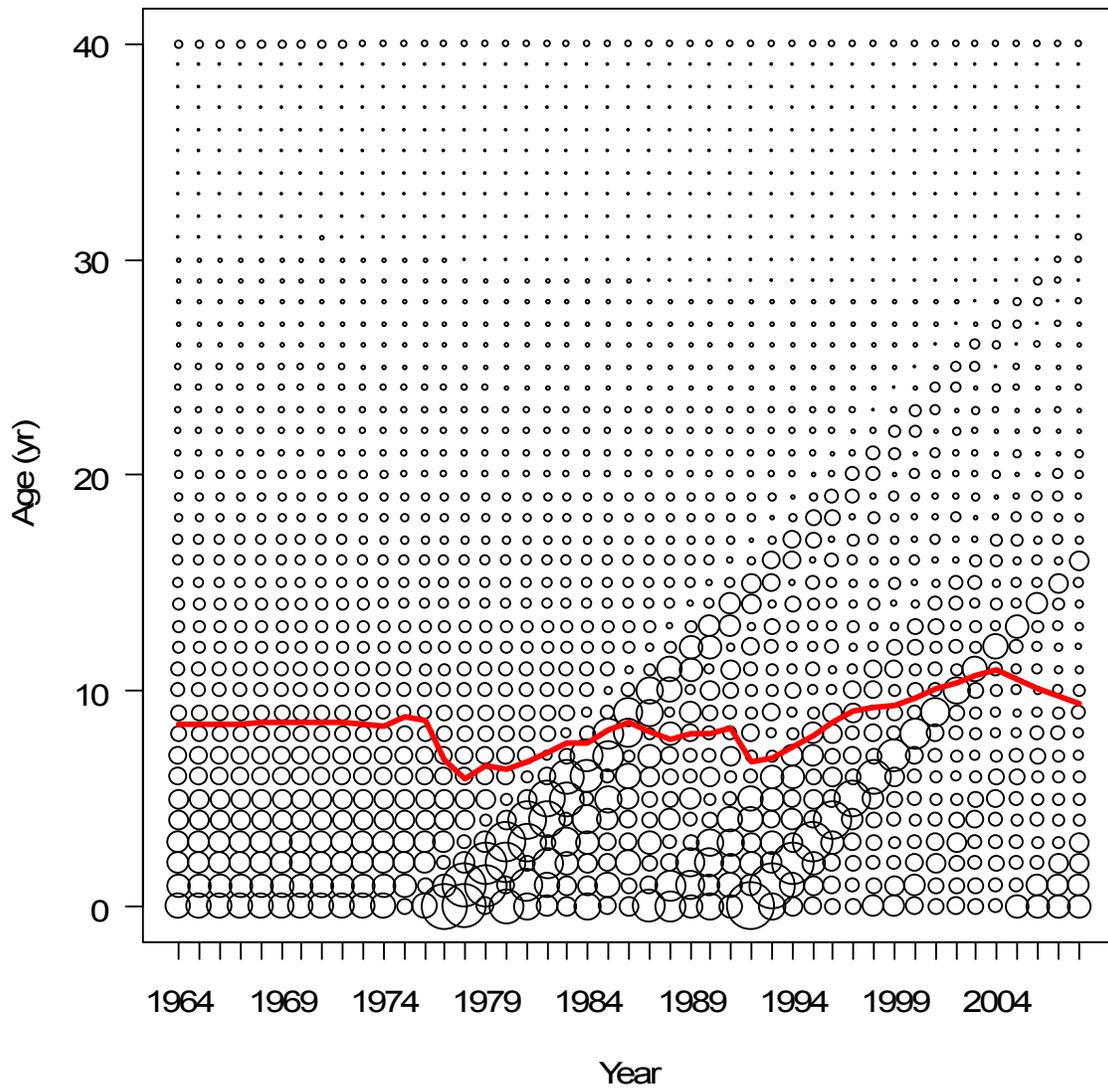


Figure A5-11. Surfclam stock number at age estimates from the SS3 model. The size of the circles is indicates the number of estimated clams at each age in each year.

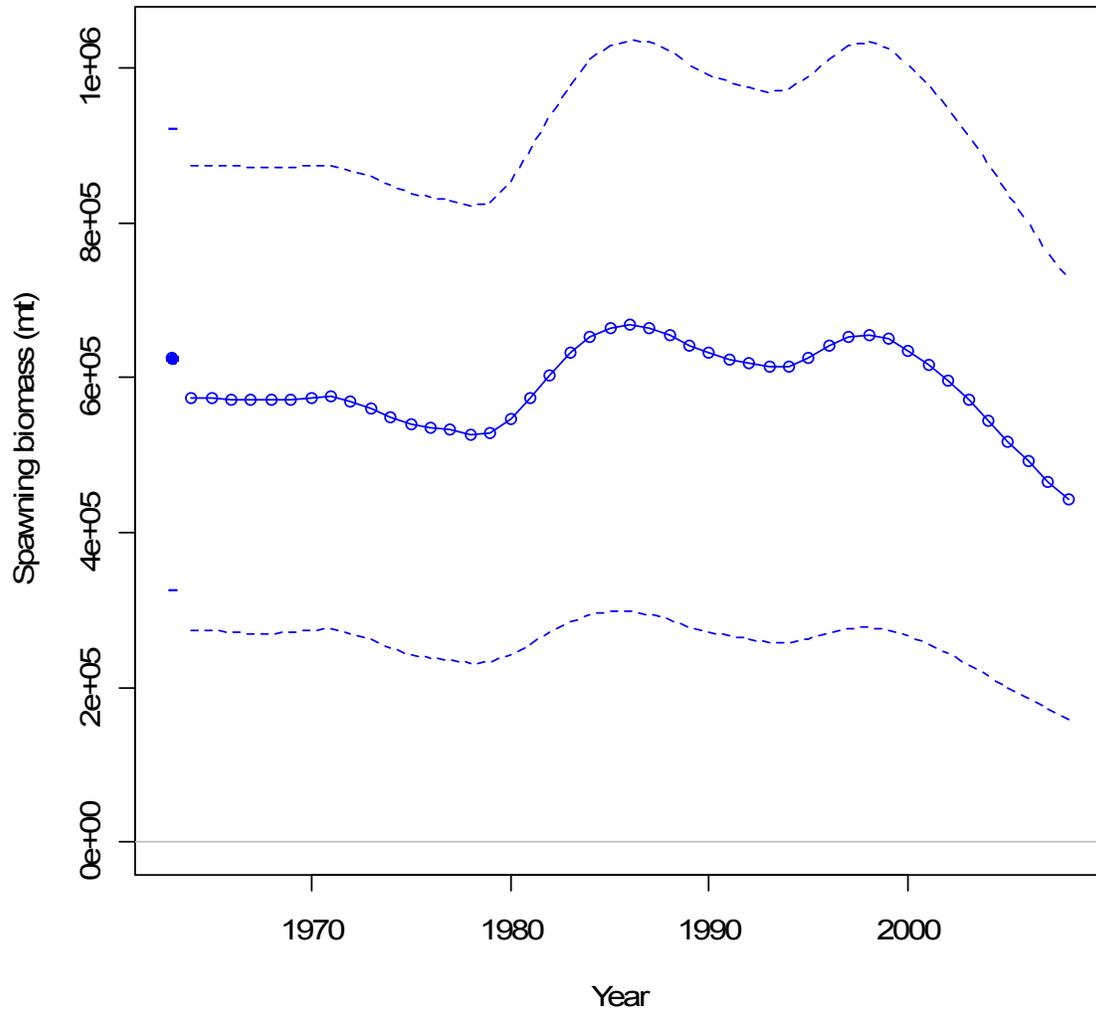


Figure A5-12. Surfclam spawning biomass estimates the SS3 model with approximate 95% confidence intervals. The figure is intended to demonstrate uncertainty. The absolute value of the estimates is not reliable due to lack of biological data for surfclams.

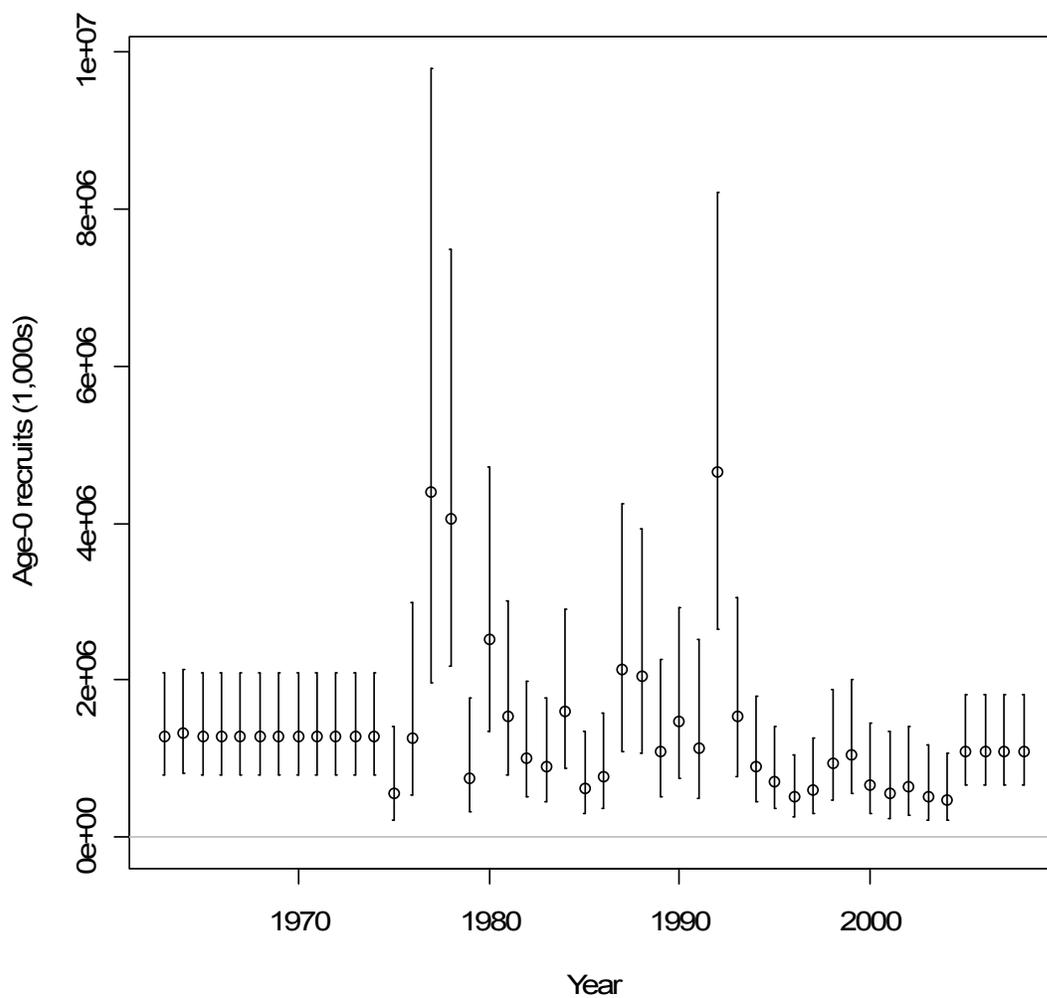


Figure A5-13. Surfclam recruitment estimates (age 0) from the SS3 model with approximate 95% confidence intervals. The figure is intended to demonstrate uncertainty.

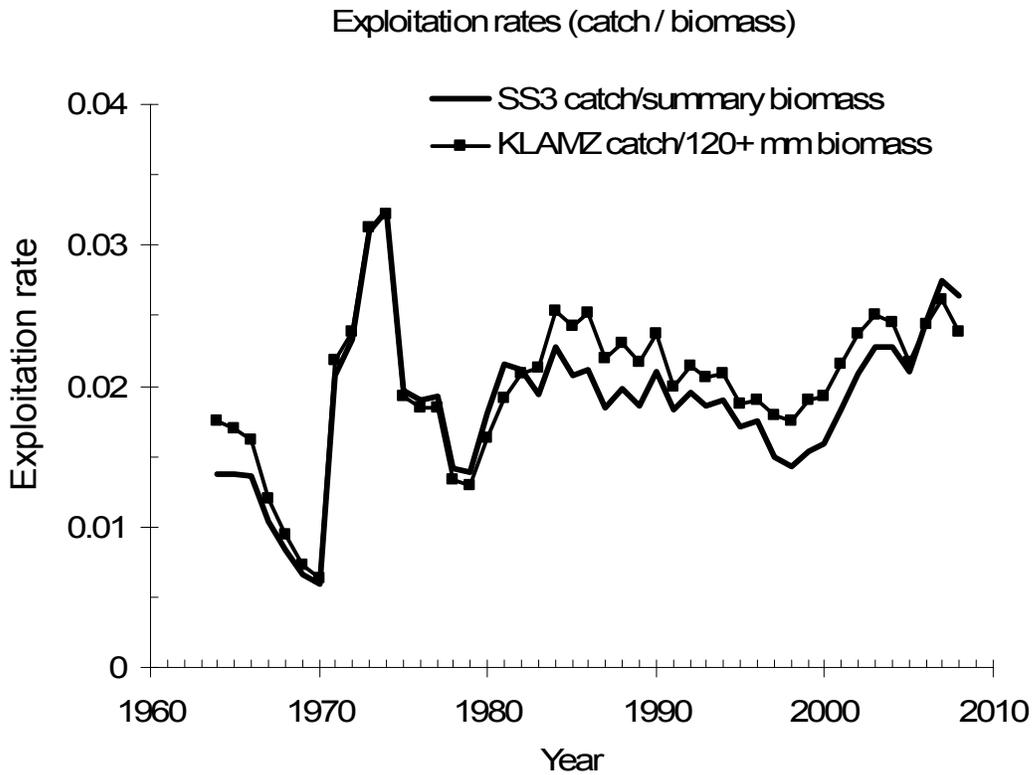
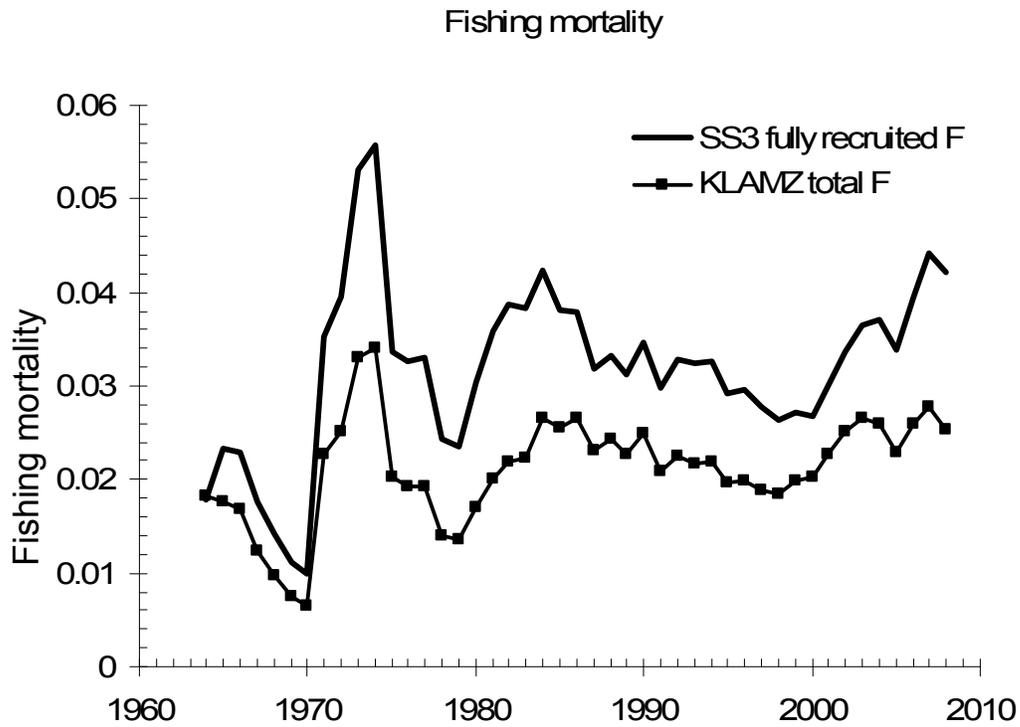


Figure A5-14. *Top:* Common measures of fishing mortality from the SS3 and KLAMZ models. *Bottom:* Simple exploitation rates estimates (catch / biomass) from the SS3 and KLAMZ models.

## **Appendix A6: Surfclam annulus verification study**

In summary, several lines of evidence support the procedures used to age surfclams sampled during NEFSC clam surveys since the 1970s. In particular, ring counts from the chondrophores of surfclam shells sampled during NEFSC clam surveys correspond to age and assumptions about the location of the first annulus appear valid (Appendix Figure A6-4).

The 2005 *Atlantic Surfclam Ageing Workshop* (Jacobson et al. 2006) noted that, in spite of the strong correlation between the number of annular marks in shell valves and sectioned chondrophores, chondrophores have not been formally validated as an ageing structure. Additionally, there is uncertainty as to both the mechanism and seasonal timing associated with annulus formation. In particular, the interpretation of the last annual mark may depend on latitude as well as sample date. To address both of these concerns, the Fishery Biology Program, in collaboration with staff in the Population Dynamics Branch and the surfclam industry, has undertaken a study which is nearing completion.

Monthly samples were collected on a monthly basis by industry vessels from three geographic regions including Cape Cod, northern New Jersey, and Delmarva from August 2007-December 2008 totaling over 2,200 clams. Sample size ranged from approximately 50-75 clams per month in each of the three areas. Clams were measured and weighed, and chondrophores were sectioned. Digital images of sectioned chondrophores were taken and measurements were taken on the image from the umbo to each annulus. Edge type and width were also annotated.

Approximately 1,400 clams have been aged to date (work is ongoing and a full report is forthcoming). Surfclams in samples ranged from 85 to 194 mm SL and ages ranged 2 to 30 years. Preliminary results indicate that hyaline zones identified as annuli occur only once per year, during August-September. In both 2007 and 2008, annulus formation began earlier in more northern locations with an approximate one month difference in formation from the northern-most to the southern-most regions (Appendix Figures A6-1 through A6-3, respectively).

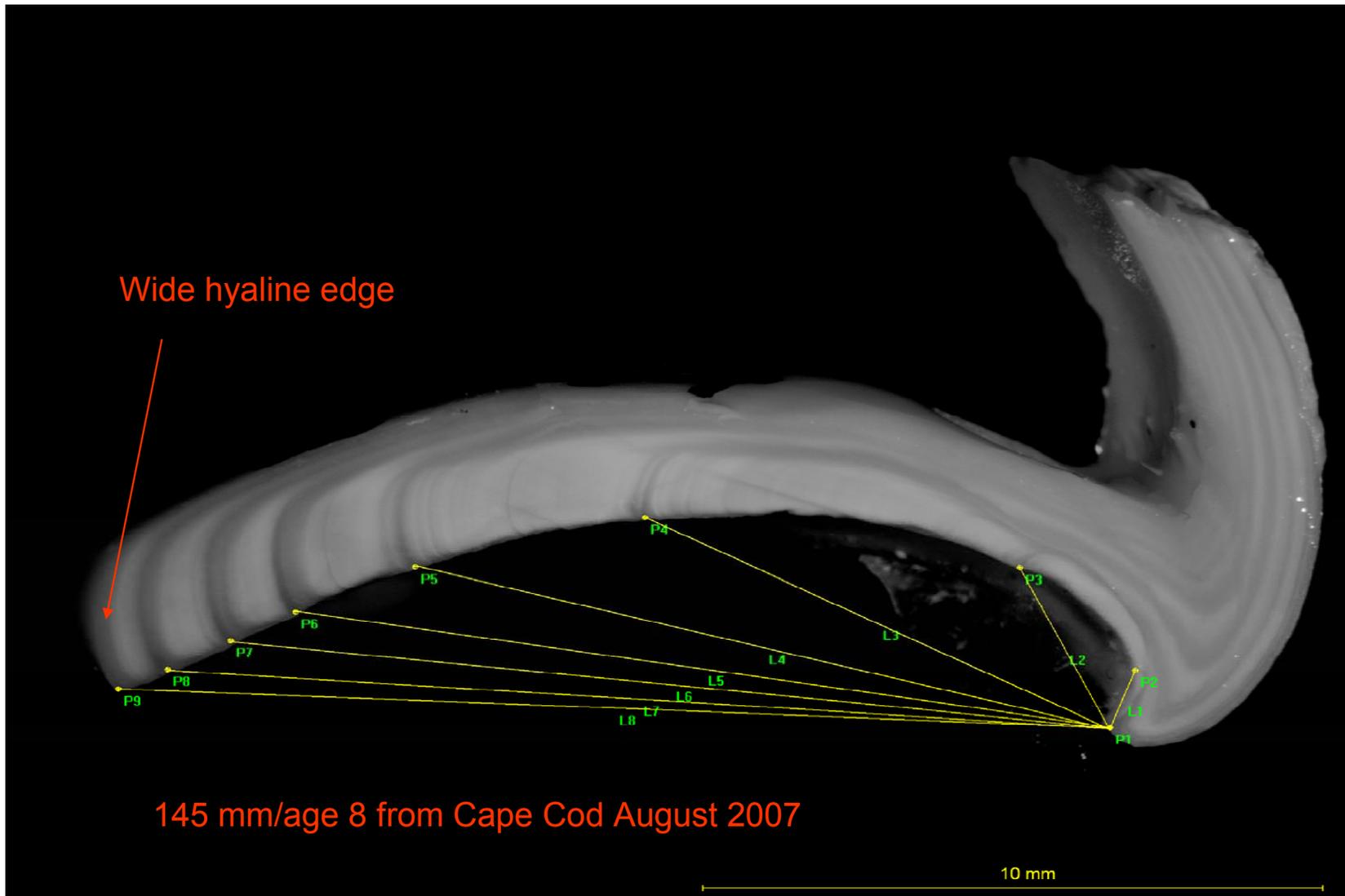
### **Verification of first annulus**

The first hyaline zone close to the umbo (Appendix Figure A6-4) is assumed to be the first annulus in ageing surfclams (Ropes 1980). In a separate but relevant study, shell valves and chondrophores from young-of-the-year (juvenile) surf clams were collected during June 16 to August 11, 2005 by New Jersey's Division of Fish and Wildlife (Jeff Normant, NJ DFW, personal communication). The samples were taken off the coast of New Jersey from grab samples during routine survey work and used to determine if current assumptions about the first annulus are valid. Small surfclams in the sample ranged from 3-14 mm SL. Sectioned chondrophores from these small shells lacked a hyaline zone at the umbo, indicating that the first annulus had not yet formed. This result is consistent with the current assumption that the first annulus forms during September-October following spawning in the NJ region.

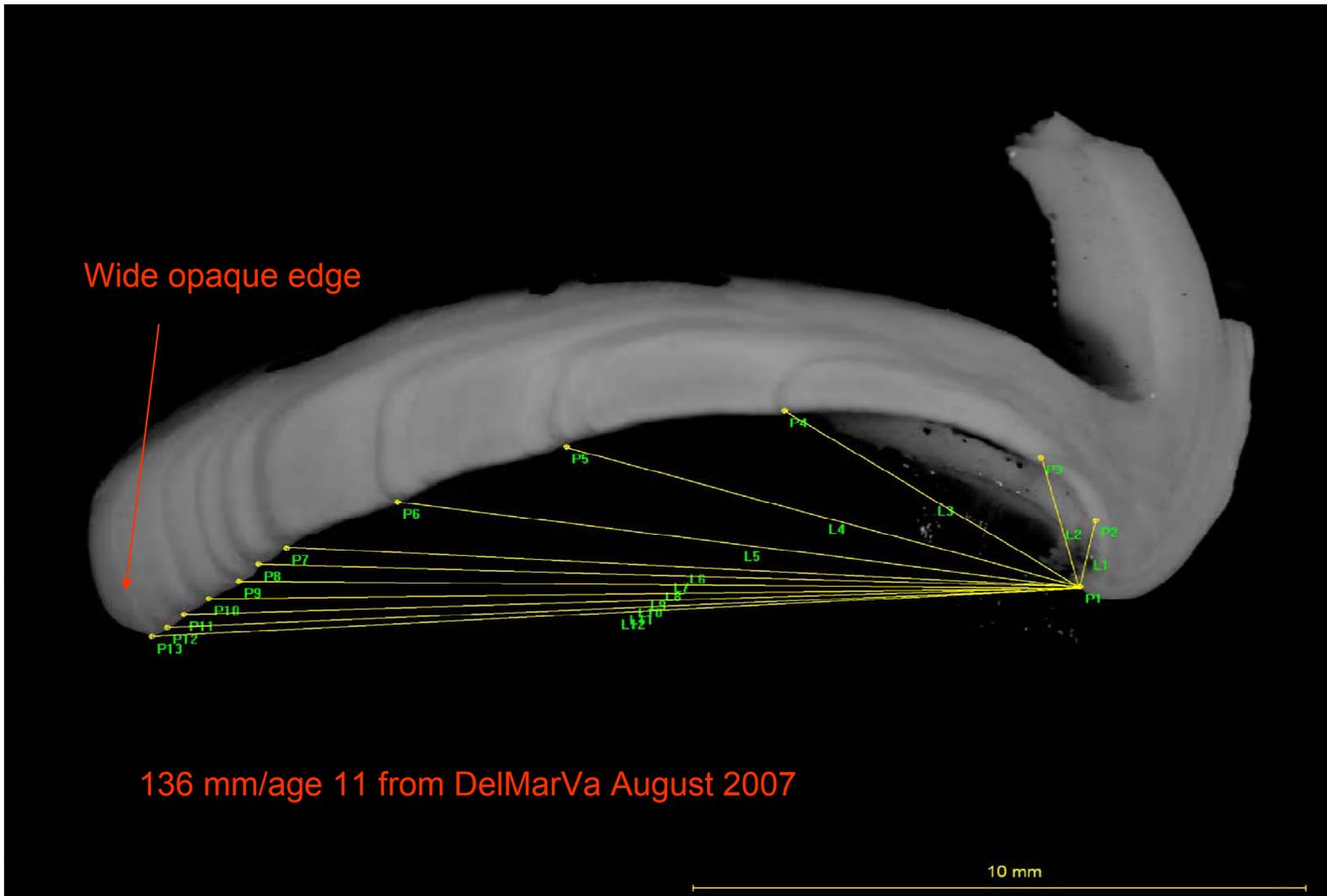
Samples of larger surfclams also support the current assumption about the first annulus. The range of shell valve lengths at the first annulus formed during September-October in larger surfclams from the NJ region was 9-19 mm which is larger than the range of shell lengths for juvenile clams (3-14 mm SL) caught two to three months previously. As additional evidence, the observed range 9-19 mm SL is consistent with predicted sizes at age 1 estimated from growth modeling performed by Picariello (2006).

## References:

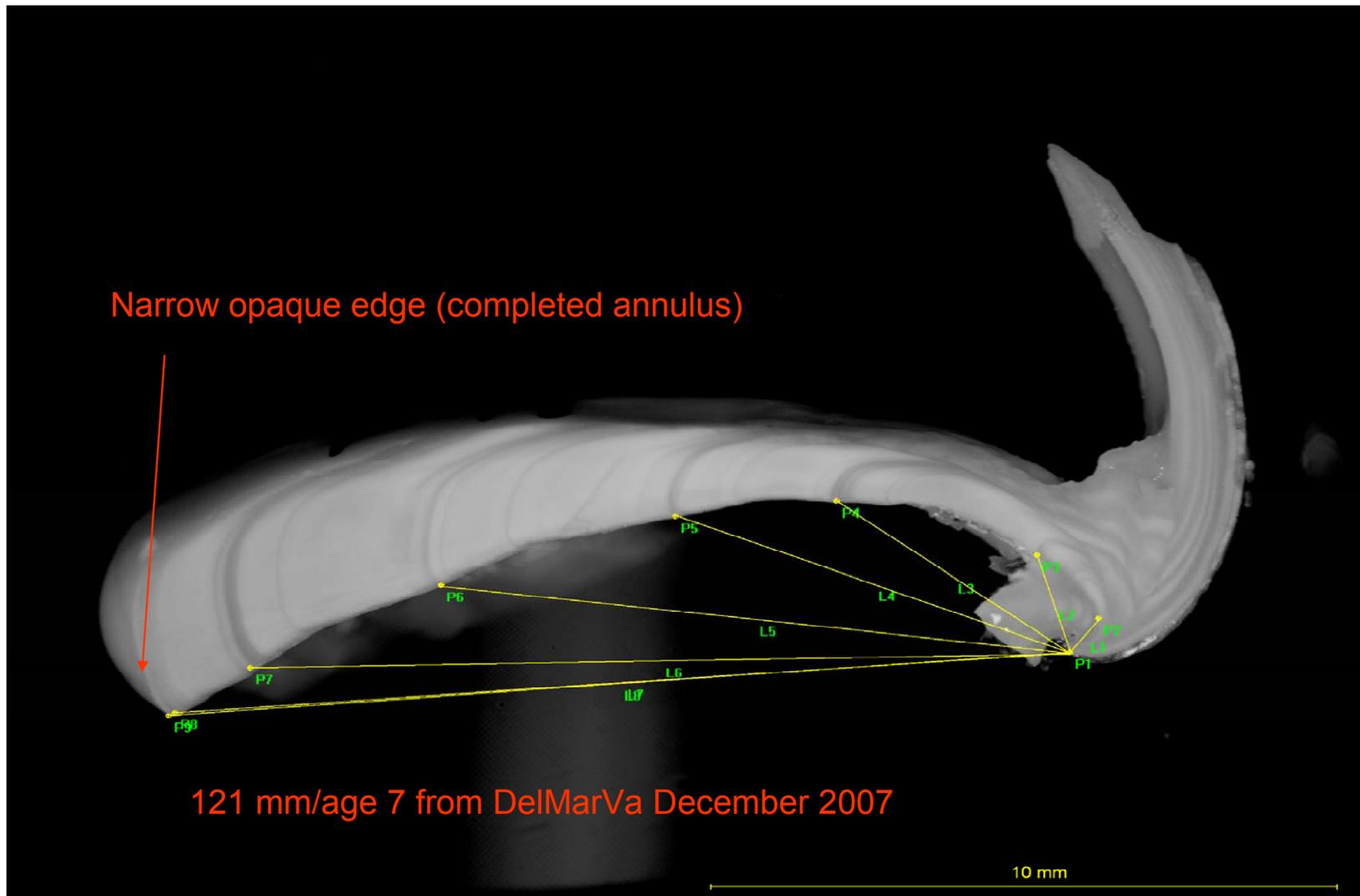
- Jacobson L, Sutherland S, Burnett J, Davidson M, Harding J, Normant J, Picariello A, Powell E. 2006. Report from the Atlantic Surfclam (*Spisula solidissima*) Aging Workshop, Northeast Fisheries Science Center, Woods Hole, MA, 7-9 November 2005. NEFSC Ref Doc. 06-12. 24 p
- Picariello A. 2006. The effects of climate change on the population ecology of the Atlantic surf clam, *Spisula solidissima*, in the Middle Atlantic Bight. M.Sc. thesis, The College of William & Mary in Virginia, 169 pp.
- Ropes JW. 1980. Biological and fisheries data on the Atlantic surf clam, *Spisula solidissima* (Dillwyn). Tech. Serv. Rep. 24, Woods Hole Lab, NMFS, NOAA, Woods Hole, MA 02543, 88 p.



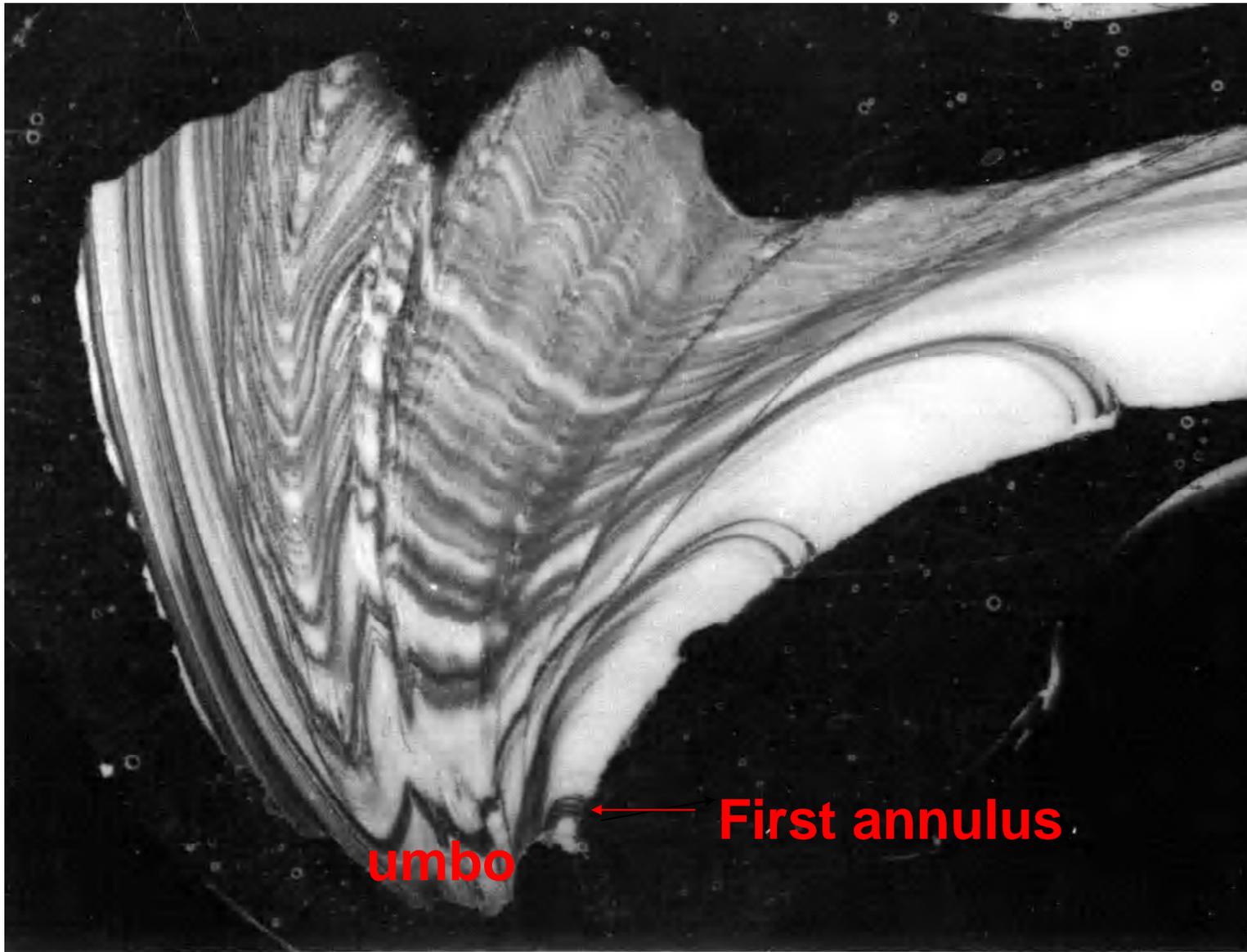
Appendix Figure A6-1. A sectioned chondrophore from a surfclam caught in August off Cape Cod, Massachusetts, the northernmost of the three sampling sites. Note the wide hyaline (transparent; it appears darker on the black background) outer edge indicating the annulus is in the process of forming.



Appendix Figure A6-2. A sectioned chondrophore from a surfclam caught in August off Ocean City, Maryland, the southernmost of the three sampling sites. Note the wide opaque (lighter shell material) outer edge indicating the annulus has not started forming.



Appendix Figure A6-3. A sectioned chondrophore from a surfclam caught in December off Ocean City, Maryland, the southernmost of the three sampling sites. Note the narrow opaque (lighter shell material) outer edge indicating the annulus has completely formed (the hyaline material has stopped being laid down).



Appendix Figure A6-4. The first annulus can be seen here in a section of an adult surfclam chondrophore. This was verified by comparing when the first annulus was laid down by samples of young-of-the-year surfclams to the location of this mark on the shell of adult surfclams.

## **Appendix A7. History and basis of natural mortality estimates for surfclams.**

Natural mortality is an important uncertainty for surfclams. This appendix contains an excerpt from the surfclam stock assessment in 2000 (NEFSC 2000) that reviews the information available at that time concerning natural mortality of surfclams. In particular, it documents the basis for the current estimate of  $M=0.15 \text{ y}^{-1}$ . This information is provided solely for the convenience of Reviewers.

The excerpt is from: *NEFSC. 2000. Surfclams, p. 311-477. In: Report of the 30th Northeast Regional Stock Assessment Workshop (31th SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. Northeast Fish. Sci. Cent. Ref. Doc. 00-03.* It can be downloaded from the web site:

<http://www.nefsc.noaa.gov/nefsc/publications/crd/crd0004.pdf>.

**STOCK SIZE MODELS  
AND BIOLOGICAL REFERENCE  
POINTS (BRPs)**

This section contains results from models that estimate stock biomass, natural mortality, fishing mortality and exploitation rates, and biological reference points. As a first step, it is important to identify plausible values for the instantaneous rate of natural mortality ( $M$ , defined in terms of numbers of surfclams per year), a key parameter in most stock assessment calculations. According to the Stock Assessment Review Committee responsible for the last surfclam assessment (NEFSC 1998, p. 72, *italics added*):

“The current [1997] assessment assumes a nominal natural mortality rate ( $M$ ) = 0.05. By inference, this rate implies that, if not fished, 5% of the animals should survive to age 60. This conflicts with aging information which has documented few animals older than age 30, even in areas not subject to massive dieoffs in 1976. Given the sensitivity of net productivity, DeLury population estimates and YPR calculations to  $M$ , additional studies to refine the assumed  $M$  are considered a high priority.”

Revised estimates (see summary table below and details following) were based on recent age and growth studies (Weinberg and Helser 1996) and a variety of methods. Considering problems with certain estimates (see detailed descriptions below), results suggest a plausible range of  $M=0.10-0.20\text{ y}^{-1}$  in surfclam. Based on these results,  $M=0.15\text{ y}^{-1}$  was used in most analyses and values in the range  $0.05-0.20\text{ y}^{-1}$  were used for sensitivity analyses.

Source	Range
Weinberg (1999)	0.16-0.22 $\text{y}^{-1}$
Hoenig (1983)	0.10-0.17 $\text{y}^{-1}$
Jensen (1996)	0.18-0.33 $\text{y}^{-1}$
5% rule	0.08-0.10 $\text{y}^{-1}$
Literature survey	0.09-0.20 $\text{y}^{-1}$
All	0.08-0.22 $\text{y}^{-1}$

Weinberg (1999) used age length keys, survey length composition, survey catch rates and catch curves to estimate  $Z$  (where  $Z$  is total mortality,  $F+M$ ) for surfclam in the NNJ (survey stratum 88) and DMV (survey stratum 9) assessment areas. Estimates were for the 1976-1979 yearclasses in the 1980 to 1997 surveys starting at age 4 (length > 75 mm). Weinberg's (1999) data were collected following a hypoxic event off New Jersey and low surfclam biomass in both areas during 1976, followed by strong recruitment during 1976 (NNJ) and 1977 (DMV). Fishing mortality rates were likely less than  $0.05\text{ y}^{-1}$  in both areas and certainly less than  $0.1\text{ y}^{-1}$ . Results (see below) suggest that  $M$  for surfclams is in the range  $0.16-0.22\text{ y}^{-1}$ .

Yearclass	Z for NNJ Stratum 88 ( $\text{y}^{-1}$ )	Z for DMV Stratum 9 ( $\text{y}^{-1}$ )
1976	0.26	0.33
1977	0.26	0.28
1978	0.3	0.22
1979	--	0.22
1980	--	0.26
Mean	0.27	0.26
Mean Z - F (F=0.05 $\text{y}^{-1}$ )	0.22	0.21
Mean Z-F (F=0.1 $\text{y}^{-1}$ )	0.17	0.16

Hoenig (1983) gives linear regressions for predicting  $Z$  based on maximum observed age [ $\ln(Z)=\alpha+\beta\ln(A)$ , where  $A$  is maximum observed age] in mollusks ( $\beta=-0.832$ ,  $\alpha=1.23$ ) and all types of marine organisms ( $\beta=-0.982$ ,  $\alpha=1.44$ ). If age data were collected from an unfished or lightly fished stock, then Hoenig's method estimates  $M$ . If age data were collected from a fully exploited stock, then it estimates an upper bound for  $M$ . Predictions are imprecise but Hoenig's method is widely used in stock assessment work to identify plausible values for  $M$ . Estimates are affected by the number of animals aged (Hoenig 1983). The oldest surfclam aged by NMFS (all surveys and all areas, including areas not affected by the 1976 and areas with no fishing) was 36 years old but maximum ages of 40 years are plausible.

Maximum Age	Z ( $\text{y}^{-1}$ ) for Mollusks	Z ( $\text{y}^{-1}$ ) for All Organisms
36	0.17	0.13
37	0.17	0.12
38	0.17	0.12
39	0.16	0.12
40	0.16	0.11
41	0.16	0.11
42	0.15	0.11
43	0.15	0.11
44	0.15	0.10
45	0.14	0.10

Jensen's (1996) simple theoretical result suggests that  $M=1.5 K$ , where  $K$  is a parameter in the Von Bertalanffy model for weight at age. Results (see below) based on estimates for  $K$  in each stock area suggest  $M$  for surfclams is in the range 0.18-0.33  $y^{-1}$  (average 0.26  $y^{-1}$ ).

Assessment Area/Years	$K (y^{-1})$	$M (y^{-1})$
Average	0.176	0.26
NNJ 1989&1992	0.145	0.22
DMV 1980	0.175	0.26
DMV 1989&1992	0.117	0.18
LI (all years)	0.189	0.28
SNE (all years)	0.220	0.33
GBK (all years)	0.168	0.25
		0.26

As described above, the value  $M=0.05 y^{-1}$  used in previous assessments was chosen to give a

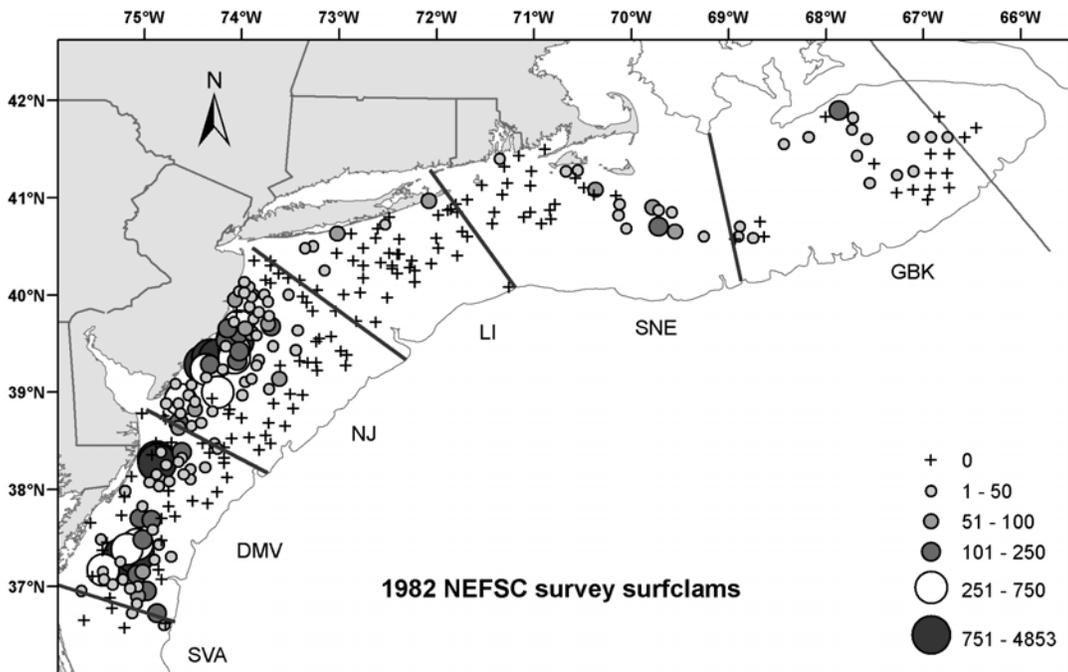
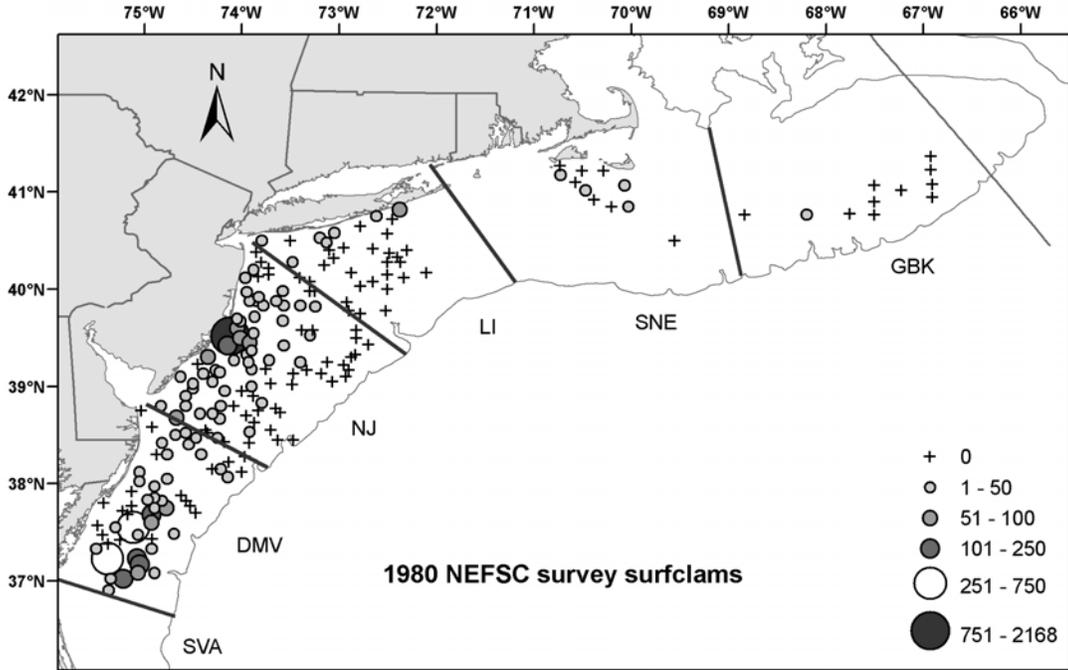
predicted 5% of animals in a theoretical population at age 60 (a measure of typical lifespan). Assuming typical lifespans of 30, 35 and 40 years, the predicted "5% rule" gives  $M$  values of 0.10, 0.088 and 0.077. Thus, the 5% rule gives lower predicted  $M$  values than other methods.

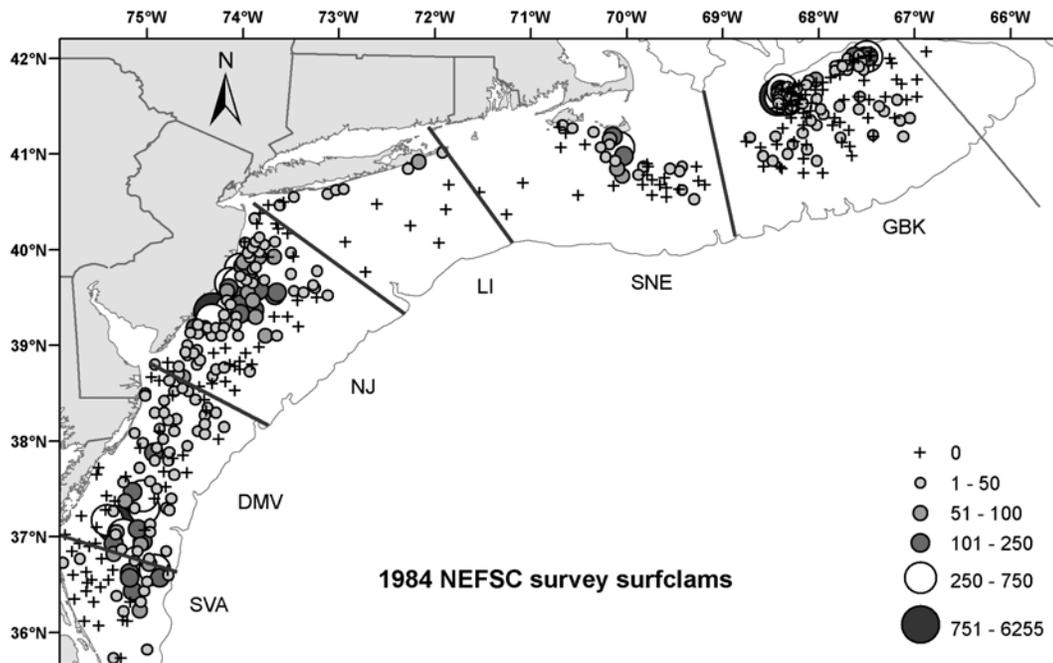
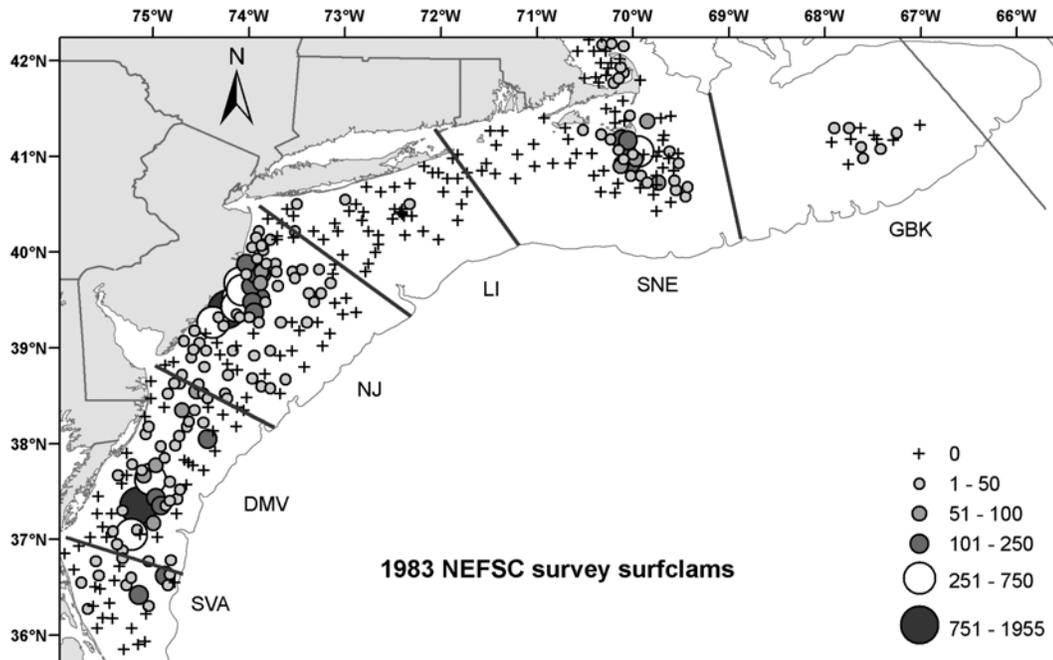
Studies on marine bivalves with life histories similar to surfclam are summarized in Weinberg (1999, and see below). The estimate ( $M=0.2 y^{-1}$ ) for an unexploited population of *S. solidissima* (Atlantic surfclam) in New Brunswick (Caddy and Billard 1976) is particularly relevant. A leukemia-like disease may explain some of the low  $S$  values reported for *Mya arenaria*. The average of estimates from literature sources is  $M=0.17$

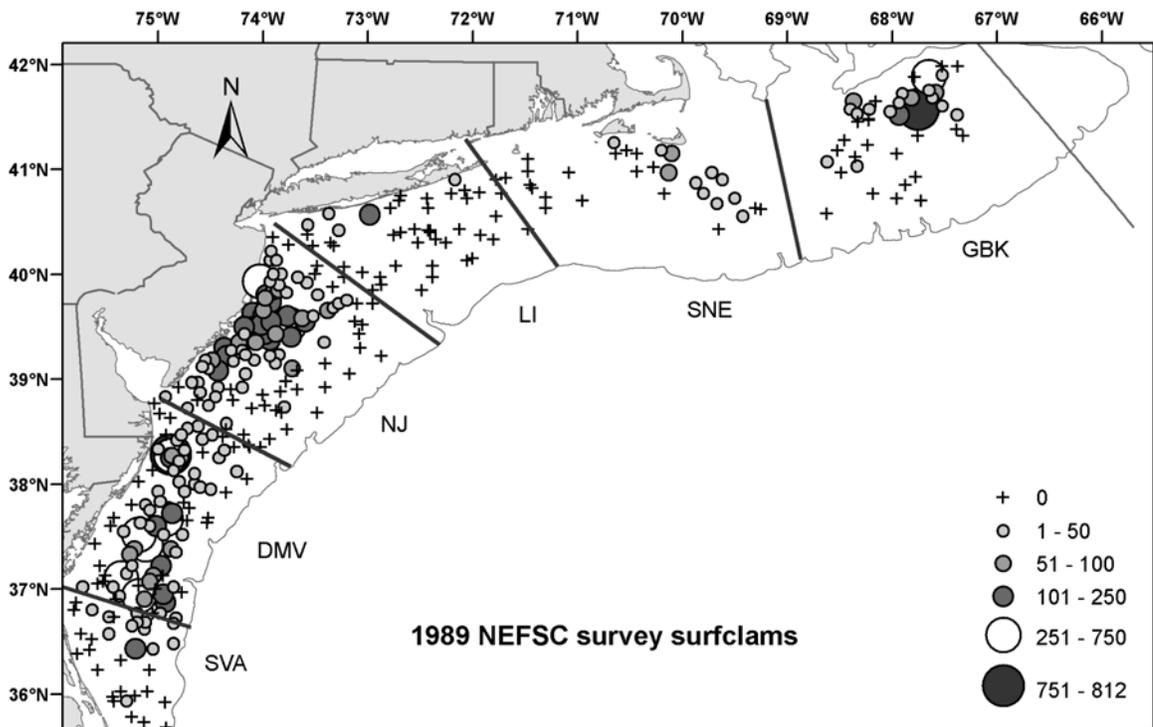
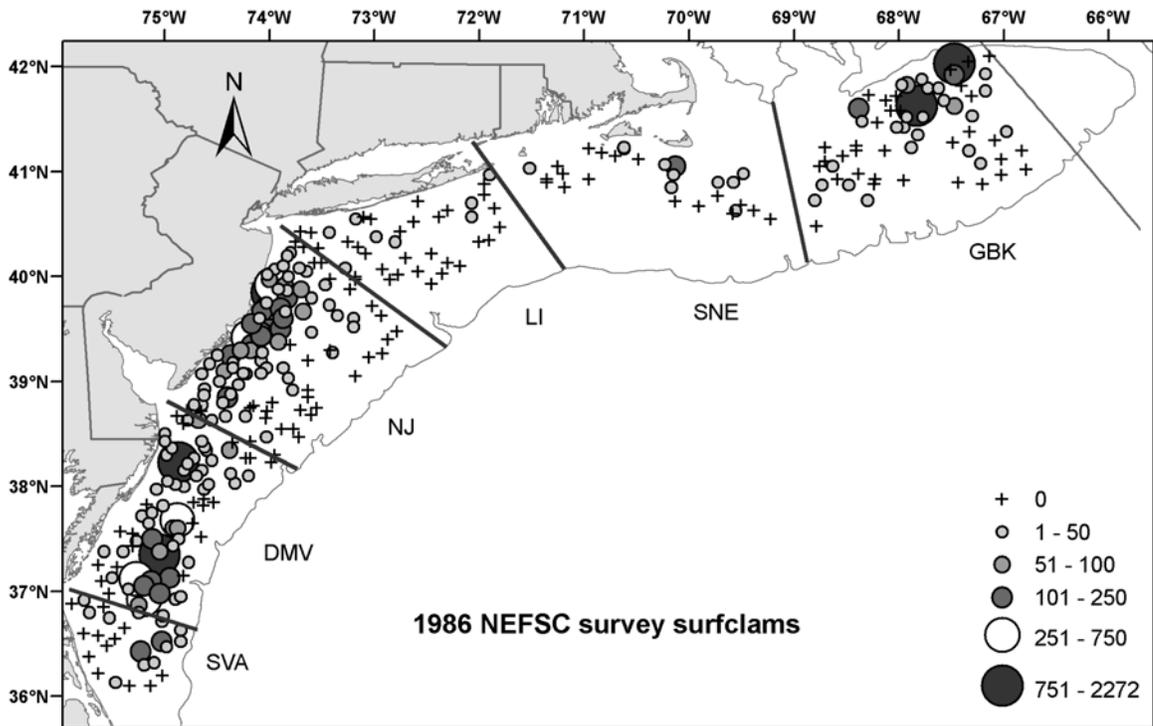
Species	$S=e^{-Mt}$ (Midrange)	$M (y^{-1})$	Source
<i>Spisula solidissima</i> (New Brunswick, unexploited population)	0.82	0.20	Caddy and Billard (1976)
<i>Panope abrupta</i>	0.95	0.05	Sloan and Robinson (1984)
<i>Mya arenaria</i>	0.73	0.32	Brousseau and Baglivo (1988); Weinberg et al. (1997)
<i>Mercenaria mercenaria</i>	0.91	0.09	Malinowski and Whitlatch (1988)
<i>Yoldia notabilis</i>	0.84	0.18	Nakaoka (1993)
<b>Average</b>	0.85	0.17	

