A. ATLANTIC SURFCLAM STOCK ASSESSMENT IN THE US EEZ FOR 2013

Terms of reference for Atlantic surfclam

1. Estimate catch from all sources including landings and discards. Describe the spatial and temporal patterns in landings, discards, fishing effort and LPUE. Characterize the uncertainty in these sources of data.

2. Present the survey data being used in the assessment (e.g., regional indices of abundance, recruitment, state surveys, age-length data, relevant cooperative research, etc.). Investigate the utility of commercial LPUE as a measure of relative abundance. Characterize the uncertainty and any bias in these sources of data.

3. Evaluate the current stock definition in terms of spatial patterns in biological characteristics, population dynamics, fishery patterns, the new cooperative survey, utility of biological reference points, etc. If appropriate, recommend one or more alternative stock definitions, based on technical grounds. Integrate these results into TOR-4.

4. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series (integrating results from TOR-3), and estimate their uncertainty. Include a historical retrospective analysis to allow a comparison with previous assessment results. Review the performance of historical projections with respect to stock size, recruitment, catch and fishing mortality.

5. State the existing ***stock status*** *definitions for "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; point estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, F_{MSY} and MSY) and provide estimates of their uncertainty. This should be carried out using the existing stock definition and, if possible, for the recommended "alternative" stock definitions from TOR-3. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the appropriateness of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.*

6. Evaluate stock status with respect to the existing assessment model and with respect to any new assessment model. Determine stock status based on the existing stock definition and, if appropriate and if time permits, for "alternative" stock definitions from TOR-3.

- *a.When working with the existing model, update it with new data and evaluate stock status (overfished and overfishing) with respect to the existing BRP estimates.*
- *b. Then use the newly proposed model and evaluate stock status with respect to "new" BRPs and their estimates (from TOR-5).*

7. Develop approaches and apply them to conduct stock projections and to compute the statistical distribution (e.g., probability density function) of the OFL (overfishing level) and candidate ABCs (Acceptable Biological Catch; see Appendix to the SAW TORs).

- *a. Provide numerical annual projections (3-5 years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment).*
- *b. Comment on which projections seem most realistic. Consider the major uncertainties in the assessment as well as sensitivity of the projections to various assumptions.*
- *c. Describe this stock's vulnerability (see "Appendix to the SAW TORs") 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 the most recent SARC reviewed assessment and review panel reports. Identify new research recommendations.

Executive Summary

TOR 1. Commercial fishery

About 20,000 mt of surfclam meats (18,600 mt from federal waters) were landed during 2011. Total landings were down slightly from the last assessment (22,519 mt in 2008). Landings during 2011 were mostly from the New Jersey (NJ 64%), Southern New England (SNE 13%) and the Georges Bank (GBK 13%) regions. The Long Island (LI) and Delmarva (DMV) regions supplied about 10% of total landings. About 74% of the total effort in 2011 occurred in NJ, with an additional 15% occurring in SNE. Landings per unit effort (LPUE) were near record low levels, approximately 40 – 60 bushels (bu) per hour except in GBK where they were approximately 290 bu h^{-1}. Commercial surfclam data are considered accurate and precise relative to many fisheries because there is no discarding and few active permits. Landings are reported both in log books and by dealers.

TOR 2. Survey

NEFSC survey data were collected in 2011 aboard the *RV Delaware II*. Recruitment of small surfclams (50 – 119 mm) for the whole EEZ stock has increased since 2005 based on survey data. Survey catch of larger surfclams recruited to the fishery (120+ mm) has been stable since 2005. Despite positive trends, both recruitment and number per tow were below average for the time series. NEFSC, Industry and academic collaborators conducted depletion and selectivity experiments from the *FV Pursuit* in 2011. New estimates of survey dredge efficiency, and selectivity were produced, as well as refinements to shell height to meat weight relationships and growth curve estimates. Age and size composition data from survey catches were used in the primary assessment model for the first time.

TOR 3. Stock definition

The current definition is a single EEZ surfclam stock which extends from Georges Bank (GBK) in the north to Southern Virginia – SVA. An alternative definition would divide the surfclam stock into northern (GBK) and southern (Southern Virginia - SVA to SNE) components. The Invertebrate Subcommittee discussed the technical merits of both approaches but no consensus was reached and conclusions were left to reviewers. The SARC56 Panel concluded the material presented did not contain sufficient information to allow it to reach a decision on stock definition. The SARC Panel noted that this does not prevent the stock assessment from being conducted by subareas, nor does it preclude area-based management. Arguments for and against both options are presented concisely in tabular form with a brief introduction.

TOR 4. Model results

The primary assessment model was a statistical catch at size model, Stock Synthesis (SS3), instead of the biomass dynamic delay difference model (KLAMZ), used previously. Using SS3 allowed the working group to make use of age and size composition data for the first time. Additional changes to the assessment model included: new estimates of capture efficiency, size selectivity, growth curves, shell length to meat weight formulas, and a new approach to modeling the stock, where the GBK and southern areas were modeled separately. Results indicate that biomass was higher and fishing mortality rates that were lower than in previous assessments. In general, population trends appear well estimated while population scale (overall level of biomass in mt) was uncertain.

TOR 5. Stock status definitions

The current overfished threshold for surfclams is ½ B_{MSY} proxy = ¼ B_{1999} and the biomass target is ½ B_{1999}. The overfishing threshold is F=M=0.15. The fishing mortality reference point was considered adequate under either the current or alternative stock definition and no changes were recommended in this assessment.

Biomass reference points depend on which stock definition is adopted. The biomass reference point was considered adequate for the current stock definition and for the southern part of the resource. However, it was not possible to estimate B_{MSY} or a proxy for GBK in the time available because surfclams on GBK have had little exploitation, biomass has changed substantially there in the absence of fishing, environmental conditions are changing and the response of surfclams to fishing could not be predicted. A B_{MSY} proxy for GBK may be an important topic for future research but the question does not affect status determinations in this assessment given that the GBK area is essentially unexploited and cannot, by definition, be overfished.

TOR 6. Stock status

The surfclam population is not overfished and overfishing is not occurring under either the current or alternative stock definitions.

TOR 7. Projections

Projections indicate that the population is unlikely to be overfished and that overfishing is unlikely to occur by 2021 under either, the current or alternative stock definitions and a wide range of assumed catches.

TOR 8. Research recommendations

Research recommendations are discussed.

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 (Figure A1), with major concentrations on Georges Bank, the south shore of Long Island, New Jersey and the Delmarva Peninsula. Surfclams are found from the intertidal zone to a depth of 128m but the highest concentrations 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, which burrow energetically, inhabit medium-grained sand, although they can also be found in fine or silted sand.

Surfclams are the largest bivalves in the western North Atlantic, reaching a maximum size of about 22 cm (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 6-7 years. Weinberg (1998), and Weinberg and Helser (1996), show that growth rates vary among regions, over time, and in response to surfclam density levels. Slower growth in surfclams in DMV and NJ during recent years coincides with mortality in near shore areas probably due to warm water (Weinberg et al 2005)

Surfclams taken in the NEFSC clam surveys are aged regularly. The surfclam shells are sectioned through the chondrophore (the attachment surface for the "hinge" ligament) and the annuli (rings) are counted. Surfclams age 30+ are relatively common and the maximum observed age exceeds 37. Most surfclams have recruited to the fishery (reached a shell length of 12 cm) by the time they are six or seven years old.

Surfclams can reach sexual maturity at three months of age (Cargnelli et al.1999). Sexes are separate, but are not distinguished in either commercial or NEFSC survey data. Spawning is thought to occur 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. Settlement to the bottom occurs after 19 to 35 days, depending on the temperature. Relationships between age/size, functional maturity and effective fecundity have not been precisely quantified.

There are two subspecies of Atlantic surfclam: The offshore subspecies *Spisula solidissima solidissima,* to which this assessment refers, and the smaller coastal subspecies (*Spisula solidissima similis*) that occupies relatively southern inshore habitats (Weinberg et al 2010). The geographic distributions of the two subspecies overlap to a limited extent in the south and in some inshore waters to the north. However, *S. s. similis* is reproductively isolated from *S. s. solidissima* and not important to the federal commercial fishery. It is likely that all *Spisula solidissima similis* along the northeast coast belong to the same biological population.

See Cargnelli et al. (1999) for a more detailed review of life history and distributional information.

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. The state of the inshore portion of the resource is discussed in Appendix A1.

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.

Because the surfclam fishery is highly localized 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 (and see Figure A1)

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Abbreviation	Assessment region
SVA	S. Virginia to N. Carolina
DMV	Delmarva
NJ	New Jersey
LI	Long Island
SNE	Southern New England
GBK	Georges Bank

The southern area consists of the regions from SVA to SNE, excluding only GBK (Figure A2). SVA is at the southern end of the species range and of relatively little importance to the stock as whole.

Georges Bank was closed to surfclam harvesting between 1989 and 2009 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. Since 2009, limited fishing on GBK has been allowed under an exempted fishing permit for the purposes of testing the PSP safety protocols developed by industry. GBK is open for fishing as of January 1, 2013, contingent on continuous testing and the absence of PSP.

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. Surfclams were previously assessed in 1992, 1994, 1997, 1999, 2003, 2005, and 2008 (NEFSC 1993, 1995, 1998, 2000, 2003, 2007, 2010). The most recent stock assessment for surfclams, NEFSC (2010) concluded that the stock was above the biomass threshold (the stock was not overfished) and that fishing mortality was below the overfishing threshold (overfishing was not occurring). However, biomass was projected to decline gradually through 2014, because recent recruitment had been low and was likely to remain low over the next five years. The uncertainty of these predictions was high due to uncertainty regarding future conditions. A "historical retrospective" analysis in this assessment includes biomass and fishing mortality estimates from previous assessments.

During the NEFSC clam surveys aboard the *R/V Delaware II*, clams were 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, shot 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 turn the sea bottom into a fluid, which allows the clams to be captured more easily.

Uncertainty in assessment results and the necessity for additional research on abundance were highlighted by NEFSC (1995) because survey catch rates were anomalously high during the 1994 survey in some regions. The anomalously high catch rates were apparently due to a change in voltage supplied to the pump on the survey dredge towed by the *R/V Delaware II*, which increased capture efficiency. Subsequently, a major effort has been made to monitor and improve understanding of the performance of the dredge used in NMFS clam surveys.

Sensors, first deployed in 1997, are used in clam surveys 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. The dredge has been operated in a consistent fashion using the same survey protocols and gear since 1997. In particular, the criteria used to reject bad tows for trend analysis have not changed. 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.

Cooperative depletion experiments are an important part of surfclam stock assessments. 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 analysis of data from four new depletion experiments.

This assessment (also described in NEFSC 2013) estimates fishing mortality and stock biomass with efficiency-corrected swept-area biomass calculators, the KLAMZ model, and Stock Synthesis, the main assessment model.

Commercial Catch (TOR-1)

Commercial landings are reported as meat weights in this assessment 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 usable meats. Landings per unit of fishing effort (LPUE) data are reported in this assessment as landings in bushels per hour fished, based on clam logbook reports. The spatial resolution of the clam logbook reports is usually one ten-minute square.

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

As in previous assessments (NEFSC 2010), for all stock assessment analyses "catch" is defined as 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. It is an upper bound; actual incidental mortality is likely to be lower. Incidental mortality to the total surfclam resource is likely low because the total area fished (e.g. 155 km^2 during 2004) is small relative to the spatial area of the resource (Wallace and Hoff, 2005). The ITQ fishery operates with little or no regulation-induced inefficiency (e.g. 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.

<u>Discard data</u>

Discards were zero during 2008-2011 (since the last assessment). Some discards occurred during 1979-1993 (Table A1). No new information about discards was available for this assessment.

<u>Age and size at recruitment to the fishery</u>

Age at recruitment to the surfclam fishery depends on growth rates which vary geographically. Recruitment appears to occur earlier in northern regions. In previous assessments (and in the KLAMZ model discussed in this assessment), commercial selectivity was assumed be knife-edged at 120 mm. Growth curves used in stock assessment modeling (described later) indicate that surfclams reach 120 mm SL and recruit to the fishery at the estimated age of about 6 y south of Georges Bank where most fishing occurs (Figure A2). The age at recruitment depends on the area being modeled (north vs. south), the time period in question, as growth may change over time. Size at recruitment depends on the fishery selectivity estimated in the model. This issue is discussed in detail in the section describing stock assessment modeling (TOR 4).

Landings, fishing effort and prices

Landings and fishing effort data for 1982-2011 were from mandatory logbooks (similar but more detailed than Vessel Trip Reports used in the groundfish fishery) with information on the location, duration and landings of each trip. Data for earlier years were from NEFSC (2003) and MAFMC (2006).

Landings data from surfclam 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 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 2011 (Table 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 18 and 25 thousand mt during 1985 to 2011. 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 the DMV region during 1979-1980. After 1980, the bulk of landings were from the NJ region (Table A3 and Figure A4). During recent years, EEZ landings from the NJ region have been about 64% of the total, DMV about 8%, and LI and SNE combined about 16%. 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 the tendency of the fishery to move north towards lightly fished areas where catch rates were higher. Landings from GBK were 13% of the total in 2011. Only three vessels were allowed to fish there, and were under the restrictions of an Experimental Fishing Permit. The high proportion of landings on GBK reflects the high catch rates there (see below).

Fishing effort has increased substantially since 1999, particularly in the DMV and NJ regions (Table A4 and Figure A5). The bulk of the fishing effort is in areas where the majority of landings come from. Fishing effort, however, has been increasing in the DMV and NJ regions as the LPUE has declined (see below).

Nominal ex-vessel prices for the inshore and EEZ fisheries have been stable, fluctuating around $9 to $11 per bushel since the mid-1990s (Table A5 and Figure A6). Ex-vessel prices (1991 dollars) decreased steadily in real terms from about $9 per bushel during the mid-1990s to less than $6.50 per bushel during 2008, before stabilizing at approximately $6.80 between 2009 and 2011. Nominal revenues for surfclam during 2011 were about $29 million, making the ITQ surfclam fishery one of the most valuable single species fisheries in the US. In 2011, the ITQ component accounted for 93% of total landings and revenues (Figure A3).

Landings per unit effort (LPUE)

Nominal landings per unit effort (LPUE) based on logbook data was computed as total landings divided by total fishing effort for all vessels and all trips (Table A6. and Figure A7.). Standardized LPUE was not estimated for this assessment because the data are not used analytically and because NEFSC (2007) showed that nominal and standardized trends were almost identical when standardized trends were estimated in separate general linear models for each region with vessel and year effects.

Nominal LPUE has been declining steadily across all regions (except GBK) since 2000. LPUE levels in, NJ, LI and SNE have been at or near record lows, falling to an estimated 41 to 44 bushels per hour in 2011. The only region aside from GBK showing a recent increase in LPUE is DMV which increased from 49 to 60 bushels per hour between 2010 and 2011. LPUE in GBK reached 352 bushels per hour in 2010 and 285 bushels per hour in 2011.

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 2010).

Spatial patterns in fishery data

Annual landings, fishing effort and LPUE were calculated by ten-minute square (TMS) from 1979-2011 (Appendix A2) and mean landings, fishing effort and LPUE were calculated by TMS for five time periods: 1980-1990, 1991-1995, 1996-2000, 2001-2005 and 2006-2011 (Figures A8 – A10). Only TMS where more than ten bu of surfclams (estimated by weight) were caught over the time period were included in the maps. TMS with reported landings less than 10 bu were probably in error, or from just a few exploratory tows. Inclusion of TMS, with less than 10 bu distorted the graphical presentations because the area fished appeared unrealistically large.

Figures A8 – A10 show the spatial patterns of the surfclam fishery over the past 32 years. In all the years, the greatest concentration of fishing effort and landings occurred in the same thirty or so TMS in the NJ region, with intermittent fishing activity in other regions. For example, during the first ten-year time period, from 1981 to1990, the highest landings and fishing effort were still concentrated off NJ, but there were some landings and fishing effort mostly offshore in DMV and SVA, and some fishing activity in SNE off of Martha's Vineyard (about 41^{o}N 70^{o}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 2006-2011, some landings came from a small offshore area in DMV, and fishing north of NJ has been mostly limited to the waters adjacent to Long Island and the experimental fishing on GBK.

TMS with the highest LPUE levels over time have been mostly in the NJ and DMV regions with irregular contributions from GBK and the Nantucket Shoals region of SNE. The exception is DMV during 2006-2011, where LPUE is noticeably lower.

Important TMS

TMS “important” to the fishery were identified by choosing the 10 TMS from with the highest mean landings during each of the following time periods 1980-1990, 1991-1995, 1996-2000, 2001-2005 and 2006-2011. For example, a TMS important during 1991-1995 could be selected regardless of its importance during earlier or later time periods. The list contains a total of 28 important TMS, because of overlap between the time periods and because the same TMS tend to remain important. The large majority of important TMS were in the NJ region (18), with 6 in the DMV region, 2 in SNE 1 in GBK. LI and SVA did not qualify in any of the time periods we examined. These plots are complicated by the “rule of three” which states that fine scale fishing location data cannot be shown for areas fished by three or fewer vessels due to confidentiality concerns. Therefore, some otherwise important TMS cannot be depicted here because they were fished by a small number of vessels. Trends in landings, effort and LPUE were plotted (Figures A11 – A13) for each TMS to show changes in conditions over time within individual TMS.

Landings and especially effort have increased recently in one TMS in the DMV region that has historically been lightly fished, but trends show most of the important TMS in the DMV region have seen declining effort and landings over time. Several have not had any reported landings in recent years. Landings and effort have increased in two important TMS in NJ and two in SNE, and appear to be increasing recently (although they are still at low levels) in one of the two NJ TMS that have continuously supported the highest landings in the region for the last 30 years.

With the exception of GBK, there are very few important ten-minute squares in which the LPUE has trended upwards 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. Samplers began collecting from SNE once again in 2010 and collected over 2000 lengths in 2011. 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 – A18). Surfclams from the SNE region are larger than surfclams from more southern areas. 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. Commercial size distributions are discussed in detail in the SS3 model section (see below).

NEFSC and Cooperative clam surveys (TOR-2)

Survey data used in this assessment were from NEFSC clam surveys conducted during 1982-2011 by the *R/V Delaware II* during summer (June-July), using a standard NEFSC survey hydraulic dredge with a submersible pump. The survey dredge had 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 differed from commercial dredges because it was smaller (5 ft instead of 8-12.5 ft blade), had the small mesh liner, and because the pump was mounted on the dredge instead of the deck of the vessel. The survey dredge was 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 were 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 Georges Bank (GBK) during 2005 and provided marginal coverage in 1982, 1983, and 1984. Individual strata in other areas were sometimes missed. Strata and regions not sampled during a particular survey were “filled” for assessment purposes by borrowing data from the same stratum in the previous and/or next survey, if these data were available (Table A8.). Survey data were 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 adopted. A model-based imputation was investigated for this assessment, but the imputation tended to over-emphasize unsampled years and areas. Alternative approaches to imputing missing strata remain a possibility but were not further pursued in this assessment.

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 were ignored and survey catches were adjusted to a standard tow distance of 1.5 nm based on ship's speed and tow start/ stop times recorded on the bridge.

Stations used to measure trends in surfclam abundance were 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. This generally occurred when stake holders or the assessment lead wished to increase sampling intensity in a stratum of particular interest. Stations added this way were different from other random stations in that they deviated from the pre-determined sampling design described above. They were otherwise random with respect to location within a stratum and thus are called "quasi random". Other non-random stations are occupied for a variety of purposes (e.g. depletion experiments) but not used to estimate trends in abundance.

Occasionally, randomly selected stations are too rocky or rough to tow through, 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 considered 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 almost all survey tows, all Atlantic surfclams in the survey dredge were counted and shell length was measured to the nearest mm. A few very large catches were subsampled. Mean meat weight (kg) per tow was computed with shell length-meat weight (SLMW) equations (updated in this assessment) based on fresh meat weight samples obtained during the 1997-2011 surveys (see below).

Locations and catches of all stations in the 2011 survey have been mapped (Figure A19.) and maps for previous surveys can be found in Appendix A3.

Survey tow distance and gear performance based on sensor data

There are some applications where it is desirable to know the tow distance with more certainty than is provided using the nominal tow distance. Beginning with the 1997 survey, sensors were used to monitor depth (ambient pressure), differential pressure (the difference in pressure between the interior of the pump manifold and the ambient environment at fishing depth), voltage, frequency (hertz) and amperage of power supplied to the dredge, x-tilt (port- starboard angle, or roll), y-tilt (fore-aft angle, or pitch) and ambient temperature during survey fishing operations. At the same time, sensors on board the ship monitor electrical frequency, GPS position, vessel bearing and vessel speed. Most of the sensor data are averaged and recorded at 1 second intervals. These metrics of tow performance can be used to accurately gauge the true distance fished by the dredge.

Analysis of sensor data from the 2011 NEFSC survey

The survey sensor package (SSP) was deployed on the NEFSC clam survey dredge during the 2011 survey. The SSP provided differential pressure measurements on 187 out of 430 total tows. On other tows (generally between tows 161 and 371) the SSP did not function properly. Back up sensors (Vemco Minilog depth/temperature recorders) failed to produce useful information due a gradual calibration drift that overlapped the period during which no SSP data was recorded. Because the shift in baseline pressure was systematic and began at an unknown point, no data from the Minilog recorders was used. Electric current supplied to the pump on the survey dredge was successfully logged for every tow (Figure A20).

A predictive relationship exists between the electric current supplied to the dredge and the differential pressure in the dredge pump manifold (Figure A21). This relationship was explored in the previous assessment (NEFSC 2009). The previous assessment provided a tolerance point for minimum differential pressure of 35 PSI based on analysis of dredge operation (NEFSC 2009). The current approach maintains that minimum tolerance but does not use the previous upper bound for differential pressure (40 PSI), because pump pressure was generally higher in 2011 (Figure A22).

The parameters estimated in 2009 do not provide a good fit to the data from the 2011 survey. It is likely that the operating specifications have changed somewhat due to alterations in procedure and equipment. For example, the dredge pump was rebuilt and the electrical supply line was replaced after the 2009 survey. These pieces of equipment will have slightly different properties from those used in 2009, and thus produce a subtly different relationship between current and differential pressure.

We compared four different models for predicting differential pressure from current supplied to the pump. We used only current measured while the dredge was fishing (fishing seconds - see below). Current was the smoothed mean (7 second moving average) of three different amperage meters on the research vessel. Our models were fit to the smoothed (7 second moving average) differential pressure recorded by the SSP for the 187 tows where it functioned (Figure A21). The models tested were: a simple power function (M1), the model fit to the data from 2009 (M2), a cubic spline (M3) and a Loess spline (M4, Figure A23). Model selection was based on the models ability to correctly distinguish the tows with SSP data in which differential pressure that was above or below tolerance (35 PSI). Predicted differential pressure was plotted against observed values. Where predicted and observed values were together above or below the tolerance line, the model was considered to have segregated correctly. When the predicted and observed values did not agree on whether or not the differential pressure was above 35 PSI, the model failed to segregate correctly. The cubic spline model produced the highest percentage of correctly segregated points (Figure A24).

The cubic spline fit was then used to predict the differential pressure for all tows, including those for which we measured differential pressure. If the model predicted differential pressure was below 35 PSI for more than 25% of the fishing seconds that tow was considered a "bad" and not used in this assessment for calculating swept area abundance or biomass from surveys since 1997 (Table A9). These tows were, however, used in conventional trend analysis, unless there was an obvious problem noted by the survey crew, because historical surveys did not have sensors.

Determination of time fishing

The determination of time fishing, the "fishing seconds" for each tow was based on a measurement of the pitch of the dredge during each second of the tow. Pitch was recorded by two different instruments: the SSP, which functioned intermittently, and a Star Oddi inclinometer which functioned consistently. Data from each instrument was smoothed using a 7 second moving average and then parsed for time below the "critical angle".

The choice of critical angle has implications for the calculation of tow distance for each tow. When the dredge is above the critical angle it is assumed to be pitched too steeply for the blade to penetrate the sediment. If the dredge is pitched below the critical angle, it assumed to be near enough to horizontal that the blade should penetrate and thus be actively fishing.

An ideal critical angle is as close to zero as possible. When the dredge is bouncing over rough terrain it is unlikely to be fishing effectively and those seconds should be excluded. There is however, a certain amount of pitch that is within fishing tolerance and a certain amount of noise in the data. If the critical angle is too small, many seconds when the dredge was actually fishing would be excluded, which would tend to bias estimates of tow distance down. It is therefore important to find a critical angle for tow distance that is neither too small, nor too large.

The critical angle in the last assessment was 5.16 degrees, a value chosen because it represents a blade penetration of 1 inch (in.) on level ground. Our examination of the sensor data from 2011 provided no compelling reason to use a different critical angle (Figure A25). That is, shifting the critical angle upwards produced only slightly longer tows on average and this shift was not sufficient to trigger a reconsideration of the mechanically derived, blade penetration based estimate, used previously. Therefore the critical angle used in the current assessment was also 5.16 degrees.

NEFSC clam survey trends and size composition

NEFSC clam survey data (Table A10.) were tabulated for small (50-119 mm SL, Figure A26.) and large (120+ mm SL, Figure A27) 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 95% confidence intervals were based on the CV for stratified means and assume that the means were log normally distributed.

Survey trends for small surfclams (Figure A26.) show low recruitment levels during recent years in the Delmarva (DMV) and New Jersey (NJ) regions, approximately average recent recruitment levels in Southern Virginia (SVA), and Southern New England (SNE), high recruitment levels in Long Island (LI) and low recruitment in GBK. Recruitment appears to be increasing in SVA, LI, and possibly DMV. Survey trends for fishable (120+mm) surfclams (Figure A27.) show low abundance in the SVA, DMV and NJ region during recent years. In comparison, the other regions are either increasing (GBK and possibly LI) or variable (SNE). Based on survey data for the entire stock, recruitment was increasing, but fishable abundance was slightly below average during 2011 (Figures A28 – A29).

Shell length composition data (Figure A30.) 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

Surfclam ages are considered to be reliable and the aging process has been studied in detail (See Appendix A4 NEFSC 2009; Jacobson et al 2006; and http://www.nefsc.noaa.gov/fbp/QA-QC/data/surfclam/).

In this assessment, "recognizable" recruitment events are year classes that are strong enough to be detected by visual examination. "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 2011when surveys occurred. Ages ranged from 1-37 (Figures A31 – A36). Specific year classes and trends in age composition are discussed in the context of the assessment model (see TOR 4).

Dredge efficiency

Estimation of dredge efficiency is based primarily on the results of depletion experiments conducted with industry and academic collaborators aboard commercial vessels (NEFSC 2009). In 2011 additional depletion experiments were carried out aboard the *FV Pursuit* (see below). Procedures for estimating dredge efficiencies were modified considerably for this assessment based on Hennen et al (2011) and the incorporation of previously unrecognized uncertainty.

Dredge position during depletion experiments was approximated by vessel position, which was measured via GPS every one second. The true start and stop times for a tow were determined using a Star Oddi inclinometer mounted on the dredge which recorded the angle of the dredge every 1 second. The inclinometer data were smoothed with a 7 second moving average. The dredge was assumed to be fishing when the smoothed dredge angle was less than a_{crit} degrees and the dredge was assumed not fishing when the smoothed inclinometer subsequently increased to an angle greater than a_{crit} degrees. The value a_{crit} was determined by testing critical angles between 2 and 12 degrees and comparing the total tow distance and average tow distance across all depletion experiments (Figure A37). There was an asymptote at angles greater than 8 degrees. That is, total tow distance and average tow distance did not change appreciably with any critical angle between 8 and 12 degrees. We selected 10 degrees as a critical angle. The time stamps for the true start and stop times were used to determine the vessel position during the tow. These data were smoothed with a loess spline (span =0.75, degree = 2) to both longitude and latitude. The choice of smoothing algorithm did not make appreciable differences in the total tow distance across depletion experiments or in the average distance per tow within an experiment (Figure A38). The smoothed vessel positions were used in the patch model to determine tow paths.

The previous assessment (NEFSC 2009) used an estimator for survey dredge capture efficiency that was based on the ratio of observed density in the “set up tows” with the density estimate derived from depletion experiments conducted at the same site. Set up tows were conducted aboard the *RV Delaware II* using the survey dredge described above. They were 5 parallel tows evenly spaced over 1 km at the sites selected for depletion experiments. The set up tows were oriented perpendicularly to the expected direction of depletion tows. The estimator was:

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

where *e* is estimated survey efficiency, *d* is the observed density in setup tows and *D* is the estimated depletion experiment density. The implicit assumption of this analysis is that *d* and *D* are estimating the same true density. The estimated survey efficiency used for several calculations in this assessment was the median of all the usable depletion experiments (NEFSC 2009).

Survey dredge efficiency has been difficult to estimate with reasonable precision. It is likely that dredge efficiency is affected by local conditions such as substrate properties, currents and wind. It may be highly variable from site to site. We found that although the quantity *d* was reasonably stable from site to site it carried a high variance (Figure A39.) relative to the quantity *D*. This variance was ignored in previous assessments. Uncertainty in d was carried into the estimate of *e* in this assessment.

We considered a suite of independent variables that might provide additional information about *e*. In 2008, a series of repeat tows were conducted using survey gear in the same location towed previously by the NMFS survey (NEFSC 2009). These "repeat stations" thus provide information about the ability of the survey gear to capture clams when compared to commercial gear. The commercial gear has relatively well understood selectivity. The density observed in the commercial gear was scaled to approximate true density, using its estimated selectivity curve $D_L = \frac{D_{L(obs)}}{Slx_L}$. Thus the observed catch in the survey dredge divided by the rescaled catch in the commercial dredge provided a second measure of survey dredge efficiency.

The selectivity stations (described below) were also a potential source of information on survey dredge efficiency. At selectivity stations, the observed survey density was compared to the rescaled (see above) commercial catch at the same site.

The data from these three sources were truncated. All values larger than 1.0 were discarded due to implausibility (catch in the survey dredge must be less than or equal to the total number of available clams). All sites where 0 clams were caught were not used based on the assumption that if clams were available, the gear would catch at least one of them during a 5 minute tow.

The resulting estimates of survey dredge efficiency from all of these sources of information together provide the set of prior knowledge on survey dredge efficiency (Figure A40.). Each individual estimate has an associated CV. For the depletion sites the CV was estimated directly from the numerical estimation procedure used to fit the Patch model. For the repeat and selectivity sites the CV was based on the pure error variance derived from the set of combined estimates. These values were bootstrapped 100000 times using a weighted bootstrap procedure in which the weights were proportional to the inverse CV associated with each estimate. A bounded (0,1) log normal prior distribution was fit to the bootstrapped data set (Figure A41.). The mean and CV of the log normal distribution were 0.234 and 1.32, respectively. The log normal distribution described by these parameters was the prior distribution for survey *q* used in the assessment models. The mean is similar to the estimate of survey dredge efficiency used in the last assessment (0.256), though the CV is considerably larger when compared to the previous value (0.13).

New Depletion Experiments

The 2011 depletion experiments were analyzed using standard Patch methodology with one exception. We employed a new method for calculating the hit matrix (Hennen et al, 2011). Three of the four SC depletion experiments worked well. Estimated densities ranged from 0.184 – 0.416 clams per m^2 (Table A11). Estimated efficiencies ranged from 0.556 – 0.738. These values are similar to values from previous assessments.

Maps of the tow sequences from the depletion plots show thorough coverage of study sites with high degrees of overlap between tows, which follows procedures recommended by (Hennen et al, 2011) (Figure A42). Recommended patch model diagnostics include examining the catch vs. expected catch, the catch per unit of effective area and the likelihood residuals (Figure A43-A46). We generated likelihood profiles for each of the three estimated parameters for each experiment (Figure A47-A49). The confidence intervals shown in Table 1 are based on the likelihood profiles.

The one depletion study that did not produce reasonable estimates (SC11-04) suffered from a very low catch in the 13th tow of the depletion sequence. Altering this value toward the expected catch changes the Patch model results to estimated values that closely agree with results from the other three SC depletion experiments. We examined all the available logs for tow 13 and found no errors. Inclinometer and pressure sensors did not indicate any mechanical problems during this tow and the tow was of normal length. In short there was no *a priori* reason to exclude this tow from the depletion sequence.

Size selectivity

Survey dredge selectivity was previously calculated using Millar's (1992) SELECT model and precision was estimated using Miller's beta-binomial model (NEFSC 2009). Selectivity was estimated for this assessment using a generalized linear mixed model (Pinheiro and Bates 2000). The data were collected by the *R/V Delaware II* and *F/V Pursuit* during cooperative selectivity experiments in 2008 and 2011. Data from the experiments were used to estimate size-selectivity for the NEFSC clam survey dredge which is used on the *R/V Delaware II*. The data were also used to estimate size selectivity for the commercial dredge used by the *F/V Pursuit* when repeating NEFSC 2008 and 2011 clam survey stations. The commercial dredge was configured for survey operations, rather than commercial fishing operations. Thus, the size selectivity estimates for the commercial dredge used by the *F/V Pursuit* 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: one R/V tow; one F/V repeat tow with the modified commercial dredge; and one F/V selectivity tow with a commercial dredge lined with wire mesh.

The *F/V Pursuit* has two dredges, each 12.5 feet (3.8 m) wide, which are towed separately. The knives on both dredges were set at 5.25 inches (13.3 cm) for surfclam cooperative survey operations. The starboard dredge used for F/V selectivity tows was lined with 1-inch (2.54 cm) hexagonal wire mesh 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 occurred. 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 measure the effects of both the dredge and shaker table on shell length data. The entire catch was measured following R/V tows following standard survey protocols. The number of bushels was counted for F/V tows and a subsample of three full bushels was measured.

For F/V selectivity tows, the lined dredge was towed for 45 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 three full bushel samples were measured to the nearest mm. Inclinometer 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 1 mm shell length size groups. Survey size selectivity was estimated using data from R/V (survey and repeat) tows and FV selectivity data from 40 total sites (10 mm bin summaries in Table A12 – A13).

<u>Previous selectivity estimates</u>

In the last assessment, the Invertebrate Subcommittee decided that the dome shaped curve was the best estimate of size selectivity for the NEFSC survey dredge (NEFSC 2009). Beta-binomial confidence intervals suggested that the domed shaped pattern was real although most of the evidence was based on only two SL groups (160 and 170 mm SL).

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 - 120 psi on a commercial dredge).

The selectivity experiments conducted in 2011 were designed to address questions about the appropriateness of a domed shape selectivity curve.

Current selectivity estimates

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 (Table A12.; Figure A50.).

Selectivity was modeled as a generalized additive model (GAM) where the shell length bin was a factor, predicting the binomial proportion of the survey catch over the total catch (R/V + F/V).

$$p_L = e^{a+s(L)+s(sta)+offset(s.a.ratio)}$$

Where p_L is the binomial proportion (logit link) estimated for shell length L with intercept α and vector of model terms evaluated over L. The *s()* terms indicate a spline over the indicated variables, in this case shell length (L) and a random effect due to station and year. The final term is an offset (MacCullagh and Nelder, 1989) based on the ratio of swept areas between the respective tows at each station. For example, at station 7 the lined dredge swept 242.4 m^2 while the research dredge was towed 318.2 m^2 (Figure A51). Area swept by each gear is a potential source of bias because clams can be unevenly distributed on the sea floor. The nominal time fished for the lined dredge is 45 s compared to 5 min. for a nominal survey tow. The commercial dredge however, is much larger and is towed at a faster speed, which tends to minimize the differences between the gears in area swept.

Using the GAM methodology allowed greater flexibility in the model, when compared to assuming any particular shape. The basis dimension (k) in a spline determines the amount of "wiggle" allowed in the spline. Wood (2009)**1** suggests an objective method for choosing a basis dimension in splines. This method allows the data to determine the shape required to adequately fit them rather than the modeler.

The last assessment assumed a double logistic shape when modeling selectivity (though the fit from the double logistic was contrasted with a logistic fit, which allowed for a comparison of at least two shape families in the model selection process). The double logistic shape is described by a monotonic increase to a peak value, and a subsequent horizontal surface, followed by a monotonic decrease. The current approach estimates a spline along the range shell lengths and thus the peak may occur at any point and multimodal shapes are allowed.

The inclusion of random effects based on station is important because there is a great deal of variation in selectivity between stations. Variation across stations is essentially a nuisance parameter in our assessment because we are interested in the general selectivity over all possible stations, rather than the differences between them. Because we believe that clams taken from a particular place and time would tend to experience similar selectivity when compared to clams taken from a different place and time, it is appropriate to model selectivity using random effects.

Approximate confidence intervals were estimated using

$$CI_L = elogit(\rho_L \pm 1.96 * \sigma_L)$$

1 See R package mgcv documentation: http://127.0.0.1:19246/library/mgcv/html/choose.k.html

Where CI_L is the approximate confidence interval for length L, ρ_L is the corresponding selectivity estimate, σ_L is its standard error and *elogit* is the inverse of the logit function.

It is clear from the model results (Figure A52) that the domed selectivity curve estimated in the last assessment is appropriate. It is also clear that the domed shape is present in most of stations we sampled (Figure A53.). That is, the dome shape is not driven by data from a single site.

The ρ_L estimates were rescaled in some applications so that the highest value was fully selected, that is, equal to 1.0 (Figure A54.). This was necessary because selectivity may be used in product with gear capture efficiency which is defined as the probability of capture (between zero and one) for an organism fully selected by the sampling gear.

Rescaled selectivity was applied to the survey data using the inverse estimated ρ_L as a multiplier for the aggregate animals of each size on each tow. That is, if n_L animals in size class L were caught on a survey tow, we multiplied n_L by $1/\rho_L$, thus n_L/ρ_L rather than n was used to compute the stratified means for the survey index used in the KLAMZ assessment models. The SS3 models estimated selectivity internally and this adjustment to the survey data was not made.

Fishery selectivity

Fishery selectivity experiments were conducted on the F/V Pursuit. A modified fishery dredge (described above) was towed for five minutes as part of the selectivity sequence. The catch by size from this tow was compared to the lined dredge catch at each site. The selectivity estimates for each size class were found using models similar to the ones described above. Data from 2008 was combined with data from 2011. The same model (eq. 1) with offsets based on swept area ratios (Figure A55.) was preferred by AIC. Rescaled fishery selectivity estimates were useful for comparison to internally estimated commercial selectivity from SS3 (Figure A54.).

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. The survey meat weight equivalents are inputs in the stock assessment models used to estimate stock biomass, which is reported in units of meat weight.

Meat weights for surfclam include all of the soft tissues within the shell. All meat weights greater than 0.5 kg were assumed to be data entry error, and were removed from the analysis.

Generalized linear mixed models (GLMM; Venables & Dichmont 2004) were used to predict clam meat weight, using equations of the form:

$$MW = e^{a+b_0 ln(L)+b_1 ln(c_1)+b_2 ln(c_2)+\cdots+b_n ln(c_n)}$$

where *MW* was meat weight, *L* was shell length, $c_1,...,c_n$ were covariate predictors (e.g., region; in the basic model these are absent), and *a* and the b_i were parameters to be estimated. Examination of the variance of the weights as a function of shell length indicated that weight increased approximately linearly with shell height, implying that the Poisson family was appropriate for the distributions of meat weights (McCullagh & Nelder 1989). The GLMMs in all analyses therefore used the Poisson family with a log link. Because shell length/weight relationships for clams at the same station are likely to be more similar than those at other stations, we considered the sampling station as a grouping factor ("random effect") in the analysis.

We fit models with fixed effects for year and region (Table A14.). Neither of these factors proved to be important using AIC (Table A14). The best model by AIC and BIC was a model with fixed effects for shell length and depth and random effects for shell length slope and the intercept, using both the year and the station as the grouping variables.

$$E(MW) = exp\left(\alpha(1 + r_{sta}) + \beta(lnL + r_{sta}) + \gamma lnD + \delta_{Reg} + \epsilon_{Yr}\right)$$

where $E(MW)$ is the expected meat weight (in g) and r_{sta} is the grouping variable for the random effects (station). The important predictors of meat weight are: ln(length), ln(depth), region and year.

Random effects improved the model fit (i.e., decreased the AIC, Table A14.) in all analyses, demonstrating that individuals at the same sampling site are more similar to each other than to the general population. When multiple samples are collected at each site and random effects are not accounted for, the results typically overstate the precision of parameter estimates. This occurs because the analysis assumes that within-site observations are independent when, in fact, they often are highly correlated.

The GLMM approach also allows specification of the appropriate variance structure of the response variable, while a log-transformed regression implicitly assumes that variance increases with the square of the mean; an assumption that appears incorrect for clam weights.

The curves from (NEFSC 2009) and the current assessment are not substantially different at common commercial meat weights though the current model predicts somewhat heavier meats at small shell lengths and lighter meats at large shell lengths (Figure A56.). The largest observed clam used in the model fitting was 190 mm. The curve for the current assessment was generated using a depth of 33 m, which is the average depth of the survey stations over all years used in the analysis.

Regional differences in meat weight are meaningful, though some of the differences between regions can be explained by the different depths found there (Figure A57.). The largest meats at length, given constant depth were found in Georges Bank, but the largest meats given the depths actually observed in each region were found in Southern New England.

Age and growth

Surfclams in age and growth samples were measured at sea and the shells were retained for aging in the laboratory. Shells for aging were 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 (NEFSC 2009).

Age and length samples are available for most regions but not from every survey (Table A15). DMV and NJ were the most consistently sampled regions (Table A15). GBK was the least consistently sampled.

Plots of age vs. shell length by year and region (Figures A58 – A62) 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 2009), maximum size was lower after 1994 in DMV and NJ.

Von Bertalanffy parameters for growth in shell length were estimated for each region and each survey year for which sufficient data existed (Table A16). The Von Bertalanffy growth curve used in the calculations was:

$$L_a = L_\infty\left(1 - e^{(-K(a-t_0))}\right)$$

Where L_a is size (meat weight in g or SL in mm) at age a, and L_∞, K and t_0 are Von Bertalanffy parameters (the curves for growth in SL and weight have different parameter values). DMV and NJ have experienced significant declines in L_∞ through time. This result follows from weighted regression of the year specific parameter estimates against time, where the weights were the inverse standard errors of the parameters in question (Figures A63 - 64). NJ has experienced a significant decline in the growth constant K as well, demonstrating that clams in NJ are taking longer to reach a smaller size than they once did (Figure A65). Weighted regressions of parameter estimates in other regions did not indicate any significant trends over time.

Commercial LPUE

Commercial LPUE was not considered an adequate measure of relative abundance for this assessment because of the sessile nature of the species and the corresponding behavior exhibited by fishers. In general clam fishers use a fine spatial scale area until catch rates drop below economically profitable levels. They then move to another location and repeat the process. Thus catch rates tend to remain relatively stable over time even when population abundances fluctuate (See Appendix A2)

Stock Definitions (TOR-3)

Surfclams and ocean quahogs in the US EEZ (federal waters) have been managed as a single stock by the Mid-Atlantic Fishery Management Council for the last 35 years. The inshore portions of the resource off the coast of each state (<3 nm from shore) have been managed independently by state authorities. Two options for defining stocks in the EEZ surfclam resource were evaluated on technical grounds (biology, applicability of MSY reference points, fishing patterns and survey coverage) while excluding policy related considerations. The first (status-quo) option defines a single stock that extends over the entire range of the EEZ resource from Cape Hatteras in the south to the northern edge of Georges Bank. The second option defines two stocks by separating Georges Bank (GBK) from the area to the south along a traditional boundary based on NEFSC shellfish survey (depth) strata lines (Figure A66). The southern area (SNE - SVA) extends from Southern New England (just southwest GBK) in the north to Cape Hatteras in the Southern Virginia/North Carolina region in the south.

This discussion and TOR were triggered by difficulties noted in recent assessments (SARC 49 NEFSC 2010, page 43) and recommendations by SARC reviewers (SARC 49 summary report; NEFSC 2010, pages 9-11). The Invertebrate Working Group did not achieve consensus on this issue and so the decision about which approach is better is left to reviewers. Arguments for and against defining two stocks are presented in Table A17 – A18.

The working group did agree on a shared working definition of a stock for use in its deliberations. The definition, extracted from the NOAA Fisheries Glossary (Blackhart, et al. 2006; http://www.st.nmfs.gov/st4/documents/F_Glossary.pdf), reads:

A part of a fish population usually with a particular migration pattern, specific spawning grounds, and subject to a distinct fishery. A fish stock may be treated as a total or a spawning stock. Total stock refers to both juveniles and adults, either in numbers or by weight, while spawning stock refers to the numbers or weight of individuals that are old enough to reproduce.[6]

Comment: In theory, a unit stock is composed of all the individual fish in an area that are part of the same reproductive process. It is self-contained, with no emigration or immigration of individuals from or to the stock. On practical grounds, however, a fraction of the unit stock is considered a "stock" for management purposes (or a management unit), as long as the results of the assessments and management remain close enough to what they would be on the unit stock.[5]

[5]*United Nations Food and Agricultural Organization. Fisheries Glossary.* http://www.fao.org/fi/glossary/default.asp

[6]*Northeast Fisheries Science Center. Definition of Fisheries Technical Terms. http://www.nefsc.noaa.gov/techniques/tech_terms.html*

Some recent developments in the fishery are relevant. The GBK region was closed to fishing due to risk of PSP contamination in 1990 and is nearly virgin. The fishing industry developed protocols during 2008-2011 for determining if PSP is present prior to fishing and subsequent laboratory testing once clams from GBK are landed. The protocols were tested during experimental fishing on GBK during 2011 and 2012 and have been approved. GBK will open for fishing by all permitted vessels during 2013. Industry sources expect landings from the GBK region will amount to about1 million bu per year (about 1/3 of recent landings) over the next few years.

Fishing on GBK involves long (multiday) trips by a small number of vessels (currently 3) which are substantially larger than the rest of the fleet, capable of fishing with two large dredges simultaneously and generally able to work under rough conditions. In contrast, smaller boats make day trips with a single and often smaller dredge in southern regions. The surfclam resource is believed to be lightly exploited.

Abundance has trended down in the south and up on GBK due to environmental effects but is near its target biomass as a whole. Under either the current or alternative stock definitions, surfclams are not likely to be overfished, nor is overfishing likely to be occurring.

Assessment model results (TOR 4)

Stock Synthesis (SS3[2]**)** replaced KLAMZ (Appendix A4) as the primary model in this assessment (Methot, in press). SS3 was preferable because it made better use of survey age data in estimating recruitment and in making forecasts. In addition, the SS3 model was more flexible and capable of handling multiple assessment areas as might be needed in future. SS3 models for surfclam were explored in the previous assessment, but the KLAMZ model was used to provide management advice (Appendix 2 in NEFSC 2010). KLAMZ models were updated for this assessment, and discussion and results, including the bridge to the current assessment, are available in Appendix A5.

Separate SS3 models were developed for surfclams in the southern and GBK areas. No final SS3 model is available for the combined southern plus GBK region assumed in KLAMZ models and previous assessments. Preliminary models that combined the two areas with no internal spatial subdivision were developed but abandoned after a great deal of work. Divergent population dynamics (i.e. different biomass and mortality trends, changes in proportion of total biomass in the two areas over time, very limited fishing on GBK, and differences in occurrence of strong year classes) made it too difficult to estimate "average" population dynamics for the areas combined. Also, data were lost when the areas were combined because surveys were not available for the entire combined assessment region in some years. In this assessment, biomass, fishing mortality,

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2 Stock Synthesis Model version SS-V3.24f compiled for 64-bit linux.

recruitment and other estimates for the combined regions were estimated by combining estimates for the southern and GBK areas.

Fishery and survey selectivity were functions of size rather than age in SS3 models (Table A20). Conditional ages at length data, rather than traditional age composition data, were used in fitting models. The conditional age vector with elements $n_{t,a,L}$ for example, gives the proportion or number of observed ages (a) from samples of length L in year t of the NEFSC clam survey. The major advantage of the conditional approach is that more information about growth (including variance in size at age) and yearclass strength is preserved. Size compostion data are not used twice (once as size composition data and once in calculation of traditional catch at age). Finally, the sampling distribution of condtional age data is probably easier and more accurately characterized as a multinomial conditional on the number of ages $n_{t,L}$ actually sampled. The traditional type of age data was included in the model for qualitative for use in evaluating goodness of fit and recruitment patterns. Traditional age composition data had no effect on model estimates.

The SS3 models for surfclams were more complex than KLAMZ, but relatively simple compared with many other SS3 models. We estimated fewer parameters relative to other models for many other species because NEFSC clam surveys are carried out every three years, the fishery is relatively uncomplicated, and because no other survey data were available (Table A20-A21). Simple approaches with relatively few parameters increased model stability, and aligned with the philosophy of KLAMZ models used in previous surfclam assessments. The same types of data were available for both areas, although more precise and numerous data were available for the southern area (Figures A68 – A69). The additional data for the south made it possible to estimate additional catchability and selectivity parameters, as well as biomass and mortality over a longer time period. It was necessary to borrow these parameter estimates from the south in modeling surfclams on GBK because data were so limited and catches were nearly zero.

Dome shaped survey selectivity curves with parameters fixed at field study estimates were used in SS3 models for surfclams in the south and on GBK. Field estimates were used because they were relatively precise, based on a great deal of data, and were obtained from designed experiments carried out in association with the stratified random survey using actual survey sampling gear (Figure A54). When survey selectivity parameters were estimated by SS3 in preliminary runs, different selectivity curves with broader domes were obtained. Estimating selectivity improved goodness of fit, but retrospective and other analyses indicated that model stability was substantially reduced. Moreover, field study survey selectivity estimates were relatively precise and were considered likely to be directly applicable to survey catches.

The number of trips sampled by port agents was used as initial effective sample sizes for fishery length data in each year. The number of survey tows that caught surfclams was used as initial effective sample size for survey size composition data in each year. The number of fish aged in each size group and year was used as the initial effective sample size for survey conditional catch at age data. Initial log scale standard deviations for survey abundance trend data were derived from the CV for mean numbers per tow in each year assuming that errors were lognormal. These initial specifications for length and age data were "tuned" (adjusted up or down) based on preliminary model fits by multiplying the values for each type of data by a constant that was the same for all observations of the same data type. The initial standard deviations for survey trend data were tuned based on preliminary model fits by adding a constant to the standard deviation for each observation in the time series.

In three anomalous cases for length data in the southern area (fishery length data for 1982 and 1989 and survey length data for 1984), effective samples sizes were fixed at a low value (effective N=10) to avoid distorting fit to the rest of the data in the model (see below). The survey length data for 1984 was anomalous because of a single very large catch of surfclams (the largest catch in the survey time series) that consisted almost entirely of 7-8.9 cm SL surfclams.

<u>Prior for survey dredge capture efficiency</u>

A prior distribution based on field study estimates of survey dredge capture efficiency was used to help estimate the catchability parameter for minimum swept area abundance from clam survey data. Survey dredge efficiency is key in estimating surfclam abundance in SS3, particularly because fishing mortality rates appear to be quite low (Figure A41). The model ignored the trend in swept-area abundance (likelihood weight=10^{-5}) but goodness of fit to the prior was included in the objective function. Catchability (q) and capture efficiency (e) are closely related:

$$I = qN$$
$$q = \frac{aeu}{A}$$

where I is mean number per tow in the survey, N is stock abundance (fully selected by the survey dredge for this derivation), A is stock area, a is the area swept by the dredge and u accommodates the change from survey units (mean number per standardized tow) to population abundance.

The time series of minimum survey swept-area abundance estimates (N') were developed assuming e=1 for use with the prior. These estimates were for surveys conducted beginning in 1997, when sensors were used to monitor dredge performance and to calculate area swept accurately. Minimum swept area abundance was calculated:

$$N' = \frac{AI}{au}$$

where survey mean number per tow (I) was calculated after adjusting the catches in each survey tow to a standard tow distance (a) based on sensor measurement of tow distance and after discarding a few tows with poor dredge performance due to problems identified using sensors (see TOR 2). Stock area (A) was the area covered by the survey (assumed to be the stock area) reduced by an estimate of the fraction of the stock area which is untowable by the survey dredge (untowable ground was assumed to be unsuitable habitat). In theory, catchability for the swept area abundance data is the same as capture efficiency because $q=N'/N=e$. Thus, the catchability coefficient from SS3 was an estimate of dredge capture efficiency that could be compared to the prior for capture efficiency based on field studies.

The prior for log efficiency in SS3 was normally distributed because the prior distribution for efficiency was lognormal. The original lognormal distribution had a mean of 0.234 and a CV of 1.304. The standard deviation of the normal prior for log efficiency was $\sigma = \sqrt{log(1 + CV^2)} = 0.997$ and the mean was $log(0.234) - 0.5\sigma^2 = -1.95$.

Comparing SS3 and KLAMZ

Care is required in comparing estimates from KLAMZ and SS3. Biomass results from SS3 were for ages 6+ (south) and 7+ (GBK where growth is slower) on January 1 (unless noted otherwise) to approximate the biomass of surfclams 12+ cm SL estimated in KLAMZ. Annual exploitation rates from SS3 were catch weights divided by biomass of ages 6+ (south) and 7+ (GBK) on January 1 and should be roughly comparable in both models.

Fishery selectivity assumptions and fishing mortality estimates differ in SS3 and KLAMZ and make comparisons more difficult. Fishing mortality rates were not comparable because estimates from SS3 related catch numbers to area abundance for fully recruited size groups (about 15-17 cm SL in the southern region and 14+ cm in GBK). Estimates from KLAMZ related catch weight to population biomass, assuming that all surfclams 12+ cm SL were fully recruited to the fishery.

Recruitment estimates from the two models were not comparable because recruitment was estimated as a smooth random walk in KLAMZ and as independent estimates around a constant mean in SS3. Age composition data used in SS3 were informative and made it possible to model recruitment in a more complicated and realistic manner. Moreover, recruitment was the biomass of clams 12-12.9 cm SL (approximately age 6 y) in KLAMZ and numbers of age 0 recruits on January 1 in SS3.

Issues

The primary issues encountered in using SS3 in preliminary runs for surfclams in the southern area were: 1) choice of growth parameters to be estimated, 2) fit to fishery size composition data for sizes 14+ cm SL, 3) lack of fit to survey data (overall trends as well as size composition data for 1982, 1983 and 1986), and 4) lack of fit to commercial size data for the largest surfclams. The most important issue in using SS3 for GBK surfclams was sparse data that limited estimation of key parameters and contributed additional uncertainty.

Decisions about growth parameters were important because growth assumptions were key elements in fitting the age structured SS3 model to commercial and survey size data and because growth has changed over time in the southern area. SS3 uses von Bertalanffy growth curves with five parameters. L_{min} was the predicted size at a_{min}, L_{max} was the predicted size at a_{max}, K was the von Bertalanffy growth rate parameter, where a_{min}=5 y and a_{max}=30 y are user specified ages. SD_{min} was the standard error in size for surfclams at age a_{min}, and SD_{max} was the standard error in size at age a_{max}. In addition, growth is assumed to linear between 0 and L_{min} for ages 0 to a_{min}. For GBK, growth parameters were assumed constant over time and fixed at estimates made externally from survey data.

L_{min}, L_{max} and K for the 1975-2006 cohorts in the southern area were estimated in three separate preliminary model runs as random walks. Cohorts born before 1975 or after 2006 were assumed to have the same growth curve as the 1975 or 2006 cohorts. Annual steps in the random walk were assumed to have log scale standard deviations of 0.05 so that parameters might change by about 5% per year on average. Results suggested relatively fast growth to large size (high K and L_{max}) for the 1978-1983 cohorts (Figure A70). The variability in L_{max} was unrealistically large (about 12-23 cm SL compared to about 16 cm SL from external estimates). The working group concluded that the apparent variability in L_{max} was probably due to anomalous survey size data for 1982-1984 and 1986 which remain unexplained (see below). In the absence of an explanation for the survey size data, growth parameters were assumed to be constant over time in the south. The group assumed that the obvious changes in growth after 1994 in the southern areas were relatively unimportant for the stock as a whole because abundance and biomass there was a relatively small fraction of the total after 1994.

Next, fifteen preliminary model runs were carried out estimating individual growth parameters or sets of growth parameters with all parameters assumed constant over time (Table A22 and Figure A71). External parameter estimates from growth curves were used as starting values for estimated parameters or for parameters not estimated. The two best models, based on total negative log likelihood (NLL) estimated relatively high L_{min}, low K values, and implausible growth curves. In contrast, the model with the third lowest NLL, which estimated L_{min} and L_{max} only, seemed to provide relatively good fit and a plausible growth curve. Therefore L_{min} and L_{max} were estimated in final SS3 models for the southern area with other growth parameters fixed at initial values.

SS3 did not fit survey trend data as well as initially expected based on KLAMZ model results (Figure 2 in Appendix A5). A sensitivity analysis was carried out with a preliminary model that used a large likelihood weight (λ=100) for survey fit. This caused the fit to the survey trend data to improve. Fit to all length and age data, however, degraded substantially (Table A23). Estimated trends were similar except during the late 1980s and early 1990s (Figure A72) The working group concluded that the survey trend data were relatively noisy and that SS3 did not fit the trend closely because there was no evidence in the length and age data that the variability in the survey trend was real.

Three sensitivity runs with a preliminary model were used to address lack of fit to the very peaked survey length composition data for 1982-1983 and 1986 in the southern area. Run 1 placed a high weight (λ=100) on all of the survey size data in the model. Run 2 increased the weight on just the 1982-1983 and 1986 survey size data by multiplying the assumed effective samples sizes by 10. Run 3 dropped the survey size data for 1982-1983 and 1986 entirely. The run with a high weight on all survey sizes indicated faster growth in area biomass to a higher level during the early 1980s. However, the working group noted that the lack of fit seemed relatively unimportant because: 1) biomass estimates for 1988-2011 were similar in all runs (Figure A73), 2) there were no problems fitting survey age data for 1982-1983 or 1986, and 3) the survey size data for 1984 (down weighted due to one large tow) were not as peaked as in the problematic years. Based on these considerations, the Working Group decided to include lack of fit to early survey size composition data as a research recommendation but to ignore it otherwise in SS3 models.

The lack of fit to commercial size composition data at large sizes (14-18 cm SL) suggests that natural mortality (M) increased for large surfclams or that commercial selectivity was dome shaped such that large clams were less likely to be caught. Natural mortality has been fixed at 0.15 in surfclam assessments since 2000 (NEFSC 2000, see appendix 7 in NEFSC 2009 for a discussion of M estimates for surfclam). Sensitivity analyses were run with a preliminary model that estimated natural morality rates for clams age 7+ y, 8+ y, etc. while maintaining M=0.15 y^{-1} for younger ages. The estimated natural mortality rates were always about 0.15 y^{-1}. These results indicate that the model was able to fit the survey age data (which show surfclams 30+ y in age routinely) reasonably well under the assumption that M=0.15 y^{-1} for all ages and size groups. In contrast, the lack of fit to commercial size composition data at large sizes was nearly eliminated when a dome-shaped fishery selectivity curve was estimated in the model.

The improvement in model fit with dome-shaped fishery selectivity in the south was puzzling. External estimates of commercial fishery selectivity based on field experiments indicate that the commercial clam dredges used to harvest surfclams (Figure A54) and ocean quahogs (Thorarinsdottir et al. 2010) have logistic, rather than domed fishery selectivity patterns. Industry contributors to the Working Group reported that clam dredges are designed to collect large surfclams with high efficiency because large clams provide a higher meat yield.

Based on these considerations, the Working Group concluded that the lack of large individuals in commercial samples from the southern area was probably due to removal of large surfclams by relatively heavy fishing on the productive grounds where the fishery is concentrated. In other words, the apparently domed relationship between length composition and fishery length samples from the southern area was probably due to logistic gear selectivity combined with removal of large clams (relative to the area as a whole) on fishing grounds.

Based on the considerations above, a dome shaped fishery selectivity pattern was estimated in the basecase model for the southern area. However, Georges Bank is essentially virgin. Therefore, the Working Group assumed that the fishery selectivity pattern for Georges Bank had the same shape (same parameters) as estimated for the southern area on the left hand side for small surfclams. The right hand side for large surfclams was assumed to be asymptotic resulting in a typical logistic selectivity pattern. No selectivity parameters were estimated for GBK because commercial size data for GBK were too few and too noisy.

Fit and estimates from basecase models

Goodness of fit for final basecase models (Tables A24) was generally good, with the exception of the early survey size composition data described above. The estimated catchability (survey dredge capture efficiency) estimate for swept area abundance in the south (*e*=0.33) was larger than the mode and mean of the experimentally derived prior (see TOR 2), but seems plausible. Fit to conditional age at length was good based on observed and predicted mean age and variance in ages at size, although there were patterns in bubble plots for age at length residuals (see Appendix A6). The models fit traditional survey age composition data very well even though they were not used in fitting the model, which relied on conditional age at length information. Strong year classes estimated by the models were clearly visible in the traditional age composition data, indicating that the conditional and traditional age data convey the same information. Full diagnostics of the model fit are available in Appendix A6.

In the southern area, biomass and fishing mortality were estimated with reasonable precision, while recruitment trends were relatively uncertain in recent years (Figures A74 – A76, Table A25). Biomass and recruitment were less precisely estimated in the northern area (Figures A77 – A79, Table A26).

Likelihood profile analysis

Likelihood profile analyses was an important uncertainty analysis that was carried out for surfclams in the southern area by fixing the catchability coefficient for the NMFS clam survey at successive values that bracketed the best estimate and estimating all of the other parameters in the model. To ease interpretation, results were presented in terms of the catchability coefficient for swept-area abundance in each run (i.e. for survey dredge efficiency). The profile was not carried out using dredge efficiency *per se* as the fixed variable for southern area runs because dredge efficiency interacts with its prior distribution. Instead, we report the dredge efficiency estimate that was obtained for each fixed value of clam survey catchability. Points where the negative log likelihood in profile analysis was the minimum value + 1.92 likelihood units were used to approximate 95% confidence bounds (Figure A80).

Likelihood profile results for the south indicate that goodness of fit for the survey trend was best near the basecase model run (Table A27). Fishery and survey length data support higher dredge efficiency estimates (lower biomass) while survey age data support lower dredge efficiency estimates (higher biomass). Biomass estimates were sensitive to dredge efficiency but trends and the status ratio (B2011/B1999) were not (Figure A80). The 95% confidence interval for dredge efficiency based on the profile analysis was about 0.24 to 0.43, the confidence interval for biomass was about 625,000 to 1,025,000 mt, and the confidence interval for B2011/B1999 was about 0.43 to 0.49 (Figure A80).

Preliminary runs showed that the likelihood surface for the GBK region was nearly the same over a relatively wide range of fixed dredge efficiency values. In other words, none of the data provided information about the overall abundance of GBK surfclams. Therefore, no likelihood profile analysis was performed for GBK and the working group concluded that biomass estimates for GBK were no more (and possibly much less) certain that the estimated dredge efficiency from the south.

Internal retrospective

The internal retrospective pattern for the southern area was minimal, Mohn's rho was only ρ = 0.02 for a nine year "peal" (after dropping nine 2002-2010) (Figure A81). The retrospective pattern in the GBK area was more substantial (Mohn's ρ = 0.30), but the confidence bounds of each successive peel overlapped considerably, indicating the retrospective probably did not constitute a substantial bias (Figure A82). Given limitations in the data for GBK (including no 2005 survey) it is not clear that better results could be expected.

Whole stock results

Whole stock biomass estimates for clams 12+ cm SL were the sum of the biomass estimates from each area $B_W = B_S + B_N$. Because the estimation error associated with the two areas was independent, the variance of the sum of the biomasses was $\sigma_W^2 = \sqrt{\sigma_N^2 + \sigma_S^2}$. Whole stock fishing mortality was $F_W = \frac{(C_S+C_N)}{(\bar{N}_S+\bar{N}_N)}$ where C_S and C_N were the catch in numbers from each area and $\bar{N}_S$ and $\bar{N}_N$ were average fully selected abundances $\bar{N} = \sum_L s_L \frac{N_L(1-e^{-Z_L})}{Z_L}$, where the total mortality rate (Z) was based only on fully selected lengths and s_L was commercial fishery size selectivity. Whole stock results are discussed in TOR 6 and are listed in Table A26B.

Historical retrospective

When the summary biomass estimates from both the northern and southern areas area were summed, the results were higher than biomass estimates from previous assessments (Table A28, Figure A83). Direct comparability is nuanced because the current assessment makes use of new data sources (e.g. age and size structure), and because the comparison of age 6+ (south) and 7+ (north) to animals greater than 12 cm is only approximately direct.

Older versions of the surfclam assessment used swept area biomass estimates as the primary means of determining stock status. These analyses were updated in appendix (A8).

Performance of historical projections

The previous assessment projected a combined GBK + south biomass of 868 thousand mt in 2011. This estimate was based on the "industry estimate" catch (20 – 23 thousand mt including incidental mortality). Actual catch was within this range. The current assessment estimated 1,100 thousand mt. The current estimate is outside the approximate 95% asymptotic confidence bounds (717 – 1,051 thousand mt) implied by the CV of the previous estimate (0.10). It is, however, difficult to compare forecast and current estimates because of the changes in estimates described above.

Updated and redefined biological reference points and scientific adequacy of existing and redefined BRPs (TOR 5)

According to the FMP for Atlantic surfclams, overfishing occurs whenever the annual fishing mortality rate on the entire (GBK + south) surfclam resource (stock) is larger than the over fishing limit (OFL). The OFL for Atlantic surfclam is based on the F_{MSY} proxy. The stock is overfished if total biomass falls below $B_{Threshold}$, which is estimated as ½ B_{MSY} proxy. When stock biomass is less than the biomass threshold, the fishing mortality rate threshold is reduced from F_{MSY} to zero in a linear fashion.

The current proxy for $F_{MSY} = M = 0.15$ y^{-1} was not revised in this assessment. However, its interpretation is revised because of the change in stock assessment models. In the KLAMZ model used previously, F=0.15 y^{-1} was effectively a biomass weighted mortality measure that corresponded (under certain conditions) to the standard abundance weighted mortality rates estimated in SS3. Moreover, fishery selectivity was assumed knife-edged at 120+ mm in KLAMZ but was estimated in SS3 to be dome-shaped with selectivity near one at sizes 160+ mm on GBK and 160-170+ mm SL in the south. At the OFL, all surfclams 120+ mm SL would experience F=0.15 based on the KLAMZ model but only surfclams 160+ or 160-170+ mm SL would experience F=0.15 based on the SS3 model. In effect, the OFL under SS3 is lower from a biological perspective than under KLAMZ. The potential split into two stocks (GBK and south) does not affect the current proxy because it can be applied under any set of stock definitions.

The current proxy for B_{MSY} in the current stock unit (GBK + south) is one-half of the estimated fishable biomass during 1999. The current proxy for $B_{Threshold}$ (which is used to identify overfished stocks) is B_{MSY} /2 or B_{1999}/4. Biomass in 1999 and related biological reference points under the current stock definition were re-estimated in this assessment (see below).

