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Stock Assessment of the Atlantic Surfclam

by Northeast Fisheries Science Center

July 2016

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Stock Assessment of the Atlantic Surfclam

by Northeast Fisheries Science Center

NOAA, National Marine Fisheries Service,

Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
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Part I

Executive summary

This assessment is for Atlantic surfclam in the US EEZ (federal waters, 3-200 nm from shore) individual transferable quota (ITQ) fishery (Appendix XVIII). The assessment divides the US stock into a northern (Georges Bank or GBK) and a southern area (south of GBK to Cape Hatteras) for modeling purposes (Figures 2 and 1). However, the resource is managed as a single stock so estimates for the north and south are combined for status determination.

TOR 1. Estimate catch from all sources including landings and discards. Map the spatial and temporal distribution of landings, discards, fishing effort, and gross revenue, as appropriate. Characterize the uncertainty in these sources of data.

Commercial landings and fishing effort data are reported by processors based on cage tags, in logbooks by ten-minute square (TNMS) and considered reliable. Catch includes a 12% allowance for incidental mortality. Atlantic surfclam discards were near zero except during 1982-1993 when minimum size regulations were used (Table 1).

Landings, fishing effort and landings per unit effort (LPUE, bu per hour fished) shifted north after 2000 as fishery productivity in the south declined (Figures 8-13). During 2006-2015, total landings declined from about 27 to 18 (mean 21) thousand mt (Tables 2-3 and Figures 3-4). Fishing effort after 2006 varied without trend or declined in the south but is still relatively high. Effort increased dramatically in in the north (Table 4 and Figure 5). Processors prefer large Atlantic surfclam but the sizes of landed Atlantic surfclam have declined in the south (Figures 17-22).

TOR 2. Present the survey data being used in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, etc.). Use logbook data to investigate regional changes in LPUE, catch and effort. Characterize the uncertainty and any bias in these sources of data. Evaluate the spatial coverage, precision, and accuracy of the new clam survey.

The NEFSC clam survey used the *RV Delaware II* and a small 5 ft dredge (RD) prior to 2012 and a commercial fishing vessel and modified commercial dredge (MCD) since. The entire resource was surveyed with the RD in 2011 (Tables 8-9). The MCD was used in 2012 and 2015 in the south but only on GBK in 2013. Data from the two periods are not comparable although capture efficiency and size selectivity estimates can be used to calculate relatively consistent swept-area stock size for 1997-2015. Based on two swept-area estimates, biomass declined in the south after 2011 (Figure 47). It is not possible to evaluate recent trends off GBK.

Landings per unit effort declined steadily for the stock as a whole and in the south to near record lows in 2015 but is high on GBK (Table 6 and Figure 7). Survey data and other information indicate that the biological condition of the Atlantic surfclam resource as a whole and in the south is better than fishery conditions would suggest. Landings, effort and LPUE do not reliably measure trends in overall Atlantic surfclam stock size because the fishery operates in relatively few TNMS such that most of the stock and habitat are not accessed by the fishery (Figures 14-16).

TOR 3. Determine the extent and relative quality of benthic habitat for Atlantic surfclam in the Georges Bank ecosystem to refine estimates of stock size based on swept area calculations.

The proportion of untrawlable ground that is potentially poor clam habitat was recalculated to be 14% which is slightly higher than the 12% figure used in this assessment. New information will be available soon for refining these imprecise estimates (Appendix XXIV).

TOR 4. Quantify changes in the depth distribution of Atlantic surfclam over time. Review changes over time in Atlantic surfclam biological parameters such as length, width, and growth.

The distribution of Atlantic surfclam in the south is shifting towards deeper water due to warming as suitable nearshore habitat areas have increased and offshore habitats and increased (Figures 67-72). Survey data indicate that overlap between Atlantic surfclam and ocean quahogs which inhabit relatively deep water habitat as increased (Figures 79-80). Maximum shell length had declined in the south while the von Bertalanffy growth parameter K increased (Figures 81-82).

TOR 5. Estimate annual fishing mortality, recruitment and stock biomass.

The primary assessment was a statistical catch at age model implemented in SS3. Each of two areas were assessed separately and the results were combined to provide management advice for the stock (Part VI). The scale of absolute abundance was uncertain, which is a problem typical of low fishing mortality fisheries. The trend in biomass was relatively well determined. The southern area, where recent recruitment has been strong is near its unfished biomass (B_0). The northern area, where recent recruitment has been poor is at a lower level, but still above $\frac{1}{4}B_0$. Fishing mortality is low for both areas.

TOR 6. State the existing stock status definitions for "overfished" and "overfishing". Then update or redefine biological reference points.

The current and recommended stock status definitions are listed in Table 26 (Part VII). The current stock status definitions were revised based on a management strategy evaluation (Part XIX) and assessment model improvements, because the overfishing definition depended on the estimate of absolute abundance in the assessment, which is uncertain. The recommended stock status definitions are trend based as trend is relatively well estimated in this assessment.

TOR 7. Evaluate stock status with respect to the existing model and with respect to any new model or models developed for this peer review.

The Atlantic surfclam population is not overfished and overfishing is not occurring under either the current or recommended reference point definitions and using either the previous or newly developed models (Part VIII; Tables **??**, **??**, and 27).

TOR 8. Develop stock projections.

Projections indicate that the population is unlikely to be overfished and that overfishing is unlikely to occur by 2025 using a wide range of possible biomass scales and assumed catches (Part IX; Tables 30 - 31).

TOR 9. Evaluate the validity of the current stock definition.

The invertebrate subcommittee did not reach consensus on stock definitions. All members of the workgroup agree that stock definitions are unlikely to affect management, yield, or biological risk in the near term as long as fishing mortality rates remain low and overall abundance and biomass are relatively high in both the northern and southern areas. If fishing mortality increases substantially, or a portion of the stock declines substantially, then the current stock definition has the potential to mask conditions in the affected area and lead to reduced yield and biomass. The single stock assumption also complicates and adds uncertainty to stock status determinations based on current and recommended reference points (Part X).

TOR 10. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in most recent SARC reviewed assessment and review panel reports. Identify new research recommendations.

Research recommendations were reviewed and evaluated and new ones were developed (Part XI).

Terms of Reference

A. Atlantic surfclams

1. Estimate catch from all sources including landings and discards. Map the spatial and temporal distribution of landings, discards, fishing effort, and gross revenue, as appropriate. Characterize the uncertainty in these sources of data.
2. Present the survey data being used in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, etc.). Use logbook data to investigate regional changes in LPUE, catch and effort. Characterize the uncertainty and any bias in these sources of data. Evaluate the spatial coverage, precision, and accuracy of the new clam survey.
3. Determine the extent and relative quality of benthic habitat for surfclams in the Georges Bank ecosystem to refine estimates of stock size based on swept area calculations.
4. Quantify changes in the depth distribution of surfclams over time. Review changes over time in surfclam biological parameters such as length, width, and growth.
5. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series (integrating results from TOR 3, as appropriate) and estimate their uncertainty. Include a historical retrospective analysis to allow a comparison with previous assessment results and previous projections.
6. 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. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs, particularly as they relate to stock assumptions.
7. Evaluate stock status with respect to the existing model (from previous peer reviewed accepted assessment) and with respect to any new model or models developed for this peer review.
   (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).
8. Develop approaches and apply them to conduct stock projections.
   (a) Provide numerical annual projections (five years) and the statistical distribution (e.g., probability density function) of the OFL (overfishing level) (see Appendix to the SAW TORs). Consider cases using nominal as well as potential levels of uncertainty in the model. 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 stocks vulnerability (see XXVI) to becoming overfished, and how this could affect the choice of ABC.

9. Evaluate the validity of the current stock definition. Determine whether current stock definitions may mask fishery related reductions in sustainable catch on regional spatial scales. Make a recommendation about whether there is a need to modify the current stock definition.

10. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in most recent SARC reviewed assessment and review panel reports. Identify new research recommendations.

Part II

TOR 1: Commercial

In this assessment for Atlantic surfclam the northern area was federal waters (3-200 nm from shore) on Georges Bank and the southern area was federal waters from south and west of Georges Bank to Cape Hatteras (Figures 2 and 1). Commercial landings were provided in meat weights for ease of comparison to survey data and in analyses, but were originally reported in units of industry cages. Landings per unit of fishing effort (LPUE) data were reported in this assessment as landings in bushels per hour fished, based on mandatory clam logbook reports. The spatial resolution of the clam logbook reports was 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 stock assessments (Northeast Fisheries Science Center 2013), "catch" was defined as the sum of landings, plus 12% of landings, plus discards. Based on prior calculations (Northeast Fisheries Science Center 2003), Atlantic surfclam catch in previous assessments was assumed to be 12% larger than landings to account for incidental mortality of clams in the path of the dredge. The 12% figure was considered an upper bound or overestimate because the area fished (e.g. 155 km^2 during 2004) is small relative to area covered by the stock (Walace and Hoff 2005). Furthermore, the ITQ (see below) clam fishery operates with little or no regulation induced inefficiency due to area closures, trip limits, size limits, etc. so that fishing effort and incidental mortality are reduced. The support for this estimate was reevaluated in this assessment based on data also used by (Northeast Fisheries Science Center 2003), and more realistic algebraic relationships proposed by Dr. Deborah Hart (NEFSC, Woods Hole, MA) for sea scallops in Northeast Fisheries Science Center (2014).

The ratio of Atlantic surfclam in the patch of a commercial dredge that are caught relative to those killed but not caught is $R = \frac{e}{c(1-e)}$ where e is capture efficiency and c is the fraction that die but are not caught. Indirect mortality due to contact with a clam dredge is in the range 5-20% with an extreme upper bound of 50% (Table C10 in (Northeast Fisheries Science Center 2003)). If F_L is fishing mortality for landed Atlantic surfclam and F_I is the incidental mortality rate then $F_I = \frac{F_L}{R} = \frac{F_L c(1-e)}{e}$ and $\frac{F_I}{F_L} = \frac{c(1-e)}{e}$. The ratio $\frac{F_I}{F_L}$ is the same as the ratio of numbers landed to numbers killed but not caught. If landed and incidental clams have the same size composition, then the ratio of landed weight to incidental weight is also $\frac{F_I}{F_L}$. The average efficiency of a commercial clam dredge for Atlantic surfclam is about 0.73 (Table A10 in NEFSC 2003). The range of estimates $c = 0.05$, 0.2 and 0.5 indicate that incidental losses are 2%, 7% and 18% of landings which together average about 13%. The Subcommittee concluded that the 12% incidental mortality estimate was reasonable for Atlantic surfclam.

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

Discard data

Discards were zero during 2008-2015 (since the last assessment). Some discards occurred during 1979-1993; as the result of a minimum size (shell length) requirement for landing that was is place over that period (Table 1). No new information about discards was available for this assessment.

Age and size at recruitment to the fishery

Age at recruitment to the Atlantic surfclam fishery depends on growth rates, which vary both spatially and temporally (Figures 51 – 52). The age at recruitment depends on the area being modeled (north vs. south), and 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 section (VI).

Landings, fishing effort and prices

Landings and fishing effort data for 1982-2015 were from mandatory logbook reports (similar but more detailed than standard Vessel Trip Reports used in most other fisheries) with information on the location, duration, and landings of each trip. Data for earlier years were from Northeast Fisheries Science Center (2003) and Mid-Atlantic Fishery Management Council (2006).

Landings data from Atlantic surfclam logbooks are considered accurate in comparison to other fisheries because of the Individual Transferable Quota (ITQ) and cage tag systems. However, effort data are not reliable for 1981–1990 due to regulations that restricted the duration of fishing to 6 hours. Effort data are considered reliable for years before 1985 and after 1990.

Atlantic surfclam landings were mostly from the US Exclusive Economic Zone (EEZ) during 1965 to 2011 (Table 2 and Figure 3). 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 2015. Landings have not reached the quota of 26,218 mt since it was set in 2004 because of limited markets. The quotas are set at levels much lower than might be permitted under the FMP. Approximate state landings are shown in Table 2, and more accurate state landings are available in Appendices (XVIII). Both New Jersey and New York have seen a sharp decline in Atlantic surfclam biomass within their state territorial waters over the past 15 years, and an accompanying drop in landings (XVIII).

The bulk of EEZ landings were from the DMV region (Figure 2) during 1979-1980. After 1980, the bulk of landings were from the NJ region (Table 3 and Figure 4). Landings from LI were modest but began increasing in 2001. Landings from SNE were modest but increased starting in 2004. The high proportion of landings on GBK reflects the high catch rates there (see below).

Total fishing effort increased after 1990 and has been relatively high, but stable since 2007, particularly in the DMV and NJ regions (Table 4 and Figure 5). The bulk of the fishing effort was in areas where the majority of landings come from.

Real ex-vessel prices for the inshore and EEZ fisheries have been stable, since the mid-1990s (Table 5 and Figure 6). Nominal revenues for Atlantic surfclam during 2013 were about $33 million.

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 6 and Figure 7). Standardized LPUE was not estimated for this assessment because the data are not used analytically and because Northeast Fisheries Science Center (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 in SVA, DMV and NJ, which have recently been at or near record lows. LPUE in GBK and SNE have generally been high.

LPUE is not an ideal measure of fishable biomass trends for sessile and patchy stocks like Atlantic surfclam because fishermen target high density beds and change their operations to maintain relatively high catch rates as stock biomass declines (Hilborn et al. 1992).

Spatial patterns in fishery data

Mean landings, fishing effort, and LPUE were calculated by ten-minute square (TNMS) from 1979-2015 in 5 year blocks (Figures 8 – 13). Only TNMS where more than ten bu of Atlantic surfclam were caught over the time period were included in maps. TNMS with reported landings less than 10 bu were probably in error, or from just a few exploratory tows. Inclusion of TNMS, with less than 10 bu distorted the graphical presentations because the area fished appeared unrealistically large.

Figures 8 – 13 show the spatial patterns of the Atlantic surfclam fishery over most of its history. In most blocks, the greatest concentration of fishing effort and landings occurred in the same thirty or so TNMS in the NJ region, with intermittent fishing activity in other regions and recent emphasis on SNE and GBK.

TNMS 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.

Important TNMS

TNMS "important" to the fishery were identified by choosing the 10 TNMS from with the highest mean landings during each 5 year time block. For example, a TNMS important during 1991-1995 could be selected regardless of its importance during earlier or later time periods. The list contains a subset of the total TNMS, because of overlap between the time periods and because the same TNMS tend to remain important. 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. Trends in landings, effort, and LPUE were plotted (Figures 14 – 16) for each TNMS to show changes in conditions over time within individual TNMS.

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 approximately 30 random landed Atlantic surfclam from selected fishing trips each year (Table 7).

Port sample length frequency data from the four regions show modest variation in size of landed Atlantic surfclam over time with declines in modal size in DMV and NJ since 2008 (Figures 17 – 23). Care should be taken in interpreting these due to small sample sizes in some cases (especially LI, SNE and GBK), but in general the data indicate that most landed Atlantic surfclam have been larger than 120mm SL. Commercial size distributions are discussed in detail in section (VI).

Fishery management

The Atlantic surfclam is managed by the Mid-Atlantic Fishery Management Council (Council). The Council is one of eight regional fishery management councils created when the United States (U.S.) Congress passed Public Law 94-265, the Magnuson Fishery Conservation And Management Act of 1976 (also known as Magnuson-Stevens Act or MSA). The law created a system of regional fisheries management designed to allow for regional, participatory governance. The Council develops fishery management plans and recommend management measures to the Secretary of Commerce through the National Marine Fisheries Service (NMFS) for its fisheries in the Exclusive Economic Zone of the U.S. (EEZ; 3-200 miles off the east coast). There are also fisheries for Atlantic surfclam in New Jersey, New York, and Massachusetts within state waters (within 3 miles of shore); the state authorities are responsible for managing these fisheries, although fishing and survey data for state fisheries were presented in this document (see XVIII).

Atlantic surfclam is managed with another species (Ocean quahog, *Arctica islandica*) under a single fishery management plan, that was first developed by the Council in 1977. The Atlantic surfclam fishery was initially managed through limited-entry restrictions, quarterly quotas, and fishing time restrictions. By the mid-1980s, effort limitation combined with overcapacity in the fishery meant that capacity utilization was very low, with vessels operating only 6 hours every other week in 1990. An individual transferrable quota (ITQ) system was established in 1990 which initially allocated shares to vessel owners based on a formula including historical catch and vessel size. Economic efficiency improved and management monitoring decreased as a result of initial ITQ implementation, but it also led to consolidation and displacement of labor (particularly non-vessel owning captains and crew). ITQ shares can be traded or leased to any non-foreign person or entity, with no pre-conditions of vessel ownership. Market consolidation and existing vertical integration have increased over time. From 1990 to 2005, the Atlantic surfclam fleet size decreased by about 70%.

Under the current management system, managers set an annual catch limit for Atlantic surfclam and allocate landings to the ITQ shares. The Council's annual catch limit recommendations for the upcoming fishing year(s) cannot exceed the acceptable biological catch (ABC) recommendation of its Scientific and Statistical Committee (SSC). The SSC serves as the Councils primary scientific/technical advisory body, and provides ongoing scientific advice for fishery management decisions, including recommendations for ABC, preventing overfishing, maximum sustainable yield, and achieving rebuilding targets.

In order to participate in the Atlantic surfclam fishery, fishermen must have a permit to commercially harvest and sell Atlantic surfclam (using valid ITQ shares), and there are mandatory reporting and vessel-monitoring requirements, as well as clam cage-tagging requirements. There is a minimum size for Atlantic surfclam, which can be suspended by managers if it is demonstrated the harvest of small Atlantic surfclam is below a certain threshold. Fishing areas can be closed due to environmental degradation or due to the toxins that cause paralytic shellfish poisoning (PSP). PSP is a public health concern for Atlantic surfclam. It is caused by saxitoxins, produced by the alga *Alexandrium fundyense* (red tide), that accumulate in shellfish, and has resulted in fishery closures in the Georges Bank Area of the EEZ. NMFS recently (2013) reopened portions of the closed areas to harvest of Atlantic surfclam for those vessels using a protocol for onboard screening and dockside testing to verify that clams harvested from these areas are safe. Areas can also be closed to Atlantic surfclam fishing if the abundance of small clams in an area meets certain threshold criteria. This small Atlantic surfclam closure provision was applied during the 1980's with three area closures (off Atlantic City, NJ, Ocean City, MD, and Chincoteague, VA), with the last of the three areas reopening in 1991.

Table 1: Surfclam discard estimates from 1982 through 1993. 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.

		Discards					
Year	NJ	DMV	Total	Landings (mt)	Discard proportion	Catch	Size limit (mm)
1982	3,899	2,295	6,194	16,688	37.1%	22,882	140
1983	2,507	2,127	4,634	18,592	24.9%	23,226	140
1984	2,724	2,015	4,739	22,889	20.7%	27,628	133
1985	2,186	1,725	3,911	22,480	17.4%	26,391	127
1986	2,561	239	2,800	24,521	11.4%	27,321	127
1987	1,475	415	1,890	21,744	8.7%	23,634	127
1988	1,330	106	1,436	23,378	6.1%	24,814	127
1989	1,054	258	1,312	21,888	6.0%	23,200	127
1990	1,146	123	1,269	24,018	5.3%	25,287	127
1991	561	5	566	20,615	2.7%	21,181	
1992	1,020	4	1,024	21,686	4.7%	22,710	
1993	0	0	0	21,859	0.0%	21,859	

Table 2: Atlantic surfclam landings and EEZ quotas. All figures are meat weights in mt. Total landings for 1965-1981 are from NEFSC (2003) and other years were from a dealer database (CFDBS). EEZ landings for 1965-1982 are from NEFSC (2003) while later years are from a logbook database (SFOQVR). Landings for state waters are approximated as total landings - EEZ landings and may not accurately reflect state landings. Summary statistics ignore years without fishing.

Year	Total	EEZ	State	$\frac{EEZ}{Total}$	Quota
1965	19998	14968	5030	0.75	
1966	20463	14696	5767	0.72	
1967	18168	11204	6964	0.62	
1968	18394	9072	9322	0.49	
1969	22487	7212	15275	0.32	
1970	30535	6396	24139	0.21	
1971	23829	22704	1125	0.95	
1972	28744	25071	3673	0.87	
1973	37362	32921	4441	0.88	
1974	43595	33761	9834	0.77	
1975	39442	20080	19362	0.51	
1976	22277	19304	2973	0.87	
1977	23149	19490	3659	0.84	
1978	17798	14240	3558	0.8	13880
1979	15836	13186	2650	0.83	13880
1980	17117	15748	1369	0.92	13882
1981	20910	16947	3963	0.81	13882
1982	23631	16688	6943	0.71	18506
1983	23631	18592	5039	0.79	18892
1984	30530	22889	7641	0.75	18892
1985	28316	22480	5836	0.79	21205
1986	35073	24521	10552	0.7	24290
1987	27231	21744	5487	0.8	24290
1988	28506	23378	5128	0.82	24290
1989	30081	21888	8193	0.73	25184
1990	32628	24018	8610	0.74	24282
1991	30794	20615	10179	0.67	21976
1992	33164	21686	11478	0.65	21976
1993	32878	21859	11019	0.66	21976
1994	32379	21943	10436	0.68	21976
1995	30061	19627	10434	0.65	19779
1996	28834	19827	9007	0.69	19779
1997	26311	18612	7699	0.71	19779
1998	24506	18234	6272	0.74	19779
1999	26677	19577	7100	0.73	19779
2000	31093	19778	11315	0.64	19779
2001	31237	22017	9220	0.7	21976
2002	32645	24006	8639	0.74	24174
2003	31526	24994	6532	0.79	25061

2004	26463	24197	2266	0.91	26218
2005	22734	21163	1571	0.93	26218
2006	25779	23573	2206	0.91	26218
2007	27091	24915	2176	0.92	26218
2008	25038	22510	2528	0.9	26218
2009	22283	20065	2218	0.9	26218
2010	19941	17984	1957	0.9	26218
2011	19776	18839	937	0.95	26218
2012	18378	18054	324	0.98	26218
2013	18459	18551	0	1	26218
2014	18707	18227	480	0.97	26218
2015	18473	18154	319	0.98	26218
min	15836	6396	0	0.21	13880
max	43595	33761	24139	1	26218
mean	26176	19847	6330	0.77	22309

Table 3: EEZ surfclam landings (mt meats) by stock assessment area and year. Summary statistics ignore years without fishing.

Year	SVA	DMV	NJ	LI	SNE	GBK	Other	Total
1979		12087	1099					13186
1980	64	12789	2878	17				15748
1981	568	7472	8820	87				16947
1982	1705	6679	8086	94	124			16688
1983	2226	7173	8095	263	835			18592
1984	1797	5978	11905	7	382	2765	54	22889
1985	741	7856	11245		452	2185		22480
1986	529	2853	17731	18	1223	1991	176	24521
1987	378	1303	18017		1140	907		21744
1988	558	1149	19420		1512	739		23378
1989	439	3123	16532		1361	434		21888
1990	1502	3546	17886		998	7	79	24018
1991		1634	18912	15	33		21	20615
1992		1221	20399	61	5			21686
1993		3416	18378	62	3			21859
1994		3454	18418	71				21943
1995		2752	16497		378			19627
1996		2239	17480	26	82			19827
1997		1540	16999	73				18612
1998		484	17511	117	121			18234
1999		649	18755	157	16			19577
2000		2041	17513	121	103			19778
2001		3282	17719	935	81			22017
2002	64	4489	18271	1130	52			24006
2003		1432	21669	1626	267			24994
2004		1482	19197	906	2612			24197
2005		1668	16851	759	1885			21163
2006		2773	19660	245	895			23573
2007		3073	20267	1117	458			24915
2008		3261	17517	1309	423			22510
2009		1977	14834	1798	1444	11		20065
2010		1556	11065	1181	2870	1311		17984
2011		1446	12042	409	2553	2388		18839
2012		3785	6206	307	4143	3580	33	18054
2013		3599	5359	231	4959	4403		18551
2014		3544	6063	306	5079	3236		18227
2015		2854	6156	979	4092	4074		18154
min	64	484	1099	7	3	7	21	13186
max	2226	12789	21669	1798	5079	4403	176	24994
mean	249	2960	14117	386	1084	734	9	20570

Table 4: EEZ fishing effort (hours fished by all vessels) for surfclam, by stock assessment area and year based on logbook data. Summary statistics ignore years without fishing.

Year	SVA	DMV	NJ	LI	SNE	GBK	Other	Total
1981	1337	15839	16770	204				34150
1982	2790	18050	24635	225	136			45837
1983	4190	18805	23584	536	1130			48244
1984	2603	8972	20819	27	1264	1732	42	35459
1985	397	4687	10518		1702	2608		19912
1986	236	1630	10764	38	2516	1610	675	17469
1987	262	722	11910		3781	1006		17681
1988	322	593	13175		5274	587		19950
1989	228	1616	11794		4741	389		18768
1990	1150	2065	12437		3032		898	19582
1991		1254	17243	20	107		292	18916
1992		797	21379	67				22243
1993		2423	18232	56	15			20726
1994		1930	21495	70				23495
1995		1560	18625		1058			21243
1996		1577	20994	40	287			22899
1997		1098	20383	77				21558
1998		289	19608	134	519			20550
1999		734	18146	150	148			19179
2000		1859	16787	114	368			19128
2001		2537	18461	962	148			22107
2002	112	5505	19826	1240	62			26746
2003		2366	25068	1827	177			29438
2004		3161	26444	1252	1098			31955
2005		2660	24384	1201	1321			29566
2006		5883	27186	343	1039			34451
2007		7065	34692	1577	960			44294
2008		8154	33999	2303	541			44997
2009		5667	33459	4123	2520	12		45781
2010		4125	31816	3297	5564	493		45296
2011		3071	35278	1326	7752	975		48402
2012		7398	21712	948	11478	2039	13	43588
2013		6139	19952	858	15952	3811		46712
2014		6695	18163	1031	17124	2927		45940
2015		6674	18933	3388	15213	4406		48614
min	112	289	10518	20	15	12	13	17469
max	4190	18805	35278	4123	17124	4406	898	48614
mean	345	5297	19868	738	2869	592	51	30711

Table 5: Real and nominal exvessel prices and revenues for surfclam 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 effects of small deliveries at relatively high prices. The consumer price index (CPI) used to convert nominal dollars to 2015 equivalent dollars is for unprocessed and packaged fish, which includes shellfish and finfish (Eric Thunberg, NEFSC, pers. comm.).

Year	CPI	Nominal_Prices	Real_Prices	Nominal_Revenue	Real_Revenue
1982	0.45	8.94	19.87	25.19	55.98
1983	0.46	7.57	16.31	23.21	49.98
1984	0.48	8.37	17.29	33.16	68.45
1985	0.50	9.34	18.62	34.30	68.38
1986	0.51	9.20	18.00	41.84	81.89
1987	0.53	7.83	14.78	27.64	52.20
1988	0.55	7.80	14.14	28.83	52.27
1989	0.58	7.78	13.45	30.33	52.47
1990	0.61	7.66	12.56	32.39	53.16
1991	0.63	7.51	11.82	29.98	47.21
1992	0.65	7.40	11.32	31.83	48.67
1993	0.67	7.83	11.62	33.37	49.53
1994	0.69	9.82	14.22	41.24	59.69
1995	0.71	10.58	14.89	41.25	58.05
1996	0.73	10.24	13.99	38.27	52.33
1997	0.75	10.31	13.78	35.19	47.03
1998	0.76	9.19	12.09	29.20	38.43
1999	0.78	8.79	11.32	30.42	39.17
2000	0.80	9.43	11.75	38.02	47.37
2001	0.83	9.76	11.83	39.55	47.91
2002	0.84	9.45	11.26	39.99	47.68
2003	0.86	9.64	11.24	39.43	45.96
2004	0.88	9.40	10.67	32.24	36.61
2005	0.91	9.41	10.33	27.73	30.45
2006	0.94	10.08	10.72	33.69	35.85
2007	0.97	10.48	10.85	36.84	38.12
2008	1.00	10.95	10.91	35.56	35.43
2009	1.00	11.46	11.46	33.13	33.13
2010	1.02	11.70	11.50	30.25	29.75
2011	1.05	11.59	11.06	29.73	28.35
2012	1.07	12.34	11.53	29.41	27.48
2013	1.09	12.14	11.17	29.05	26.75
2014	1.10	12.20	11.06	29.61	26.83
2015	1.10	12.73	11.54	30.50	27.65

Table 6: Nominal landings per unit effort (LPUE, bushels h^{-1}) for surfclam fishing (all vessels) in the US EEZ from logbooks. LPUE is total landings in bushels divided by total hours fished. Summary statistics ignore years without fishing.

Year	SVA	DMV	NJ	LI	SNE	GBK	Other	Total
1981	55.1	61.2	68.2	55.3				64.4
1982	79.3	48	42.6	54.2	118.2			47.2
1983	68.9	49.5	44.5	63.6	95.8			50
1984	89.5	86.4	74.2	33.6	39.2	207	166.7	83.7
1985	242.1	217.4	138.6		34.4	108.7		146.4
1986	290.7	227	213.6	61.4	63	160.4	33.8	182
1987	187.1	234	196.2		39.1	116.9		159.5
1988	224.7	251.3	191.2		37.2	163.3		152
1989	249.7	250.6	181.8		37.2	144.7		151.2
1990	169.4	222.7	186.5		42.7		11.4	159.1
1991		169	142.2	97.3	40		9.3	141.3
1992		198.7	123.7	118.1				126.4
1993		182.8	130.7	143.6	25.9			136.8
1994		232.1	111.1	131.5				121.1
1995		228.8	114.9		46.3			119.8
1996		184.1	108	84.3	37.1			112.3
1997		181.9	108.2	122.9				112
1998		217.2	115.8	113.2	30.2			115.1
1999		114.7	134	135.7	14			132.4
2000		142.4	135.3	137.6	36.3			134.1
2001		167.8	124.5	126	71			129.2
2002	74.1	105.8	119.5	118.2	108.8			116.4
2003		78.5	112.1	115.4	195.6			110.1
2004		60.8	94.1	93.8	308.5			98.2
2005		81.3	89.6	82	185.1			92.8
2006		61.1	93.8	92.6	111.7			88.7
2007		56.4	75.8	91.9	61.9			72.9
2008		51.9	66.8	73.7	101.4			64.9
2009		45.2	57.5	56.6	74.3	118.9		56.8
2010		48.9	45.1	46.5	66.9	344.9		51.5
2011		61.1	44.3	40	42.7	317.6		50.5
2012		66.3	37.1	42	46.8	227.7	329.2	53.7
2013		76	34.8	34.9	40.3	149.8		51.5
2014		68.6	43.3	38.5	38.5	143.4		51.5
2015		55.5	42.2	37.5	34.9	119.9		48.4
min	55.1	45.2	34.8	33.6	14	108.7	9.3	47.2
max	290.7	251.3	213.6	143.6	308.5	344.9	329.2	182
mean	345	5297	19868	738	2869	592	51	102.4

Table 7: Numbers of commercial trips sampled and numbers of surfclams measured in port samples from landings during 1982-2015, by region. Numbers of trips during 1982-1999 were estimated assuming 30 individuals sampled per trip, as specified in port sample instructions.

	SVA		DMV		NJ		LI		SNE		GBK	
Year	Lengths	Trips	Lengths	Trips	Lengths	Trips	Lengths	Trips	Lengths	Trips	Lengths	Trips
1982	30	1	7756	259	7477	249			30	1		
1983	30	1	5923	197	11253	375			30	1		
1984	90	3	3066	102	12751	425			90	3	30	1
1985			1832	61	7674	256			150	5	275	15
1986	23	1	1260	42	5130	171			330	11	143	7
1987			730	24	900	30			569	19		
1988			420	14	900	30			810	27		
1989			866	29	919	31			449	15		
1990			892	30	901	30			209	7		
1991			1080	36	2272	76						
1992			1170	39	1710	57						
1993			1392	46	928	31	1127	56				
1994			119	4	900	30						
1995			720	24	510	17						
1996			1154	38	1117	37						
1997			1622	54	957	32						
1998			1560	52	690	23						
1999			1720	57	856	29						
2000			600	20	3315	111	30	1				
2001			970	33	1260	42						
2002			210	7	1111	37						
2003			60	2	2455	80	198	11				
2004			18	1	425	21	441	24				
2005			410	18	1250	62	349	18				
2006			1074	50	940	47	374	20				
2007			1582	67	1568	80	994	47				
2008			1195	55	1317	67	774	38				
2009			697	31	1148	57	1127	56				
2010			450	20	1064	49	614	30	941	43	30	1
2011			578	26	2558	119	210	10	145	7	30	1
2012	30	1	919	40	1213	58	170	8	30	1	275	15
2013			604	27	1621	75	156	8	30	1	143	7
2014			325	16	1118	51			90	3	220	11
2015			521	24	819	39			150	5	482	25
min	23	1	18	1	425	17	30	1	30	1	30	1
max	90	3	7756	259	12751	425	1127	56	941	43	482	25
mean	41	1	1279	45	2383	86	505	25	270	10	181	9

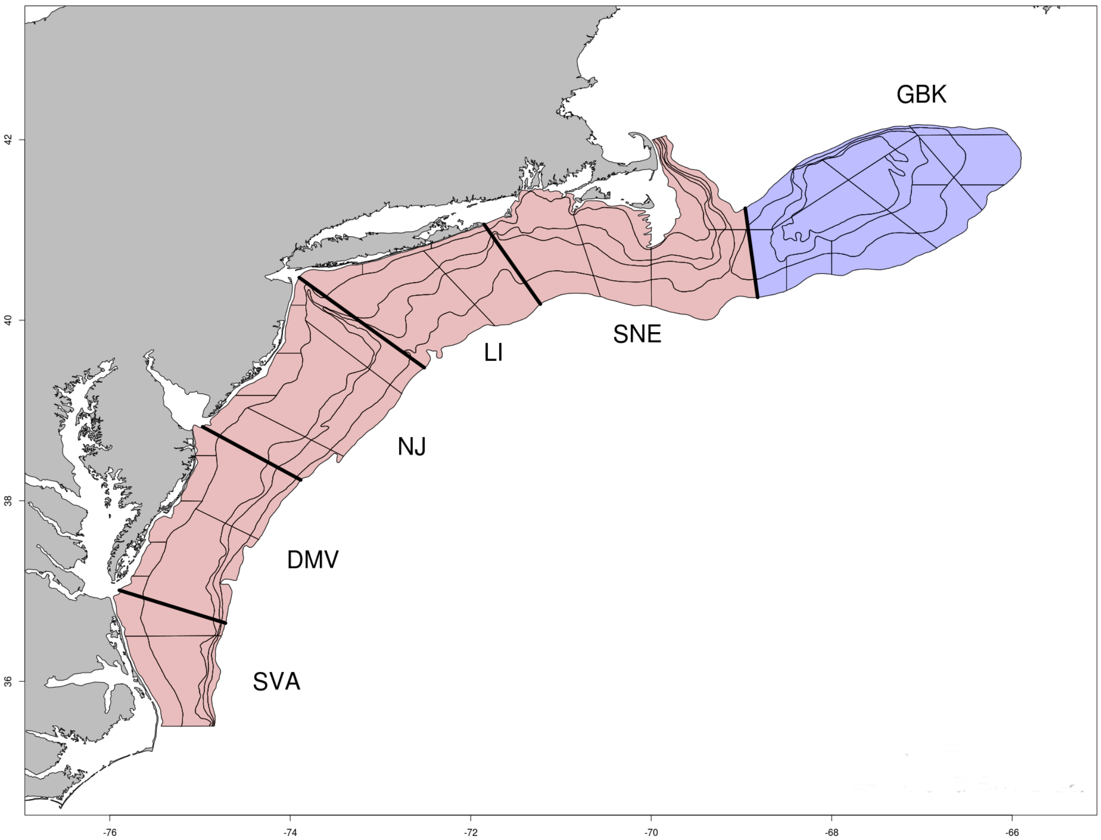


Figure 1: The Atlantic surfclam regions divided, for assessment modeling, into two areas. The northern area is blue and the southern area is pink.

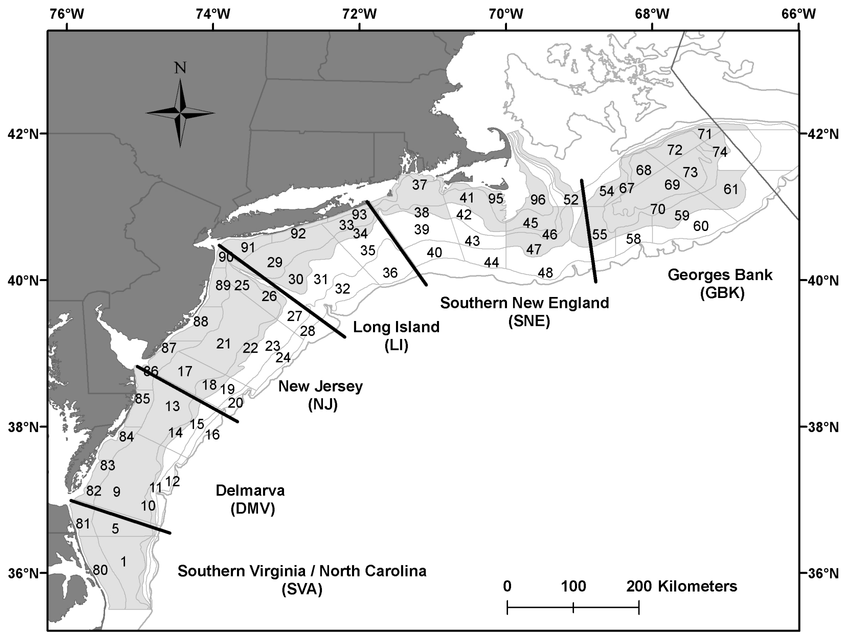


Figure 2: Surfclam stock assessment regions and NEFSC shellfish survey strata. The shaded strata are the surfclam strata that have been used in past assessments.

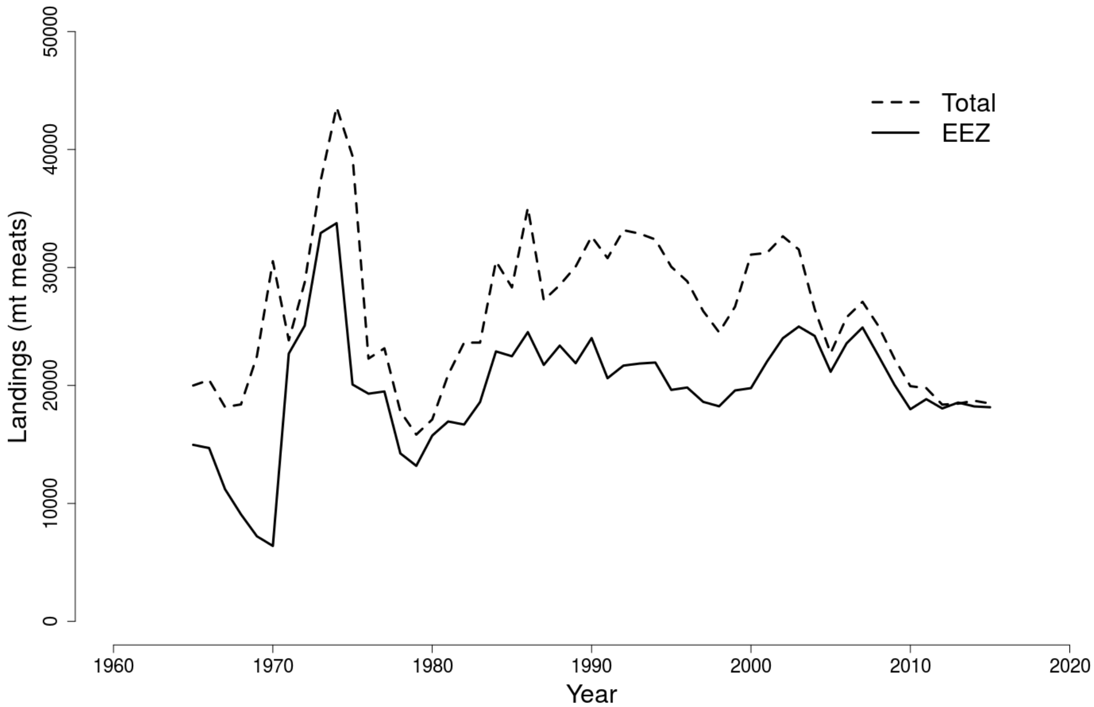


Figure 3: Atlantic surfclam landings (total and EEZ) during 1965-2015.

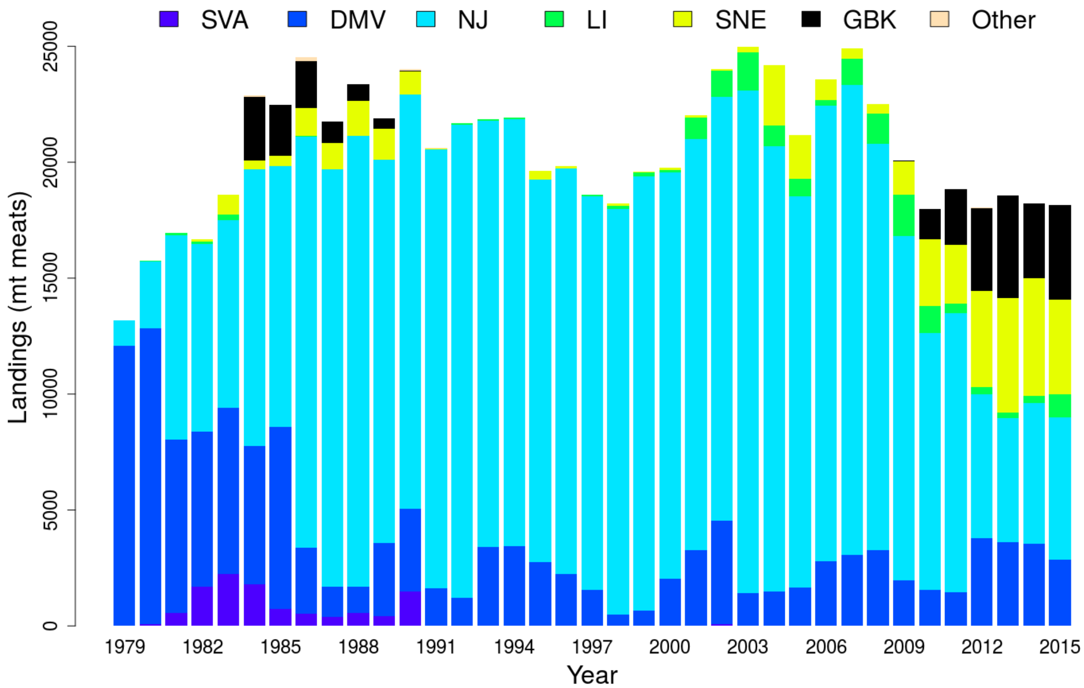


Figure 4: Surfclam landings from the US EEZ during 1979-2015, by stock assessment region.

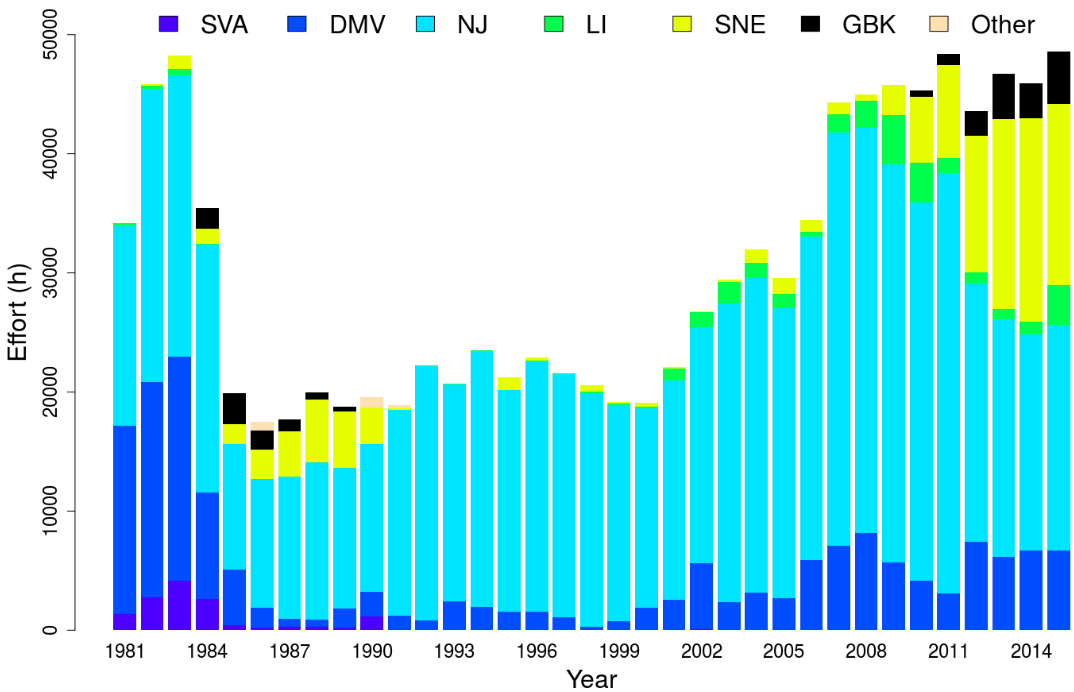


Figure 5: Surfclam hours fished from the US EEZ during 1981-2015, by stock assessment region.

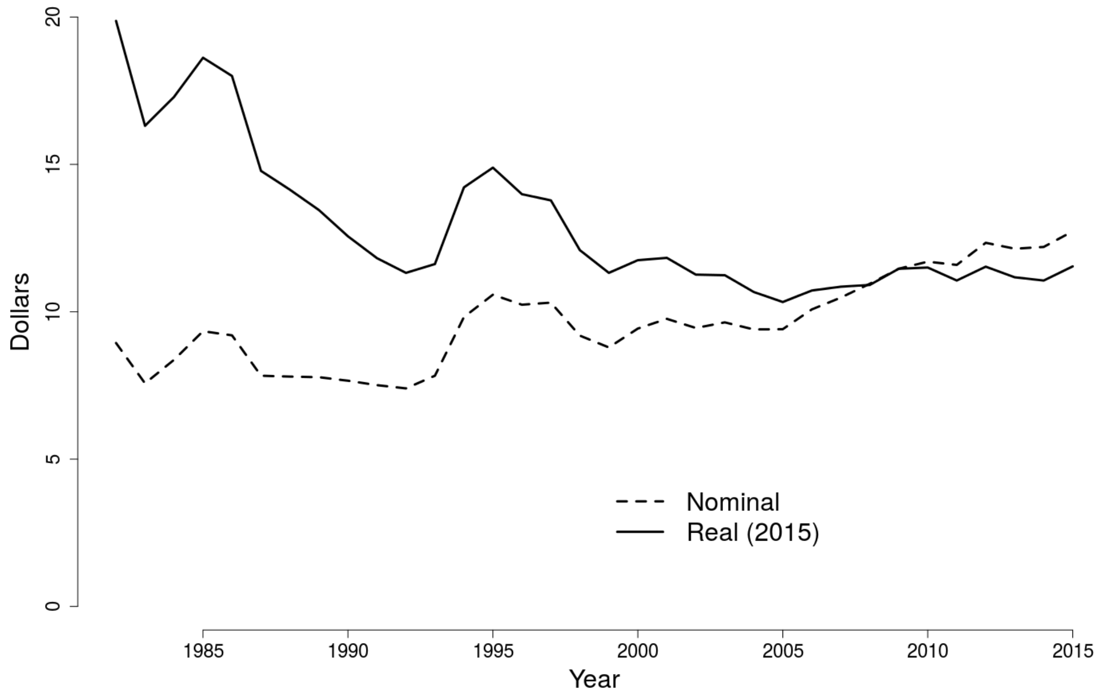


Figure 6: Nominal and 2015 dollar equivalent prices for surfclam 1981-2015.

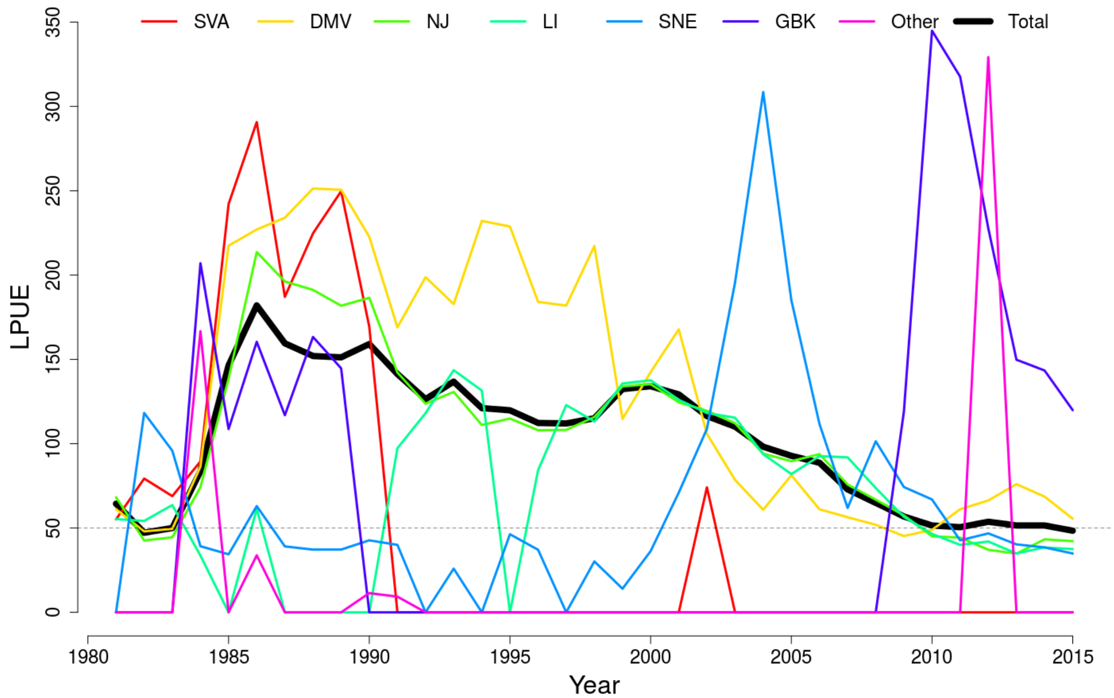


Figure 7: Nominal landings per unit effort (LPUE in bushels landed per hour fished) for surfclam, by region and overall. LPUE is total landings in bushels divided by total fishing effort. A dashed line has been added at LPUE=50 for reference.

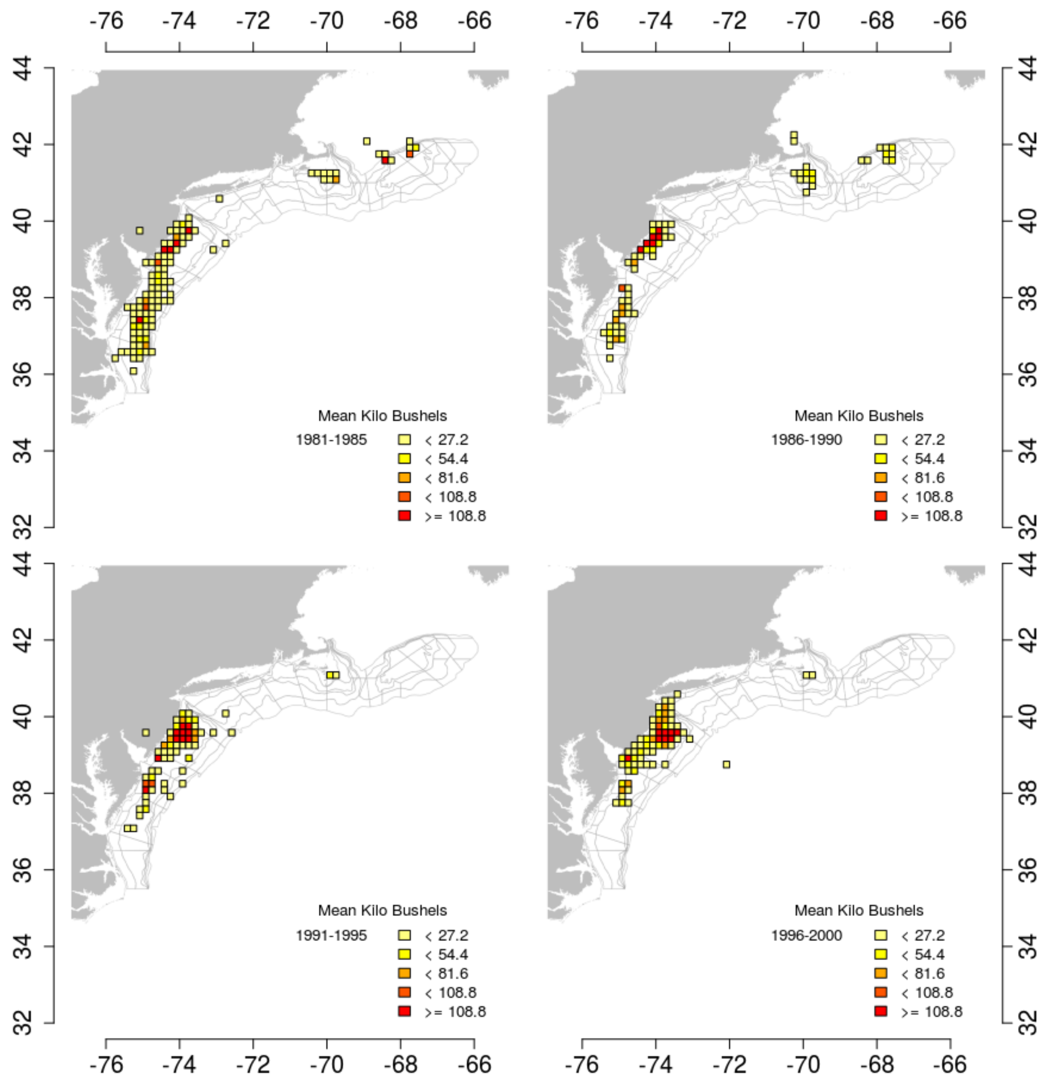


Figure 8: Average surfclam landings by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

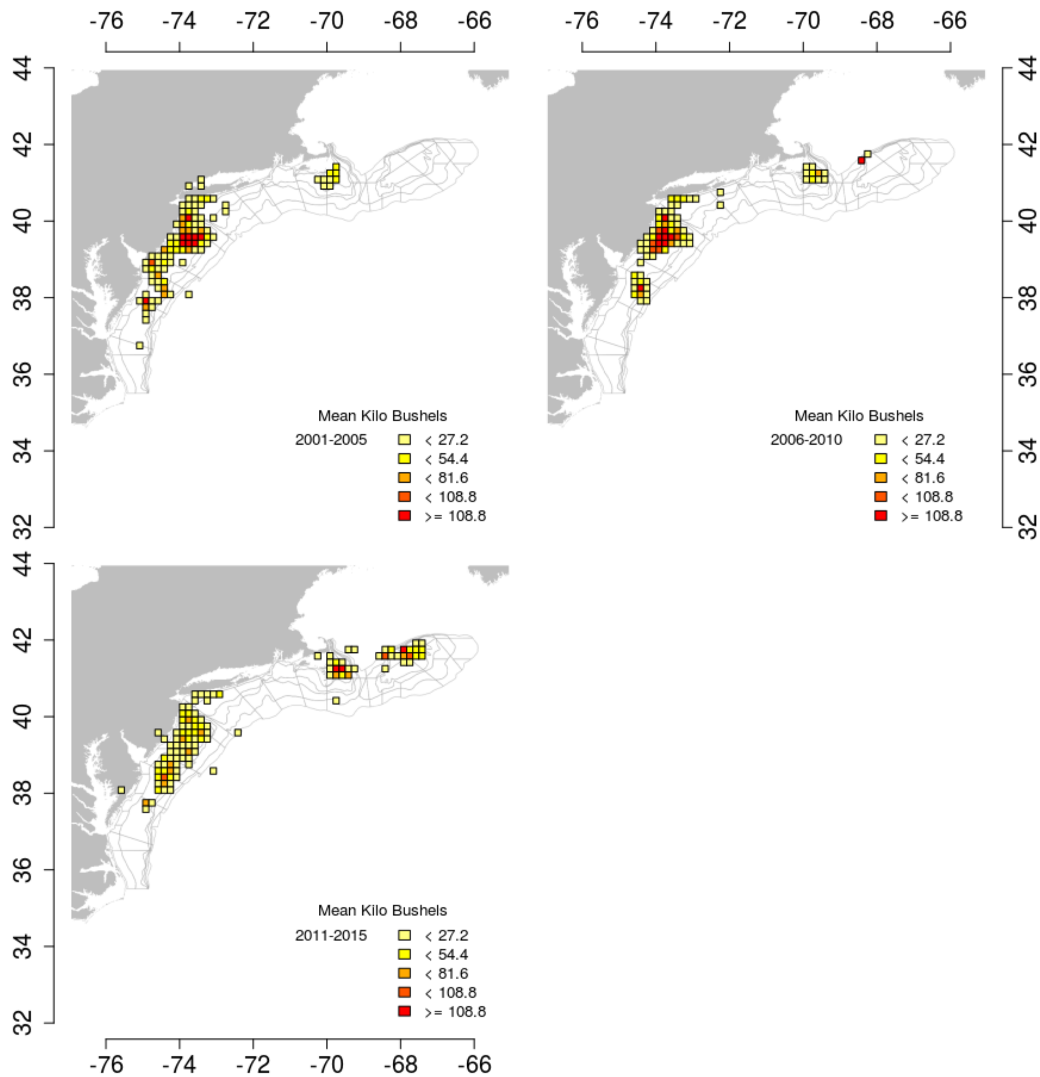


Figure 9: Average surfclam landings by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

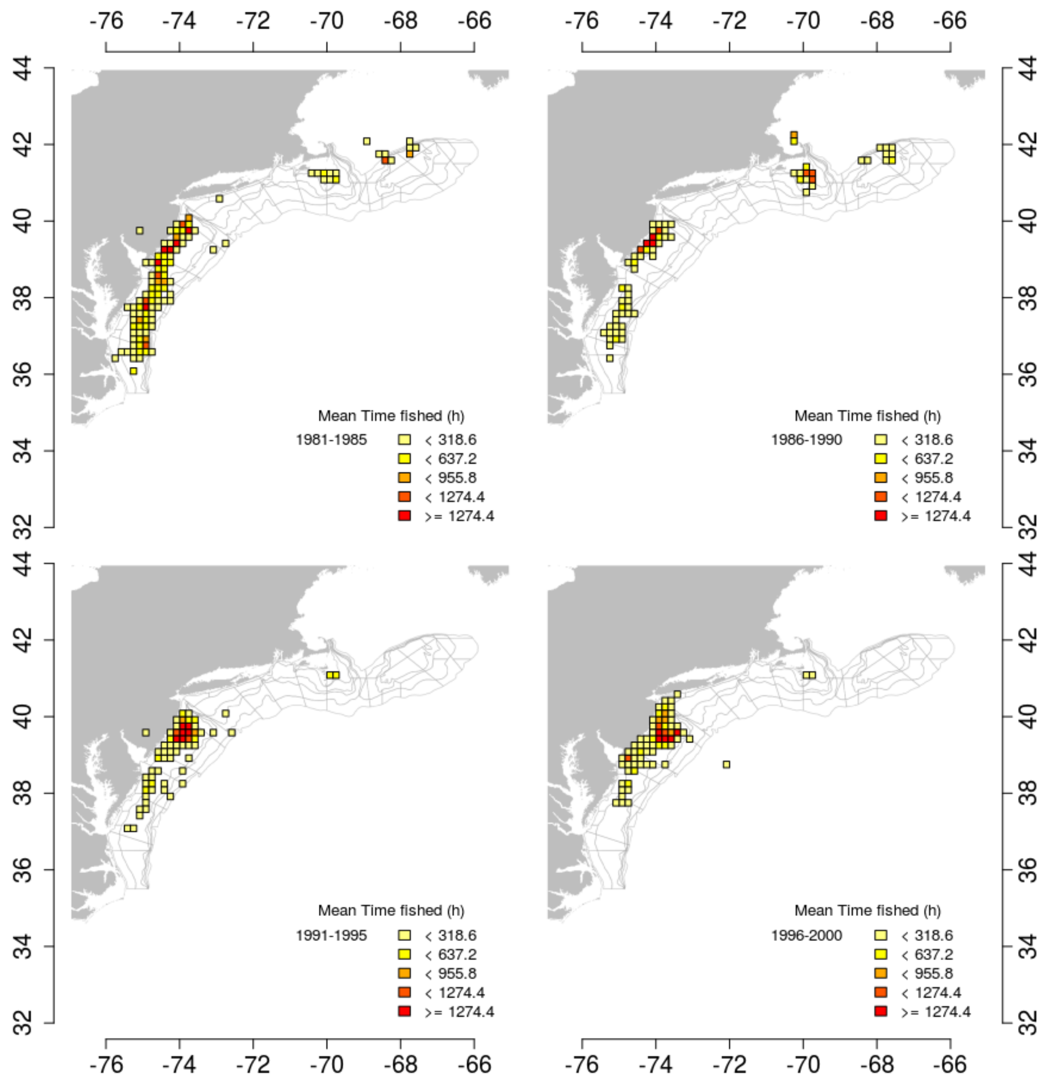


Figure 10: Average surfclam effort by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

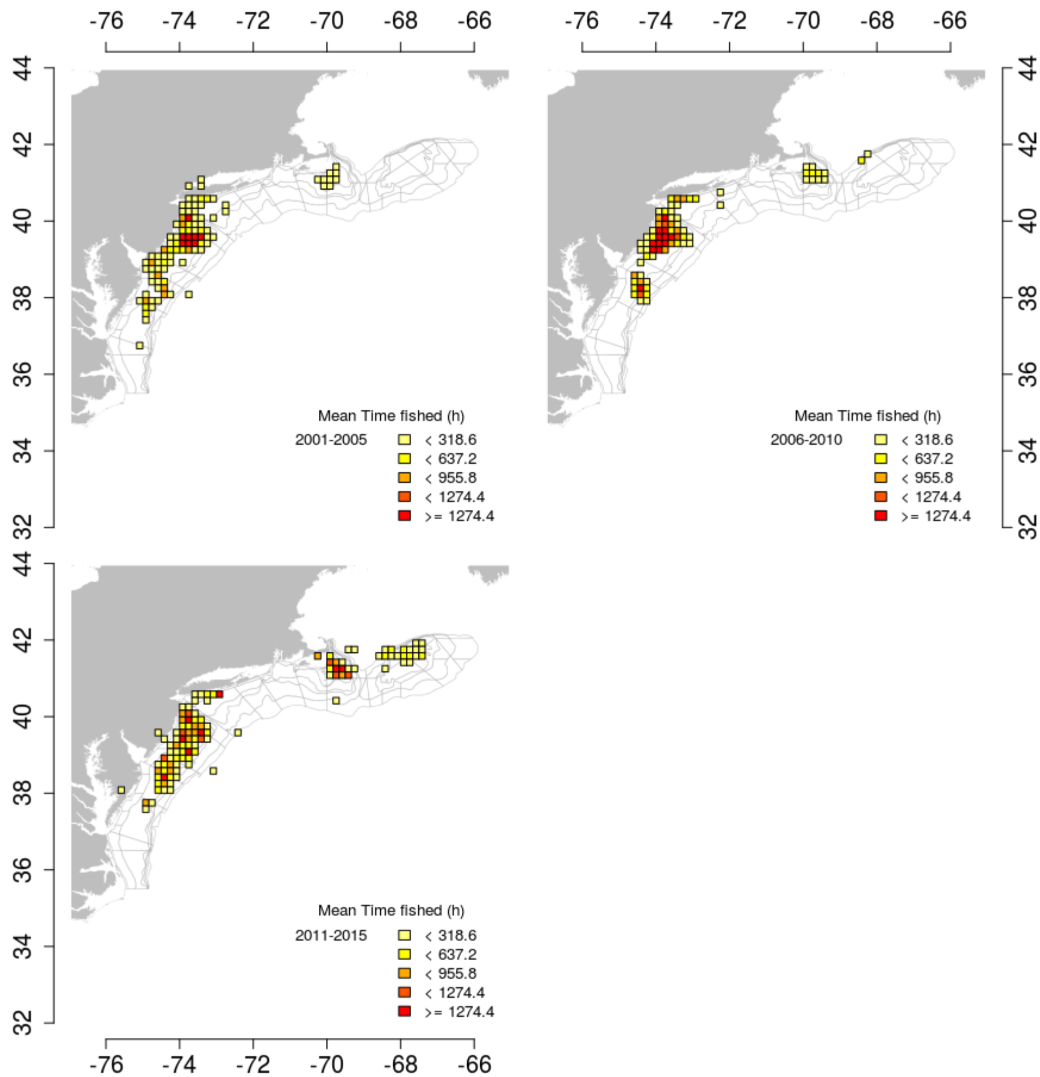


Figure 11: Average surfclam effort by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

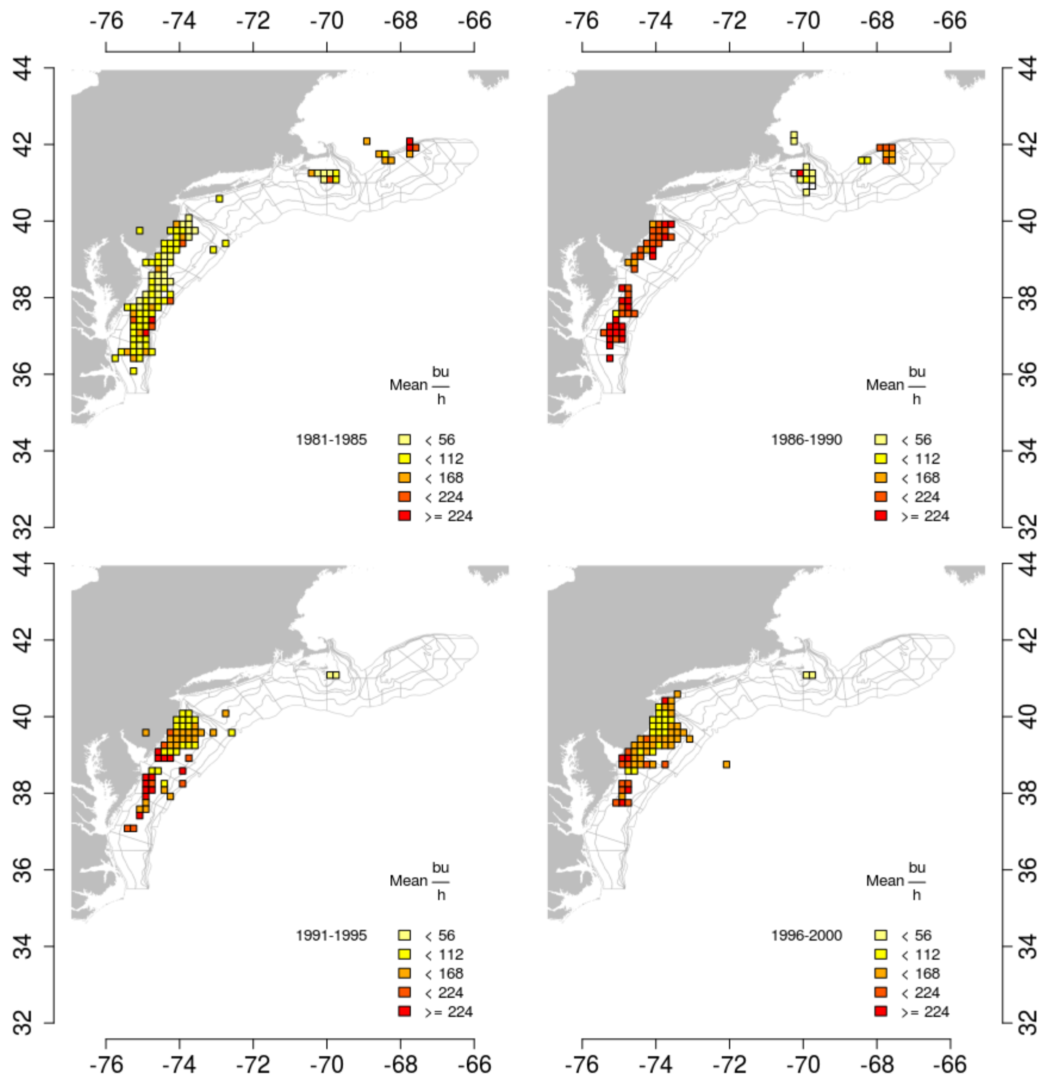


Figure 12: Average surfclam LPUE (bu. h^{-1}) by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

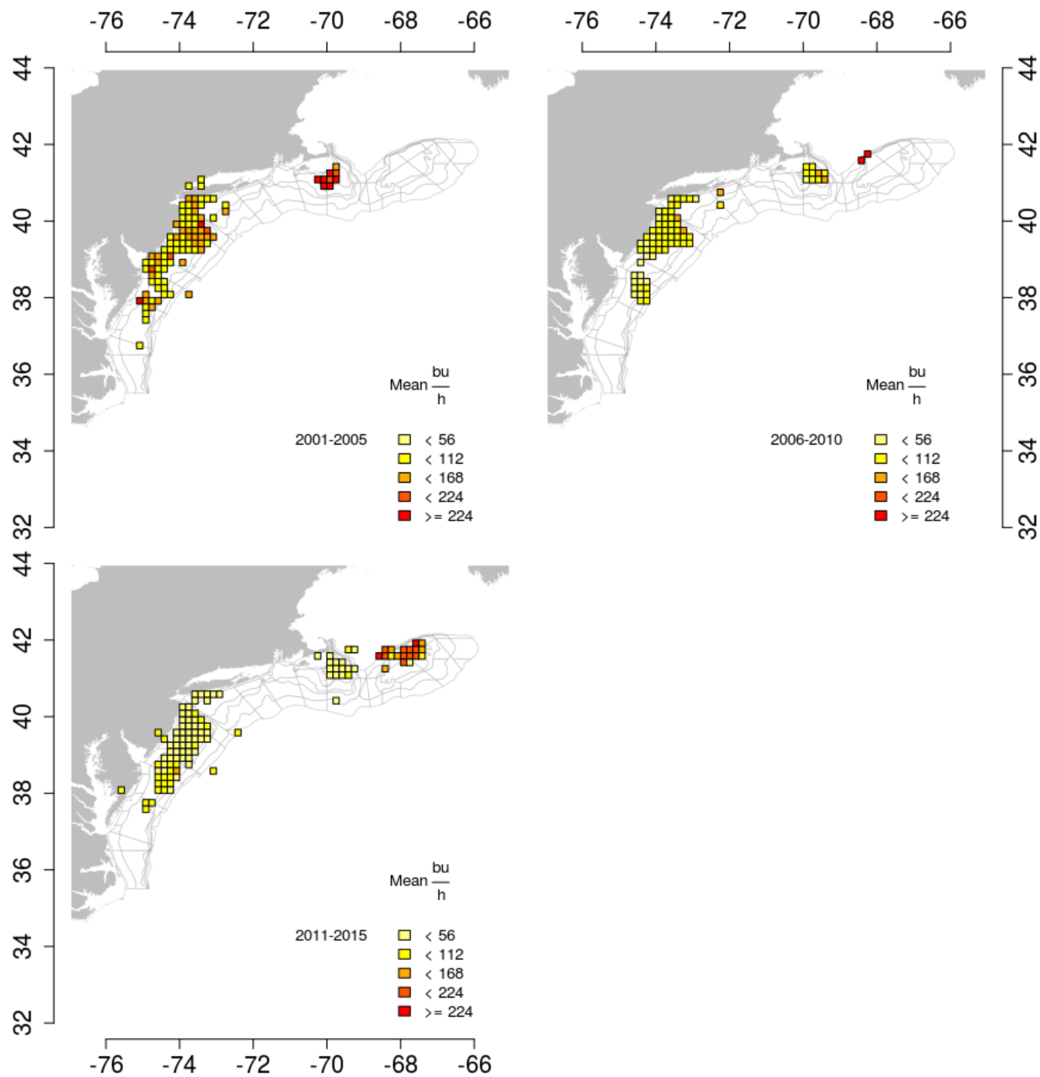


Figure 13: Average surfclam LPUE (bu. h^{-1}) by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

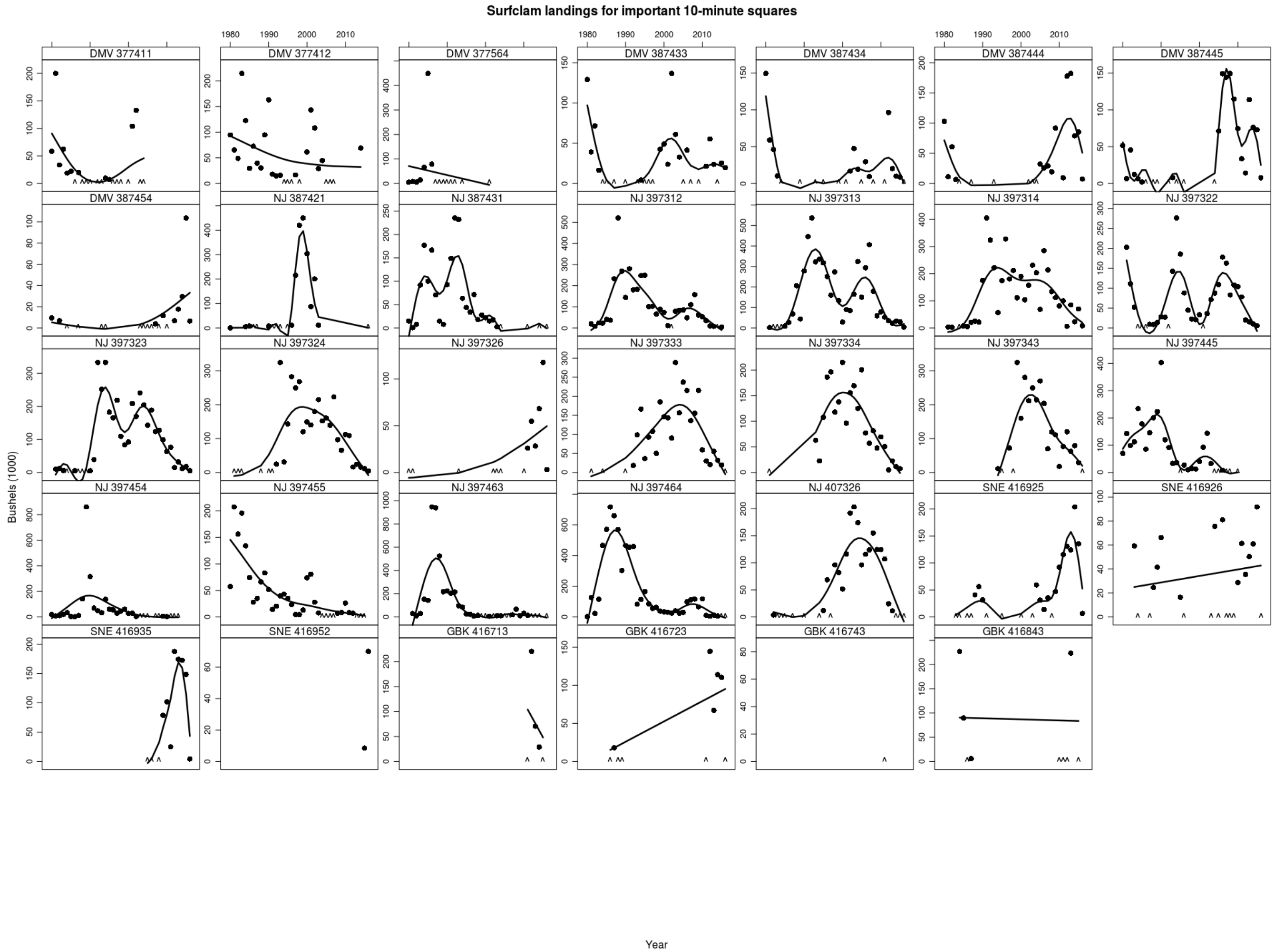


Figure 14: Annual surfclam landings in "important" ten minute squares (TNMS) during 1980-2015 based on logbook data. Important means that a square ranked in the top 10 TNMS for total landings during any five-year period (1980-1984, 1985-1989, ..., 2000-2004, 2005-2009, 2010-2015). To protect the privacy of individual firms, data are not plotted if the number of vessels is less than 3. 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.

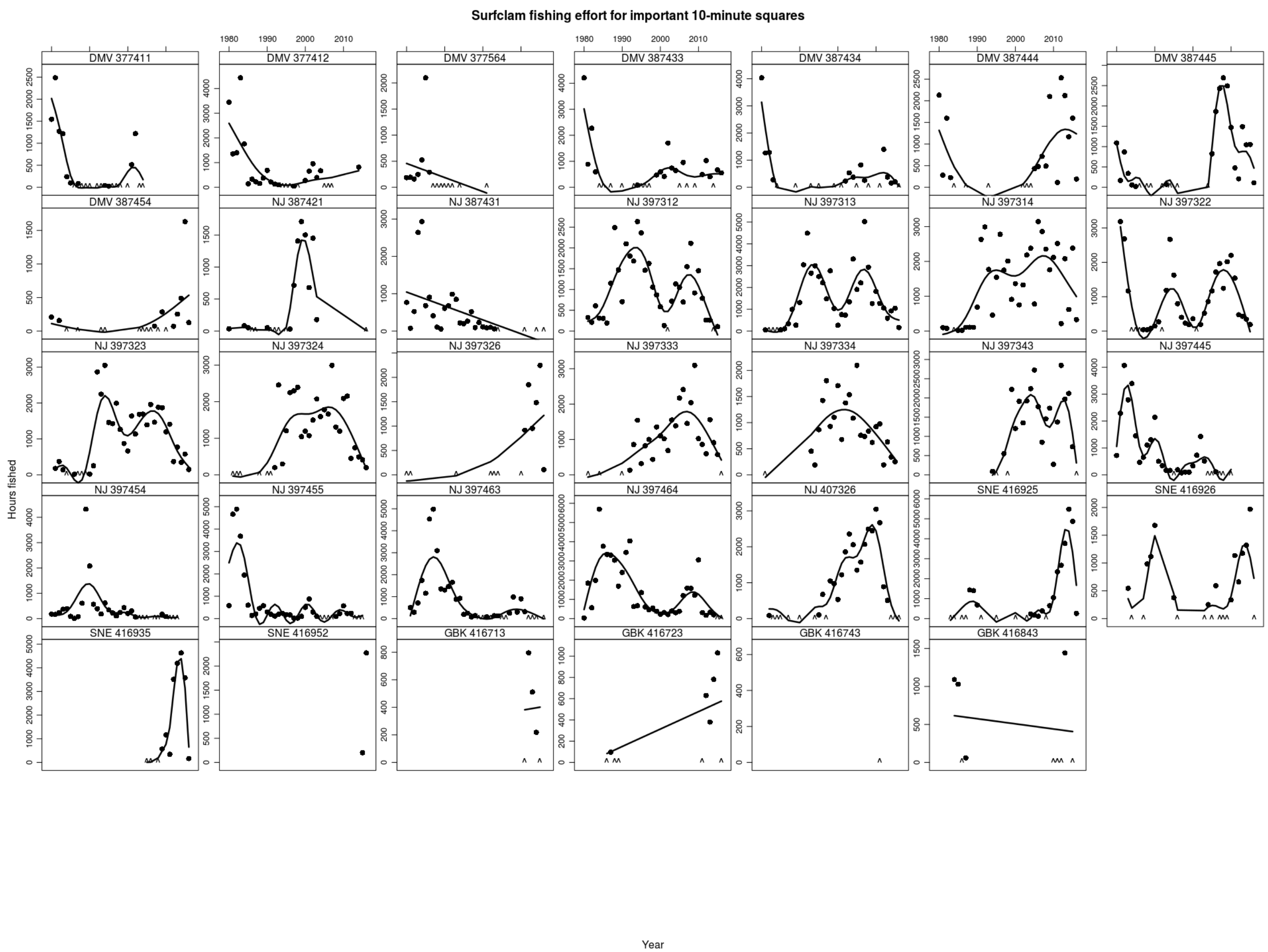


Figure 15: Annual surfclam effort (hours y^{-1}) in "important" ten minute squares (TNMS) during 1980-2015 based on logbook data. Important means that a square ranked in the top 10 TNMS for total landings during any five-year period (1980-1984, 1985-1989, ..., 2000-2004, 2005-2009, 2010-2015). To protect the privacy of individual firms, data are not plotted if the number of vessels is less than 3. Instead, a "$\wedge$" 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.

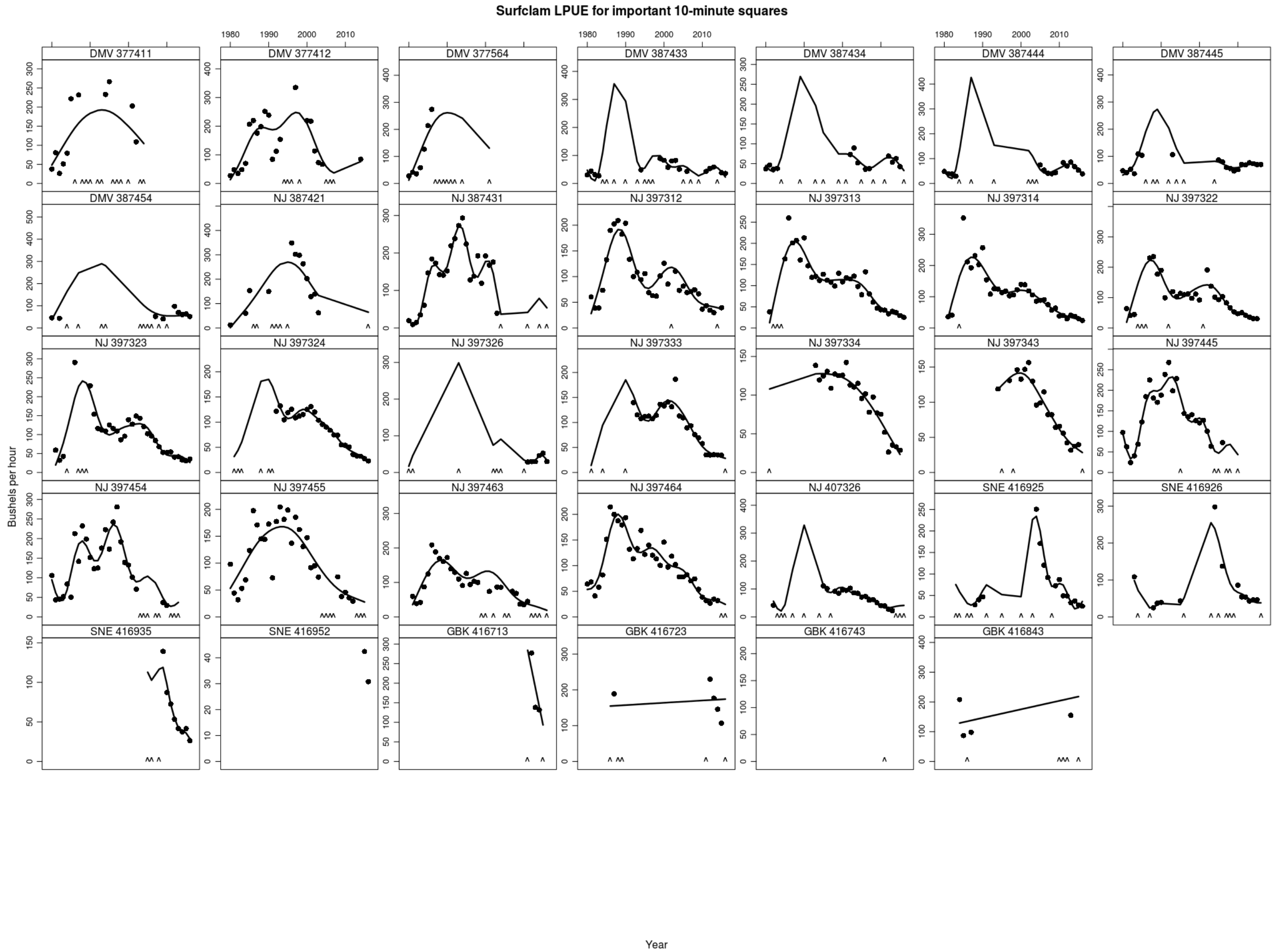


Figure 16: Annual surfclam LPUE (bu h^{-1}) in "important" ten minute squares (TNMS) during 1980-2015 based on logbook data. Important means that a square ranked in the top 10 TNMS for total landings during any five-year period (1980-1984, 1985-1989, ..., 2000-2004, 2005-2009, 2010-2015). To protect the privacy of individual firms, data are not plotted if the number of vessels is less than 3. Instead, a "$\wedge$" 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.