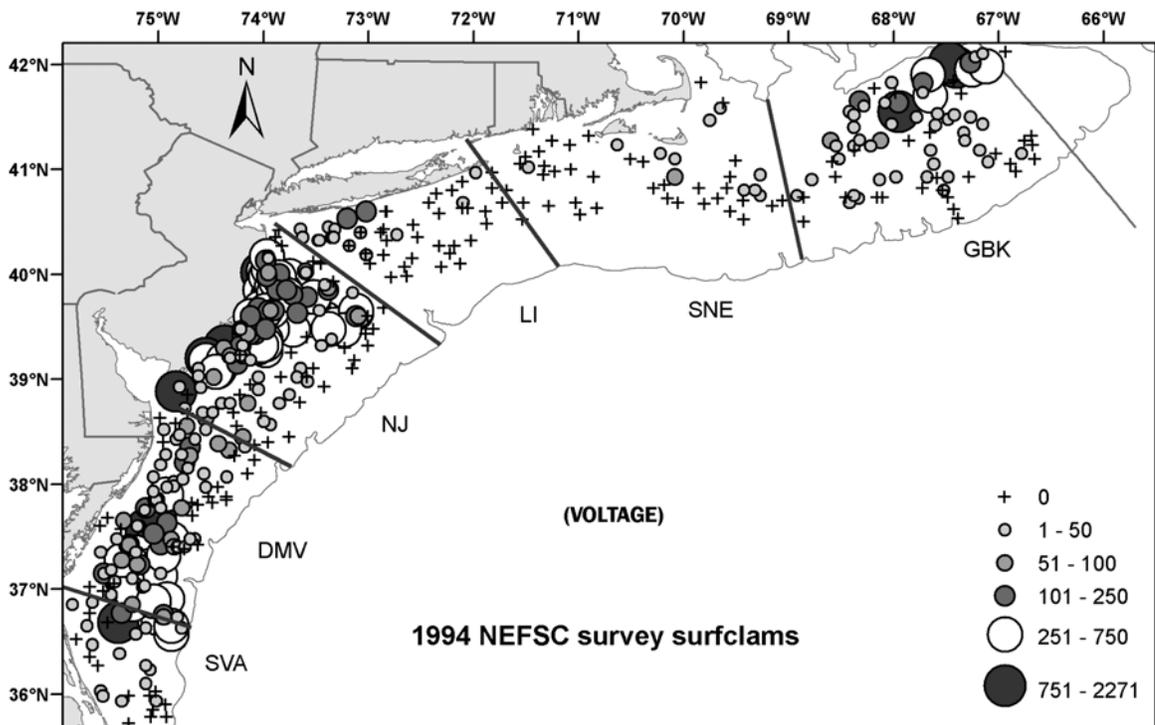
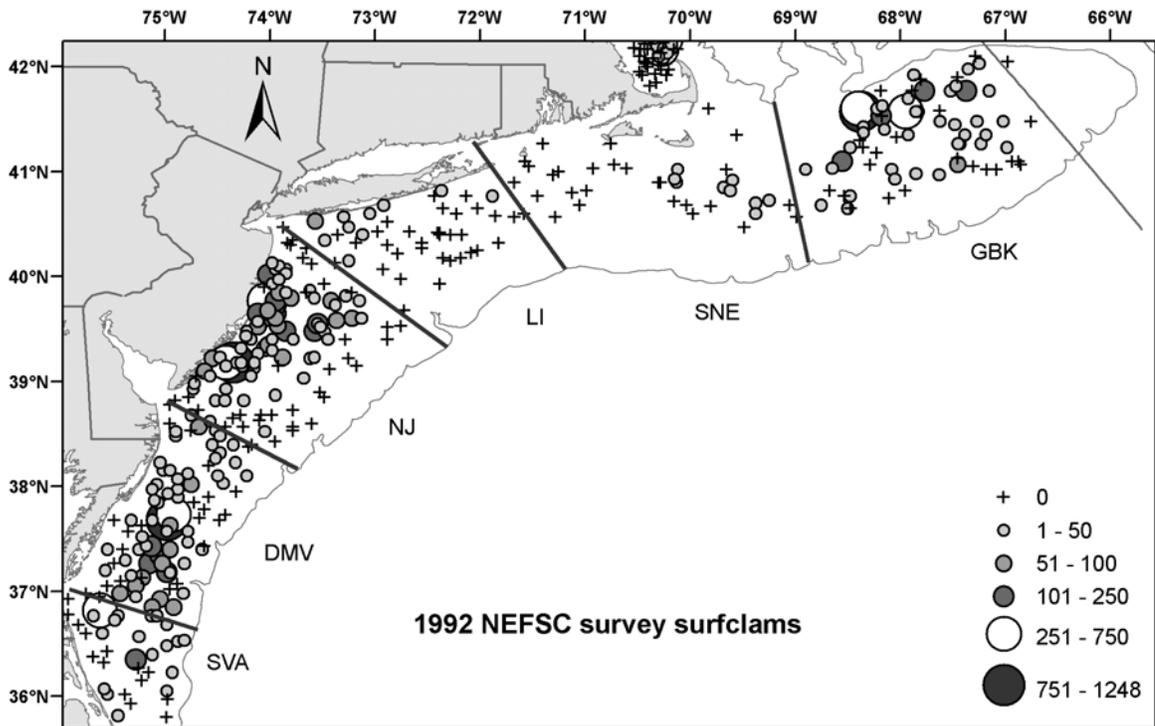
**Appendix A8: Maps**

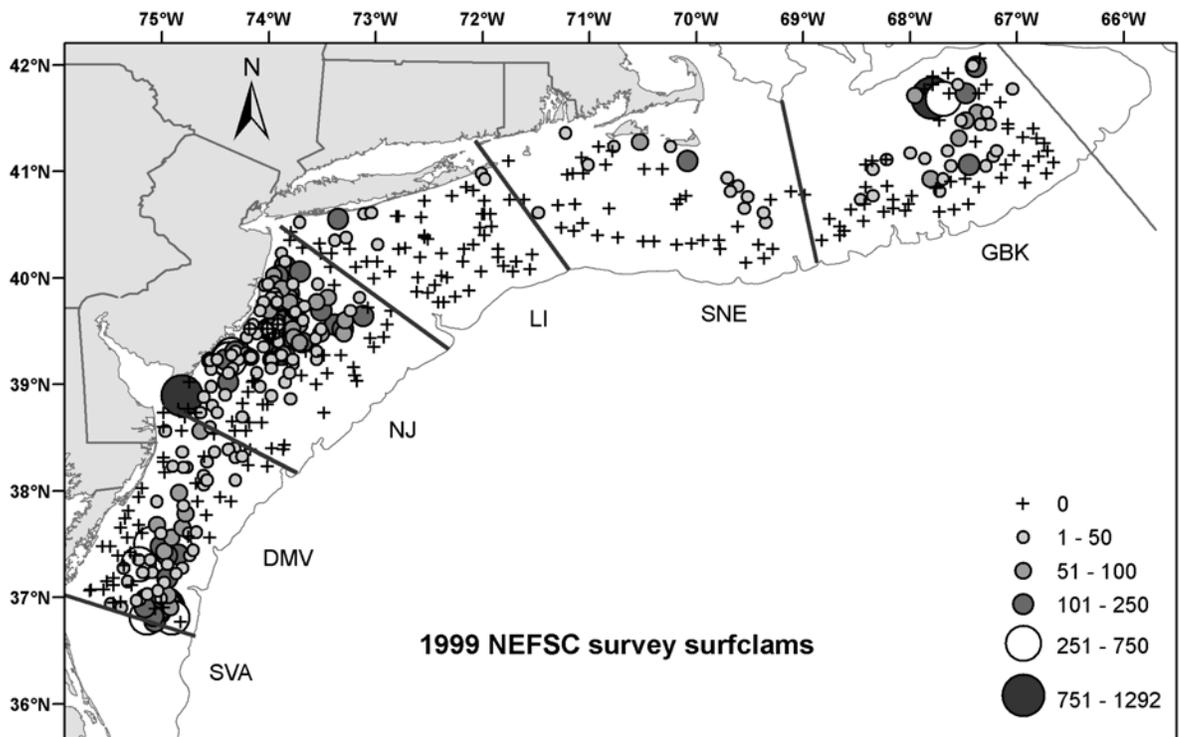
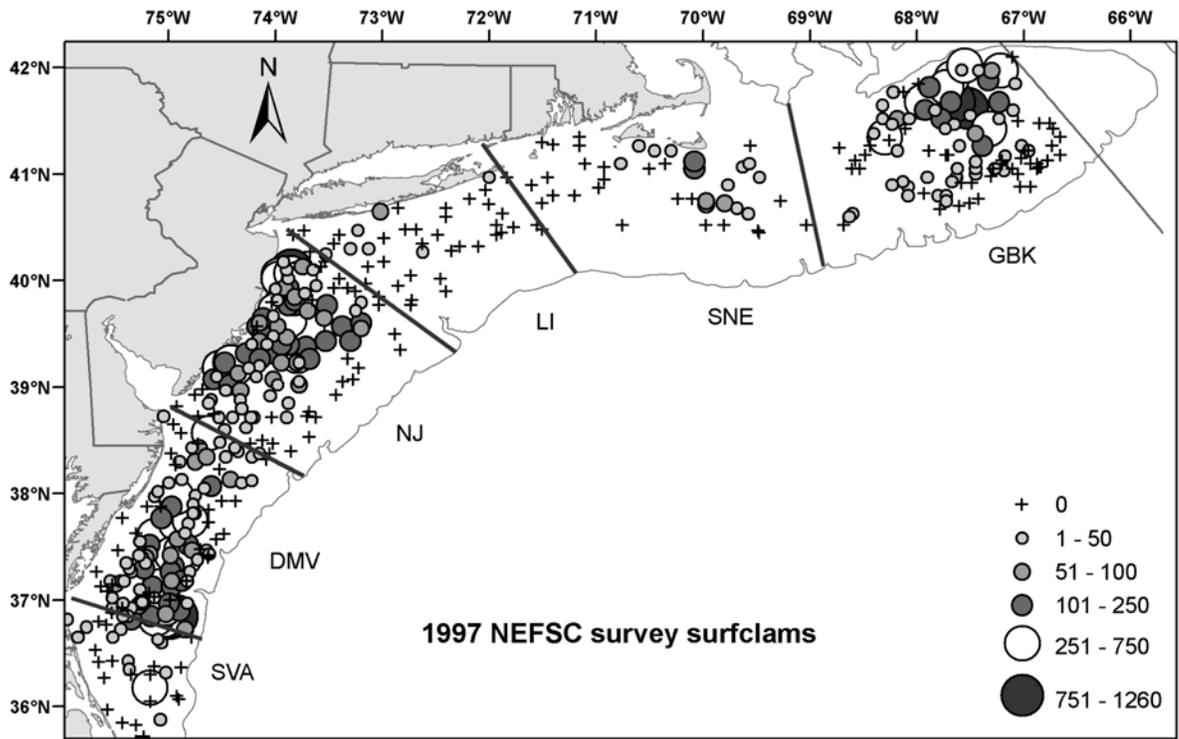
NEFSC clam survey surfclam catches since 1980. Symbols represent number per tow of clams of all sizes. The maximum number of clams caught in a tow is the highest number in the legend.

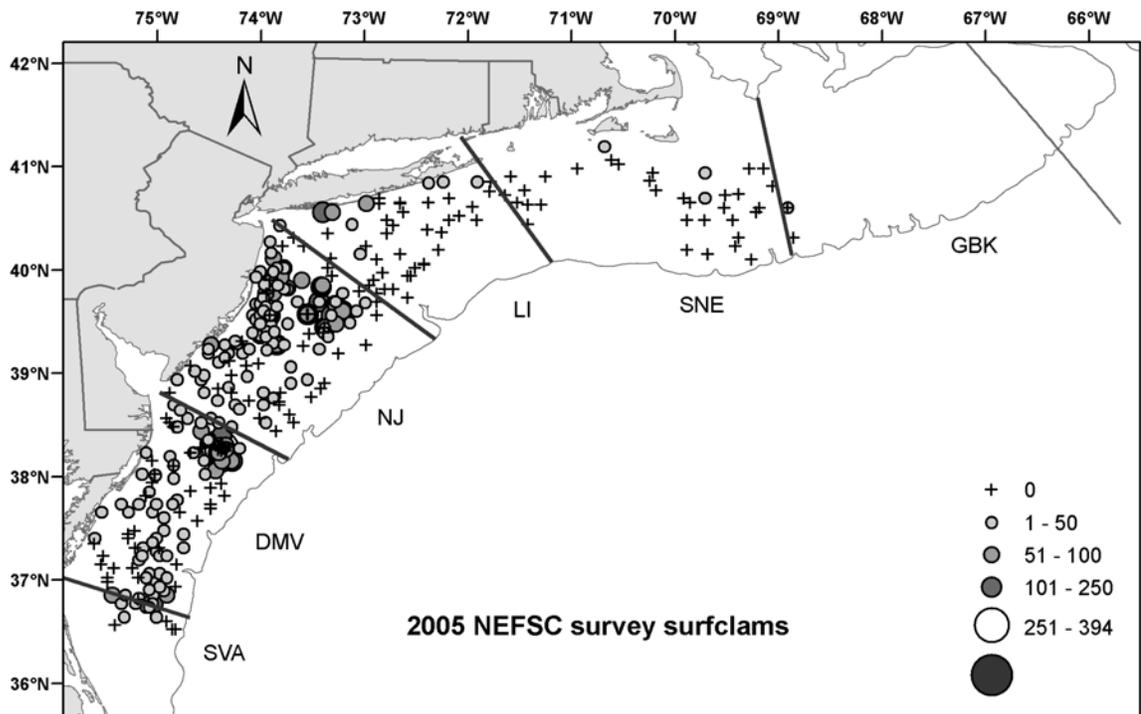
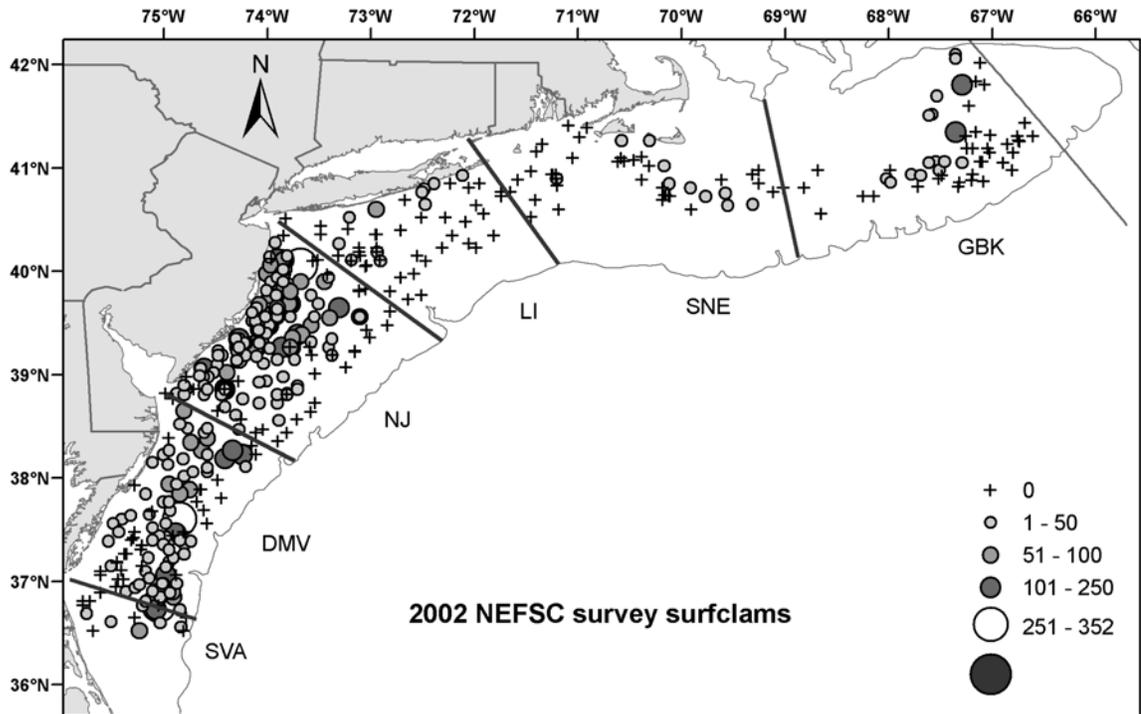


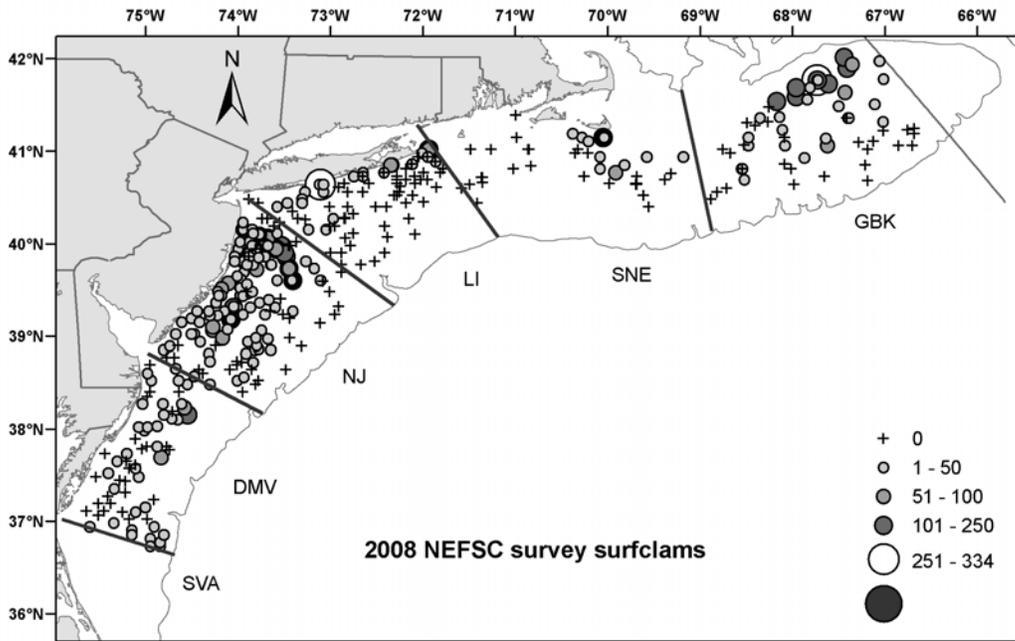












## **B. Butterfish Assessment Report**

### **Executive Summary**

#### **Term of Reference 1:**

Landings were largest in the 1970s and have been below 1000 mt since 2002. Revised discard estimates were made and included in total catch. From 1989-2008 discard estimates are made using the Standardized Bycatch Reporting Methodology (Wigley et al. 2006) and a hind-casting method was used to estimates discarding prior to 1989. The discard estimates were highly uncertain and comprise more than half of the total catch on average over the last 20 years. Recreational catches were negligible.

#### **Term of Reference 2:**

NEFSC spring, fall and winter survey data were used in the assessment. Fall and spring indices exhibited opposite trends in recent years, but the working group felt that the fall survey indices likely represent the trend in biomass more appropriately because they have better precision on average and the stock is more available to the survey during the fall. State survey data were not used due to low coverage of the stock area, and inability to form biomass indices of age 0 and 1+ fish required for the assessment model. Some state survey indices had no associated estimates of uncertainty and only two years of NEAMAP survey indices for the fall and spring are available which will not yet inform the assessment model.

#### **Term of Reference 3:**

Fishing mortality and biomass estimates are highly uncertain and also reliant on a prior distribution for the catchability of the NEFSC fall 1+ indices. While the scale of the estimates should be more appropriate than the previous assessment due to more realistic efficiency of the survey, there is still considerable uncertainty. Estimates of current (2008) fishing mortality, recruitment and spawning biomass are 0.02, 38,800 mt, and 45,000 mt, respectively.

Estimates of total mortality from survey age composition were much higher than the sum of the assumed natural mortality rate (0.8) and estimates of fishing mortality from the model. Furthermore, it appears that fishing mortality is negligible relative to natural mortality because there did not appear to be any correlation of total mortality estimates with total catch estimates.

#### **Term of Reference 4:**

The previous reference points were based on fitting a Fox surplus production model to the recruitment and biomass estimates from the assessment model ( $F_{MSY} = 0.38$ ,  $MSY = 12,200$  mt,  $B_{MSY} = 22,800$ ). The working group determined that it would be beneficial to change the reference point methodology to one that uses recruitment estimates from the final model in stochastic projections under a specified fishing mortality to obtain distributions of equilibrium yield and spawning biomass. The working group proposed  $F_{0.1} = F_{20\%} = 1.04$  as an  $F_{MSY}$  proxy. Other candidate proxies included  $F_{30\%} = 0.72$  and  $F_{40\%} = 0.52$ . Median equilibrium yield at  $F_{0.1}$  is 36,608 mt and the median equilibrium spawning biomass is  $SSB_{0.1} = 16,262$  mt. Median equilibrium yield

at  $F_{30\%}$  is 33,108 mt and the median equilibrium spawning biomass is  $SSB_{40\%} = 25,226$  mt. Median equilibrium yield at  $F_{40\%}=0.52$  is 29,166 mt and the median equilibrium spawning biomass is  $SSB_{30\%} = 34,191$  mt.  $F_{MAX}$  is undefined for this stock. The SARC did not accept any such equilibrium-based reference points (including those from the previous assessment) at this time for butterfish because the stock does not appear to be in equilibrium and, as such, these reference points would be inappropriate. Recruitment and spawning biomass appear to be in decline even though fishing mortality has been very low relative to natural mortality for more than 20 years.

**Term of reference 5:**

The estimate of current (2008) spawning biomass is 45,000 mt. The estimate of current total biomass is 88,800 mt. The current estimate of fishing mortality is 0.02. Because estimated fishing mortality has been negligible relative to natural mortality, the assessment concludes that overfishing is not likely to be occurring. The stock is in decline although this does not appear to be due to fishing mortality and the status is undefined because of uncertainty in the stock size and lack of an equilibrium-based biomass reference point.

**Term of reference 6:**

Total consumption of butterfish is on the same order of magnitude as estimates of butterfish stock landings. Total consumption of butterfish exhibits similar trends as landings estimates, until recent years. Instead of increasing uncertainty, incorporating information on consumption of butterfish may actually help to better inform and improve model fitting. It is feasible to calculate  $M$  in this context. Ignoring some form of dynamic  $M$  may provide misleading biological reference points, or at least result in incorrectly scaled model results (estimates of biomass,  $F$ , etc.).

**Term of reference 7:**

A projection methodology was proposed, but not acceptable because of the evidence that the stock was not in equilibrium. The proposed projection methodology is generally the same as that used for determining proposed reference points.

**Term of Reference 8:**

Several of the recommendations from the previous SARC were completed for this assessment.

**Terms of Reference**

1. Characterize the commercial catch including landings, effort and discards by fishery (i.e., *Loligo* fishery vs other fisheries). Characterize recreational landings. Describe the uncertainty in these sources of data. Evaluate the precision of the bycatch data with respect to achieving temporal management objectives throughout the year.
2. Characterize the survey data that are being used in the assessment (e.g., indices of abundance including RV Bigelow data, NEAMAP and state surveys, age-length data, etc.). Describe the uncertainty in these sources of data.

3. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and characterize the uncertainty of those estimates.
4. Update or redefine biological reference points (BRPs; estimates or proxies for  $B_{MSY}$ ,  $B_{THRESHOLD}$ , and  $F_{MSY}$ ; and estimates of their uncertainty). Comment on the scientific adequacy of existing and redefined BRPs.
5. Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 4).
6. Evaluate the magnitude, trends and uncertainty of predator consumptive removals on butterfish and associated predation mortality estimates and, if feasible, incorporate said mortality predation estimates into models of population dynamics.
7. Develop and apply analytical approaches and data that can be used for conducting single and multi-year stock projections and for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs).
  - a. Provide numerical short-term projections (1-5years). 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.
  - b. Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.
  - c. For a range of candidate ABC scenarios, compute the probabilities of rebuilding the stock by January 1, 2015.
  - d. Describe this stock's vulnerability to having overfished status (consider mean generation time), and how this could affect the choice of ABC.
8. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

## Introduction

Butterfish (*Peprilus triacanthus*) are distributed from the Florida to Nova Scotia, occasionally straying as far north as the Gulf of St Lawrence (Bigelow and Schroeder 2002). Butterfish is a fast growing species that schools by size, makes seasonal inshore and offshore movements, and seldom attains an age greater than 3 years. Butterfish mature at age 1, spawn during the summer months (June-August), and begin schooling at about 60 mm (Bigelow and Schroeder 2002). They exhibit a planktivorous diet, feeding mainly on zooplankton, ctenophores, chaetognaths, euphasids and other organisms. Butterfish are preyed upon by a large number of medium predatory fishes such as bluefish, weakfish, and spiny dogfish, marine mammals including pilot whales and common dolphins, seabirds such as greater shearwaters and northern gannets, large pelagic fish including swordfish, and invertebrates such as squid.

The last assessment for this stock was completed in 2003 (SARC 38, NEFSC 2004). The reference points from the assessment were fishing mortality at maximum sustainable yield,  $F_{MSY}=0.38$ ,  $MSY = 12,200$  mt and total biomass at  $MSY$ ,  $B_{MSY}=22,800$  mt.

### **Term of Reference 1: Commercial Catch**

Characterize the commercial catch including landings, effort and discards by fishery (i.e., *Loligo* fishery vs other fisheries). Characterize recreational landings. Describe the uncertainty in these sources of data. Evaluate the precision of the bycatch data with respect to achieving temporal management objectives throughout the year.

### **The Fishery**

A variety of data sources were used to derive the catch time series. Landings prior to 1963 were obtained from Murawski *et al.* (1978). Landings during 1963-2008 were obtained from the Commercial Fisheries Database System of the Northeast Fisheries Science Center. Butterfish catch data for the foreign fleets during 1963-1982 and 1983-1986 were obtained from previous stock assessment documents, Waring and Anderson (1983) and NEFSC (1990), respectively.

### **Landings**

During the late 1800's through 1928, butterfish harvested from nearshore weirs and traps located along the coast between Cape Cod and Virginia ranged between 150 and 2,800 mt annually (Murawski *et al.* 1978). Landings increased during 1929-1962, ranging between 1,000 and 7,800 mt and averaging 4,300 mt (

Figure B1). During 1949-1958, trawlers based primarily in Point Judith and New Bedford landed butterfish in mixed-species food and industrial fisheries that occurred primarily in the coastal waters of southern New England (Edwards and Lawday 1960). During 1963-1986, foreign fleets targeting squid in offshore areas, primarily *Loligo pealeii*, reported landings of butterfish. Total catches of butterfish were dominated by the foreign fleets during 1969-1976, with most of the catch occurring in the Japanese *Loligo*/butterfish fishery (Lange and Sissenwine 1980; Murawski and Waring 1979). Catches by the foreign fleets averaged 15,400 mt during 1969-1976, with a peak catch of 31,700 mt in 1973 (Figure B2.). Butterfish landings averaged 1,976 mt during 1965-1979 without any trend. During 1980-1989 landings increased sharply to over 9,000 mt in 1982, declined, and then increased to over 11,000 mt in 1984. This rapid increase in the 1980s occurred due to heavy demand for butterfish in the Japanese market. Since 1987, butterfish catches have been solely from domestic fisheries. During 1987-2001, butterfish landings ranged between 1,400 and 4,600 mt but landings gradually tapered off and there has been no directed fishery since 2001. Since 2002, butterfish have been landed as bycatch, primarily in the small-mesh (codend mesh size = 50 mm) bottom trawl fishery for *Loligo* (MAFMC 2009), and landings ranged between 400 and 900 mt during 2002-2008. In 2008 landings were 451 mt. Preliminary butterfish landings through October of 2009 are 356 mt (Table B1) However, butterfish catches by the foreign fleets are likely underestimated because Spain and Italy did not report their butterfish bycatch from the squid fisheries during 1970-1976 and there was no US observer coverage of the fisheries until 1977 (Murawski and Waring 1979; Lange and Sissenwine 1980).

Commercial landings by the United States have remained below about 5,000 mt from 1960-2002 except for a period during the mid 1980s when landings increased to 8,837 mt in 1982 and over 11,000 mt in 1984 (Figure B2; Table B1)

## Discard Estimates

Catch data between 1976 and 1986 as presented in historic assessment documents included some estimates of butterfish discards combined with landings between 1976 and 1986 (Waring and Anderson 1983, NEFSC 1990). We determined the portion of the annual total catches in these records attributable to discards by subtracting the landings obtained from the Commercial Fisheries Database System (Table B1) From descriptions of their discard estimation it appears that these discard estimates only account for discarding behavior of the directed butterfish fisheries until 1986. Because there is discarding of butterfish in other fisheries using trawl gear, it is likely that there is substantial discard not included in the reported catches.

Since the previous assessment, a Standardized Bycatch Reporting Methodology (SBRM) has been produced (Wigley *et al.* 2006) that combines landings, vessel trip report and observer sampling data to provide estimates of discard rates and total discards for specified stocks. We apply the SBRM to develop butterfish discard estimates using the “combined” ratio estimator (D2 in Wigley *et al.* 2006). Strata are defined here by quarter, gear type, and region (New England or Mid-Atlantic waters). The gear types we used in making discard estimates include “fish,” “scallop,” and “shrimp” bottom trawls (gear codes 50, 52, and 58), beach seines (gear code 70), gillnets (gear codes 100 and 110), and mid-water trawls (gear codes 170 and 370). We also stratified the data from fish bottom trawl fishing into effort using less than or greater than 4 inch mesh. Almost all estimated discards are attributable to tows where “fish” bottom trawls are used.

Annual discards between 1965 and 1988 were estimated by multiplying the regional (New England = NE or Mid-Atlantic = MA waters) average of annual discard rate estimates for “fish” bottom trawl gear using small mesh (less than 4 inches) between 1989 and 1999 and the total landings by gear type 50 in the corresponding year and region. Specifically, the estimated discard in year  $y \in \{1965, \dots, 1988\}$  is

$$\hat{D}_y = \bar{\hat{R}}_{MA,SM} L_{MA,y} + \bar{\hat{R}}_{NE,SM} L_{NE,y}$$

where  $\bar{\hat{R}}_{MA,SM} = \frac{1}{11} \sum_{y=1989}^{1999} \hat{R}_{MA,SM,y}$  and  $\bar{\hat{R}}_{NE,SM} = \frac{1}{11} \sum_{y=1989}^{1999} \hat{R}_{NE,SM,y}$  are the average of estimated discard rates for the small mesh fish bottom trawl in the respective regions and  $L_{MA,y}$  and  $L_{NE,y}$  are the landings by fish bottom trawl gear in the respective region in year  $y$ . An approximate variance estimate was obtained as

$$\hat{V}(\hat{D}_y) = \hat{V}(\bar{\hat{R}}_{MA,SM}) L_{MA,y}^2 + \hat{V}(\bar{\hat{R}}_{NE,SM}) L_{NE,y}^2$$

where

$$\hat{V}(\bar{\hat{R}}_{MA,SM}) = \frac{\sum_{y=1989}^{1999} (\hat{R}_{MA,SM,y} - \bar{\hat{R}}_{MA,SM})^2}{10}$$

and

$$\hat{V}(\bar{\hat{R}}_{NE,SM}) = \frac{\sum_{y=1989}^{1999} (\hat{R}_{NE,SM,y} - \bar{\hat{R}}_{NE,SM})^2}{10}.$$

Only the landings by gear type 50 were estimated for this period because the other gear sectors had negligible butterfish discards observed (see Table B2 to Table B10). The

discard rate estimates for the small mesh portion of the fish bottom trawl gear type were applied to all landings previous to 1989 because it was thought by the working group that smaller mesh was used by this fleet in these early years. The discard rates from 1989 to 1999 were used because of changes in regulations for *Loligo* fishery in 2000 that the working group thought would change butterfish discarding behavior.

During the 1989-2008 period the total discard estimates varied from just over 240 mt in 2007 to as high as 8927 mt in 1999, but precision of these estimates is generally poor (Table B1). In only three years is the estimated coefficient of variation as low as 0.3. The estimated discards previous to 1989 are consistently greater than 5000 mt and reach more than 10,000 mt in 1965, 1982 and 1983, but these estimates have even poorer precision because variance estimation for these discards accounts for the indirect nature of their estimation.

#### *Loligo* landings-based discard estimates

To meet this term of reference for this SARC, we also made estimates of discard rates and total discards using landed *Loligo* from sampled and unsampled trips for expansion. Since bycatch of butterfish is almost entirely obtained from fisheries using gear classified as “fish” bottom trawl gear, we restrict attention to corresponding samples and landings (Table B11). The working group thought it better to use the discard estimates with discard ratios based on all kept species because precision of those estimates was better on average and it would not be appropriate to use *Loligo* based discard rates for discard estimation in years prior to observer coverage.

#### **Total Catch**

Total catches of butterfish increased from 14,500 mt in 1965 to a peak of 39,300 mt in 1973 and were dominated by catches from the offshore foreign fleets. Total catches then declined to 11,200 mt in 1977, as effort in the foreign fisheries was reduced. Catches increased to a second peak of 21,600 mt in 1984, with the development of a domestic trawl fishery for butterfish, but then declined to 2,800 mt in 1990 as the Japanese market demand waned. During 1991-2001, catches ranged between 3,800 mt and 12,200 mt. Catches declined during 2002-2008 due to the lack of a directed fishery and ranged between 900 mt and 3,200 mt. Similar to the foreign fishery for *Loligo*, discarding of butterfish occurs primarily in the US *Loligo* fishery (Figure B3), but discarding also occurs to a lesser extent in the small-mesh fisheries for *Illex* and silver hake. Discards comprise a majority of the total butterfish catch, averaging 59% during 1987-2001 and 63% during 2002-2008 and poor precision of discard estimates results in poor precision of total catch estimates (Figure B4). Since 2002, butterfish have been landed as bycatch, primarily in the small-mesh (codend mesh size = 50 mm) bottom trawl fishery for *Loligo* (MAFMC 2009).

#### **Recreational Catch**

Recreational catch was investigated, but it was insignificant as measured by the Marine Recreational Fishery Statistics Survey (MRFSS).

### *Commercial Length Composition*

Size composition from commercial samples of butterfish generally ranged 12-25 cm during 1995-2008 with a modal length at 16-17 cm (Figure B5 and Figure B6). The number of commercial samples and fish measured was highest in 1997 and 2007 at over 6000, but the number of length samples has been greater than 1000 annually (Table B12).

### *Size Composition of Discards*

Data from observed trips were assembled to examine the size composition of the discarded and kept fraction of trips where butterfish were caught. The size composition of discarded butterfish ranged from 4-24 cm depending on the year and the fishery, but most discarded fish were less than 16 cm (

Figure B7 and Figure B8). The length in kept fraction of trips was generally greater than 10 cm and usually had a modal length from 16-18 cm.

### **Term of Reference 2: Survey data**

Characterize the survey data that are being used in the assessment (e.g., indices of abundance including RV Bigelow data, NEAMAP and state surveys, age-length data, etc.). Describe the uncertainty in these sources of data.

### **Research Survey Indices**

Research survey abundance and biomass indices are available from several sources for assessing the status of the butterfish resource. In the last assessment, survey indices from NMFS bottom trawl surveys for the winter in 1992-2002, for the spring in 1968-2002, and fall in 1968-2002 were used (NEFSC 2004). In this assessment the working group chose to use the same surveys. The spring indices used only offshore strata 1-14, 16, 19, 20, 23, 25, and 61-76 (Figure B9). The fall strata were expanded to include inshore strata 1-92, but the time period of this series of indices now starts in 1975 because inshore strata were not consistently covered prior (Figure B10). The winter strata were reduced to offshore strata 1-14 because other previously included strata were not consistently covered (Figure B11).

For spring surveys conducted during years 1973 through 1981 there was usage of a Yankee 41 trawl as well as the usual Yankee 36. Sissenwine and Bowman (1978) found that the Yankee 41 trawl caught on average 35% more biomass per tow, but found no evidence of differences in numbers per tow between the two gears. Our estimates of average biomass per tow for the spring surveys are expanded by this percentage when the Yankee 41 trawl was used. In the previous assessment there was no conversion of catches made using the Yankee 41 gear, but different catchability parameters were estimated in the assessment model. Byrne and Forrester (1991) analyzed differences in expected catches of species when different doors were used on the survey in 1985, but found no evidence for differences in catchability for butterfish. As such, we assume the same catchability of butterfish for both types of doors.

Indices are also available for several state survey programs, notably Massachusetts Division of Marine Fisheries (MADMF), Rhode Island Division of Fish and Wildlife, Connecticut Department of Environmental Protection, New Jersey Bureau of Marine Fisheries, and Virginia Institute of Marine Science (VIMS). The annual coverage for these surveys spans the period from 1978-2002 although some do not start

until after 1978. In the short time available for this assessment, only data for the MA and CT surveys were readily obtained, so only these surveys will be presented. All of the MADMF survey strata were included to form indices. The VIMS survey collects abundance indices (number/tow), but biomass indices are required for the current butterflyfish assessment model.

The Northeast Area Monitoring and Assessment Program (NEAMAP) survey covers inshore waters from Cape Hatteras to Rhode Island and has been performed with consistent strata coverage from fall 2007. As such, only two years of survey indices for the fall and spring are available which will not yet inform the assessment model (Table B13).

### ***NEFSC Surveys***

The spring survey abundance indices (stratified mean number per tow) ranged from a low of 9.9 to a high of 228 during 1968-1979, from 13.4-66.2 during 1980-1989, 8.9-112.9 during 1990-1999 and 36.8-141.4 for 2000-2008 (Table B14, Figure B12). Spring biomass indices (stratified mean wt/tow in kg) were generally highest in the early 1970s and early to mid 1980s (Table B14; Figure B13). Spring biomass indices increased slightly in the late 1990s and exhibit a slight increasing trend in the last few years.

Fall survey abundance indices were generally much higher than the winter and spring indices because of the presence of the age 0 fish in the autumn. Abundance indices were moderately high but fluctuating during 1975-1978 and very high from 1979-1990 (Table B15, Figure B12). Abundance indices exhibit declining trend since 1991. Fall biomass indices exhibit the same pattern over time as the abundance indices (Table B15; Figure B13).

The NEFSC winter survey covers 1992-2007 with abundance indices ranging from 22-186 and biomass indices range from 0.9-6.9 (Table B16, Figure B12 and Figure B13). The winter abundance indices reached highest values in 1994 and 2004 and biomass indices reached highest values in 1994 and 2000.

The estimated precision of annual survey biomass indices is poorest (average CV was 0.44) for the spring series (Table B14 to Table B16, Figure B14). The fall and winter biomass indices have similar precision with average CVs of 0.25 and 0.34, respectively.

### ***Aged NEFSC Survey Indices***

Spring survey abundance at age indices show that this survey generally catches age groups 1-3 and usually some fish from age group 4 (Table B17, Figure B15). Abundance at age indices for the fall during 1982-2008 show that this survey generally catches age groups 0-3 with the age 0 catch dominating the total catch (Table B18, Figure B16 to Figure B19).

The delay-difference biomass model (KLAMZ, see Appendix A of NEFSC 2004) used for this assessment approximates an age structured model and utilizes biomass per tow indices for two age groups (age 0 and age 1+). Aged butterflyfish data from NEFSC spring and fall surveys are available from 1982-2008. Because the NEFSC spring and winter surveys occur after January 1 (the assigned birth date) and prior to spawning (which occurs in the summer), all butterflyfish are assumed to have a nominal age greater than 0 and so these biomass indices reflect 1+ individuals only.

To obtain biomass indices for 0 and 1+ butterfish in the fall survey between 1982 and 2008, the weight at age from the fitted Schnute growth model (described below) was applied to the numbers at age in Table B18 and the 1+ biomass indices were the sum of the biomass/tow at individual ages. Indices for 1975-1981 were calculated from the relative proportions of biomass/tow of age 0 and 1+ butterfish in the respective year. The numbers at age/tow in Table E5 from SARC 17 assessment (NEFSC 1993) were multiplied by the weight/fish at age from the Schnute growth model and the proportion of biomass/tow at ages 1-4 was multiplied by the biomass/tow indices in Table B15 to get the biomass of 1+ butterfish per tow. The remainder is the annual biomass/tow index of age 0 butterfish (Table B19). The weight per fish at age for the entire series accounted for the time of year of the fall survey by adding to the nominal age the fraction of the year at which the midpoint of the survey occurred.

#### *MADMF Survey*

Numbers and biomass per tow in the MADMF spring survey were low relative to the NEFSC spring survey indices and precision of annual biomass indices was even poorer on average with CVs as high as 0.8-1.0. (Table B20; Figure B20 to Figure B22). The fall abundance index varied greatly from year to year. Large fluctuations were observed between 1987 and 1989 and rapid increases and decreases in the late 1990s and early 2000s (Table B20 and Figure B20). The fall biomass indices had similar large fluctuations (Figure B21). The precision of the fall biomass indices was much better than the spring with CVs generally between 0.2 and 0.4 (Table B20 and Figure B22). Survey catch rates from the MADMF fall survey are similar to those of the NEFSC fall survey. Unfortunately, there are no age data for the MADMF fall survey, so age 0 and age 1+ indices required for the assessment model are not available.

#### *CTDEP Survey*

The CTDEP bottom trawl survey carried out in the Long Island Sound (LIS) has abundance indices starting in 1982 in the fall and 1984 in the spring. Biomass indices begin in 1992 for both seasons. However, estimates of precision are not available for any of the series of indices. Similar to the MADMF spring survey, the abundance and biomass indices for the spring LIS are low relative to the spring NEFSC indices (Table B20 and Figure B23). The fall abundance index fluctuated greatly in the 1990s but then stabilized before dropping to its lowest levels in the last two years. The fall biomass index similarly fluctuated in the 1990s, but is showing a slight increasing trend in recent years (Table B20 and Figure B24). Together, the recent trend in both the abundance and biomass indices would suggest an increase in average size of individuals available to the LIS survey in the fall. As with the MADMF fall survey, there are no age data for the LIS survey which prohibits forming age 0 and 1+ indices.

### **Term of Reference 3: Stock biomass and fishing mortality**

Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and characterize the uncertainty of those estimates.

As in the last assessment, the KLAMZ model (see Appendix A of NEFSC 2004) is used as the assessment model. The KLAMZ model is an implementation of the delay-difference model (Deriso 1980 and Schnute 1985) developed by Dr. Larry Jacobson at

the NEFSC. In short, the KLAMZ model approximates an age structured model by tracking recruiting (to the fishery) and biomass of older fish that have previously recruited through growth and mortality by specified parameters. The model assumes all individuals to be fully selected to the fishery. Survey indices supply information on trend of the two components of the population and annual catches allow estimation of fishing mortality. We found scale of the population to be difficult to estimate without auxiliary information on the catchability of butterfish for one or more of the survey indices.

## Biological data and analysis

### Growth

Butterfish spawn during June-August and are assigned ages based on calendar years. Young-of-year butterfish born in the second half of 1983, for example, reach *nominal* age 1 on January 1, 1984 at a *biological* age of no more than 6 months. Butterfish grow rapidly and significant numbers are taken in commercial fisheries at nominal age zero as bycatch primarily during the second half of the year. Age data given in this report are nominal ages (as assigned by readers) unless otherwise specified.

Parameters of Schnute's (1985) growth model are required for the population dynamics model (KLAMZ) used to assess butterfish. The growth model is a reparameterization of the von Bertalanffy growth model for the delay-difference model and it is the same as Schnute and Fournier's (1980) length-based growth model,

$$w_a = v + (V - v) \frac{1 - \rho^{1+a-k}}{1 - \rho}$$

where  $k$  is the age at recruitment,  $w_a$  is weight at age  $a \geq k$ ,  $v$  is the weight at age  $k-1$ ,  $V$  is the weight at age  $k$ , and  $\rho = e^{-K}$  where  $K$  is the parameter for von Bertalanffy growth. The assessment model, uses estimates of  $\rho$  and  $J = v/V$  made external to the model. Note that this growth model treats change in weight with age identically to length with age in the von Bertalanffy growth model whereas other approaches account for variable rates of change in weight with length through a length-weight relationship (e.g., Quinn and Deriso 1999, pp.139-141).

Records of age 0 butterfish from winter and spring surveys were omitted because age 0 butterfish should not be available until after June. Ages used in fitting growth models were adjusted by increasing the nominal age by the average time of year of the survey where the age sample was taken. The average time of year of a given NEFSC survey (e.g. fall) changes slightly from one year to the next (Figure B25). Data from a total of 17,920 butterfish ages (0.59-5.26) and corresponding weights (0.0001 - 0.27 kg) collected between 1992 and 2009 were used to estimate the growth curve (Table B21; Figure B26).

Modeling butterfish growth in the KLAMZ model is complicated by the differences between nominal age (based on calendar years used in the model) and biological age, and because recruitment occurs at age zero and growth is rapid. As shown above, the growth parameter  $v$  should be a positive number that estimates body weight at age  $k-1$  one year prior to recruitment. In theory, the parameter  $v$  for butterfish would be body size at age  $k-1 = -1$  during the January of the year before spawning occurs. Moreover  $v$  for butterfish is negative when  $k = 0$ .

To obtain useful growth parameters for modeling butterfish, we estimated growth parameters in Schnute's model by nonlinear least squares assuming  $k=1.5$  in nominal

years ( $k=1$  in biological years). Growth parameters used in the KLAMZ model for butterfish were  $\rho=0.81211$  and  $J=v/V=0.13312$  (Table B21)

Due to the disparity between the true and assumed age at recruitment, large variability in weight at age and apparent lack of asymptotic growth among observed ages, future assessments may wish to consider whether this growth model is adequate.

Our approach to estimating growth parameters may underestimate the growth rate and biological productivity of age zero butterfish in the FPA model. Nevertheless, the parameter  $J=0.13312$  implies that body weight of young-of-year butterfish increases quickly by about  $1/J=7.5$  times per year during the first year of life. In addition, predicted weights for age zero butterfish during the second half of the year (when age zero butterfish tend to be taken by the fishery) and weight at age for all subsequent ages appears reasonable (Figure B26).

### **Natural mortality**

Natural mortality rates for butterfish were investigated in Murawski and Waring (1979). The best estimate from this study was  $M=0.8$ , and this value was also used in the present stock assessment. Other supporting evidence suggests that natural mortality rates for this species may be high. Overholtz *et al.* (2000) studied consumption of pelagic fishes and squids in the Northeast shelf ecosystem. This study suggested that butterfish were not only important in the diets of predatory fish in the region in general, but that during 1977-1997 butterfish may have been very important to predators during years when herring and mackerel biomass was low. Consumption by predators as a group and as individual species was certainly important during this time. Appendix B1 also provides updated estimates of consumption of butterfish by groundfish.

Some idea of the true instantaneous natural mortality rate can be gained from the relationship of natural mortality rate and instantaneous growth rate parameter  $K$  in the von Bertalanffy growth model of length (Gulland 1983, pp. 116-117, Jensen 1996). The intrinsic growth rate parameter estimated by fitting a von Bertalanffy growth model of length at age using the same data used to fit the Schnute growth model above (Table B22), is less than the assumed natural mortality rate, but is somewhat greater than 0.6-0.67 of  $M$ , suggested by Jensen (1996).

### **Estimates of mortality and stock size**

Because of the poor precision of the discard estimates prior to observer coverage (start in 1989) and the short generation time for butterfish, the working group thought it beneficial to begin the assessment model as close as possible to 1989. However, the previous assessment used 1965 as the starting year. The working group thought the fall survey to be the best indicator of trend in butterfish biomass because of evidence of low and perhaps inconsistent availability of butterfish to the spring and winter surveys. From survey data and observed commercial fishing tows, there appears to be far less butterfish density inshore and on the shelf during winter and spring months (Figure B27 to Figure B30). The fall indices in this assessment begin in 1975 because of the inclusion of inshore strata so poor survey information would be available to the model in the early years with a 1965 start year. There was also a concern to capture the largest scale of exploitation which occurred in the early 1970s. Furthermore, there were effects of the starting year on proposed equilibrium-based reference points. The largest recruitments

were observed prior to 1989 and so average recruitment was highest during the early period which in turn affects estimates of equilibrium yield and spawning biomass at a given fishing mortality. The working group decided to compromise between the need to include these large recruitments (between 1965 and 1988) for reference point determination and the large catches in the 1970s and the reluctance to include uncertain total catches prior to 1989 by using the 1973 model start year.

The KLAMZ model for butterfish was set up on a calendar year basis using nominal ages. In the model, new recruits are age 0 butterfish that recruit to the stock on January 1. Estimates of total biomass (ages 0+) on January 1 from the KLAMZ model for butterfish include the amount of age 0 biomass necessary (considering growth and mortality) to explain subsequent catch data and survey trend data.

### **Growth**

Growth in weight is modeled as a von Bertalanffy process (Schnute parameterization) with parameter estimates as described above,  $\rho = 0.81211$ , and  $J = \nu/V = 0.13312$  for 1973-2008.

### **Maturity**

Maturity was assumed to be 0 at age 0 and 1 for age 1+ butterfish. The model only allows two age groups and the range of potential assumptions for maturity is therefore limited. In future assessments, exploration of the sensitivity of results to this assumption would be useful particularly if other models are explored.

### **Natural Mortality**

Natural mortality was assumed to be 0.8 as in previous assessments. The model program allows for the estimation of annual changes in M by modeling it as deviations from a mean value, but this feature was not used in the current approach due to focusing on other aspects of the assessment.

### **Recruitment**

Recruitment can be modeled in 4 ways in the assessment model. Options include a Beverton-Holt or Ricker stock-recruitment model, random walk in recruitment and freely varying recruitment over time (independent recruitment events). The latter option was used in this and the previous assessment. The Beverton-Holt assumption was explored but not used.

### **Catch**

The total estimated catch (Table B1 and Figure B1) from 1973-2008 including components for landings and discards was used in the assessment model. The variance of the discard estimates was assumed as the variance of the catches which were used as weights on each of the annual catches. However, this was complicated by the required specification of a CV applied to the entire catch series. This was set to 0.1 as in the last assessment. Ultimately, this matters little because there is little if any error in the predicted catches.

### *Research Surveys for Trend*

Four sets of NMFS surveys indices were used in the butterfish KLAMZ model. These surveys included a winter 1+ (adult) survey, a spring 1+ (adult) survey, a fall age 0 (recruit) survey, and a fall 1+ (adult) survey. The winter and spring aggregate biomass indices were assumed to be sampling adult individuals because the nominal age of fish available to the surveys at these times of the year is at least 1. Massachusetts and Connecticut state surveys were evaluated, but these surveys cover a very small portion of the entire range of the stock and there is no ability to partition fall indices into 0 and 1+ series without strong assumptions. These surveys were not included in the analysis, however, their use in future butterfish assessments should be considered.

For initial fit of the final model, the CV estimates for each of the annual survey indices were used to weight these data. For the winter and spring indices, only 1+ fish are observed so the variance estimate based on the stratified design is an appropriate weight for these indices. However, the fall biomass indices are partitioned into 0 and 1+ biomass indices based on the estimated age composition. The uncertainty in the resulting indices is unknown, but we applied the variance estimates for the aggregate biomass indices to the partitioned indices. For example, the CV of the fall biomass index in 1999 was assumed for the 0 and 1+ indices in 1999. The CV of each of the yearly 0 or 1+ indices is probably higher because of sub-sampling for ages, but the correct weighting of one year relative to another within a series is likely to be retained. The final model has each of the series CVs rescaled to ensure that each of the surveys were informing the model.

### *Swept area biomass and estimating catchability*

Throughout the model development process there was difficulty in determining scale for the butterfish population. As such, we decided to use an approach used in the longfin squid assessment at SARC 34 (NEFSC 2002) that allows for uncertainty in the relationship between the index and butterfish population biomass, but also includes information about the efficiency of the survey vessel. The KLAMZ model allows for a prior distribution to be specified for any of the survey catchability parameters. We chose to consider priors for the NEFSC fall 1+ index since it covers the largest portion of the stock area and is more precise than the NEFSC spring series.

We start from first principles of the relationship between biomass and the index. Following Paloheimo and Dickey (1964), the linear mean relationship of index and biomass is through the “catchability” parameter  $Q$  which can be broken into the efficiency of the survey  $\delta_s$ , the swept area of a single tow  $a_s$ , the covered survey area  $A_s$ , and the ratio of survey area to stock area  $\rho$ ,

$$I_t = QB = \delta_s \frac{a_s}{A_s} \rho CB_t.$$

The constant  $C = 10^6$  is a change of units as necessary between those for the index (kg) and those for the biomass ( $10^3$  mt). When the survey is completely efficient ( $\delta_s = 1$ ) and the survey area is equal to the stock area ( $\rho = 1$ ),

$$I_t = \frac{a_s}{A_s} CB_t.$$

From a calibration study completed this year (Miller *et al.* 2009), we have an estimate of the efficiency of the survey vessel and gear used to collect data used in the butterfish assessment (*Albatross IV*) relative to that of the new research vessel (*Henry B. Bigelow*). This study actually estimated calibration factors for abundance and biomass indices that reflect the relative efficiency of the *Henry B. Bigelow* relative to the *Albatross IV*. To make use of this information, we can rewrite the equation in terms of two efficiency parameters,

$$I_t = \delta_{A|B} \delta_B \frac{a_S}{A_S} \rho C B_t$$

where  $\delta_{A|B}$  is the efficiency of the *Albatross IV* relative to the *Henry B. Bigelow* and  $\delta_B$  is the efficiency of the *Henry B. Bigelow*. Note that  $\delta_{A|B}$  is the inverse of the calibration factor (say  $\delta_{B|A}$ ) estimated by Miller *et al.* (2009). In their study, the calibration factor for biomass indices was parameterized as the product of the calibration factor for abundance and a calibration factor for average weight per fish, so

$$\delta_{A|B} = \frac{1}{\delta_{B|A}} = \frac{1}{\delta_{B|A,N} \delta_{B|A,\bar{w}}}.$$

The study fitted models where calibration factors (abundance and average weight per fish) were constant across seasons and where they differed by season. For butterfish, the best beta-binomial model based on likelihood ratio tests or AIC had abundance calibrations factor constant across season ( $\delta_{B|A,N} = 1.7936$ , SE = 0.1367). The best gamma model for average weight per fish had separate calibration factors for fall and spring. The estimated factor for average weight per fish in the fall was  $\delta_{B|A,\bar{w}} = 0.9342$  (SE = 0.0574). The inverse of the product of these two calibration factors is the estimated relative efficiency of the *Albatross IV* for biomass in the fall  $\delta_{A|B} = 0.5968$  (SE = 0.0978). The variance of the relative efficiency parameter was obtained by the delta method.

We do not know the efficiency of the *Henry B. Bigelow*, nor the ratio of the survey area to stock area, so we used a composite prior approach (NEFSC 2002) where we assumed a beta distribution for the product  $\delta_{A|B} \delta_B \rho$  which was parameterized by the mean and variance of the product of each treated as independent random variables. We assumed uniform distributions for  $\delta_B$  and  $\rho$  and a beta distribution for  $\delta_{A|B}$  and bounds on the range of plausible values for these parameters. The bounds determined by consensus of the working group were  $0.05 < \delta_{A|B} < 1$ ,  $0.1 < \delta_B < 0.9$  and  $0.5 < \rho < 0.9$ , but we explored the sensitivity of the results to the maxima of the uniform distributions on  $\rho$  and  $\delta_B$  using values of 0.85 and 0.95. The above ranges imply that we are certain that the efficiency of the *Albatross IV* relative to the *Henry B. Bigelow* is between 5 and 100%, the efficiency of the *Henry B. Bigelow* is between 10 and 90%, and that the survey area is anywhere between half and 90% of the stock area. The sensitivities consider the effect of assuming the efficiency of the *Henry B. Bigelow* and the ratio of survey to stock area being at most 85% or 95%. The actual ranges of the beta distribution

for  $\delta_{AB}$  are not as important because the standard error of the estimates from the calibration study induce negligible probability at the limits. We assume the mean and variance of the beta distribution for  $\delta_{AB}$  are the estimates from the calibration study. The approximate area covered by the fall survey is 46,388 nm and the approximate area swept by the average tow is 0.0112 nm, thus the product of the change of units constant and the ratio of tow area to survey area is

$$\frac{a_s}{A_s} C = 0.2414.$$

The resulting distribution of the catchability parameter as a product of random variables and scalars,  $Q = \delta_{AB} \delta_B \frac{a_s}{A_s} \rho C$ , has nearly all of the probability of values at the lower end of range (Figure B31). The mean of the swept area catchability distribution (top axis of Figure B31) is 0.21 when the maxima on the uniform distributions is 0.9. Our prior on the catchability parameter implies that the expected efficiency of the *Albatross IV* is about 20%.