Current Stock Definition (GBK + southern areas)

Reference Point	Last assessment	Revised
F_{MSY}	M=0.15 y^{-1}	Same
B_{1999}	1086 thousand mt meats	1944 thousand mt meats
B_{MSY} =½B_{1999} (target)	543 thousand mt meats	972 thousand mt meats
$B_{Threshold}$ = ½ B_{MSY}	272 thousand mt meats	486 thousand mt meats
MSY	NA	98 thousand mt meats

The possible revision of the stock definition for surfclams which would separate GBK and the southern region complicates biological reference points to some extent. The Invertebrate Subcommittee noted that B_{1999} was almost identical (probably fortuitously) to estimated virgin biomass in the basecase SS3 model for the southern area and in sensitivity analysis and preliminary runs. The Subcommittee therefore agreed that B_{1999}/2 was still a suitable proxy for B_{MSY} in the southern region. The Subcommittee concluded that B_{1999} was preferable to a formal virgin biomass estimate from an assessment model as the basis for biomass reference points because the stability of estimated trends substantially reduces uncertainty in the ratio $B_{Current}/B_{Threshold}$ when $B_{Threshold}$ =B_{1999}/4 and because of uncertainty about ongoing environmental trends. The group concluded that ratio of $B_{Current}$ over an estimate of B_{MSY} was thought unlikely to be robust particularly due to uncertainties about B_{MSY} in the face of environmental change.

The Invertebrate Subcommittee found no technical basis for establishing a B_{MSY} proxy for GBK. GBK is virgin, biomass has varied considerably there in the absence of fishing due presumably to environmental effects (Figure A77), and data for the GBK region is limited. The Subcommittee agreed that this uncertainty does not present any practical problems for determining legal status in this assessment because GBK is virgin and could not, by any definition, be overfished. Therefore, B_{MSY} for GBK is not defined but is considered an important research topic for the next assessment.

Southern Area

Reference Point	Last assessment	Revised
F_{MSY}	M=0.15 y^{-1}	Same
B_{1999}	1,086 thousand mt meats	1488 thousand mt meats
B_{MSY} =½B_{1999} **(target)**	543 thousand mt meats	744 thousand mt meats
$B_{Threshold}$ = ½ B_{MSY}	272 thousand mt meats	372 thousand mt meats
MSY	NA	74 thousand mt meats

Northern Area

Reference Point	Last assessment	Revised
F_{MSY}	M=0.15 y^{-1}	Same
B_{1999}	NA	NA
B_{MSY} =½B_{1999} **(target)**	NA	Undefined
$B_{Threshold}$ = ½ B_{MSY}	NA	Undefined
MSY	NA	29 thousand mt meats

Revised biomass reference points are higher than previous values primarily because of new information regarding the efficiency of the dredge used in NEFSC clam surveys and SS3 models that included age and length data. Conclusions about stock status are robust and would not change unless either the natural mortality estimate or biomass threshold was changed substantially.

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 performance of the simulated surfclam stock in projection analyses under the F_{MSY} proxy policy indicates that M=0.15 may not be an ideal proxy for F_{MSY} in the surfclam fishery. In addition, there is uncertainty about natural mortality in surfclams, which likely varies temporally and spatially. Reductions in biomass of surfclam in inshore southern regions are probably due, in part, to changes in environmental conditions and increasing natural mortality. On the other hand, the occurrence of old clams (> 35 y) in survey catches implies that the natural mortality rate may be lower than assumed. Sensitivity analysis indicated that the surfclam population in the south was adequately modeled using M=0.15. While there are indications that the current F_{MSY} proxy could be improved, there are no compelling reasons to change it at this time.

Stock status evaluation with respect to BRPs (TOR-6)

Current stock definition

The Atlantic surfclam stock in the US EEZ (current stock definition, GBK+south) has a low probability of being overfished ($B_{2011} > B_{Threshold}$) because the 95% confidence intervals for the biomass and reference point estimates do not overlap). The estimated stock biomass during 2011 for surfclams 120+ mm SL was 1060 thousand mt meats (CV=0.15) with a 95% confidence interval of approximately 791 to 1420 thousand mt meats. The biomass threshold is 1/4 of the

biomass estimate for 1999; $B_{Threshold}$= 486 thousand mt meats (CV= 0.14) with a 95% confidence interval of 374 to 633 thousand mt meats (Figure A84, Table A29).

Surfclam biomass in 2011 was probably above its target biomass level ($B_{2011} < B_{Target}$) because the 95% confidence intervals for the target and current biomass levels do not overlap. The biomass target is ½ of the estimated biomass during 1999; B_{Target} = 972 thousand mt (CV 0.135) with a 95% confidence interval of 747 to 1235 thousand mt (Figure A84).

The Atlantic surfclam stock in the US EEZ is not experiencing overfishing ($F_{2011} < F_{MSY}$). Fishing mortality for the entire resource (F_W) was based on a numerically weighted average of the annual fishing mortality in each area, accounting for different selectivities. The estimated fishing mortality during 2011 was F= 0.027 y^{-1}, with 95% confidence intervals of (0.016 – 0.045), which is below the management threshold OFL of F = M = 0.15 y^{-1}. The confidence interval suggests that there is virtually no probability that F exceeded the OFL during 2011 (Figure A85, Table A30).

Alternative stock definition

The alternative stock definition would separate GBK and area to the south as separate stocks. There are no reference points currently defined for the GBK area (see TOR 5). The stock was not fished between 1989 and 2009 and is essentially virgin. Therefore the stock is not overfished and overfishing is not occurring.

The estimated stock biomass in the southern area during 2011 for surfclams age 6+ (~120+ mm SL) was 703 thousand mt meats (CV=0.2) with a 95% confidence interval of approximately 481 to 1028 thousand mt meats (Figure A74). The biomass threshold is 1/4 of the biomass estimate for 1999; $B_{Threshold}$= 392 thousand mt meats (CV= 0.17) with a 95% confidence interval of 268 to 516 thousand mt meats (Figure A86, Table A31). The confidence intervals associated with B2011 and the threshold reference point in the southern area overlap. Therefore there is a possibility that the southern area is overfished. Overfished probability was calculated using the approach detailed in Shertzer et al. (2008). The distributions for B_{2011} and $B_{THRESHOLD}$ were assumed to be log normal, with means equal to their point estimates and variances equal to their delta method variances (B_{2011}~LogN(6.55,0.194); $B_{THRESHOLD}$~LogN(5.92,0.167)). 10,000,000 possible threshold values were drawn from correlated distributions with means and variances as described above, where the correlation between them was equal to the correlation between $B_{THRESHOLD}$ and B_{2011} estimated in the model (0.90). Each pair of draws was compared. Overfished status occurred when the threshold draw was greater than the biomass draw. Probabilities were equal to the number of overfished occurrences divided by the number of comparisons made. The probability of being overfished was <1% (Figure A87).

The southern area is not experiencing overfishing ($F_{2011} < F_{MSY}$). The estimated fishing mortality during 2011 was F= 0.040 y^{-1}, with 95% confidence intervals of (0.025 – 0.056), which is below the management threshold OFL of F = M = 0.15 y^{-1}. The confidence interval suggests that there is virtually no probability that F exceeded the OFL during 2011 (Figure A88, Table A32).

Projections (TOR 7)

Basecase SS3 models were used to project biomass of surfclams approximately 120+ mm SL (age 6+ y in the south and 7+ y on GBK), landings (mt and bu), fully recruited fishing mortality, and annual exploitation rates (catch weight/biomass) in the southern area, GBK area, and the combined areas during 2012-2021 (Table A33 – A35 and Figures A89 – A95). Three harvest policies were assumed: 1) F=0.15 y^{-1} (at the OFL), 2) status-quo catch (23,357 mt y^{-1}, equivalent to landings of 20,854 mt or 2.7 million bu y^{-1}) and 3) the maximum allowed catch under the current FMP or "quota level" catch (29,359 mt y^{-1}, equivalent to 26,213 mt or 3.4 million bu y^{-1}) in the combined areas (Table A34).

There is a positive probability that the stock will be overfished within the next five years. The maximum probability of overfished status coincides with the minimum biomass estimate over the five year time horizon. Using the Shertzer et al. (2008) method, the probability of the whole stock being overfished ranged from 0.005 to 0.035, depending on the projection scenario being considered (Figure A96). Under the alternate stock definition the probability of the southern area being overfished in the next 5 years ranged from 0.015 – 0.044 (Figure A97).

The most likely fishing scenario is probably status quo, because the fishery is market limited and has been fishing under quota since 2004 (Table A2). The quota scenario is therefore a reasonable upper bound on likely fishing pressure over the next five years. Using the quota scenario and the maximum probability of being overfished in *any one year* in next five ($P*$ = 0.005, or 0.015, for the whole stock and southern area respectively) the cumulative probability of being overfished *at any time* during the next five years is $1 - \prod_y \left(1 - P_y^*\right)$ = 0.015 and 0.056 (Table A36), for the whole stock and southern area respectively, where P_y^* is the $P*$ value for each year (see Shertzer et al, 2008).

Catches were landings + 12% to account for assumed incidental mortality. Catches and landings during 2012 were assumed the same as during 2011. For lack of better information, catches on GBK during 2013-2021 were assumed to be the same in the status-quo catch and quota level catch scenarios. This assumption is likely reasonable for the first few years because of processor infrastructure and fleet range limitations. Thus, any differences in total catch between scenarios or over time would probably be due to differences in southern catches. Catches from GBK may, however, increase at some point if additional vessels capable of fishing on GBK, and additional processing infrastructure, are built in the north.

Projected total landings, biomass and exploitation levels for the combined area were obtained by adding estimates for the southern and GBK areas. Fishing mortality was not computed exactly for the combined area because fishery selectivity differs between the southern and GBK areas and numbers at size was not a projection output. Approximate fishing mortality was based on numerically weighted average fishing mortality from each area.

Projected fishing mortality levels are lower than the fishing mortality threshold F=0.15 y^{-1} for the entire resource under the current stock definition under all scenarios except F=M=OFL (Figure A91; Table A36). Under the alternative stock definition, neither the southern area nor the GBK area are likely to experience overfishing under the status quo or quota scenarios (Figures A93 and A95; Table A36).

Probability distributions of the catch at the OFL were generated by repeated draws from the sampling distribution of biomass in each year. B_i, the biomass in year i was assumed to have a log normal distribution $B_i \sim Lognormal(\beta_i, \sigma_i)$, where β_i is point estimate of biomass in year i and σ_i is the delta method standard deviation estimated in the model for biomass in year i. The overfishing limit F=M=0.15 was applied to each of 1,000,000 draws from the distribution for B_i, resulting in a probability distribution of catch (Figures A98 – A200; Table A37).

Additional sensitivity analyses and decision tables based on projections are available in appendix A9.

Research recommendations (TOR 8)

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

i) Continue surfclam recruitment research. *This assessment incorporates length and age data. Age structure provides some new information that was not previously leveraged in forecasting. This change should allow for more precise estimation of the magnitude of incoming year classes and thus improve our ability to predict important recruitment events. Including age and size structure have also broadened the scope of hindcast recruitment analysis by allowing the inclusion of younger ages into the assessment model. Recruits in the old assessment were animals approximately five years old. We now use age zero animals.*

ii) Port samples should be taken from the SNE and GBK (if fishing resumes there) regions. *Collected since 2010.*

iii) Determine how much of Georges Bank is good surfclam habitat, and if depletion and selectivity experiments done in the mid-Atlantic are applicable to the Georges Bank region. *We have begun exploratory work with existing HabCam**3** images, attempting remote identification of bivalves using siphon anatomy. We hope that automated identification of live surfclam is possible and will lead to a better understanding of habitat use by surfclam. If this turns out to be too difficult it is possible that visual inspection of HabCam images will lead to habitat identification through other means, such as identifiable shell piles or shell hash. This project is still in exploratory stages, though we have applied twice for funding.*

iv) Fecundity and maturity at length information is required to improve reference point calculations and predict management effects. *No progress. This issue is technically difficult to resolve in situ and is unlikely to be addressed in the near term. Direct studies of fecundity would require specialized laboratory facilities. It is possible that academic partners may pursue this research topic.*

v) Data on the number of clams per bushel landed at different ports over time would be useful. *No progress.*

vi) Commercial length data for surfclams should be more accessible. *Commercial length data is summarized in this document and is available by request through NEFSC.*

vii) Determine whether the carrying capacity of surfclams has changed over time. *No progress. Surfclam are experiencing a range contraction as habitat degrades in the southern extreme of the historical species extent due to climate change. Carrying capacity has certainly changed over time, and clearly continues to change, though this topic has not been directly addressed analytically.*

viii) Estimate densities of spawning surfclams necessary to produce good recruitment. Is reproduction likely to be impaired if relatively dense beds of surfclams are reduced? *No progress.*

New research recommendations (not in priority order)

i) Biomass reference points need to be reconsidered.
ii) Has surfclam biomass shifted offshore into deeper water over time?
iii) Look into a better way to implement regime change into the SS3 model. Look into patterns which may match other species and climate indices.
iv) Determine the best spatial and temporal distribution to use for surfclam assessment models
v) Look at habitat on GBK

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3 See http://habcam.whoi.edu

vi) Given the increasing importance of GBK re-evaluate the optimal sampling design for the survey.
vii) Look into area specific recruitment streams for SS3 and how to accommodate the 2012 and 2013 surveys.

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Table A1. Surfclam discard estimates from 1982 through 1994. A minimum size regulation was in effect from 1982 through 1990. Within two years of dropping the minimum size regulation (1993) the discard rate had dropped to zero and has remained zero since then.

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) and while figures for other years were from a dealer database (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	0.8	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	0.7	24,290
1987	27,231	21,744	5,486	0.8	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	0.7	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	28,322	24,197	4,125	0.85	26,218
2005	26,882	21,163	5,719	0.79	26,218
2006	27,176	23,573	3,604	0.87	26,218
2007	27,094	24,915	2,179	0.92	26,218
2008	27,750	22,519	5,231	0.81	26,218
2009	22,972	20,149	2,823	0.88	26,218
2010	19,978	18,102	1,876	0.91	26,218
2011	19,908	18,587	1,320	0.93	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	27,022	19,983	7,039	0.75	21,850

Table A3. EEZ surfclam landings (mt meats) by stock assessment area and year prorated based on NEFSC (2003) for 1979 and logbook data for 1980-2011. Landings from unknown areas in each year were prorated to known areas based on logbook proportions of landings in known areas.

Year	SVA	DMV	NJ	LI	SNE	GBK	Other	Total EEZ
1979	0	11,836	1,350	0	0	0	0	13,186
1980	64	12,788	2,878	17	0	0	0	15,748
1981	568	7,472	8,820	88	0	0	0	16,947
1982	1,705	6,679	8,086	94	125	0	0	16,688
1983	2,225	7,173	8,095	264	836	0	0	18,592
1984	1,797	5,979	11,905	7	382	2,766	54	22,889
1985	741	7,856	11,246	0	452	2,185	0	22,480
1986	529	2,853	17,730	17	1,223	1,991	177	24,521
1987	378	1,303	18,017	0	1,140	907	0	21,744
1988	558	1,149	19,420	0	1,512	739	0	23,378
1989	439	3,123	16,532	0	1,361	433	0	21,888
1990	1,502	3,546	17,887	0	998	7	79	24,018
1991	0	1,634	18,913	15	33	0	21	20,615
1992	0	1,221	20,399	61	5	0	0	21,686
1993	0	3,414	18,365	62	3	0	14	21,859
1994	0	3,454	18,418	71	0	0	0	21,943
1995	0	2,752	16,497	0	378	0	0	19,627
1996	0	2,239	17,479	26	82	0	0	19,827
1997	0	1,540	16,999	73	0	0	0	18,612
1998	0	484	17,511	117	121	0	0	18,234
1999	0	648	18,755	157	16	0	0	19,577
2000	0	2,042	17,513	121	103	0	0	19,778
2001	0	3,282	17,719	935	81	0	0	22,017
2002	64	4,489	18,271	1,130	52	0	0	24,006
2003	0	1,432	21,693	1,625	267	0	0	25,017
2004	0	1,482	19,197	906	2,612	0	0	24,197
2005	0	1,668	16,850	759	1,885	0	0	21,163
2006	0	2,773	19,660	245	895	0	0	23,573
2007	0	3,073	20,268	1,117	458	0	0	24,915
2008	0	3,261	17,517	1,317	423	0	0	22,519
2009	0	1,978	14,881	1,827	1,451	11	0	20,149
2010	0	1,583	11,144	1,184	2,888	1,302	0	18,102
2011	0	1,427	11,908	437	2,420	2,397	0	18,587
Min	0	484	1,350	0	0	0	0	13,186
Max	2,225	12,788	21,693	1,827	2,888	2,766	177	25,017
Mean	320	3,565	15,513	384	673	386	10	20,851

Table A4. EEZ fishing effort (hours fished by all vessels) for surfclam, by stock assessment area and year based on logbook data. 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.

Year	SVA	DMV	NJ	LI	SNE	GBK	Other	Total EEZ
1982	2,790	18,050	24,636	225	137	0	0	45,838
1983	4,191	18,805	23,584	536	1,130	0	0	48,245
1984	2,603	8,972	20,819	27	1,264	1,732	42	35,459
1985	397	4,686	10,518	0	1,702	2,608	0	19,911
1986	236	1,629	10,764	38	2,516	1,610	675	17,469
1987	262	722	11,910	0	3,780	1,006	0	17,680
1988	322	593	13,175	0	5,274	587	0	19,950
1989	228	1,615	11,794	0	4,741	389	0	18,768
1990	1,150	2,065	12,437	0	3,032	0	898	19,582
1991	0	1,254	17,243	21	107	0	293	18,917
1992	0	797	21,379	67	0	0	0	22,243
1993	0	2,423	18,232	57	15	0	5	20,731
1994	0	1,930	21,495	70	0	0	0	23,495
1995	0	1,560	18,625	0	1,059	0	0	21,244
1996	0	1,577	20,994	40	287	0	0	22,899
1997	0	1,098	20,383	77	0	0	0	21,558
1998	0	289	19,608	134	518	0	0	20,550
1999	0	734	18,146	151	149	0	0	19,180
2000	0	1,859	16,787	115	368	0	0	19,128
2001	0	2,536	18,461	962	148	0	0	22,108
2002	112	5,505	19,826	1,241	62	0	0	26,747
2003	0	2,367	25,034	1,828	176	0	0	29,405
2004	0	3,161	26,409	1,244	1,093	0	0	31,907
2005	0	2,654	24,379	1,207	1,364	0	0	29,604
2006	0	5,883	27,102	343	1,022	0	0	34,350
2007	0	7,065	34,664	1,587	960	0	0	44,276
2008	0	8,154	33,916	2,308	541	0	0	44,920
2009	0	5,669	33,648	4,195	2,528	12	0	46,053
2010	0	4,201	32,103	3,314	5,614	479	0	45,712
2011	0	3,067	35,043	1,361	7,339	1,084	0	47,894
Min	0	289	10,518	0	0	0	0	17,469
Max	4,191	18,805	35,043	4,195	7,339	2,608	898	48,245
Mean	410	4,031	21,437	705	1,564	317	64	28,527

Table A5. Real and nominal prices for surfclams based on dealer data. Average price was computed as total revenues divided by total landed meat weight during each year, rather than as annual averages of prices for individual trips, to reduce bias due to small deliveries at relatively high prices. The consumer price index (CPI) used to convert nominal dollars to 2010 equivalent dollars is for unprocessed and packaged fish, which includes shellfish and finfish.

Year	CPI	Prices ($ / bu)		Revenue (million $)	
		Nominal	Real ($2010)	Nominal	Real ($2010)
1982	0.50	8.94	17.89	25.186	50.406
1983	0.52	7.57	14.58	23.207	44.678
1984	0.54	8.37	15.54	33.156	61.521
1985	0.56	9.34	16.82	34.303	61.780
1986	0.57	9.20	16.21	41.841	73.725
1987	0.58	7.83	13.40	27.644	47.336
1988	0.60	7.80	12.91	28.826	47.721
1989	0.63	7.78	12.40	30.330	48.384
1990	0.65	7.66	11.76	32.393	49.755
1991	0.67	7.51	11.13	29.975	44.464
1992	0.69	7.40	10.72	31.832	46.125
1993	0.71	7.83	11.10	33.369	47.307
1994	0.72	9.82	13.64	41.241	57.261
1995	0.74	10.58	14.39	41.246	56.098
1996	0.75	10.24	13.66	38.275	51.085
1997	0.76	10.31	13.53	35.189	46.151
1998	0.77	9.19	11.92	29.200	37.869
1999	0.78	8.79	11.24	30.421	38.881
2000	0.80	9.43	11.80	38.025	47.568
2001	0.82	9.76	11.95	39.555	48.390
2002	0.83	9.45	11.37	39.988	48.141
2003	0.85	9.64	11.37	39.427	46.487
2004	0.87	9.59	10.99	35.209	40.377
2005	0.90	9.50	10.55	33.123	36.764
2006	0.93	10.19	10.95	35.908	38.608
2007	0.96	10.49	10.96	36.844	38.497
2008	0.98	10.96	11.20	39.441	40.316
2009	0.99	11.43	11.56	34.050	34.442
2010	1.00	11.67	11.67	30.240	30.240
2011	1.02	11.52	11.28	29.732	29.110

Table A6. Nominal landings per unit effort (LPUE, bushels h^{-1}) for surfclam fishing (all vessels) in the US EEZ from logbooks. LPUE is defined as 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	GBK	Other	All areas
1982	79	48	43	54	118			47
1983	69	49	45	64	96			50
1984	89	86	74	35	39	207	165	84
1985	242	217	139		34	109		146
1986	291	227	214	59	63	160	34	182
1987	187	234	196		39	117		159
1988	224	251	191		37	163		152
1989	249	251	182		37	144		151
1990	169	223	187		43		11	159
1991		169	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	310			98
2005		82	90	82	179			93
2006		61	94	93	114			89
2007		56	76	91	62			73
2008		52	67	74	101			65
2009		45	57	56	74	120		57
2010		49	45	46	67	352		51
2011		60	44	42	43	287		50
Min	74	45	44	42	14	120	9	50
Max	74	232	142	143	310	352	390	141
Mean	74	127	102	101	86	253	199	104

Table A7. Numbers of commercial trips sampled and numbers of surfclams measured in port samples from landings during 1982-2011, by region. Numbers of trips during 1982-1999 were estimated assuming 30 individuals sampled per trip, as specified in port sample instructions.

	DMV		NJ		LI		SNE		GBK	
Year	Trips	Lengths	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				
2009	31	932	59	1771	43	1296				
2010	25	751	43	1293	36	1086	3	90	15	450
2011	28	780	126	3706	52	1460	70	2097	7	240
Min	2	60	17	510	1	30	1	30	7	240
Max	259	7,756	425	12,751	23	690	27	810	15	450
Mean	53	1,584	92	2,768	11	343	10	296	11	345

Table A8. Number of successful random tows in NEFSC clam surveys used for survey trends and efficiency corrected swept area biomass. “Holes” (unsampled survey strata in some years) were filled by borrowing from adjacent surveys were possible (borrowed totals are negative numbers in gray-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.

	Years												
Stratum	**1982**	**1983**	**1984**	**1986**	**1989**	**1992**	**1994**	**1997**	**1999**	**2002**	**2005**	**2008**	**2011**
SVA													
1	**-10**	10	14	7	10	10	10	10	**-10**	0	0	0	0
2	0	0	0	**-1**	1	2	1	1	**-1**	0	0	0	0
5	4	9	13	8	8	8	7	8	**-16**	8	8	**-17**	9
6	1	1	1	1	1	1	1	1	**-3**	2	1	**-1**	0
80	**-6**	6	9	3	7	7	8	7	**-7**	0	0	0	0
81	**-4**	4	7	3	5	5	5	5	**-10**	5	**-10**	5	0
DMV													
9	30	26	35	29	37	37	38	37	37	38	37	31	15
10	2	2	3	3	3	3	3	3	3	3	3	2	4
13	19	18	25	20	20	20	21	20	19	20	18	15	7
14	2	2	3	3	3	3	5	3	3	3	3	**-26**	23
82	1	1	1	1	1	1	1	1	2	2	**-3**	1	0
83	2	2	2	2	2	2	2	2	2	2	2	2	0
84	4	3	3	4	4	4	4	4	3	4	4	4	4
85	5	5	4	5	5	5	5	5	5	5	5	5	5
86	2	2	3	3	3	2	3	3	3	3	3	3	5
NJ													
17	11	11	18	12	12	12	12	12	12	12	12	12	5
18	3	3	**-6**	3	3	3	3	3	3	3	3	3	5
21	18	18	22	19	20	20	20	20	33	27	20	28	15
22	3	3	**-6**	3	3	3	5	3	3	3	3	3	5
25	9	9	13	8	9	9	9	9	8	9	9	13	8
26	2	2	**-5**	3	3	3	3	3	3	3	3	3	3
87	8	7	10	9	9	9	9	9	9	16	8	9	6
88	15	15	24	17	20	20	20	21	21	20	17	19	6
89	15	15	21	15	18	17	18	19	18	18	15	18	4
90	2	2	3	2	2	2	2	2	2	2	2	1	4

Table A8. Cont...

Stratum	1982	1983	1984	1986	1989	1992	1994	1997	1999	2002	2005	2008	2011
	Years												
LI													
29	11	10	**-20**	10	10	10	10	10	10	10	10	16	10
30	7	8	**-14**	6	6	6	6	6	5	6	7	12	4
33	4	4	**-8**	4	4	4	5	4	4	4	4	10	4
34	2	2	**-4**	2	2	2	5	2	1	2	2	8	6
91	3	2	4	4	3	3	3	3	3	3	3	5	11
92	2	2	3	2	2	2	2	2	2	2	2	5	11
93	1	2	2	1	1	1	1	1	1	2	1	4	6
SNE													
37	7	4	**-7**	3	**-6**	3	5	4	4	3	**-3**	3	2
38	3	2	**-5**	3	3	3	5	3	3	3	2	3	7
41	6	5	7	5	6	6	6	6	5	6	6	6	4
45	3	7	9	4	4	4	4	4	4	2	4	4	7
46	2	5	5	3	2	3	5	3	3	2	3	3	6
47	4	3	4	2	2	4	4	4	3	1	7	4	8
94	1	2	**-2**	0	**-1**	1	2	2	**-4**	2	**-2**	2	5
95	4	14	11	4	4	4	4	4	4	4	**-8**	4	5
96	**-12**	12	**-13**	1	1	3	2	4	**-4**	0	**-1**	1	0
GBK													
54	0	**-3**	3	3	**-6**	3	3	3	**-3**	0	**-2**	2	2
55	3	**-3**	**-3**	3	1	3	3	3	2	2	**-4**	2	3
57	0	0	**-2**	2	1	2	5	2	2	2	**-4**	2	11
59	1	4	**-5**	1	2	6	5	5	4	5	**-9**	4	16
61	8	1	**-6**	5	**-12**	7	5	6	6	6	**-11**	5	5
65	0	0	**-3**	3	**-5**	2	4	3	**-4**	1	**-1**	1	3
67	0	**-5**	5	5	7	7	7	7	**-7**	0	**-2**	2	1
68	1	**-8**	7	3	6	6	5	5	**-5**	0	**-6**	6	0
69	2	5	**-11**	6	6	6	7	6	8	**-8**	**-4**	4	1
70	1	2	**-6**	4	**-8**	4	4	4	3	2	**-6**	4	19
71	0	**-2**	2	3	1	2	3	3	1	2	**-3**	1	3
72	2	**-10**	8	1	8	8	8	8	6	**-6**	**-4**	4	5
73	1	1	**-4**	3	6	6	6	6	5	6	**-9**	3	5
74	3	**-4**	1	3	**-7**	4	4	4	3	3	**-6**	3	11

Table A9. NEFSC clam survey stations for which the model predicted differential pressure below the threshold (35 PSI) for more than 25% of fishing seconds. These stations were not used in the current assessment.

Station	Strata	Depth	Lat	Lon	Region
143	13	42	38.27442	74.5733	DMV
145	14	54	38.30777	74.23925	DMV
70	87	27	39.06597	74.40457	NJ
254	26	48	39.88967	73.32147	NJ
46	26	65	40.14597	73.65233	NJ
31	29	33	40.43415	73.34963	LI
292	38	55	40.91837	71.60237	SNE
294	37	39	41.27432	71.40202	SNE
481	94	28	41.3911	71.23802	SNE
482	94	28	41.44353	71.38292	SNE
343	57	70	40.81365	68.01625	GBK
342	57	65	40.84938	68.01197	GBK
341	57	64	40.85402	68.0533	GBK
375	59	62	40.90093	67.91472	GBK
376	70	53	40.97942	67.84257	GBK
377	70	57	40.98083	67.77793	GBK
394	59	73	41.022	67.17712	GBK
390	59	59	41.10465	67.51712	GBK
391	59	58	41.14662	67.4156	GBK
409	73	46	41.43885	67.35357	GBK
419	74	53	41.79002	67.36272	GBK
430	72	54	41.9348	67.45007	GBK
180	23	55	38.89438	73.53642	OTH

Table A10. (On the following pages.) NEFSC clam survey data for surfclam abundance (mean N/tow) and biomass (mean kg/tow). Data are for three size groups: prerecruits (50-119mm), fishable clams (120+mm) and all clams greater than 50mm. Survey holes (strata with no sampling) are filled by borrowing, but no imputed data were used for this table.

		Prerecruits (50-119 mm SL)				**Large fishable (120+ mm SL)**				**All surfclams 50mm and above**						
	Year	N / Tow	CV	KG / Tow	CV	N / Tow	CV	KG / Tow	CV	N / Tow	CV	KG / Tow	CV	N Tows	Pos. Tows	N Strata
SVA	1982	3.53	0.88	0.19	0.90	3.73	0.92	0.404995	0.86	7.26	0.90	0.595757	0.872	25	6	5
	1983	6.60	0.62	0.35	0.64	5.71	0.62	0.649399	0.59	12.31	0.58	0.994758	0.565	30	12	5
	1984	7.85	0.37	0.43	0.40	21.82	0.31	2.536182	0.294	29.66	0.30	2.961469	0.287	44	17	5
	1986	1.50	0.35	0.08	0.42	22.20	0.75	2.413548	0.735	23.69	0.72	2.495099	0.72	23	13	6
	1989	3.11	0.75	0.11	0.70	9.78	0.83	1.199442	0.819	12.89	0.81	1.310352	0.808	32	13	6
	1992	18.15	0.86	1.22	0.91	12.10	0.77	1.279377	0.783	30.25	0.65	2.497773	0.648	33	18	6
	1994	43.38	0.46	1.03	0.31	6.38	0.44	0.656494	0.355	49.76	0.40	1.689041	0.276	33	19	6
	1997	10.31	0.44	0.42	0.46	0.49	0.46	0.047867	0.44	10.80	0.43	0.4673	0.448	32	14	6
	1999	9.32	0.41	0.33	0.36	1.22	0.46	0.134403	0.473	10.54	0.38	0.460503	0.331	47	21	6
	2002	13.69	0.61	0.49	0.62	5.66	0.55	0.641627	0.55	19.35	0.58	1.132064	0.565	15	7	3
	2005	3.65	0.66	0.07	0.57	0.00	0.00	0	0	3.65	0.66	0.068276	0.573	14	4	3
	2008	10.23	0.30	0.24	0.29	0.00	0.00	0	0	10.30	0.29	0.24407	0.286	18	11	2
	2011	15.40	0.29	0.38	0.28	0.14	1.00	0.010603	1	15.54	0.29	0.395325	0.27	9	8	1
DMV	1982	157.13	0.46	9.58	0.46	21.36	0.23	3.524782	0.32	178.49	0.42	13.10507	0.407	68	47	9
	1983	30.68	0.54	1.98	0.62	31.21	0.46	3.855335	0.364	61.88	0.49	5.831617	0.439	61	41	9
	1984	184.10	0.74	6.94	0.62	34.91	0.28	4.327025	0.276	219.01	0.63	11.26841	0.395	79	58	9
	1986	58.77	0.43	3.99	0.46	74.79	0.38	8.290292	0.326	133.56	0.39	12.278	0.365	70	53	9
	1989	16.71	0.54	1.02	0.55	31.24	0.26	3.782973	0.245	47.94	0.26	4.807792	0.233	78	53	9
	1992	13.49	0.28	0.75	0.38	28.86	0.29	3.591607	0.242	42.35	0.28	4.339855	0.258	77	58	9
	1994	68.70	0.33	3.57	0.43	60.96	0.21	7.35485	0.201	129.67	0.23	10.92903	0.218	83	66	9
	1997	77.18	0.17	4.30	0.20	54.53	0.24	6.127452	0.225	131.71	0.17	10.42328	0.19	82	64	9
	1999	29.61	0.28	1.94	0.28	26.36	0.22	3.002235	0.205	55.98	0.23	4.939529	0.21	78	47	9
	2002	16.47	0.28	0.75	0.27	20.70	0.21	2.756585	0.192	37.17	0.22	3.511343	0.186	81	58	9
	2005	6.44	0.42	0.31	0.43	4.76	0.26	0.616634	0.282	11.19	0.27	0.922988	0.237	75	45	9
	2008	9.61	0.23	0.36	0.25	2.64	0.35	0.361625	0.348	12.34	0.23	0.729765	0.266	89	50	9
	2011	43.27	0.25	1.78	0.29	9.32	0.40	0.98473	0.427	51.92	0.26	2.690627	0.309	66	37	9
NJ	1982	33.10	0.30	2.18	0.32	32.78	0.22	4.690181	0.212	65.88	0.19	6.874827	0.178	85	60	10
	1983	27.78	0.51	1.88	0.55	25.38	0.22	3.434296	0.207	53.16	0.30	5.319006	0.251	85	63	10
	1984	15.93	0.23	0.80	0.23	29.97	0.20	4.038403	0.186	45.90	0.18	4.835422	0.179	126	86	10
	1986	10.33	0.21	0.55	0.21	29.68	0.18	4.44884	0.18	40.01	0.17	4.999115	0.17	91	70	10
	1989	9.88	0.29	0.52	0.30	31.53	0.15	4.439793	0.134	41.40	0.15	4.964282	0.135	99	75	10

	1992	16.46	0.33	0.94	0.43	23.22	0.16	3.357078	0.152	39.68	0.20	4.297829	0.166	98	73	10
	1994	67.39	0.20	2.93	0.19	82.77	0.17	11.57065	0.167	150.16	0.16	14.50123	0.166	103	85	10
	1997	17.91	0.16	1.07	0.17	83.72	0.13	11.78592	0.121	101.63	0.13	12.85891	0.12	112	91	10
	1999	8.02	0.25	0.42	0.31	50.58	0.21	7.266118	0.189	58.60	0.21	7.689472	0.193	120	93	10
	2002	10.68	0.16	0.49	0.15	35.03	0.17	5.6948	0.165	45.71	0.14	6.188908	0.155	115	99	10
	2005	7.81	0.20	0.41	0.22	19.09	0.18	2.874266	0.17	26.90	0.16	3.283292	0.162	92	73	10
	2008	10.07	0.14	0.44	0.14	17.05	0.16	2.537086	0.168	27.11	0.13	2.97367	0.155	109	93	10
	2011	11.70	0.21	0.52	0.21	14.12	0.18	2.063531	0.192	25.82	0.16	2.586211	0.172	61	44	10

Table A10. Cont…

		Prerecruits (50-119 mm SL)				Large fishable (120+ mm SL)				All surfclams 50mm and above						
	Year	N / Tow	CV	KG / Tow	CV	N / Tow	CV	KG / Tow	CV	N / Tow	CV	KG / Tow	CV	N Tows	Pos. Tows	N Strata
LI	1982	0.03	1.00	0.002434	1	3.99	0.61	0.743364	0.606	4.03	0.61	0.745798	0.604	29	5	7
	1983	0.17	0.61	0.004333	0.613	0.41	0.72	0.057422	0.716	0.58	0.60	0.061755	0.688	29	4	7
	1984	0.56	0.30	0.020969	0.366	1.64	0.34	0.283652	0.353	2.20	0.22	0.304621	0.319	55	14	7
	1986	0.58	0.39	0.020603	0.403	1.72	0.61	0.305768	0.61	2.30	0.45	0.32637	0.567	29	8	7
	1989	2.24	0.87	0.088874	0.871	3.48	0.72	0.504931	0.726	5.72	0.78	0.593806	0.747	28	5	7
	1992	5.73	0.44	0.319383	0.476	2.54	0.33	0.295907	0.316	8.28	0.39	0.61529	0.373	28	10	7
	1994	4.23	0.17	0.211863	0.194	7.24	0.19	0.938826	0.208	11.48	0.17	1.150689	0.199	32	12	7
	1997	1.44	0.49	0.082004	0.533	4.17	0.64	0.604188	0.64	5.62	0.59	0.686193	0.622	28	6	7
	1999	1.61	0.64	0.048118	0.507	10.71	0.65	1.594682	0.607	12.32	0.65	1.6428	0.604	30	9	7
	2002	0.85	0.45	0.034689	0.439	1.94	0.67	0.331373	0.664	2.80	0.59	0.366062	0.636	29	8	7
	2005	1.42	0.34	0.062799	0.382	12.62	0.50	1.84611	0.479	14.04	0.47	1.908909	0.47	29	9	7
	2008	1.47	0.24	0.063645	0.236	3.52	0.24	0.534445	0.239	5.00	0.21	0.59809	0.23	60	22	7
	2011	4.57	0.26	0.156991	0.207	10.20	0.25	1.536774	0.253	14.76	0.21	1.693766	0.241	52	33	7
SNE	1982	2.58	0.29	0.131607	0.354	12.40	0.41	2.293756	0.418	14.99	0.33	2.425363	0.392	42	19	9
	1983	0.84	0.40	0.048743	0.435	7.88	0.39	1.712466	0.387	8.72	0.38	1.761209	0.385	54	24	9
	1984	0.81	0.36	0.042455	0.44	10.84	0.34	2.285845	0.336	11.65	0.34	2.3283	0.337	63	26	9
	1986	1.12	0.14	0.032305	0.252	4.12	0.68	0.872532	0.701	5.24	0.54	0.904837	0.678	25	11	8
	1989	1.18	0.43	0.051921	0.429	4.57	0.33	0.93215	0.332	5.75	0.31	0.984071	0.326	29	12	9
	1992	1.15	0.56	0.036055	0.482	2.49	0.58	0.558217	0.584	3.64	0.44	0.594272	0.55	31	9	9
	1994	1.26	0.52	0.077467	0.612	1.69	0.53	0.366591	0.549	2.96	0.45	0.444058	0.502	38	11	9
	1997	2.95	0.31	0.150038	0.362	12.28	0.30	2.555287	0.308	15.23	0.25	2.705325	0.298	34	15	9
	1999	2.60	0.42	0.102415	0.454	4.30	0.66	1.009042	0.663	6.90	0.45	1.111458	0.604	34	16	9
	2002	1.01	0.69	0.066557	0.719	3.85	0.27	0.825208	0.221	4.86	0.31	0.891765	0.229	24	9	8
	2005	1.33	0.08	0.052673	0.083	1.62	0.24	0.402845	0.241	2.95	0.14	0.455517	0.215	35	14	9

	2008	1.46	0.10	0.062659	0.126	5.01	0.63	1.03101	0.582	5.37	0.47	0.866775	0.545	32	11	9
	2011	1.35	0.09	0.051196	0.088	1.97	0.29	0.437128	0.278	3.07	0.18	0.434453	0.249	45	13	9
GBK	1986	20.00	0.79	0.783168	0.776	4.97	0.52	0.822095	0.549	24.97	0.68	1.605262	0.527	44	20	14
	1989	5.21	0.34	0.329709	0.425	24.86	0.73	3.523909	0.732	30.07	0.66	3.853617	0.704	75	37	14
	1992	15.54	0.40	0.800933	0.457	7.89	0.33	1.125339	0.342	23.43	0.33	1.926272	0.32	66	43	14
	1994	30.01	0.33	1.83765	0.347	45.84	0.39	6.734682	0.414	75.85	0.33	8.572331	0.375	70	47	14
	1997	58.55	0.31	3.402449	0.334	23.52	0.25	3.150657	0.245	82.07	0.28	6.553106	0.26	65	45	14
	1999	24.01	0.41	1.558739	0.416	29.59	0.31	3.945581	0.311	53.60	0.35	5.50432	0.337	59	34	14
	2002	22.09	0.52	1.358712	0.551	27.05	0.43	3.811007	0.417	49.15	0.46	5.169719	0.439	43	23	11
	2008	7.21	0.28	0.478127	0.335	33.02	0.25	4.605182	0.246	39.23	0.21	4.942882	0.224	45	29	14
	2011	7.62	0.21	0.513838	0.243	30.53	0.25	4.718915	0.246	43.79	0.24	6.109591	0.243	91	52	14

Table A11. Patch model results and approximate 95% confidence intervals for all surfclam depletion experiments conducted in 2011. The model for SC11-04 did not converge on a solution so no delta method confidence intervals are available.

Experiment	Tows	Density	CI	Efficiency	CI	Dispersion	CI
SC11-02	20	0.231	(0.14,0.25)	0.738	(0.53,0.90)	5.878	(2.95,10.65)
SC11-02S	18	0.184	(0.19,0.29)	0.556	(0.35,0.71)	4.904	(2.4,9.0)
SC11-03	15	0.416	(0.29,0.85)	0.571	(0.23,0.90)	4.156	(1.85,8.05)
SC11-04	17	0.163	NA	1	NA	6.438	NA

Table A12. 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" = 10 for the 20-29 mm SL group because individuals in the 20-29 mm size group were observed in F/V selectivity tows at 10 sites.

SL group	F/V lined dredge N	F/V unlined dredge N	R/V N	F/V lined dredge N positive stations	F/V unlined dredge N positive stations	R/V N positive stations
20-29	21	3	2	10	1	2
30-39	147	6	5	19	2	5
40-49	327	8	13	20	1	5
50-59	237	18	15	17	1	6
60-69	217	8	45	20	2	10
70-79	218	9	84	20	2	16
80-89	282	68	90	18	8	17
90-99	269	439	100	17	15	15
100-109	235	765	106	18	16	19
110-119	242	949	129	17	21	19
120-129	275	1256	132	18	21	20
130-139	227	1182	115	21	21	21
140-149	184	895	121	20	20	19
150-159	200	883	153	18	20	17
160-169	193	721	98	15	16	11
170-179	96	310	45	10	15	10
180-189	17	39	2	5	9	4
190-199	0	3	0	0	0	0

Table A13. Numbers of surfclams in survey dredge selectivity experiments by length bin and station (2011). For example, “3:8” means that 3 surfclams of a particular length at a particular station were measured in catches by the *R/V Delaware II* and 8 surfclams were measured in catches by the *F/V Pursuit*.

SL bin	Sta 7	Sta 23	Sta 28	Sta 34	Sta 43	Sta 49	Sta 50	Sta 51	Sta 52	Sta 53	Sta 56
6	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0
16	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:1	0:0	0:0	0:0
26	0:1	0:0	0:0	0:0	0:1	0:1	0:0	0:2	0:0	0:5	0:2
36	0:2	0:2	0:1	0:2	2:7	0:8	0:1	0:8	0:0	1:7	0:8
46	0:1	0:3	0:4	0:5	0:8	0:8	0:0	0:12	0:0	1:5	0:1
56	0:2	0:4	0:2	0:8	1:9	0:12	0:0	0:5	0:1	1:12	0:0
66	0:1	0:1	1:1	0:2	1:10	1:9	1:1	0:3	0:0	0:6	0:3
76	2:3	0:0	0:1	0:7	2:2	4:4	2:0	1:7	2:0	2:5	2:5
86	2:1	0:0	0:0	2:5	0:1	0:3	2:2	1:2	1:1	3:5	0:1
96	1:1	4:1	0:0	0:3	2:2	0:2	1:1	1:4	1:1	0:1	1:4
106	3:2	2:1	1:0	3:3	3:2	3:3	1:0	5:3	1:1	3:5	1:3
116	2:2	3:1	3:0	2:5	2:3	3:0	1:0	4:6	0:0	4:2	1:1
126	9:1	4:3	3:0	3:8	1:3	5:4	2:1	8:8	1:0	1:3	2:1
136	10:6	4:2	6:3	10:10	4:6	6:9	3:1	5:9	2:3	5:8	2:2
146	11:8	4:4	6:7	3:8	5:5	7:9	3:3	3:6	0:3	5:8	4:2
156	9:7	7:4	8:5	7:8	6:4	8:10	1:8	9:9	3:4	6:10	9:4
166	6:7	2:0	8:2	5:9	3:4	6:9	2:3	4:6	1:7	5:9	9:9
176	2:1	0:0	4:0	2:7	2:3	6:3	0:0	0:1	0:2	4:6	6:8
186	0:0	0:0	0:0	0:4	0:1	0:0	0:0	0:0	0:0	0:1	0:1

SL bin	Sta 141	Sta 156	Sta 167	Sta 234	Sta 236	Sta 239	Sta 240	Sta 247	Sta 255	Sta 279
6	0:0	0:1	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0
16	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0
26	1:6	0:1	0:2	0:0	0:1	0:0	1:1	0:2	0:1	0:1
36	1:9	2:13	0:3	1:5	0:2	0:2	0:13	0:1	0:12	0:4
46	5:10	1:15	0:3	1:9	1:12	0:1	1:11	0:0	0:6	0:3
56	6:9	3:11	0:2	0:7	1:3	0:2	1:0	0:3	0:8	0:9
66	9:12	7:12	1:3	1:7	0:3	0:9	3:5	1:8	6:8	0:4
76	8:12	6:12	2:2	1:7	0:4	2:7	6:11	2:7	9:9	2:9
86	10:11	8:10	1:2	8:10	1:1	6:11	7:11	3:9	10:11	1:9
96	10:8	8:12	3:1	4:10	0:0	7:11	4:10	3:9	9:11	0:5
106	11:9	6:12	3:2	5:10	1:1	5:10	5:9	2:6	6:9	0:2
116	12:11	6:12	4:3	4:10	3:0	7:9	3:9	5:9	12:10	0:5
126	9:10	5:12	3:1	2:9	0:1	7:11	3:7	4:8	10:8	1:4
136	3:4	3:5	2:2	2:8	4:1	5:9	2:9	8:10	5:3	5:4
146	2:2	0:3	3:2	1:8	3:1	6:8	1:4	5:6	1:2	0:4
156	0:0	1:0	0:0	0:3	1:1	0:4	2:1	4:6	0:0	0:6
166	0:0	0:0	0:0	0:2	0:3	0:0	0:0	0:2	0:0	0:4
176	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:1
186	0:0	0:1	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0

Table A14. Estimated model parameters and (standard errors) for a selection of competing models predicting clam meat weight from shell length. Region effects are highlighted with colors corresponding to the row of the model they were estimated in.

Formula	Intercept	Length	Depth	Density	Region	AIC	BIC
MW ~ Len+(1|Sta)	-8.6041 (0.00941)	2.7249 (0.01431)				4911	4928
MW ~ Len+Dpth+(1|Sta)	-8.3705 (0.00934)	2.7227 (0.01433)	-0.0644 (0.0263)			4908	4930
MW ~ Len+(Len+1|Sta)	-8.6406 (0.0097)	2.7336 (0.02425)				4715	4742
MW ~ Len+Dpth+(Len+1|Sta)	-8.6236 (0.00966)	2.73 (0.02423)	-0.0614 (0.02721)			4712	4745
MW ~ Len+Reg+(Len+1|Sta)	-8.6383 (0.0174)	2.7276 (0.0245)			a	4695	4756
MW ~ Len+Dens+(Len+1|Sta)	-8.6347 (0.01001)	2.7363 (0.02445)	-0.00572 (0.00688)			4716	4749
MW ~ Len+(Len+1|Sta)+(Len+1|Yr)	-8.611 (0.0244)	2.7277 (0.04988)				4706	4750
MW ~ Len+Dpth+(Len+1|Sta)+(Len+1|Yr)	-8.3439 (0.02602)	2.7237 (0.04939)	-0.0714 (0.02675)			4701	4750
MW ~ Len+Reg+(Len+1|Sta)	-8.6383 (0.0174)	2.7276 (0.0245)			b	4695	4756
MW ~ Len+Dpth+Reg+(Len+1|Sta)	-7.976 (0.01687)	2.7175 (0.02426)	-0.1743 (0.03104)		c	4667	4734
MW ~ Len+Dpth+Reg+(Len+1|Sta)+(Len+1|Yr)	***-7.8622 (0.03454)***	***2.7061 (0.05402)***	***-0.1925 (0.02999)***		***d***	***4645***	***4728***
MW ~ Len+Dpth+Dens+Reg+(Len+1|Sta)+(Len+1|Yr)	-7.8391 (0.03551)	2.71 (0.05461)	-0.1951 (0.02983)	-0.0661 (0.06804)	e	4644	4732

Region	a	b	c	***d***	e
SVA	0.044 (0.07141)	0.044 (0.07141)	0.0129 (0.07043)	***-0.06 (0.06786)***	0.1714 (0.04491)
DMV	0	0	0	***0***	0
NJ	0.0162 (0.02251)	0.0162 (0.02251)	-0.00407 (0.02194)	***0.00247 (0.02111)***	-0.0824 (0.0308)
LI	-0.0219 (0.0307)	-0.0219 (0.0307)	-0.0889 (0.03172)	***-0.0816 (0.03101)***	0.2049 (0.03058)

SNE	0.1869 (0.04799)	0.1869 (0.04799)	0.1651 (0.04597)	***0.1808 (0.04497)***	-0.2668 (0.31418)
GBK	0.1141 (0.03001)	0.1141 (0.03001)	0.1792 (0.03096)	***0.2009 (0.03072)***	-0.0104 (0.0063)
OTH	-0.261 (0.32725)	-0.261 (0.32725)	-0.1631 (0.32651)	***-0.246 (0.31299)***	0.00636 (0.02111)

Table A15. Number of age samples by region and survey year.

Year	SVA	DMV	NJ	LI	SNE	GBK
1982	5	796	927	40	123	4
1983	142	422	934	6	369	0
1984	0	0	0	0	0	643
1986	64	748	1216	45	71	413
1989	60	102	566	53	42	86
1992	11	134	257	47	54	311
1994	0	299	476	0	0	0
1997	0	626	227	0	0	50
1999	0	510	496	22	50	178
2002	29	327	779	31	20	54
2005	17	322	523	21	6	0
2008	0	138	459	99	39	105
2011	26	122	144	72	17	82

Table A16. Growth curve (Von Bertalanffy) parameter estimates and standard errors for each region, by year.

Region	Year	n	L_{max}	L_{max} se	K	K se	t_0	t_0 se
DMV	1978	199	163.562	1.820	0.319	0.017	-0.010	0.096
DMV	1980	391	166.575	1.289	0.340	0.020	1.246	0.150
DMV	1981	446	173.336	1.855	0.248	0.014	0.451	0.154
DMV	1982	801	175.458	1.641	0.205	0.008	0.114	0.129
DMV	1983	564	176.522	2.512	0.214	0.013	0.113	0.190
DMV	1986	812	183.819	3.002	0.135	0.010	-1.204	0.366
DMV	1989	162	141.828	2.541	0.327	0.045	0.596	0.316
DMV	1992	145	172.122	6.760	0.161	0.025	-0.829	0.473
DMV	1994	299	149.550	1.661	0.343	0.022	1.437	0.134
DMV	1997	626	151.399	3.251	0.148	0.014	-1.472	0.395
DMV	1999	510	136.421	1.924	0.238	0.027	-0.314	0.482
DMV	2002	356	156.831	4.395	0.168	0.021	-1.223	0.434
DMV	2005	339	150.595	2.750	0.161	0.012	-0.735	0.235
DMV	2008	228	158.314	2.583	0.201	0.014	-0.607	0.197
DMV	2011	149	120.448	3.027	0.399	0.051	0.301	0.225
NJ	1978	289	163.504	2.858	0.313	0.025	0.207	0.147
NJ	1980	452	171.610	1.564	0.286	0.015	0.825	0.139
NJ	1981	641	170.430	1.330	0.316	0.013	0.703	0.094
NJ	1982	927	173.358	1.431	0.264	0.009	0.256	0.087
NJ	1983	934	176.348	1.733	0.244	0.010	0.267	0.109
NJ	1986	1216	175.558	1.866	0.177	0.008	-0.465	0.174
NJ	1989	566	162.936	2.012	0.238	0.015	0.585	0.183
NJ	1992	257	166.971	4.115	0.187	0.023	-0.422	0.432
NJ	1994	476	159.587	2.181	0.197	0.017	-0.580	0.356
NJ	1997	227	165.551	2.053	0.212	0.018	-0.046	0.291
NJ	1999	496	160.889	1.379	0.264	0.015	0.235	0.172
NJ	2002	779	163.876	1.728	0.209	0.015	-0.838	0.279
NJ	2005	523	164.111	2.418	0.150	0.013	-1.211	0.455
NJ	2008	807	158.901	2.251	0.152	0.011	-1.458	0.320
NJ	2011	145	154.582	3.475	0.216	0.031	-0.367	0.555
LI	1980	29	159.445	2.372	0.365	0.055	0.451	0.396
LI	1981	27	171.114	17.901	0.108	0.065	-5.719	4.260
LI	1982	40	156.713	1.856	0.800	0.213	2.815	0.198
LI	1986	45	165.899	3.402	0.222	0.039	0.023	0.695
LI	1989	53	163.122	3.557	0.259	0.034	0.529	0.394
LI	1992	47	155.779	3.029	0.307	0.036	0.008	0.314
LI	1999	22	167.863	4.719	0.302	0.044	0.550	0.283
LI	2002	31	174.942	8.130	0.250	0.059	0.313	0.594
LI	2005	21	160.095	7.630	0.210	0.070	-0.598	1.226
LI	2008	254	150.733	2.409	0.409	0.038	0.830	0.182
LI	2011	73	168.560	5.403	0.196	0.049	-0.784	1.258
SNE	1980	61	177.066	6.484	0.111	0.038	-7.483	3.807
SNE	1981	38	162.605	3.761	0.444	0.088	1.335	0.311
SNE	1982	123	160.352	2.398	0.222	0.025	0.642	0.378
SNE	1983	369	167.890	1.656	0.265	0.023	-0.209	0.350
SNE	1986	71	163.625	2.624	0.316	0.038	1.571	0.258
SNE	1989	42	171.995	5.179	0.422	0.079	2.009	0.350
SNE	1992	54	162.448	2.304	0.203	0.024	0.586	0.317

SNE	1999	50	174.800	6.337	0.210	0.041	-0.084	0.560
SNE	2002	20	162.292	5.311	0.452	0.118	1.539	0.525
SNE	2008	103	171.954	2.818	0.172	0.023	-1.036	0.677
SNE	2011	18	168.488	23.305	0.058	0.267	-37.007	193.965
GBK	1984	643	146.693	3.221	0.266	0.022	0.871	0.153
GBK	1986	413	148.950	3.236	0.225	0.019	0.267	0.175
GBK	1989	86	152.814	5.196	0.197	0.040	-0.250	0.765
GBK	1992	311	148.733	2.815	0.270	0.020	1.085	0.155
GBK	1997	50	138.772	7.371	0.194	0.045	-0.007	0.683
GBK	1999	178	145.613	3.129	0.355	0.033	0.581	0.160
GBK	2002	54	143.216	4.762	0.427	0.095	2.136	0.416
GBK	2008	315	147.423	2.587	0.204	0.023	-0.654	0.387
GBK	2011	83	146.346	2.053	0.486	0.189	2.249	1.109

Table A17. Points made to support splitting the Atlantic surfclams into two stocks with counterpoints. The status quo is a single stock and the alternative is two stocks with the break southwest of Georges Bank. Under this option, the Georges Bank (GBK) stock in the north would be separated from the South Virginia/ North Carolina to Southern New England (SVASNE) stock in the south. Points made to support maintaining the status quo and counterpoints are listed in Table A18.

Pro	Con	References
Spatial Patterns in Biological and Other Characteristics		
Growth curves and shell length-meat weight differ markedly between GBK and the southern region.	The differences are clinal or continuous and the split could be made elsewhere or not at all.	Table Table A14, Table A16, Figure A57, A58-62; Kim and Powell (2004); Marzec, et al. (2006); Weinberg (2005)
Post-settlement survival has decreased in the south but not on GBK.	Southern and northern portions of a large stock should respond differently to environmental change. The differences are clinal or concentrated in shallow water south of New Jersey and the split could be made elsewhere or not at all.	NEFSC 2010
Georges Bank tends to retain larvae spawned there due to a persistent gyre current. Published larval drift models for scallops show substantial movement of larvae from GBK to the south, but none from the south to GBK. A detailed unpublished surfclam larval drift presented to the Working Group indicates no movement of larvae from GBK to Southern New England and other southern areas occurs or *vice-versa* assuming no daily mortality during the assumed 35 day larval lifetime observed in culture (X. Zhang and D. Haidvogel, IMCS, Rutgers).	Larval drift models are not definitive and do not cover the whole time period of interest or all possible oceanographic conditions when substantial interchange may occur, particularly between GBK and Southern New England which is directly to the south. In certain circumstances, up to 10% of GBK larvae would reach Southern New England and these larvae would be 'unsuccessful' in the model, but near a reasonable size for metamorphosis in a biological sense.	Miller et al 1998; Werner et al 1993; Gilbert et al 2010; Tian et al 2009; Table A19
Georges Bank and MAB surfclam habitats are entirely within different and well recognized eco-regions.		Fogarty et al. (2011)

The split south of GBK crosses an area that separates the two major concentrations of the resource in the south (off New Jersey) and on GBK.	The split could be made elsewhere or not at all.	Appendix A7
	Population Dynamics	
Surfclams in GBK and south resemble two independent populations based on abundance, recruitment and life history trends.	The northern and southern portions of SVASNE differ as well, why not identify three stocks?	POPULATION DYNAMICS (Figures A26, A27, A74, A75, A77 and A78)
Strong year classes occur independently and more often in the south and often over wide areas within the region.	Recruitment patterns are regional and the split could be made elsewhere or not at all.	Fig A67
	Fishery Patterns	
The split south of GBK crosses an area of relatively low fishing activity and catch.		See Table A3, Figures A3,A4, and A8
	Practical	
The new cooperative survey cannot sample the whole resource in one year but can be extended to include all of the SVASNE area.	Does not mean the split has to be made at GBK. Spatially explicit assessment models could be developed to handle areas incompletely sampled in annual surveys.	
Including GBK in a whole stock assessment model means that certain survey years cannot be included because GBK was not sampled in all years.	Areas can modeled separately but managed together, with results combined.	
Previous reviews of the surfclam assessment have been critical of the current stock definition.	Restoration of fishing on GBK invalidates some of these previous criticisms.	
The proposed boundary is along lines historically used to assess the stock and to collect survey data.	Historical use and best practice are not necessarily the same.	
	Utility of Biological Reference Points	
”Average” biological reference points for two quasi-populations with different population dynamics do not result in MSY for either population unit, particularly when differences are as large as for GBK and the southern region.	The same argument can be made with respect to different portions of the southern area.	Hart, D. R. 2001. Can. J. Fish. Aquat. Sci. 58:2351–2358.

The surfclam stock could be removed entirely in the south or on GBK without triggering an overfishing or overfished status determination because biomass would remain > Bmsy/2 for the combined areas.	This scenario is unlikely to occur in either GBK or the southern area now that GBK is open to fishing	
Combining two quasi-populations with different population dynamics obscures the condition of both.	Assessments should contain information about both stock components and other important regions, regardless of stock definitions.	

Table A18. Points made to support maintaining the status-quo (single) stock definition for surfclams, with counterpoints. The status quo is a single stock and the alternative is two stocks with the break just southwest of Georges Bank.

Pro	Con	References
Split is a needless departure from historical precedent.	Historical precedent is not necessarily best practice particularly given biological and ecological changes.	
Scallops and ocean quahogs (other sessile bivalves) are managed as one stock	Many species (lobsters and relatively sessile fish such as goosefish and flounders) with interconnected meta-populations are managed as separate stocks. Precedent does not define best practice.	
Split made at the proposed point is not optimal - this aspect should be studied further before management action occurs	GBK is the most distinct region based on biological characteristics, oceanography, geography, larval dispersal and general ecological classifications. Additional divisions in the south can be made later if warranted.	
No genetic differences were found among samples of surfclams from Georges Bank to Virginia.	Lack of significant differences in genetic studies does not prove population homogeneity.	Weinberg, J.W. 2005. Mar. Biol. 146(4): 707-716
Recruitment in SNE may come from GBK at periods that have not been observed in models	There is insufficient age data for SNE to evaluate this hypothesis. However, the limited available data indicate that recruitment patterns differ between the major population centers (GBK in the north and New Jersey and Delmarva in the south).	TABLE A19

Table A19. Summary of unpublished results from surfclam larval drift simulation study courtesy of X. Zhang and D. Haidvogel (IMCS, Rutgers). Tables show the percentage of settlers released (columns) that settled successfully in each area (row) over 35 simulated days (the approximate larval stage duration) assuming no larval mortality. For example, of all the larvae released on Georges Bank, about 9.4% had settled on Georges Bank by the end of 35 days and none had settled elsewhere. Larvae were released from all major areas of surfclam habitat at five day intervals from May 21 to October 16, 2006-2009 (30 release dates) with results from all years and release dates summarized below. The size of each simulated larva was tracked in the model and larvae grew at a rate that depended on age, temperature and available food concentrations. Simulated larvae moved passively in horizontal directions but vertical movements were active at speeds dependent on size and water temperature. Larvae settled after they reached 260 µm, reached habitat with suitable water temperatures. They were considered dead if they had not settled in 35 days. The Regional Ocean Modeling System (ROMS) model used in simulations included forcing by rivers, tides, wind, radiation, air temperatures, humidity, etc. with a spatial resolution of 8 x 12 Km (120 x 160) grids.

		Release area (south on left, north on right)					
		Southern Virginia	DelMarva	New Jersey	Long Island	Southern New England	Georges Bank
		All years					
Settlement area (south bottom, north top)	Georges Bank	0	0	0	0	0	19.3556
	Southern New England	0	0	0	0.0167	0.3667	0
	Long Island	0	0	0.2130	37.1663	0.3333	0
	New Jersey	0	0.0683	78.7130	88.6910	0.1750	0
	DelMarva	1.9334	40.6430	80.9640	8.2167	0	0
	Southern Virginia	40.0997	85.8250	12.2463	0	0	0

Table A20. Structure of SS3 models used for surfclams in the southern and GBK areas.

Model aspect	Southern area	GBK area	Note
Natural mortality (M)	$0.15\ y^{-1}$		Constant for all ages and all years
Age bins	0-32+ y	0-30+ y	Few ages ≥ 30+ y
Population length bins	1, 2, … 19, 20 cm SL		
Time	1965-2011	1984-2011	South: starts first year with catch data and 17 y before first survey in 1982. North: starts first year with survey and catch data.
Seasons/ subareas/ morphs	None		
Commercial fleets	1		
Fishery size selectivity	Double normal (dome shaped), five parameters estimated and assumed constant over time	Double normal (logistic shaped) with left hand side from parameters estimated for south	Not estimable for GBK because of noisy and limited (2010-2011) commercial size data
Surveys	1 (2 variants)		NEFSC clam survey and minimum swept-area abundance based on clam survey data
Survey trend size selectivity	Field estimates		Double-normal selectivity curve fit externally to original GAM model estimates from field data (see parameter table)
Survey trend catchability	Estimated	Estimated	
Minimum swept area biomass size selectivity	Mirrors (same as) survey trend size selectivity		
Minimum swept area biomass catchability (capture efficiency)	Mean unbiased log scale parameter with normal prior	Fixed at estimate for southern area	Trend ignored in fitting model (weight 10-5) but catchability is calculated and compared to prior
Recruit model	Beverton-Holt with fixed steepness=0.95, estimate virgin recruitment and recruit variance		In effect, recruitments vary randomly around a constant mean estimated in the model and with a variance estimated in the model. Steepness is not important because biomass has never been low.
Recruit dev years	1965-2013	1969-2011	
Last early year with no bias adjustment	1919	1959	Adjusted based on preliminary fits
First year no full bias adjustment	1969	1974	
Last year full bias adjustment	2008	2006	
First recent year no bias adjustment	2012	2013	
Max bias adjustment	0.97	0.87	
Fishing mortality method	Hybrid method, 6 iterations (exact F)		Use Pope's approximation next time for speed if fishing mortality estimates remain low

Table A21. Parameters estimated internally and externally in SS3 models for surfclams in the southern and GBK regions. Numbers of parameters are summarized in the last rows.

Parameter	Southern area	SD (if estimated)	GBK area	CV (if estimated)	Note
M at ages 5 and 30 y	0.15	n/a	Same as south		
Length at age 4	10.245	0.045431	9.3017	0.10797	
Length at age 30	16.019	0.068704	14.846	0.11077	
Von Bertalanffy K	0.22379	n/a	0.253	n/a	
SD of size at ages 5 and 30 y	1.84	n/a	Same as south	n/a	
Shell length-meat weight					
Multiplier	0.000094	n/a	0.0001055	n/a	
Exponent	2.73325	n/a	2.73325	n/a	
Spawner-recruit					
Log virgin recruitment (R0)	14.893	0.13793	13.867	0.19071	
Steepness	0.95	n/a	Same as south		
Standard deviation	0.61803	0.064875	0.77469	0.086266	
Initial fishing mortality	0.016052	0.0024872	0	n/a	
Log catchability (capture efficiency) for swept area abundance	-1.1086	n/a	Same as south		This is a dummy parameter for comparison to capture efficiency prior
Size selectivity - fishery					
Peak	15.519	0.10544	15.4	n/a	GBK fishery selectivity parameters for left-hand side of double normal selectivity curve are fixed at same values as south. Parameters for right-hand side are fixed at values to ensure asymptotic pattern
Top	-9.7169	7.9249	10	n/a	
Asc-width	1.5949	0.076367	1.61	n/a	
Dsc-width	1.1254	0.1768	10	n/a	
Init	-999	n/a	-999	n/a	
Final	-999	n/a	-999	n/a	
Size selectivity - survey trend and swept-area abundance					
Peak	8.81897	n/a	Same as south		Estimated externally by fitting the double normal selectivity function to selectivity at size estimates from a mixed-effects GAM model.
Top	-0.64891	n/a			
Asc-width	2.23919	n/a			
Dsc-width	2.3557	n/a			
Init	-999	n/a			
Final	-0.817434	n/a			
N estimated parameters excluding recruit deviations	9		4		
N estimated recruit deviations	47		43		
Total N estimated parameters	56		47		

Table A22. Growth parameter estimates and goodness of fit from preliminary SS3 model runs for surfclams in the southern region. The lowest negative log likelihood values are shown in bold and the models are sorted from left (poorest fit) to right (best fit).

Statistic or growth parameter	Southern growth pars, normal prior on log q	Estimate Growth SD@Lmax	Estimate Lmax	Estimate K	Estimate Lmax and K	Estimate Growth SD@Lmin	Estimate both size@age SD	Estimate Lmin	Estimate Lmin and SD@Lmin	Estimate Lmin and Lmax	Estimate Lmin and K	Estimate all growth pars
NLL	1,248	1,245	1,241	1,235	1,234	1,216	1,205	1,167	1,166	1,156	1,128	1,122
Lmin	10.99	10.99	10.99	10.99	10.99	10.99	10.99	**11.79**	**11.76**	**11.81**	**11.91**	**11.97**
Lmax	16.19	16.19	**15.82**	16.19	**16.07**	16.19	16.19	16.19	16.19	**15.79**	16.19	**16.34**
K	0.22	0.22	0.22	**0.17**	**0.18**	0.22	0.22	0.22	0.22	0.22	**0.13**	**0.13**
SD min	1.84	1.84	1.84	1.84	1.84	**2.09**	**2.13**	1.84	**1.89**	1.84	1.84	**1.80**
SD max	1.84	**1.72**	1.84	1.84	1.84	1.84	**1.60**	1.84	1.84	1.84	1.84	**1.70**

Table A23. Goodness of fit for two preliminary SS3 models with likelihood weights on survey trend: lambda=1 and lambda=100. The lowest negative log likelihood values are shown in bold.