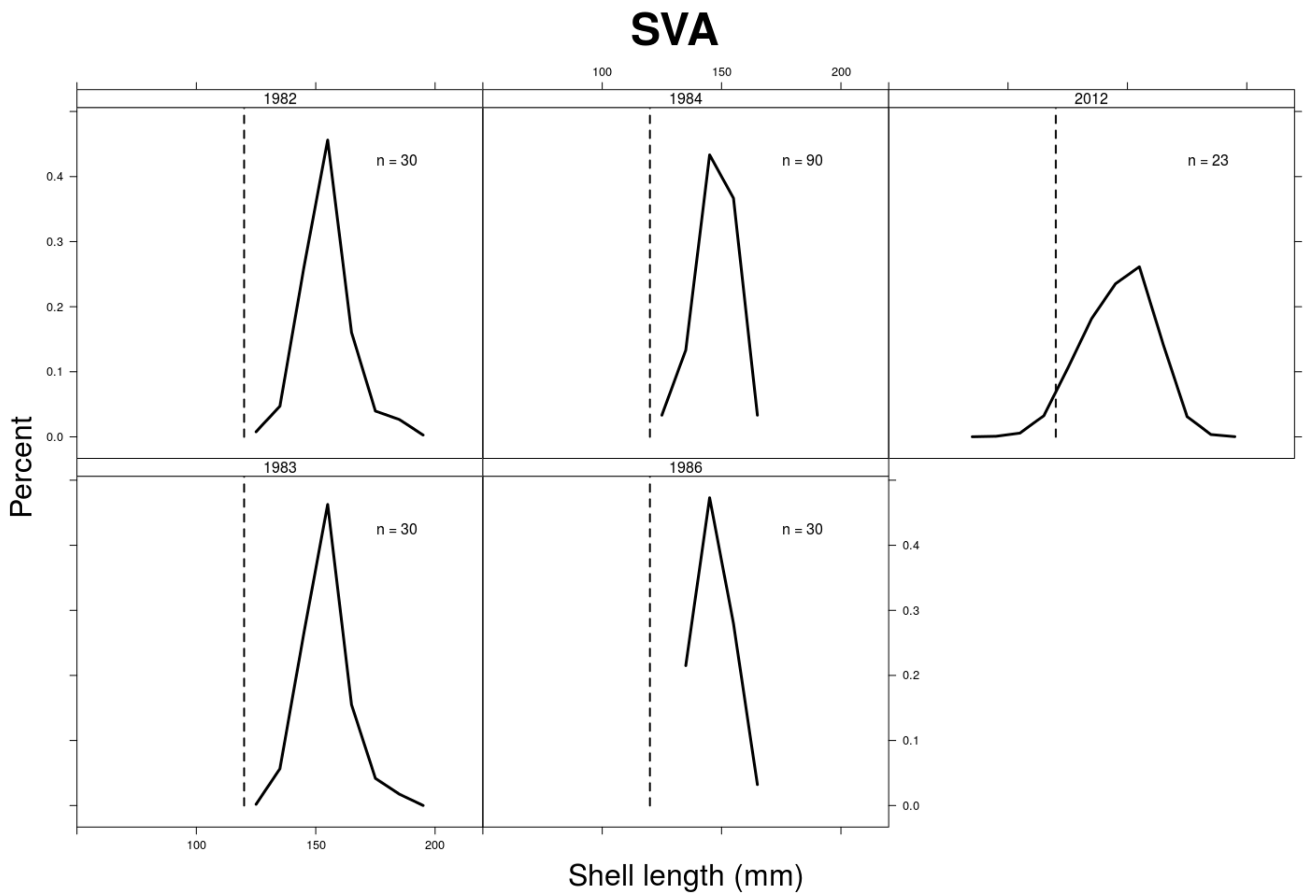


Figure 17: Length compositions for Atlantic surfclam from port samples of landings from the SVA region. Sample sizes are the number of clams measured in each year.

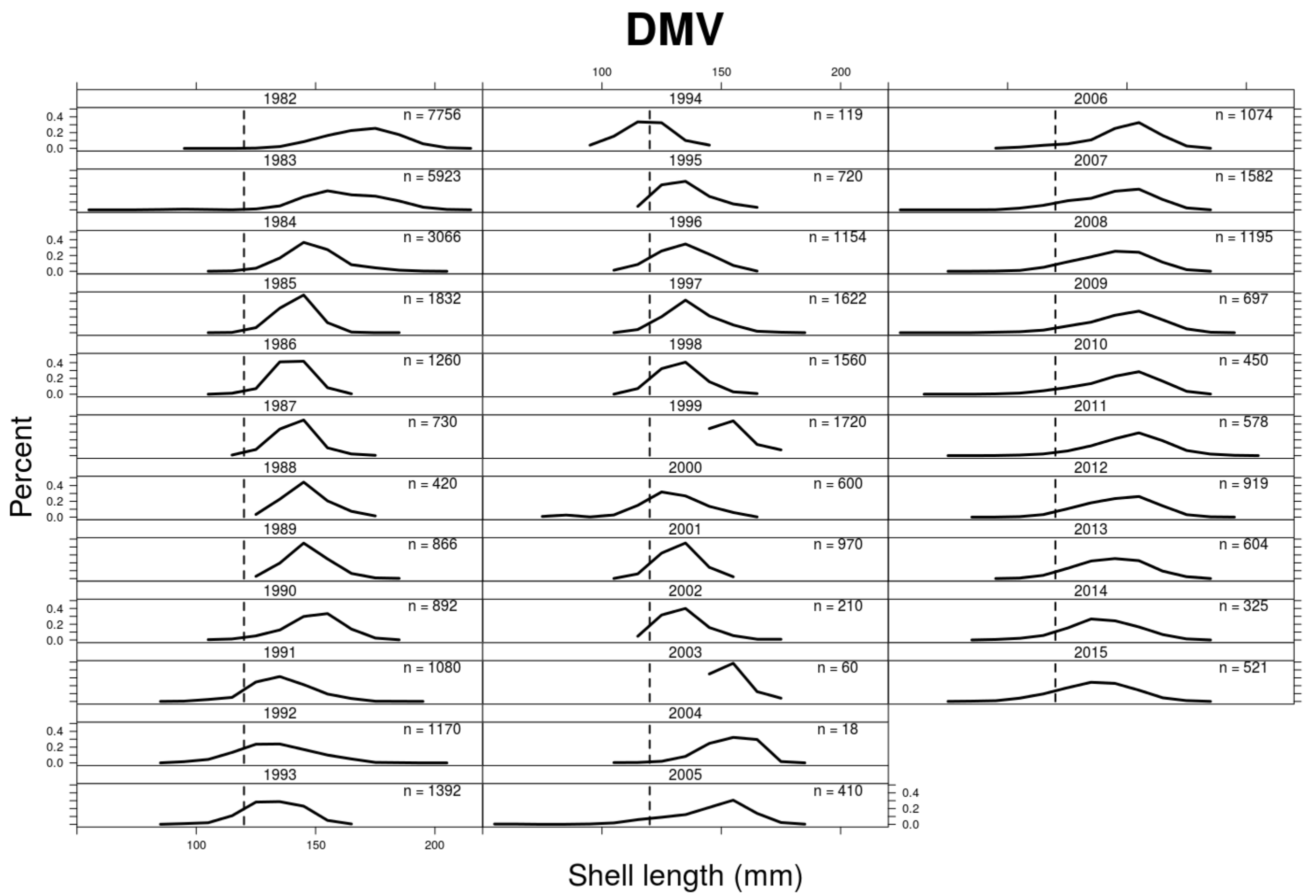


Figure 18: Length compositions for Atlantic surfclam from port samples of landings from the DMV region. Sample sizes are the number of clams measured in each year.

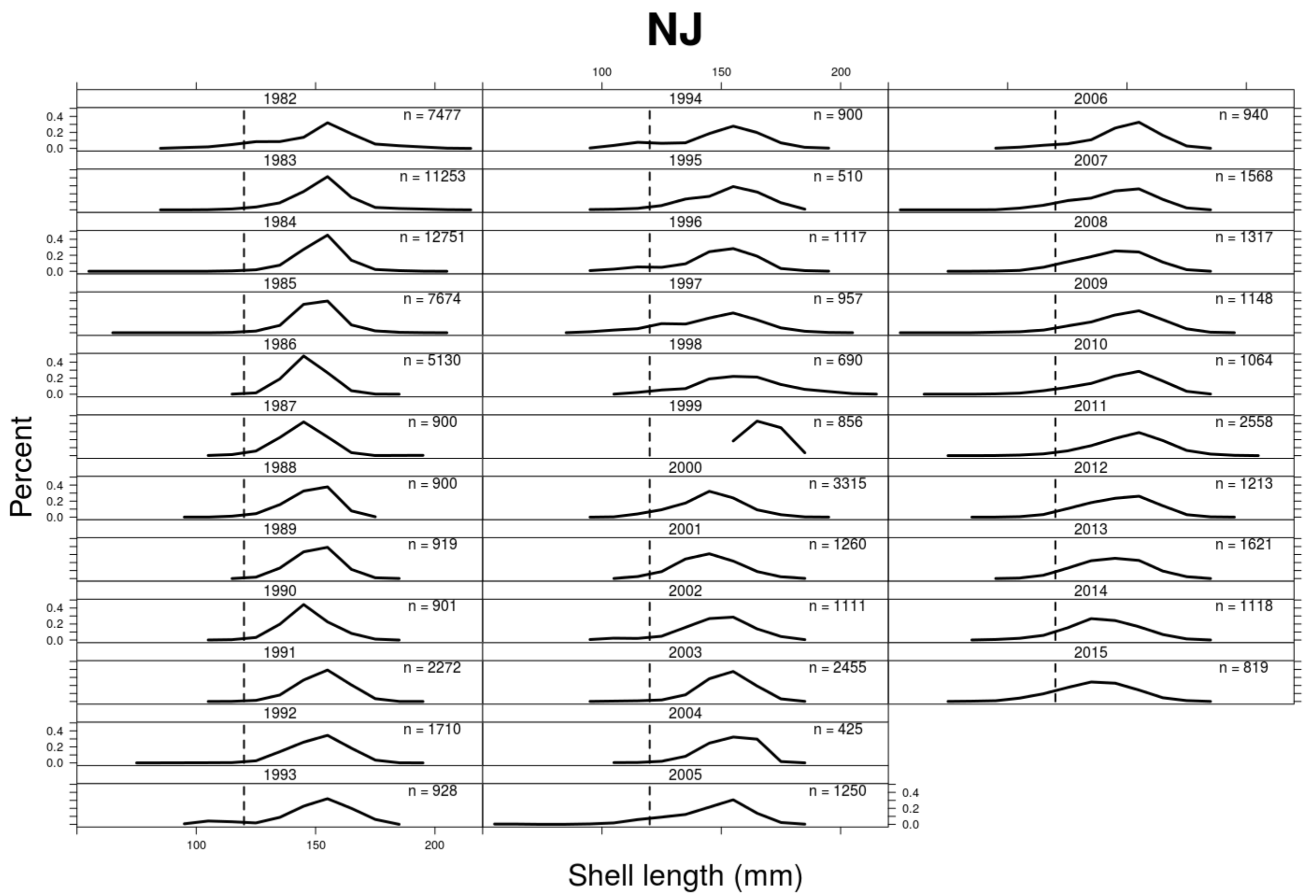


Figure 19: Length compositions for Atlantic surfclam from port samples of landings from the NJ region. Sample sizes are the number of clams measured in each year.

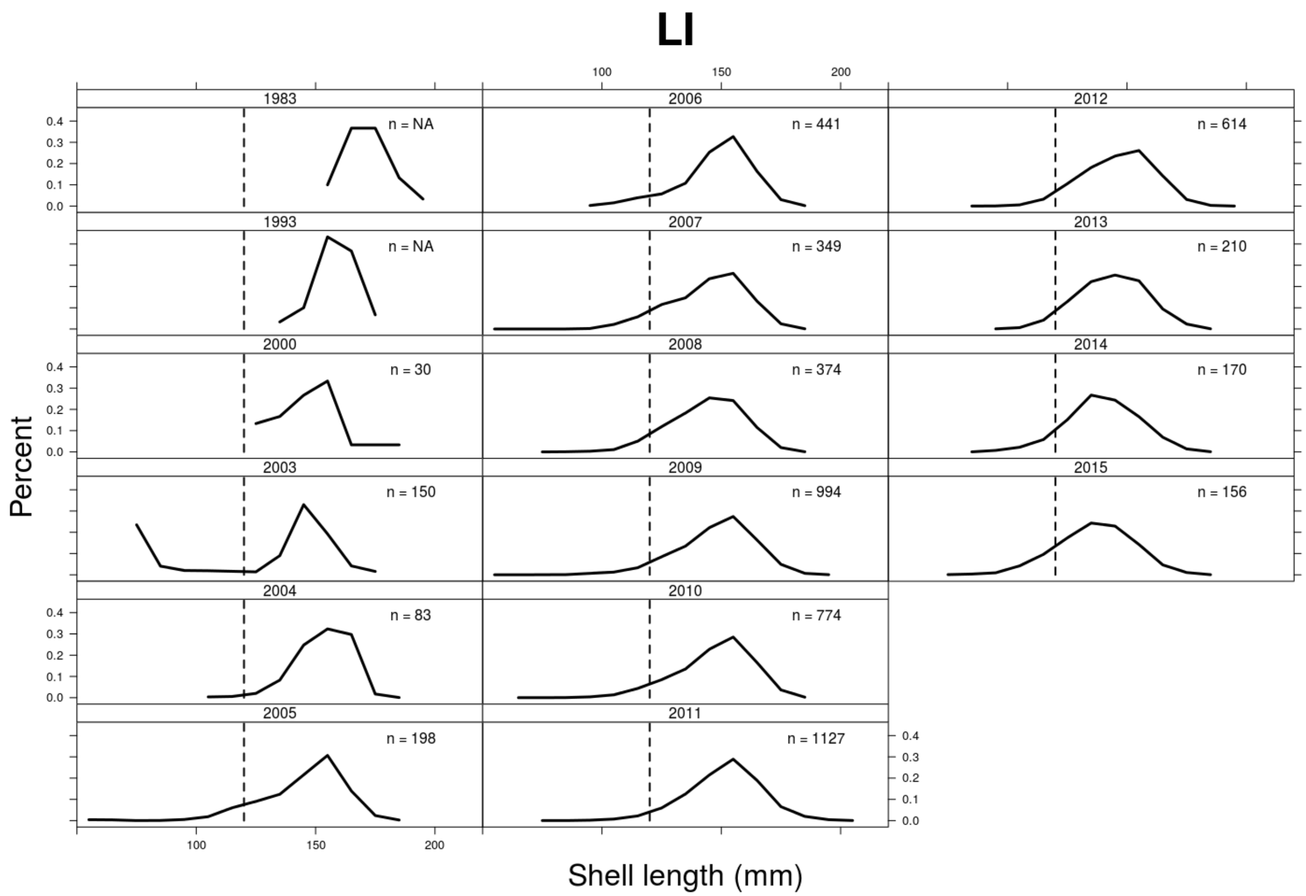


Figure 20: Length compositions for Atlantic surfclam from port samples of landings from the LI region. Sample sizes are the number of clams measured in each year.

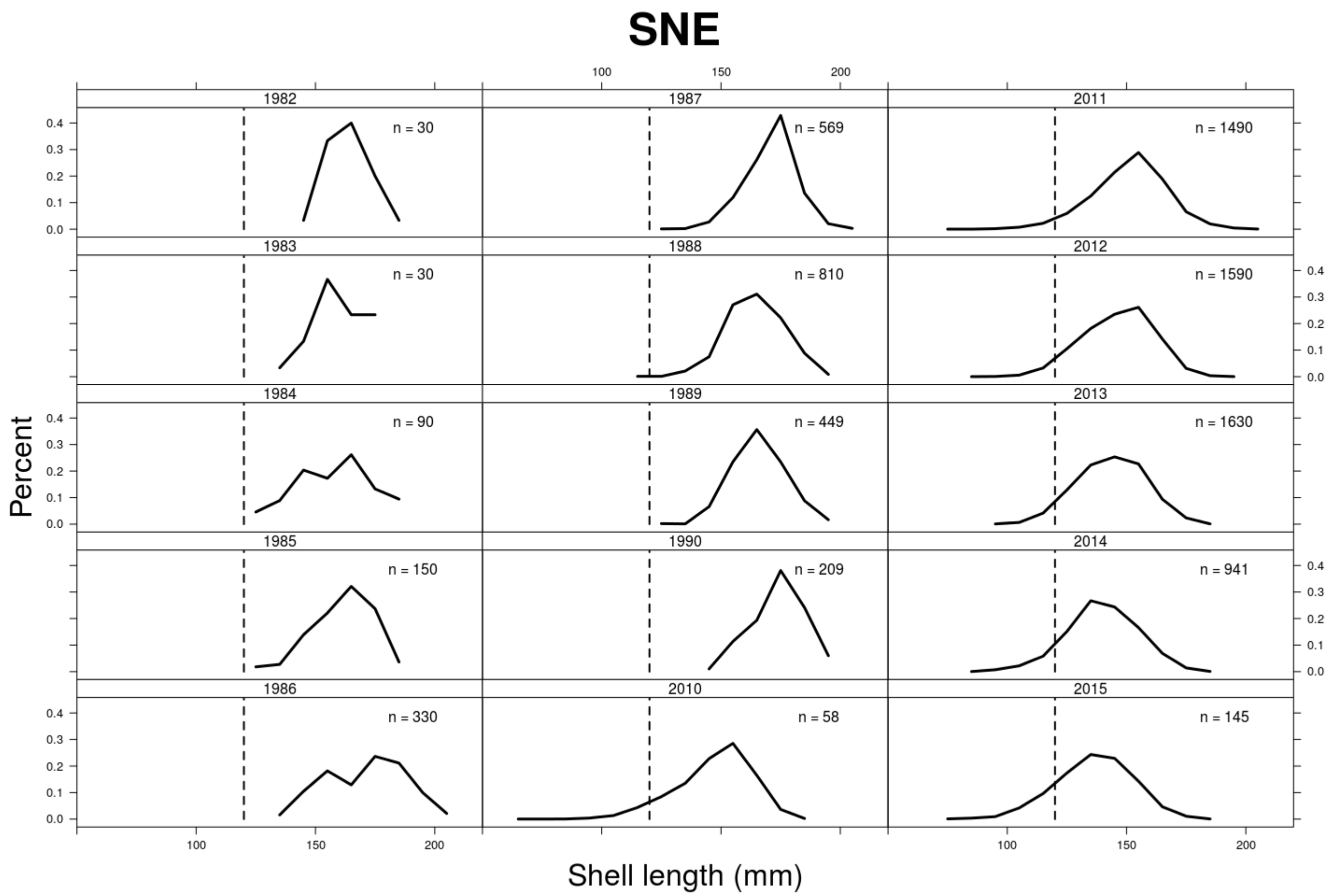


Figure 21: Length compositions for Atlantic surfclam from port samples of landings from the SNE region. Sample sizes are the number of clams measured in each year.

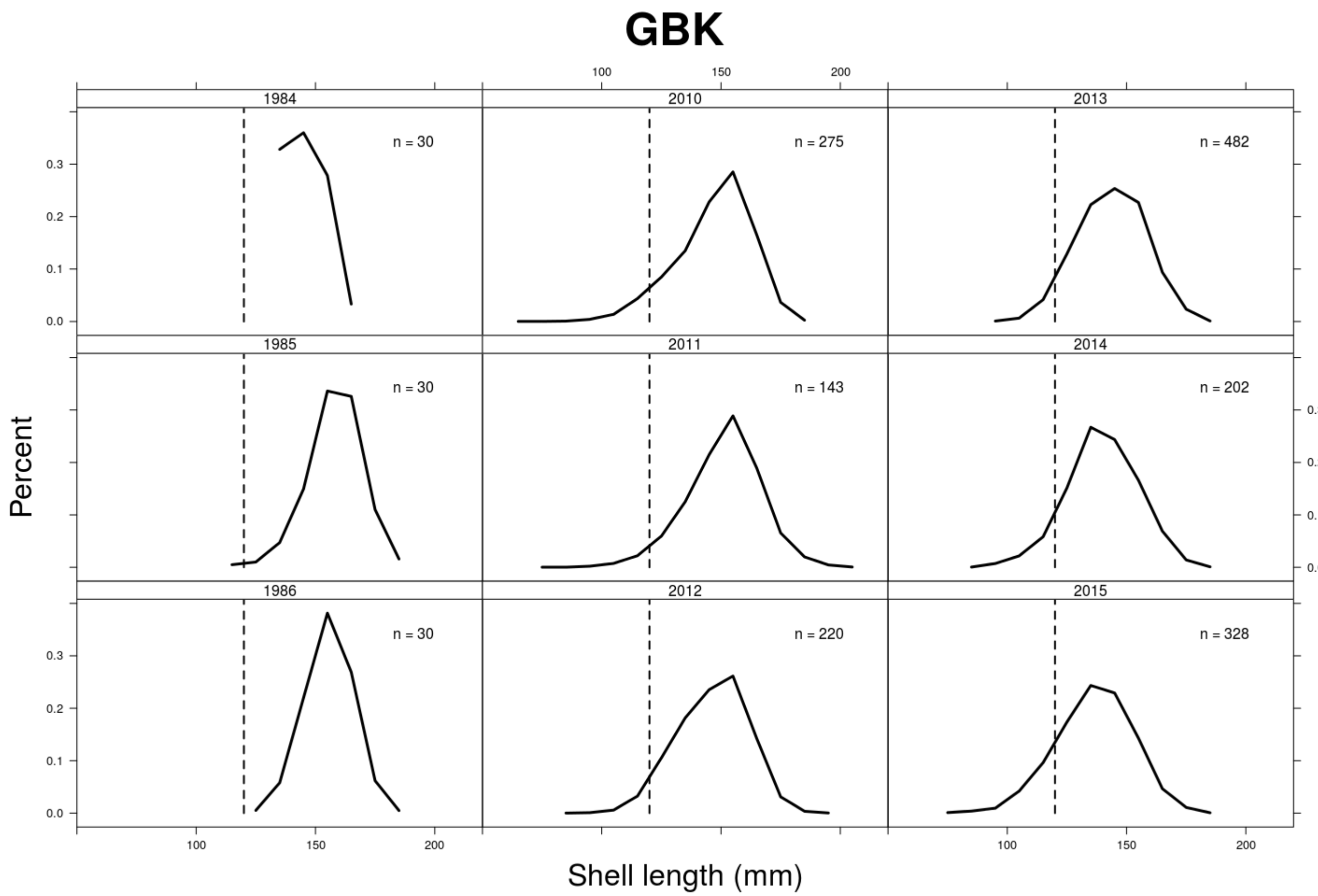


Figure 22: Length compositions for Atlantic surfclam from port samples of landings from the GBK region. Sample sizes are the number of clams measured in each year.

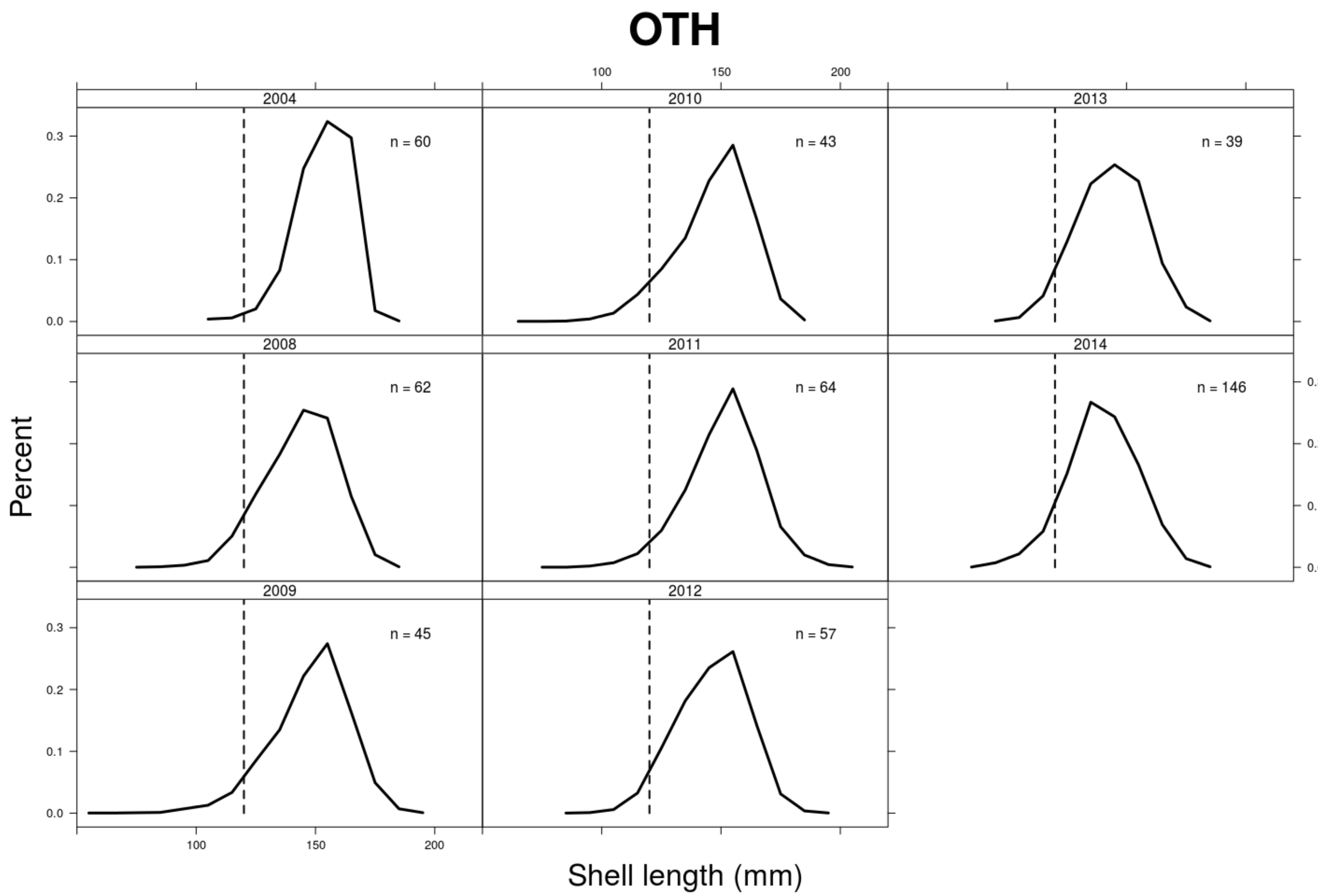


Figure 23: Length compositions for Atlantic surfclam for which no area was recorded (OTH). Sample sizes are the number of clams measured in each year.

Part III

TOR 2: Survey

NEFSC clam surveys

Survey data used in this assessment were from 2 different sampling platforms. The first was the NEFSC clam surveys conducted during 1982–2011 by the *RV 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 (Atlantic surfclam 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 Atlantic surfclam 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 Northeast Fisheries Science Center (2003). The second survey platform was the *ESS Pursuit*, a commercial vessel that was contracted to conduct the NEFSC clam survey since 2012, when the *RV Delaware II* was retired. The *ESS Pursuit* used a modified commercial dredge described in detail in Hennen et al. (2016). Surveys conducted from the *ESS Pursuit* have taken place in August each year since 2012.

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 (Northeast Fisheries Science Center 2003)).

NEFSC clam surveys were organized around NEFSC shellfish strata and stock assessment regions (Figure 2). Most Atlantic surfclam landings originate from areas covered by the survey. The survey did not cover GBK during 2005 and provided marginal coverage there 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 8). Survey data were never borrowed from surveys before the previous, or beyond the next survey. A model–based imputation was investigated for the last assessment (Northeast Fisheries Science Center 2013), but the imputation tended to over–emphasize unsampled years and areas. Alternative approaches to imputing missing strata were not further pursued in this assessment.

Surveys followed a stratified random sampling design, allocating a pre-determined number of tows to each stratum. A standard tow was 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 was typically longer than 0.125 nm (Weinberg et al. 2002). These problems were eliminated in 2012 when the survey was switched to the *ESS Pursuit*. For trend analysis, when using data from before 2012, 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 start and stop times recorded on the bridge. Stations used to measure trends in Atlantic 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. Other non-random stations were occupied for a variety of purposes (e.g. selectivity experiments) but not used to estimate trends in abundance. Locations and catches of all stations in the survey have been mapped (Figures 24–27).

Occasionally, randomly selected stations were found to be too rocky or rough to tow, particularly on GBK. The proportion of random stations that could not be fished was an estimate of the proportion of habitat in an area that was not suitable habitat for Atlantic surfclam (IV). These estimates were used in the calculation of Atlantic surfclam swept-area biomass (see below).

Following most survey tows, all Atlantic surfclam in the survey dredge are counted and shell length is measured to the nearest mm. 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 1997–2015 surveys (see below).

Survey tow distance and gear performance based on sensor data

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), 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 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.

Determination of time fishing

The determination of time fishing, the "fishing seconds" for each tow (after 1997), was based on a measurement of the pitch of the dredge during each second of the tow. Pitch data were smoothed using a 7 second moving average and then compared to a "critical angle" to determine when the dredge was fishing effectively. When the dredge was above the critical angle it was assumed to be pitched too steeply for the blade to penetrate the sediment. When the dredge was pitched below the critical angle, it was assumed to be near enough to horizontal that the blade should penetrate and thus be actively fishing.

It is important to find a critical angle for tow distance that is neither too small, nor too large. 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. Further discussion of the determination of critical angle as well as summaries of dredge performance by year are in appendices (XXVII–XXIX).

NEFSC clam survey trends and composition data

NEFSC clam survey data for Atlantic surfclam, including the number and weight caught per tow were tabulated by year, region and for the entire stock (Table 9). Mean numbers per tow were used in the plots of trends 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 Atlantic surfclam (Figure 43) provide some evidence for recruitment trends over time. Recruitment appears to be increasing in DMV, NJ, LI, and SNE since the last assessment. Survey trends for fishable (120+mm) Atlantic surfclam (Figures 44) show evidence of decreasing abundance in the SVA, and possibly LI regions, but there are increasing trends in abundance in DMV, NJ and SNE. We cannot make inference on trends in abundance or recruitment on GBK because there is only one data point available from the new survey. Based on survey data for the entire southern area, recruitment and fishable abundance have been increasing since the last assessment 2011 (Figures 45 – 46).

Survey age–length keys and stratified mean length composition data were used to estimate the age composition of Atlantic surfclam 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 2015 when surveys occurred. Ages ranged from 1-37 (Figures 30 – 35). Specific year classes and trends in length and age composition are discussed in the context of the assessment model (see V).

Shell length composition data (Figures 37 – 42) can be helpful in visually identifying shifts in population demography. For example, there is evidence of recent recruitment in the southern area regions.

Dredge efficiency

Changes to the NEFSC survey involved changes to the survey gear. In particular, shifting the survey dredge from the research dredge (RD) used on the *RV Delaware II* to the modified commercial dredge (MCD) used on the *ESS Pursuit* was an important modification in that it necessitated a re-evaluation of capture efficiency. Fortunately the MCD was the same dredge that was used in previous depletion experiments (Northeast Fisheries Science Center 2013) so estimates of capture efficiency already exist. These are discussed in detail in XV and Northeast Fisheries Science Center (2013).

Estimates of survey dredge efficiency were used to generate prior distributions for capture efficiency for each survey in the assessment model (see V). A comparison of the prior distribution for the RD to the prior distribution for the MCD shows that the MCD has higher and more precisely estimated efficiency (Figure 178).

Size selectivity

Selectivity data were collected on the *ESS Pursuit* during selectivity experiments in 2008 – 2015. Data from the experiments were used to estimate size-selectivity for the MCD. The MCD was configured for survey operations, rather than commercial fishing operations. Thus, the size selectivity estimates for the commercial dredge used by the *ESS Pursuit* during cooperative survey work are not directly applicable to commercial catch data. Selectivity experiments are described in Hennen et al. (2016).

The data available for each selectivity study site included shell length data from: one MCD tow, and one F/V selectivity tow using either a commercial dredge lined with wire mesh or a specially designed selectivity dredge (SD). Gear testing work done in 2014 showed that the SD and the lined commercial dredge should be interchangeable in selectivity studies (Hennen et al. (2016)).

Shell length data from selectivity experiments conducted since the last assessment were tabulated using 1 mm shell length size groups (Tables 10 – 11). Survey size selectivity was estimated using data from 47 total sites.

Selectivity was modelled as a generalized additive mixed model (GAMM), where the shell length bin was a factor, predicting the binomial proportion of the survey catch over the total catch (SD + MCD). The fully saturated model was

$$P_L = e^{(\alpha + s(L) + s[YrSta, L] + offset)} \quad (1)$$

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 variables, in this case shell length (L) and a random effect (indicated with braces) due to station and year. The final term is an offset (Pinheiro and Bates (2006)) based on the tow distance at each station. Tow distance 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, while the SD was towed for 2 min.

Using the GAMM 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 modeller.

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 (Figure 48). 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

$$CI_L = elogit^{(\rho_L \pm 1.96\sigma_L)} \quad (2)$$

[1] See R package mgcv documentation

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

Selectivity estimates (Tables 13 – 14; Figure 49) were used to generate swept area and survey index plots (Figures 43 – 47) and are useful for comparison to assessment model results.

Shell length, meat weight relationships

The shell length-meat weight (SLMW) relationships are important because they are used to convert numbers of Atlantic surfclam 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 Atlantic 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 and Dichmont (2004)) were used to predict clam meat weight, using equations of the form:

$$MW = e^{(\alpha+\beta_0 ln(L)+\beta_1 c_1+\beta_2 c_2+\cdots+\beta_n c_n)} \tag{3}$$

where MW was meat weight, L was shell length, $c_1, \cdots, c_n$ were covariate predictors (*e.g.*, region or depth), and α and β_i were the estimated parameters. 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 reasonable for the distributions of meat weights (McCullagh and Nelder (1989)). The GLMM in all analyses used the quasi-Poisson family with a log link. Quasi-Poisson is a Poisson distribution with a variance inflation parameter that relaxes the Poisson requirement that the mean must equal the variance. Because shell length to meat weight relationships for Atlantic surfclam 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 17). The best model by AIC and BIC was a model with fixed effects for shell length, depth, and region and random effects for shell length slope and the intercept, using both the year and the station as the grouping variables.

Regional differences in meat weight are meaningful, particularly for the largest animals (Figure 58), though some of the differences between regions can be explained by the different depths found there (Figure 59).

Age and growth

Atlantic surfclam were measured at sea and the shells were retained for ageing in the laboratory. Shells for ageing 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 (Northeast Fisheries Science Center 2010). Age and length samples are available for most regions, but not from every survey (Table 15).

Plots of age vs. shell length by year and region (Figures 51 – 57) indicate that growth patterns have been relatively constant in most regions over time with DMV and NJ, where growth has slowed and maximum size has decreased over the last two decades.

Von Bertalanffy parameters for growth in shell length were estimated for each region and each survey year for which sufficient data existed (Table 16). The Von Bertalanffy growth curve used in the calculations was:

$$L_a = L_\infty(1 - e^{(-k(a-t_0))}) \tag{4}$$

Where L_a was length (mm) at age a, and L_∞, k and t_0 are Von Bertalanffy parameters.

Atlantic surfclam are thought to mature very early. Data are limited but Atlantic surfclam off New Jersey may reach maturity as early as 3 months after settlement and at lengths of less than 5 mm (Chintala and Grassle 1995; Chintala 1997).

Survey trends and LPUE for important ten-minute squares

We analyzed commercial LPUE and survey data for 1982 - 2011 for important ten-minute squares (TNMS see section II) in the southern New Jersey and Delmarva regions where fishing is traditionally concentrated to better understand potential fishing effects on key southern fishing grounds. Modes in size composition data from the commercial catch declined steadily in these areas over the last decade (Figures 17 – 23) but the declines are not clear in survey size composition data through 2011 when survey gear changed (Figures 37 – 42), probably due to size selective removals of large clams on fishing grounds. Survey and LPUE data suggest that abundance trends in areas where fishing occurs were similar to trends for the New Jersey and Delmarva regions as a whole. Thus, fishing seems to have had modest effects on abundance in TNMS where fishing was highest.

TNMS were much smaller than survey strata and not all squares were sampled during each year. We therefore analyzed the data "as is" (ignoring the unsampled squares) and after filling the holes with imputed survey "data" from a GAM model. The GAM model (mgcv library in the R programming language) was $gam(N_{tow} \sim s(Y, tnms) + tnms)$. In this model, N_{tow} is the number of Atlantic surfclam caught in the tow, Y is the survey year (continuous) and $tnms$ is the ten-minute square (a categorical factor). About 5% of survey tows had zero catch so we fit the model using the default log link function assuming errors from a Tweedie distribution, which is a combination of a logistic distribution (for zero observations) and a Gamma distribution (for positive catches). Given these specifications, the model handles zero and non-zero catches directly while estimating a different intercept (average catch rate) and different interannual trends for each TNMS. In effect, there was a separate model for each TNMS.

The imputed data from the fitted GAM model (R^2 = 0.48, deviance explained=75%, N=299) amount to interpolations between years with observed data and extrapolations for missing years at the beginning and end of the time series (Figure 60). Extrapolation is possible in the mgcv GAM software as long as the years involved are within the range of years in the dataset as a whole, even though the models for different TNMS are nearly independent. The surveys were usually triennial so that interpolations and extrapolations were over relatively long periods of time (1-11 years).

Extrapolation is not valid from a statistical point of view and should (along with interpolations over many years) be viewed with caution but the analysis was exploratory and results did not depend strongly on using imputed data (see below).

Interannual time series for the New Jersey and Delmarva regions were calculated by averaging all values (observed and/or predicted values) for each region and year. TNMS were the same size so the annual averages amounted to stratified random mean numbers per survey tow. Results with and without imputed data were similar (Figure 61). All results indicate that abundance declined rapidly during 1995-2005 (on fishing grounds) to current relatively low levels (Figure 62).

LPUE and survey data for important TNMS show that LPUE remained high as abundance declined off New Jersey (correlation coefficient $\rho = 0.2$, Figure 62). Survey trends in important TNMS and for New Jersey as a whole were strongly correlated ($\rho = 0.79$). In contrast to New Jersey, trends in survey and LPUE in important TNMS off Delmarva had a linear relationship and were strongly correlated ($\rho = 0.59$). Survey trends in important TNMS and for Delmarva as a whole were also strongly correlated ($\rho = 0.52$).

Evaluation of new survey

Spatial coverage

The assessment working group reviewed information showing fishing activity and survey catches in an area south of Nantucket that is not routinely surveyed, they also evaluated several approaches for identifying Atlantic surfclam habitat based on data from multiple surveys, multi-beam acoustic data, published studies, environmental measurements and habitat suitability models (Appendix XXIV). Such data would be useful for expanding the survey to cover new grounds, restratification and in improving the NEFSC clam survey design. The approaches presented appeared potentially useful and should be further developed for consideration by a future working group tasked specifically with evaluating survey design. NEFSC Survey Branch personnel and program managers would need to be heavily involved in the discussions.

Changes in the spatial distribution of biomass

We calculated relative swept-area survey biomass of Atlantic surfclam (all sizes) by region and area during 2012-2015. No adjustments were made for capture efficiency, size selectivity or changes when the new survey began in 2012 to keep the analysis simple and because these parameters may be the same for all regions in the same year and should tend to "cancel out". The proportion of biomass in year y and region r was calculated $p_{y,r} = \frac{p_{y,r}}{\sum_s p_{y,s} A_s}$ where A_s is the area (nm^2) of one of the regions. The northern and southern areas were sampled in different years after 2011, so data from the survey in the northern area during 2013 was used in these calculations for both 2012 and 2015.

Results show the increase in the proportion of total biomass in GBK and declines off DMV during 1982-2011 measured using the old survey dredge (Figure 63). These patterns were attributed to rising water temperatures in the last assessment. Unexpectedly, proportions of total biomass on

GBK dropped during 2012-2015 while fractions in NJ and DMV increased based on survey data from the new dredge. Biomass indices increased after 2011 in all regions because the new dredge is more efficient and sweeps more ground. However, increases during 2012-2015 in the south were larger than increases in the north. It is possible that these patterns reflect changes in spatial distribution but they may also be due to reduced capture efficiency in the new survey using the MCD in the relatively rough and rocky GBK region. The latter possibility could be investigated by conducting depletion studies on GBK to estimate capture efficiency directly.

Precision

The MCD survey was expected to be more precise than the original survey because the new dredge is more efficient (see XV), tow distance is more consistent (see below) and because the area swept by a tow in the new survey is larger (RCD mean about 580 m^2 with CV=25% and MCD mean=1764 m^2 with CV=11%). However, there was no clear reduction in CVs for survey abundance indices (stratified mean catch per tow) with the MCD (Table 9 and Figures 43–46). Lower numbers of tows beginning in 2012 reduced the precision of abundance indices for the southern area. There is no evidence that the variance among individual tows in the same stratum was reduced after 2012 (Table 8 and Figure 43–46). However, swept-area stock size estimates were probably more precise (Figure 46) when using the MCD despite little or no improvement in abundance indices because capture efficiency estimates for the MCD are more precise than estimates for the RD (Figure (Table 8) and XV).

Borrowing should be less common in the future because NEFSC expects to survey the northern and southern areas completely during sequential years rather than in parts (see XIII for a discussion of the borrowing required for this assessment). This plan and the goal of reducing the frequency of unsampled strata are important because of the difficulties in borrowing lengths and ages from other years now that length and age data are used in the assessment model. Borrowing from adjacent surveys is a type of imputation, but further work on imputation techniques is warranted. NEFSC (2007) used negative binomial GAM models to impute catches for strata with no data that could not be filled by borrowing but with modest effect on results. Model based approaches might have larger effect if all strata with missing data were imputed.

The total number of stations in the NEFSC clam survey is limited by the time devoted to the survey with deductions for transit time, bad weather, etc. The proportion of the total number of random survey stations in each stratum for each region (northern or southern) in the new survey was based on stratum area and on the mean catch and variance in catch for Atlantic surfclam plus ocean quahogs in previous surveys (Cochran 1977). This standard approach minimizes the variance of the total stratified mean catch per tow but does not minimize the variance for either individual species.

It might be possible to improve overall precision of the clam survey by changing the relative amounts of time used to sample the northern and the southern areas in subsequent years without changing the total time or cost for the survey as a whole.

The precision of stratified random mean estimates like clam survey abundance estimates depends on the number of tows and variance in catches within each stratum (Table 8). The reduction in the number of tows in the southern area after 2011 increased the standard deviation and CVs of the stratified means.

Tow distance with the RD varied strongly with depth and among years when tow procedures changed unintentionally (Figure 64). Tow distances since 2012 have been less variable in general and relatively constant across depth and years. These changes should improve precision of survey data for recent years.

Analysis of precision was complicated by limited number or zero samples in some strata and years, a high proportion of tows with no catch (about 60%), different temporal trends among strata, and the tendency for variance to increase with the mean catch per tow. We dealt with these problems by considering variance in the proportion of positive tows and variance in log catch for positive tows separately, and by calculating the variance of randomized quantile residuals from models with likelihoods that were calculated using the compound Tweedie distribution which accommodates both zeroes and positive values. These analyses used data from random tows with sensor data collected since 1997, from strata that were sampled consistently (in all surveys) in each region (Table 18). In particular, we used survey data from northern strata 55, 57, 59, 61, 70-71 and 73-74 sampled during 1997, 1999, 2002, 2008, 2011 (RD), and 2014 (MCD) and data for southern strata 9, 10, 13, 17, 18, 21-22, 25-26, 29-30, 33-34 and 84-93 sampled during 1997, 1999, 2002, 2005, 2008, 2011 (RD), 2012 and 2015 (MCD) in the south.

To begin, we calculated the mean and standard deviations for a dummy variable that identified positive tows (=1 if Atlantic surfclam were caught and 0 otherwise) and for log of Atlantic surfclam catch in positive tows (Figure 65). There were no obvious changes in the proportion of positive tows in the new survey or in the variance of the dummy variable or log positive catch. Higher proportions and lower variance in the dummy variable for positive tows might be expected using a dredge that affords higher precision although positive tows are likely at even low Atlantic surfclam densities using either survey dredge (XXI).

Next, we fit a series of GLM and GAM models to catches (tows with and without catch combined) and used AIC to determine the "best" (by AIC) model (Table 19). The best model (gamB) explained 45% of the total deviance, 23% of the total variance and the residuals were close to normally distributed. The distributions and standard deviation of residuals from the best model do not indicate increases in precision of individual tows beginning in 2012 (Figure 66).

Table 8: 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. In 2012 and later the NEFSC survey was conducted from a commercial platform using different gear, and tows were not borrowed across gear types. Starting in 2012, not all regions were sampled in each survey year. Instead the survey was conducted in either the northern or southern area. Areas intentionally not sampled are left blank in those years. 2014 was not intended to be a survey year, but some strata were sampled in order to fill holes left over from 2013. SNE was surveyed in 2013 (except stratum 96, which was surveyed in 2014), but the survey results were borowed to 2012 and not used in 2013. Survey strata not used for surfclams are not shown.

Strata	1982	1983	1984	1986	1989	1992	1994	1997	1999	2002	2005	2008	2011	2012	2013	2014	2015
SVA																	
1	-10	10	14	7	10	10	11	10	-10	0	0	0	0	0			0
2	0	0	0	-1	1	2	1	1	-1	0	0	0	0	0			0
5	4	9	13	8	8	8	7	8	-16	8	8	-17	9	8			6
6	1	1	1	1	1	1	1	1	-3	2	1	-1	0	0			0
80	-6	6	9	3	7	7	8	7	-7	0	0	0	0	0			0
81	-4	4	7	3	5	5	5	5	-10	5	-5	0	0	0			0
DMV																	
9	30	26	35	29	37	37	39	39	38	39	36	31	15	9			9
10	2	2	3	3	3	3	3	3	3	3	3	2	4	3			4
13	19	18	25	20	20	20	21	22	19	20	18	15	7	5			4
14	2	2	3	3	3	3	5	3	3	3	3	-26	23	6			8
82	1	1	1	1	1	1	1	1	2	2	-3	1	-1	0			0
83	2	2	2	2	2	2	2	2	2	2	2	2	-2	-3			3
84	4	3	3	4	4	4	4	4	3	4	4	4	4	3			3
85	6	5	4	5	5	5	5	5	5	5	3	5	5	13			16
86	2	2	3	3	3	2	3	3	3	3	3	3	5	3			3
NJ																	
17	11	11	17	12	12	12	12	14	12	12	12	12	5	5			4
18	3	3	-6	3	3	3	3	3	3	3	3	3	5	4			3
21	18	18	21	19	20	20	23	26	39	29	20	28	15	9			9
22	3	3	-6	3	3	3	5	3	3	3	3	3	5	4			3
25	9	9	13	8	9	9	9	12	8	9	9	13	8	4			24
26	2	2	-5	3	3	3	3	3	3	3	3	3	3	3			3
87	8	7	10	9	9	9	9	9	9	16	8	9	6	10			3
88	15	15	24	17	20	20	20	21	23	20	17	19	6	7			4

89	14	15	21	15	18	17	17	19	18	18	15	18	4	5			11
90	2	2	3	2	2	2	2	2	2	2	2	1	4	3			13
LI																	
29	11	10	-20	10	10	10	10	10	11	10	10	16	10	5			2
30	7	8	-14	6	6	6	6	6	7	6	7	12	4	5			3
33	4	4	-8	4	4	4	5	4	4	4	4	10	4	4			3
34	2	2	-4	2	2	2	5	2	2	2	2	8	6	6			3
91	2	2	4	4	3	3	3	3	3	3	3	5	11	4			13
92	2	2	3	2	2	2	2	2	2	2	2	5	11	7			5
93	1	1	2	1	1	1	1	1	1	2	1	4	6	4			7
SNE																	
37	7	4	-7	3	-6	3	5	4	4	3	-3	-2	2	-2	2		2
38	3	2	-5	3	3	3	5	3	3	3	2	3	7	-6	6		2
41	6	5	7	5	6	6	6	6	5	6	6	6	4	-4	4		3
45	3	7	9	4	4	4	4	4	4	3	3	4	7	-4	4		3
46	2	5	5	3	2	3	5	3	3	2	3	3	6	-4	4		0
47	4	3	4	2	2	4	5	4	3	1	7	4	8	-10	10		0
94	1	2	-2	0	-1	1	2	2	-4	2	-2	-5	5	0	0		0
95	4	14	11	4	4	4	4	4	4	4	-8	4	5	-6	6		2
96	-12	12	-13	1	1	3	2	4	-4	0	-1	1	-1	-2	0	2	0
GBK																	
54	0	-3	3	3	-6	3	3	3	-3	0	-2	2	2		-5	5	
55	3	-3	-3	3	1	3	3	3	2	2	-4	2	3		7		
57	0	0	-2	2	1	2	5	2	2	2	-4	2	11		11		
59	1	4	-5	1	2	6	5	5	4	5	-9	4	16		10		
61	8	1	-6	5	-12	7	6	6	6	6	-11	5	5		5		
65	0	0	-2	2	-4	2	4	3	-4	1	-1	-3	3		4		
67	0	-5	5	5	7	7	7	7	-7	0	-2	2	1		-9	9	
68	1	-8	7	3	6	6	5	5	-5	0	-6	6	-6		-5	5	
69	2	5	-11	6	6	6	7	6	8	-8	-4	4	1		3		
70	1	2	-6	4	-8	4	4	4	3	2	-6	4	19		9		
71	0	-2	2	3	1	2	3	3	1	2	-3	1	3		5		
72	2	-10	8	1	8	8	8	8	6	-6	-4	4	5		3		
73	1	1	-4	3	6	6	6	6	5	6	-9	3	5		7		
74	3	-4	1	3	-7	4	4	4	3	3	-6	3	11		4		

Table 9: Trends in abundance and biomass for surfclam > 50 mm shell length during 1982-2015 based on NEFSC clam survey data. Survey values are the clams caught in the survey dredge. Stock values are the survey values adjusted to account for the selectivity of the survey dredge. Fishable values are the stock values adjusted to account for the selectivity of a commercial dredge. Figures include original plus borrowed tows. The column "N strata" includes strata sampled by tows borrowed from the previous and subsequent surveys if needed.

	Survey				**Stock**				**Fishable**						
Year	$\frac{N}{tow}$	CV	$\frac{kg}{tow}$	CV	$\frac{N}{tow}$	CV	$\frac{kg}{tow}$	CV	$\frac{N}{tow}$	CV	$\frac{kg}{tow}$	CV	N tows	Pos. tows	N strata
								SVA							
1982	7.26	0.90	0.60	0.87	8.25	0.88	0.64	0.87	7.26	0.90	0.60	0.87	25	6	5
1983	12.31	0.58	0.99	0.57	15.76	0.55	1.10	0.55	12.31	0.58	0.99	0.57	30	12	5
1984	29.66	0.30	2.96	0.29	35.22	0.28	3.15	0.28	29.66	0.30	2.96	0.29	44	17	5
1986	23.69	0.72	2.50	0.72	25.07	0.70	2.58	0.71	23.69	0.72	2.50	0.72	23	13	6
1989	12.89	0.81	1.31	0.81	18.41	0.77	1.44	0.80	12.89	0.81	1.31	0.81	32	13	6
1992	30.25	0.65	2.50	0.65	35.64	0.60	2.69	0.64	30.25	0.65	2.50	0.65	33	18	6
1994	49.76	0.40	1.69	0.28	391.41	0.68	5.32	0.49	49.76	0.40	1.69	0.28	33	19	6
1997	10.80	0.43	0.47	0.45	58.99	0.77	0.93	0.48	10.80	0.43	0.47	0.45	32	14	6
1999	10.54	0.38	0.46	0.33	58.65	0.77	0.93	0.45	10.54	0.38	0.46	0.33	47	21	6
2002	19.35	0.58	1.13	0.57	32.87	0.52	1.48	0.56	19.35	0.58	1.13	0.57	15	7	3
2005	3.65	0.66	0.07	0.57	39.31	0.80	0.43	0.73	3.65	0.66	0.07	0.57	14	4	3
2008	10.30	0.29	0.24	0.29	59.70	0.39	0.89	0.31	10.30	0.29	0.24	0.29	18	11	2
2011	15.54	0.29	0.40	0.27	63.54	0.26	1.18	0.27	15.54	0.29	0.40	0.27	9	8	1
2012	80.75	0.46	3.71	0.43	119.80	0.50	4.97	0.46	80.75	0.46	3.71	0.43	8	8	1
2015	65.33	0.50	2.72	0.51	116.67	0.51	4.19	0.51	65.33	0.50	2.72	0.51	6	6	1
								DMV							
1982	178.49	0.42	13.11	0.41	223.73	0.41	15.09	0.41	178.49	0.42	13.11	0.41	68	47	9
1983	61.88	0.49	5.83	0.44	75.08	0.43	6.27	0.43	61.88	0.49	5.83	0.44	61	41	9
1984	219.01	0.63	11.27	0.40	406.22	0.76	16.40	0.53	219.01	0.63	11.27	0.40	79	58	9
1986	133.56	0.39	12.28	0.36	150.01	0.37	13.00	0.36	133.56	0.39	12.28	0.36	70	53	9
1989	47.94	0.26	4.81	0.23	54.03	0.25	5.08	0.23	47.94	0.26	4.81	0.23	78	53	9
1992	42.35	0.28	4.34	0.26	54.42	0.24	4.70	0.25	42.35	0.28	4.34	0.26	77	58	9
1994	129.67	0.23	10.93	0.22	232.77	0.21	12.77	0.20	129.67	0.23	10.93	0.22	83	66	9
1997	131.71	0.17	10.42	0.19	170.75	0.15	11.67	0.18	131.71	0.17	10.42	0.19	82	64	9

1999	55.98	0.23	4.94	0.21	62.78	0.22	5.26	0.21	55.98	0.23	4.94	0.21	78	47	9
2002	37.17	0.22	3.51	0.19	53.35	0.24	3.96	0.19	37.17	0.22	3.51	0.19	81	58	9
2005	11.19	0.27	0.92	0.24	16.62	0.24	1.06	0.23	11.19	0.27	0.92	0.24	75	45	9
2008	12.34	0.23	0.73	0.27	29.41	0.21	1.06	0.24	12.34	0.23	0.73	0.27	89	50	9
2011	51.92	0.26	2.69	0.31	123.43	0.26	3.98	0.26	51.92	0.26	2.69	0.31	66	37	9
2012	91.04	0.46	6.77	0.51	113.74	0.42	7.55	0.49	91.04	0.46	6.77	0.51	45	31	8
2015	254.95	0.23	15.75	0.21	329.20	0.25	18.36	0.22	254.95	0.23	15.75	0.21	50	32	8
NJ															
1982	65.88	0.19	6.87	0.18	80.15	0.18	7.45	0.17	65.88	0.19	6.87	0.18	85	60	10
1983	53.16	0.30	5.32	0.25	63.69	0.27	5.72	0.25	53.16	0.30	5.32	0.25	85	63	10
1984	45.90	0.18	4.84	0.18	73.87	0.22	5.41	0.18	45.90	0.18	4.84	0.18	126	86	10
1986	40.01	0.17	5.00	0.17	51.24	0.17	5.36	0.17	40.01	0.17	5.00	0.17	91	70	10
1989	41.40	0.15	4.96	0.14	51.26	0.16	5.29	0.14	41.40	0.15	4.96	0.14	99	75	10
1992	39.68	0.20	4.30	0.17	52.73	0.19	4.68	0.16	39.68	0.20	4.30	0.17	98	73	10
1994	150.16	0.16	14.50	0.17	338.76	0.37	17.67	0.17	150.16	0.16	14.50	0.17	103	85	10
1997	101.63	0.13	12.86	0.12	110.99	0.12	13.42	0.12	101.63	0.13	12.86	0.12	112	91	10
1999	58.60	0.21	7.69	0.19	70.44	0.20	8.10	0.19	58.60	0.21	7.69	0.19	120	93	10
2002	45.71	0.14	6.19	0.15	56.13	0.12	6.59	0.15	45.71	0.14	6.19	0.15	115	99	10
2005	26.90	0.16	3.28	0.16	31.83	0.15	3.49	0.16	26.90	0.16	3.28	0.16	92	73	10
2008	27.11	0.13	2.97	0.16	42.82	0.12	3.35	0.15	27.11	0.13	2.97	0.16	109	93	10
2011	25.82	0.16	2.59	0.17	37.86	0.16	2.91	0.16	25.82	0.16	2.59	0.17	61	44	10
2012	189.85	0.16	22.86	0.17	206.73	0.16	24.00	0.17	189.85	0.16	22.86	0.17	54	47	10
2015	390.53	0.35	35.31	0.30	433.68	0.35	37.63	0.30	390.53	0.35	35.31	0.30	77	63	10
LI															
1982	4.03	0.61	0.75	0.60	4.16	0.61	0.77	0.60	4.03	0.61	0.75	0.60	29	5	7
1983	0.58	0.60	0.06	0.69	0.89	0.56	0.07	0.65	0.58	0.60	0.06	0.69	29	4	7
1984	2.20	0.22	0.30	0.32	3.06	0.14	0.33	0.29	2.20	0.22	0.30	0.32	55	14	7
1986	2.30	0.45	0.33	0.57	3.05	0.38	0.35	0.54	2.30	0.45	0.33	0.57	29	8	7
1989	5.72	0.78	0.59	0.75	9.28	0.79	0.68	0.76	5.72	0.78	0.59	0.75	28	5	7
1992	8.28	0.39	0.62	0.37	12.46	0.37	0.71	0.37	8.28	0.39	0.62	0.37	28	10	7
1994	11.48	0.17	1.15	0.20	15.73	0.16	1.26	0.19	11.48	0.17	1.15	0.20	32	12	7
1997	5.62	0.59	0.69	0.62	6.21	0.57	0.72	0.62	5.62	0.59	0.69	0.62	28	6	7
1999	12.32	0.65	1.64	0.60	17.34	0.66	1.77	0.61	12.32	0.65	1.64	0.60	30	9	7
2002	2.80	0.59	0.37	0.64	4.10	0.61	0.40	0.63	2.80	0.59	0.37	0.64	29	8	7
2005	14.04	0.47	1.91	0.47	15.73	0.44	2.00	0.46	14.04	0.47	1.91	0.47	29	9	7

2008	5.00	0.21	0.60	0.23	7.18	0.20	0.65	0.23	5.00	0.21	0.60	0.23	60	22	7
2011	14.77	0.21	1.70	0.24	24.09	0.24	1.90	0.23	14.77	0.21	1.70	0.24	52	33	7
2012	58.69	0.28	8.33	0.30	61.94	0.28	8.65	0.30	58.69	0.28	8.33	0.30	35	18	7
2015	88.61	0.26	9.06	0.17	103.03	0.27	9.70	0.17	88.61	0.26	9.06	0.17	36	29	7
SNE															
1982	14.99	0.33	2.43	0.39	18.44	0.29	2.57	0.38	14.99	0.33	2.43	0.39	42	19	9
1983	8.72	0.38	1.76	0.39	9.76	0.37	1.84	0.38	8.72	0.38	1.76	0.39	54	24	9
1984	11.65	0.34	2.33	0.34	14.12	0.31	2.44	0.33	11.65	0.34	2.33	0.34	63	26	9
1986	5.24	0.54	0.90	0.68	10.85	0.27	1.02	0.62	5.24	0.54	0.90	0.68	25	11	8
1989	5.75	0.31	0.98	0.33	7.35	0.32	1.05	0.32	5.75	0.31	0.98	0.33	29	12	9
1992	3.64	0.44	0.59	0.55	6.79	0.44	0.67	0.51	3.64	0.44	0.59	0.55	31	9	9
1994	2.96	0.45	0.44	0.50	3.92	0.41	0.48	0.49	2.96	0.45	0.44	0.50	38	11	9
1997	15.23	0.25	2.71	0.30	21.52	0.19	2.89	0.29	15.23	0.25	2.71	0.30	34	15	9
1999	6.90	0.45	1.11	0.60	12.05	0.33	1.25	0.56	6.90	0.45	1.11	0.60	34	16	9
2002	4.86	0.31	0.89	0.23	5.55	0.27	0.93	0.23	4.86	0.31	0.89	0.23	24	9	8
2005	2.95	0.14	0.46	0.21	5.54	0.18	0.52	0.19	2.95	0.14	0.46	0.21	35	14	9
2008	5.37	0.47	0.87	0.54	7.35	0.34	0.94	0.52	5.37	0.47	0.87	0.54	32	11	9
2011	3.07	0.18	0.43	0.25	5.31	0.15	0.50	0.23	3.07	0.18	0.43	0.25	45	13	9
2012	5.44	0.30	1.14	0.27	6.45	0.32	1.20	0.26	5.44	0.30	1.14	0.27	38	10	8
2015	19.11	0.71	3.16	0.68	20.54	0.71	3.30	0.68	19.11	0.71	3.16	0.68	11	6	5
GBK															
1982	3.27	0.14	0.20	0.11	10.14	0.16	0.34	0.12	3.27	0.14	0.20	0.11	22	10	9
1983	6.09	0.39	0.75	0.59	10.14	0.27	0.86	0.53	6.09	0.39	0.75	0.59	48	26	12
1984	8.56	0.34	1.13	0.46	14.48	0.23	1.28	0.43	8.56	0.34	1.13	0.46	65	31	14
1986	24.97	0.68	1.61	0.53	86.32	0.78	2.61	0.60	24.97	0.68	1.61	0.53	44	20	14
1989	30.07	0.66	3.85	0.70	35.99	0.57	4.07	0.69	30.07	0.66	3.85	0.70	75	37	14
1992	23.43	0.33	1.93	0.32	44.00	0.27	2.40	0.30	23.43	0.33	1.93	0.32	66	43	14
1994	75.85	0.33	8.57	0.38	97.98	0.29	9.33	0.36	75.85	0.33	8.57	0.38	70	47	14
1997	82.07	0.28	6.55	0.26	119.17	0.26	7.75	0.26	82.07	0.28	6.55	0.26	65	45	14
1999	53.60	0.35	5.50	0.34	69.53	0.34	6.05	0.34	53.60	0.35	5.50	0.34	59	34	14
2002	49.15	0.46	5.17	0.44	67.41	0.42	5.74	0.43	49.15	0.46	5.17	0.44	43	23	11
2005	39.70	0.21	4.95	0.23	48.54	0.18	5.26	0.23	39.70	0.21	4.95	0.23	71	38	14
2008	39.23	0.21	4.94	0.22	44.69	0.20	5.20	0.22	39.23	0.21	4.94	0.22	45	29	14
2011	43.79	0.24	6.12	0.24	48.38	0.23	6.40	0.24	43.79	0.24	6.12	0.24	91	52	14
2013	94.62	0.53	11.24	0.51	100.10	0.53	11.69	0.51	94.62	0.53	11.24	0.51	87	33	14

							SVAtoSNE								
1982	64.30	0.28	5.41	0.24	79.64	0.28	6.05	0.25	64.30	0.28	5.41	0.24	249	137	40
1983	32.23	0.26	3.20	0.22	38.87	0.23	3.44	0.22	32.23	0.26	3.20	0.22	259	144	40
1984	71.19	0.46	4.82	0.23	124.46	0.59	6.22	0.33	71.19	0.46	4.82	0.23	367	201	40
1986	47.40	0.27	4.82	0.23	55.65	0.25	5.12	0.23	47.40	0.27	4.82	0.23	238	155	40
1989	26.00	0.15	2.87	0.13	31.69	0.15	3.06	0.13	26.00	0.15	2.87	0.13	266	158	41
1992	26.93	0.17	2.72	0.15	35.23	0.15	2.96	0.15	26.93	0.17	2.72	0.15	267	168	41
1994	79.35	0.13	6.79	0.12	206.95	0.26	8.64	0.12	79.35	0.13	6.79	0.12	289	193	41
1997	62.81	0.10	6.37	0.10	83.39	0.12	6.91	0.10	62.81	0.10	6.37	0.10	288	190	41
1999	33.15	0.14	3.64	0.13	47.17	0.19	3.93	0.13	33.15	0.14	3.64	0.13	309	186	41
2002	26.21	0.11	3.05	0.11	34.87	0.12	3.32	0.11	26.21	0.11	3.05	0.11	264	181	37
2005	13.86	0.13	1.60	0.14	19.72	0.14	1.75	0.14	13.86	0.13	1.60	0.14	245	145	38
2008	13.75	0.11	1.34	0.13	25.78	0.10	1.59	0.12	13.75	0.11	1.34	0.13	308	187	37
2011	25.35	0.15	1.88	0.14	52.11	0.17	2.40	0.13	25.35	0.15	1.88	0.14	233	135	36
2012	95.65	0.15	10.46	0.15	109.13	0.15	11.13	0.14	95.65	0.15	10.46	0.15	180	114	34
2015	226.10	0.22	18.60	0.19	267.39	0.21	20.34	0.19	226.10	0.22	18.60	0.19	180	136	31

Table 10: Shell length composition data used to estimate dredge selectivity for surfclams between 2012 and 2015. Number of surfclams caught (no.) and positive stations (pos.) for the modified commercial dredge used for the NEFSC survey and a lined dredge presumed to catch all animals available. Some of the stations were targeting ocean quahog and few surfclams were captured at these sites.

SL group	Lined no.	Survey no.	Lined pos.	Survey pos.
0-10	0	0	0	0
10-20	1	0	1	0
20-30	5	0	2	0
30-40	16	0	6	0
40-50	35	0	10	0
50-60	57	0	9	0
60-70	54	2	6	1
70-80	55	11	6	4
80-90	64	44	9	4
90-100	89	142	6	5
100-110	115	212	7	5
110-120	86	193	6	4
120-130	68	221	5	4
130-140	90	277	5	4
140-150	91	308	4	4
150-160	75	289	3	3
160-170	40	164	3	2
170-180	5	18	2	2
180-190	0	4	0	1
190-200	1	0	1	0

Table 11: Numbers of surfclams in survey dredge selectivity experiments by length bin and station between 2012 and 2015. For example, 3:8 in the row corresponding to shell length (SL) bin 40−50 indicates that 3 surfclams between 40 and 50 mm were caught in the survey dredge and 8 surfclams were caught in the selectivity dredge at that station. Stations with very few total surfclams caught were ocean quahog stations, but are included for completeness.

SL bin	Sta 33	Sta 53	Sta 59	Sta 67	Sta 113	Sta 117	Sta 150	Sta 162	Sta 170
0-10	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0
10-20	0:0	0:0	0:0	0:0	0:0	0:0	1:0	0:0	0:0
20-30	0:0	0:0	0:0	0:0	0:0	0:0	2:0	0:0	0:0
30-40	3:0	4:0	0:0	1:0	1:0	0:0	4:0	0:0	0:0
40-50	7:0	6:0	1:0	1:0	5:0	0:0	8:0	1:0	1:0
50-60	10:0	8:0	4:0	1:0	26:0	1:0	3:0	0:0	0:0
60-70	2:0	2:0	12:2	0:0	30:0	0:0	7:0	0:0	0:0
70-80	1:4	1:0	12:2	0:0	38:4	0:0	2:1	0:0	0:0
80-90	5:12	3:0	1:2	0:0	39:10	0:0	11:20	1:0	0:0
90-100	5:15	2:8	0:0	0:0	51:42	0:0	26:76	2:0	3:0
100-110	4:27	7:24	0:0	0:0	62:68	0:0	35:92	2:0	4:0
110-120	3:41	5:44	0:0	0:0	47:66	0:0	24:42	6:0	1:0
120-130	6:67	5:38	0:0	0:0	49:100	0:0	7:16	0:0	1:0
130-140	8:100	21:94	0:0	0:0	55:78	0:0	5:5	0:0	1:0
140-150	16:125	51:116	0:0	0:0	22:66	0:0	2:1	0:0	0:0
150-160	27:189	44:80	0:0	0:0	4:20	0:0	0:0	0:0	0:0
160-170	16:140	23:24	0:0	0:0	1:0	0:0	0:0	0:0	0:0
170-180	4:16	1:2	0:0	0:0	0:0	0:0	0:0	0:0	0:0
180-190	0:4	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0
190-200	1:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0
0-10	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0
10-20	0:0	0:0	0:0	0:0	0:0	0:0	1:0	0:0	0:0
20-30	0:0	0:0	0:0	0:0	0:0	0:0	2:0	0:0	0:0
30-40	3:0	4:0	0:0	1:0	1:0	0:0	4:0	0:0	0:0
40-50	7:0	6:0	1:0	1:0	5:0	0:0	8:0	1:0	1:0
50-60	10:0	8:0	0:0	1:0	26:0	1:0	3:0	0:0	0:0
60-70	2:0	2:0	0:0	0:0	30:0	0:0	7:0	0:0	0:0
70-80	1:4	1:0	0:0	0:0	38:4	0:0	2:1	0:0	0:0
80-90	5:12	3:0	0:0	0:0	39:10	0:0	11:20	1:0	0:0
90-100	5:15	2:8	0:0	0:0	51:42	0:0	26:76	2:0	3:0
100-110	4:27	7:24	0:0	0:0	62:68	0:0	35:92	2:0	4:0
110-120	3:41	5:44	0:0	0:0	47:66	0:0	24:42	6:0	1:0
120-130	6:67	5:38	0:0	0:0	49:100	0:0	7:16	0:0	1:0
130-140	8:100	21:94	0:0	0:0	55:78	0:0	5:5	0:0	1:0
140-150	16:125	51:116	0:0	0:0	22:66	0:0	2:1	0:0	0:0
150-160	27:189	44:80	0:0	0:0	4:20	0:0	0:0	0:0	0:0
160-170	16:140	23:24	0:0	0:0	1:0	0:0	0:0	0:0	0:0
170-180	4:16	1:2	0:0	0:0	0:0	0:0	0:0	0:0	0:0
180-190	0:4	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0

190-200	1:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0

SL bin	Sta 178	Sta 182	Sta 184
0-10	0:0	0:0	0:0
10-20	0:0	0:0	0:0
20-30	0:0	3:0	0:0
30-40	0:0	3:0	0:0
40-50	0:0	4:0	0:0
50-60	0:0	3:0	1:0
60-70	0:0	0:0	1:0
70-80	0:0	1:0	0:0
80-90	1:0	2:0	1:0
90-100	0:0	0:1	0:0
100-110	1:1	0:0	0:0
110-120	0:0	0:0	0:0
120-130	0:0	0:0	0:0
130-140	0:0	0:0	0:0
140-150	0:0	0:0	0:0
150-160	0:0	0:0	0:0
160-170	0:0	0:0	0:0
170-180	0:0	0:0	0:0
180-190	0:0	0:0	0:0
190-200	0:0	0:0	0:0
0-10	0:0	0:0	0:0
10-20	0:0	0:0	0:0
20-30	0:0	3:0	0:0
30-40	0:0	3:0	0:0
40-50	0:0	4:0	0:0
50-60	0:0	3:0	1:0
60-70	0:0	0:0	1:0
70-80	0:0	1:0	0:0
80-90	1:0	2:0	1:0
90-100	0:0	0:1	0:0
100-110	1:1	0:0	0:0
110-120	0:0	0:0	0:0
120-130	0:0	0:0	0:0
130-140	0:0	0:0	0:0
140-150	0:0	0:0	0:0
150-160	0:0	0:0	0:0
160-170	0:0	0:0	0:0
170-180	0:0	0:0	0:0
180-190	0:0	0:0	0:0
190-200	0:0	0:0	0:0

Table 13: Results from generalized additive model fits to selectivity data. The response variable is number of surfclams caught in the survey dredge (a modified commercial dredge) compared to the number of surfclams caught in a lined dredge. The predictors are length bin (L), and a year−station (YrSta) effect. Some models included an offset based on the tow distance at each station. The s indicates a spline function and RE indicates random effects. The best model by AIC included random effects for each year−station combination in both intercept and length.

Model	AIC	BIC
s(L)+s(YrSta,RE)+s(YrSta,L,RE)	3223	3633
s(L)+s(YrSta,RE)	3594	3831
s(L)	6838	6879

Table 14: The MCD survey dredge (post 2011) selectivity coefficients estimated using the best (by AIC) selectivity model, by size bin.

Length	Selx	uci	lci	Length	Selx	uci	lci
5	0.054	0.683	0.002	101	0.787	0.807	0.765
7	0.046	0.571	0.002	103	0.804	0.823	0.785
9	0.039	0.454	0.002	105	0.818	0.835	0.800
11	0.033	0.346	0.002	107	0.829	0.845	0.811
13	0.029	0.257	0.003	109	0.837	0.852	0.820
15	0.025	0.189	0.003	111	0.843	0.858	0.826
17	0.022	0.140	0.003	112	0.847	0.863	0.830
18	0.020	0.105	0.003	114	0.850	0.866	0.833
20	0.018	0.081	0.004	116	0.853	0.869	0.835
22	0.016	0.065	0.004	118	0.855	0.872	0.836
24	0.015	0.053	0.004	120	0.857	0.874	0.837
26	0.014	0.045	0.005	122	0.858	0.877	0.838
28	0.014	0.040	0.005	124	0.860	0.879	0.839
30	0.014	0.036	0.005	126	0.862	0.882	0.840
32	0.014	0.033	0.006	128	0.865	0.886	0.842
34	0.014	0.031	0.006	130	0.868	0.889	0.844
36	0.014	0.030	0.007	132	0.871	0.893	0.846
38	0.015	0.029	0.008	134	0.875	0.897	0.848
40	0.016	0.029	0.008	136	0.878	0.901	0.851
41	0.017	0.030	0.009	137	0.882	0.905	0.854
43	0.018	0.030	0.010	139	0.885	0.908	0.857
45	0.019	0.032	0.011	141	0.888	0.912	0.859
47	0.020	0.033	0.012	143	0.891	0.915	0.861
49	0.022	0.035	0.014	145	0.893	0.917	0.862
51	0.024	0.038	0.015	147	0.894	0.919	0.862
53	0.027	0.041	0.017	149	0.895	0.921	0.862
55	0.030	0.045	0.020	151	0.895	0.922	0.861
57	0.033	0.049	0.022	153	0.895	0.923	0.859
59	0.038	0.055	0.026	155	0.894	0.923	0.857
61	0.043	0.061	0.030	157	0.893	0.922	0.853
63	0.050	0.070	0.035	159	0.891	0.922	0.849
64	0.058	0.080	0.042	160	0.888	0.921	0.844
66	0.069	0.094	0.051	162	0.885	0.920	0.839
68	0.083	0.110	0.062	164	0.882	0.919	0.833
70	0.101	0.131	0.077	166	0.880	0.918	0.827
72	0.123	0.156	0.096	168	0.877	0.917	0.822
74	0.150	0.188	0.119	170	0.875	0.916	0.817
76	0.184	0.225	0.149	172	0.873	0.916	0.813
78	0.225	0.269	0.186	174	0.873	0.917	0.809
80	0.273	0.320	0.231	176	0.873	0.918	0.808
82	0.327	0.375	0.282	178	0.874	0.920	0.807
84	0.385	0.434	0.340	180	0.877	0.923	0.808
86	0.446	0.493	0.401	182	0.880	0.927	0.809
88	0.507	0.551	0.463	183	0.884	0.931	0.811
89	0.564	0.605	0.523	185	0.889	0.937	0.814
91	0.617	0.654	0.579	187	0.895	0.942	0.817
93	0.664	0.697	0.630	189	0.901	0.948	0.819

95	0.704	0.733	0.673	191	0.907	0.954	0.822
97	0.738	0.763	0.710	193	0.913	0.959	0.824
99	0.765	0.788	0.740	195	0.919	0.964	0.825

Table 15: Number of age samples in NEFSC clam surveys by survey year and region.

Year	SVA	DMV	NJ	LI	SNE	GBK
1978	0	199	289	0	0	0
1980	2	389	452	29	61	0
1981	45	401	641	27	38	0
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	114	133	71	15	75
2012	13	43	148	86	0	0
2013	0	0	0	0	35	58
2014	0	0	0	0	4	38
2015	32	139	362	141	12	0

Table 16: Growth curve (Von Bertalanffy) parameter estimates and standard errors for each region by year. Year and region combinations that did not provide sufficient data for model convergence are not shown. SVAtoSNE is the southern area and GBK is the northern area.

Region	Year	n	L_∞	$L_\infty se$	K	K se	t_0	$t_0 se$
SVA	1983	142	183.8	13.75	0.205	0.045	-0.266	0.451
SVA	1986	64	142.2	5.01	0.535	0.192	1.688	0.720
SVA	1989	60	136.9	3.58	0.417	0.098	0.471	0.428
SVA	1992	11	156.1	9.36	0.258	0.077	-0.565	0.608
SVA	2002	29	142.4	19.68	0.230	0.161	-1.426	1.836
SVA	2005	17	122.6	18.35	0.366	0.195	-0.191	0.443
SVA	2011	26	113.0	7.47	0.624	0.159	0.231	0.226
SVA	2012	16	112.9	5.66	0.854	0.236	0.333	0.254
SVA	2015	32	108.9	5.21	0.514	0.145	-0.096	0.463
DMV	1982	796	175.2	1.67	0.206	0.008	-0.380	0.129
DMV	1983	422	176.5	2.49	0.209	0.014	-0.494	0.220
DMV	1986	748	184.2	3.05	0.134	0.010	-1.706	0.374
DMV	1989	102	144.1	3.40	0.302	0.052	0.005	0.462
DMV	1992	134	172.7	7.27	0.159	0.027	-1.320	0.523
DMV	1994	299	149.5	1.66	0.343	0.022	0.937	0.134
DMV	1997	626	151.4	3.25	0.148	0.014	-1.972	0.395
DMV	1999	510	136.4	1.92	0.238	0.027	-0.814	0.482
DMV	2002	327	156.5	4.36	0.172	0.022	-1.567	0.445
DMV	2005	322	151.1	2.99	0.157	0.013	-1.326	0.298
DMV	2008	138	159.0	3.52	0.200	0.018	-1.012	0.221
DMV	2011	115	121.9	3.23	0.361	0.049	-0.261	0.275
DMV	2012	43	149.2	11.23	0.152	0.065	-2.528	2.166
DMV	2015	140	144.3	8.18	0.115	0.029	-4.022	1.329
NJ	1982	927	173.4	1.43	0.264	0.009	-0.244	0.087
NJ	1983	934	176.3	1.73	0.244	0.010	-0.233	0.109
NJ	1986	1216	175.6	1.87	0.177	0.008	-0.965	0.174
NJ	1989	566	162.9	2.01	0.238	0.015	0.085	0.183
NJ	1992	257	167.0	4.11	0.187	0.023	-0.922	0.432
NJ	1994	476	159.6	2.18	0.197	0.017	-1.080	0.356
NJ	1997	227	165.6	2.05	0.212	0.018	-0.546	0.291
NJ	1999	496	160.9	1.38	0.264	0.015	-0.265	0.172
NJ	2002	779	163.9	1.73	0.209	0.015	-1.338	0.279
NJ	2005	523	164.1	2.42	0.150	0.013	-1.711	0.455
NJ	2008	459	157.1	2.27	0.185	0.015	-1.317	0.306
NJ	2011	140	155.1	4.09	0.179	0.029	-1.525	0.714
NJ	2012	175	165.1	4.33	0.144	0.023	-2.964	0.882
NJ	2015	366	156.3	3.00	0.136	0.016	-3.091	0.702
LI	1982	40	156.7	1.86	0.800	0.213	2.315	0.198
LI	1986	45	165.9	3.40	0.222	0.039	-0.477	0.695
LI	1989	53	163.1	3.56	0.259	0.034	0.029	0.394
LI	1992	47	155.8	3.03	0.307	0.036	-0.492	0.314
LI	1999	22	167.9	4.72	0.302	0.044	0.050	0.283

LI	2002	31	174.9	8.13	0.250	0.059	-0.187	0.594
LI	2005	21	160.1	7.63	0.210	0.070	-1.098	1.226
LI	2008	99	150.4	3.62	0.424	0.060	0.400	0.262
LI	2011	72	163.7	4.64	0.226	0.052	-0.534	1.015
LI	2012	86	153.4	6.15	0.269	0.066	-0.458	0.737
LI	2015	141	170.6	7.26	0.123	0.030	-4.188	1.517
SNE	1982	123	160.4	2.40	0.222	0.025	0.142	0.378
SNE	1983	369	167.9	1.66	0.265	0.023	-0.709	0.350
SNE	1986	71	163.6	2.62	0.316	0.038	1.071	0.258
SNE	1989	42	172.0	5.18	0.422	0.079	1.509	0.350
SNE	1992	54	162.4	2.30	0.203	0.024	0.086	0.317
SNE	1999	50	174.8	6.34	0.210	0.041	-0.584	0.560
SNE	2002	20	162.3	5.31	0.452	0.118	1.039	0.525
SNE	2008	39	172.9	5.14	0.161	0.033	-1.592	0.952
SNE	2013	35	169.6	4.42	0.499	0.192	2.081	0.852
SNE	2015	12	171.6	28.62	0.099	0.093	-5.357	7.271
GBK	1984	643	146.7	3.22	0.266	0.022	0.371	0.153
GBK	1986	413	149.0	3.24	0.225	0.019	-0.233	0.175
GBK	1989	86	152.8	5.20	0.197	0.040	-0.750	0.765
GBK	1992	311	148.7	2.82	0.270	0.020	0.585	0.155
GBK	1997	50	138.8	7.37	0.194	0.045	-0.507	0.683
GBK	1999	178	145.6	3.13	0.355	0.033	0.081	0.160
GBK	2002	54	143.2	4.76	0.427	0.095	1.636	0.416
GBK	2008	105	146.4	3.70	0.212	0.036	-1.018	0.550
GBK	2011	75	144.9	2.10	0.545	0.206	2.084	0.931
GBK	2013	59	136.4	3.78	0.421	0.106	0.929	0.596
GBK	2014	40	144.7	3.61	0.223	0.061	-0.645	1.299
south	1982	1891	169.9	1.00	0.239	0.007	-0.399	0.083
south	1983	1873	172.6	1.08	0.249	0.008	-0.246	0.092
south	1986	2144	176.6	1.42	0.165	0.006	-1.130	0.153
south	1989	823	159.7	1.67	0.245	0.014	-0.057	0.165
south	1992	503	164.8	2.18	0.201	0.013	-0.712	0.212
south	1994	775	152.4	1.14	0.292	0.014	0.399	0.139
south	1997	853	162.8	3.28	0.130	0.011	-2.364	0.379
south	1999	1078	150.5	1.38	0.233	0.014	-0.754	0.225
south	2002	1186	162.8	1.74	0.186	0.012	-1.646	0.247
south	2005	889	160.1	1.78	0.155	0.008	-1.337	0.213
south	2008	735	156.5	1.62	0.214	0.012	-0.899	0.179
south	2011	368	155.4	2.51	0.189	0.015	-1.176	0.280
south	2012	320	160.5	3.35	0.165	0.020	-2.275	0.578
south	2013	35	169.6	4.42	0.499	0.192	2.081	0.852
south	2015	691	159.1	3.12	0.120	0.012	-3.789	0.612
All	1982	1895	169.9	1.00	0.239	0.007	-0.394	0.083
All	1983	1873	172.6	1.08	0.249	0.008	-0.246	0.092
All	1984	643	146.7	3.22	0.266	0.022	0.371	0.153
All	1986	2557	172.0	1.24	0.186	0.006	-0.543	0.098

All	1989	909	158.2	1.55	0.247	0.014	-0.050	0.161
All	1992	814	161.4	1.93	0.208	0.011	-0.359	0.155
All	1994	775	152.4	1.14	0.292	0.014	0.399	0.139
All	1997	903	162.0	3.14	0.132	0.011	-2.241	0.355
All	1999	1256	149.4	1.21	0.254	0.013	-0.547	0.166
All	2002	1240	162.7	1.74	0.185	0.011	-1.646	0.244
All	2005	889	160.1	1.78	0.155	0.008	-1.337	0.213
All	2008	840	154.8	1.49	0.216	0.012	-0.899	0.172
All	2011	443	152.8	1.98	0.204	0.015	-1.006	0.254
All	2012	320	160.5	3.35	0.165	0.020	-2.275	0.578
All	2013	94	151.6	3.74	0.369	0.081	0.987	0.581
All	2014	44	149.1	7.14	0.144	0.054	-2.690	2.346
All	2015	691	159.1	3.12	0.120	0.012	-3.789	0.612

Table 17: Results from model fits to predict meat weight. Predictors are ln(shell length) (L), ln(depth) (D), density (ρ), and region (R). Random effects are enclosed in parentheses and are limited to station (St), year (both affecting the estimate of the intercept), and length (affecting the estimate of the length coefficient). Regional coefficients are shown. SVA is assumed to have coefficient equal to 0.