## Assessment Model Run Results

### *Sensitivity Analysis Results*

Various sensitivity runs were completed to narrow model choices to a few candidates for a final model; the 1973-1986 discards, the prior distribution for catchability, and the natural mortality rate were the inputs the model that we explored.

### *1973-1986 Discards*

Because the discard estimates in early assessments (e.g., NEFSC 1990) for years previous to observer coverage were much smaller than those we estimated we fit model where total catch included either the new discard estimates previous to 1987 or the discard estimates from the early assessments (Figure B32). As might be expected, the spawning and recruitment biomass estimates are lower when the early discard estimates are used because the size of the population is well defined by the prior on the fall 1+ catchability parameter and if there were fewer fish caught, then there were fewer fish alive (Figure B33 to Figure B34). Likewise, the fishing mortality estimates are lower during the period prior to 1987 because the catches were not as great using the early discard estimates (Figure B35). The later fishing mortality estimates are higher because the biomass levels are lower during this period but the catches are the same.

### *Prior distributions for catchability*

As mentioned above, the working group thought it useful to compare model results at different assumed values for the maxima of the uniform distributions used as priors for the efficiency of the Bigelow and the ratio of the survey to stock area. When the maxima of the two uniform distributions are decreased to 0.85, the expected value of the prior distribution on the catchability parameter will also decrease. Likewise the expected value of the prior distribution will increase when the maxima are set at 0.95. As expected, when the lower maxima are used, the spawning and recruitment biomass

estimates are higher because the expectation of the prior and estimated catchability are lower (Figure B36 to Figure B37). Similarly, the biomass estimates are lower when the higher maxima are used. The inverse relationship occurs for the fishing mortality rate estimates because the catches are constant (Figure B38). With larger biomasses, the same catch is obtained with lower fishing mortality and vice versa.

Both the spring and winter indices are better fit with higher maxima on the uniform distributions (Table B23). However, the fall indices are better fit with lower maxima. The total maximized objective function value decreases with increased maxima, but the prior on the catchability parameter is included.

### *Natural Mortality*

The final model assumes the natural mortality rate is 0.8 as in previous assessments. We fit alternative models where the natural mortality rate was 0.6, 0.7, 0.9 and 1.0. Based on the maximized total objective function value, the higher values of natural mortality provide better fit (Table B24). The spring and winter survey data are fit slightly better at higher values of natural mortality, but both the fall 0 and 1+ survey data are fit better at lower values of natural mortality. The catch data are fit slightly better at higher natural mortality values, but these data are fit almost exactly in all cases. The resulting spawning biomass estimates did not trend in a constant direction upward with increased natural mortality (Figure B39), but the recruitment biomass estimates did (Figure B40). Fishing mortality estimates generally decreased at higher natural mortality (Figure B41).

### *Retrospective analysis*

We also fit models to discover whether retrospective patterns in biomass and fishing mortality exist. We fit models to data with terminal years of 2003 to 2008. From these fits there is not consistent pattern in terminal year spawning biomass, recruitment biomass or fishing mortality estimates and the annual estimates do not change dramatically as subsequent years of data are made available (Figure B42 to Figure B44).

### *Final Model*

The final model uses the new discard estimates, natural mortality rate of 0.8, and the base case prior distribution on the catchability parameter for the NEFSC fall 1+ indices.

## **Biomass**

The spawning biomass estimates are substantially greater than those estimated at the last assessment due to the use of the prior distribution on the fall 1+ catchability (Table B25 and Figure B45). The catchability estimate for the fall 1+ indices from the last assessment implies that the efficiency of the survey is greater than 100%. From the final model, the highest spawning biomass estimate was around 200,000 mt in 1975, but the current spawning biomass estimate (2008) is 45,000 mt. Recruitment estimates are also substantially higher than those estimated in the last assessment on average and are highly variable (Table B25 and Figure B46). The largest estimated recruitment was around 185,000 mt in 1974 and dropped to around 16,000 mt in the following year. Both

spawning and recruitment biomass estimates have been in decline on average over the period of the analysis.

As a check of the plausibility of the biomass estimates from the model, an heuristic method described in Appendix B that takes fishing mortalities and survey efficiencies as inputs with catches and fall biomass indices was used to create an “envelope” or range of independent plausible annual biomass values over time. This analyses concludes that the annual biomass estimates from the KLAMZ model were generally within the envelope of independent plausible values.

### **Fishing Mortality**

The estimated fishing mortality rates were much lower than the previous assessment (Table B25 and Figure B47). This again is a result of the use of the prior on the fall 1+ catchability parameter. Since the total catches have not changed dramatically from the previous assessment, but the biomass available to fishing has increased substantially, a lower fishing mortality is required to obtain the same catch. The highest estimated fishing mortality (0.21) occurred in the year with the greatest catch (1973) and fishing mortality generally remained greater than 0.1 until 1978. Since then, fishing mortality has generally stayed below 0.1 and current (2008) estimated fishing mortality is 0.02.

### **Stock Recruitment**

As determined in the last assessment, meaningful estimation of a stock-recruitment relationship for butterfish is not feasible due to highly variable recruitment over the range of estimated spawning biomasses (Figure B48). Furthermore, these relationships are likely to be estimated with non-negligible bias in most cases due to usage of estimates of spawning biomass rather than true values (e.g., Walters and Ludwig 1981, Ludwig and Walters 1981).

Recruitment biomass has been highly variable for the butterfish stock over a range of about 40,000-200,000 mt of spawning biomass. Average recruitment during 1974-2008 was around 65,000 mt. Average recruitment in the last 10 years (1999-2008) is around 40,500 mt.

Both spawning biomass and recruitment estimates have been declining over time and the trajectory of the stock-recruitment relationship for butterfish reveals that these declines do not appear to be related to either fishing mortality (Figure B49) or known sources of predation. The equilibrium replacement lines corresponding to  $F_{0.1} = 1.04$  (See TOR 4) and  $F=0$  suggest that population would be declining even in the absence of fishing mortality. The  $F_{0.1}$  replacement line exceeds all historical values, suggesting that fishing mortality rates this high would accelerate population decline. Results further support the notion that either natural mortality is much greater than the assumed  $M=0.8$  or that an increasing trend in natural mortality has occurred.

### *Precision of Estimates*

The KLAMZ model output includes variance estimates for fishing mortality and total biomass but not separately for recruitment biomass and spawning biomass (Table B26 and Table B27). There is generally large uncertainty ( $CV>0.5$ ) in both the total biomass and fishing mortality indices.

### *Model Diagnostics*

Residuals for the winter and fall age 0 surveys show no real trend over time, but the residuals for the spring indices show an increasing trend and fall age 1+ show a slight decreasing trend in the last 10 years (Table B28 to Table B31 and Figure B50). These trends in residuals occur because the fall 1+ and spring 1+ indices have opposite trend over this period (Figure B51). The residuals of the fall age 0 indices are generally small in absolute value relative to the other surveys because they are fit very well in the model. This was due to difficulty in determining the appropriate scaling factors to apply to the CVs of each of the surveys to obtain appropriately scaled residuals for all surveys simultaneously. The catches are predicted extremely accurately by the model (Figure B52).

### **Total Mortality Estimates from Survey Age Composition**

We made annual estimates of total mortality by age from fall and spring survey age composition estimates (Table B17 and Table B18) as

$$\hat{Z}_{a,y} = \ln(\hat{N}_{a,y}) - \ln(\hat{N}_{a+1,y+1}).$$

We made mortality estimates for ages 0, 1 and 2 from fall age composition estimates and ages 0 and 1 from spring age composition estimates. Total mortality estimates varied greatly across years for a given age when estimated from either survey (Figure B53 and Figure B54). The average of mortality estimates for age 1 butterfish was approximately 1.5 when estimated from fall age composition and closer to 2.0 when estimated from spring age composition. Age 2 mortality estimates average near 2.0 and 3.0 from spring and fall age composition, respectively. Mortality estimates for age 0 from the fall age composition also average near 2.0. For all ages and surveys, there does not appear to be any trend in total mortality over time despite changes in total catch estimates over the same period. This may imply that fishing mortality is a small component of total mortality.

### **Summary**

The biomass estimates are substantially larger and the fishing mortality estimates substantially smaller than the corresponding estimates from the last assessment (NEFSC 2004). This is primarily due to the use of a prior distribution for the NEFSC fall 1+ catchability parameter. If the catches of butterfish have not decreased due to abundance, the low estimates of fishing mortality rate are not unreasonable. Furthermore, to have fishing mortality estimates similar to those in the last assessment requires a catchability for the fall 1+ indices that is near or greater than 100%.

The magnitude of assumed natural mortality relative to estimated annual fishing mortality corresponds to the lack of trend in total mortality estimates from the survey age composition. Nevertheless, the total mortality estimates tend to be substantially larger than the sum of assumed natural mortality and estimated fishing mortality from the final KLAMZ model which may imply true natural mortality is higher than that assumed in the final model.

#### **Term of Reference 4: Updated or redefined biological reference points**

Update or redefine biological reference points (BRPs; estimates or proxies for  $B_{MSY}$ ,  $B_{THRESHOLD}$ , and  $F_{MSY}$ ; and estimates of their uncertainty). Comment on the scientific adequacy of existing and redefined BRPs.

The Mid Atlantic Fishery Management Council manages butterfish as part of the Atlantic Mackerel, Squid, and Butterfish (MSB) Fishery Management Plan. Overfishing for this species is defined as occurring when the fishing mortality rate at maximum sustainable yield ( $F_{MSY}$ ) is exceeded. The current overfishing definition is based on an MSY of 12,175 mt and a fishing rate of  $F_{MSY}=0.38$ . The biomass target for this stock is defined as total biomass at equilibrium harvest of maximum sustainable yield ( $B_{MSY}=74,550$  mt) and the minimum biomass threshold is defined as  $\frac{1}{2} B_{MSY}$ . ***But see below (in bold italics) for comments and decisions by the SARC-49 review panel regarding butterfish reference points (BRPs).***

#### **Reference Point and Stock Status Methodology**

The previous assessment used a Fox surplus production model (Fox 1970) to estimate reference points for the stock. There is an implicit density-dependence assumption in the Fox model, whereas the assessment model assumes no relationship between stock and recruitment nor does the projection methodology. To make reference points consistent with the assessment and projection models, we propose using deterministic projections to determine the equilibrium relationship between fishing mortality rate and resulting yield and spawning biomass per recruit. The SPROJDDIF program written in FORTRAN by Dr. Larry Jacobson at the NEFSC provides a means to make either deterministic or stochastic projections of the KLAMZ model (see Appendix A of NEFSC 2004). The SPROJDDIF program will use assumptions about recruitment that are consistent with the model used to fit the data. For butterfish we assume no relationship of spawning and recruitment biomass so SPROJDDIF will use the mean and variance of recruitment estimates provided by the KLAMZ model fit to make stochastic projections of recruitment and subsequent spawning biomass estimate under assumed constant fishing mortality rates or constant catch specifications.

Given a specified  $F_{MSY}$  proxy, the Working Group proposed to determine spawning biomass at MSY ( $SSB_{MSY}$ ) and status of the stock by stochastic projections using SPROJDDIF. To do this, we completed 7,000 bootstraps for the final model using BOOTADM (see Appendix A of NEFSC 2004) and made 1 projection 50 years into the future for each bootstrap.  $SSB_{MSY}$  is the median spawning biomass in year 50 at the prescribed fishing mortality rate. Estimates of uncertainty and confidence intervals for  $SSB_{MSY}$  and stock status can also be obtained from the 7,000 projections. Stock status could either be based on the spawning biomass estimate in 2008 from fit of the final model or the median of the biomass estimates in year 0 of the projections.

To determine an  $F_{MSY}$  proxy, the Working Group performed deterministic projections for equilibrium fishing mortalities between 0 and 2. These projections provide the relationship of equilibrium fishing mortality to equilibrium yield per recruit, spawning biomass per recruit, and spawning potential ratio (Figure B55 to Figure B57). For these deterministic projections we used the same SPROJDDIF software above, but we used estimates from the final model rather than bootstraps. There was no defined  $F_{MAX}$  for butterfish due to the high rates of growth and natural mortality.  $F_{0.1} = 1.04$

resulted in a catch/recruit ratio of 0.76 and  $F_{30\%}$  dropped the ratio 12% to 0.67 and  $F_{40\%}$  dropped the ratio 24% to 0.58. The spawning potential ratio at  $F_{0.1}$  was 20%. In lieu of an  $F_{MAX}$ , we proposed that  $F_{0.1} = 1.04$  is used as an  $F_{MSY}$  proxy ( $F_{Threshold}$ ) and  $F_{30\%}=0.72$  is used as an  $F_{Target}$ .

The Working Group performed stochastic projections for fishing mortalities at the  $F$  values corresponding to 20, 30 and 40% spawning potential ratios (Table B32). Median equilibrium yield at  $F_{MSY}=F_{0.1}=1.04$  was 36,608 mt and the median equilibrium spawning biomass was 16,262 mt. Median equilibrium yield at  $F_{30\%}=0.72$  was 33,108 mt and the median equilibrium spawning biomass was 25,226 mt. Median equilibrium yield at  $F_{40\%}=0.52$  was 29,166 mt and the median equilibrium spawning biomass was 34,191 mt. There was large uncertainty in the equilibrium yield and spawning biomasses. Current (2008) spawning biomass was greater than the median equilibrium spawning biomass at each of the fishing mortalities and current fishing mortality was less than those fishing mortalities. The high equilibrium yields at low equilibrium spawning biomasses when  $F=F_{0.1}$  or  $F=F_{30\%}$  reflects the high growth rate and reproductive potential for butterflyfish. However, the high variability in recruitment coupled with high uncertainty in biomass and fishing mortality estimates resulted in large uncertainty in spawning biomass and yield in any given year.

When the stock is in equilibrium, this methodology is preferred for both reference determination and stock projection because it puts the determination of both current and future status of the stock within a consistent framework.

When the Fox surplus production model was fit to the biomass and surplus production estimates resulting from the final model,  $F_{MSY} = 0.233$ ,  $MSY = 17,400$  mt and  $B_{MSY} = 74,550$  mt (Table B32). However, the fit was very poor and the  $B_{MSY}$  (and consequently  $F_{MSY}$ ) estimates were very poorly defined (Figure B58). Note also that the biomass reference point was for total rather than spawning biomass.

***Upon review at SARC 49, the stock was determined to not be in equilibrium because of declining biomass over the entire time series of the model in the absence of significant fishing mortality. Given the lack of equilibrium the use of equilibrium-based reference points was found to be unacceptable and the proposed reference points were rejected. The reference points from the previous assessment were also found to be unacceptable for the same reason as well as the unlikely scale of the estimates biomass and fishing mortality upon which the reference points were based.***

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

Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 4).

Current (2008) spawning biomass (45,000 mt ) was greater than the median equilibrium spawning biomass at the proposed  $F_{MSY}$  proxy ( $SSB_{0.1} = SSB_{20\%} = 16,262$  mt) as well as at the other considered fishing mortality reference points ( $F_{30\%}=0.72$ ,  $F_{40\%}=0.52$ ). Similarly, current  $F$  (0.02) was lower than the candidate  $F_{MSY}$  proxies. ***However, these reference points were not accepted by the SARC panel due to the determination by reviewers that the stock is not in equilibrium. Despite the rejection of the reference points, there was a consensus at SARC 49 that overfishing was not likely to be occurring.*** There are sizable corresponding uncertainty in estimates of current

fishing mortality and biomass (Table B26 and Table B27) as well as the  $SSB_{MSY}$  (Table B32) (spawning biomass with  $F = F_{MSY} = F_{0.1}$ ).

**Term of Reference 6: Predator consumptive removals and predation.**

Evaluate the magnitude, trends and uncertainty of predator consumptive removals on butterfish and associated predation mortality estimates and, if feasible, incorporate said mortality predation estimates into models of population dynamics.

See Appendix B2.

**Term of Reference 7: Projections**

Develop and apply analytical approaches and data that can be used for conducting single and multi-year stock projections and for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs).

- a. Provide numerical short-term projections (1-5 years). 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.
- b. Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.
- c. For a range of candidate ABC scenarios, compute the probabilities of rebuilding the stock by January 1, 2015.
- d. Describe this stock's vulnerability to having overfished status (consider mean generation time), and how this could affect the choice of ABC.

**Projection Methodology**

If the stock needed to be rebuilt, the same stochastic projection methods describe above for TOR 5 could be used for short term projections. In fact, the same set of bootstraps used above for determining median equilibrium spawning biomass and yield can be used here. However, the working group suggested that recent recruitment (1999-2008) should be used for the short term projections because recruitment has been low relative to earlier in the time period. As the stock was estimated to be above the  $SSB$  at the candidate  $F_{MSY}$  proxies, projections carried out at each of the potential  $F_{MSY}$  proxies (not rebuilding fishing mortalities) with the full series of recruitments resulted in the expected probability of  $<0.5$  of being overfished in the first few years and converge to 0.5 (Figure B59). Also as expected, the probability of being overfished increased to around 0.75 when recent recruitments (lower on average than the entire time series) were used and fishing was assumed to occur at the  $F_{MSY}$  proxies (Figure B60). Note that the fishing mortalities used in these projections were substantially higher than the current (2008) fishing mortality (0.02). Continued fishing at the status quo with projections based on recruitment estimates for the last 10 years would result in a probability less than 0.01 of spawning biomass being below the proposed  $SSB_{MSY}$  (Figure B61). Fishing at  $F=0.52$  resulted in 30% probability of the stock being below the proposed  $SSB_{MSY}$  whereas fishing at  $F=0.72$  resulted in 50% probability of being below the proposed  $SSB_{MSY}$  when future recruitment was based on recent recruitment (Figure B61). Median spawning

biomass climbed to 54,000 mt and yield increased to about 1400 mt when the current fishing mortality rate persists and future recruitment is based on recent recruitment (Figure B62).

The user can also specify in SPROJDDIF program constant catch to find probability of F exceeding candidate  $F_{MSY}$  proxies. When catch was assumed constant at 2008 levels fishing mortality remained at or below 0.03 whether recruitment was based on the full time series of recruitment estimates or those from the last 10 years (Table B33). If catch was assumed to double, fishing mortality remained below 0.05 in either case. When the swept area catchability for the fall 1+ indices was assumed to be 0.006 rather than 0.16 as estimated in the final model, fishing mortality rates were negligible whether catches are assumed the same as 2008 or twice the 2008 catch (Table B34). When the swept area catchability for the fall 1+ indices was assumed to be 0.49, fishing mortalities were still below 0.1 whether catches are the same or twice as large as those in 2008.

### **Term of Reference 8: Research Recommendations**

Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

### **SARC 38 Research Recommendations**

1) *A study of the characteristics of inshore and offshore components should be initiated. A study of growth, morphometrics, distribution and other factors related to inshore and offshore butterfish should be conducted.*

Examination of characteristics of the inshore and offshore components has not been conducted. Comparison of seasonal distribution was examined.

2) *Further work on potential information (for example the VTR database) for the estimation of discards of butterfish from all sources should be undertaken. Other methods and stratification and time averaging of the discard data for estimating discards should be explored.*

New methods for estimation of discards based on observer data was undertaken and adopted for use in the assessment.

3) *A close examination of the NMFS Observer data from 2003 was warranted for its application in the next butterfish assessment. Observer coverage was transferred to only a few vessels in the *Illex* fishery and hence was greatly expanded because of the transfer of effort into the scallop fishery by large Mid-Atlantic trawlers.*

New methods for estimation of discards based on observer data was undertaken and adopted for use in the assessment.

4) *Explore alternative methods for estimating natural mortality.*

The assessment examined sensitivity and likelihood values for a variety of M values but no alternative methods of estimation were made. Trends in consumption were examined as indicative of annual variation in M.

5) *Explore using landings of target species as a denominator in the discard ratio, based on VTR matched trips (trips with reported landings of target species and butterfish discards).*

New methods for estimation of discards based on observer data was undertaken and adopted for use in the assessment.

*6) Explore the utility of incorporating into the assessment model ecological relationships, predation, and oceanic events that influence butterfish population size on the continental shelf and its availability to the resource survey.*

Predation on butterfish was examined in detail although the results were not directly incorporated into the assessment model.

*7) Explore the use of an age-based model for future assessments.*

The recommendation was limited by the availability of age data from commercial fisheries.

*8) Further investigate the estimation of suitable biological reference points. Stock status determination is currently based on an  $F_{msy}$  proxy ( $F_{0.1}=1.01$ ,  $B_{msy}$  has not been previously estimated). New biological reference points were estimated in the delay-difference model for butterfish. However, there is considerable uncertainty in these estimates and they are subject to change.*

Biological reference points were updated and again based on the model results for consistency. Alternative methods were also explored.

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## Tables

Table B1. Butterfish USA landings (MT), estimated USA discards (and coefficient of variation (CV), foreign landings, and total catch (using new discard estimates) during 1965-2008.

Year	US Landings	Foreign Landings Historic Discards		New Discard		Total Catch (Revised Discards)
				Estimates	New Discard CV	
1965	2944	749		10402.58	1.64	14095.58
1966	2461	3865		9978.09	1.63	16304.09
1967	2245	2316		9247.5	1.6	13808.5
1968	1585	5437		8941.83	1.63	15963.83
1969	2198	15378		8590.13	1.56	26166.13
1970	1731	12450		7968.76	1.59	22149.76
1971	1566	8913		7277.52	1.56	17756.52
1972	704	12221		6080.02	1.53	19005.02
1973	1521	31679		6105.67	1.56	39305.67
1974	1778	15465		5640.11	1.59	22883.11
1975	1973	12764		5147.79	1.59	19884.79
1976	1376	14437	152	5663.26	1.53	21476.26
1977	1296	3312	152	6598.97	1.59	11206.97
1978	3615	1699	61	7971.15	1.47	13285.15
1979	2646	1107	185	8443.37	1.47	12196.37
1980	5172	1392	184	9126.17	1.49	15690.17
1981	4855	1400	0	8743.93	1.48	14998.93
1982	8837	1578	68	10213.72	1.45	20628.72
1983	4743	630	162	10036.98	1.45	15409.98
1984	11715	429	257	9494.46	1.38	21638.46
1985	4633	804	106	7703.15	1.39	13140.15
1986	4418	164	0	7397.01	1.3	11979.01
1987	4578	0		6905.27	1.23	11483.27
1988	2107	0		6920.56	1.21	9027.56
1989	3216	0		4480.03	0.85	7696.03
1990	2298	0		532.93	0.37	2830.93
1991	2189	0		4886.71	0.99	7075.71
1992	2754	0		5025.15	0.54	7779.15
1993	4608	0		7577.07	0.32	12185.07
1994	3634	0		6300.37	0.36	9934.37
1995	2067	0		6465.52	0.5	8532.52
1996	3555	0		1047.48	0.72	4602.48
1997	2794	0		985.98	1.04	3779.98
1998	1966	0		6378.44	1.68	8344.44
1999	2110	0		8927.16	0.36	11037.16
2000	1449	0		7014.89	0.23	8463.89
2001	4404	0		4474.27	0.47	8878.27
2002	872	0		2348.41	1.25	3220.41
2003	536	0		2113.51	1.44	2649.51
2004	537	0		1246.16	0.3	1783.16
2005	437	0		642.13	0.21	1079.13
2006	554	0		845.47	0.72	1399.47
2007	674	0		241.31	0.61	915.31
2008	451	0		1178.39	0.56	1629.39

Table B2. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for “fish” bottom trawl (gear code = 50 and mesh size less than 4 inches) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic				New England			
	Ratio	Total Catch (mt)	Discards (mt)	CV	Ratio	Total Catch (mt)	Discards (mt)	CV
1989	0.022	14849.7	327.3	0.60	0.032	10677.4	343.0	0.32
1990	0.024	14410.8	349.2	0.44	0.005	11763.7	63.8	1.08
1991	0.036	17743.7	641.3	0.40	0.034	10473.0	351.3	0.32
1992	0.072	17247.7	1242.1	0.28	0.08	11279.6	902.0	0.51
1993	0.048	19523.1	938.7	0.74	0.006	13782.0	88.3	0.68
1994	0.074	17878.3	1321.9	1.04	0.279	13530.7	3776.1	0.36
1995	0.037	17463.3	640.9	1.31	0.004	11557.1	41.6	1.04
1996	0.031	23818.6	744.8	0.82	0.012	14609.0	169.5	1.45
1997	0.01	24601.2	248.4	2.21	0.009	11492.2	108.4	2.22
1998	0.003	28953.5	100.0	1.09	0.025	14607.2	370.4	0.80
1999	0.263	18145.5	4778.2	0.39	0.047	13303.6	628.7	0.63
2000	0.004	19357.9	73.9	1.36	0.117	9728.9	1140.4	0.69
2001	0.008	13368.2	106.4	4.18	0.035	12729.9	448.0	0.33
2002	0.143	12140.0	1732.3	0.90	0.016	8654.0	137.7	1.30
2003	0.14	12498.5	1752.0	1.66	0.016	9368.6	154.6	0.47
2004	0.02	31427.5	625.6	0.47	0.045	9016.0	404.0	0.43
2005	0.027	16922.9	450.7	0.28	0.014	7451.4	103.8	0.33
2006	0.011	37205.7	403.9	1.44	0.015	8666.9	128.8	0.40
2007	0.002	14935.8	29.3	3.46	0.009	11081.7	100.5	0.50
2008	0.014	20567.1	280.0	0.84	0.066	8831.0	583.8	0.76

Table B3. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for “fish” bottom trawl (gear code = 50 and mesh size greater than 4 inches) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic				New England			
	Ratio	Total Catch (mt)	Discards (mt)	CV	Ratio	Total Catch (mt)	Discards (mt)	CV
1989	0.003	1463.4	4.4	0.35	0	41411.8	5.9	0.55
1990	0.001	1699.2	1.6	0.64	0.002	55075.1	117.9	0.85
1991	0.005	2161.1	11.6	0.50	0.001	49171.0	51.1	0.53
1992	0.007	2194.5	15.0	0.87	0	39275.2	5.8	0.76
1993	0	2170.1	0.1	1.54	0	32234.4	0.6	1.29
1994	0	2683.8	0.2	0.77	0	25936.9	2.4	0.44
1995	0.005	5404.7	25.3	1.03	0	30538.5	4.9	0.86
1996	0	5838.5	2.8	1.41	0.001	36679.2	24.3	14.86
1997	0	5919.3	1.5	0.74	0.001	32028.2	31.9	0.83
1998	0	6866.9	2.5	0.29	0	33224.9	0.2	0.57
1999	0.001	7794.3	6.6	0.96	0	32605.6	0.6	1.37
2000	0.401	6389.7	2559.7	0.32	0.001	36877.8	28.1	0.68
2001	0.001	7285.3	5.6	0.71	0	44410.8	0.4	0.59
2002	0	7292.8	0.3	0.34	0	40569.8	0.7	0.70
2003	0	6940.8	0.7	0.45	0	42864.3	0.3	0.45
2004	0	9446.1	3.7	0.66	0	39100.5	0.7	0.26
2005	0.001	11538.0	7.3	0.44	0	34591.4	0.4	0.40
2006	0.001	9802.6	9.7	0.48	0	27821.9	0.6	0.27
2007	0.001	7413.9	5.8	0.56	0	28085.0	5.1	0.74
2008	0.001	8432.6	10.6	0.48	0	29980.6	0.4	0.26

Table B4. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for “fish” bottom trawl (gear code = 50 and unknown meshsize) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic				New England			
	Ratio	Total Catch (mt)	Discards (mt)	CV	Ratio	Total Catch (mt)	Discards (mt)	CV
1989	0.03	26329.4	790.9	1.82	0.08	39566.4	3008.5	1.17
1990	0	28129.7	0.0	NA	0	47038.3	0.0	NA
1991	0.08	36841.4	2931.3	1.63	0.02	49809.0	896.9	0.61
1992	0.05	43745.9	2095.1	1.21	0.02	47705.9	762.8	1.02
1993	0.02	34376.7	625.2	0.5	0.14	41446.0	5922.7	0.39
1994	0	35994.8	150.1	0.54	0.03	39843.3	1046.3	1.16
1995	0.01	22474.5	328.4	1.32	0.21	25371.5	5419.4	0.57
1996	0	20322.0	53.8	0.75	0	28555.7	47.4	0.66
1997	0	20763.2	69.1	11.78	0.02	25483.7	519.3	0.36
1998	0.18	23067.0	4196.2	2.48	0.06	28980.1	1708.4	1.55
1999	0.04	17120.7	760.9	2.92	0.11	25440.5	2751.1	0.51
2000	0.09	14275.5	1246.4	0.63	0.07	27110.0	1965.3	0.4
2001	0.11	9183.8	997.0	0.67	0.11	27071.5	2912.4	0.67
2002	0	8887.6	8.7	2.36	0.02	24054.4	468.3	5.28
2003	0	8604.3	20.8	43.51	0.01	23728.8	183.9	0.91
2004	0.01	13185.4	78.5	0.75	0	39950.2	131.8	1.15
2005	0.01	11739.1	60.0	0.58	0	22919.8	18.1	0.4
2006	0.02	13082.0	273.0	0.6	0	14146.8	28.2	0.46
2007	0	6850.9	29.9	2.07	0.01	13831.7	70.1	1.03
2008	0.03	6812.9	189.7	2.22	0.01	11686.4	96.0	0.92

Table B5. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for “scallop” bottom trawl (gear code = 52) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic				New England			
	Ratio	Total Catch (mt)	Discards (mt)	CV	Ratio	Total Catch (mt)	Discards (mt)	CV
1989	NA	133.4	NA	NA	NA	NA	NA	NA
1990	NA	158.8	NA	NA	NA	42.8	NA	NA
1991	NA	57.0	NA	NA	NA	NA	NA	NA
1992	NA	36.8	NA	NA	NA	NA	NA	NA
1993	NA	106.0	NA	NA	NA	34.0	NA	NA
1994	NA	120.1	NA	NA	NA	1.6	NA	NA
1995	NA	241.6	NA	NA	NA	7.8	NA	NA
1996	NA	90.2	NA	NA	NA	3.1	NA	NA
1997	NA	145.0	NA	NA	NA	0.4	NA	NA
1998	NA	706.9	NA	NA	NA	0.0	NA	NA
1999	NA	332.9	NA	NA	NA	1.1	NA	NA
2000	NA	688.6	NA	NA	NA	1.1	NA	NA
2001	NA	748.8	NA	NA	NA	0.8	NA	NA
2002	0	548.9	0	NA	NA	NA	NA	NA
2003	NA	1546.6	NA	NA	NA	1.5	NA	NA
2004	0	1104.1	0.5	0.649	NA	42.4	NA	NA
2005	0	3732.7	0.0	0.557	NA	3.4	NA	NA
2006	0	3088.9	0.5	0.532	NA	5.2	NA	NA
2007	0	1444.6	0.2	1.051	NA	40.0	NA	NA
2008	0	1619.0	0	NA	NA	89.5	NA	NA

Table B6. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for “shrimp” bottom trawl (gear code = 58) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic				New England			
	Ratio	Total Catch (mt)	Discards (mt)	CV	Ratio	Total Catch (mt)	Discards (mt)	CV
1989	NA	NA	NA	NA	0	4343.3	0.1	1.39
1990	NA	NA	NA	NA	0	5167.4	0.2	1.01
1991	NA	NA	NA	NA	0	3875.8	0.8	1.27
1992	NA	NA	NA	NA	0	3446.7	1.5	0.28
1993	NA	NA	NA	NA	0	2206.3	0.0	0.90
1994	NA	37.9	NA	NA	0	3349.1	0.2	0.51
1995	NA	62.6	NA	NA	0	5836.9	1.1	0.31
1996	NA	7.7	NA	NA	0	9025.6	3.7	0.65
1997	NA	1059.7	NA	NA	0.001	6089.7	6.0	0.45
1998	NA	208.3	NA	NA	NA	3306.0	NA	NA
1999	NA	239.3	NA	NA	NA	1456.0	NA	NA
2000	NA	352.9	NA	NA	NA	2134.8	NA	NA
2001	NA	91.6	NA	NA	0	825.6	0.0	1.07
2002	NA	264.7	NA	NA	0	307.5	0.0	NA
2003	NA	100.6	NA	NA	0.001	855.5	0.5	0.96
2004	NA	282.6	NA	NA	0	1114.3	0.0	1.05
2005	NA	123.2	NA	NA	0.001	875.3	0.5	0.63
2006	NA	341.9	NA	NA	0	1296.0	0.1	0.72
2007	NA	1645.0	NA	NA	0	2337.7	0.0	0.80
2008	NA	1911.7	NA	NA	0	2114.8	0.0	0.59

Table B7. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for seine fishing (gear code = 70) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic				New England			
	Ratio	Total Catch (mt)	Discards (mt)	CV	Ratio	Total Catch (mt)	Discards (mt)	CV
1989	NA	1080.8	NA	NA	NA	0.3	NA	NA
1990	NA	1017.1	NA	NA	NA	NA	NA	NA
1991	NA	898.7	NA	NA	NA	2.9	NA	NA
1992	NA	1110.8	NA	NA	NA	20.7	NA	NA
1993	NA	1414.4	NA	NA	NA	4.0	NA	NA
1994	NA	1728.0	NA	NA	NA	NA	NA	NA
1995	NA	1335.8	NA	NA	NA	0.6	NA	NA
1996	NA	1563.6	NA	NA	NA	140.8	NA	NA
1997	NA	2481.1	NA	NA	NA	175.1	NA	NA
1998	0	2064.9	0	NA	NA	247.5	NA	NA
1999	0	2527.6	0	NA	NA	NA	NA	NA
2000	0	1595.1	0.01	2.70	NA	NA	NA	NA
2001	0	1494.7	0	NA	NA	NA	NA	NA
2002	0	1605.5	0	NA	NA	0.6	NA	NA
2003	0	1908.3	0	NA	NA	NA	NA	NA
2004	0	1184.8	0	NA	NA	NA	NA	NA
2005	0	1369.9	0.1	0.19	NA	NA	NA	NA
2006	0	56.5	0	NA	NA	NA	NA	NA
2007	0	1293.1	0	NA	NA	NA	NA	NA
2008	0.007	755.4	5.0	1.41	NA	NA	NA	NA

Table B8. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for gillnet gear (gear code = 100 or 110) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic				New England			
	Ratio	Total Catch (mt)	Discards (mt)	CV	Ratio	Total Catch (mt)	Discards (mt)	CV
1989	NA	3892.2	NA	NA	0	21189.6	0	NA
1990	0	3777.0	0	NA	0	23185.0	0.3	0.56
1991	0	5969.3	0	NA	0	20998.0	0.2	0.29
1992	0	5936.0	0	NA	0	20374.9	0.2	0.26
1993	0	8759.8	0.2	7.65	0	23183.0	0.6	0.77
1994	0	8462.9	0.8	0.36	0	21887.4	0.1	0.92
1995	0	9150.8	0.3	0.34	0	24999.9	0.3	0.60
1996	0	15366.4	0.2	0.45	0	22279.7	0	NA
1997	0	18133.4	1.0	0.73	0	19223.1	0	NA
1998	0	20329.9	0.5	1.06	0	20930.8	0.0	1.01
1999	0	18592.3	1.1	0.70	0	16762.2	0.0	1.32
2000	0	16164.9	0.4	0.58	0	14826.5	0.1	0.94
2001	0	13570.2	3.1	1.30	0	14613.2	0	NA
2002	0	12544.3	0.2	0.77	0	14967.8	0.0	0.84
2003	0	13390.7	0	NA	0	16693.6	0.0	0.82
2004	0	11609.2	0.2	0.79	0	19119.5	0.1	0.51
2005	0	14193.5	0.7	0.70	0	13580.1	0.0	0.64
2006	0	7645.7	0.1	0.44	0	13725.5	0.0	0.76
2007	0	15363.8	0.1	1.02	0	15209.0	0.0	0.95
2008	0	10706.7	0	NA	0	17318.3	0.0	0.74

Table B9. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for scallop dredge gear (gear code = 132) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic				New England			
	Ratio	Total Catch (mt)	Discards (mt)	CV	Ratio	Total Catch (mt)	Discards (mt)	CV
1989	NA	240.4	NA	NA	NA	5483.3	NA	NA
1990	NA	268.5	NA	NA	NA	763.0	NA	NA
1991	NA	281.2	NA	NA	NA	733.4	NA	NA
1992	NA	265.5	NA	NA	NA	547.3	NA	NA
1993	NA	332.5	NA	NA	NA	445.4	NA	NA
1994	NA	1972.8	NA	NA	NA	1379.8	NA	NA
1995	NA	1272.5	NA	NA	NA	1721.4	NA	NA
1996	NA	2624.5	NA	NA	NA	1610.5	NA	NA
1997	0	2613.0	0	NA	NA	1914.9	NA	NA
1998	0	3087.5	0	NA	NA	1701.7	NA	NA
1999	0	3493.2	0	NA	NA	3608.5	NA	NA
2000	0	5141.2	0	NA	0	2456.9	0	NA
2001	NA	9242.8	NA	NA	NA	4275.2	NA	NA
2002	0	10085.4	0	NA	0	2747.1	0	NA
2003	0	11960.6	0.4	0.68	0	3404.9	0	NA
2004	0	12276.1	0	NA	0	3489.7	0.0	0.28
2005	0	13930.7	0	NA	0	6962.7	0	NA
2006	0	16721.0	0	NA	0	9749.4	0	NA
2007	0	20918.6	0	NA	0	7289.6	0	NA
2008	0	15863.9	0.0	0.66	0	4313.3	0	NA

Table B10. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for mid-water trawl gear (gear code = 170 or 370) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic				New England			
	Ratio	Total Catch (mt)	Discards (mt)	CV	Ratio	Total Catch (mt)	Discards (mt)	CV
1989	NA	NA	NA	NA	NA	322.5	NA	NA
1990	NA	2.1	NA	NA	NA	362.8	NA	NA
1991	0.004	549.2	2.1	0.43	0	1786.2	0	NA
1992	0	163.9	0	NA	NA	2349.5	NA	NA
1993	0	128.0	0	NA	0	4925.5	0	NA
1994	0	578.2	0.3	0.07	0	7313.0	0	NA
1995	0	3623.6	1.2	0.16	0	30980.4	0	NA
1996	NA	5492.9	NA	NA	NA	37856.3	NA	NA
1997	NA	7844.3	NA	NA	NA	36926.6	NA	NA
1998	NA	8525.5	NA	NA	NA	43337.6	NA	NA
1999	NA	5384.0	NA	NA	0	10827.6	0	NA
2000	0	6640.0	0	NA	0	2424.2	0	NA
2001	NA	10852.3	NA	NA	0	353.6	0	NA
2002	0	5612.9	0	NA	NA	3156.0	NA	NA
2003	0	16191.2	0	NA	0	16004.4	0	NA
2004	0	21948.4	0	NA	0	14158.9	0.5	0.71
2005	0	11052.6	0	NA	0	27318.3	0.5	0.61
2006	0	22138.1	0.3	0.95	0	24891.9	0.3	0.67
2007	0	4601.9	0.0	1.47	0	13386.7	0.1	1.07
2008	0	15863.9	0.0	0.66	0	4313.3	0	NA

Table B11. Annual ratio estimates (discarded butterfish to kept *Loligo* squid), total catch of *Loligo* squid, discard estimates, and coefficient of variation for “fish” bottom trawl (gear code = 50) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic				New England			
	Ratio	Total Catch (mt)	Discards (mt)	CV	Ratio	Total Catch (mt)	Discards (mt)	CV
1989	0.058	12055.4	696.8	0.39	0.271	9718.3	2631.2	0.38
1990	0.081	7912.7	639.6	122.10	0.240	6419.3	1538.2	2.20
1991	0.185	11445.7	2119.8	0.67	0.385	7384.8	2844.5	0.87
1992	0.193	13491.9	2606.9	0.23	1.487	4419.2	6572.5	0.44
1993	0.109	16780.4	1834.9	4.76	1.499	5102.1	7649.1	0.29
1994	0.315	14649.3	4620.1	1.57	0.589	7656.5	4509.3	0.65
1995	0.260	10874.2	2826.4	0.97	0.616	5505.4	3393.3	0.74
1996	0.457	6781.0	3096.2	0.34	0.063	4806.0	300.8	1.17
1997	0.078	11585.8	902.4	1.15	0.065	3837.1	247.7	1.74
1998	0.170	10814.7	1835.2	0.68	0.080	7927.2	631.2	0.86
1999	0.727	11680.3	8487.1	1.04	0.196	7189.2	1405.6	0.46
2000	0.730	11931.3	8711.7	0.31	0.216	5164.9	1118.0	10.35
2001	0.143	8447.3	1205.1	0.29	0.404	4744.5	1915.9	8.44
2002	0.153	9868.3	1509.9	0.72	0.128	5256.2	670.5	3.27
2003	1.428	5520.7	7883.5	0.43	0.177	6303.6	1114.9	0.50
2004	0.067	8498.4	567.1	0.52	0.198	5062.6	1003.9	0.32
2005	0.047	8223.7	389.6	0.36	0.028	5295.5	150.2	0.94
2006	0.087	9505.5	826.5	0.79	0.047	4909.8	233.0	1.85
2007	0.091	4813.3	438.3	1.26	0.064	6694.4	429.6	10.69
2008	0.241	5930.4	1427.9	0.29	0.085	4880.0	414.4	5.65

Table B12. U.S. commercial butterfish samples and lengths collected, 1994-2008.

Year	Qtr				total	
	1	2	3	4		
1994	Total Sum of samples		3	4	7	14
	Total Sum of lengths		142	419	724	1285
1995	Total Sum of samples		3	4	7	14
	Total Sum of lengths		142	419	724	1285
1996	Total Sum of samples	3	1	5	7	16
	Total Sum of lengths	400	115	421	791	1727
1997	Total Sum of samples	30	8	4	22	64
	Total Sum of lengths	2998	826	398	1928	6150
1998	Total Sum of samples	9	7	4	5	25
	Total Sum of lengths	893	618	383	467	2361
1999	Total Sum of samples	12	8	5	3	28
	Total Sum of lengths	1239	728	521	237	2725
2000	Total Sum of samples	3	3	1	3	10
	Total Sum of lengths	345	280	108	295	1028
2001	Total Sum of samples	6	14	7	1	28
	Total Sum of lengths	637	1446	714	114	2911
2002	Total Sum of samples	6	1	2	3	12
	Total Sum of lengths	617	98	215	313	1243
2003	Total Sum of samples	9	9	7	3	28
	Total Sum of lengths	930	931	774	312	2947
2004	Total Sum of samples	5	12	17	7	41
	Total Sum of lengths	540	1117	1755	682	4094
2005	Total Sum of samples	11	9	9	10	39
	Total Sum of lengths	1124	924	903	975	3926
2006	Total Sum of samples	10	17	7	16	50
	Total Sum of lengths	988	1795	731	1638	5152
2007	Total Sum of samples	13	10	23	17	63
	Total Sum of lengths	1433	1005	2232	1761	6431
2008	Total Sum of samples	13	10	12	7	42
	Total Sum of lengths	1374	1043	980	694	4091

Table B13. Abundance (number/tow) and biomass indices (kg/tow) provided by the Northeast Monitoring and Assessment Program for the fall and spring.

Year	Spring		Fall	
	Number/tow	Kg/tow	Number/tow	Kg/tow
2007			70.71	2.82
2008	44.53	2.29	207.34	4.71
2009	64.72	2.01		

Table B14. NEFSC spring abundance and biomass indices (number and weight per tow) and corresponding coefficients of variation (CV) for 1968-2008 from data collected in offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76).

Year	Number	CV	Weight	CV
1968	33.44	0.59	1.98	0.629
1969	30.77	0.803	3.08	0.831
1970	9.94	0.284	0.53	0.292
1971	21.72	0.563	0.77	0.407
1972	228.09	0.962	6.66	0.916
1973	68.70	0.33	5.35	0.404
1974	25.26	0.486	1.72	0.484
1975	121.07	0.197	4.00	0.192
1976	31.15	0.441	1.31	0.291
1977	7.01	0.345	0.56	0.331
1978	4.70	0.287	0.25	0.324
1979	12.86	0.368	1.05	0.426
1980	58.18	0.242	3.20	0.258
1981	43.81	0.212	2.47	0.301
1982	49.19	0.419	2.55	0.425
1983	64.74	0.421	3.90	0.676
1984	15.84	0.423	0.71	0.368
1985	37.84	0.447	1.60	0.404
1986	66.21	0.461	2.78	0.408
1987	15.62	0.398	0.57	0.31
1988	13.35	0.381	0.48	0.304
1989	32.31	0.806	0.76	0.666
1990	8.93	0.452	0.36	0.386
1991	27.84	0.712	1.01	0.588
1992	17.95	0.213	0.61	0.207
1993	26.68	0.401	0.81	0.317
1994	36.29	0.276	1.45	0.273
1995	42.11	0.593	2.21	0.774
1996	11.47	0.398	0.51	0.311
1997	112.87	0.382	3.41	0.398
1998	41.07	0.612	2.14	0.742
1999	76.23	0.594	2.46	0.655
2000	36.77	0.36	0.99	0.333
2001	61.21	0.37	1.89	0.156
2002	46.57	0.447	1.70	0.399
2003	47.70	0.601	1.39	0.731
2004	115.35	0.338	2.06	0.325
2005	37.46	0.388	1.26	0.361
2006	70.87	0.395	1.98	0.357
2007	141.41	0.537	4.77	0.505
2008	130.57	0.723	3.06	0.582

Table B15. NEFSC fall abundance and biomass indices (number and weight per tow) and corresponding coefficients of variation (CV) for 1975-2008 from data collected in inshore strata (1-92) and offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76).

Year	Number	CV	Weight	CV
1975	45.69	0.221	2.60	0.279
1976	139.58	0.221	5.80	0.214
1977	87.00	0.226	5.21	0.284
1978	154.51	0.249	4.62	0.165
1979	287.89	0.240	11.50	0.224
1980	325.19	0.275	14.69	0.483
1981	279.17	0.304	10.10	0.255
1982	108.83	0.238	4.50	0.255
1983	440.50	0.260	12.49	0.210
1984	347.75	0.308	11.35	0.265
1985	375.77	0.242	14.79	0.222
1986	182.21	0.195	6.78	0.175
1987	114.04	0.274	4.58	0.281
1988	309.07	0.161	7.14	0.174
1989	392.48	0.346	12.00	0.268
1990	358.52	0.223	8.74	0.222
1991	187.42	0.402	5.16	0.327
1992	237.21	0.256	4.38	0.245
1993	252.41	0.227	9.63	0.215
1994	495.19	0.444	12.51	0.327
1995	111.51	0.248	5.45	0.257
1996	85.13	0.190	2.65	0.255
1997	251.02	0.108	4.38	0.132
1998	207.41	0.313	6.34	0.373
1999	243.54	0.354	4.84	0.278
2000	211.74	0.247	7.09	0.236
2001	86.16	0.225	3.06	0.296
2002	102.37	0.188	2.40	0.186
2003	193.44	0.138	3.96	0.169
2004	92.04	0.234	3.02	0.289
2005	53.44	0.204	1.16	0.240
2006	181.00	0.221	4.87	0.201
2007	54.83	0.167	1.50	0.286
2008	131.91	0.212	2.70	0.206

Table B16. NEFSC winter abundance and biomass indices (number and weight per tow) and corresponding coefficients of variation (CV) for 1992-2007 from data collected in offshore strata (1-14 and 61-76).

Year	Number	CV	Weight	CV
1992	22.10	0.241	0.85	0.226
1993	117.86	0.461	2.62	0.399
1994	186.25	0.715	6.87	0.637
1995	151.57	0.558	3.82	0.512
1996	74.38	0.615	1.49	0.375
1997	40.91	0.209	1.94	0.253
1998	44.65	0.412	1.10	0.275
1999	46.44	0.213	1.55	0.228
2000	151.65	0.331	5.00	0.310
2001	75.01	0.401	3.66	0.391
2002	43.90	0.296	1.89	0.241
2003	50.62	0.360	1.38	0.356
2004	180.75	0.528	3.43	0.456
2005	25.19	0.251	1.19	0.279
2006	45.20	0.232	1.75	0.232
2007	116.85	0.322	2.86	0.333

Table B17. Abundance indices (number per tow) for NEFSC spring surveys in offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76) during 1982-2008 for ages 0-3 and 4+.

Year	0	1	2	3	4+
1982	0	36.10	10.31	2.31	0.48
1983	0	33.82	23.00	7.04	0.89
1984	0	10.88	3.90	0.99	0.07
1985	0	30.19	4.92	2.22	0.52
1986	0	53.05	12.05	1.01	0.10
1987	0	13.93	1.43	0.23	0.03
1988	0	11.29	1.88	0.18	0.01
1989	0	25.64	5.71	0.96	0.01
1990	0	7.22	1.36	0.31	0.04
1991	0.03	25.67	1.50	0.63	0.02
1992	0	16.10	1.61	0.23	0.01
1993	0	23.56	2.71	0.42	0
1994	0	29.56	5.65	1.04	0.044
1995	0	26.55	12.95	2.61	0
1996	0	7.73	2.41	1.28	0.05
1997	0	107.72	4.50	0.66	0
1998	0	18.32	21.54	1.21	0
1999	0	64.97	9.30	1.96	0
2000	0	34.71	1.70	0.33	0.04
2001	0	49.28	11.14	0.79	0
2002	0	38.19	6.03	2.12	0.24
2003	0	39.36	5.49	2.66	0.18
2004	0	114.07	1.18	0.08	0.02
2005	0	28.23	7.74	1.01	0.48
2006	0	66.26	3.15	1.08	0.39
2007	0	120.77	17.23	3.20	0.21
2008	0	120.53	9.26	0.69	0.08

Table B18. Abundance indices (number per tow) for NEFSC fall surveys in inshore strata (1-92) and offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76) during 1982-2008 for ages 0-3 and 4+.

Year	0	1	2	3	4+
1982	74.28	26.52	7.54	0.50	0
1983	341.34	83.41	13.43	2.29	0.03
1984	287.43	43.91	13.23	3.17	0.00
1985	281.25	80.31	11.85	2.28	0.09
1986	140.48	27.94	11.49	1.99	0.32
1987	77.32	29.95	6.54	0.22	0
1988	275.32	20.96	12.70	0.10	0
1989	329.46	47.26	14.85	0.92	0
1990	320.81	32.93	3.77	1.02	0
1991	163.50	19.94	3.65	0.34	0
1992	223.30	9.42	4.39	0.10	0
1993	192.53	49.56	9.49	0.83	0
1994	462.33	21.98	9.40	1.46	0.02
1995	45.63	41.67	24.13	0.08	0
1996	63.56	17.31	4.00	0.27	0
1997	231.46	16.92	2.51	0.14	0
1998	149.78	48.64	8.26	0.74	0
1999	226.15	15.28	2.09	0.03	0
2000	164.44	41.94	4.98	0.38	0
2001	62.60	14.81	8.53	0.22	0
2002	88.12	10.99	3.15	0.11	0
2003	178.35	12.78	1.68	0.40	0.21
2004	66.56	16.26	8.04	0.69	0.49
2005	45.68	5.23	1.71	0.81	0.02
2006	154.96	19.78	5.25	0.93	0.08
2007	39.12	13.76	1.94	0.02	0
2008	123.06	7.69	1.09	0.06	0

Table B19. Biomass per tow for 0 and 1+ butterfish in NEFSC fall surveys as estimated using growth parameter estimates and numbers at age during 1982-2008 in Table B18 and numbers at age for 1975-1981 from Table E5 in NEFSC (1994).

Year	Age 0	Age 1+
1975	0.803	1.793
1976	3.236	2.568
1977	1.470	3.741
1978	2.922	1.702
1979	5.588	5.910
1980	6.090	8.598
1981	5.374	4.726
1982	1.472	2.383
1983	6.699	6.605
1984	5.623	4.290
1985	5.572	6.289
1986	2.731	3.055
1987	1.489	2.448
1988	5.215	2.460
1989	6.281	4.347
1990	5.976	2.446
1991	3.005	1.570
1992	4.174	0.986
1993	3.550	3.944
1994	8.496	2.366
1995	0.836	4.741
1996	1.204	1.447
1997	4.326	1.264
1998	3.033	3.844
1999	4.551	1.133
2000	2.970	2.999
2001	1.139	1.701
2002	1.592	0.959
2003	3.311	0.999
2004	1.248	1.880
2005	0.862	0.575
2006	2.906	1.801
2007	0.763	1.017
2008	2.223	0.566

Table B20. Massachusetts spring (1982-2008) and fall (1982-2008) and Connecticut (Long Island Sound Survey) spring (1984-2008) and fall (1982-2008) abundance and biomass indices (number and weight per tow).

Year	MA Spring Number	MA Spring Weight	MA Fall Number	MA Fall Weight	CT Spring Number	CT Spring Weight	CT Fall Number	CT Fall Weight
1982	0.184	0.283	319.296	2.344			51.93	
1983	2.31	0.046	314.958	1.435			89.72	
1984	4.733	0.722	102.333	5.371	8.92		63.41	
1985	10.508	0.199	166.836	1.881	0.62		60.09	
1986	2.665	0.019	296.035	2.872	2.38		146.67	
1987	1.184	0.239	17.128	2.942	0.25		174.87	
1988	1.063	0.495	1387.95	1.914	0.46		154.65	
1989	0.261	0.619	181.665	1.464	0.8		170.59	
1990	15.551	0.218	231.682	4.615	1.6		301.72	
1991	28.526	0.086	366.505	0.697	2.17		87.73	
1992	0.933	0.104	1151.021	12.269	2.6	0.43	93.05	6.31
1993	1.86	0.023	1270.304	2.59	0.48	0.1	320.06	4.12
1994	4.999	0.897	608.334	2.685	1.71	0.31	173.74	3.4
1995	14.454	1.191	600.737	3.355	1.06	0.19	186.62	10.26
1996	4.568	0.061	550.701	9.257	3.22	0.73	355.49	9.3
1997	9.011	0.151	660.385	10.778	6.16	1.27	477.91	6.97
1998	5.299	0.334	1576.006	7.613	6.51	1.06	125.97	13.27
1999	1.019	0.427	649.108	5.66	1.9	0.52	142.89	15.43
2000	43.393	0.345	164.4	6.848	3.35	0.69	165.07	4.45
2001	19.373	0.385	118.074	8.318	2.94	0.79	112.86	7.8
2002	16.776	0.403	424.988	14.713	7.09	1.48	175.37	6.56
2003	14.173	0.042	1011.975	7.985	3.17	0.64	197.24	3.47
2004	4.395	1.706	184.228	3.284	2.1	0.41	140.23	6.24
2005	2.231	1.476	649.279	1.843	2.27	0.55	154.53	7.85
2006	13.246	0.875	199.643	3.973	18.67	2.3	181.71	7.73
2007	81.109	0.907	465.435	3.546	3.48	0.66	51.93	5.82
2008	10.544	0.33	878.692	2.881	4.64	1.06	89.72	8.97

Table B21. Growth parameter estimates based on age and weight data collected in surveys between 1992-2009. Schnute's (1985) parameterization was fitted by non-linear least squares.

Parameter	Estimate	SE
$v$	0.0067	0.00037
$V$	0.0502	0.00026
$\rho$	0.8121	0.01176

Table B22. Length at age growth von Bertalanffy parameter estimates based on age and length data collected in surveys between 1992-2009. Schnute's (1985) parameterization was fitted by non-linear least squares.

	Estimate	SE
Linf	19.189	0.1957
K	0.6771	0.0235
t0	-0.214	0.0224

Table B23. Maximized objective function components at assumed maxima on the uniform priors for the ratio of survey to stock area and efficiency of the Bigelow.

	0.85	0.9	0.95
Spring 1+	24.224	24.139	24.058
Winter 1+	5.496	5.489	5.483
Fall 0	2.973	2.997	3.019
Fall 1+	12.508	12.569	12.628
Catch	0.002	0.003	0.003
Total	48.772	48.641	48.512

Table B24. Maximized objective function components at assumed values of natural mortality (M) from 0.6-1.0 in the final model.