Label	Lambda = 1	Lambda = 100
Recruitment	**2.132**	10.016
Parm_priors	**0.051**	0.220
Survey trend	-3.768	**-7.582**
Lengths		
Fishery	**197.2**	199.4
Survey	**163.0**	176.7
Survey ages	**1,748**	1,873
Naked sum	**2,107**	2,251

SWAN Q=efficiency	0.19	0.27

B2011	1,020,610	611,096
B2011/B1999	0.49	0.36

Table A24. Data used in SS3 models for surfclams in the southern and GBK areas.

Data type	Southern area	GBK area	Note
Catches (mt meat weight)	1965-2011		Landings+discard+12% assumed incidental mortality
Historical catches (used to calculate initial biomass)	Average 1965-1969 = 12,802 mt		Landings+discard+12% assumed incidental mortality
Fishery length composition, 3-18 cm SL in 1 cm bins	N=30: 1982- 2011	N=2: 2010-2011	Southern area size data for 1982 and 1999 down-weighted (effective N=10).
Fishery age data	None		
Survey abundance data	N=13: 1982-1984, 1986, 1989, 1992, 1994, 1997, 1999, 2002, 2005, 2008, 2011	N=10: 1984, 1986, 1989, 1992, 1994,1997, 1999, 2002, 2008, 2011	Mean numbers per tow, without adjustments based on sensor data
Survey length data, 3-18 cm in cm bins	Same as survey abundance data		Southern area size data for 1984 downweighted (effective N=10) due to very large catch of surfclams almost entirely 7-8.9 cm SL
Survey age data (0-30+ y in 1 year age bins)	N=10: 1982-1983, 1986, 1989, 1992, 1999, 2002, 2005, 2008, 2011	N=9: 1984, 1986, 1989, 1992, 1997,1999, 2002, 2008, 2011	Age data were not collected from entire southern and GBK areas during some years
Minimum swept area abundance	N=6: 1997, 1999, 2002, 2005, 2008, 2011	N=5: 1997, 1999, 2002, 2008, 2011	Survey catches adjusted on a station-specific basis for tow distance using sensor data, total area adjusted for unsuitable habitat, bad tows discarded
Survey timing	0.51		Mean Julian date / 365
Likelihood weights	All 1.0 except 10^{-5} for minimum swept area abundance trend		
Initial growth parameters	External estimates		External estimates using all available age data for each region. L_{min} and L_{max} were estimated in final models (see parameter table) while other growth parameters were left at initial values.
Maturity	50% mature at age 2 1		Information about age specific fecundity limited
Age reader precision	Age data assumed unbiased with standard deviations for ageing errors increasing linearly from 0.144 y at age 0 y to 0.531 y at age 30 y		Based on between age reader comparison experiments and QA/QC experiments (ages read twice by same reader). All age data were collected by same reader.
Shell length - meat weight	External estimates		Estimates (ignoring depth effects) updated in this assessment

Table A25. Biomass (ages 6+ y or approximately 120+ mm SL, thousand mt), recruitment (10^9 age zero surfclams) and fully recruited fishing mortality (F) estimates from SS3 for the **southern area** with CVs.

Year	Biomass	CV.B	Recruitment	CV.R	F	CV.F
Virgin	1250	0.14	2937	0.14	NA	NA
1964	1160	0.14	2937	0.14	NA	NA
1965	1160	0.14	2133	0.22	0.02	0.16
1966	1157	0.14	2354	0.20	0.02	0.16
1967	1154	0.14	1767	0.21	0.02	0.16
1968	1155	0.14	2005	0.19	0.01	0.16
1969	1157	0.14	1515	0.20	0.01	0.15
1970	1162	0.14	1109	0.22	0.01	0.15
1971	1135	0.14	1109	0.21	0.03	0.15
1972	1101	0.14	1321	0.19	0.04	0.15
1973	1044	0.14	1958	0.18	0.05	0.16
1974	990	0.15	2319	0.17	0.06	0.16
1975	922	0.15	2917	0.17	0.04	0.16
1976	856	0.15	6987	0.16	0.04	0.16
1977	794	0.15	10658	0.15	0.04	0.17
1978	746	0.15	7661	0.16	0.03	0.17
1979	733	0.15	7911	0.15	0.03	0.17
1980	738	0.15	9529	0.15	0.04	0.17
1981	768	0.15	4859	0.16	0.05	0.17
1982	950	0.15	3995	0.16	0.04	0.17
1983	1277	0.15	4278	0.16	0.03	0.17
1984	1484	0.15	2822	0.18	0.03	0.17
1985	1684	0.15	2621	0.19	0.02	0.17
1986	1929	0.15	4001	0.18	0.02	0.17
1987	1974	0.15	3253	0.18	0.02	0.17
1988	1967	0.15	3094	0.19	0.02	0.17
1989	1956	0.15	3915	0.18	0.02	0.17
1990	1880	0.16	2607	0.19	0.02	0.17
1991	1789	0.16	3034	0.19	0.02	0.17
1992	1756	0.16	4698	0.18	0.02	0.17
1993	1696	0.16	3428	0.18	0.02	0.17
1994	1634	0.16	1712	0.19	0.02	0.17
1995	1608	0.16	1236	0.20	0.02	0.17
1996	1539	0.16	1672	0.19	0.02	0.17
1997	1490	0.16	1738	0.19	0.02	0.17
1998	1511	0.17	2998	0.19	0.02	0.17
1999	1488	0.17	2759	0.19	0.02	0.18
2000	1399	0.17	1465	0.20	0.02	0.18
2001	1294	0.17	552	0.24	0.03	0.18
2002	1207	0.17	849	0.22	0.03	0.18
2003	1128	0.18	851	0.23	0.04	0.18
2004	1104	0.18	1438	0.22	0.04	0.19
2005	1079	0.18	2240	0.21	0.03	0.19
2006	1013	0.18	2027	0.23	0.04	0.19
2007	912	0.19	1906	0.25	0.05	0.20
2008	827	0.19	1594	0.27	0.05	0.20
2009	750	0.19	2115	0.31	0.04	0.21
2010	706	0.20	3017	0.39	0.04	0.21
2011	703	0.20	1704	0.55	0.04	0.21

Table A26. Biomass (ages 7+ y or approximately 120+ mm SL, thousand mt), recruitment (10^9 age zero surfclams) and fully recruited fishing mortality (F) estimates from SS3 for the **northern (i.e., GBK) area** with CVs.

Year	Biomass	CV.B	Recruitment	CV.R	F	CV.F
1982	380	0.19	1053	0.19	0.00	0.00
1983	380	0.19	1053	0.19	0.00	0.00
1984	504	0.20	2056	0.24	0.01	0.20
1985	508	0.19	949	0.32	0.01	0.20
1986	522	0.19	1383	0.28	0.01	0.21
1987	523	0.19	1520	0.27	0.00	0.21
1988	532	0.18	1707	0.26	0.00	0.20
1989	521	0.19	1041	0.31	0.00	0.20
1990	518	0.19	1000	0.31	0.00	0.20
1991	541	0.19	750	0.35	0.00	0.00
1992	522	0.19	883	0.38	0.00	0.00
1993	520	0.16	3289	0.25	0.00	0.00
1994	522	0.16	3597	0.24	0.00	0.00
1995	532	0.18	1636	0.29	0.00	0.00
1996	517	0.17	1553	0.27	0.00	0.00
1997	500	0.17	1469	0.29	0.00	0.00
1998	475	0.17	1583	0.31	0.00	0.00
1999	456	0.18	849	0.39	0.00	0.00
2000	528	0.18	241	0.62	0.00	0.00
2001	610	0.18	354	0.54	0.00	0.00
2002	616	0.18	314	0.55	0.00	0.00
2003	616	0.18	234	0.51	0.00	0.00
2004	610	0.18	319	0.39	0.00	0.00
2005	608	0.18	356	0.33	0.00	0.00
2006	578	0.18	380	0.35	0.00	0.00
2007	526	0.18	300	0.43	0.00	0.00
2008	481	0.18	156	0.57	0.00	0.00
2009	437	0.18	171	0.58	0.00	0.19
2010	394	0.18	240	0.62	0.00	0.19
2011	357	0.18	385	0.69	0.01	0.19

Table A26B. Biomass (approximately 120+ mm SL, thousand mt), recruitment (10^9 age zero surfclams) and fully recruited fishing mortality (F) estimates from SS3 for the **whole stock** with CVs.

Year	Biomass	cv	Recruitment	cv	F	cv
1982	1331	0.12	5048	0.14		
1983	1657	0.12	5331	0.14		
1984	1987	0.12	4878	0.15	0.021	0.166
1985	2191	0.13	3570	0.16	0.019	0.164
1986	2451	0.13	5384	0.15	0.018	0.261
1987	2497	0.13	4773	0.15	0.016	0.261
1988	2500	0.13	4801	0.15	0.016	0.262
1989	2477	0.13	4956	0.16	0.015	0.262
1990	2398	0.13	3607	0.16	0.017	0.262
1991	2330	0.13	3783	0.17	0.015	0.262
1992	2278	0.13	5581	0.16	0.016	0.262
1993	2216	0.13	6717	0.15	0.016	0.165
1994	2156	0.13	5309	0.17	0.017	0.166
1995	2140	0.13	2872	0.19	0.015	0.167
1996	2055	0.13	3225	0.16	0.016	0.168
1997	1990	0.13	3207	0.17	0.015	0.169
1998	1986	0.13	4581	0.16	0.015	0.170
1999	1944	0.14	3608	0.17	0.017	0.171
2000	1927	0.13	1707	0.19	0.017	0.173
2001	1903	0.13	906	0.26	0.020	0.175
2002	1823	0.13	1163	0.22	0.022	0.177
2003	1744	0.13	1086	0.21	0.024	0.180
2004	1714	0.13	1758	0.19	0.024	0.184
2005	1687	0.13	2596	0.19	0.022	0.187
2006	1591	0.13	2407	0.20	0.025	0.190
2007	1439	0.14	2206	0.22	0.029	0.194
2008	1307	0.14	1749	0.26	0.028	0.198
2009	1187	0.14	2286	0.29	0.027	0.275
2010	1100	0.14	3257	0.37	0.025	0.277
2011	1060	0.14	2089	0.47	0.027	0.280

Table A27. Likelihood profile analysis for survey dredge efficiency, biomass, and biomass status (B2011/B1999) using the basecase SS3 model for surfclams in the southern area. Minimum likelihood values for each term are highlighted.

Label	Q=0.18	Q=0.26	Q=0.3	Q=0.33 (basecase)	Q=0.38	Q=0.44	Q=0.49
TOTAL	2036.0	2032.5	2031.7	**2031.5**	2032.0	2033.9	2036.1
Recruitment	3.479	3.035	**2.940**	2.948	3.124	3.791	4.728
Parm_priors	**0.057**	0.217	0.318	0.383	0.504	0.672	0.808
Parm_softbounds	0.003	0.003	0.003	0.003	0.003	0.003	**0.003**
Survey	-3.013	-3.385	-3.568	**-3.604**	-3.444	-2.738	-1.915
Lengths							
Fishery lengths	204.210	203.237	202.930	202.790	202.615	202.516	**202.515**
Survey lengths	151.100	149.685	149.213	148.976	148.614	148.219	**147.954**
Survey ages	1680.2	**1679.7**	1679.9	1680.1	1680.6	1681.4	1682.0

B2011	1,387,280	915,528	772,377	702,902	599,781	493,921	**428,446**
B2011/B1999	0.51	0.49	0.48	0.47	0.46	0.44	**0.42**

Table A28. Table comparing the biomass estimates from previous surfclam assessments. Note that in the current assessment animals greater than 120 mm are 6 and older in the southern area and 7 and older in the north, due to differing growth rates.

Year	2012	SAW 49 (NEFSC 2009)	SAW 44 (NEFSC 2007)	SAW 37 (NEFSC 2003)	SAW 30 (NEFSC 2000)	SAW 26 (NEFSC 1998)
Shell length (mm)	~120+ (age 6+ South, 7+ North)	120+	120+	120+ in NJ; 100+ elsewhere	120+ in NJ; 100+ elsewhere	All
Method	SS3	KLAMZ	KLAMZ	SWAB	KLAMZ	SWAB
Year	Biomass	Biomass	Biomass			
1981		831	1,020			
1982	1,331	862	1,036			
1983	1,657	889	1,059			
1984	1,987	916	1,083			
1985	2,191	935	1,141			
1986	2,451	954	1,225			
1987	2,497	973	1,271			
1988	2,500	988	1,290			
1989	2,477	1,003	1,289			
1990	2,398	1,021	1,285		1,200	
1991	2,330	1,029	1,283		1,200	
1992	2,278	1,045	1,290		1,200	
1993	2,216	1,059	1,476		1,200	
1994	2,156	1,070	1,613		1,200	
1995	2,140	1,082	1,709		1,200	
1996	2,055	1,088	1,780	1,146	1,200	1,113
1997	1,990	1,090	1,842		1,300	
1998	1,986	1,092	1,824	1,460	1,300	
1999	1,944	1,086	1,799			
2000	1,927	1,074	1,723			
2001	1,903	1,059	1,628	803		
2002	1,823	1,037	1,531			
2003	1,744	1,012	1,415			
2004	1,714	984	1,292			
2005	1,687	955				
2006	1,591	931				
2007	1,439	905				
2008	1,307					
2009	1,187					
2010	1,100					
2011	1,060					

Table A29. Whole stock biomass status estimates for 2011 with cv and approximate 95% confidence intervals.

	Biomass	cv	lci	uci
2011	1060	0.143	802	1401
Target	972	0.135	747	1235
Threshold	486	0.135	373	633

Table A30. Whole stock F status estimates for 2011 with cv and approximate 95% confidence intervals.

	F	cv	lci	uci
2011	0.027	0.271	0.016	0.045
Threshold	0.15			

Table A31 Southern area biomass status estimates for 2011 with cv and approximate 95% confidence intervals.

	Biomass	cv	lci	uci
2011	703	0.196	481	1028
Target	744	0.168	537	1032
Threshold	372	0.168	268	516

Table A32. Southern area F status estimates for 2011 with cv and approximate 95% confidence intervals.

	F	cv	lci	uci
2011	0.040	0.211	0.025	0.056
Threshold	0.15			

Table A33. Projected biomass and biomass status ($B/B_{threshold}$ where $B_{threshold}=B_{1999}/4$) during 2012-2021 for surfclams in the southern, GBK and combined areas.

Year	Southern area			GBK area			Southern + GBK		
	F=0.15 (M)	Status-quo catch	Quota	F=0.15 (M)	Status-quo catch	Quota	F=0.15 (M)	Status-quo catch	Quota
Biomass (mt)									
2011	704,366	704,366	704,366	370,217	370,217	370,217	1,074,583	1,074,583	1,074,583
2012	699,480	699,480	699,480	338,866	338,866	338,866	1,038,346	1,038,346	1,038,346
2013	690,839	690,839	690,839	308,580	308,580	308,580	999,419	999,419	999,419
2014	633,310	677,921	672,888	252,941	271,536	271,536	886,251	949,457	944,424
2015	604,667	686,541	676,966	208,410	238,833	238,833	813,077	925,374	915,799
2016	617,034	731,098	717,356	175,171	212,330	212,330	792,205	943,428	929,686
2017	585,090	725,516	708,212	154,269	194,626	194,626	739,359	920,142	902,838
2018	597,117	761,170	740,671	160,621	202,314	202,314	757,738	963,484	942,985
2019	614,769	800,317	777,001	172,120	214,381	214,381	786,889	1,014,698	991,382
2020	632,270	837,938	812,136	185,038	227,946	227,946	817,308	1,065,884	1,040,082
2021	648,414	873,215	845,220	197,790	241,864	241,864	846,204	1,115,079	1,087,084
Biomass / Bthreshold (Bthreshold=B1999/4)									
1999	1,513,100			506,882			2,019,982		
Bthreshold	378,275			126,721			504,996		
2011	1.86	1.86	1.86	2.92	2.92	2.92	2.13	2.13	2.13
2012	1.85	1.85	1.85	2.67	2.67	2.67	2.06	2.06	2.06
2013	1.83	1.83	1.83	2.44	2.44	2.44	1.98	1.98	1.98
2014	1.67	1.79	1.78	2.00	2.14	2.14	1.75	1.88	1.87
2015	1.60	1.81	1.79	1.64	1.88	1.88	1.61	1.83	1.81
2016	1.63	1.93	1.90	1.38	1.68	1.68	1.57	1.87	1.84
2017	1.55	1.92	1.87	1.22	1.54	1.54	1.46	1.82	1.79
2018	1.58	2.01	1.96	1.27	1.60	1.60	1.50	1.91	1.87
2019	1.63	2.12	2.05	1.36	1.69	1.69	1.56	2.01	1.96
2020	1.67	2.22	2.15	1.46	1.80	1.80	1.62	2.11	2.06
2021	1.71	2.31	2.23	1.56	1.91	1.91	1.68	2.21	2.15

Table A34. Projected landings (mt and bu) during 2012-2021 for surflclams in the southern, GBK and combined areas.

Year	Southern area			GBK area			Southern + GBK		
	F=0.15 (M)	Status-quo catch	Quota	F=0.15 (M)	Status-quo catch	Quota	F=0.15 (M)	Status-quo catch	Quota
	Landings (mt, catch - 12% incidental mortality)								
2011	16,089	16,089	16,089	2,127	2,127	2,127	18,216	18,216	18,216
2012	18,728	18,728	18,728	2,127	2,127	2,127	20,854	20,854	20,854
2013	60,767	13,145	18,504	28,352	7,710	7,710	89,119	20,854	26,213
2014	57,705	13,145	18,504	23,444	7,710	7,710	81,150	20,854	26,213
2015	55,609	13,145	18,504	19,570	7,710	7,710	75,178	20,854	26,213
2016	54,683	13,145	18,504	16,829	7,710	7,710	71,512	20,854	26,213
2017	54,690	13,145	18,504	15,235	7,710	7,710	69,925	20,854	26,213
2018	55,444	13,145	18,504	14,658	7,710	7,710	70,102	20,854	26,213
2019	56,660	13,145	18,504	14,827	7,710	7,710	71,488	20,854	26,213
2020	58,057	13,145	18,504	15,448	7,710	7,710	73,505	20,854	26,213
2021	59,431	13,145	18,504	16,279	7,710	7,710	75,710	20,854	26,213
Landings (bu, catch - 12% incidental mortality)									
2011	2,086,796	2,086,796	2,086,796	275,848	275,848	275,848	2,362,644	2,362,644	2,362,644
2012	2,429,011	2,429,011	2,429,011	275,848	275,848	275,848	2,704,859	2,704,859	2,704,859
2013	7,881,636	1,704,882	2,399,944	3,677,240	999,977	999,977	11,558,875	2,704,859	3,399,921
2014	7,484,494	1,704,882	2,399,944	3,040,787	999,977	999,977	10,525,280	2,704,859	3,399,921
2015	7,212,525	1,704,882	2,399,944	2,538,250	999,977	999,977	9,750,776	2,704,859	3,399,921
2016	7,092,540	1,704,882	2,399,944	2,182,694	999,977	999,977	9,275,234	2,704,859	3,399,921
2017	7,093,374	1,704,882	2,399,944	1,976,028	999,977	999,977	9,069,402	2,704,859	3,399,921
2018	7,191,136	1,704,882	2,399,944	1,901,184	999,977	999,977	9,092,320	2,704,859	3,399,921
2019	7,348,932	1,704,882	2,399,944	1,923,129	999,977	999,977	9,272,061	2,704,859	3,399,921
2020	7,530,109	1,704,882	2,399,944	2,003,590	999,977	999,977	9,533,699	2,704,859	3,399,921
2021	7,708,252	1,704,882	2,399,944	2,111,404	999,977	999,977	9,819,657	2,704,859	3,399,921

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Table A35. Projected fully recruited fishing mortality and exploitation rates (catch weight / biomass ages 6+) during 2012-2021 for surfclams in the southern, GBK and combined areas.

Year	Southern area			GBK area			Southern + GBK		
	F=0.15 (M)	Status-quo catch	Quota	F=0.15 (M)	Status-quo catch	Quota	F=0.15 (M)	Status-quo catch	Quota
	Fully recruited fishing mortality								
2011	0.037	0.037	0.037	0.009	0.009	0.009	0.028	0.028	0.028
2012	0.044	0.044	0.044	0.010	0.010	0.010	0.033	0.033	0.033
2013	0.150	0.031	0.044	0.150	0.039	0.039	0.150	0.034	0.042
2014	0.150	0.031	0.044	0.150	0.044	0.044	0.150	0.035	0.043
2015	0.150	0.031	0.044	0.150	0.050	0.050	0.150	0.035	0.044
2016	0.150	0.030	0.043	0.150	0.055	0.055	0.150	0.035	0.044
2017	0.151	0.029	0.042	0.150	0.059	0.059	0.150	0.035	0.044
2018	0.151	0.028	0.040	0.151	0.061	0.061	0.150	0.035	0.043
2019	0.151	0.026	0.038	0.151	0.060	0.060	0.150	0.034	0.042
2020	0.151	0.025	0.037	0.151	0.058	0.058	0.150	0.033	0.040
2021	0.151	0.024	0.035	0.151	0.056	0.056	0.150	0.032	0.039
Exploitation rate (catch/biomass)									
2011	0.026	0.026	0.026	0.006	0.006	0.006	0.019	0.019	0.019
2012	0.030	0.030	0.030	0.007	0.007	0.007	0.022	0.022	0.022
2013	0.099	0.021	0.030	0.103	0.028	0.028	0.100	0.023	0.029
2014	0.102	0.022	0.031	0.104	0.032	0.032	0.103	0.025	0.031
2015	0.103	0.021	0.031	0.105	0.036	0.036	0.104	0.025	0.032
2016	0.099	0.020	0.029	0.108	0.041	0.041	0.101	0.025	0.032
2017	0.105	0.020	0.029	0.111	0.044	0.044	0.106	0.025	0.033
2018	0.104	0.019	0.028	0.102	0.043	0.043	0.104	0.024	0.031
2019	0.103	0.018	0.027	0.096	0.040	0.040	0.102	0.023	0.030
2020	0.103	0.018	0.026	0.094	0.038	0.038	0.101	0.022	0.028
2021	0.103	0.017	0.025	0.092	0.036	0.036	0.100	0.021	0.027

Table A36. Cumulative probability of being in overfished status in any of the years 2013 – 2017, under a variety of catch scenarios.

Catch scenario	P[overfished][1]	P[overfishing][1]
	Whole stock	
Status Quo	0.019	0.000
Quota	0.022	0.000
OFL (F = M) catch	0.123	0.990
	Southern Area	
Status Quo	0.053	0.000
Quota	0.061	0.000
OFL (F = M) catch	0.162	0.990
	Northern Area	
Status Quo	NA	0.000
Quota	NA	0.000
OFL (F = M) catch	NA	0.990

1 Probabilities are cumulative (2013 - 2017)

Table A37. Estimated catch at the OFL for the next five years by area.

Year	Mean	Median	CV
	Whole stock		
2014	92324	90886	0.179
2015	85693	84191	0.189
2016	81658	80102	0.198
2017	79908	78326	0.202
2018	80124	78516	0.203
	Southern area		
2014	66202	34622	0.223
2015	63969	62304	0.233
2016	62950	61221	0.239
2017	63027	61249	0.242
2018	63908	62117	0.243
	Northern area		
2014	27302	26252	0.286
2015	22879	21915	0.3
2016	19721	18860	0.306
2017	17849	17056	0.308
2018	17180	16412	0.309

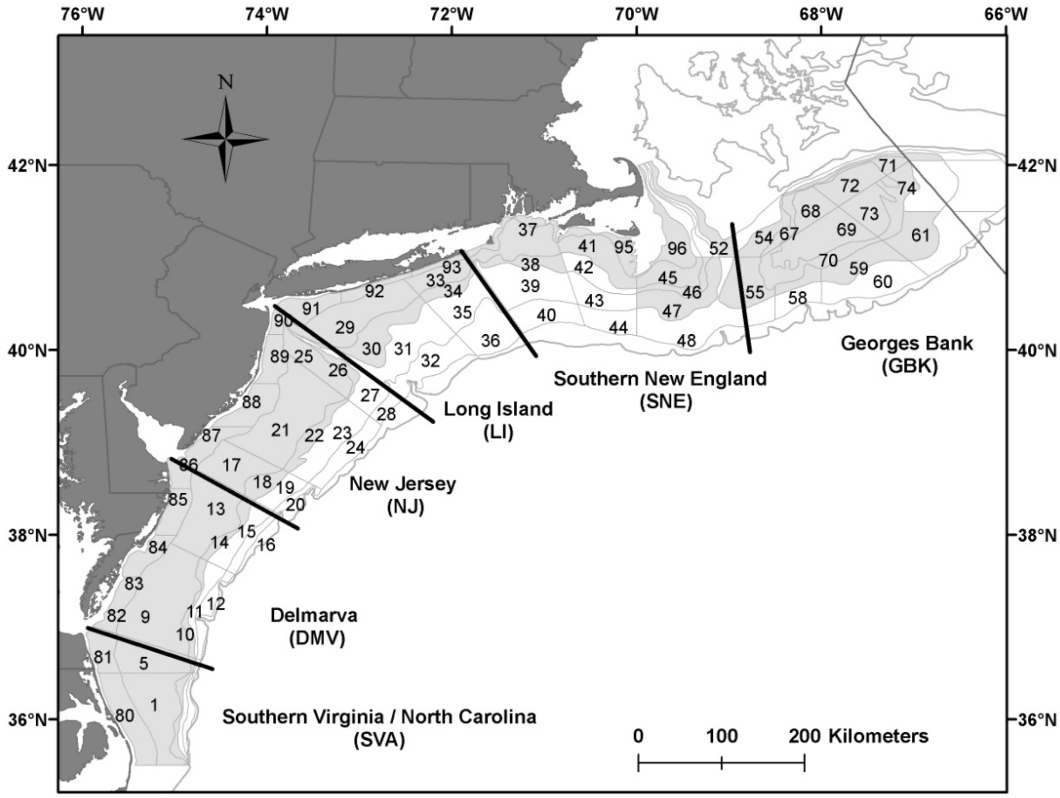

Figure A1. Surfclam stock assessment regions and NEFSC shellfish survey strata. The shaded strata are where surfclams are found.

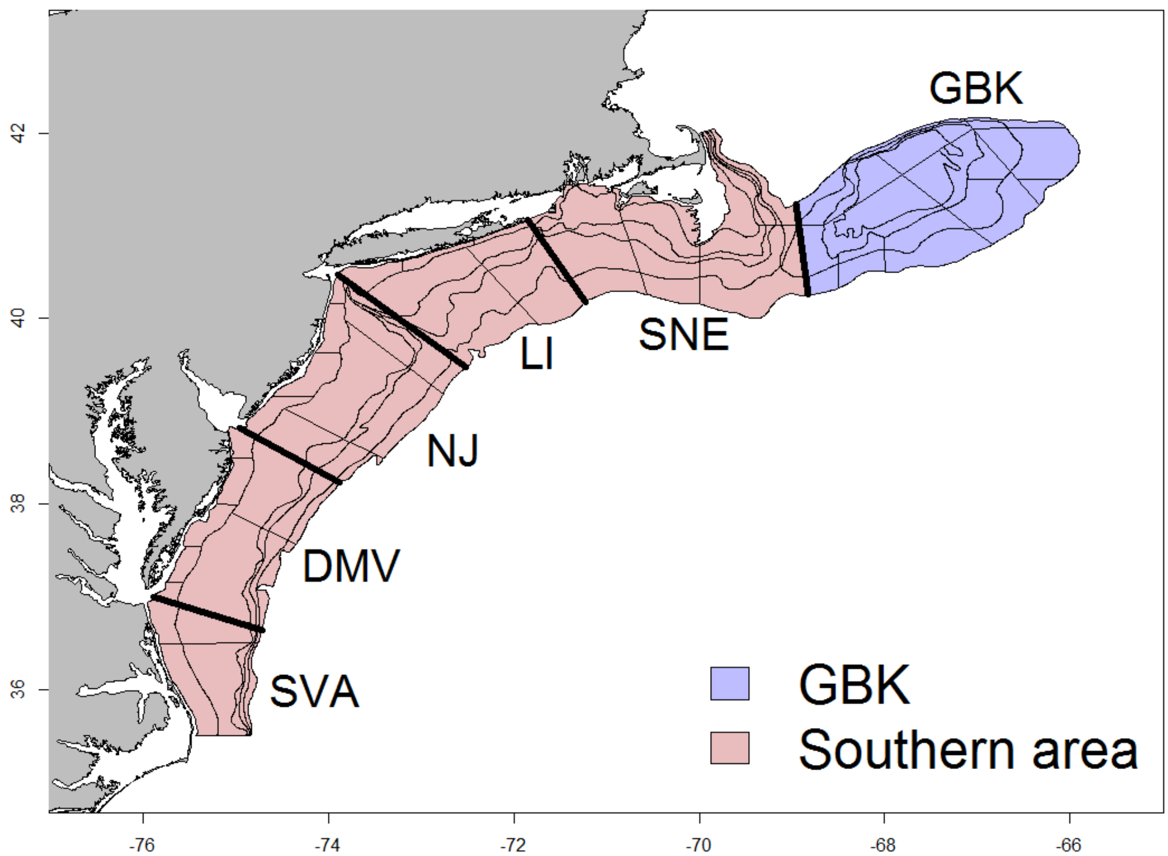

Figure A2. The surfclam regions divided into two areas.

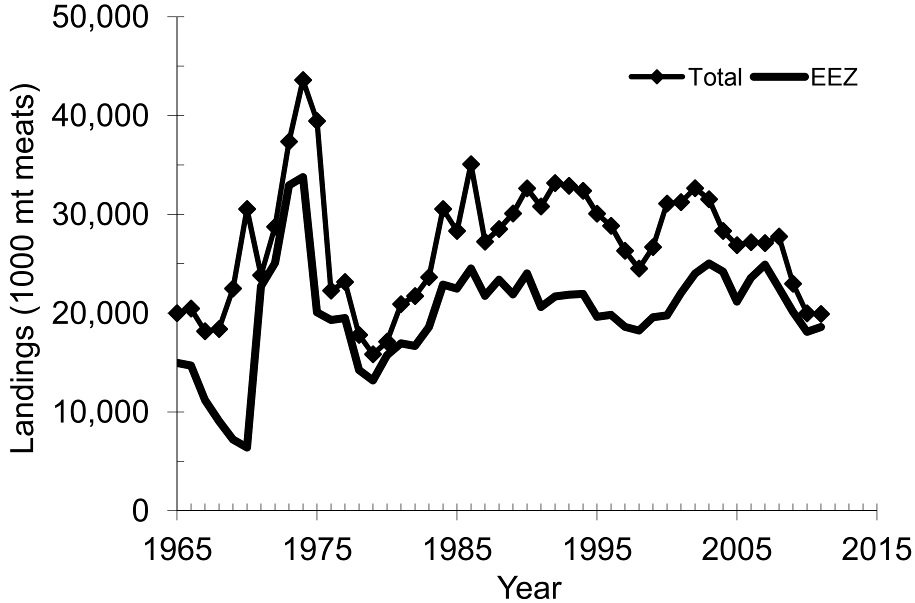

Figure A3. Surfclam landings (total and EEZ) during 1965-2011.

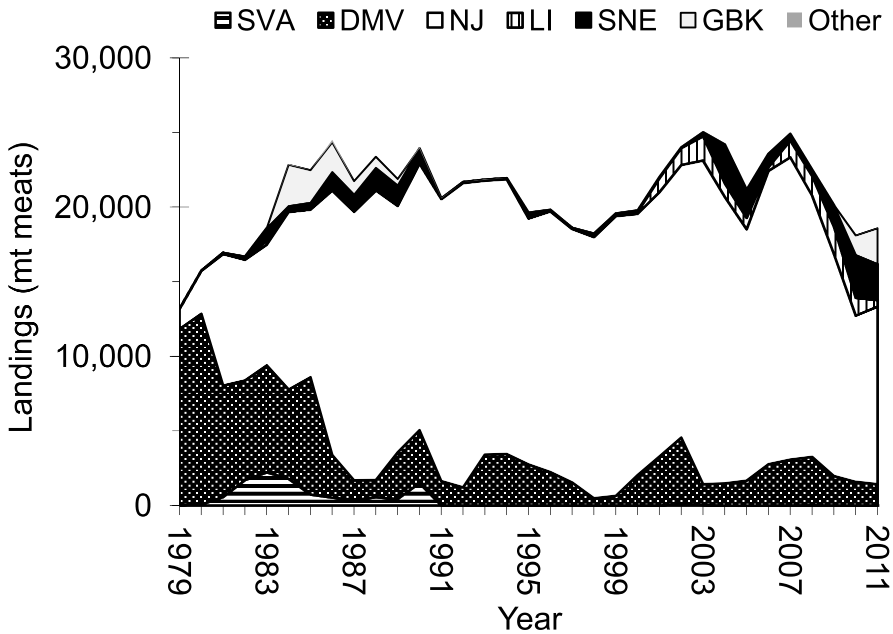

Figure A4. Surfclam landings from the US EEZ during 1979-2011, by stock assessment region.

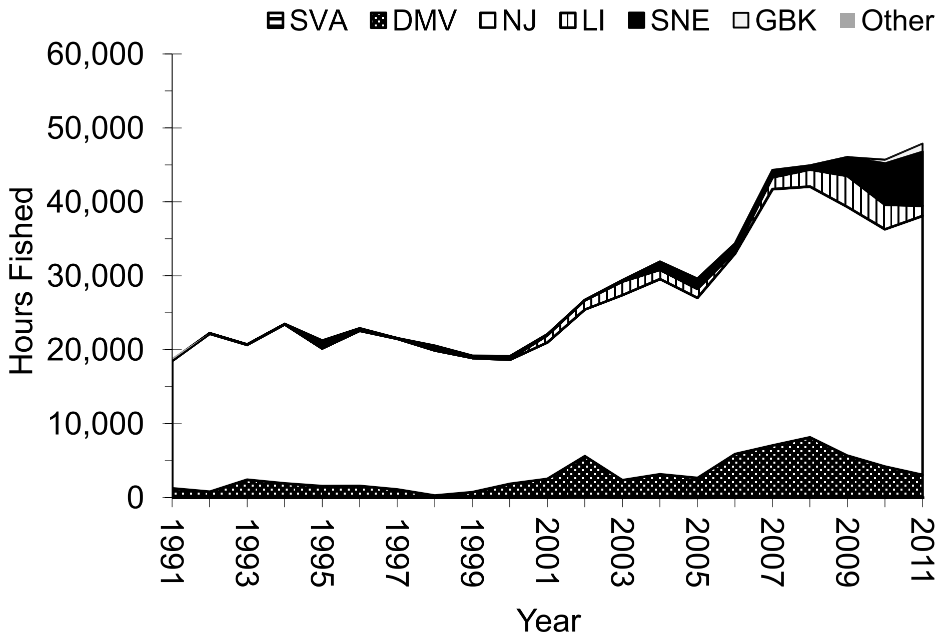

Figure A5. Surfclam hours fished from the US EEZ during 1991-2011, by stock assessment region.

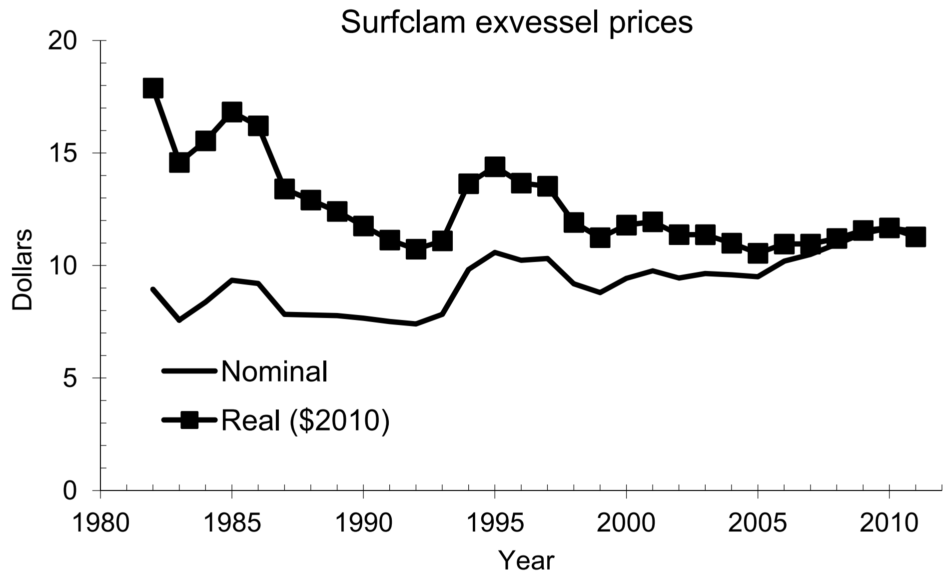

Figure A6. Nominal and 2010 dollar equivalent prices for surfclam 1981-2011.

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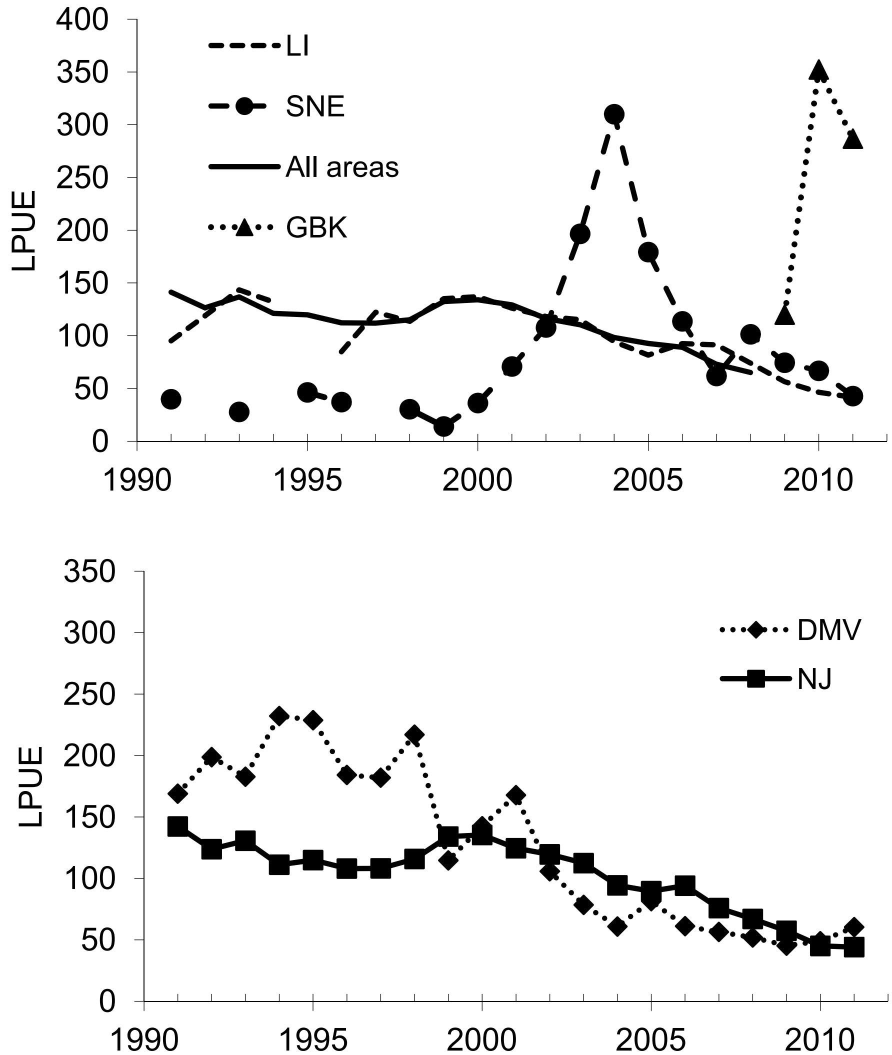


Figure A7. Nominal landings per unit effort (LPUE in bushels landed per hour fished) for surfclam, by region. LPUE is total landings in bushels divided by total fishing effort

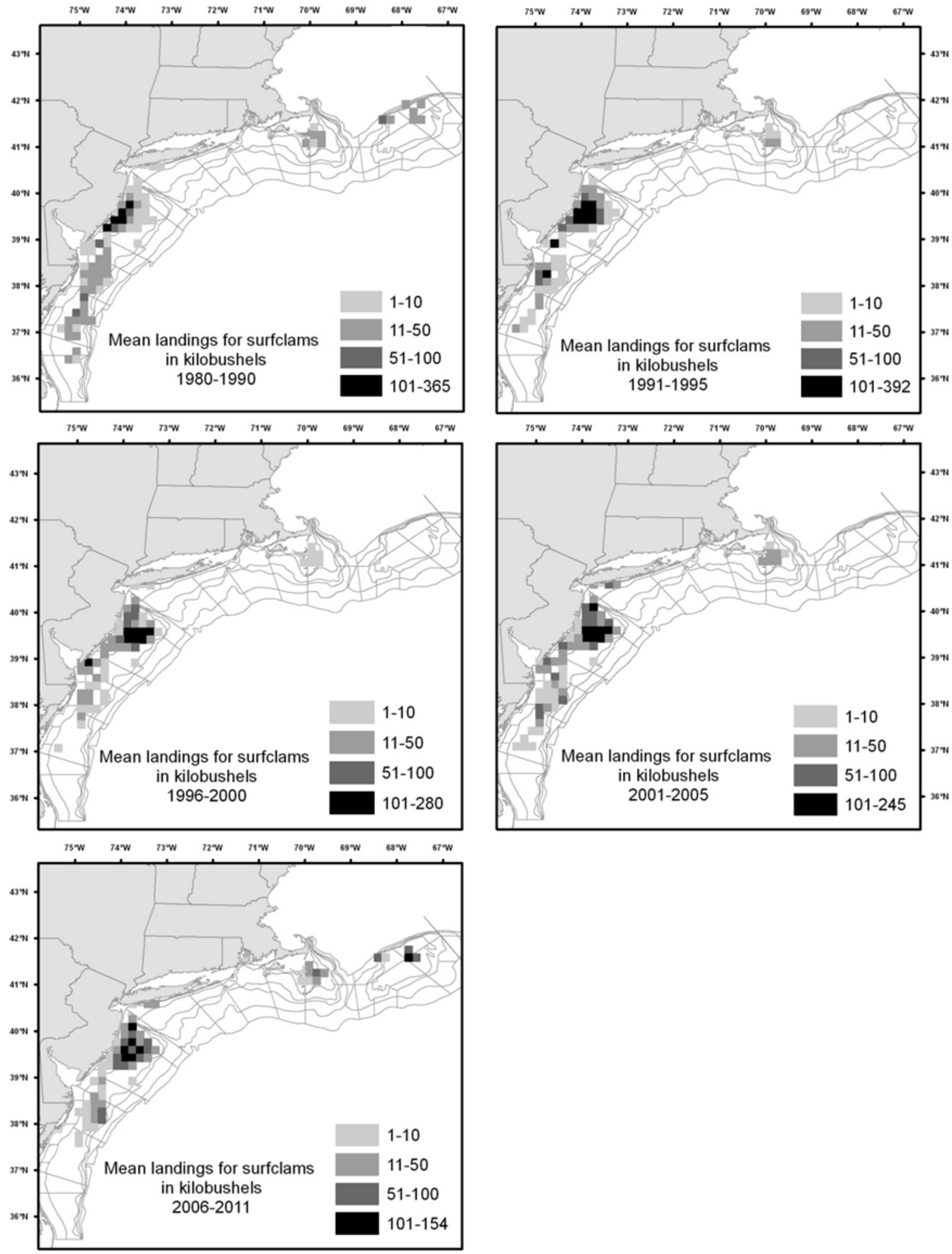


Figure A8. Average surfclams landings by ten-minute squares over time.

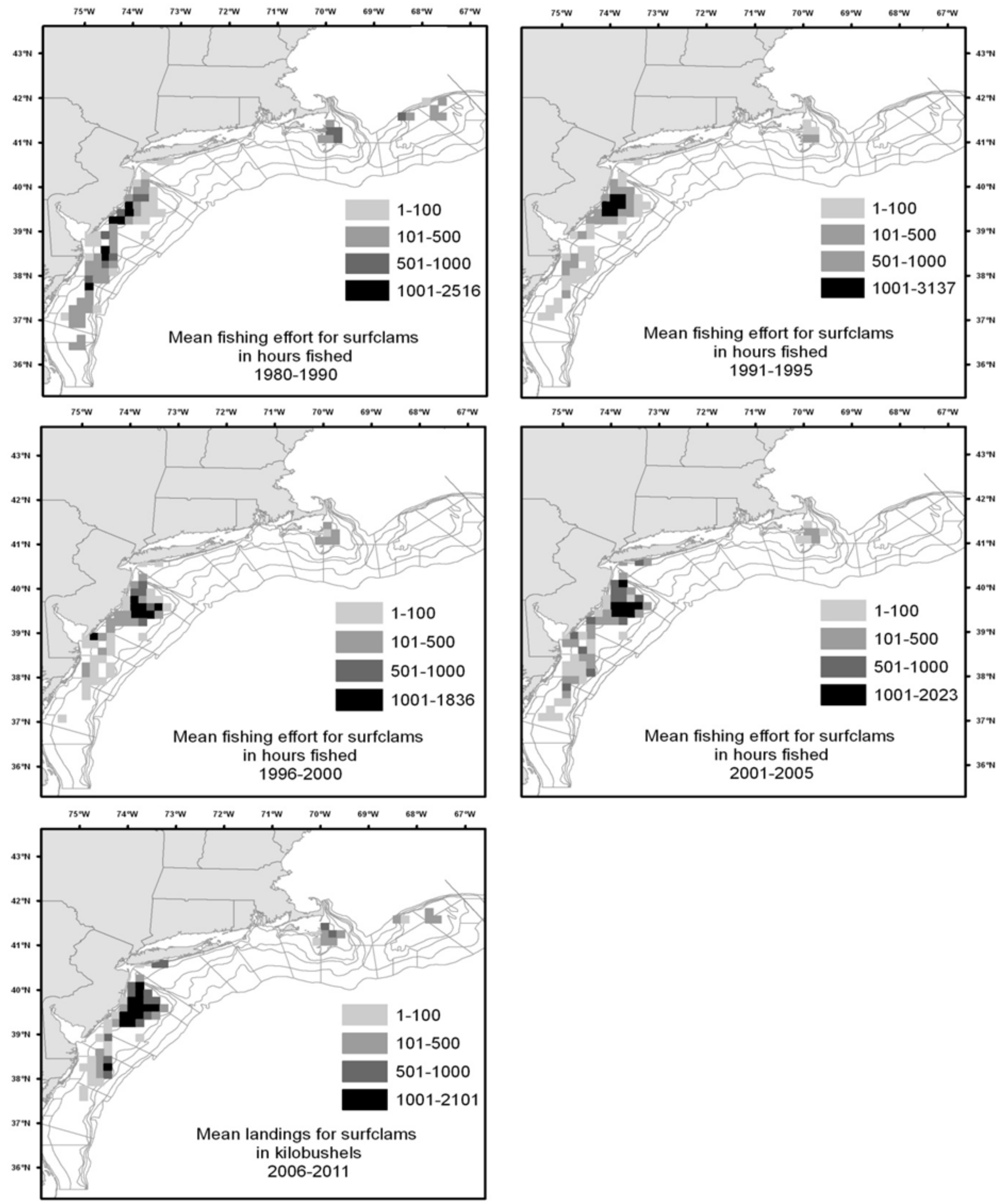


Figure A9. Average surfclam effort by ten-minute squares

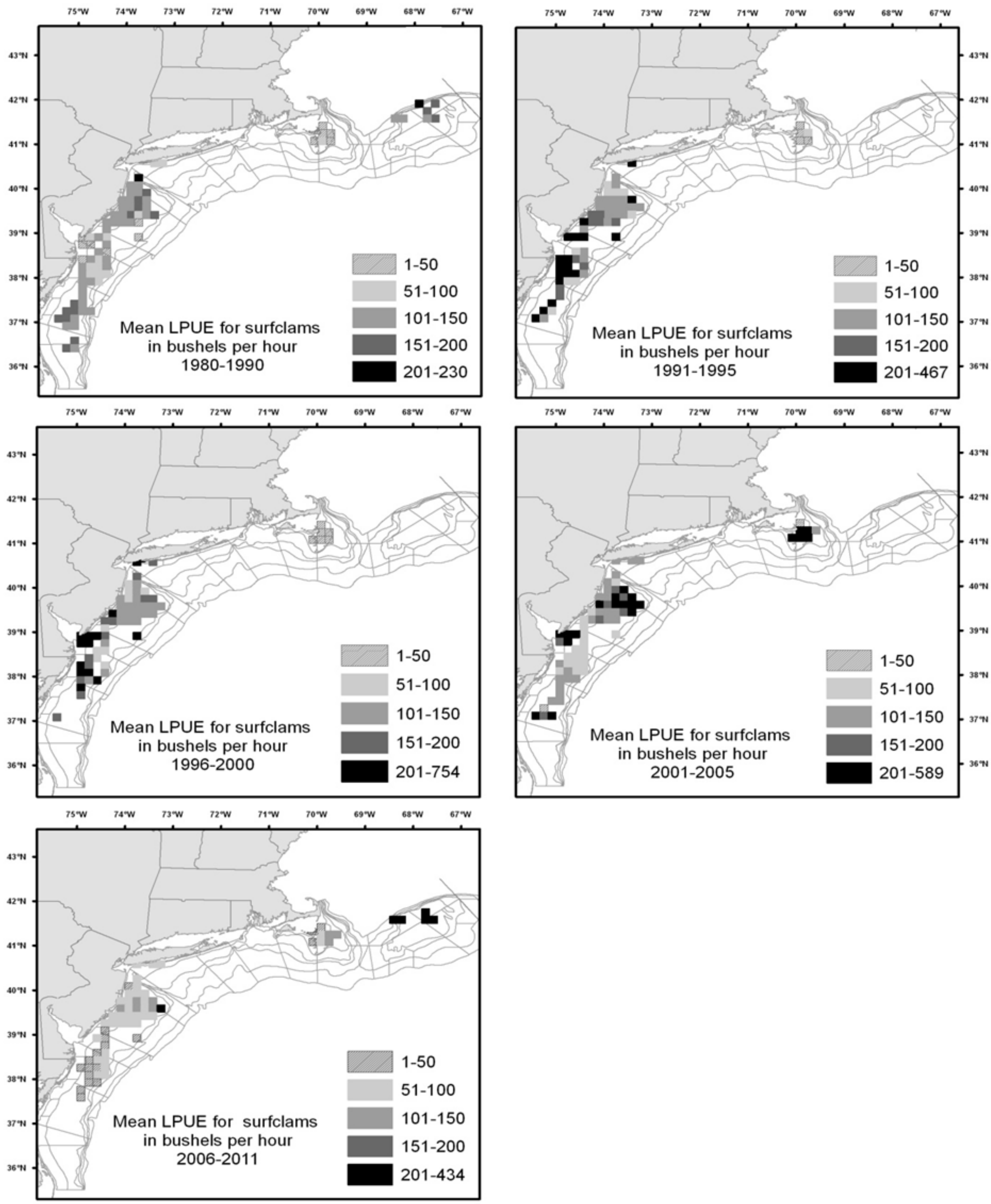


Figure A10. Average surfclam LPUE (bu. h^{-1}) by ten-minute squares over time.

Surfclam landings for important 10-minute squares

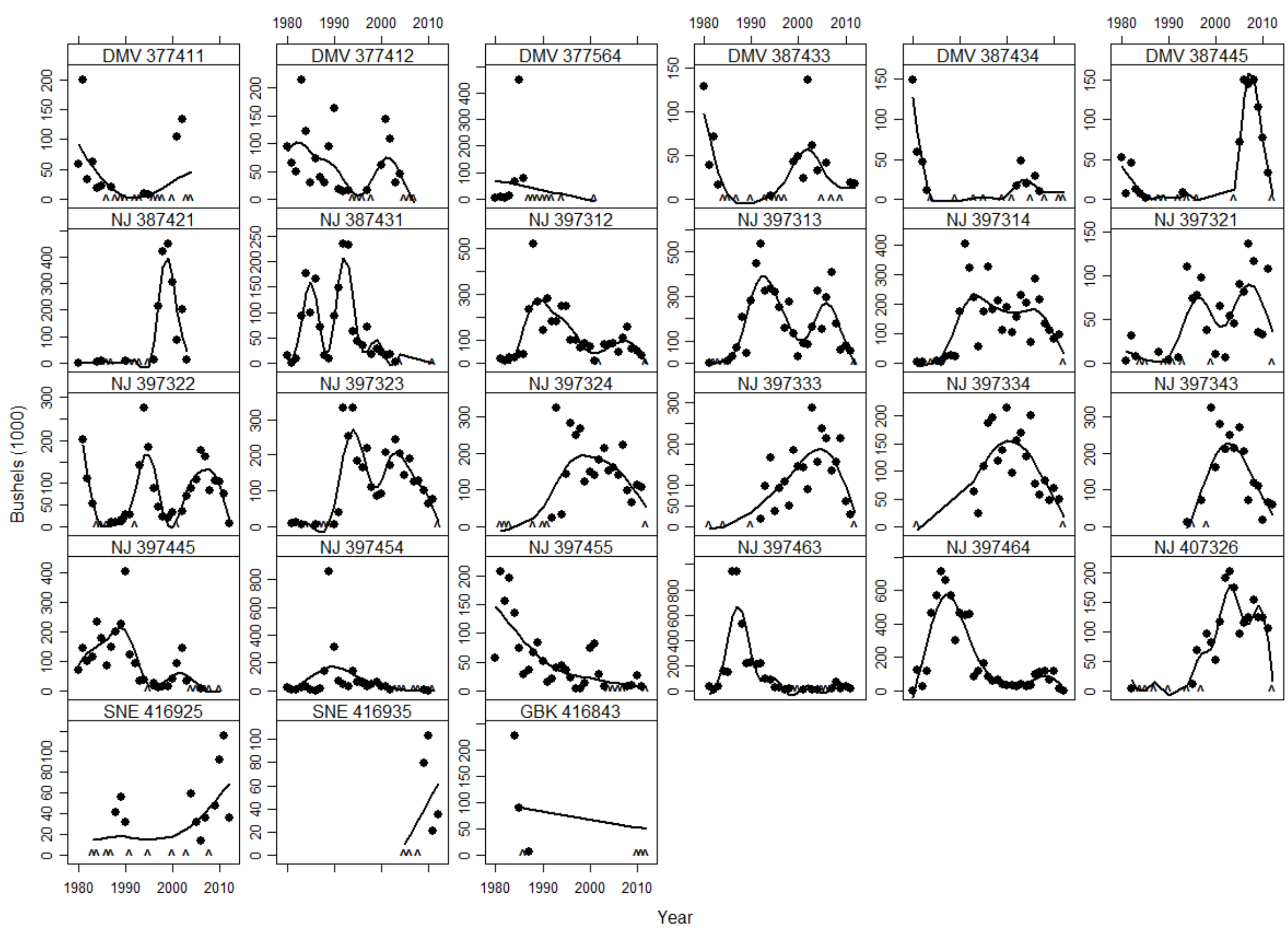


Figure A11. Annual surfclam landings in "important" ten minute squares (TNMS) during 1980-2012 based on logbook data. Important means that a square ranked in the top 10 TNMS for total landings during any five-year period (1980-1984, 1985-1989, …, 2000-2004, 2005-2009, 2010-2012). Data for 2012 are incomplete and preliminary. To protect the privacy of individual firms, data are not plotted if the number of vessels is less than 2. Instead, a "^" is shown on the x-axis to indicate where data are missing. The solid dark line is a spline intended to show trends. The spline was fit too all available data, including data not plotted.

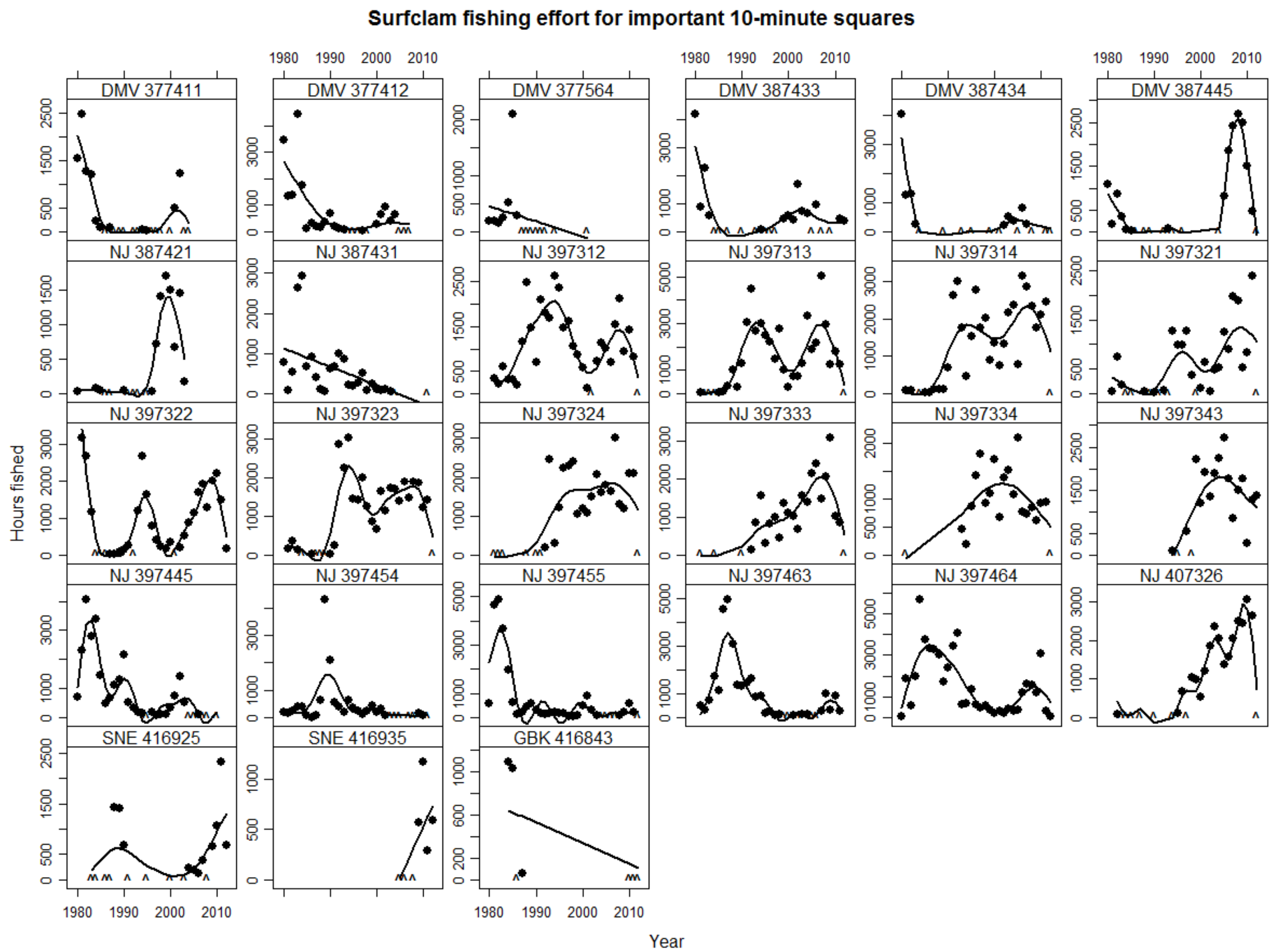


Figure A12. Annual surfclam effort (hours y^{-1}) in "important" ten minute squares (TNMS) during 1980-2012 based on logbook data. Important means that a square ranked in the top 10 TNMS for effort during any five-year period (1980-1984, 1985-1989, …, 2000-2004, 2005-2009, 2010-2012). Data for 2012 are incomplete and preliminary. To protect the privacy of individual firms, data are not plotted if the number of vessels is less than 2. Instead, a "^" is shown on the x-axis to indicate where data are missing. The solid dark line is a spline intended to show trends. The spline was fit too all available data, including data not plotted.

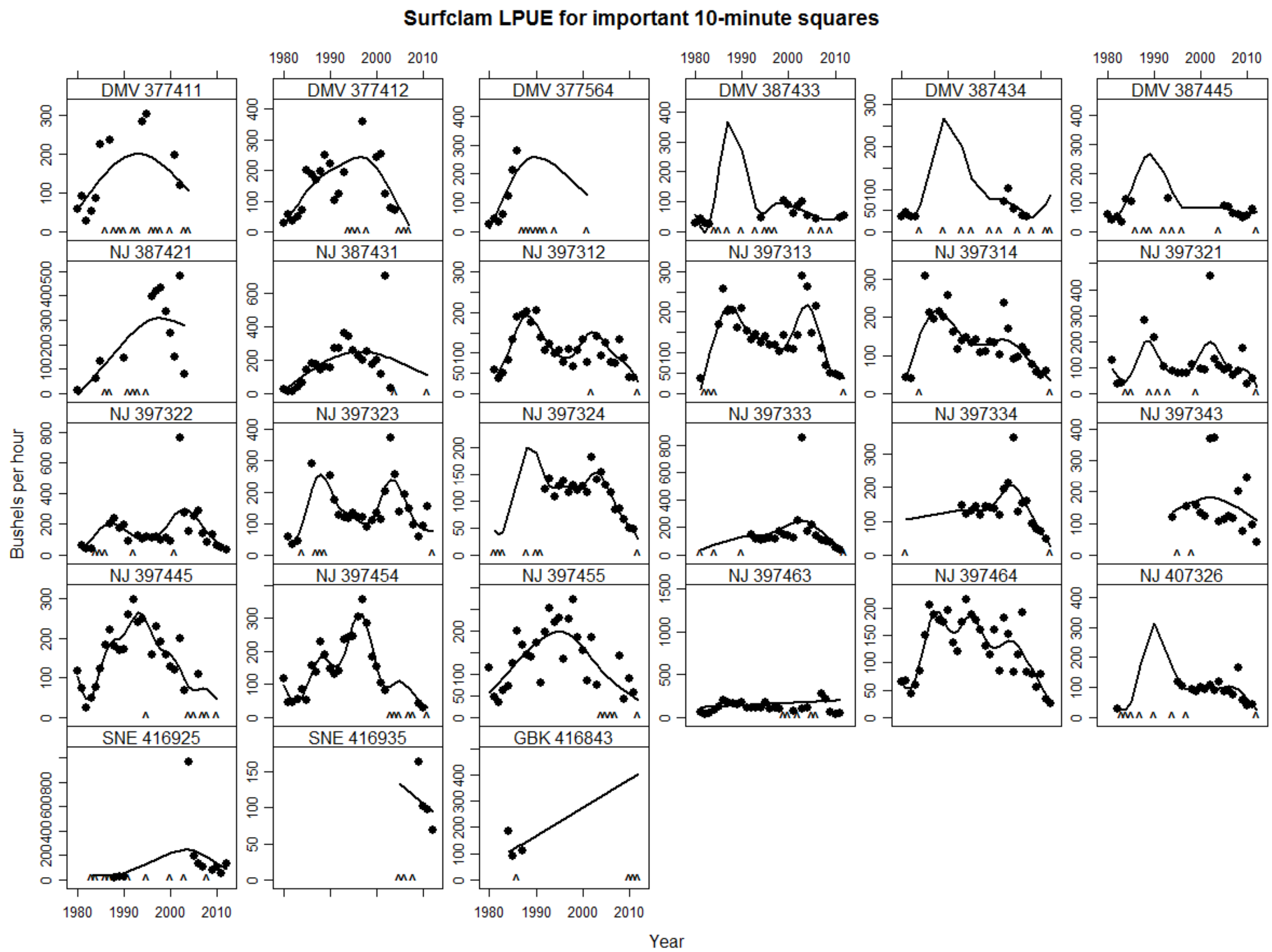


Figure A13. Annual surfclam LPUE (bu h^{-1}) in "important" ten minute squares (TNMS) during 1980-2012 based on logbook data. Important means that a square ranked in the top 10 TNMS for total LPUE during any five-year period (1980-1984, 1985-1989, …, 2000-2004, 2005-2009, 2010-2012). Data for 2012 are incomplete and preliminary. To protect the privacy of individual firms, data are not plotted if the number of vessels is less than 2. Instead, a "^" is shown on the x-axis to indicate where data are missing. The solid dark line is a spline intended to show trends. The spline was fit too all available data, including data not plotted.

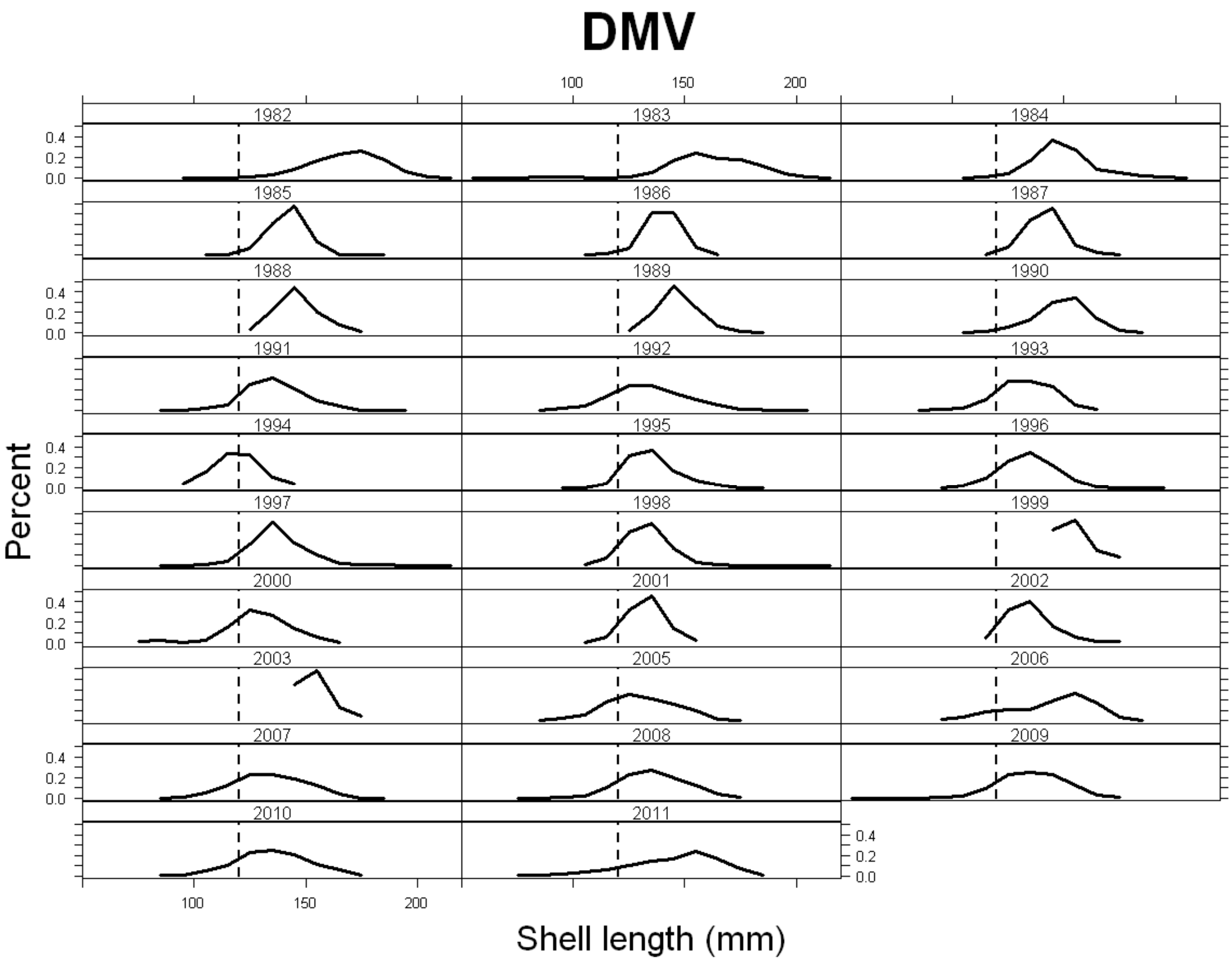


Figure A14. Length compositions of port-sampled landed surfclams from the DMV region.