Formula	int	L	D	ρ	R	AIC	BIC
L+D+R+(L+St)+(L+Year)	-8.03 (0.05)	2.7 (0.044)	-0.16 (0.021)		X	26780	26864
L+D+Density+R+(L+St)+(L+Year)	-8.03 (0.05)	2.7 (0.044)	-0.16 (0.021)	-0.003 (0.004)	X	26781	26871
L+R+(L+St)+(L+Year)	-8.56 (0.049)	2.7 (0.044)			X	26833	26911
L+D+R+(L+St)	-8.25 (0.045)	2.73 (0.021)	-0.13 (0.022)		X	26855	26921
L+R+(L+St)	-8.68 (0.045)	2.73 (0.021)			X	26886	26946
L+D+(L+St)+(L+Year)	-8.12 (0.034)	2.69 (0.056)	-0.1 (0.019)			27237	27292
L+(L+St)+(L+Year)	-8.49 (0.03)	2.7 (0.057)				27264	27312
L+Density+(L+St)	-8.67 (0.008)	2.75 (0.021)		-0.02 (0.004)		27315	27351
L+D+(L+St)	-8.67 (0.008)	2.73 (0.021)	-0.06 (0.02)			27317	27353
L+(L+St)	-8.69 (0.008)	2.74 (0.021)				27325	27355
L+D+(St)	-8.45 (0.007)	2.73 (0.011)	-0.06 (0.019)			27744	27768
L+(St)	-8.67 (0.007)	2.73 (0.011)				27752	27770

Formula	DMV	NJ	LI	SNE	GBK
L+D+R+(L+St)+(L+Year)	0.02 (0.044)	0.03 (0.043)	-0.01 (0.045)	0.21 (0.054)	0.22 (0.049)
L+D+Density+R+(L+St)+(L+Year)	0.02 (0.044)	0.04 (0.043)	-0.01 (0.045)	0.21 (0.054)	0.22 (0.05)
L+R+(L+St)+(L+Year)	-0.03 (0.045)	0 (0.044)	-0.009 (0.046)	0.19 (0.056)	0.1 (0.049)
L+D+R+(L+St)	0.02 (0.047)	0.02 (0.046)	-0.03 (0.048)	0.18 (0.056)	0.18 (0.051)
L+R+(L+St)	-0.02 (0.047)	-0.002 (0.046)	-0.03 (0.049)	0.17 (0.057)	0.09 (0.049)
L+D+(L+St)+(L+Year)					
L+(L+St)+(L+Year)					
L+Density+(L+St)					
L+D+(L+St)					
L+(L+St)					
L+D+(St)					
L+(St)					

Table 18: Numbers of successful random survey tows with sensor data used to evaluate the precision of the MCD survey. Tows are shown in the year they were made (with no borrowing).

Year	South	North
1997	266	57
1999	216	30
2002	251	28
2005	208	
2008	241	12
2011	221	84
2012	131	
2013	35	64
2014	1	19
2015	164	

Table 19: Models relating the proportion of positive tows in the survey to year and stratum used to evaluate the precision of the MCD survey, where C_t is catch in tow t, yr is year as a factor, and str is the stratum.

Model	Formula	Family	Link	df	AIC
glmA	$C_t = yr$	Tweedie(p=1.7)	log	9	14,060
glmB	$C_t = str$	Tweedie(p=1.7))	log	31	13,923
gamA	$C_t = s(yr, by = str)$	Tweedie(p=1.7)	log	67	14,160
gamB	$C_t = s(yr, by = str) + str$	Tweedie(p=1.7)	log	118	13,495

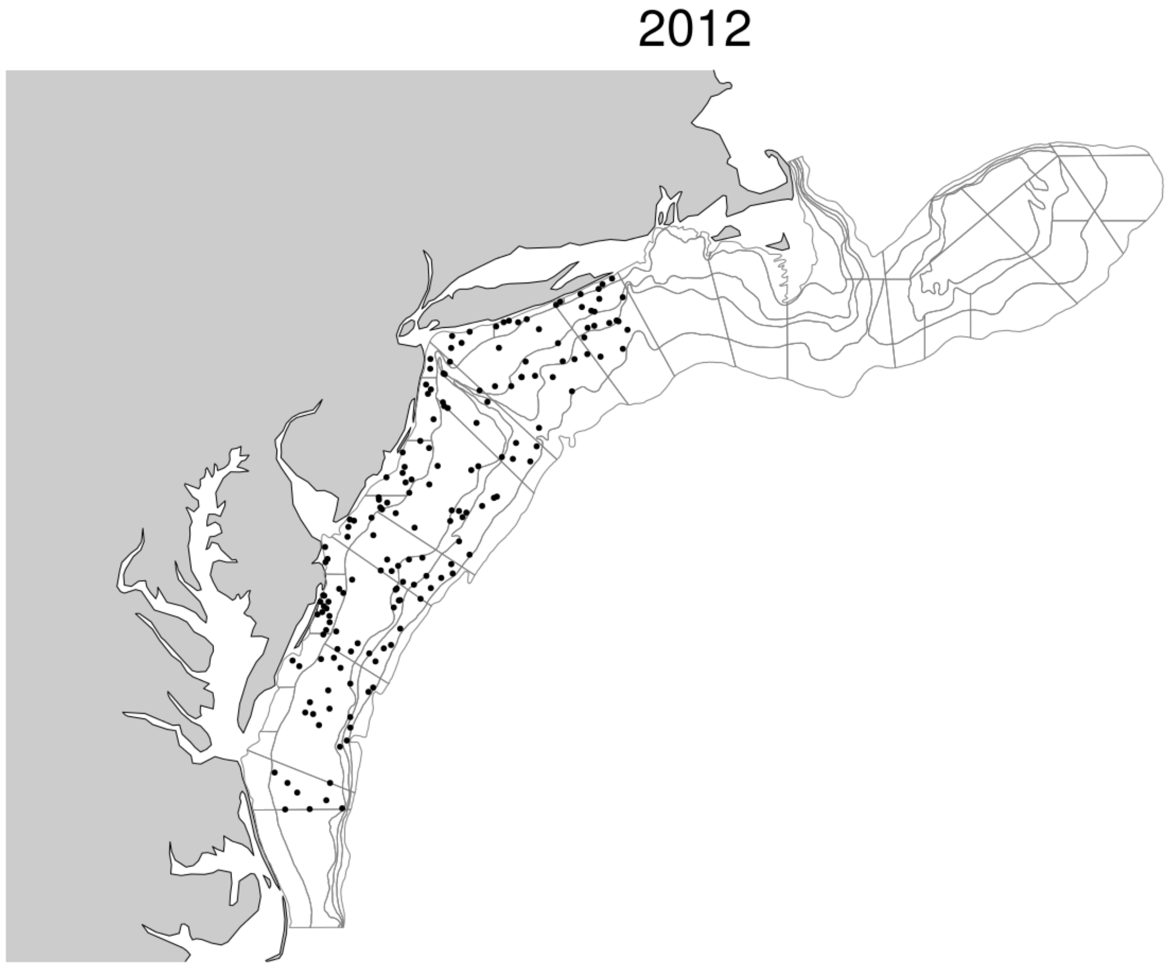


Figure 24: Station locations from the 2012 survey

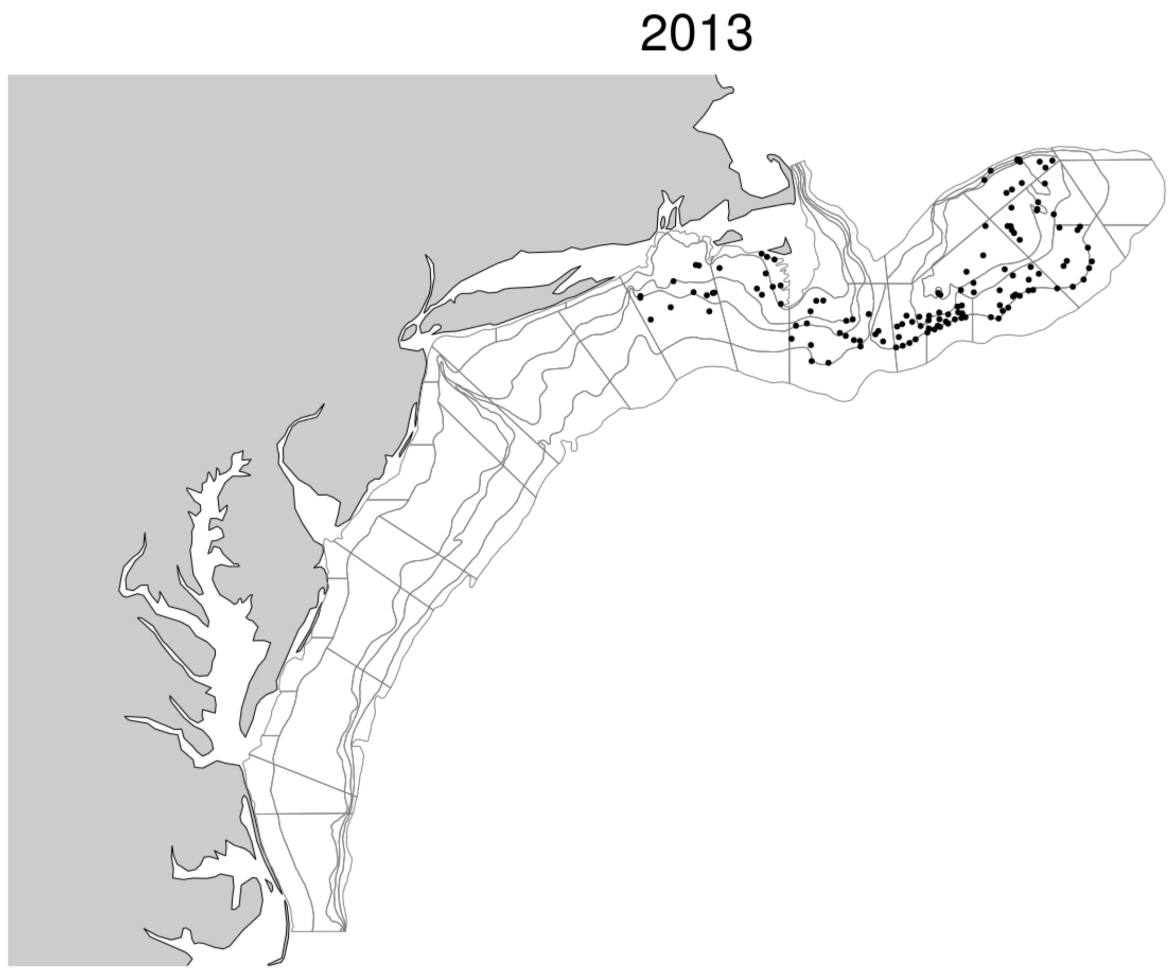


Figure 25: Station locations from the 2013 survey

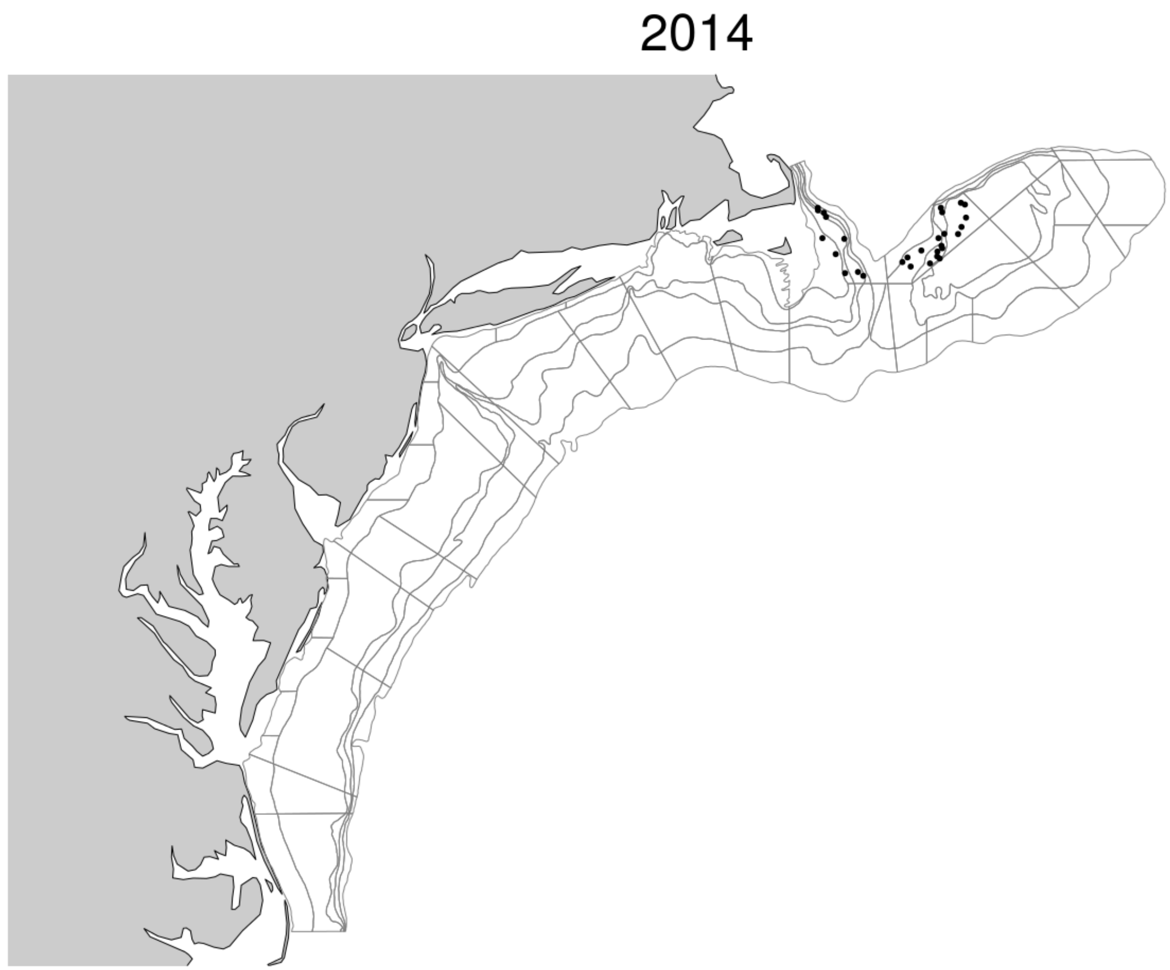


Figure 26: Station locations from the 2014 survey

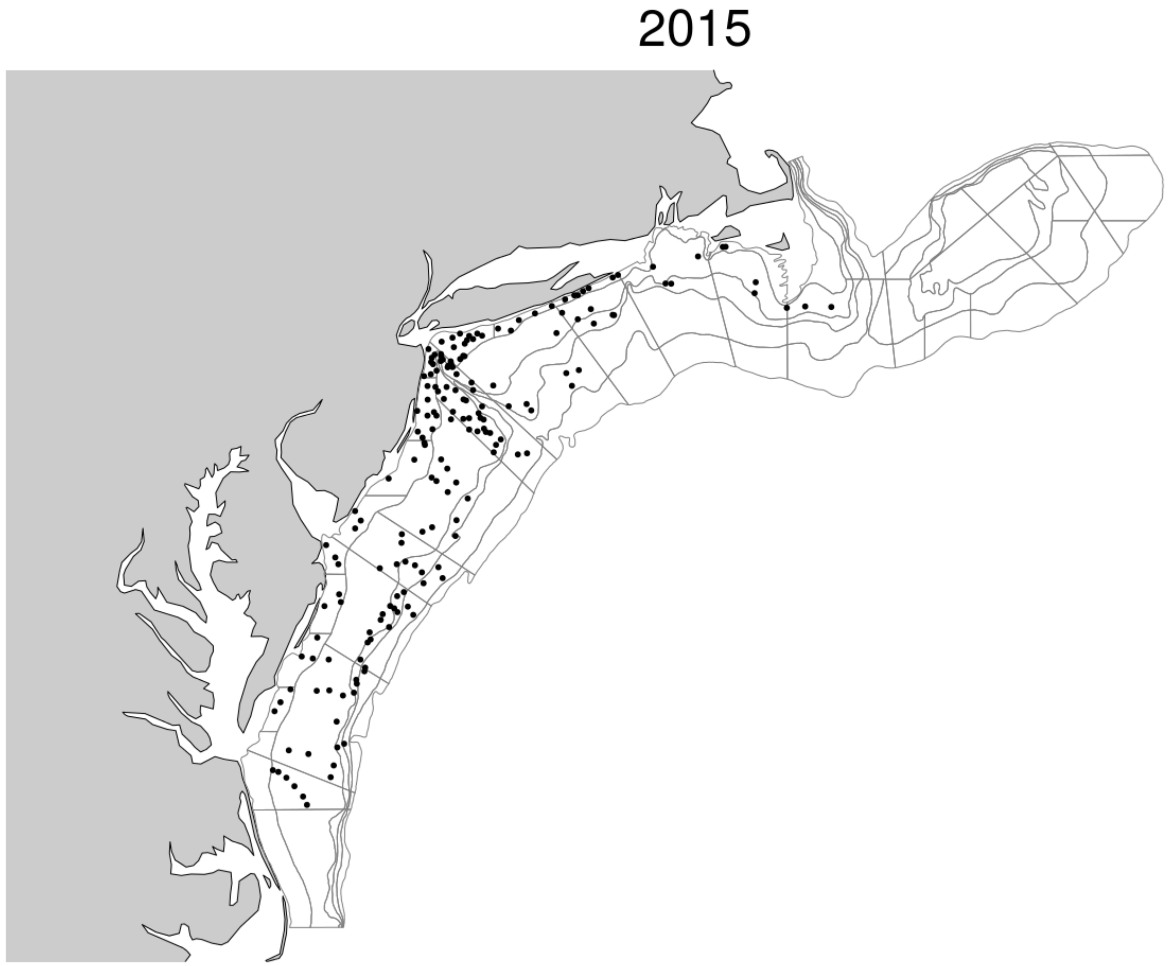


Figure 27: Station locations from the 2015 survey

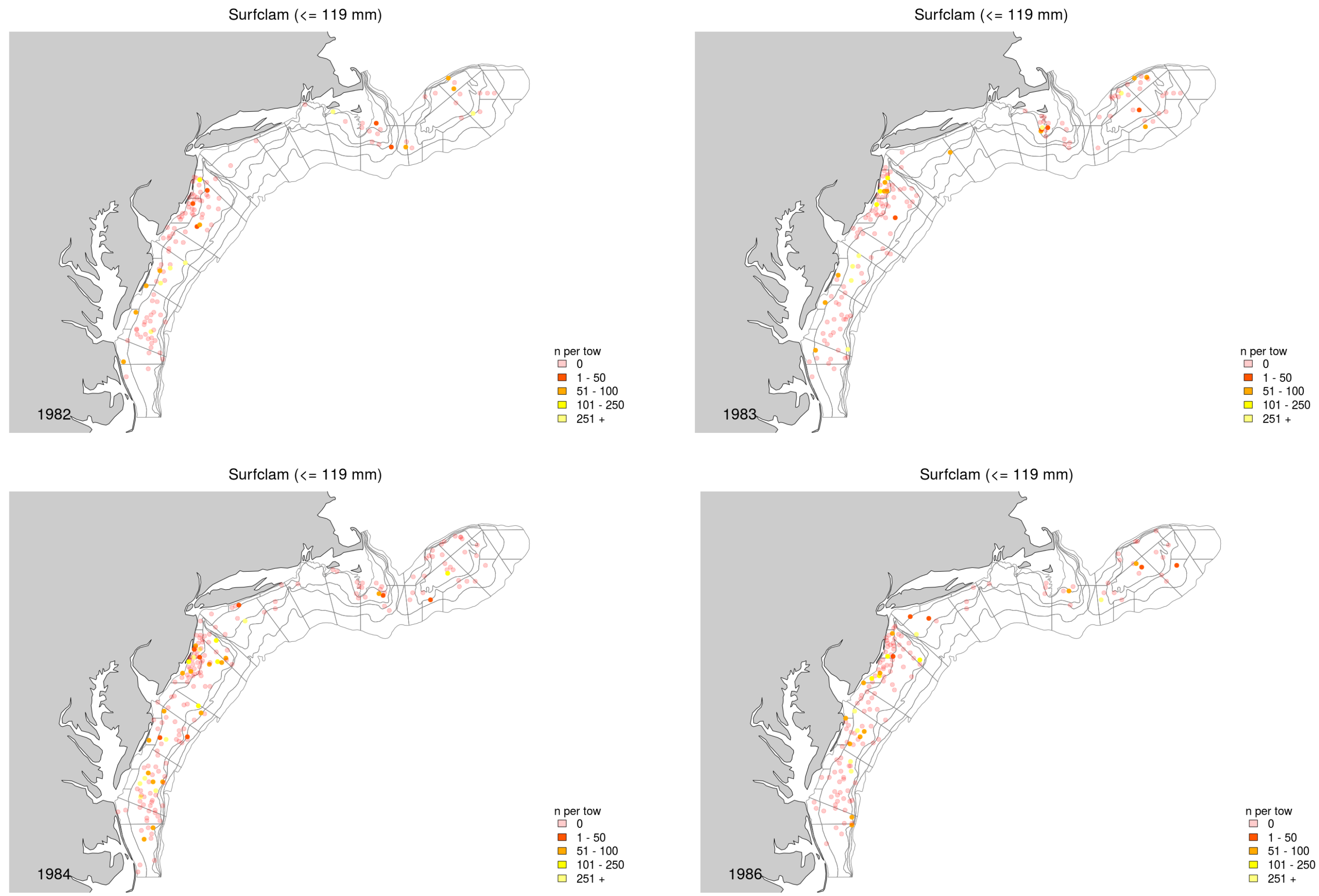


Figure 28: Survey stations where small ($<= 119\ mm$) surfclam were caught, by year.

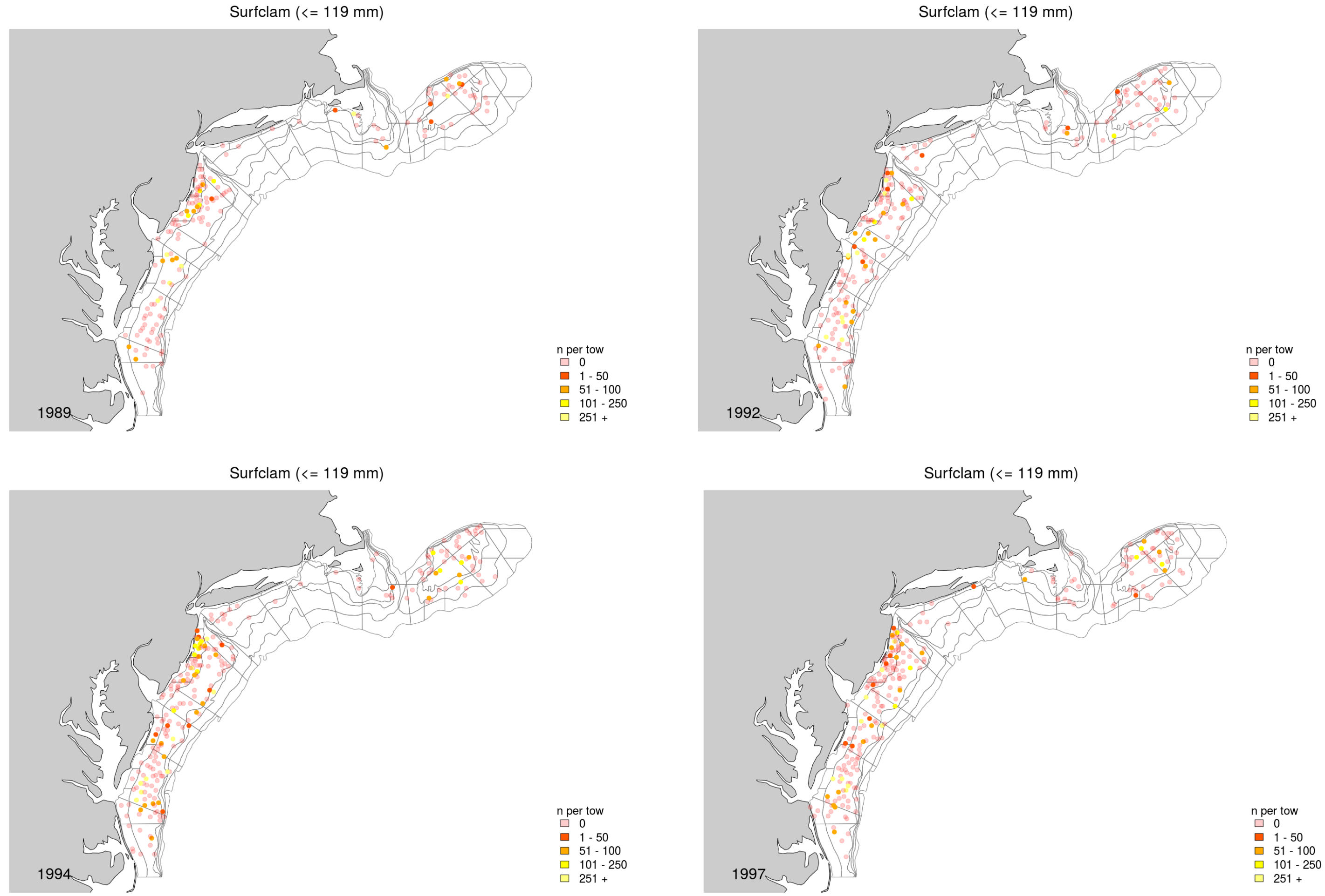
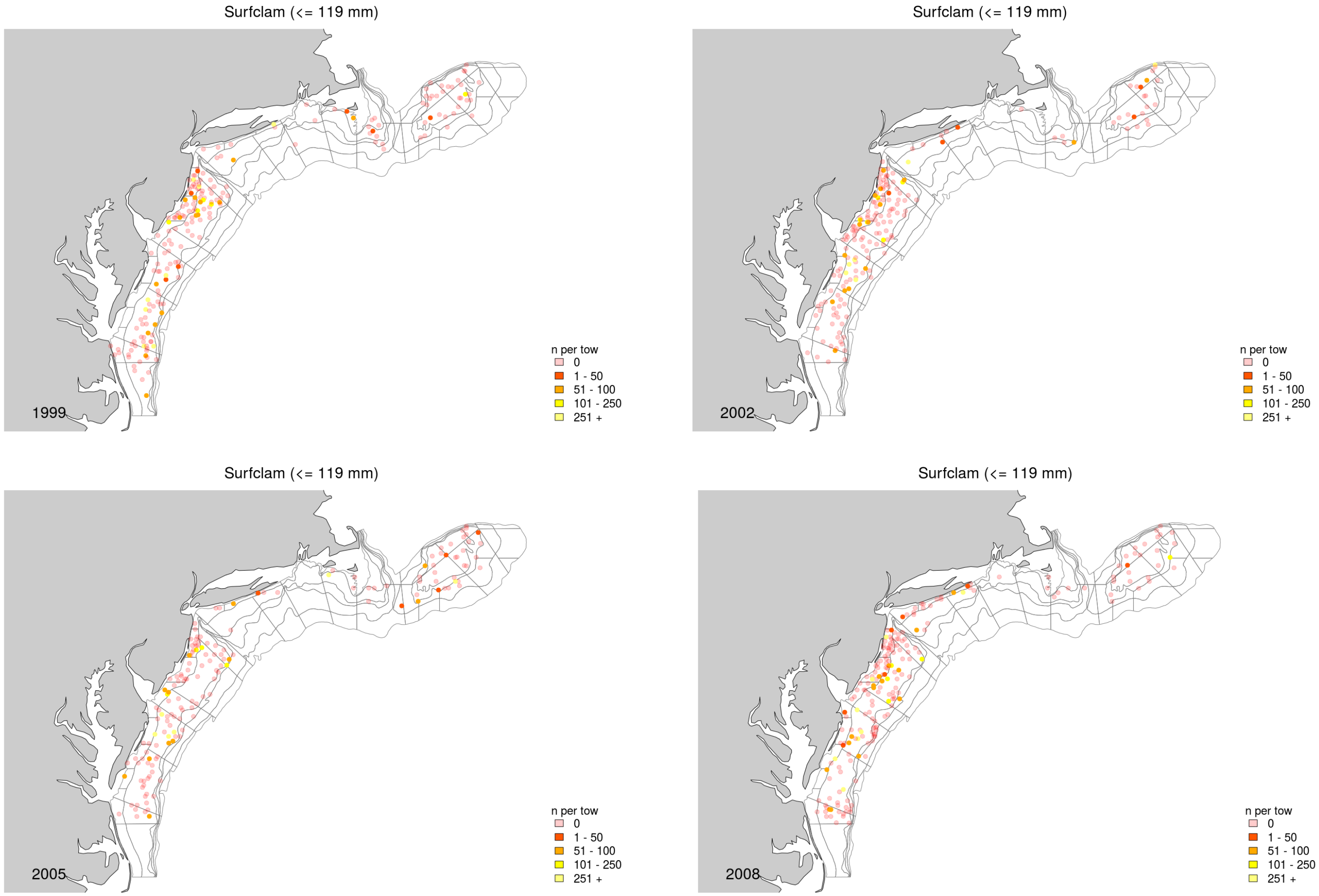


Figure 28 cont.



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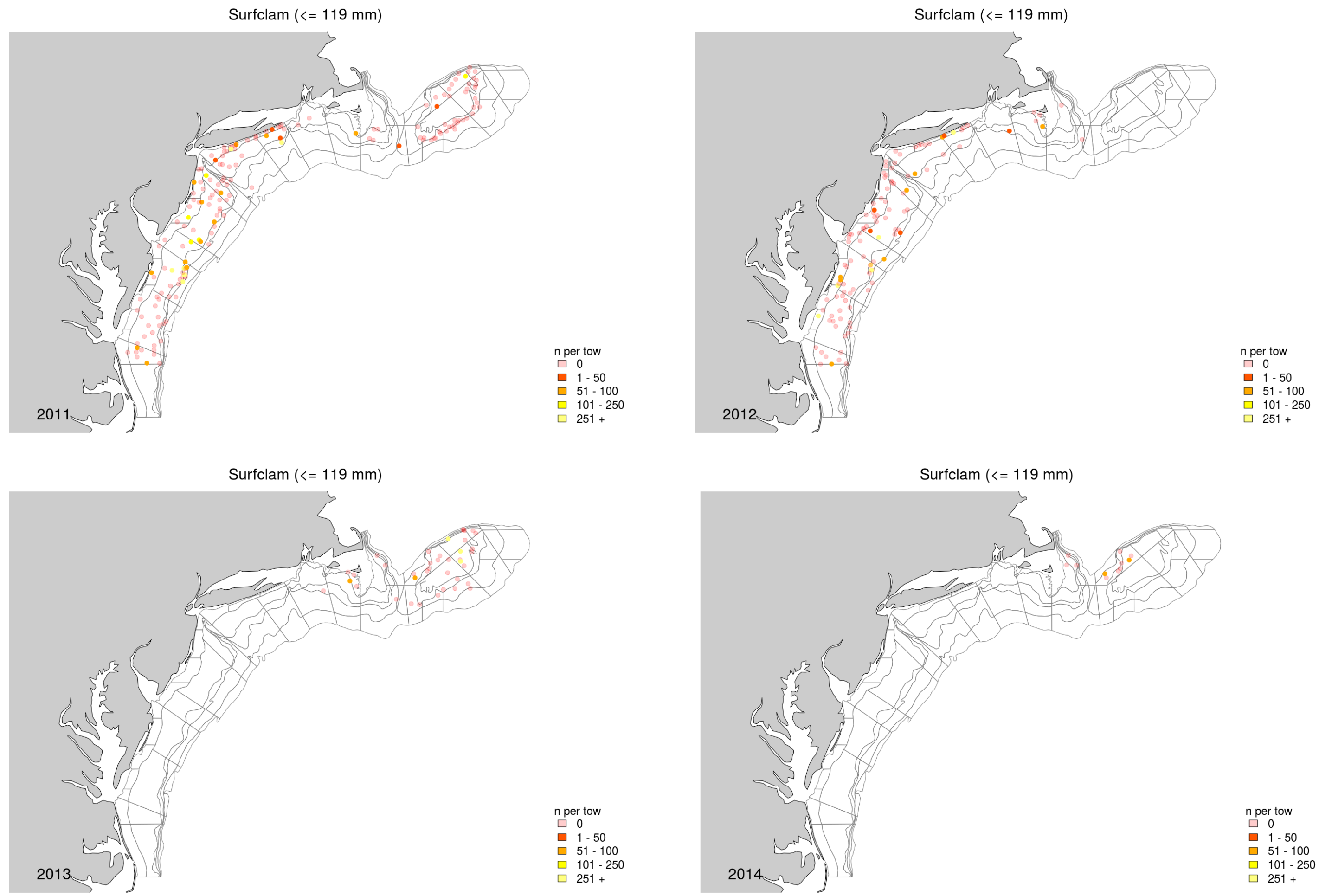

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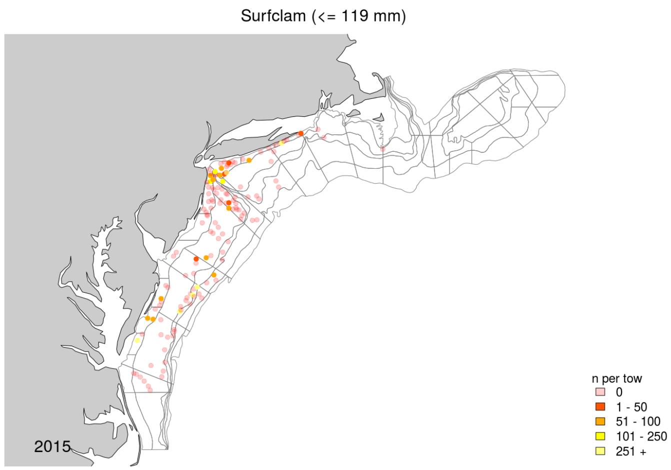


Figure 28 cont.

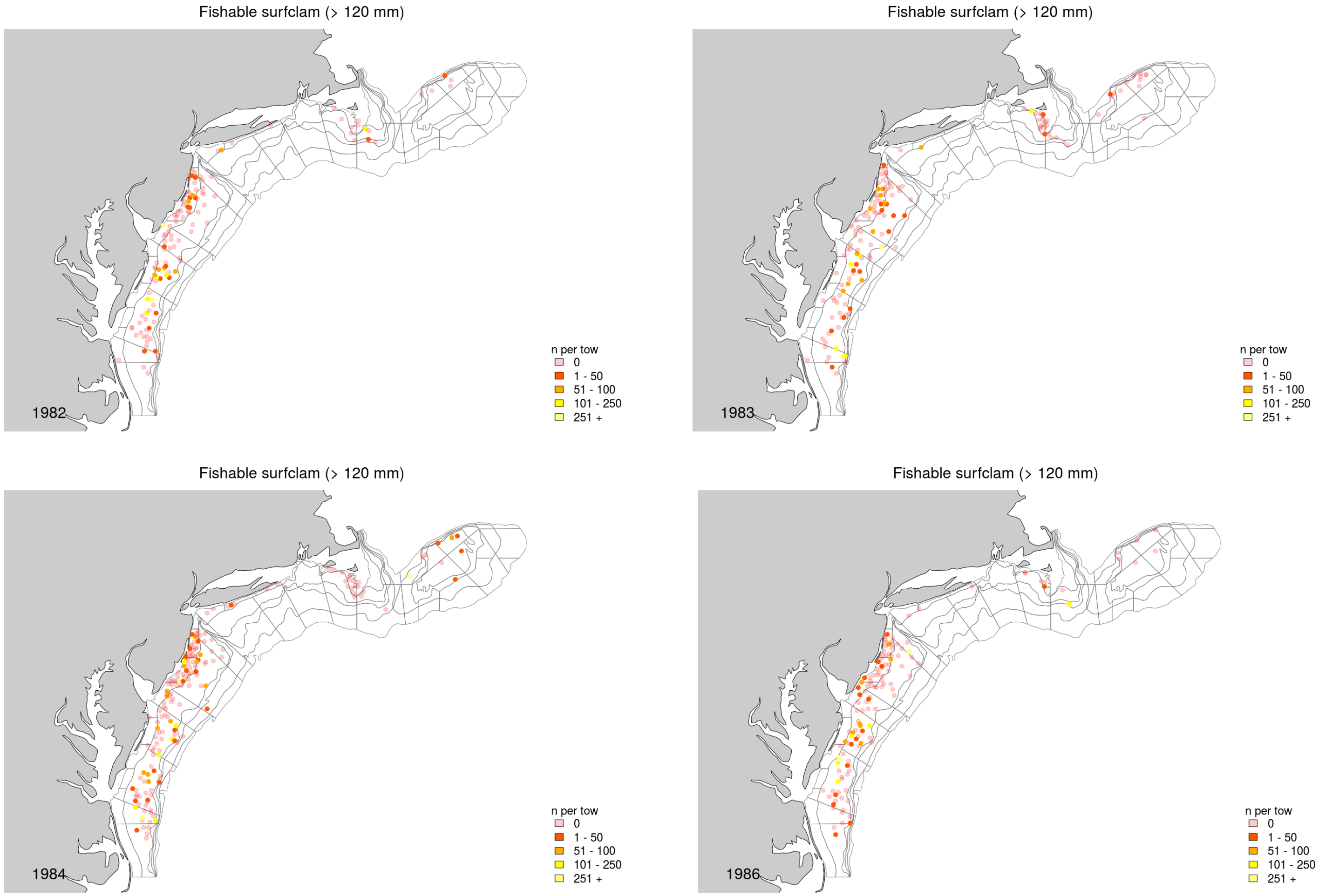
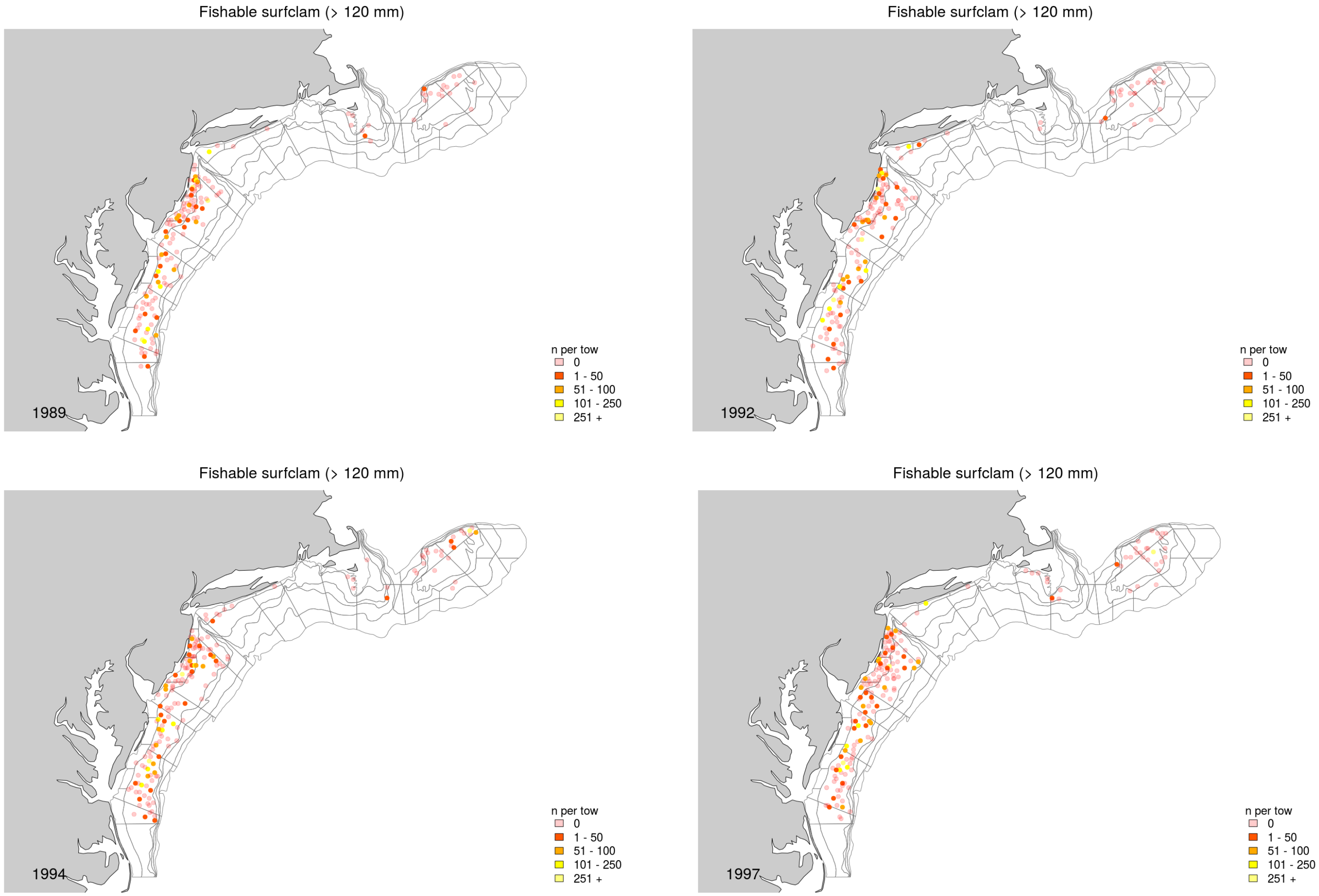


Figure 29: Survey stations where large ($> 120\ mm$) surfclam were caught, by year.



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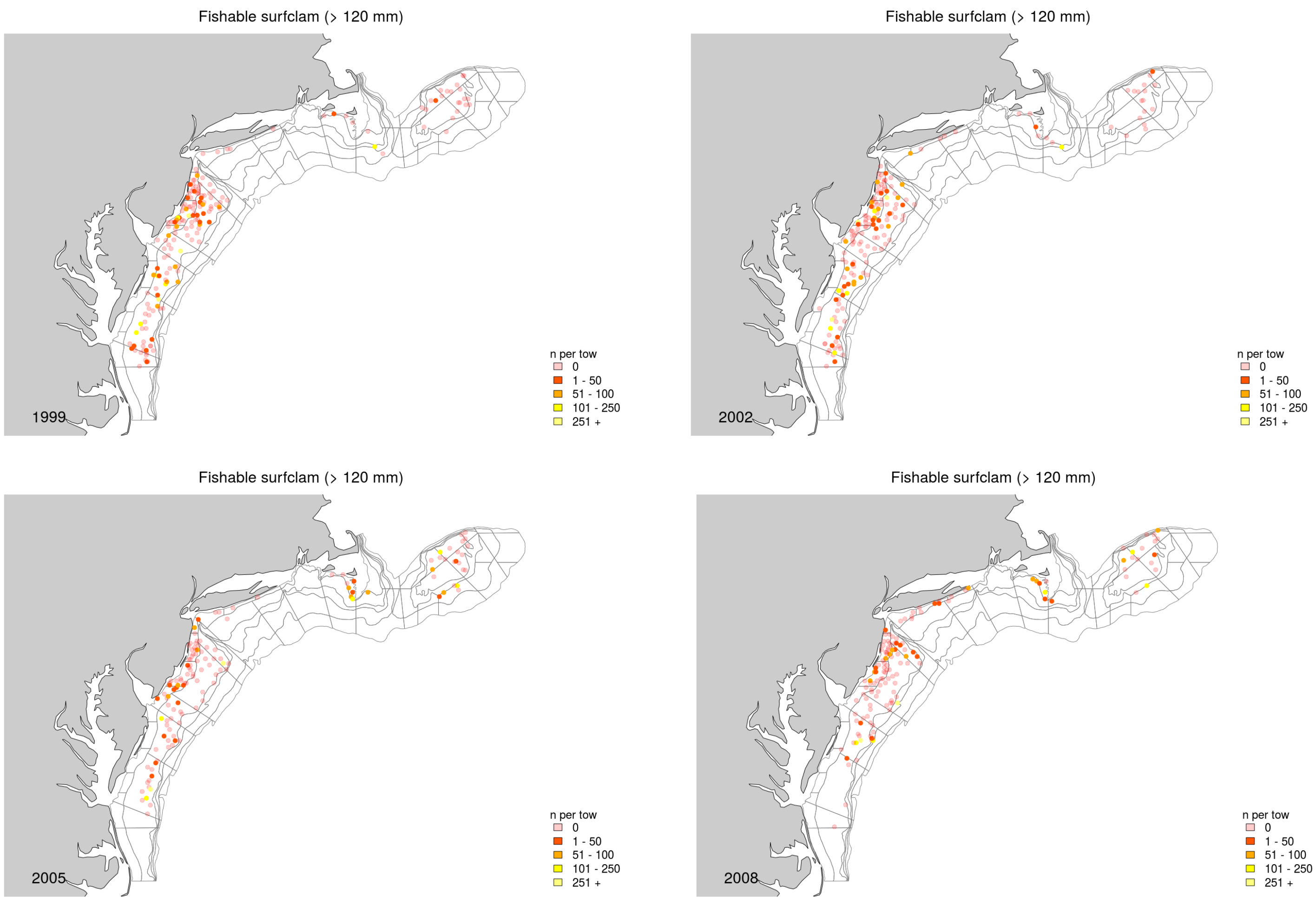

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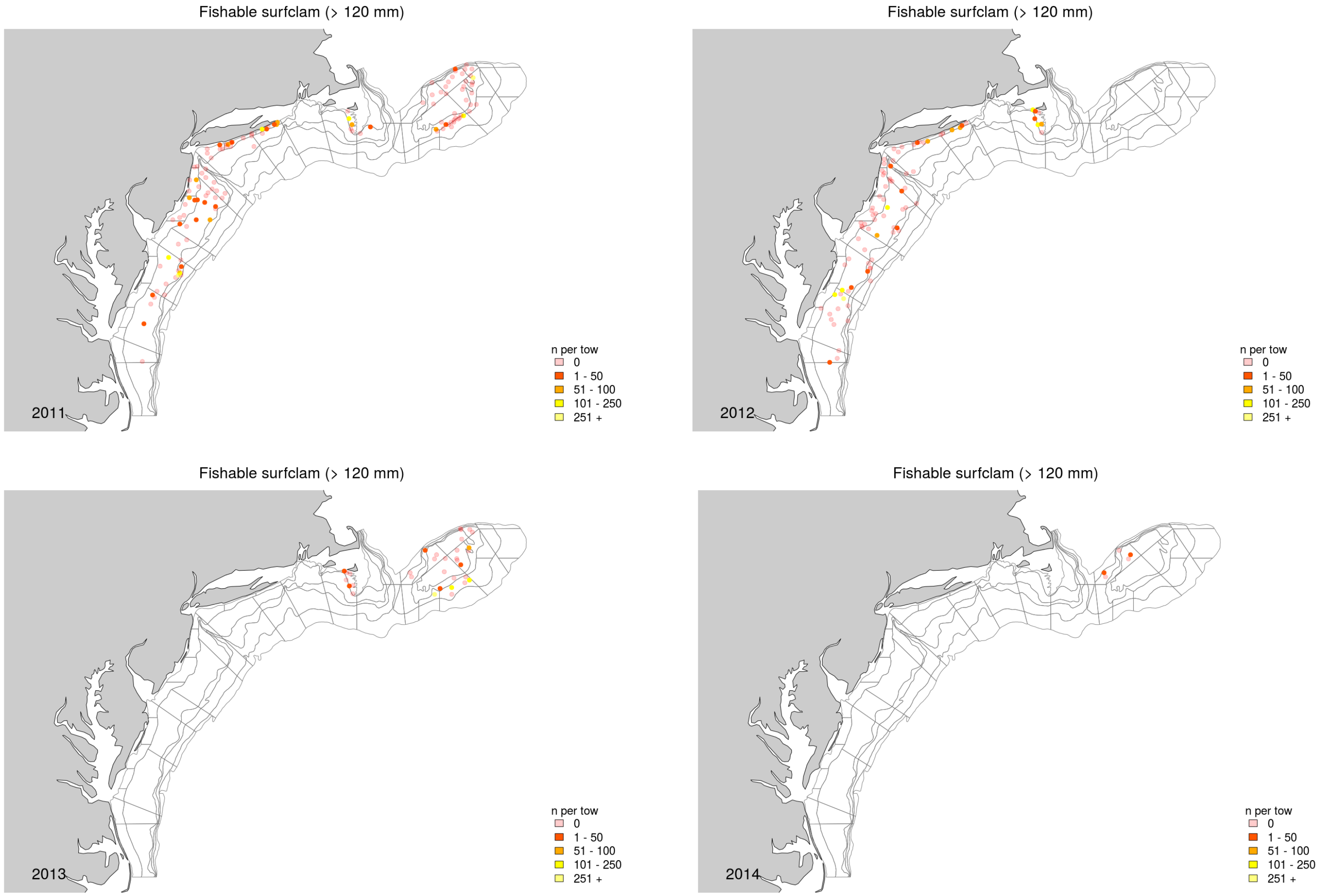

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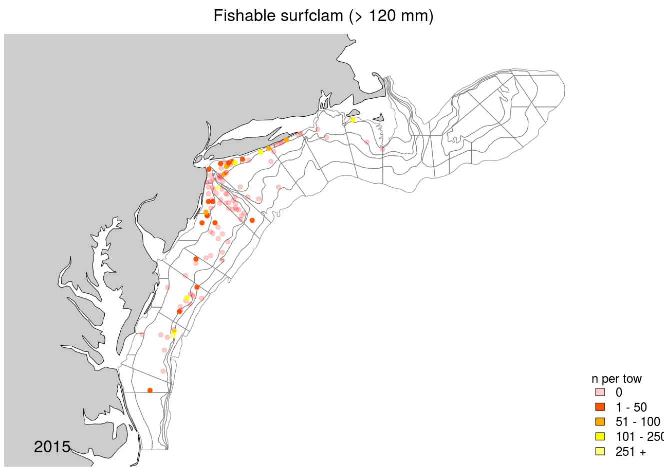

Figure 29 cont.

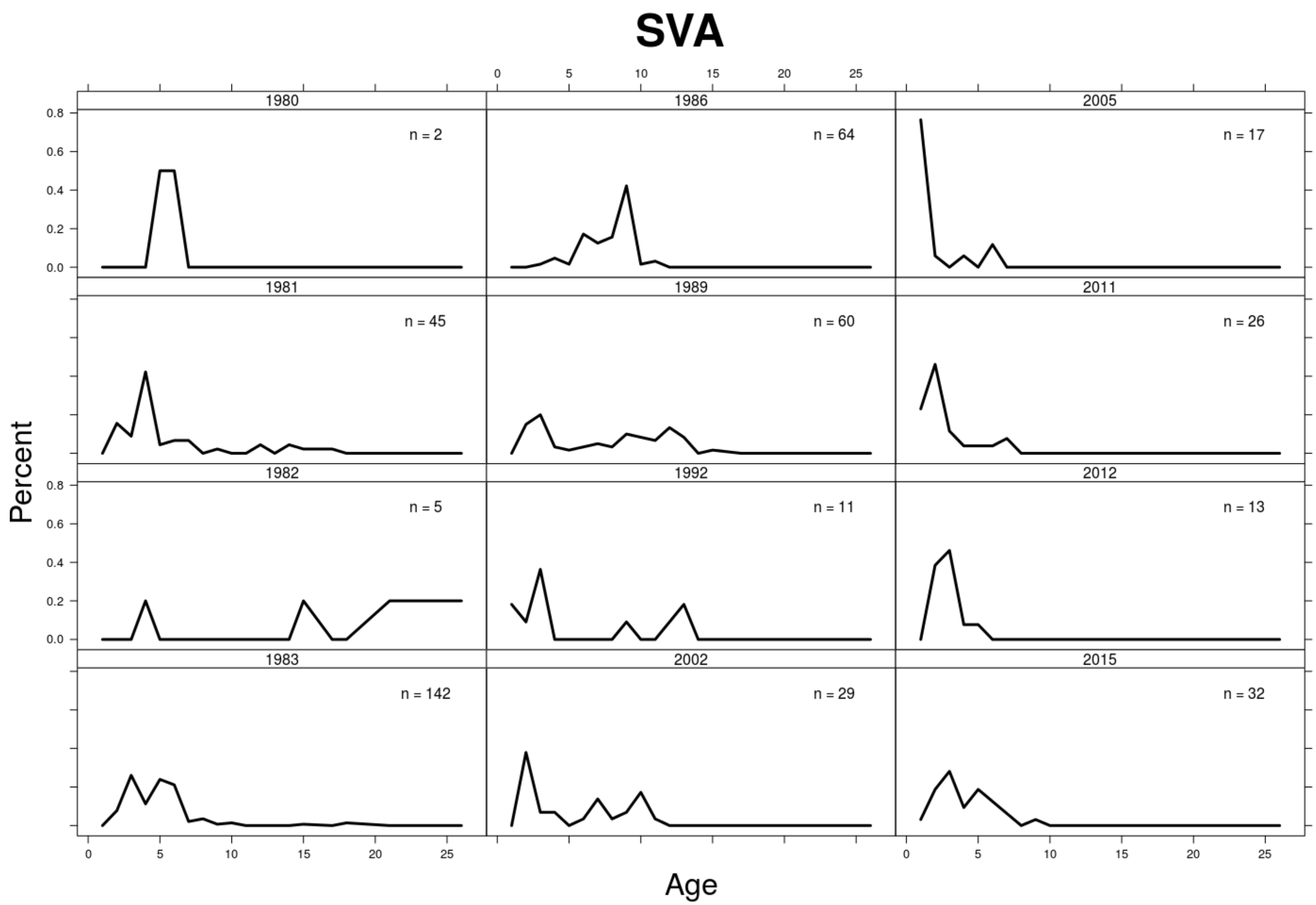

Figure 30: Age composition of Atlantic surfclam in NEFSC surveys in SVA, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

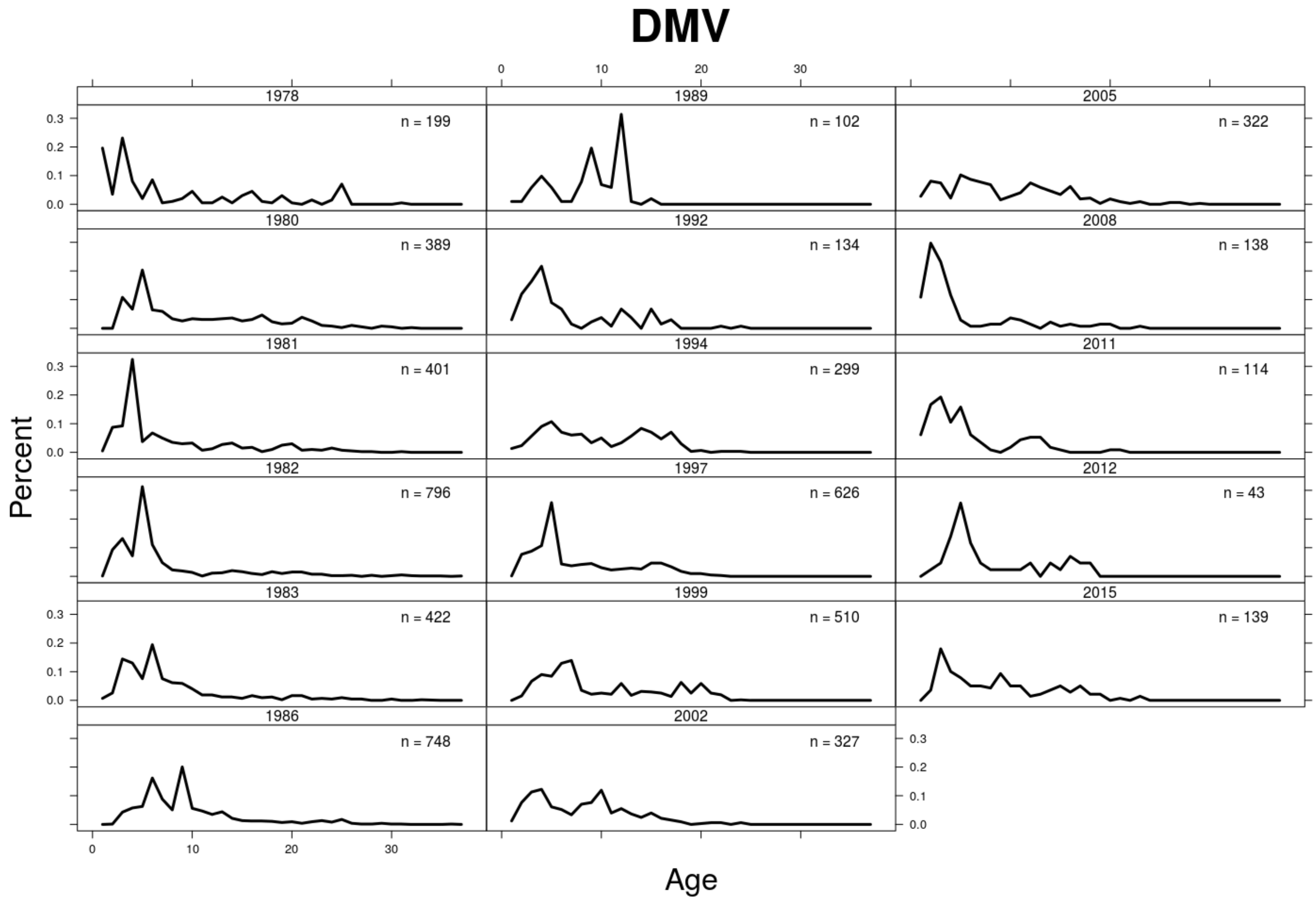

Figure 31: Age composition of Atlantic surfclam in NEFSC surveys in DMV, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

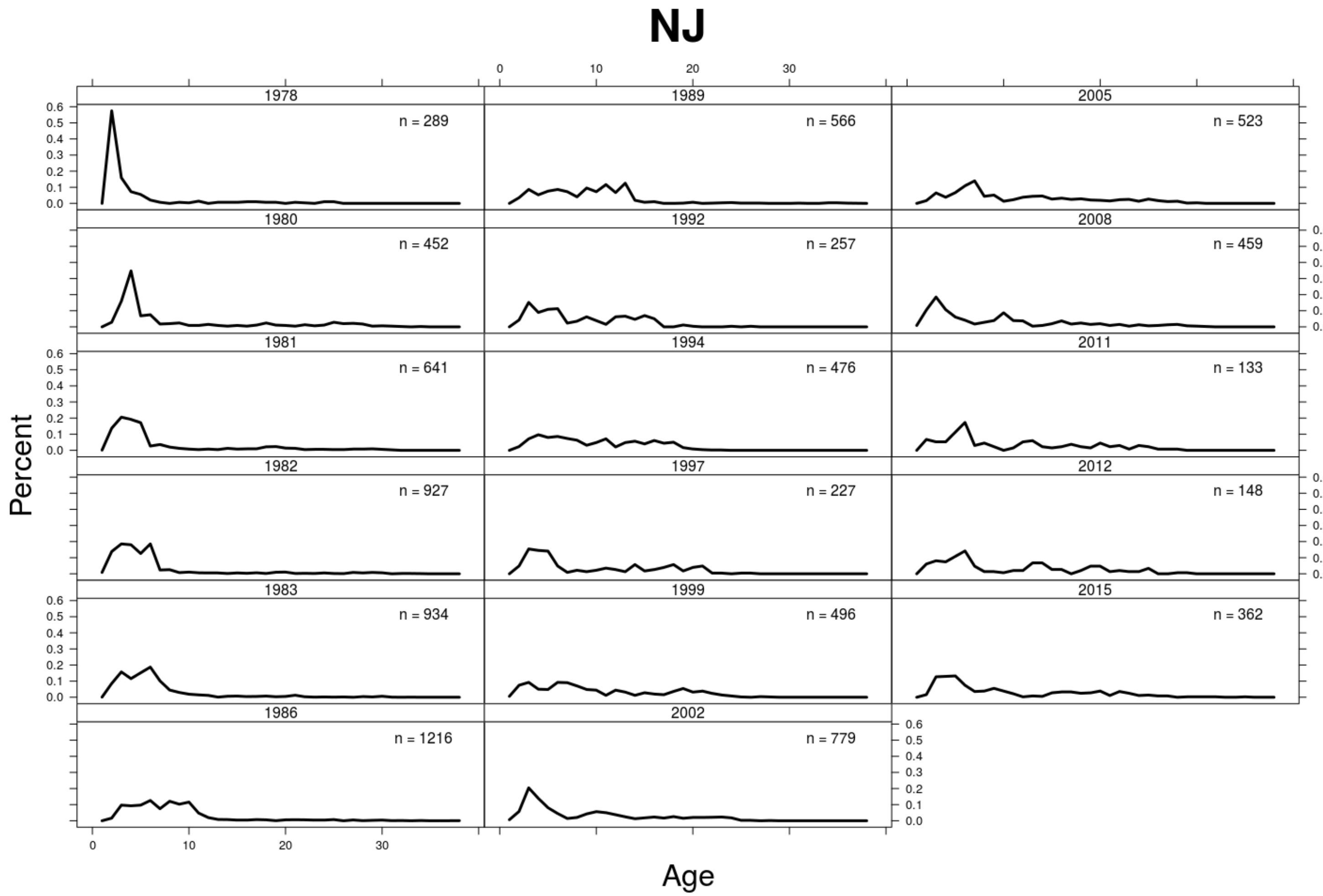

Figure 32: Age composition of Atlantic surfclam in NEFSC surveys in NJ, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

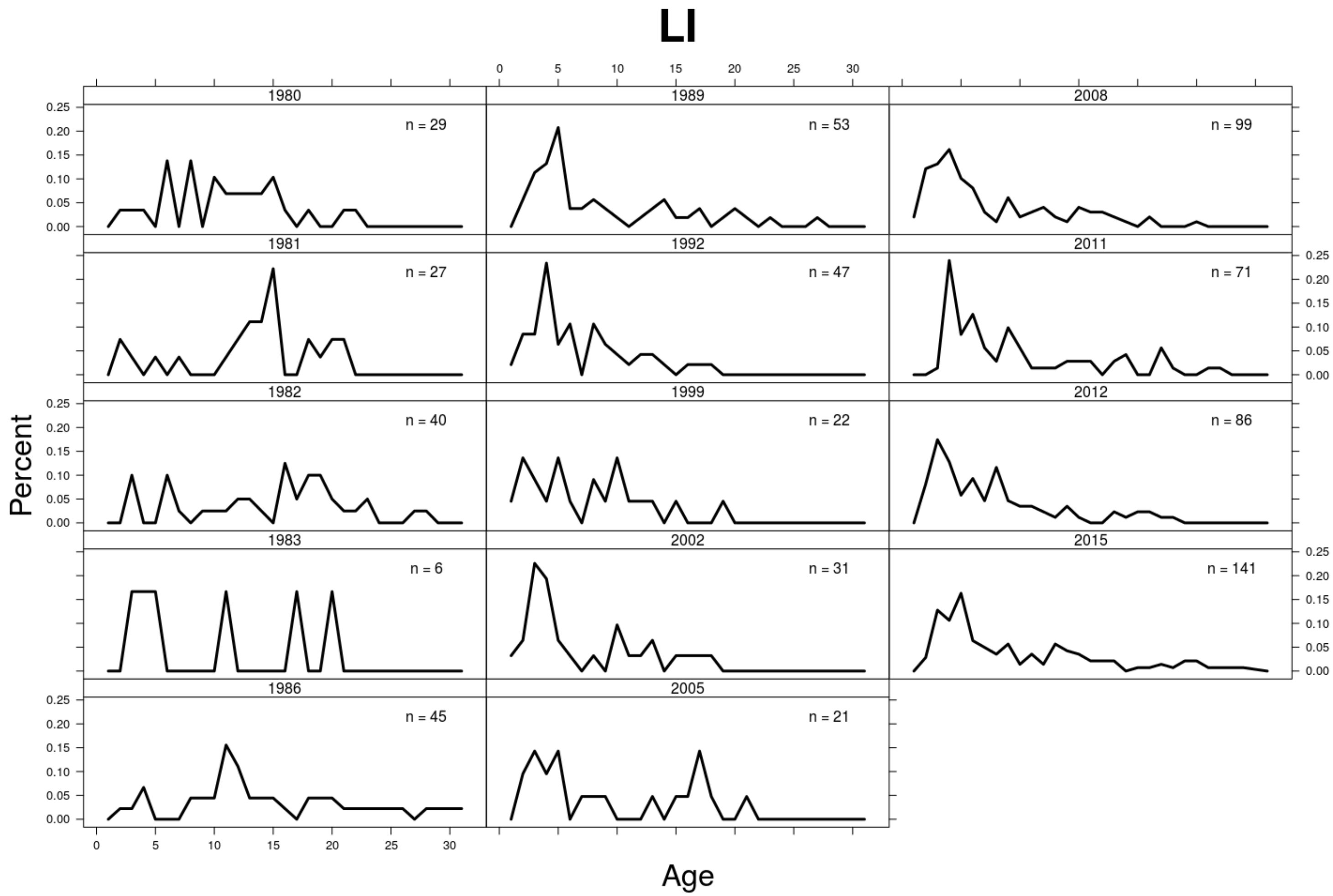

Figure 33: Age composition of Atlantic surfclam in NEFSC surveys in LI, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

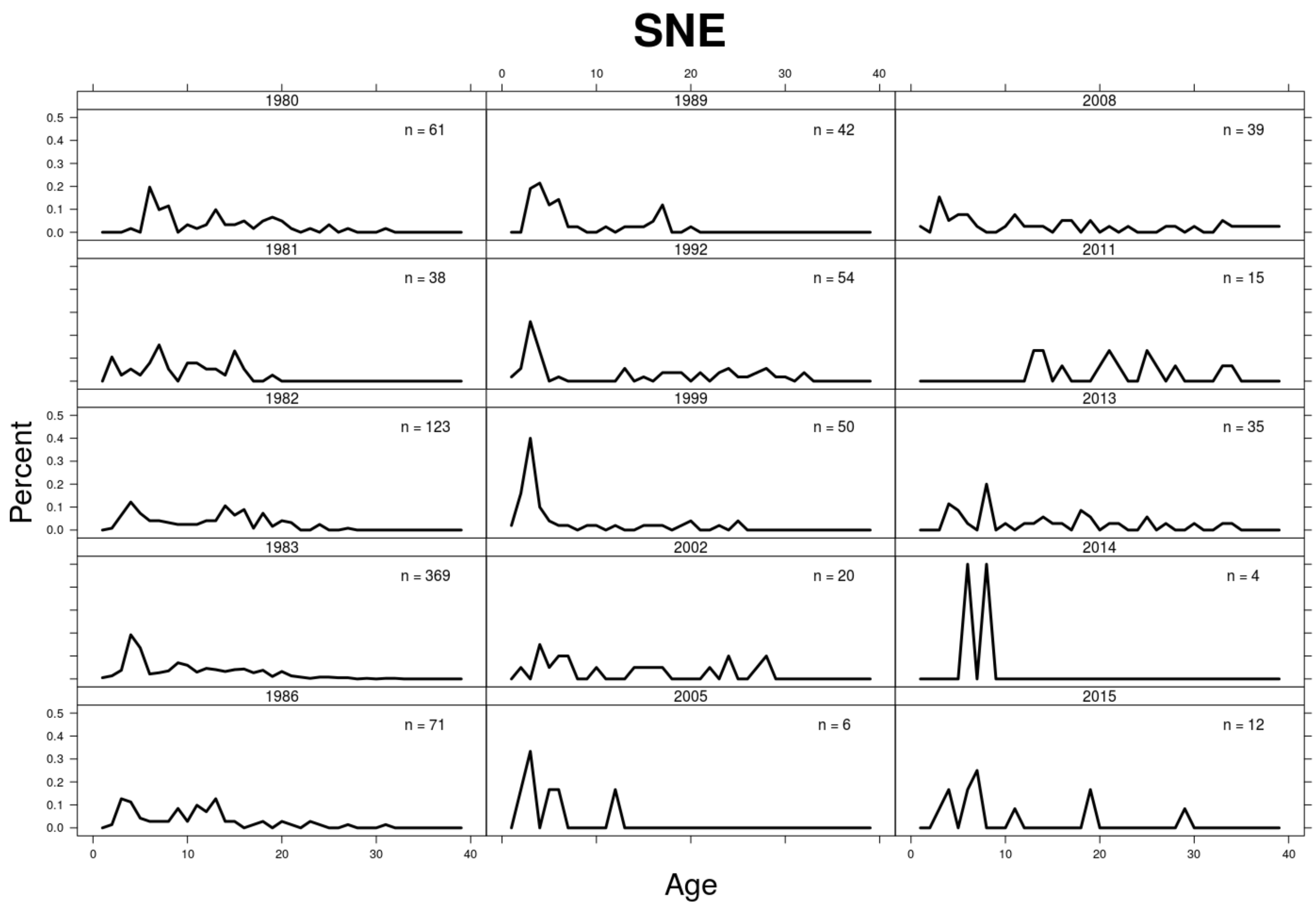

Figure 34: Age composition of Atlantic surfclam in NEFSC surveys in SNE, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

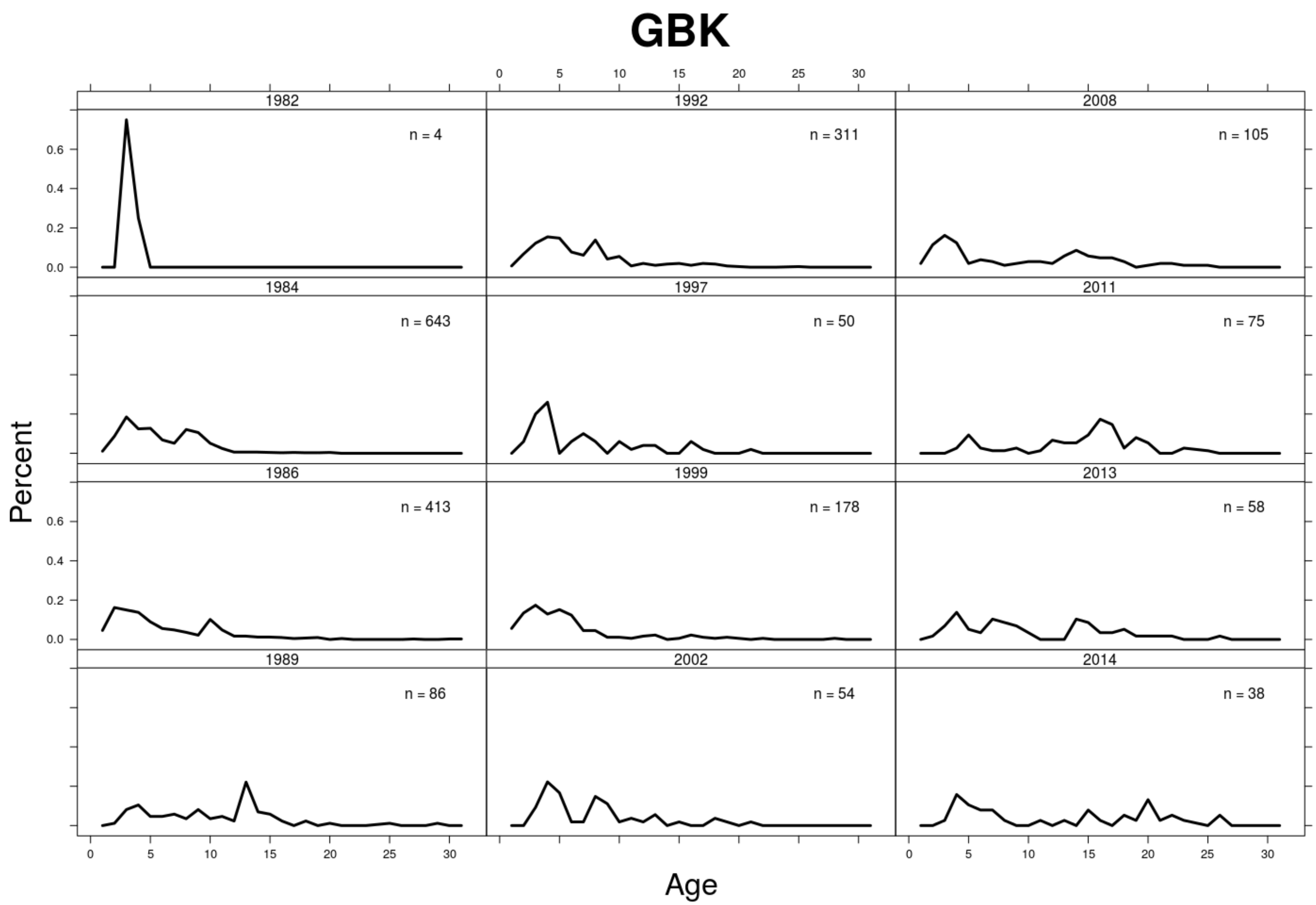

Figure 35: Age composition of Atlantic surfclam in NEFSC surveys in the northern area (GBK), including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

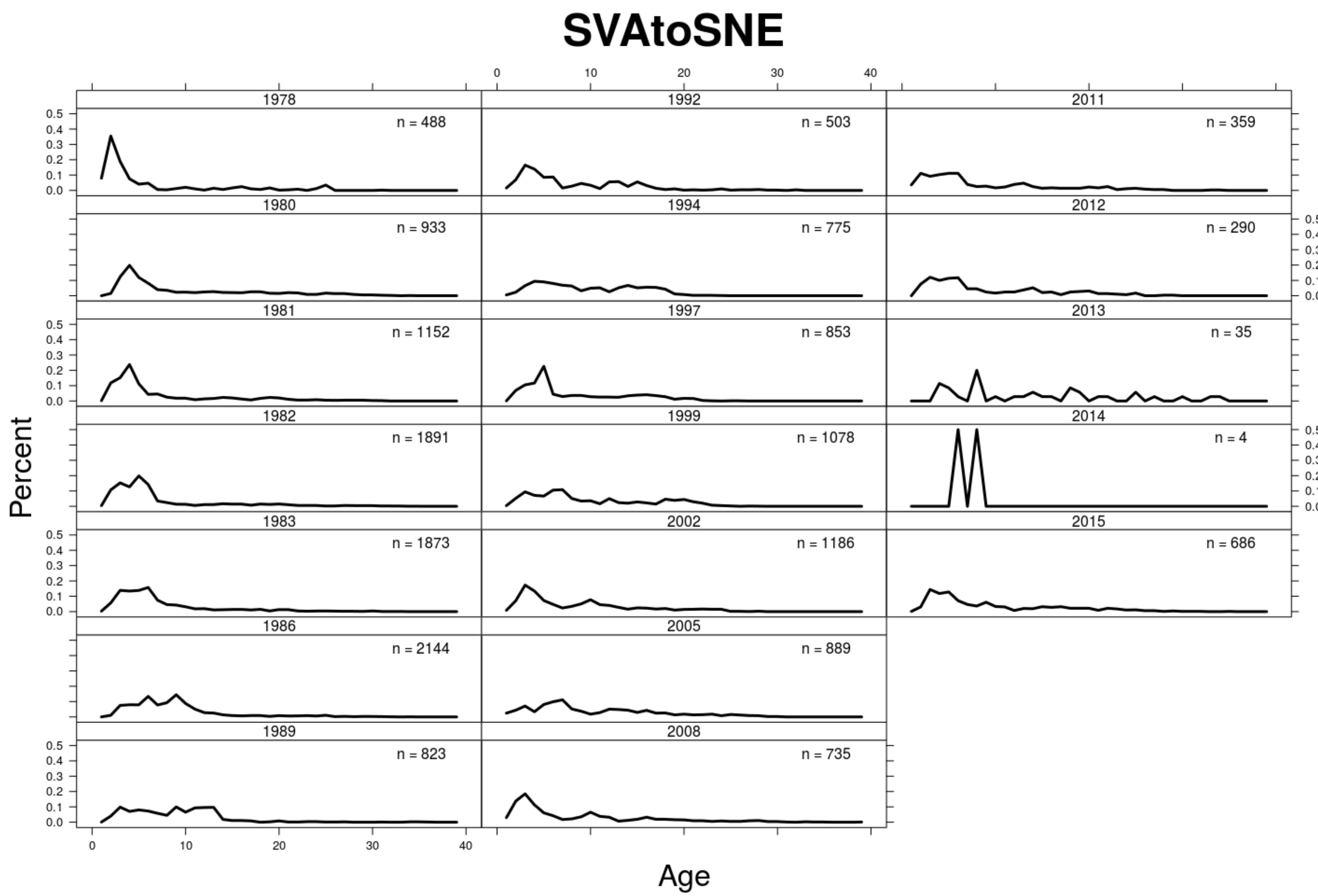

Figure 36: Age composition of Atlantic surfclam in NEFSC surveys in the southern area (SVAtoSNE), including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

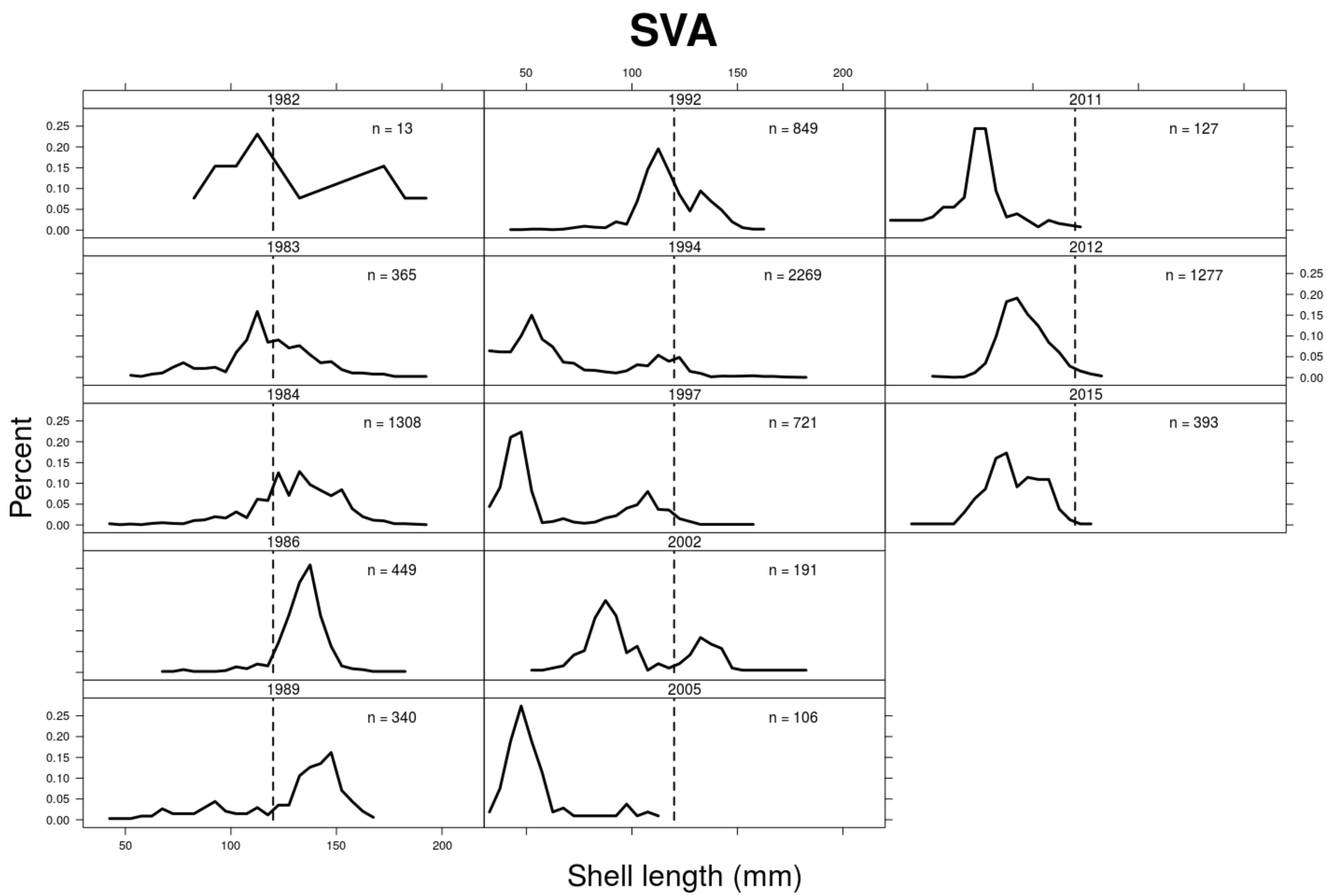

Figure 37: Length composition of Atlantic surfclam in NEFSC surveys in SVA, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