	0.6	0.7	0.8	0.9	1
Spring 1+	24.972	24.979	24.139	23.994	23.872
Winter 1+	5.990	5.731	5.489	5.308	5.154
Fall 0	2.884	2.910	2.997	3.051	3.126
Fall 1+	13.590	13.136	12.569	12.356	12.217
Catch	0.005	0.003	0.003	0.002	0.001
Total	50.904	50.222	48.641	48.152	47.810

Table B25. Estimated annual population parameter from the final model.

Year	Recruits (kmt)	Total Biomass (kmt)	Spawning Biomass (kmt)	Ave Biomass (kmt)	F	IGR (Recruits)	IGR (spawning biomass)	IGR (all)	Surplus Production (kmt)
1973	NA	245.71	NA	184.54	0.21	NA	NA	0.41	105.47
1974	184.78	319.26	134.48	253.56	0.09	0.53	0.24	0.41	-85.29
1975	15.56	215.13	199.57	157.51	0.13	0.53	0.25	0.27	-24.96
1976	63.59	175.15	111.56	128.08	0.17	0.53	0.18	0.31	-38
1977	28.71	120.4	91.69	88.69	0.13	0.53	0.2	0.28	13.82
1978	61.86	125.63	63.77	95.24	0.14	0.53	0.19	0.36	78.64
1979	122.38	193.63	71.25	155.31	0.08	0.53	0.22	0.42	86.18
1980	146.01	269.74	123.73	215.25	0.07	0.53	0.25	0.4	19.85
1981	106.42	276.74	170.32	216.29	0.07	0.53	0.24	0.35	-68.39
1982	29.31	196.36	167.05	142.71	0.14	0.53	0.22	0.27	37.82
1983	118.06	218.58	100.52	170.41	0.09	0.53	0.18	0.37	30.41
1984	104.62	236.52	131.9	181.54	0.12	0.53	0.23	0.36	12.91
1985	94.67	232.04	137.37	180.85	0.07	0.53	0.23	0.35	-34.59
1986	47.53	186.94	139.4	141.56	0.08	0.53	0.22	0.3	-45.71
1987	26.7	131.92	105.22	96.8	0.12	0.53	0.2	0.26	34.7
1988	88.66	157.88	69.22	124.51	0.07	0.53	0.18	0.38	29.74
1989	82.58	180.27	97.69	142.98	0.05	0.53	0.23	0.37	22.56
1990	84.13	196.61	112.47	157.69	0.02	0.53	0.23	0.36	-28.34
1991	40.28	165.99	125.71	127.31	0.06	0.53	0.22	0.3	11.31
1992	75.77	171.81	96.04	134.35	0.06	0.53	0.2	0.34	8.57
1993	69.91	174.16	104.25	134.21	0.09	0.53	0.22	0.34	57.48
1994	119.81	221.93	102.12	177.24	0.06	0.53	0.22	0.39	-58.57
1995	14.55	155.25	140.69	116.31	0.07	0.53	0.24	0.27	-41.94
1996	22.01	106.85	84.84	80.04	0.06	0.53	0.18	0.25	30.58
1997	75.15	133.95	58.8	107.3	0.04	0.53	0.17	0.37	7.8
1998	52.87	138.67	85.8	107.62	0.08	0.53	0.23	0.35	43.28
1999	92.81	175.3	82.49	138.28	0.08	0.53	0.22	0.39	-1.53
2000	56.58	164.78	108.2	128.01	0.07	0.53	0.24	0.34	-39.32
2001	20.57	118.74	98.17	88.04	0.1	0.53	0.21	0.27	-20.11
2002	28.24	91.88	63.64	70.43	0.05	0.53	0.18	0.29	26.31
2003	62.35	115.69	53.34	93.05	0.03	0.53	0.19	0.38	-16.1
2004	22.81	97.44	74.63	75.97	0.02	0.53	0.23	0.3	-21.29
2005	16.36	74.77	58.41	57.55	0.02	0.53	0.2	0.27	22.74
2006	53.03	96.68	43.65	78.08	0.02	0.53	0.18	0.37	-19.52
2007	13.05	76.02	62.97	58.97	0.02	0.53	0.23	0.28	8.49
2008	38.81	83.81	44.99	66.64	0.02	0.53	0.19	0.35	NA

Table B26. Estimated total biomass and standard errors for the final model.

Year	Total Biomass	SE
1973	245.71	239.78
1974	319.26	187.28
1975	215.13	130.4
1976	175.15	105.2
1977	120.4	77.49
1978	125.63	76.63
1979	193.63	116.28
1980	269.74	162.53
1981	276.74	165.19
1982	196.36	120.05
1983	218.58	134.15
1984	236.52	142.15
1985	232.04	143.06
1986	186.94	116.62
1987	131.92	84.37
1988	157.88	98.7
1989	180.27	112.98
1990	196.61	123.46
1991	165.99	103.19
1992	171.81	105.81
1993	174.16	104.98
1994	221.93	135.94
1995	155.25	98.33
1996	106.85	69.39
1997	133.95	82.81
1998	138.67	84.86
1999	175.3	105.66
2000	164.78	100.61
2001	118.74	74.3
2002	91.88	59.51
2003	115.69	72.04
2004	97.44	60.68
2005	74.77	46.49
2006	96.68	59.11
2007	76.02	46.67
2008	83.81	50.63

Table B27. Estimated annual fishing mortality rate and standard errors for the final model.

Year	F	SE
1973	0.213	0.219
1974	0.09	0.054
1975	0.126	0.081
1976	0.168	0.108
1977	0.126	0.086
1978	0.139	0.09
1979	0.078	0.049
1980	0.073	0.046
1981	0.069	0.043
1982	0.144	0.094
1983	0.09	0.058
1984	0.119	0.075
1985	0.073	0.046
1986	0.085	0.055
1987	0.119	0.08
1988	0.073	0.047
1989	0.054	0.035
1990	0.018	0.011
1991	0.056	0.036
1992	0.058	0.037
1993	0.091	0.057
1994	0.056	0.035
1995	0.073	0.048
1996	0.058	0.038
1997	0.035	0.022
1998	0.078	0.05
1999	0.08	0.05
2000	0.066	0.041
2001	0.101	0.066
2002	0.046	0.03
2003	0.028	0.018
2004	0.023	0.015
2005	0.019	0.012
2006	0.018	0.011
2007	0.016	0.01
2008	0.024	0.015

Table B28. Predicted values, residuals and estimated catchability (Q) for the NEFSC spring 1+ survey.

Year	Time	Index	Scaled CV	Predicted	Residual	Standardized Resid	Q
1973	1973.31	5.35	0.81	NA	NA	NA	NA
1974	1974.27	1.72	0.97	1.83	-0.06	-0.08	0.02
1975	1975.26	4	0.38	2.7	0.39	1.06	0.02
1976	1976.26	1.31	0.58	1.47	-0.12	-0.21	0.02
1977	1977.3	0.56	0.66	1.2	-0.76	-1.26	0.02
1978	1978.31	0.25	0.65	0.82	-1.17	-1.98	0.02
1979	1979.29	1.05	0.85	0.96	0.09	0.12	0.02
1980	1980.29	3.2	0.52	1.67	0.65	1.33	0.02
1981	1981.3	2.47	0.6	2.29	0.08	0.14	0.02
1982	1982.26	2.55	0.85	2.23	0.13	0.18	0.02
1983	1983.26	3.9	1.35	1.35	1.06	1.04	0.02
1984	1984.24	0.71	0.74	1.81	-0.93	-1.42	0.02
1985	1985.22	1.6	0.81	1.93	-0.19	-0.27	0.02
1986	1986.24	2.78	0.82	1.92	0.37	0.52	0.02
1987	1987.28	0.57	0.62	1.39	-0.88	-1.55	0.02
1988	1988.24	0.48	0.61	0.95	-0.68	-1.22	0.02
1989	1989.22	0.76	1.33	1.38	-0.6	-0.59	0.02
1990	1990.23	0.36	0.77	1.59	-1.48	-2.17	0.02
1991	1991.23	1.01	1.18	1.76	-0.56	-0.6	0.02
1992	1992.23	0.61	0.41	1.33	-0.79	-1.98	0.02
1993	1993.25	0.81	0.63	1.42	-0.57	-0.97	0.02
1994	1994.24	1.45	0.55	1.42	0.02	0.04	0.02
1995	1995.25	2.2	1.55	1.94	0.13	0.11	0.02
1996	1996.25	0.51	0.62	1.16	-0.81	-1.42	0.02
1997	1997.24	3.41	0.8	0.81	1.44	2.05	0.02
1998	1998.23	2.14	1.48	1.19	0.58	0.54	0.02
1999	1999.23	2.46	1.31	1.14	0.76	0.77	0.02
2000	2000.27	0.99	0.67	1.47	-0.4	-0.66	0.02
2001	2001.24	1.89	0.31	1.35	0.34	1.11	0.02
2002	2002.24	1.7	0.8	0.88	0.67	0.95	0.02
2003	2003.24	1.39	1.46	0.74	0.63	0.59	0.02
2004	2004.24	2.06	0.65	1.05	0.67	1.13	0.02
2005	2005.19	1.26	0.72	0.84	0.41	0.63	0.02
2006	2006.24	1.98	0.71	0.61	1.18	1.84	0.02
2007	2007.24	4.77	1.01	0.89	1.68	2.01	0.02
2008	2008.26	3.06	1.16	0.62	1.6	1.73	0.02

Table B29. Predicted values, residuals and estimated catchability (Q) for the NEFSC winter 1+ survey.

Year	Time	Index	Scaled CV	Predicted	Residual	Standardized Resid	Q
1992	1992.15	0.84	1.09	3.23	-1.34	-1.52	0.04
1993	1993.12	2.62	0.62	3.55	-0.3	-0.53	0.04
1994	1994.11	6.87	0.38	3.52	0.67	1.81	0.04
1995	1995.13	3.82	0.51	4.78	-0.23	-0.47	0.04
1996	1996.13	1.49	0.82	2.88	-0.66	-0.92	0.04
1997	1997.12	1.94	0.72	2.01	-0.04	-0.05	0.04
1998	1998.13	1.1	0.95	2.92	-0.97	-1.21	0.04
1999	1999.12	1.55	0.8	2.83	-0.6	-0.85	0.04
2000	2000.14	5	0.45	3.68	0.31	0.72	0.04
2001	2001.11	3.66	0.52	3.37	0.08	0.17	0.04
2002	2002.13	1.89	0.73	2.16	-0.14	-0.21	0.04
2003	2003.13	1.38	0.85	1.82	-0.28	-0.38	0.04
2004	2004.12	3.43	0.54	2.57	0.29	0.57	0.04
2005	2005.12	1.19	0.92	2.01	-0.52	-0.67	0.04
2006	2006.13	1.75	0.76	1.49	0.17	0.25	0.04
2007	2007.13	2.86	0.59	2.16	0.28	0.51	0.04

Table B30. Predicted values, residuals and estimated catchability (Q) for the NEFSC fall 0 survey.

Year	Time	Index	Scaled CV	Predicted	Residual	Standardized Resid	Q
1975	1975.82	0.8	0.28	0.8	0.01	0.03	0.07
1976	1976.82	3.24	0.21	3.15	0.03	0.13	0.07
1977	1977.83	1.47	0.28	1.47	0	0.01	0.07
1978	1978.78	2.92	0.17	3.18	-0.08	-0.52	0.07
1979	1979.79	5.59	0.22	6.59	-0.17	-0.75	0.07
1980	1980.8	6.09	0.48	7.87	-0.26	-0.56	0.07
1981	1981.78	5.37	0.26	5.78	-0.07	-0.29	0.07
1982	1982.71	1.47	0.26	1.55	-0.05	-0.2	0.07
1983	1983.72	6.7	0.21	6.45	0.04	0.19	0.07
1984	1984.72	5.62	0.27	5.61	0	0.01	0.07
1985	1985.74	5.57	0.22	5.21	0.07	0.3	0.07
1986	1986.71	2.73	0.18	2.62	0.04	0.24	0.07
1987	1987.71	1.49	0.28	1.44	0.03	0.12	0.07
1988	1988.72	5.21	0.17	4.92	0.06	0.34	0.07
1989	1989.69	6.28	0.27	4.68	0.3	1.12	0.07
1990	1990.71	5.98	0.22	4.87	0.21	0.94	0.07
1991	1991.71	3	0.33	2.27	0.28	0.89	0.07
1992	1992.7	4.17	0.25	4.26	-0.02	-0.09	0.07
1993	1993.7	3.55	0.21	3.85	-0.08	-0.38	0.07
1994	1994.69	8.5	0.33	6.77	0.23	0.71	0.07
1995	1995.69	0.84	0.26	0.81	0.03	0.11	0.07
1996	1996.71	1.2	0.25	1.24	-0.03	-0.11	0.07
1997	1997.71	4.33	0.13	4.29	0.01	0.05	0.07
1998	1998.7	3.03	0.37	2.94	0.03	0.09	0.07
1999	1999.7	4.55	0.28	5.15	-0.12	-0.45	0.07
2000	2000.7	2.97	0.24	3.17	-0.07	-0.28	0.07
2001	2001.71	1.14	0.3	1.12	0.02	0.05	0.07
2002	2002.71	1.59	0.19	1.6	0	-0.02	0.07
2003	2003.71	3.31	0.17	3.58	-0.08	-0.47	0.07
2004	2004.7	1.25	0.29	1.32	-0.05	-0.19	0.07
2005	2005.7	0.86	0.24	0.95	-0.09	-0.4	0.07
2006	2006.7	2.91	0.2	3.08	-0.06	-0.29	0.07
2007	2007.7	0.76	0.29	0.76	0.01	0.03	0.07
2008	2008.73	2.22	0.21	2.22	0	0	0.07

Table B31. Predicted values, residuals and estimated catchability (Q) for the NEFSC fall 1+ survey.

Year	Time	Index	Scaled CV	Predicted	Residual	Standardized Resid	Q
1975	1975.82	1.79	0.84	4.53	-0.93	-1.27	0.04
1976	1976.82	2.57	0.64	2.31	0.1	0.18	0.04
1977	1977.83	3.74	0.85	1.99	0.63	0.85	0.04
1978	1978.78	1.7	0.5	1.4	0.19	0.42	0.04
1979	1979.79	5.91	0.67	1.69	1.25	2.05	0.04
1980	1980.8	8.6	1.45	2.98	1.06	1	0.04
1981	1981.78	4.73	0.77	4.13	0.13	0.2	0.04
1982	1982.71	2.38	0.77	3.99	-0.52	-0.76	0.04
1983	1983.72	6.61	0.63	2.41	1.01	1.74	0.04
1984	1984.72	4.29	0.8	3.24	0.28	0.4	0.04
1985	1985.74	6.29	0.67	3.48	0.59	0.98	0.04
1986	1986.71	3.06	0.53	3.44	-0.12	-0.24	0.04
1987	1987.71	2.45	0.84	2.47	-0.01	-0.01	0.04
1988	1988.72	2.46	0.52	1.67	0.39	0.79	0.04
1989	1989.69	4.35	0.8	2.45	0.57	0.81	0.04
1990	1990.71	2.45	0.67	2.94	-0.18	-0.3	0.04
1991	1991.71	1.57	0.98	3.19	-0.71	-0.86	0.04
1992	1992.7	0.99	0.74	2.37	-0.88	-1.33	0.04
1993	1993.7	3.94	0.64	2.6	0.42	0.71	0.04
1994	1994.69	2.37	0.98	2.58	-0.09	-0.11	0.04
1995	1995.69	4.74	0.77	3.55	0.29	0.42	0.04
1996	1996.71	1.45	0.76	2.08	-0.36	-0.54	0.04
1997	1997.71	1.26	0.4	1.47	-0.15	-0.39	0.04
1998	1998.7	3.84	1.12	2.18	0.57	0.63	0.04
1999	1999.7	1.13	0.84	2.07	-0.6	-0.83	0.04
2000	2000.7	3	0.71	2.74	0.09	0.14	0.04
2001	2001.71	1.7	0.89	2.4	-0.34	-0.45	0.04
2002	2002.71	0.96	0.56	1.58	-0.5	-0.96	0.04
2003	2003.71	1	0.51	1.36	-0.31	-0.64	0.04
2004	2004.7	1.88	0.87	1.96	-0.04	-0.06	0.04
2005	2005.7	0.57	0.72	1.49	-0.95	-1.48	0.04
2006	2006.7	1.8	0.6	1.1	0.49	0.88	0.04
2007	2007.7	1.02	0.86	1.66	-0.49	-0.66	0.04
2008	2008.73	0.57	0.62	1.14	-0.7	-1.23	0.04

Table B32. Candidate  $F_{MSY}$  proxies and corresponding median equilibrium yields and biomasses (mt) based on 7000 bootstraps and projections. Fox-model-based reference points are estimated within the KLAMZ model. Previous reference points were also based on the Fox model.

F Reference point	F	Yield	95% CI	Spawning Biomass	95% CI	Total Biomass	95% CI
$F_{0.1}$ (= $F_{20\%}$ )	1.04	36,608	10,912-139,261	16,262	4,828-61,600	65,306	19,546-243,587
$F_{30\%}$	0.72	33,108	10,561-117,116	25,226	8,069-90,387	75,752	24,534-263,642
$F_{40\%}$	0.52	29,166	9,779-99,358	34,191	11,570-116,722	85,810	29,178-286,435
$F = 0$	0	0	0	89,881	35,281-255,747	145,296	56,998-405,540
SARC 38	0.38	12,200				22,800	
$F_{MSY}$ (Fox)	0.23	17,400				74,550	
$F_{MAX}$ (Empirical)	NA	NA		NA			

Table B33. Estimates from the base model and median fishing mortality and spawning biomass in constant catch projections when recruitments from either the entire time series (1974-2008) or the last 10 years (1999-2008) are used to generate future recruitments. Medians are based on 7000 bootstraps and 1 projection for each bootstrap.

Fall 1+ Model Q	0.04					
Fall 1+ Swept Area Q	0.16					
SSB <sub>2008</sub>	45,993 mt					
R <sub>2008</sub>	38,814 mt					
B <sub>2008</sub>	83,807 mt					
F <sub>2008</sub>	0.02					
	1974-2008 Recruitment			1999-2008 Recruitment		
	Catch = 0	Catch = 1630 mt	Catch = 3260 mt	Catch = 0	Catch = 1630 mt	Catch = 3260 mt
F <sub>2009</sub>	0	0.02	0.04	0	0.03	0.05
F <sub>2010</sub>	0	0.02	0.04	0	0.03	0.05
F <sub>2011</sub>	0	0.02	0.03	0	0.02	0.05
F <sub>2012</sub>	0	0.02	0.03	0	0.02	0.05
F <sub>2013</sub>	0	0.01	0.03	0	0.02	0.05
SSB <sub>2009</sub>	43,904 mt	43,904 mt	43,904 mt	43,897 mt	43,897 mt	43,897 mt
SSB <sub>2010</sub>	61,016 mt	59,376 mt	58,056 mt	48,863 mt	47,570 mt	46,268 mt
SSB <sub>2011</sub>	74,811 mt	72,511 mt	70,457 mt	52,015 mt	49,985 mt	47,956 mt
SSB <sub>2012</sub>	82,568 mt	80,220 mt	77,779 mt	54,495 mt	52,121 mt	49,695 mt
SSB <sub>2013</sub>	85,596 mt	84,217 mt	81,607 mt	54,841 mt	52,264 mt	49,682 mt

Table B34. Estimates from the models where catchability of the fall1+ indices is assumed to be 0.001 or 0.12 and corresponding median fishing mortality and spawning biomass in constant catch projections when recruitments from the entire time series (1974-2008) are used to generate future recruitments. Medians are based on 100 bootstraps and 10 projection for each bootstrap.

Fall 1+ Model Q	0.001			0.12		
Fall 1+ Swept Area Q	0.006			0.49		
SSB <sub>2008</sub>	1,108,000 mt			17,873 mt		
R <sub>2008</sub>	899,274 mt			16,944 mt		
B <sub>2008</sub>	2,007,280 mt			34,817 mt		
F <sub>2008</sub>	0.001			0.06		

	Catch = 0	Catch = 1630 mt	Catch = 3260 mt	Catch = 0	Catch = 1630 mt	Catch = 3260 mt
F <sub>2009</sub>	0	0.0010	0.0019	0	0.05	0.10
F <sub>2010</sub>	0	0.0008	0.0015	0	0.04	0.08
F <sub>2011</sub>	0	0.0007	0.0015	0	0.04	0.07
F <sub>2012</sub>	0	0.0007	0.0014	0	0.03	0.07
F <sub>2013</sub>	0	0.0007	0.0013	0	0.03	0.07
SSB <sub>2009</sub>	1,077,099 mt	1,077,099 mt	1,077,099 mt	18,403 mt	18,403 mt	18,403 mt
SSB <sub>2010</sub>	1,368,321 mt	1,367,019 mt	1,365,717 mt	26,871 mt	25,544 mt	24,222 mt
SSB <sub>2011</sub>	1,694,726 mt	1,692,646 mt	1,690,565 mt	35,342 mt	33,271 mt	31,201 mt
SSB <sub>2012</sub>	1,783,808 mt	1,781,382 mt	1,778,956 mt	39,422 mt	36,995 mt	34,550 mt
SSB <sub>2013</sub>	1,894,167 mt	1,891,599 mt	1,889,028 mt	41,783 mt	39,176 mt	36,547 mt

## Figures

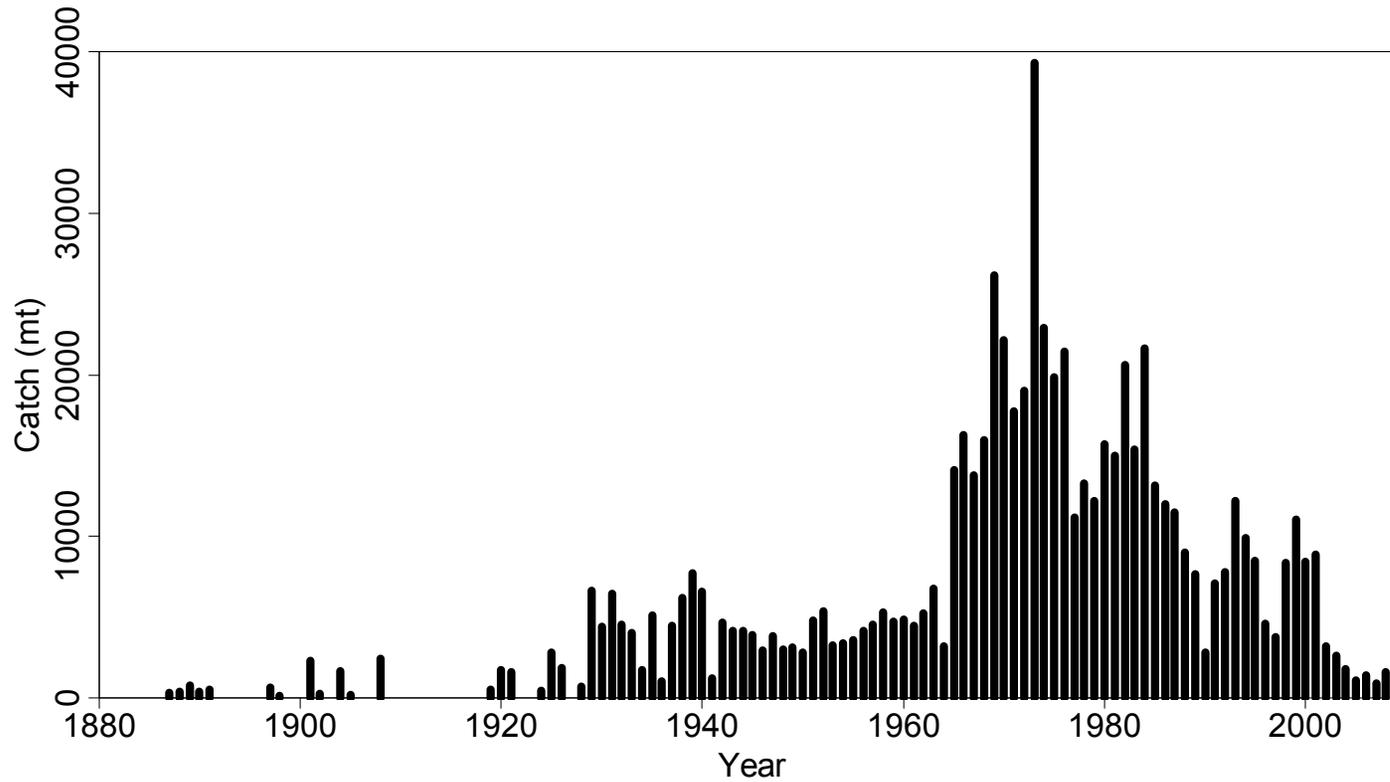


Figure B1. Total catch from from 1887 to 2008. Annual catch data are missing for some years prior to 1930 and total catch between 1965 and 1988 includes discards estimated by applying an average of discard rates for trawl gear estimated between 1989 and 1999 to annual landings of all species between 1965 and 1988 by trawl gear.

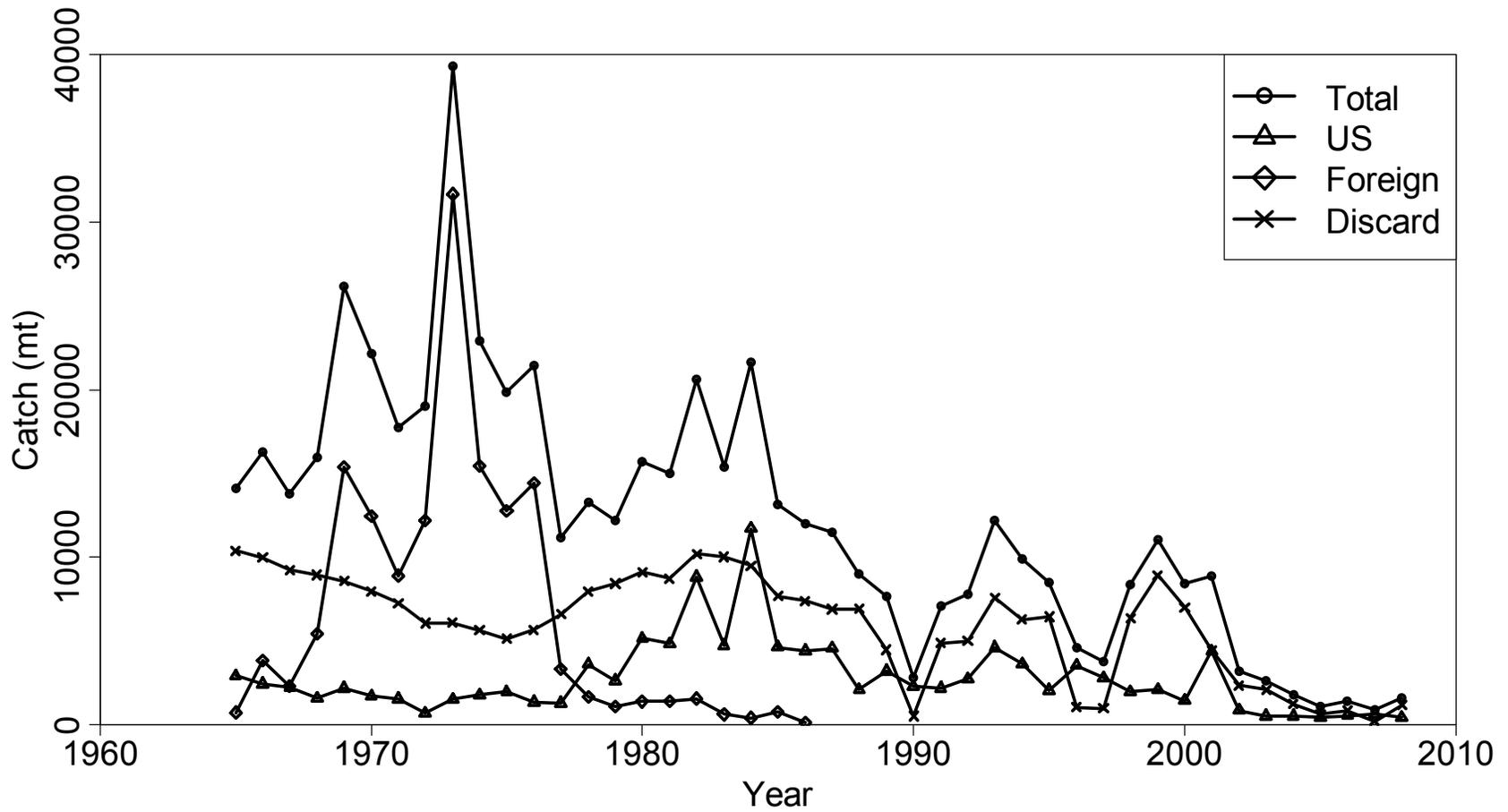


Figure B2. Total (circle), US (triangle), and foreign (diamond) landings and estimated discards (x) of butterfish between 1965 and 2008.

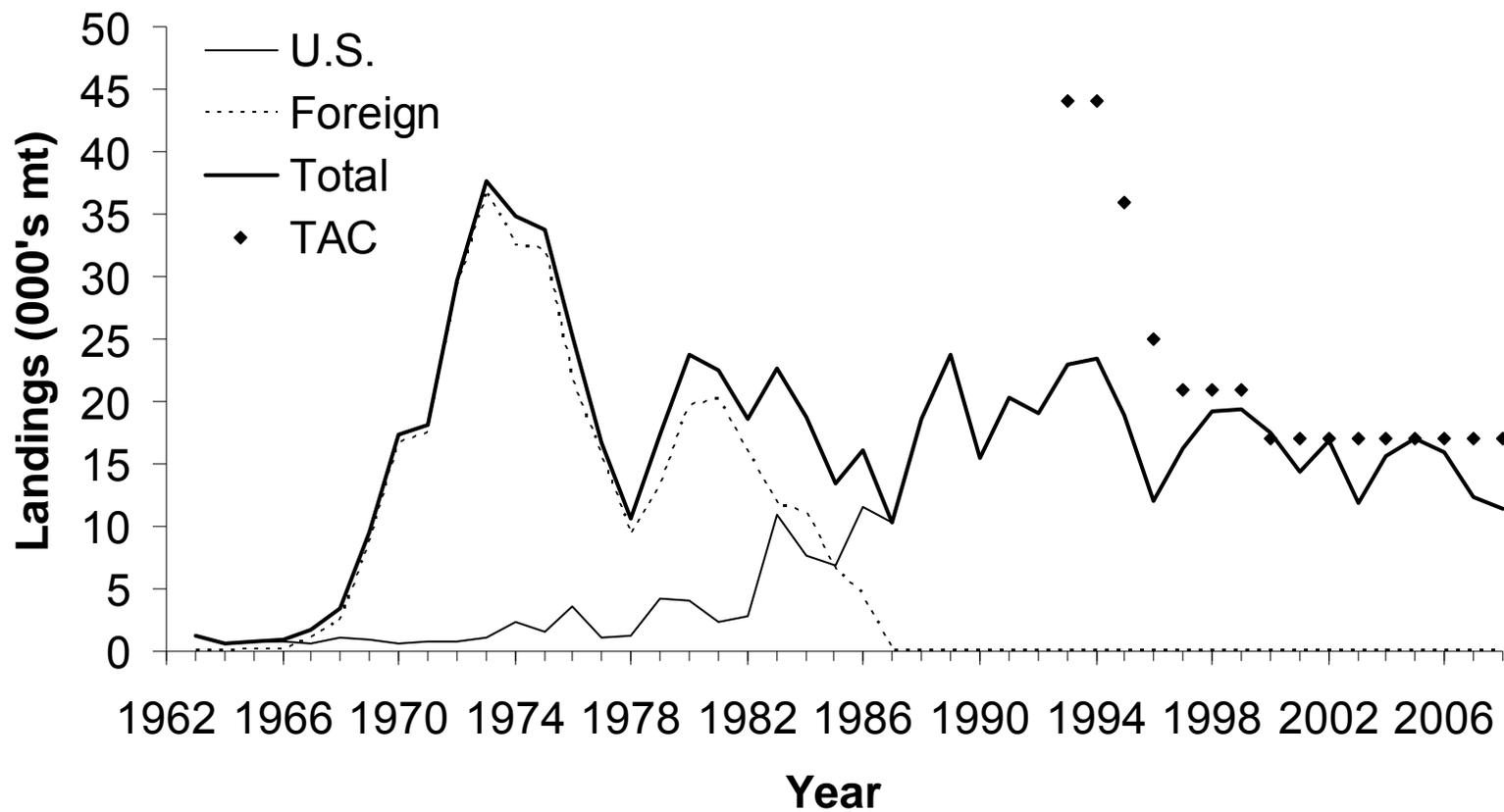


Figure B3. US, foreign, and total *Loligo* landings and total allowable catches (TACs).

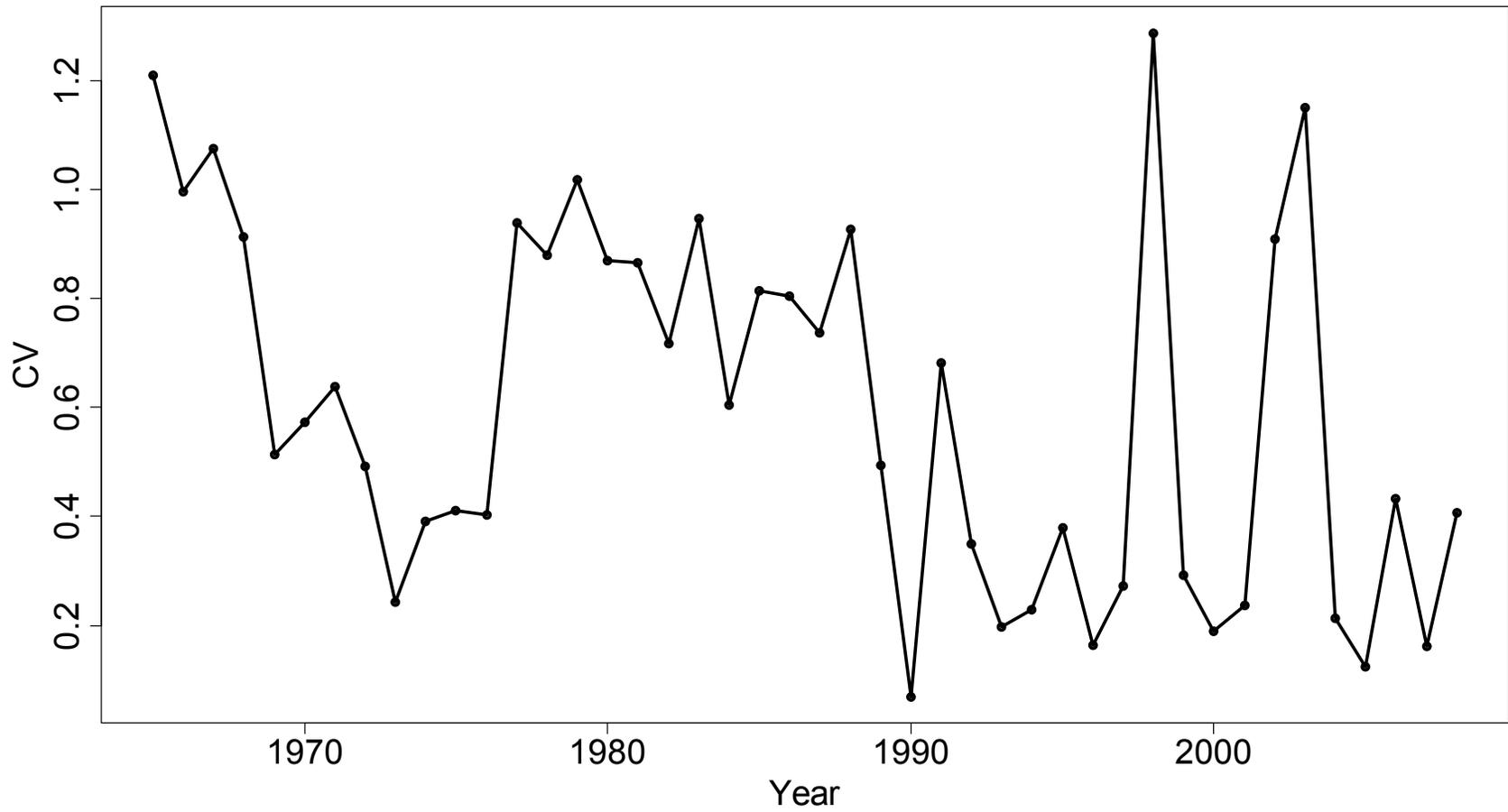


Figure B4. Coefficient of variation of total catch estimates reflecting variance estimates associated with discard estimates.

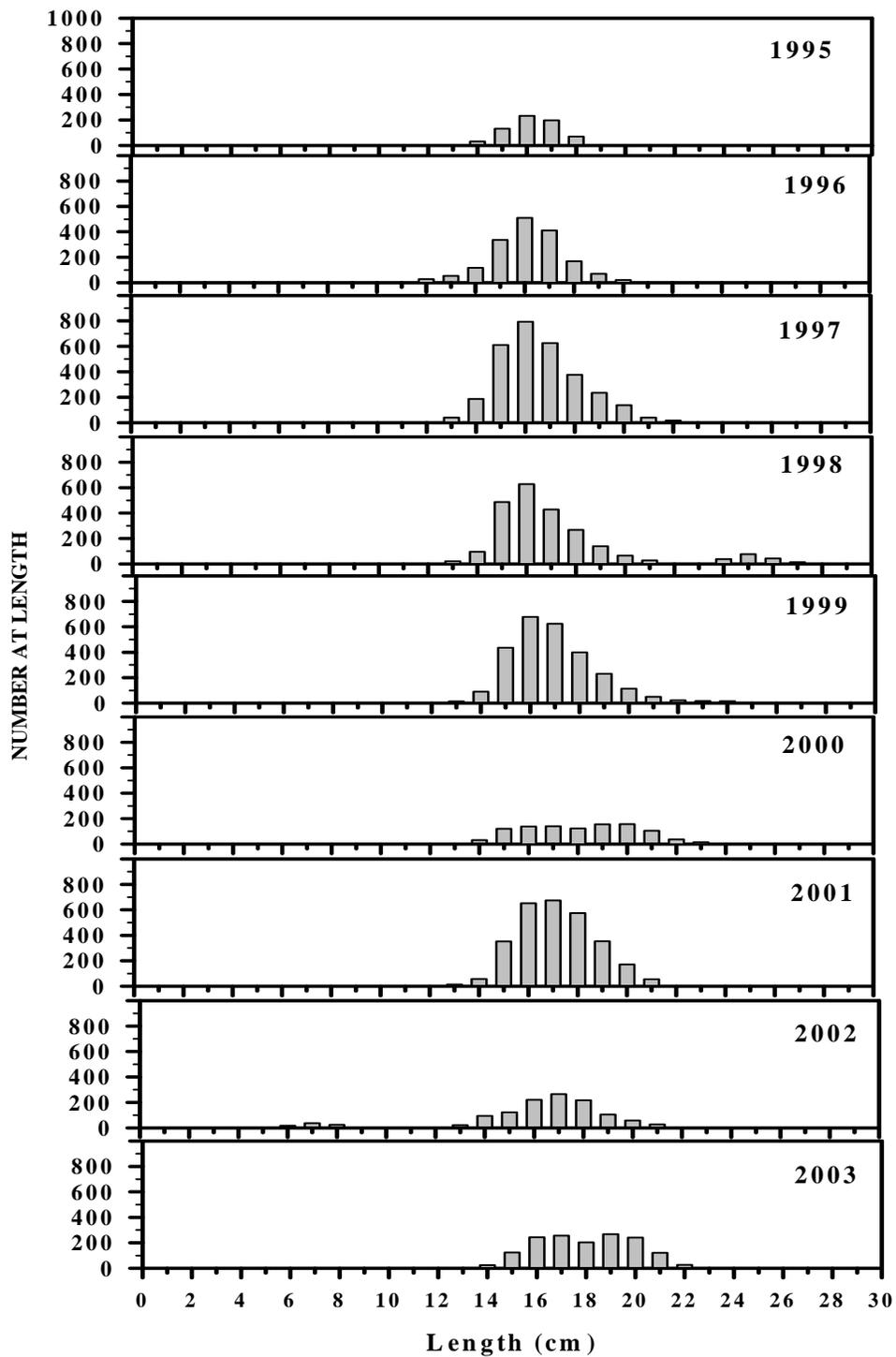


Figure B5. Size composition data from commercial landings of butterfish during 1995-2003.

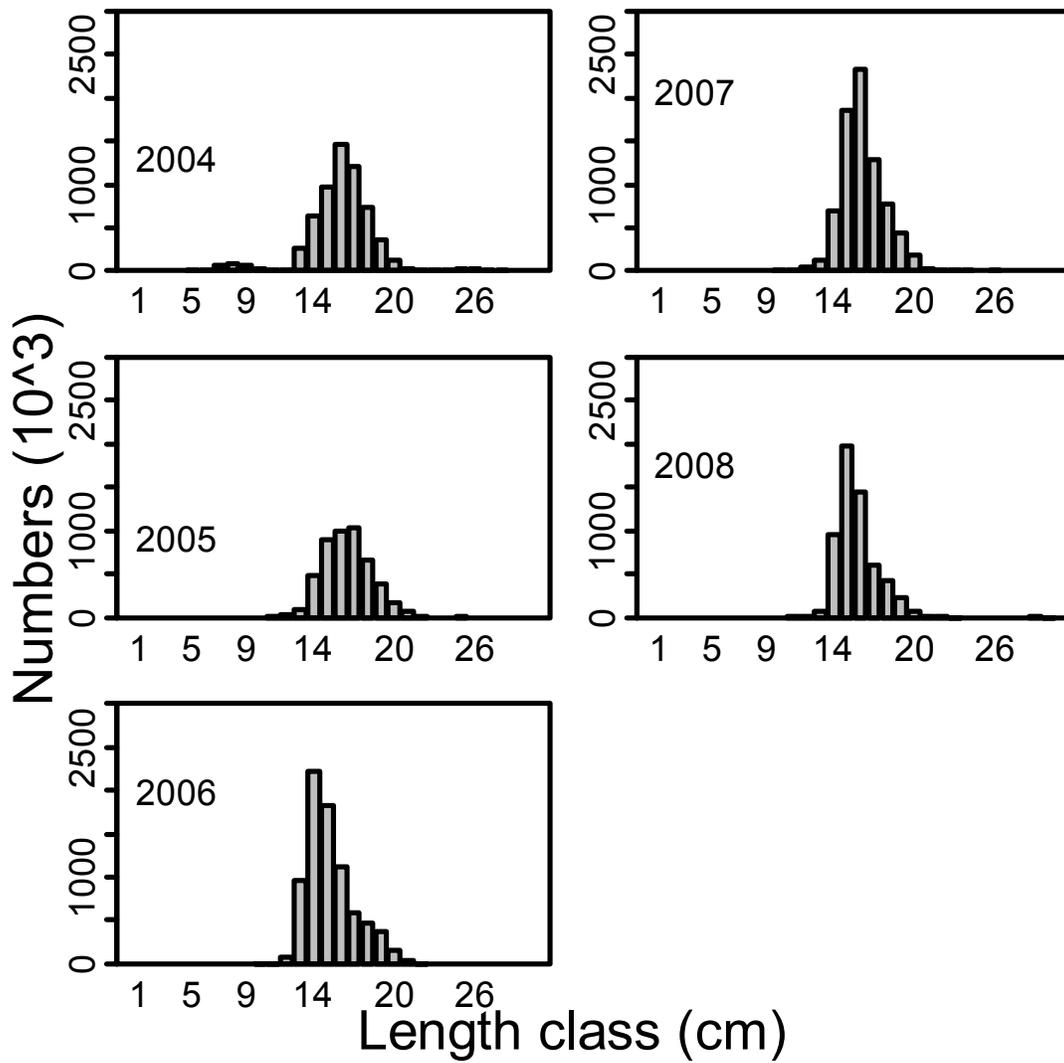


Figure B6. Size composition data from commercial landings of butterfish between 2004 and 2008 accounting for sampling by market category.

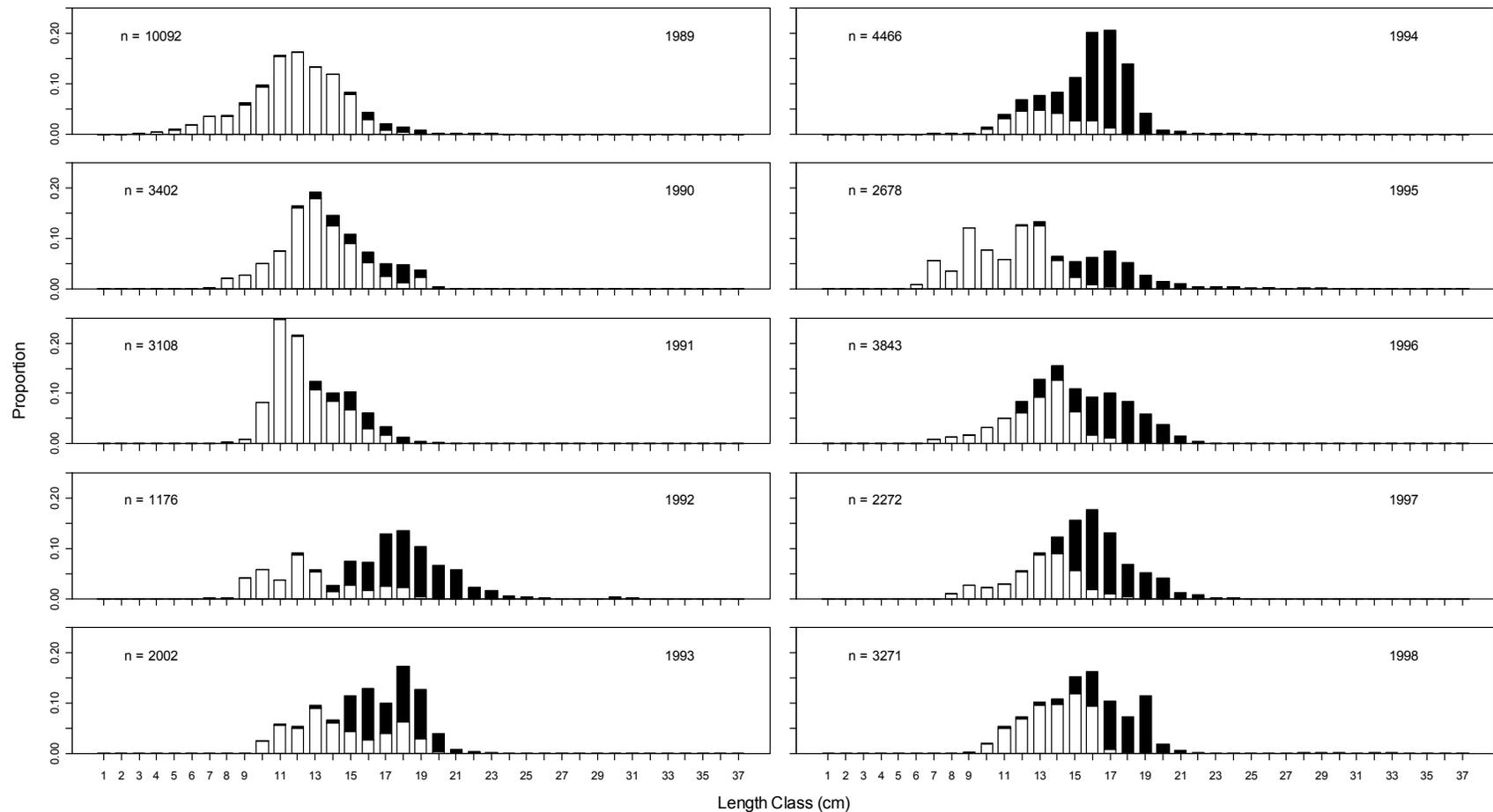


Figure B7. Length composition for NMFS Observer Program for butterfish between 1989 and 1998 with kept fish in black and discard in white. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

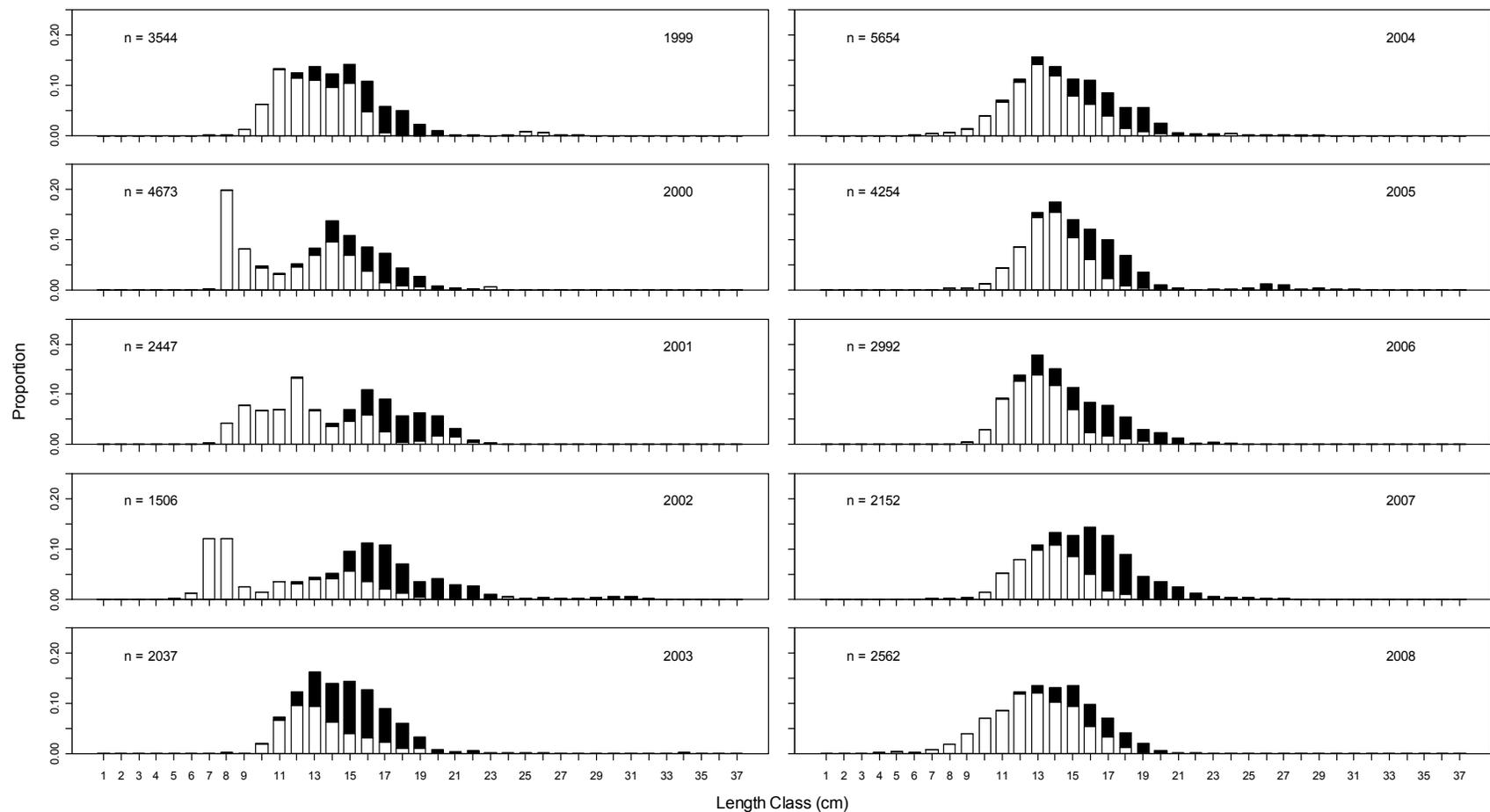


Figure B8. Length composition for NMFS Observer Program for butterfish between 1999 and 2008 with kept fish in black and discard in white. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

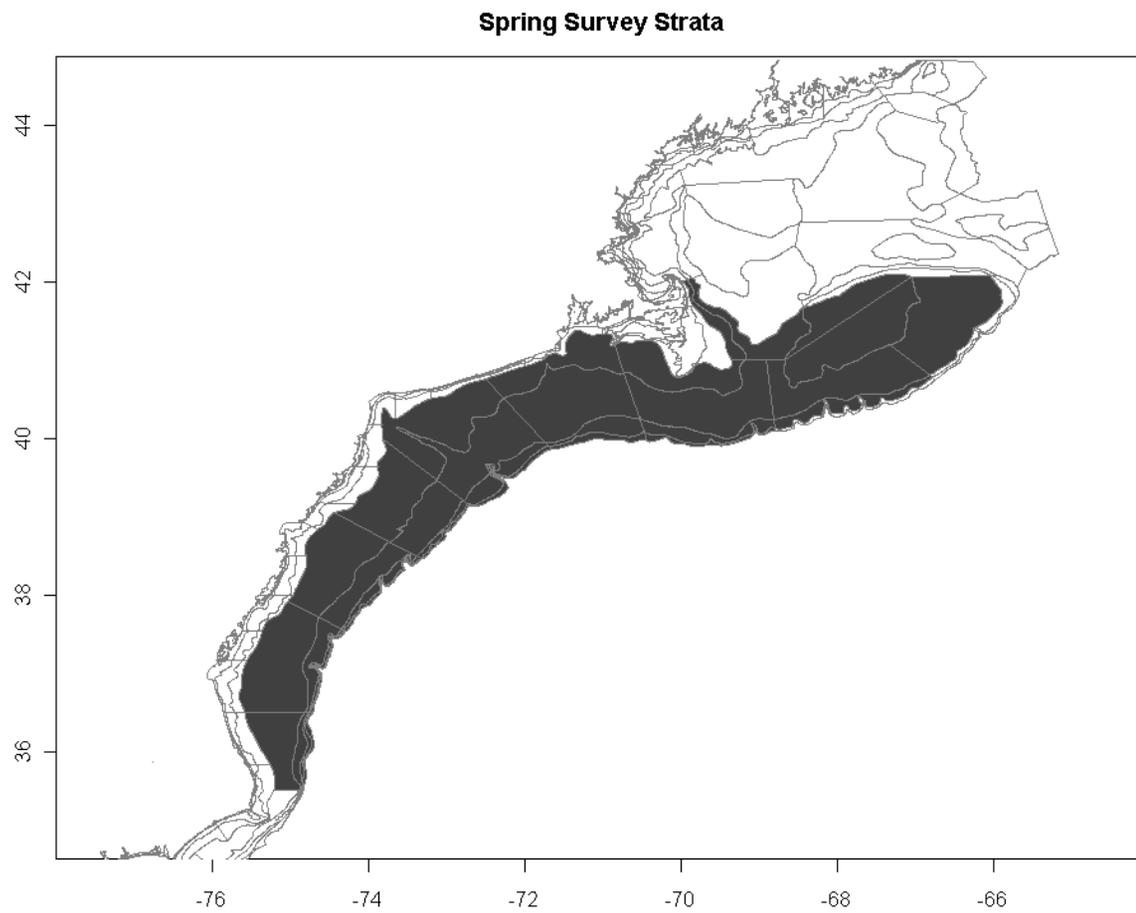


Figure B9. Strata used for NEFSC spring survey biomass indices.