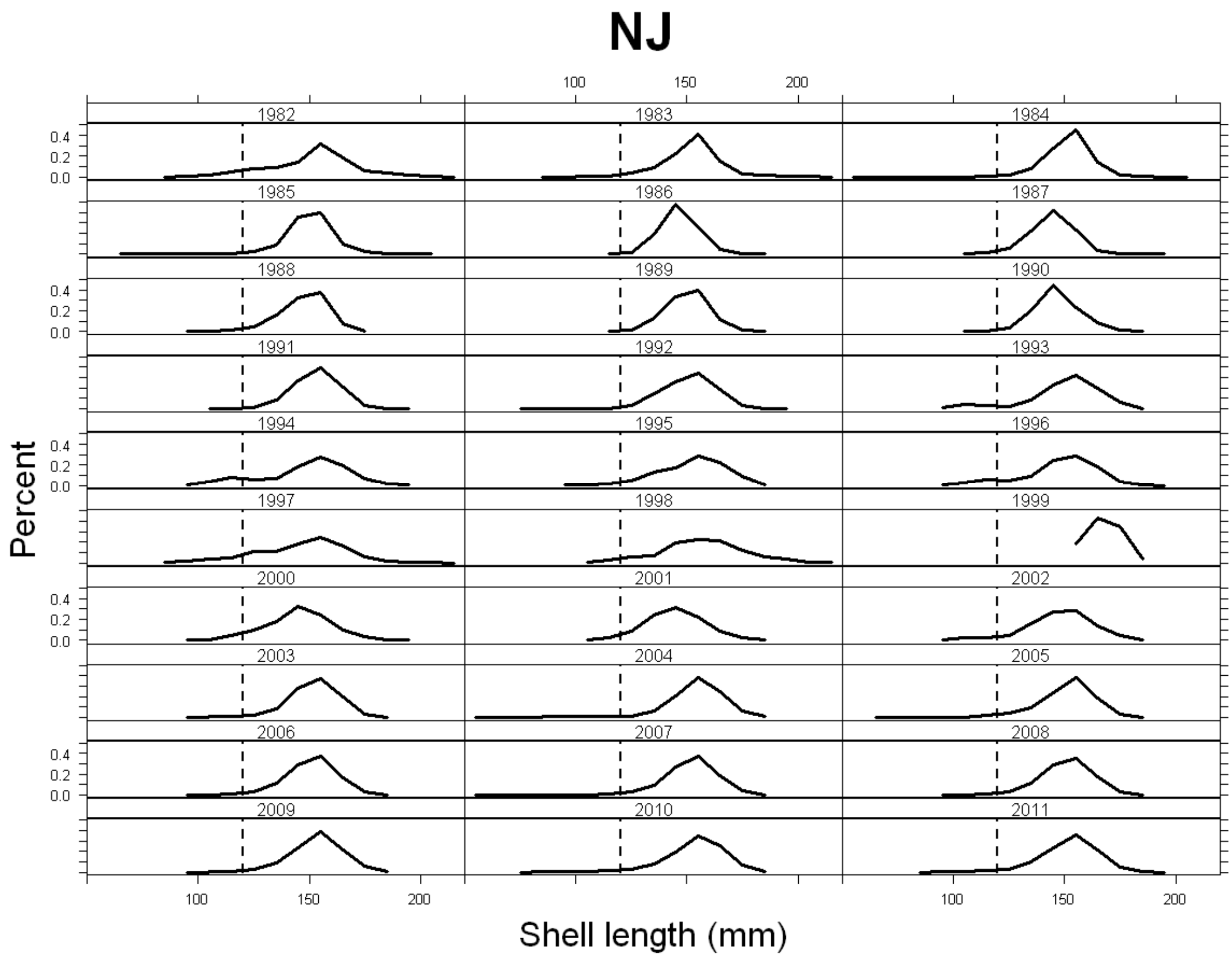


Figure A15. Length compositions of port-sampled landed surfclams from the NJ region.

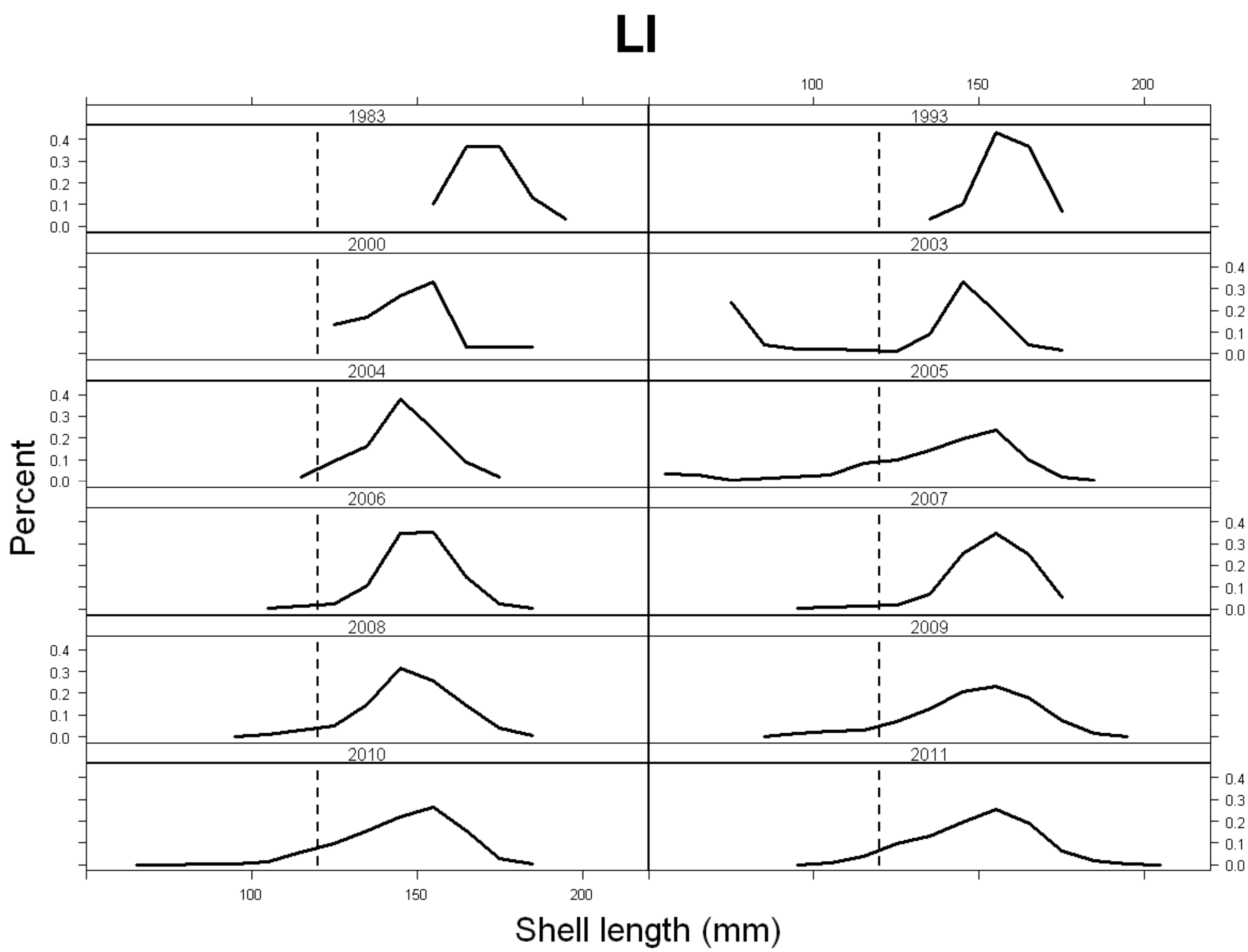


Figure A16. Length compositions of port-sampled landed surfclams from the LI region.

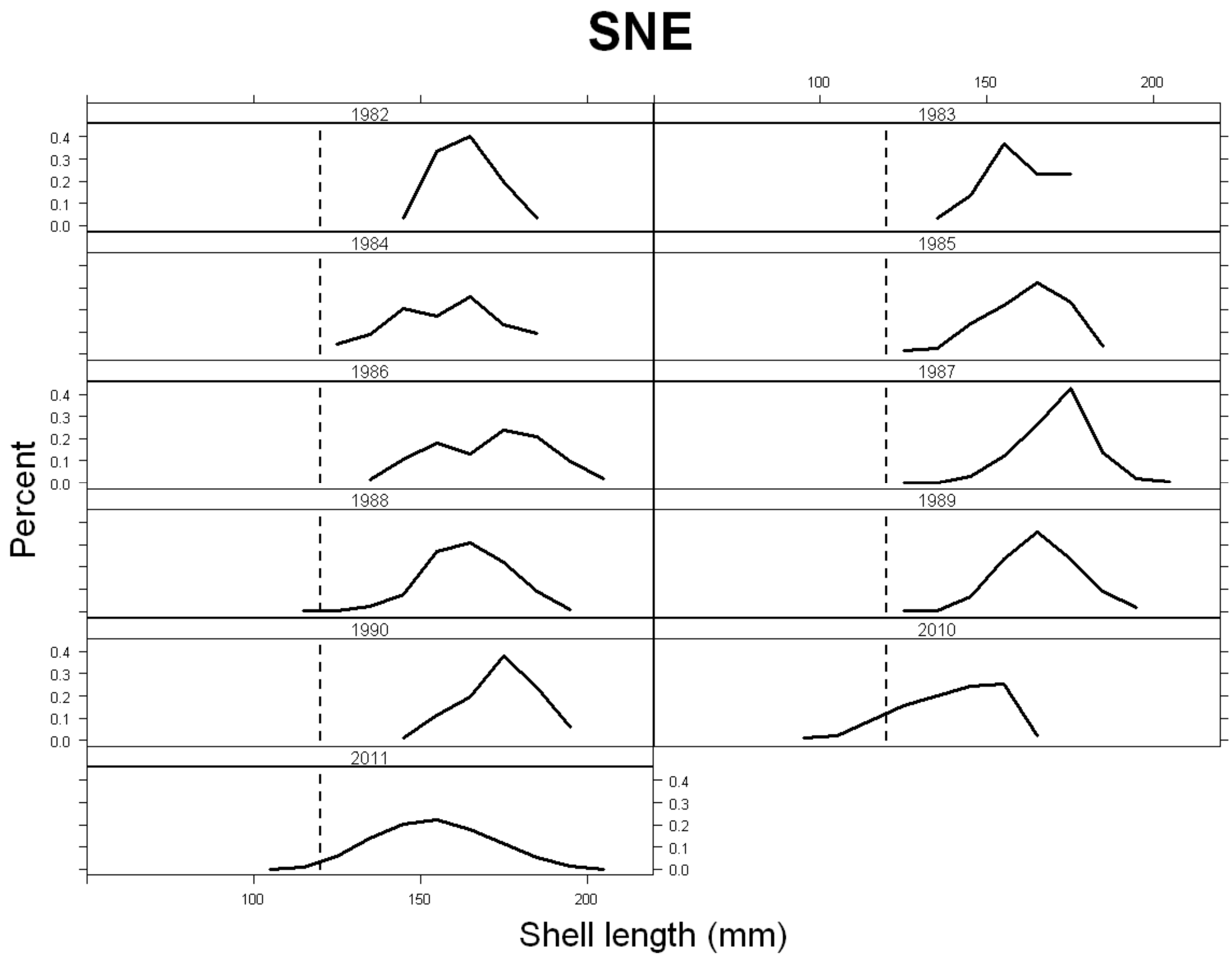


Figure A17. Length compositions of port-sampled landed surfclams from the SNE region.

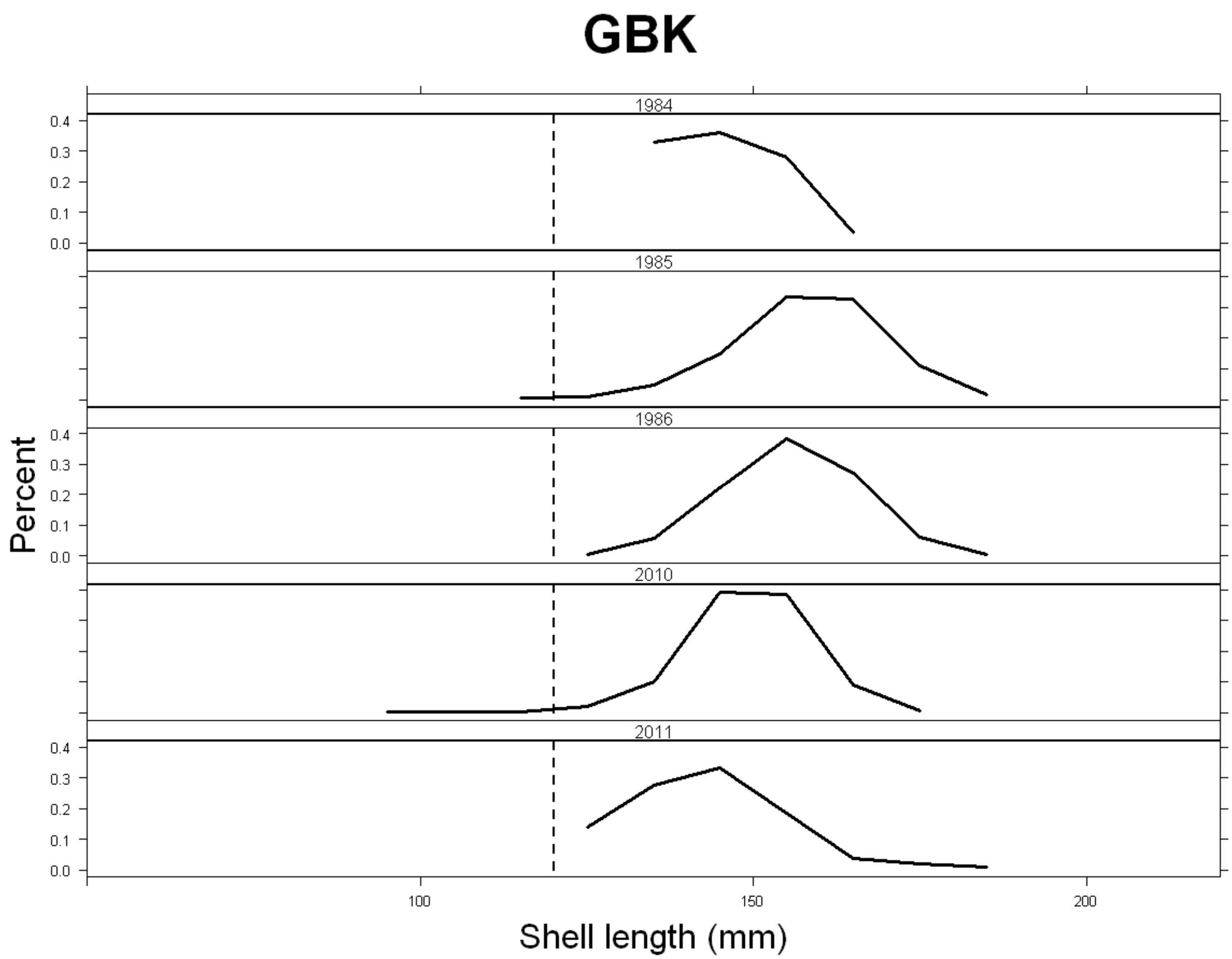


Figure A18. Length compositions of port-sampled landed surfclams from the GBK region.

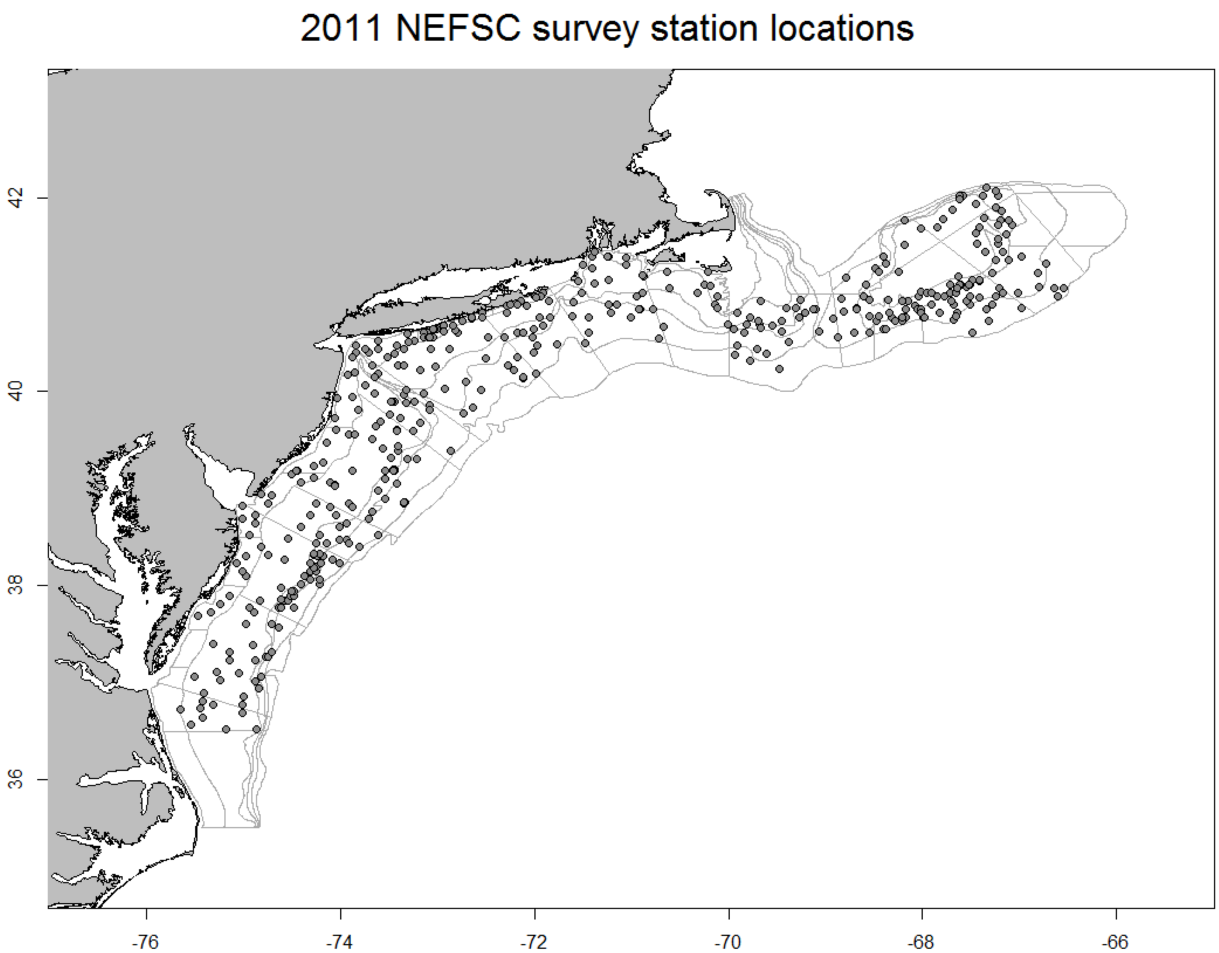


Figure A19. Station locations from the 2011 NEFSC survey

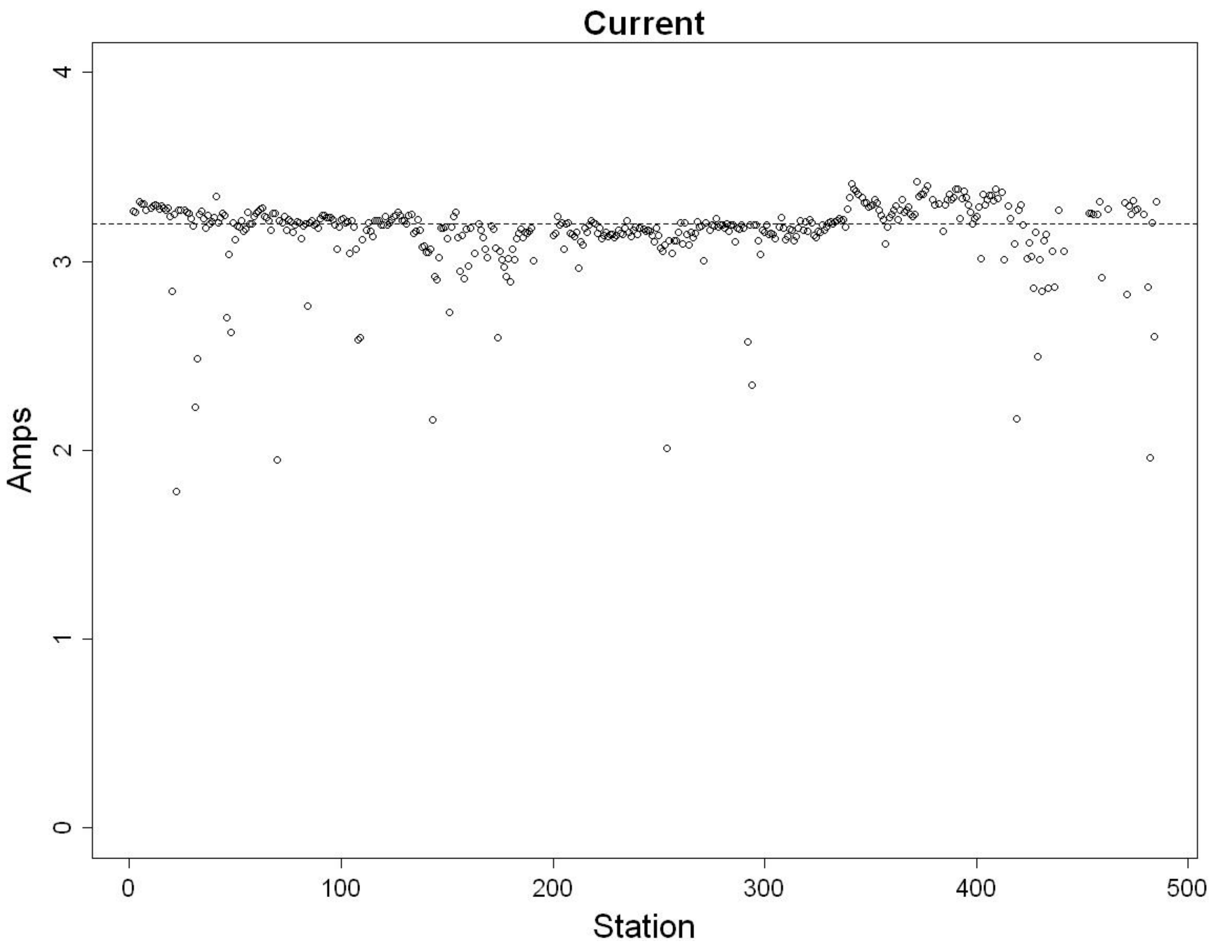


Figure A20. Amperage by tow for the 2011 NEFSC clam survey. The dashed line is for reference only.

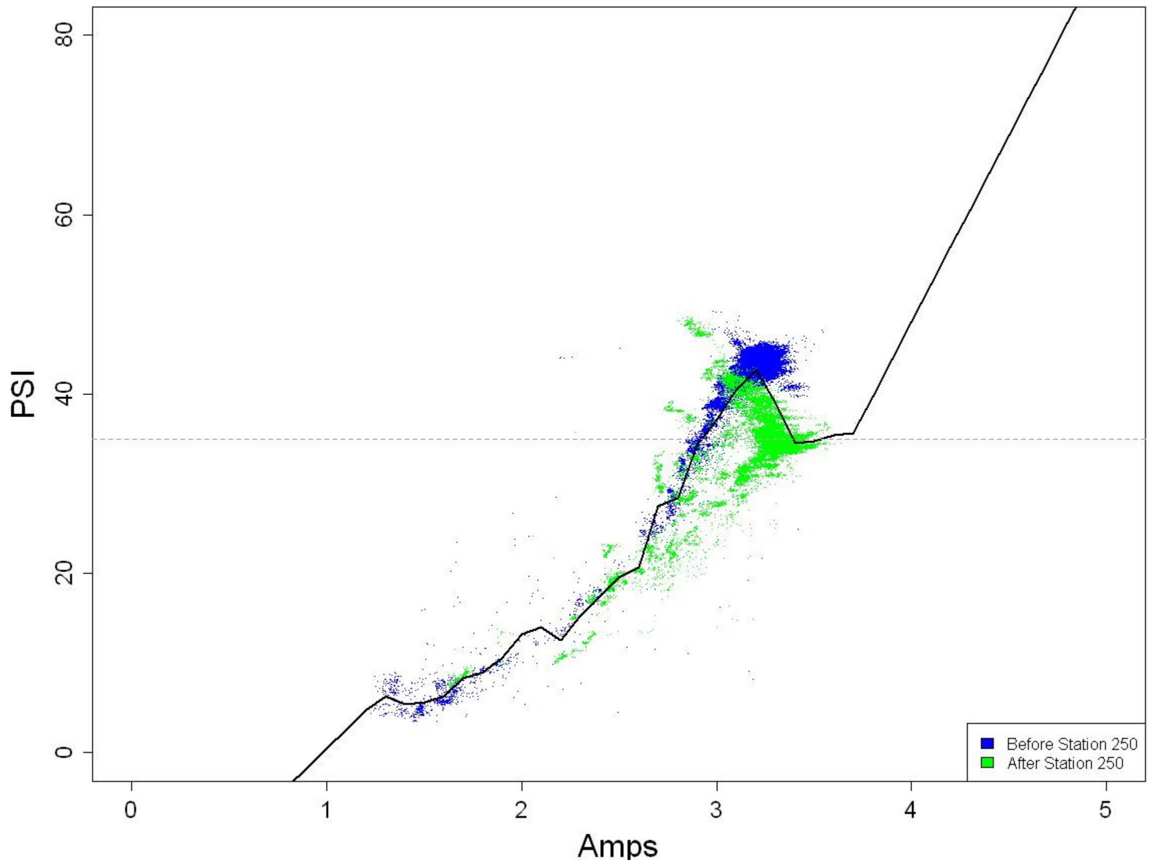


Figure A21. The relationship between amperage and differential pressure over all fishing seconds while the SSP was operational. The blue dots are observations recorded before the SSP failed at station 161 and the green dots are observations after the SSP began working again at station 371. The line plotted is the cubic spline fit to the data.

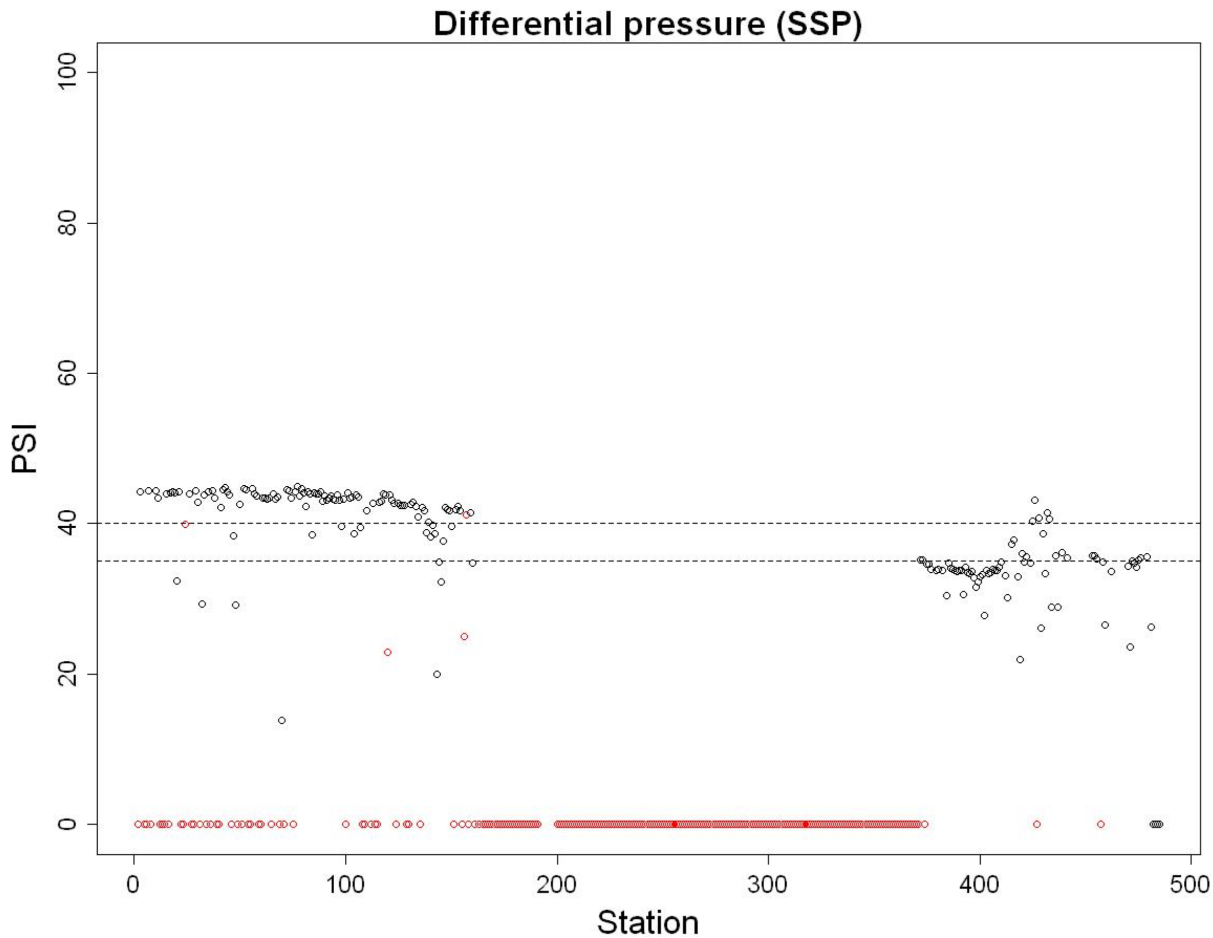


Figure A22. Differential pressure by tow during the 2011 NEFSC survey. The black circles are tows for which differential pressure was recorded by the SSP and the red circles are tows for which there is no SSP data. The dashed lines represent the upper and lower bounds for differential pressure tolerance found for the 2009 survey.

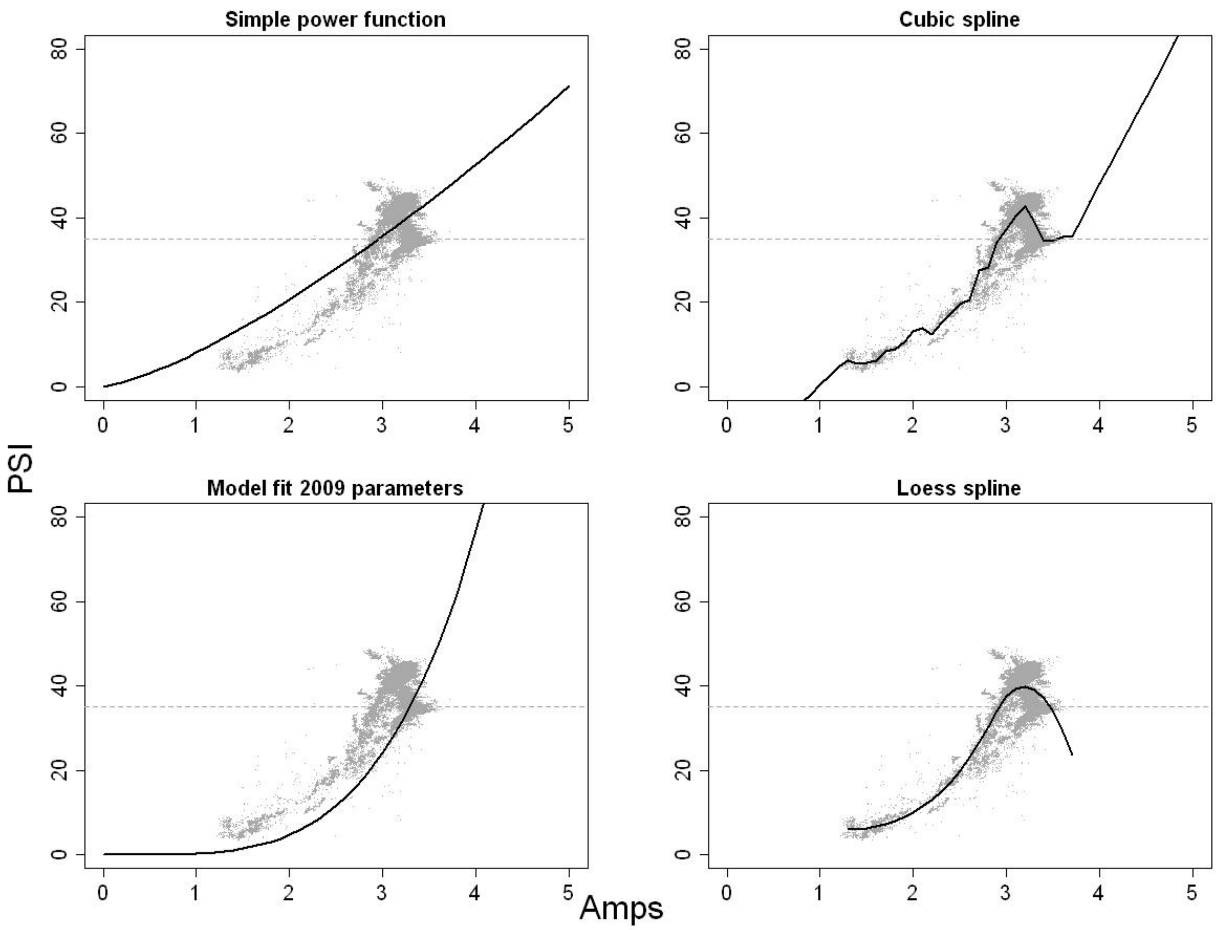


Figure A23. Model fits from four competing models to predict differential pressure from current supplied to the dredge pump on the 2011 NEFSC survey. The tolerance for adequate pump pressure (35 PSI) is shown with the dashed gray line.

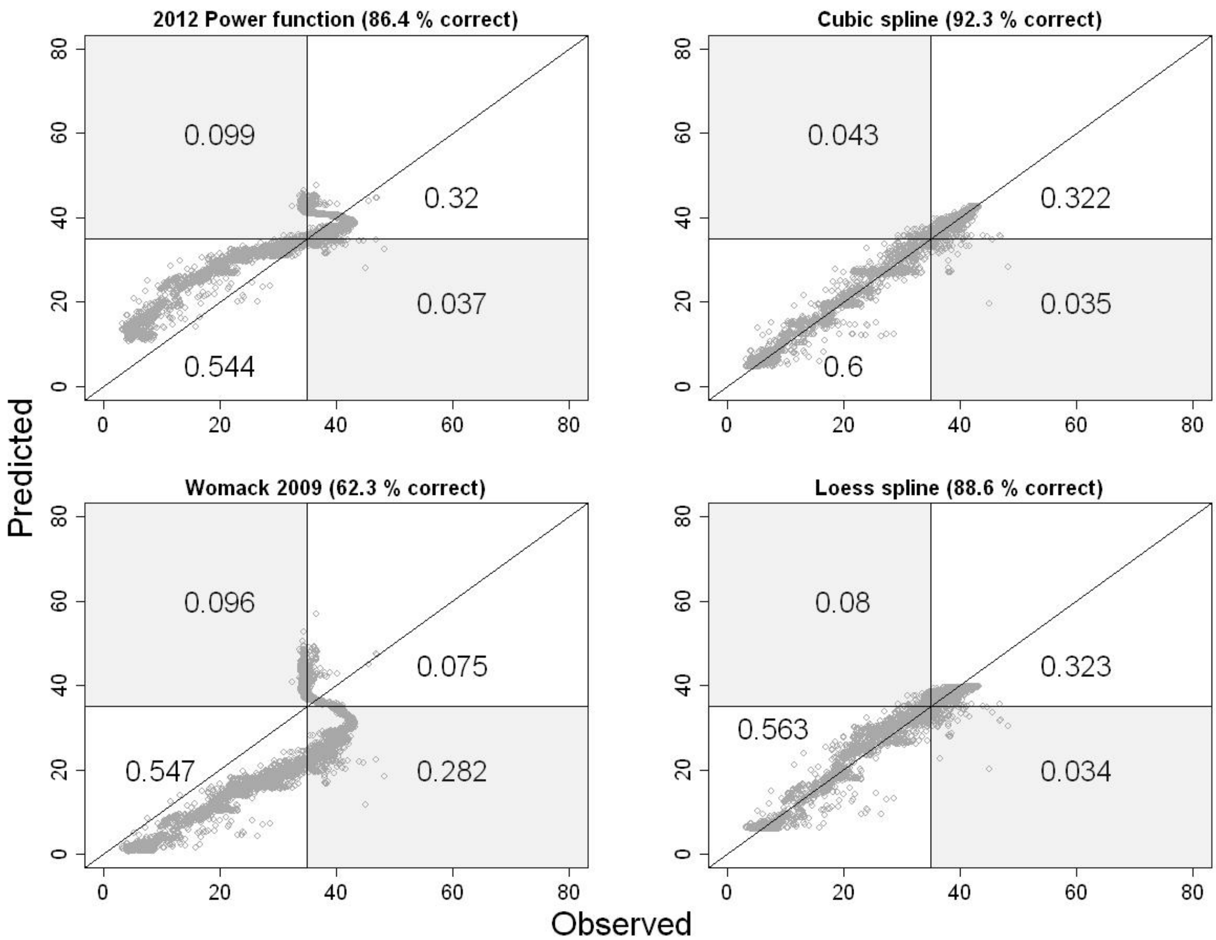


Figure A24. A comparison of four different models used to predict differential pressure from current. The shaded areas represent quadrants where the predicted and observed values disagree regarding the acceptability of a differential pressure measurement. The unshaded quadrants are areas where the predicted and observed values are in agreement. The numbers inside the plot area represent the fraction of points that fall within quadrant. Differential pressures less than 35 PSI are below tolerance for a successful fishing second. The predicted = observed line is also shown for reference.

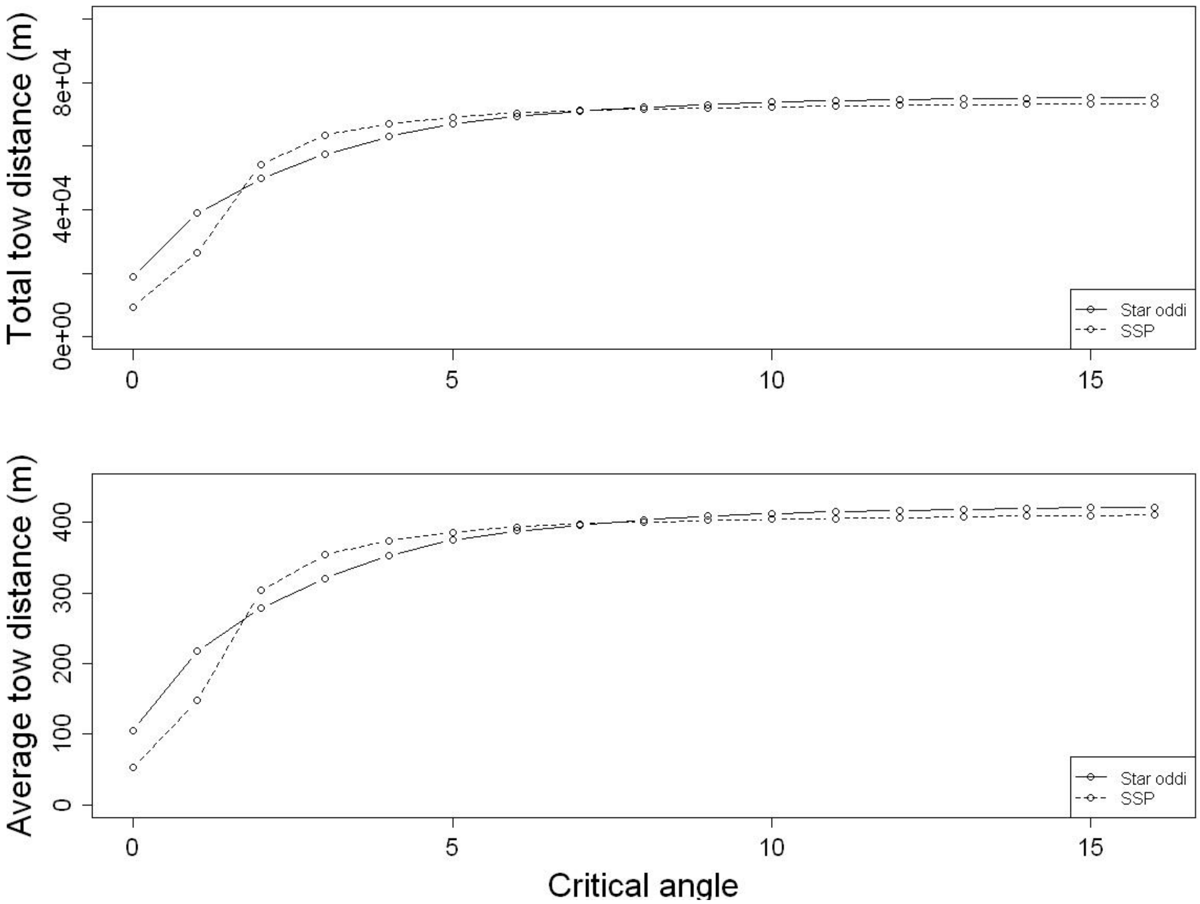


Figure A25. Average and total tow distance over all stations by critical dredge angle

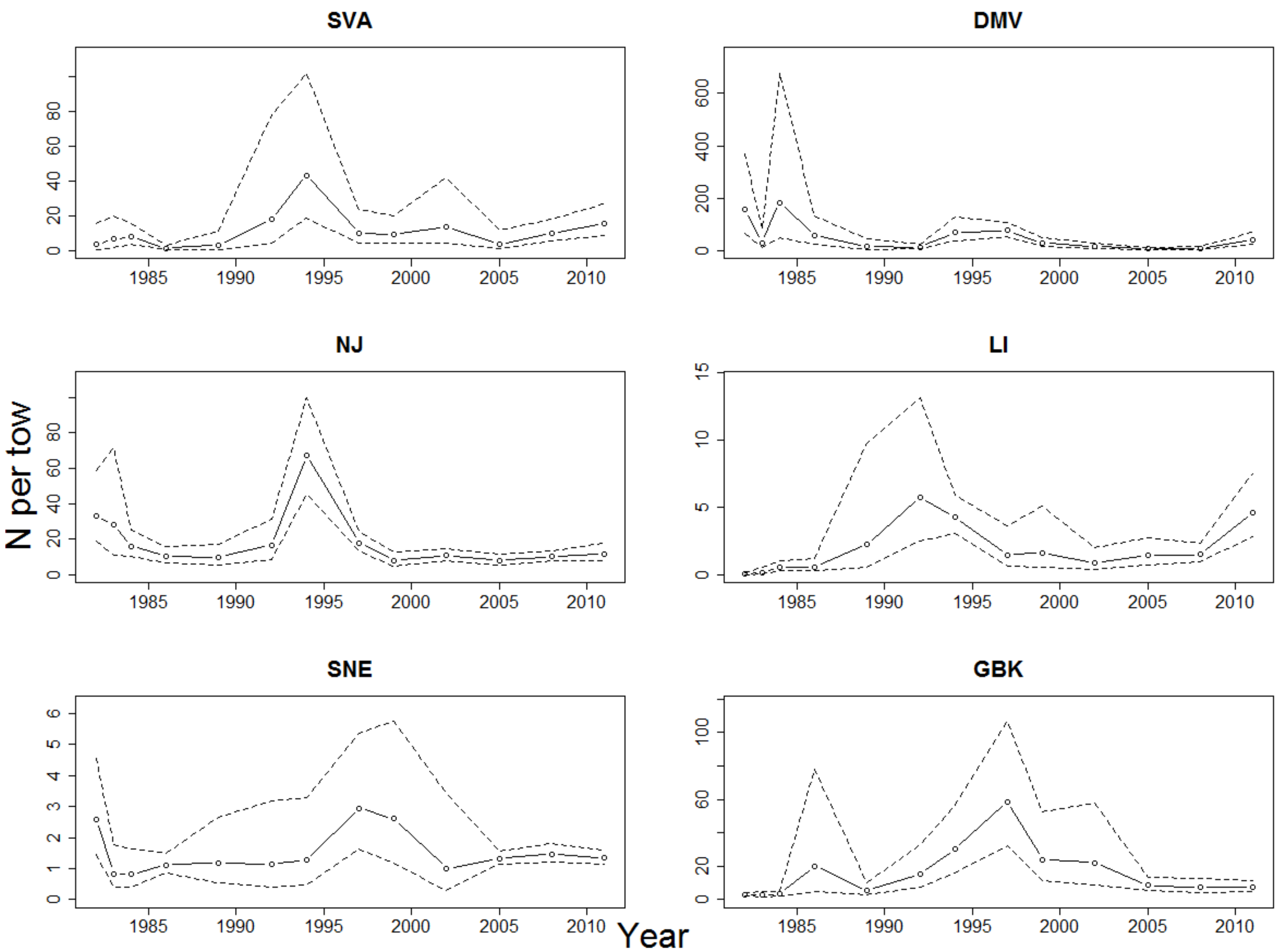


Figure A26. Surfclam 50 – 119 mm SL from NEFSC surveys adjusted for selectivity, with approximate 95% asymmetric confidence intervals, by region.

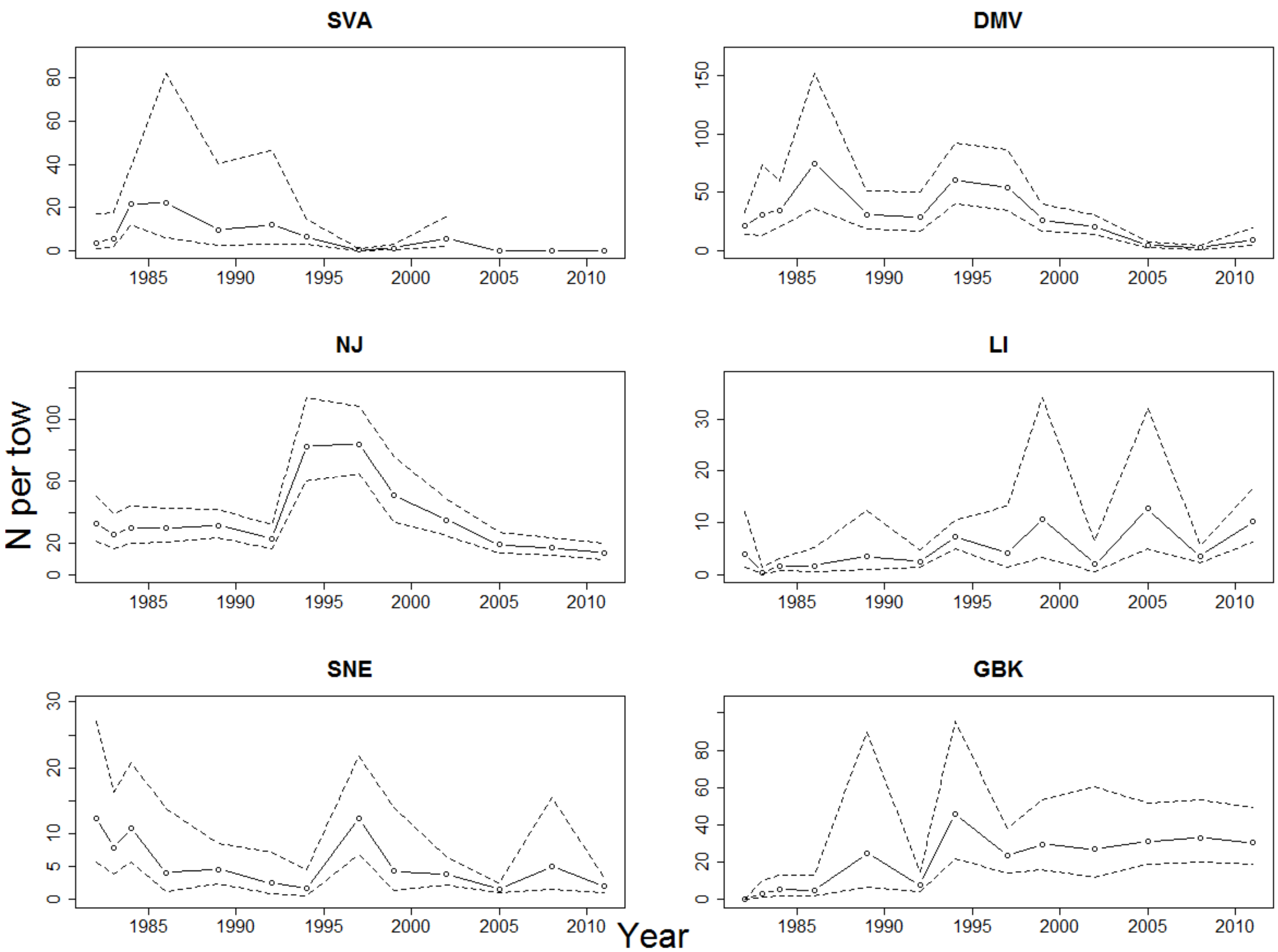


Figure A27. Surfclam larger than 120 mm SL from NEFSC surveys adjusted for selectivity, with approximate 95% asymmetric confidence intervals, by region.

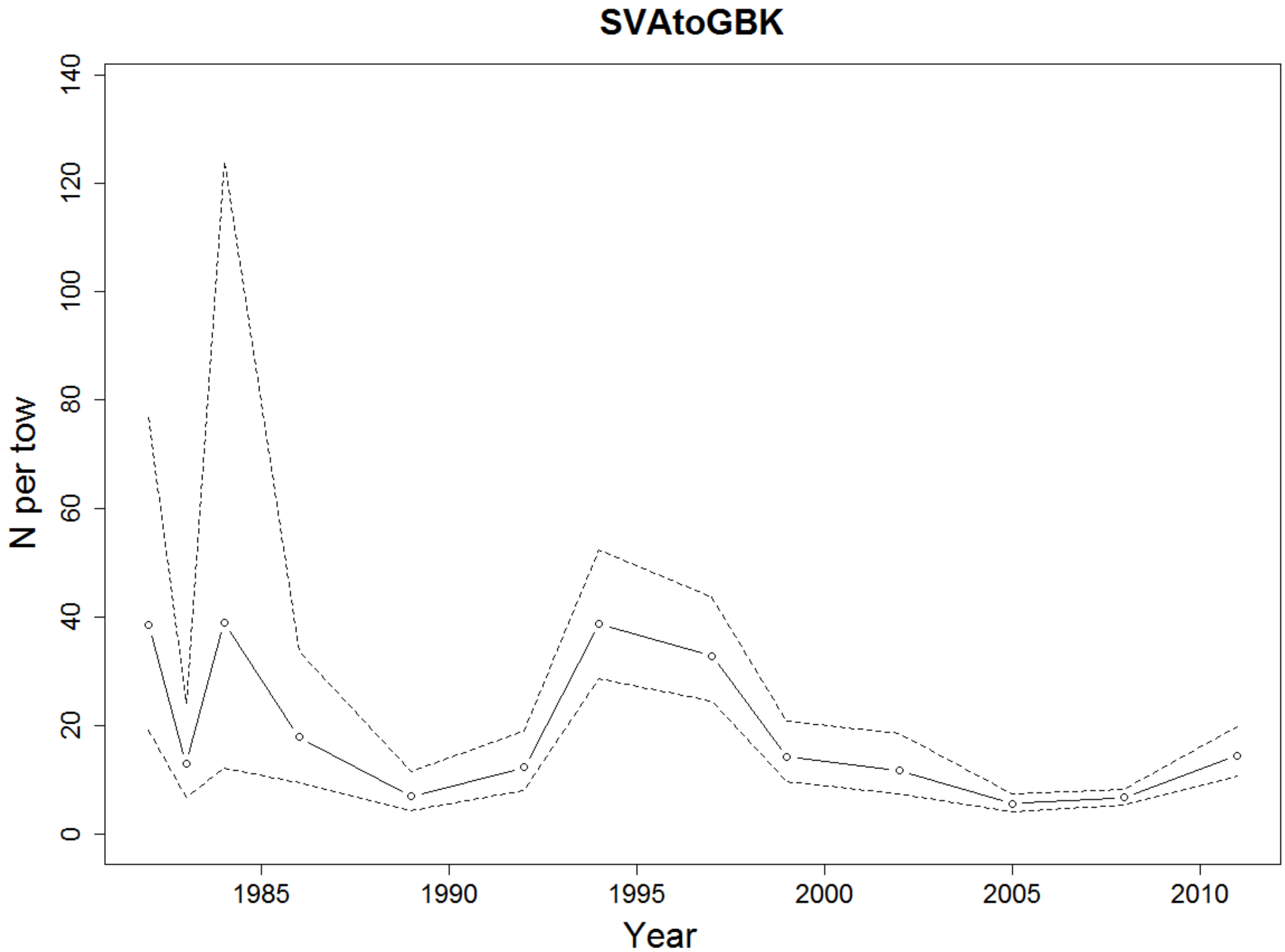


Figure A28. Surfclam 50 – 119 mm SL from NEFSC surveys adjusted for selectivity, with approximate 95% asymmetric confidence intervals for the whole stock.

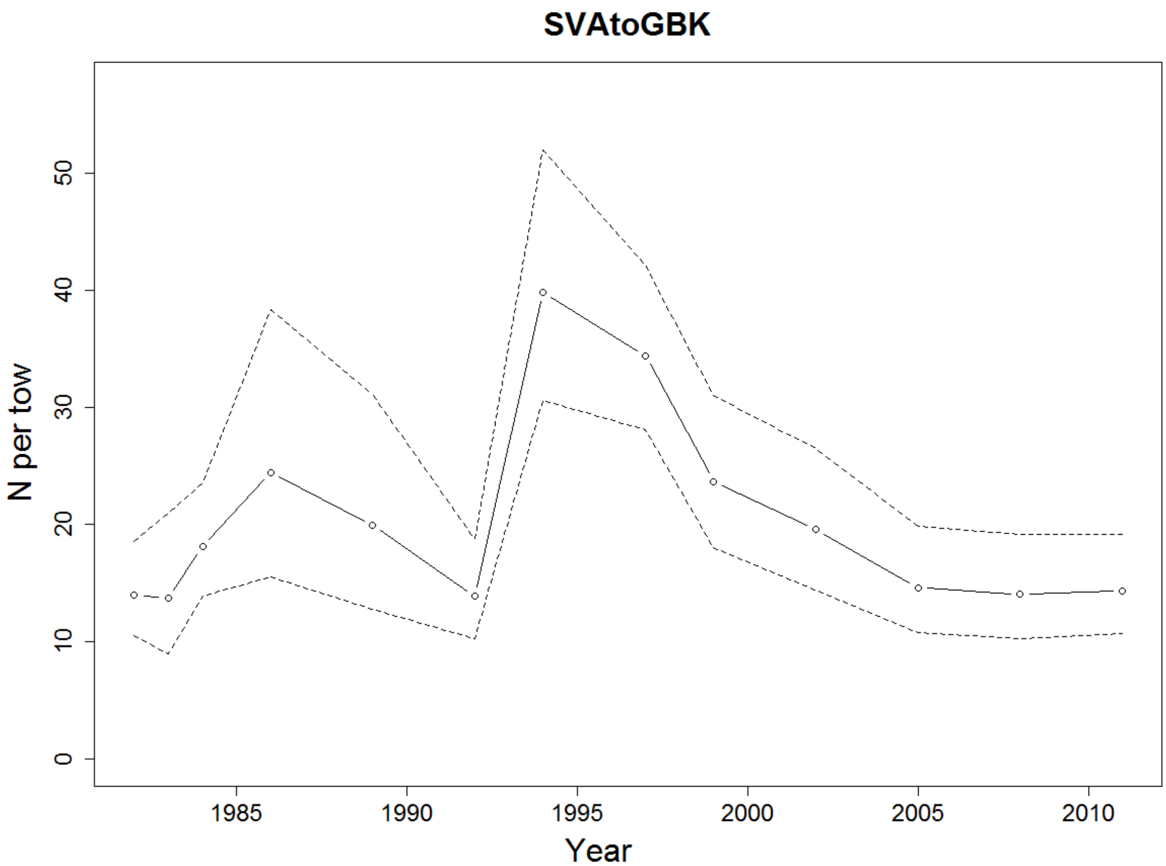
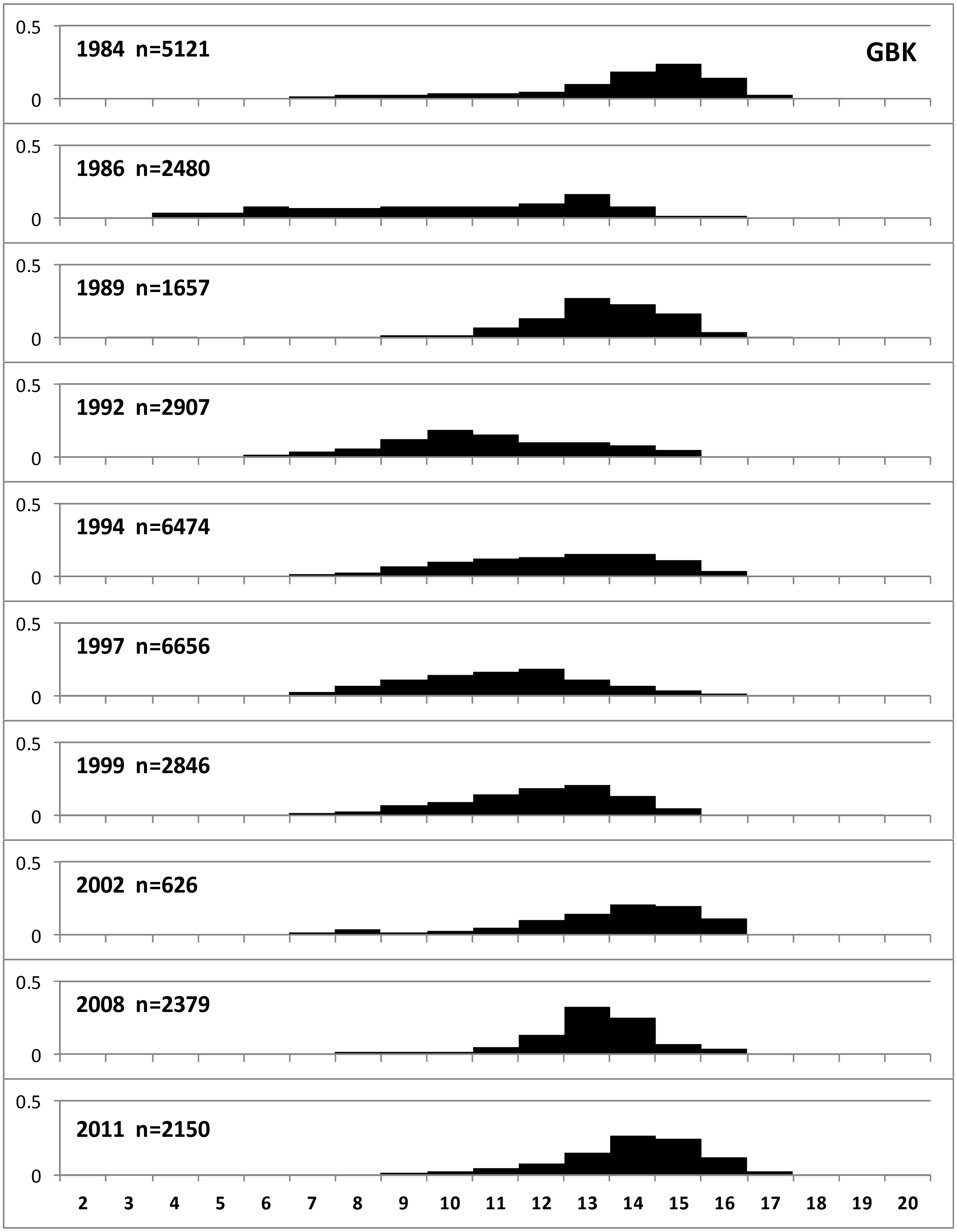
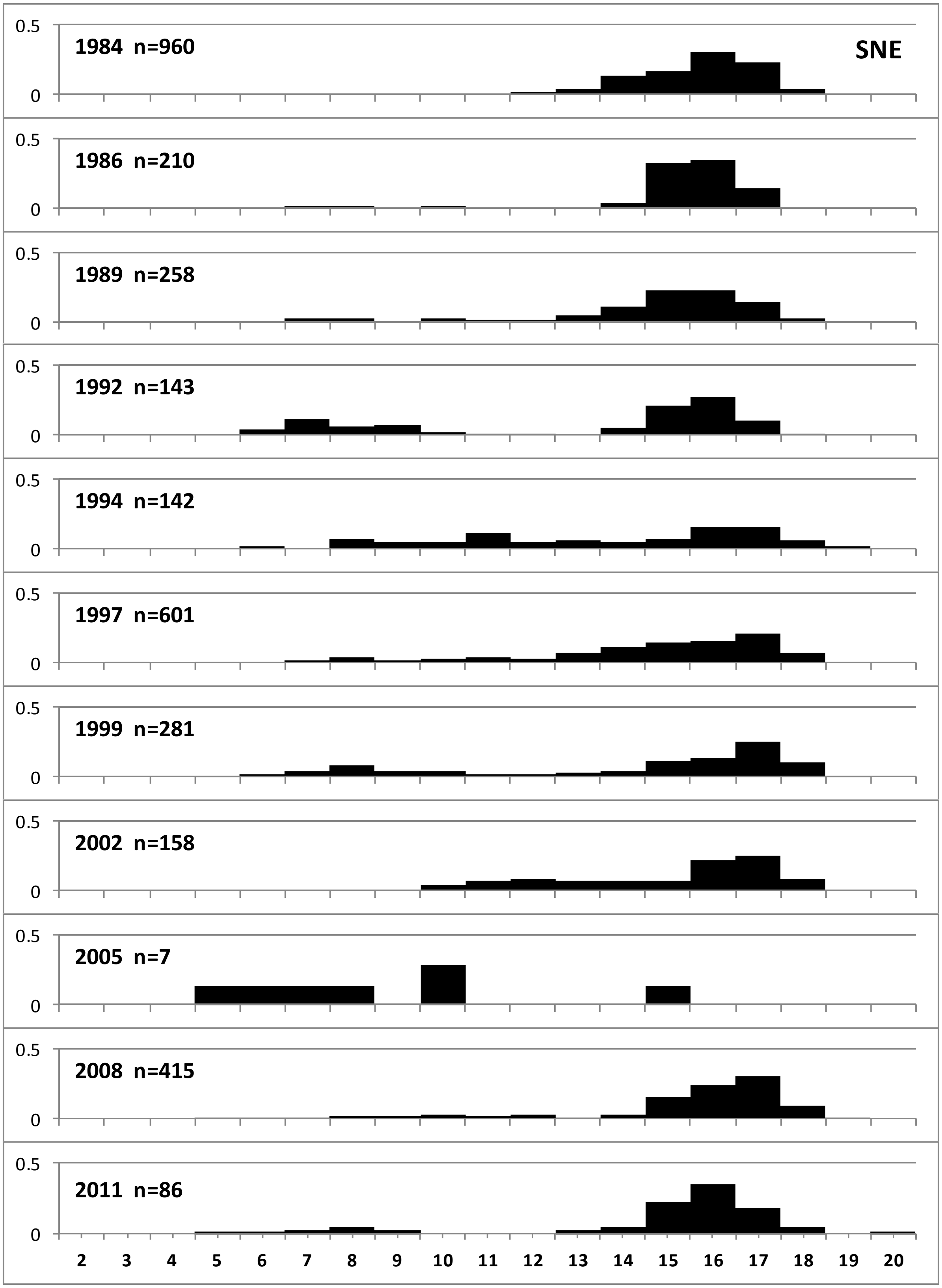
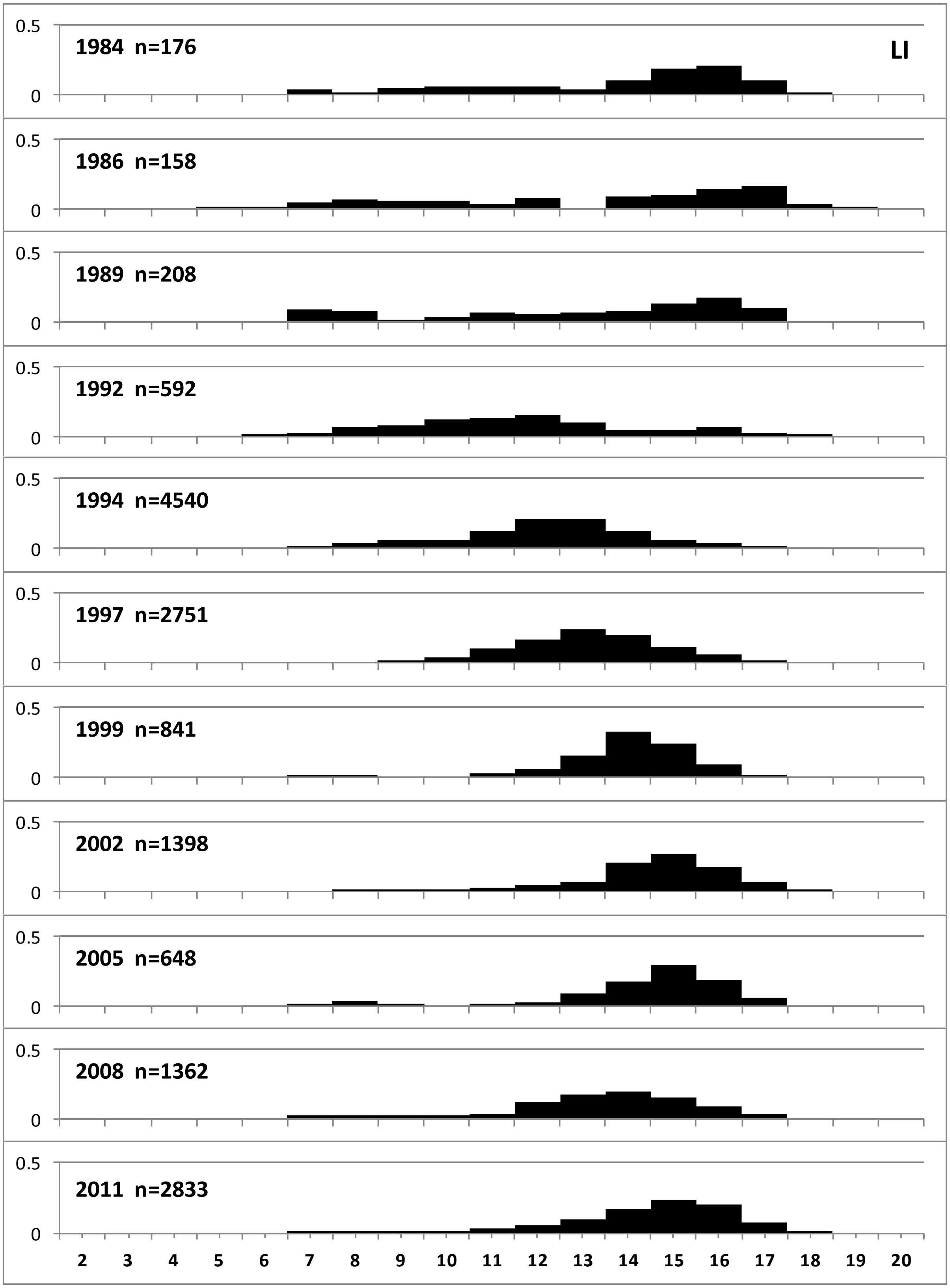


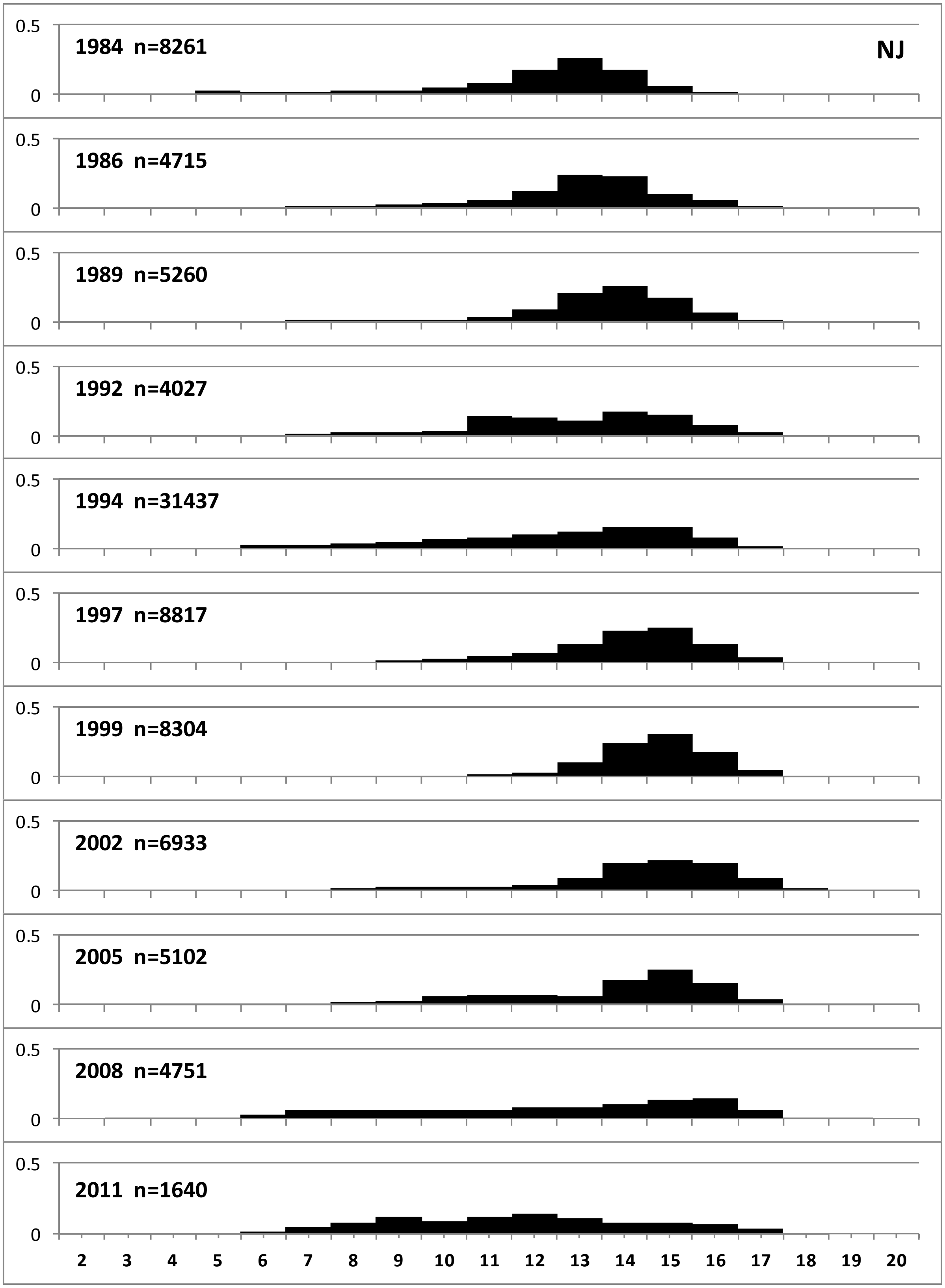
Figure A29. Surfclam larger than 120 mm SL from NEFSC surveys adjusted for selectivity, with approximate 95% asymmetric confidence intervals, for the whole stock.