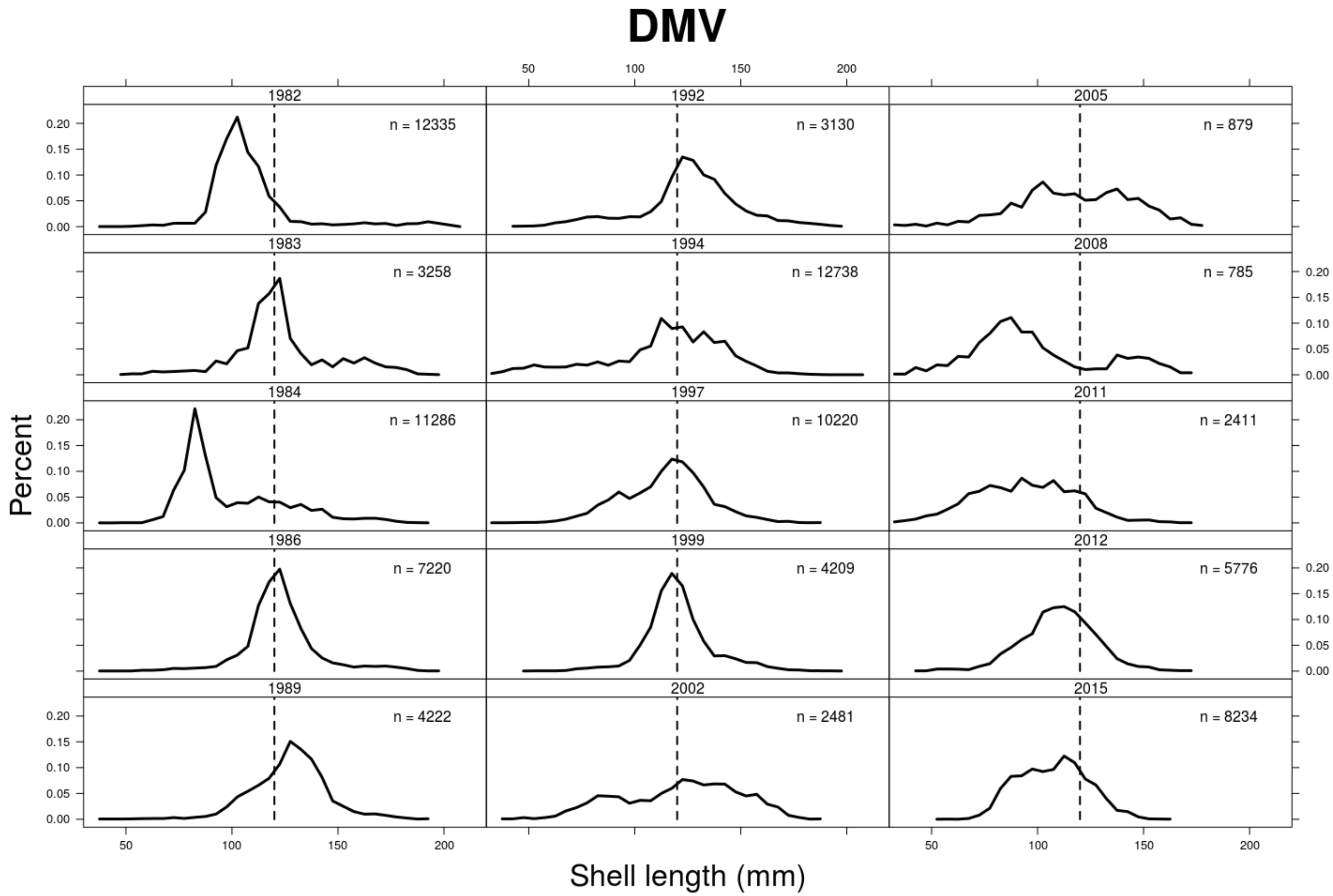

Figure 38: Length composition of Atlantic surfclam in NEFSC surveys in DMV, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

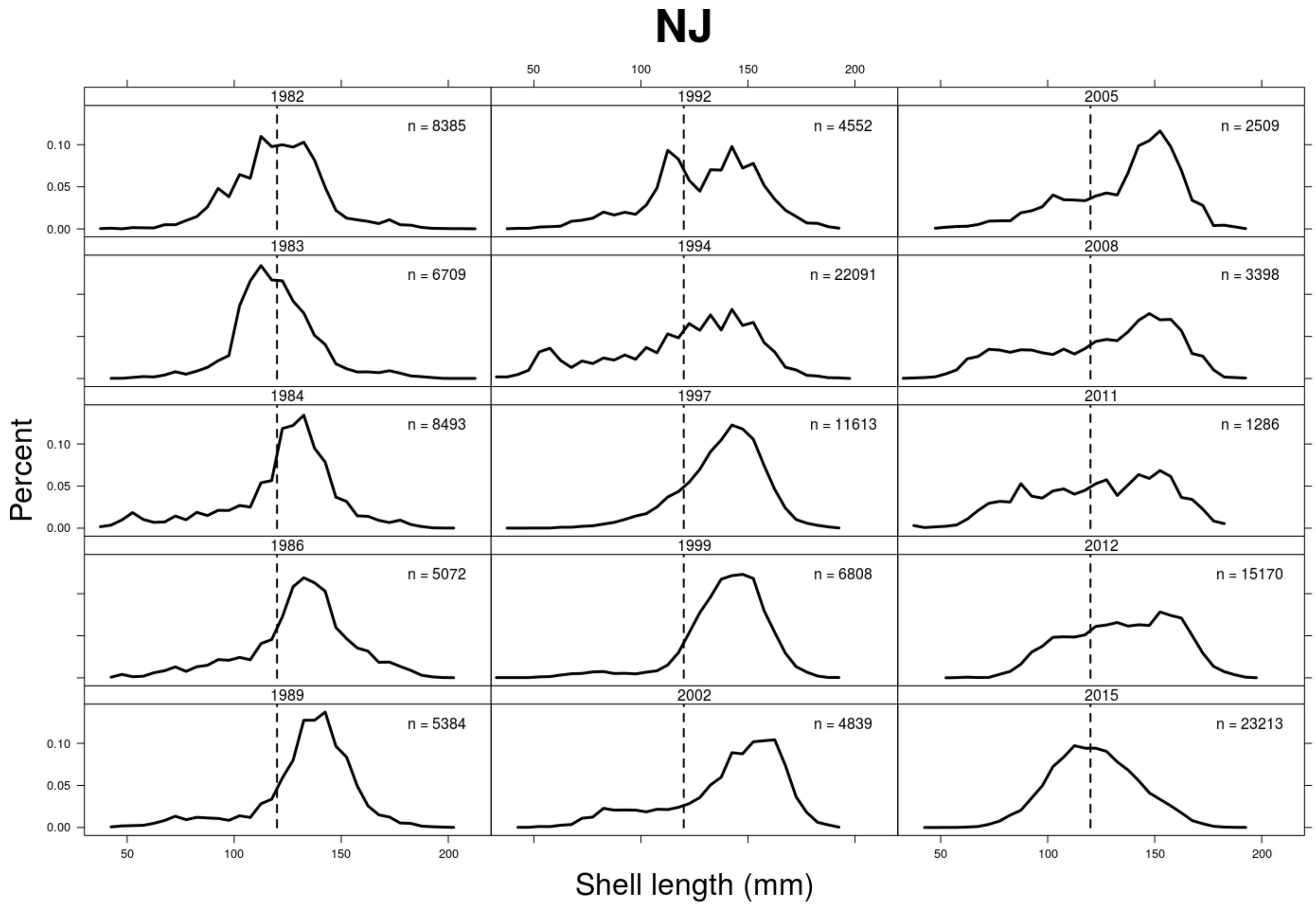

Figure 39: Length composition of Atlantic surfclam in NEFSC surveys in NJ, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

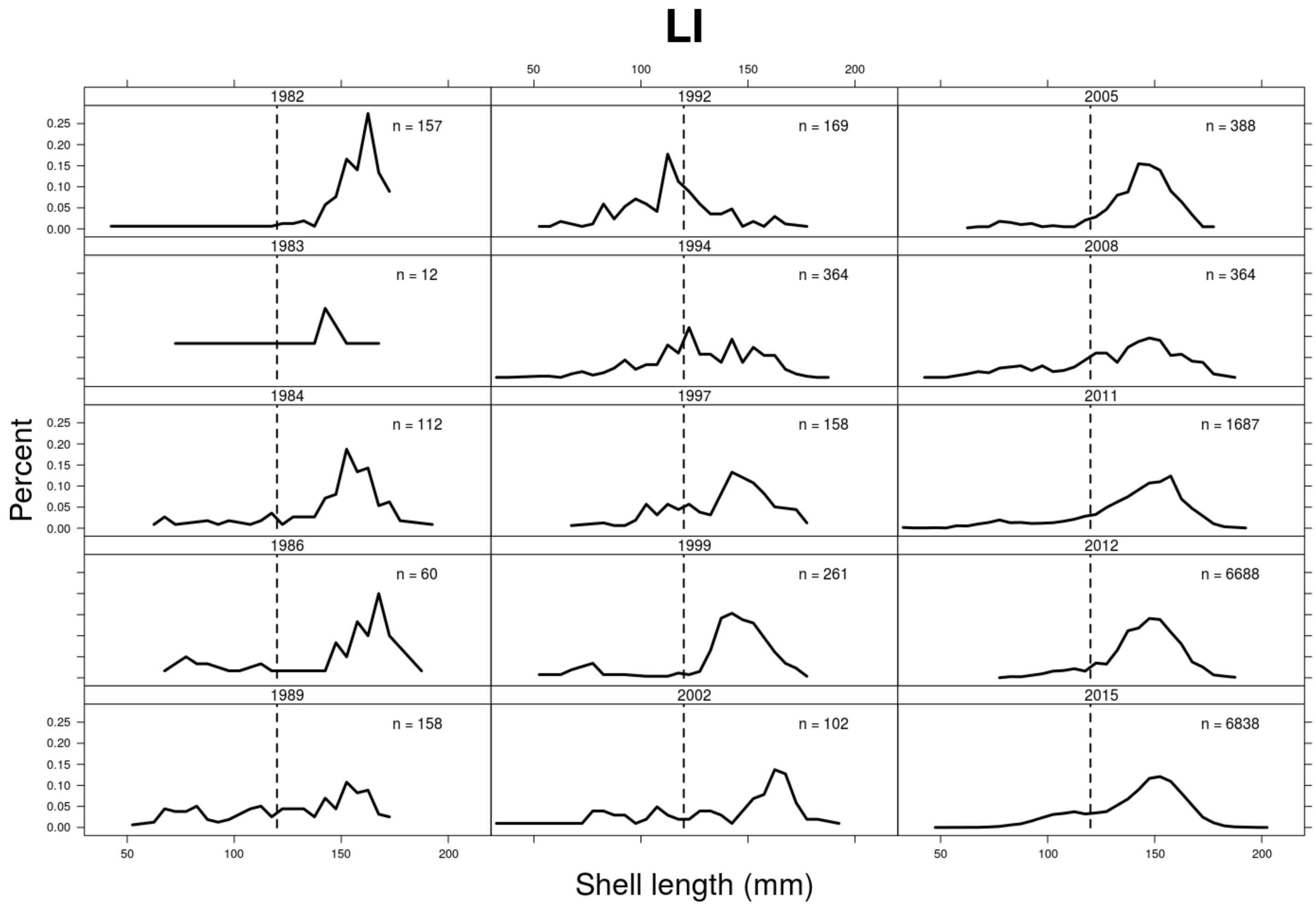

Figure 40: Length composition of Atlantic surfclam in NEFSC surveys in LI, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

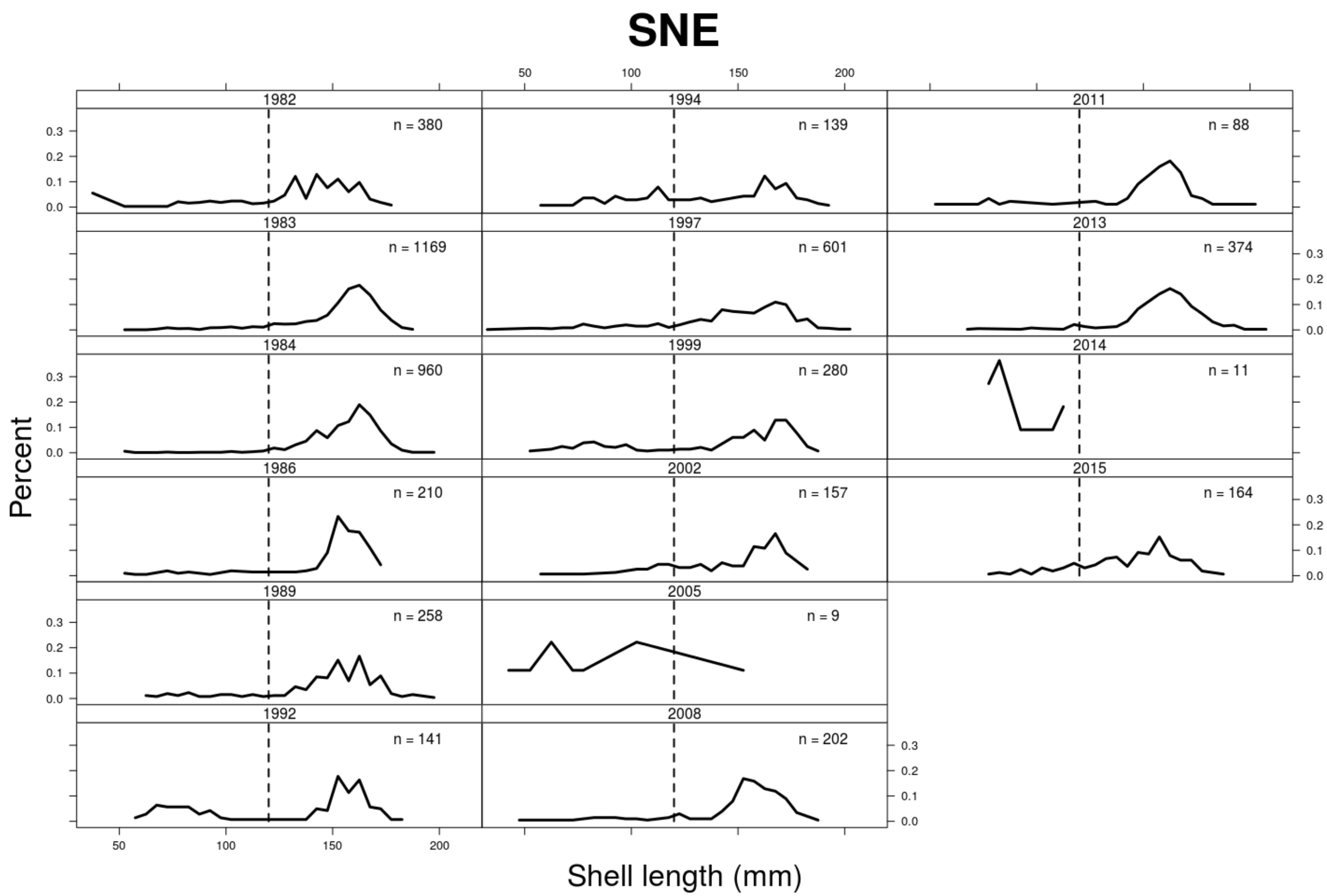

Figure 41: Length composition of Atlantic surfclam in NEFSC surveys in SNE, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

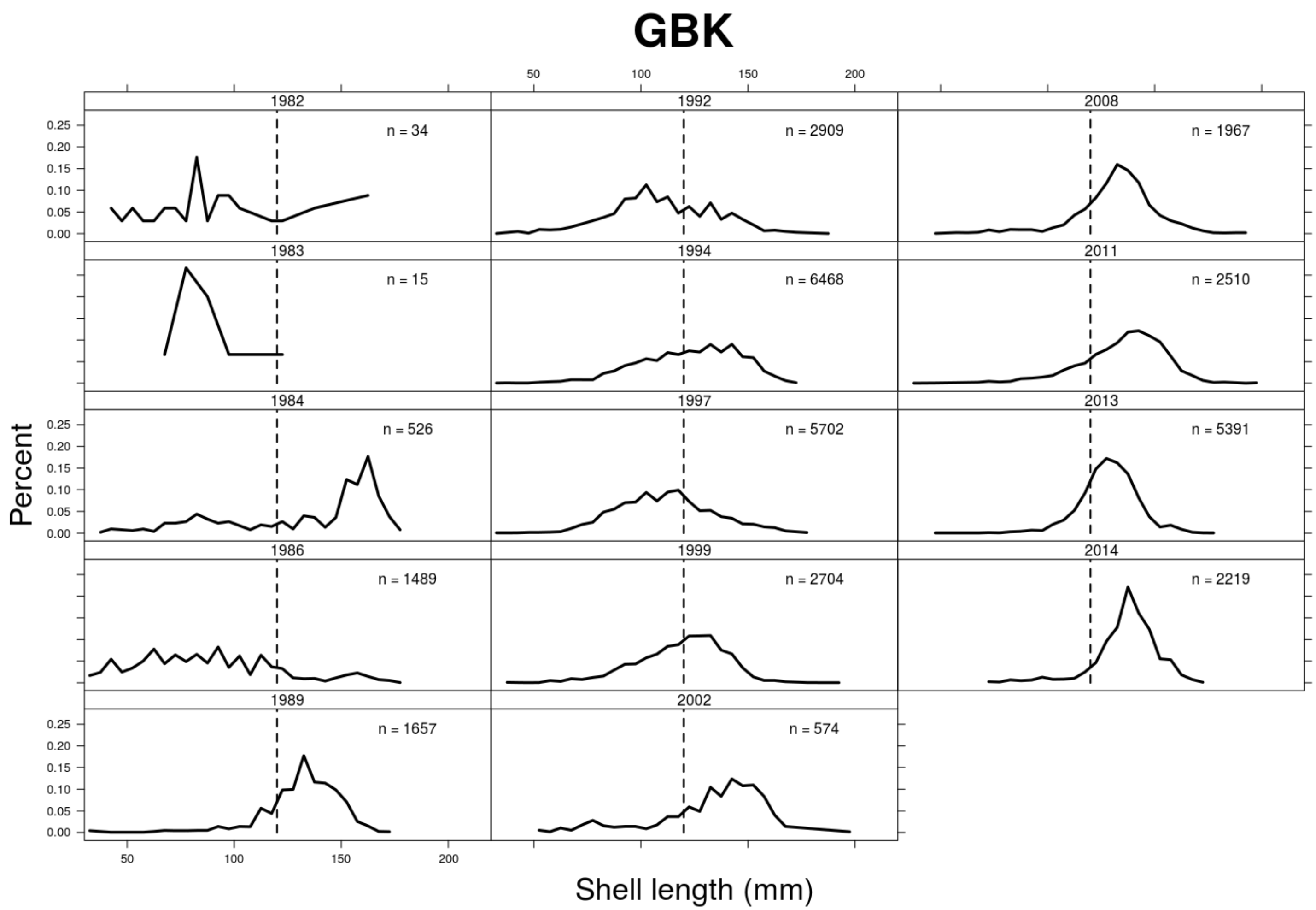

Figure 42: Length composition of Atlantic surfclam in NEFSC surveys in GBK, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

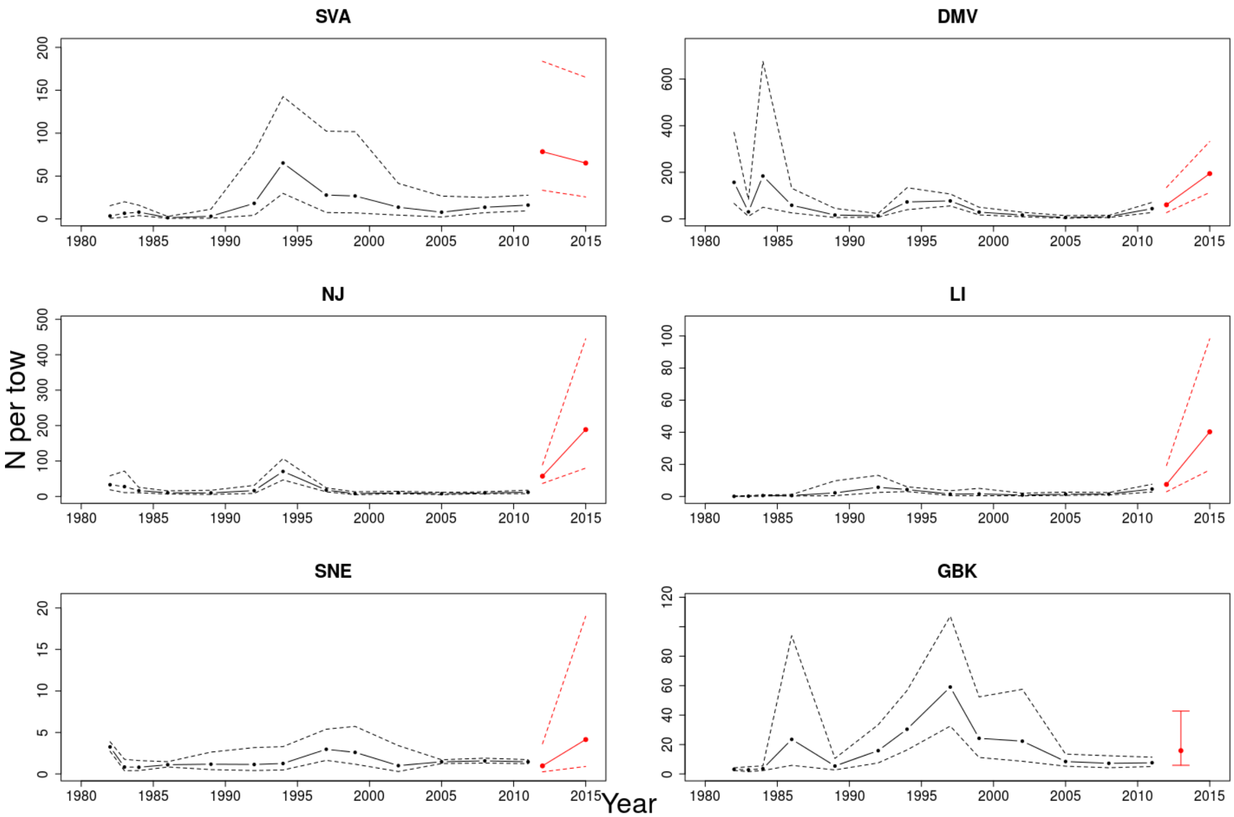

Figure 43: Surfclam 50 – 119 mm from NEFSC surveys adjusted for selectivity, but not efficiency, with approximate 95% asymmetric confidence intervals, by region. Beginning in 2012, the survey was conducted from a commercial platform using a dredge with higher capture efficiency. Results from the new survey platform are shown as a separate series in red. GBK and SNE were not sampled in 2012 and SVA, DMV, NJ and LI were not sampled in 2013 or 2014.

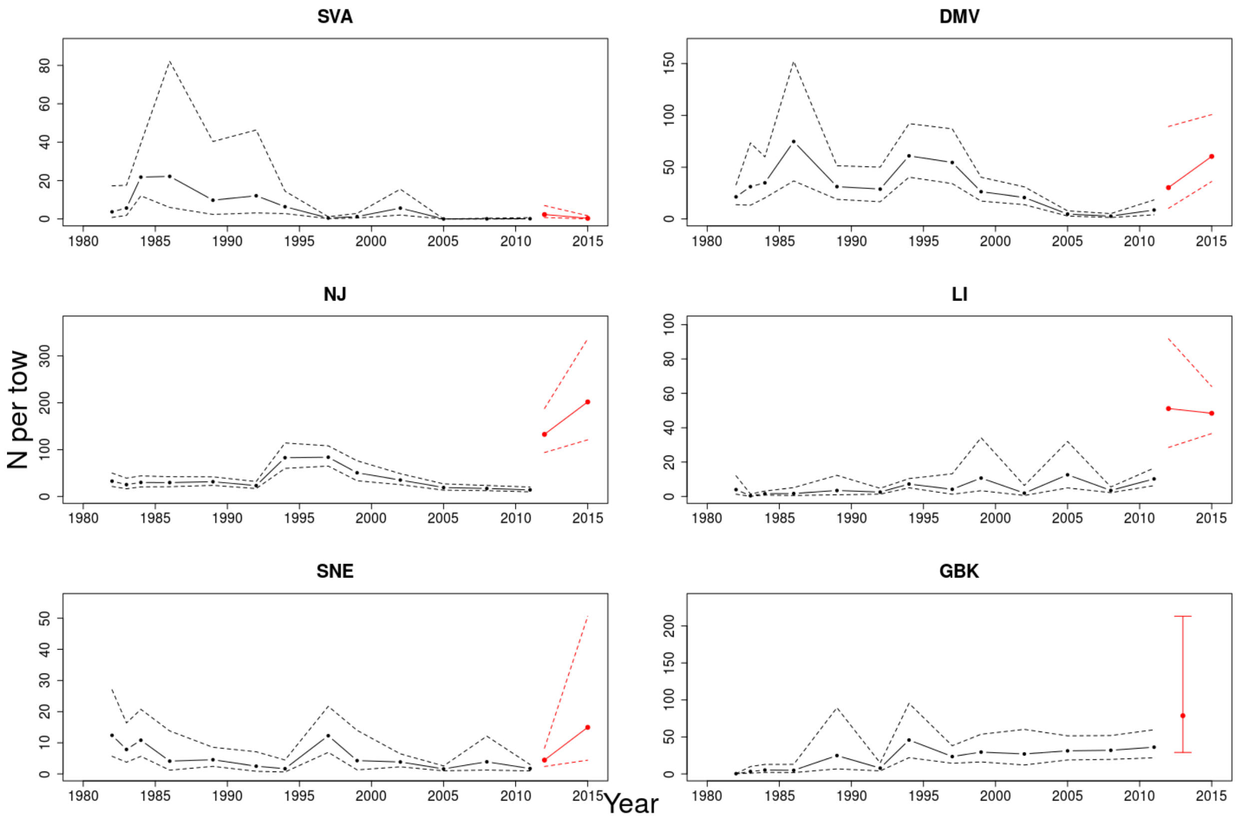

Figure 44: Surfclam > 119 mm from NEFSC surveys adjusted for selectivity, but not efficiency, with approximate 95% asymmetric confidence intervals, by region. Beginning in 2012, the survey was conducted from a commercial platform using a dredge with higher capture efficiency. Results from the new survey platform are shown as a separate series in red. GBK and SNE were not sampled in 2012 and SVA, DMV, NJ and LI were not sampled in 2013 or 2014.

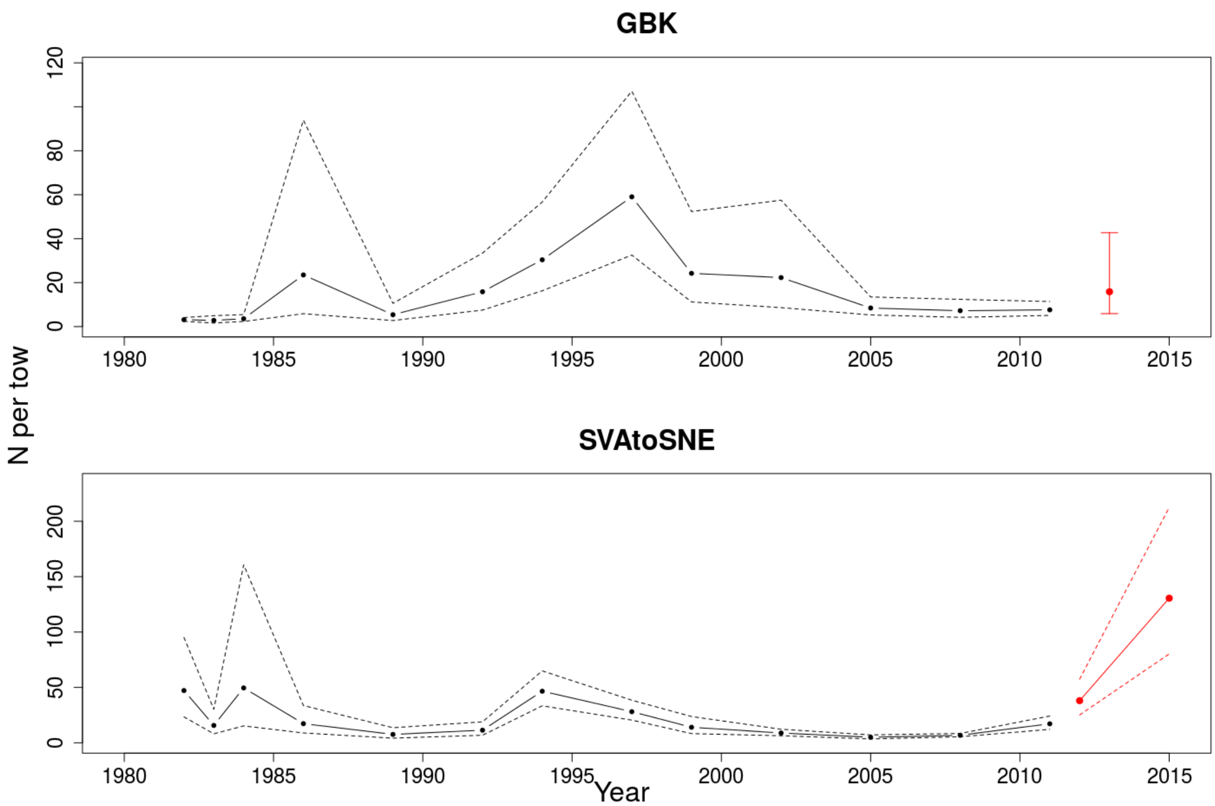

Figure 45: Surfclam 50 – 119 mm from NEFSC surveys adjusted for selectivity, but not efficiency, with approximate 95% asymmetric confidence intervals, by area. Beginning in 2012, the survey was conducted from a commercial platform using a dredge with higher capture efficiency. Results from the new survey platform are shown as a separate series in red. GBK and SNE were not sampled in 2012 and SVA, DMV, NJ and LI were not sampled in 2013 or 2014.

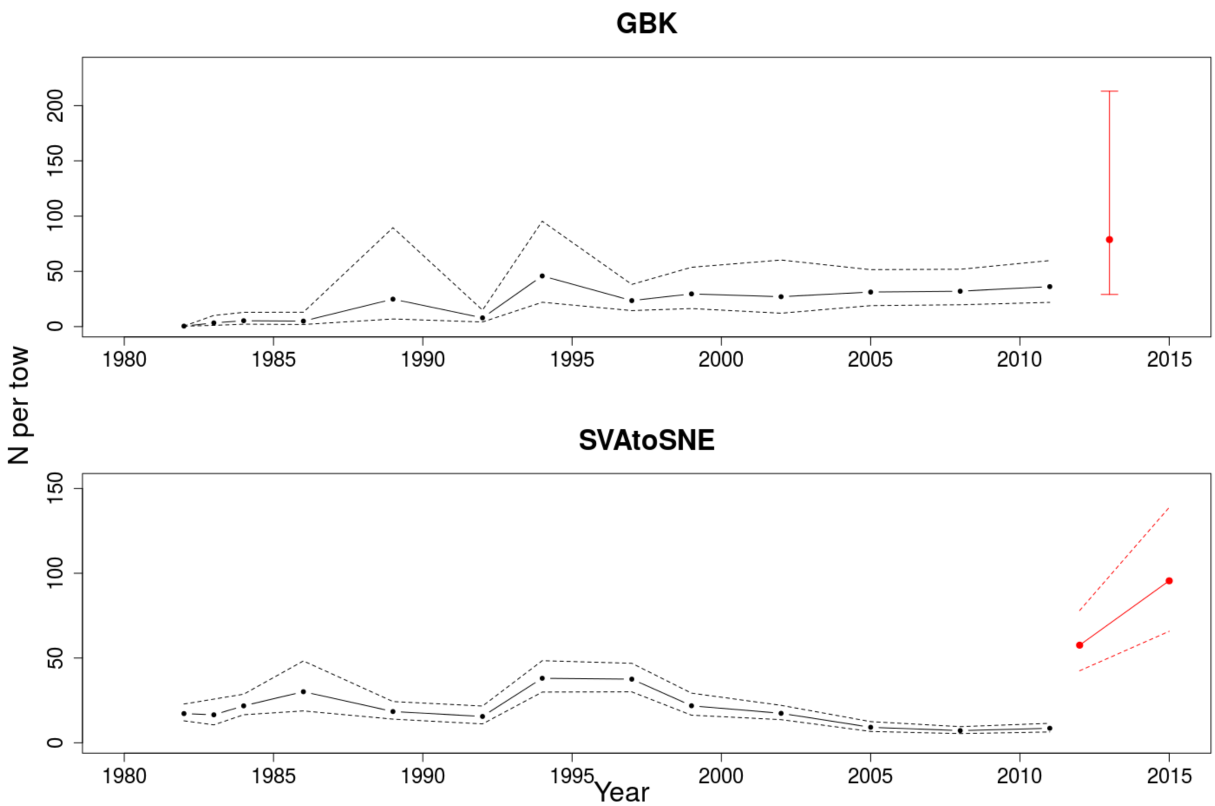

Figure 46: Surfclam > 119 mm from NEFSC surveys adjusted for selectivity, but not efficiency, with approximate 95% asymmetric confidence intervals, by area. Beginning in 2012, the survey was conducted from a commercial platform using a dredge with higher capture efficiency. Results from the new survey platform are shown as a separate series in red. GBK and SNE were not sampled in 2012 and SVA, DMV, NJ and LI were not sampled in 2013 or 2014.

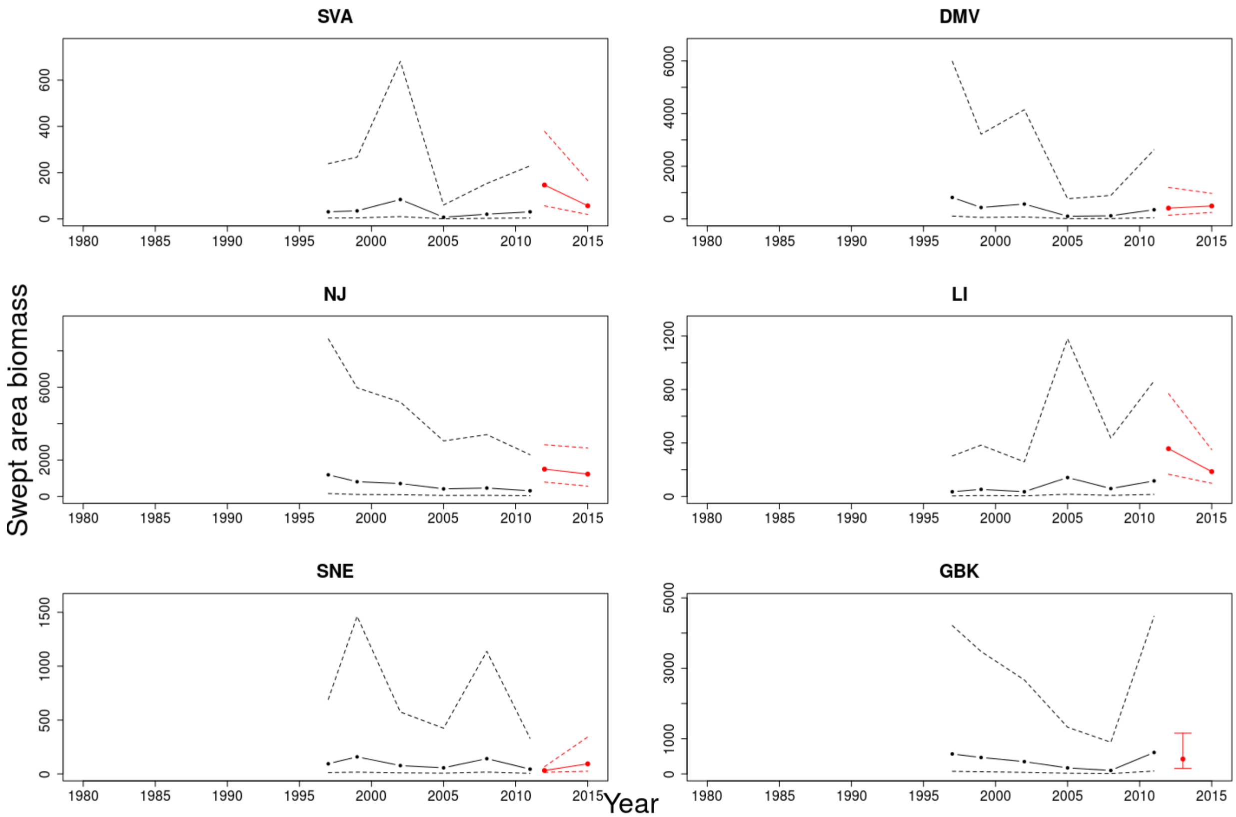

Figure 47: Surfclam swept area biomass from NEFSC surveys adjusted for selectivity and efficiency, with approximate 95% asymmetric confidence intervals, by area. Beginning in 2012, the survey was conducted from a commercial platform using a dredge with higher capture efficiency. Results from the new survey platform are shown as a separate series in red. GBK and SNE were not sampled in 2012 and SVA, DMV, NJ and LI were not sampled in 2013 or 2014.

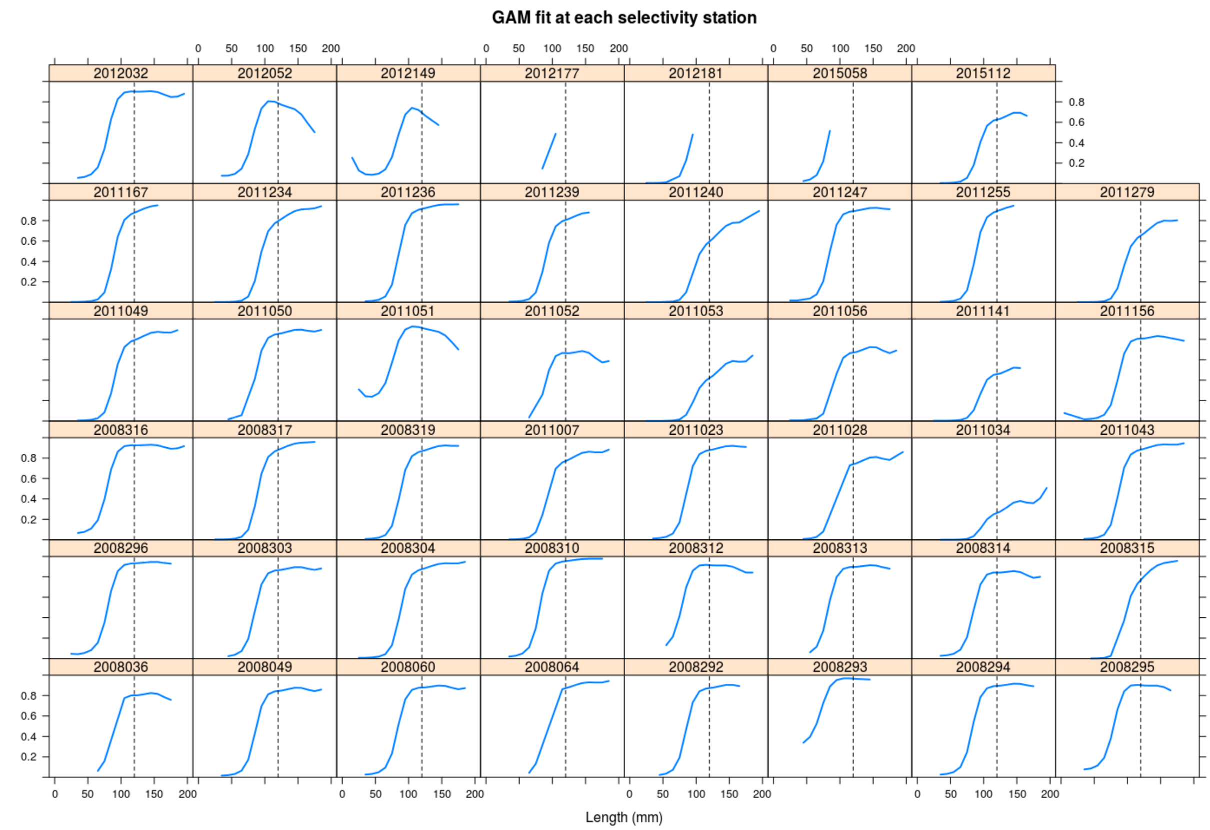

Figure 48: GAM fits to the selectivity data for Atlantic surfclam from field experiments (MCD compared to lined dredge) by year and station. The plots generally indicate flat topped selectivity curves.

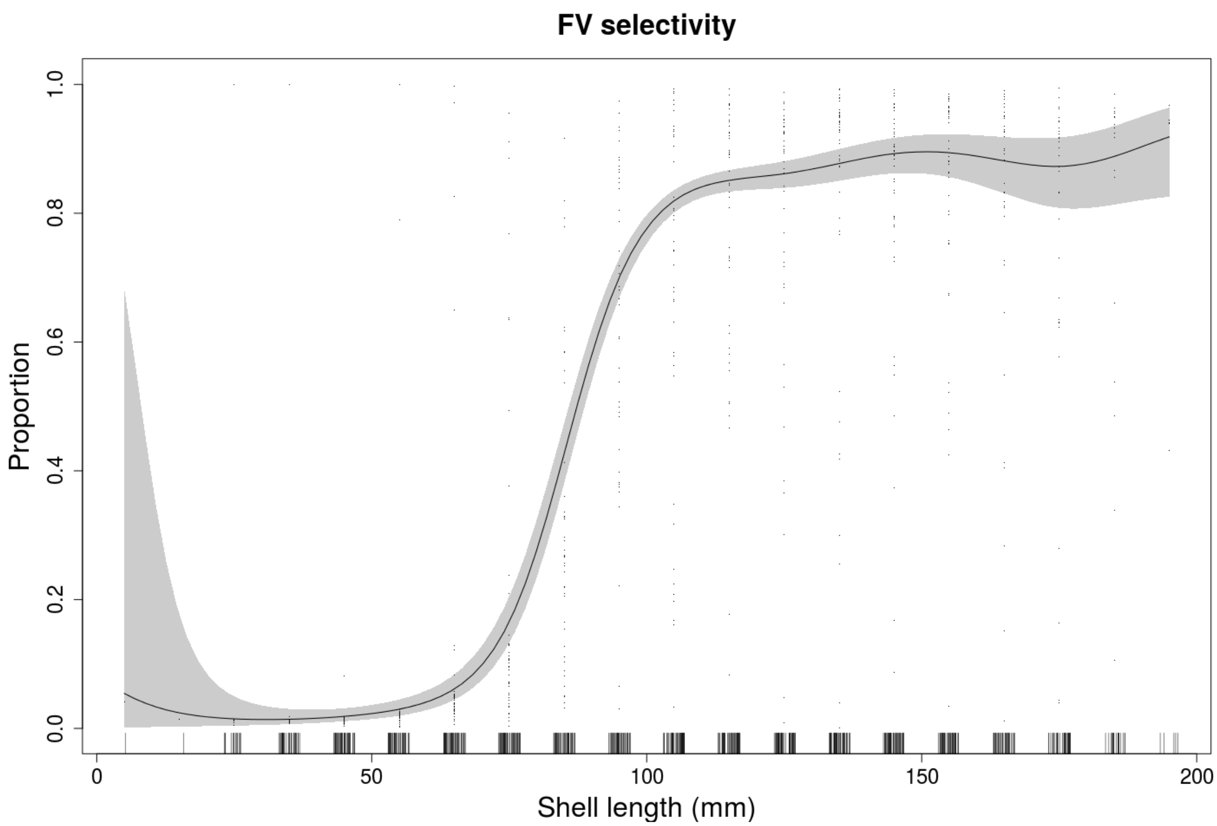

Figure 49: The GAM fit to all the selectivity data for Atlantic surfclam in the MCD in all years. The best (by AIC) model included random effects in both the intercept and spline over length. The data density is shown in the rug plot along the horizontal axis and relative confidence is represented by the shaded region.

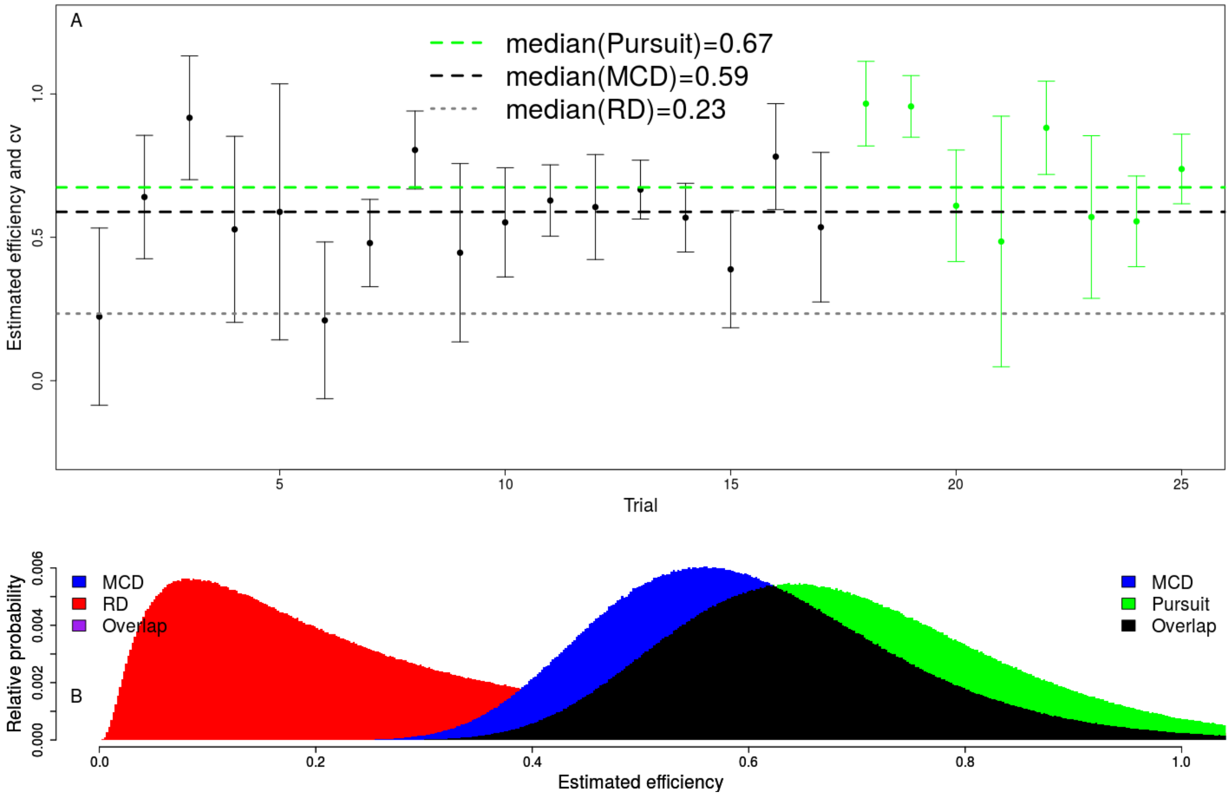

Figure 50: Panel A) Modified commercial dredge (MCD) capture efficiency estimates (all vessels) compared to median values for the survey dredge (RD) as well as the specific dredge used on the current survey (Pursuit). Panel B) A comparison of the distributions of capture efficiency for each dredge where each is shown as a truncated lognormal distribution based on the medians and confidence intervals shown in panel A. The MCD and Pursuit dredge had higher and more precisely estimated capture efficiency than the RD.

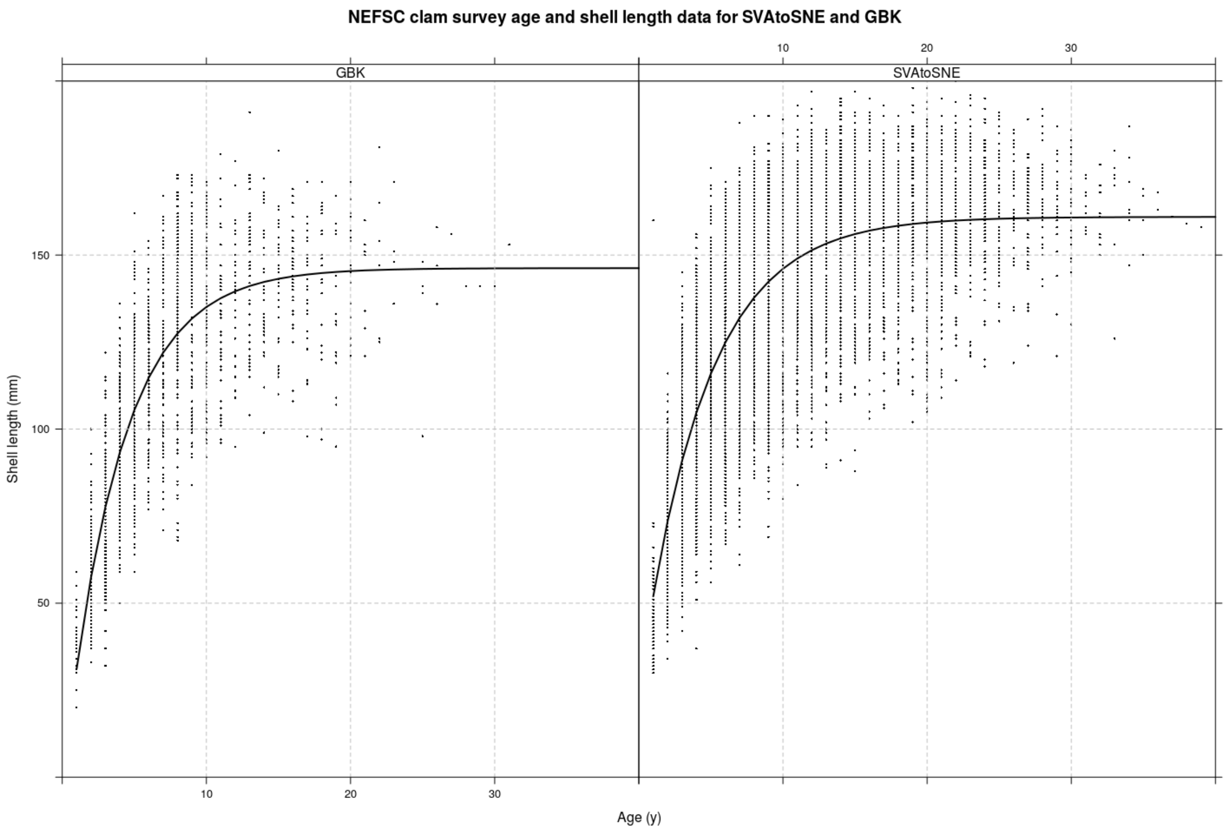

Figure 51: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve in different areas.

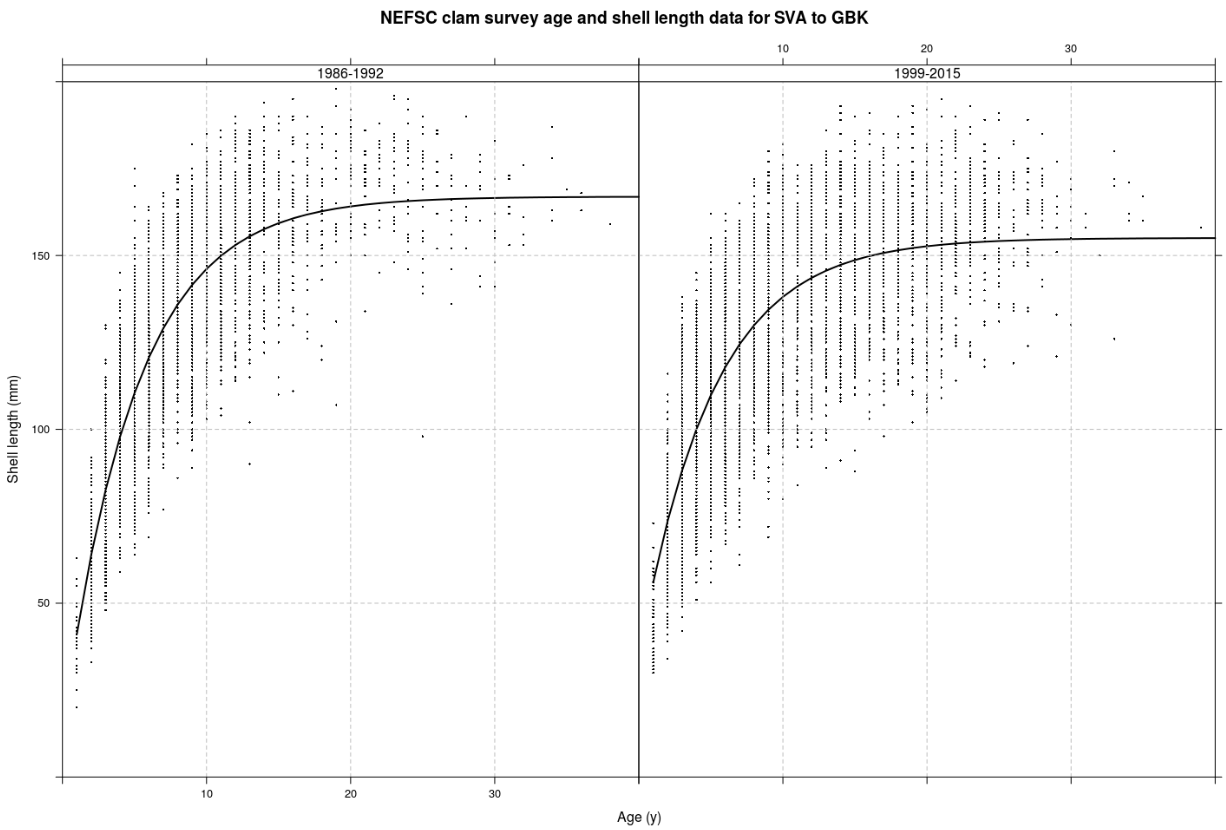

Figure 52: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve in different eras for the whole stock.

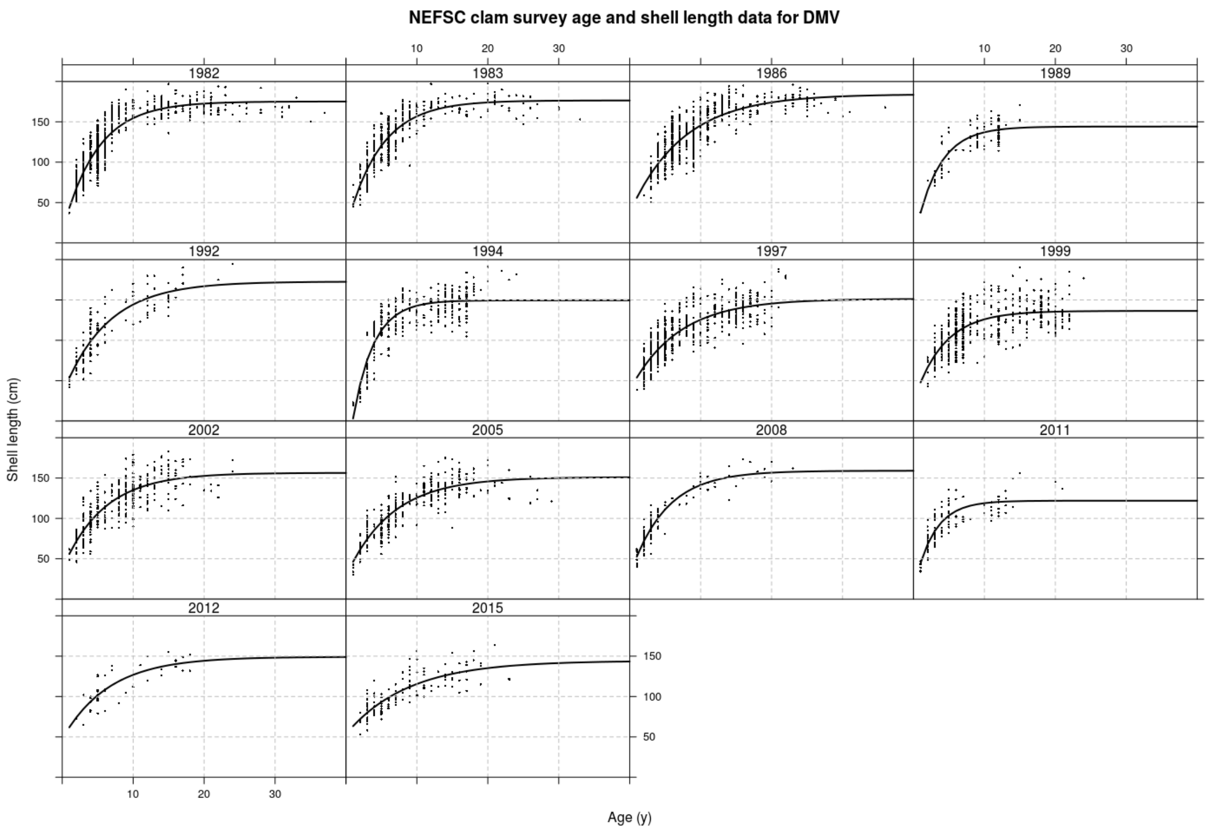

Figure 53: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the DMV region in each survey year.

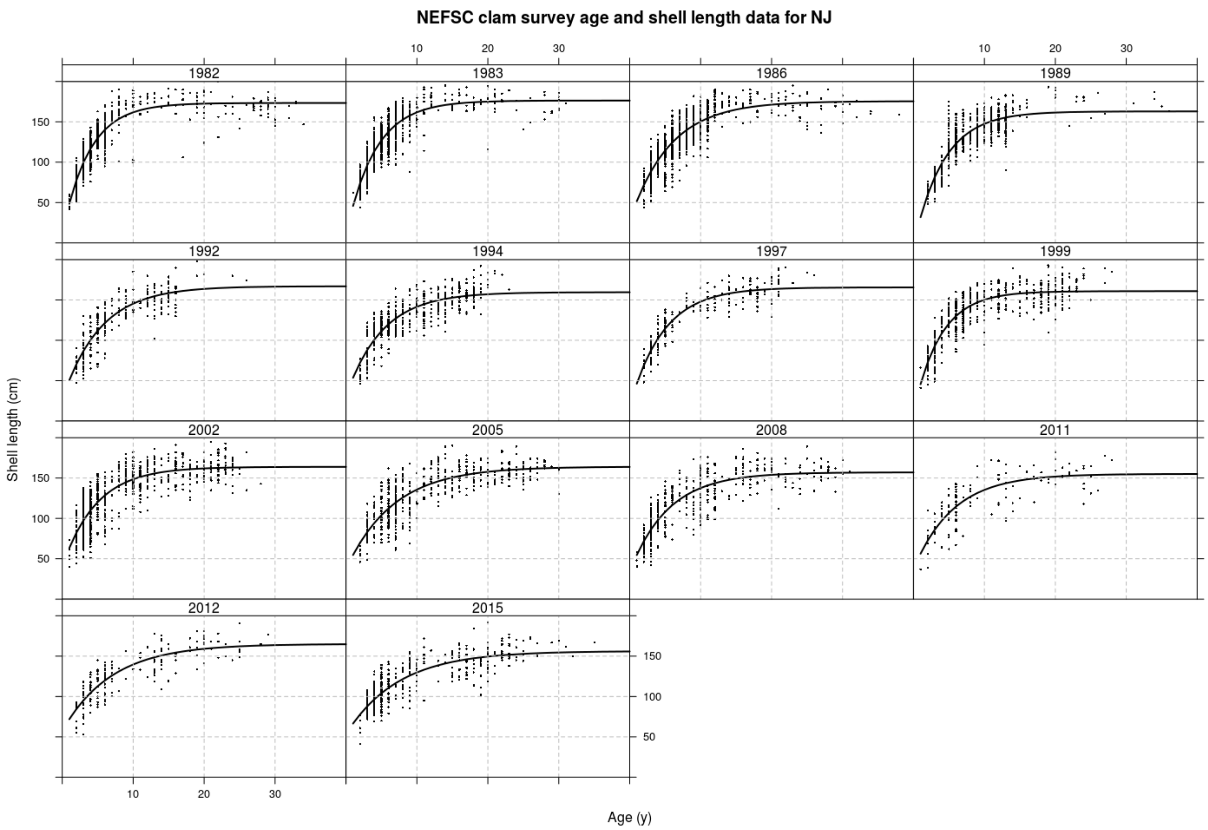

Figure 54: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the NJ region in each survey year.

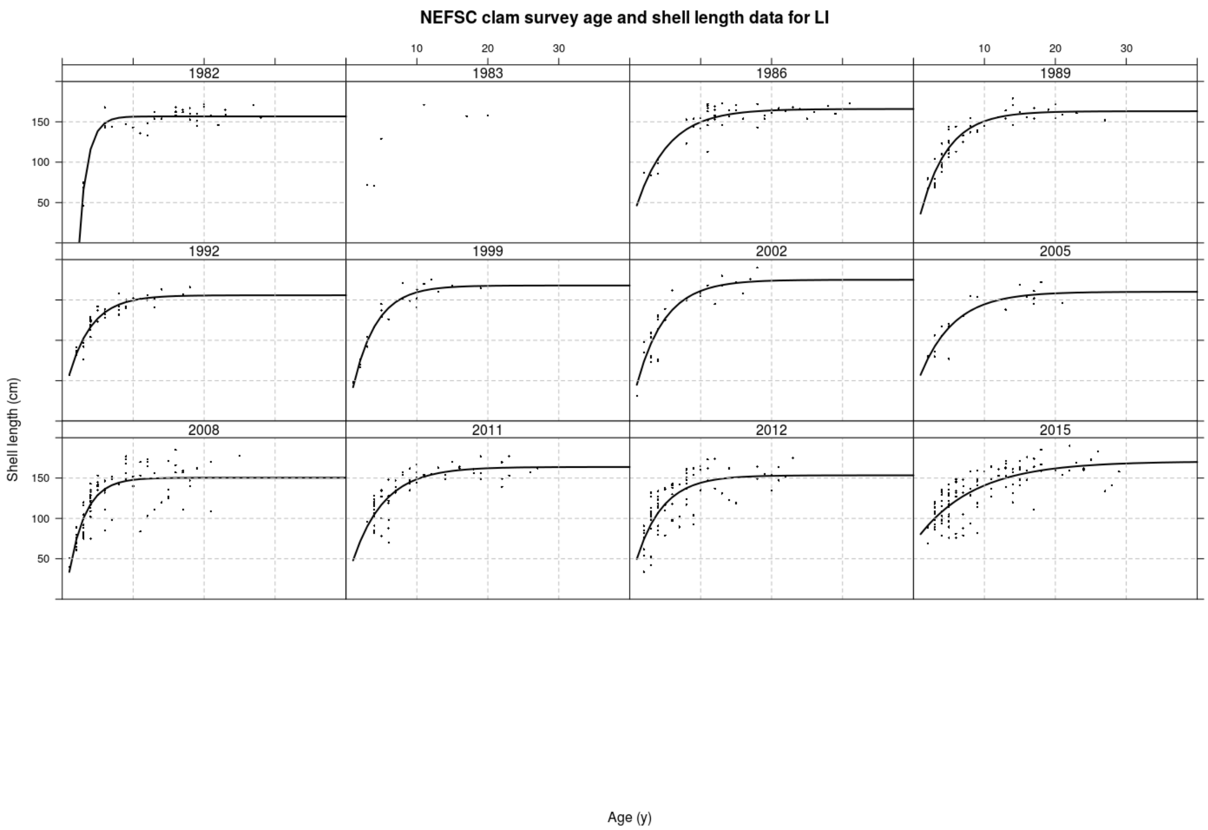

Figure 55: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the LI region in each survey year.

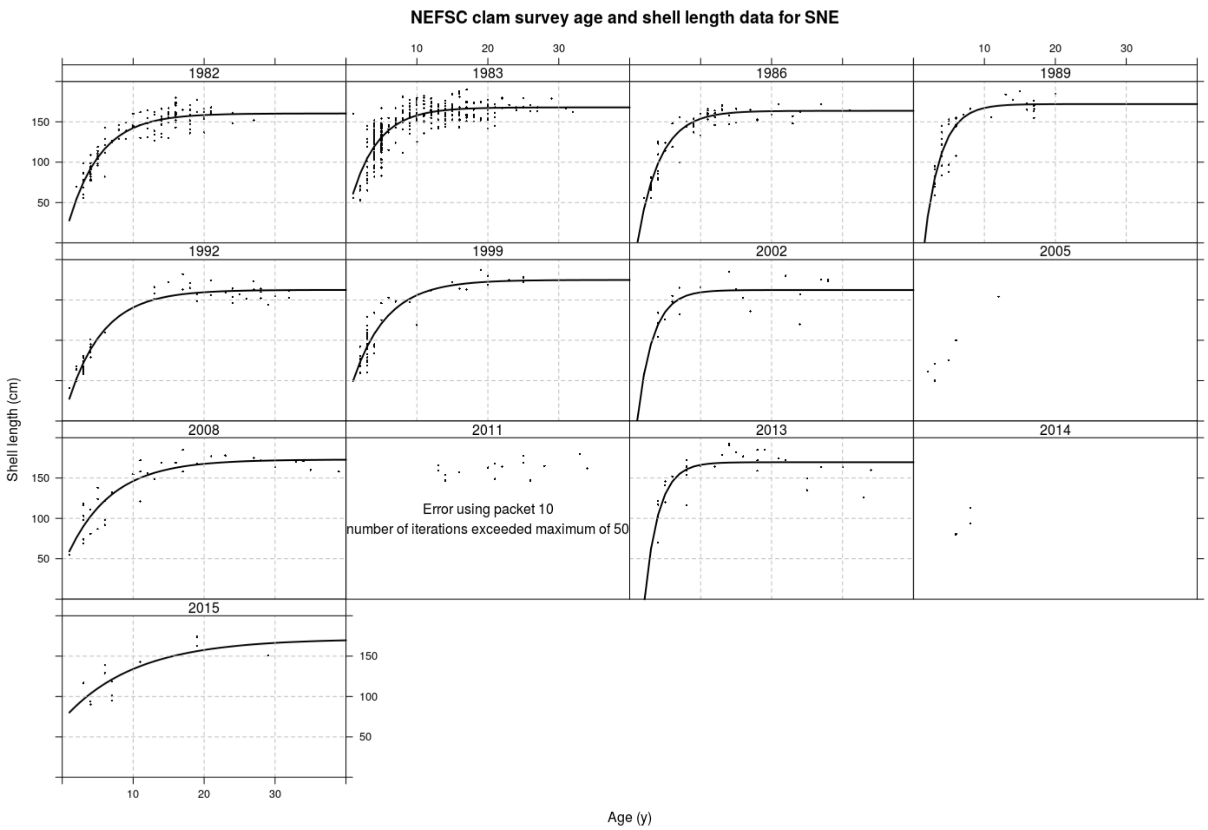

Figure 56: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the SNE region in each survey year.

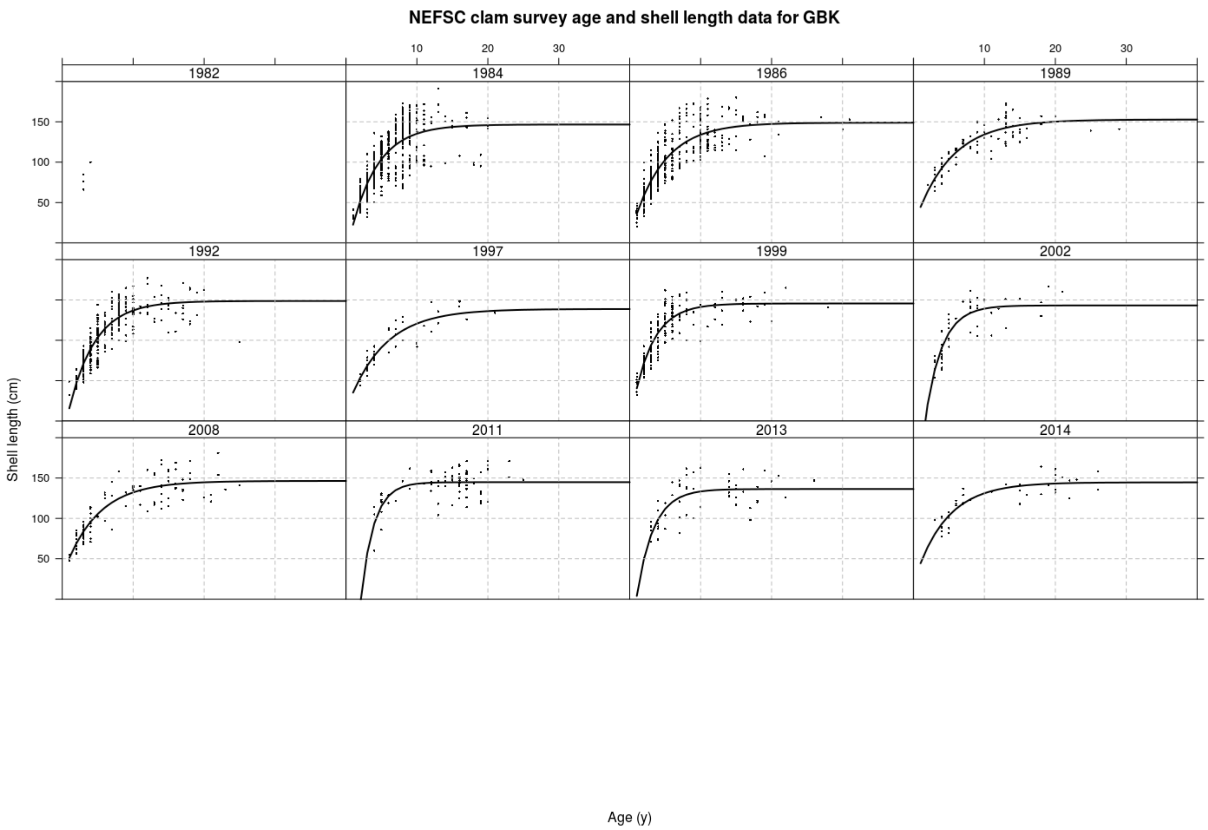

Figure 57: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the GBK region in each survey year.

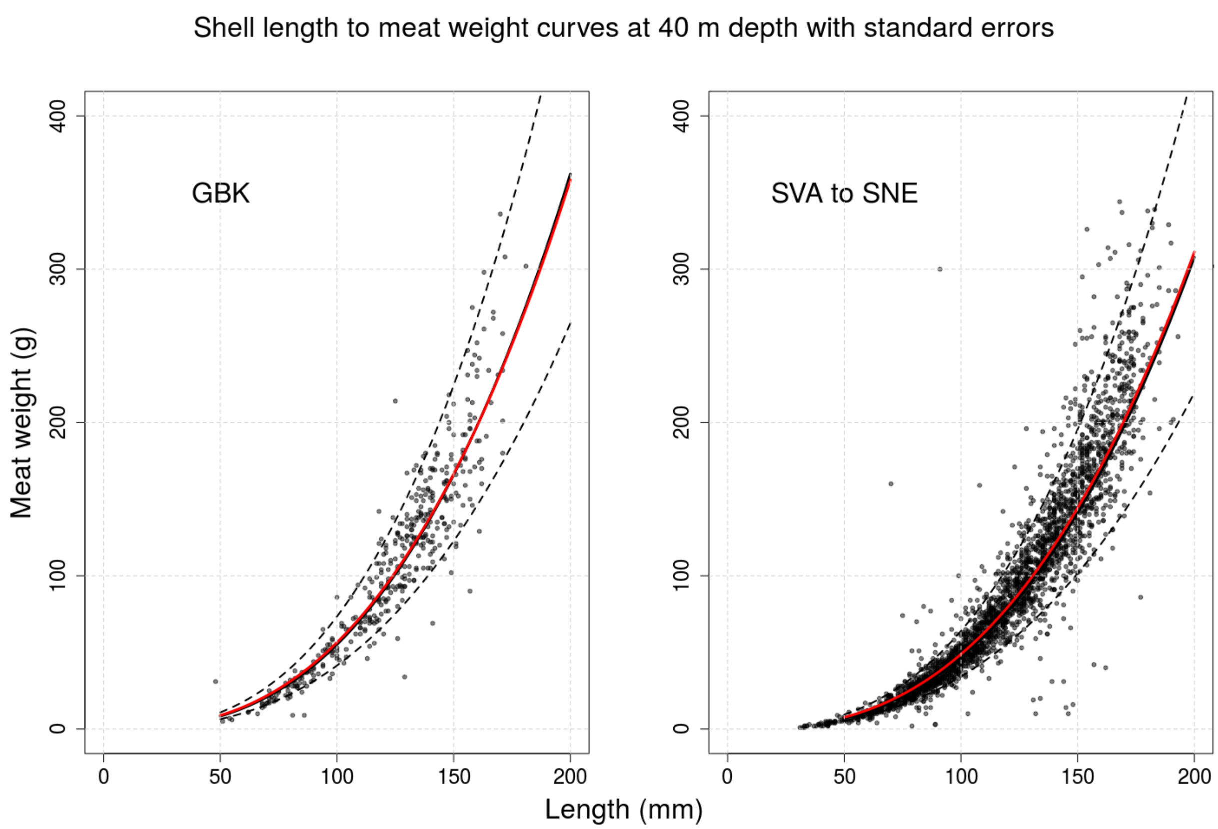

Figure 58: Broad scale area differences in allometric relationships for Atlantic surfclam based on survey data. The same depth (40 m) was used to generate the curves for each area. The 95% confidence regions are represented by the dotted line.

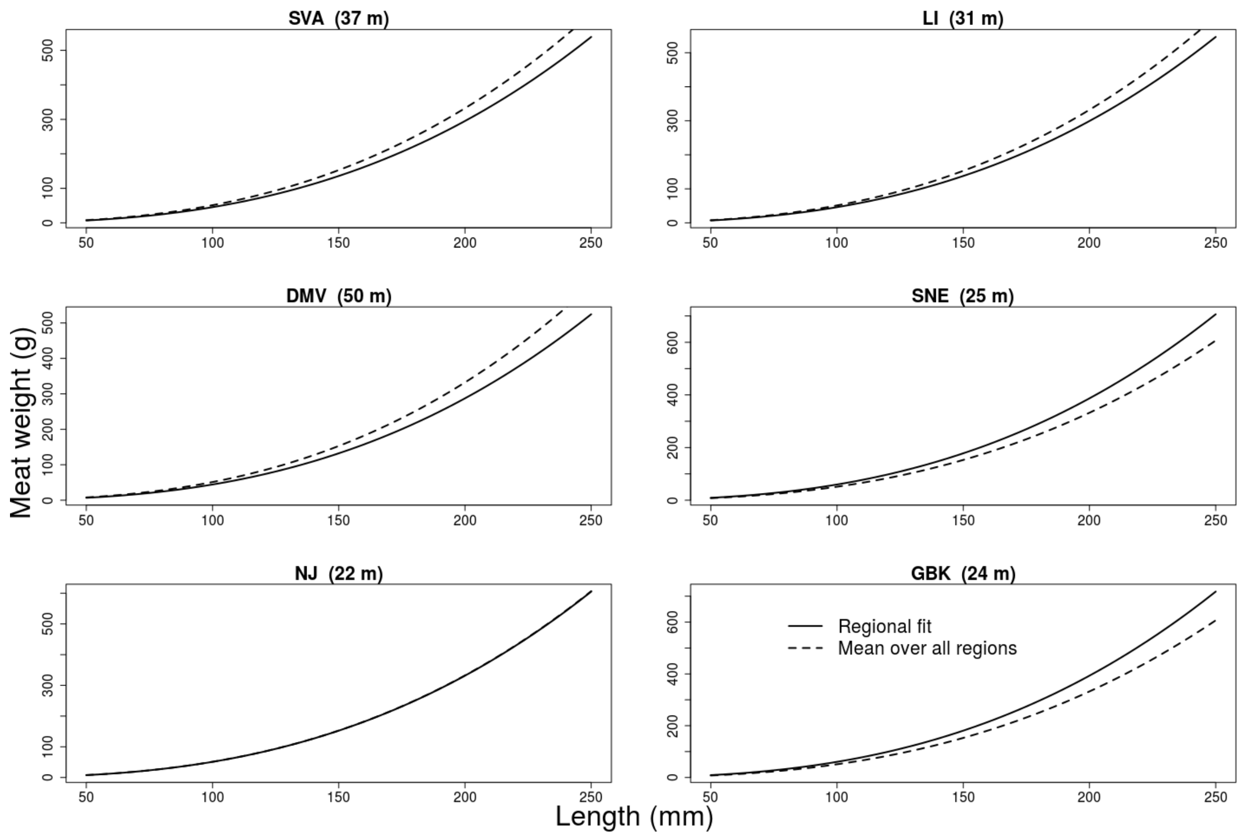

Figure 59: Regional differences in allometric relationships for Atlantic surfclam based on survey data. The median depth in each region was used to generate the curves. The global mean is represented by the dotted line.

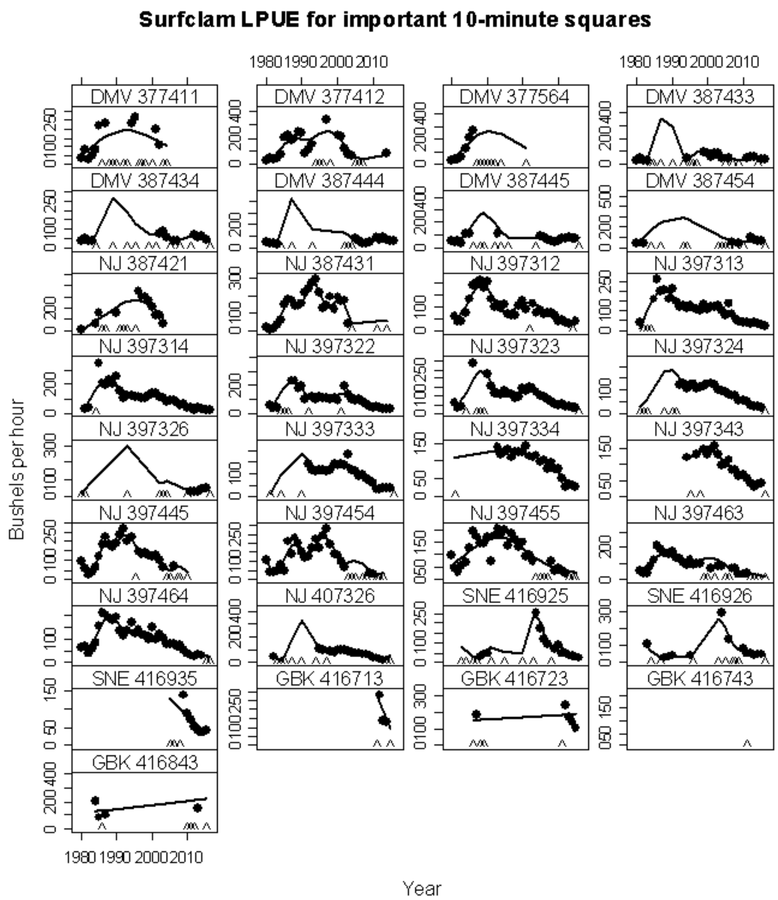

Figure 60: Observed and predicted survey catch rates in ten-minute squares that are important to the fishery.

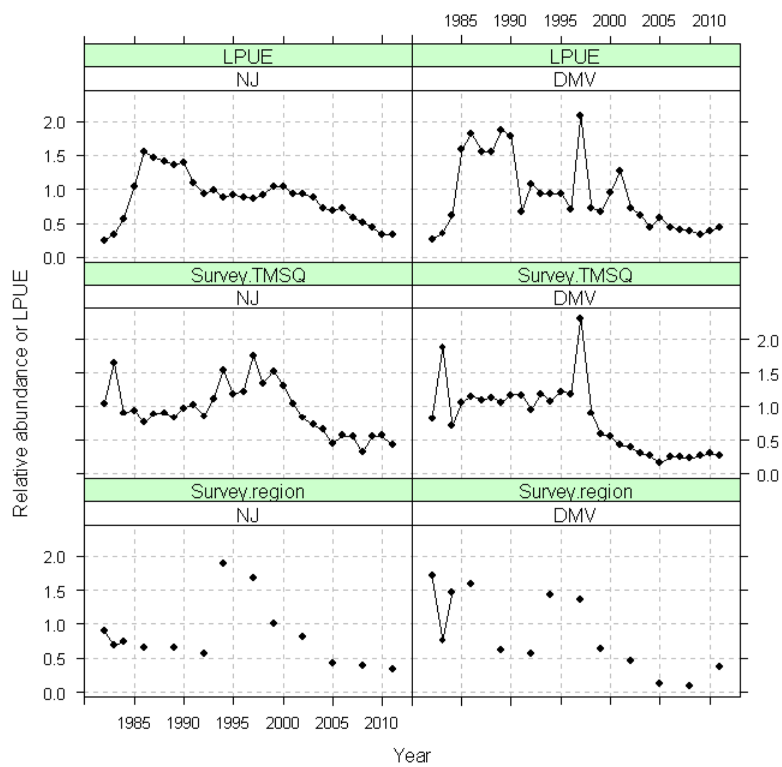

Figure 61: LPUE and survey abundance trends for Atlantic surfclam during 1982-2011 in the New Jersey (left) and Delmarva (right) regions (rescaled for convenience in plotting). LPUE and "Survey.TMSQ" are commercial catch rate and survey trends for important ten-minute squares. "Survey.region" is the survey trend for the entire region (all ten-minute squares).

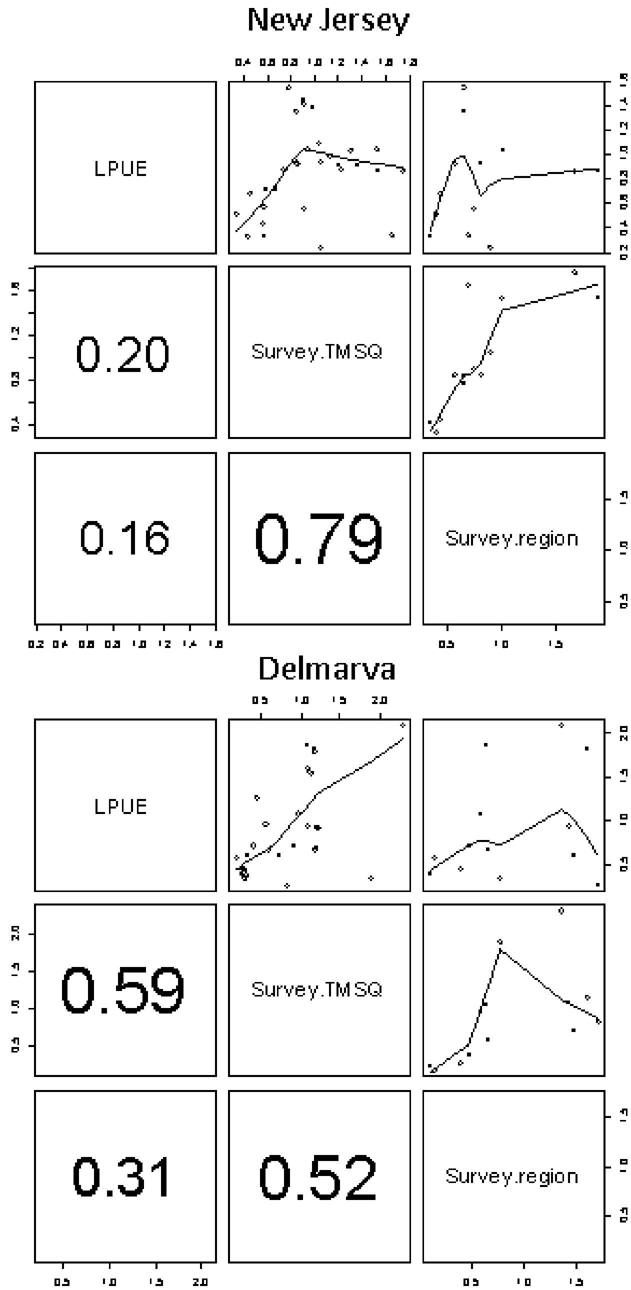

Figure 62: Relationships between LPUE and survey abundance trends for Atlantic surfclam during 1982-2011 in the New Jersey (top) and Delmarva (bottom) areas (rescaled for convenience in plotting). LPUE is commercial catch rates in important TNMS. Survey.TNMS is the survey trend in important TNMS. "Survey.region" is the survey trend for the entire region (all ten-minute squares). Scatter plots with smooth lines to show trends are above the diagonal in each panel and correlation statistics are below the diagonal.