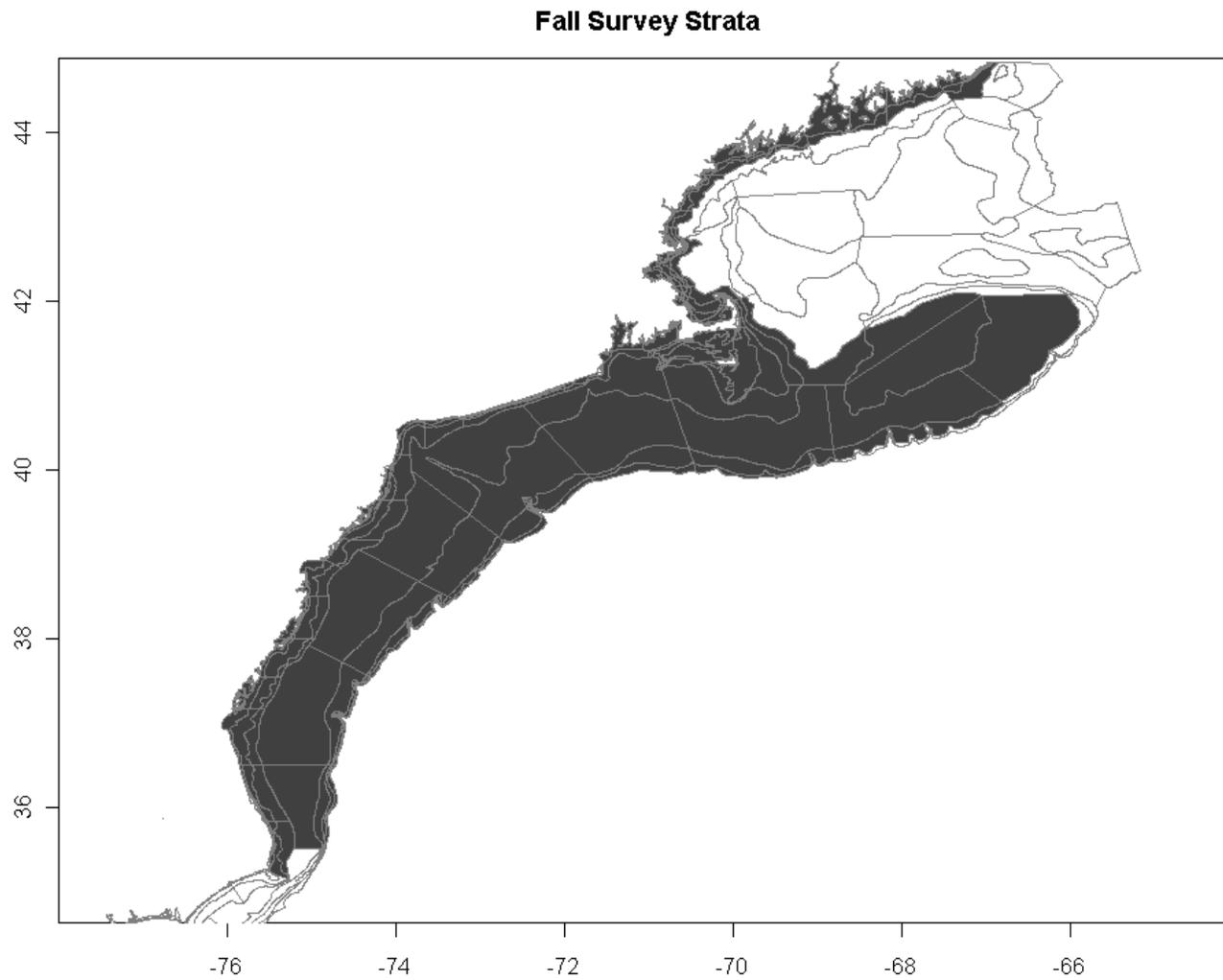


Figure B10. Strata used for NEFSC fall survey biomass indices.

**Winter Survey Strata**

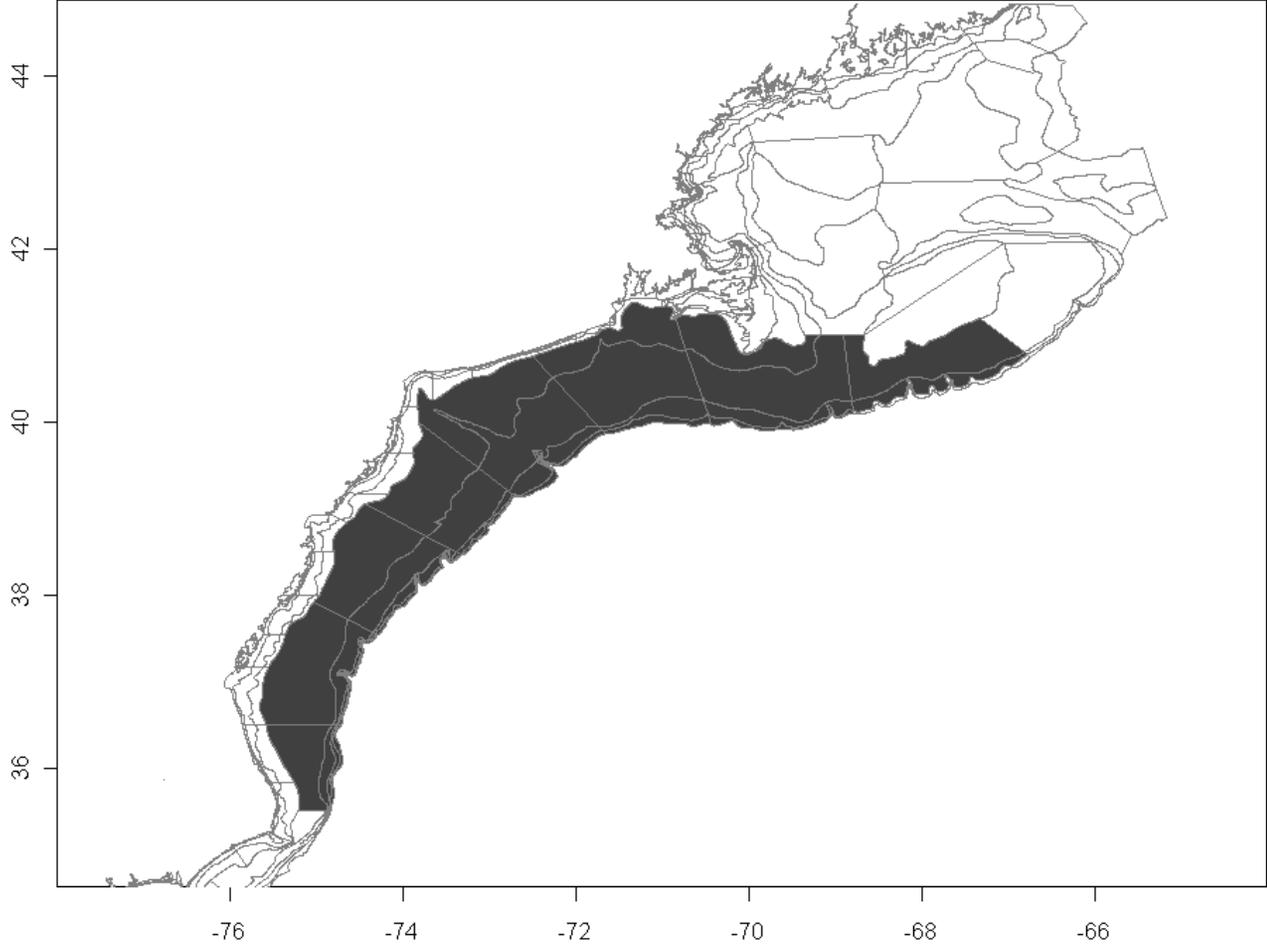


Figure B11. Strata used for NEFSC winter survey biomass indices.

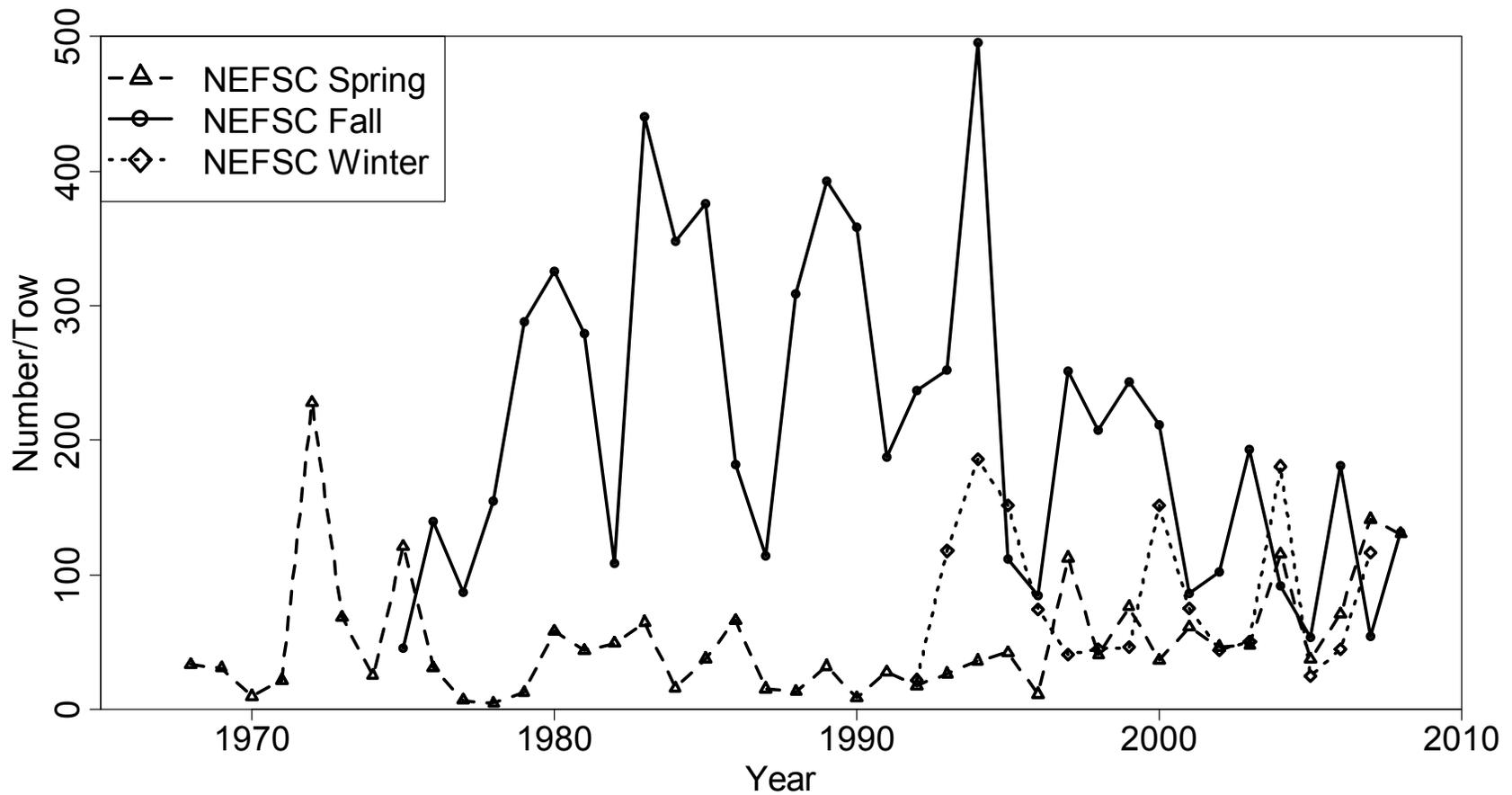


Figure B12. NEFSC spring (triangle), and autumn (circle) and winter (diamond) survey stratified mean number per tow for butterfish. Spring estimates include data from offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76), fall estimates include data from inshore (1-92) and offshore (1-14, 16, 19, 20, 23, 25, and 61-76) strata, and winter estimates include data from offshore strata(1-14 and 61-76).

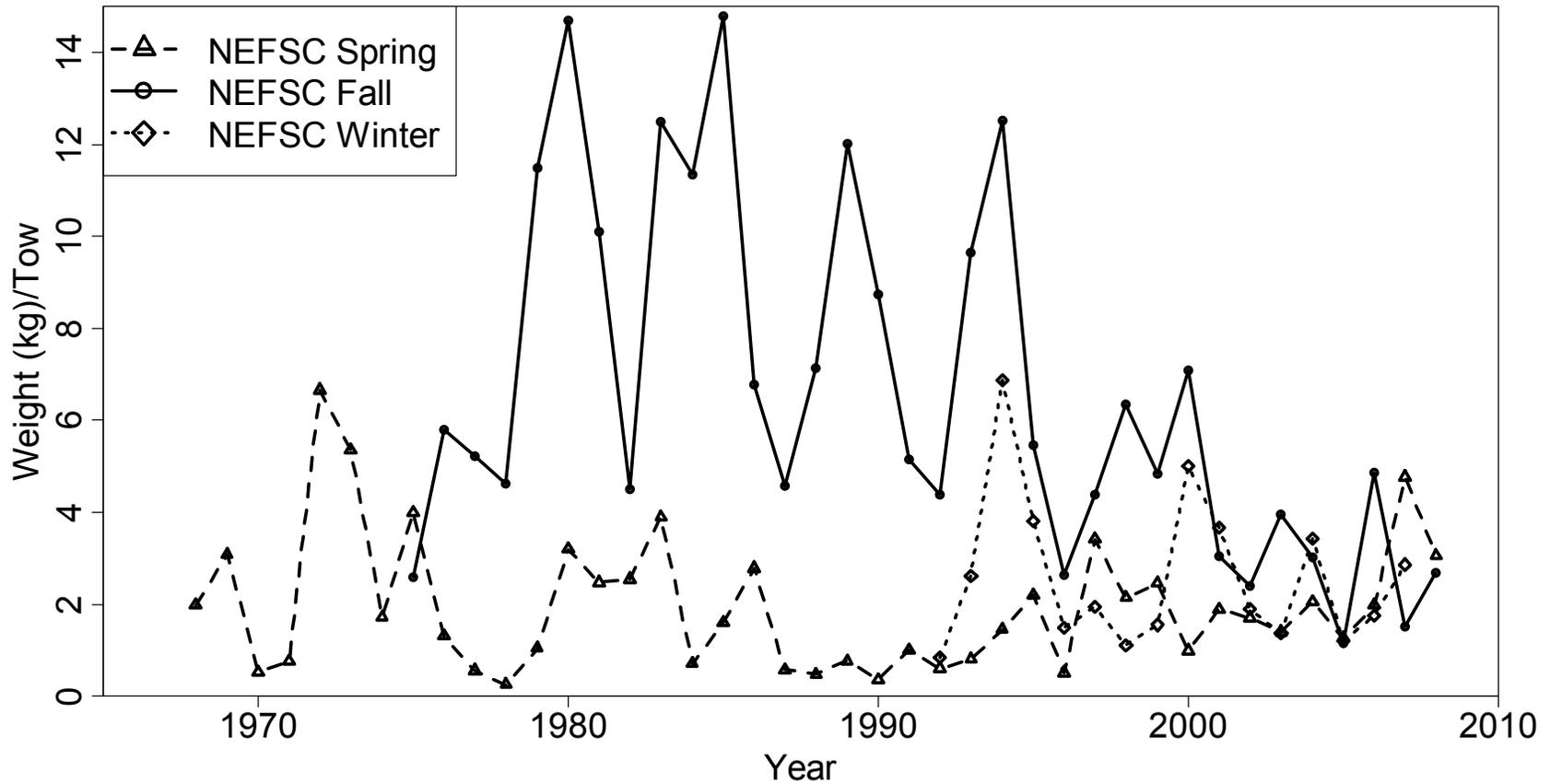


Figure B13. NEFSC spring (triangle), and autumn (circle) and winter (diamond) survey stratified mean weight per tow for butterfish. Spring estimates include data from offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76), fall estimates include data from inshore (1-92) and offshore (1-14, 16, 19, 20, 23, 25, and 61-76) strata, and winter estimates include data from offshore strata(1-14 and 61-76).

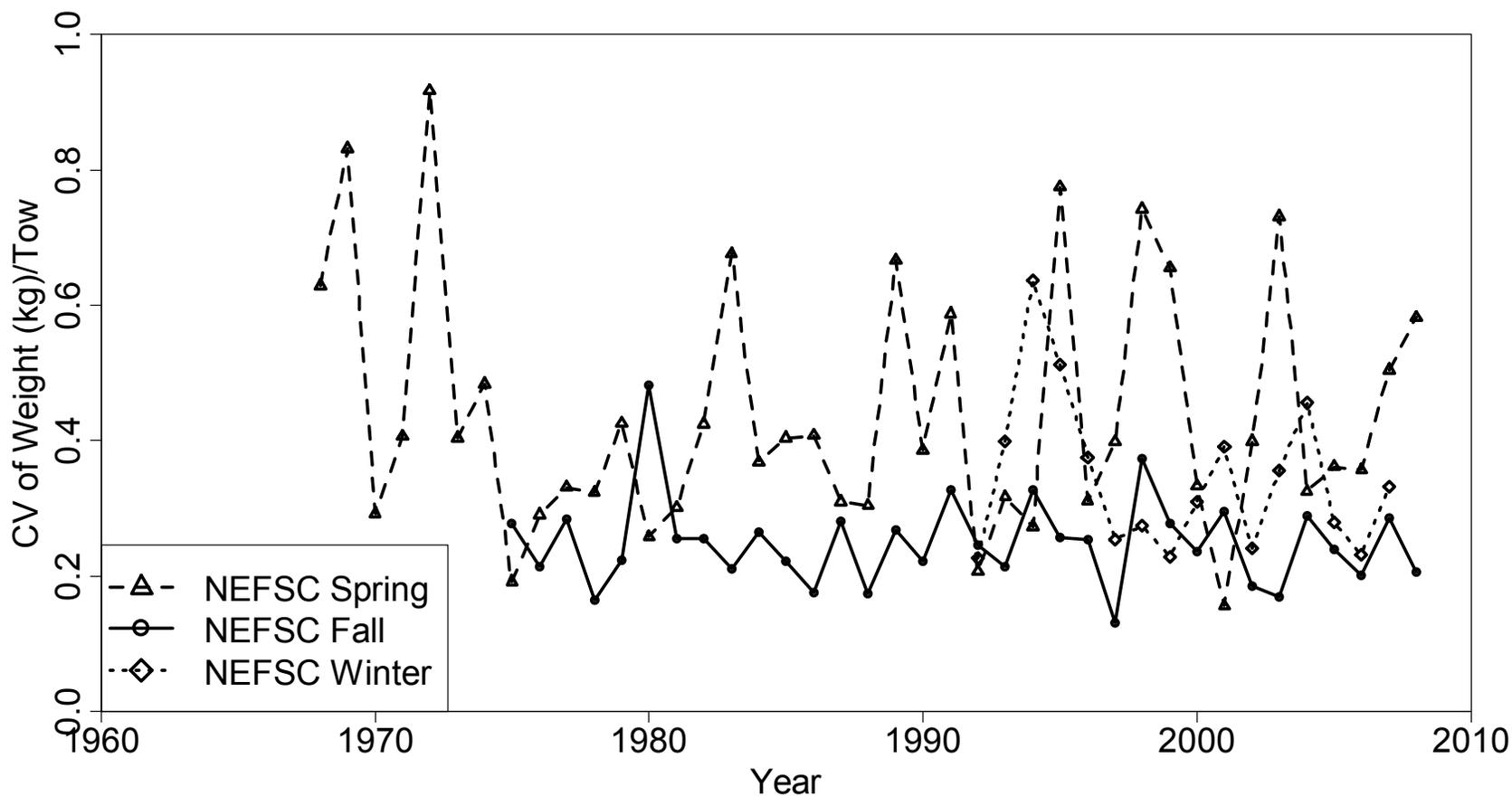


Figure B14. Coefficient of variation (CV) for NEFSC spring (triangle), and autumn (circle) and winter (diamond) survey stratified mean weight per tow for butterfish. Spring estimates include data from offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76), fall estimates include data from inshore (1-92) and offshore (1-14, 16, 19, 20, 23, 25, and 61-76) strata, and winter estimates include data from offshore strata(1-14 and 61-76).

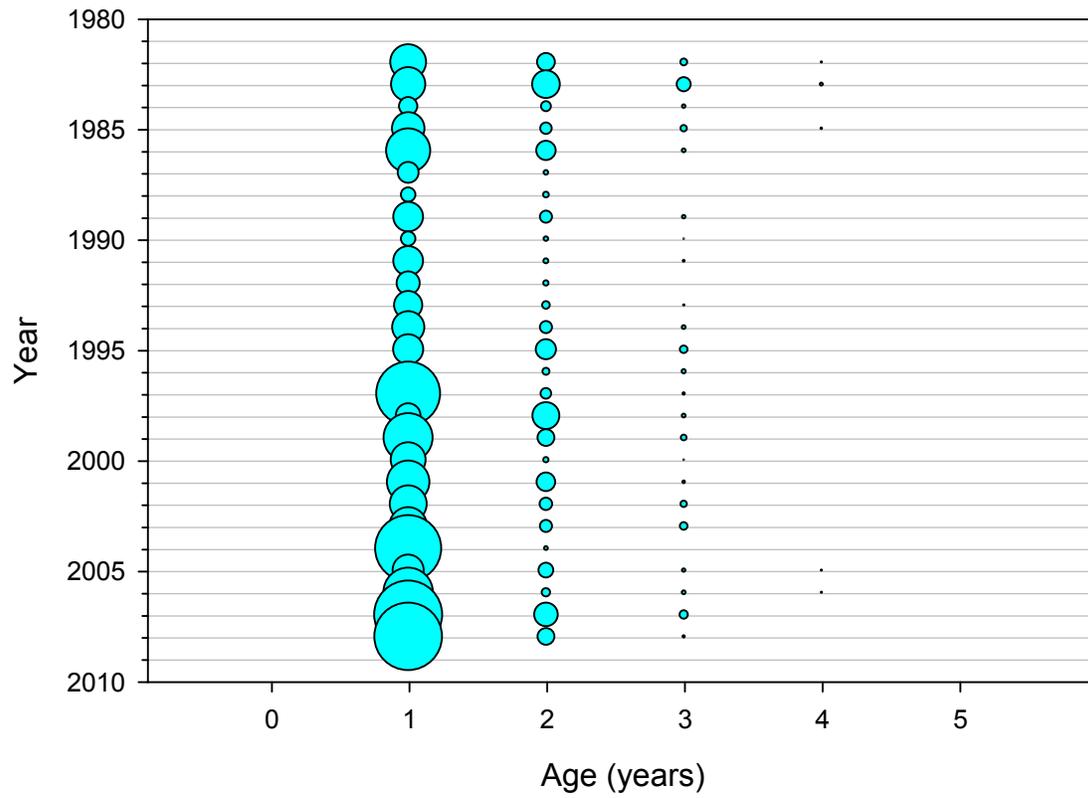


Figure B15. Age composition of butterfish in NEFSC spring bottom trawl surveys, 1982-2008.

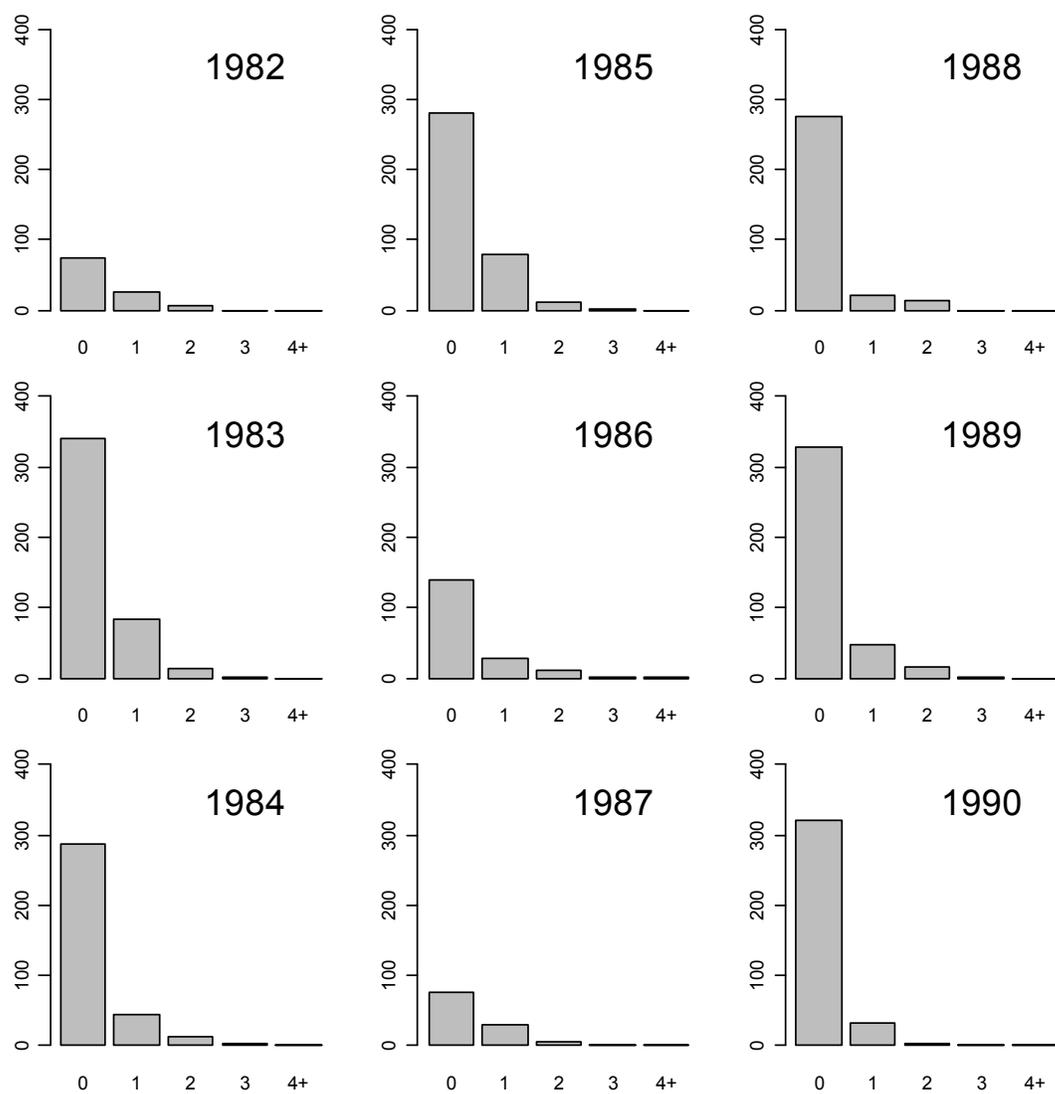


Figure B16. Annual (1982-1990) age composition (numbers/tow) for the NEFSC fall survey combining inshore and offshore strata.

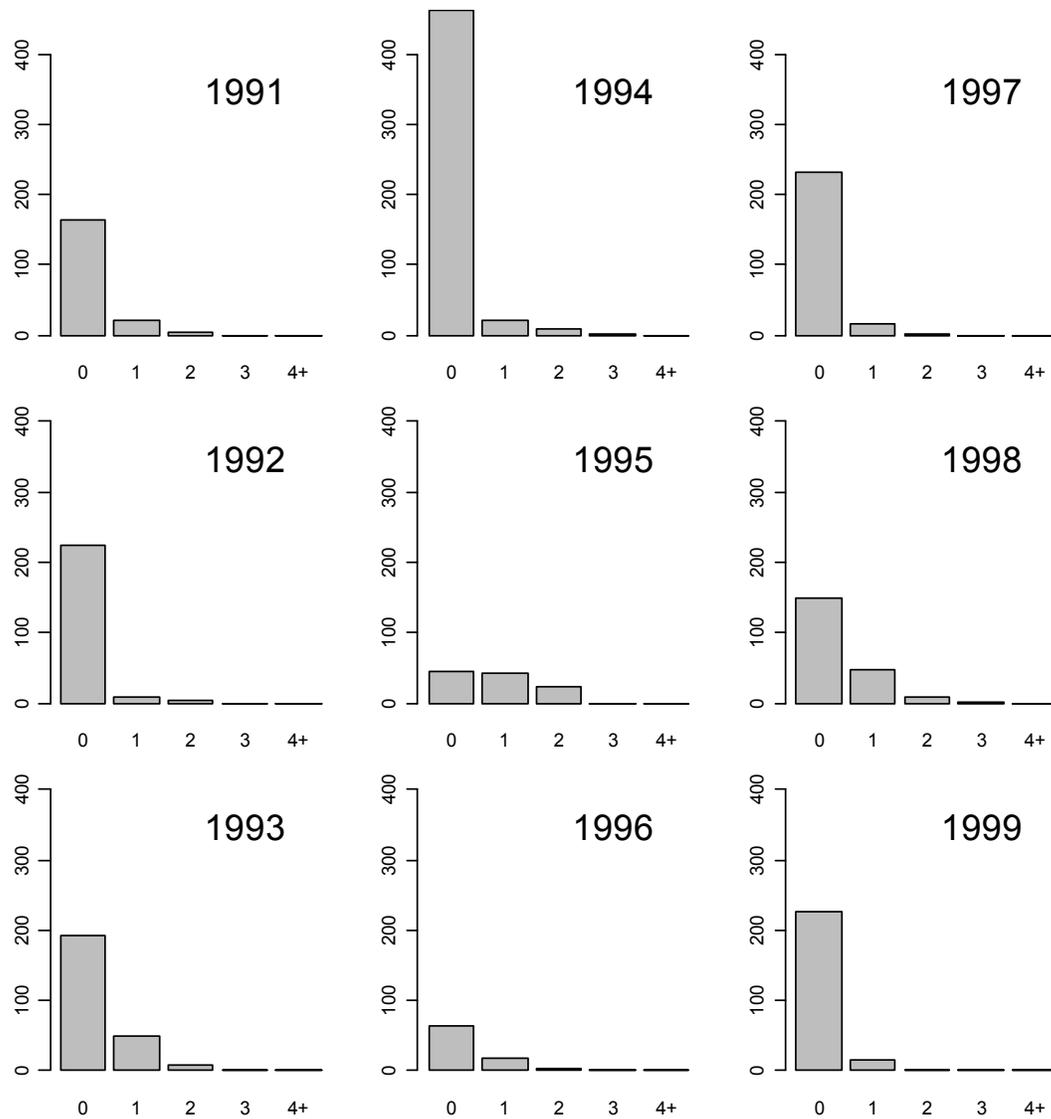


Figure B17. Annual (1991-1999) age composition (numbers/tow) for the NEFSC fall survey combining inshore and offshore strata.

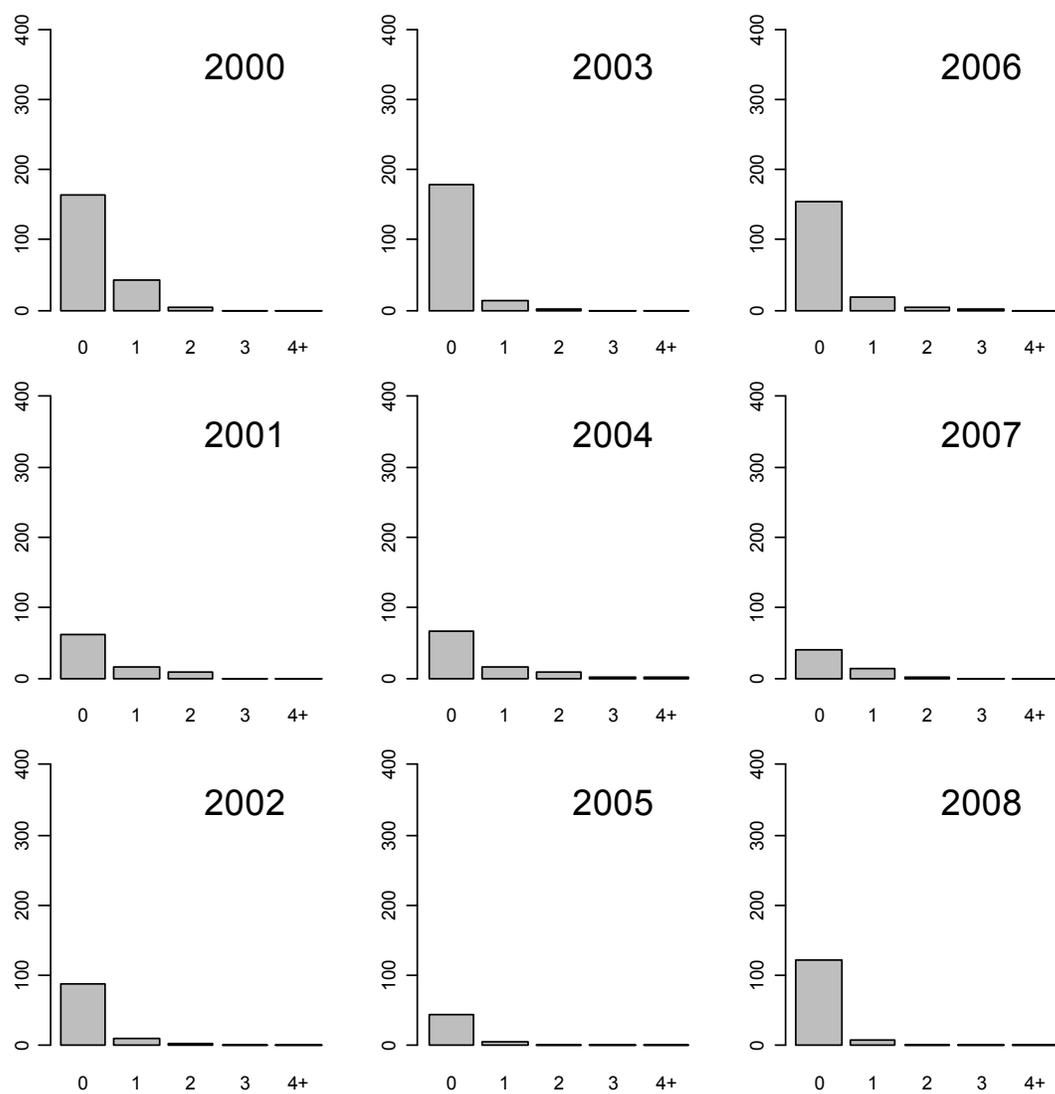


Figure B18. Annual (2000-2008) age composition (numbers/tow) for the NEFSC fall survey combining inshore and offshore strata.

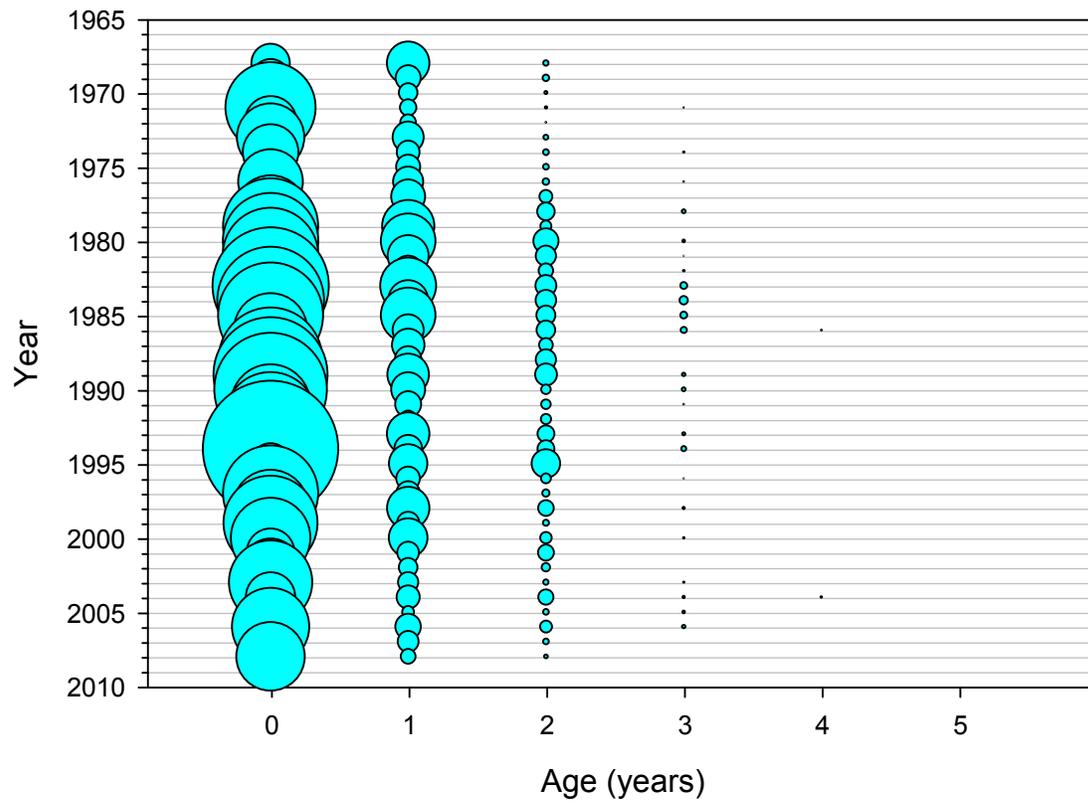


Figure B19. Age composition of butterfish in NEFSC fall bottom trawl surveys, 1968-2008.

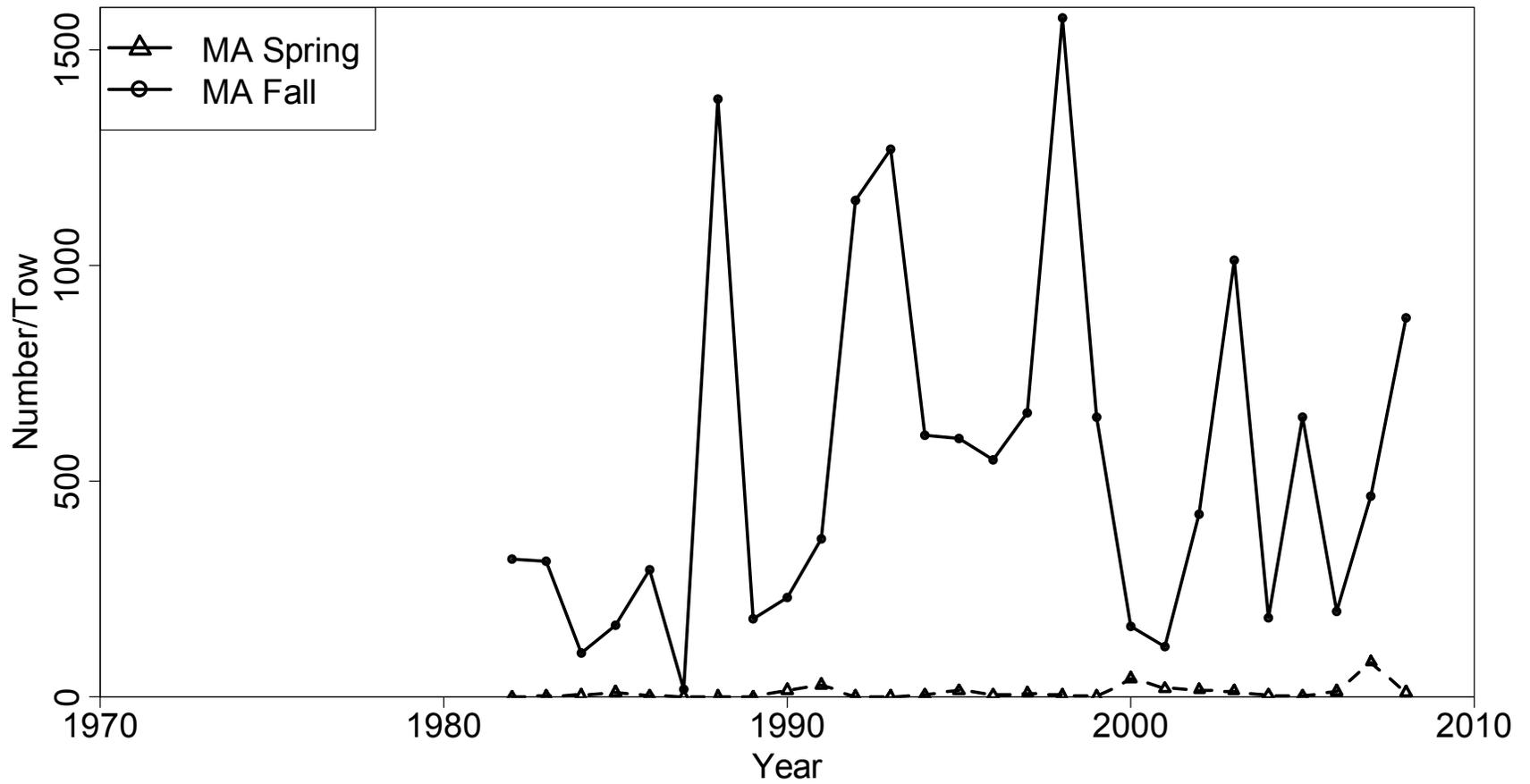


Figure B20. Massachusetts state survey stratified mean number per tow for butterfish in spring (triangle), and fall (circle).

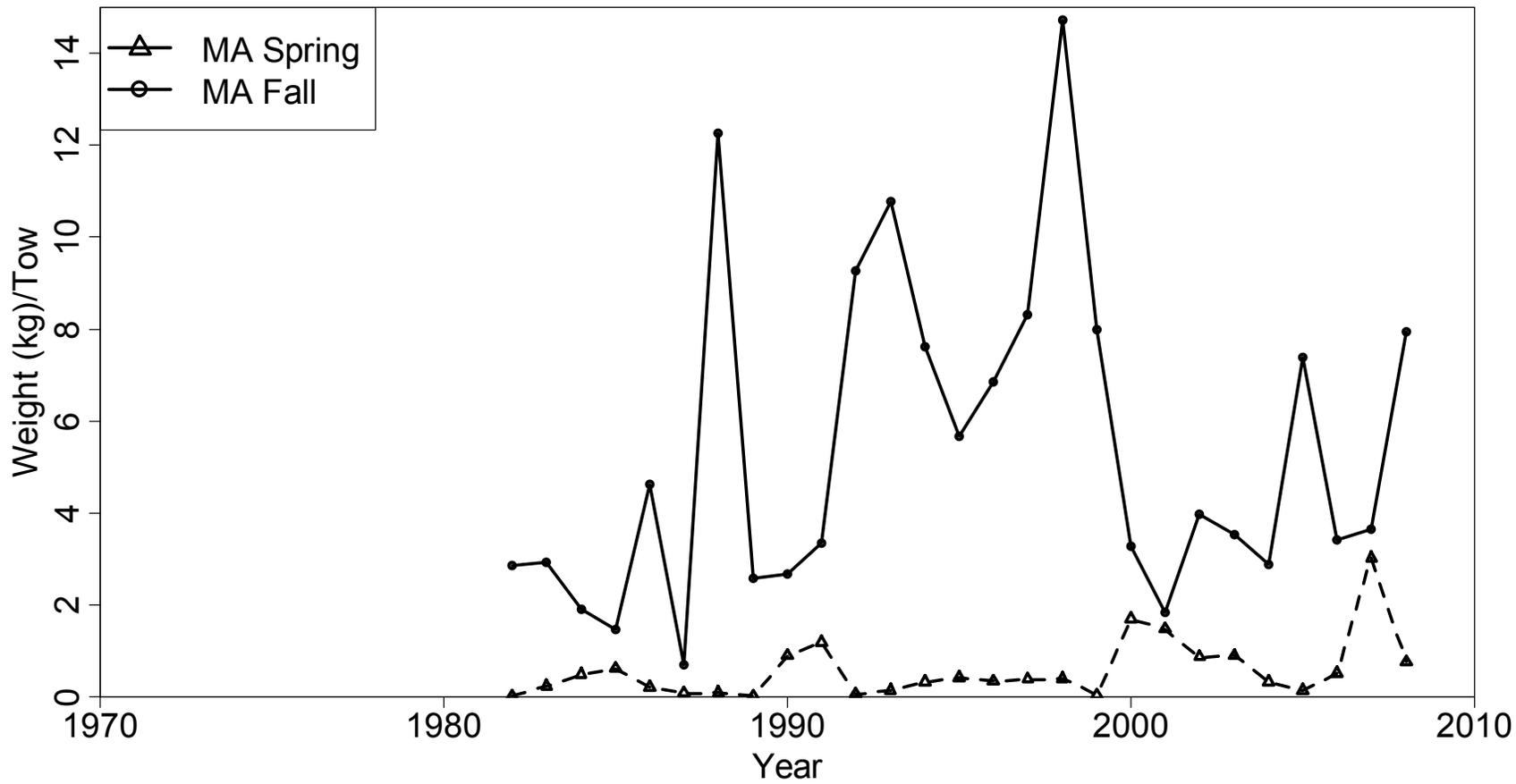


Figure B21. Massachusetts state survey stratified mean weight per tow for butterfish in spring (triangle), and fall (circle).

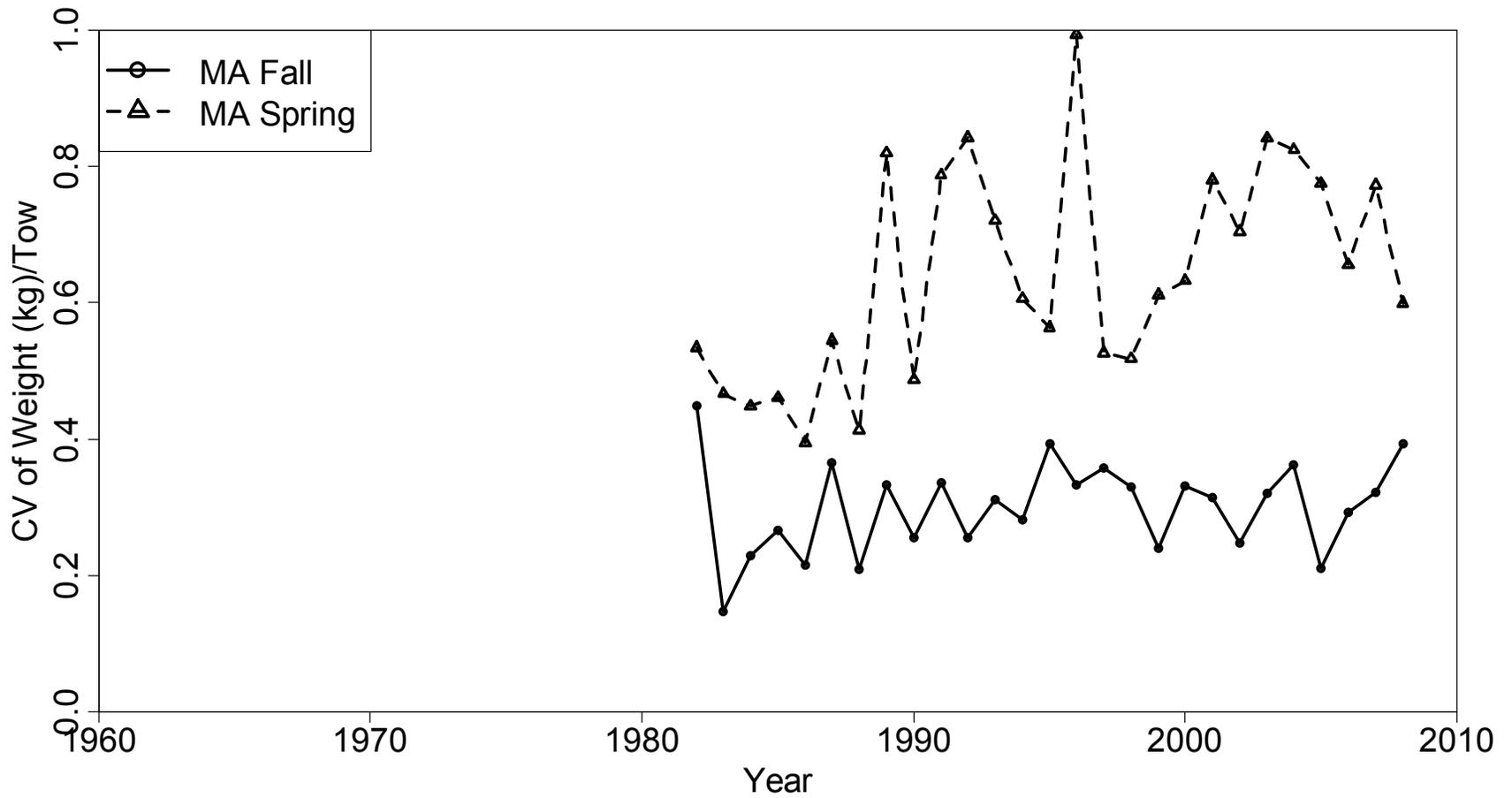


Figure B22. Coefficient of variation (CV) of Massachusetts state survey stratified mean weight per tow for butterfish in spring (triangle), and fall (circle).

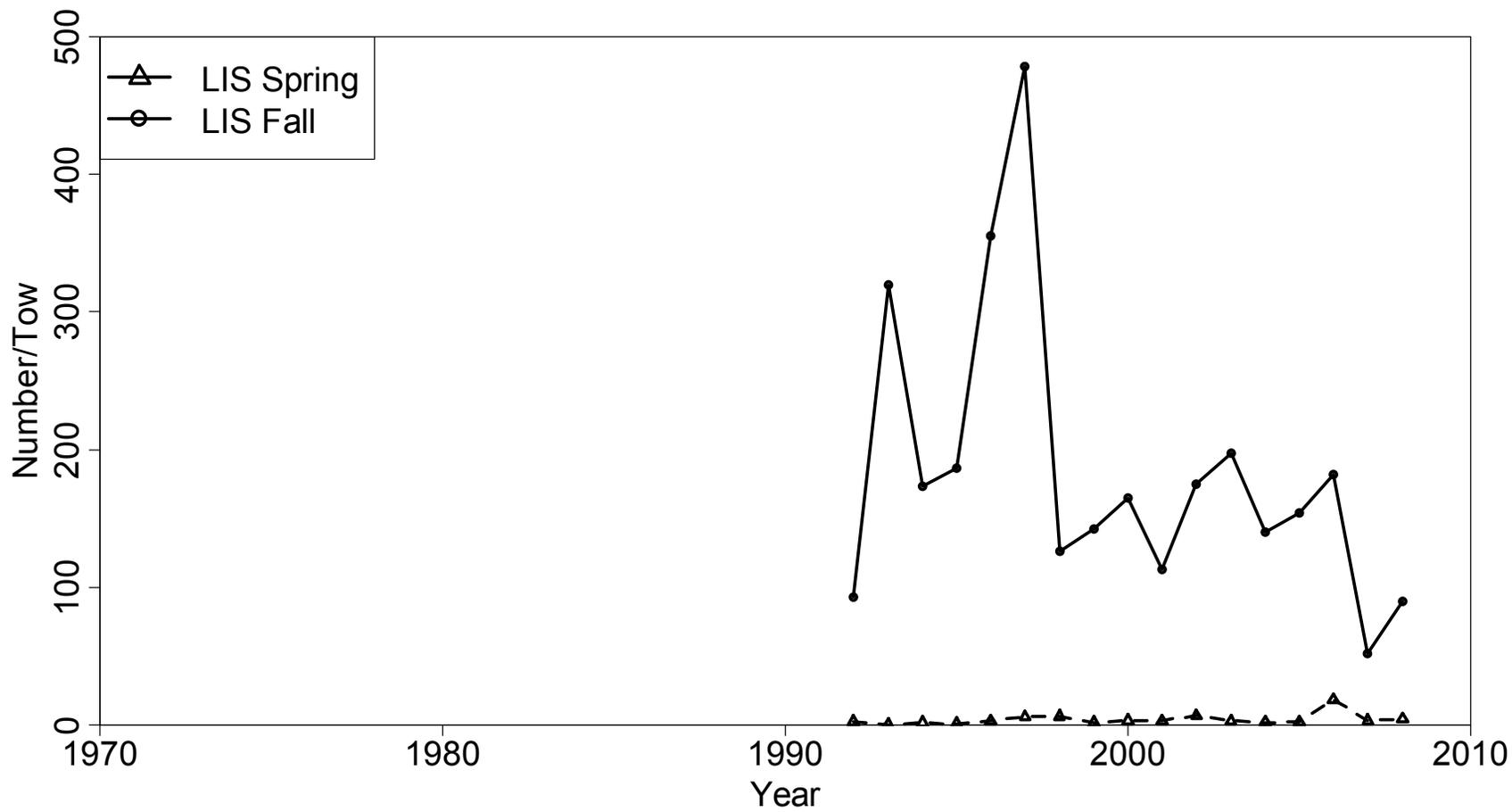


Figure B23. Connecticut state survey (Long Island Sound) number per tow for butterfish in spring (triangle), and autumn (circle).

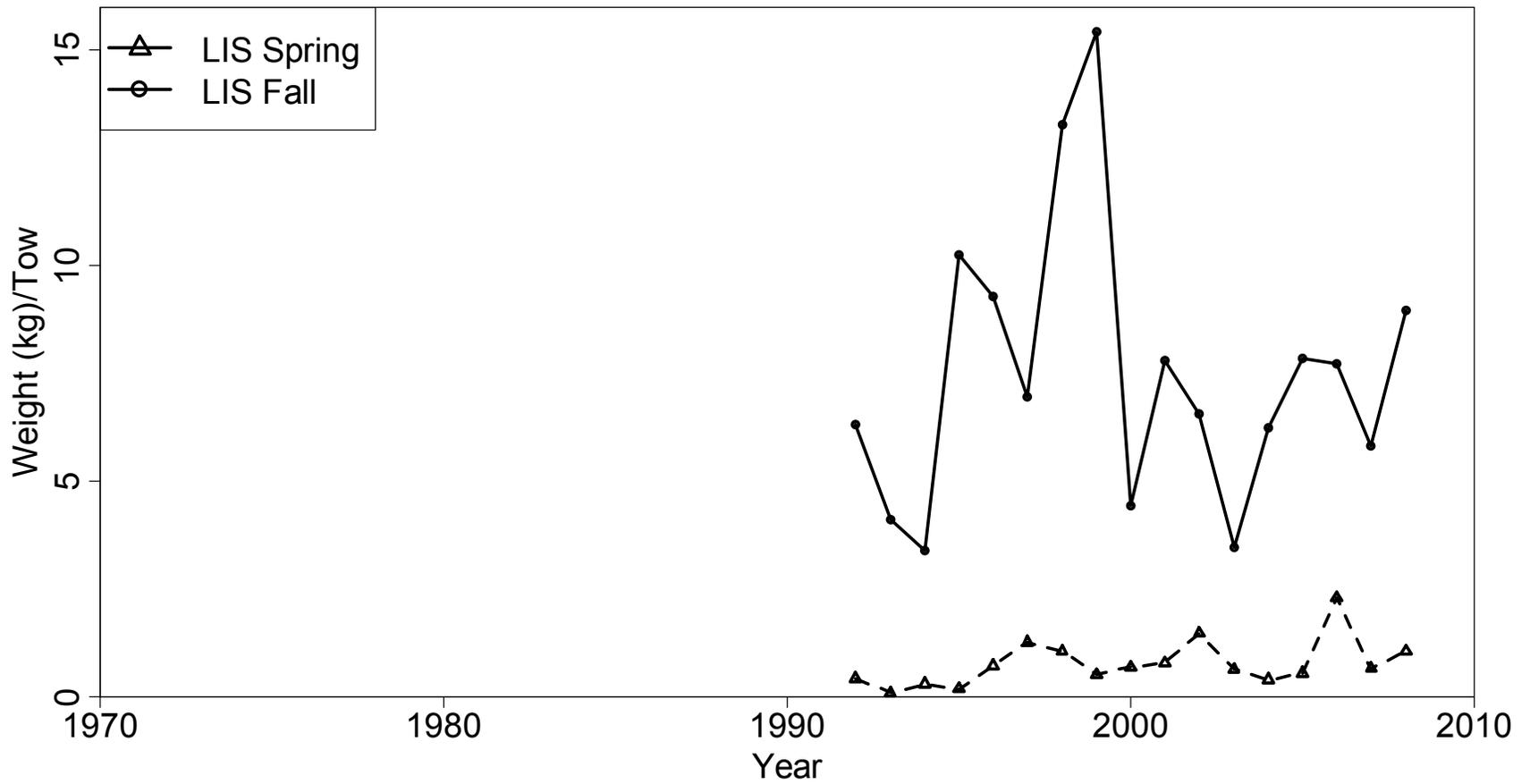


Figure B24. Connecticut state survey (Long Island Sound) weight per tow for butterfish in spring (triangle), and autumn (circle).