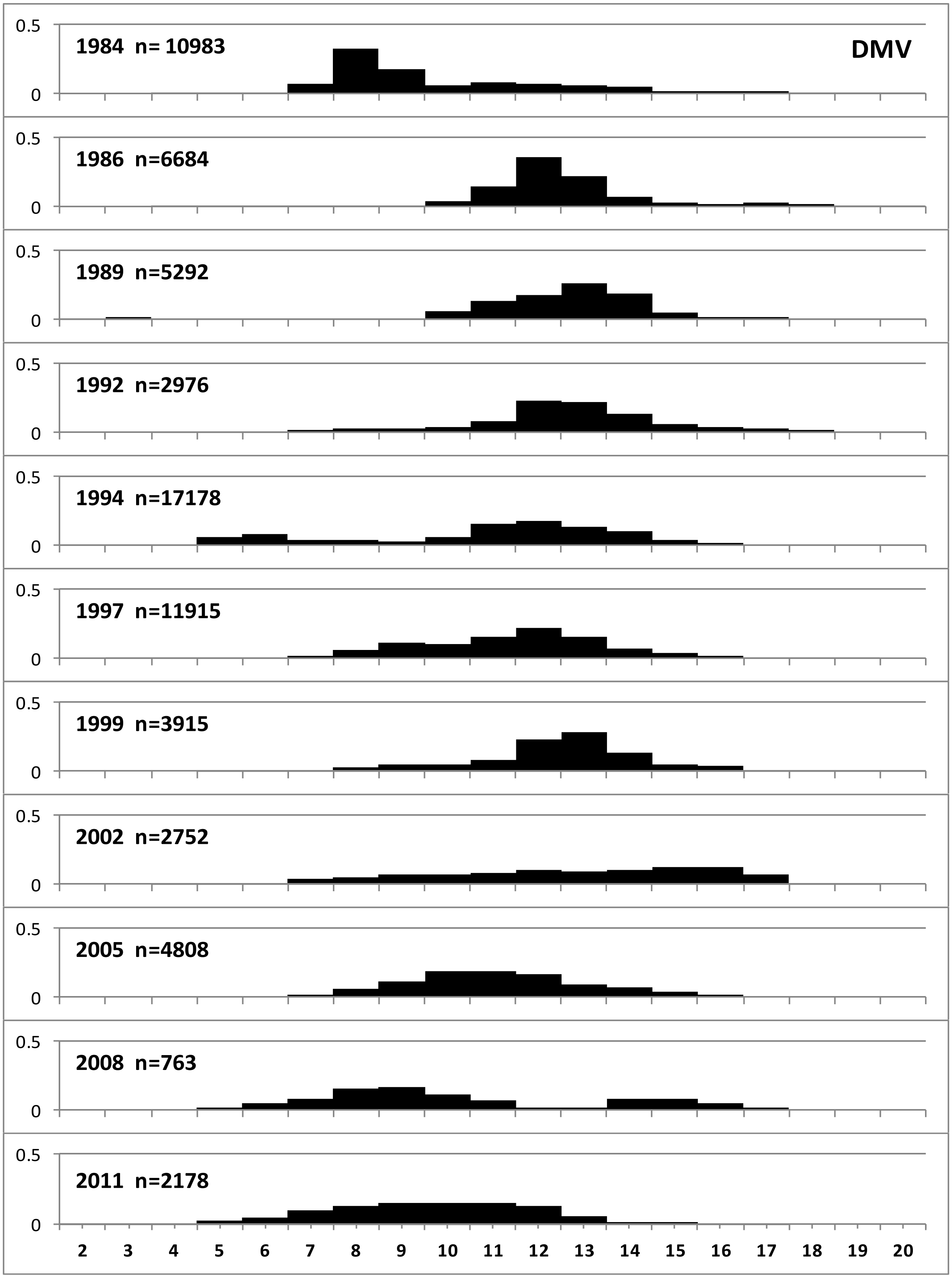
Figure A30. (Following pages) Survey length composition by region.

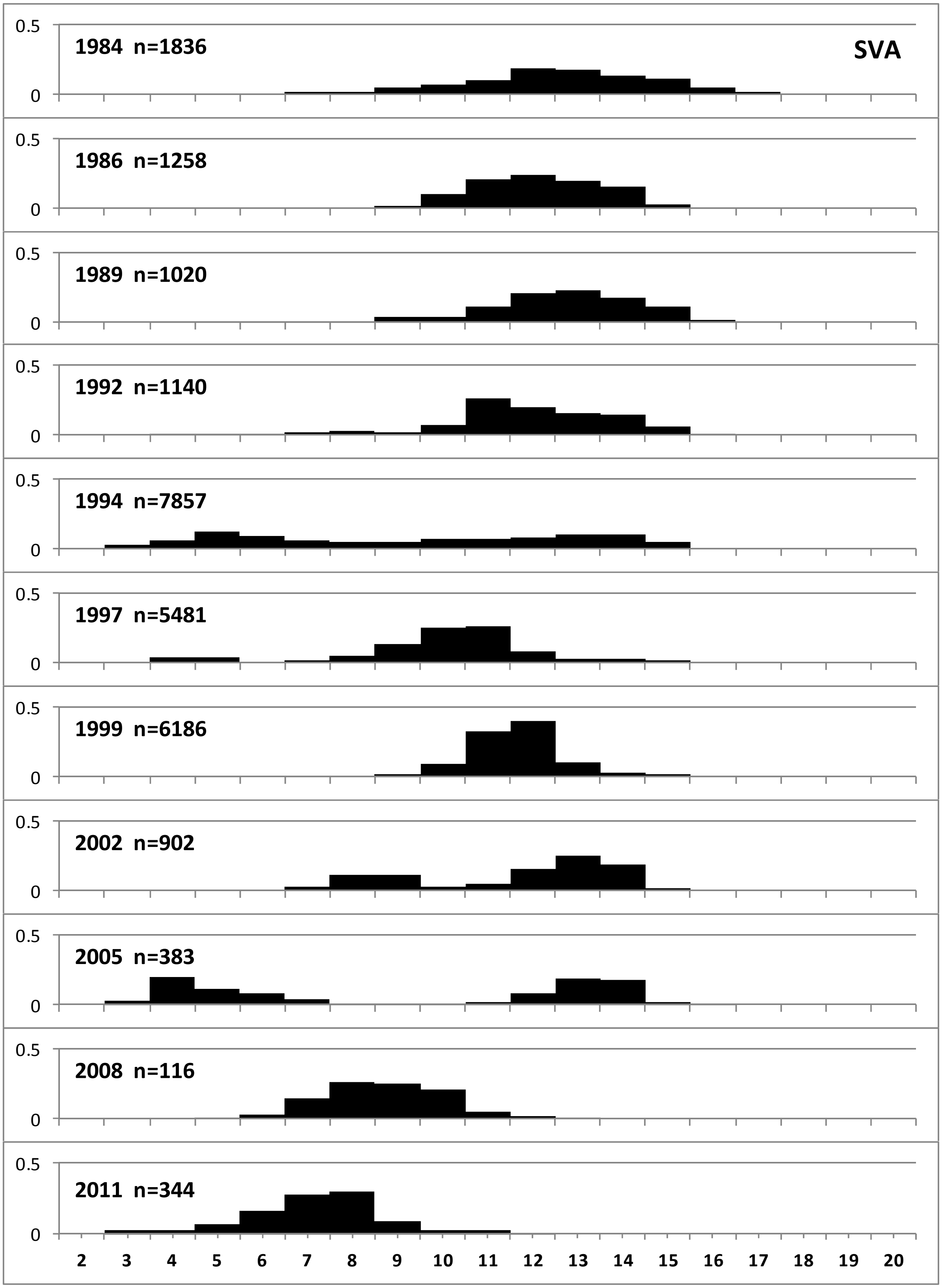

0.5
0
1984 n=5121
GBK
1986 n=2480
1989 n=1657
1992 n=2907
1994 n=6474
1997 n=6656
1999 n=2846
2002 n=626
2008 n=2379
2011 n=2150
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20


SNE
0.5
0
1984 n=960
1986 n=210
1989 n=258
1992 n=143
1994 n=142
1997 n=601
1999 n=281
2002 n=158
2005 n=7
2008 n=415
2011 n=86
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20


LI
1984 n=176
1986 n=158
1989 n=208
1992 n=592
1994 n=4540
1997 n=2751
1999 n=841
2002 n=1398
2005 n=648
2008 n=1362
2011 n=2833
0.5
0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20


NJ
1984 n=8261
1986 n=4715
1989 n=5260
1992 n=4027
1994 n=31437
1997 n=8817
1999 n=8304
2002 n=6933
2005 n=5102
2008 n=4751
2011 n=1640
0.5
0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20


DMV
1984 n= 10983
1986 n=6684
1989 n=5292
1992 n=2976
1994 n=17178
1997 n=11915
1999 n=3915
2002 n=2752
2005 n=4808
2008 n=763
2011 n=2178
0.5
0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20


SVA
1984 n=1836
1986 n=1258
1989 n=1020
1992 n=1140
1994 n=7857
1997 n=5481
1999 n=6186
2002 n=902
2005 n=383
2008 n=116
2011 n=344
0.5
0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

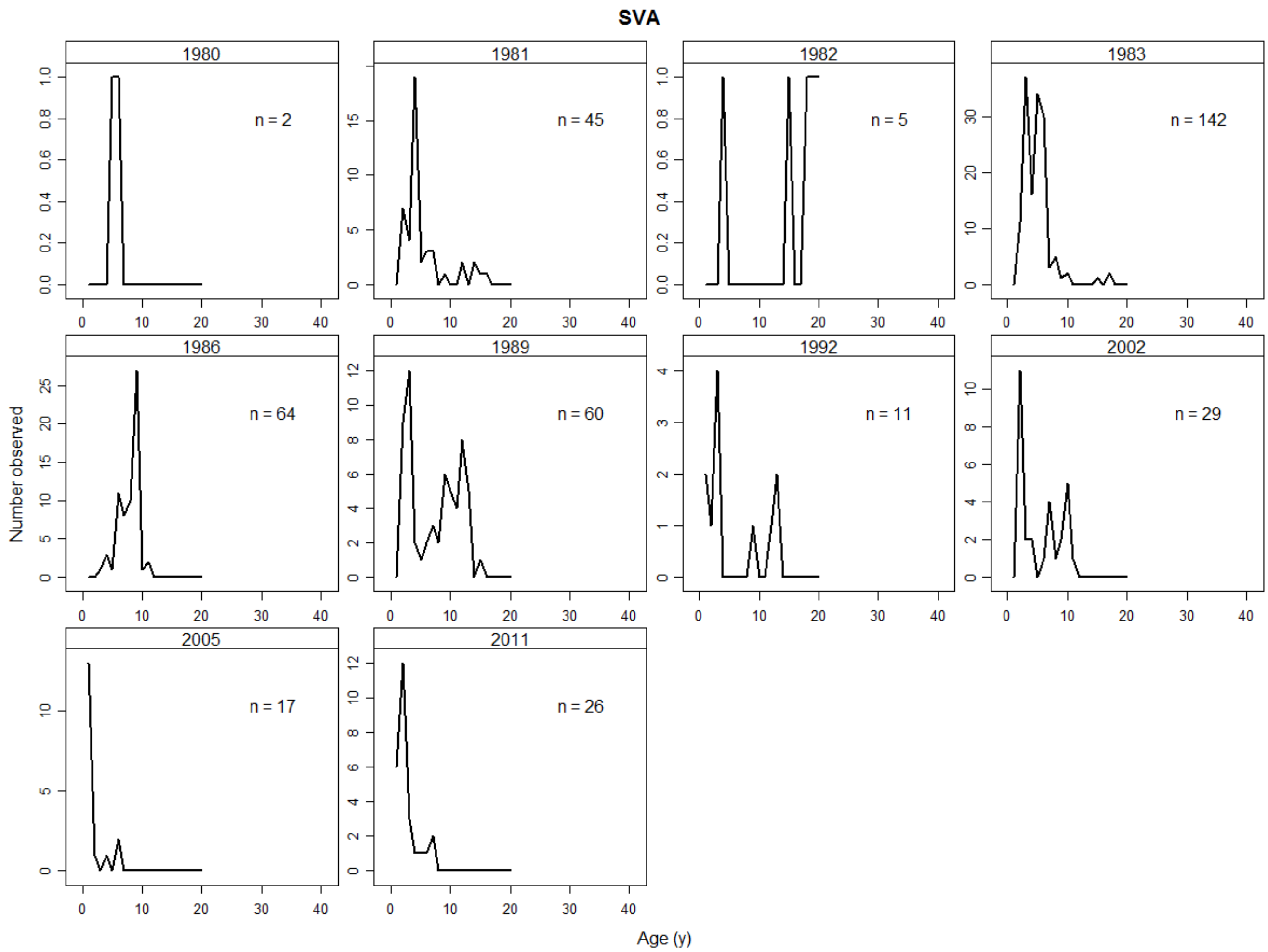


Figure A31. Age composition of NEFSC surveys in SVA

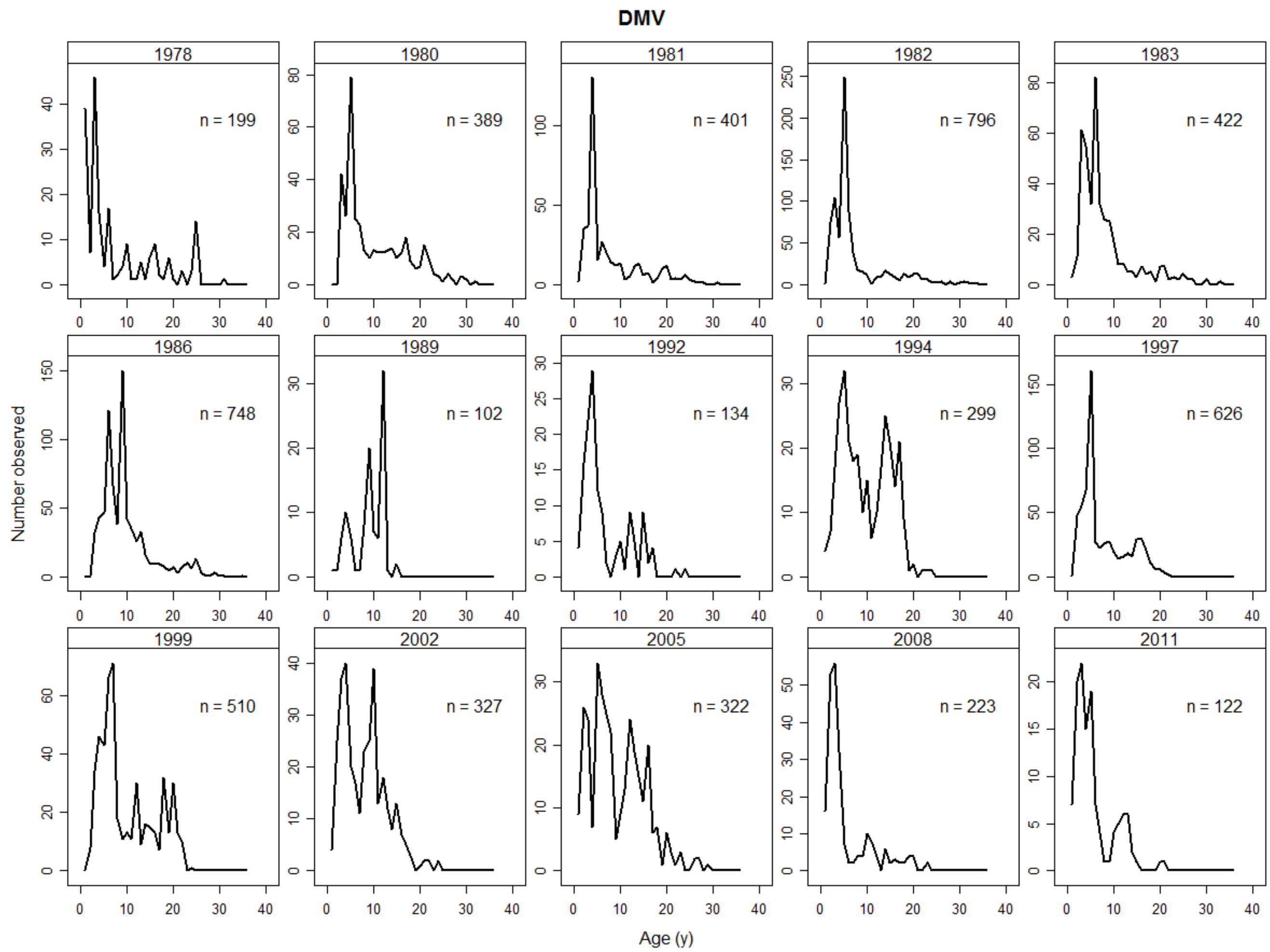


Figure A32. Age composition of NEFSC surveys in DMV.

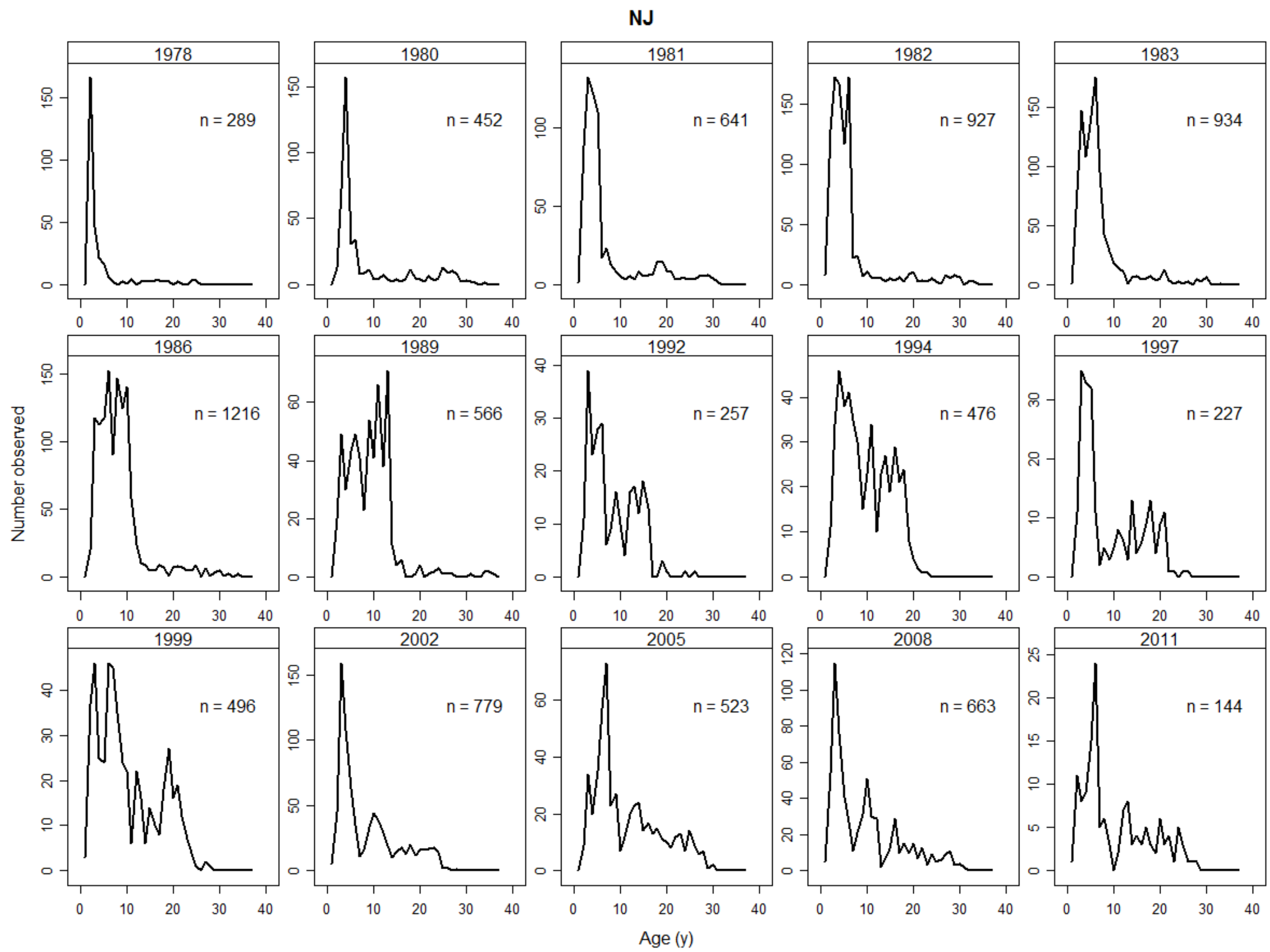


Figure A33. Age composition of NEFSC surveys in NJ.

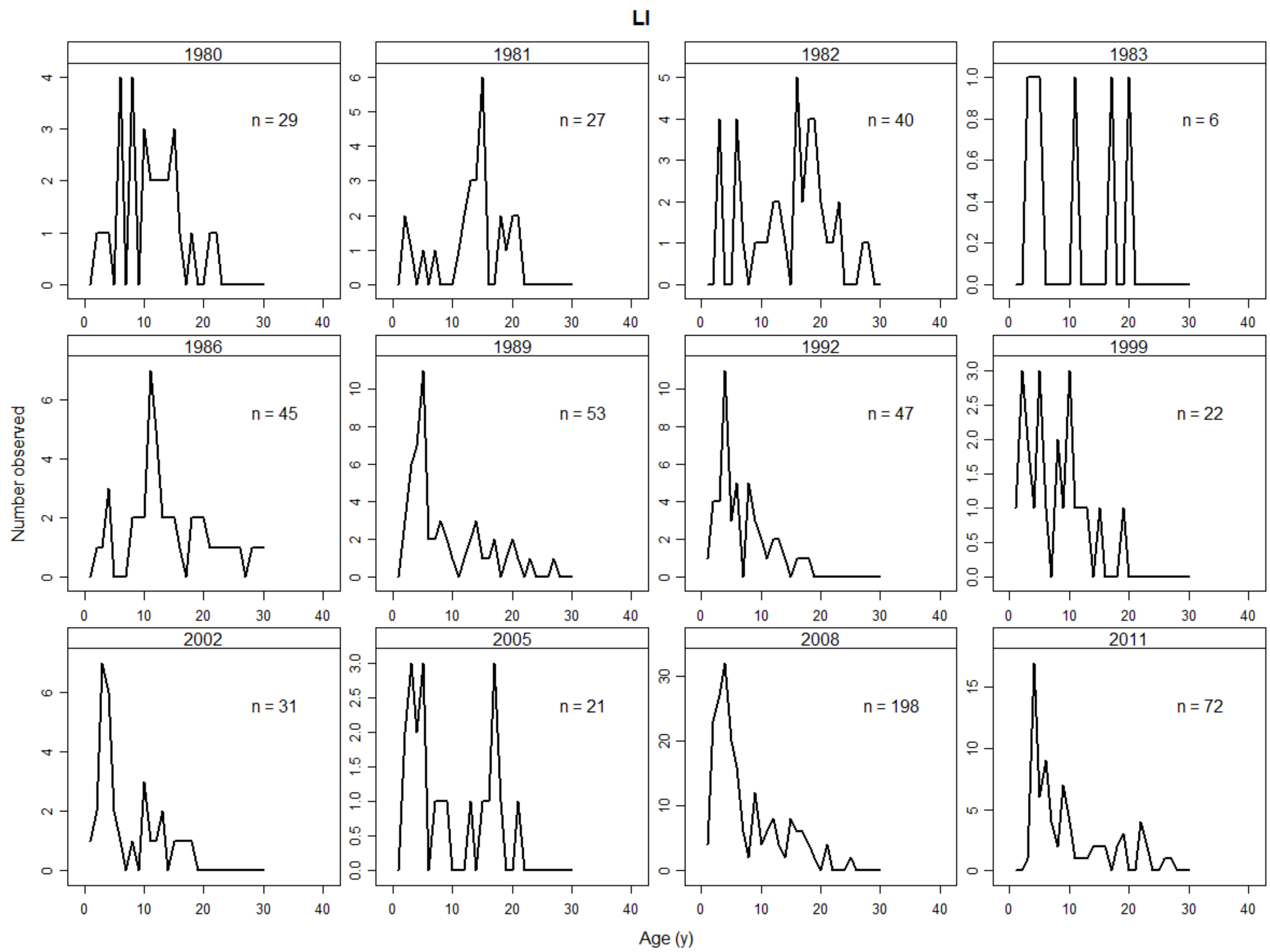


Figure A34. Age composition of NEFSC surveys in LI.

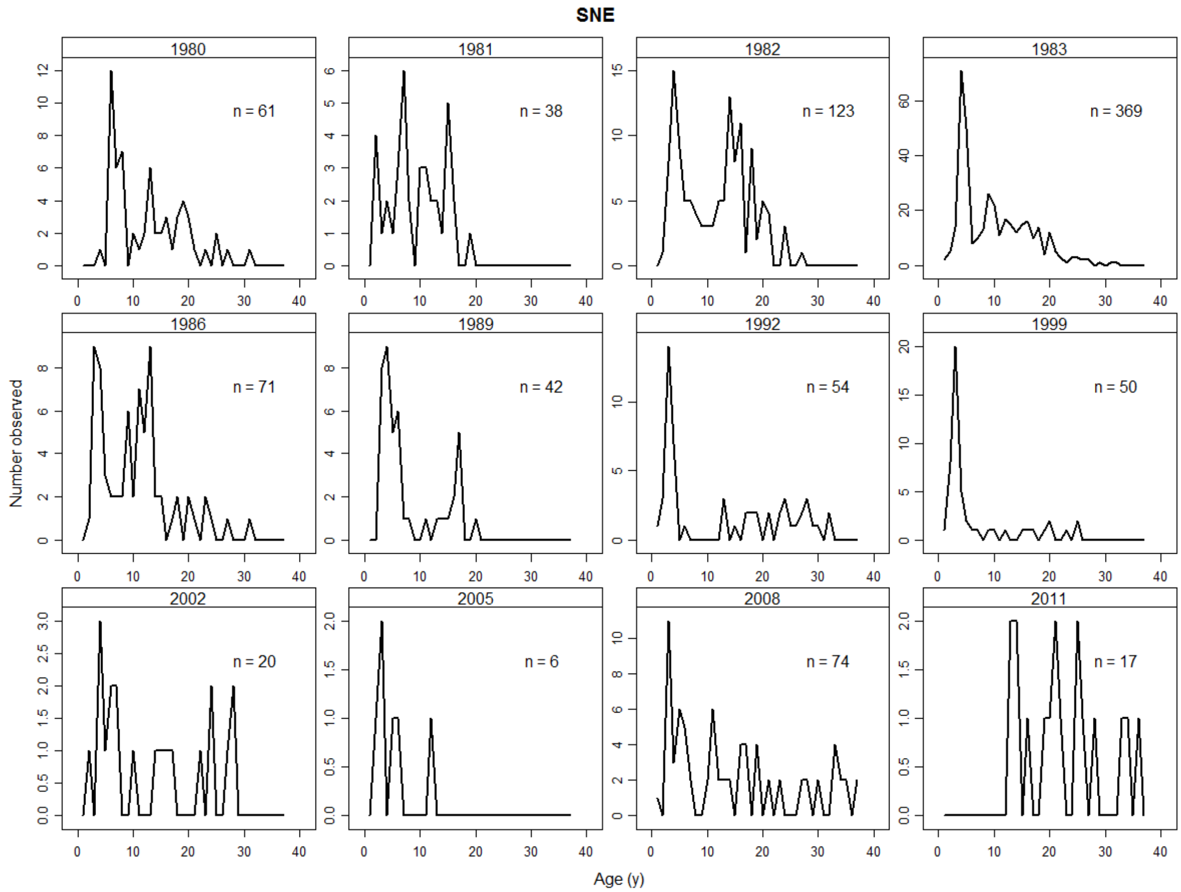


Figure A35. Age composition of NEFSC surveys in SNE.

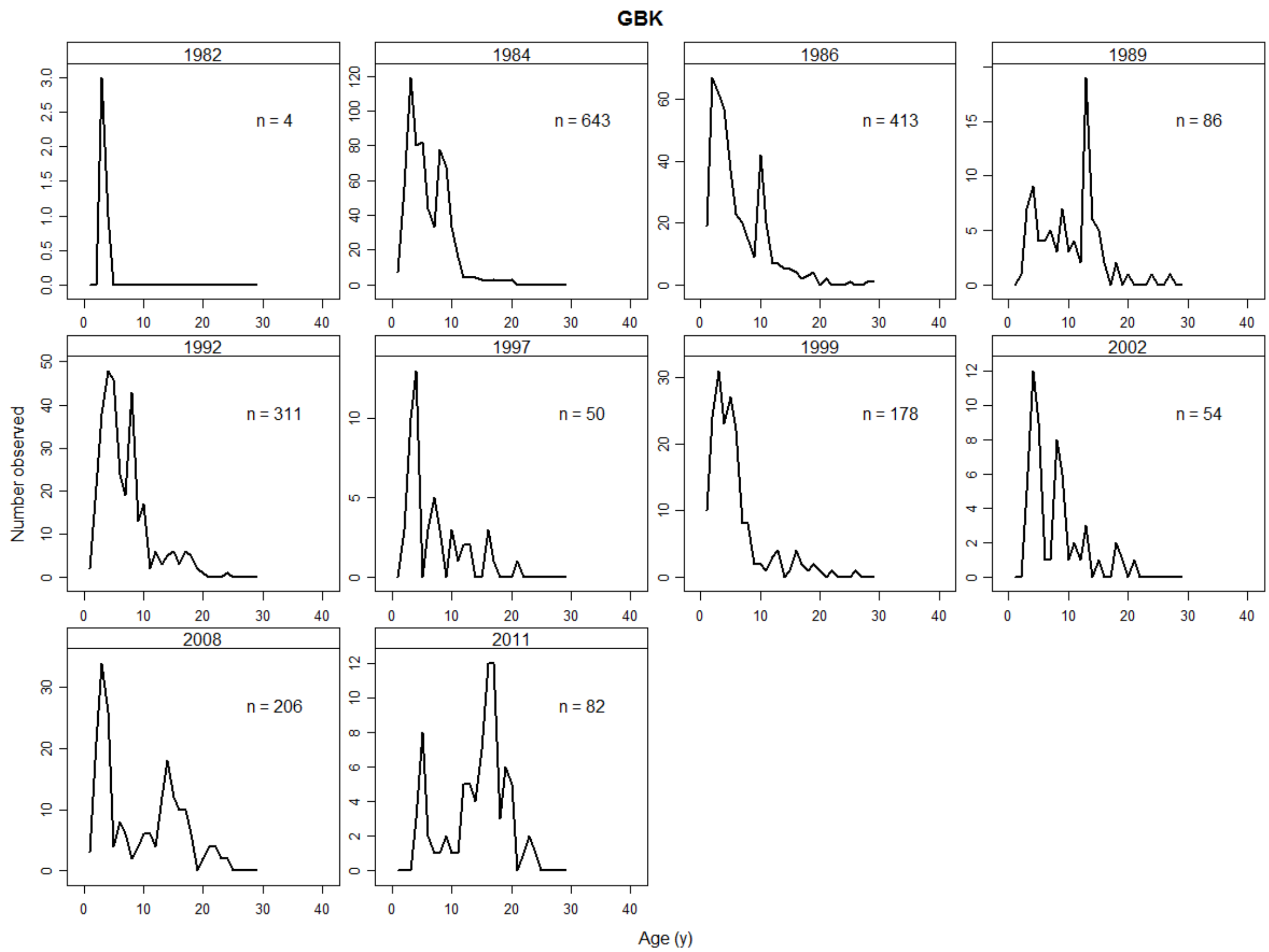
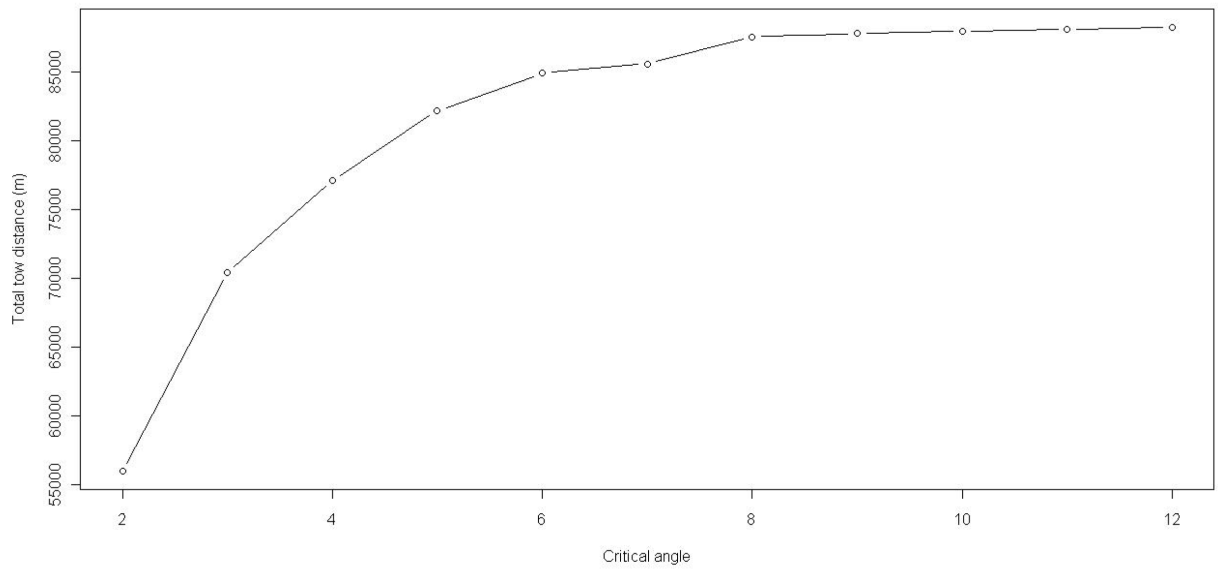


Figure A36. Age composition of NEFSC surveys in GBK.



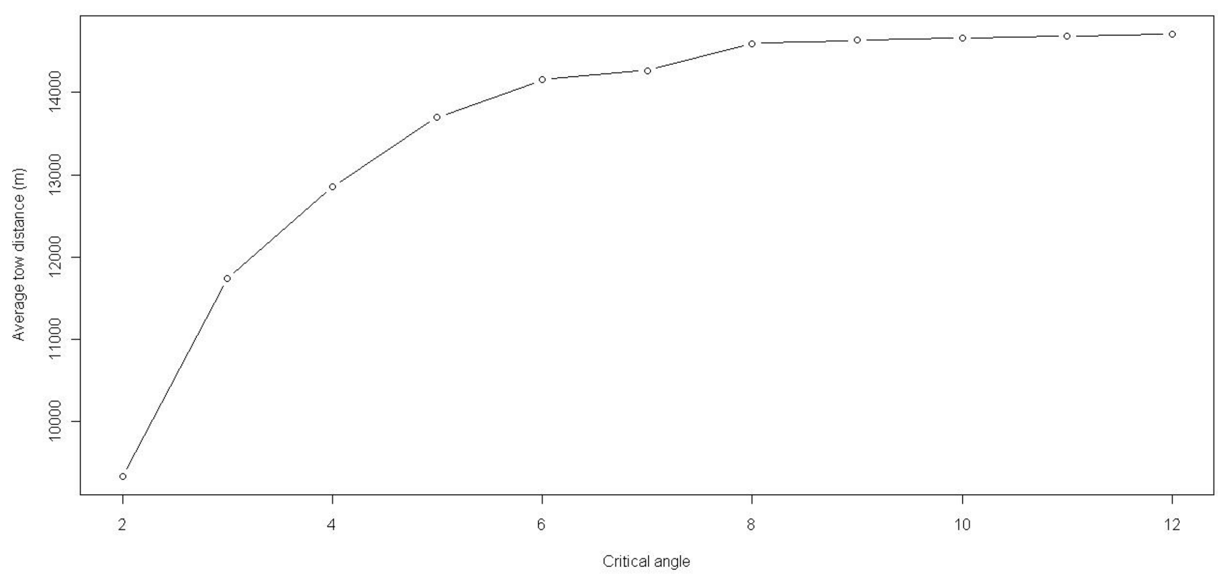


Figure A37. Total and average tow distance across all depletion experiments conducted in 2011 by the critical angle measured by the inclinometer and used to determine if the dredge was actively fishing. A larger critical angle results in more time fishing. The curve appears to asymptote at approximately 8 degrees and any critical angle between 8 and 12 degrees will produce approximately the same total and average tow distance.

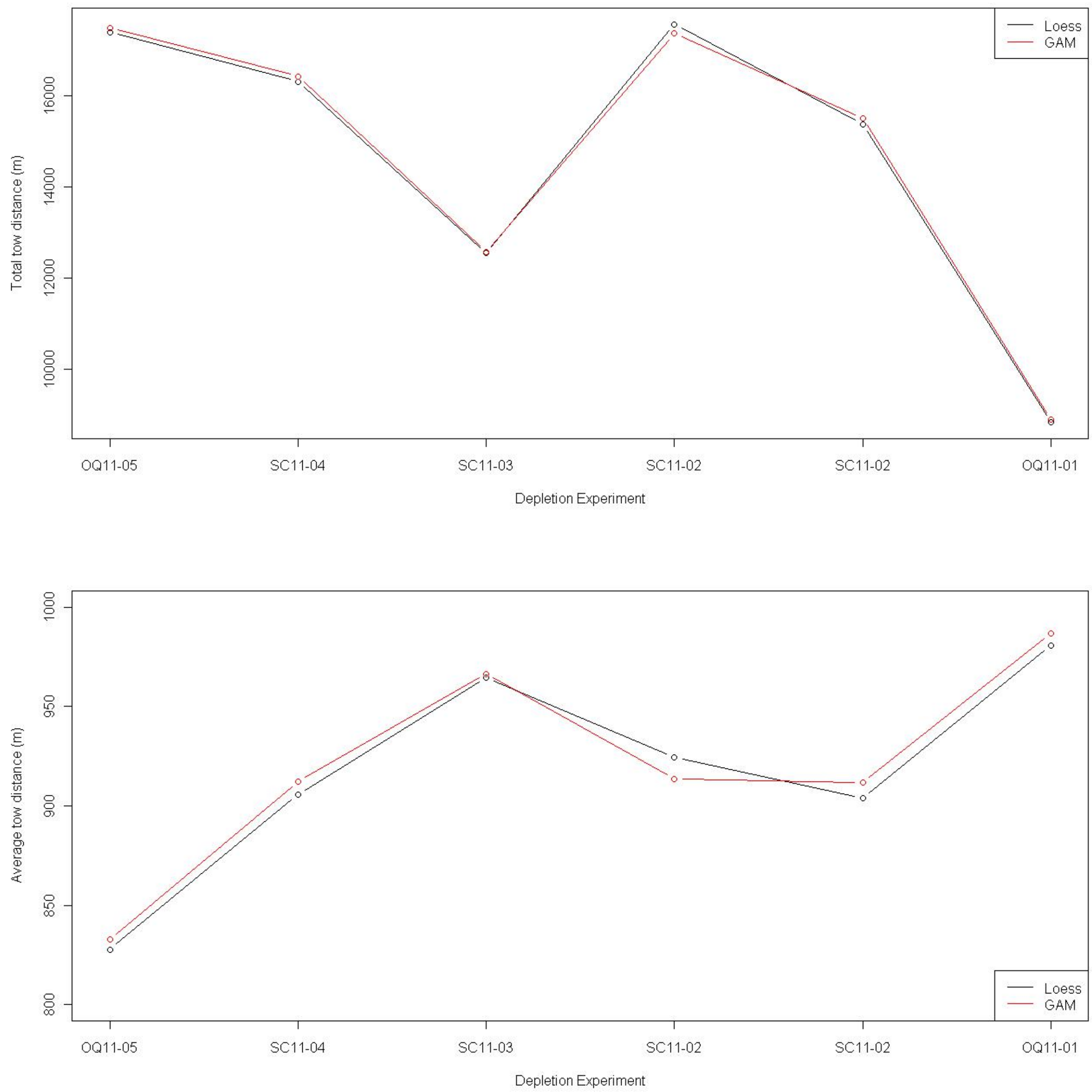


Figure A38. The total and average tow distance across all tows within each depletion experiment (including to Ocean quahog experiments) calculated using two common smoothing algorithms: loess and GAM splines. The choice of smoother did not appear to bias tow distance systematically.

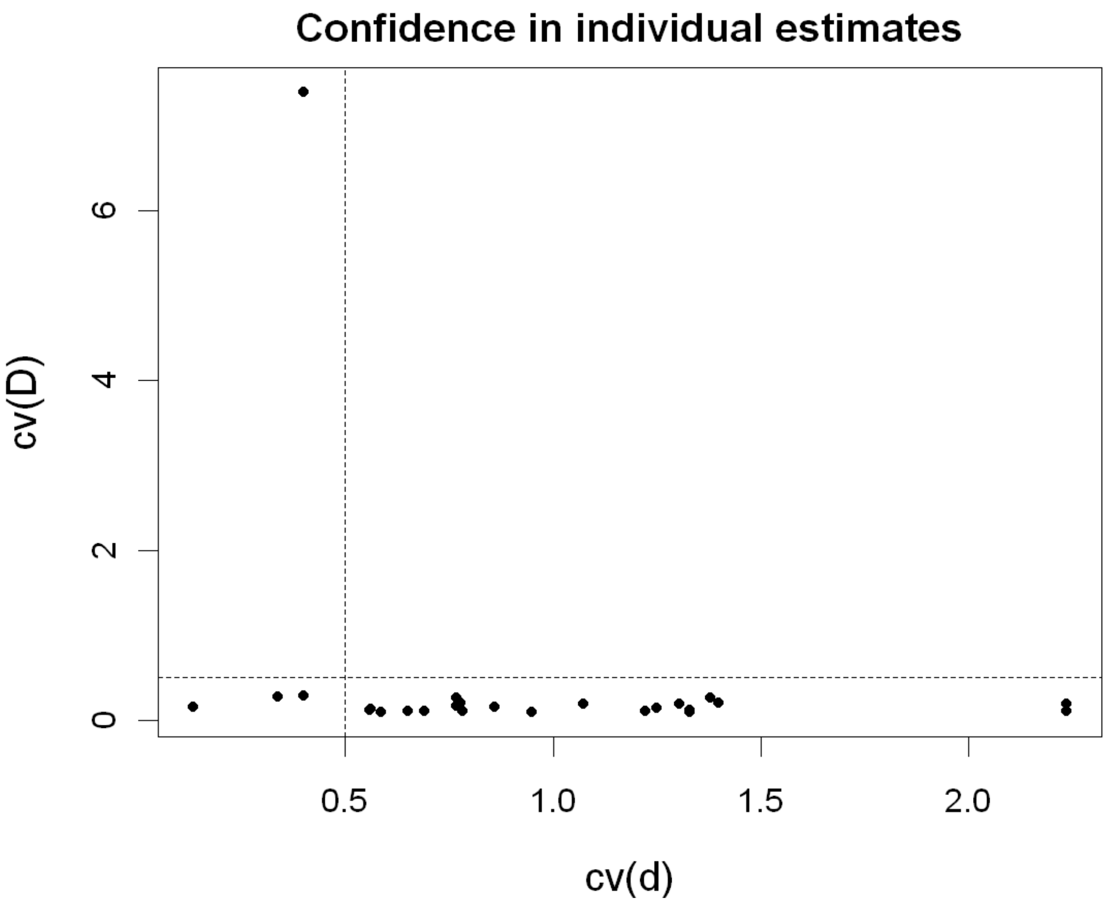


Figure A39. A comparison of the relative confidence in the components of the ratio used to estimate dredge efficiency. *D* is the density estimated in depletion experiments using the Patch model, while *d* is the density estimated using the set ups tows. The variability in *d* is relatively high compared to the variability in *D*. The dotted lines are for reference and represent a CV = 0.5 for each component.

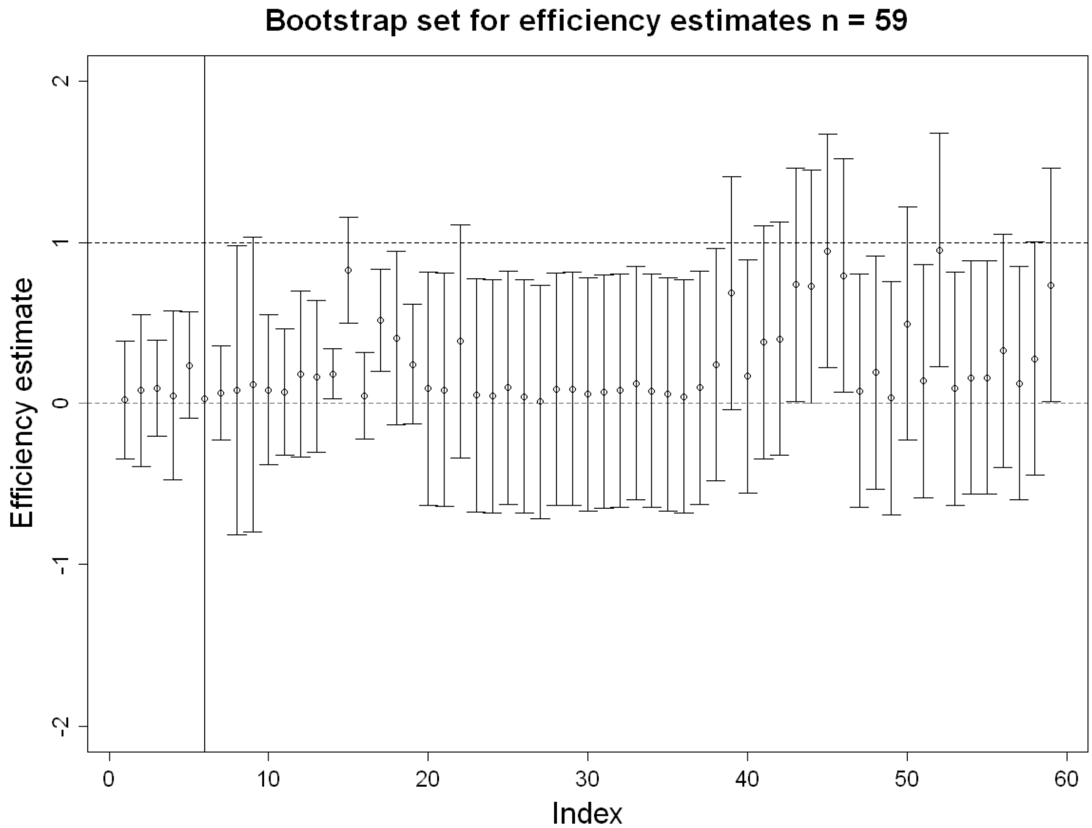


Figure A40. The set of prior knowledge for dredge efficiency estimates. Each individual estimate is shown with an error bar representing the magnitude of its CV.

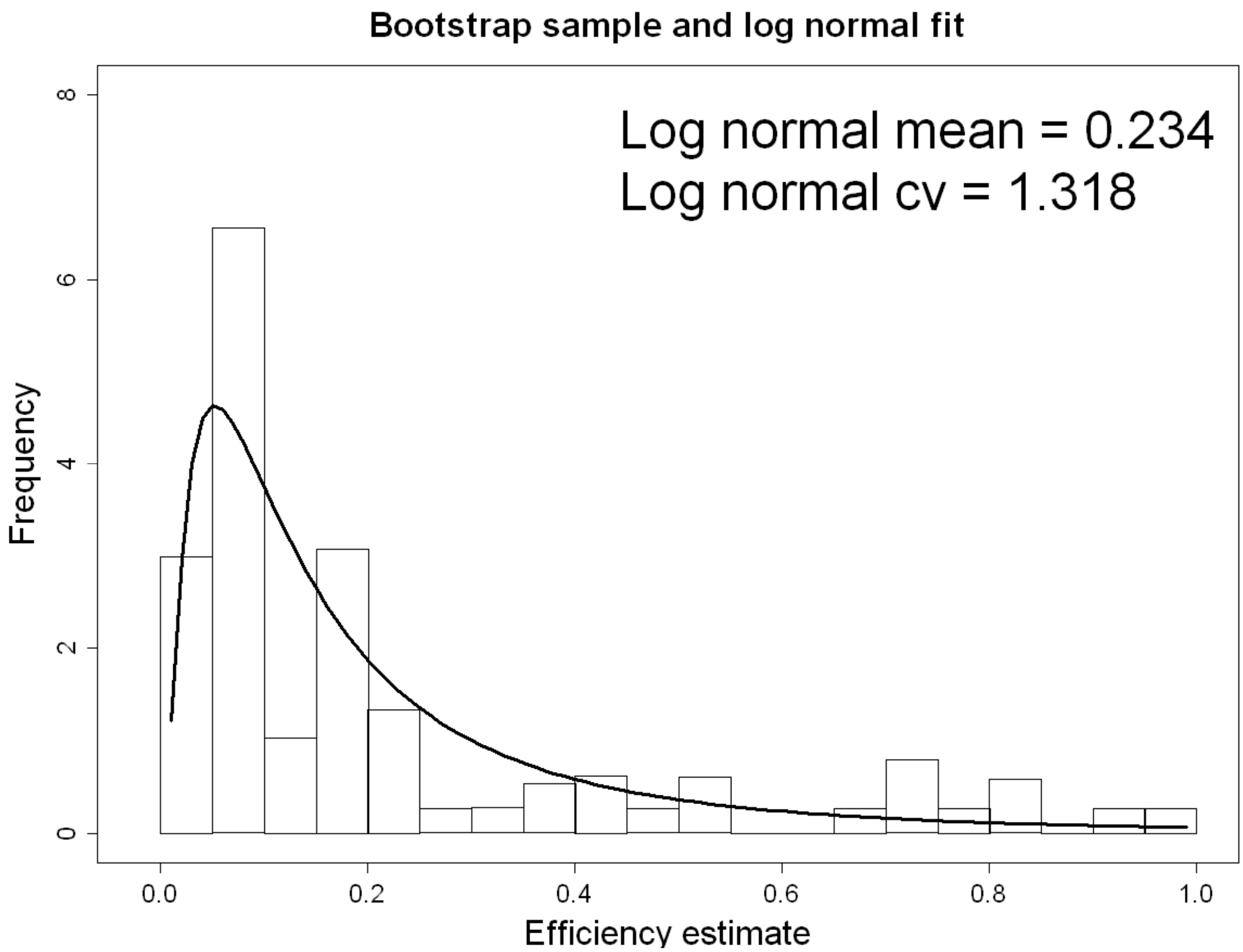


Figure A41. Bootstrapped data set and log normal fit. The distribution shown here is the prior distribution for survey dredge efficiency used in the assessment.

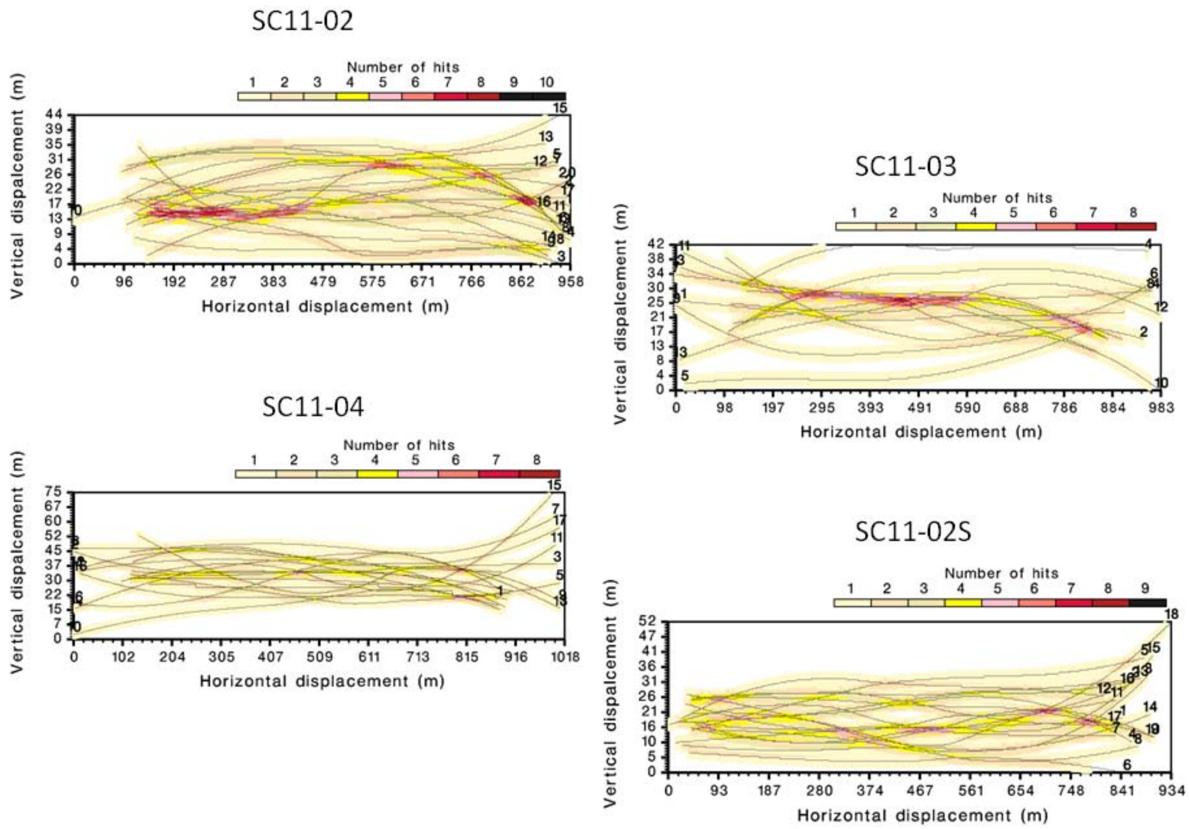


Figure A42. Maps of the tow sequence for all surfclam depletion experiments conducted in 2011.

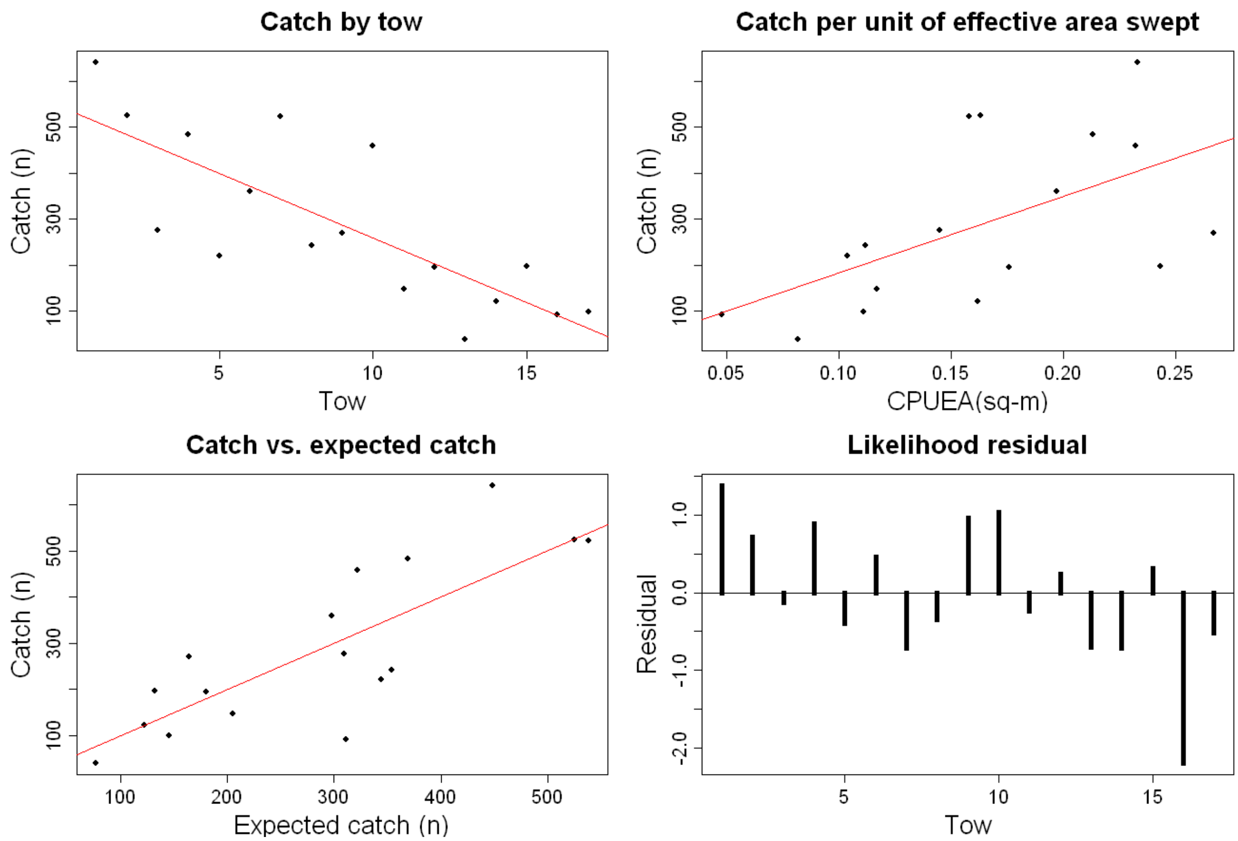


Figure A43. Patch model diagnostics for depletion experiment SC11-04. These include: catch by tow, catch per unit of effective area swept, catch vs. expected catch and the likelihood residuals from the patch model fit. Effective area swept accounts for the proportion of ground that is being repeatedly fished for the first, second, third, etc... overlapping tow. The expected catch is the catch predicted by the Patch model.

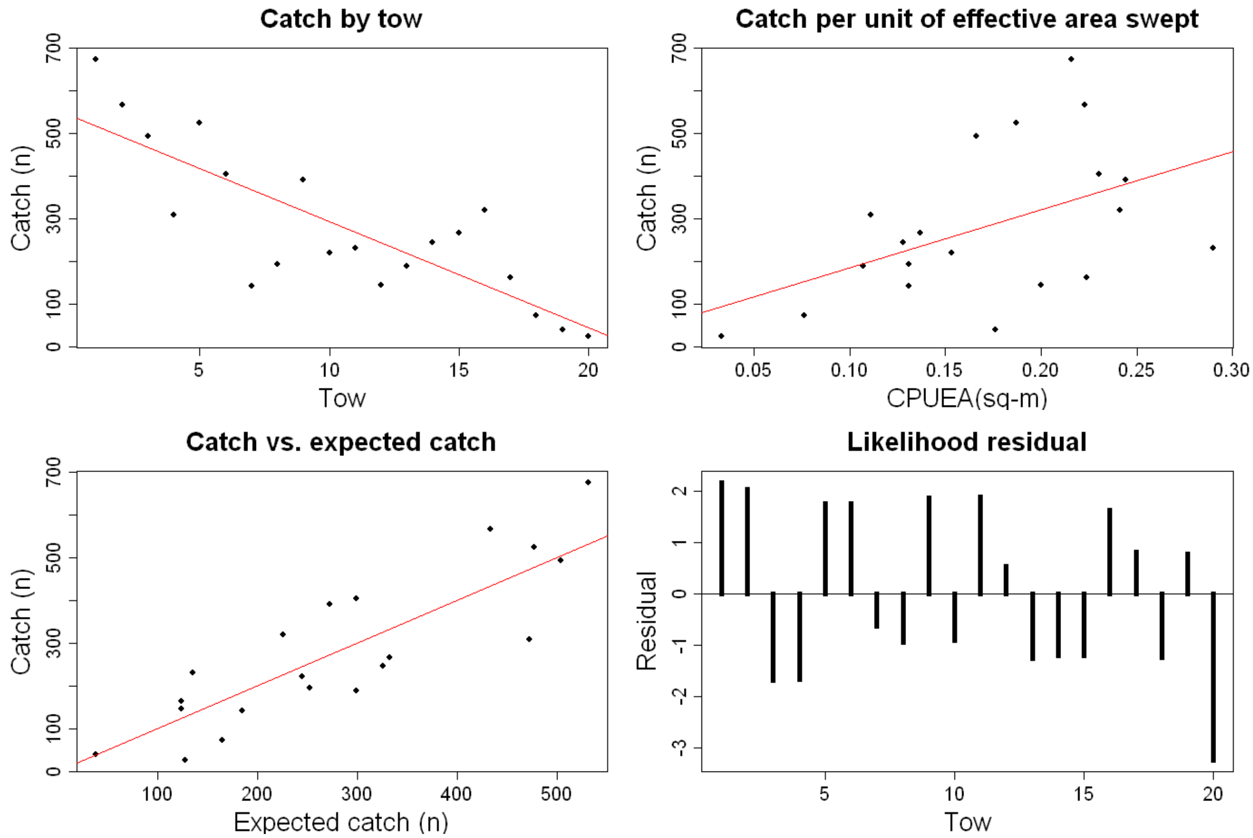


Figure A44. Patch model diagnostics for SC11-02.