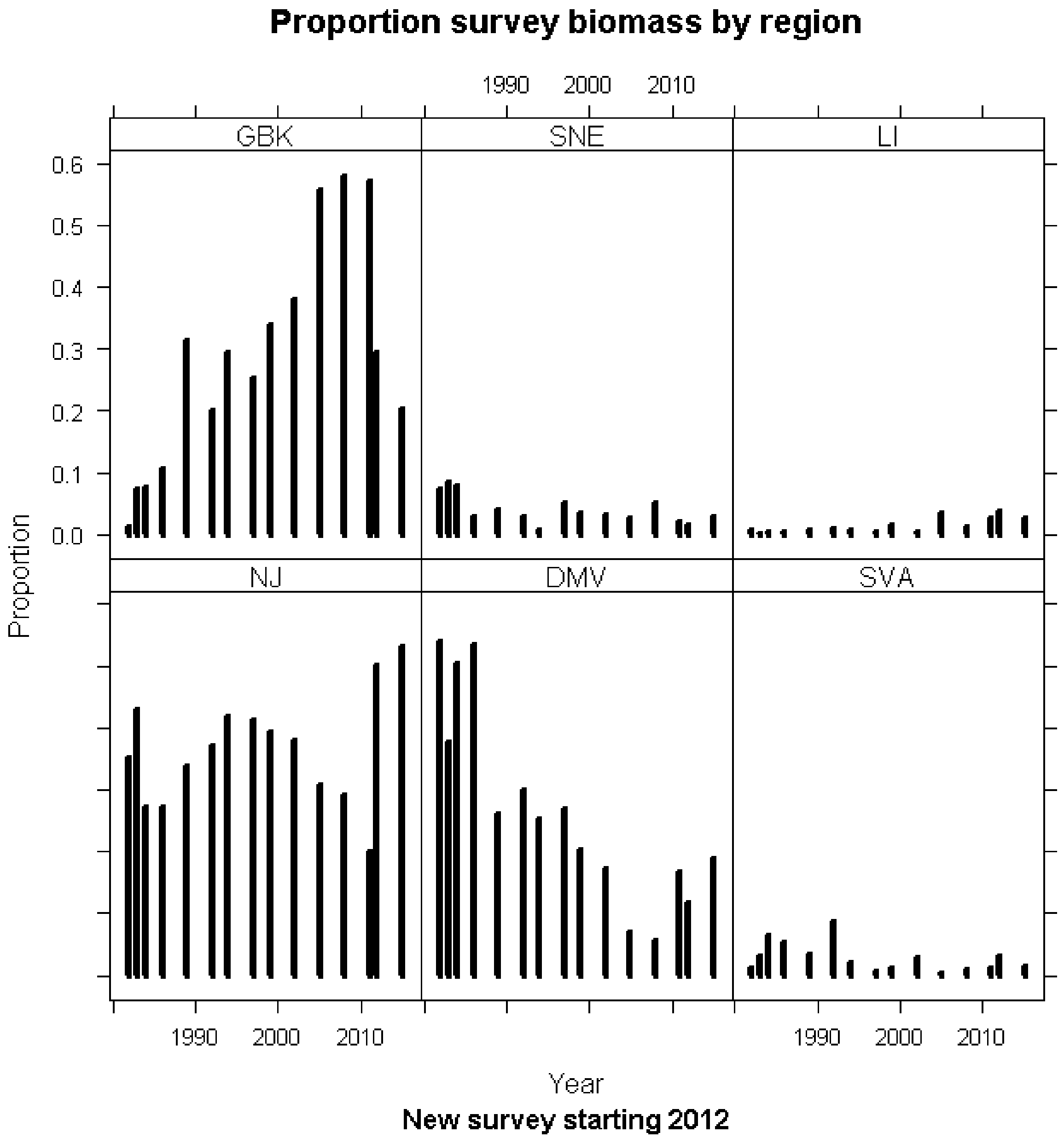

Figure 63: Proportions of relative survey biomass for surfclams by region during 1982-2015. For example, the proportion of total biomass on GBK during 2015 is about 20% and the sum of values plotted for 2015 in all regions is 100%. Estimates for 1982-2011 may not be comparable to estimates for 2012-2015 because a new survey using a different vessel, gear, etc. started in 2012.

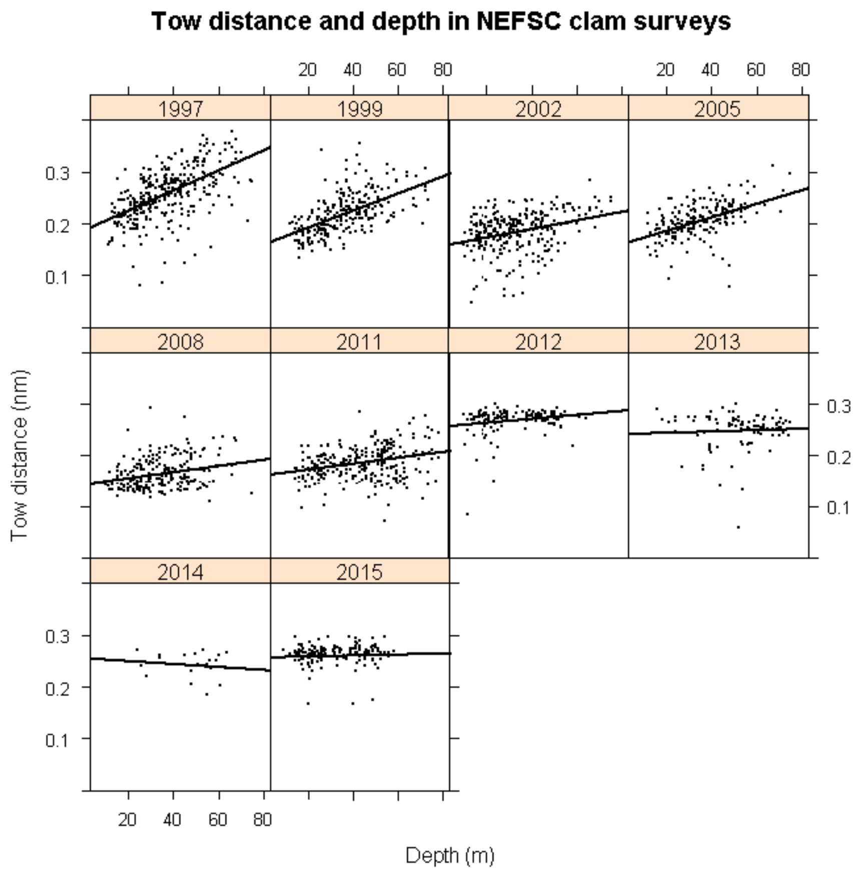

Figure 64: Relationships between tow depth and tow distance from inclinometer measurements in NEFSC clam surveys during 2007-2011 (RD) and 2012-2015 (MCD).

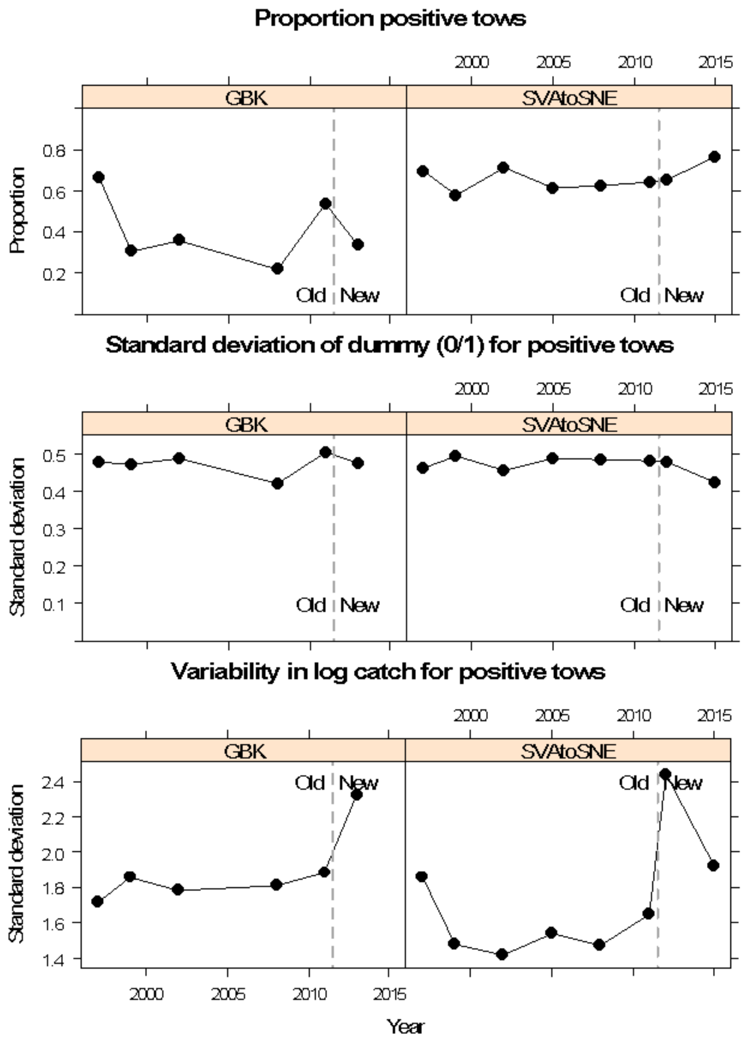

Figure 65: Trends in proportion positive tows (top), the standard deviation of a dummy variable that identifies positive tows (=0 if Atlantic surfclam catch was zero and 1 otherwise), and the standard deviation of log transformed catches (positive tows only) for Atlantic surfclam in NEFSC clam surveys during 1997-2015.

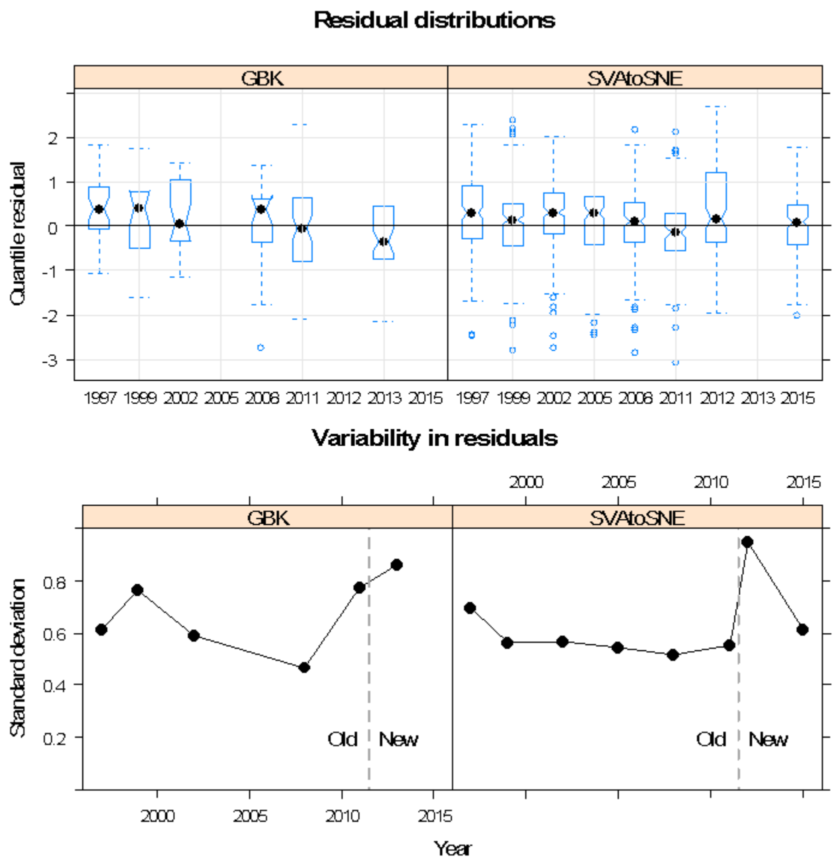

Figure 66: Top, distributions of randomized quantile residuals from the best GAM model (Tweedie family) fit to consistently sampled NEFSC clam survey strata. Bottom: standard deviations for residual distributions in top panel.

Part IV

TOR 3: Habitat

This TOR was driven by concern that relatively high densities of clams measured by survey tows in easy to sample areas on Georges Bank might be applied to rocky low density habitats that are difficult to sample such that model and swept-area biomass estimates are biased high. In stock assessment calculations, stock biomass $B = \frac{bA}{ae} = bQ$ where b is mean catch per tow, A is the area surveyed (the parameter of concern), a is area swept and e is capture efficiency. In recent assessments, the area surveyed on Georges Bank (A) was reduced by 12% assuming that the proportion of untowable stations represents grounds that were poor habitat with no Atlantic surfclam. For this assessment, the working group reviewed survey procedures and recalculated the proportion of untowable ground.

A list of random survey stations is prepared prior to the first leg of each clam survey and the captain determines towability when the ship reaches each random station. In the past, during the 1999, 2002, and 2005 surveys (Georges Bank was not surveyed in 2005), untowable stations were noted in station logs using a special "SHG=151" code. In the more recent survey during 2013-2014, text in comment fields and other SHG codes can be used to determine if a station was untowable, if the dredge was filled with rocks and no Atlantic surfclam, or the dredge was damaged by rocks. Based on "151" codes, 12/83=14% of random stations on GBK were not trawlable. In later years, 13/74=18% of random stations were not trawlable. The combined average (14%) is somewhat higher than the 12% figure used in this assessment. New habitat databases and models under development will soon be available for refining estimates of poor Atlantic surfclam habitat for GBK (Appendix XXIV). In addition, procedures for dealing with untrawlable stations in the survey may need to be modified so that this information is collected routinely and is clear in the survey database.

Part V

TOR 4: Depth and changes in biological parameters

As ocean temperatures increase, the distribution and biology of Atlantic surfclam are potentially changing with potential effects on fishery productivity. For example, increasing water temperature may result in changes to the biological parameters that describe growth (Munroe et al. 2016). Increasing water temperature may also be driving a shift in Atlantic surfclam distribution, to deeper water in the southern area (Weinberg et al. 2002). It is reasonable to assume that any responses to temperature would be strongest in the southern-most regions (SVA, DMV and NJ), where ocean temperatures are warmest and probably nearest the warm water tolerance for Atlantic surfclam.

Depth and temperature

Survey stations are distributed randomly relative to depth within a stratum and the same strata tend to be sampled over time within a region (Table 8). Therefore, if the depth distribution of Atlantic surfclam were trending over time, the depth at which most of the animals were caught within a region might be expected to increase. Plots of the depth at which the median cumulative catch within each region occurs over time show this relationship in two regions, DMV and NJ (Figures 67 – 72).

Warming coastal waters might change the spatial overlap between Atlantic surfclam in relatively shallow water and ocean quahogs that are found in adjacent deeper water. Overlap is important because the fishery operates most efficiently where only one species is caught. The depth at which 95% of the cumulative catch of Atlantic surfclam was taken during 1982-2011 clam surveys was used as the offshore habitat boundary for Atlantic surfclam and the depth at which 5% of the cumulative quahog catch was used as the inshore boundary for ocean quahogs (Figure 79). In the 1980s and with the exception of the LI region, the two habitat boundaries were similar indicating that the habitat was partitioned across depth as expected. There was no evidence that the inshore boundary of ocean quahog habitat changed in later years but there was clear evidence that the offshore boundary of Atlantic surfclam habitat shifted to deeper water in the southern NJ and DMV regions and, surprisingly, in the northern most GBK region. By the mid- to late 1990s, the overlap in Atlantic surfclam and ocean quahog habitat was pronounced in the south. The shift on GBK may have been due to increases in Atlantic surfclam abundance (Figure 44). In contrast, abundance generally decreased after 1982 in the south and the change in habitat boundaries was more likely. Results for LI were anomalous given that the offshore boundary for Atlantic surfclam was consistently deeper than the inshore boundary for ocean quahogs, probably due to high density beds of ocean quahogs in cold shallow water (Figure 79) and the increased presence of clay as substrate, which tends to contain more ocean quahog than Atlantic surfclam.

The sampling properties of presence-absence data from NEFSC survey tows were characterized analytically (Appendix XXII). Results show that survey tows are almost certain to detect clams at relatively low densities (roughly 0.013 per m^2, corresponding to about 15 encounters per tow in the RD). Thus, presence absence data are useful for detecting clams at relatively low densities but not for tracking trends in abundance when density is higher. Based on these results, presence-absence data were used in this assessment to quantify extent but neither quality of habitat nor density of clams.

Presence-absence GAM models showed that the probability of co-occurrence (both species in the same tow) decreased almost linearly during 1982-2011 in the SNE region while increasing almost linearly in the LI and NJ regions (Figure 80 and Appendix XXI). Trends were not statistically significant in the DMV and GBK regions where strong changes in abundance may complicate interpretation.

The amount of habitat for Atlantic surfclam was quantified by dividing the area surveyed consistently in each region into relatively small areas based on latitude and longitude as well as two other coordinate systems (Appendix XXIII). Presence-absence GAM models with time and position as predictor variables were selected from a set of candidates based on AIC. Habitat was quantified by summing the predicted probability of a positive tow from the best model over all of the small areas in each region and year. Results suggest that habitat area declined in the south in the DMV area due to losses in shallow water, increased along the central Mid-Atlantic Bight (NJ and LI areas) due to increases in deep water and varied without trend in the north (SNE and GBK areas). Temperature data were not available but these changes were likely due to water temperatures increasing above the preferred range for Atlantic surfclam in nearshore coastal areas off DMV (Weinberg 2005) and above the lower bound of the preferred range in deep waters off NJ and LI.

Temperature was recorded as part of the survey station data (beginning in 2002), and may be a useful indicator of habitat preference for Atlantic surfclam. Plots of the temperature and depth recorded at each survey station over time, against the total number of Atlantic surfclam caught are provided here (Figures 73 – 78). The results indicate that temperature and depth preferences vary by region, but appear to be relatively consistent over (recent) time. This may be indicative of local adaptation, or there may be other local factors, potentially correlated with temperature and depth, that influence habitat preference in each region.

Changes in biological parameters

If increasing ocean temperature negatively affects the fitness of Atlantic surfclam, one might expect to see decreases in the biological parameters that describe growth, particularly in the southernmost regions where water temperatures are highest. Analysis indicates that DMV and NJ have experienced declines in average maximum length (L_∞) through time (Figure 81). NJ and SNE have shown decreases in the rate at which an animal approaches its theoretical maximum size (K; Figure 82).

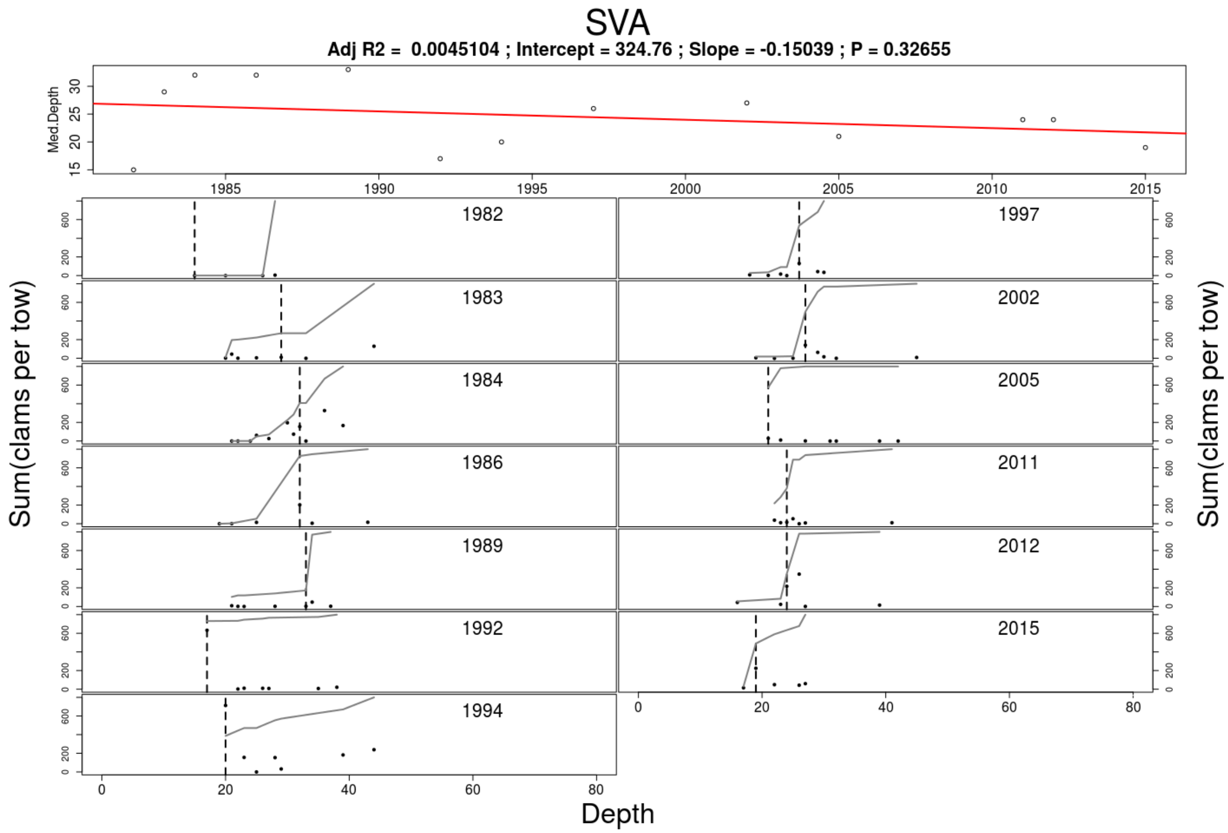

Figure 67: Total surfclams caught at depth by year in SVA (bottom panel). The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The plot above is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years. Inshore (shallow) strata were not well sampled in recent years and were excluded from this analysis.

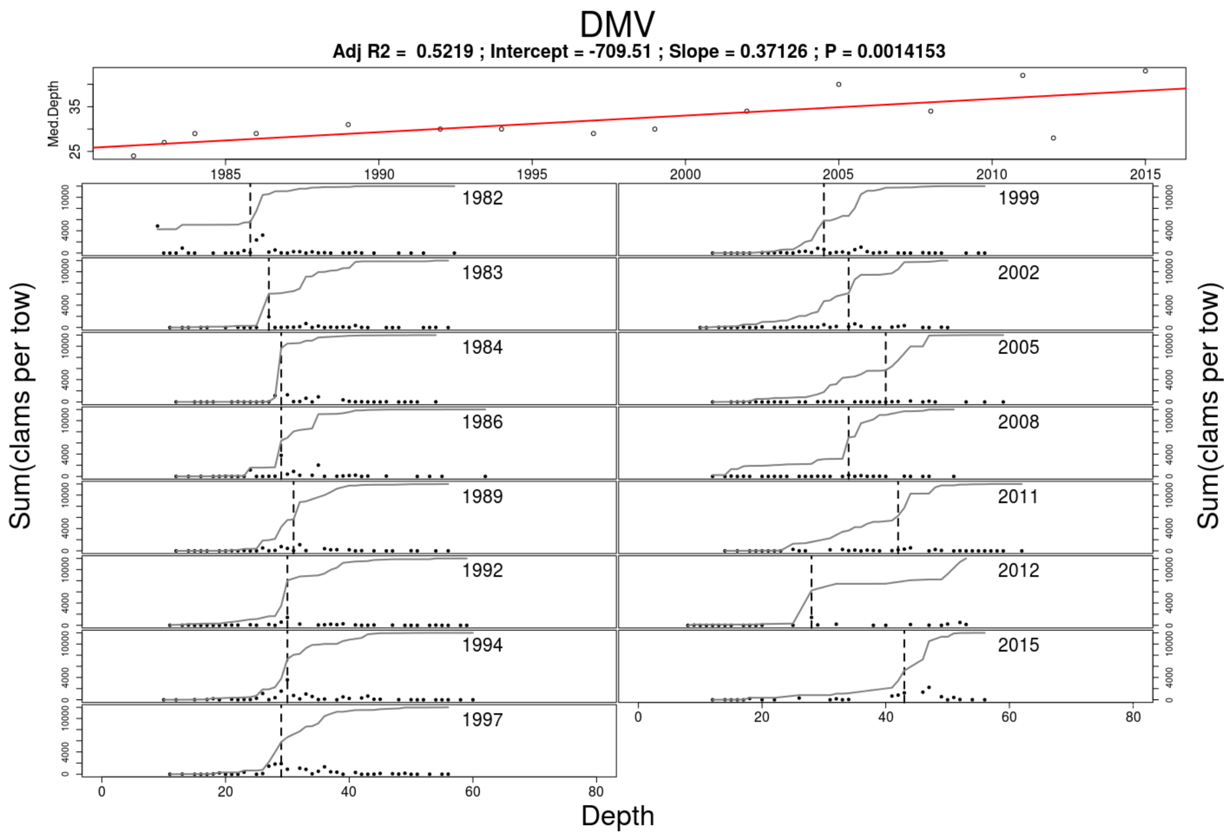

Figure 68: Total surfclams caught at depth by year in DMV (bottom panel). The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The plot above is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years. Inshore (shallow) strata were not well sampled in recent years and were excluded from this analysis.

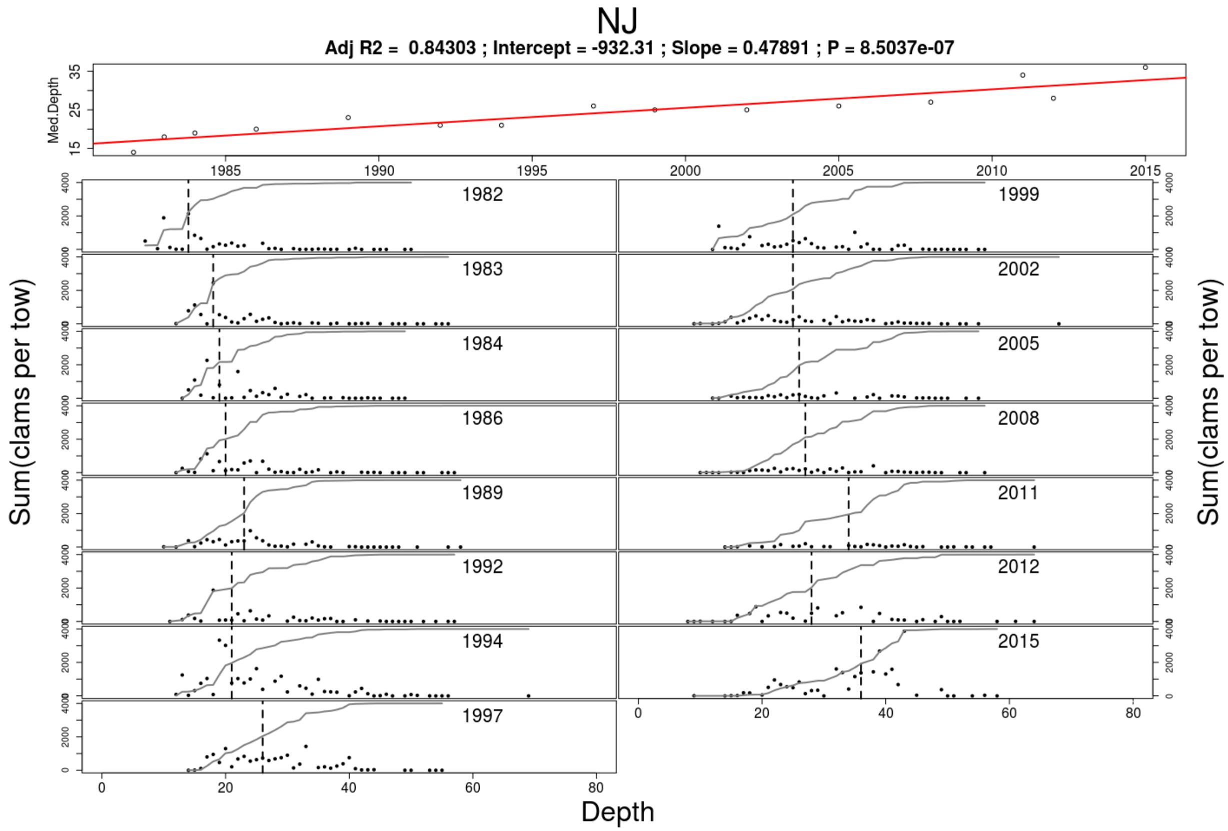

Figure 69: Total surfclams caught at depth by year in NJ (bottom panel). The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The plot above is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years.

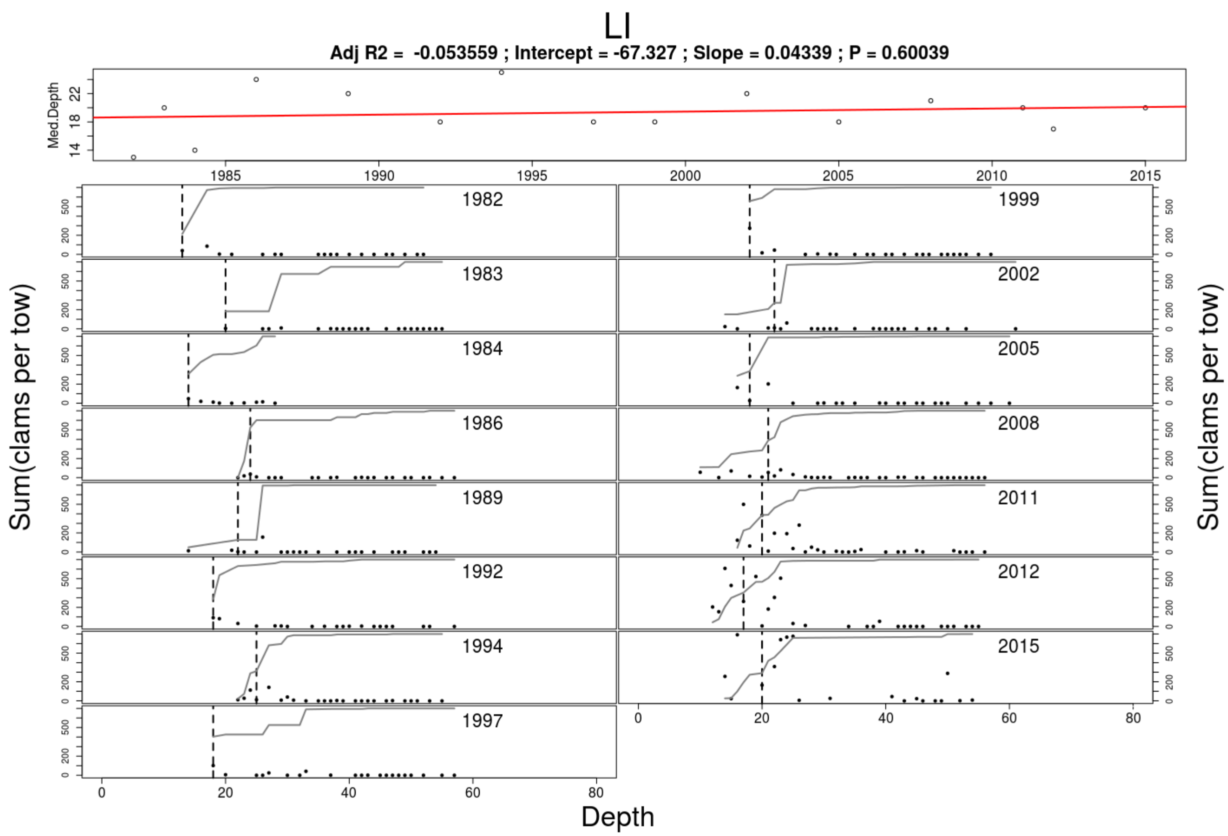

Figure 70: Total surfclams caught at depth by year in LI (bottom panel). The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The plot above is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years.

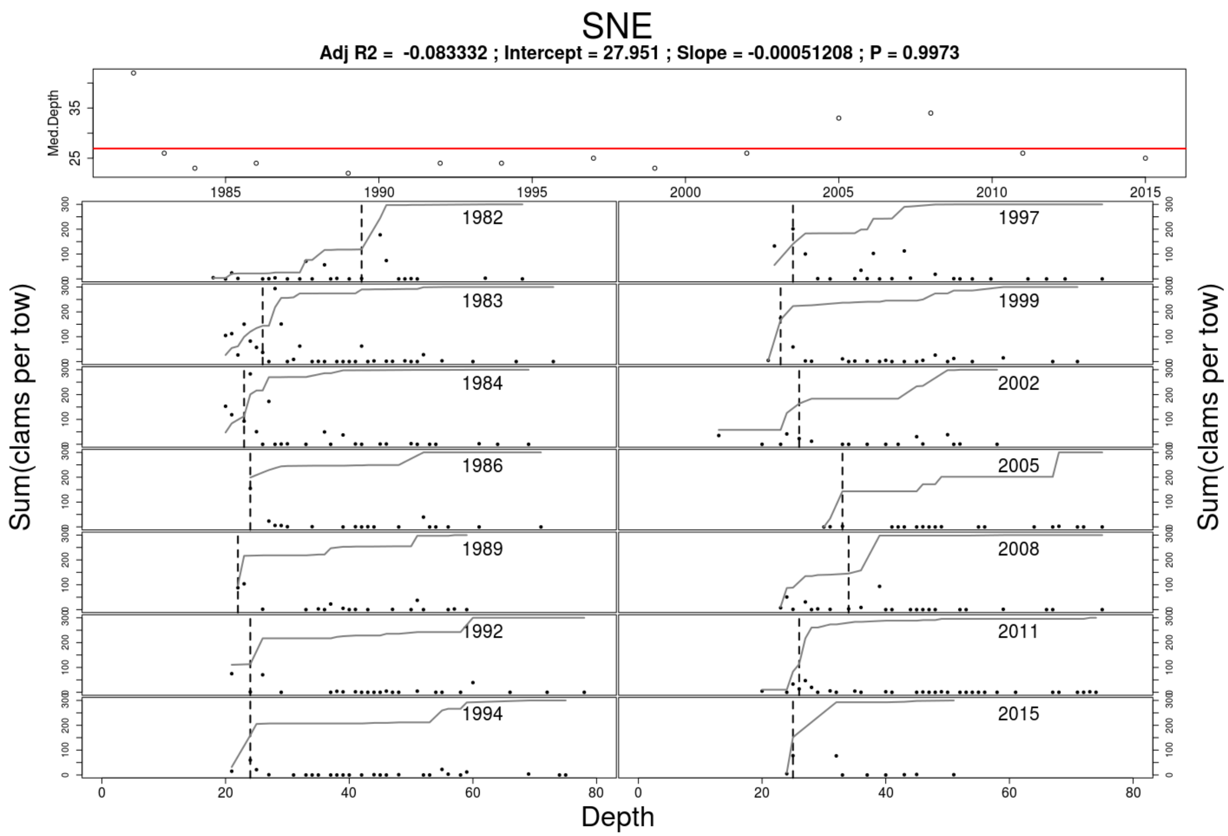

Figure 71: Total surfclams caught at depth by year in SNE (bottom panel). The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The plot above is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years.

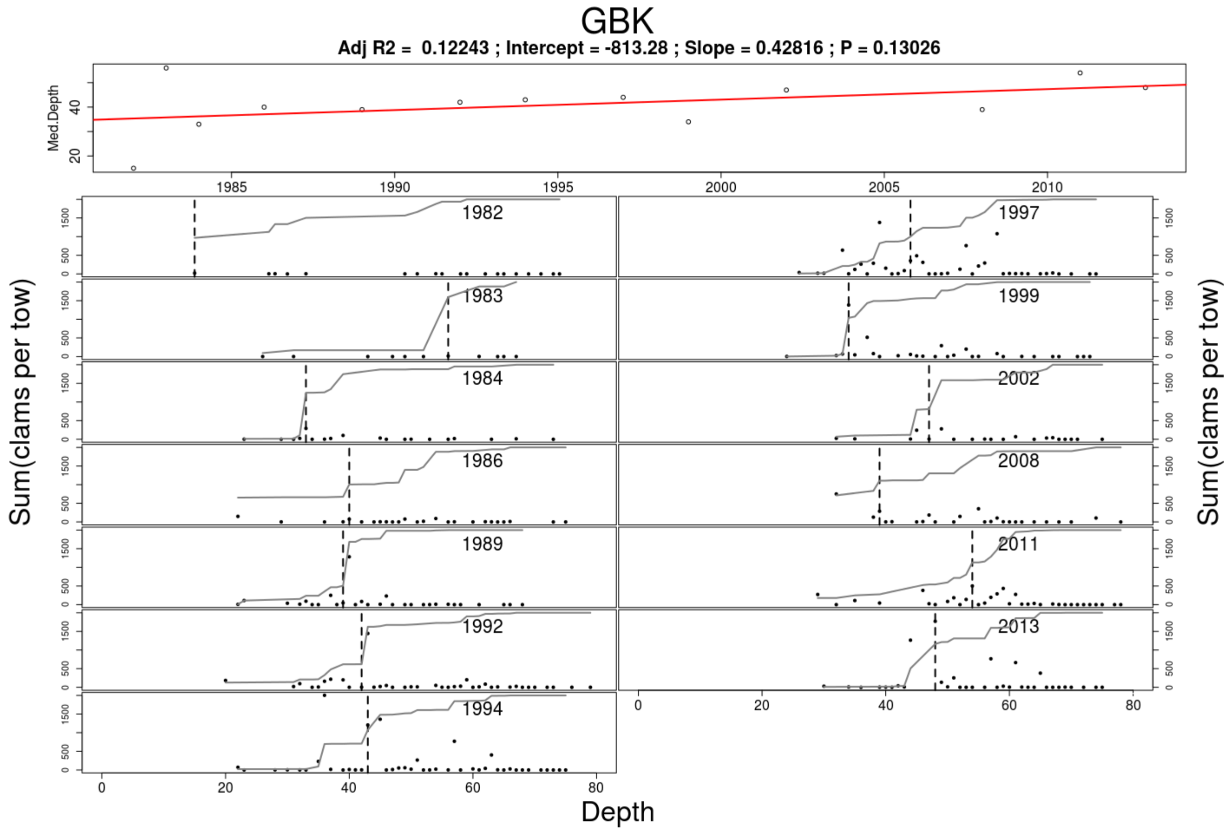

Figure 72: Total surfclams caught at depth by year in GBK (bottom panel). The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The plot above is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years.

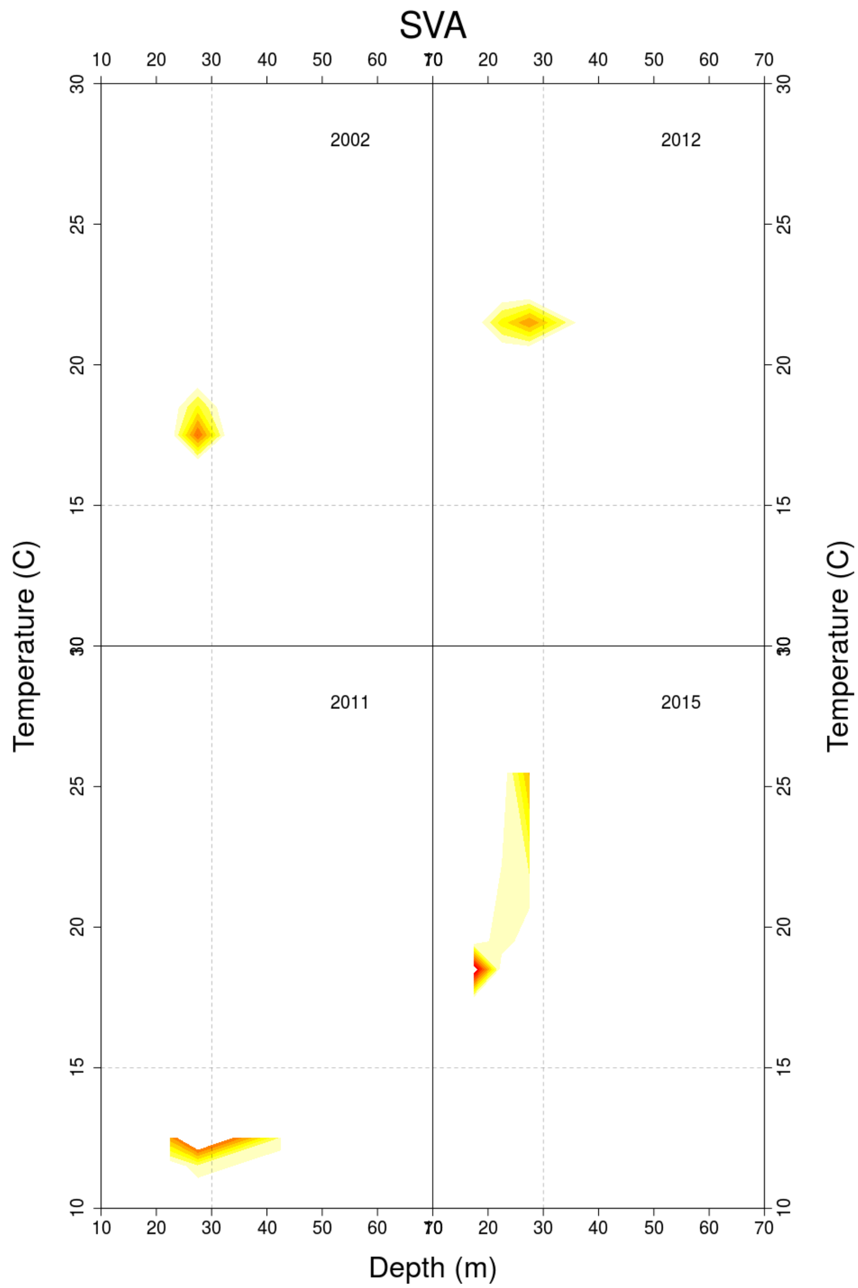

Figure 73: Total surfclams caught in the NEFSC clam survey at depth and temperature by year in SVA. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at 15° C and 30 m depth are for reference only.

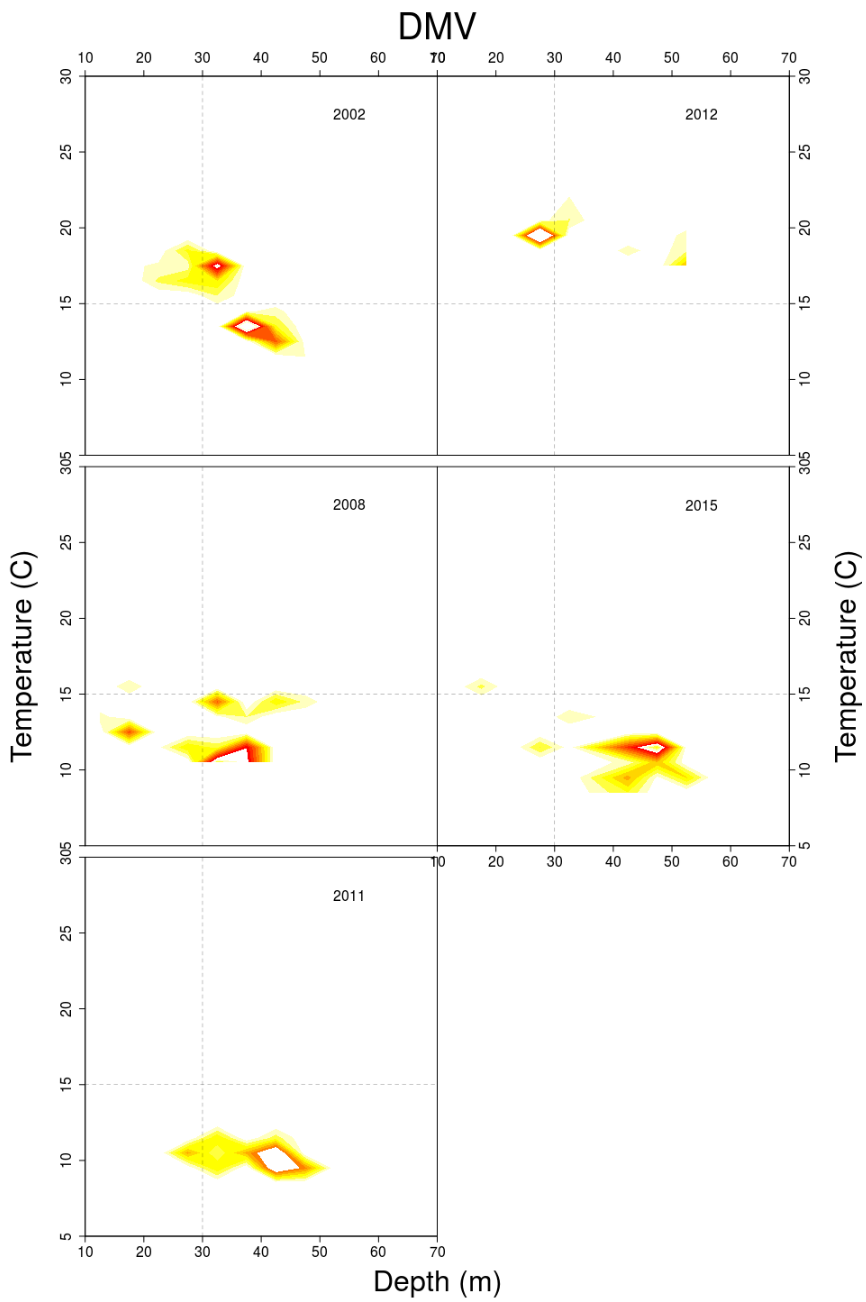

Figure 74: Total surfclams caught in the NEFSC clam survey at depth and temperature by year in DMV. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at 15° C and 30 m depth are for reference only.

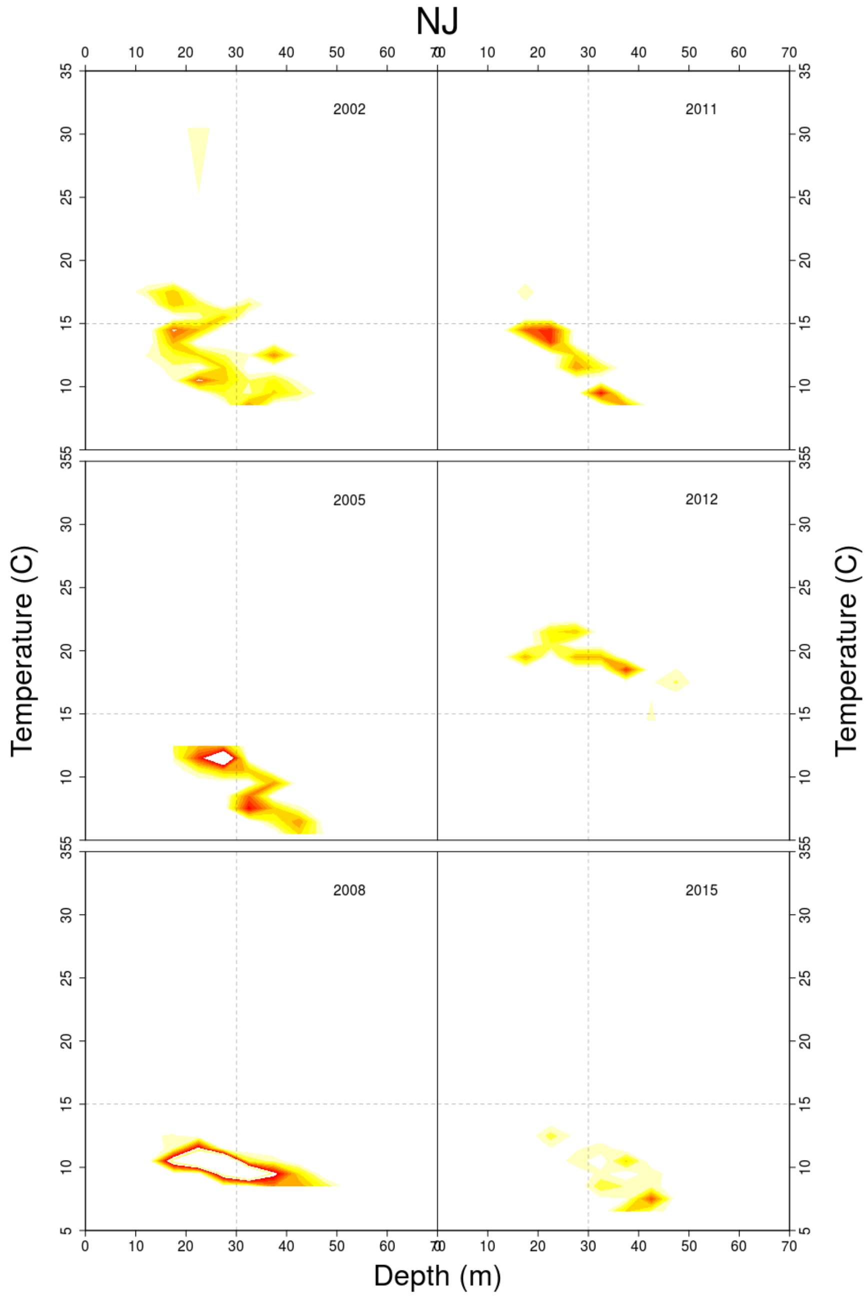

Figure 75: Total surfclams caught in the NEFSC clam survey at depth and temperature by year in NJ. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at 15° C and 30 m depth are for reference only.

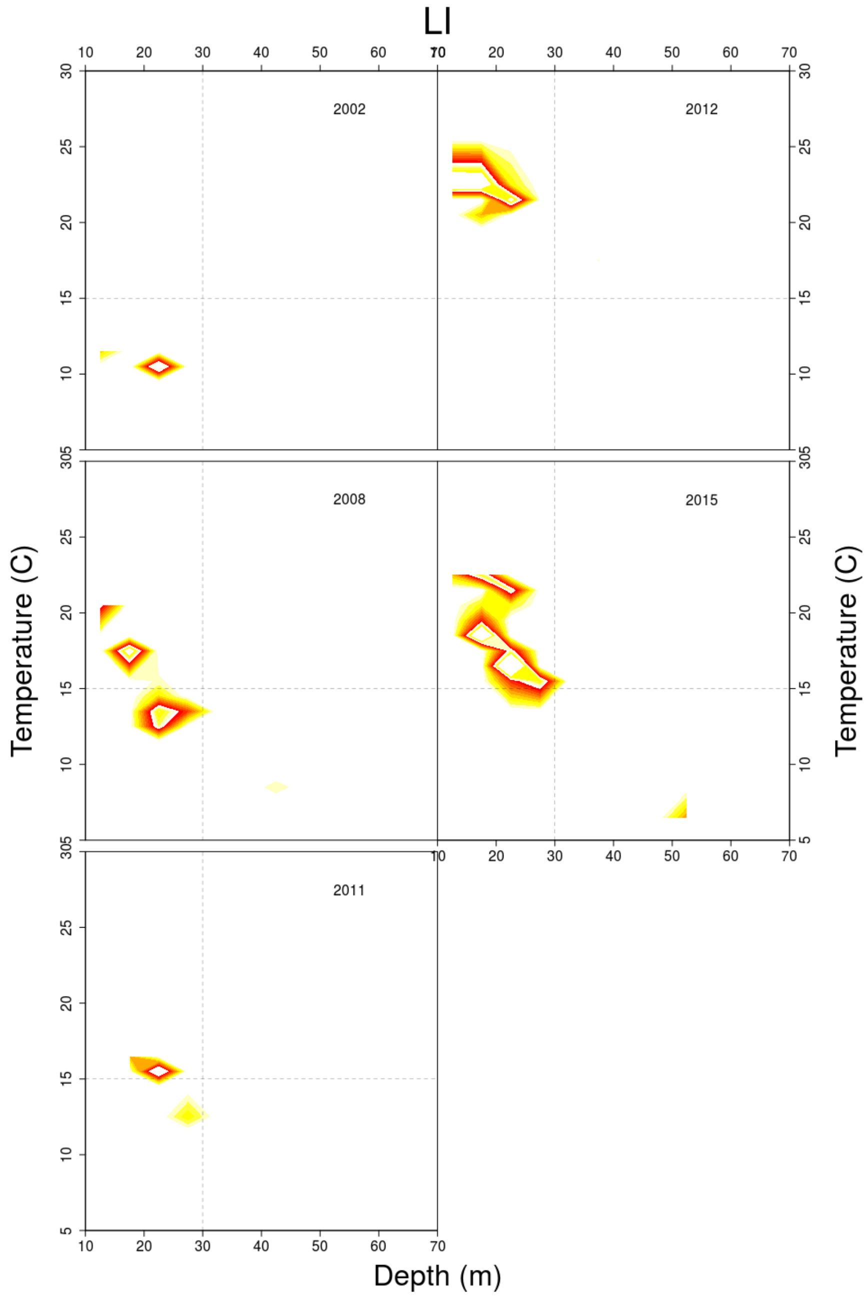

Figure 76: Total surfclams caught in the NEFSC clam survey at depth and temperature by year in LI. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at $15°$ C and 30 m depth are for reference only.

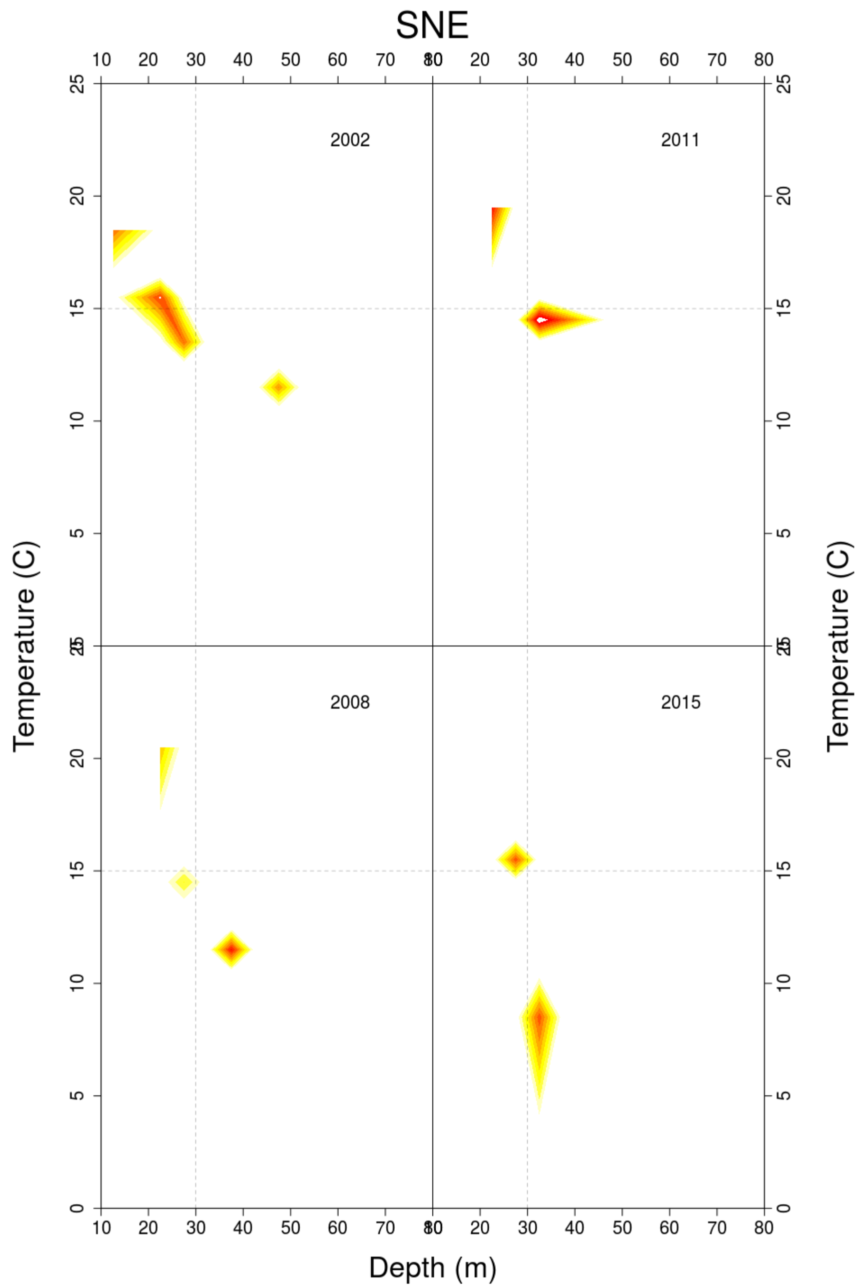

Figure 77: Total surfclams caught in the NEFSC clam survey at depth and temperature by year in SNE. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at $15°$ C and 30 m depth are for reference only.

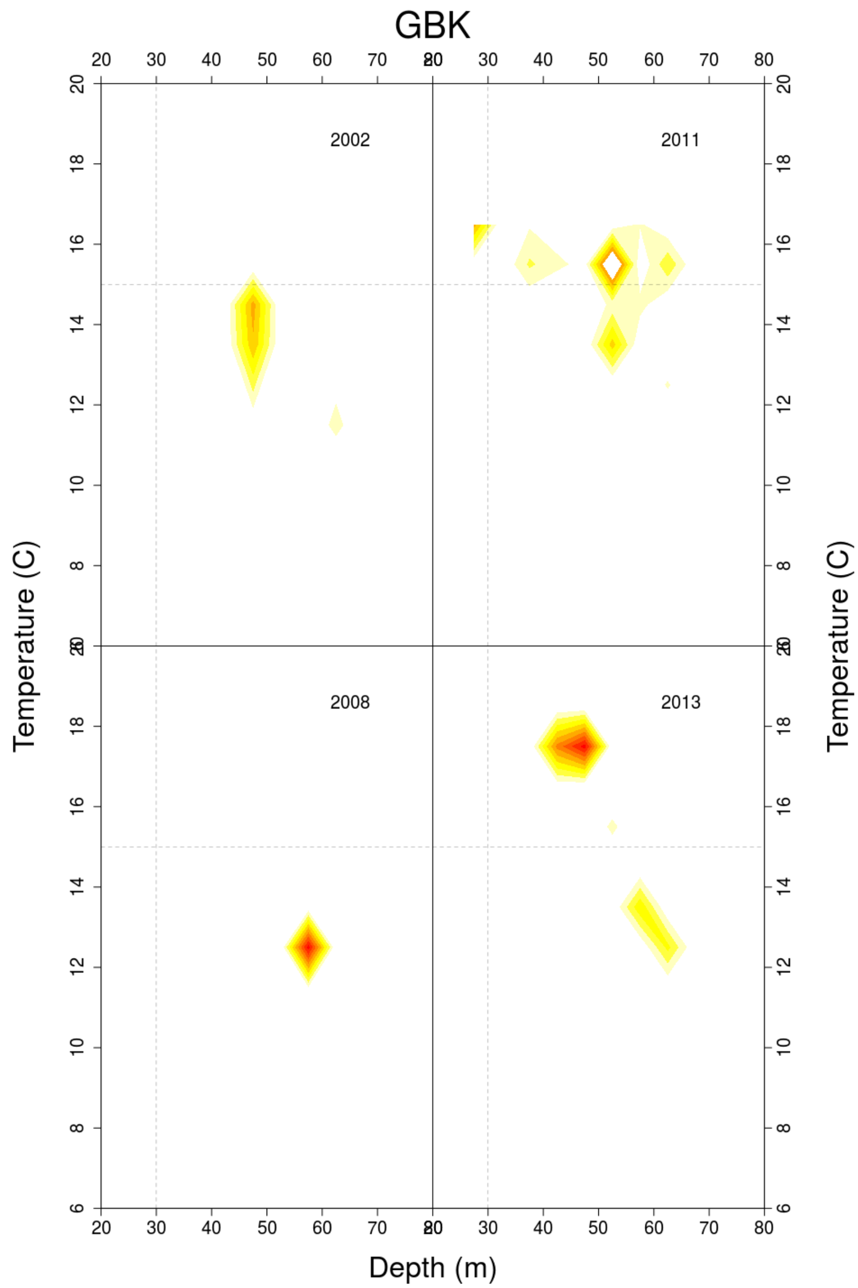

Figure 78: Total surfclams caught in the NEFSC clam survey at depth and temperature by year in GBK. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at $15°$ C and 30 m depth are for reference only.

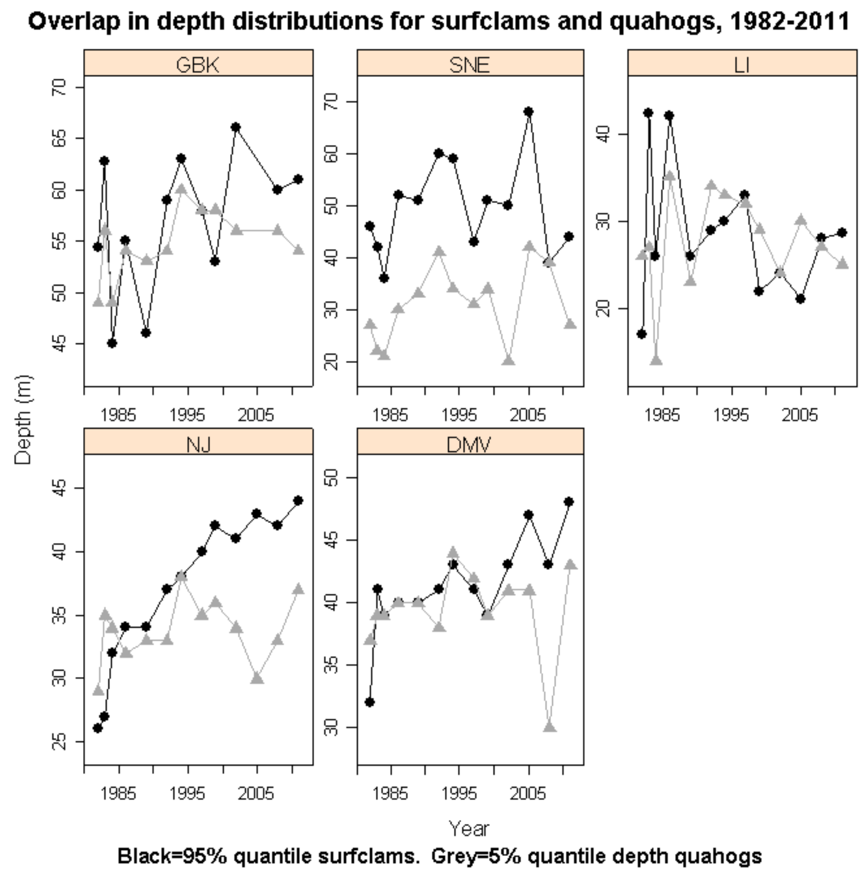

Figure 79: Trends in the offshore habitat boundary for Atlantic surfclam and the inshore habitat boundary for ocean quahog over time. The offshore boundary in each region is the 95% percentile for cumulative catch with depth in NEFSC clam surveys. The inshore habitat boundary for ocean quahogs is the 5% percentile for cumulative catch.

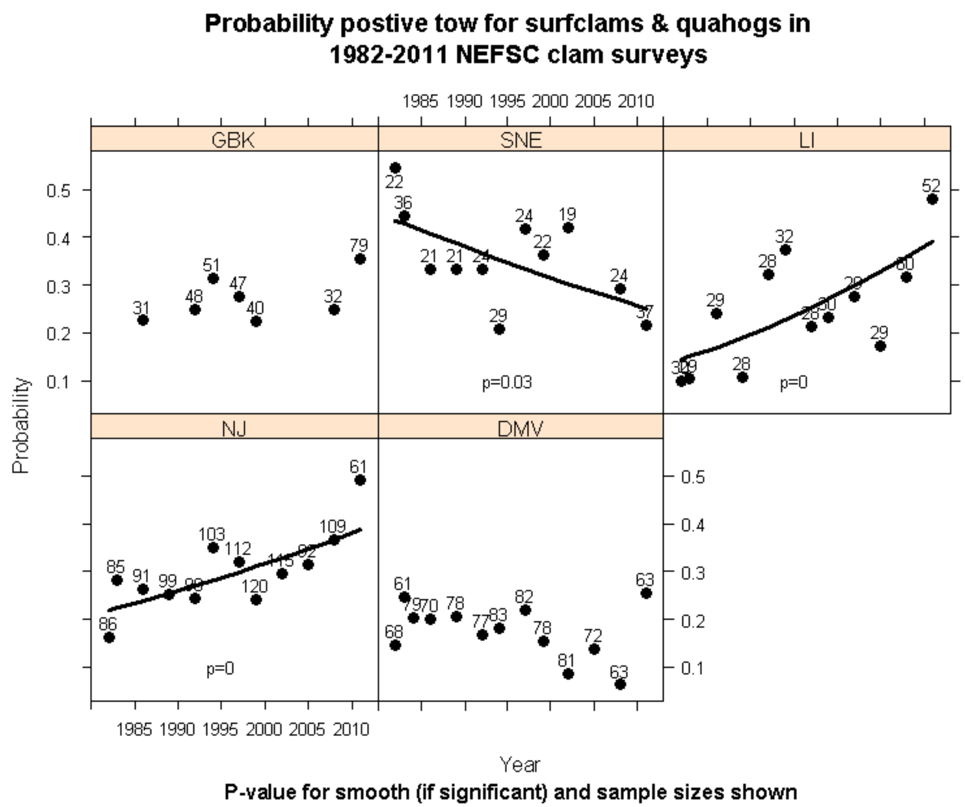

Figure 80: Probability that both Atlantic surfclam and ocean quahogs were taken in the same tow during 1982-2011 clam surveys in consistently sampled strata. Logistic regression lines and p-values are shown if the trend was statistically significant ($p < 0.1$).

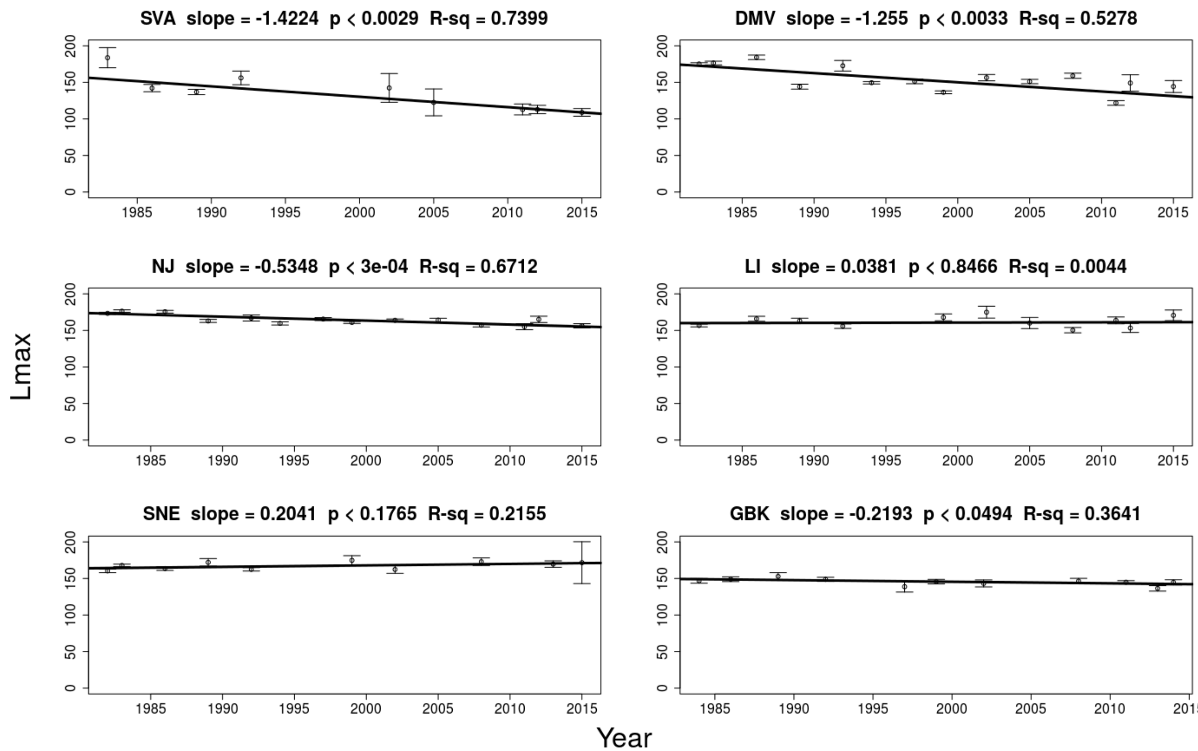

Figure 81: Estimated values of the parameter L_∞ for Atlantic surfclam in NEFSC clam surveys, over time in each region. The L_∞ values for each region were fit with an inverse variance weighted regression, and the slope, p-value and R^2 that result are shown above each plot.

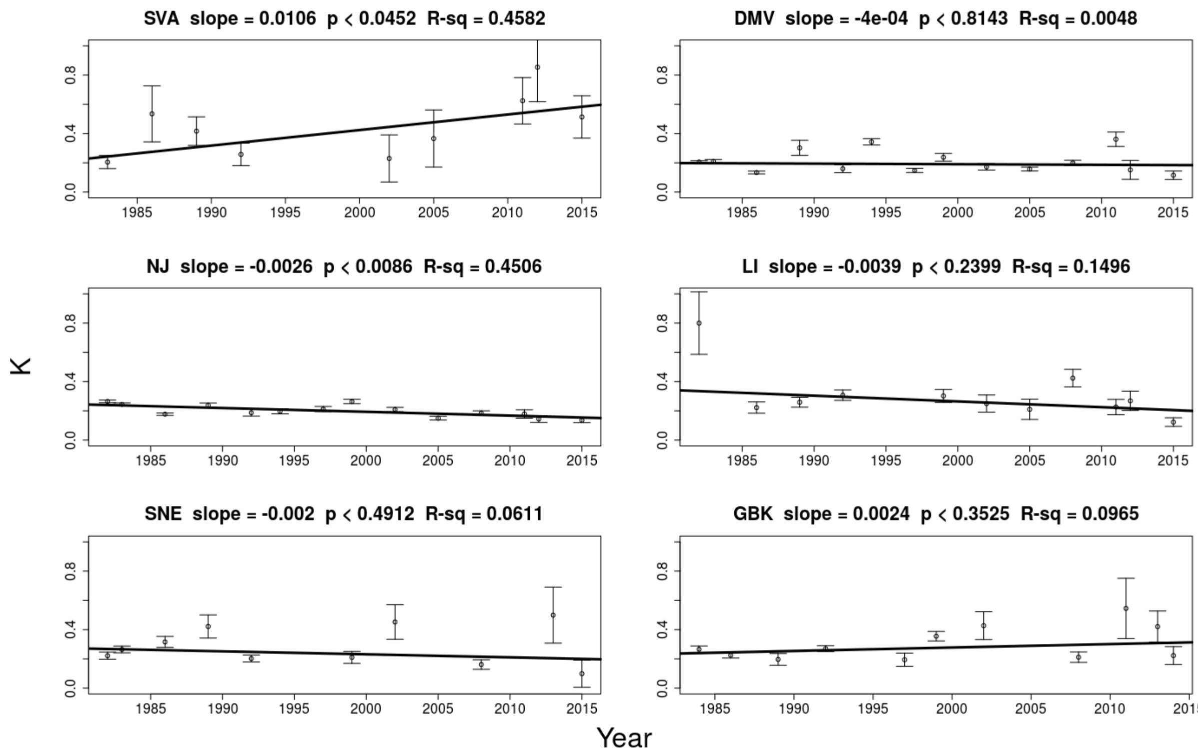

Figure 82: Estimated values of the parameter K for Atlantic surfclam in NEFSC clam surveys, over time in each region. The K values for each region were fit with an inverse variance weighted regression, and the slope, p-value and R^2 that result are shown above each plot.

Part VI

TOR 5: Model

The Atlantic surfclam assessment model was implemented in SS3[2] (Methot and Wetzel 2013). Separate SS3 models were developed for Atlantic surfclam in the southern and northern areas. 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 in the north, and differences in occurrence of strong year classes) made it too difficult to estimate "average" population dynamics for the areas combined. Also, data would be lost if the areas were combined because surveys were not available for the entire combined assessment region in some years. In this assessment, biomass, fishing mortality, recruitment, and other quantities for the combined regions were estimated by combining elements for the southern and northern areas.

Configuration

Fishery and survey selectivity were functions of size rather than age in SS3 models. Conditional age at length data, rather than traditional age composition data, were used in fitting models. The conditional age vector with indices 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 year-class strength is preserved. Size composition data are not used twice (once as size composition data and once in calculation of traditional catch at age). Finally, the sampling distribution of conditional age data is probably easier and more accurately characterized as a multinomial, conditional on the number of ages (at t and L) actually sampled.

The same types of data (Figures 83 and 107) were available for both areas, although more precise and numerous data were available for the southern area. The additional data for the south made it possible to estimate additional catchability, recruitment and selectivity parameters, as well as biomass and mortality over a longer time period (Tables 20 – 21). It was necessary to borrow some of these parameter estimates from the south in modelling Atlantic surfclam in the north because data were so limited and catches were nearly zero over much of the time series.

Dome shaped survey selectivity curves with parameters fixed at field study estimates were used in SS3 models for the MCD survey in the south and north and the RD survey in the south (Figures 87 – 111). 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 49; Northeast Fisheries Science Center (2013)). Allowing the model for the north to estimate the ascending limb of the RD survey selectivity curve was helpful in reducing diagnostic problems.

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 Atlantic surfclam was used as

[2] Stock Synthesis Model version SS-V3.24Y compiled for 64-bit linux.

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 (and assumed 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 based on the recommendations of (Francis 2011). The initial standard deviations for survey trend data were tuned, if necessary, based on preliminary model fits by adding a constant to the standard deviation for each observation in the time series (Francis 2011).

Priors for survey dredge capture efficiency

The prior distributions for survey dredge capture efficiencies were important because the models are not otherwise strongly informed regarding scale. The last Atlantic surfclam assessment (Northeast Fisheries Science Center 2013) details the work that was done to estimate a prior for the distribution of capture efficiency for the research dredge (RD) last used in 2011. Appendix XV details the work done to estimate a prior for the distribution of the modified commercial dredge (MCD) used since 2011.

Issues

South

The Atlantic surfclam assessment for the south is unable to estimate scale (absolute stock size) although trends in biomass were estimated more reliably. This is typical of a low F fishery. In general, there are several different scenarios involving combinations of selectivity, biological parameters and biomass scale that might explain the observed population dynamics when fishing mortality cannot account for it. Therefore the model is easily shifted from one scale to another based on small changes in the data or model.

Some of the issues with the assessment model for the south stem from the fact that there are only two years of data in the MCD survey. Because of this limitation, the prior distribution on the MCD survey catchability was very influential (see section VI).

The base model has some poorly determined parameters (Table 22). Most of these are recruitment deviations, which are generally difficult to estimate when the survey and commercial gear do not sample the youngest animals well. Both the survey and commercial gear have selectivity curves such that they are unlikely to capture very many animals less than about 3 years old. Therefore, poorly determined recruitment deviations are not unexpected. The model has particular trouble estimating the Q parameter associated with the catchability of the MCD survey. This is probably because the survey contributes only two data points to the model. This parameter is therefore strongly influenced by its prior distribution. Sensitivities in which the prior distribution was turned off were run and are discussed in section VI. The other poorly determined parameter is the one that describes the width of the plateau of the selectivity curve for the fishery (see Figure 87). This parameter was difficult to determine because the commercial length comps show conflicting tendencies over time. In the early years of the fishery the length composition was heavily weighted towards longer clams, and in later years the composition was broader and shows a higher proportion of smaller clams. This pattern was difficult to fit with one selectivity curve. Sensitivity runs designed to estimate this parameter better using time varying selectivity are described in section VI.

Other potential issues are the use of assumed parameter values for M, steepness and growth. The growth values estimated in the model were near the experimentally derived values presented in part III and the M value used was based on observed longevity. There was no experimental basis for the assumed steepness ($h = 0.95$) used in the assessment model as there were no observations of recruitment at low stock size available. The h used was high and resulted in no apparent relationship between spawning biomass and recruitment. Sensitivities testing each of these assumptions are described in section VI.

North

The Atlantic surfclam assessment model for the north is also uncertain relative to scale. As in the south, the model does not have enough information to estimate scale with precision because the population is lightly fished and there is little contrast in the survey indices. The model from the north also suffers from a shorter time series for catch, survey, age composition, and length composition data.

The estimated biomass trend in the early part of the time series does not fit the survey index well. The early part of the time series is uncertain relative to trend because the survey index increased rapidly in the absence of any prior fishery removals that would have accounted for the population being in a depleted state (where the increase would represent recovery). There is no support for a low biomass in the early part of the time series in the composition data either. With no mechanism to explain the increase from 1984 to 1995 (or more precisely the low biomass in 1984), the model does not believe the survey. Sensitivities to explore the affect of forcing the model to fit the survey index better are discussed in section VI.

The base model has some poorly determined parameters (Table 24). Most of these are recruitment deviations, which are generally difficult to estimate when the survey and commercial gear do not sample the youngest animals well. Model precision can be drastically improved by increasing the weighting on the MCD survey. This approach was not taken because the MCD survey consists of only one data point and because increased model precision is not desirable when the information provided to the assessment is uncertain. In the case of the northern area, the model has little meaningful information and should not reflect an unrealistically precise estimate of biomass. Sensitivity runs in which the MCD index was heavily weighted and also removed from the calculation of the likelihood surface are described in section VI.

Fit and estimates from basecase models

South

The biological parameters used in the assessment model were based on experimentally derived values (Figures 84 – 86). Fishery selectivity was estimated and retained the domed shape seen in the last assessment (Figure 87). The fit to the surveys was acceptable and the residuals did not show trends or high variance (Figures 88 – 90). The fit to the composition data was generally tight, with the possible exception of the MCD survey which showed conflicting length composition over only two years and was difficult to fit well with one selectivity pattern (Figures 91 – 103). Parameter estimates are shown in Table 21.

North

The biological parameters used in the assessment model were based on experimentally derived values (Figures 108 – 110). Fishery selectivity was partially estimated and shared the domed shape seen in the model for the south (Figure 111). The fit to the surveys was reasonable given the constraints of the data and the residuals did not have high variance (Figures 112 – 113). The fit to the composition data was generally tight, with the possible exception of the MCD survey which had only a single year of data (Figures 91 – 103). Selectivity for the MCD survey was assumed because allowing the model to fit a single year of data would have resulted in overfitting. Parameter estimates are shown in Table 21.

Likelihood profile analysis

South

Likelihood profile analysis of the model for the southern area consisted of fixing the unfished recruitment parameter (R_0) at successive values that bracketed the R_0 solution (from the base case model) and estimating all of the other parameters in the model.

Likelihood profile results for the south indicate that goodness of fit for the priors on survey catchability were best near the basecase model run (Table 23 and Figure 105). Survey age data support support higher R_0 (higher biomass) and length composition data lower R_0 (lower biomass). However, the differences in total likelihood were small (Table 23). The one area of data conflict that appears to make a substantial difference in total likelihood is between the parameter prior distributions (on survey catchability), which prefers the solution, and the age composition data, which prefer a lower values of R_0.

North

There is model tension between the RD survey index and its composition data (Table 25 and Figure 126) in the model for the north. The composition data support a higher R_0 (higher biomass), while the survey data support a smaller R_0 (lower biomass). The biomass scale at the solution is set by prior distributions on survey catchability, which affect the MCD survey and RDscale index (RDscale did not contribute to the likelihood in the north because the Q were not estimated and RDscale was not fit for trend see Table 20).

Sensitivities

Experimental model runs testing the effects of model manipulations (for example with either extra parameters or fewer sources of data) were informative.

South

Natural mortality was fixed at $M = 0.15$, based on the observed longevity of Atlantic surfclam in the base model, and an experimental run was conducted to estimate it. M was estimable and decreased with age (Figure 128). Estimating M produced a slightly better fit to the commercial length composition data, but a slightly worse fit to the survey length composition data compared to the base run. The fits to other data were unchanged. There was virtually no change in either the trend or scale of biomass and the base model was preferred due to parsimony.

The growth parameter K was fixed at values derived in the last assessment (Northeast Fisheries Science Center 2013) in the base model run. An experimental run attempted to estimate it. The Von Bertalanffy K parameter and the coefficients of variation around the growth curve were estimable. The estimated K was slightly less than the K assumed in the base model, while the estimated parameters describing uncertainty around the growth curve were nearly identical to the values used in the base model. Estimating growth had virtually no effect on the model fit and the base model was preferred due to parsimony.

There is experimental evidence that growth has changed over time in at least part of the southern stock area (Figure 81). In one sensitivity run growth was allowed to vary over time. The closest SS3 equivalent to the Von Bertalanffy L_∞ parameter was estimated for two time blocks (<2000 and >1999). This run had a negligible effect on the biomass estimates in the model (Figure 129). An additional run in which the Von Bertalanffy K parameters were fit in each of the time blocks produced only slight changes as well. This run improved the fit to the length composition very slightly at a minor cost to the fit of the conditional age at length composition data. There was virtually no change in either the trend or scale of biomass and the base model was preferred due to parsimony.

Although commercial selectivity was estimated, it may have changed over time. The evidence for this is in the apparent lack of fit to commercial length composition data that occurs in the early years of the time series (Figure 91) and the fact that the the model has trouble estimating the parameter describing the width of the plateau of the commercial selectivity curve (Table 22). The gear used by the commercial fishery has not changed substantially over time so any changes in fishery selectivity were probably due to changes in behavior. That is, the fishery probably targeted the beds with the largest and oldest clams first, and then later moved to beds of smaller clams when those were fished down. Sensitivity runs where commercial length composition was allowed to vary in time blocks (<1986 and >1985) produced better fits to the commercial length composition data. The overall fit to the commercial length composition data was already fairly good, however, and there was virtually no change in either the trend or scale of biomass and the base model was preferred due to parsimony.

The base model somewhat underfits the RD survey (Figure 90). This base case solution is fairly stable. In order to force the model into a fit tight enough to reduce the standard deviation of the standardized residuals of the fit the RD survey, the lambda (likelihood weighting component) of the RD survey had to be increased by a factor of 10. Forcing the model to better fit the RD survey trend changed the overall biomass trend somewhat (Figure 130). It also caused a degradation in the fit to the composition data, and the conditional age at length composition data in particular. Biomass scale was unchanged and given the large weight being put on the survey data, the base model was preferred.

There is tension between the survey data and the composition data (Figure 105). The weights associated with each of these data sources determines the shape and scale of the model to some extent. A sensitivity run in which the variance associated with the composition data (both length, and age at length composition data) was increased relative to the base model, so that the harmonic mean of the effective sample size matched the mean of the input sample size (implicitly decreasing the information content of the RD survey). This was compared to the base model and the previous sensitivity run (Figure 130) in which the weight of the RD survey was increased (implicitly decreasing the information content of the composition data). The trade off between the composition data and the RD survey indices are clear in the comparison in that weighting the composition data more heavily tends to smooth out the biomass trajectory, while weighting the RD survey tends to introduce additional topography to the trend. All three runs show similar scales, while the base model is a compromise between the two in trend.

Profile analysis showed that the prior distribution associated with the MCD survey was influential in the base model solution. A sensitivity run in which the prior was not used confirmed this. The scale of estimated biomass shifted considerably, though the trend was very similar to the base run (Figure 131). The fits to the composition data were not affected by the removal of the prior distribution on catchability. When the prior distribution for the RD survey was removed, the effect on the model was almost undetectable, further indicating that the prior on the MCD survey is influential. When both prior distributions were removed, the model estimated a lower biomass (R_0 near the lower end of the range covered in the likelihood profile analysis), but the trend and fit to composition data were similar to the base model.