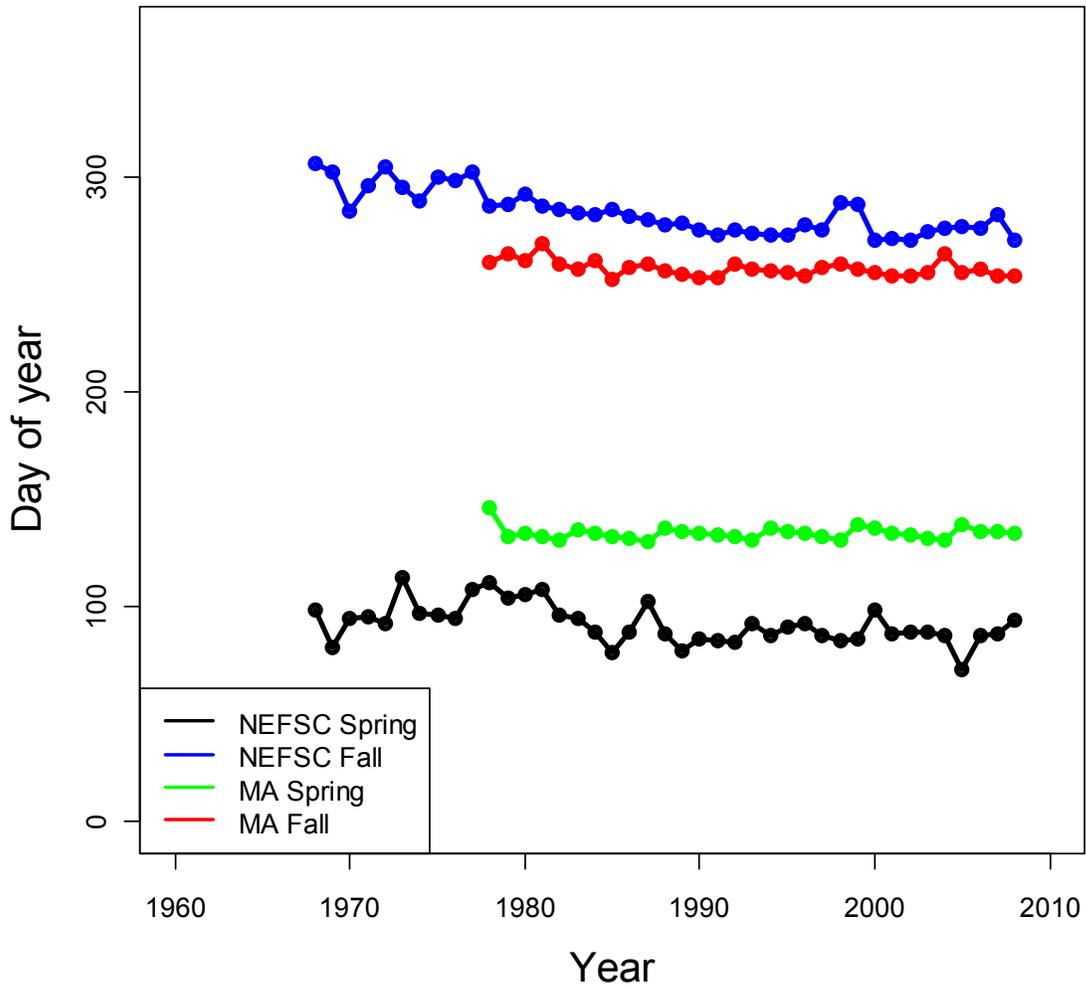


Figure B25. Average Julian day for NEFSC and Massachusetts state annual surveys.

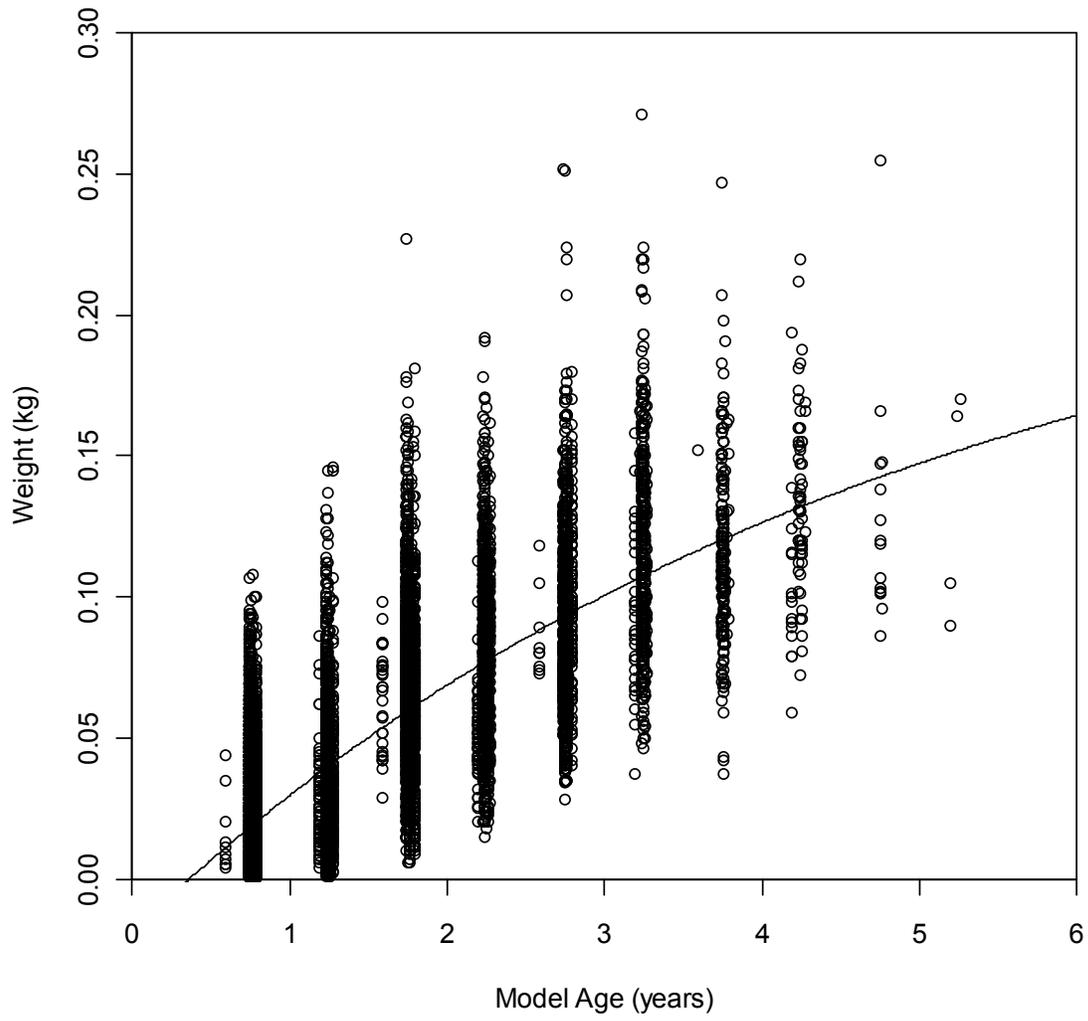


Figure B26. Attributed model age and weight and predicted weight at age from fitted Schnute (1985) growth model fit to NEFSC survey data from 1992-2009.

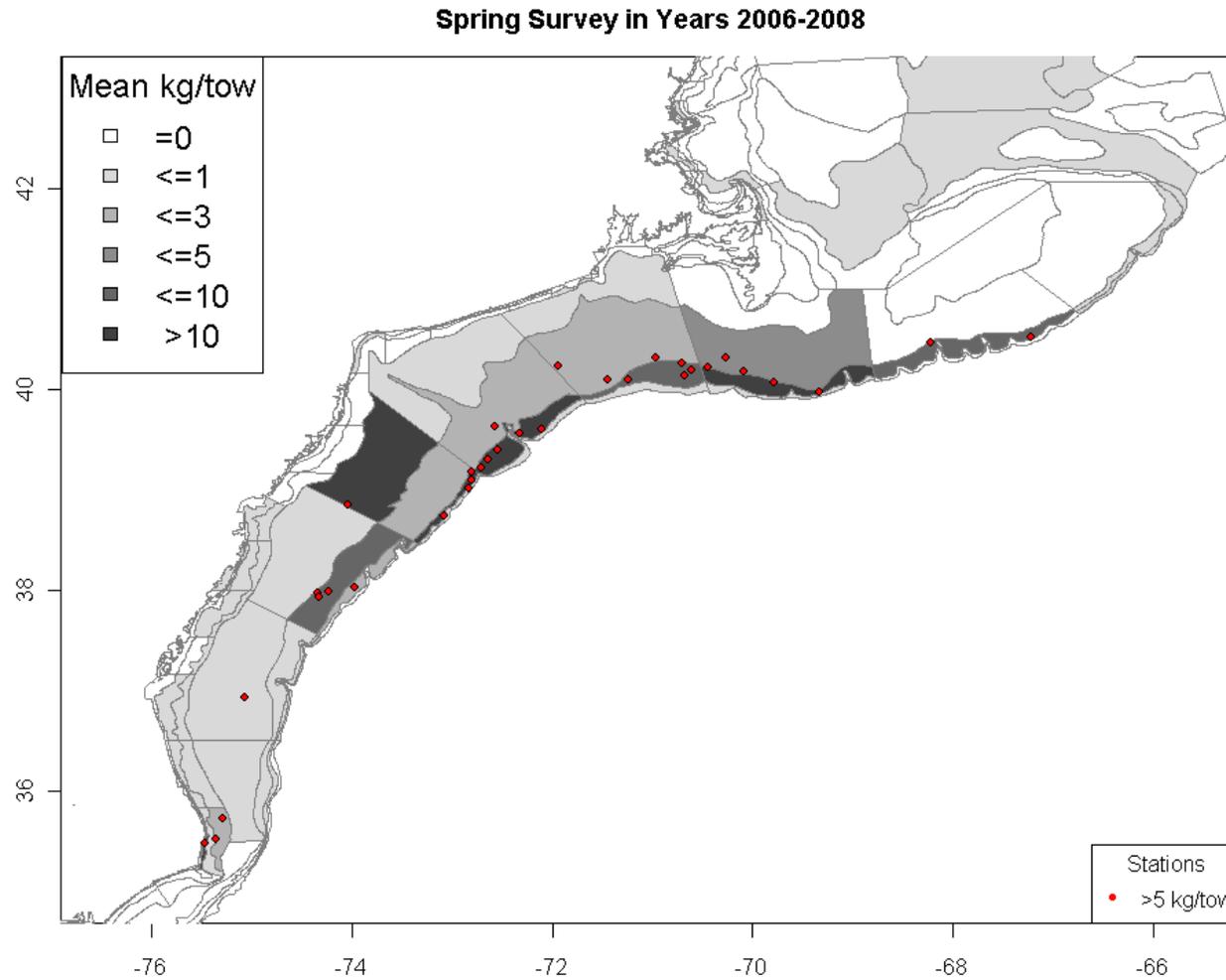


Figure B27. Mean butterfish catch (kg) per tow by stratum in the NEFSC spring survey for all sampled stations between 2006 and 2008 and location of stations where greater than 5 kg were observed.

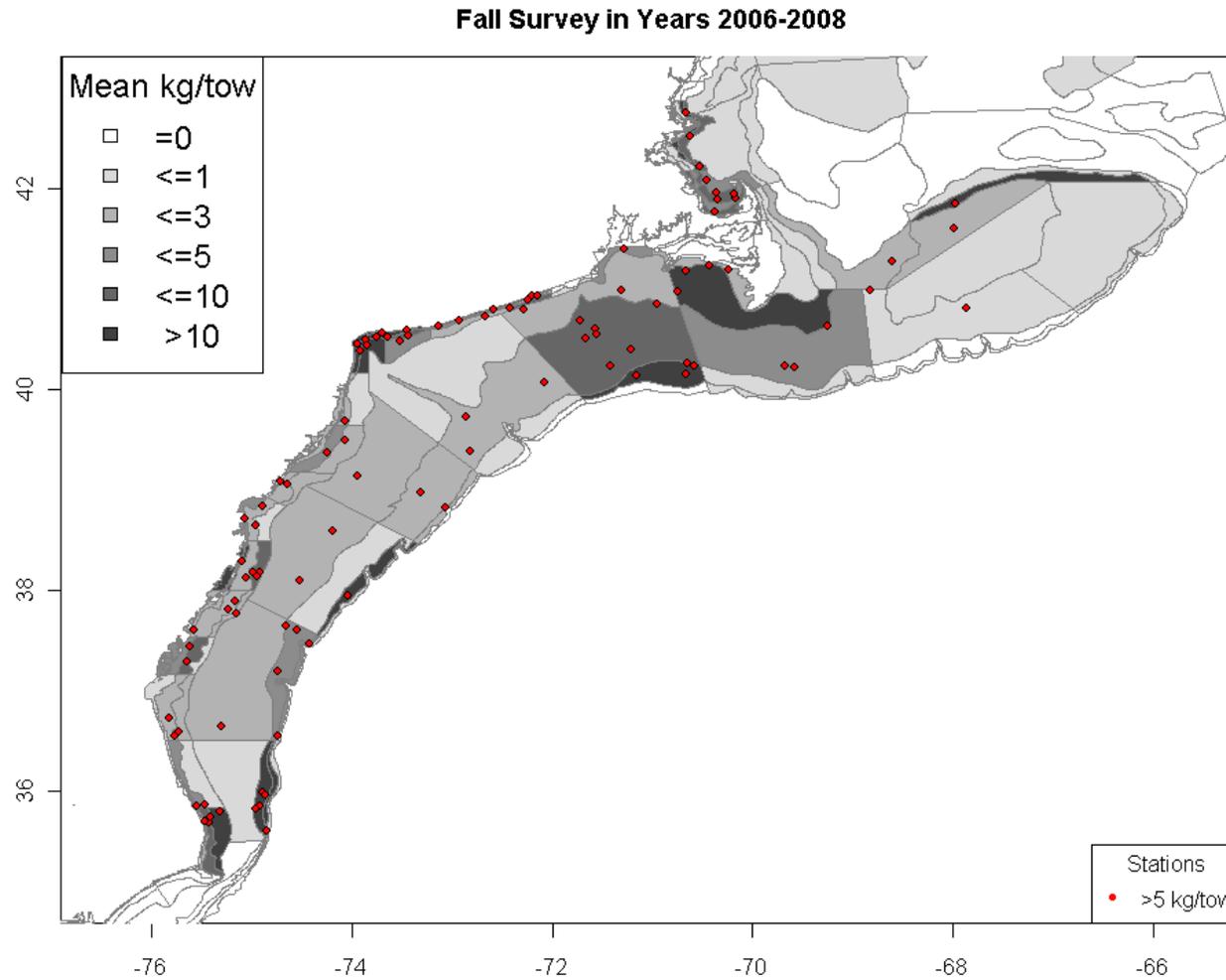


Figure B28. Mean butterfish catch (kg) per tow by stratum in the NEFSC fall survey for all sampled stations between 2006 and 2008 and location of stations where greater than 5 kg were observed.

Butterfish Catch by Otter Trawls in 2007

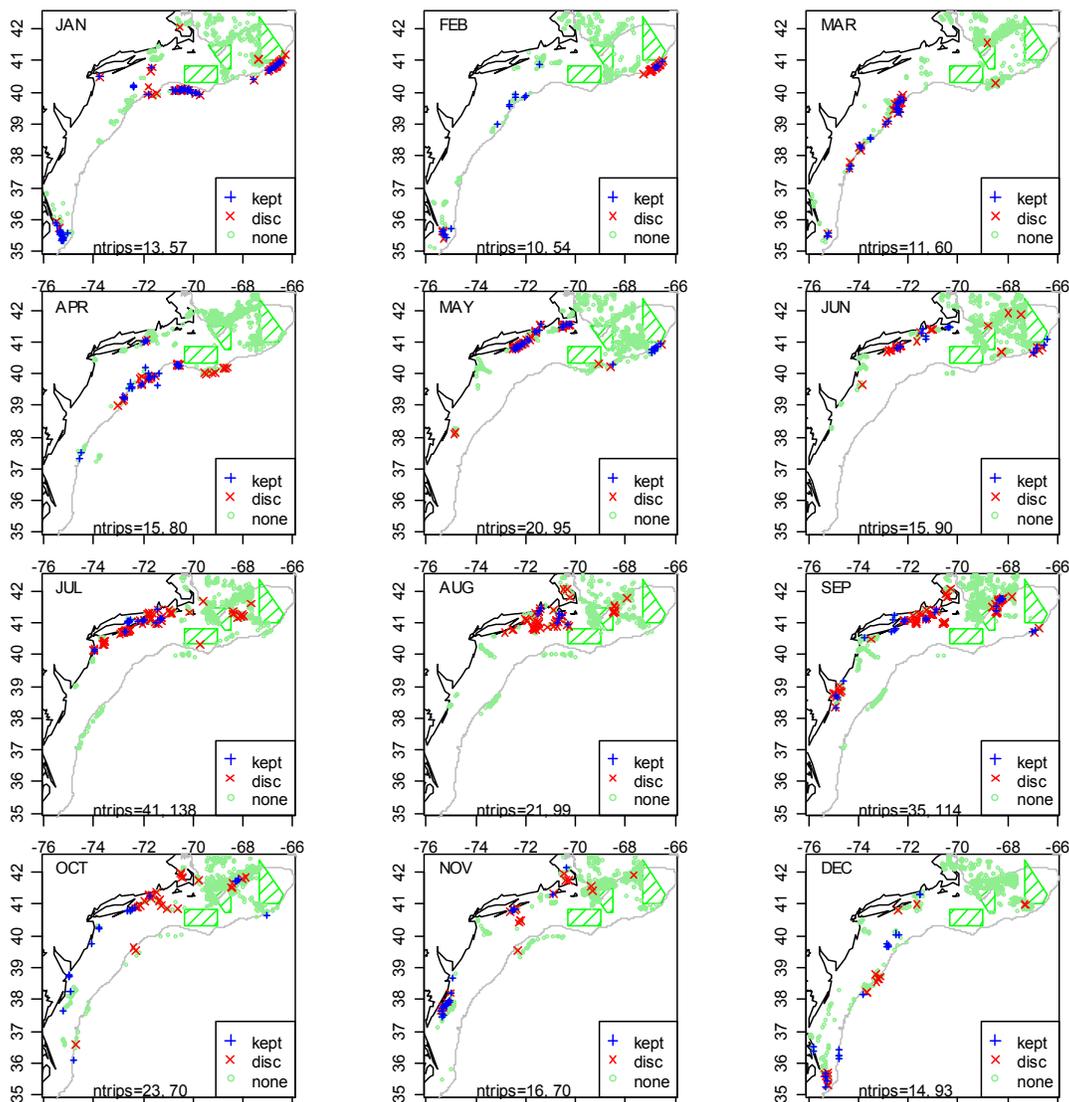


Figure B29. Observed commercial bottom trawl tows in 2007 where butterfish were absent (green circle), present and kept (blue +), and present and discarded (red x).

Butterfish Catch by Otter Trawls in 2008

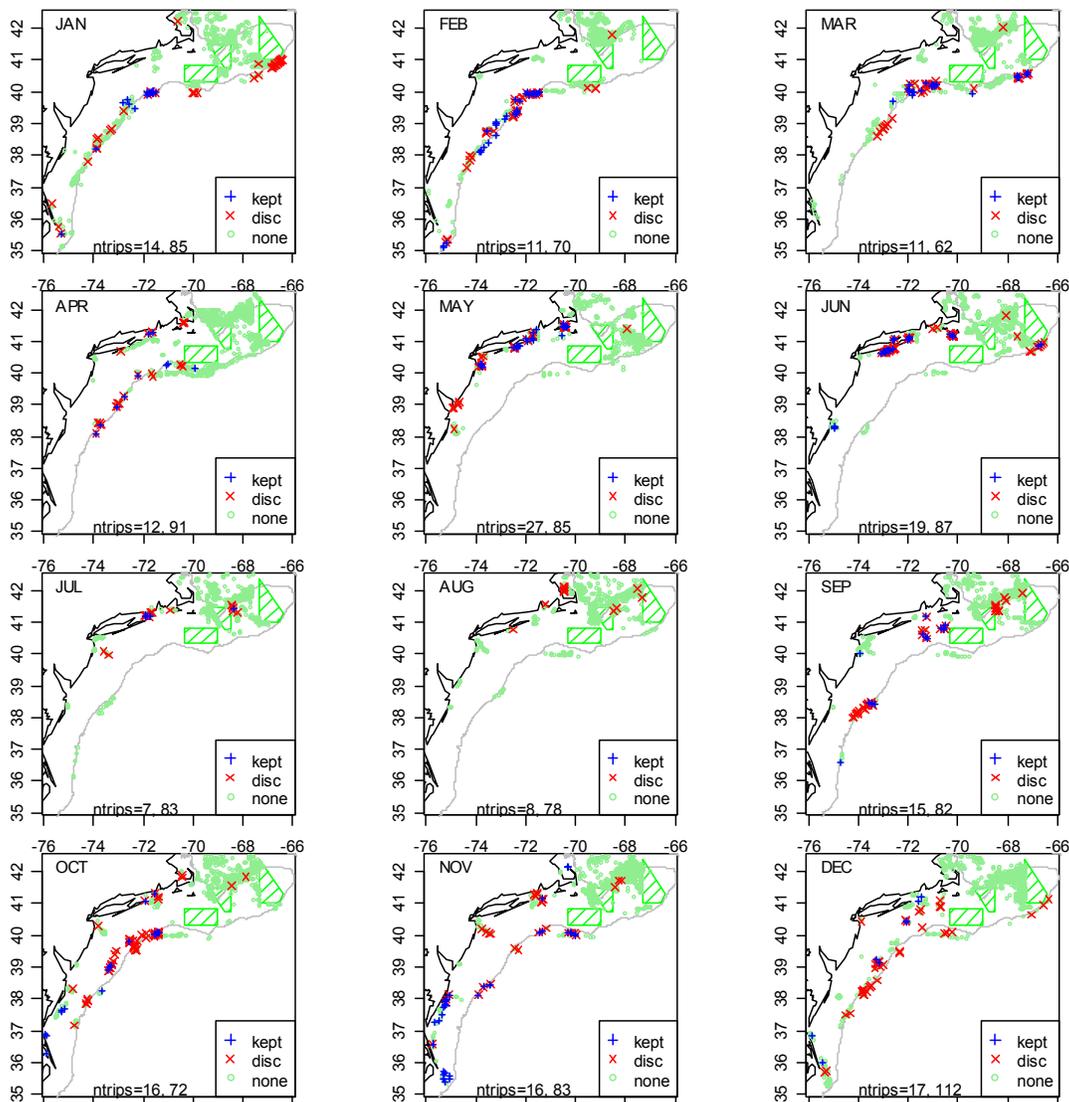


Figure B30. Observed commercial bottom trawl tows in 2008 where butterfish were absent (green circle), present and kept (blue +), and present and discarded (red x).

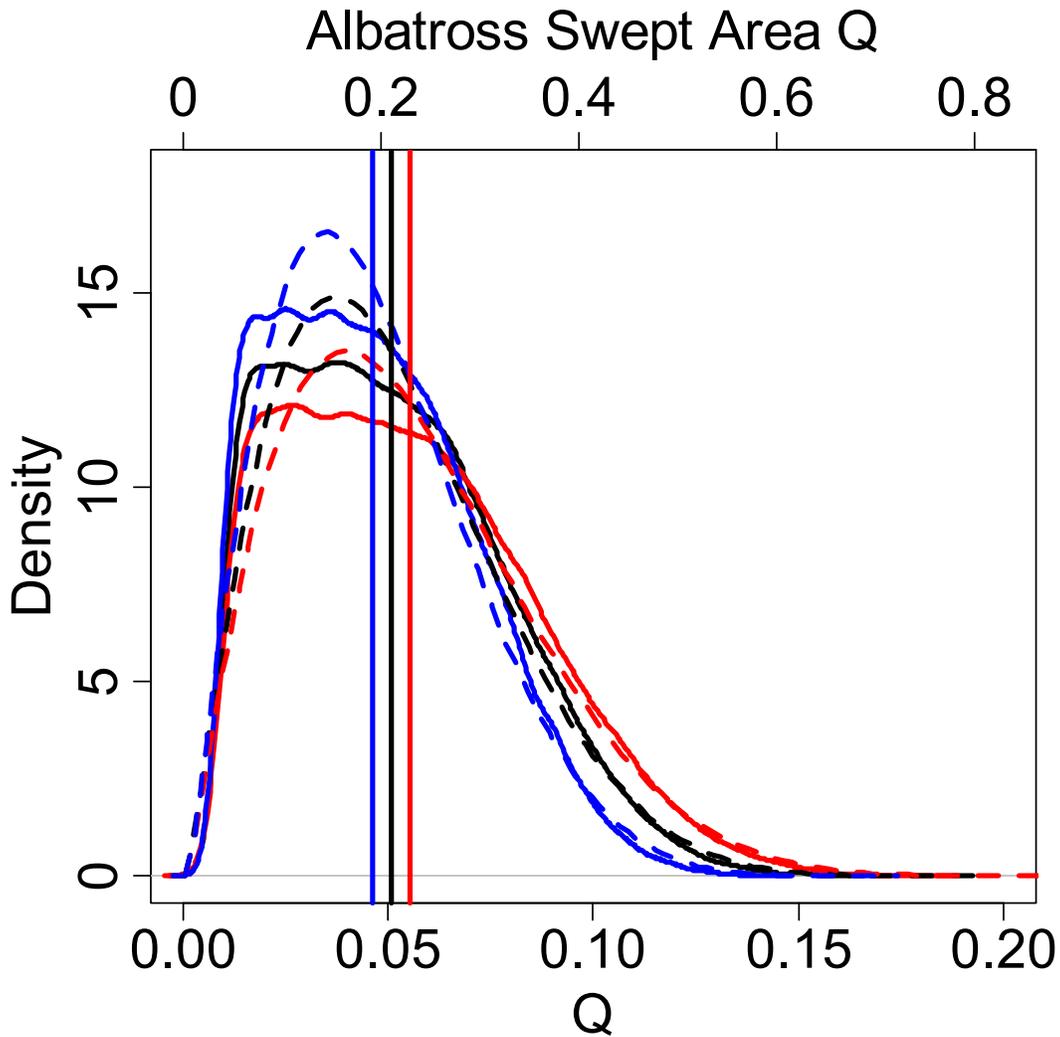


Figure B31. Empirical distribution (solid black) of the catchability parameter (swept area catchability on the top axis) for the NEFSC fall adult index as a product of known scalars and of random variables for unknown components and beta distribution (dashed black) with the same mean and variance used as a prior in the final model. Blue and red represent corresponding distributions when maxima for the ratio of survey and stock area and the efficiency of the Bigelow are 0.85 and 0.95. Vertical solid lines are the means of the distributions.

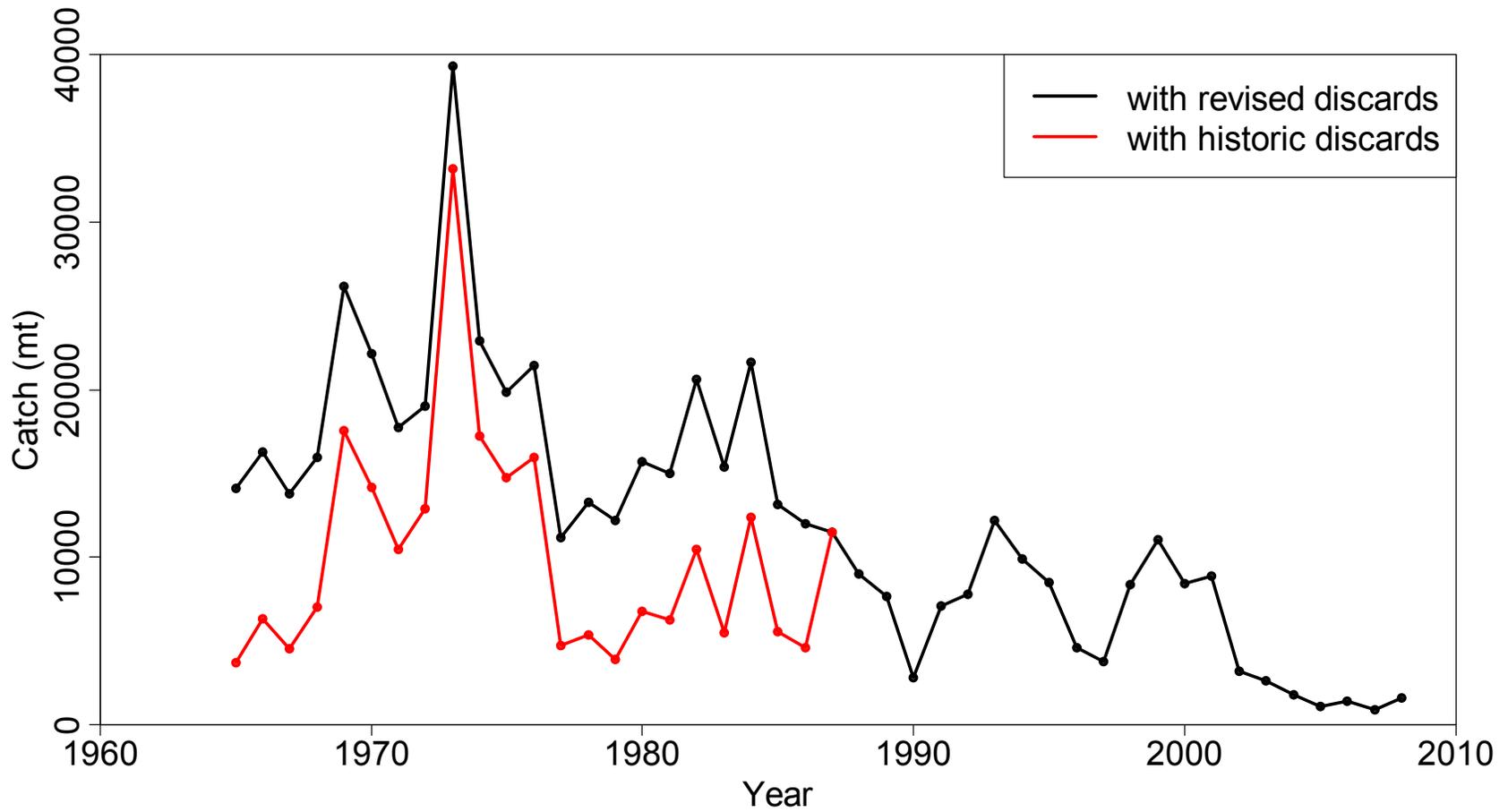


Figure B32. Total Catch including US landings, foreign catch and US new discard estimates (black) or US discards as reported by Waring and Anderson (1983) and NEFSC (1990) (red).

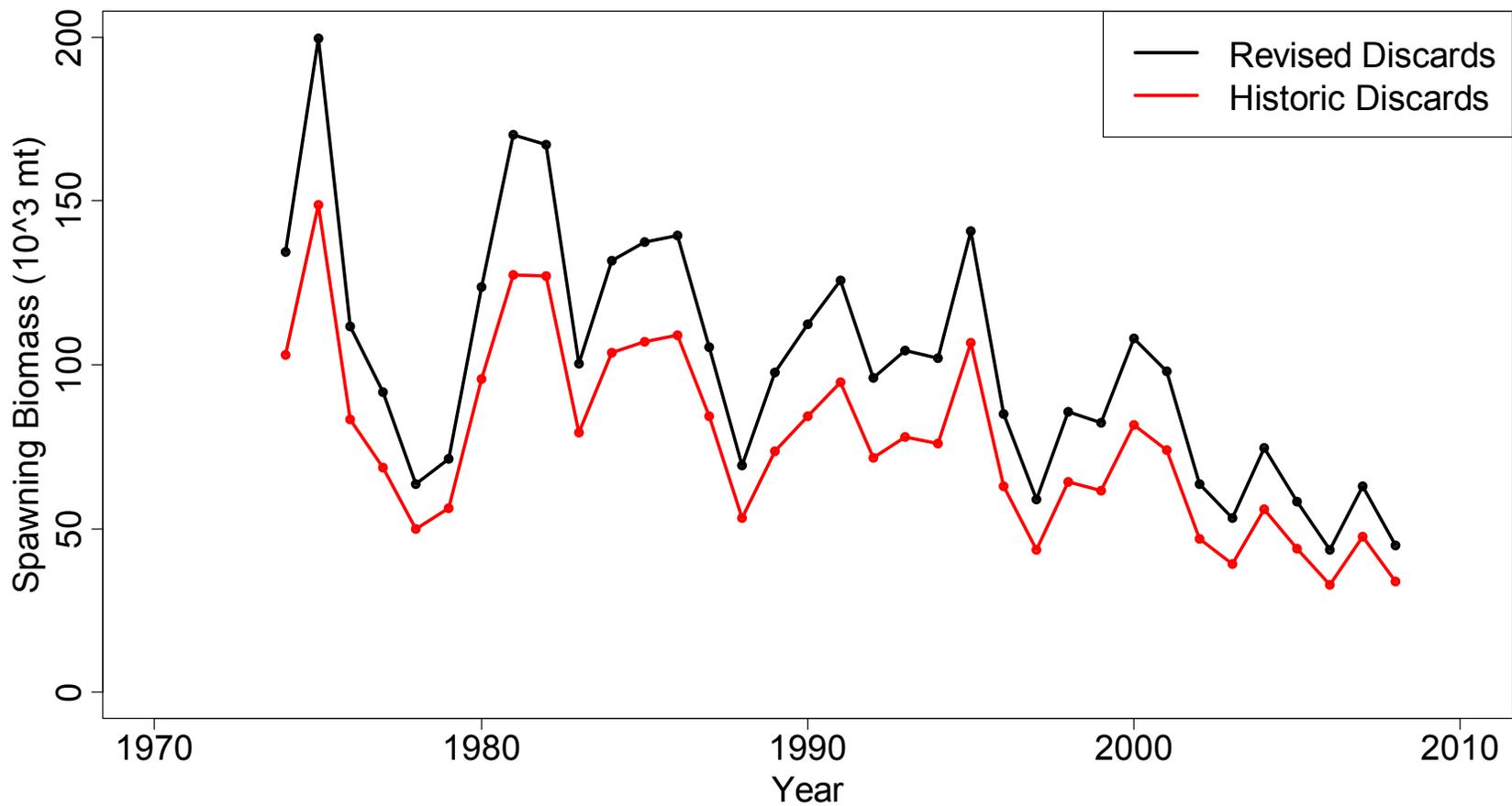


Figure B33. Estimates of spawning biomass from the final model when revised discard estimates between 1973 and 1986 are used in the total catch (black) (final model) or the discard estimates provided in early assessment documents are used in the total catch (red).

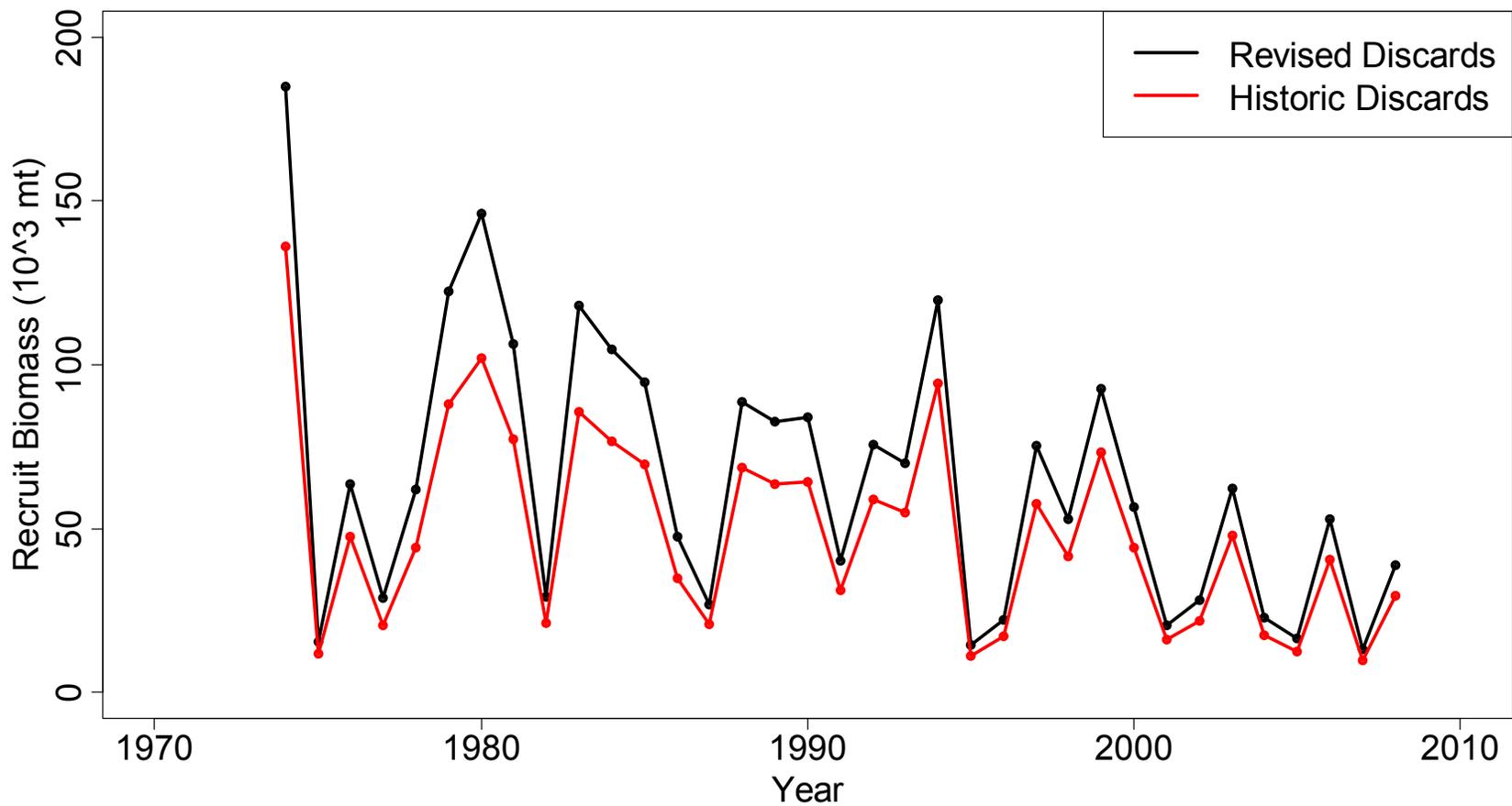


Figure B34. Estimates of recruit biomass from the final model when revised discard estimates between 1973 and 1986 are used in the total catch (black) (final model) or the discard estimates provided in early assessment documents are used in the total catch (red).

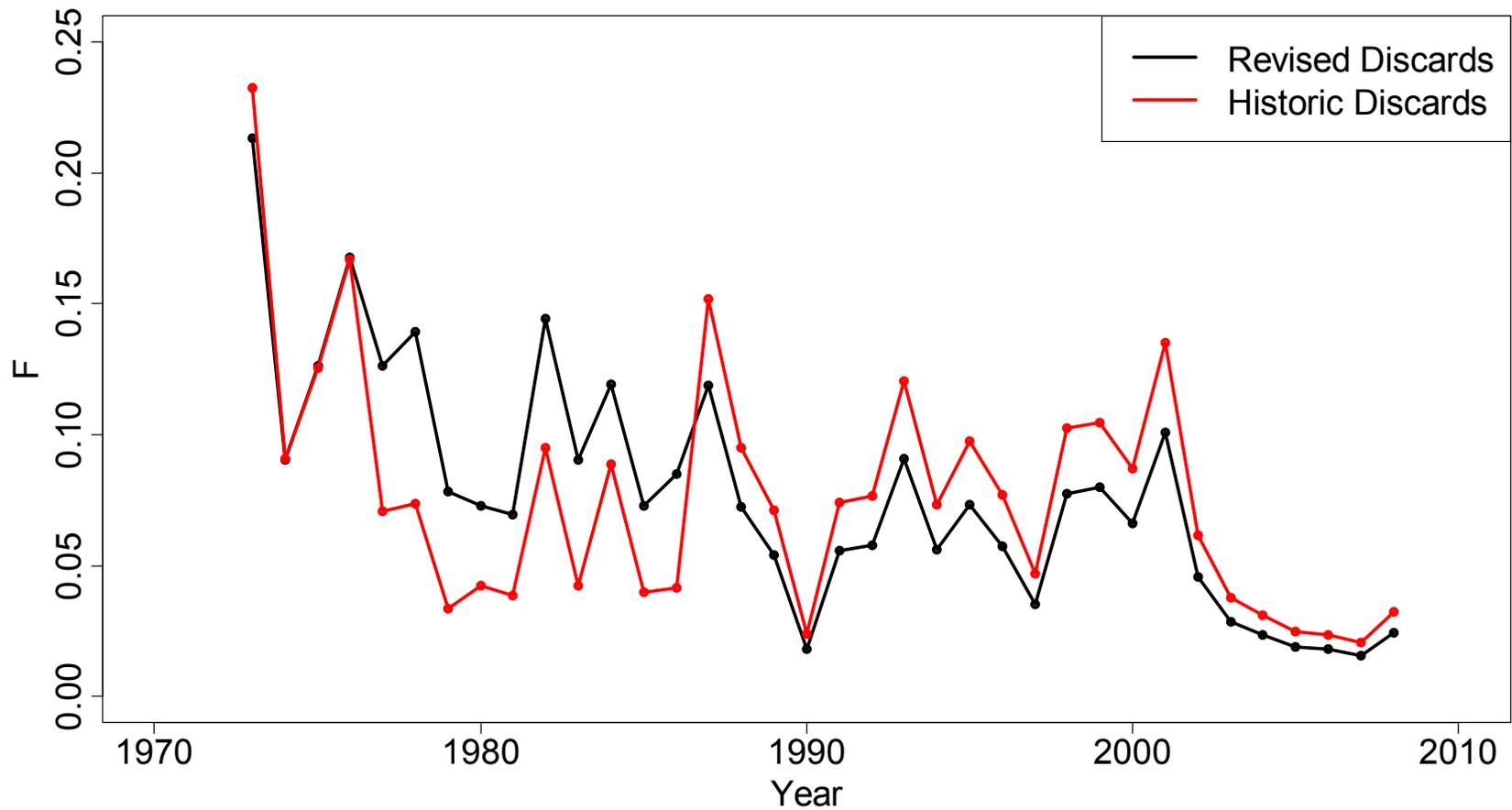


Figure B35. Estimates of fishing mortality from the final model when revised discard estimates between 1973 and 1986 are used in the total catch (black) (final model) or the discard estimates provided in early assessment documents are used in the total catch (red).

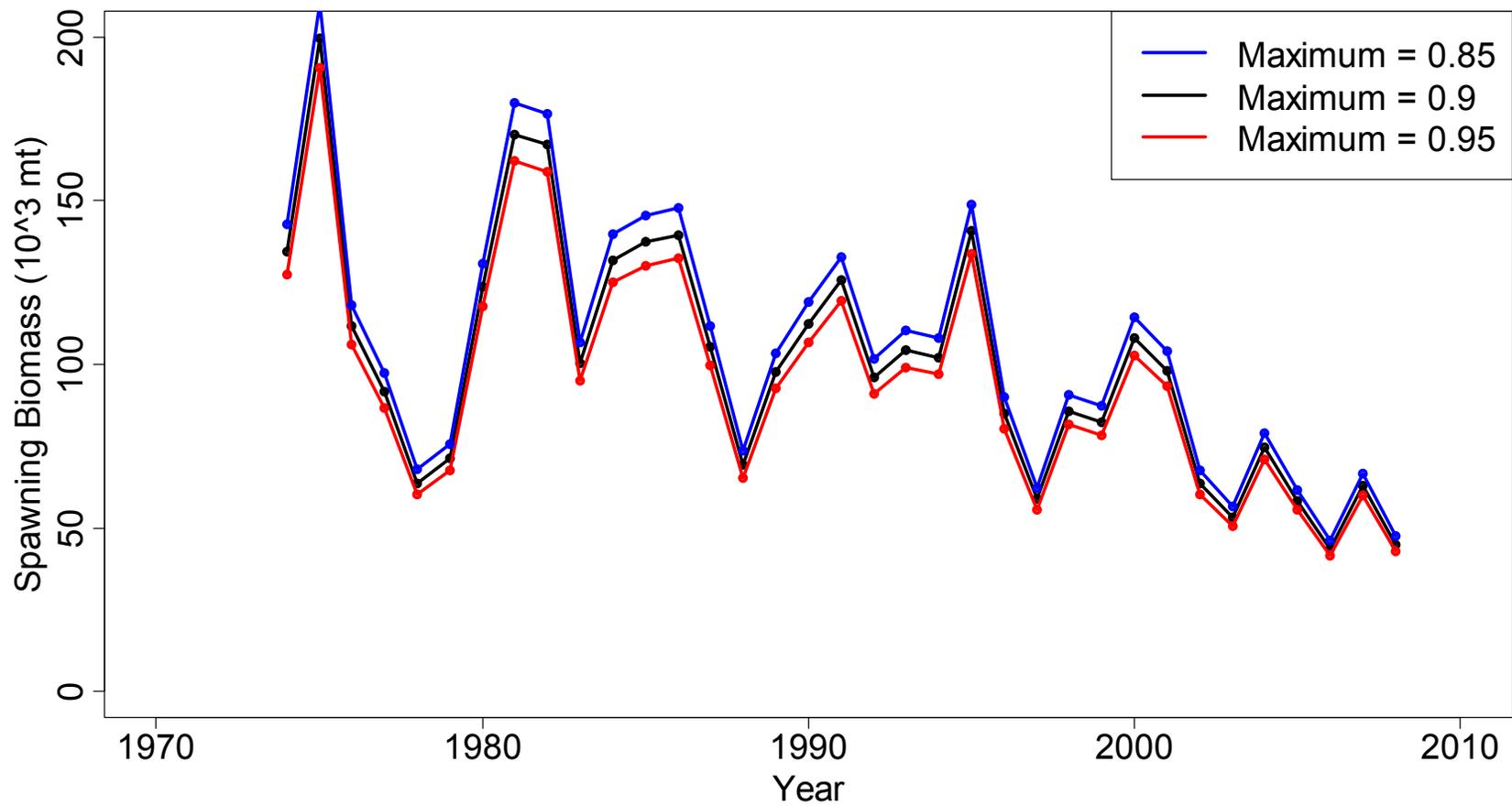


Figure B36. Estimates of spawning biomass from the final model under assumed maxima for the ratio of survey to stock area and the efficiency of the *Henry B. Bigelow*.

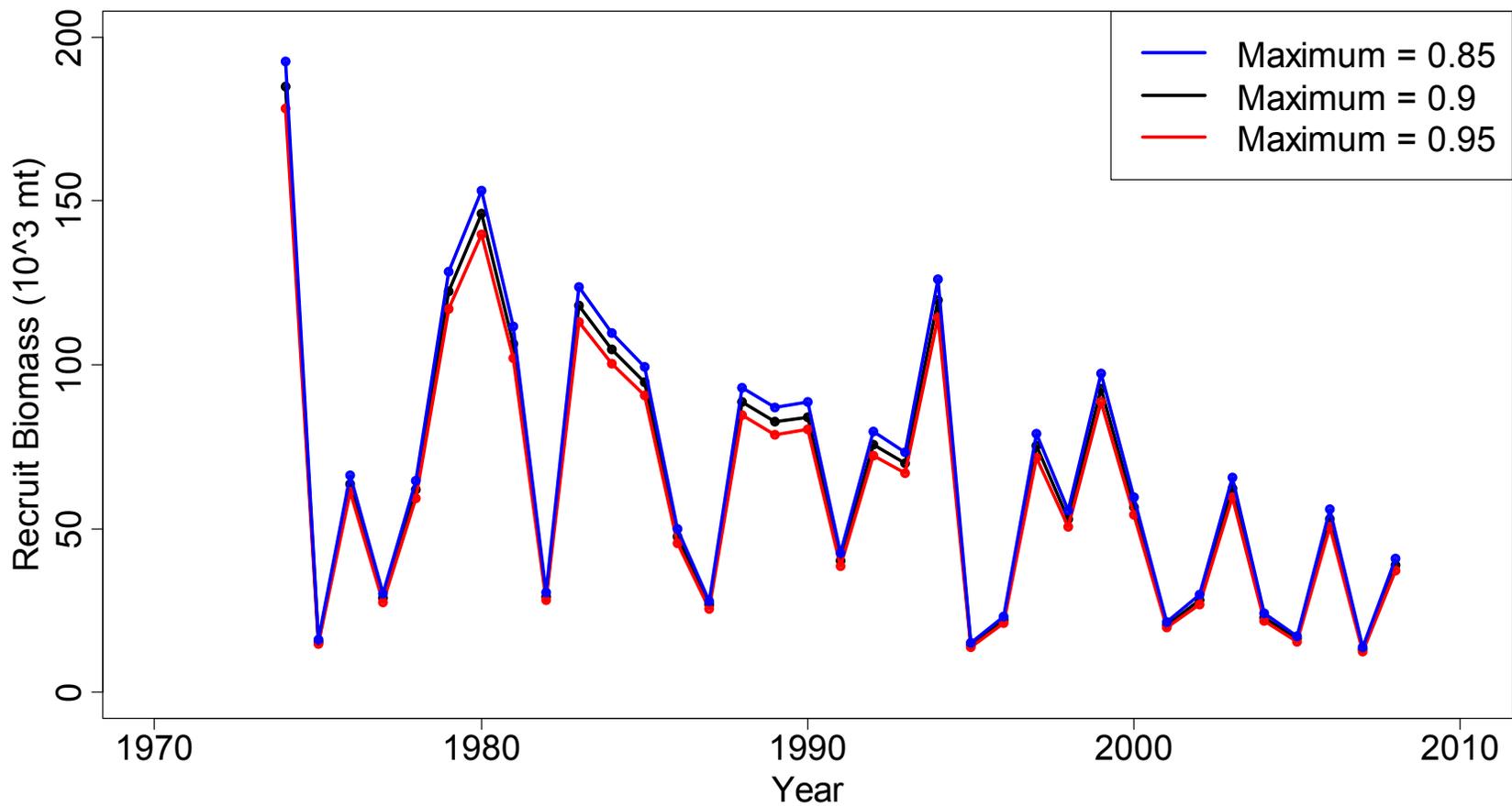


Figure B37. Estimates of recruitment biomass from the final model under assumed maxima for the ratio of survey to stock area and the efficiency of the *Henry B. Bigelow*.

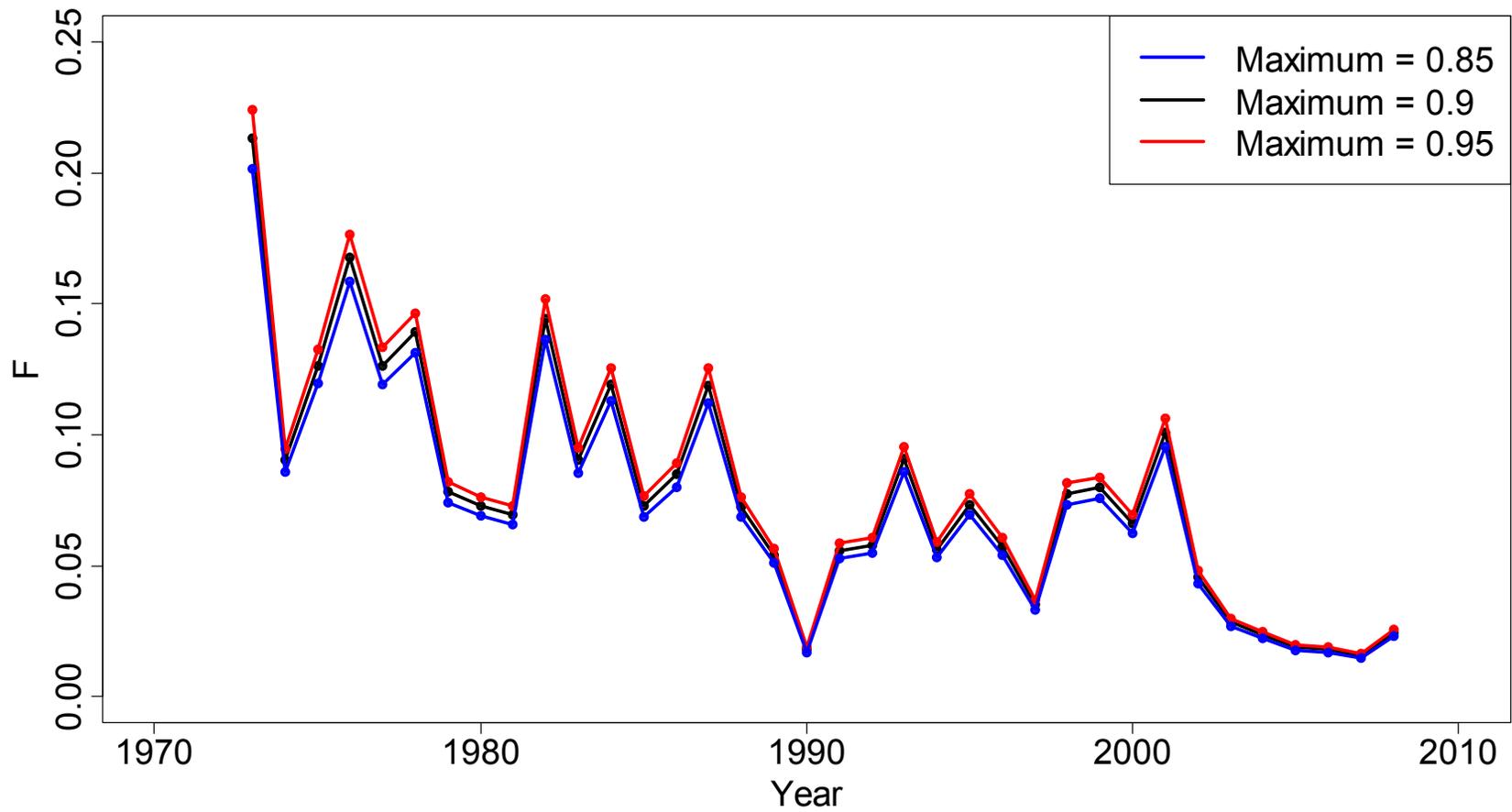


Figure B38. Estimates of spawning biomass from the final model under assumed maxima for the ratio of survey to stock area and the efficiency of the *Henry B. Bigelow*.

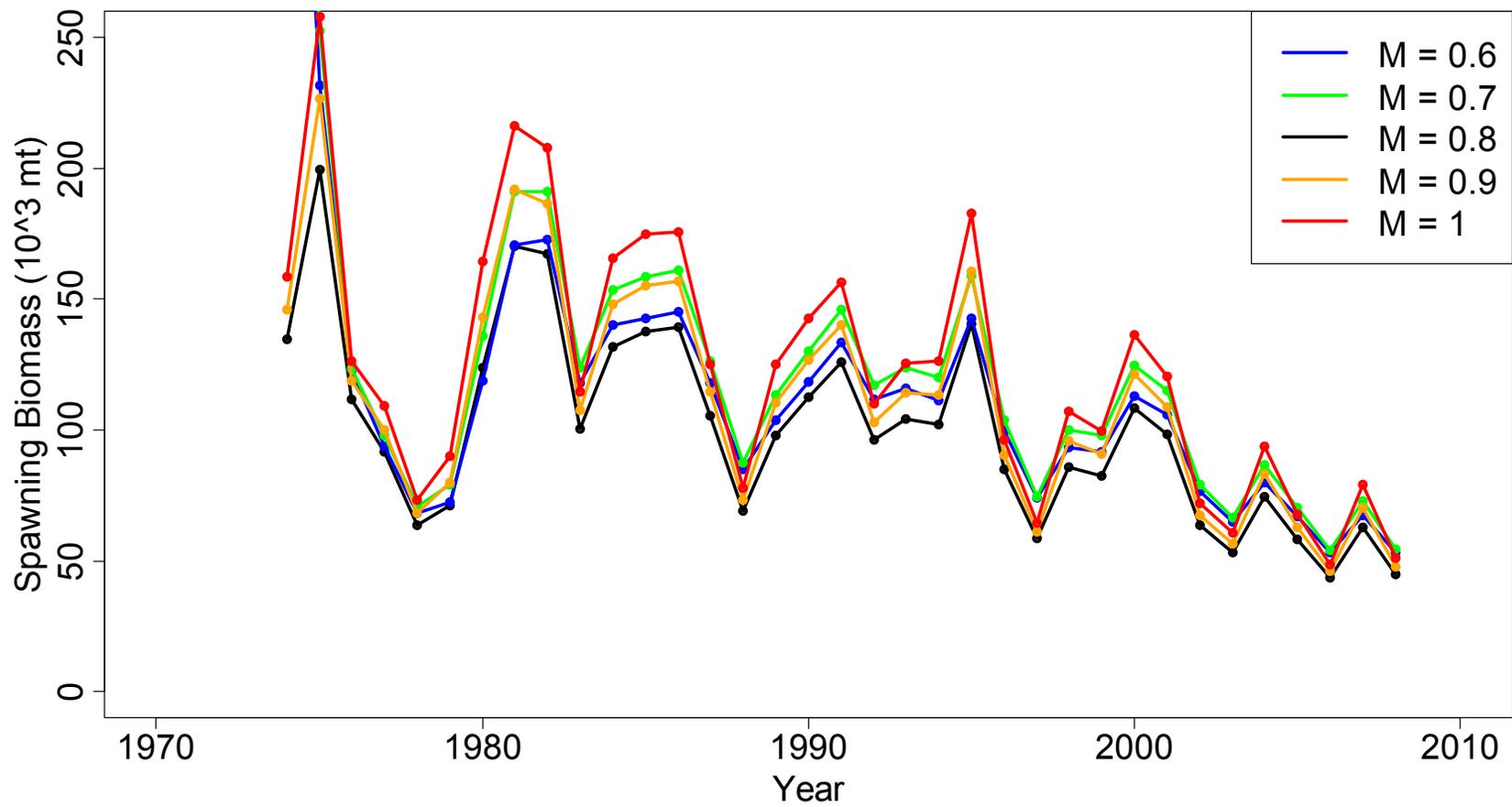


Figure B39. Estimates of spawning biomass from the final model under assumed natural mortality rates between 0.6 and 1.0.