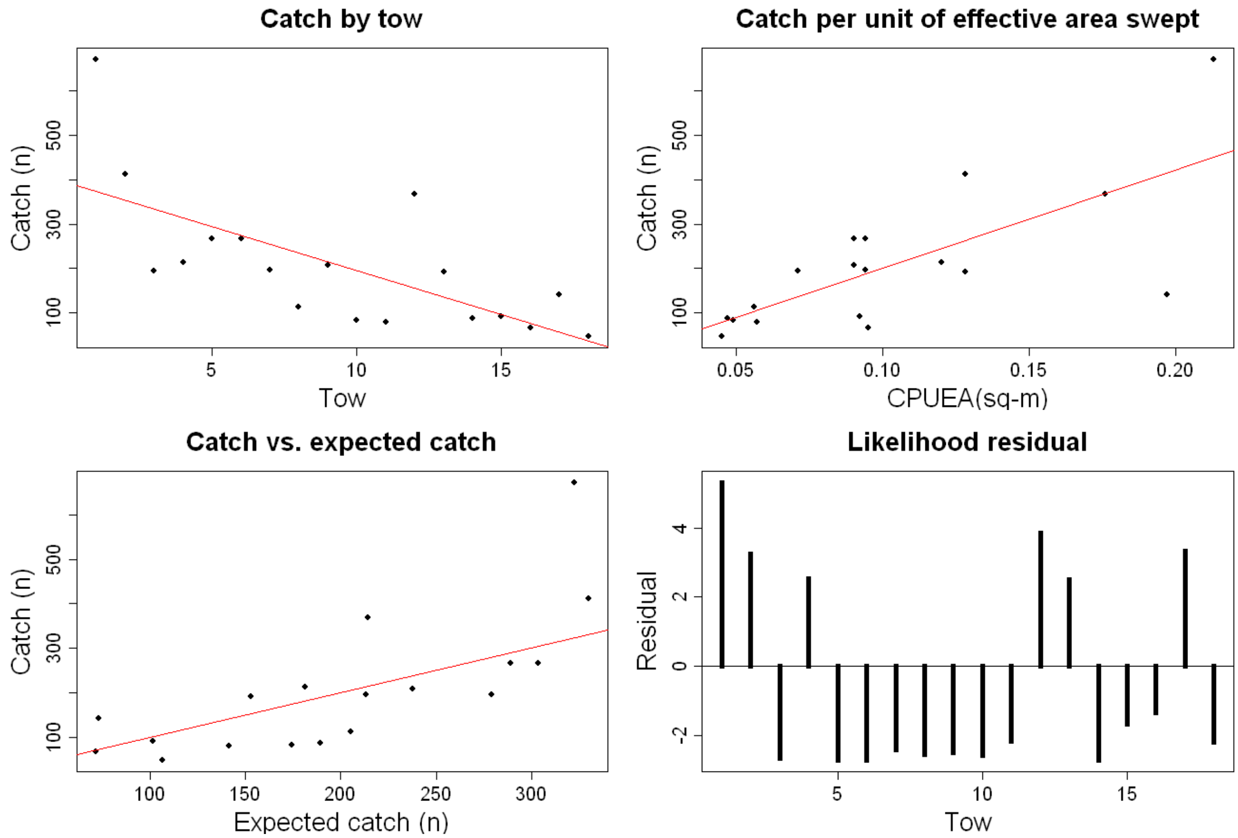


Figure A45. Patch model diagnostics for SC11-02S.

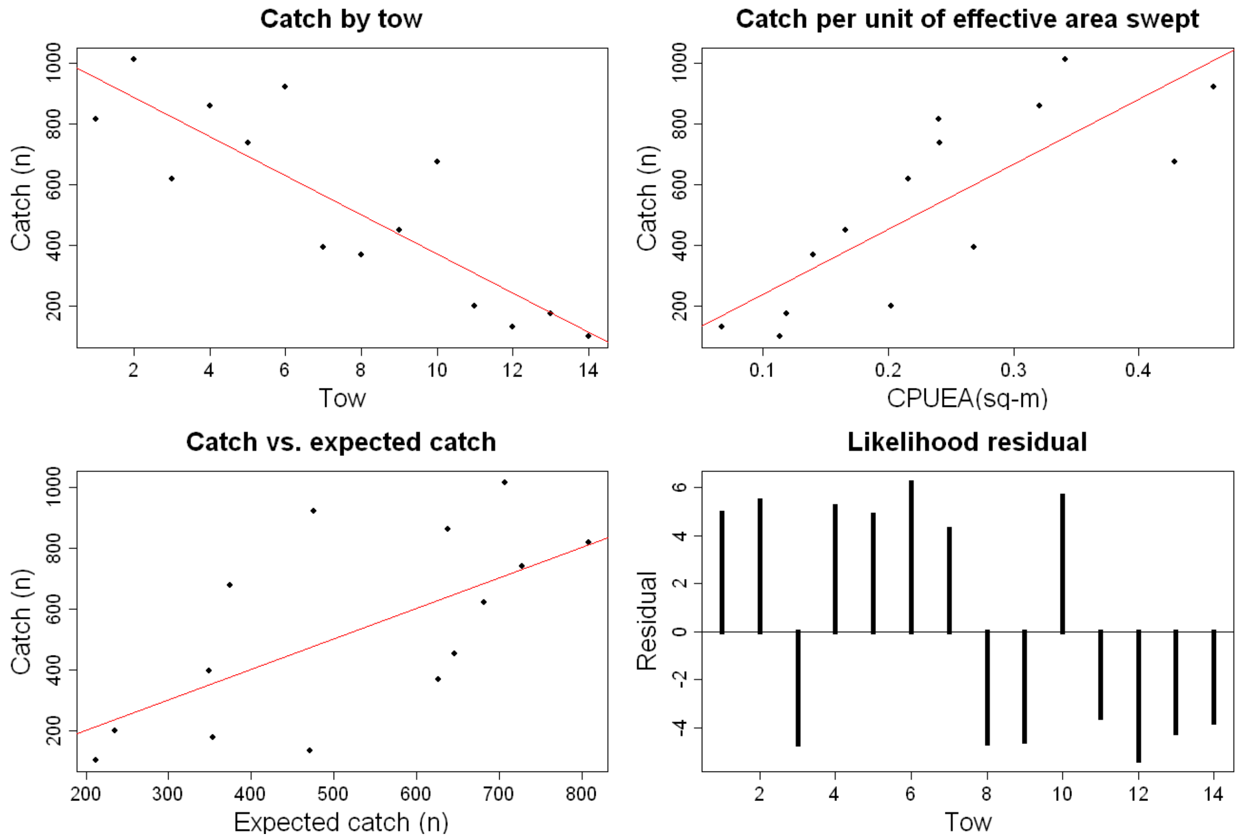


Figure A46. Patch model diagnostics for SC11-03.

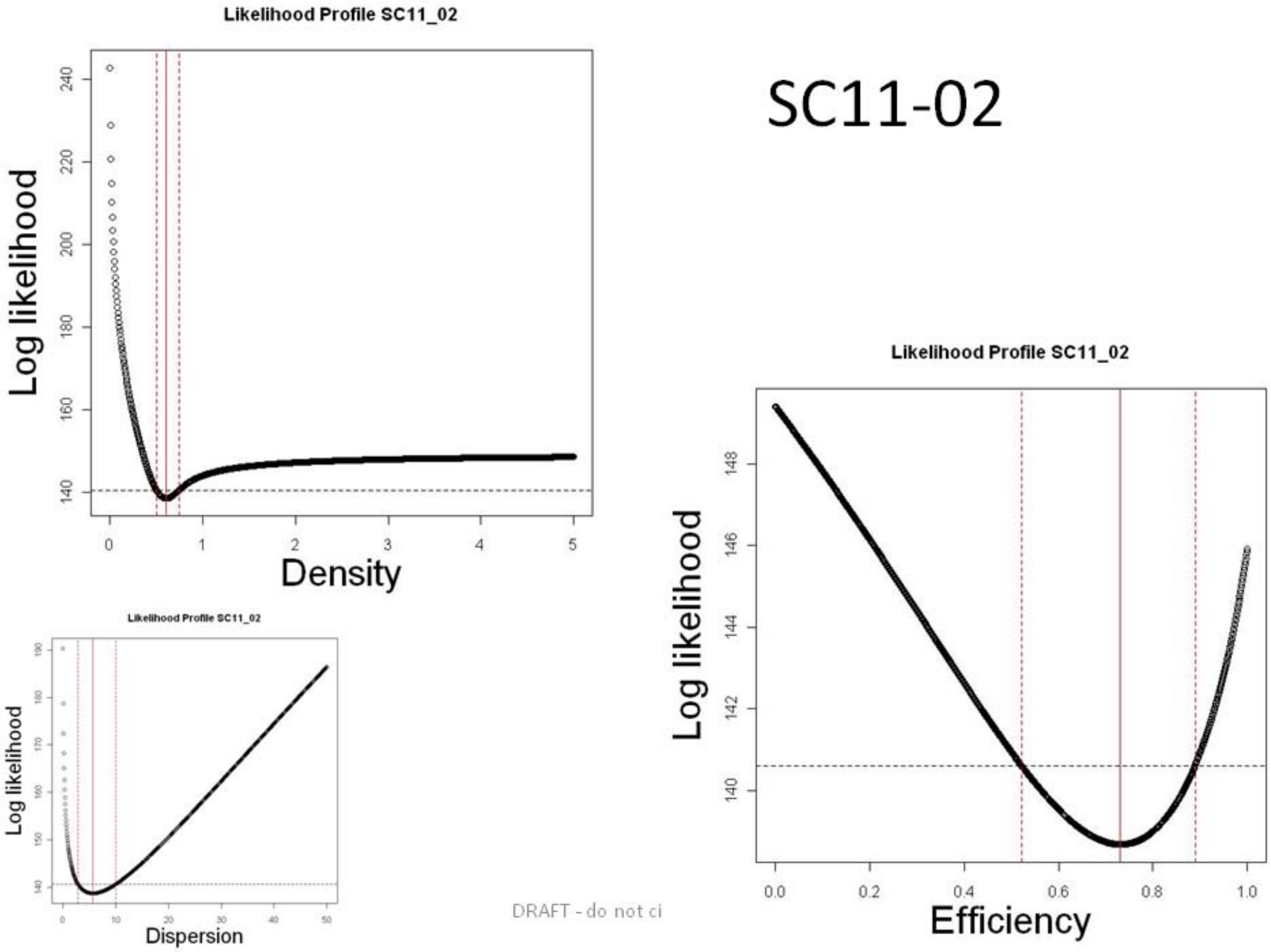


Figure A47. Likelihood profiles for SC11-02. The red lines are the estimates and delta method approximate 95% confidence intervals.

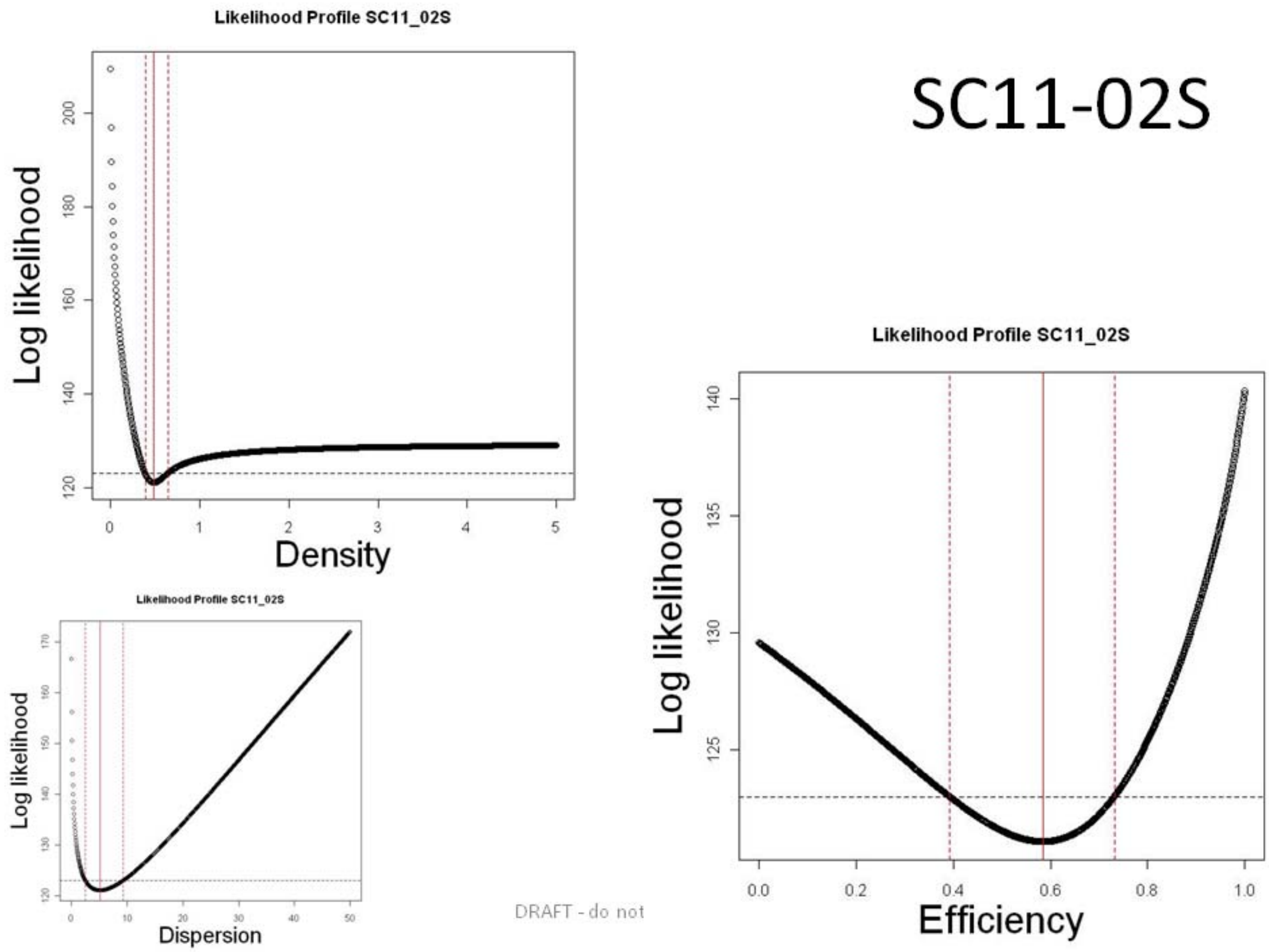


Figure A48. Likelihood profiles for SC11-02S.

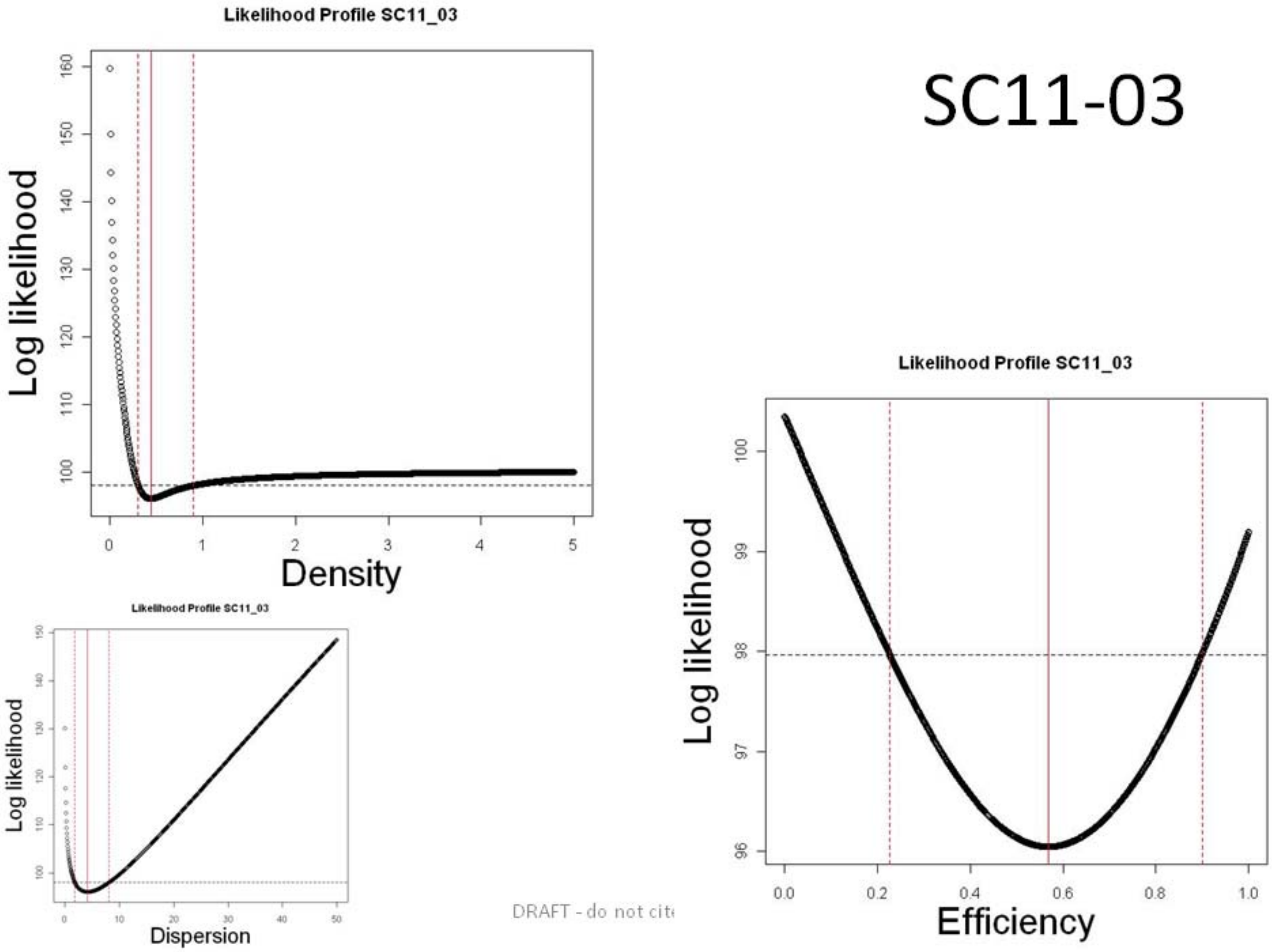


Figure A49. Likelihood profiles for SC11-03.

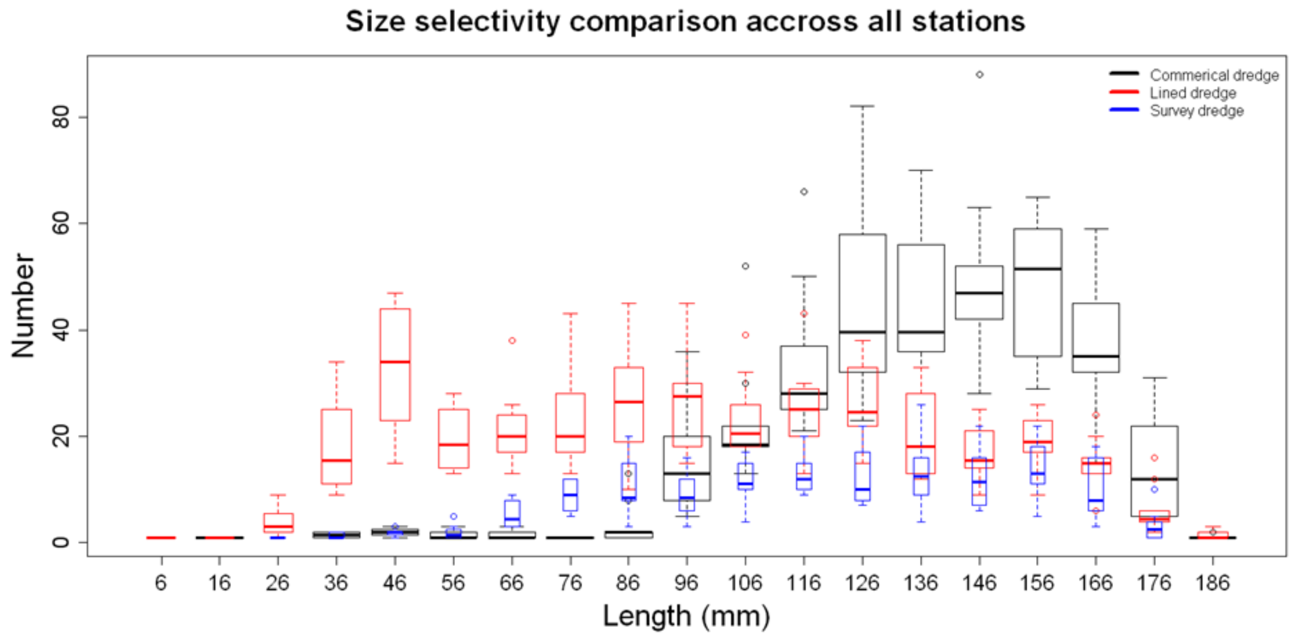


Figure A50. Surfclam shell height composition data used to estimate selectivity of the NEFSC survey clam dredge. Summarized here using 1 cm bins.

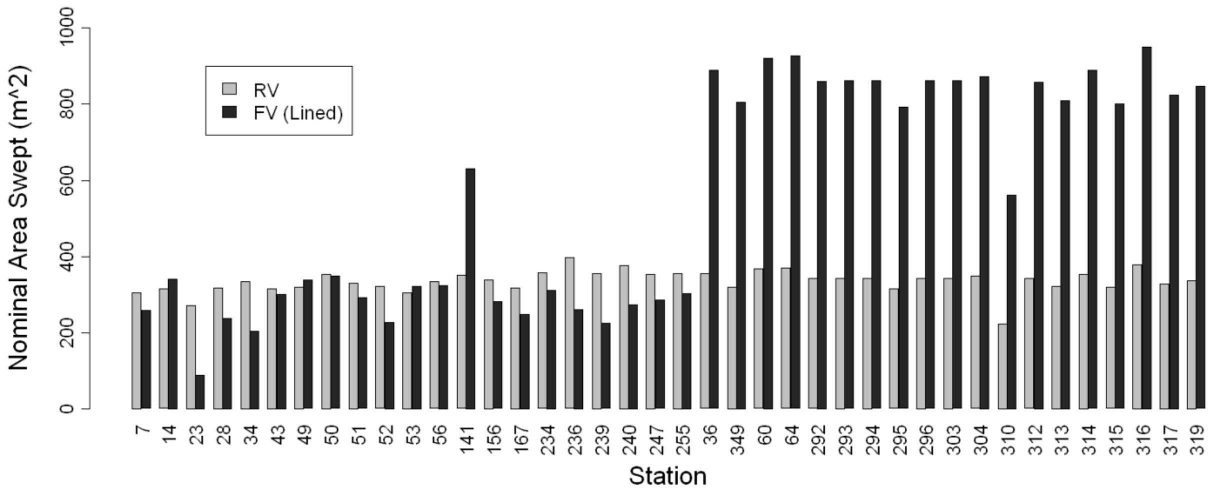


Figure A51. Swept area comparison at each station in survey selectivity experiments in 2008 and 2011.

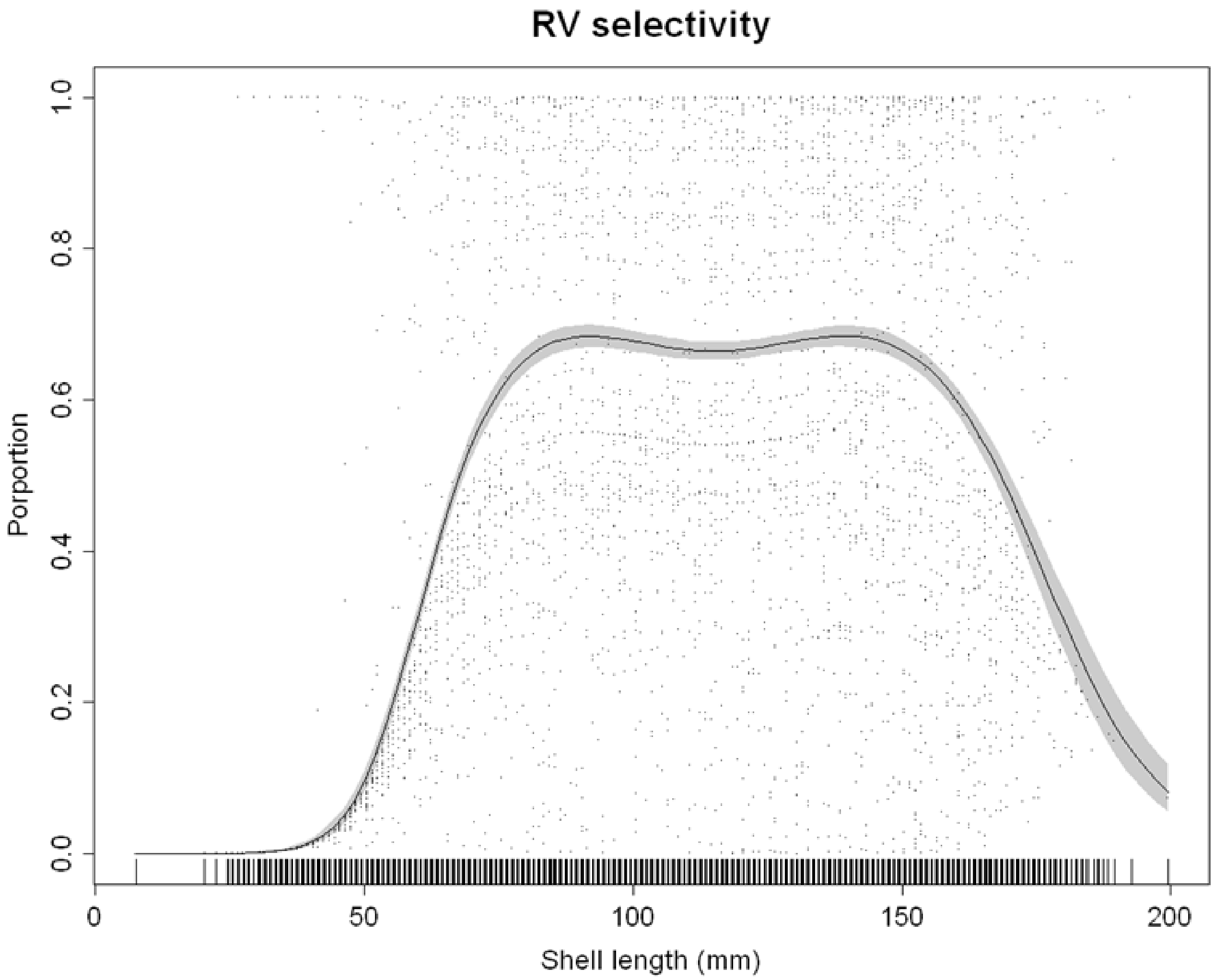


Figure A52. GAM model fit to selectivity data. The dots are the residuals, the gray band is the +/- 2 standard error confidence interval, and the rug plot above the x axis indicate data density (weights). Much of the variance shown is eliminated in modeling by the offset term which adjust for differences in area swept and the overall proportion of samples in the test gear.

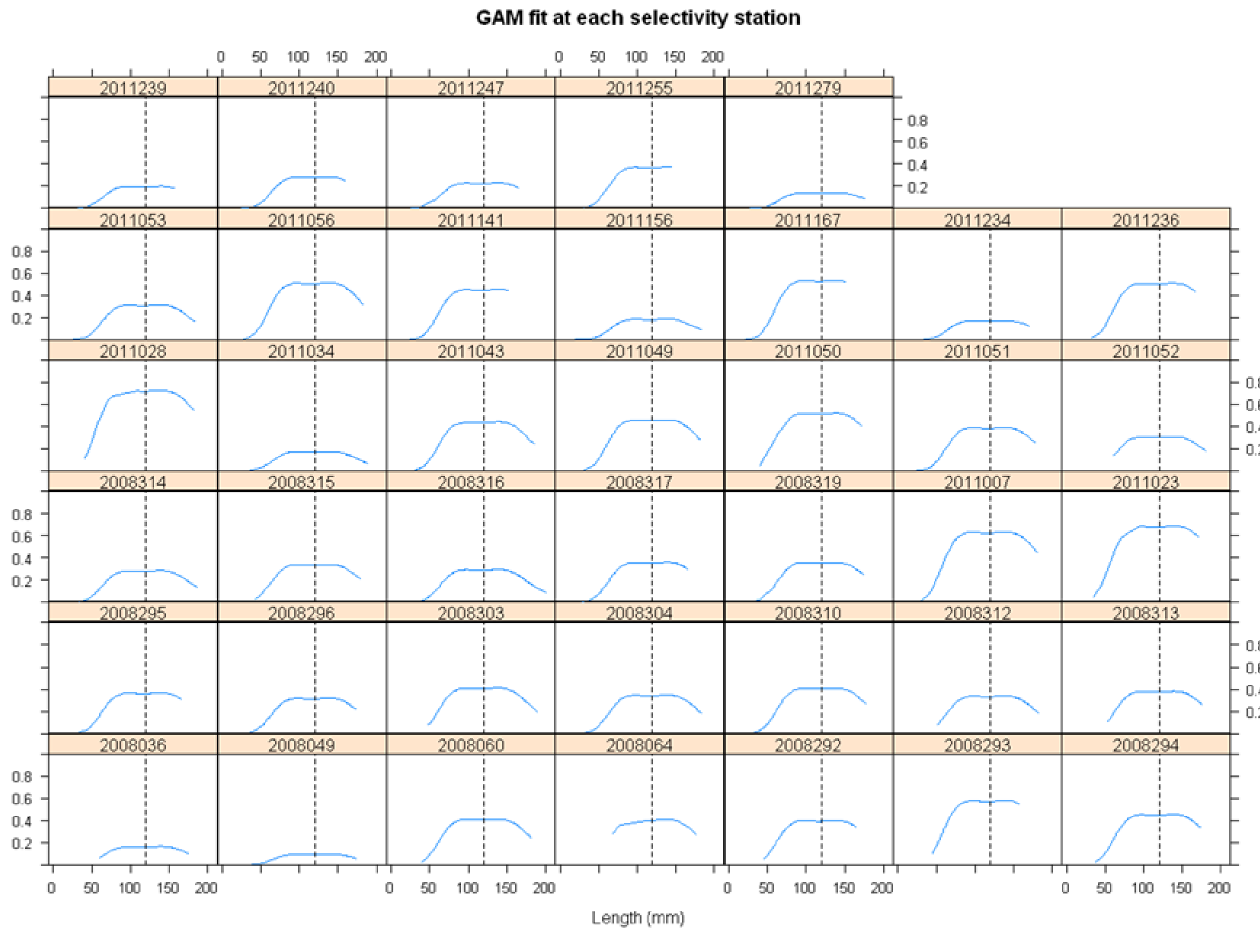


Figure A53. GAM fit at each station. This plot demonstrates that the domed shape is pervasive and not driven data from one or a few stations.

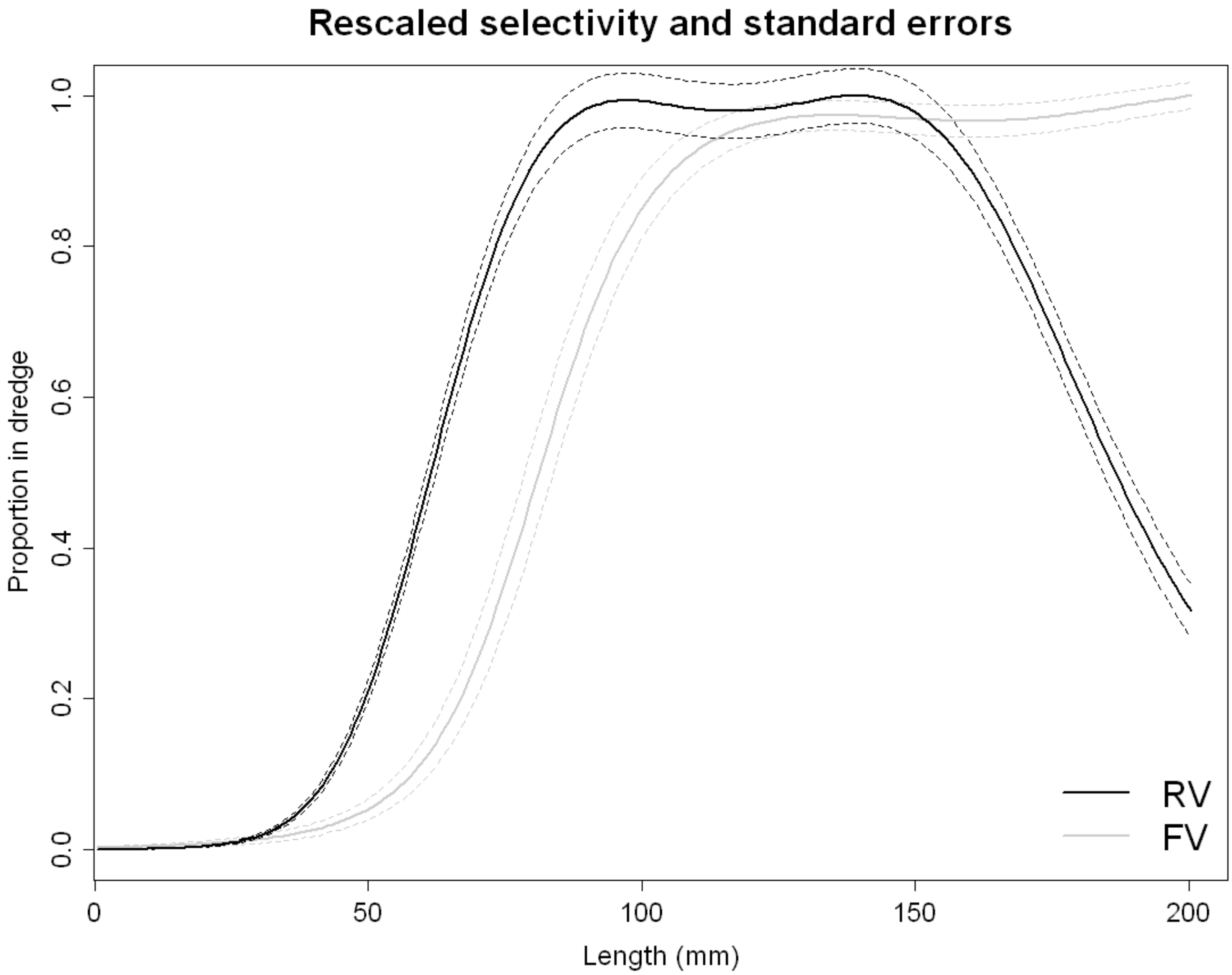


Figure A54. Rescaled selectivity fits for both survey and commercial dredges with +/- 2 standard errors.

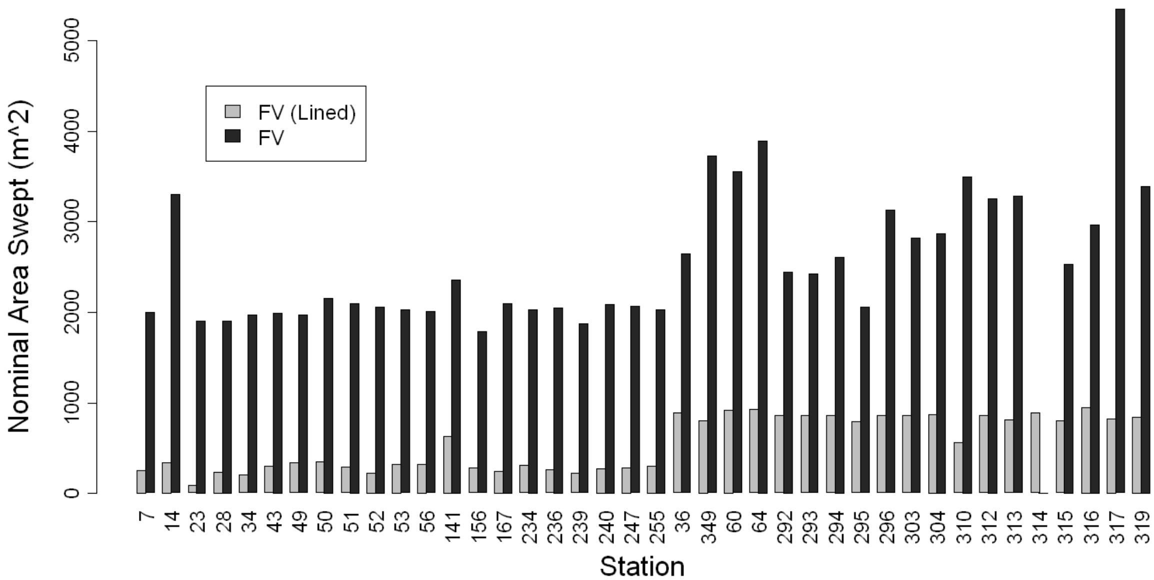


Figure A55. Swept area comparison at each station in commercial selectivity experiments in 2008 and 2011. Tow length for commercial station 314 is not available and station 314 was not used.

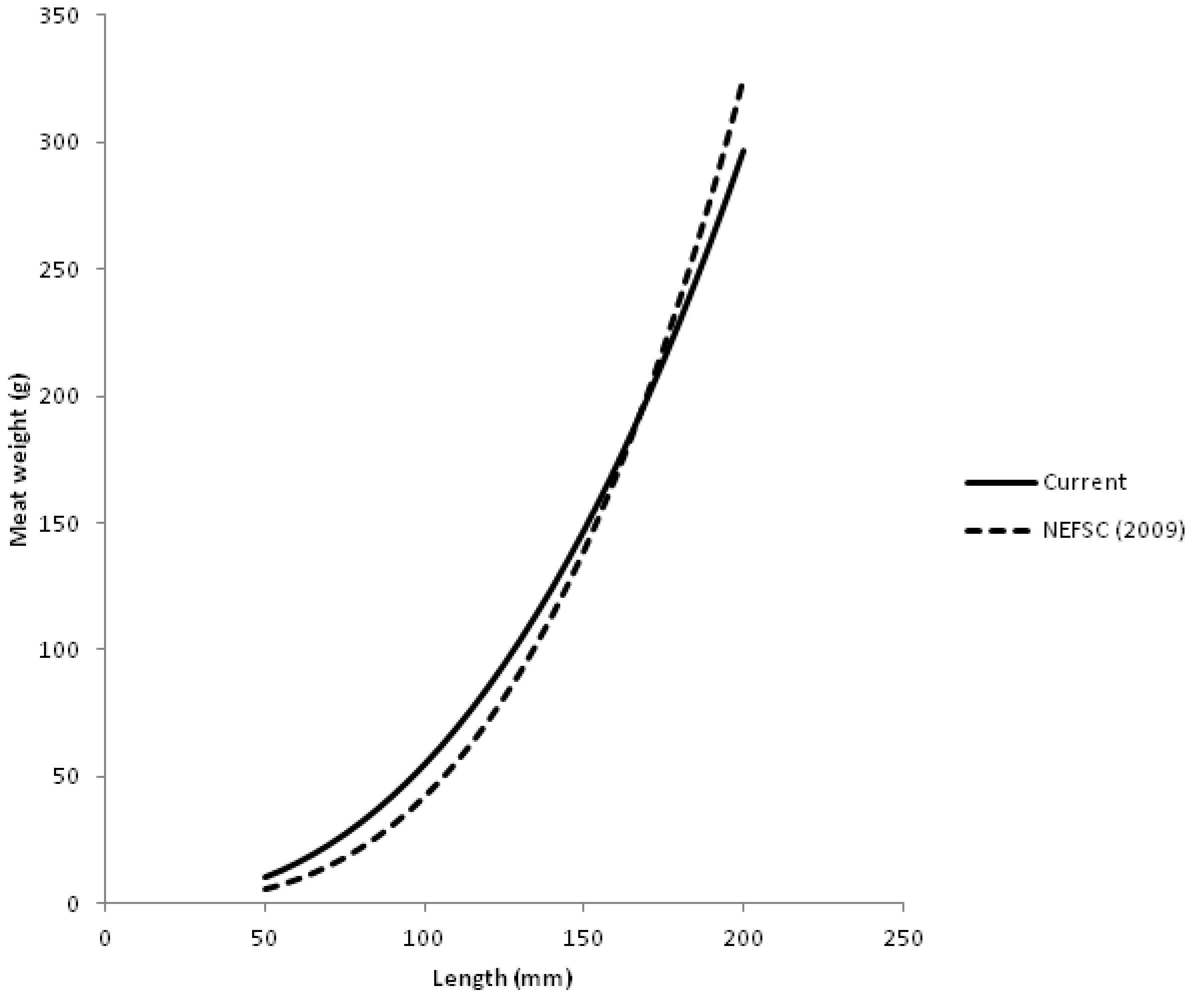
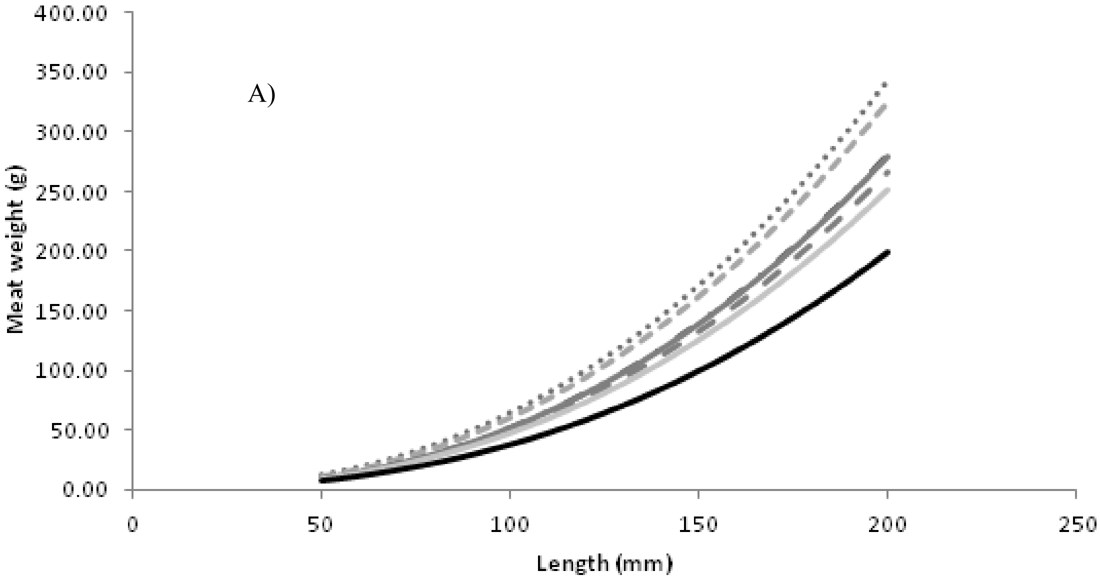


Figure A56. Length to meat weight curves from the last assessment and the current analysis. Both are based on general data, without regional or year effects. The average depth over all stations (33 m) was used to generate the curve for the current assessment in this figure.



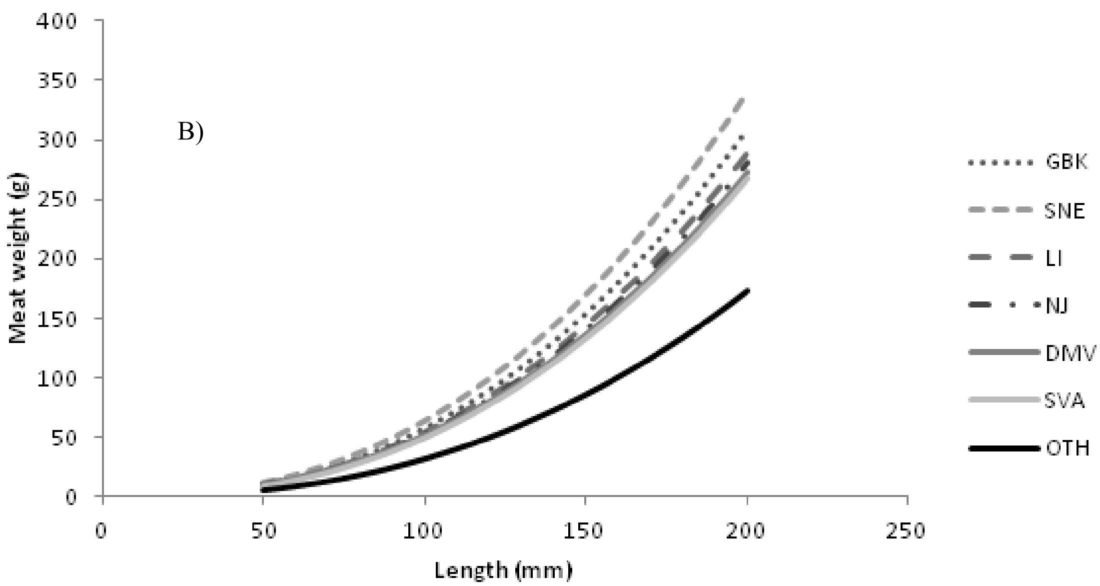


Figure A57. Regional differences in allometric relationships for surfclam. The same depth (33 m) was used to generate the curves for each region in A) and regional median depth was used to generate the curves in B).

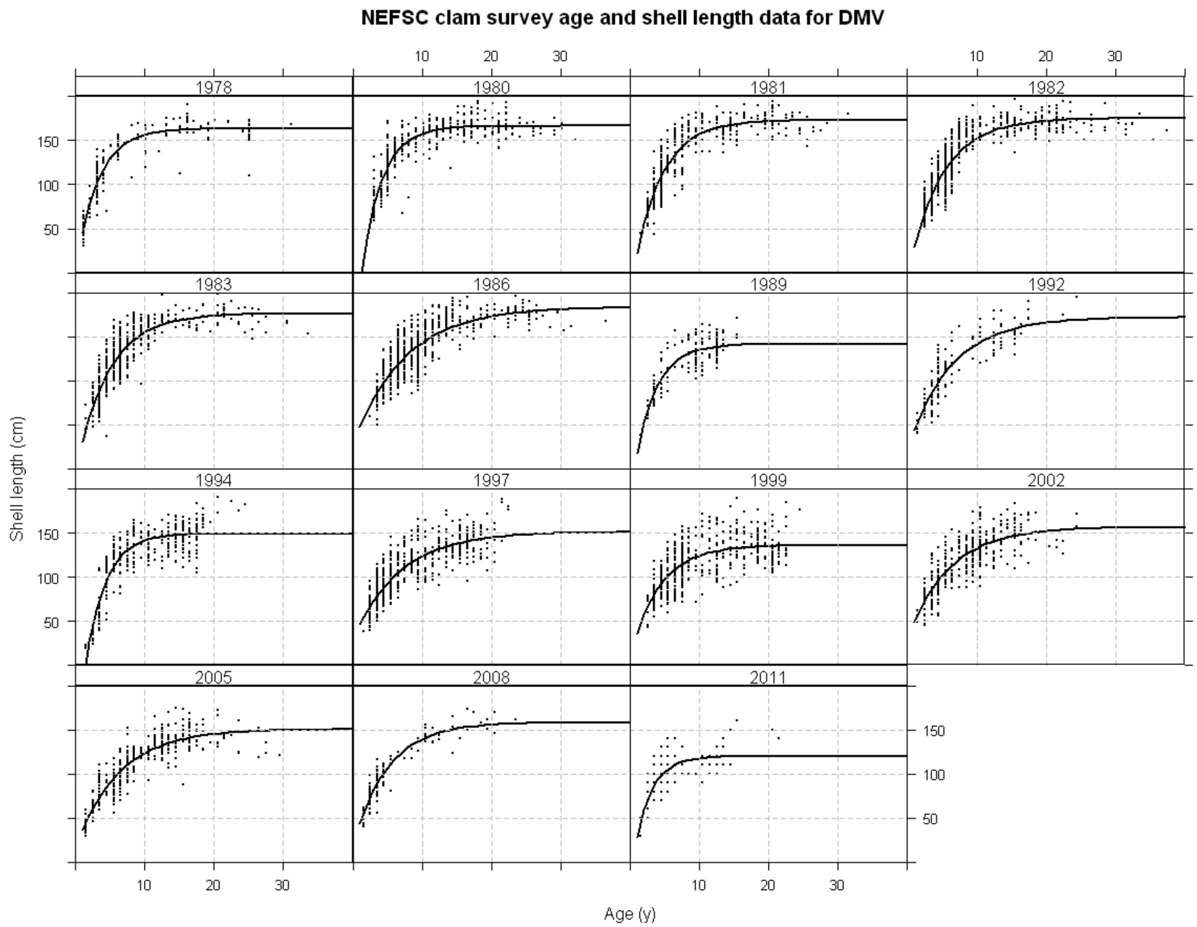


Figure A58. Age vs. length with fitted Von Bertalanffy growth curve for the DMV region in each survey year.

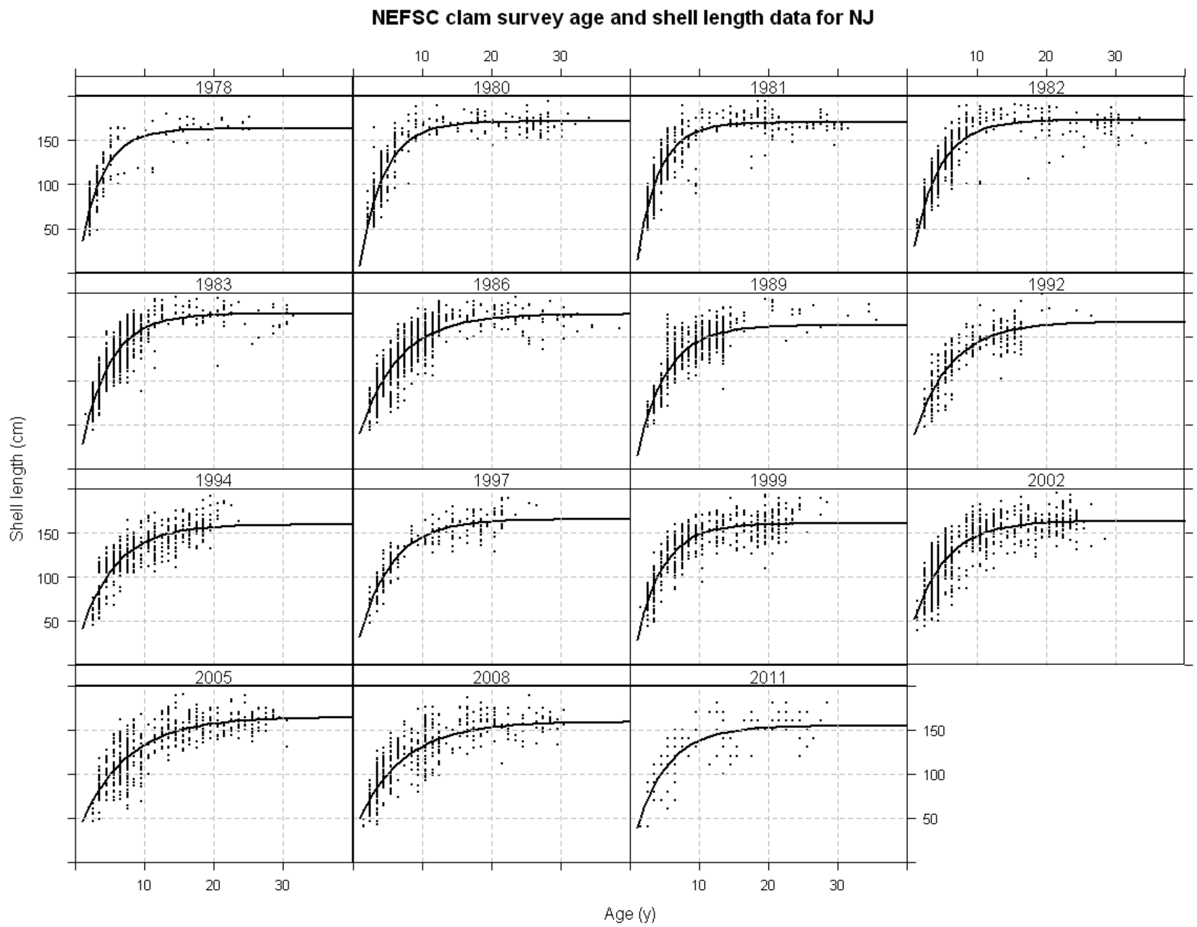


Figure A59. Age vs. length with fitted Von Bertalanffy growth curve for the NJ region in each survey year.

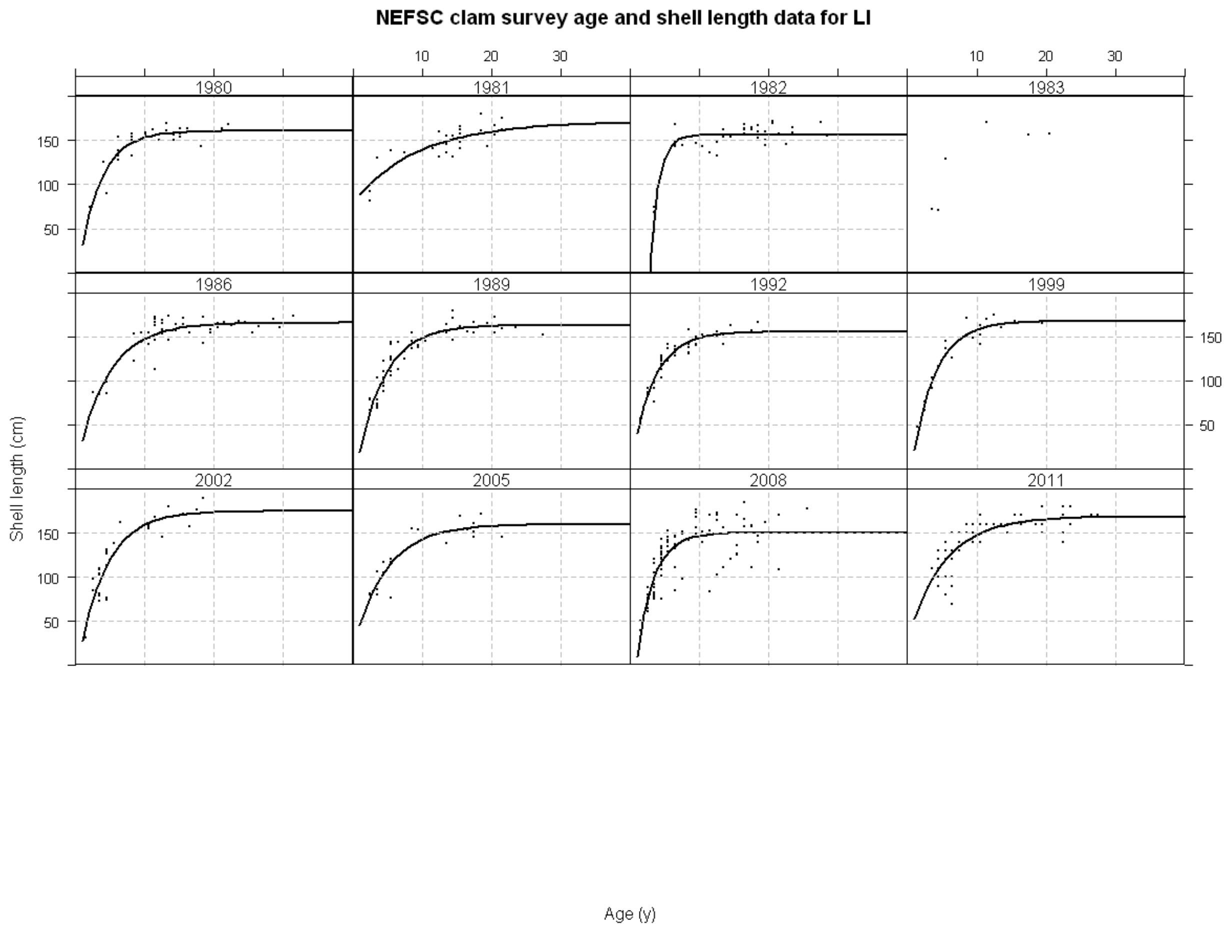


Figure A60. Age vs. length with fitted Von Bertalanffy growth curve for the LI region in each survey year.

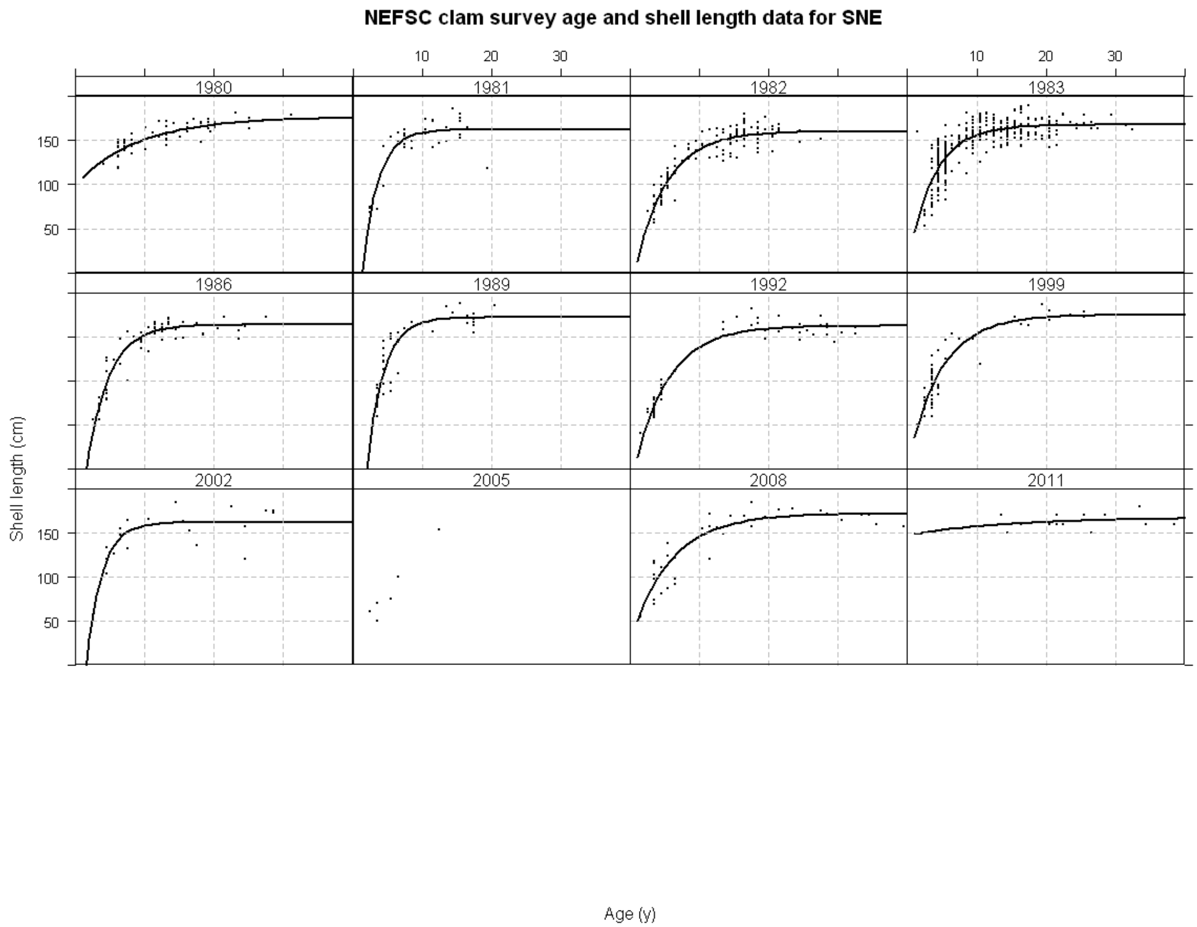


Figure A61. Age vs. length with fitted Von Bertalanffy growth curve for the SNE region in each survey year.

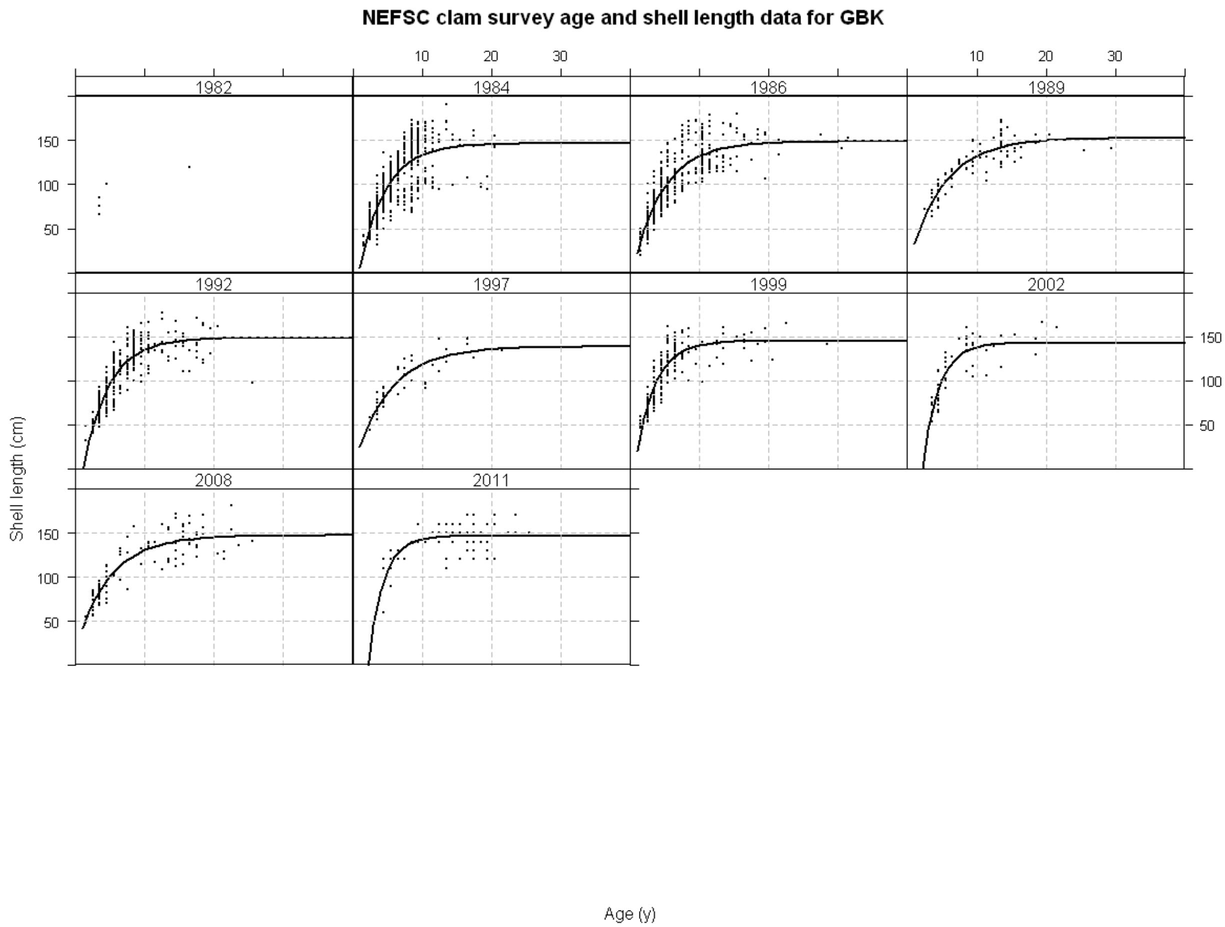


Figure A62. Age vs. length with fitted Von Bertalanffy growth curve for the GBK region in each survey year.

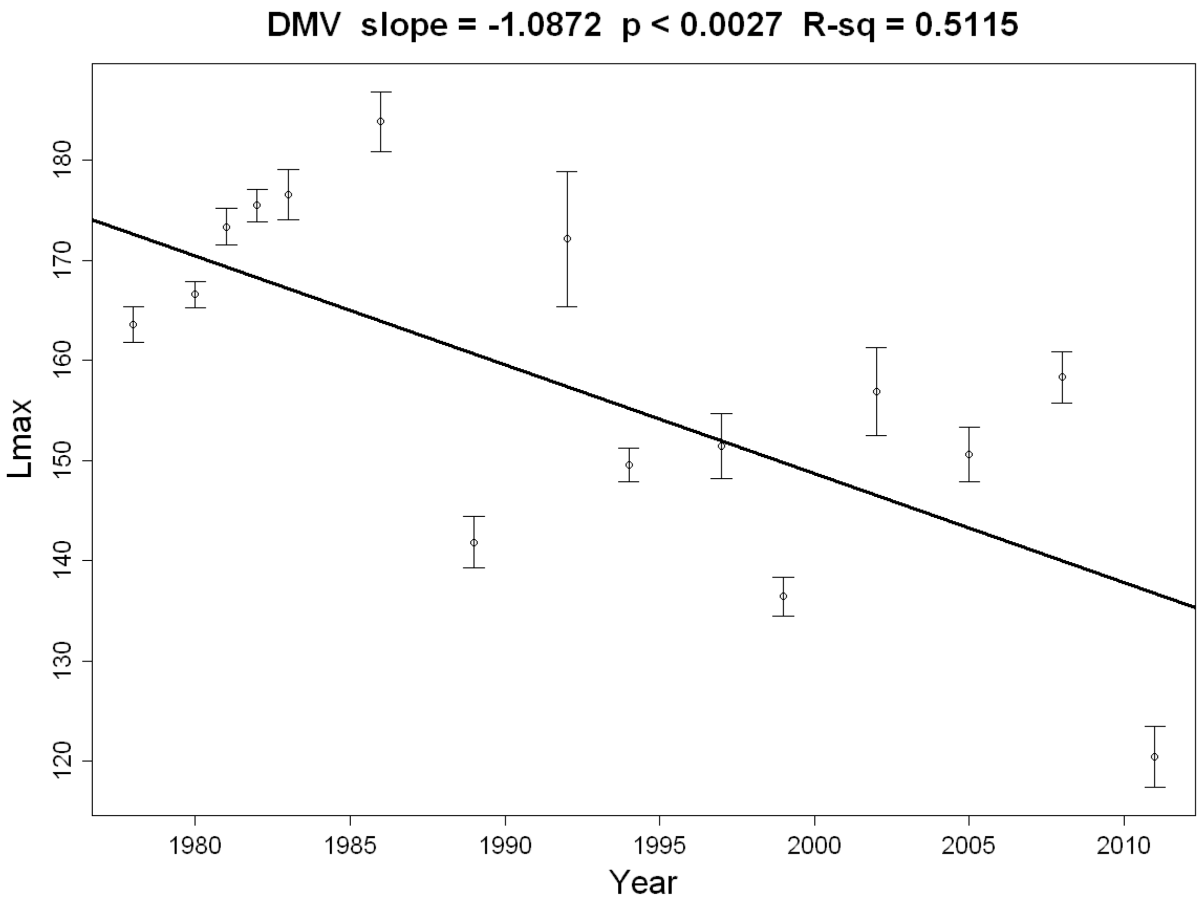


Figure A63. Weighted regression of estimated L_∞ in DMV over time.

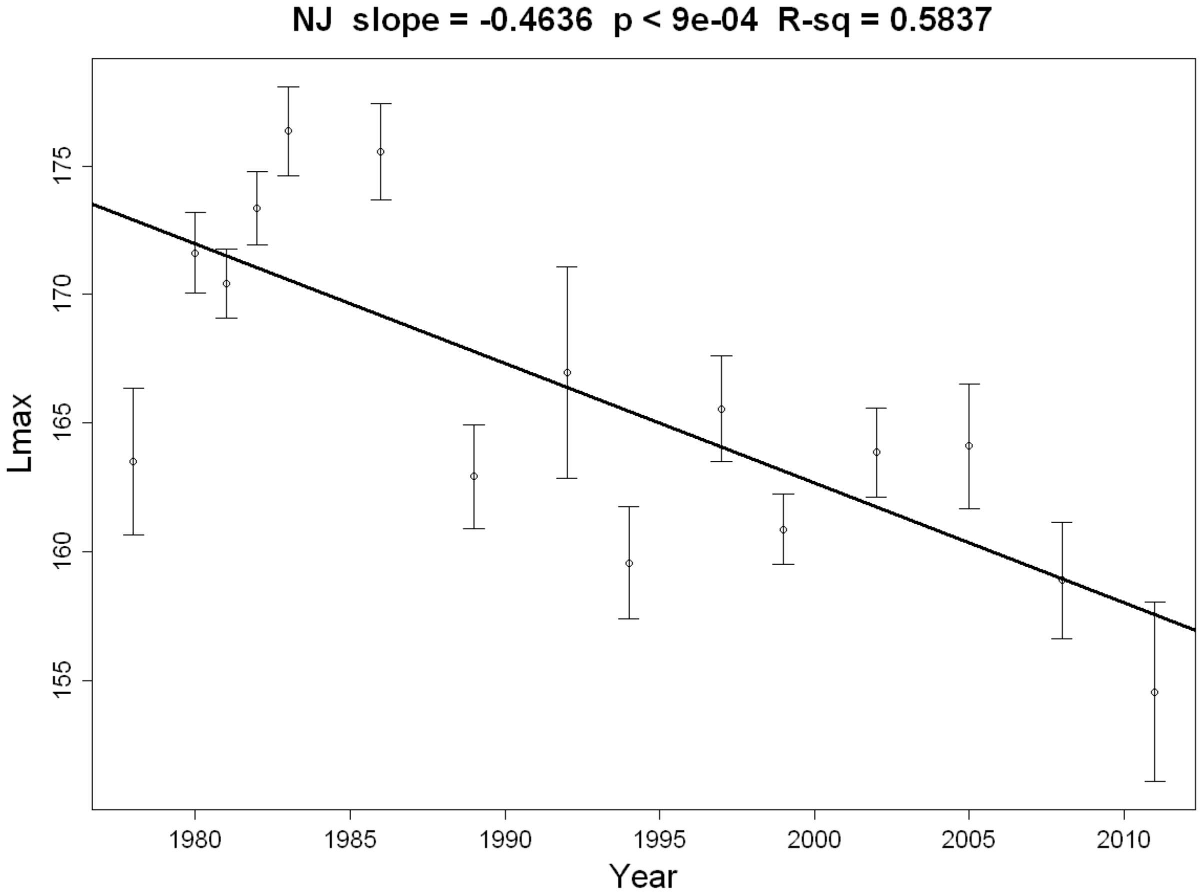


Figure A64. Weighted regression of L_∞ estimated in NJ over time.