The MCD survey has only two data points in the base model, which is a small sample size to use for estimating trend. When the MCD survey index contribution to the likelihood was removed (multiplied by $\lambda = 0$), the scale of the estimated biomass shifted and trend was not strongly affected (Figure 132). This implies that the MCD survey and its prior are important for setting scale in the assessment model, but that they do not have a strong influence on the trend, even over the period that the MCD survey covers (>2011).

The steepness of the stock recruit relationship is assumed ($h = 0.95$) in the base model. There are no observations of the stock at low biomass in the time series (typical of a low F fishery) and so there is little information available with which to estimate steepness. A sensitivity run estimated steepness at 0.33 ($cv = 0.54$; Figure 133), but it is difficult to credit this estimate given the lack of information available to the model. The lower steepness value had little affect on the scale, trend or fit of the model, but would have an affect on biological reference points, if they were derived from the stock-recruit relationship. This aspect will be discussed further in VII.

The split survey in 2012 and 2013 caused some difficulty in compiling the data for the assessment model. In particular, the inclusion of 2013 data with the 2012 ages (Table 15) introduced additional observation error in the conditional age at length composition data. The error in the length composition data was expected to matter less because Atlantic surfclam grow relatively slowly, are fished lightly and the length composition from one year to the next should not change very much. A sensitivity run in which the conditional age at length information from 2013 was left out of the model was indistinguishable from the base run (Figure 134).

A comparison of the biomass time series estimated in several sensitivity runs demonstrated that the model was relatively stable in trend (Figure 136). Allowing flexibility in the model by estimating more parameters, including time varying growth and natural mortality, produced runs that started and ended at similar biomass levels and had confidence intervals with a high degree of overlap. The run that used no prior information for estimating the catchability of the surveys had a different scale than the other runs, but showed a similar trend. In general, the model for the southern area was stable over many different configurations.

North

The assessment model for the north does not fit the survey well in the early part of the time series. One possible explanation for this is that the population was in a period of low recruitment and is currently in a period of high recruitment. A sensitivity run in which the parameter R_0 was estimated for each of two time periods (before 1995 and after) did estimate a lower R_0 for the early part of the time series, but did not substantively improve the fit to the survey index (Figure 137).

It was not possible to estimate recruitment variation (around the stock recruitment curve) in the model for the north in any of the runs tested. It is possible that the assumed value for recruitment variation was too low to provide the model enough flexibility to fit the early part of the RD survey well. A sensitivity run in which the recruitment variation was increased by 100% did not improve the fit to the survey (Figure 138).

Forcing the model to fit the RD survey better, by increasing its likelihood weight by a factor of ($\lambda = 10$), caused a degradation in the fit to the composition data (Figures 139 – 140). It was necessary to increase the weight on the survey by an order of magnitude before the model was able to fit the early RD index well (Figure 141).

The model was sensitive to the inclusion and relative weighting of the MCD survey. The MCD survey contributed only one year to the model. The MCD composition data were not particularly well fit by the model using an assumed selectivity, but it was not reasonable to allow the model to estimate selectivity given the single data point. When the variance associated with the MCD survey index was reduced (increasing its relative information content), the model produced a far more certain biomass estimate for the whole time series (Figure 142). While this result improved model diagnostics, it relied heavily on the information provided by a single data point and is therefore unstable. This is easily demonstrated by removing the MCD index from the likelihood calculation (making its contribution 0), which resulted in a model with a different biomass scale. The change in scale indicates that the entire model depends heavily on the catchability parameter for the MCD survey. The dependence on the prior for the MCD index in setting scale was clear from sensitivity runs in which the MCD index was included but the prior on catchability for it was not (Figure 143).

The inclusion of the 2014 conditional age at length composition with the 2013 data introduced additional observation error to the model. Removing the age data from 2014 would be expected to cause a bigger change in the model for the north, than the corresponding removal of 2013 data from the model for the south, because a higher proportion of the total data for the north came from the staggered year (Table 15). A sensitivity run in which the conditional age at length information from 2014 was left out of the model was similar to the base run (Figure 144), and the base run was preferred in order to make use of more the available data and because the differences were minor relative to the uncertainty in the model.

A comparison of the biomass time series estimated in several sensitivity runs demonstrated that the model was relatively stable in trend (Figure 145), except when the trend was forced to fit the early part of the survey time series in the run called "WeightRD". Allowing flexibility in the model by including time varying recruitment, or increasing the variance around recruitment produced runs that started and ended at similar biomass levels and had confidence intervals with a high degree of overlap. Removing either the trend or the prior on catchability for the MCD survey tended to reduce the scale of the estimated biomass, though trends were still similar (Figure 146).

Internal retrospective

South

There is a shift in scale when the MCD survey drops out of the assessment (retrospective peels that do not include years after 2011; Figure 147). The Atlantic surfclam model for the southern area however, does not have a retrospective pattern in trend, which can be seen in a plot of the relative biomass from each retrospective run (Figure 148). Relative biomass was determined by dividing the biomass in each year and run by 25% of the virgin biomass estimated in that run.

North

The shift in scale in the model for the northern area is larger than in the southern area, and the trend is less stable over 10 peels of retrospective analysis (Figure 149 - 150).

Whole stock results

A simulation testing the relative merits of different approaches to combining F from multiple areas when absolute abundance was poorly determined, demonstrated that the abundance weighted average F was negatively biased when the correlation between abundance and F was close to -1 (See XX). The simulation also showed that the geometric mean of the F from each of two areas was close to the true combined F at all correlation levels. However, the geometric mean was strongly negatively biased when F is very low and in fact undefined when $F = 0$, which is true for a substantial proportion of the Northern area time series. The abundance weighted mean was therefore the preferred method of calculating combined F for the stock and determining the stock status relative to 2015.

Whole stock fishing mortality was $F_W = \frac{(C_S + C_N)}{(\widehat{N_S} + \widehat{N_N})}$ where C_S and C_N were the catch in numbers from each area and $\widehat{N_S}$ and $\widehat{N_N}$ were average fully selected abundances

$$\widehat{N_a} = \sum_L s_L \frac{N_L(1 - e^{Z_L})}{Z_L}$$

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 part VIII.

The F in projections was far enough from zero to allow the use of the geometric mean as a method for combining F from different areas. Therefore, the whole stock fishing mortality in projections was $F_W = e^{log(F_S)+log(F_N)}$. Whole stock projection results are discussed in IX. Fortunately, this choice had little effect on the whole stock results because F was so low. If F increases in the future it may be prudent to revisit the method for combining F from different areas in order to minimize the potential bias caused by correlation between F and abundance (XX).

Whole stock spawning biomass estimates for clams was $SSB_W = e^{log(\frac{SSB_S}{SSB_{Threshold,S}})+log(\frac{SSB_N}{SSB_{Threshold,N}})}$, where $SSB_{Threshold,A} = \frac{SSB_{0,A}}{4}$ and A was area (either N or S). The variance around $\frac{SSB_A}{SSB_{Threshold,A}}$ was

$$\sigma^2_{SSB_A} = \left(\frac{\widehat{SSB_A}}{\widehat{SSB_{Threshold}}}\right)^2 \left(\frac{\sigma^2_{SSB_A}}{\widehat{SSB_A}^2} + \frac{\sigma^2_{Threshold,A}}{\widehat{SSB_{Threshold,A}}^2} - \left(\frac{2 * cov[SSB_A, SSB_{Threshold}]}{(\widehat{SSB_A} * \widehat{SSB_{Threshold}})}\right)\right)$$

Historical retrospective

The estimated whole stock biomass in this assessment is higher in scale than previous assessments (Figure 151). The scale shift over time reflects the difficulty in determining scale in the Atlantic surfclam assessment, progress as priors for catchability were developed, and is typical of a low F fishery.

Table 20: Structure of SS3 models used for surfclams in the southern and northern areas.

Model aspect	South	North	Note
M	0.15	0.15	Constant for all ages and years
Age bins	0–30	0–30	
Length bins	1–20 cm	1–20 cm	
Time	1965–2015	1984–2015	
Seasons/morphs/subareas	0	0	
Commercial fleets	1	1	
Fishery selectivity	Double normal	Double normal	
Surveys (trend)	2	2	RD (trend) RD-SWAN (scale) MCD (scale and trend)
Survey selectivity RD	Double normal	Double normal	Based on field estimates
Survey selectivity MCD	Double normal	Double normal	Based on field estimates
Survey catchability (RD-SWAN)	Estimated	Fixed	Uses informative prior distribution
Survey catchability (MCD)	Estimated	Fixed	Uses informative prior distribution
Recruitment Model	Beverton-Holt	Beverton-Holt	Fixed steepness, estimated R_0 and variance (south)
Recruit dev years	1965–2015	1969–2015	
Bias Adjustment parameters	1955,1976,2008,2015,0.79	1961,1974,2006,2015,0.87	
F method	Hybrid	Hybrid	6 iterations (exact F)

Table 21: Parameters estimated internally and externally in SS3 base models for Atlantic surfclam in the southern and northern areas. Parameters listed as fixed or estimated apply to both areas. Parameters listed as estimated in one area are fixed in the other. Numbers of parameters are summarized in the last rows.

Parameter	South	North	Note
M	0.15	0.15	Fixed
Length at age 4	9.613	9.184	Estimated
Length at age 30	16.255	14.912	Estimated
Von Bertalanffy K	0.224	0.253	Fixed
CV of size at ages 5 y	0.172	0.17	Estimated in South
CV of size at age 30 y	0.088	0.077	Estimated in South
Shell length to meat weight multiplier	9e-05	0.00011	Fixed
Shell length to meat weight exponent	2.733	2.733	Fixed
Spawner recruit R_0	16.018	14.251	Estimated in South
Spawner recruit steepness	0.95	0.95	Fixed
Spawner recruit sd	0.861	1	Estimated
Catchability RD	0.103	0.098	Estimated in South (with prior)
Catchability MCD	0.738	0.661	Estimated in South (with prior)
Fishery selectivity peak	15.107	15.075	Estimated
Fishery selectivity top	-8.65802	-2.12929	Estimated in South
Fishery selectivity asc. width	1.638	2.199	Estimated
Fishery selectivity dec. width	1.375	0.553	Estimated in South
Fishery selectivity init	-999	-999	Fixed
Fishery selectivity final	-999	-999	Fixed
Survey (RD) selectivity Peak	8.819	9.534	Estimated in North
Survey (RD) selectivity top	-0.64891	-0.64891	Fixed
Survey (RD) selectivity asc. width	2.239	1.909	Estimated in North
Survey (RD) selectivity dec. width	2.356	2.356	Fixed
Survey (RD) selectivity init	-999	-999	Fixed
Survey (RD) selectivity final	-0.81743	-0.81743	Fixed
Survey (MCD) selectivity Peak	11	11	Fixed
Survey (MCD) selectivity top	1.1	1.1	Fixed
Survey (MCD) selectivity asc. width	2.239	2.239	Fixed
Survey (MCD) selectivity dec. width	8	8	Fixed
Survey (MCD) selectivity init	-999	-999	Fixed
Survey (MCD) selectivity final	-0.81743	-0.81743	Fixed
Initial F	0.005	0	Estimated in South
Total estimated (-recruit deviations)	13	9	
Recruit deviations	51	32	
Total estimated	64	41	

Table 22: Parameter estimates and estimated precision in a basecase model run for Atlantic surfclam in the southern area . This table shows the thirty parameters that are the least precisely determined, ranked by coefficient of variation.

name	value	std.dev	cv
Q_parm[2]	-0.30	11120.00	36566.92
recdev2015	-0.01	0.85	78.57
recdev1975	-0.02	0.53	23.84
recdev1994	-0.04	0.43	11.87
recdev1966	-0.06	0.68	11.76
recdev1965	-0.07	0.69	9.99
recdev1974	-0.06	0.51	9.10
recdev1987	0.06	0.53	8.78
recdev1984	-0.06	0.50	8.48
recdev2007	0.07	0.53	7.13
recdev1982	0.09	0.50	5.57
recdev1986	0.10	0.44	4.57
recdev2014	-0.19	0.83	4.33
recdev1968	-0.15	0.63	4.27
recdev1967	-0.16	0.67	4.19
recdev2012	0.15	0.60	3.95
selparm[2]	-8.66	28.69	3.31
recdev1973	-0.18	0.54	2.98
recdev1998	-0.13	0.34	2.67
recdev2013	-0.31	0.73	2.32
recdev1993	0.25	0.59	2.32
recdev1969	-0.29	0.62	2.14
recdev2011	-0.45	0.75	1.66
recdev1985	-0.38	0.59	1.56
recdev1972	-0.41	0.58	1.40
recdev2006	-0.30	0.41	1.35
recdev1970	-0.48	0.61	1.27
recdev1971	-0.53	0.59	1.13
recdev1983	0.35	0.38	1.09
recdev2008	0.45	0.49	1.09

Table 23: Likelihood profile over unfished recruitment parameter (R0). The values in the table are the differences, in likelihood units, between each profile run and the minimum likelihood for that row (likelihood component). Conflicts within the data are apparent when the minimum likelihood values (gray cells) occur in different columns for each row. That is, different likelihood components within the model were minimized at different values of R0. Because R0 is important for setting the scale of estimated biomass in the model (Relative B; last row), data conflicts around R0 tend to increase uncertainty in scale. The coloumn corresponding to the minimum total likelihood is shown in italics.

ln(R0)	14.5	15	15.5	*16.02*	16.5	17
Total	24.1	9.75	2.3	*0*	1.93	7
Parm priors	22.8	10.7	3.2	*0*	0.8	4.5
RDtrend	0	2.4	3.9	*5.1*	5.8	6
RDscale	0	0	0.1	*0.3*	0.4	0.6
ComLen	0	0.2	0.3	*0.4*	0.4	0.3
LenRD	1	0.1	0	*0.1*	0.4	0.7
LenMCD	0	0	0.2	*0.4*	0.5	0.7
AgeRD	4.9	2.2	1	*0.3*	0	0
AgeMCD	2.9	1.8	1.1	*0.6*	0.3	0
Relative B	1	1.6	2.6	*4.2*	6.4	9.5

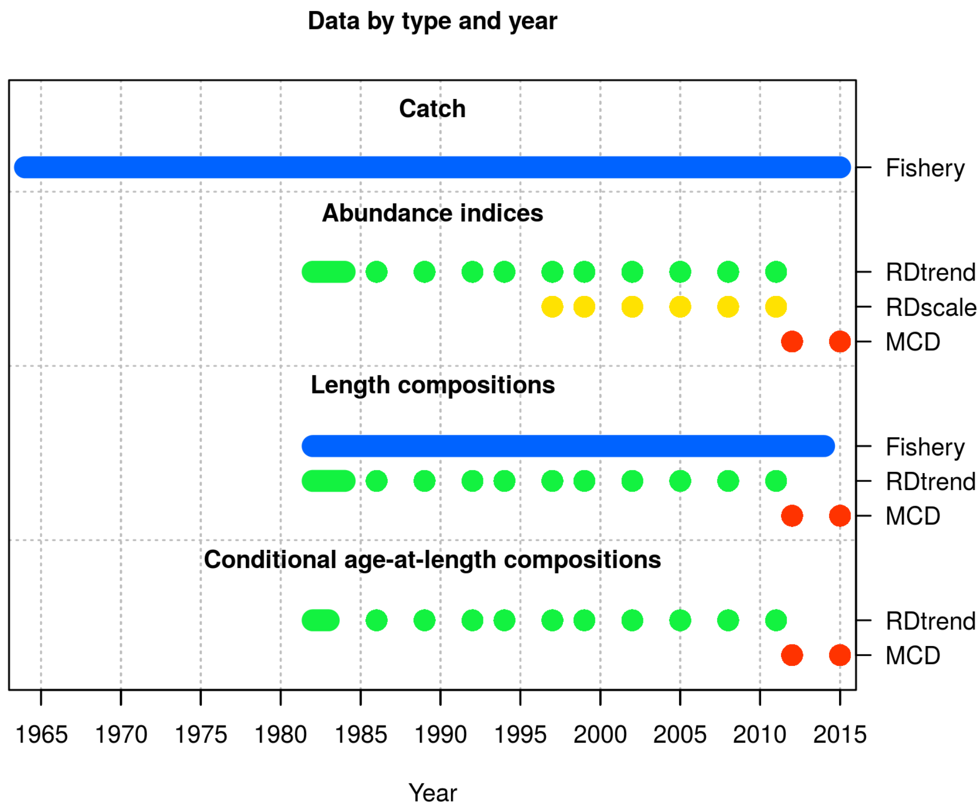

Figure 83: Data included in the Atlantic surfclam assessment model for the southern area. RD scale was not included in the likelihood.

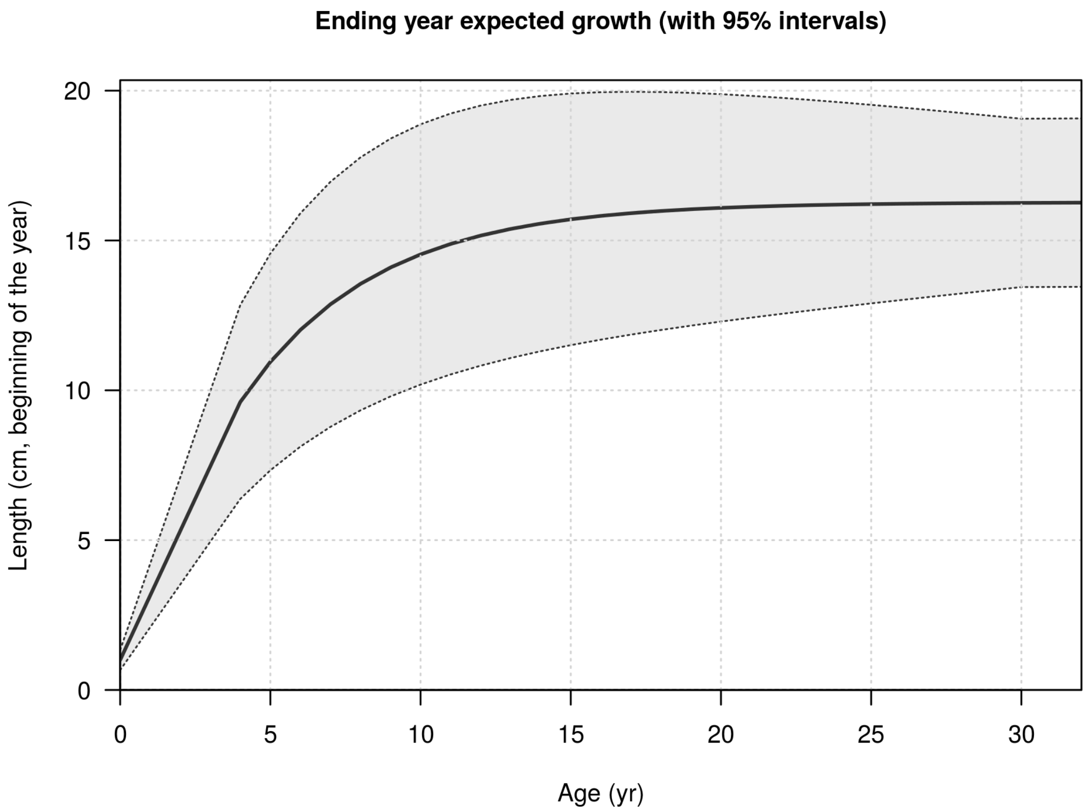

Figure 84: Length at age relationship from the assessment model for Atlantic surfclam in the southern area.

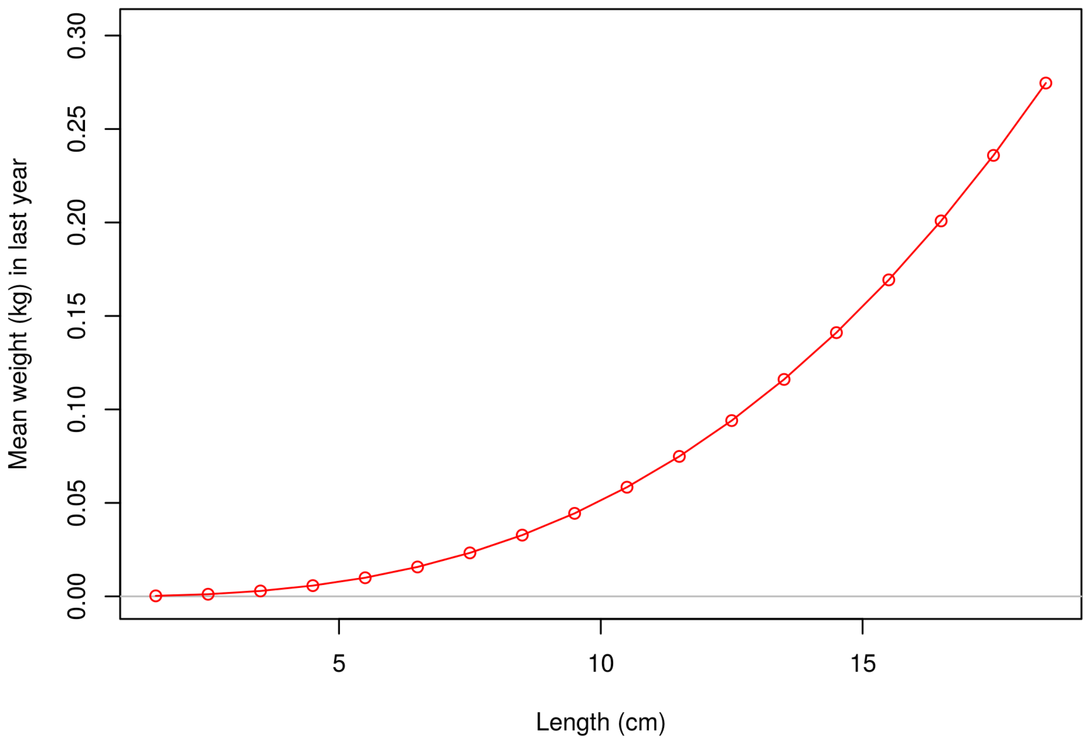

Figure 85: Weight at length relationship used in the assessment model for Atlantic surfclam in the southern area.

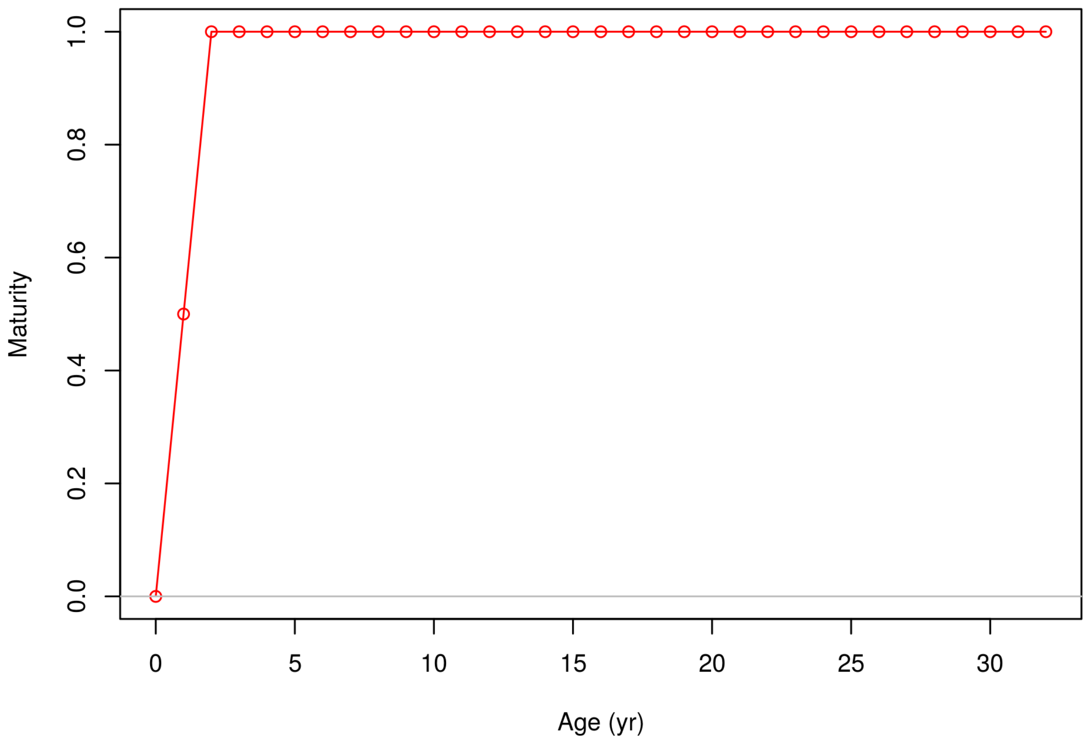

Figure 86: Maturity at age relationship used in the assessment model for Atlantic surfclam in the southern area.

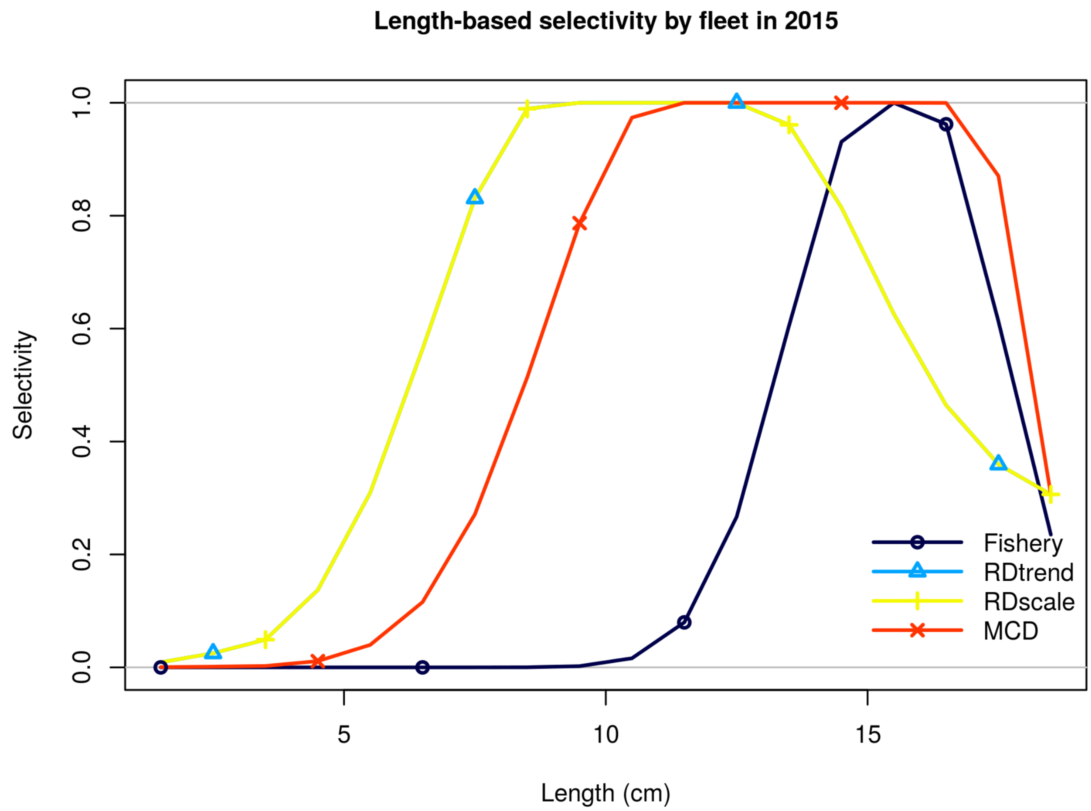

Figure 87: Comparison of selectivity curves for each fleet included in the assessment model for Atlantic surfclam in the southern area. RD trend and RD scale have identical selectivities because they are from the same survey (RD scale was not included in the likelihood).

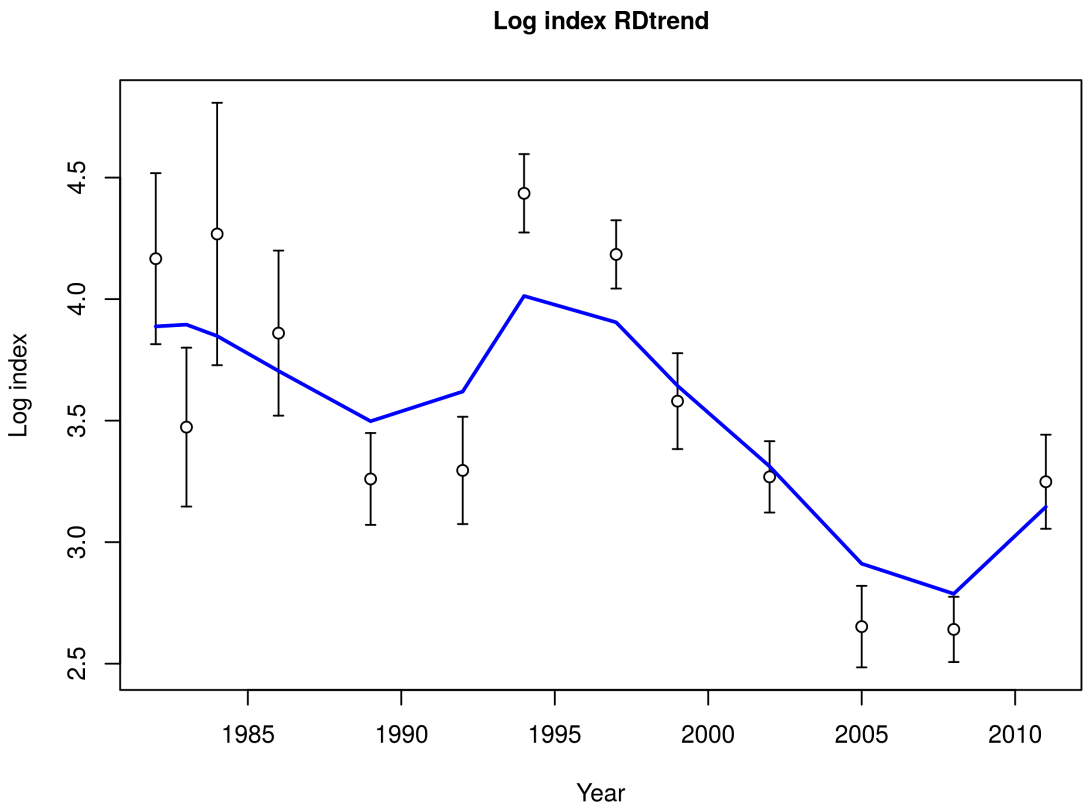

Figure 88: Fit to log index data on log scale for RDtrend survey for Atlantic surfclam in the southern area. Vertical lines are 95% confidence intervals.

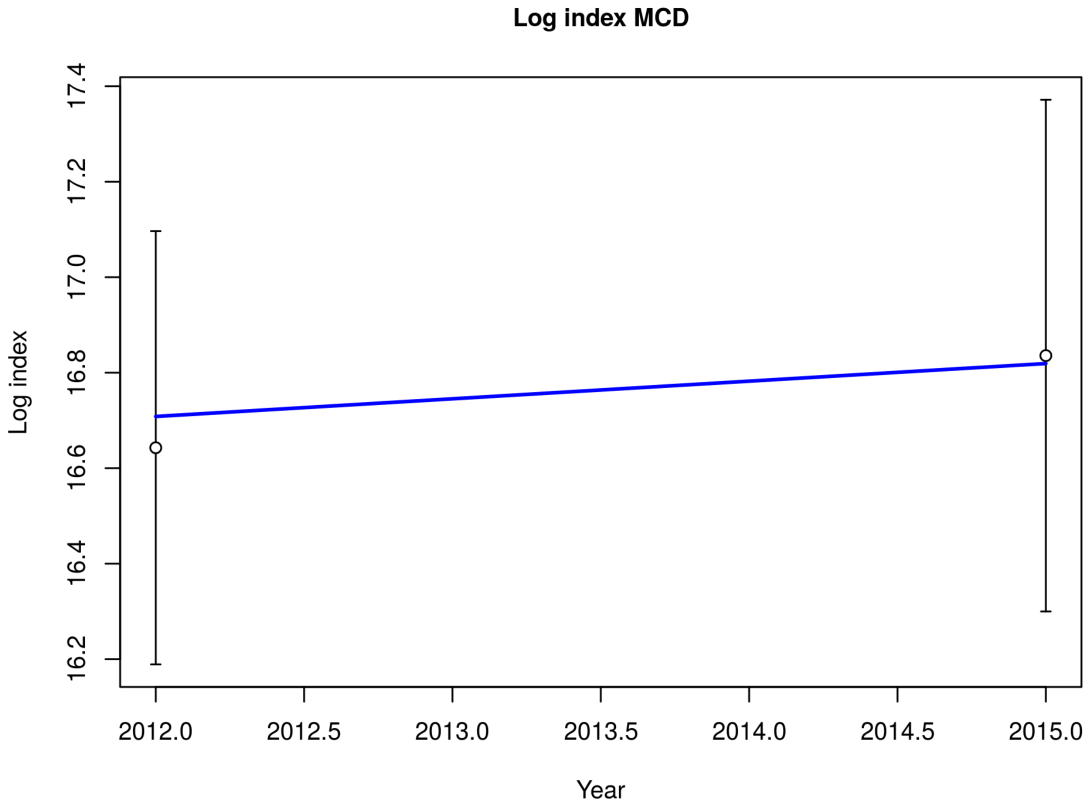

Figure 89: Fit to log index data on log scale for MCD survey for Atlantic surfclam in the southern area. Vertical lines are 95% confidence intervals.

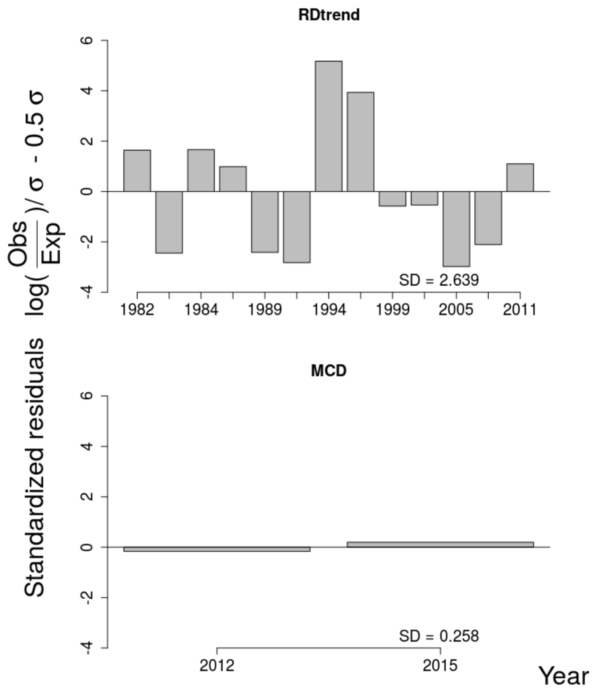

Figure 90: Residuals from the model fits to each survey index used in the assessment model for Atlantic surfclam in the southern area by year. The standard deviation of the residuals over the time series is indicated above the horizontal axis.

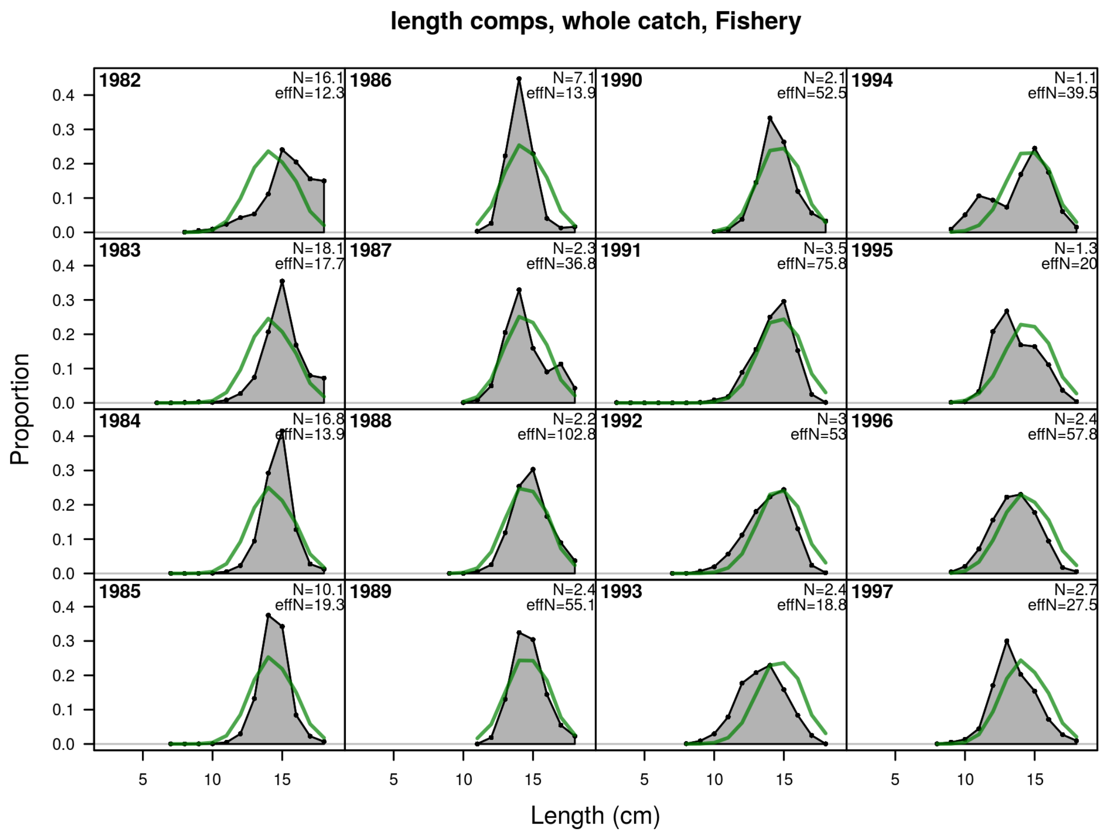

Figure 91: Model fit to length composition data from the commercial fishery used in the assessment model for Atlantic surfclam in the southern area.

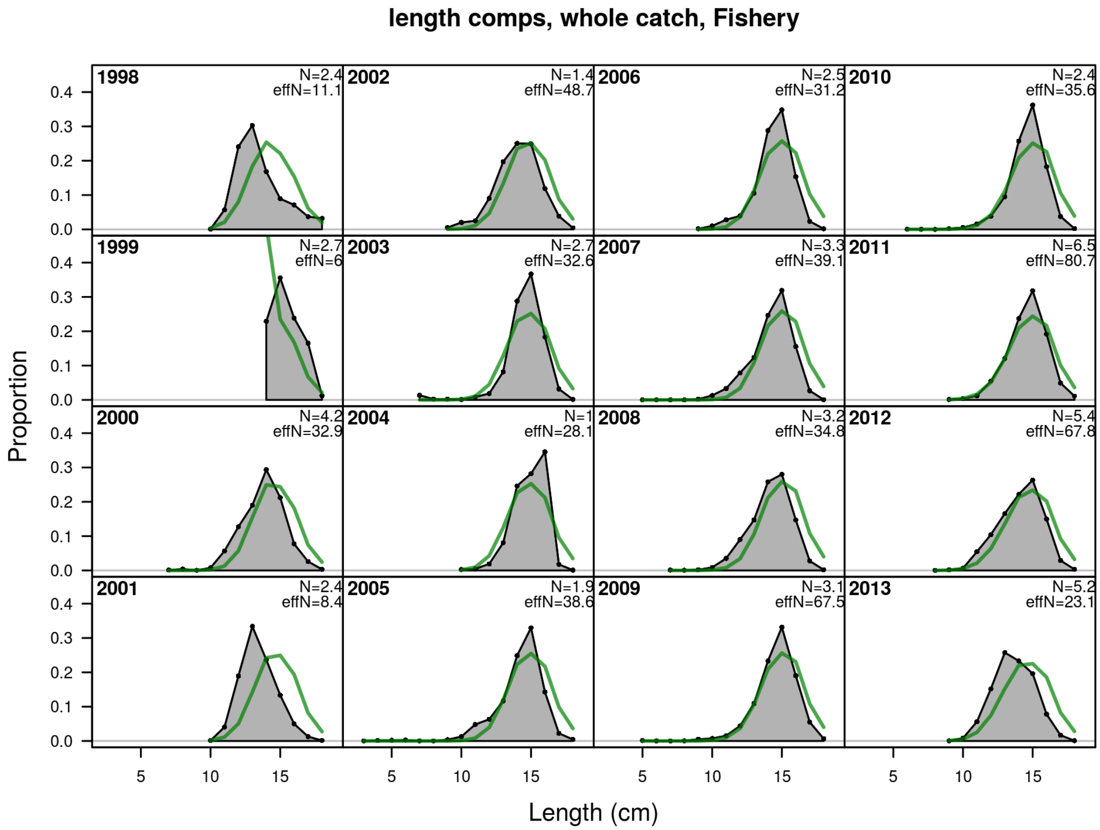

Figure 91 cont.

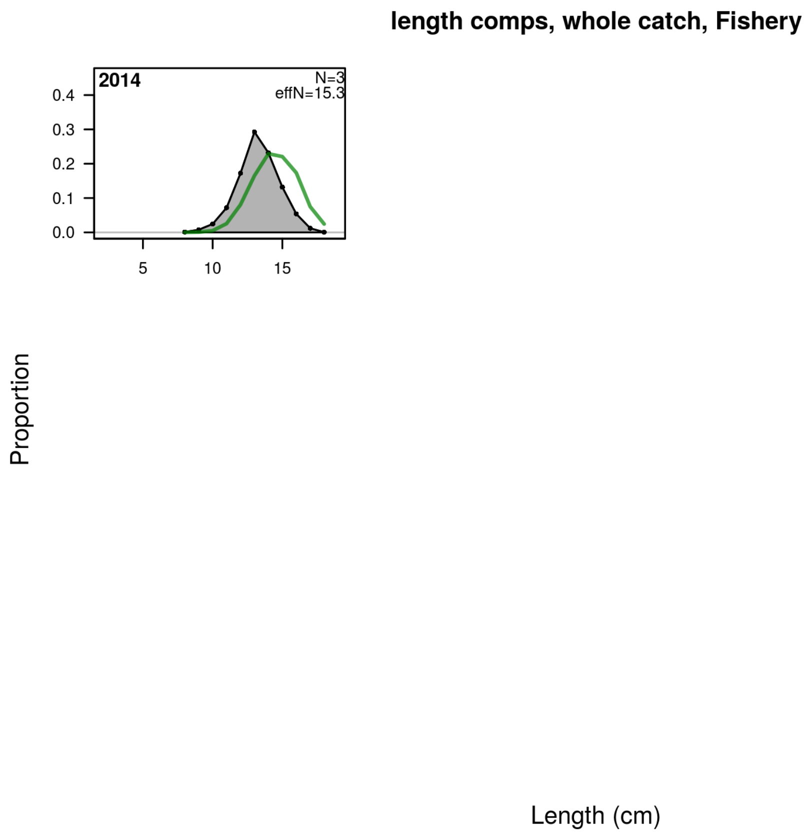

Figure 91 cont.

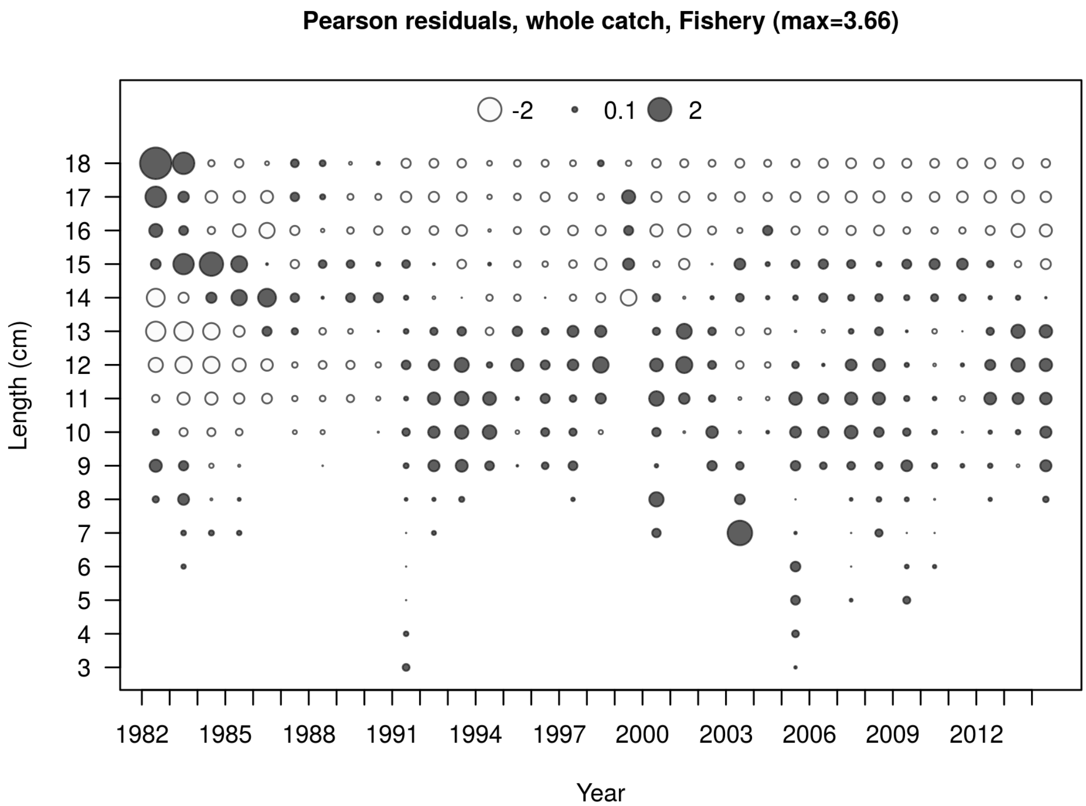

Figure 92: Pearson residuals from the fit to commercial length composition data used in the assessment model for Atlantic surfclam in the southern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

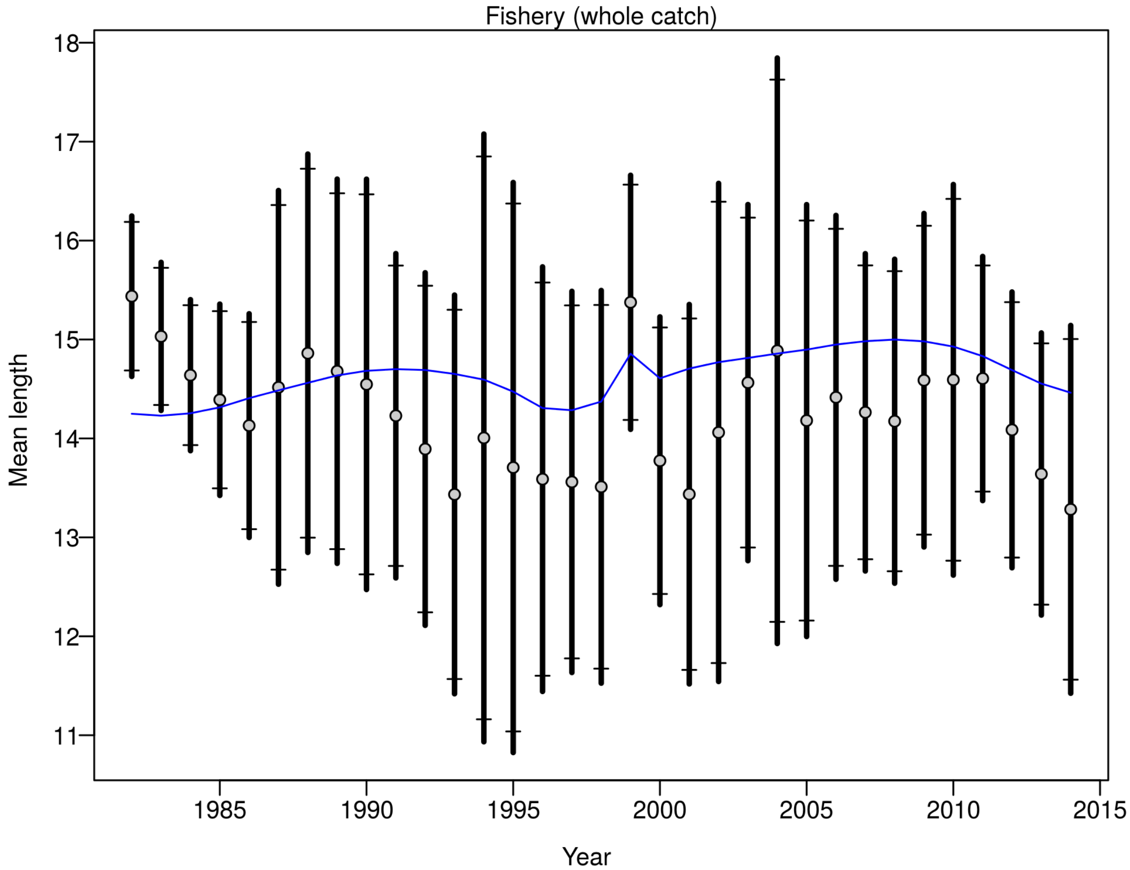

Figure 93: Observed mean length vs. the mean length predicted by the model based on fits to commercial length composition data used in the assessment model for Atlantic surfclam in the southern area.

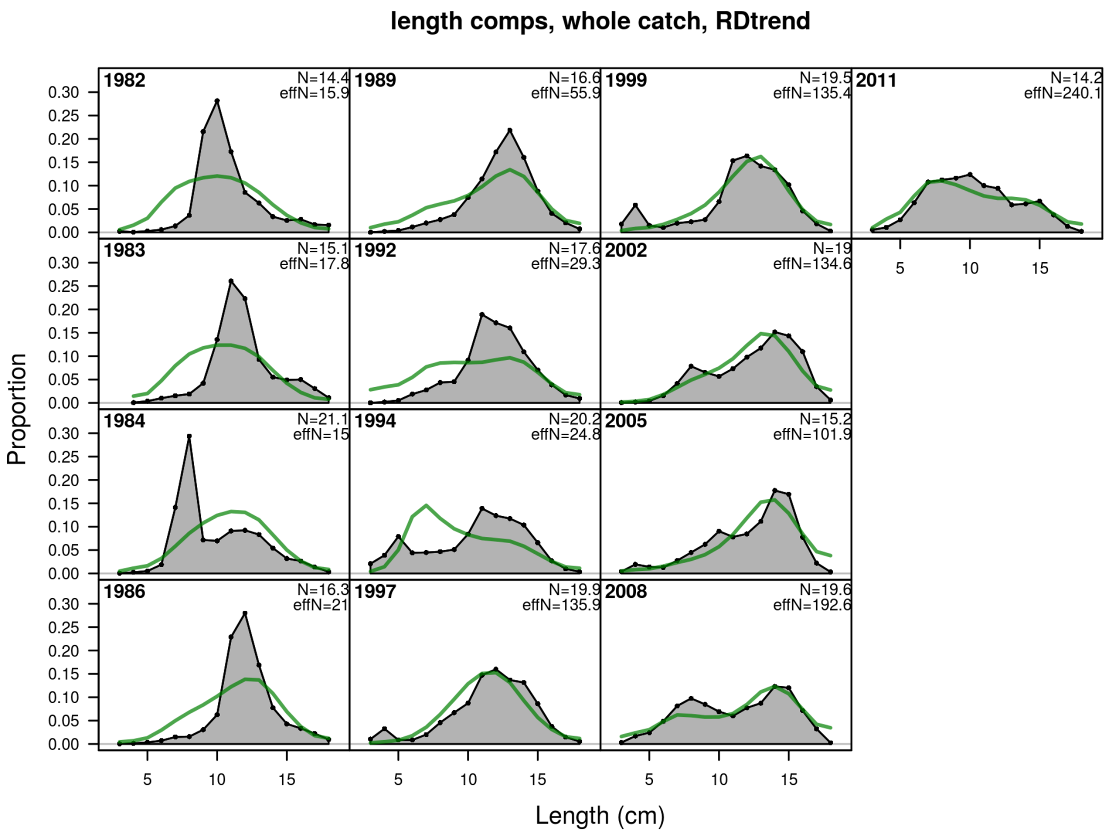

Figure 94: Model fit to length composition data from the NEFSC survey (RD) used in the assessment model for Atlantic surfclam in the southern area.

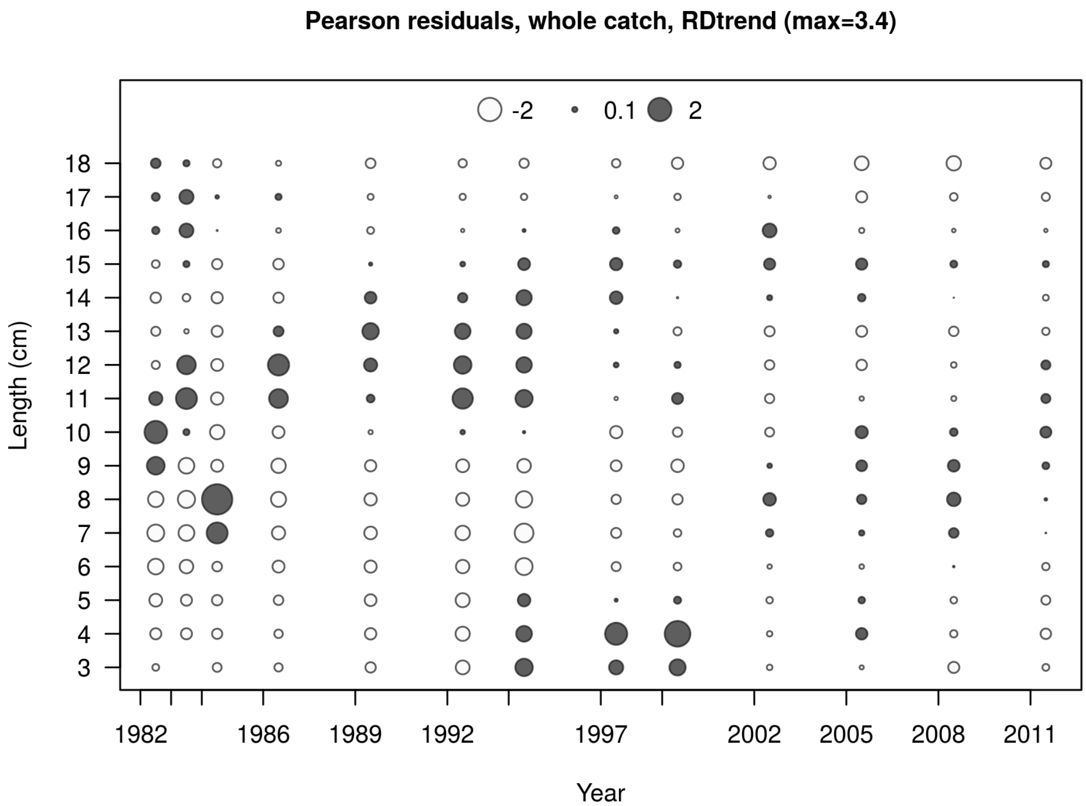

Figure 95: Pearson residuals from the fit to NEFSC survey (RD) length composition data used in the assessment model for Atlantic surfclam in the southern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

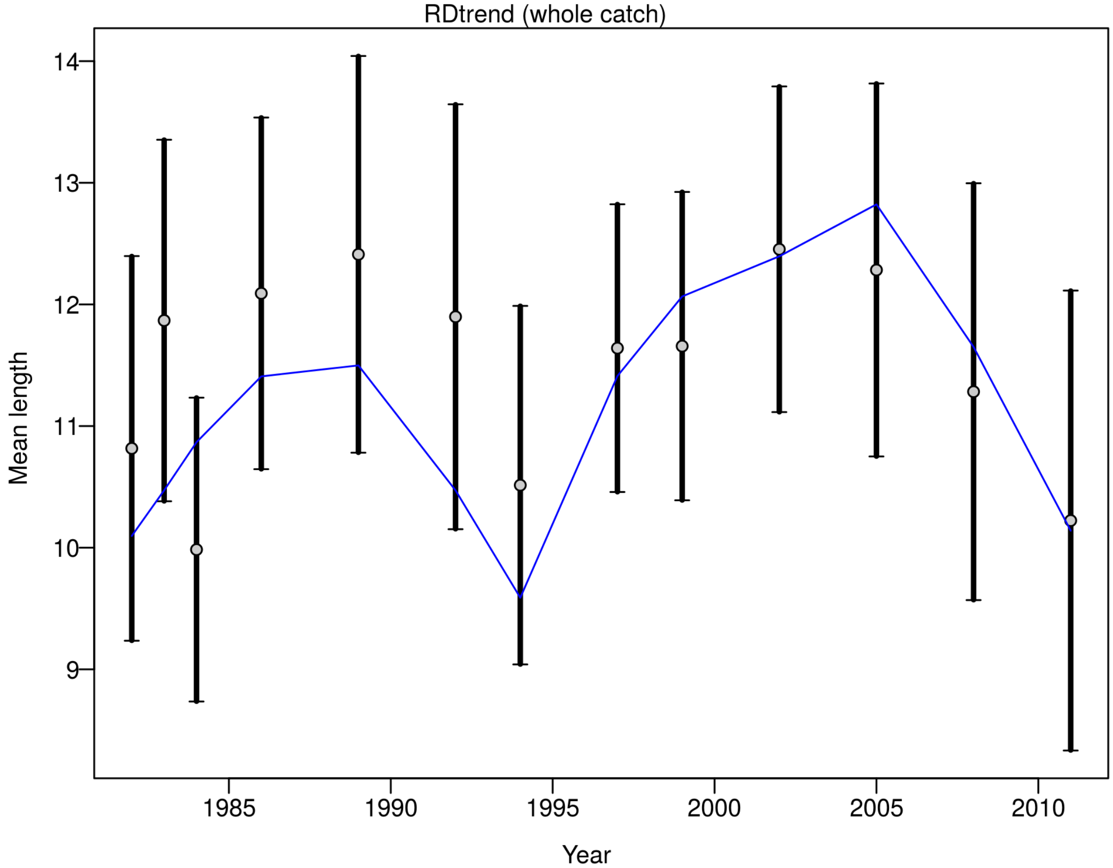

Figure 96: Observed mean length vs. the mean length predicted by the model based on fits to NEFSC survey (RD) length composition data used in the assessment model for Atlantic surfclam in the southern area.

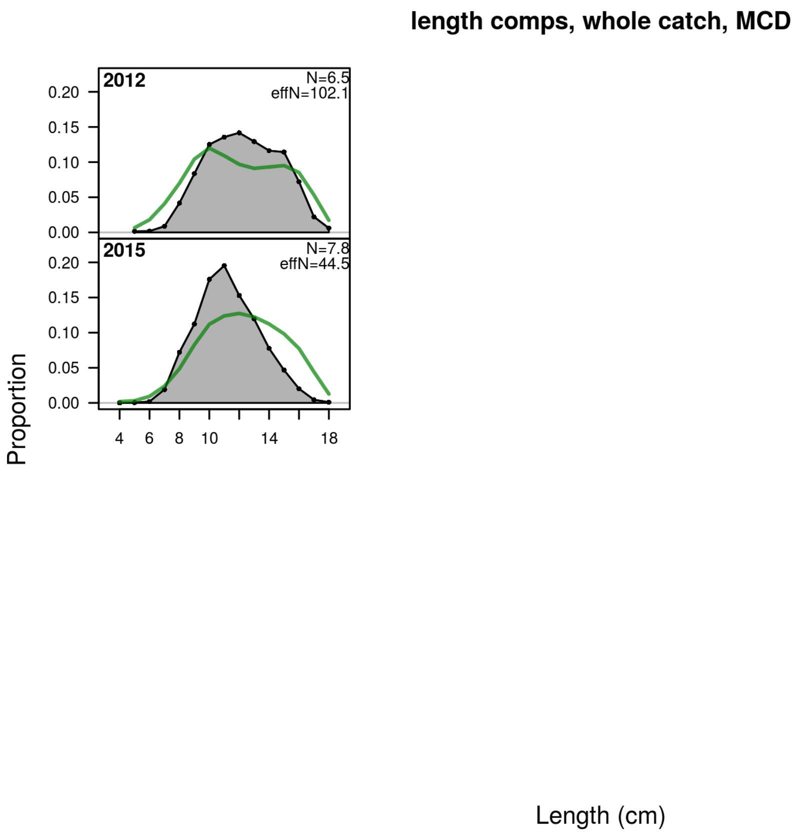

Figure 97: Model fit to length composition data from the NEFSC survey (MCD) used in the assessment model for Atlantic surfclam in the southern area.

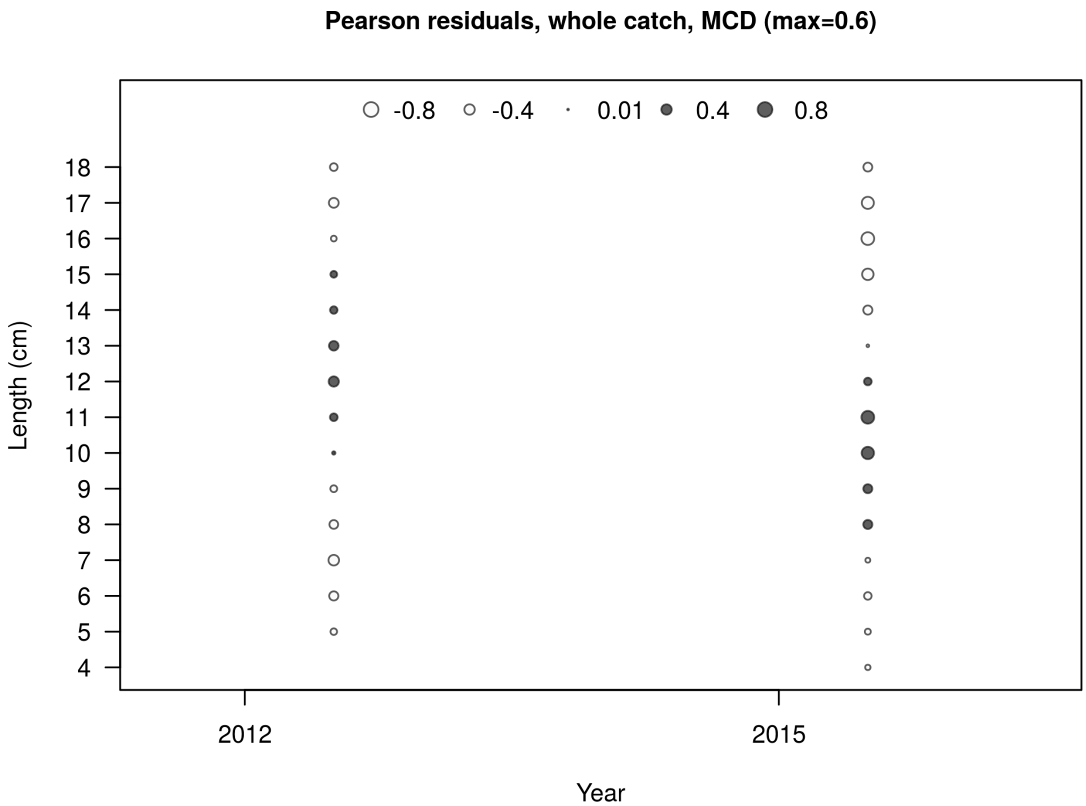

Figure 98: Pearson residuals from the fit to NEFSC survey (MCD) length composition data used in the assessment model for Atlantic surfclam in the southern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

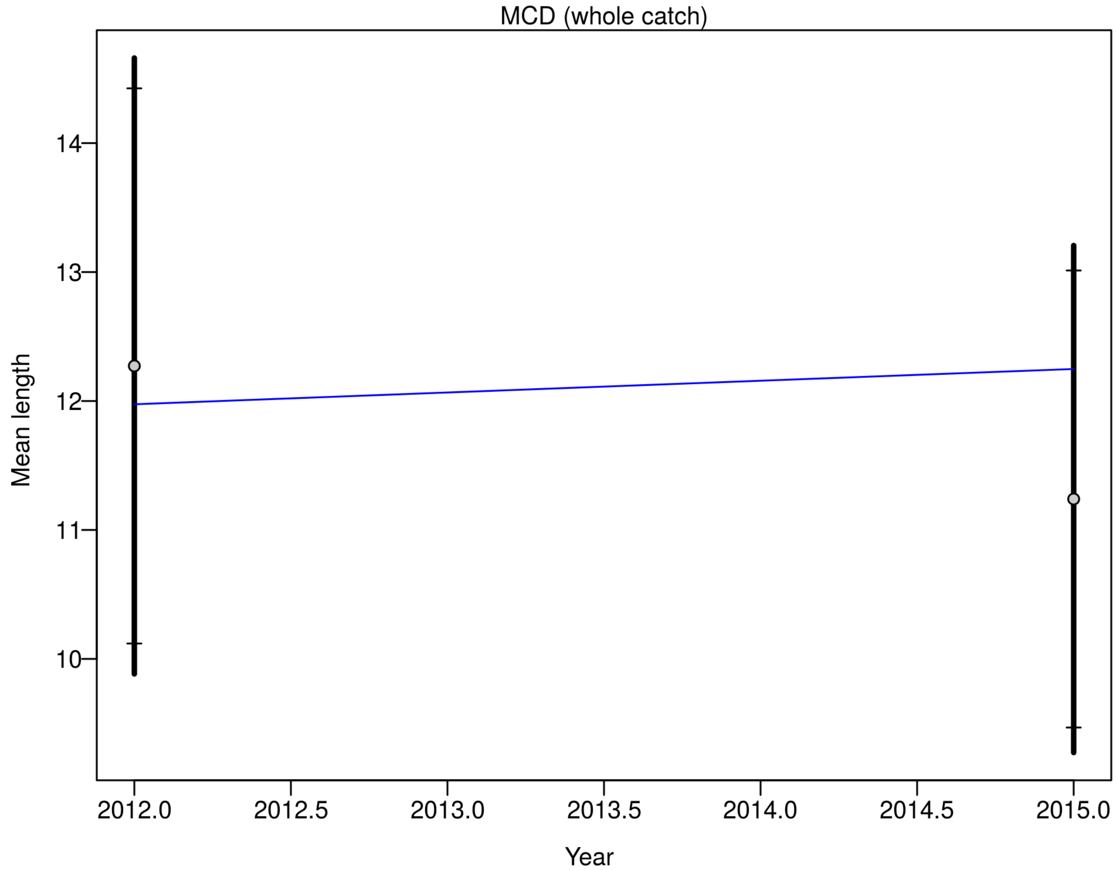

Figure 99: Observed mean length vs. the mean length predicted by the model based on fits to NEFSC survey (MCD) length composition data used in the assessment model for Atlantic surfclam in the southern area.

Pearson residuals, whole catch, RDtrend (max=28.63)

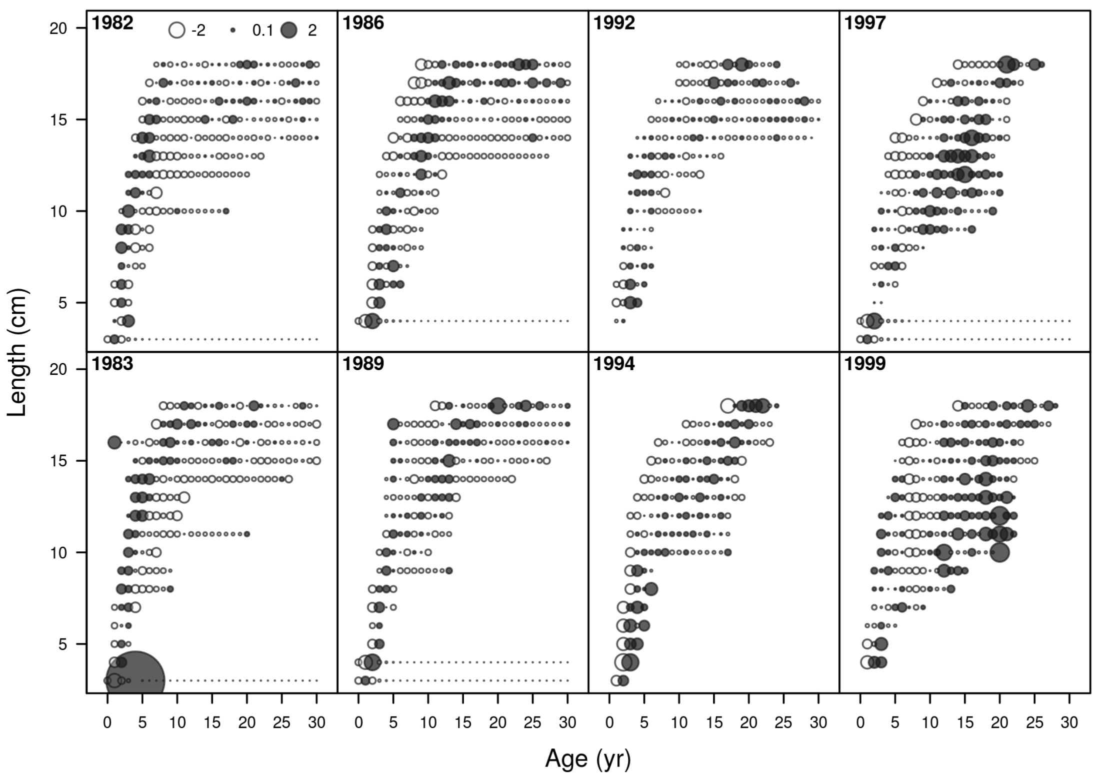

Figure 100: Pearson residuals from the fit to NEFSC survey (RD) conditional age at length composition data used in the assessment model for Atlantic surfclam in the southern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

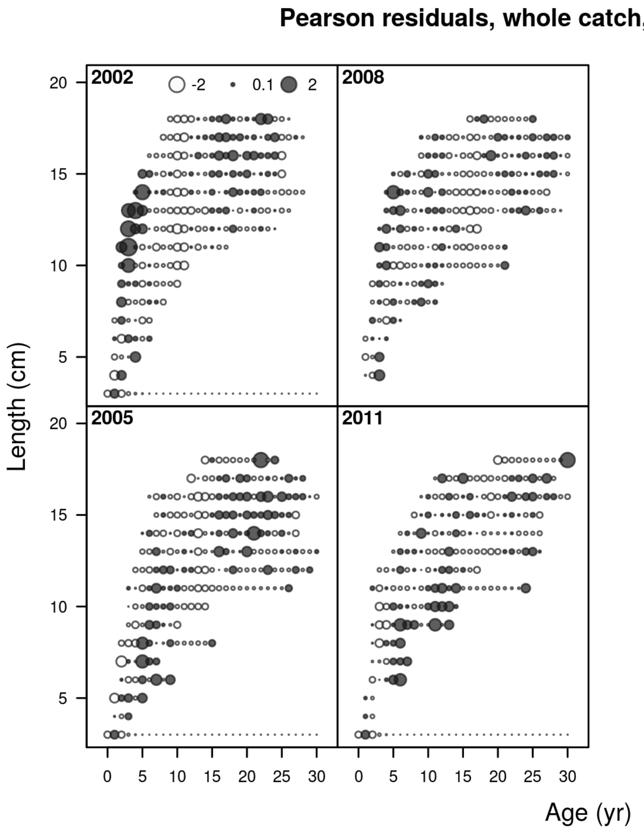

Figure 100 cont.

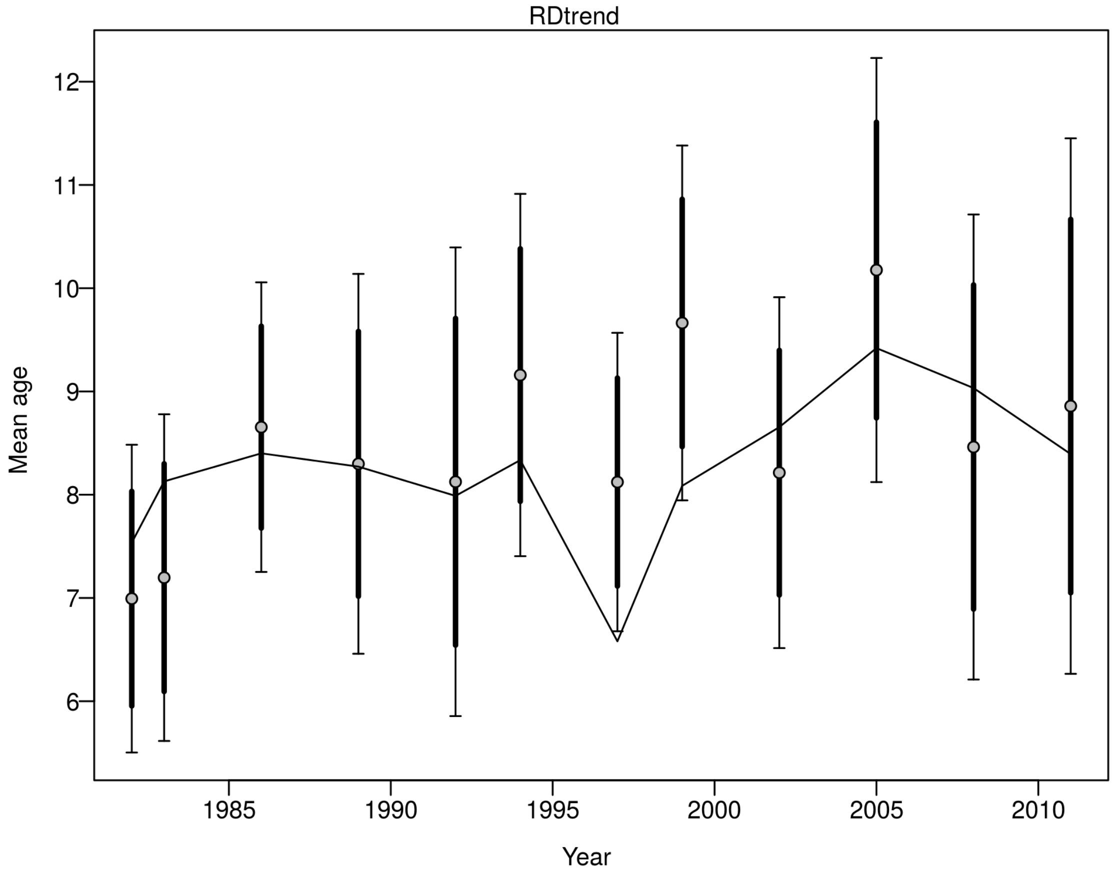

Figure 101: Observed mean age vs. the mean age predicted by the model based on fits to NEFSC survey (RD) age at length conditional composition data used in the assessment model for Atlantic surfclam in the southern area. The thicker vertical lines show the standard deviation of the observed data and the thinner lines show the standard deviation after accounting for the data weighting adjustments used in the model.

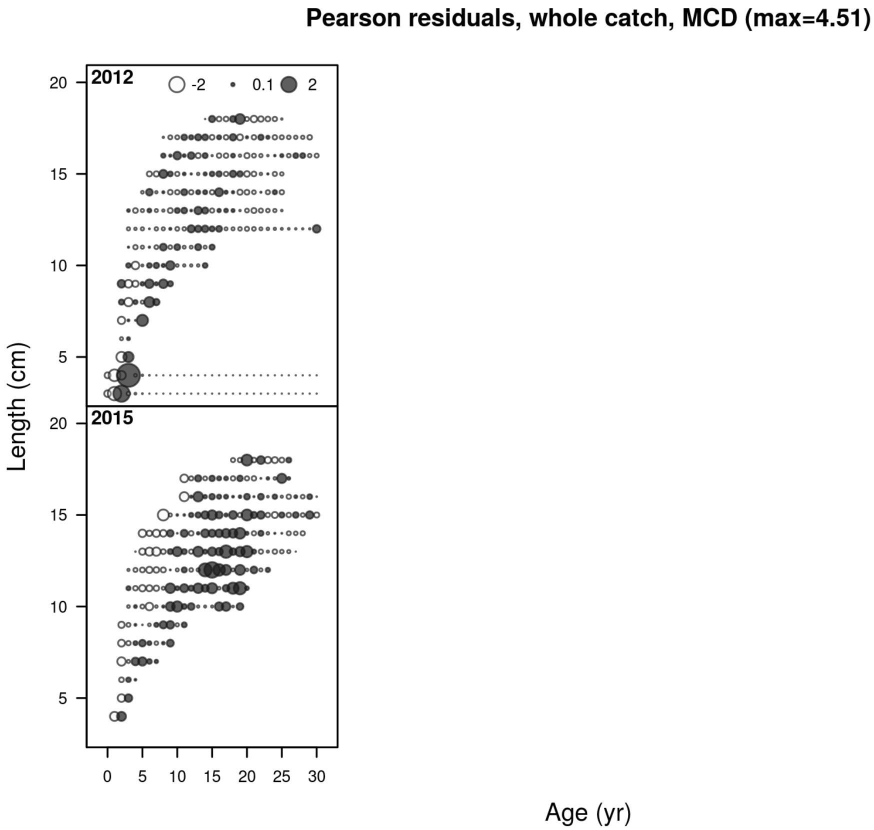

Figure 102: Pearson residuals from the fit to NEFSC survey (MCD) conditional age at length composition data used in the assessment model for Atlantic surfclam in the southern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

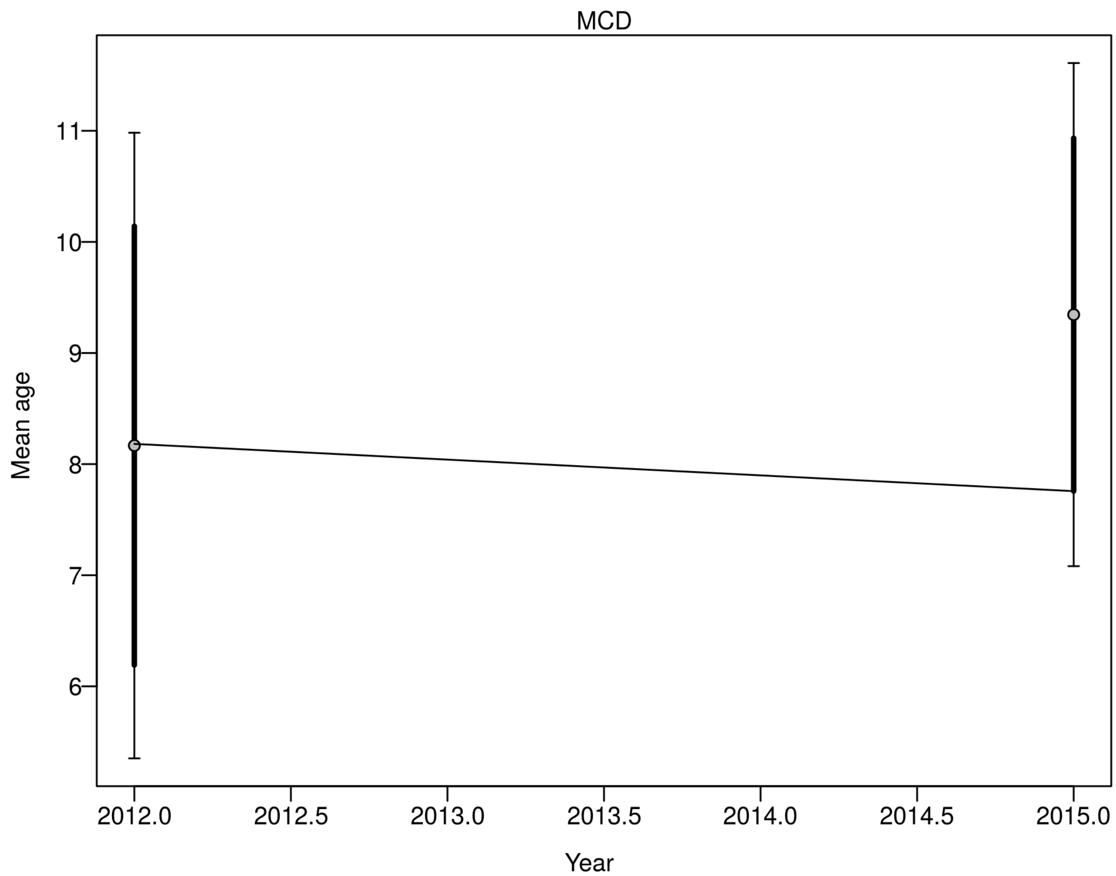

Figure 103: Observed mean age vs. the mean age predicted by the model based on fits to NEFSC survey (MCD) age at length conditional composition data used in the assessment model for Atlantic surfclam in the southern area. The thicker vertical lines show the standard deviation of the observed data and the thinner lines show the standard deviation after accounting for the data weighting adjustments used in the model.

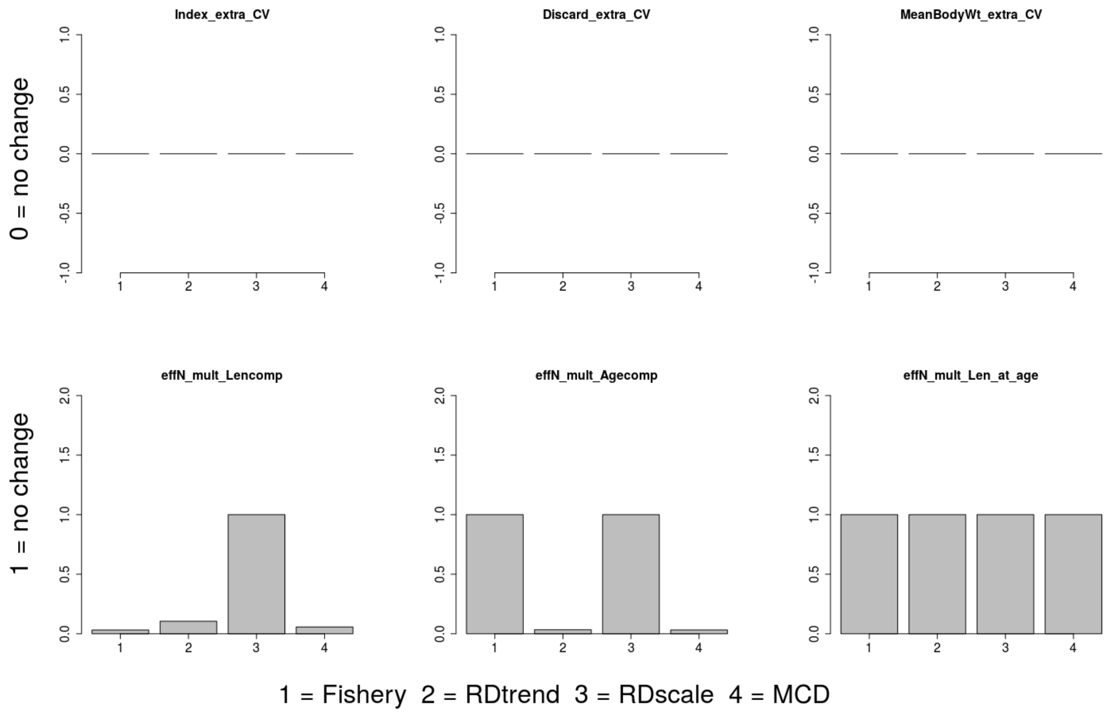

Figure 104: Adjustments made to variance components of model parameters used in the assessment model for Atlantic surfclam in the southern area. The bar plots reflect data weighting decisions. In the top row deviations from 0 are the amount added to the standard deviation around input parameters. In the bottom row, the value shown in the bar plot is multiplied by the input effective sample size associated with each composition component. Thus, for example a value of less than 1 represents a reduction in the relative weight of a component.