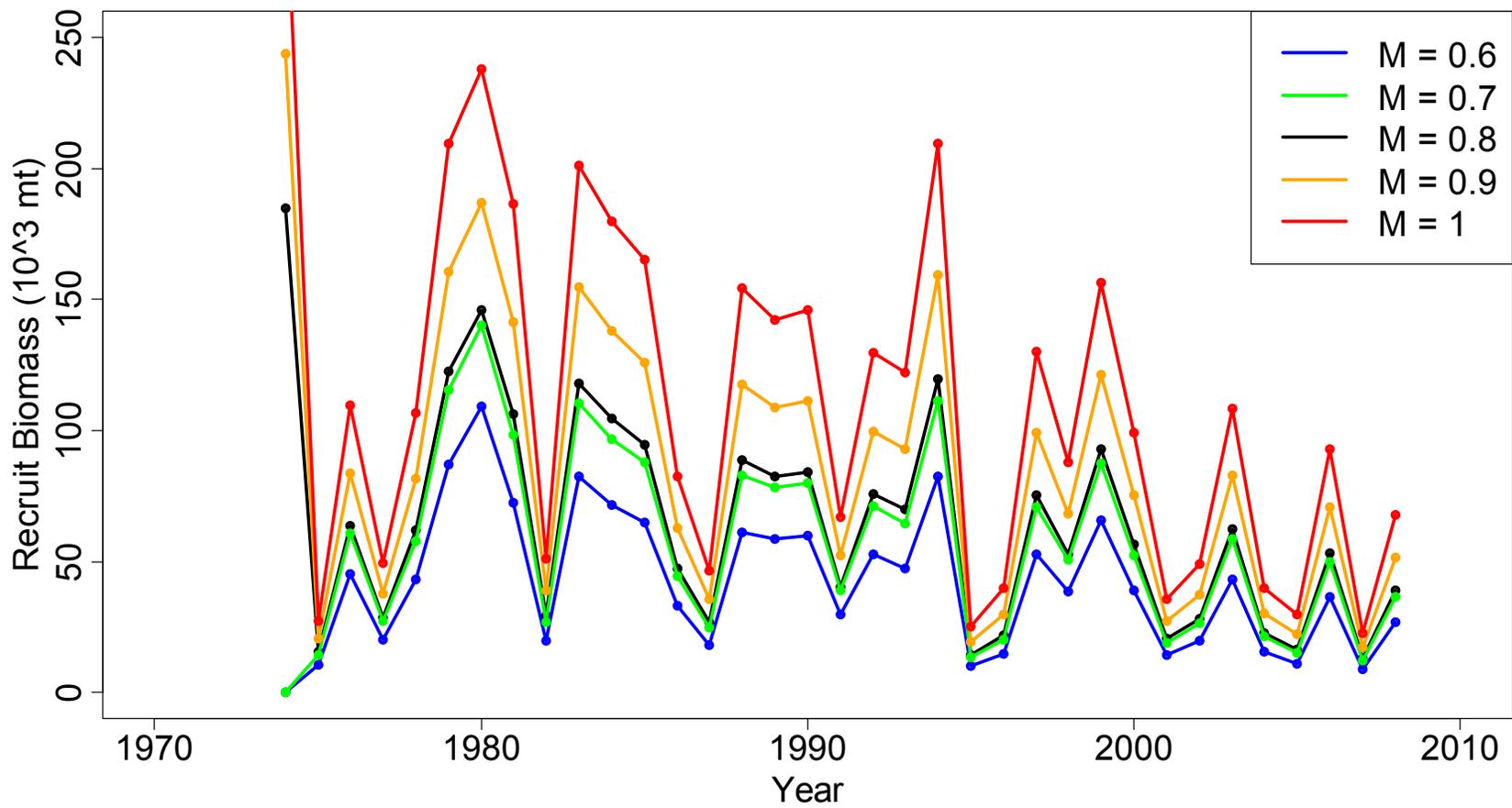


Figure B40. Estimates of recruitment biomass from the final model under assumed natural mortality rates between 0.6 and 1.0.

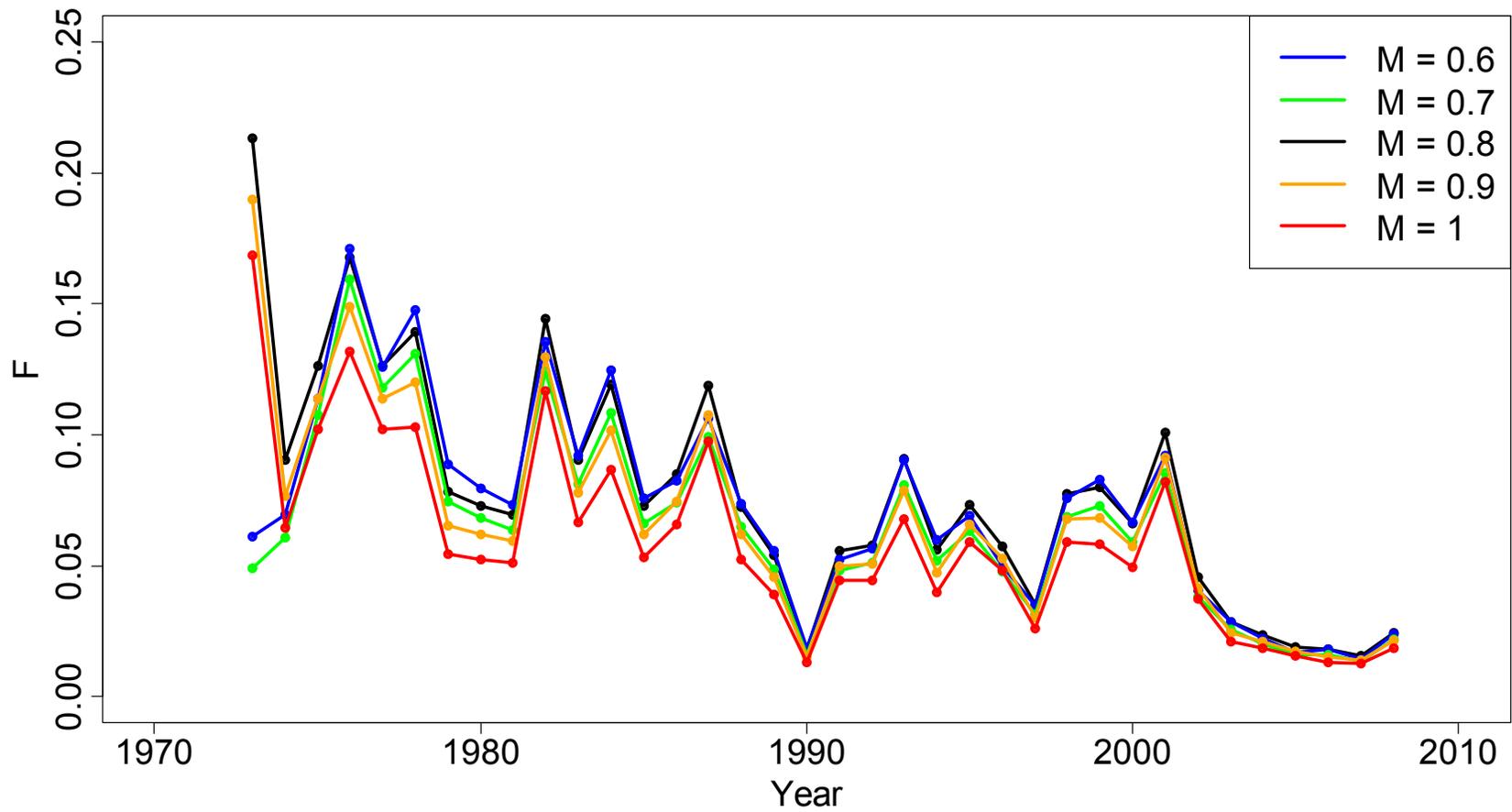


Figure B41. Estimates of fishing mortality from the final model under assumed natural mortality rates between 0.6 and 1.0.

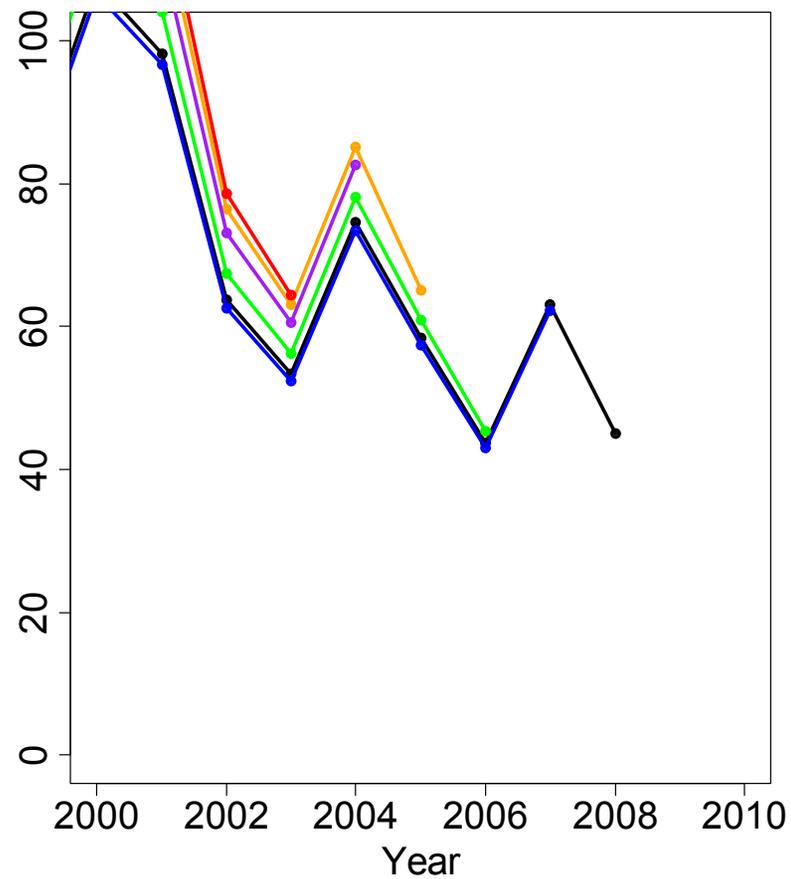
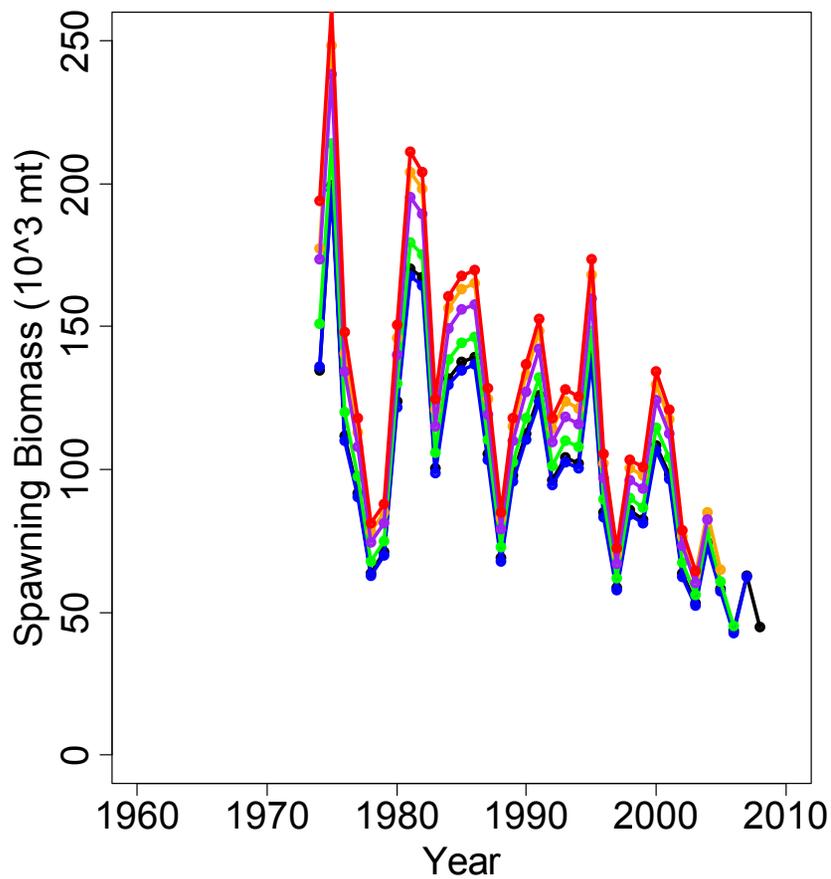


Figure B42. Retrospective behaviour of spawning biomass estimates from the final model.

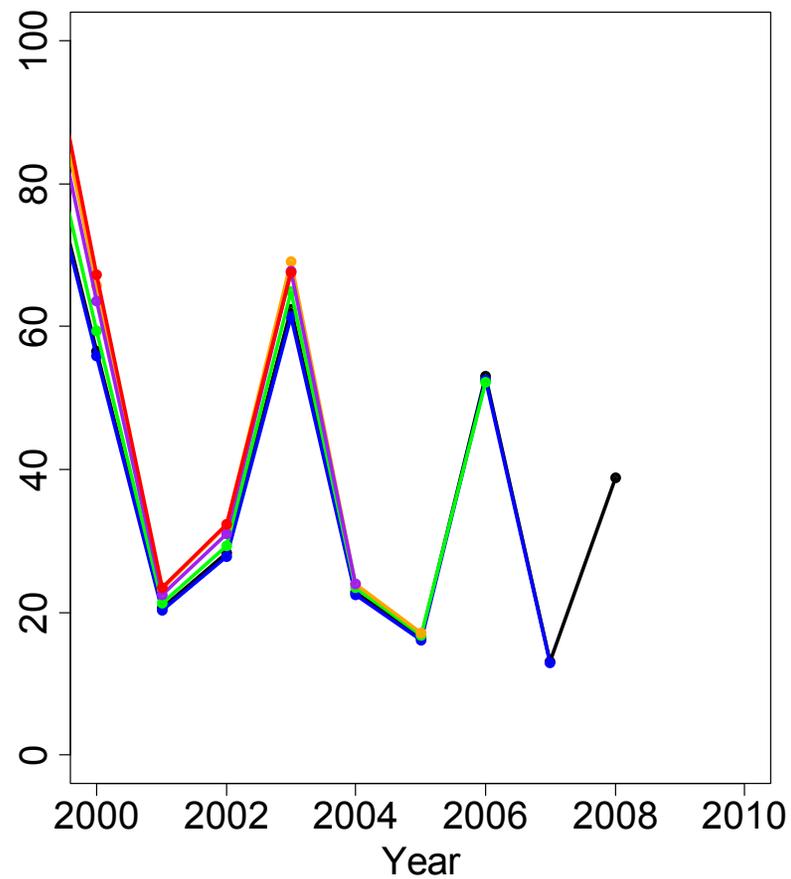
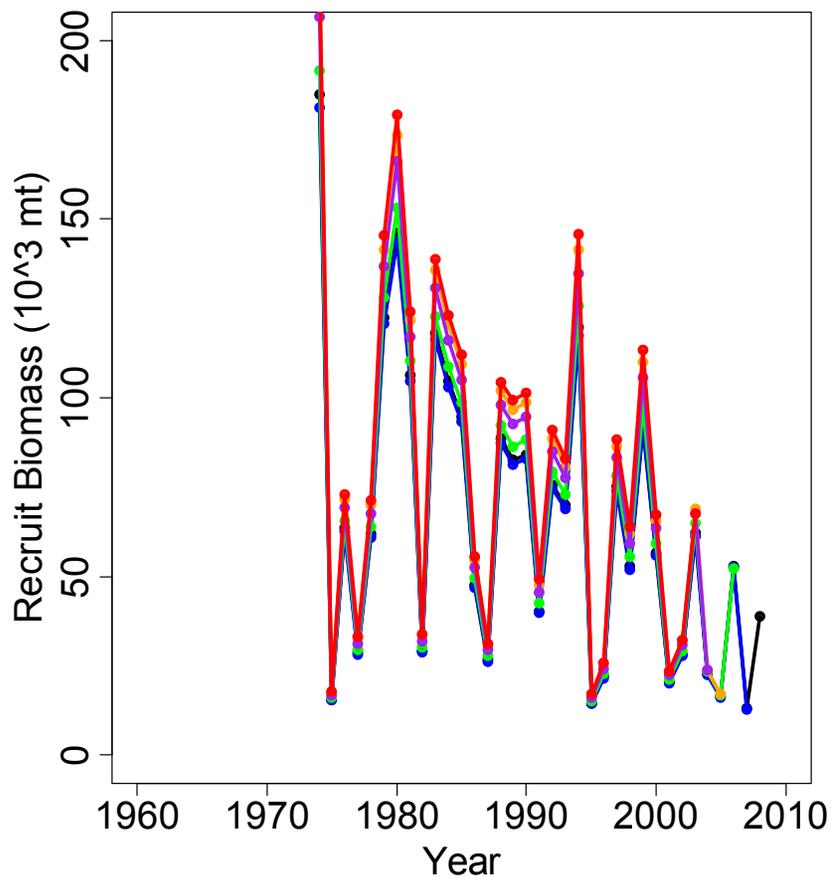


Figure B43. Retrospective behaviour of recruitment biomass estimates from the final model.

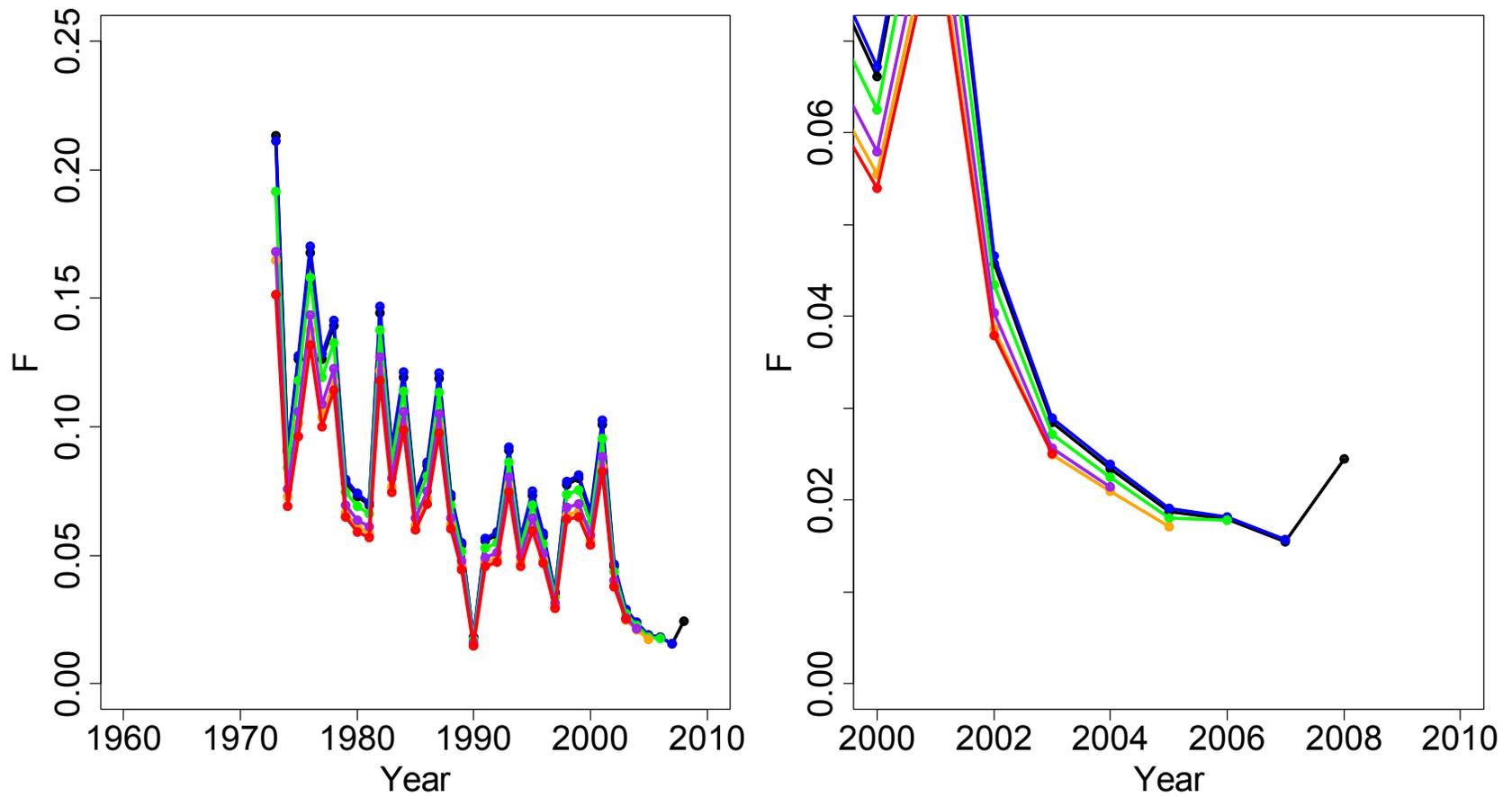


Figure B44. Retrospective behaviour of fishing mortality estimates from the final model.

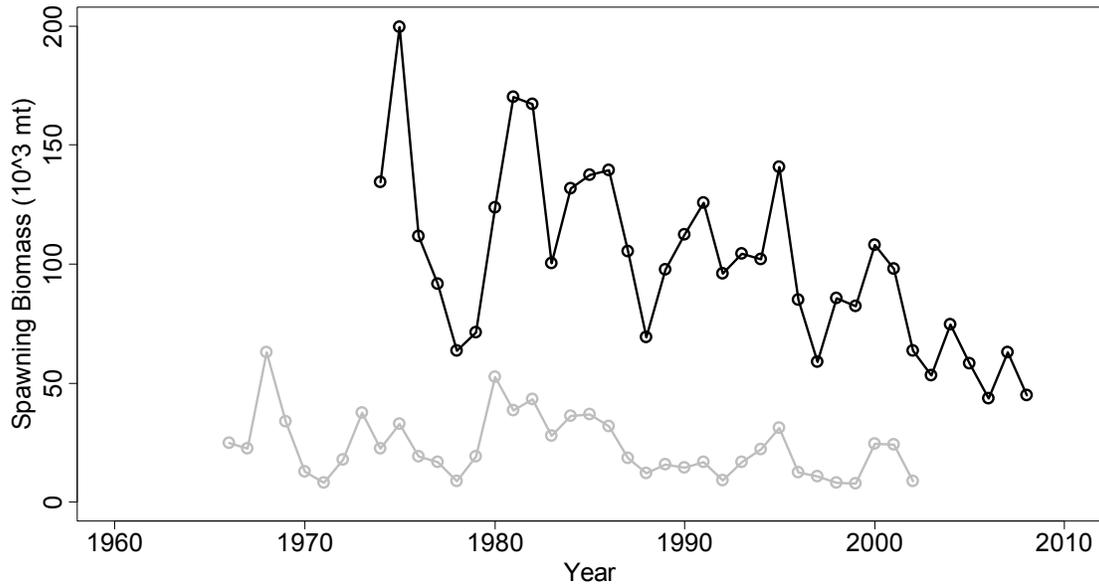


Figure B45. Estimated spawning biomasses from NEFSC (2004) (grey) and final model (black).

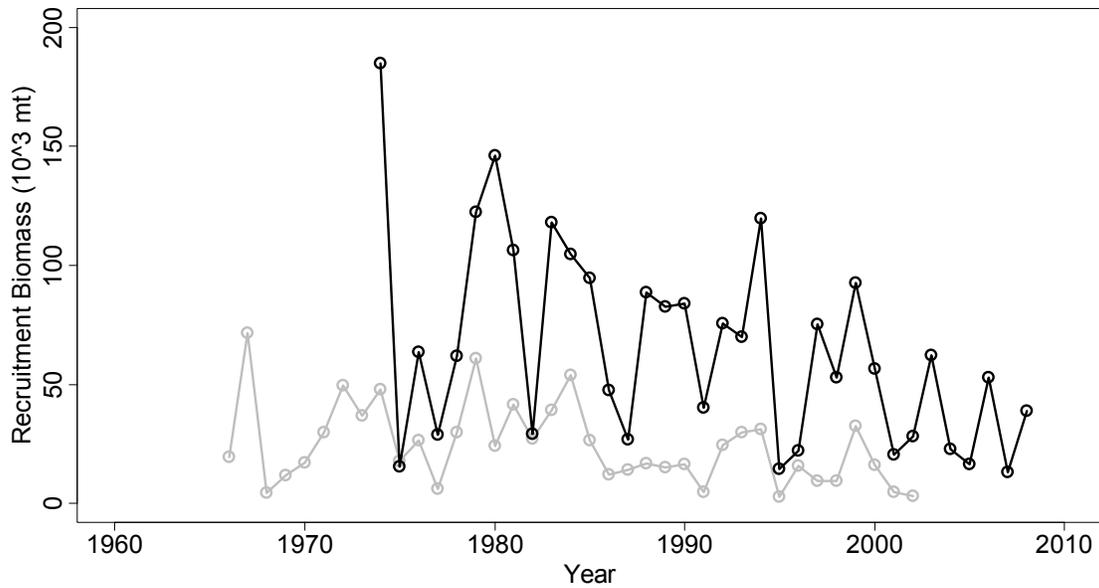


Figure B46. Estimated recruitment biomasses from NEFSC (2004) (grey) and final model (black).

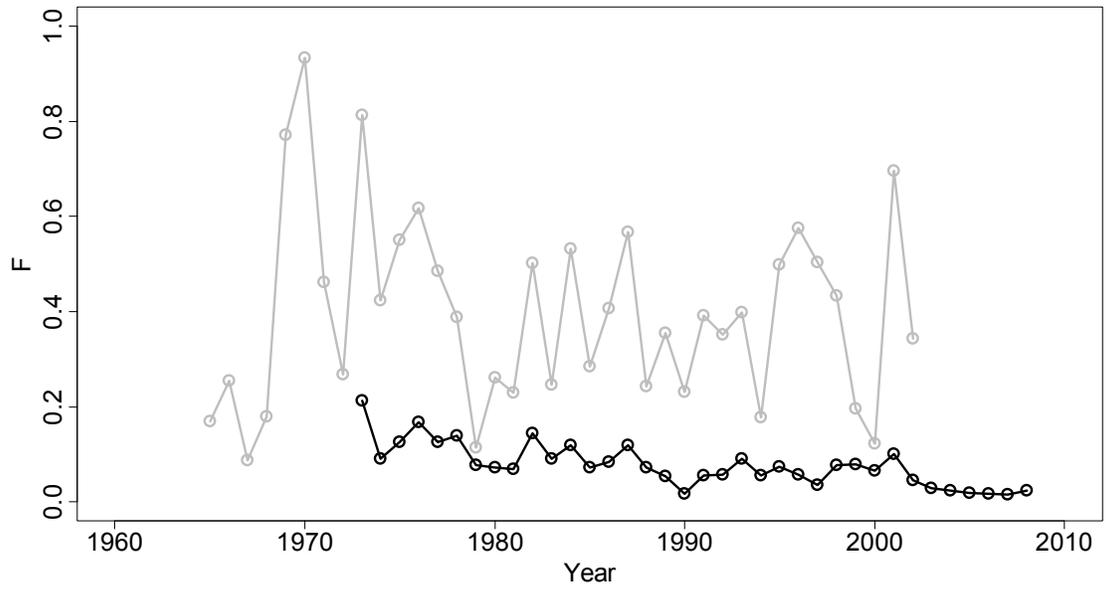


Figure B47. Estimated fishing mortality from NEFSC (2004) (grey) and final model (black).

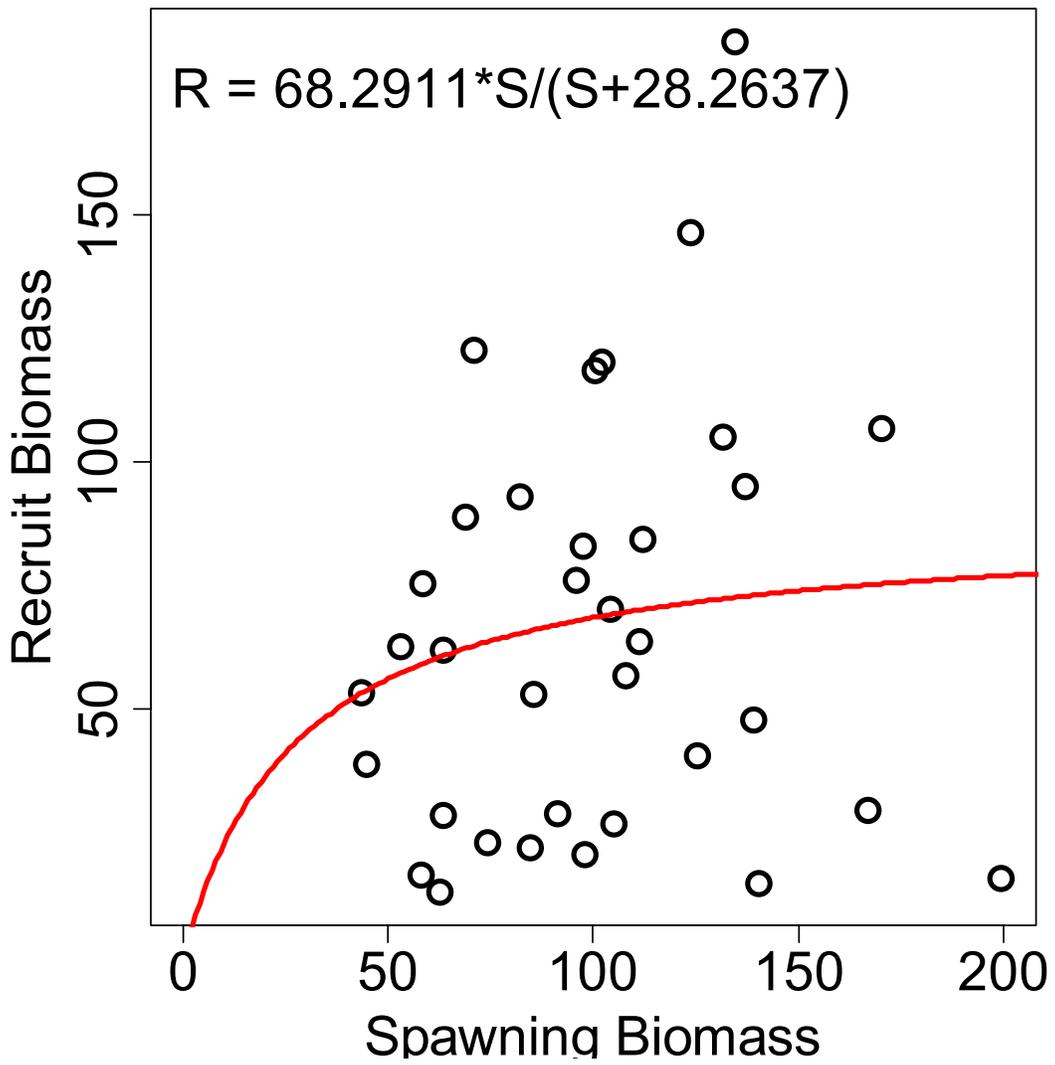


Figure B48. Recruitment and spawning biomass estimates from the final model. Red line represents bias corrected (1.29) estimated Beverton-Holt spawner-recruit curve.

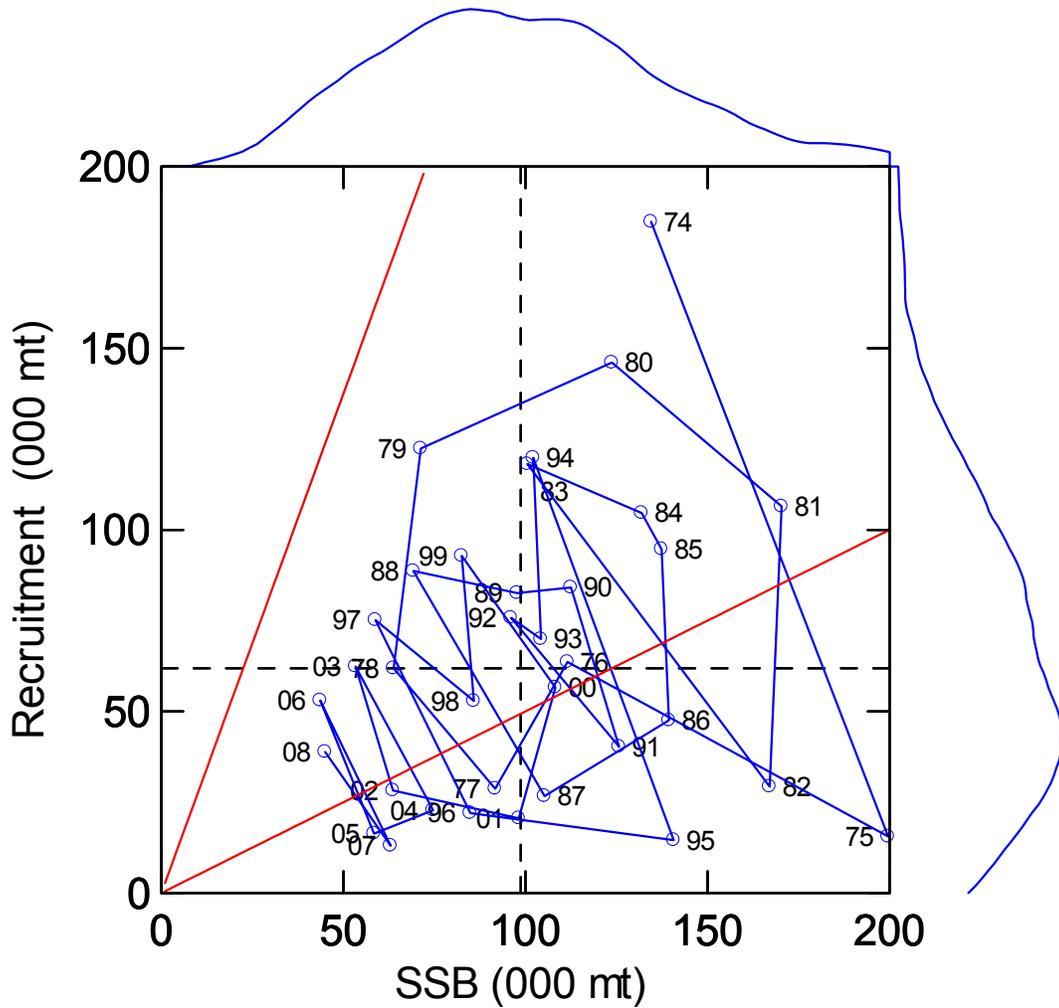


Figure B49. Relationship between recruitment vs spawning stock biomass (SSB) in year  $t$  for years 1974 to 2008. The point label refers to year of spawning. The nonparametric kernel distributions of  $R$  and  $SSB$  are depicted in the margins. Median  $R$  (61,860 mt) and  $SSB$  (98,700 mt) values are represented by dashed lines. The solid diagonal lines represent replacement lines for  $F_{0.1}=1.04$  (steeper slope) and  $F=0$  (shallow slope).

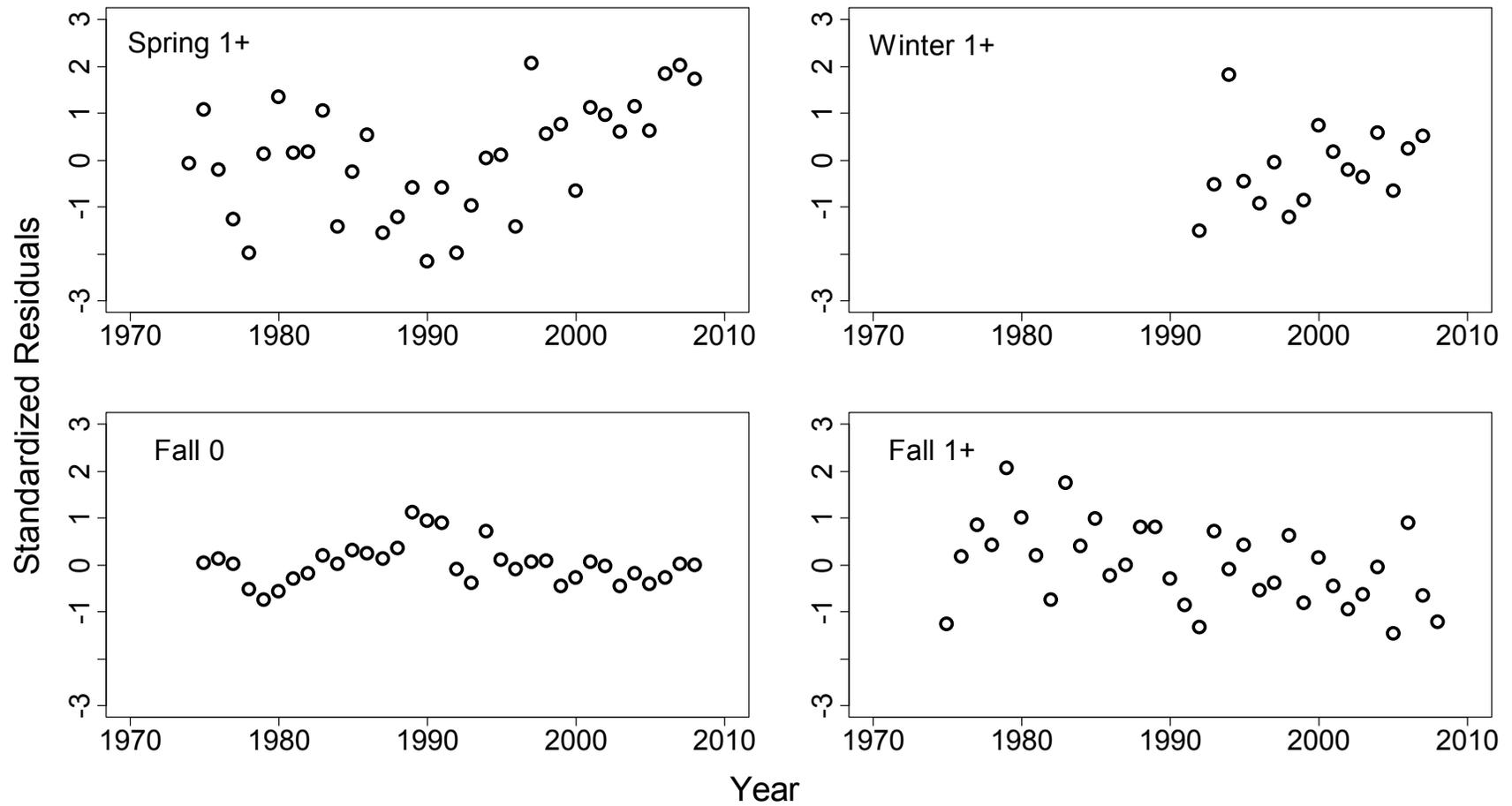


Figure B50. Standardized Residuals over time from final model for NEFSC survey indices.

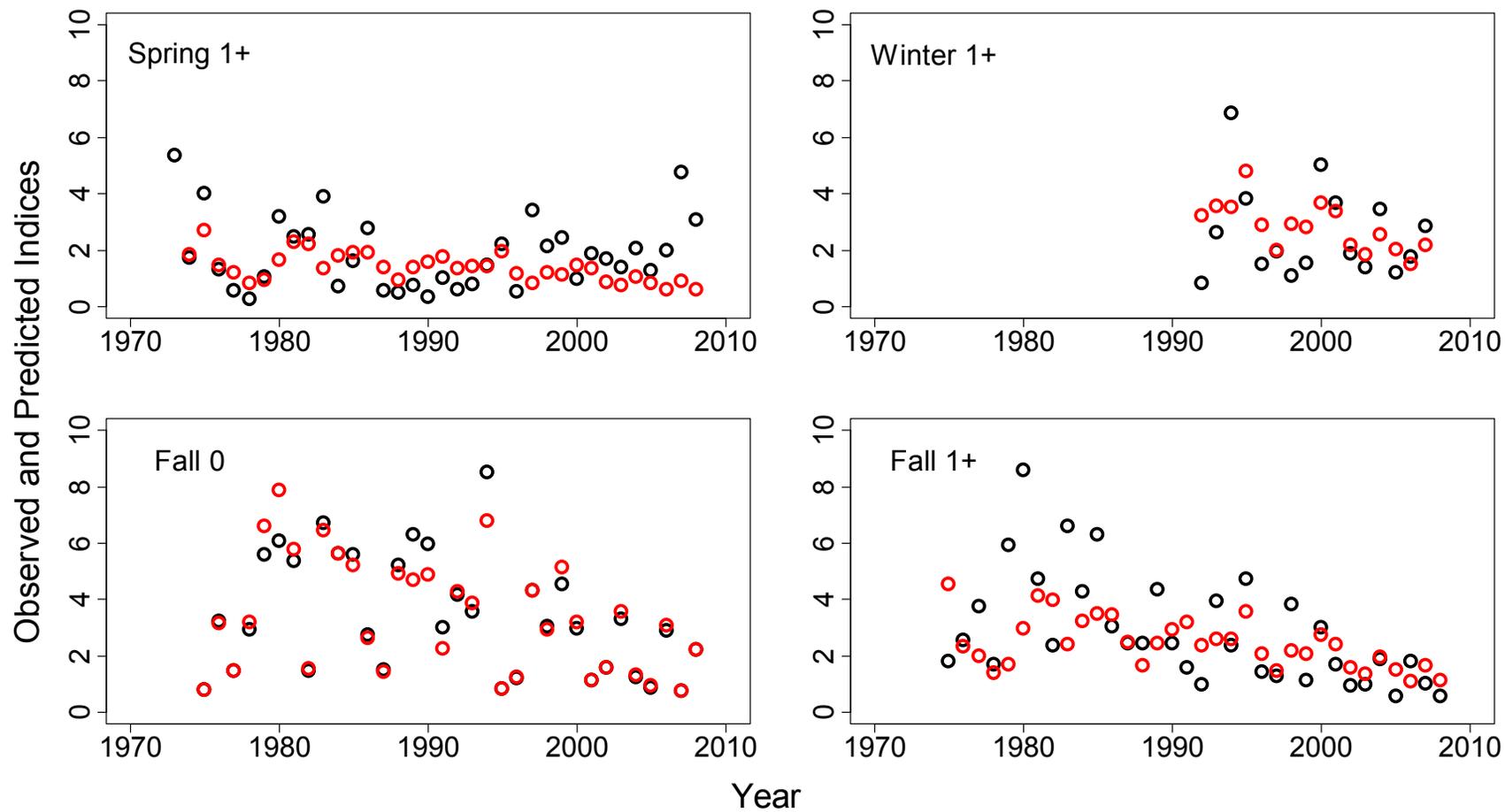


Figure B51. Observed NEFSC survey indices (black) and predicted values from the final model (red).

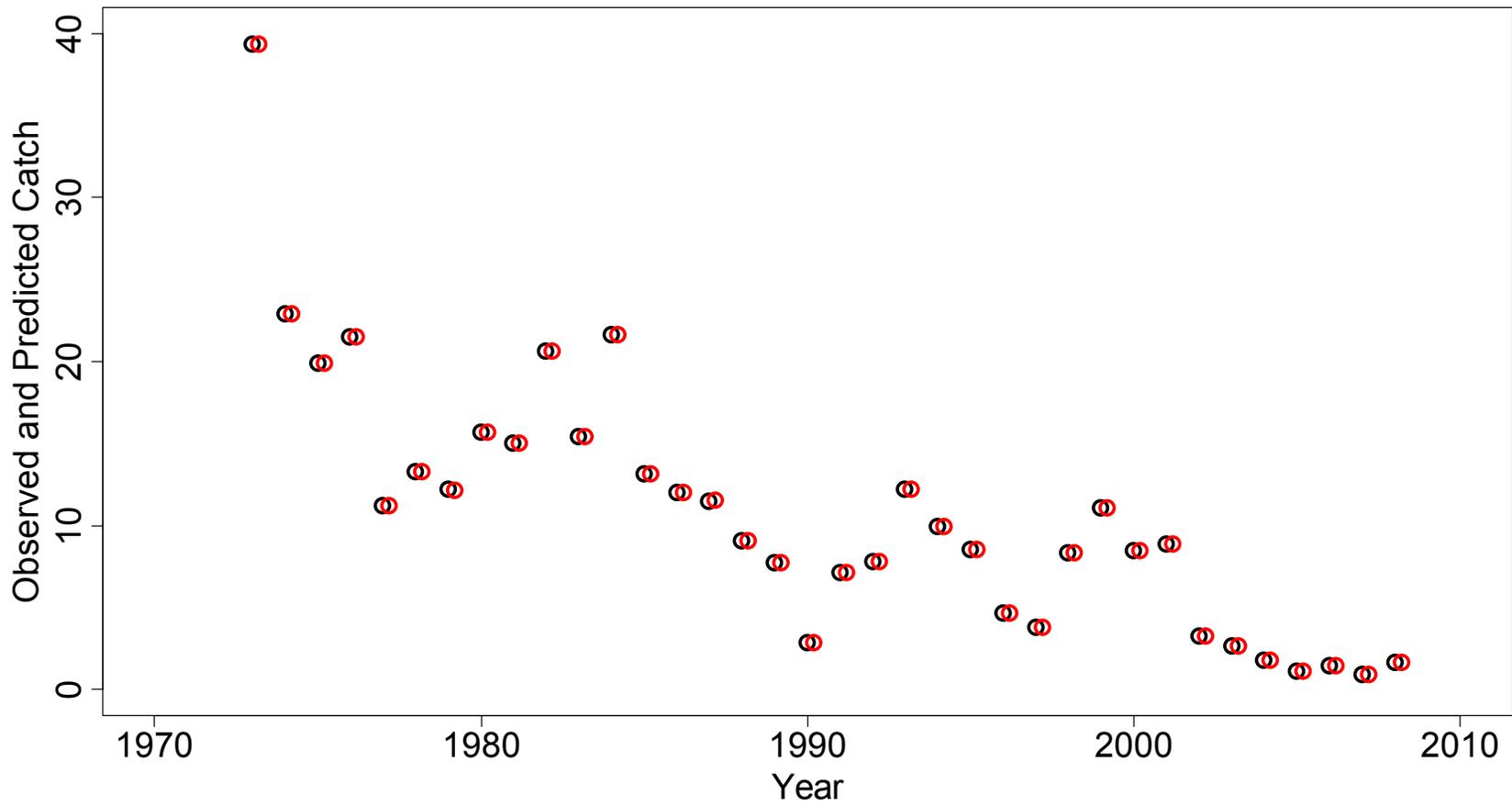


Figure B52. Observed Catches (kmt) (black) and predicted values from the final model (red).

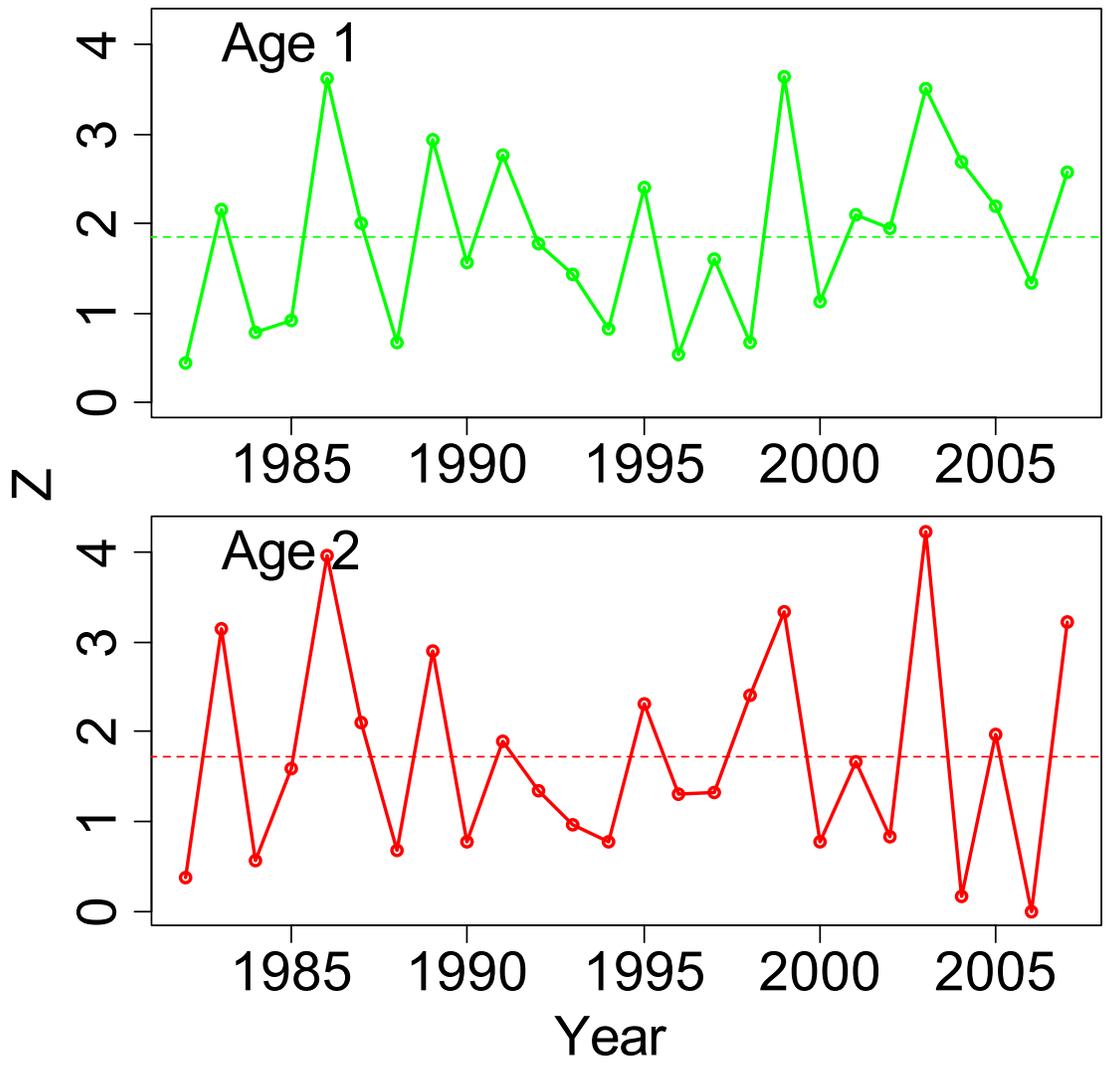


Figure B53. Annual estimates of total instantaneous mortality by year and age from spring survey age composition estimates (Table B17).

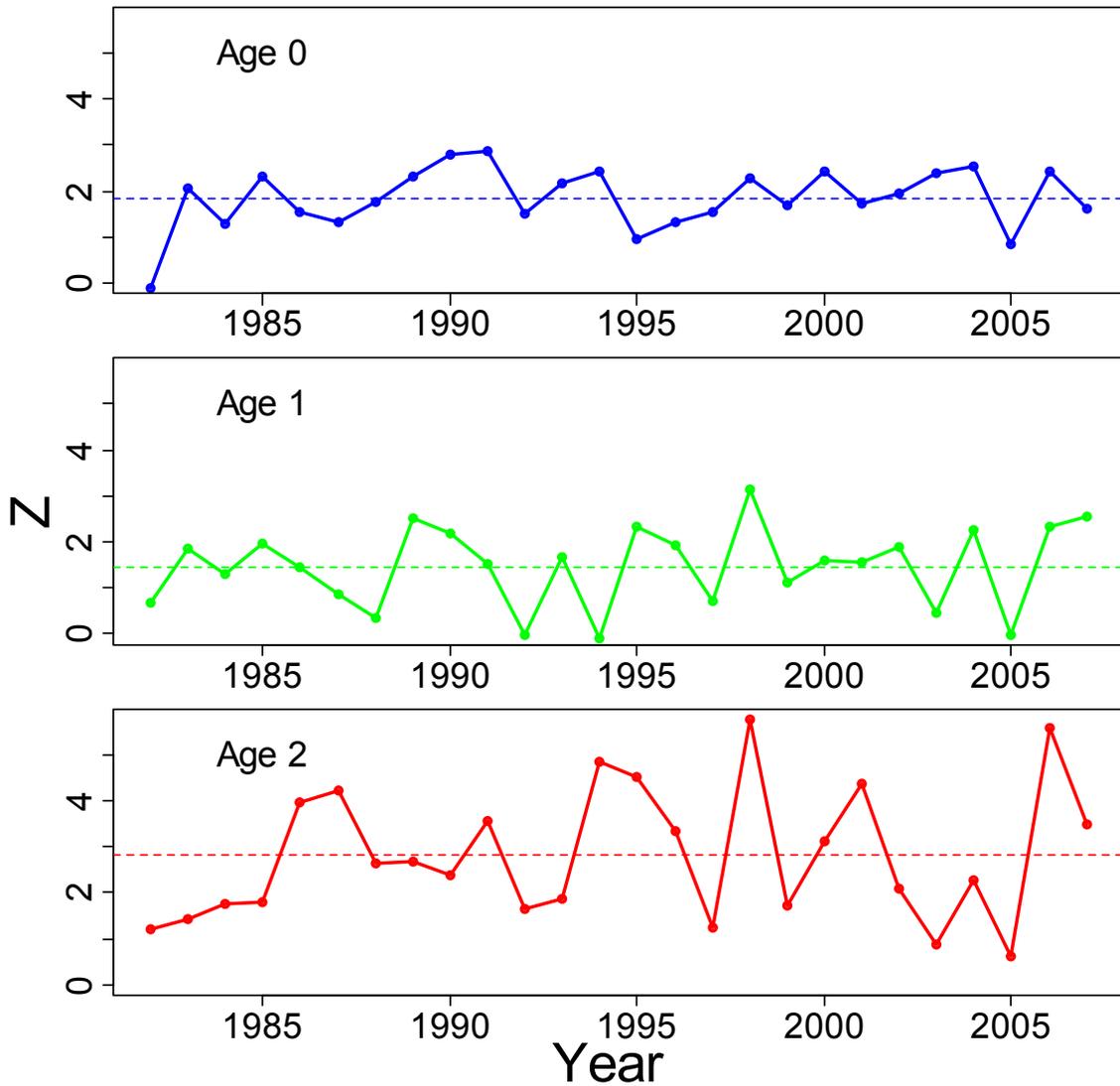


Figure B54. Annual estimates of total instantaneous mortality by year and age from fall survey age composition estimates (Table B18).

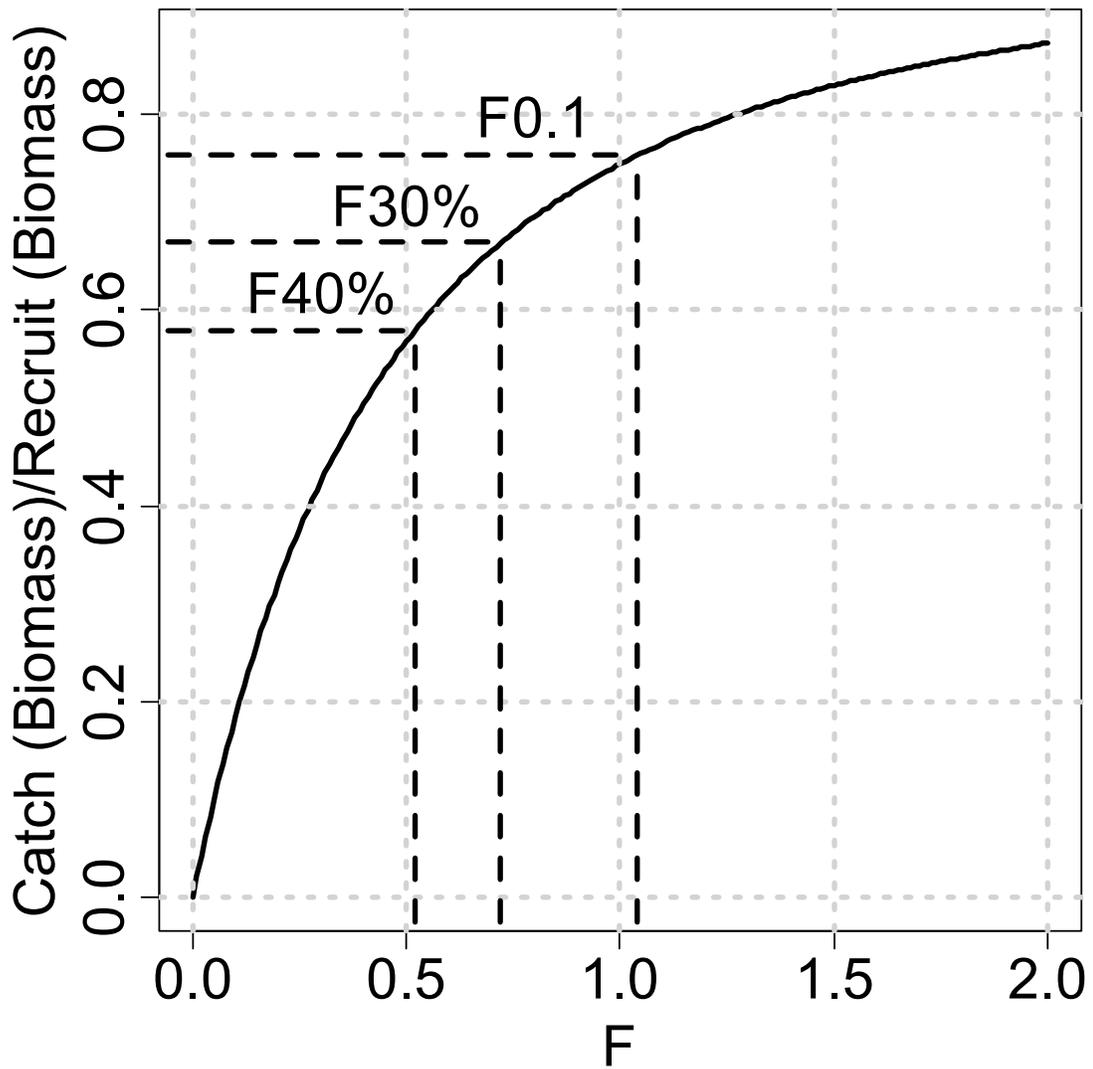


Figure B55. Equilibrium ratio of catch biomass to recruitment biomass with constant fishing mortality. Results are obtained by using the BOOTADM bootstrapping and SPROJDDIF projection software written for the KLAMZ model by Dr. Larry Jacobson. Non-stochastic projections were carried out 50 years into the future.