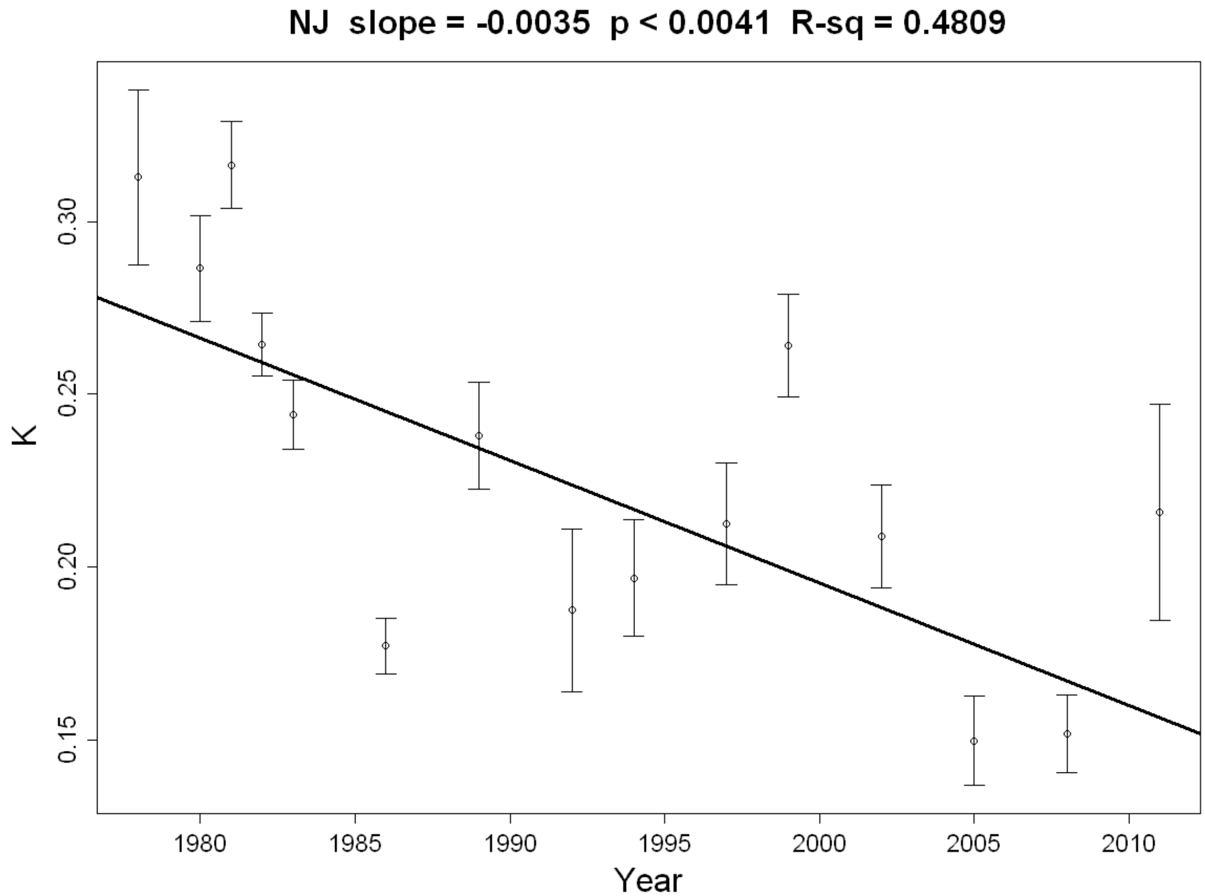


Figure A65. Weighted regression of *K* estimated in NJ over time.

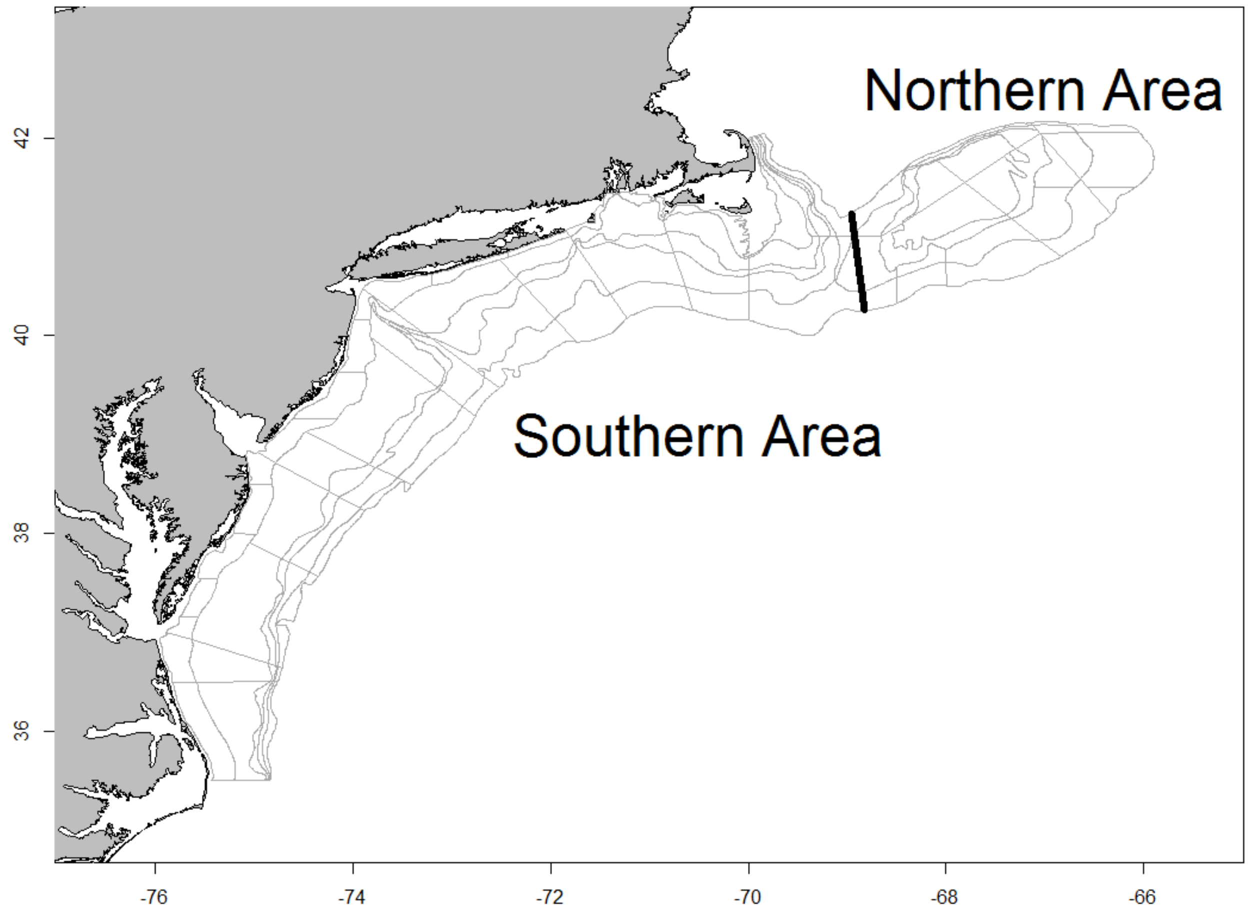


Figure A66. The proposed stock division. The northern area is GBK and the southern area is the remaining portion of the surfclam range in the US EEZ.

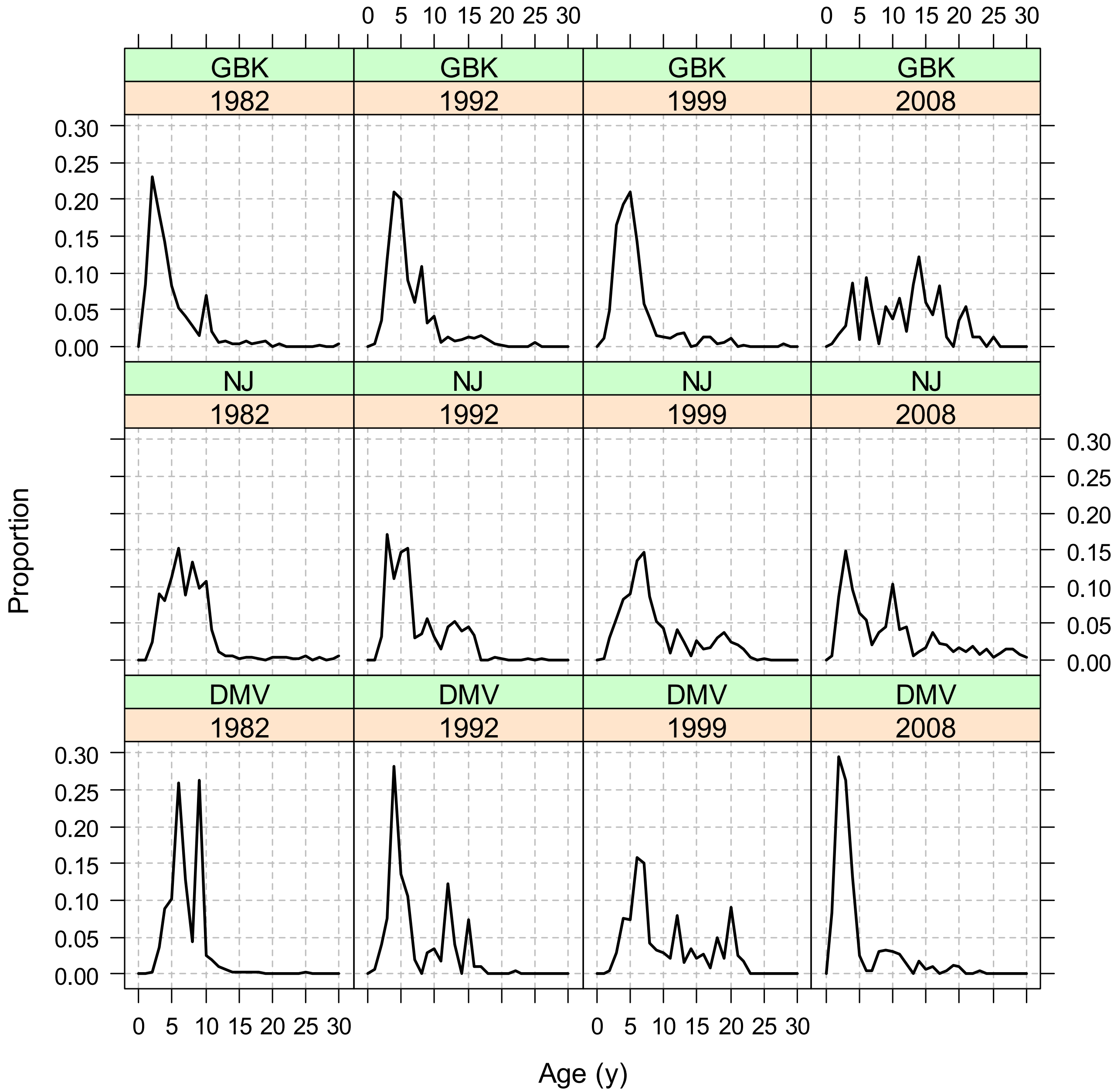


Figure A67. Survey age composition data for survey years and regions with at least 100 age samples. The first column, for example, shows the age composition of survey data for Georges Bank (GBK) in the north and New Jersey (NJ) and Delmarva (DMV) in the south during 1982.

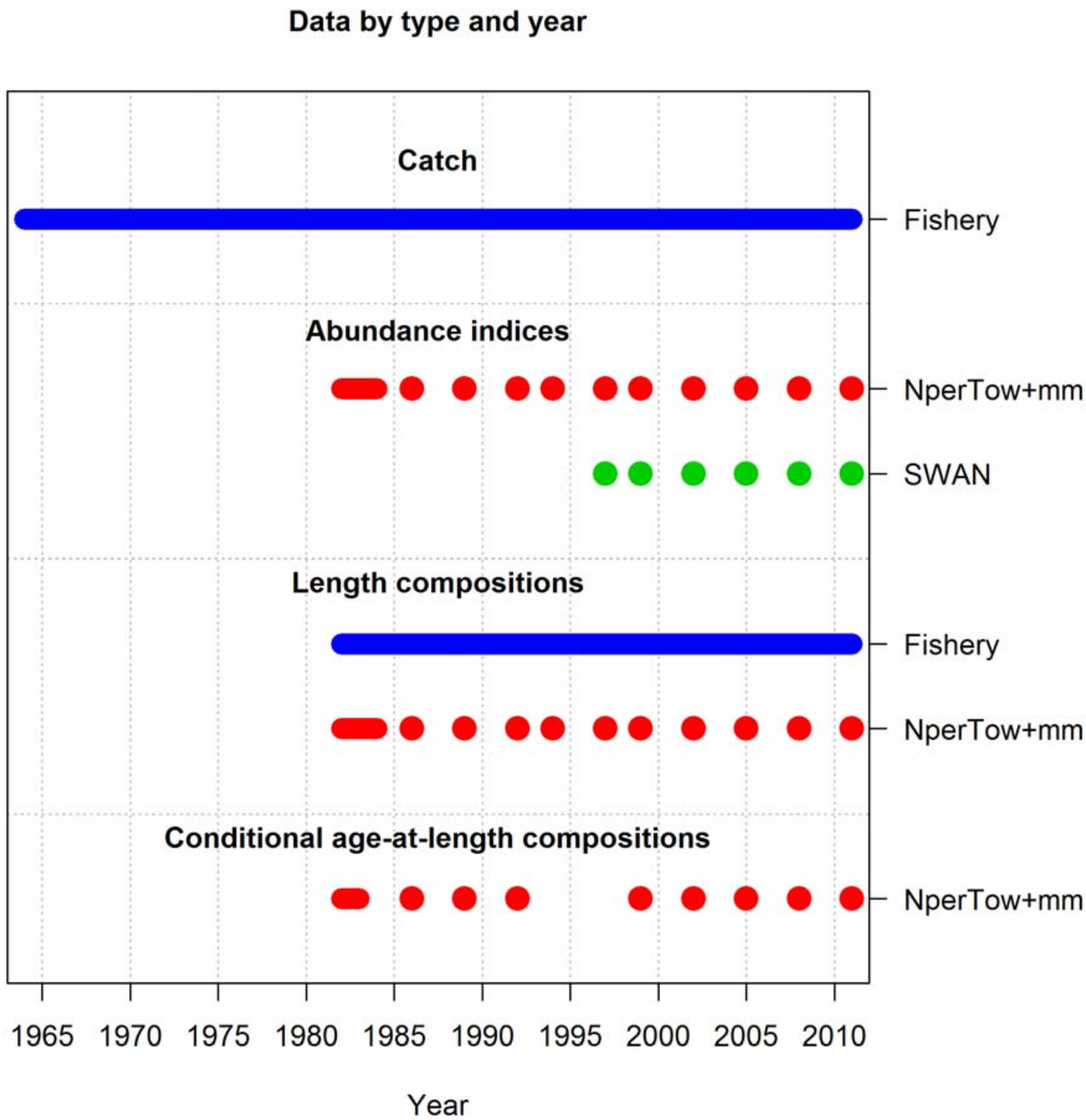


Figure A68. Data and availability by year in the SS3 model for surfclams in the southern area.

igure A69. Data and availability by year in the SS3 model for surfclams in the GBK area.

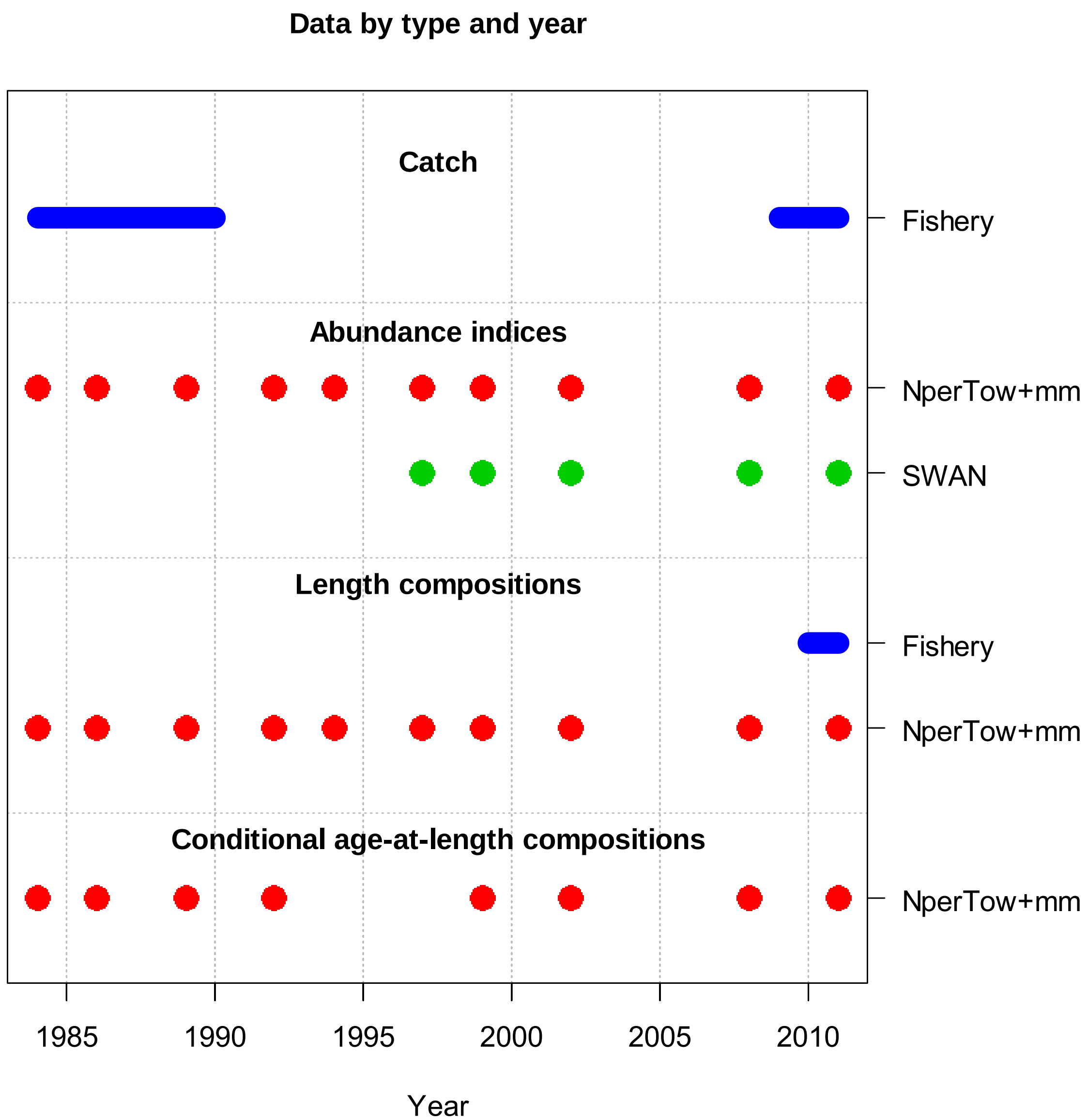


Figure A69. Data and availability by year in the SS3 model for surfclams in the GBK area.

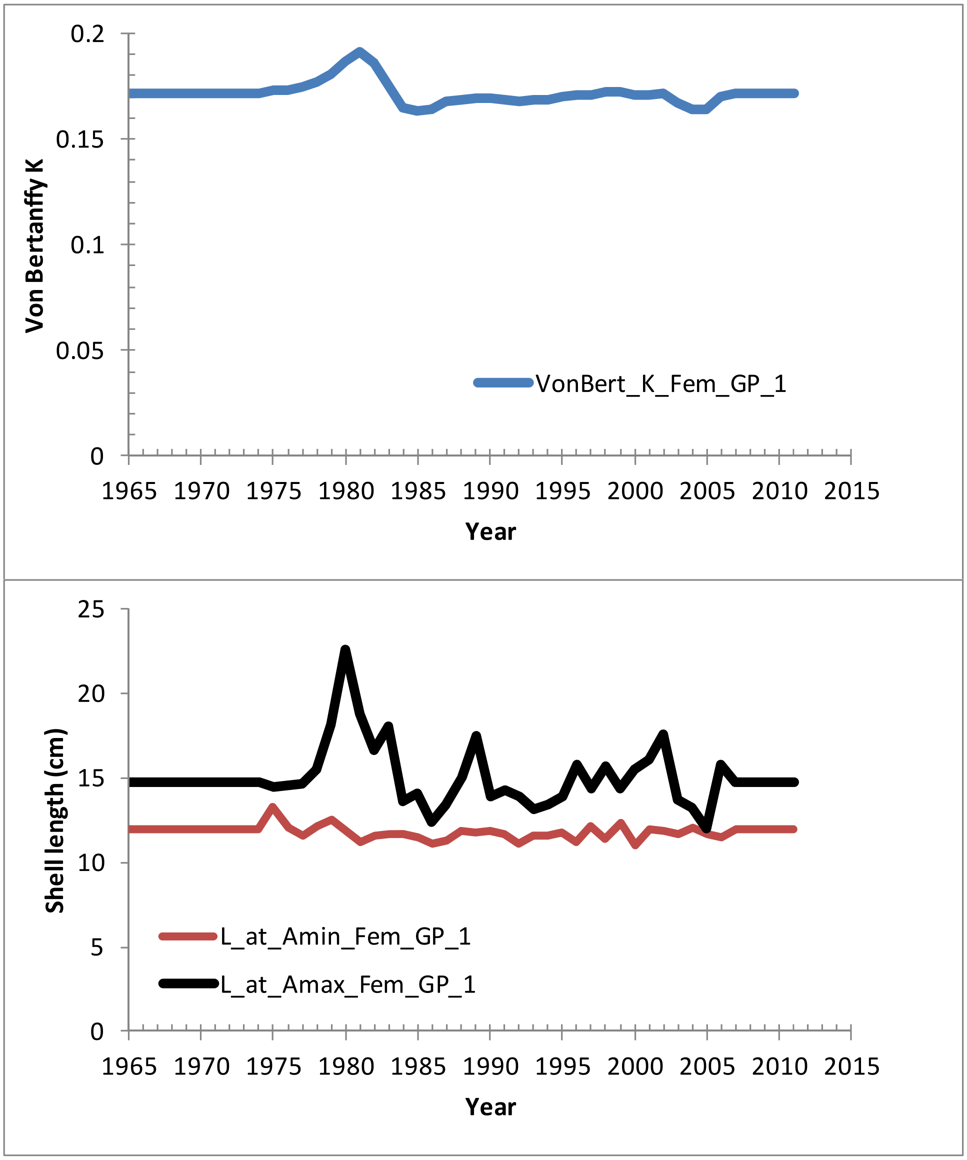


Figure A70. Results of sensitivity analyses in which growth parameters for surfclams in the southern area were estimated as random walks.

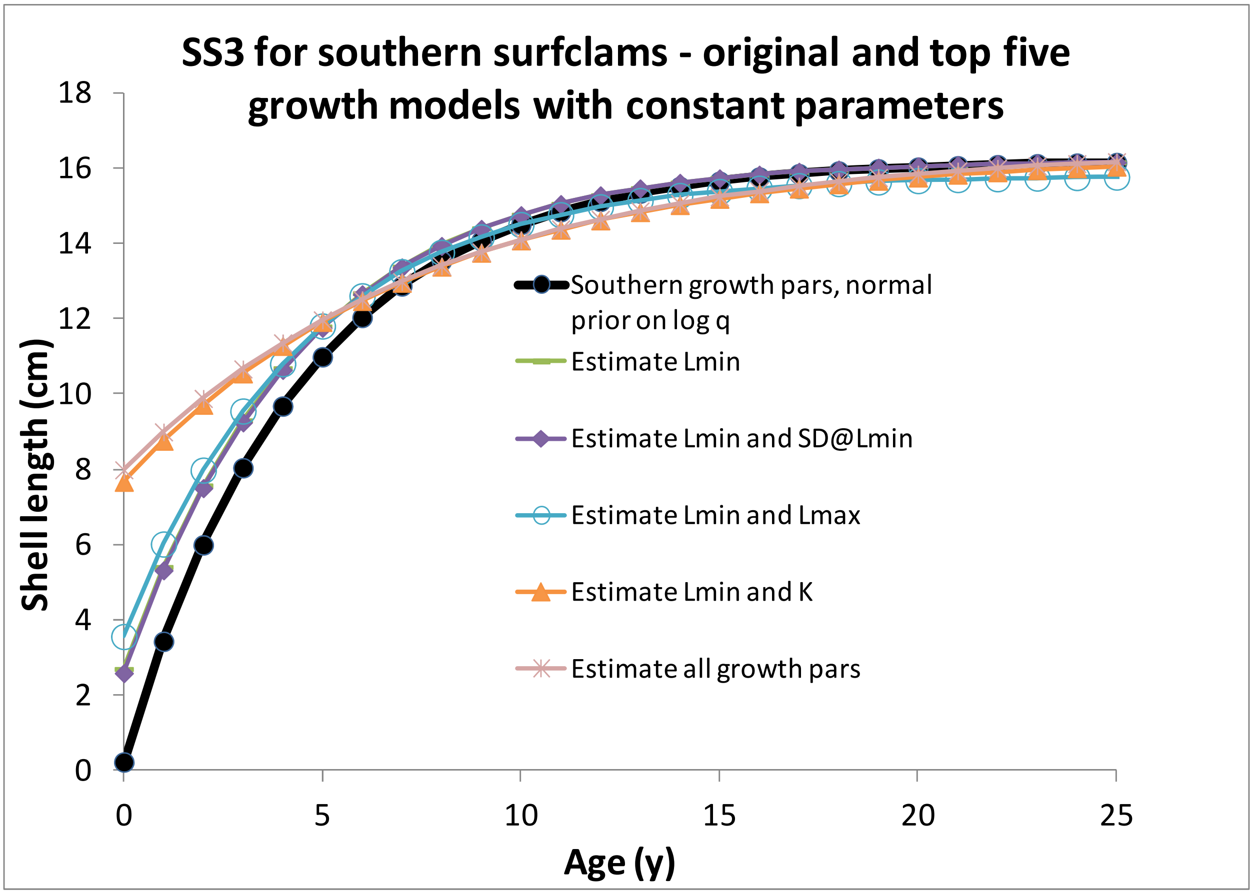


Figure A71. Growth curves estimated in preliminary SS3 model runs for surfclams in the south. The first curve listed in the legend is from external (initial) estimates of all growth parameter values that were fixed in SS3. The rest of the curves listed in the legend from top to bottom gave the best fit (lowest NLL) for the entire model and are listed in order of improving goodness of fit (decreasing NLL). The preferred growth model configuration was "Estimate Lmin and Lmax" (light blue line with open circle). In SS3, with Amin=4, growth at ages 0-4 is approximated by a linear term through zero so that the important of differences on the far left hand side are minimized.

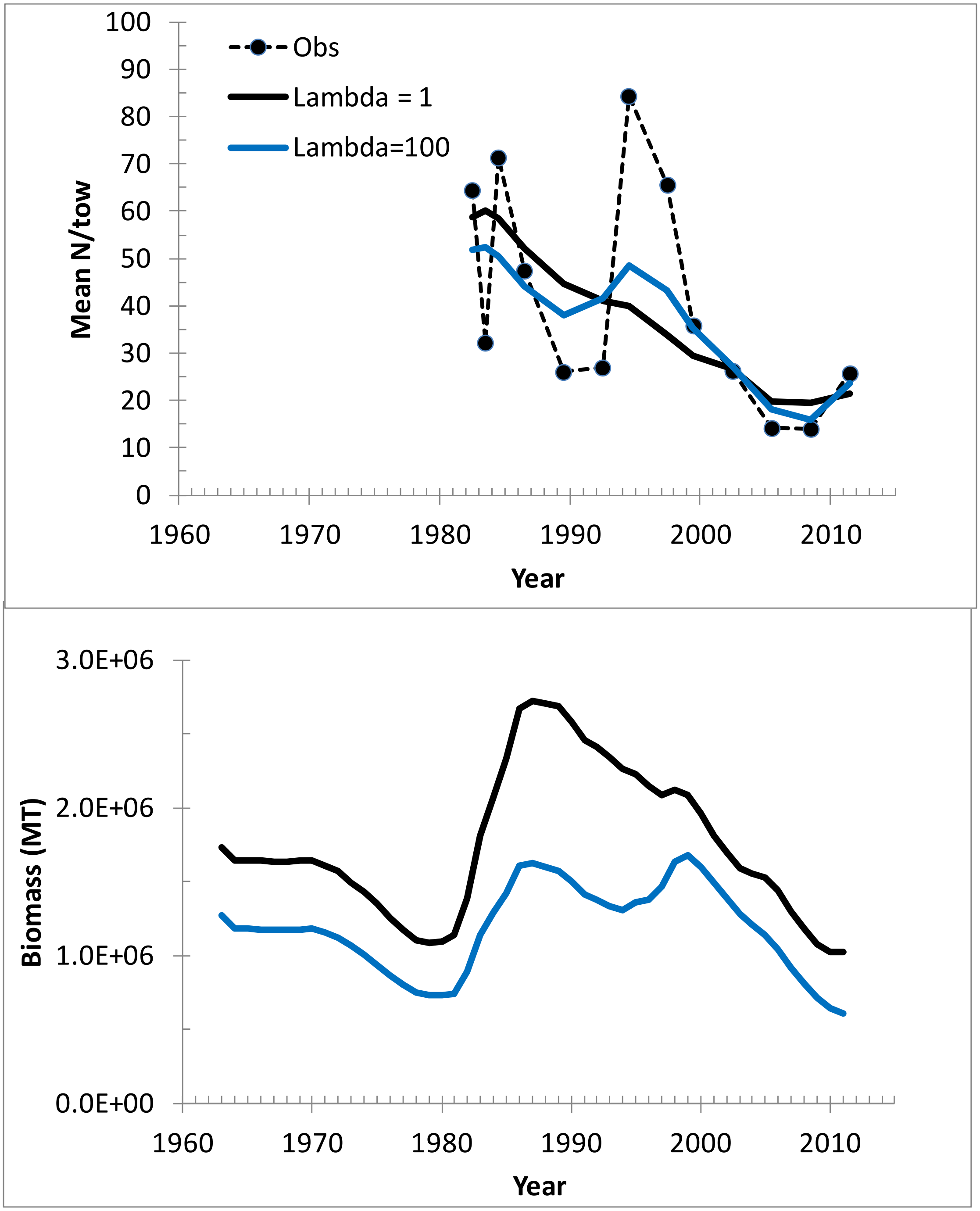


Figure A72. Observed survey data, predicted survey values and biomass estimates from two preliminary SS3 models with likelihood weights for survey trends lambda=1 and lambda=100.

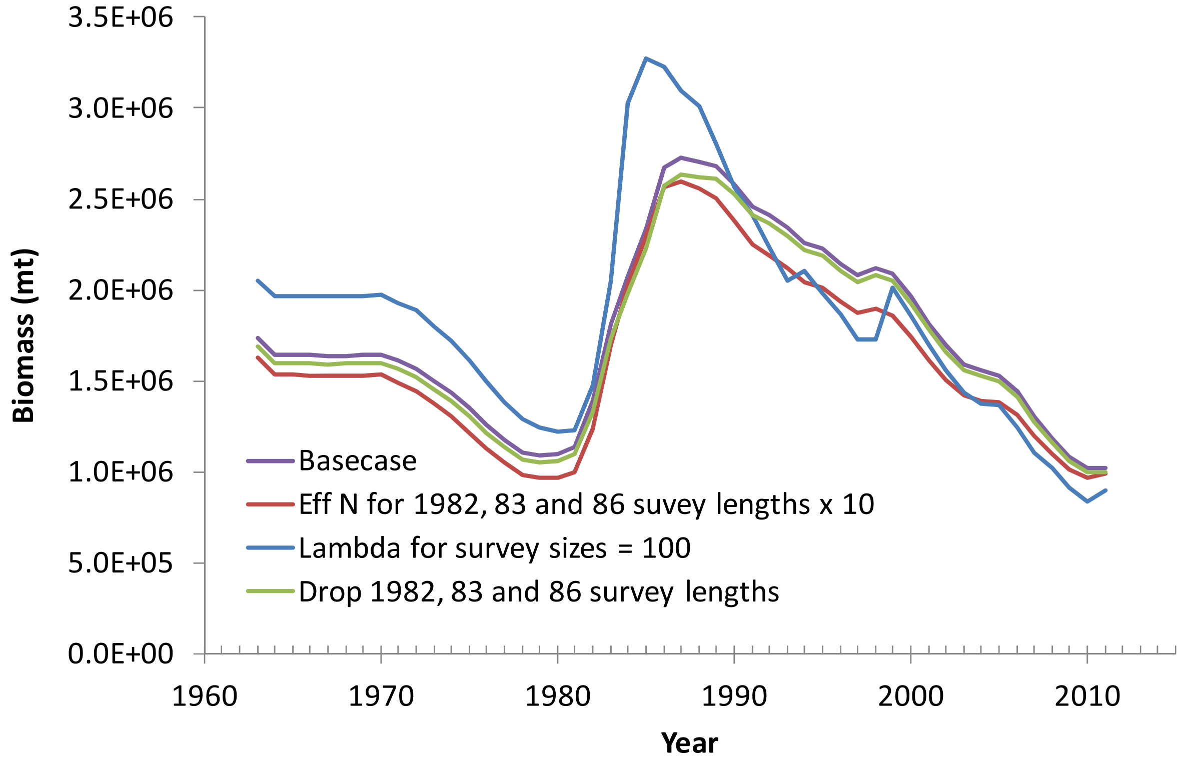


Figure A73. Biomass estimates from sensitivity analyses using a preliminary SS3 model for surfclams in the southern area to address lack of fit to survey size data for 1982, 1983 and 1986.

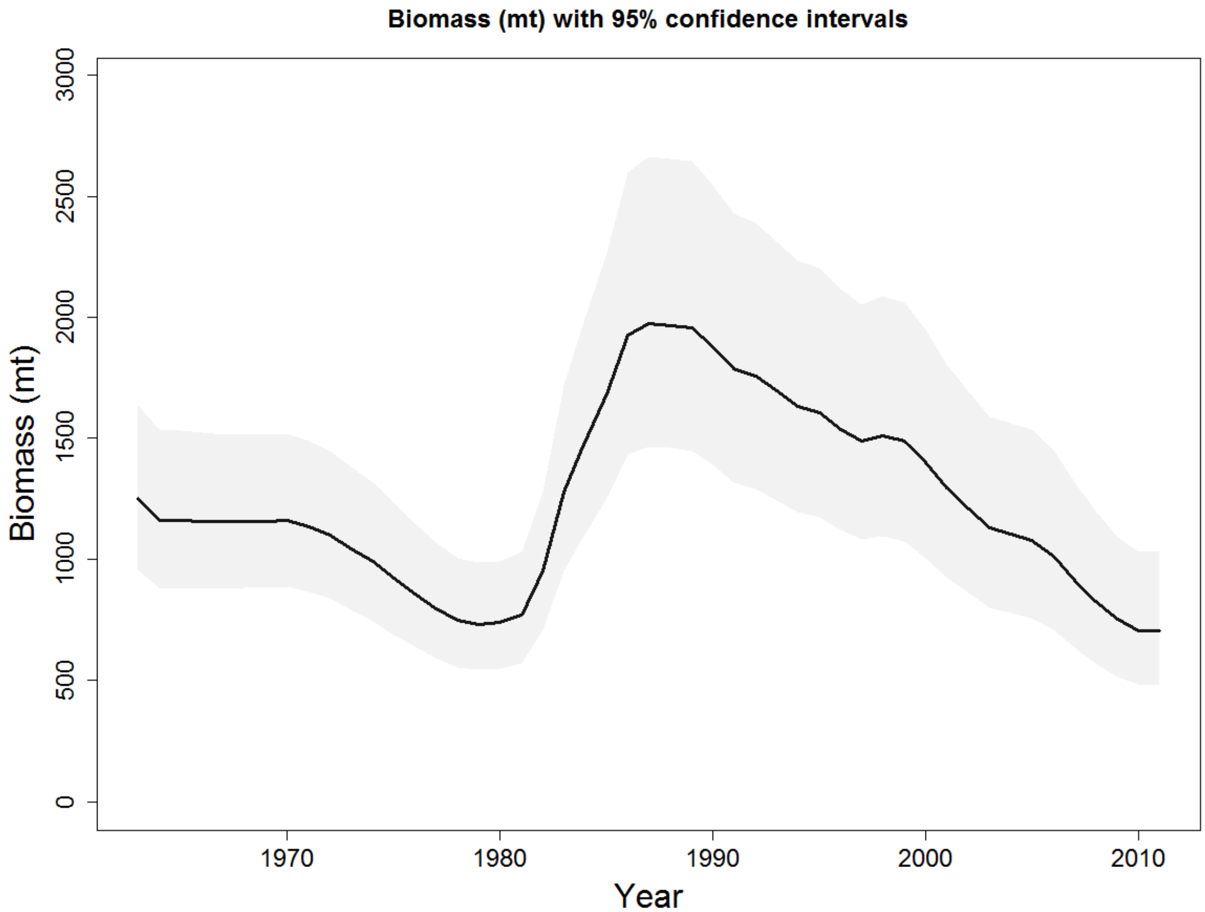


Figure A74. Biomass estimates for surfclams in the southern area from SS3, with 95% confidence intervals.

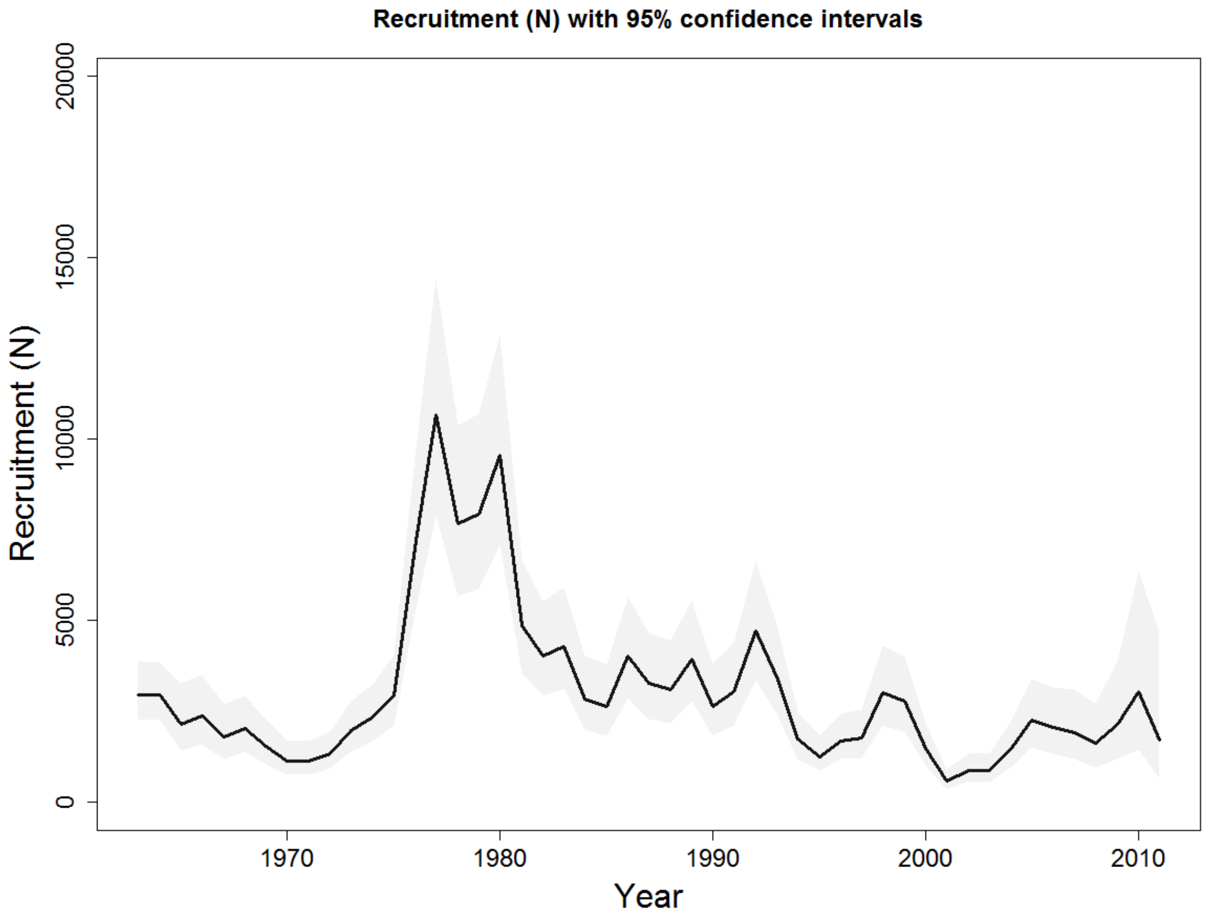


Figure A75. Recruitment estimates (thousands, age 0) for surfclams in the southern area from SS3, with 95% confidence intervals.

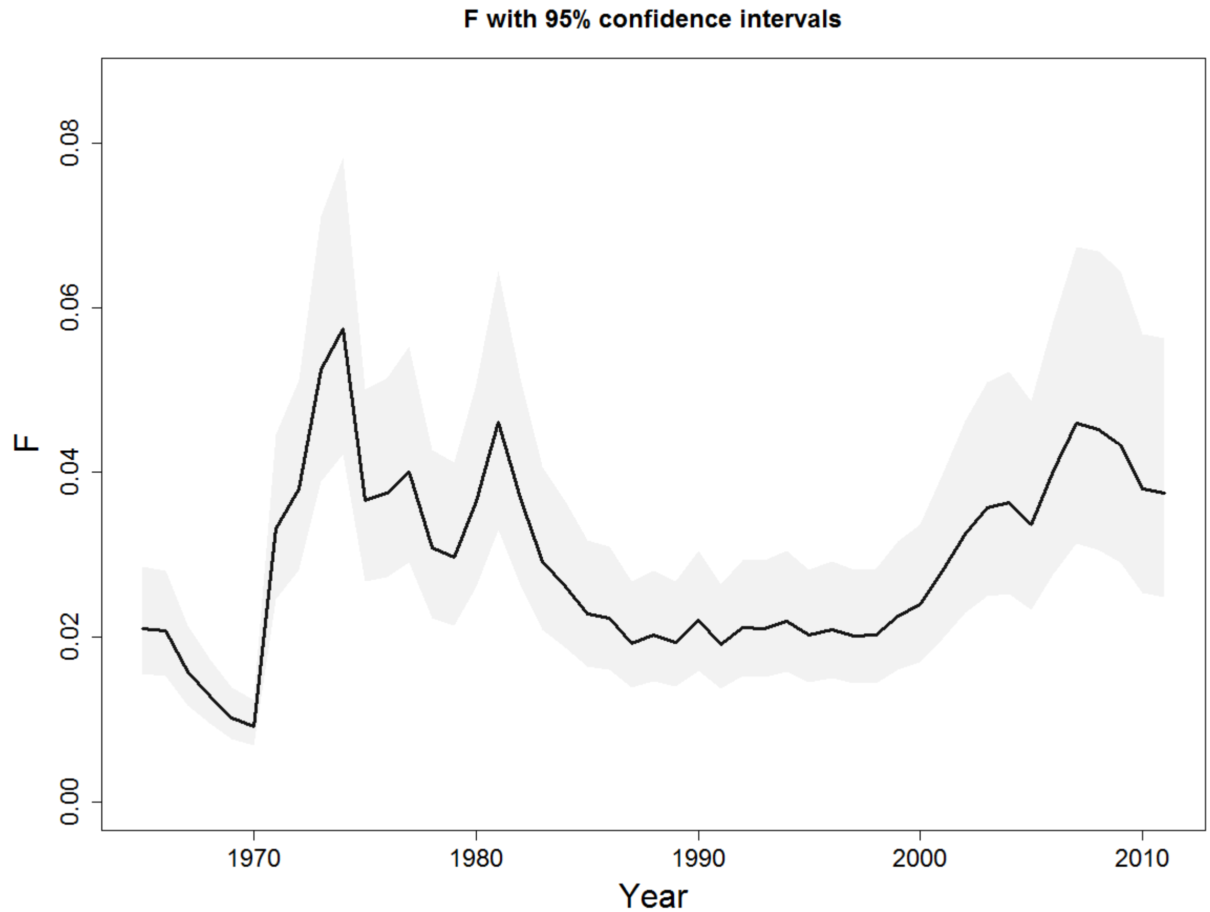


Figure A76. Fully recruited fishing mortality estimates for surfclams in the southern area from SS3, with 95% confidence intervals.

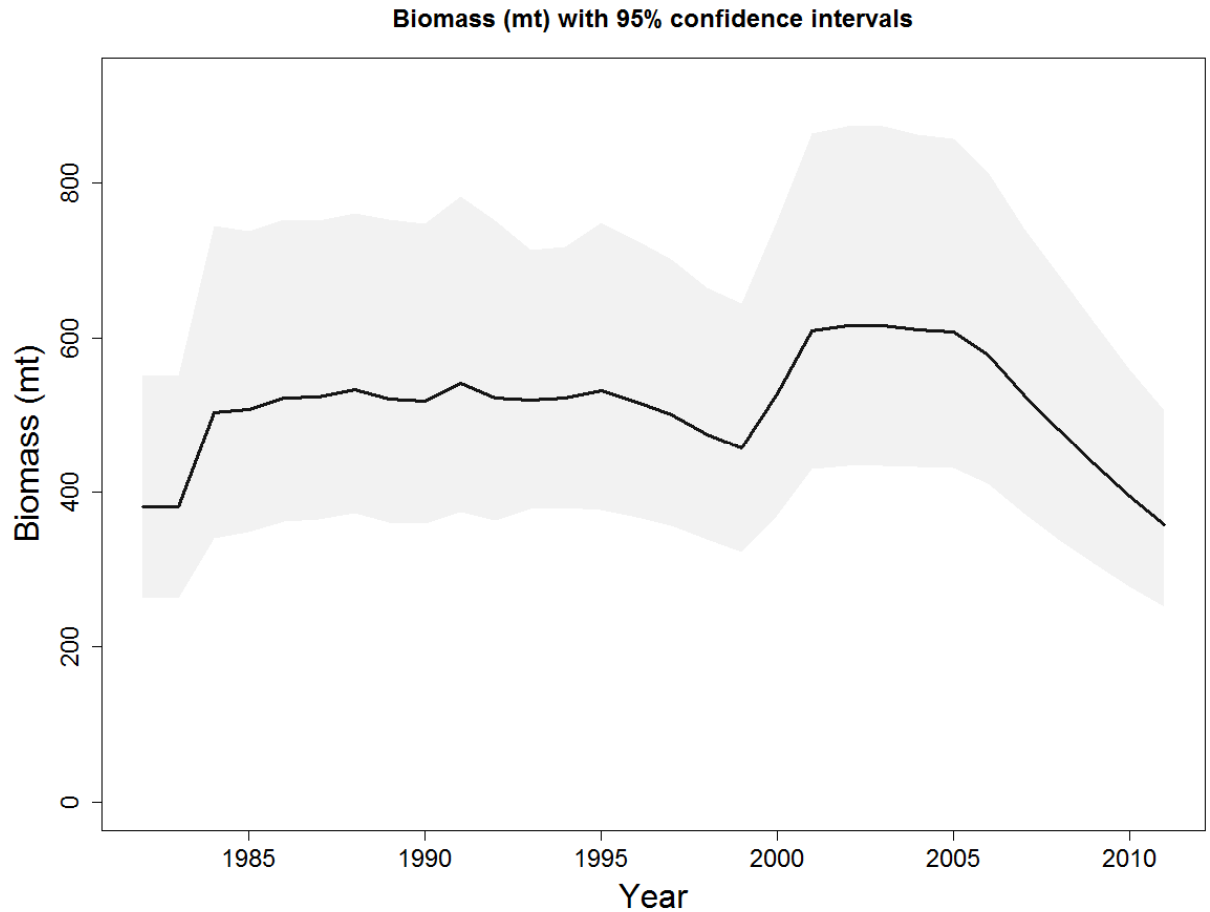


Figure A77. Biomass estimates for surfclams in the GBK area from SS3, with 95% confidence intervals.

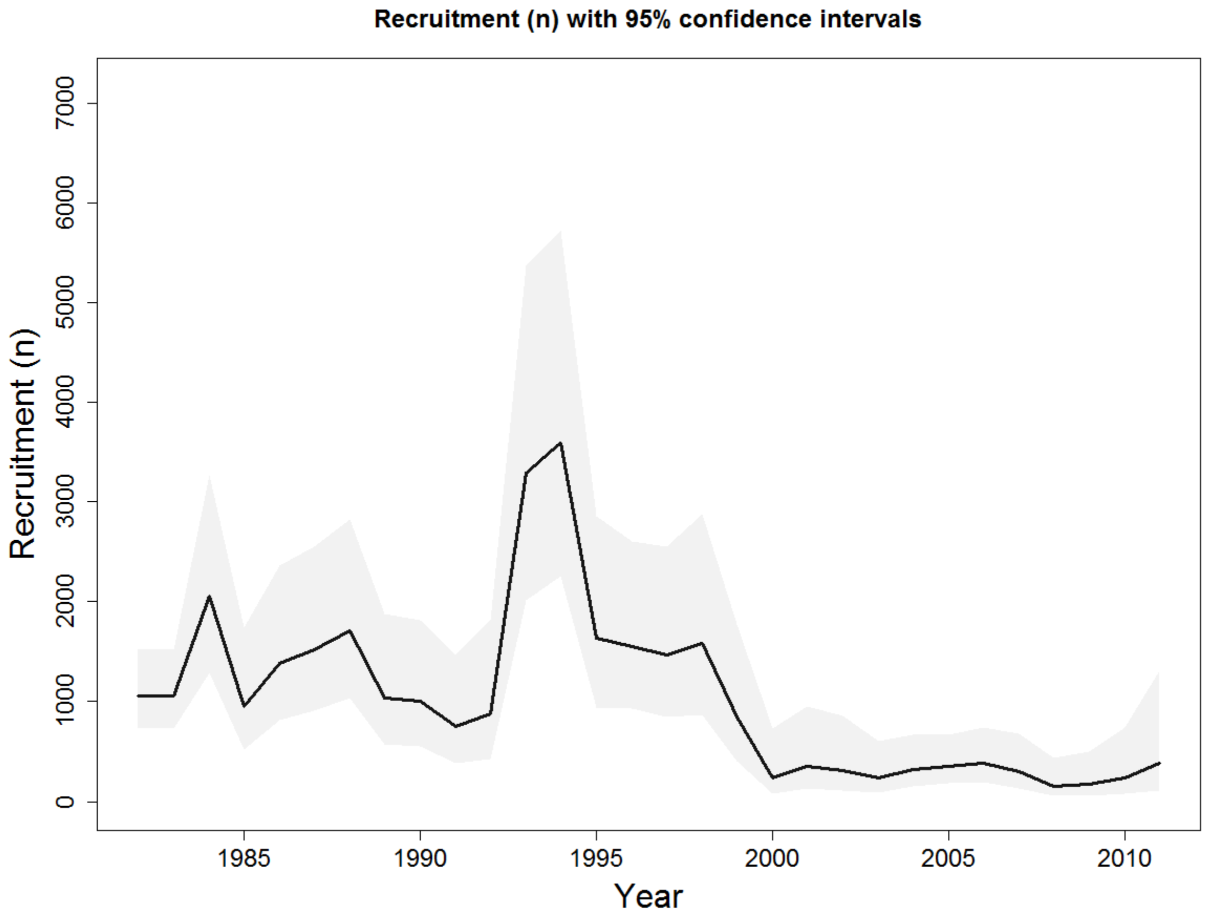


Figure A78. Recruitment estimates (thousands, age 0) from the northern area from SS3, with 95% asymptotic confidence intervals.

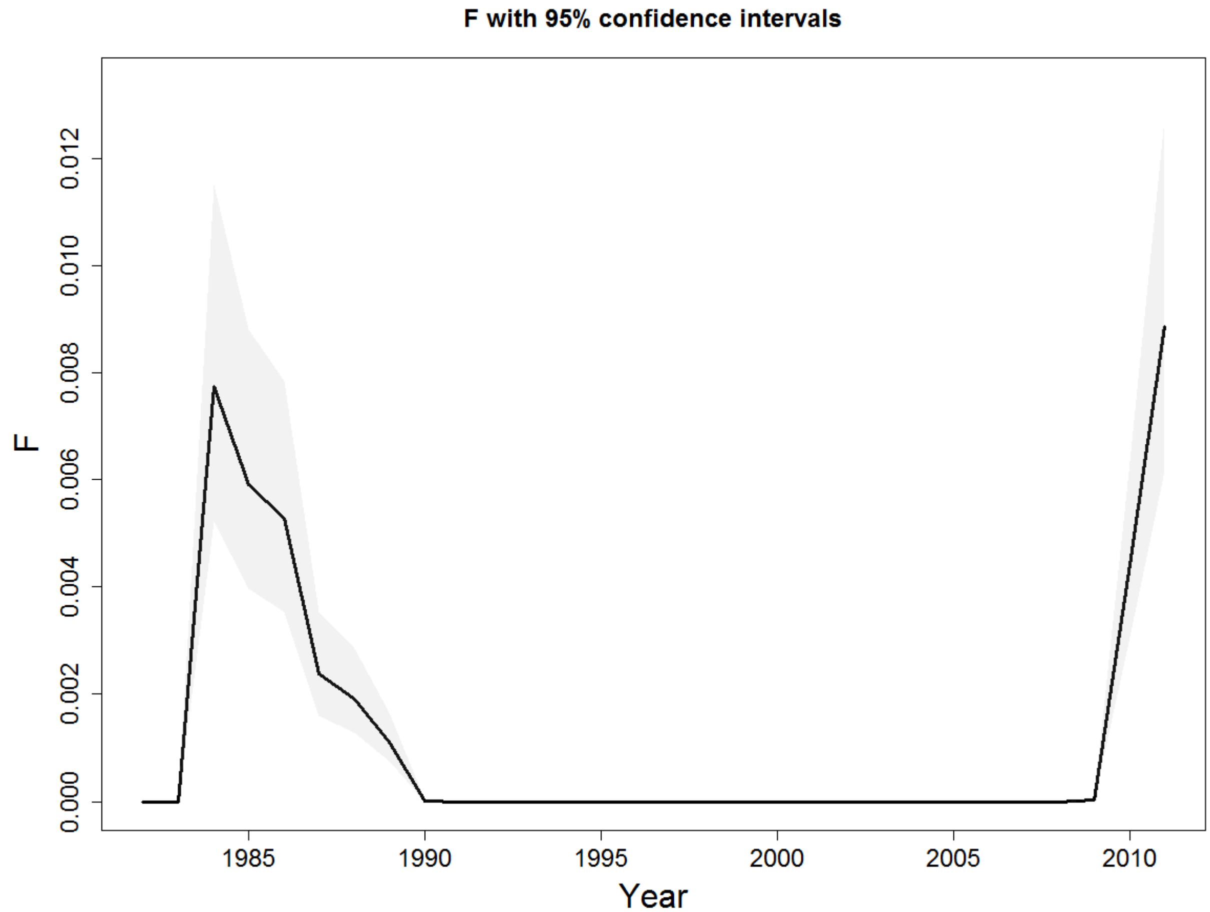


Figure A79. Fully recruited fishing mortality estimates from the GBK area, with 95% confidence intervals.

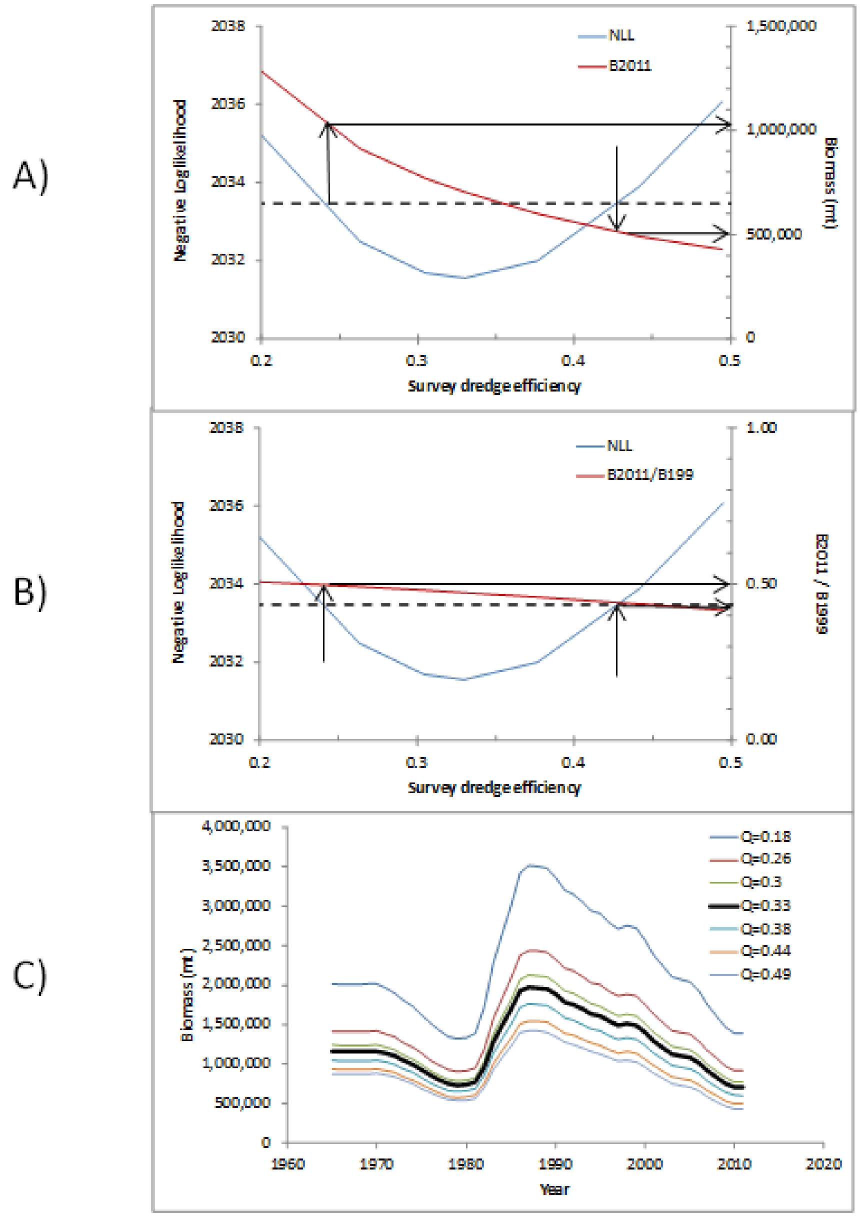


Figure A80. Likelihood profile analysis for survey dredge efficiency, 2011 biomass and the biomass status ratio (B_{2011}/B_{1999}) using the basecase SS3 model for surfclams in the southern area. The dashed line in panels A) and B) can be used to find bounds for approximate 95% confidence intervals. In particular, if two vertical lines are drawn through the intersection of the dashed black and blue likelihood lines, then the confidence interval bounds for dredge efficiency are found where the vertical lines intersect the x-axis and where the vertical lines intersect the red lines for biomass (A) and status ratio (B). Panel C) shows the effect on estimated biomass trend of fixing survey dredge efficiency at values between Q=0.18 and 0.49.

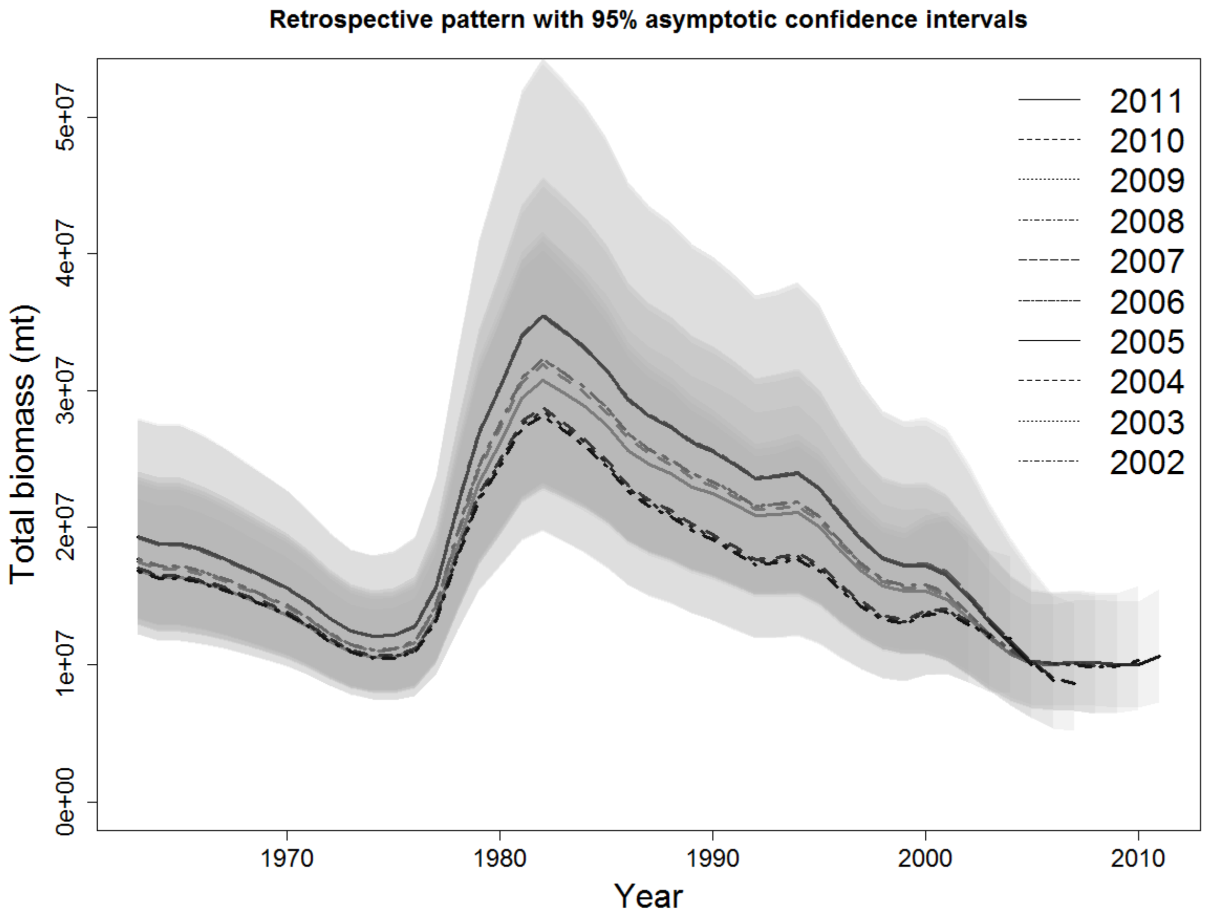


Figure A81. Internal retrospective pattern for biomass (ages 6+ y) from the southern area SS3 model. Mohn's ρ = 0.02 (9 year peel).

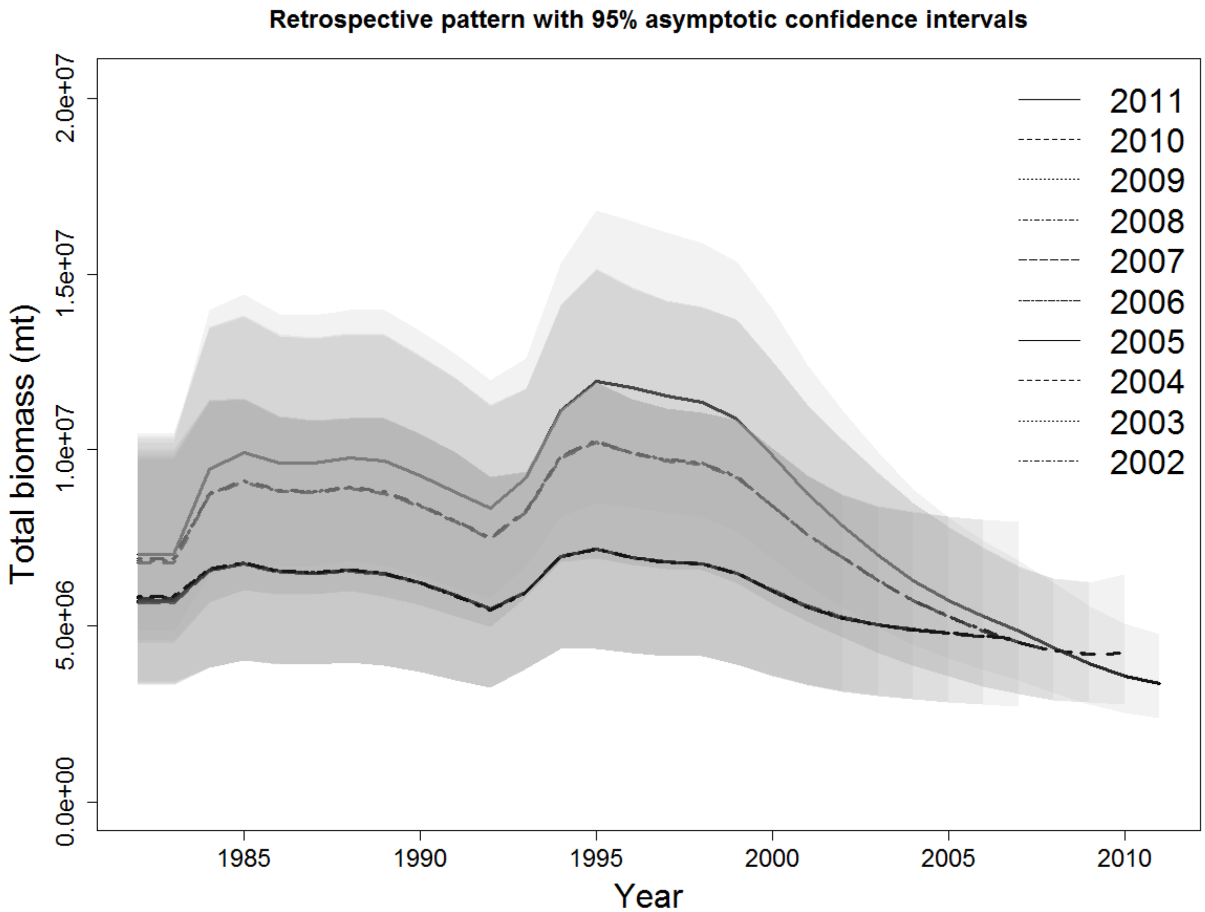


Figure A82. Internal retrospective pattern based on total biomass (ages 7+ y) from the GBK SS3 model. Mohn's $\rho = 0.30$ (9 year peel).