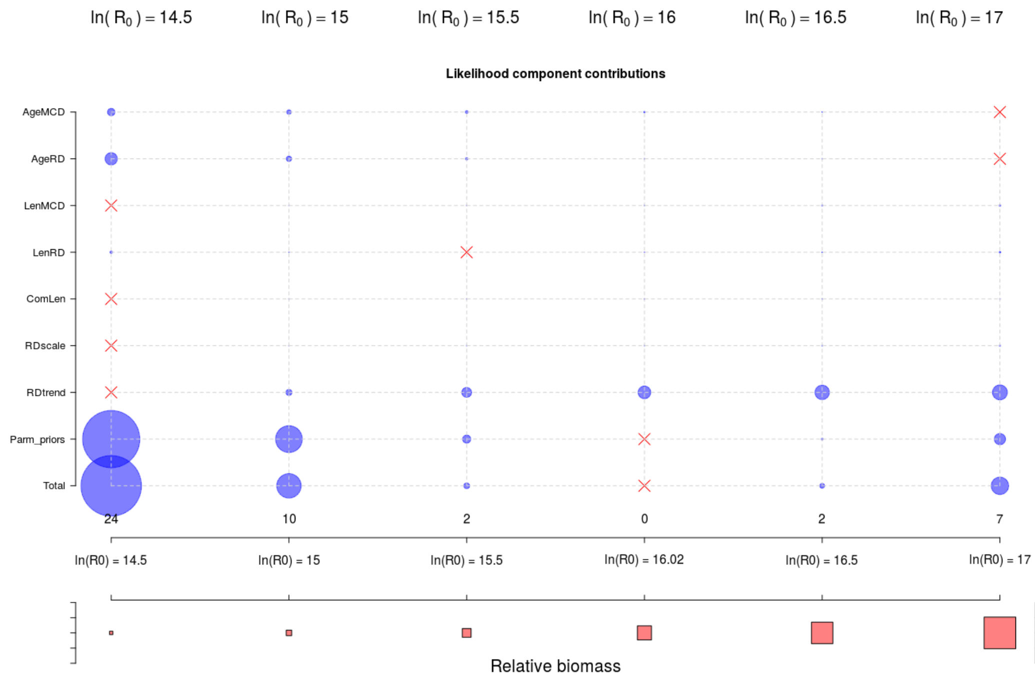

Figure 105: Likelihood profile over the virgin recruitment parameter (R0). A total of 5 model runs are depicted here. In each case, the R0 parameter was fixed at a different value. The columns of the large plot show how the component and total likelihoods change as the R0 parameter is varied. Each column of the large bubble plot represents one model run and the non-zero likelihood components in each run are shown in rows. For each row, the minimum likelihood component value was subtracted from each individual value, such that the minimum value in each row is represented by a red x. Bubbles are proportional to the values of each likelihood component in each run. The base value for R0 is the value at the model solution (middle column). The difference (in likelihood units) between each column and the minimum total likelihood is shown just above the x axis. Conflicts within the data are apparent when the minimum likelihood values (red x's) occur in different columns for each row. The red boxes show the relative difference in estimated terminal year biomass between runs.

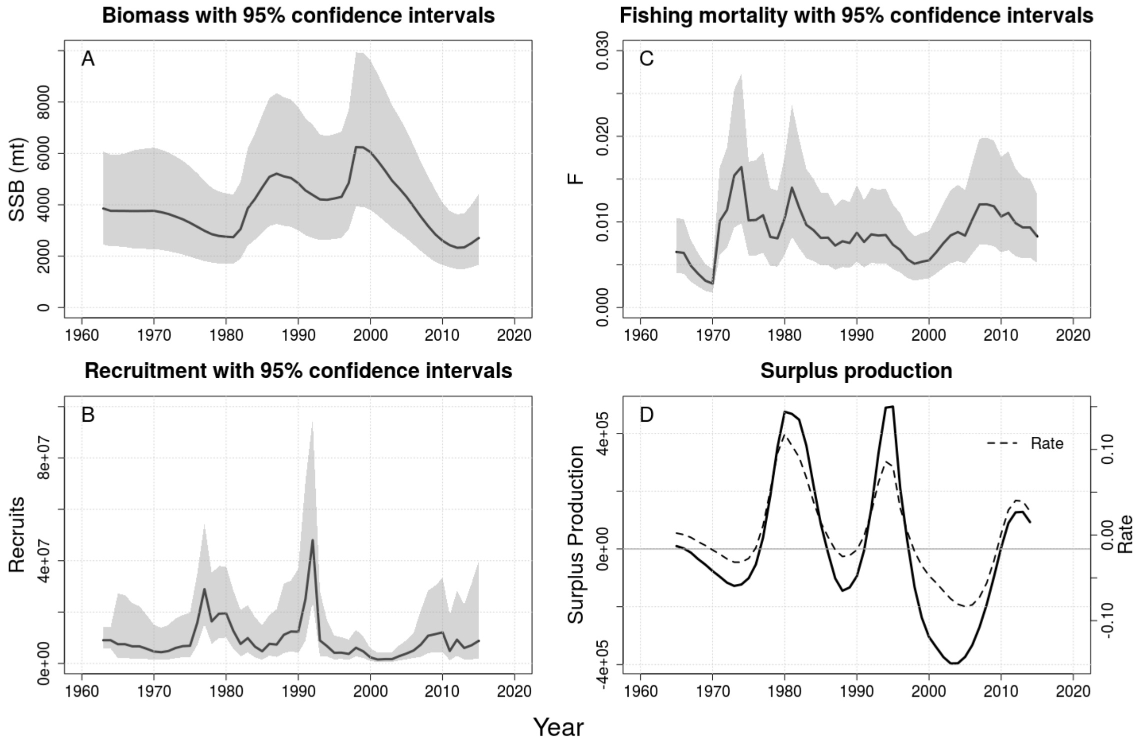

Figure 106: Estimated SSB and approximate 95% asymmetric confidence interval (A), estimated recruitment and approximate 95% asymmetric confidence interval (B), estimated fully selected fishing mortality and approximate 95% asymmetric confidence interval (C), and surplus production with surplus production rate (D), for the southern area.

Table 24: Parameter estimates and estimated precision in a basecase model run for Atlantic surfclam in the northern area. This table shows the thirty parameters that are the least precisely determined, ranked by coefficient of variation.

name	value	std.dev	cv
recdev1973	-0.06	0.42	7.09
recdev1990	-0.06	0.45	6.93
recdev2005	-0.08	0.44	5.47
recdev1989	0.12	0.37	3.19
recdev2004	-0.17	0.50	2.85
recdev1977	-0.12	0.33	2.65
recdev2006	0.18	0.43	2.40
selparm[2]	-2.13	4.89	2.30
recdev2014	-0.54	0.99	1.81
recdev2015	-0.54	0.99	1.81
recdev2013	-0.55	0.99	1.80
recdev1985	0.19	0.34	1.79
recdev1999	0.32	0.52	1.66
recdev1971	-0.35	0.52	1.46
recdev1980	0.16	0.23	1.38
recdev1991	0.42	0.51	1.21
recdev1983	0.23	0.27	1.16
recr_std2015	884760.00	1013800.00	1.15
recr_std2014	842830.00	965640.00	1.15
recr_std2013	802040.00	918190.00	1.14
recdev1978	0.23	0.25	1.10
recdev1992	0.49	0.53	1.08
recdev2002	-0.68	0.72	1.05
recr_std2012	448290.00	467970.00	1.04
recdev1982	0.23	0.23	1.00
recdev2007	-0.57	0.57	0.99
recdev1986	0.35	0.34	0.96
recr_std2001	237510.00	225330.00	0.95
recdev2003	-0.69	0.65	0.94
recdev1970	-0.64	0.60	0.93

Table 25: Likelihood profile over unfished recruitment parameter (R0). The values in the table are the differences, in likelihood units, between each profile run and the minimum likelihood for that row (likelihood component). Conflicts within the data are apparent when the minimum likelihood values (gray cells) occur in different columns for each row. That is, different likelihood components within the model were minimized at different values of R0. Because R0 is important for setting the scale of estimated biomass in the model (Relative B; last row), data conflicts around R0 tend to increase uncertainty in scale. The coloumn corresponding to the minimum total likelihood is shown in italics.

ln(R0)	12	13.00	*14*	*14.24*	15	16
Total	7.7	2.1	*0*	*0*	1.2	5.8
Parm priors	1.6	0.5	*0*	*0*	0.2	0.9
RDtrend	0	0.5	*1*	*1.1*	1.5	1.9
RDscale	141.3	52.5	*5.5*	*0.4*	0	35.7
MCD	7.7	2.3	*0.1*	*0*	0.7	4.1
ComLen	0	0.2	*0.2*	*0.3*	0.3	0.3
AgeRD	0.3	0.4	*0.3*	*0.3*	0.2	0
AgeMCD	0	0.1	*0.2*	*0.2*	0.3	0.5
Relative B	1	3.1	*8.5*	*10.9*	23	61.4

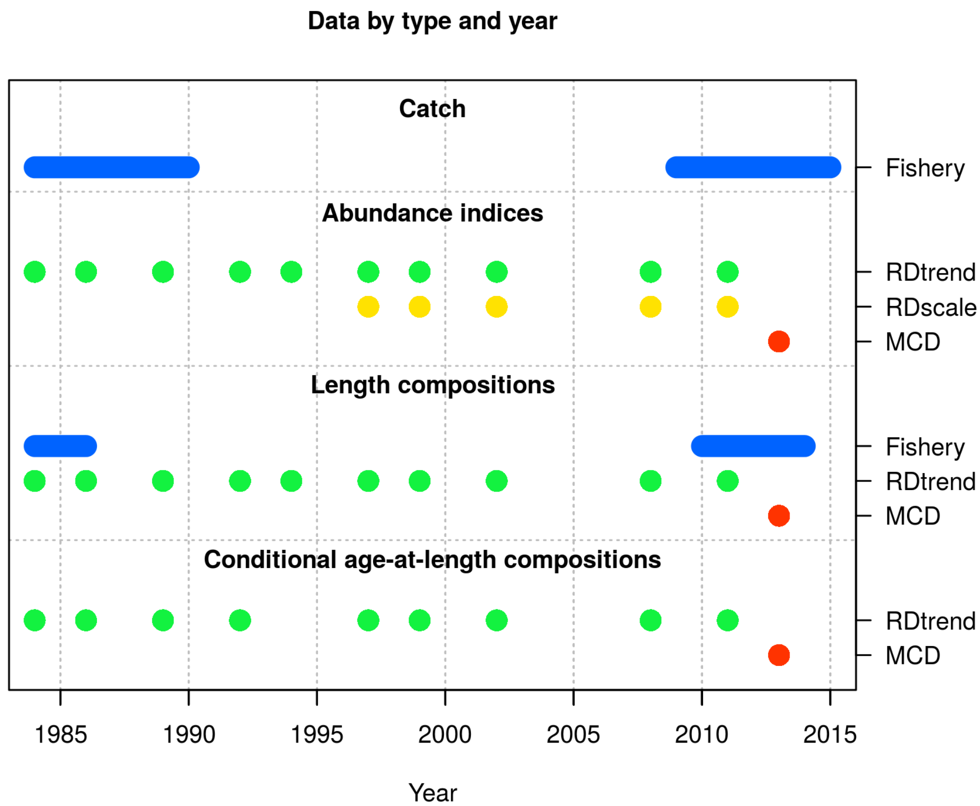

Figure 107: Data included in the Atlantic surfclam assessment model for the northern area. RD scale was not included in the likelihood.

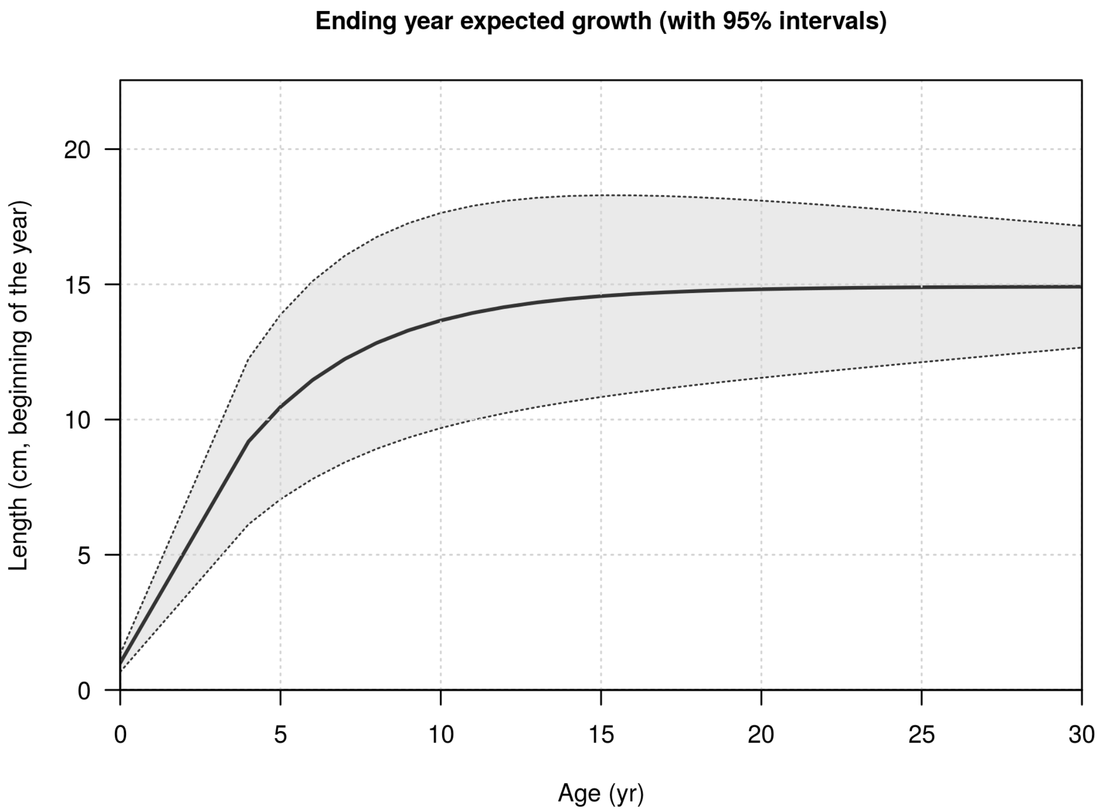

Figure 108: Length at age relationship used in the assessment model for Atlantic surfclam in the northern area.

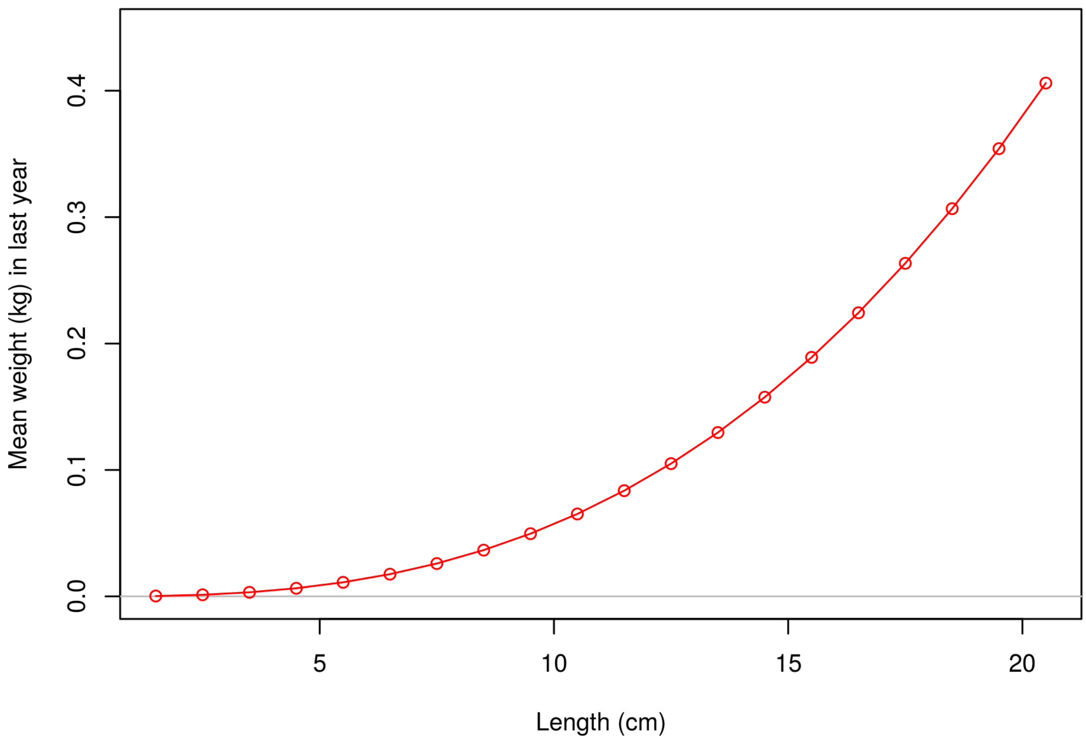

Figure 109: Weight at length relationship used in the assessment model for Atlantic surfclam in the northern area.

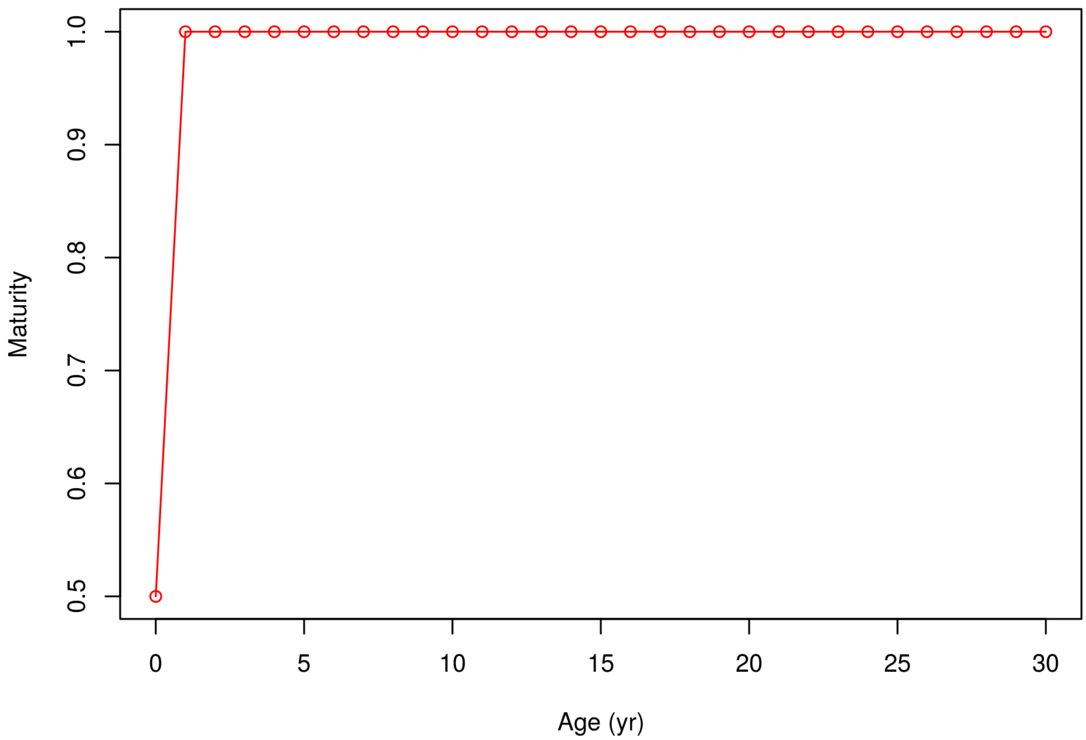

Figure 110: Maturity at age relationship used in the assessment model for Atlantic surfclam in the northern area.

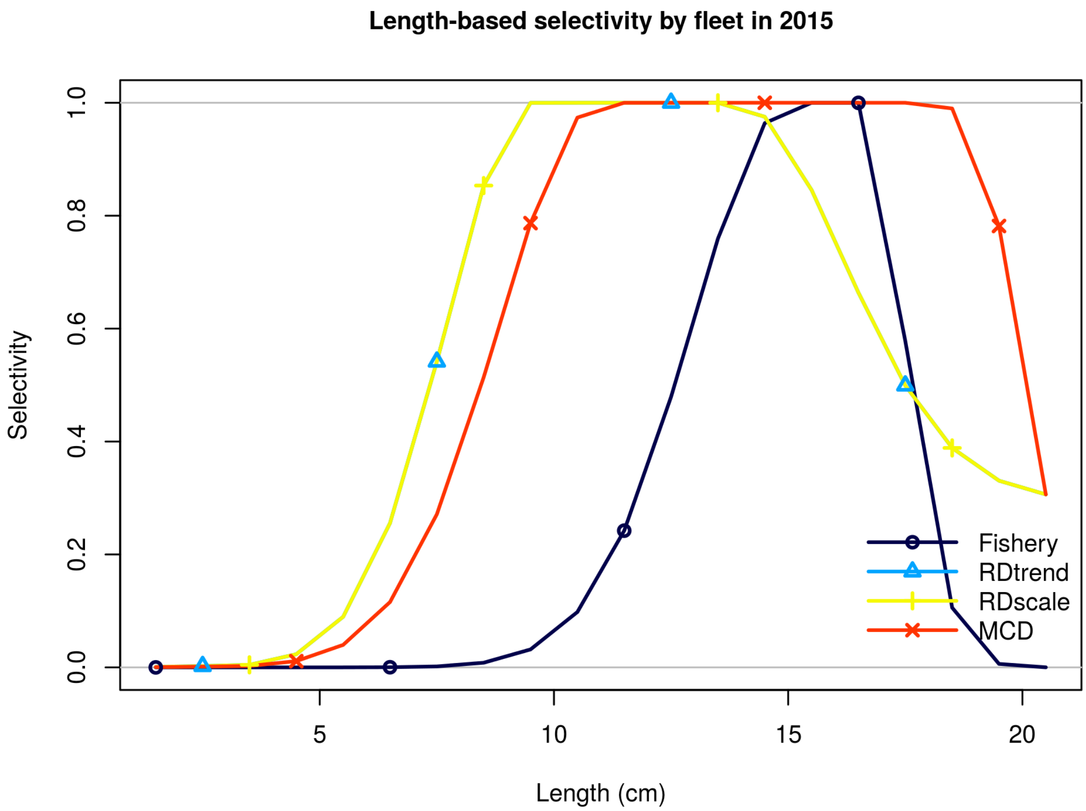

Figure 111: Comparison of selectivity curves for each fleet included in the assessment model for Atlantic surfclam in the northern area. RD trend and RD scale have identical selectivities because they are from the same survey (RD scale was not included in the likelihood).

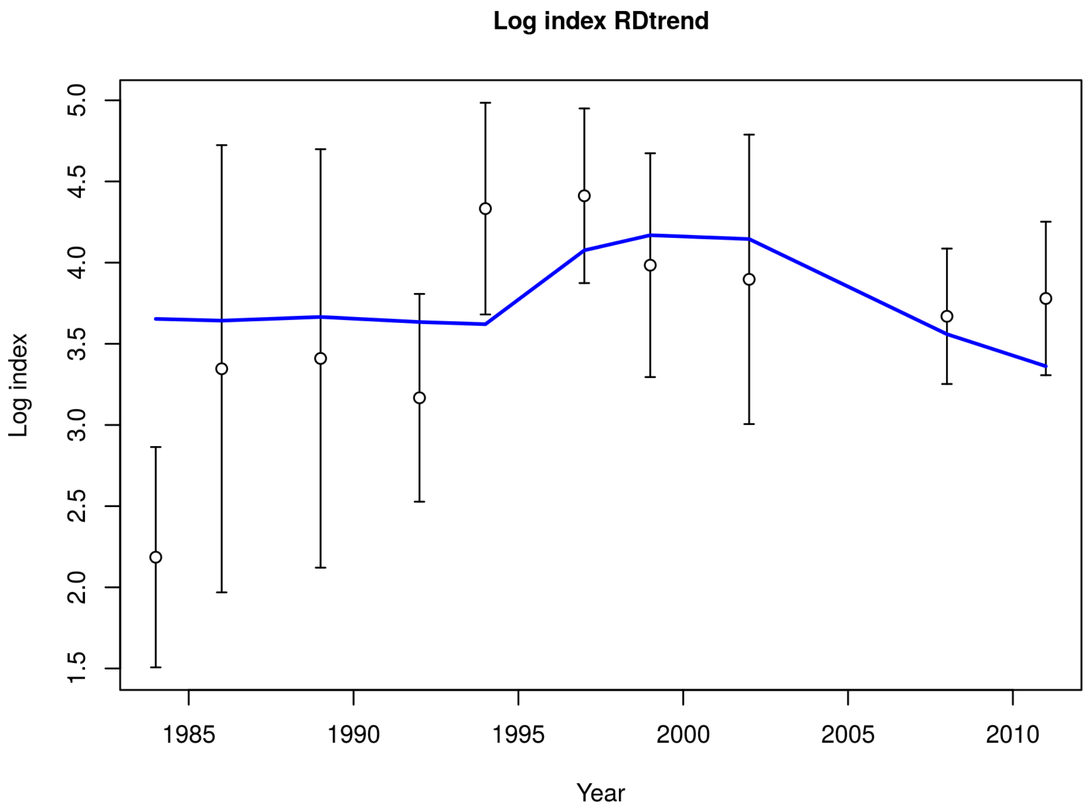

Figure 112: Fit to log index data on log scale for RDtrend survey for Atlantic surfclam in the northern area. Vertical lines are 95% confidence intervals.

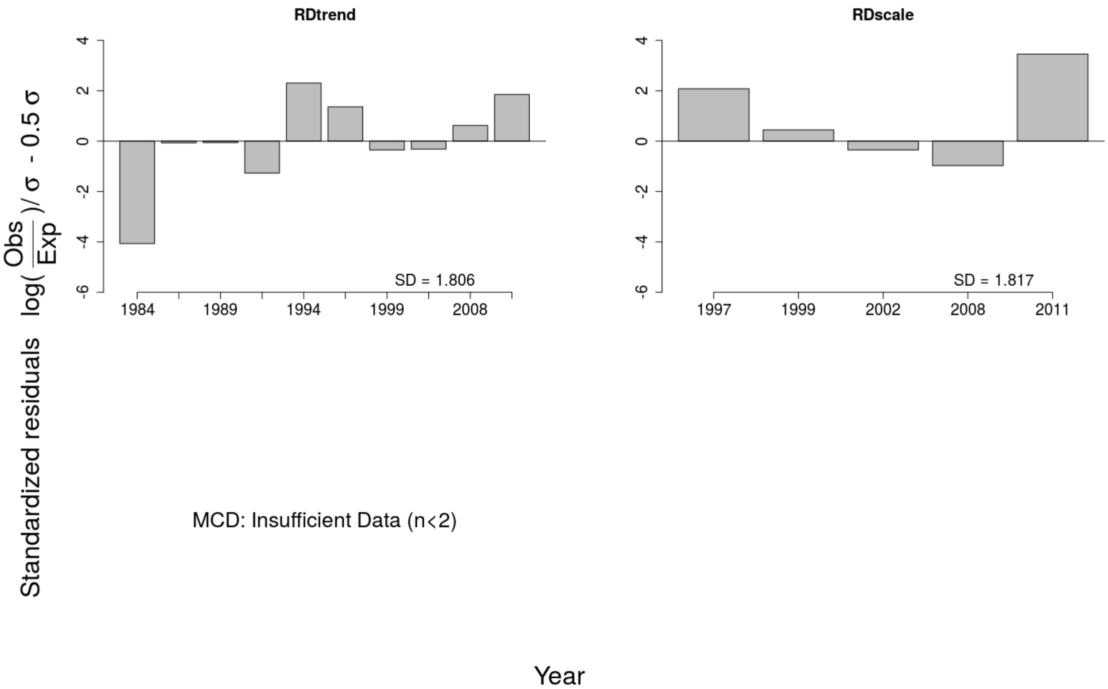

Figure 113: Residuals from the model fits to each survey index used in the assessment model for Atlantic surfclam in the northern area by year. The standard deviation of the residuals over the time series is shown over the horizontal axis.

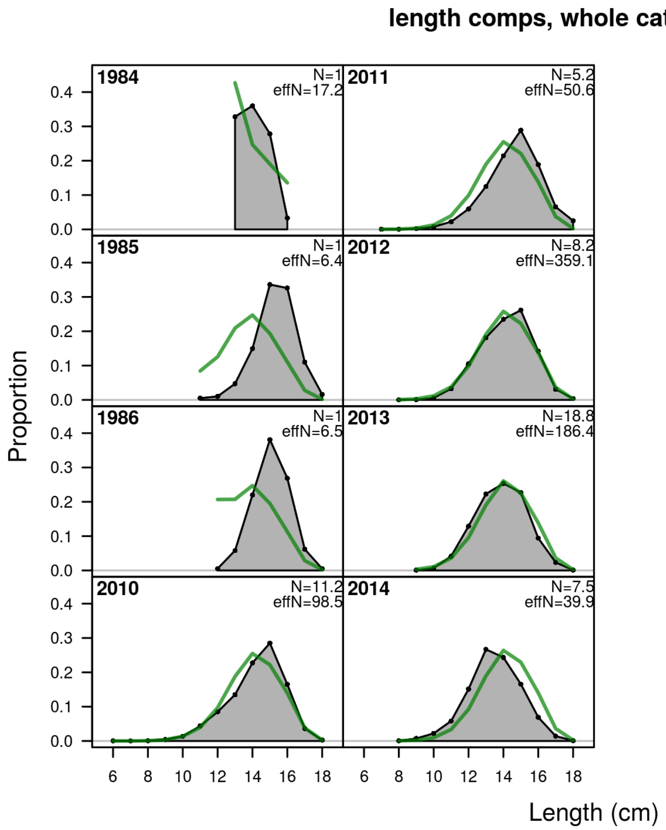

Figure 114: Model fit to length composition data from the commercial fishery used in the assessment model for Atlantic surfclam in the northern area.

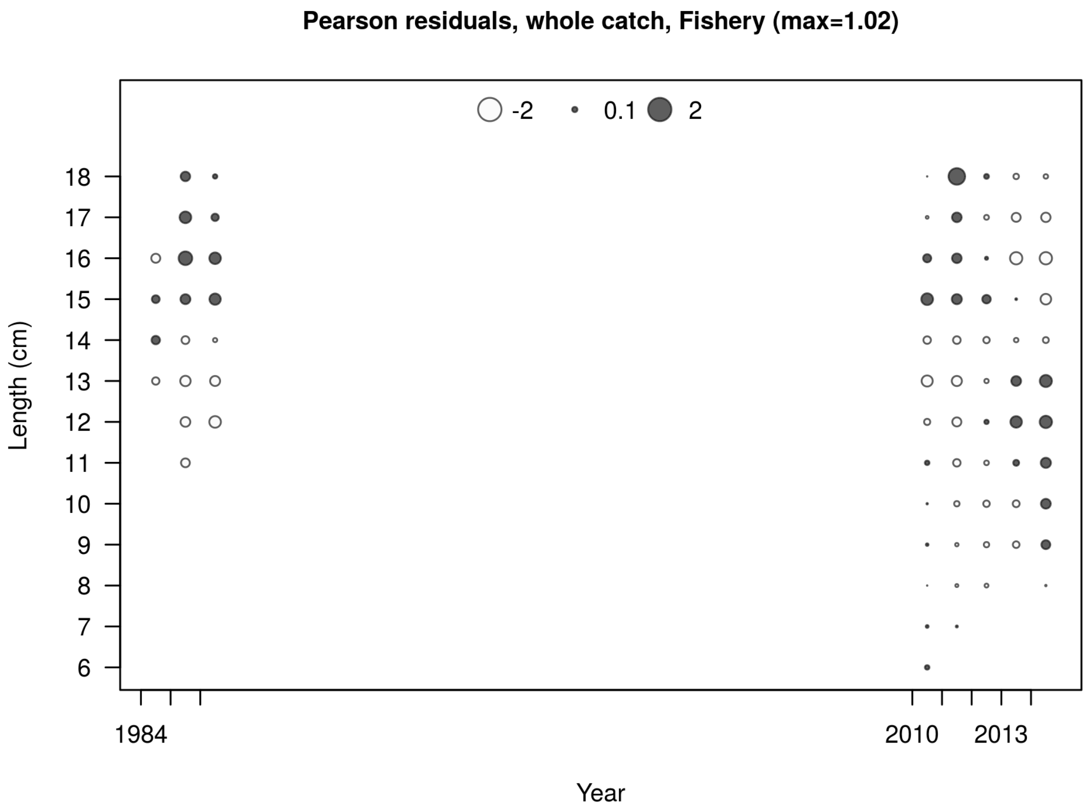

Figure 115: Pearson residuals from the fit to commercial length composition data used in the assessment model for Atlantic surfclam in the northern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

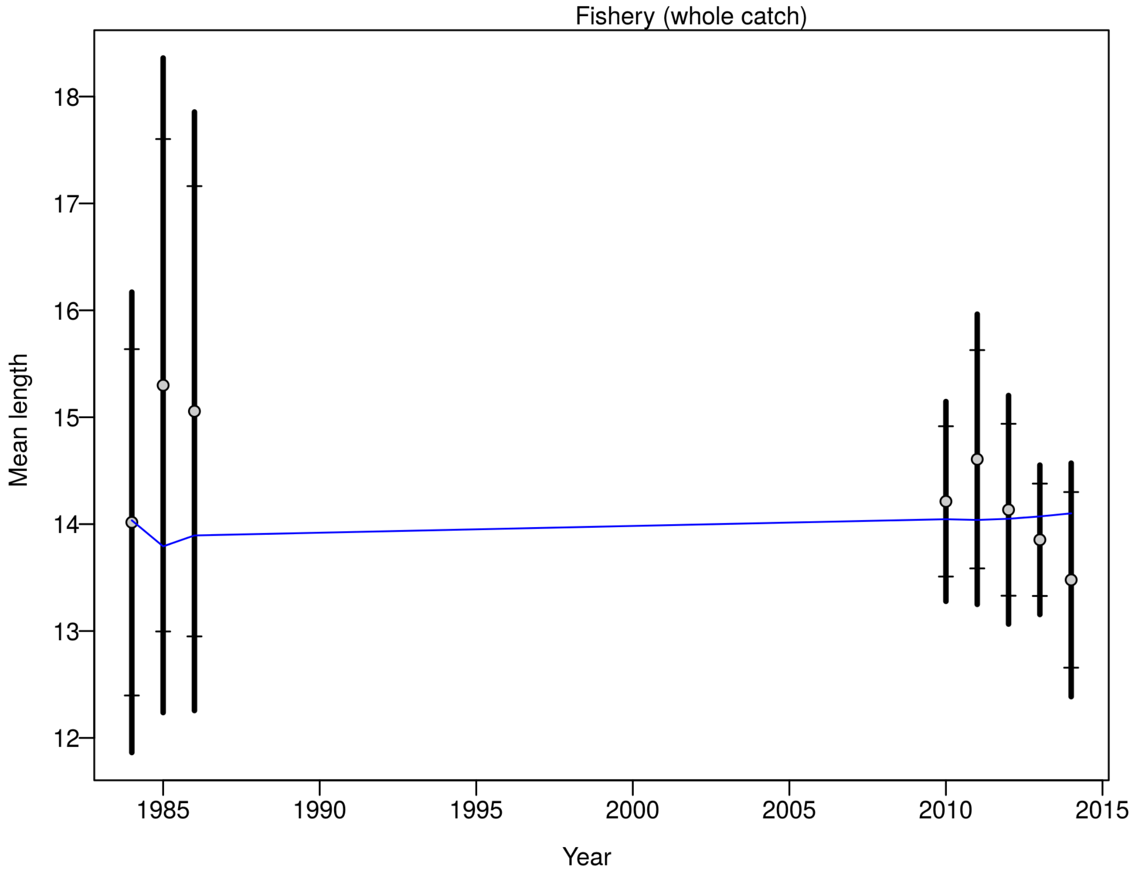

Figure 116: Observed mean length vs. the mean length predicted by the model based on fits to commercial length composition data.

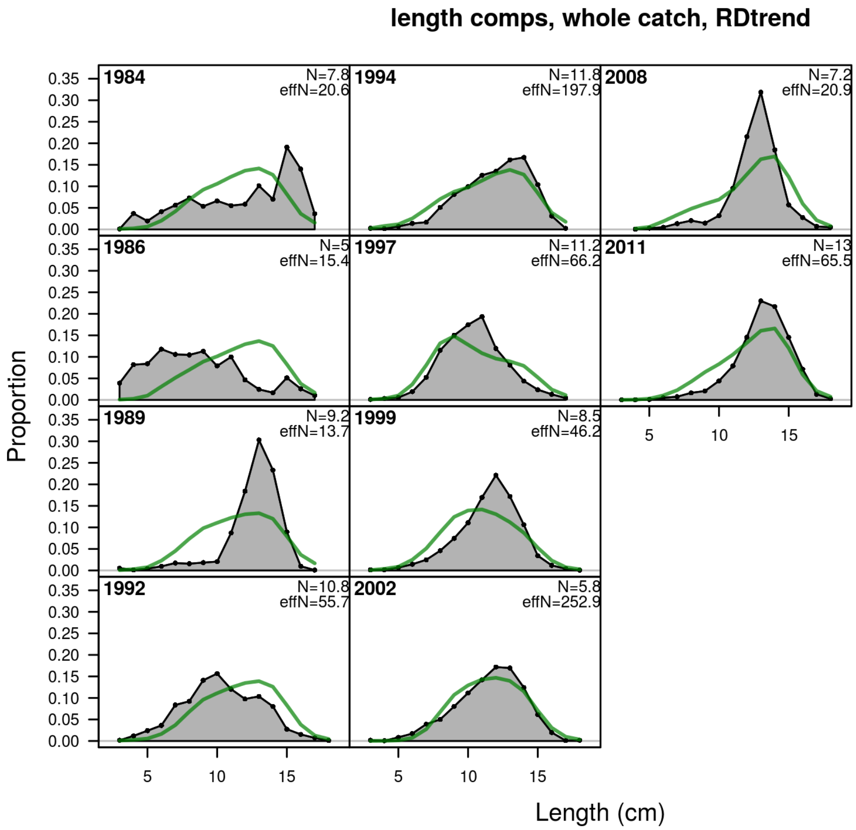

Figure 117: Model fit to length composition data from the NEFSC survey (RD) used in the assessment model for Atlantic surfclam in the northern area.

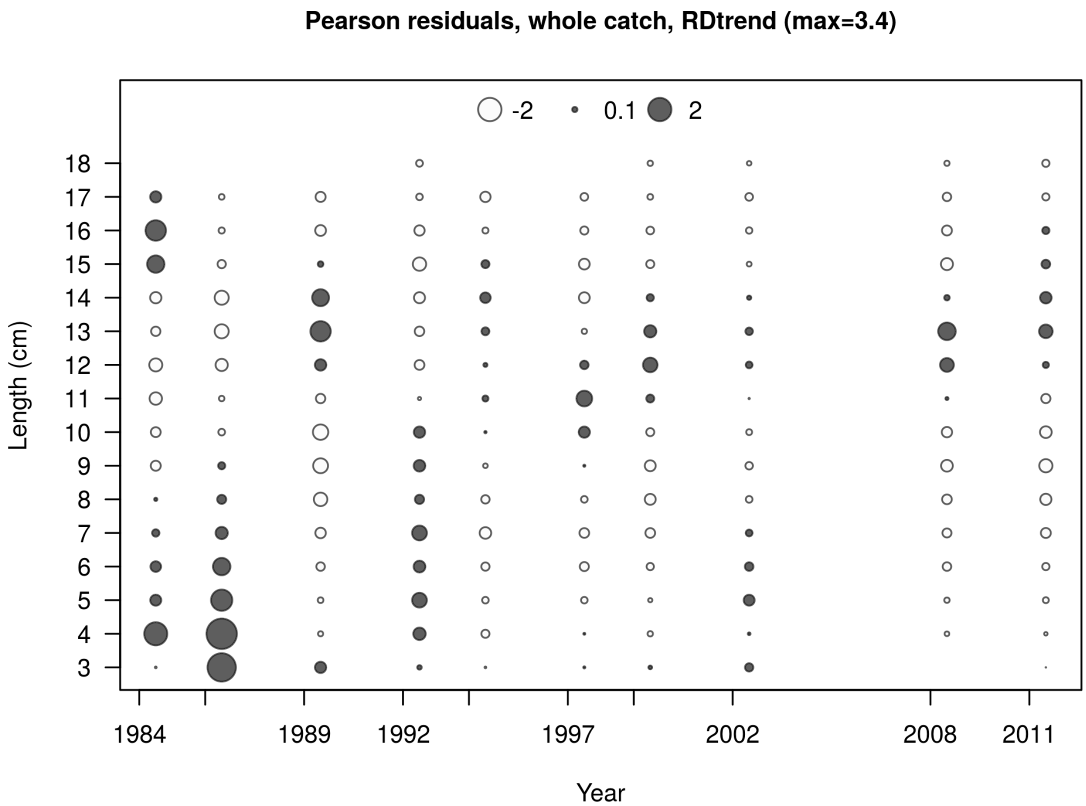

Figure 118: Pearson residuals from the fit to NEFSC survey (RD) length composition data used in the assessment model for Atlantic surfclam in the northern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

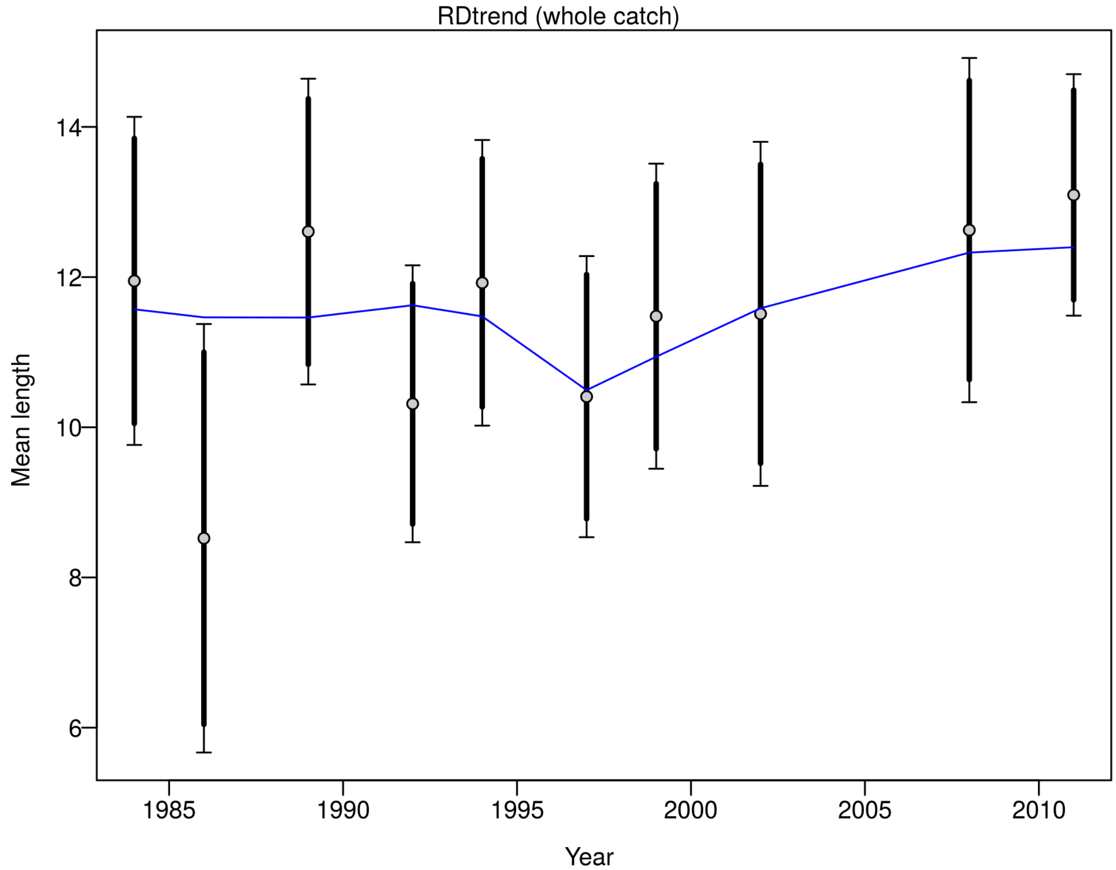

Figure 119: Observed mean length vs. the mean length predicted by the model based on fits to NEFSC survey (RD) length composition data used in the assessment model for Atlantic surfclam in the northern area. The thicker vertical lines show the standard deviation of the observed data and the thinner lines show the standard deviation after accounting for the data weighting adjustments used in the model.

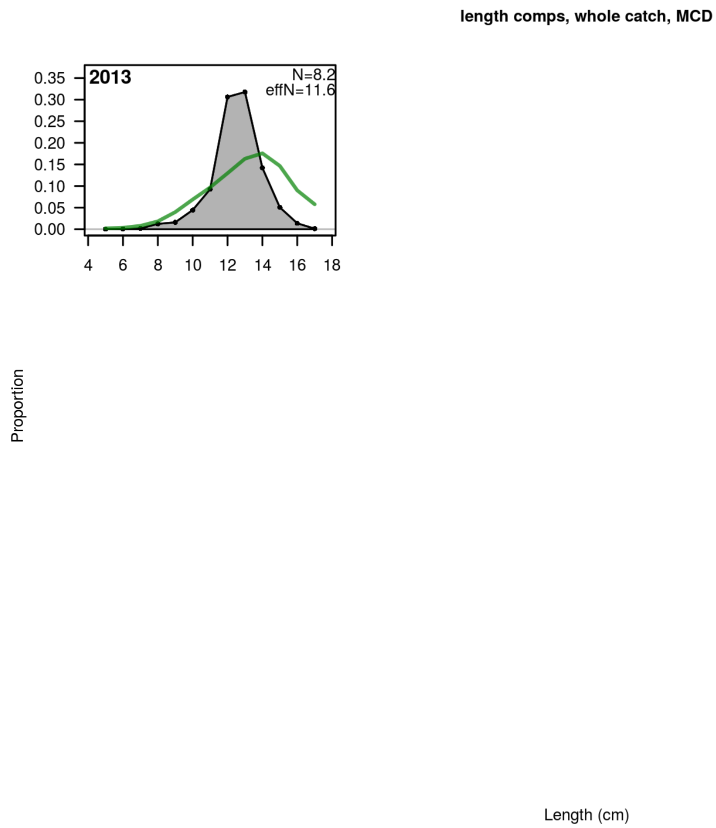

Figure 120: Model fit to length composition data from the NEFSC survey (MCD) used in the assessment model for Atlantic surfclam in the northern area.

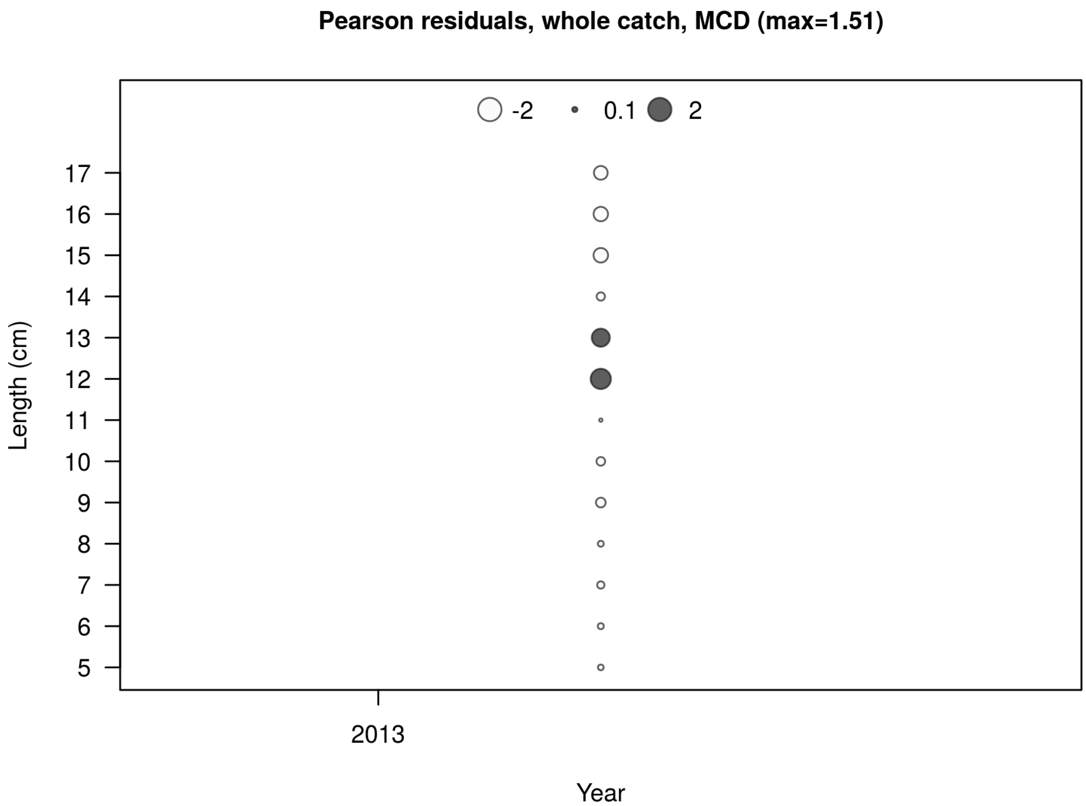

Figure 121: Pearson residuals from the fit to NEFSC survey (MCD) length composition data used in the assessment model for Atlantic surfclam in the northern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

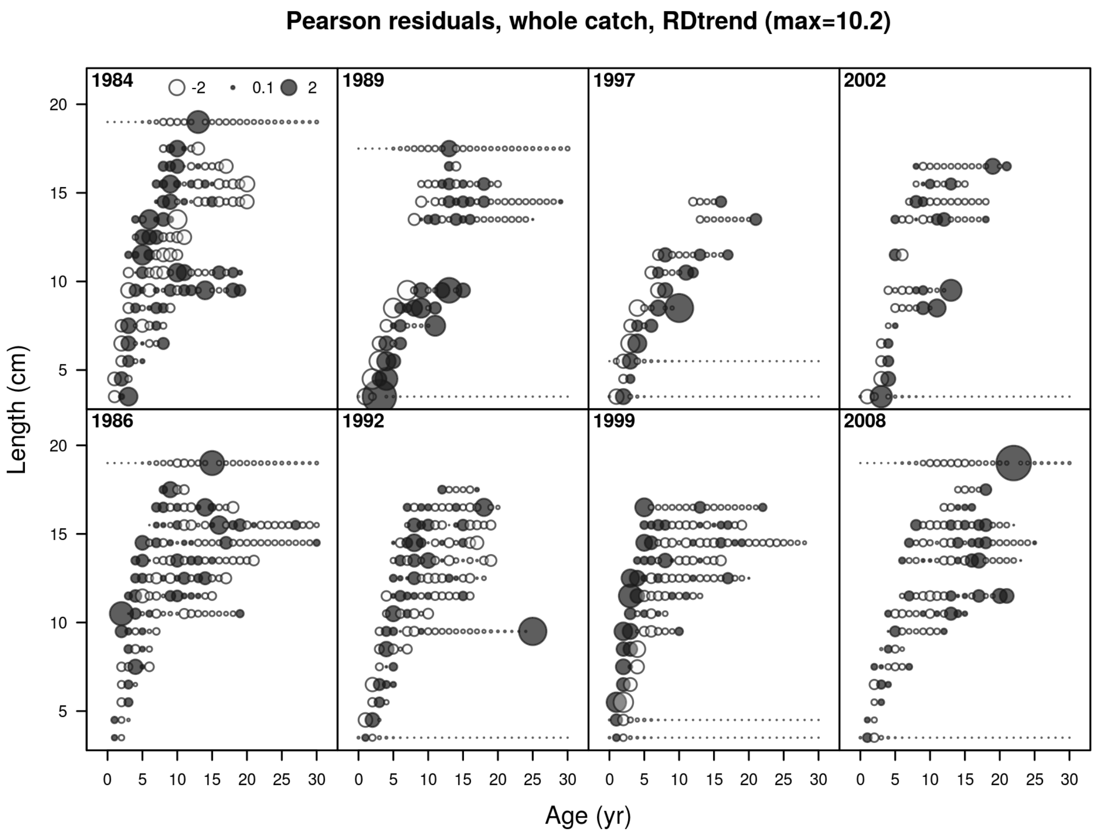

Figure 122: Pearson residuals from the fit to NEFSC survey (RD) conditional age at length composition data used in the assessment model for Atlantic surfclam in the northern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

Pearson residuals, whole catch, RDtrend (max=10.2)

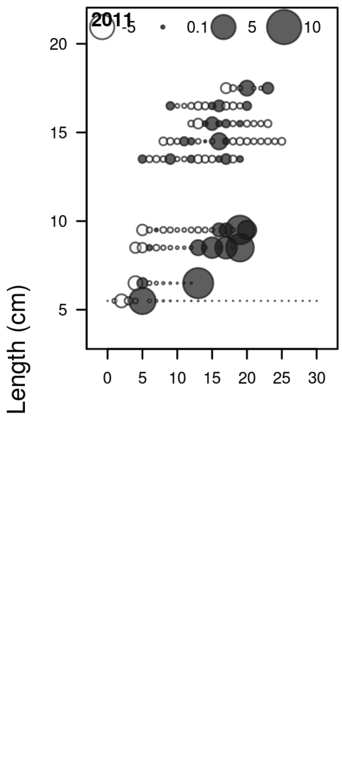

Figure 100 cont.

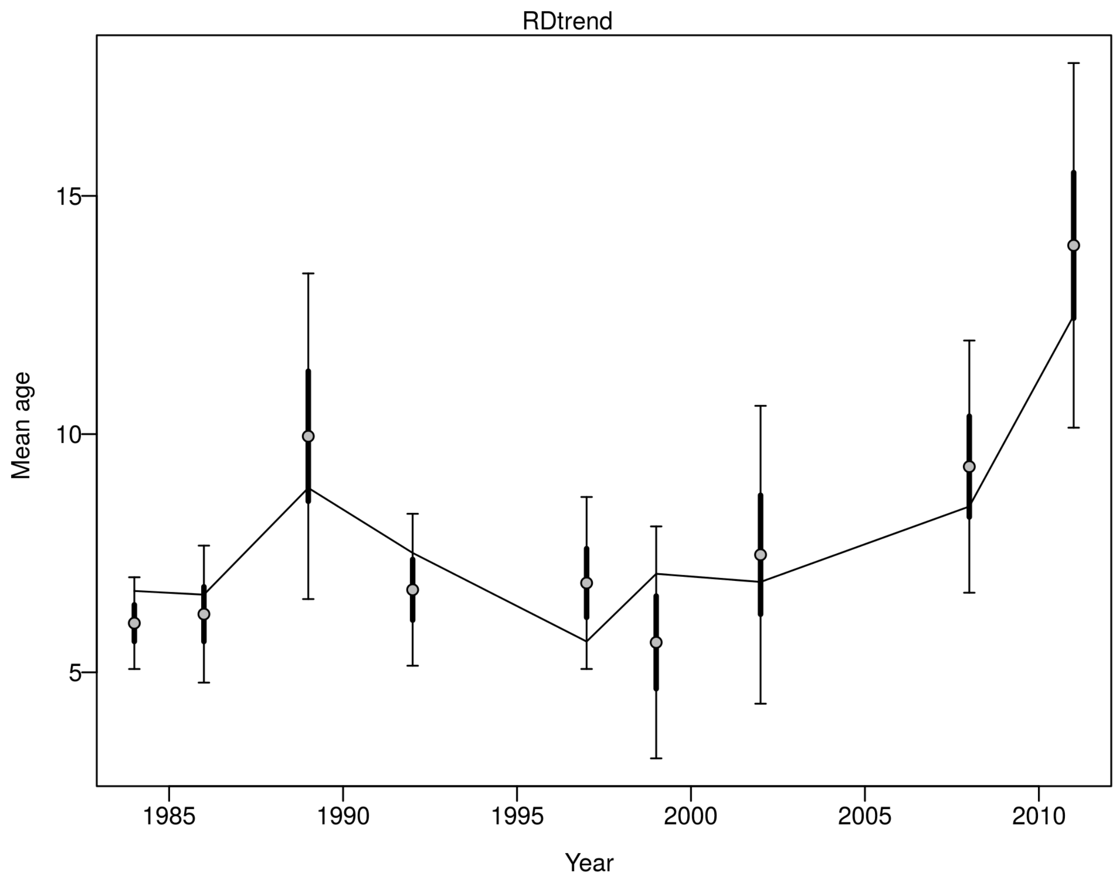

Figure 123: Observed mean age vs. the mean age predicted by the model based on fits to NEFSC survey (RD) age at length conditional composition data used in the assessment model for Atlantic surfclam in the northern area. The thicker vertical lines show the standard deviation of the observed data and the thinner lines show the standard deviation after accounting for the data weighting adjustments used in the model.

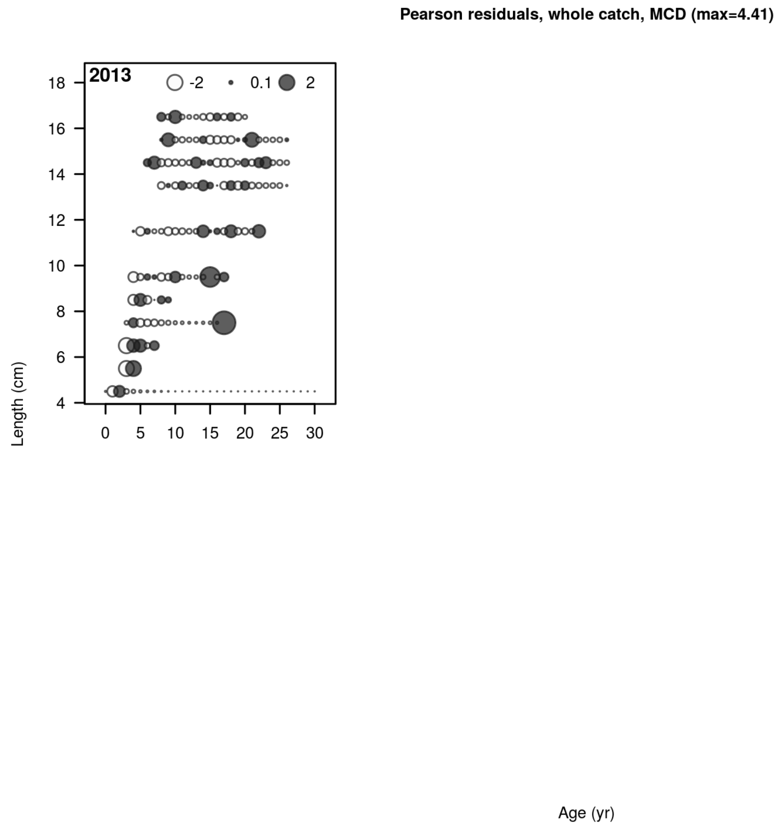

Figure 124: Pearson residuals from the fit to NEFSC survey (MCD) conditional age at length composition data used in the assessment model for Atlantic surfclam in the northern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

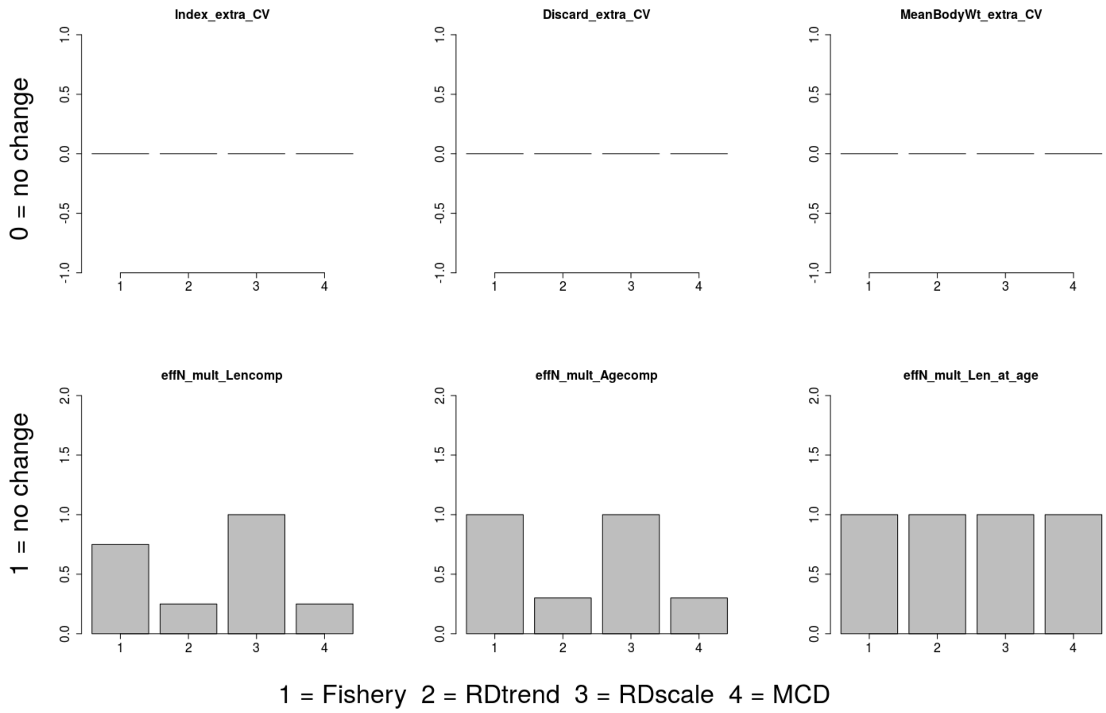

Figure 125: Adjustments made to variance components of model parameters used in the assessment model for Atlantic surfclam in the northern area. The bar plots reflect data weighting decisions. In the top row deviations from 0 are the amount added to the standard deviation around input parameters. In the bottom row, the value shown in the bar plot is multiplied by the input effective sample size associated with each composition component. Thus, for example a value of less than 1 represents a reduction in the relative weight of a component.

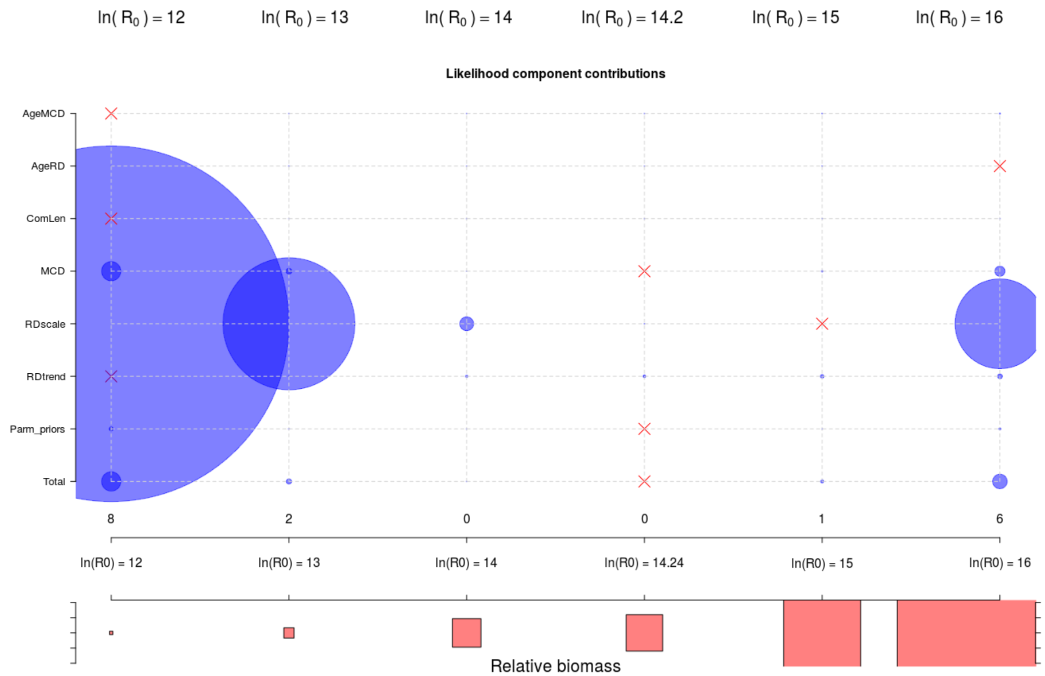

Figure 126: Likelihood profile over the virgin recruitment parameter (R0). A total of 5 model runs are depicted here. In each case, the R0 parameter was fixed at a different value. The columns of the large plot show how the component and total likelihoods change as the R0 parameter is varied. Each column of the large bubble plot represents one model run and the non-zero likelihood components in each run are shown in rows. For each row, the minimum likelihood component value was subtracted from each individual value, such that the minimum value in each row is represented by a red x. Bubbles are proportional to the values of each likelihood component in each run. The base value for R0 is the value at the model solution (middle column). The difference (in likelihood units) between each column and the minimum total likelihood is shown just above the x axis. Conflicts within the data are apparent when the minimum likelihood values (red x's) occur in different columns for each row. The red boxes show the relative difference in estimated terminal year biomass between runs.

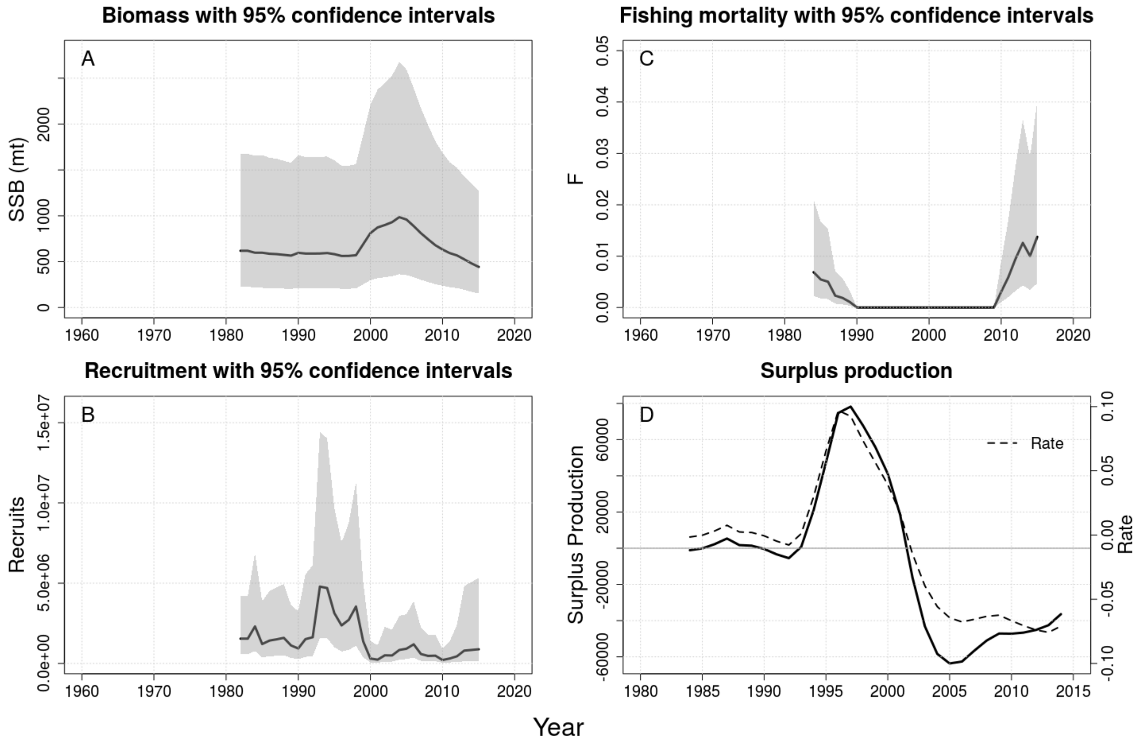

Figure 127: Estimated summary biomass and approximate 95% asymmetric confidence interval (A), estimated recruitment and approximate 95% asymmetric confidence interval (B), estimated fully selected fishing mortality and approximate 95% asymmetric confidence interval (C), and surplus production with surplus production rate (D), for Atlantic surfclam in the northern area.

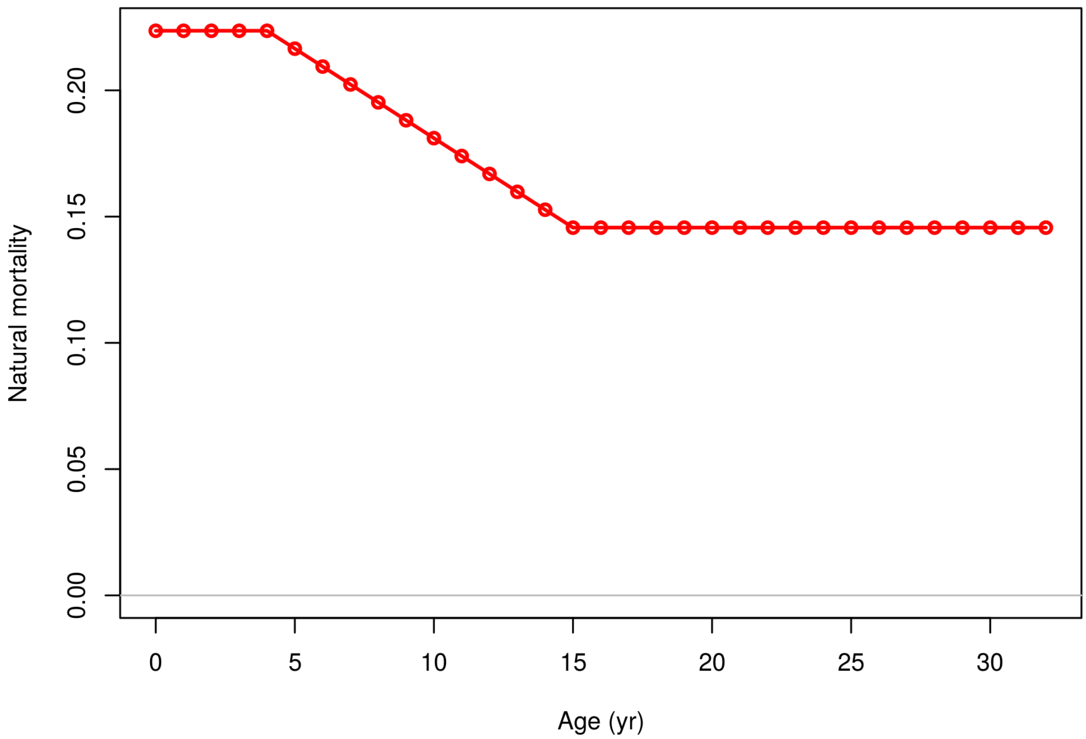

Figure 128: Natural mortality at age estimated in a model sensitivity run for Atlantic surfclam in the southern area.

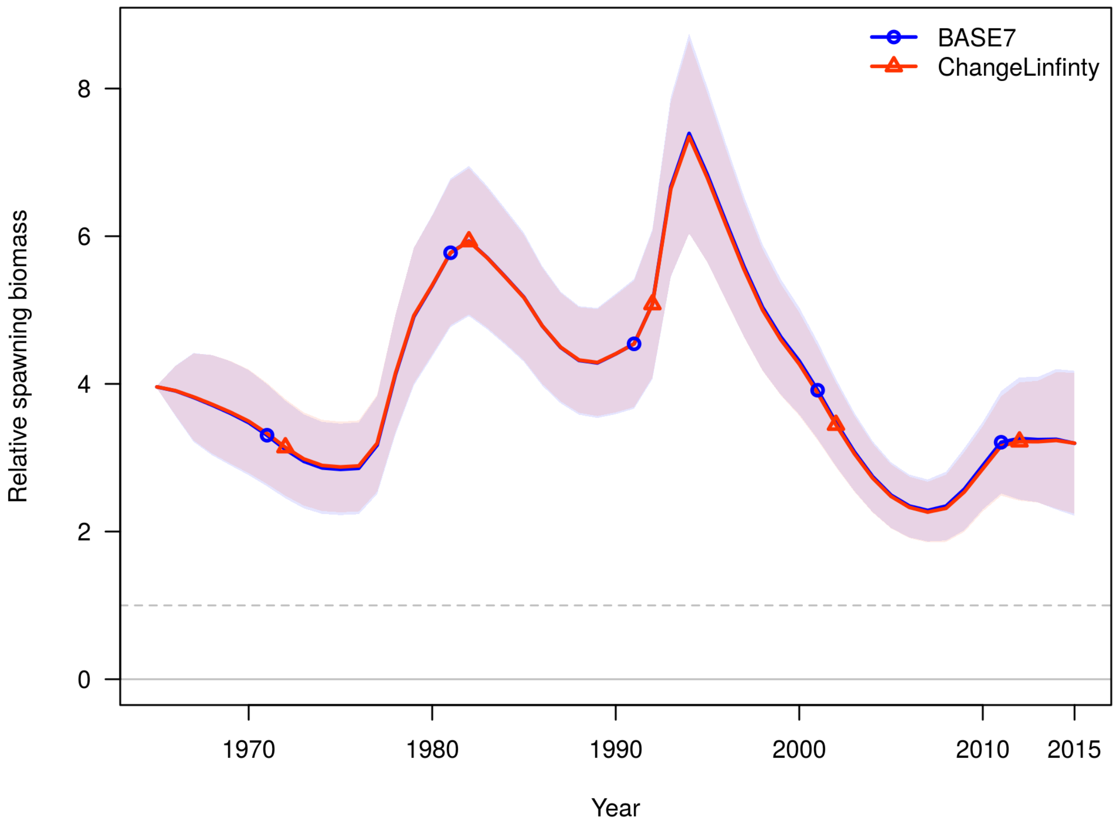

Figure 129: A comparison of the biomass trends of the base model (BASE7) for Atlantic surfclam in the southern area and a sensitivity run in which the length at A_{max} was estimated for each of two time blocks (<2000 and >1999). There was very little difference between the two runs. The trends depict the ratio of the biomass in each year to B_0 and include a dashed line at $\frac{B}{B_0} = 0.25$.

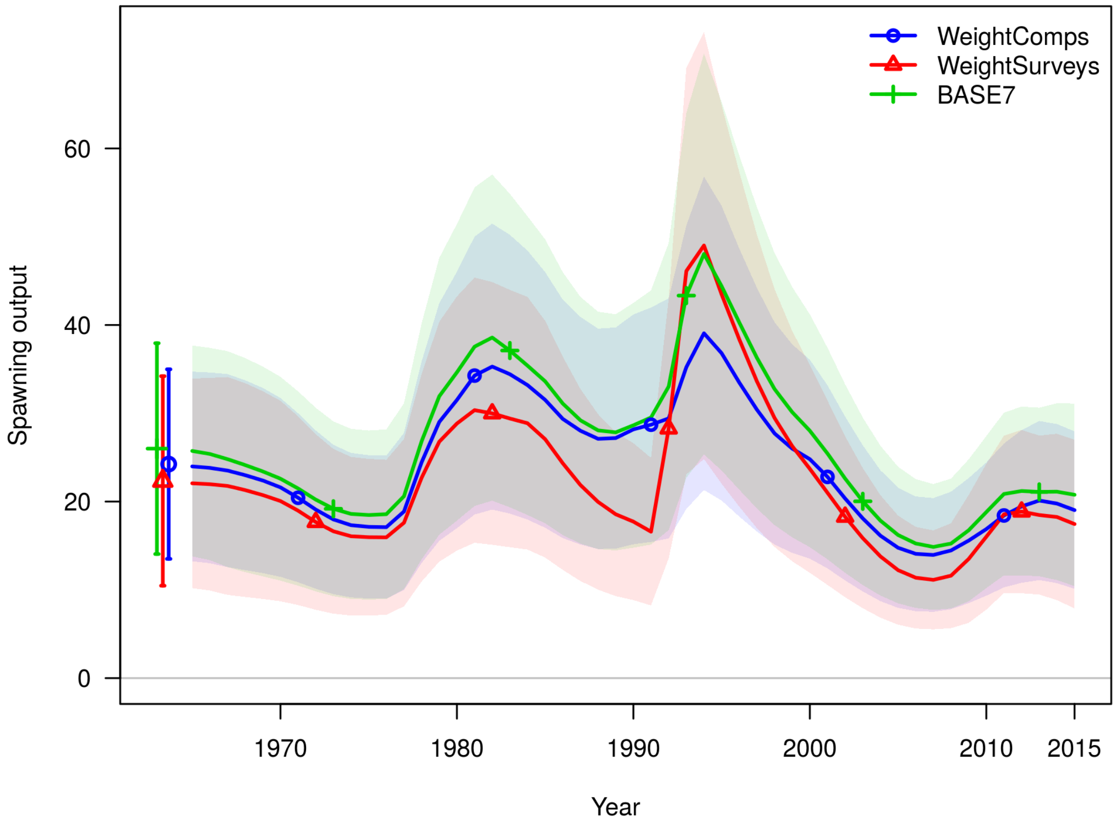

Figure 130: A comparison of the estimated biomass scales between the base run for Atlantic surfclam in the southern area (BASE7) and sensitivity runs in which the likelihood component associated with the fit the RD survey was increased by an order of magnitude (WeightSurveys), and where the variance associated with the composition data (both length and age at length) was adjusted so that the harmonic mean of the effective sample size matched the mean of the input sample size.

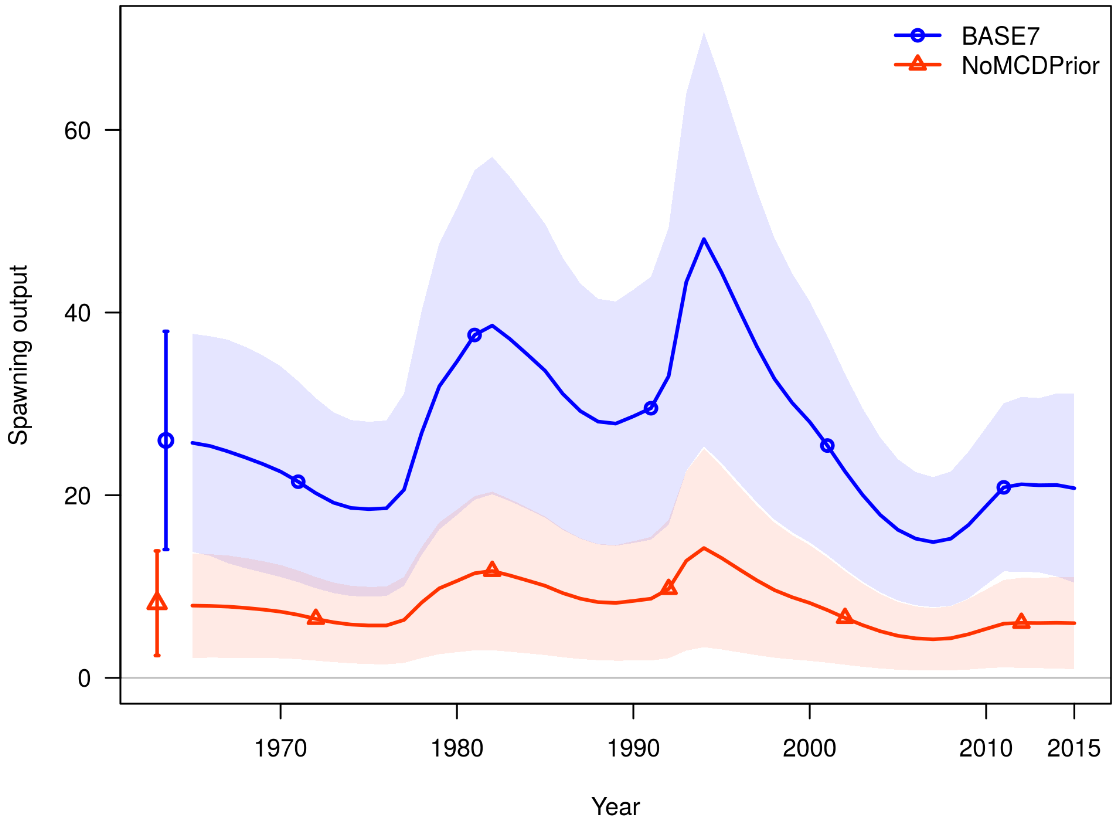

Figure 131: Biomass scale in a model sensitivity run for Atlantic surfclam in the southern area in which the prior for the MCD survey was not used compared to the base model (BASE7). The scale differs between the two but the trend is similar.

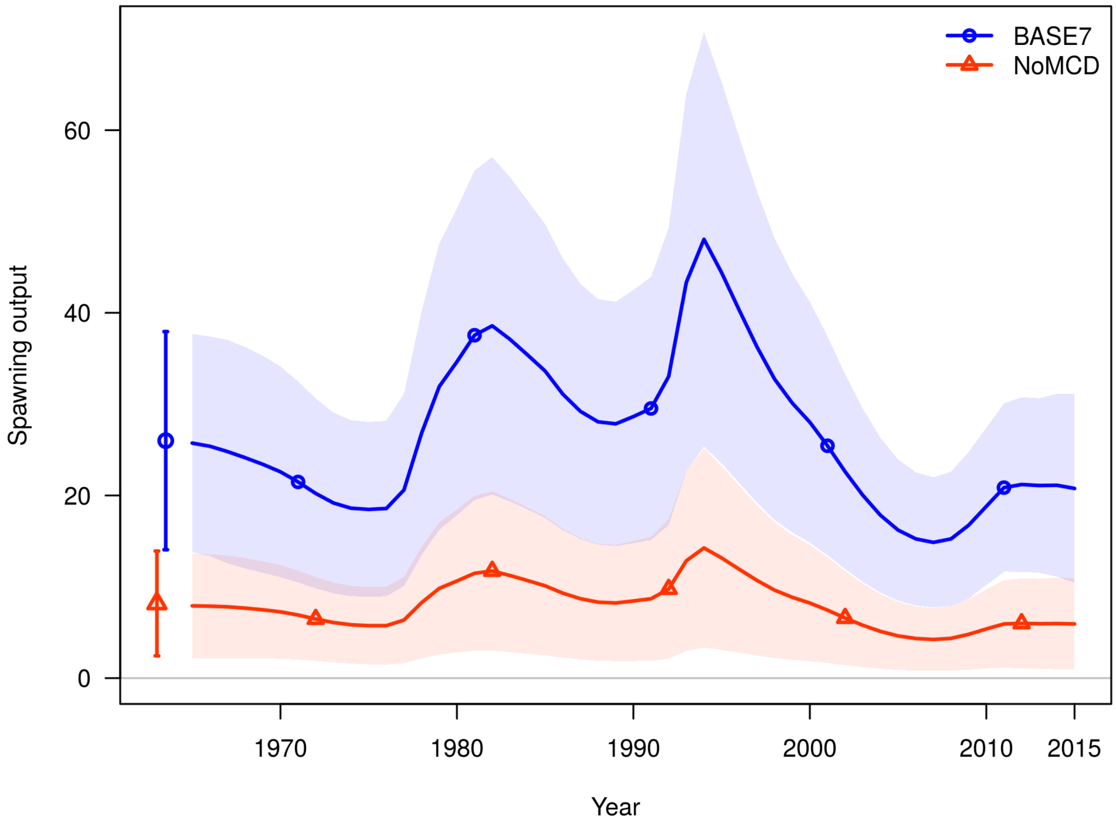

Figure 132: Biomass trend in a model sensitivity run for Atlantic surfclam in the southern area in which the likelihood component associated with the fit the MCD survey was reduced to 0, compared to the base model (BASE7). The scale differs between the two but the trend is similar.