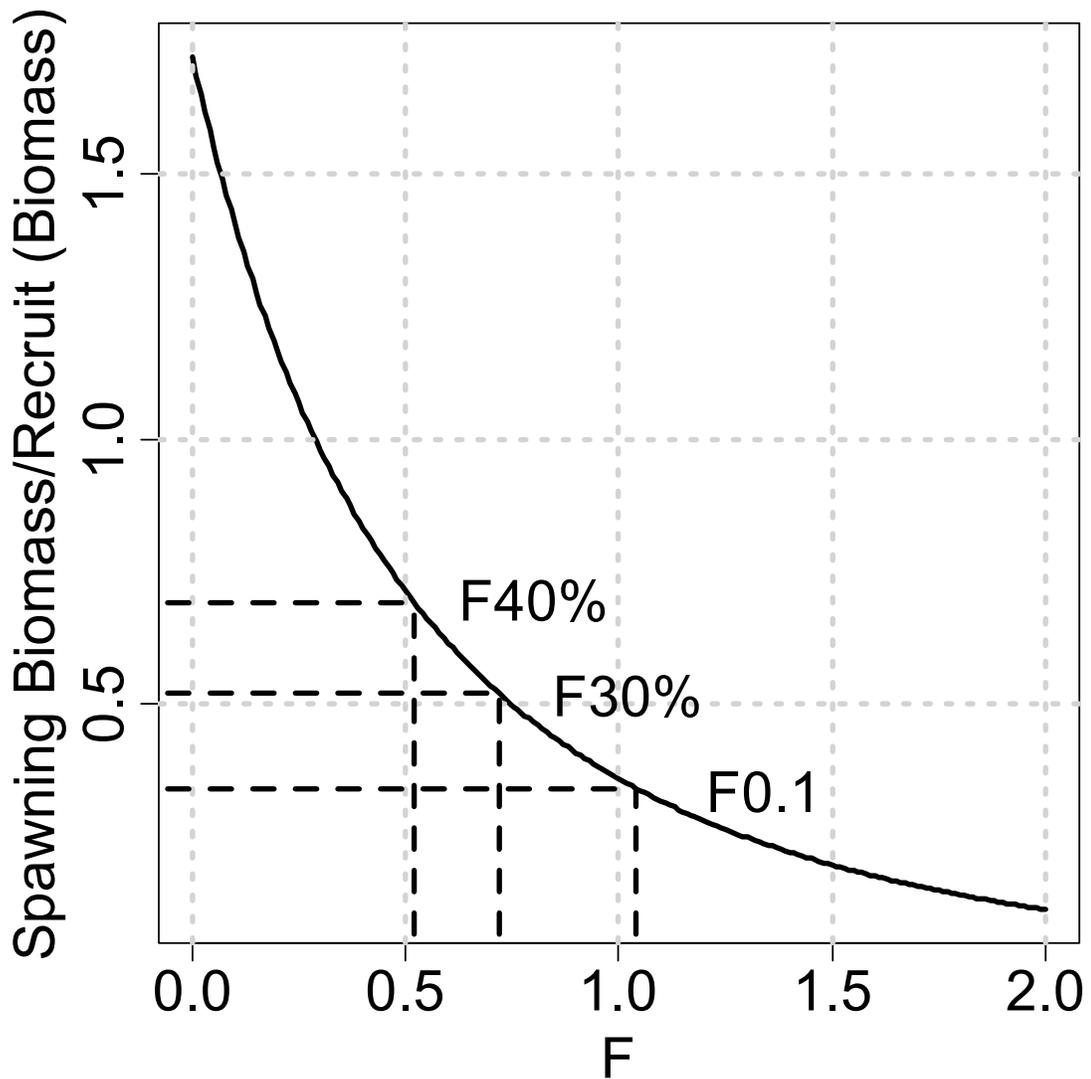


Figure B56. Equilibrium ratio of spawning biomass to recruitment biomass with constant fishing mortality. Results are obtained by using the BOOTADM bootstrapping and SPROJDDIF projection software written for the KLAMZ model by Dr. Larry Jacobson. Non-stochastic projections were carried out 50 years into the future.

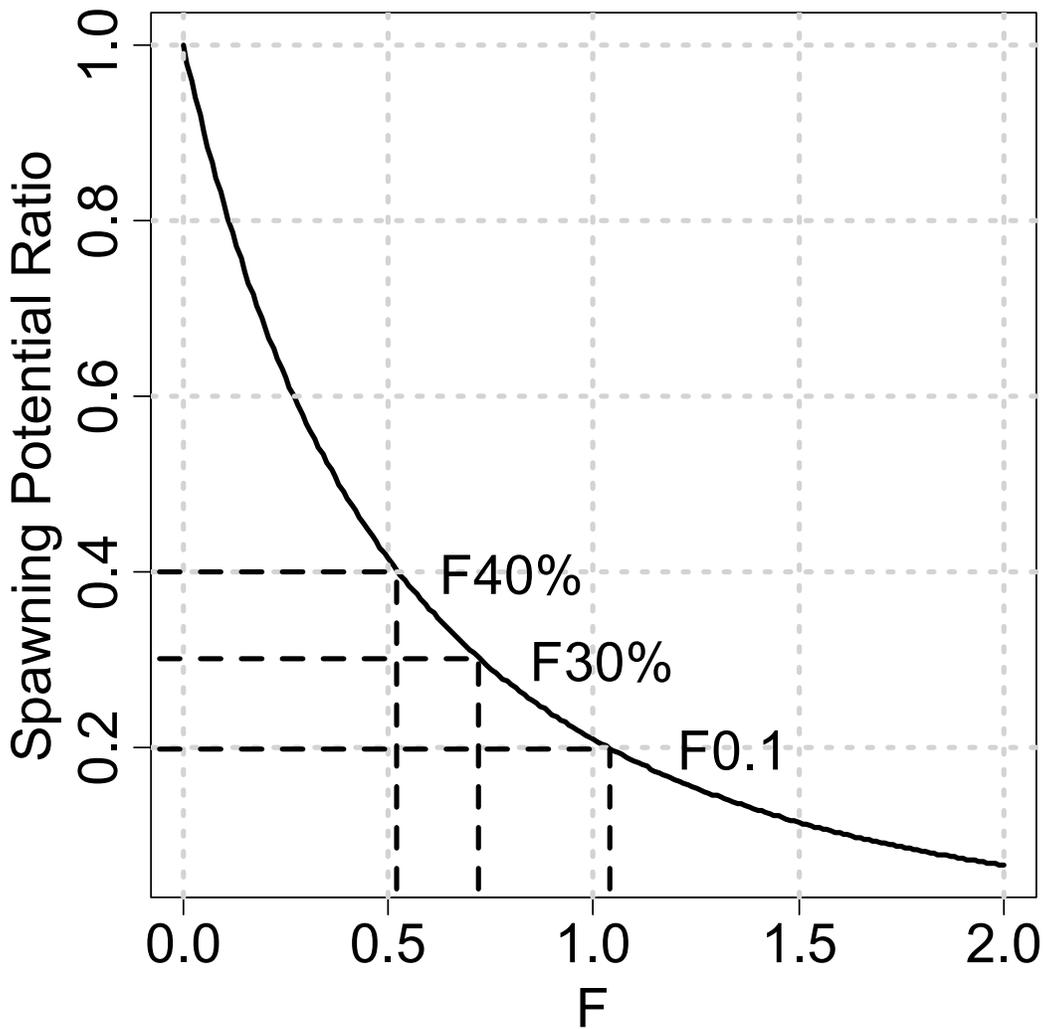


Figure B57. Equilibrium spawning potential ratio with constant fishing mortality. Results are obtained by using the BOOTADM bootstrapping and SPROJDDIF projection software written for the KLAMZ model by Dr. Larry Jacobson. Non-stochastic projections were carried out 50 years into the future.

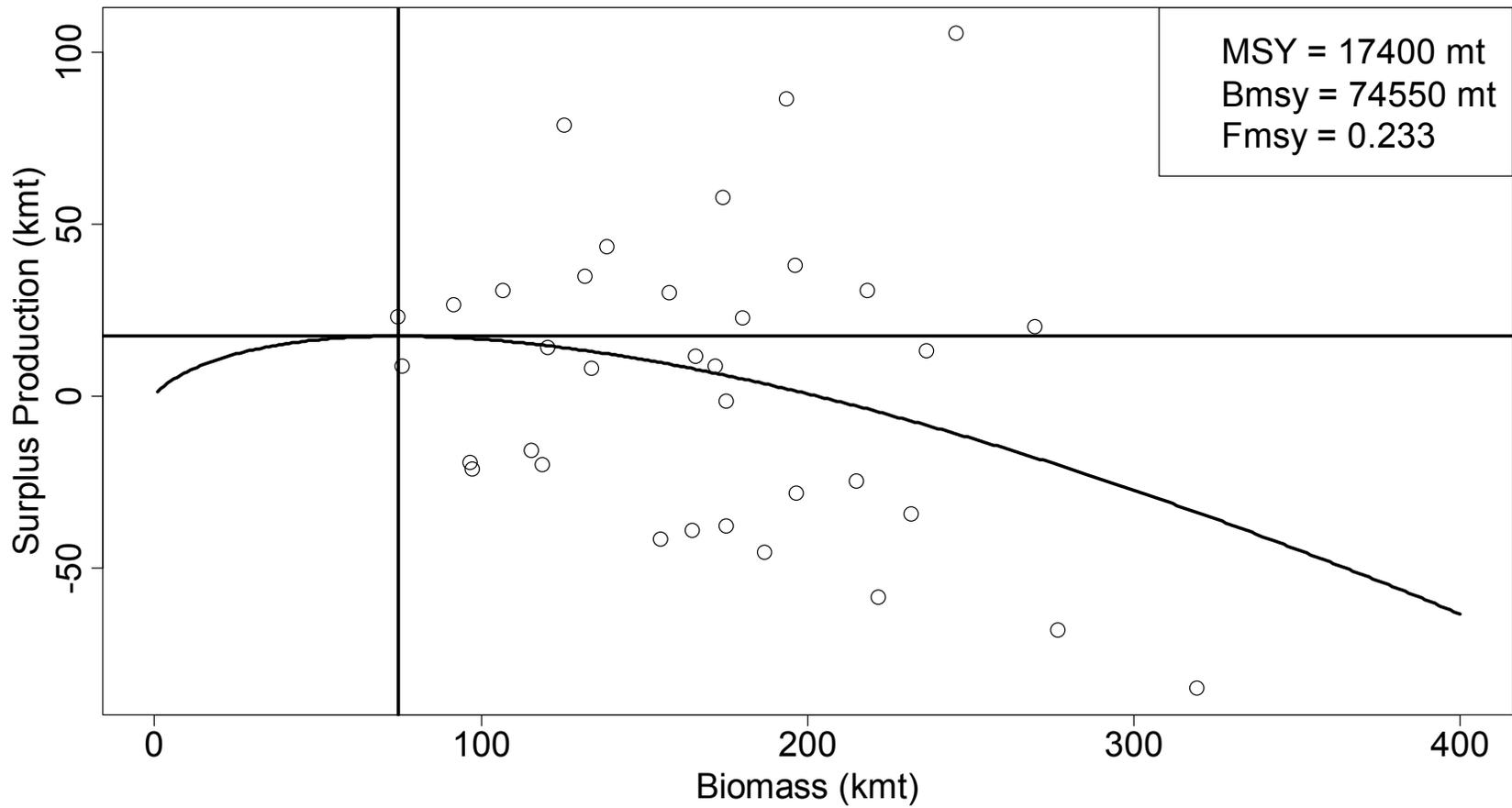


Figure B58. Fox surplus production curve as estimated internal to the final KLAMZ model.

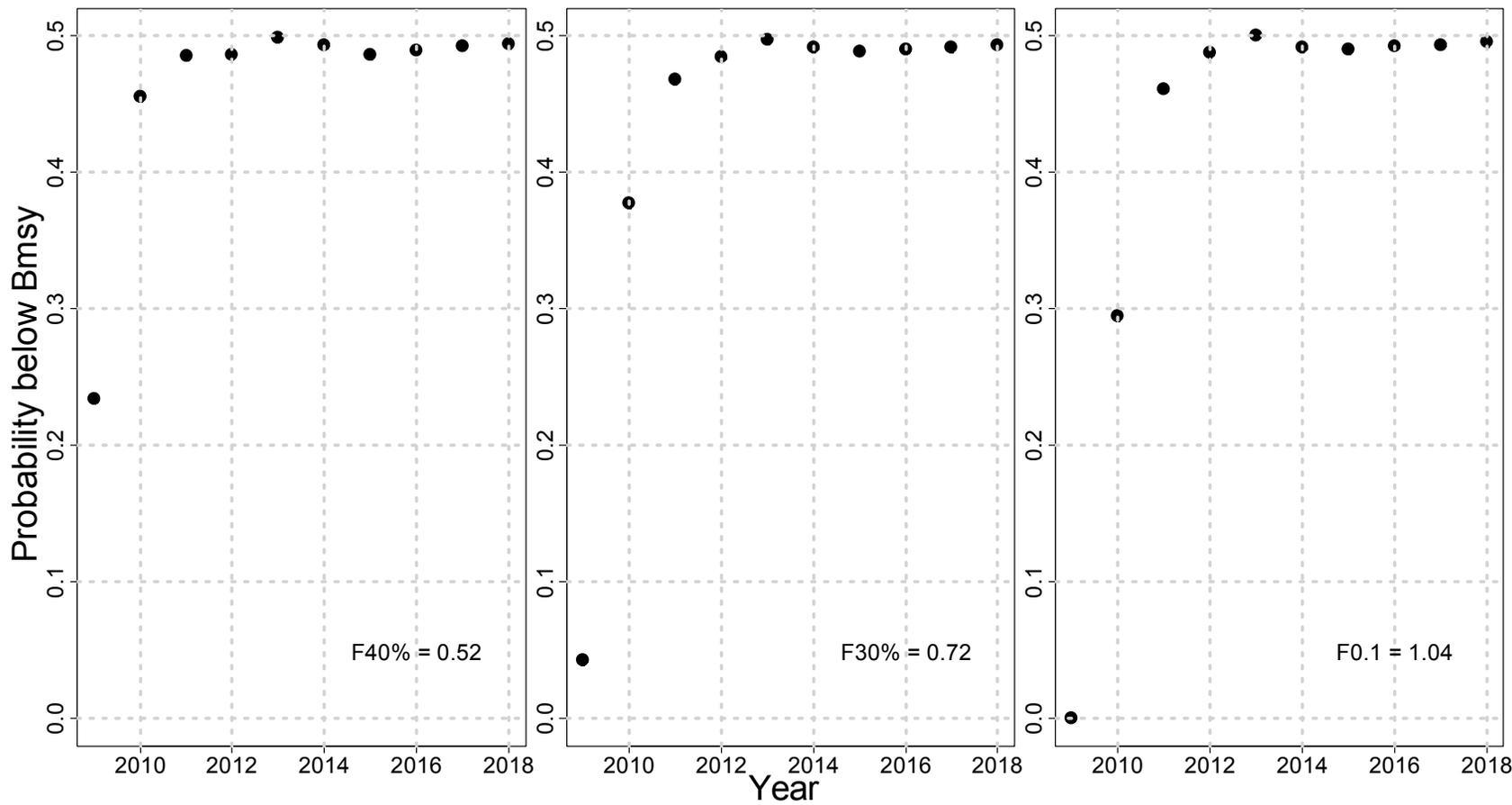


Figure B59. Probabilities of median biomass being below the corresponding candidate  $SSB_{MSY}$  proxies when fishing at candidate  $F_{MSY}$  proxies and the entire recruitment series is used.

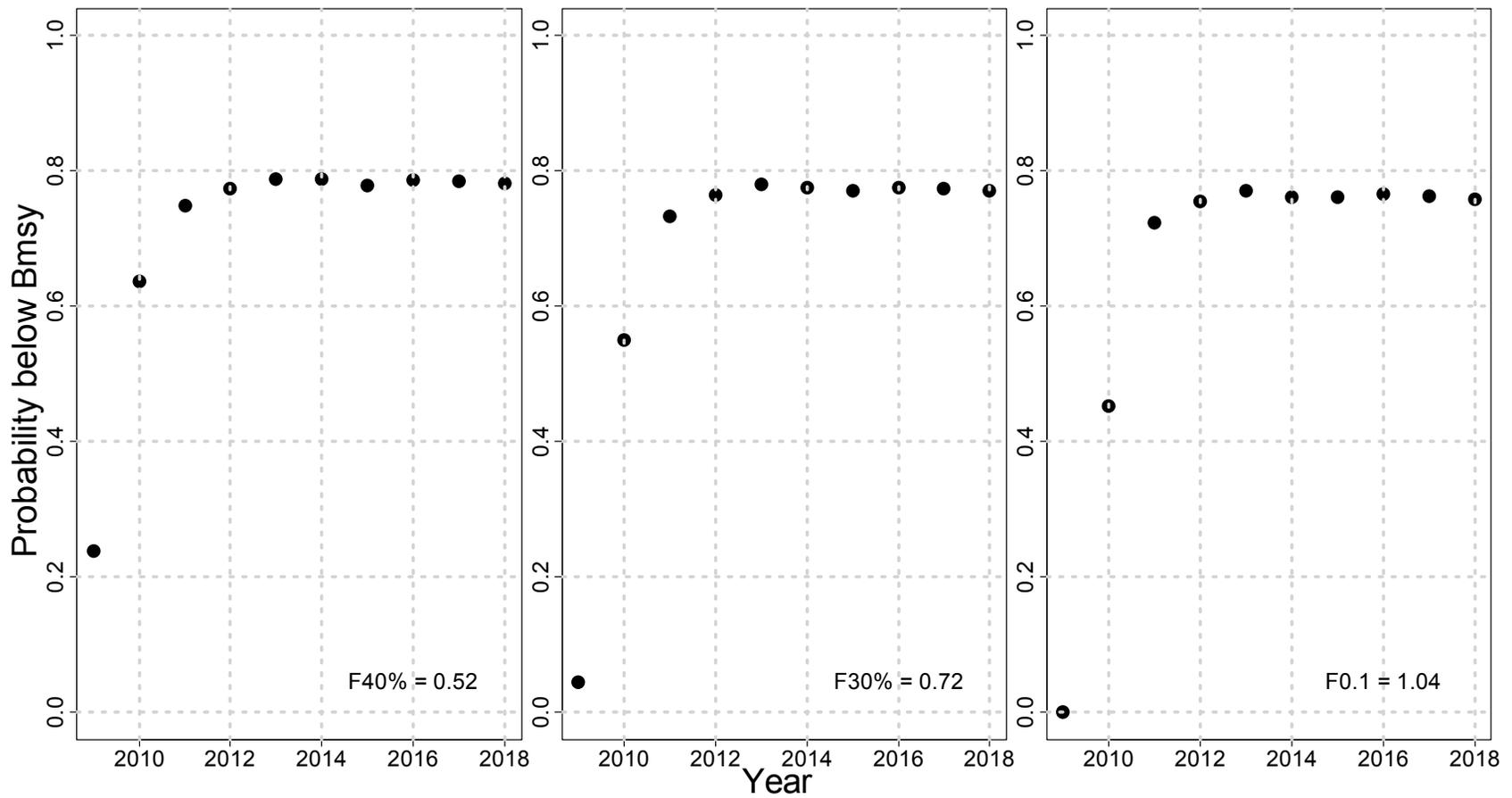


Figure B60. Probabilities of median spawning biomass being below the corresponding candidate  $SSB_{MSY}$  when fishing at candidate  $F_{MSY}$  proxies and recruitment is based on recruitment estimates for the last 10 years (1999-2008).

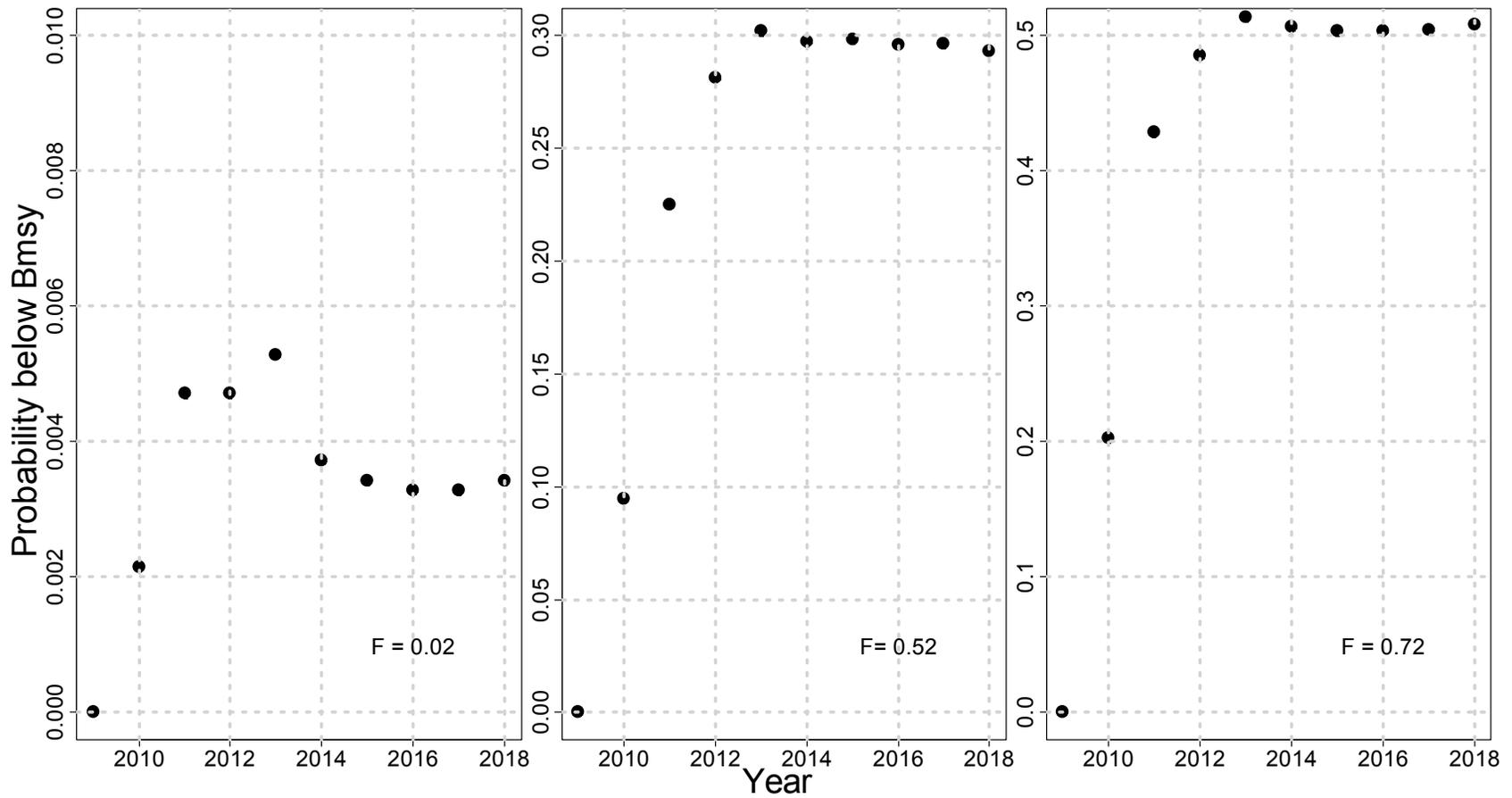


Figure B61. Probabilities of median spawning biomass being below the proposed  $SSB_{MSY}$  for potential constant fishing mortality rates ( $F=F_{2008}=0.02$ ,  $F=0.52$ , and  $F=0.72$ ) when recruitment is based on recruitment estimates for the last 10 years (1999-2008).

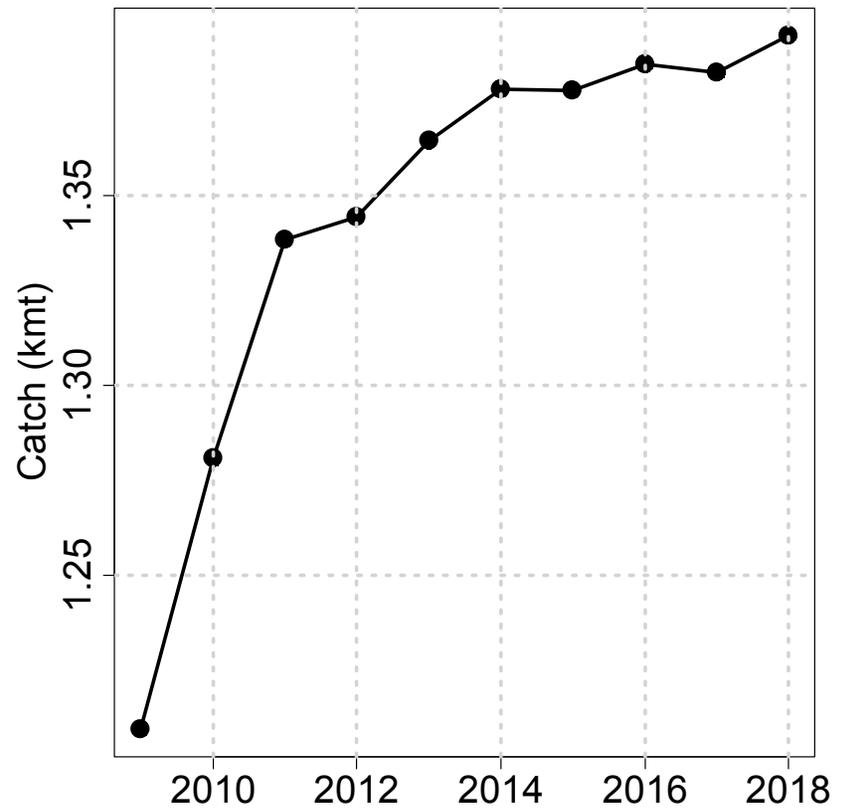
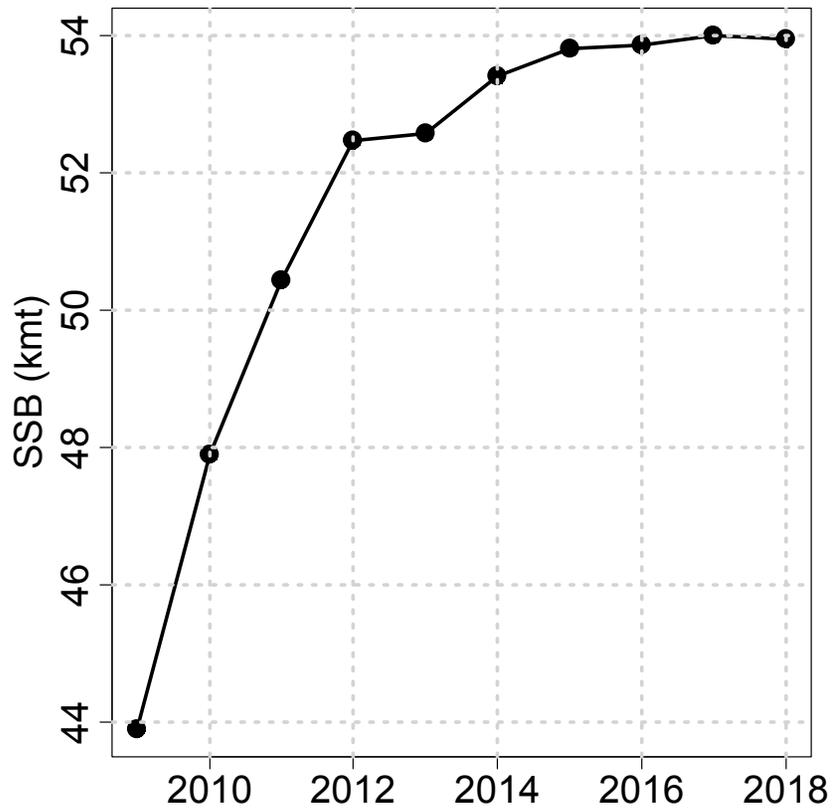


Figure B62. Median spawning biomass and catch for constant fishing at  $F=F_{2008}=0.02$  when recruitment is based on recruitment estimates for the last 10 years (1999-2008).

## **Appendix B1: Term of Reference 6**

*Evaluate the magnitude, trends and uncertainty of predator consumptive removals on butterfish and associated predation mortality estimates and, if feasible, incorporate said mortality predation estimates into models of population dynamics.*

### **Introduction**

Food habits were evaluated for a wide range of butterfish predators. The total amount of food eaten and the type of food eaten were the primary food habits data examined. From these basic food habits data, diet composition of butterfish, per capita consumption, total consumption, and the amount of butterfish removed by these butterfish predators were calculated. Combined with abundance estimates of these predators, when summed the total amount of butterfish removed by predators was calculated. Contrasts to estimates of landings (see above) were conducted to place this source of mortality into context and to fully address the Term of Reference.

### **Methods**

Every predator that contained butterfish was identified from the NEFSC Food Habits Database System (FHDBS). From that original list, a subset of predators was analyzed to elucidate which predators consistently ate butterfish with a diet composition of >1% for any five year block. The consistent butterfish predators are listed in Table B.6.1.

Estimates were calculated on a seasonal basis (two 6 month periods) for each predator species, summed for each annum. Although the food habits data collections started quantitatively in 1973, not all species of butterfish predators were sampled during the full extent of this sampling program. For more details on the food habits sampling protocols and approaches, see Link and Almeida (2000). This sampling program was a part of the NEFSC bottom trawl survey program; for background and context, further details of the survey program can be found in Azarovitz (1981) and NEFC (1988).

This approach followed previously established and described methods for estimating consumption, using an evacuation rate model methodology. For further details, see Durbin et al. (1983), Ursin et al. (1985), Pennington (1985), Overholtz et al. (1991, 1999, 2000, 2008), Tsou & Collie (2001a, 2001b), Link & Garrison (2002), Link et al. (2002, 2006, 2008, 2009), Methratta & Link (2006), Link & Sosebee (2008), Overholtz & Link (2006, 2007), Tyrrell et al. (2007, 2009), Link and Idoine (2009), Moustahfid et al. (2009a, 2009b), and NEFSC (2006, 2007a, 2007b, 2008). The main data inputs are mean stomach contents ( $S_i$ ) for each butterfish predator  $i$ , diet composition ( $D_{ij}$ ) where  $j$  is the specific prey butterfish, and  $T$  is the bottom temperature taken from the bottom trawl surveys (Taylor et al. 2005). Estimates of variance about all these variables (data inputs) were calculated. Further particulars of these estimators can be found in Link and Almeida (2000). Units for stomach estimates are in g.

As noted, to estimate per capita consumption, the gastric evacuation rate method was used (Eggers 1977, Elliott and Persson 1978). There has been copious experience in this region using these models (see references listed above). The two main parameters,  $\alpha$  and  $\beta$ , were set to 0.004 and 0.11 respectively based upon prior studies and sensitivity

analyses (NEFSC 2007a, 2007b). The exception is that  $\alpha$  was set to 0.002 for elasmobranch predators to reflect their slightly lower metabolism than teleost fishes.

Once daily per capita consumption rates were estimated for each butterflyfish predator those estimates were then scaled up to a seasonal estimate by multiplying the number days in each half year, which were then multiplied by the diet composition  $D_{ij}$  that was butterflyfish, to estimate the seasonal per capita consumption of butterflyfish, which were then summed to provide an annual estimate, which were then scaled by the total stock abundance of each predator to estimate a total amount of butterflyfish ( $j$ ) removed by any predator  $i$ , where either the swept area estimate of abundance or stock assessment value for each predator for each year were used, with a cutoff of 20 cm to exclude predators incapable of consuming butterflyfish. These predator species-specific consumptions were then summed across all  $i$  predators to estimate a total amount of butterflyfish removed by all consistent butterflyfish predators.

## Results

Total consumptive removals by all consistent butterflyfish predators exhibited two increasing trends, one in the early to mid 1980s and another more recently (Figure B.6.1.a). These estimates have averaged around 4-6 MT yr<sup>-1</sup>. When examining only the amount of consumptive removals by age class, the same trends and patterns follow, with most of the consumption being on adults (~80%) (Figure B.6.1.a). For more explicit presentation of the step-by-step consumptive removal results, please contact the working group, as has been done in prior assessments (NEFSC 2007a, 2007b).

When comparing the total amount of butterflyfish consumed by all predators to landings (Figure B.6.1.b), landings dominated earlier in the time series (1970s), but some of the same patterns (or at least magnitudes) were seen in the 1980s for both estimates. Finally, since the early 2000s consumptive removals are a much larger source of removals than are landings.

## Sources of Uncertainty

1. Minimum swept area estimates for some predator abundance does not account for  $q$  for all predators; these are likely lower estimates of predator abundance and thus these consumption estimates should be viewed as conservative estimates.
2. Size cutoffs to allocate between juvenile and adult butterflyfish assumed fixed and consistent sizes across predators and time; they may be more dynamic.
3. Is the  $\alpha$  too low compared to literature? These too may be somewhat conservative, but are within the range of those generally reported.
4. Some fish predators that did not consistently eat butterflyfish (e.g. pollock) were dropped.
5. Also, these estimates did not include a wide range of other (non-fish) predators known to consume butterflyfish (e.g., seabirds, squids, marine mammals). Collectively this relatively limited set of predators thus may result in these being fairly conservative estimates of overall predatory removals of butterflyfish.
6. Spatio-temporal overlap considerations between predators and butterflyfish were not taken into account fully.
7. Diet compositions of butterflyfish in these predators amount to a relatively small amount. Thus these estimates may either be an underestimate of diet composition

contributed by butterfish or reflective of non-preference by predators for butterfish.

### **Summary**

1. Total consumption of butterfish is on the same order of magnitude as estimates of butterfish stock landings.
2. Total consumption of butterfish exhibits similar trends as landings estimates, until recent years.
3. Butterfish were usually coincident with squid in the diets of these predators (not shown).
4. Variances about these estimates (available, not shown) have CVs on the order of 0.5 to 1, often much tighter than estimates of butterfish discard/bycatch (see above).
5. Instead of increasing uncertainty, incorporating information on consumption of butterfish may actually help to better inform and improve model fitting.
6. It is feasible to calculate M in this context
7. Ignoring some form of dynamic M may provide misleading BRPs, or least result in incorrectly scaled model results (estimates of B, F, etc.).

### **Recommendations**

1. At the least, consumptive removals should be able to be used as a qualitative index in butterfish assessment, providing context.
2. These results provide further justification for modifying M (to be dynamic) in the assessment model, which should be modeled explicitly.
3. Consumptive removals may be able to be included as a covariate to a dynamically modeled M.
4. Even a simple ratio of Consumptive Removals/Biomass can be used to scale, inform and approximate M used in the model apart from a separate estimation procedure for M.
5. The Consumptive removals are able to be incorporated as a separate “fleet” a la Overholtz et al., Moustahfid et al., etc., and this should be done.
6. Incorporating Consumptive removals should help to stabilize, inform and otherwise improve the KLAMS model as an ESAM.
7. Partitioning total mortality into Z and M2 (with some minimal assumed M1) will have implications for projections and BRPs, but it is feasible.
8. Extant Multispecies models should also be considered to provide further context; although not shown, they confirm these general consumptive removal results.
9. Given the high co-occurrence of butterfish with squids-- in time, space, and the fishery-- future assessments should consider a joint assessment of these species using some form of MS model. Such models are extant and have been reviewed, albeit not for this particular application.

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## **Appendix B2: Coastal/Pelagic Working Group**

### ***Coastal/Pelagic Working Group***

Meeting September 21-22, 2009

Woods Hole, MA

November 4, 2009

Woods Hole, MA (conference call/Webex)

Dr. Timothy Miller – NEFSC – lead assessment scientist  
Dr. Chris Legault – NEFSC  
Lisa Hendrickson – NEFSC  
Dr. Paul Rago – NEFSC- chief, Population Dynamics Branch  
Katherine Sosebee – NEFSC  
Dr. Mark Terceiro – NEFSC  
Dr. Jason Link – NEFSC  
Gary Shepherd – NEFSC – chair Coastal/Pelagic  
Carrie Nordeen – NMFS RO  
Dr. Olaf Jensen – Industry advisor  
Dr. Vidar Wepstead – Industry advisor  
Jason Didden – MAFMC  
Greg DiDomenico – Garden State Seafood Association  
Brad Sewell – Natural Resources Defense Council  
Pamela Lyons Gromen – Natural Resources Defense Council

### Appendix B3: Butterfish predators

Species of consistent butterfish predators.

Smooth Dogfish	<i>Mustelus canis</i>
Spiny Dogfish	<i>Squalus acanthias</i>
Silver Hake	<i>Merluccius bilinearis</i>
Summer Flounder	<i>Paralichthys dentatus</i>
Bluefish	<i>Pomatomus saltatrix</i>
Goosefish	<i>Lophius americanus</i>

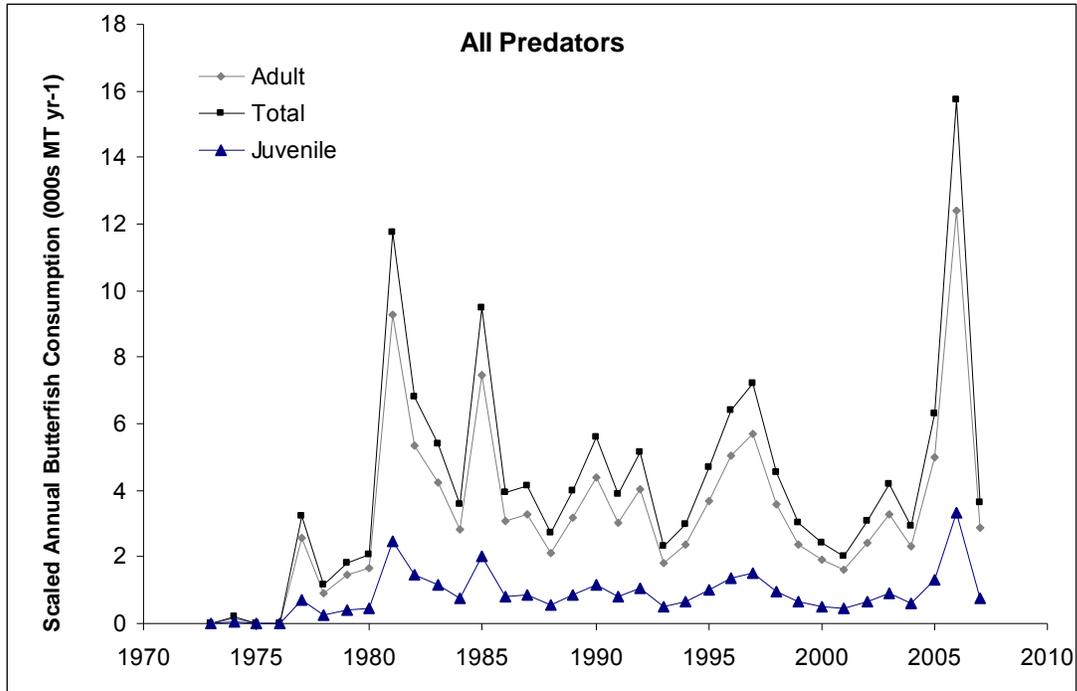


Figure B3.1.a. Total butterfish biomass consumed by all predators. The total is split into juvenile and adult butterfish consumed

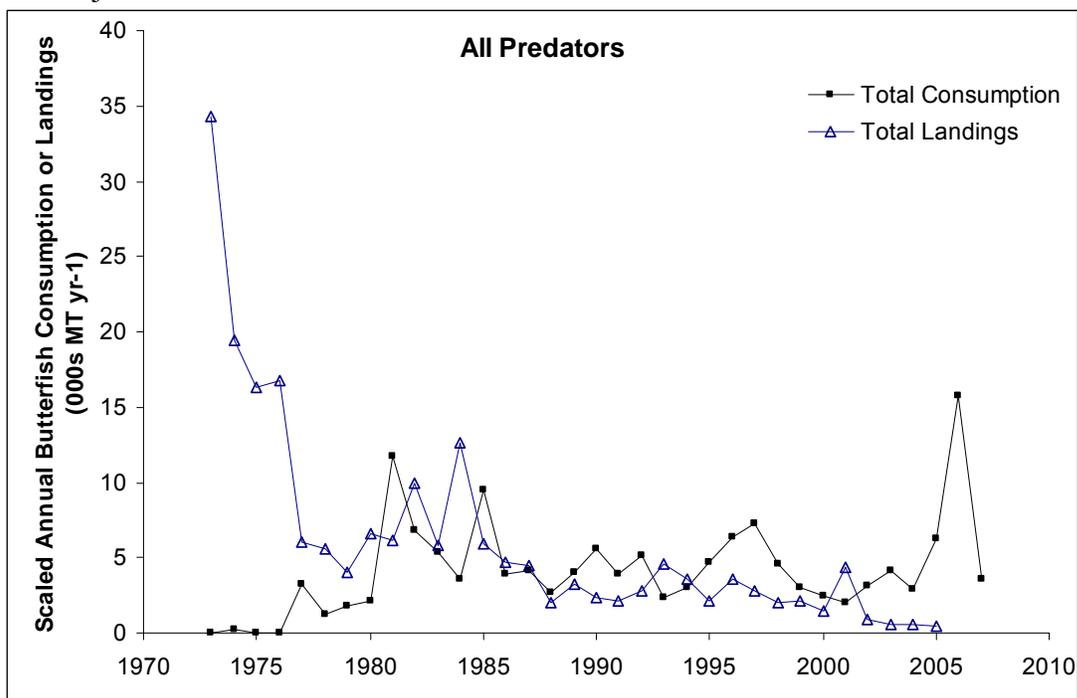


Figure B3.1.b. Total butterfish biomass consumed by all predators compared to butterfish landings.

## Appendix B4: Envelope Method

Stock assessment models typically incorporate two primary sources of information: estimates of total catch (landings plus discards), and fishery-independent indices of abundance. The former quantities provide estimates of population scale, the latter quantities provide measures of trend. Total catch provides some insight into the scale of the population but without additional information it is impossible to determine if total catch is the result of a low fishing mortality rate applied to a large population or a high fishing mortality rate applied to a small population. Fishery independent stock size estimates from trawl surveys, expressed in terms of average catch per tow, approximate the true population size subject to an arbitrary scalar that reflects gear efficiency, availability, and the variability in the realization of the sampling design. Collectively these factors are called catchability and denoted as the parameter  $q$ .

The uncertainty in the interpretation of these two basic quantities is addressed explicitly in an assessment model but the underlying relationships can be obscured by complexity of the mathematics and tradeoffs among poorly estimated parameters. Here we propose a simple approach to reconcile these perspectives on stock size that provides a feasible range or “envelope” of population sizes. The purpose of this exercise is not to replace the delay-difference model used in this assessment. Instead the purpose is to demonstrate that the assessment model is consistent with the implications simpler measures of stock size.

Let  $I_t$  represent the observed index of biomass at time  $t$  and  $C_t$  represent the catch at time  $t$ . The estimated total biomass consistent with the index is

$$B_t = \frac{I_t}{q} \quad (1)$$

where  $q$  is an assumed value. The biomass consistent with observed catch can be obtained from the catch equation as

$$B_t = \frac{C_t}{\frac{F}{F+M} (1 - e^{-(F+M)})} \quad (2)$$

where  $F$  is unknown. Thus biomass can be written as a function of arbitrary scalars  $q$  and  $F$ . These equations can be generalized and written as

$$\begin{aligned} \hat{B}_{1,t} &= B(I_t, q_{Low}) \\ \hat{B}_{2,t} &= B(I_t, q_{High}) \\ \hat{B}_{3,t} &= B'(C_t, F_{Low}, M) \\ \hat{B}_{4,t} &= B'(C_t, F_{High}, M) \end{aligned} \quad (3)$$

In theory the above measures of stock biomass should be consistent. Prior information on the suitable range for  $q$  can be obtained from analyses of relative survey catchability as detailed in the main body of the report. The suitable range of  $F$  values can

obtained from analogy with other fisheries, or more simply by picking a wide range of values.

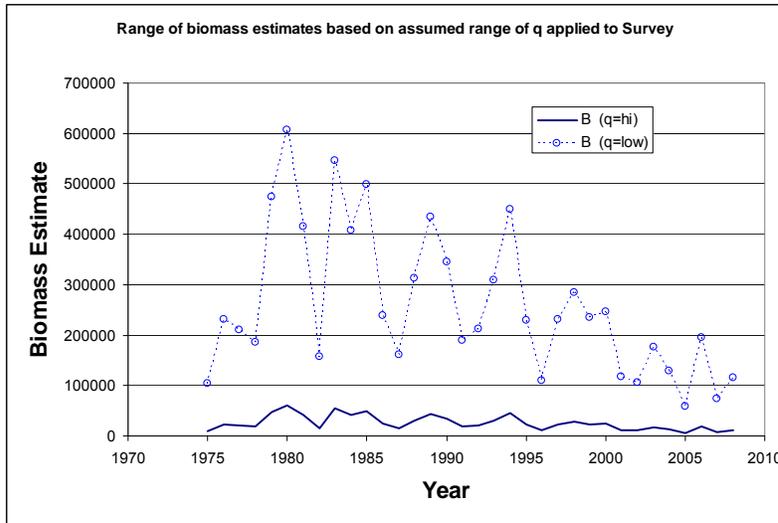
By inspection it is evident that  $B_{1,t}$  and  $B_{3,t}$  constitute an upper range, and  $B_{2,t}$  and  $B_{4,t}$  constitute a lower range. Upper and lower bounds consistent with these estimates are

$$\begin{aligned}\widehat{B}_{upper,t} &= \min(B_{1,t}, B_{3,t}) \\ \widehat{B}_{lower,t} &= \max(B_{2,t}, B_{4,t})\end{aligned}\tag{4}$$

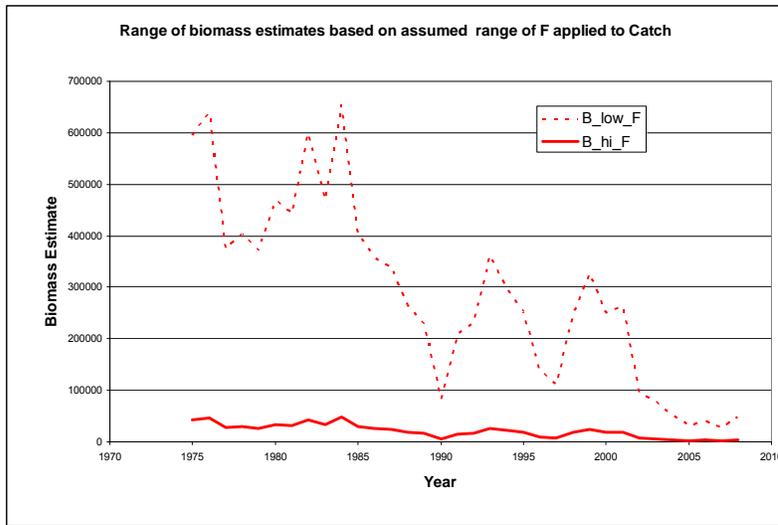
These bounds describe a set of feasible options that are consistent with the assumed ranges of  $q$  and  $F$ . In theory, a more sophisticated population model should lie within this feasible range.

Figure B.B1 illustrates the application of the envelope method using equations 1 to 4. Results suggest that biomasses necessary to support observed catches in the early 1980's were as high as 400,000 mt. Current population sizes since 2001 are likely to have been below 100,000 mt. The trend in minimum biomass estimates (high  $F$ , high  $q$ ) is less pronounced but similar in relative trend. A comparison with biomass estimates from the final model run (Figure B.B2).

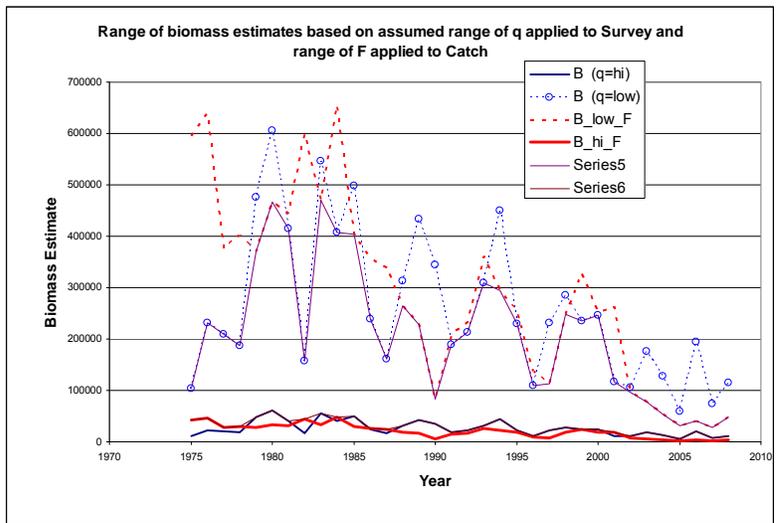
The envelope concept can also be extended to compute a range of feasible  $F$  values consistent with derived biomass estimates from Eq. 4. Assuming that  $B_{1,t}$  and  $B_{2,t}$  approximate average biomass at time  $t$ , then the ratio of  $C_t$  to  $B_{1,t}$  or  $B_{2,t}$  is a measure of biomass weighted  $F$ . These estimates can then be compared directly with the estimates of  $F$  from the KLAMZ model. Figure B.B3 suggests a comparable range of values except in 2003 to 2008. In these years the model-based estimate of  $F$  was about 0.03 which was lower than the lowest value of  $F$  ( $=0.05$ ) used to construct the biomass series based on  $B_{3,t}$ .



A.



B.



C. Superposition of A and B with feasible set identified by Eq. 4.

Figure B4.1. Illustration of the envelope estimation method for the NEFSC fall survey index (A), and total catch (B). Panel C represents the feasible envelope of biomass estimates.

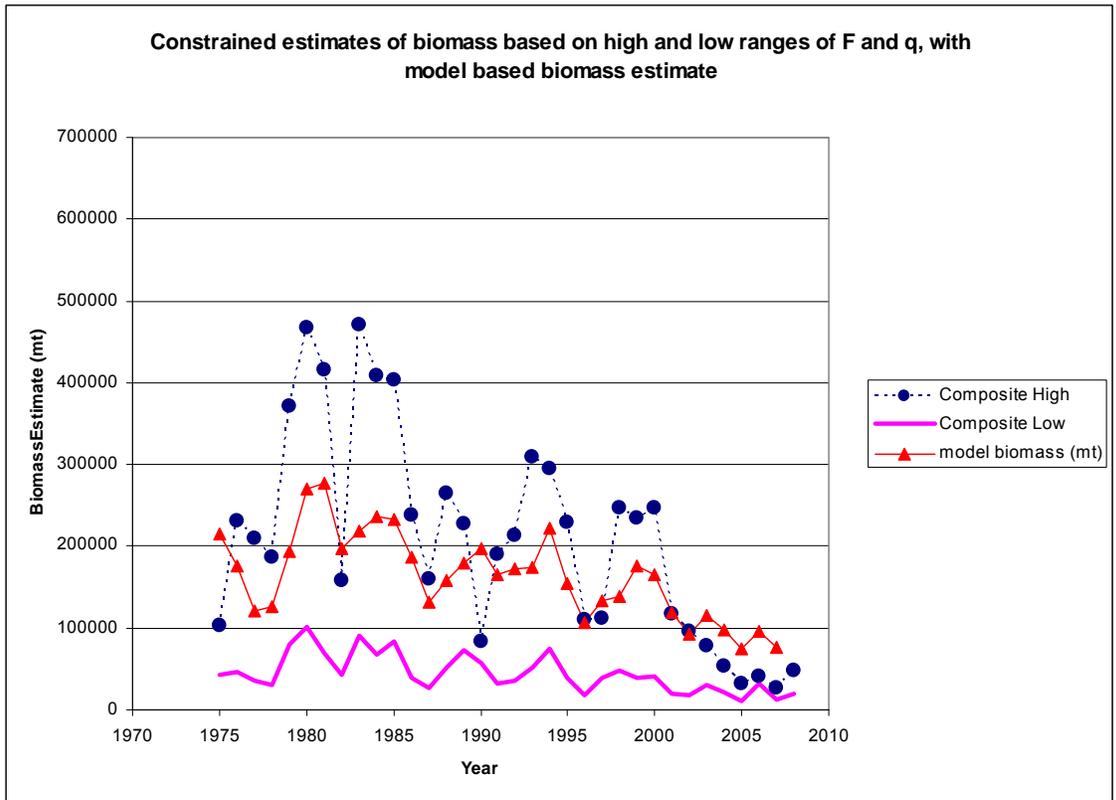


Figure B4.2. Comparison of the envelope measure of stock biomass with model based estimates.

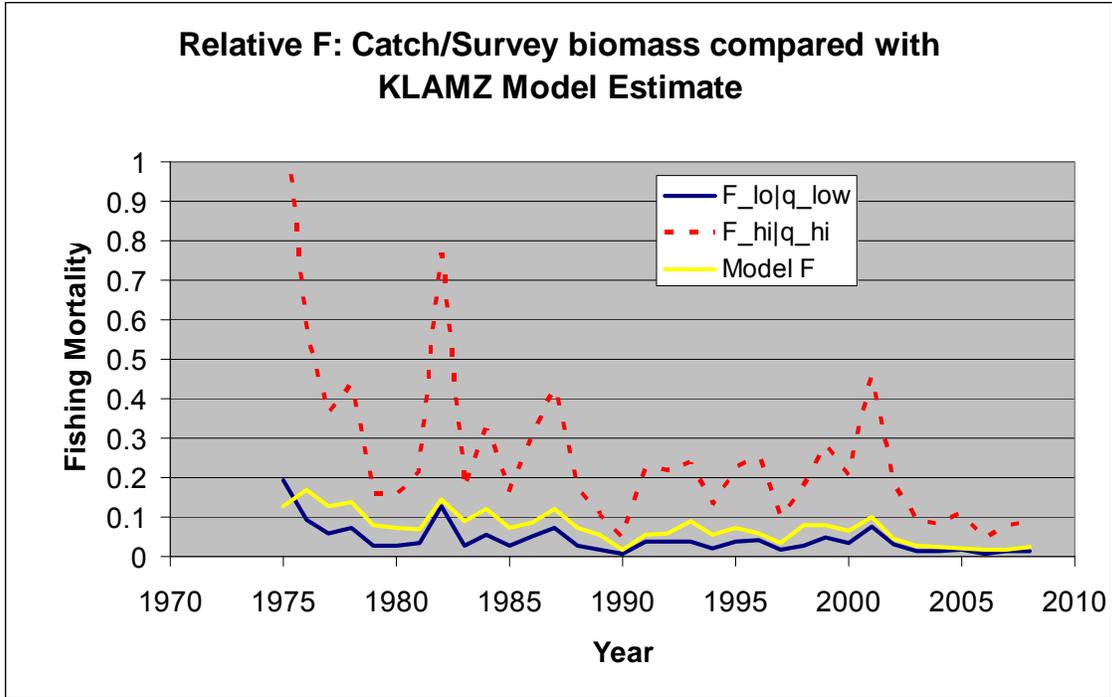


Figure B4.3. Comparison of KLAMZ estimate of fishing mortality with envelope derived from ratio of  $C_t$  to  $B_t$  derived from assumed range of  $q$  applied to survey indices.

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