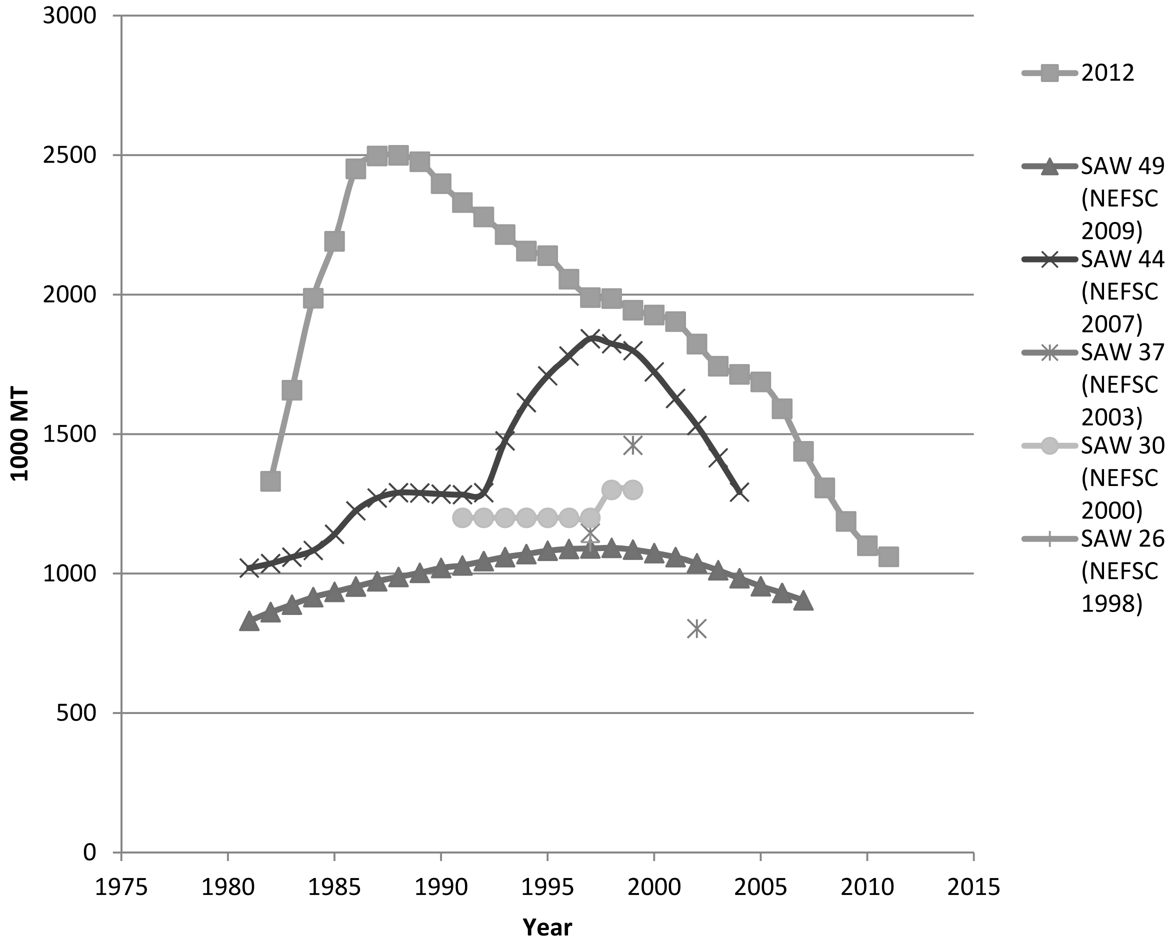


Figure A83. Historical retrospective comparing the biomass estimates for surfclams in the southern + GBK area from previous surfclam assessments.

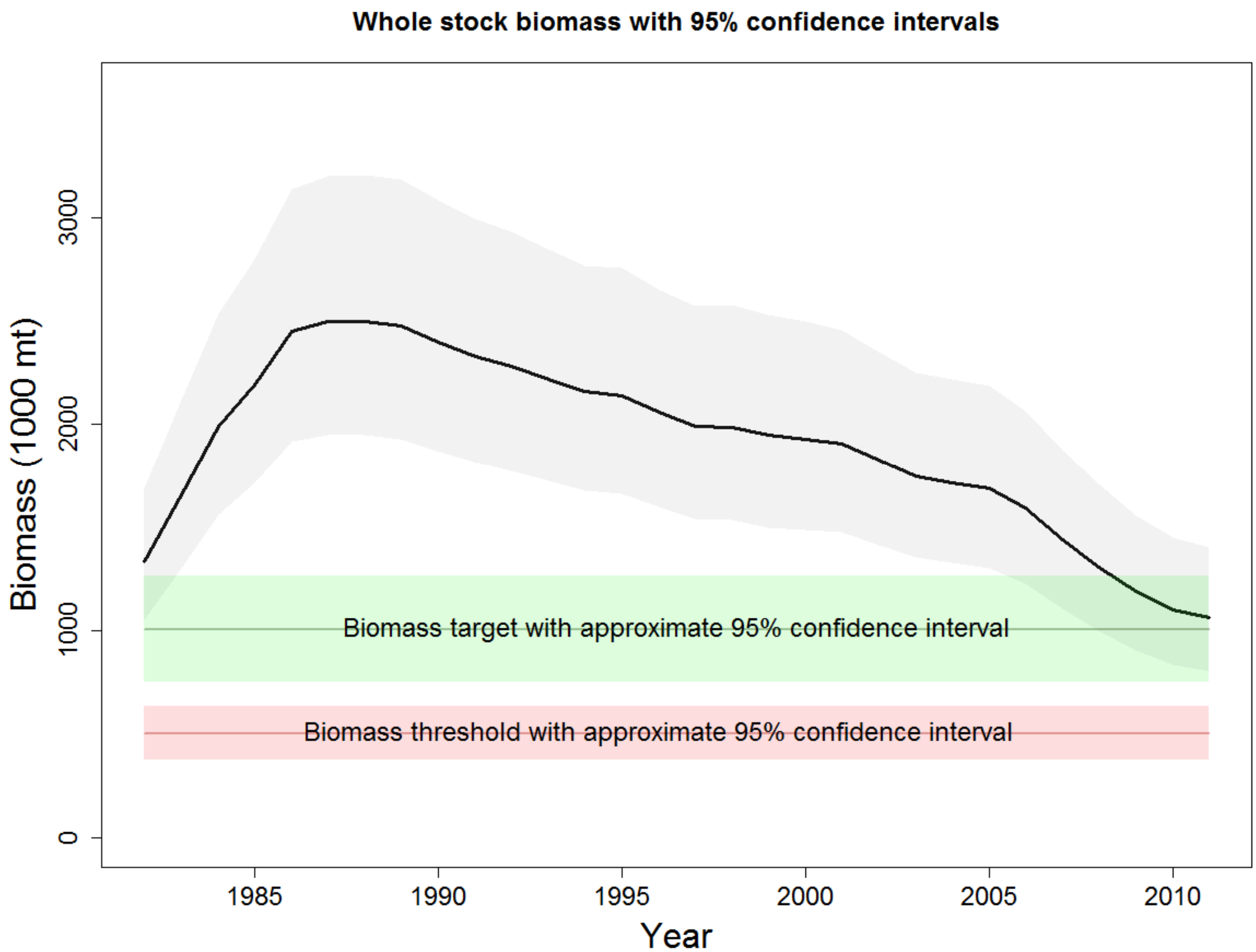


Figure A84. Whole stock biomass status estimates with cv and approximate 95% confidence intervals.

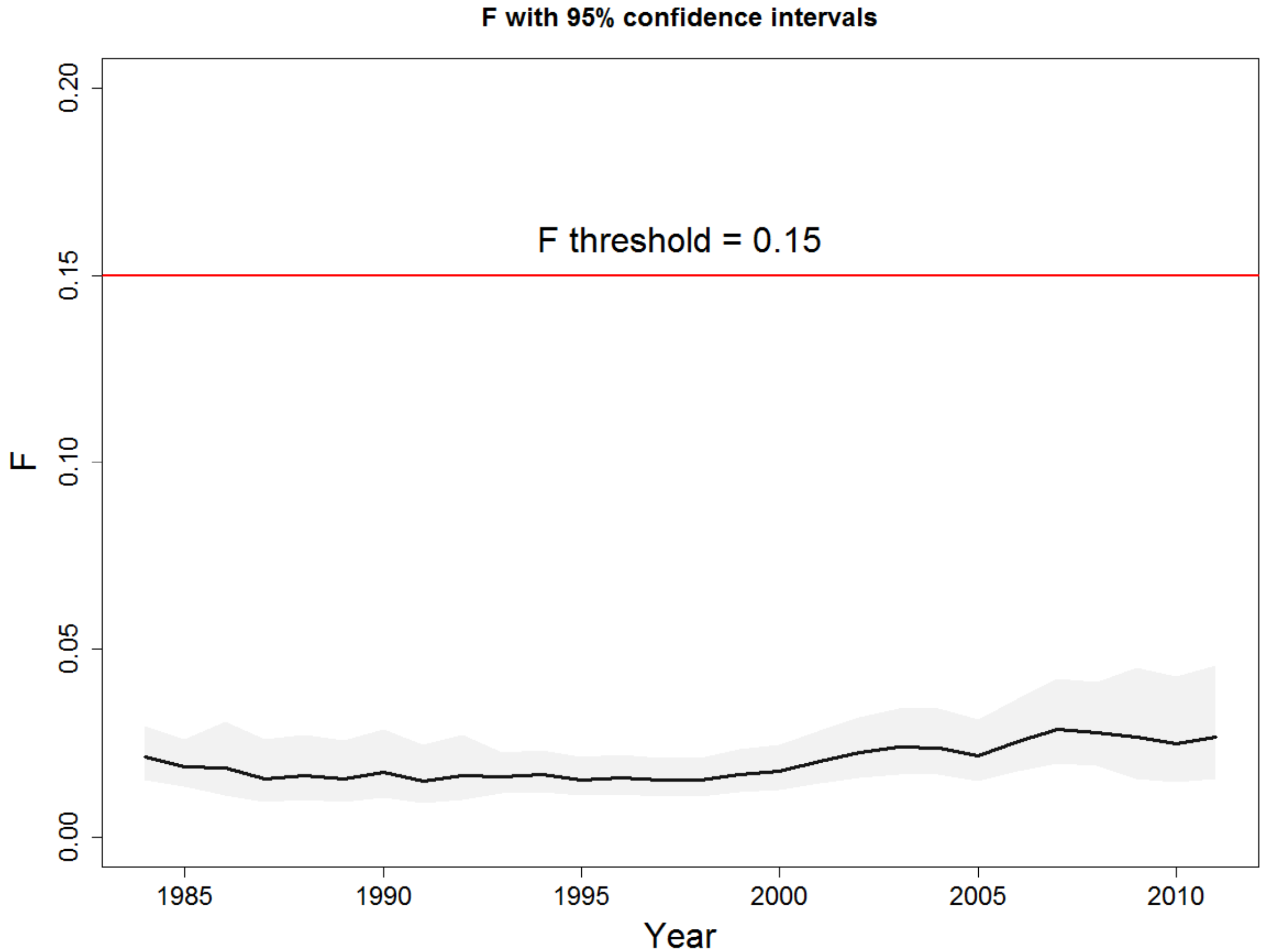


Figure A85. Whole stock F status estimates with cv and approximate 95% confidence intervals.

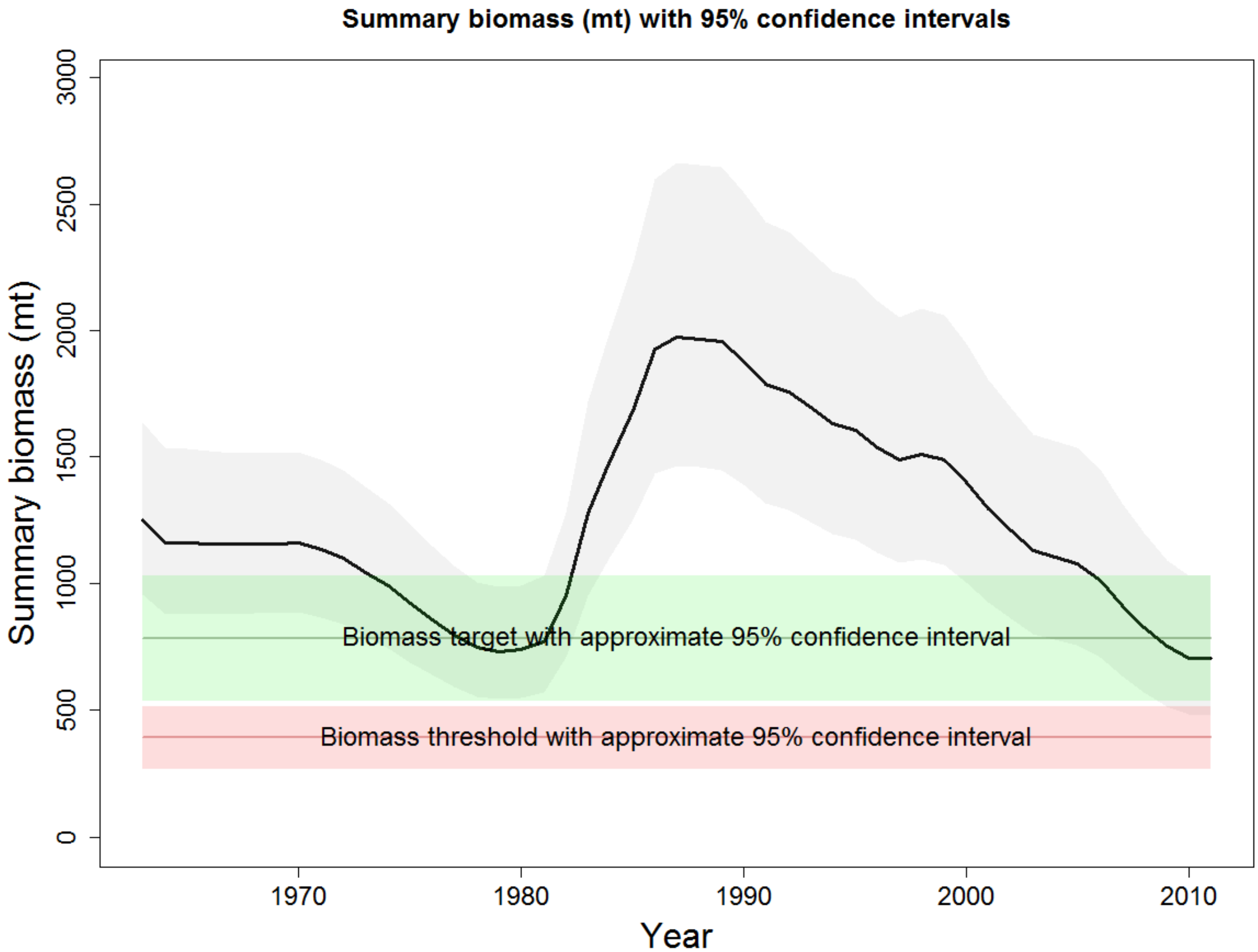


Figure A86. Southern area biomass status estimates with cv and approximate 95% confidence intervals.

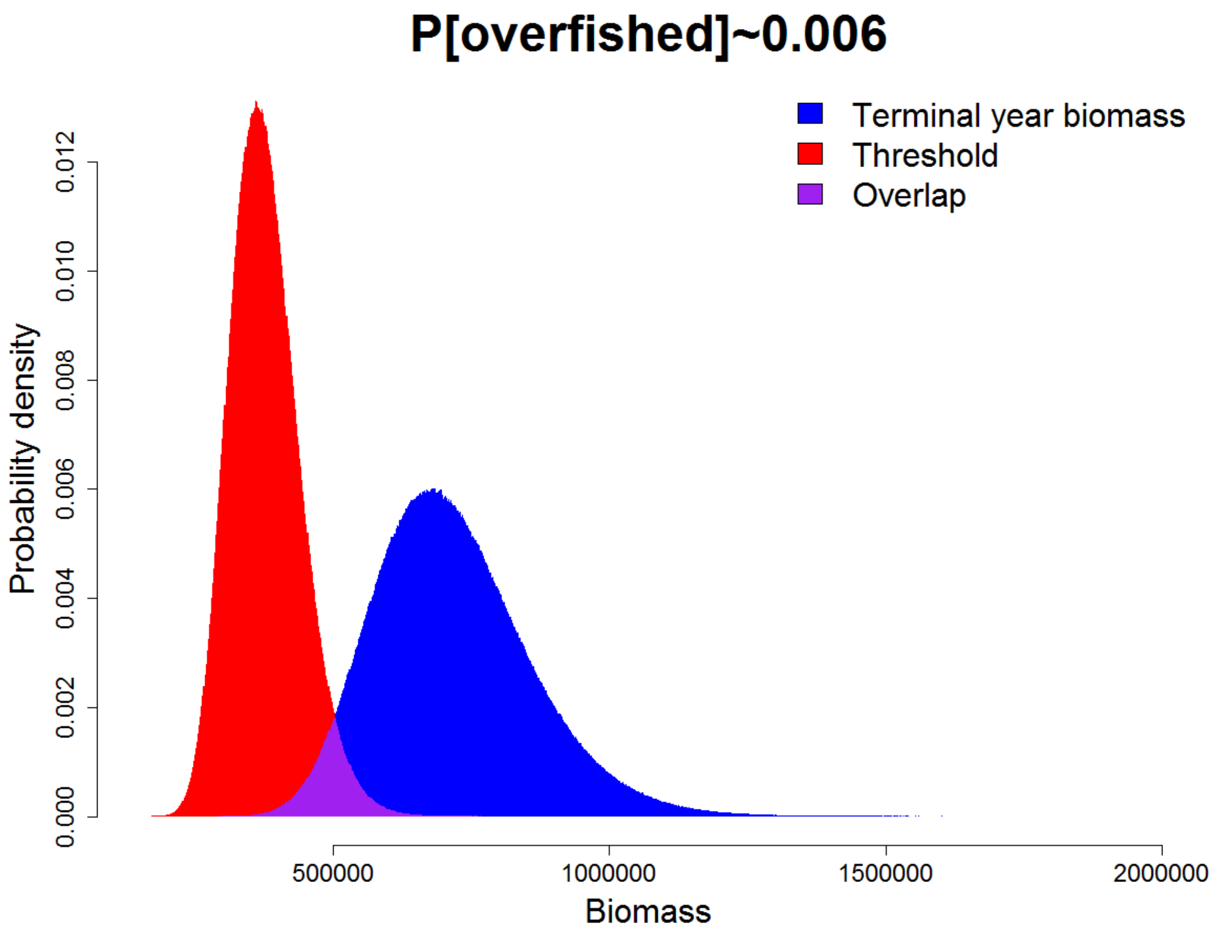


Figure A87. The distributions for B_{2011}~LogN(6.55,0.194) and $B_{THRESHOLD}$~LogN(5.92,0.167). The probability of being overfished is based on the methods of Shertzer et al. (2008).

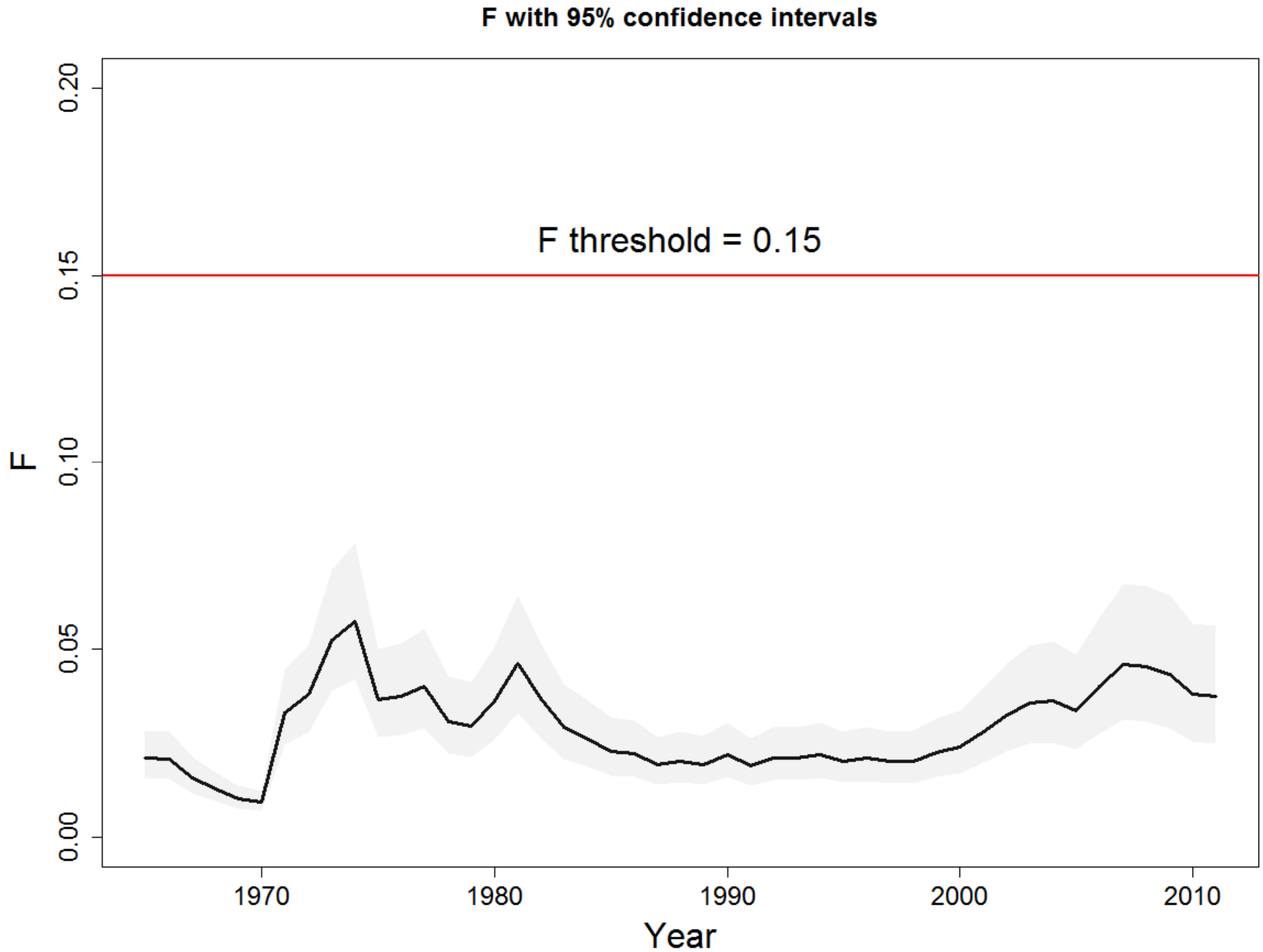


Figure A88. Southern area F status estimates with cv and approximate 95% confidence intervals.

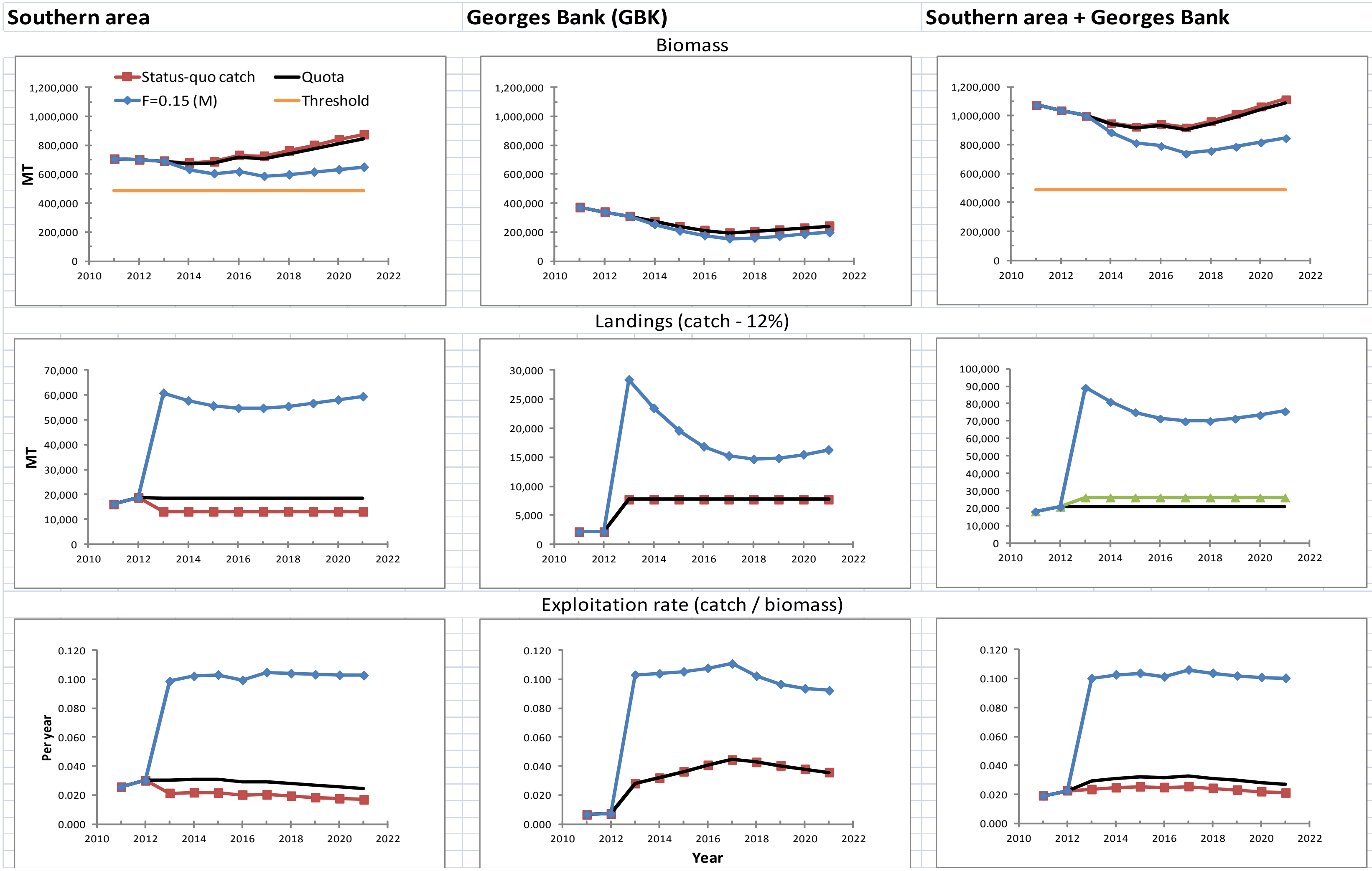


Figure A89. Projected biomass, landings and exploitation rates during 2012-2021 for surfclams in the southern, GBK and combined areas.

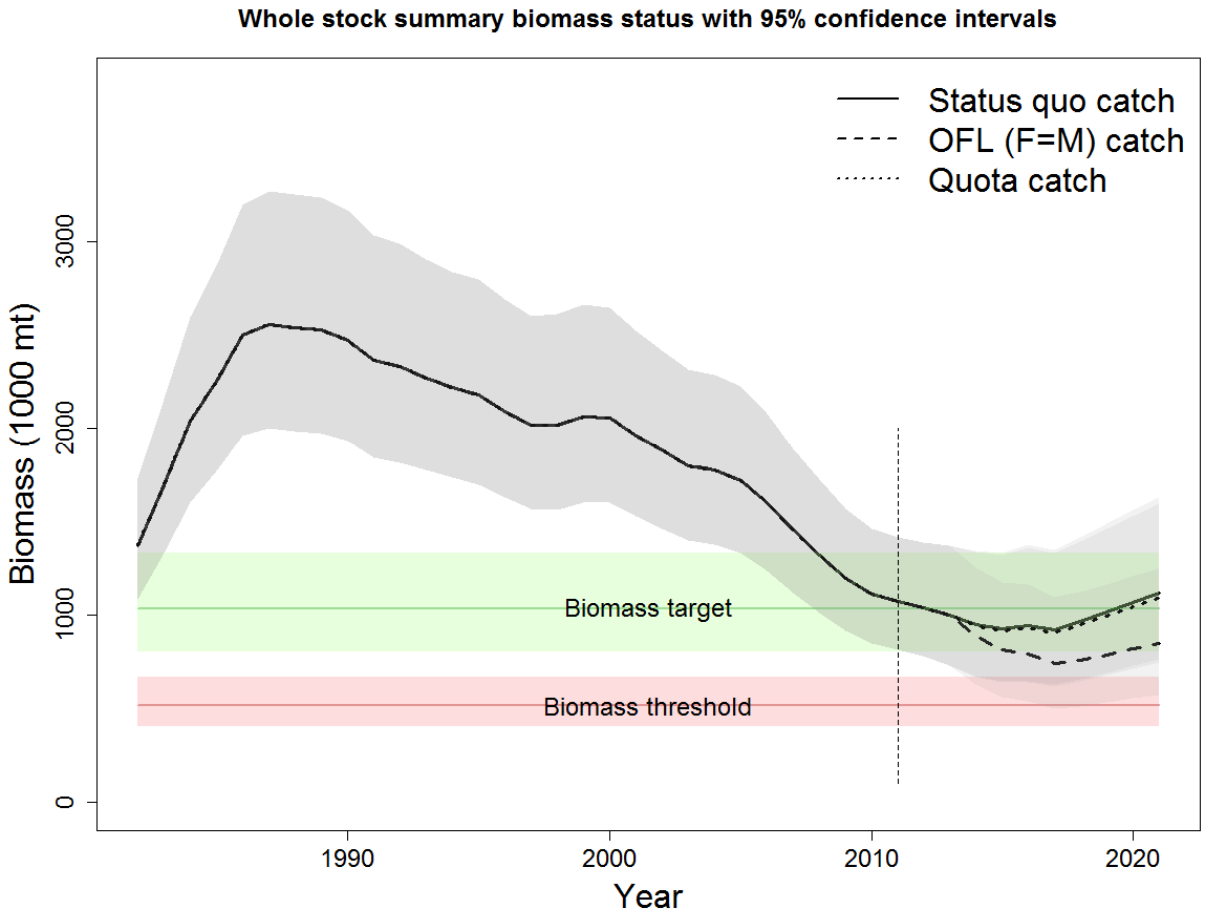


Figure A90. Summary biomass and 95% confidence intervals including projections for the whole stock, relative to biomass reference points. The dashed vertical line marks the terminal model year, 2011.

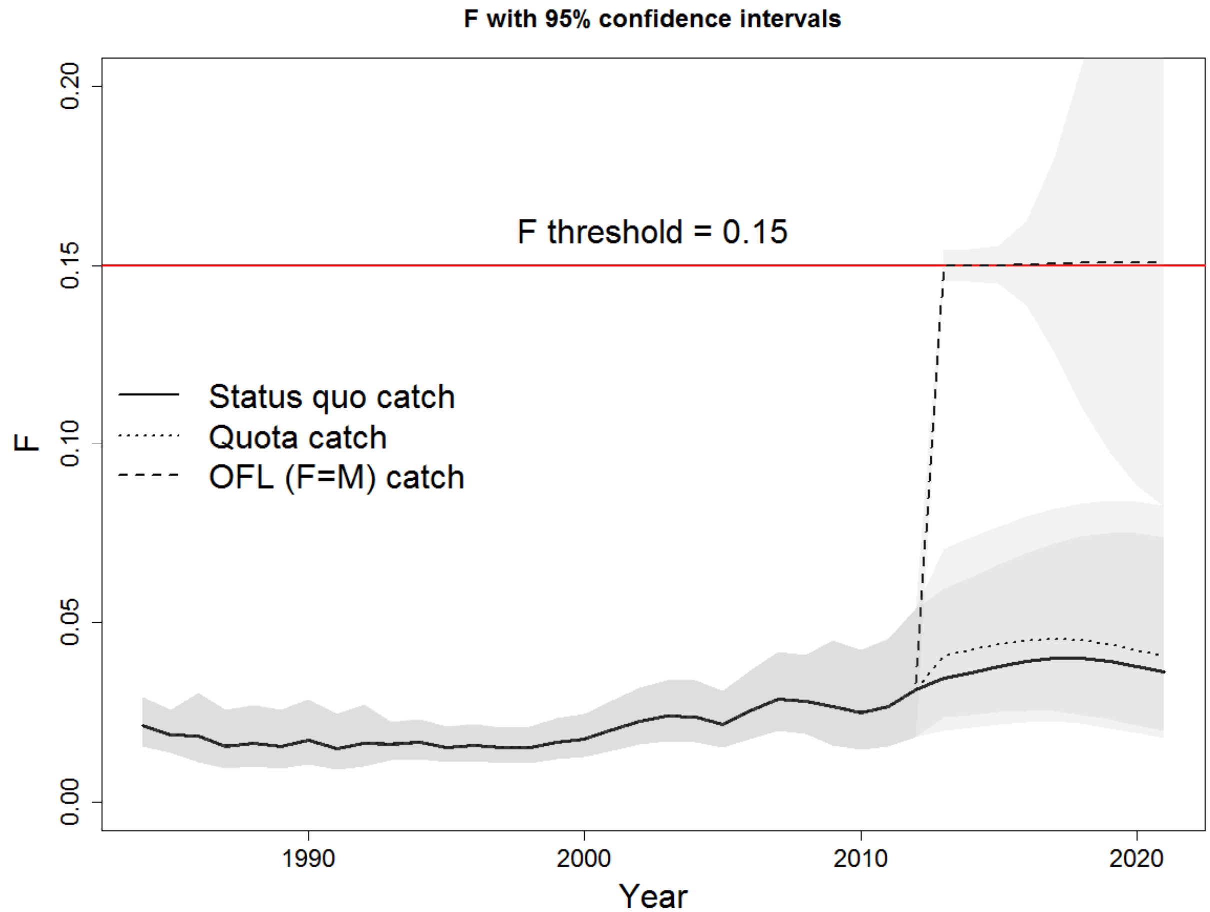


Figure A91. Annual fishing mortality and 95% confidence intervals including projections for the whole stock, relative to reference points.

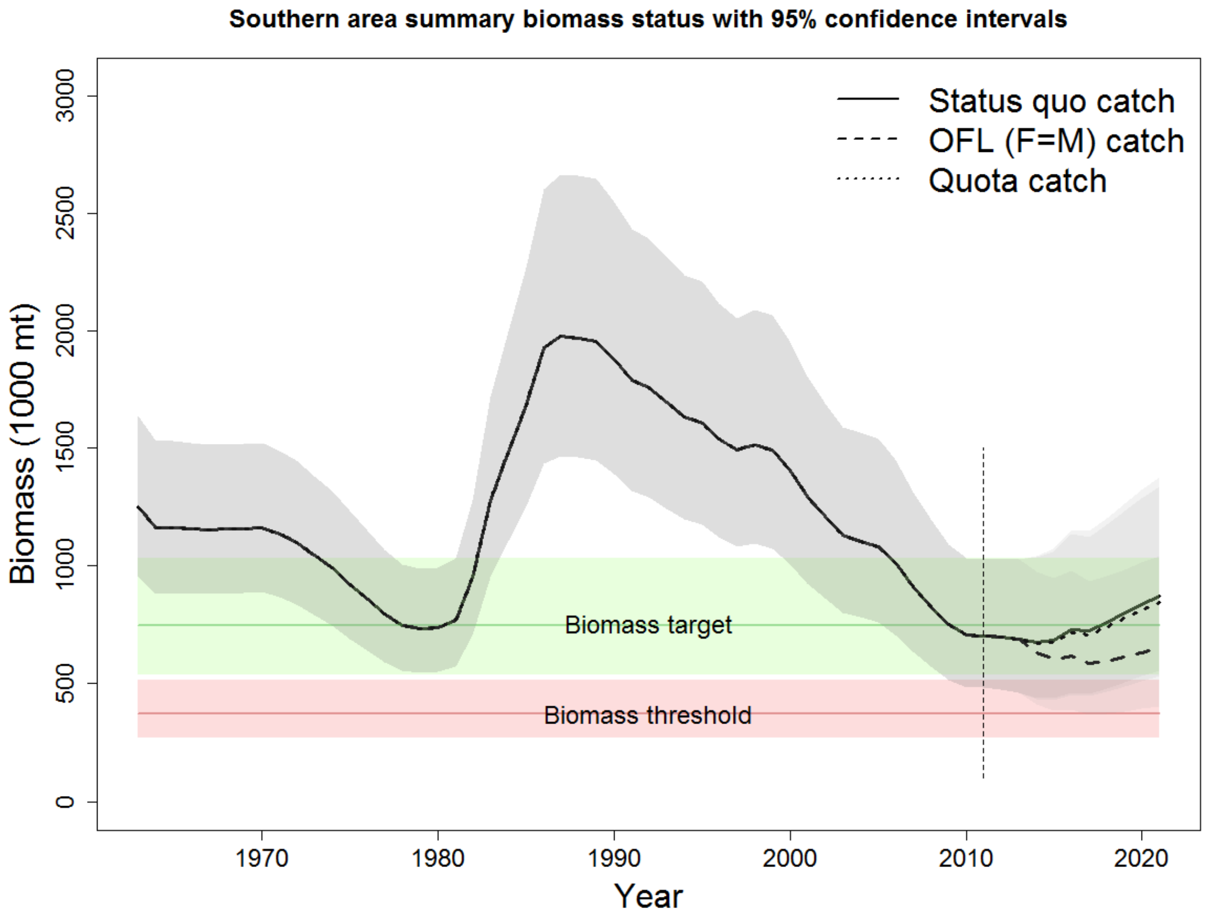


Figure A92. Summary biomass and 95% confidence intervals including projections for the southern area, relative to possible biomass reference points. The dashed vertical line marks the terminal model year, 2011.

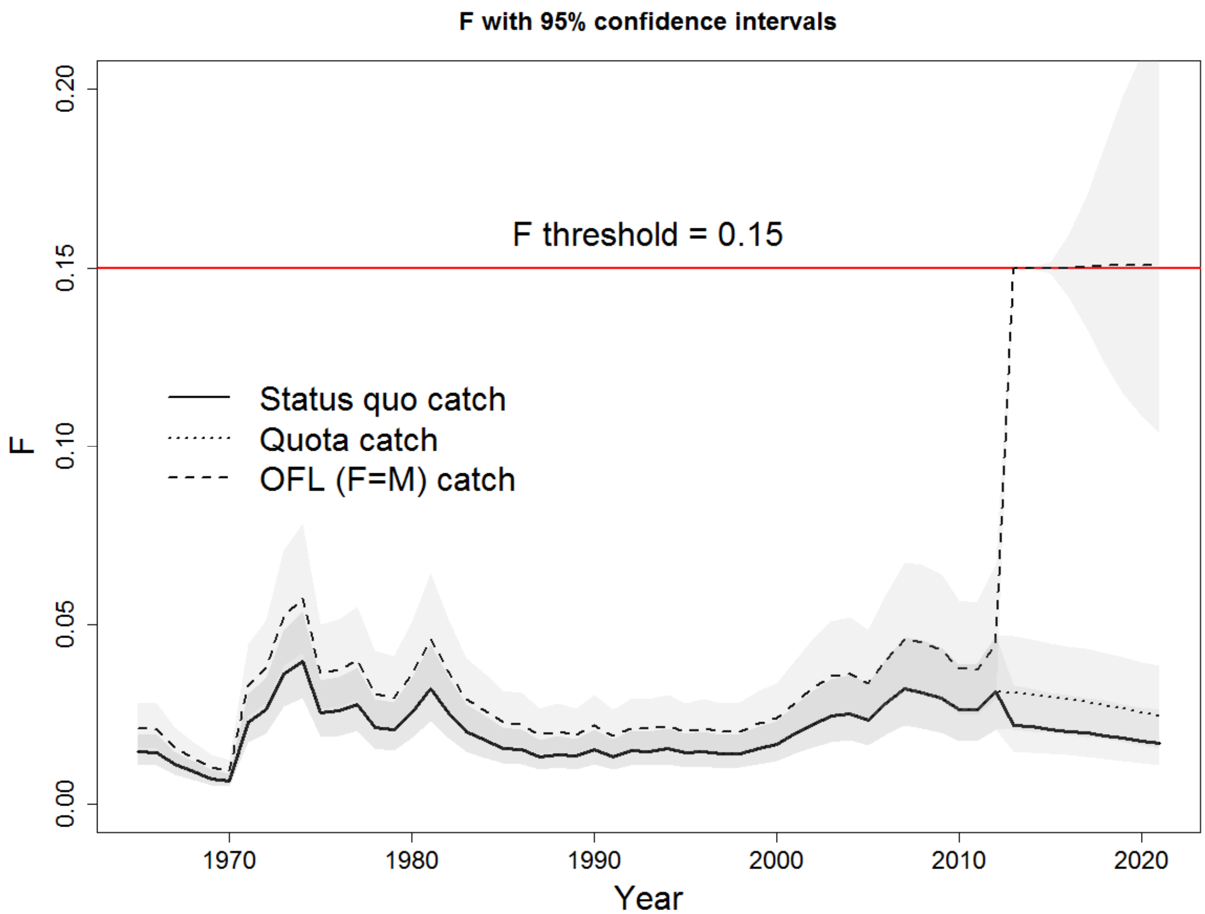


Figure A93. Annual fishing mortality and 95% confidence intervals including projections for the southern area, relative to reference points.

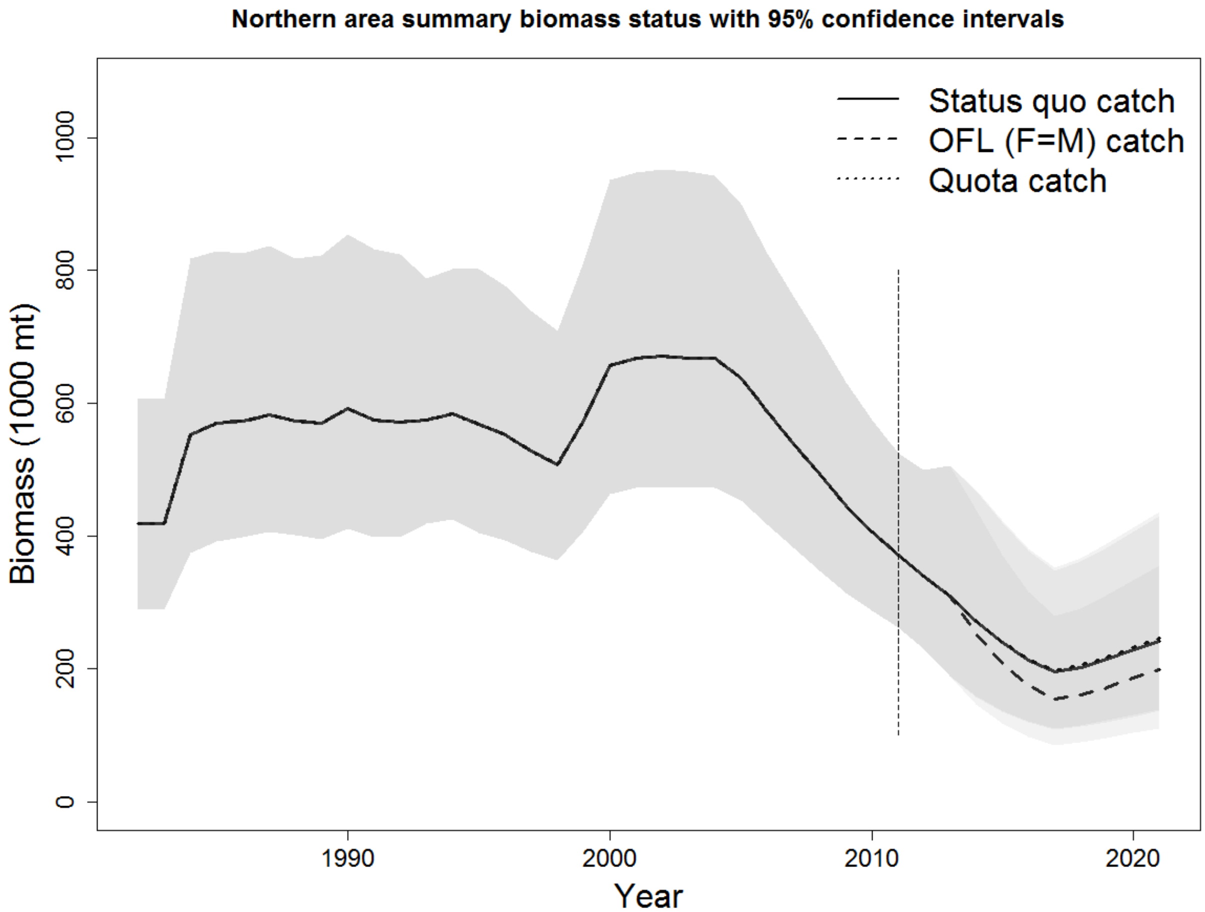


Figure A94. Summary biomass and 95% confidence intervals including projections for the northern area, relative to possible biomass reference points. The dashed vertical line marks the terminal model year, 2011.

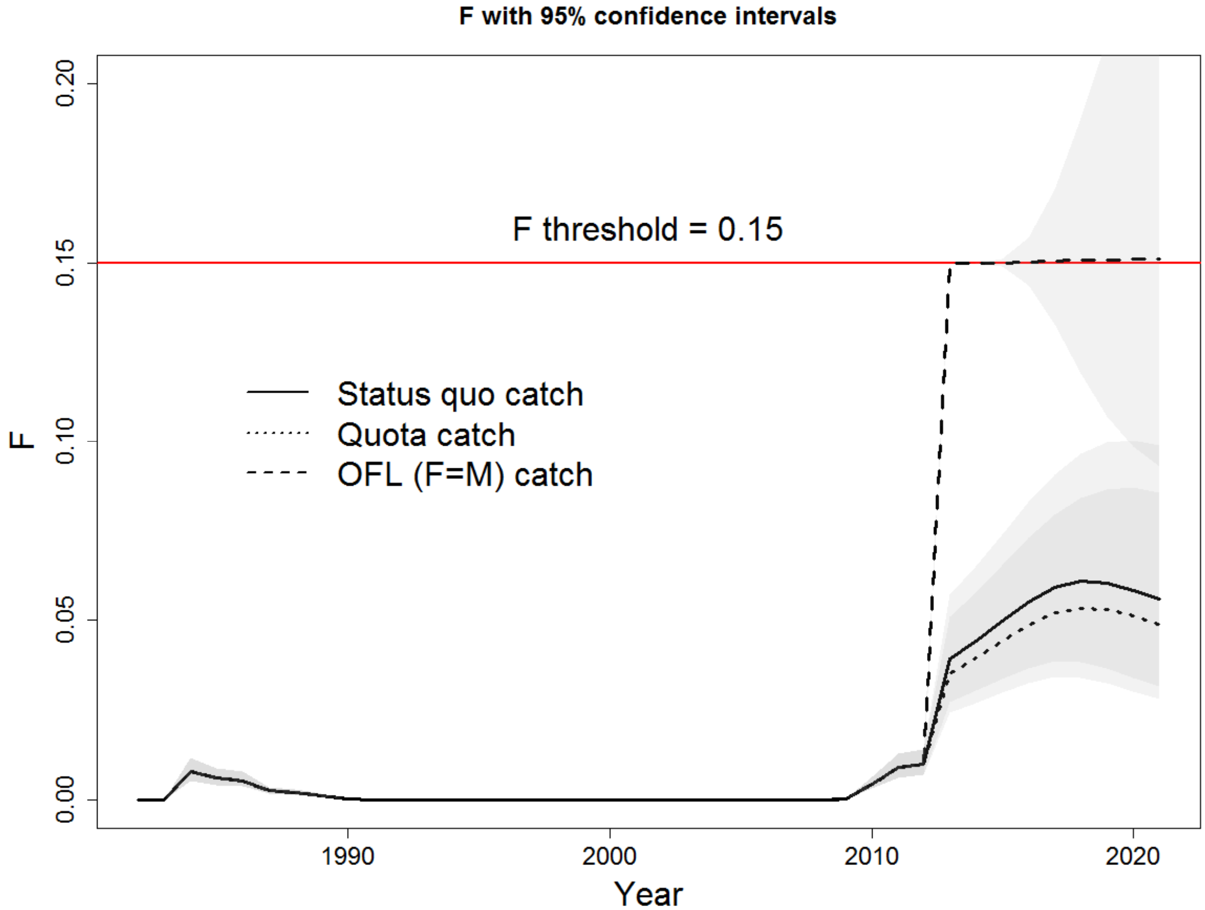


Figure A95. Annual fishing mortality and 95% confidence intervals including projections for the northern area, relative to reference points.

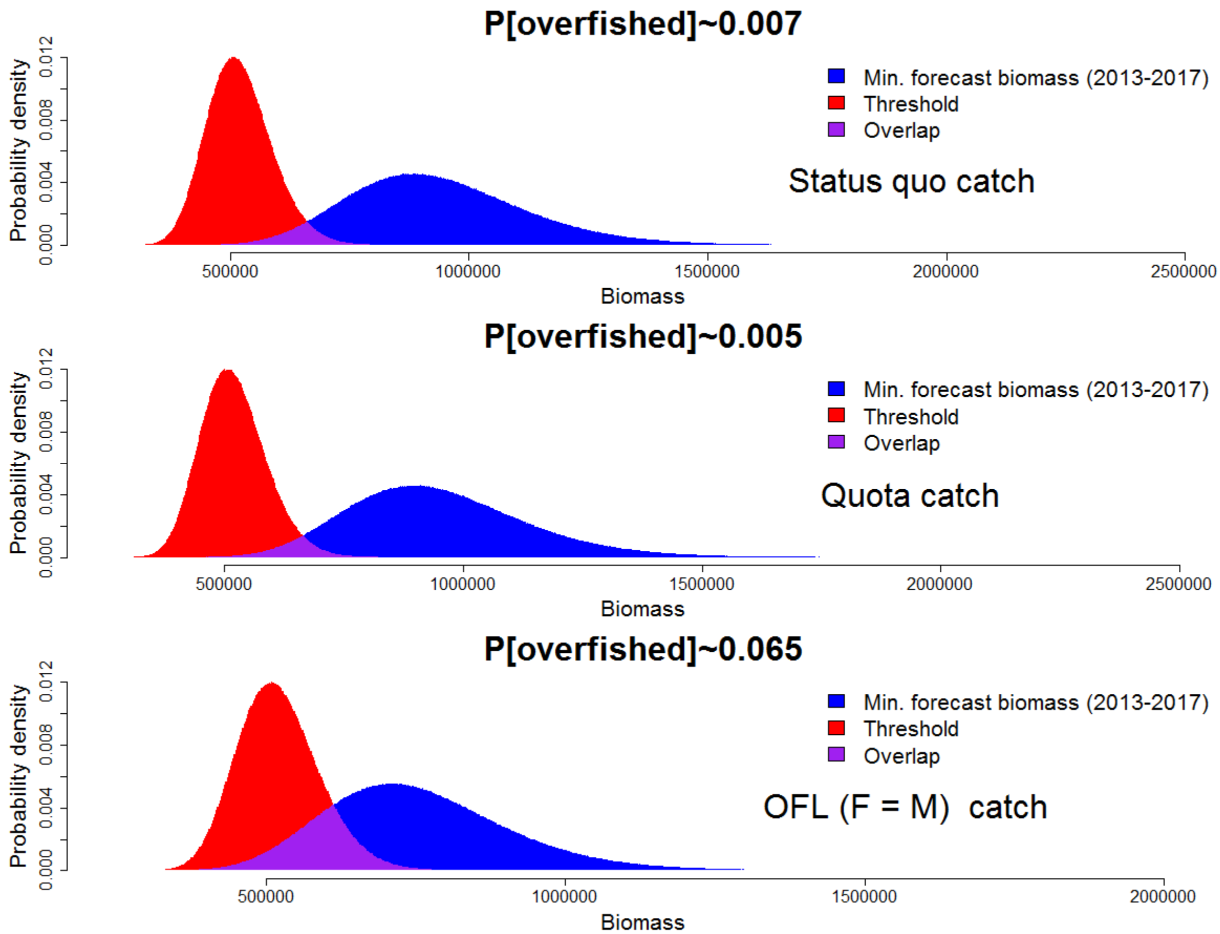


Figure A96. The maximum probability of the whole stock being overfished in any one of the next five years (2013 – 2017), given the three projection scenarios.

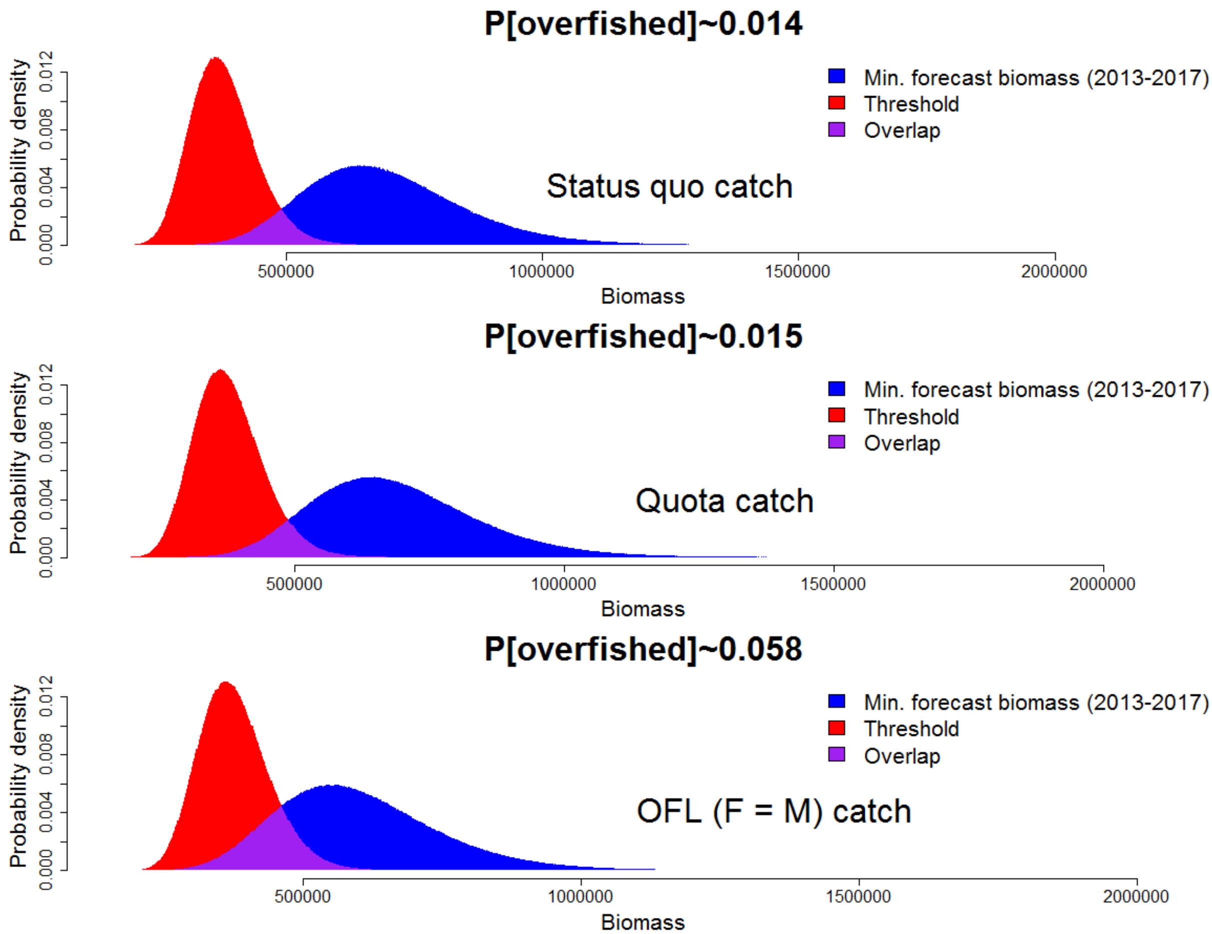


Figure A97. The maximum probability of the southern area being overfished in any one of the next five years (2013 – 2017), given the three projection scenarios.

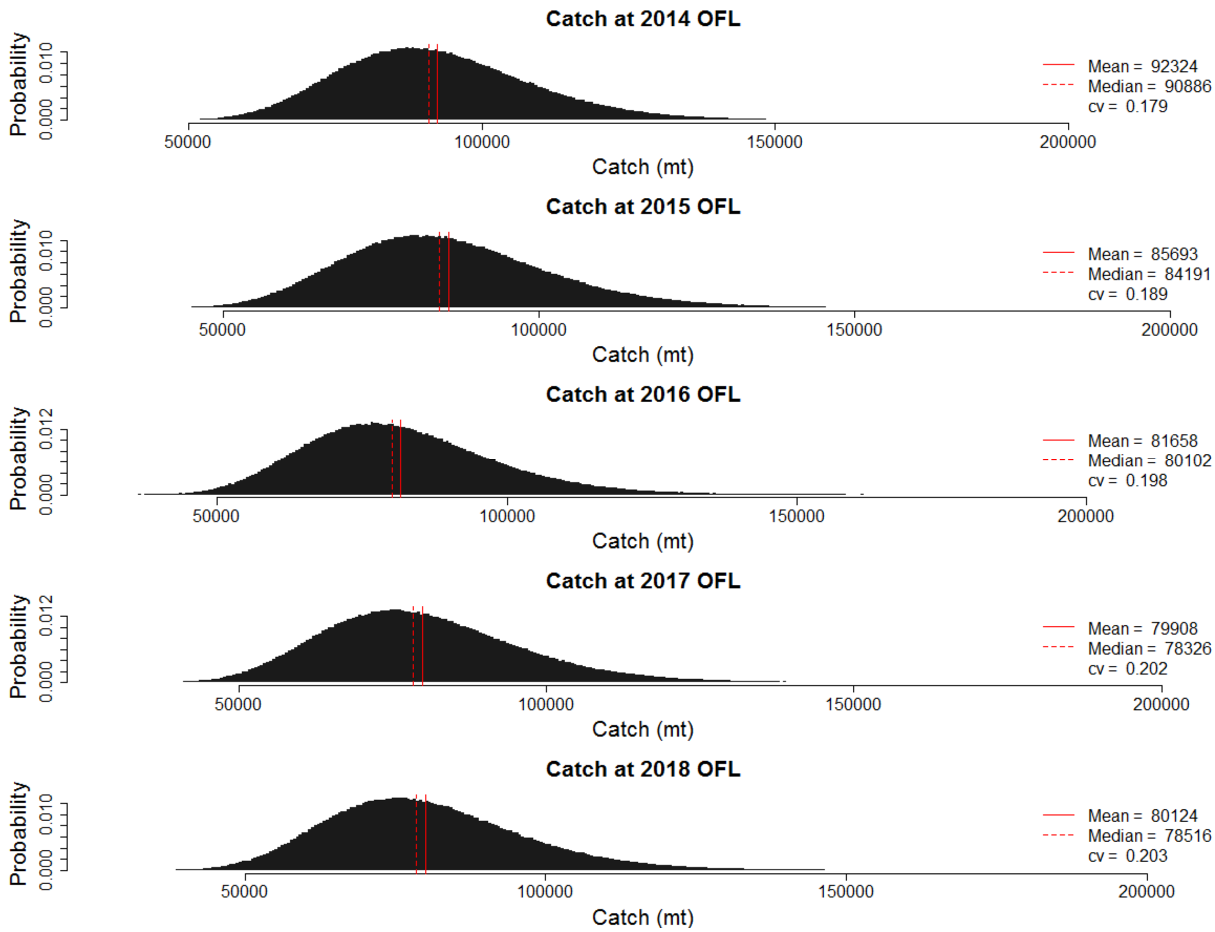


Figure A98. Probability distribution of the catch at the OFL for each of the next five years in projection for the whole stock.

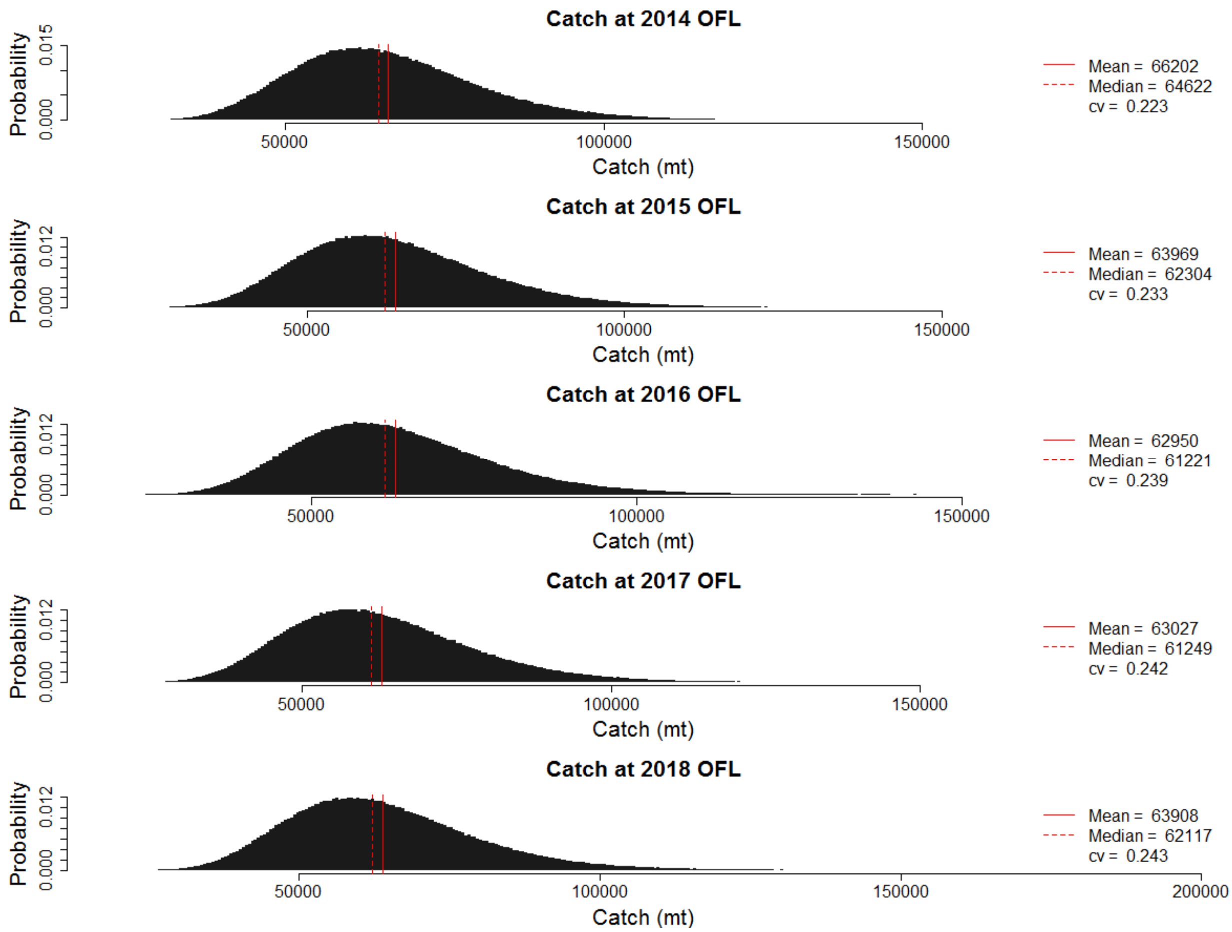


Figure A99. Probability distribution of the catch at the OFL for each of the next five years in projection for the southern area.

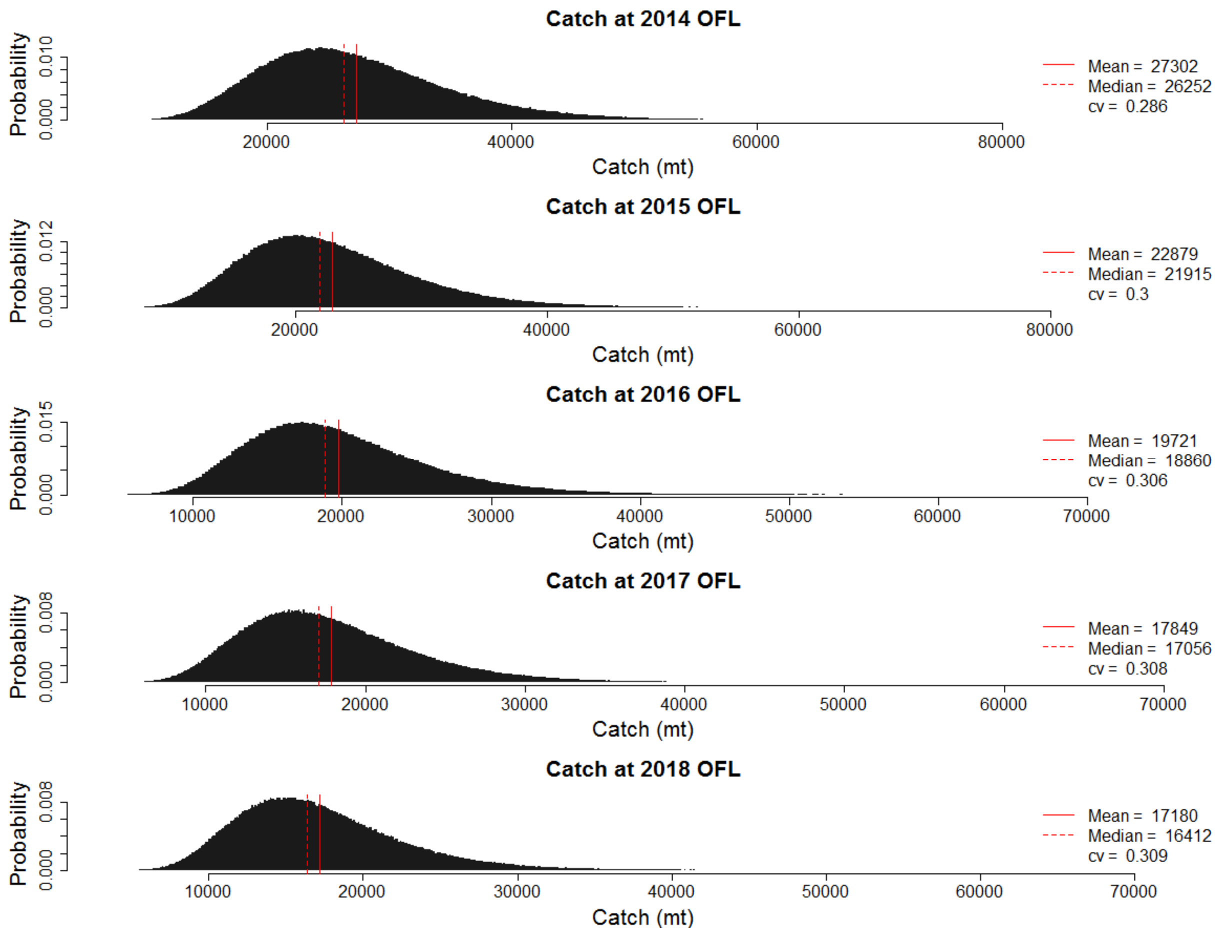


Figure A100. Probability distribution of the catch at the OFL for each of the next five years in projection for the GBK area.