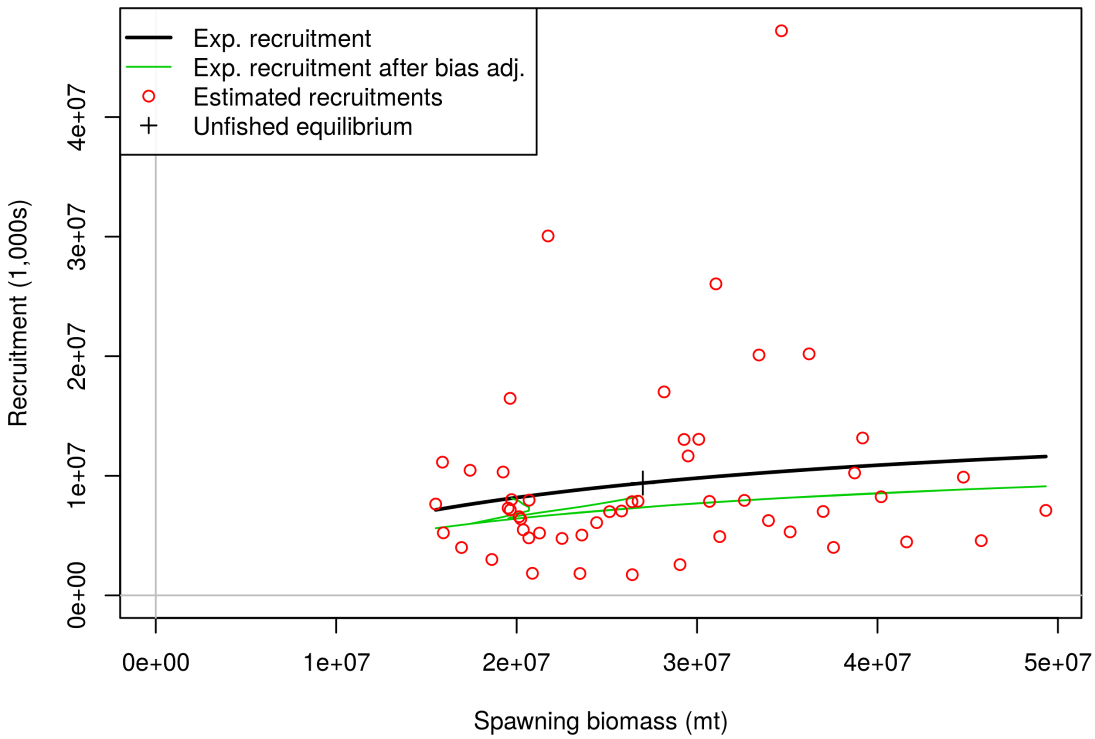

Figure 133: Stock recruit relationship with steepness estimated in a model sensitivity run for Atlantic surfclam in the southern area. There is no information to inform the left side of the stock recruit curve because no low stock sizes have been observed.

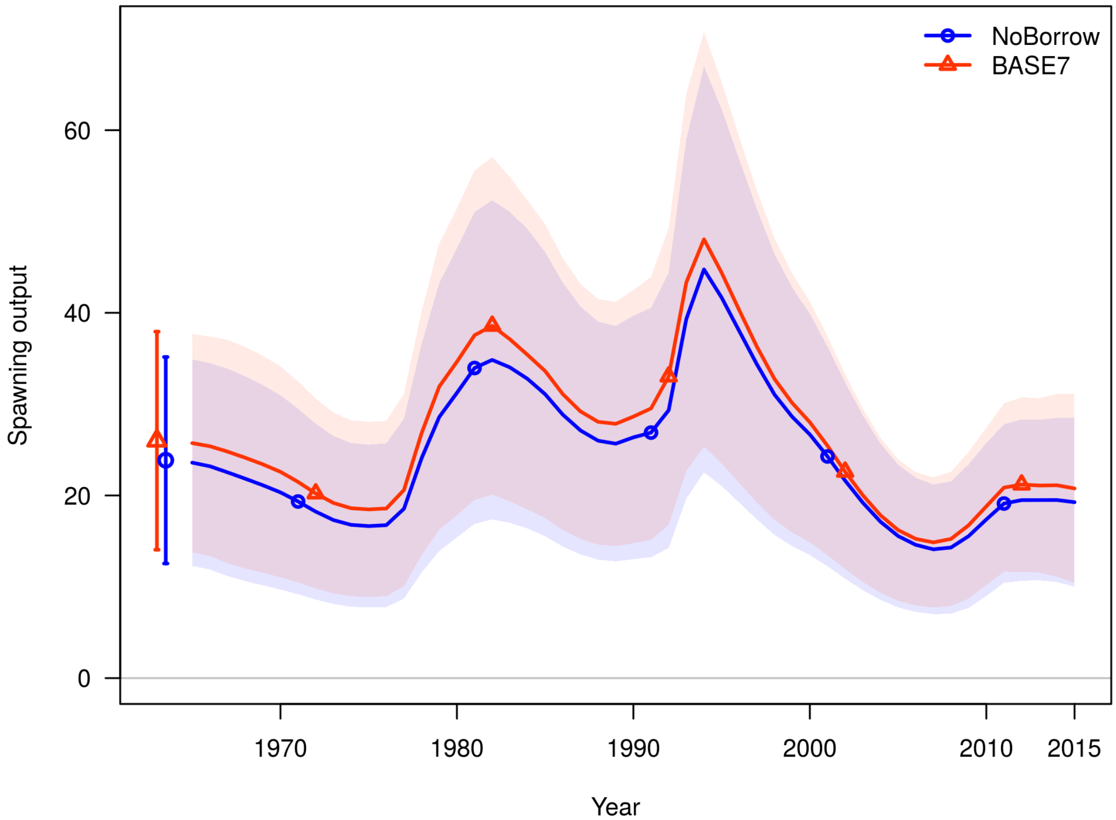

Figure 134: Biomass scale and uncertainty from 2 model runs, one in which the conditional age at length data was not borrowed from 2013 to 2012 (NoBorrow) and the other being the base model run for Atlantic surfclam in the southern area (BASE7). The biomass trajectories from each run were nearly identical.

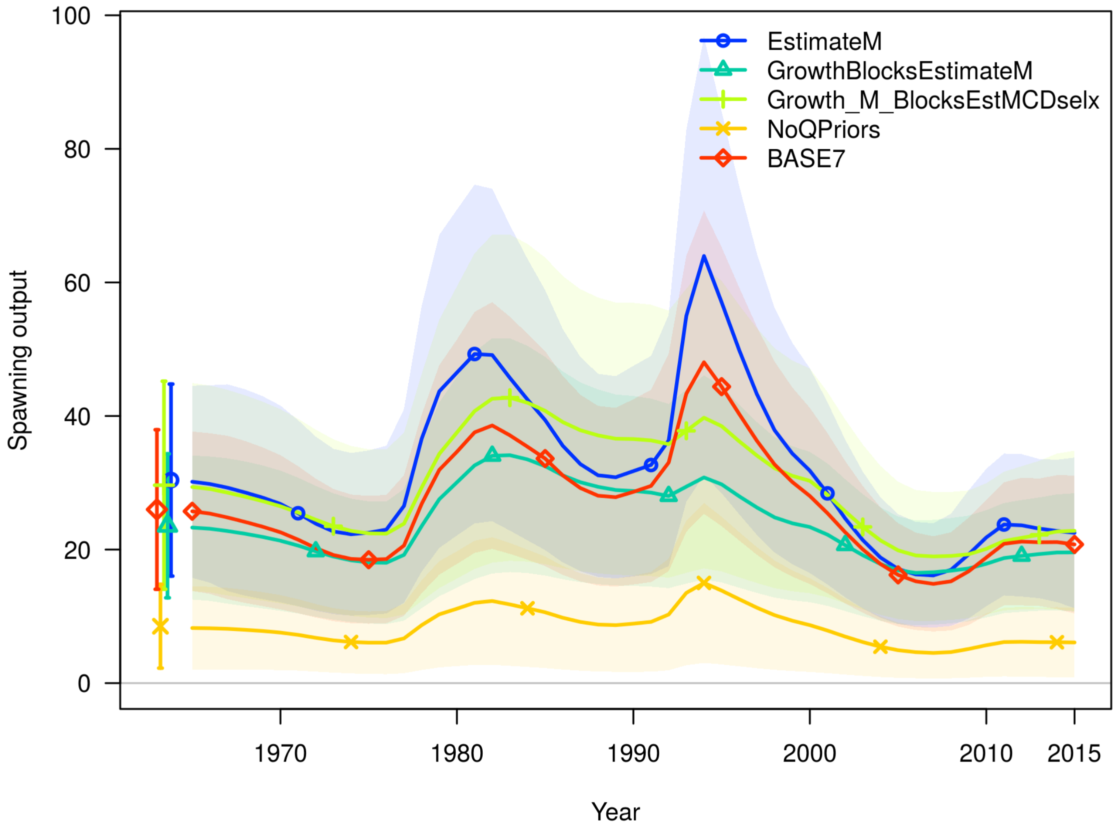

Figure 135: Biomass scale and uncertainty from several sensitivity model runs compared to the base run (BASE7) for Atlantic surfclam in the southern area. Each of the runs produced similar trends and only the run in which no prior distributions for catchability were used produced large differences in scale.

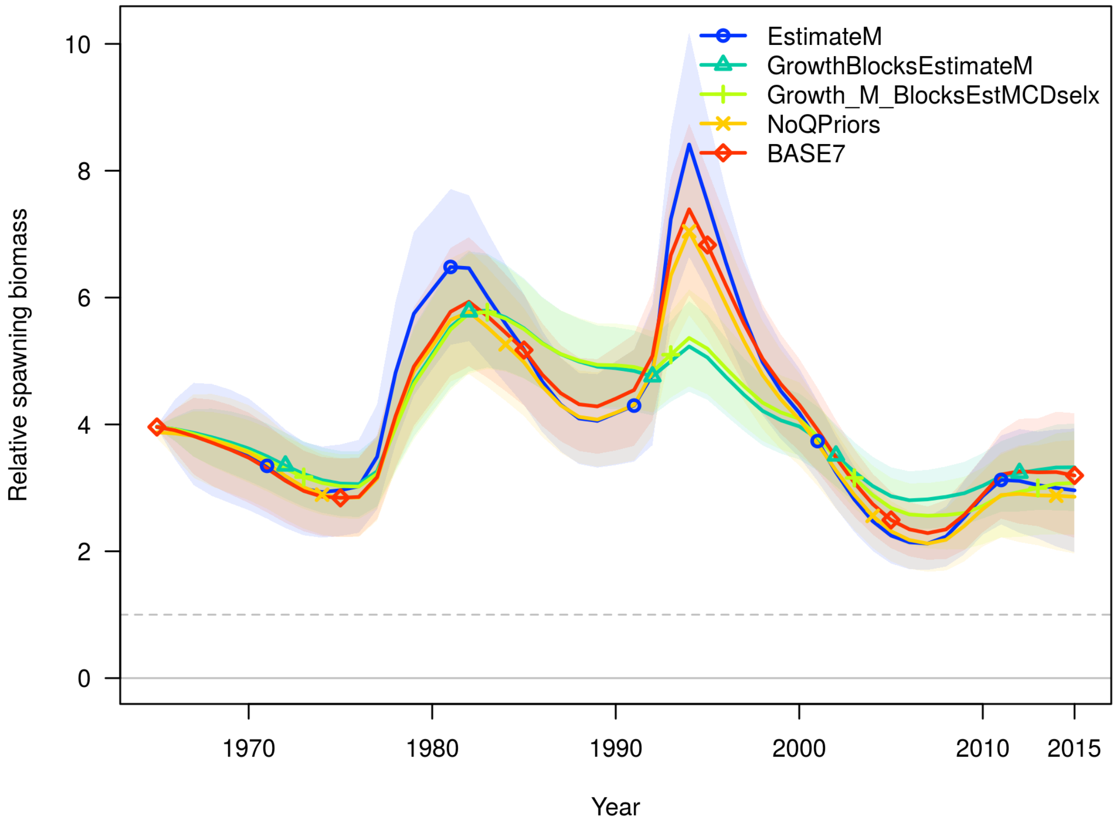

Figure 136: Relative spawning biomass and uncertainty from several sensitivity model runs compared to the base run (BASE7) for Atlantic surfclam in the southern area. Each of the runs produced similar trends. There was very little difference between the two runs. The trends depict the ratio of the biomass in each year to B_0 and include a dashed line at $\frac{B}{B_0} = 0.25$.

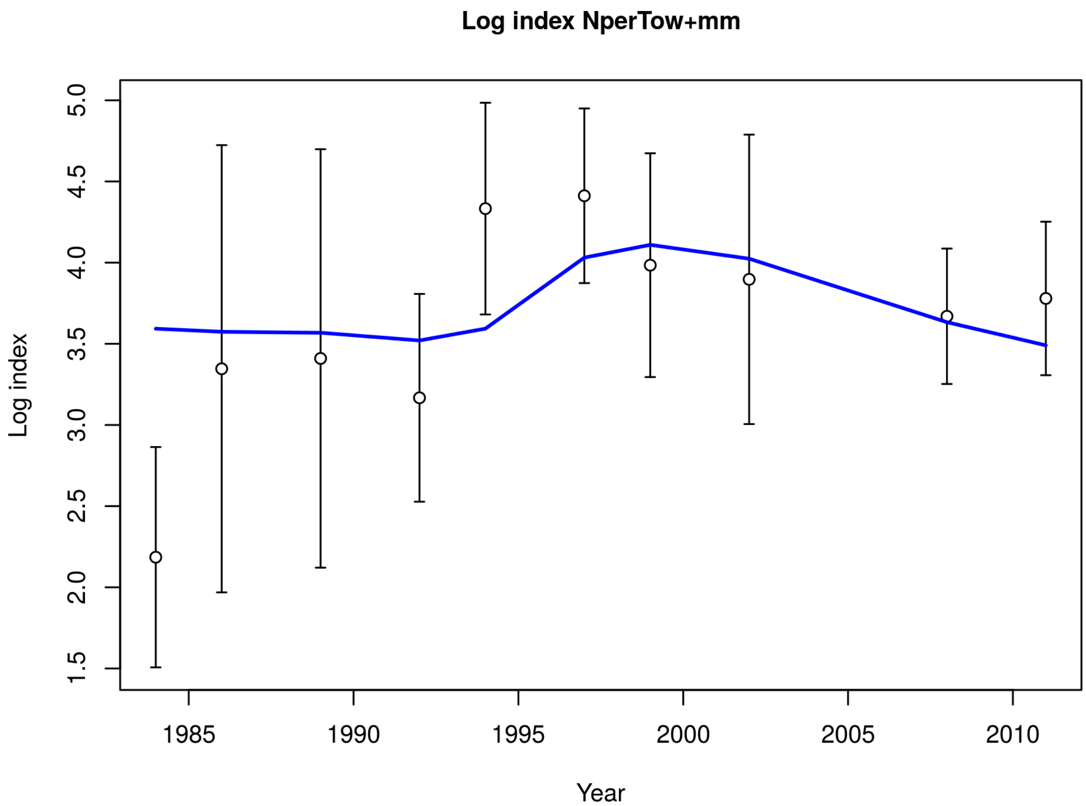

Figure 137: Model fit to the log of the RD survey index estimated in a model sensitivity run for Atlantic surfclam in the northern area in which the R_0 parameter was allowed to vary over time in two blocks (before and after 1995).

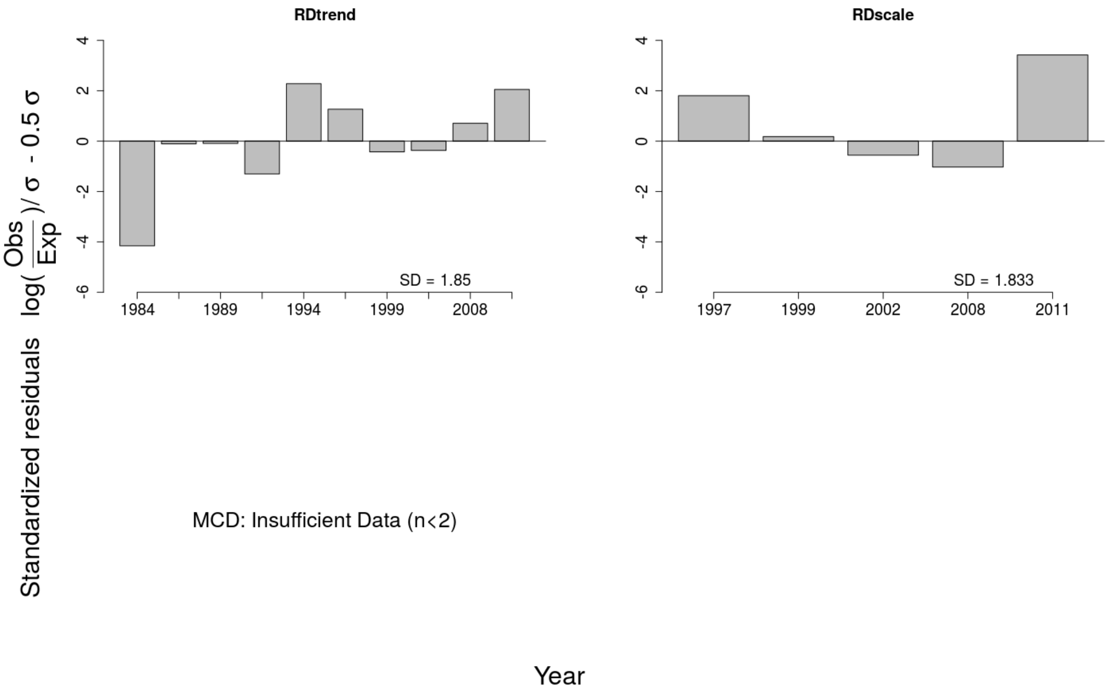

Figure 138: Standardized residuals from the model fit to the RD survey index estimated in a model sensitivity run for Atlantic surfclam in the northern area in which recruitment variance was increased by 100%.

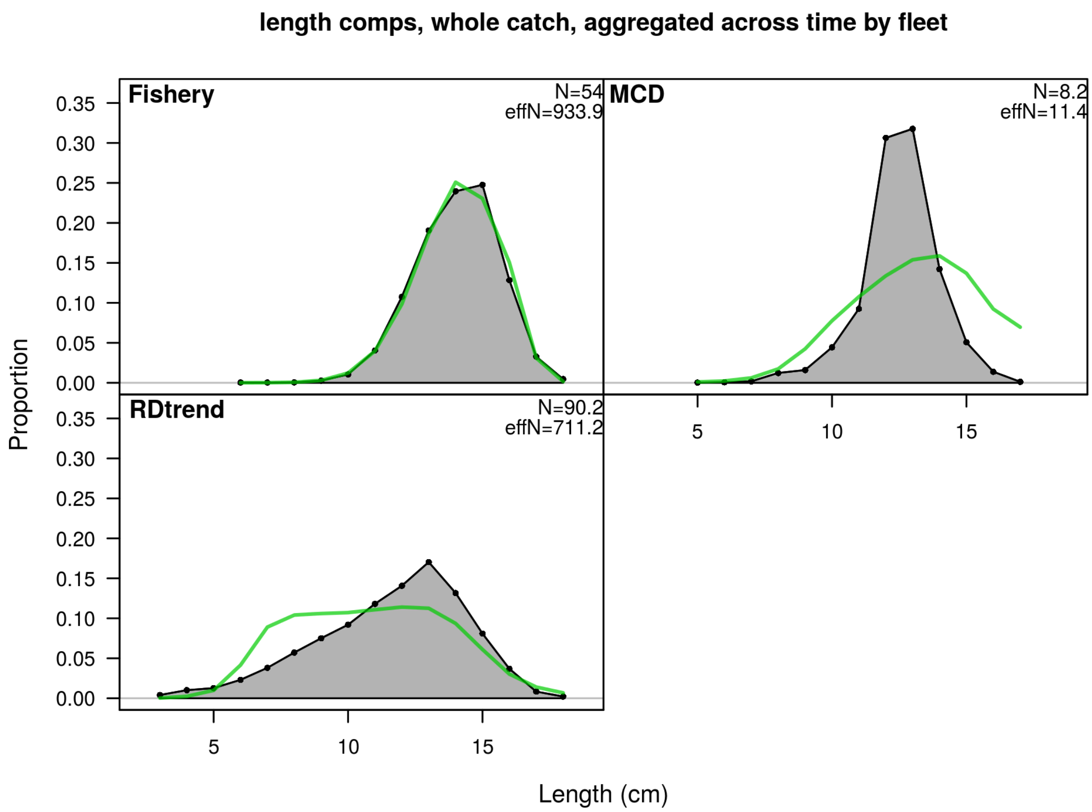

Figure 139: Length composition fits in a model sensitivity run for Atlantic surfclam in the northern area in which the weight of the likelihood component associated with the RD survey was increased by 1000%.

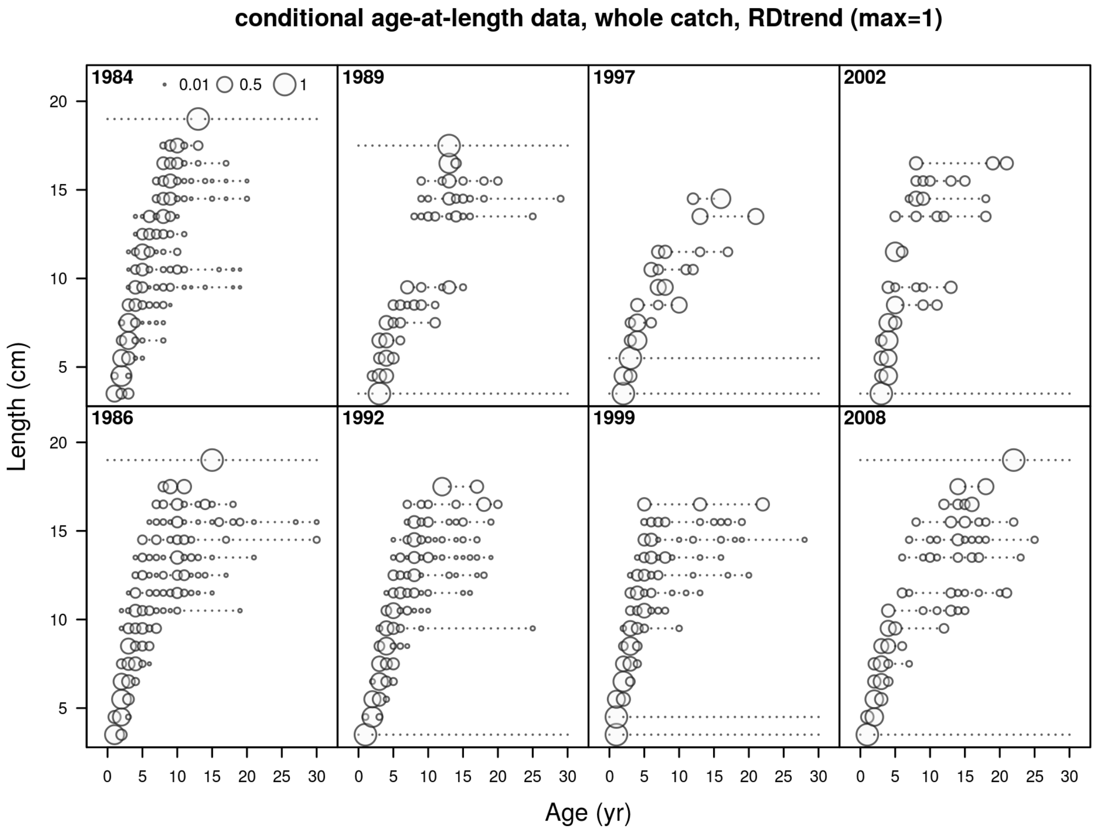

Figure 140: Standardized residuals from conditional age at length composition fits in a model sensitivity run for Atlantic surfclam in the northern area in which the weight of the likelihood component associated with the RD survey was increased by 1000%.

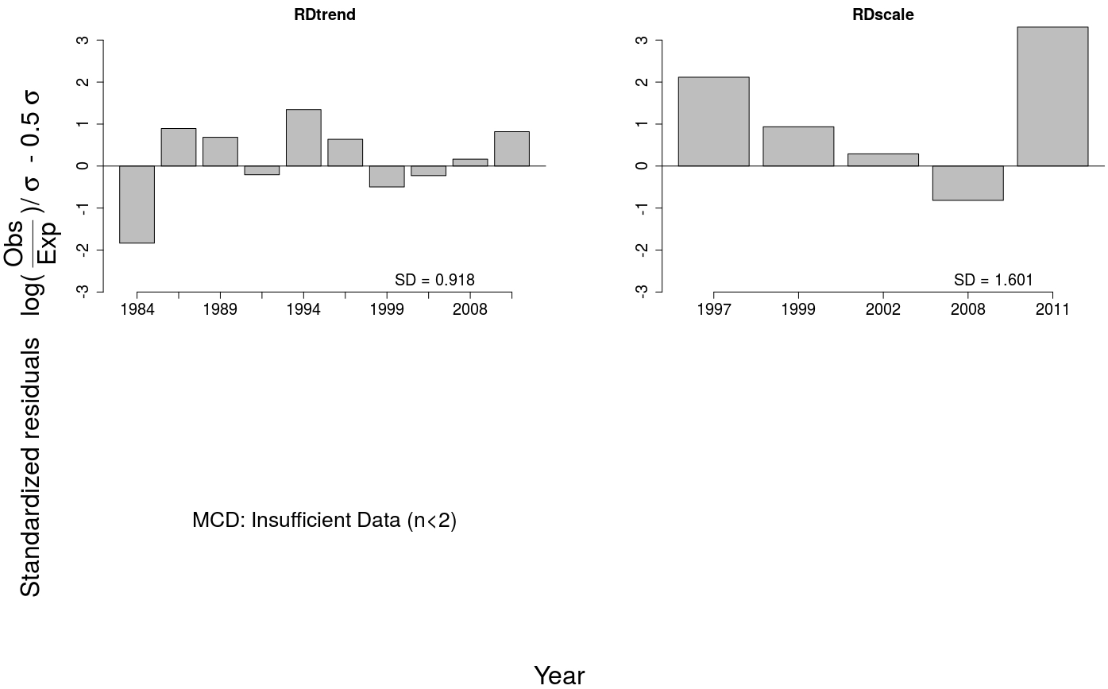

Figure 141: Standardized residuals from the model fit to the RD survey index estimated in a model sensitivity run for Atlantic surfclam in the northern area in which recruitment variance was increased by 100%.

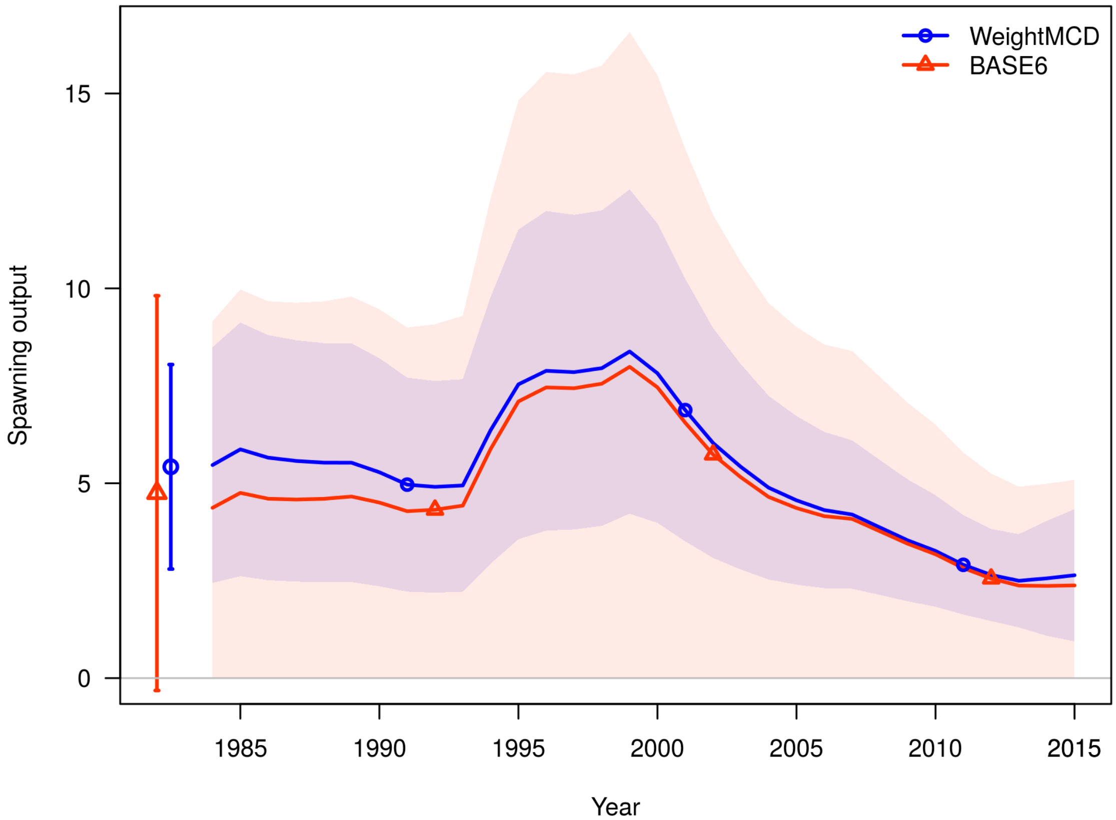

Figure 142: Estimated biomass from a model sensitivity run for Atlantic surfclam in the northern area in which the relative variance associated with the MCD survey index was reduced by about 50%, compared to estimated biomass from the base model run (BASE6).

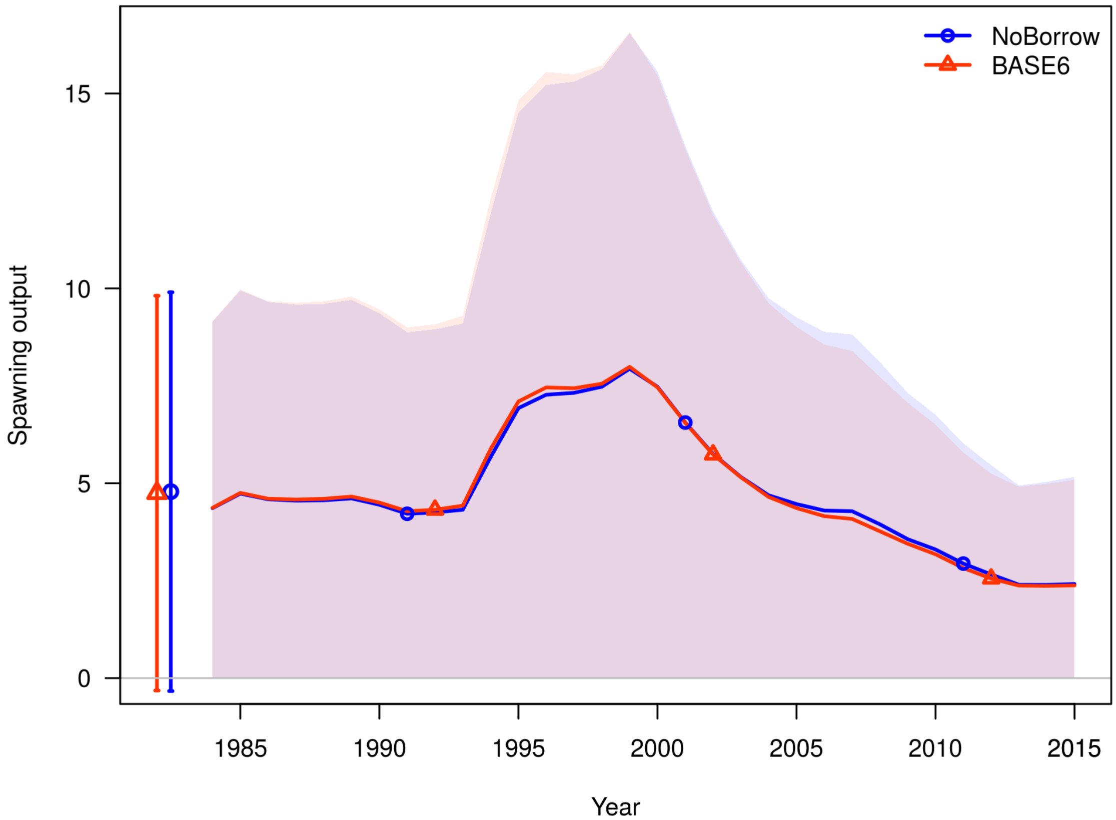

Figure 143: Biomass scale and uncertainty from 2 model runs, one in which the likelihood weight on the MCD survey trend information was set to 0 (RemoveMCD) and the other being the base model run for Atlantic surfclam in the northern area (BASE6). The biomass trajectories from each run were similar but the scale was not.

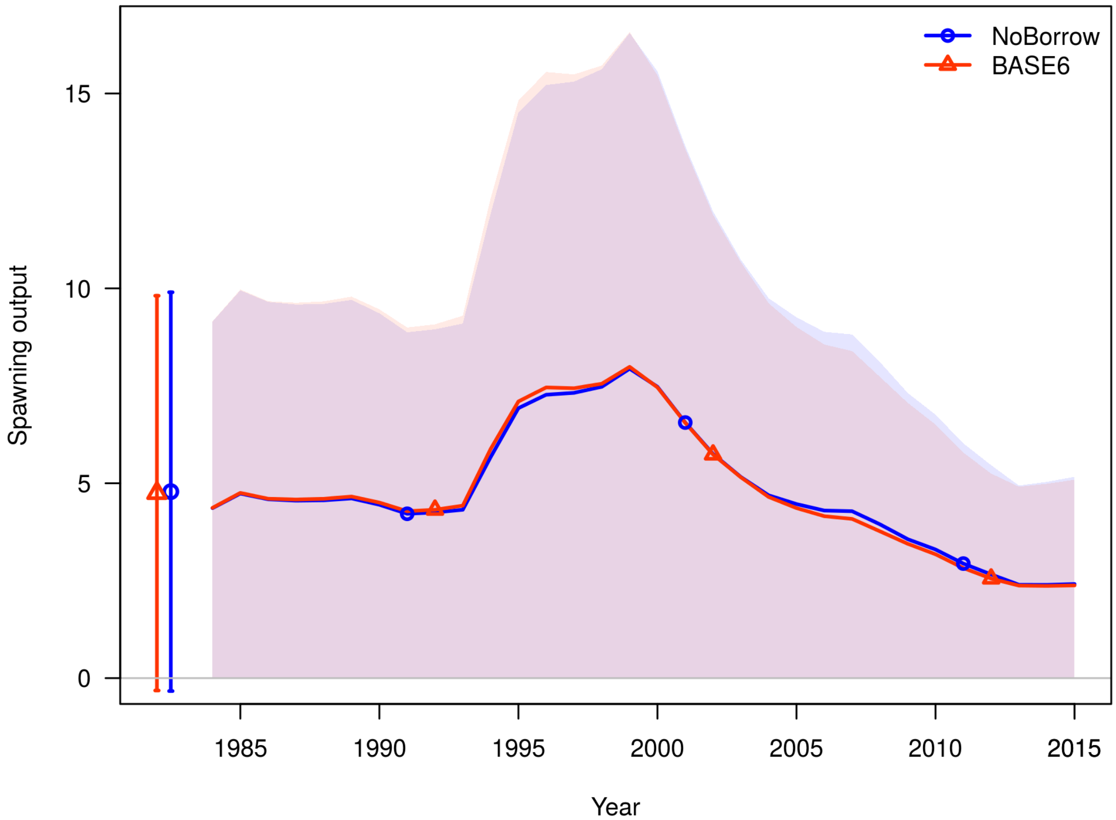

Figure 144: Biomass scale and uncertainty from 2 model runs, one in which the conditional age at length data was not borrowed from 2014 to 2013 (NoBorrow) and the other being the base model run for Atlantic surfclam in the northern area (BASE6). The biomass trajectories from each run were similar and the confidence regions overlapped.

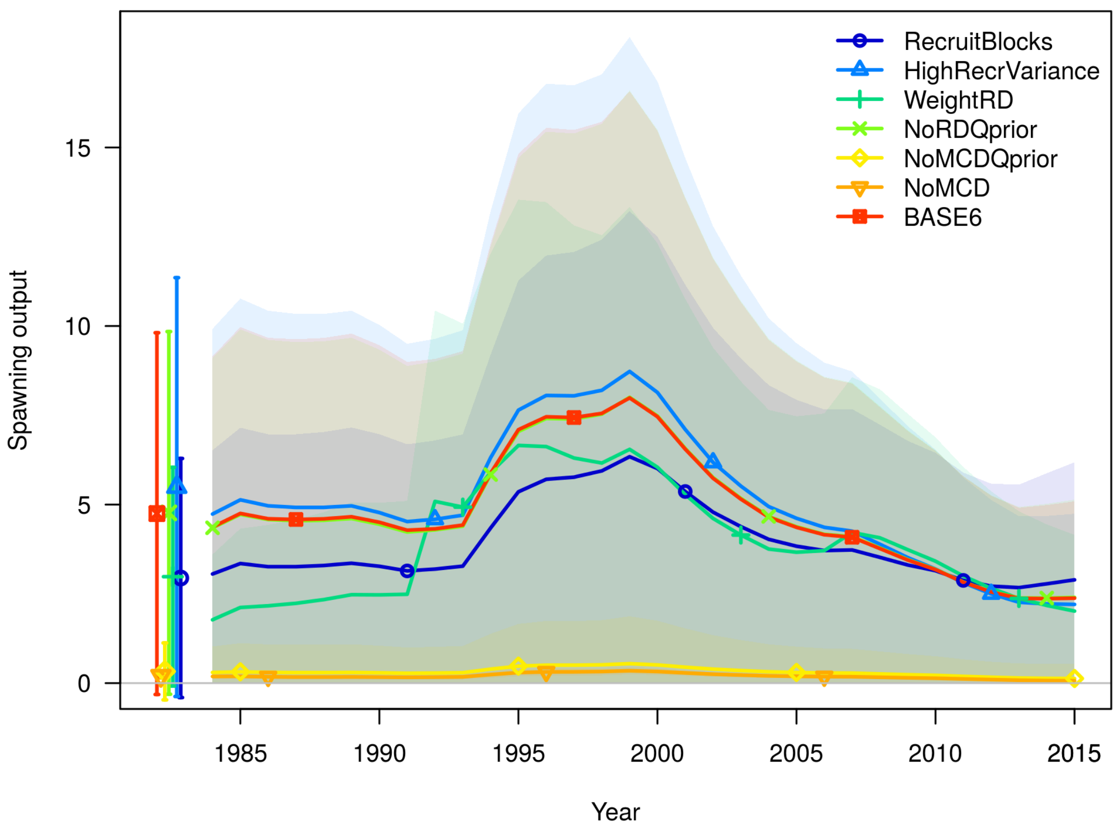

Figure 145: Biomass scale and uncertainty from several sensitivity model runs compared to the base run (BASE6) for Atlantic surfclam in the northern area. Each of the runs produced similar trends except when the model was forced to fit the early survey time series (WeightRD), but different scales when the information from the MCD survey was removed (NoMCD) or when the prior distribution for the catchability of the MCD was turned off (NoMCDprior).

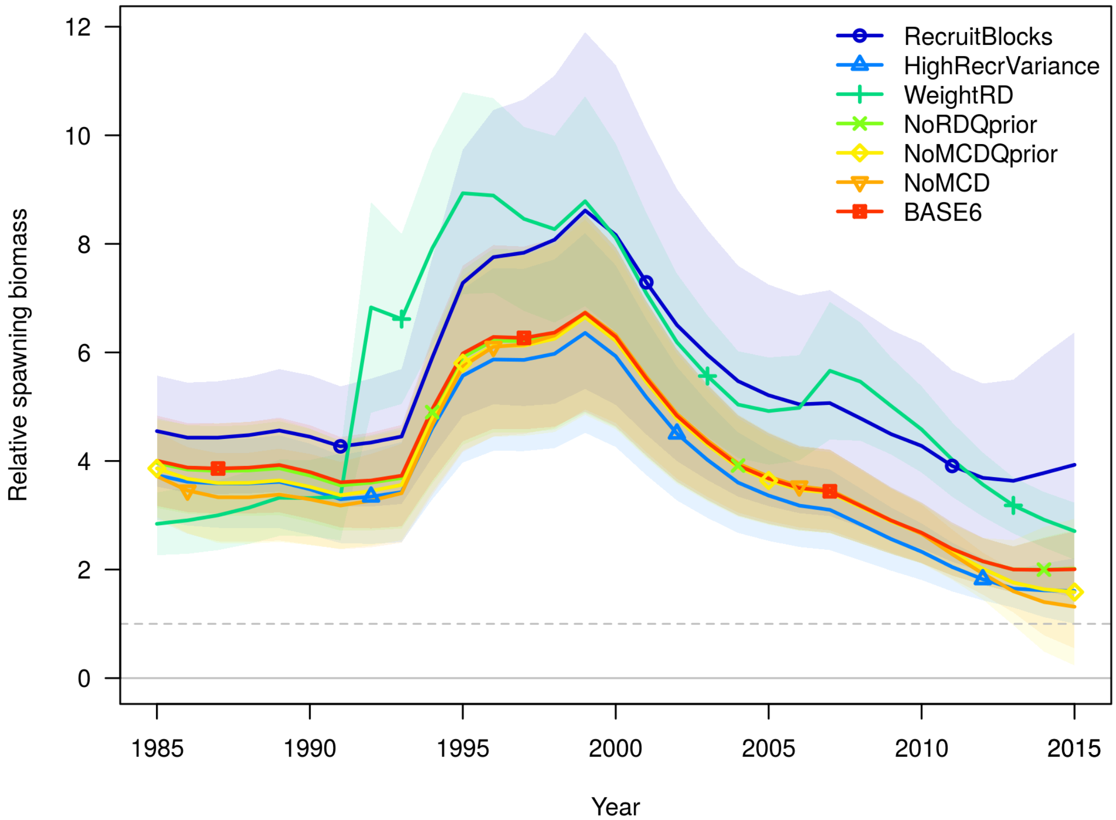

Figure 146: Relative spawning biomass and uncertainty from several sensitivity model runs compared to the base run (BASE6) for Atlantic surfclam in the northern area. Each of the runs produced similar trends except when the model was forced to fit the early survey time series (WeightRD). There was very little difference between the two runs. The trends depict the ratio of the biomass in each year to B_0 and include a dashed line at $\frac{B}{B_0} = 0.25$.

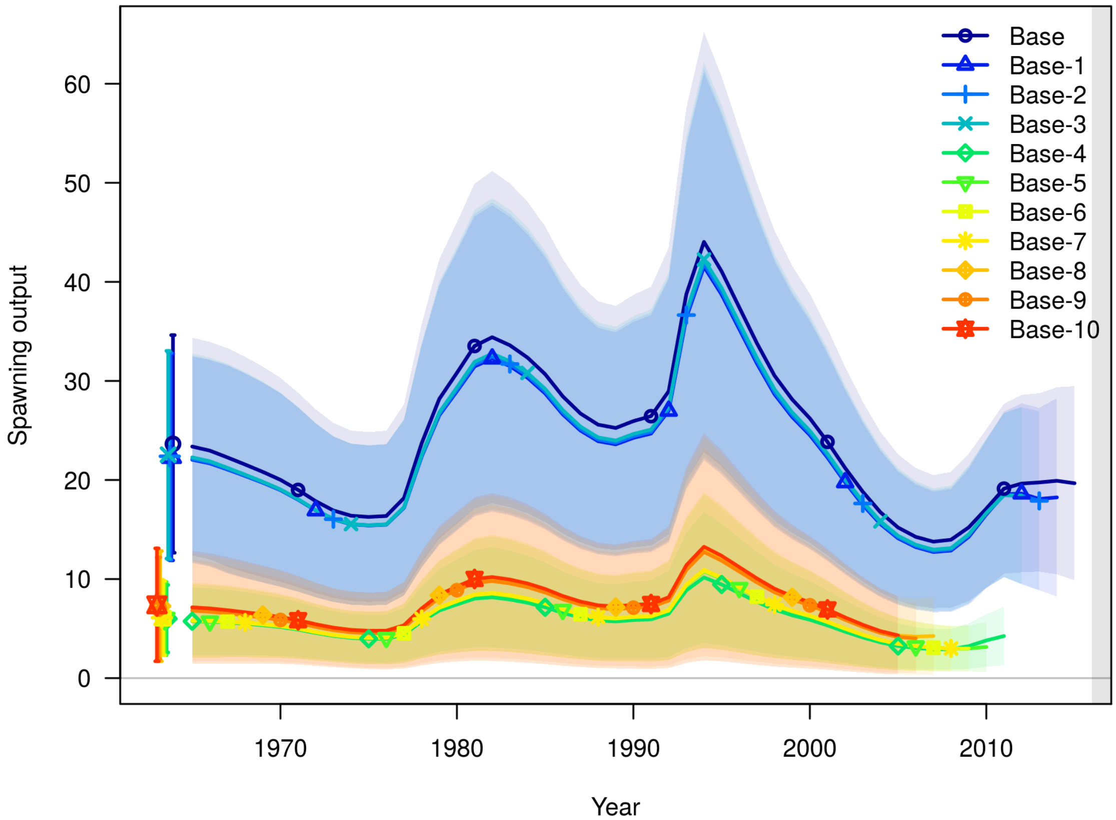

Figure 147: Biomass scale and uncertainty from 10 retrospective runs of the model for the southern area. The biomass scale shifts when the MCD survey is removed from the model. The dashed line represents a theoretical threshold value where the biomass is equal to 25% of the virgin biomass estimated in each retrospective run.

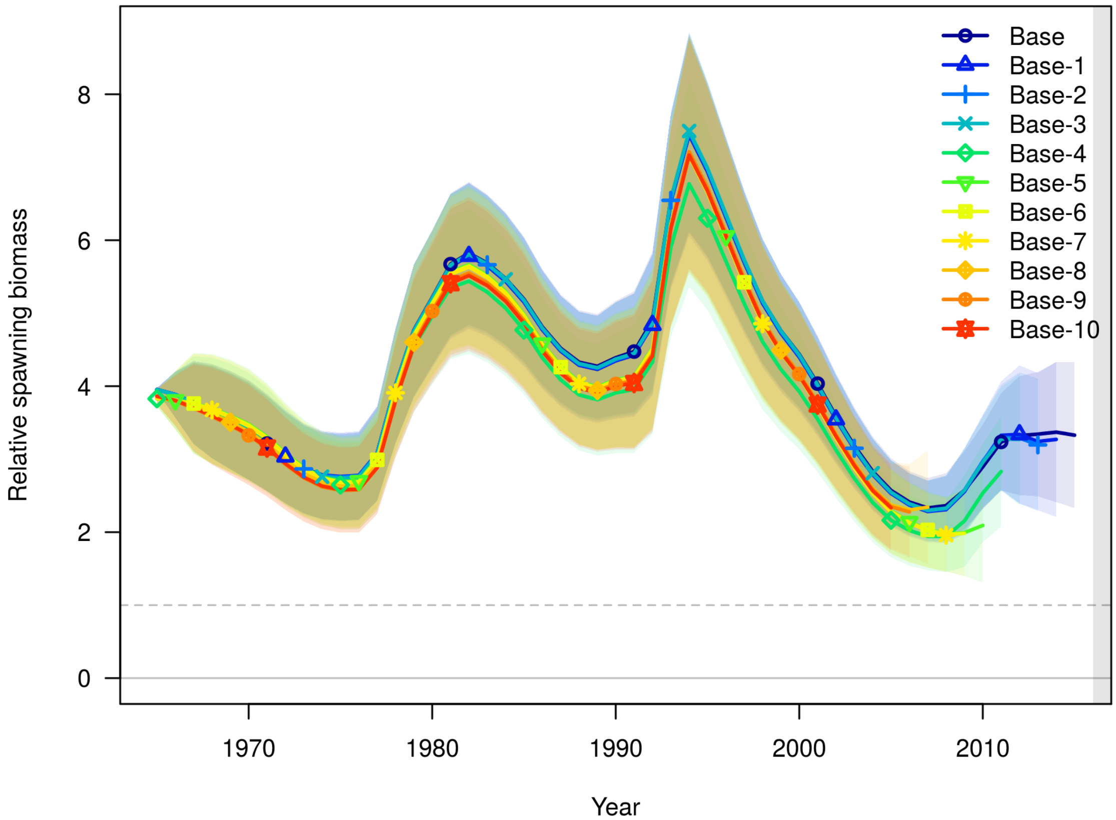

Figure 148: Relative spawning biomass and uncertainty from 10 retrospective runs of the model for the southern area. The trend in biomass is robust to the removal of data from recent years.

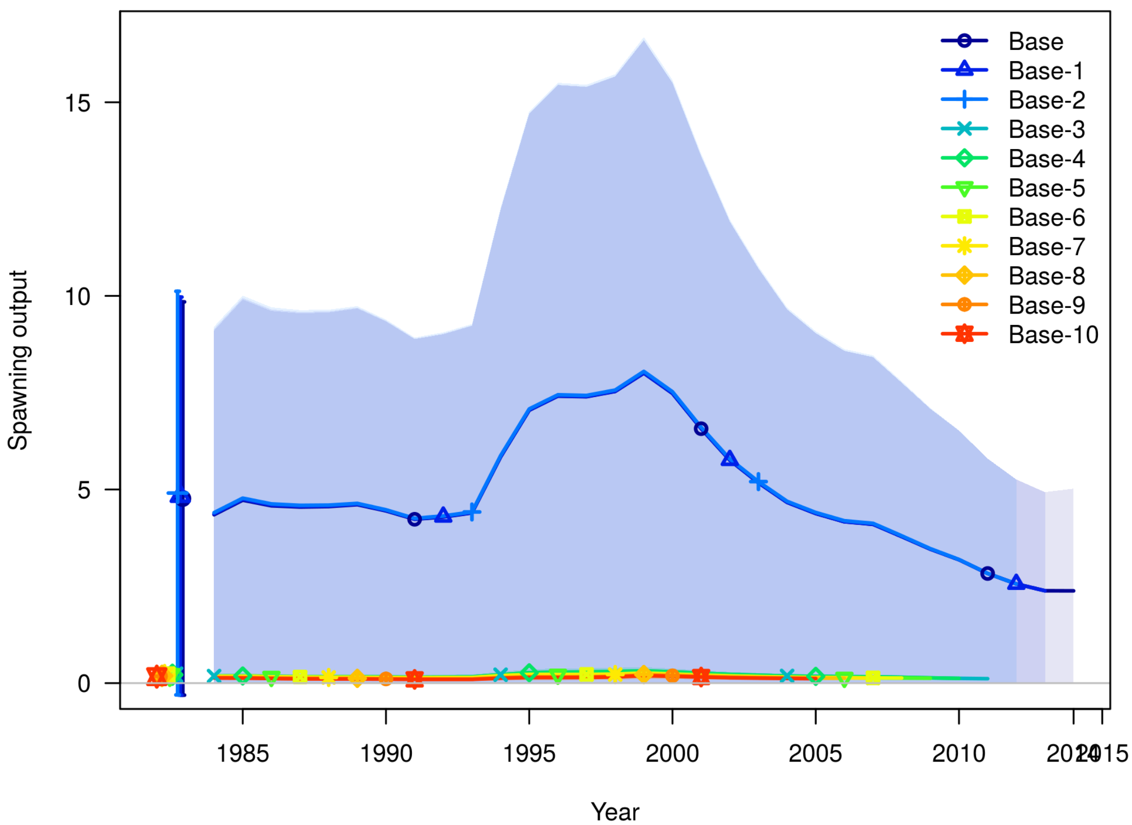

Figure 149: Biomass scale and uncertainty from 10 retrospective runs of the model for the northern area. The biomass scale shifts when the MCD survey is removed from the model.

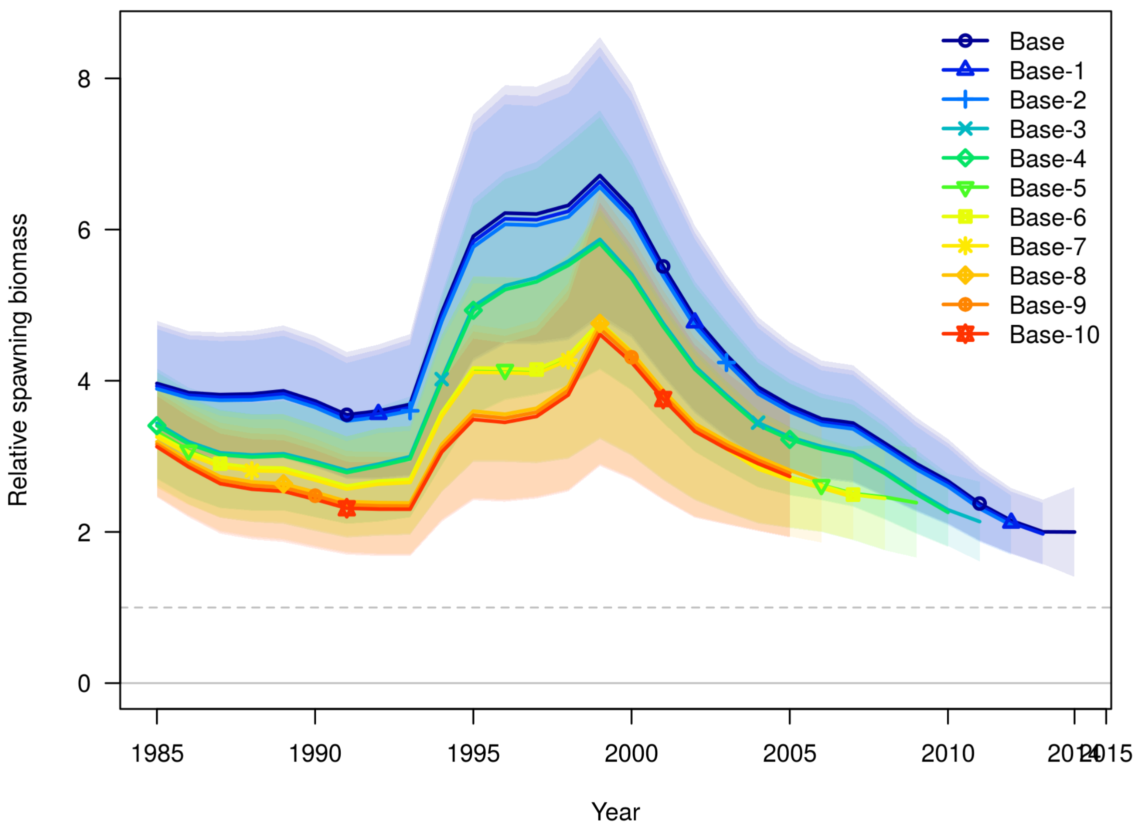

Figure 150: Relative spawning biomass and uncertainty from 10 retrospective runs of the model for the northern area. The dashed line represents a theoretical threshold value where the biomass is equal to 25% of the virgin biomass estimated in each retrospective run.

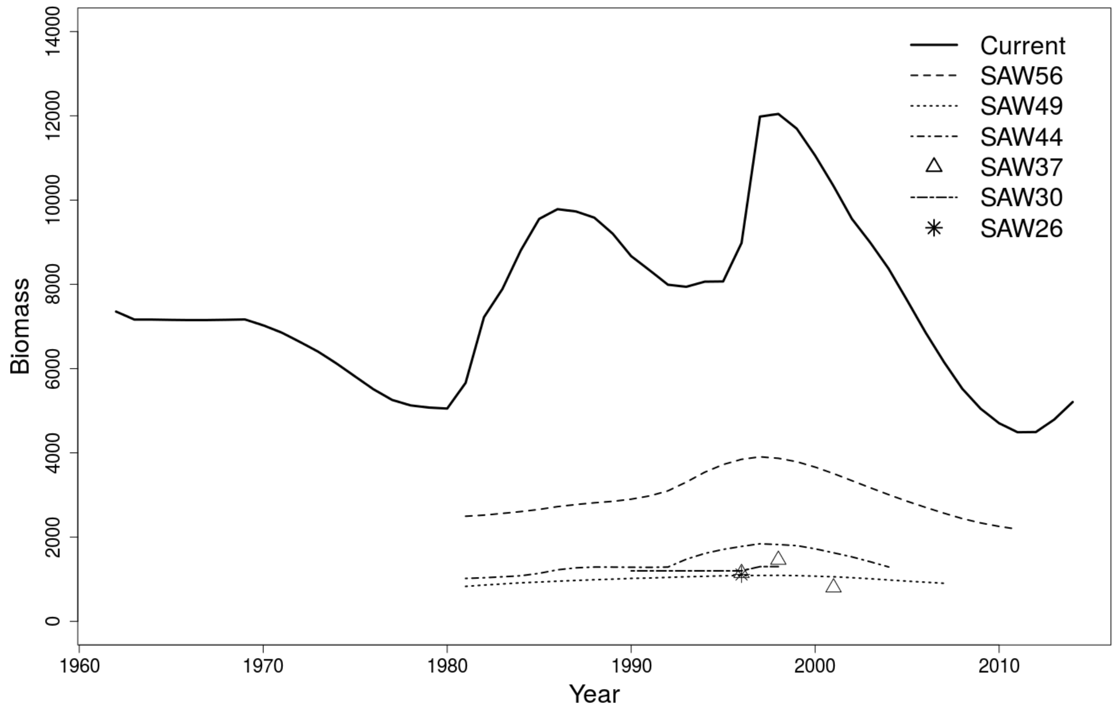

Figure 151: Historical retrospective plot showing the biomass trajectory from each of the previous Atlantic surfclam assessments.

Part VII

TOR 6: Reference points

Current reference points

According to the harvest control rule in the FMP for Atlantic surfclam, overfishing occurred whenever the annual fishing mortality rate on the whole stock was larger than the overfishing limit (OFL), which was defined as a proxy for F_{MSY} ($F_{Threshold} = M = 0.15\,y^{-1}$). B_{Target} was defined as a proxy for B_{MSY} ($B_{Target} = \frac{1}{2}B_{1999}$ where B_{1999} was near the highest estimated biomass in previous assessments). The stock was overfished if total biomass fell below $B_{Threshold}$, which was $\frac{1}{2}B_{MSY}$ ($B_{Threshold} = \frac{1}{2}B_{MSY} = \frac{1}{4}B_{1999}$).

Current and recommended biological reference points (BRP) for Atlantic surfclam are proxies because spawner-recruit relationships required to determine F_{MSY} and B_{MSY} directly have not been estimated (low stock size has never been observed). Both current and recommended biomass reference points are based on trends/status ratios such as $\frac{B_{2015}}{B_{Threshold}}$ rather than absolute biomass estimates because the overall level of Atlantic surfclam biomass is uncertain. The current fishing mortality reference point is a fishing mortality rate but the recommended reference point is based on relative catch, again because of the uncertainty in biomass.

Reference points may be selected based on fishery performance and/or policy (risk aversion). Recommendations in this assessment are based on fishery performance criteria leaving MAFMC to consider policy to consider risk involved in setting catch targets, with the advice of its Scientific and Statistical Committee.

The $B_{MSY} = \frac{1}{2}B_{1999\,proxy}$ currently used for Atlantic surfclam has no theoretical justification beyond the notion that the biomass in 1999 was high at that time and might approximate carrying capacity. The major advantage was that both B_{1999} and biomass in the terminal year (e.g. B_{2015}) were estimated in the same model so that uncertainty in the overall scale of population size cancelled out in ratios used to determine stock status such as $\frac{B_{2015}}{\frac{1}{2}B_{1999}}$. In effect, the current approach is based on estimated trends in biomass but not on the absolute size of the estimates themselves. This property is important because sensitivity and historical retrospective analyses in this assessment show that estimated stock size trends are more robust for Atlantic surfclam than estimates of scale (Figures 142 - 151).

F_{MSY} and proxies depend on spawner-recruit, and yield/spawning biomass per-recruit relationships. Proxies for F_{MSY} are often set at some fraction of M ($F_{MSY} = cM$, $c < 1$ such that M is an upper bound for F_{MSY}) or at the fishing mortality rate corresponding to some fraction of maximum average reproductive output per recruit ($F_{SPR\%}$, Zhou et al. 2012). Existing $F_{SPR\%}$ proxies are not applicable to Atlantic surfclam because the analyses on which they are based generally assume that individuals mature and recruit to the fishery at about the same time. In addition, F_{MSY} cannot be computed directly because we have never observed a low stock size and thus have no way to characterize the stock recruit relationship. The current $F_{MSY\,proxy}$, $F = M = F_{Threshold}$ relies on biomass scale, and status determination relative to fishing mortality was therefore subject to the uncertainty associated with scale in the assessment.

Simulation analyses can be used to identify robust reference points that work well across a range of potential spawner-recruit curves and life-history patterns. This assessment includes management strategy evaluation (MSE) simulations which were tailored to Atlantic surfclam and the uncertainties about their life history and dynamics (XIX). The MSE analysis included two scenarios of particular interest. The primary scenario reflects current practice in managing two spatial areas (Northern and Southern) with different biological properties and independent recruitment patterns as a single unit. The secondary scenario uses separate harvest control rules for each unit and provides a means for assessing the potential costs and benefits of managing the two regions as a unit or separately.

MSE

MSE simulations were used to evaluate how MAFMC control rule parameters (a simplified version) affect average biomass relative to virgin biomass $\frac{SSB}{B_0}$[3], average relative yield measured as $\frac{Y}{B_0}$, interannual variation in yield cv(Y) and the proportion of years with no fishing ($t_{F=0}$). Simulations included a relatively wide and realistic range of random inputs for recruitment parameters, natural mortality, Beverton-Holt and Ricker spawner-recruit patterns, and other important, but uncertain parameters (XIX).

MSE results for combined region management and assuming both Beverton-Holt and Ricker recruitment patterns showed that $F_{Threshold}$ (F_{MSY} proxy) in the simulations, B_{Target} (B_{MSY} proxy) and $B_{Threshold}$ were all important for Atlantic surfclam in the MAFMC control rule (Figures 230 - 231). However, a wide range of different combinations of these parameters performed well based on MSE results. To simplify analysis we base recommendations on results for $F_{Threshold} < M = 0.15$ (an upper bound for F_{MSY}) and MAFMC control rule values of B_{MSY}=B_{Target}=$\frac{1}{2}B_0$, $B_{Threshold}$=$\frac{1}{4}B_0$.

For simulations at B_{Target}=$\frac{1}{2}B_0$, and considering combined area management, and with two spawner-recruit patterns, $F_{Threshold}$ values near 0.12 maximized yield while maintaining relatively high average spawning biomass with low interannual variation in yield and infrequent years with no fishing (Tables 41 - 44 and Figures 232 - 233).

Recommendations

$F_{MSY\,proxy} = 0.12$ is preferred over $F_{MSY proxy} = 0.15$ because higher levels of biomass, lower levels of variation in catch and less frequent years with no fishing would be expected according to the MSE (Appendix XIX). $F_{MSY\,proxy} = 0.12$ is lower than the upper bound estimate $M = 0.15$, as should be expected. It is slightly larger than the range of $F_{MSY} = cM$ proxies for finfish with $0.63 < c < 0.74$ and $0.09 < F_{MSY} < 0.11$ (Zhou et al. (2012)). $F_{Threshold} = 0.12$, $B_{Threshold} = \frac{1}{4}B_0$ and $B_{Target} = \frac{1}{2}B_0$ provided high levels of catch and stock biomass at relatively low levels of variation in catch and years with no fishing. There is no reason to change the biomass reference points $B_{Target} = \frac{1}{2}B_0$ or $B_{Threshold} = \frac{1}{2}B_{Target}$ because they performed well in MSE simulations. These results were robust to assumptions about the underlying spawner recruit curve (Figures 232 - 233).

[3]Because Atlantic surfclam mature before age 1, there is no practical difference between B_0 and SSB_0 and the terms may be used interchangeably

Based on the MSE analysis, mean stock biomass would increase by about one-third at $F_{Threshold} = 0.12$, with no change in mean yield if Atlantic surfclam in both areas were managed separately although variance in catch and the number of years with no catch would increase (Figure 231). The simulations assume that all available yield is taken. Changes in average biomass, average yield, variance in catch, and years with no fishing would be smaller in the current fishery where catches are low relative to the levels calculated using the MAFMC control rule.

The recommendation $F_{Threshold} = 0.12$ is superior to $F_{Threshold} = 0.15$ on theoretical grounds but it shares an important implementation problem given that estimated fishing mortality rates are uncertain due to uncertainty in the scale of the biomass estimates. Thus, it would be very difficult to reliably compare an estimated fishing mortality rate to $F_{Threshold}$ and determine if overfishing is occurring. The assessment working group concluded it would be better to employ an $F_{Threshold}$ reference point based on trends using the average fishing mortality rate between 1982 and 2015 (the period for which we have survey data) in the southern area.

$$E_{y=1982}^{2015}[F_y] = F^*$$

The catch during that time period did not appear to result in overfishing. There is no evidence of overfishing in the current age/size compositions and current biomass estimates are near B_0 (see VI and XXV). The highest average fishing mortality between 1982 and 2015 for the southern area in sensitivity analyses was $F^*_{Max} = 0.03$. There is a high probability that $\frac{F_{MSY}}{F^*} > 4$ because

$$\frac{F_{MSY}}{F^*_{Max}} = \frac{0.12}{0.03} = 4$$

and F^*_{Max} was taken from the sensitivity run with the lowest biomass and thus highest F of any model run for the southern area. In addition, catch curve total mortality $(F + M)$ estimates for the southern area during this time period averaged 0.14, compared to the assumed M of 0.15. Empirical exploitation rates < 0.05, provding further evidence that F was low (XXV). Thus any F^* calculated from another model run would likely be lower than F^*_{Max}.

The recommended fishing mortality reference point is

$$F_{OFL} = F_{Threshold} = F^* \frac{F_{MSY}}{F^*_{Max}}$$

rather than a specific rate such as 0.12. It is important that F^* be calculated using the period between 1982 and 2015 in this, and in future assessments, as that was a period during which overfishing was very unlikely. Allowing the years that compose the reference point to shift over time would allow the reference point to normalize to current behavior. That is, the reference point would decrease during a regime of less fishing pressure and increase during a regime of more fishing pressure, which is not a desirable characteristic for a reference point.

There are three primary advantages to this recommendation. First, the status ratio used to identify overfishing

$$\frac{F_y}{F_{Threshold}} = \frac{F_y}{F^* \frac{F_{MSY}}{F^*_{Max}}}$$

provides information about relative exploitation rates that is not available in the ratio $\frac{F_y}{0.12}$ given the high degree of certainty in estimated trends and high degree of uncertainty in the scale of biomass estimates. Second, the recommended reference point is robust because it will adjust to changes in the scale of Atlantic surfclam biomass estimates, which can be expected in future assessments, at least over the short term. Finally, the scaling factor $\frac{F_{MSY}}{F^*_{Max}}$ can be re-examined and/or replaced as biomass estimates improve.

Table 26: Biological reference points used in the last assessment and the revised values used in the current assessment.

Reference point	Previous assessment	Revised
$F_{MSY} = F_{Theshold}$	$M = 0.15$	$F^* \frac{F_{MSY}}{F^*_{Max}}$
K	B_{1999}	B_0
$B_{MSY} = B_{Target}$	$\frac{B_{1999}}{2}$	$\frac{B_0}{2}$
$\frac{B_{MSY}}{2} = B_{Threshold}$	$\frac{B_{1999}}{4}$	$\frac{B_0}{4}$

Part VIII

TOR 7: Stock status

The assessment model was configured some what differently from the base model in the last assessment (Northeast Fisheries Science Center 2013), with the most important change being the addition of the new survey MCD survey. No new data from the RD survey has been collected since the previous assessment. It was not possible to add the new survey data to the previous assessment model because it was not configured to accept data from a different survey. Therefore, the previous assessment model cannot be directly compared to the model used in the current assessment, though a reasonable effort has been made to do so in (XVII). It is, however, possible to compare the current assessment estimates of biomass and fishing mortality to the current and recommended biological reference points.

current reference points

Comparing the terminal biomass (B_{2015}) and fishing mortality estimates (F_{2015}) to the current reference points (Table 26) shows a low probability of either overfishing or overfished status for the Atlantic surfclam stock in the US EEZ (Table 27; Figure 152). The current $F_{threshold}$ was a point estimate with no associated uncertainty. Therefore the probability of overfishing was equal to the probability of overlap between the distribution of F_{2015} and the point estimate of $F_{threshold}$.

recommended reference points

There is a near zero probability that the Atlantic surfclam stock in the US EEZ is experiencing overfishing ($F_{2015} < F_{Threshold}$; Table 28; Figure 154), and there is a low probability that the Atlantic surfclam stock in the US EEZ is overfished ($B_{2015} < B_{Threshold}$; Table 29; Figure 155). According to the recommended reference point definitions, the Atlantic surfclam stock is not overfished and overfishing is not occurring.

Tables

Table 27: Whole stock biomass and fishing mortality status estimates with cv and approximate 95% confidence intervals, using the current reference points from the previous assessment. The table shows the overlap between the distributions of the threshold and the terminal B (P[overlap]) and the probability of overfished status (P[overfishing]), which accounts for the correlation between the threshold and the terminal B. The current F reference point was a point estimate with no uncertainty and therefore the probability of overfishing was equal to the overlap.

	Estimate	CV	LCI	UCI	P[overlap]	P[overfishing]
SSB_{2015}	46355730	0.635	1	144974076	0.434	0.000
SSB Threshold	19076275	0.149	6455642	56369955		
F_{2015}	0.009	0.637	0.003	0.029	0.000	0.000
F Threshold	0.15					

Table 28: Whole stock Atlantic surfclam fishing mortality status estimates with cv and approximate 95% confidence intervals.

	F	CV	LCI	UCI
$\frac{F_{2015}}{F_{Threshold}}$	0.295	0.224	0.191	0.456

Table 29: Whole stock Atlantic surfclam biomass status estimates with cv and approximate 95% confidence intervals.

	Ratio	CV	LCI	UCI
$\frac{SSB_{2015}}{SSB_{Threshold}}$	2.54	0.696	0.74	8.71

Figures

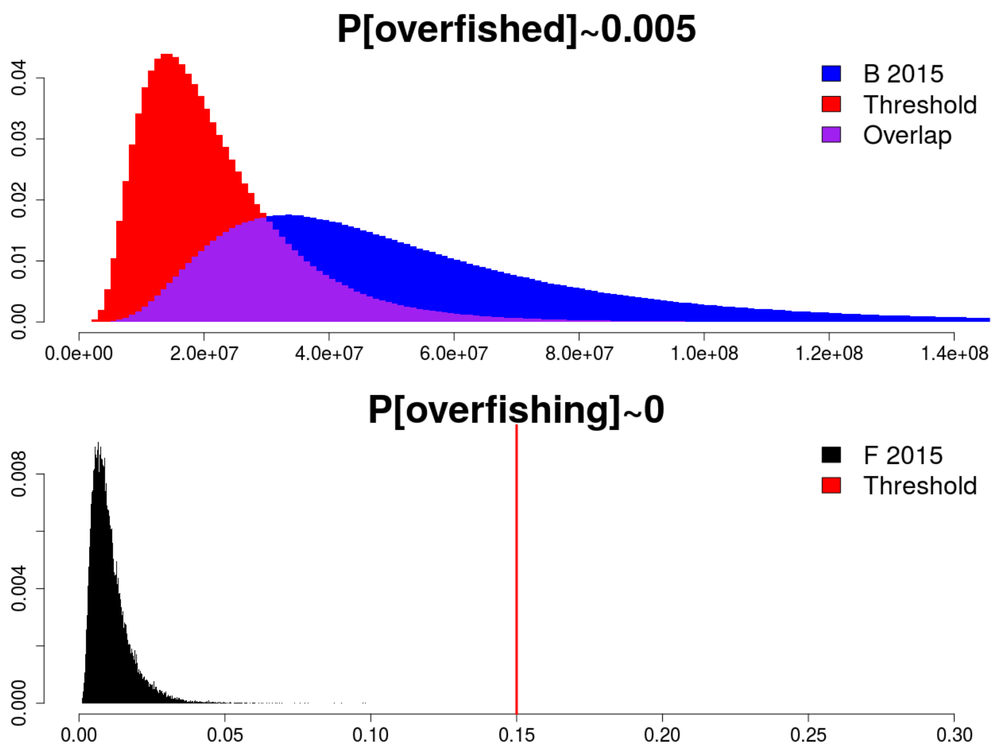

Figure 152: Probability of overfished and overfishing status during 2015 using the current reference points from the previous assessment. The overfished probability (upper panel) presented in this figure accounts for the positive correlation between the reference point ($\frac{B_{1999}}{4}$) and the biomass in 2015, which results in a probability of overfished status that is less than the apparent overlap between the two distributions. The current $F_{Threshold}$ is a point estimate and uncorrelated to F_{2015}. Therefore, the probability of overfishing was equal to the probability of overlap between the distribution of F_{2015} and the point estimate of $F_{threshold}$.

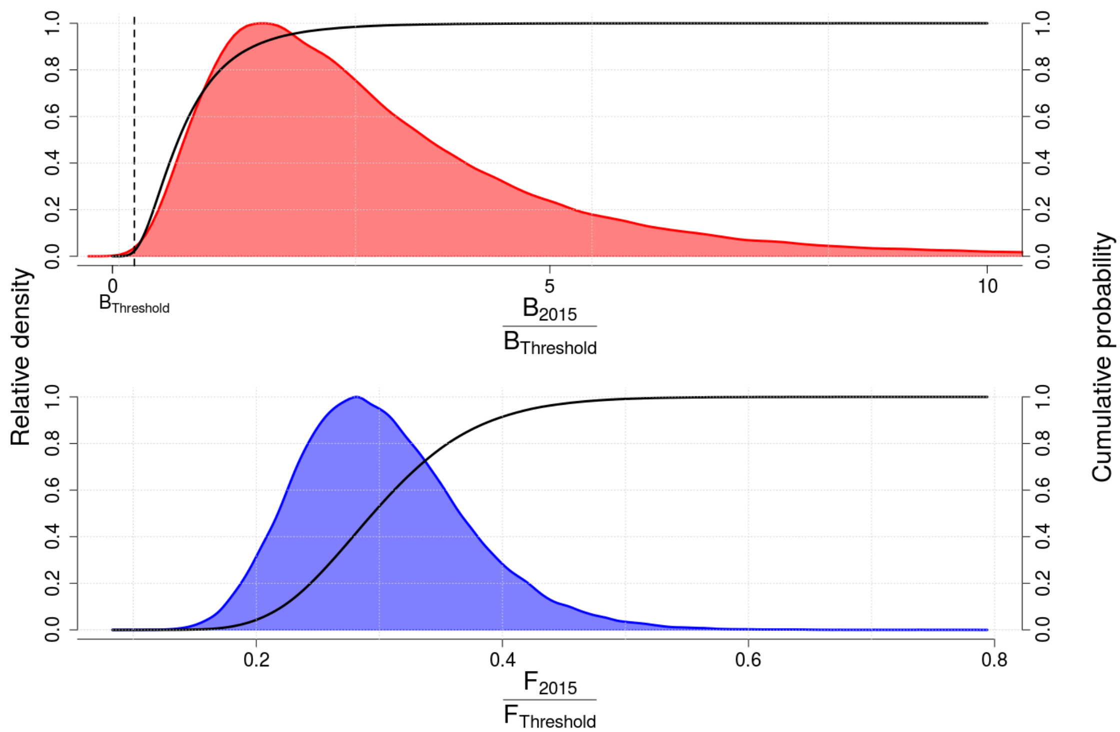

Figure 153: Probability distributions of $\frac{B_{2015}}{B_{Threshold}}$ and $\frac{F_{2015}}{F_{Threshold}}$, using the recommended reference points. The probability of overfished status during 2015 is equal to the area of the red, upper curve that is less than $B_{Threshold}$. The probability of overfishing status during 2015 is equal to the area of the blue, lower curve that is greater than $F_{Threshold}$. The probability of overfished and overfishing status can be approximated by the elevation (y axis scale) at which the solid line representing the cumulative probability distribution crosses the dashed vertical line representing the reference point in each plot. The probability distributions presented in this figure account for the positive correlation between the reference points ($B_{Threshold} = \frac{B_0}{4}$ and $F_{OFL} = F_{Threshold} = F^* \frac{F_{MSY}}{F^*_{Max}}$) and the fishing mortality and biomass estimates in 2015, as well as the uncertainty in the estimation of both the point estimates and their respective reference points.

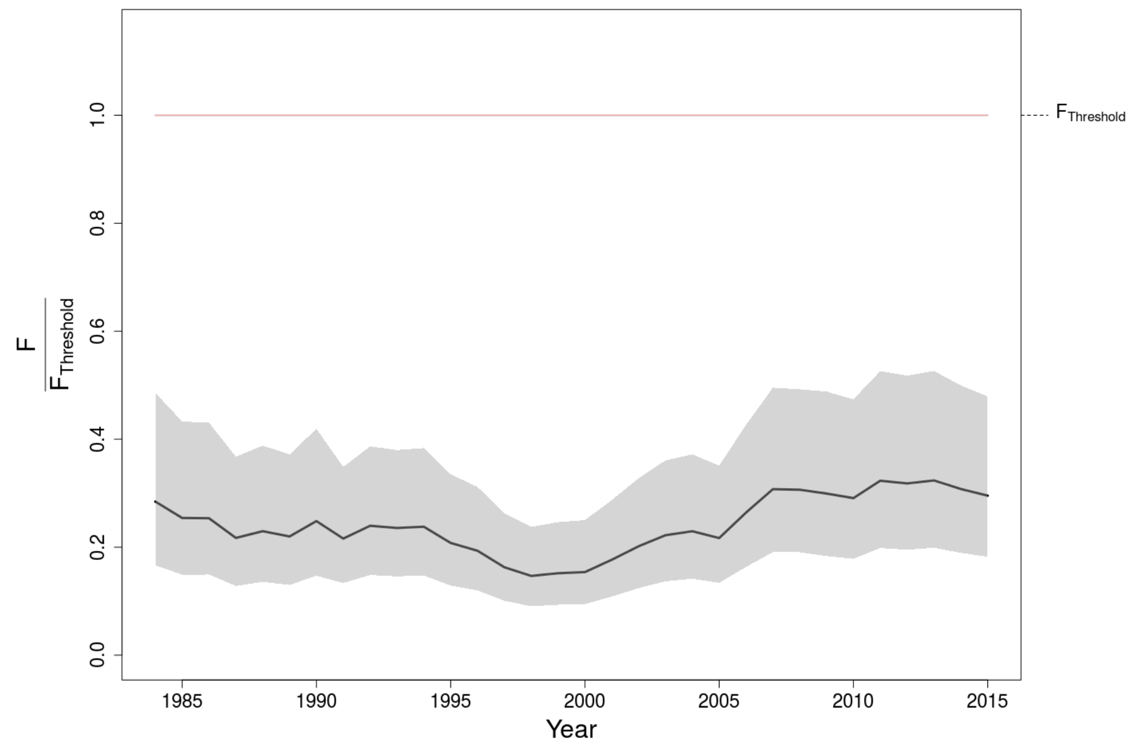

Figure 154: The time series of the ratio of fishing mortality estimates to the recommended F threshold, with the 95% confidence interval. The confidence interval accounts for the correlation between F and $F_{Threshold}$. Over fishing would occur if the ratio exceed 1.0.

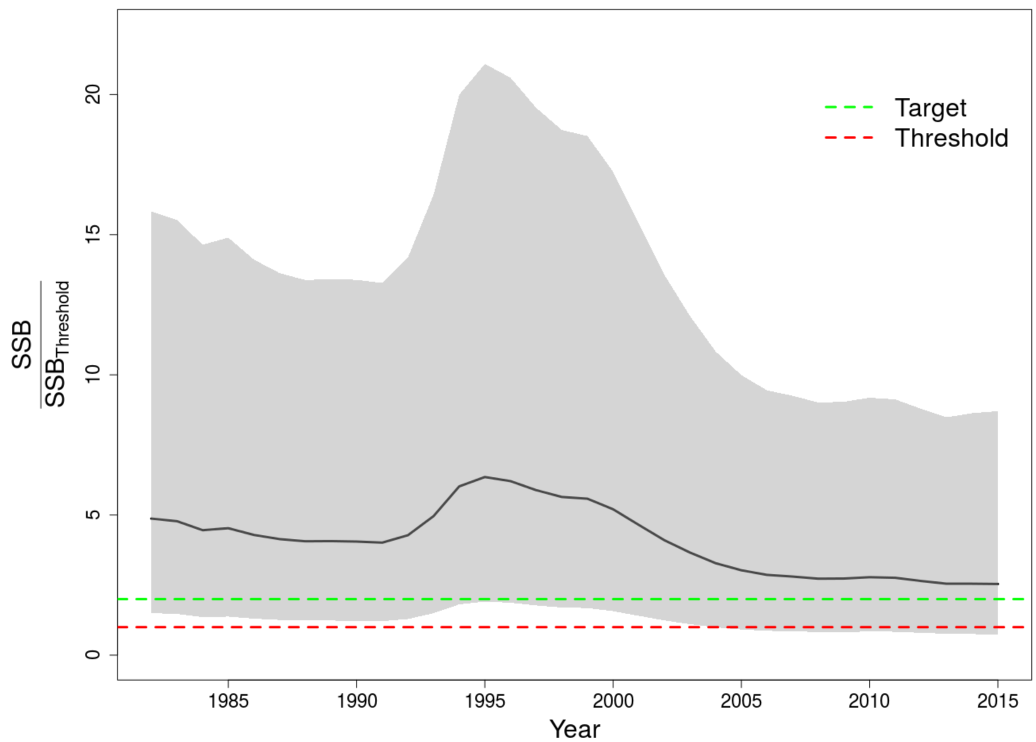

Figure 155: The time series of the ratio of biomass estimates to the unfished biomass (B_0), with the 95% confidence interval. The confidence interval accounts for the correlation between B and B_0. Overfished status would occur if the ratio went below 0.25.

Part IX

TOR 8: Projections

Basecase models were used to project biomass of Atlantic surfclam, catch (mt), and fully recruited fishing mortality in both areas, and in the combined stock during 2016-2025 (Tables 30 - 31 and Figure 156). Three harvest policies were assumed: 1) $F = F_{Threshold} = F_{OFL}$ (F at the OFL), 2) status quo catch (20333 mt) and 3) the maximum allowed catch under the current FMP or "quota level" catch (29364 mt) in the combined areas. Results indicate that biomass will remain higher than the biomass threshold and projected fishing mortality levels will be lower than the fishing mortality threshold for the entire resource.

Projection calculations were carried out in SS3 for the two areas using basecase models. Results for the whole stock were derived by combining projections for the northern and southern areas. Thus, the distribution of catches, relative growth rates, etc., were the same as in the terminal years of the base case models. Catches were landings multiplied by 1.12 to account for assumed 12% incidental mortality. Catches during 2016 were assumed the same as during 2015. For lack of better information, catches in the northern area during 2016-2025 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.

Projections for each year assumed time series average recruitment with uncertainty in starting stock size equal to the uncertainty in the final (non-forecast) model year (Figure 157). Projected total catch for the combined area was obtained by adding catches estimates for the southern and northern areas. Fishing mortality for the combined area (whole stock) was computed as the geometric mean (see Appendix XX) of the F from each area (calculated separately for each catch scenario). Overfishing status determination in each year (y) for the combined area was computed as $\frac{F_y}{F_{Threshold}} = \frac{F_y}{F^* \frac{F_{MSY}}{F^*_{Max}}}$ (see VII), where F^* was the mean F for the whole stock between 1982 and 2015 (Table 31). Whole stock spawning stock biomass was the sum of the spawning stock biomass from each area. These were considered unreliable due to scale uncertainty and are only included to document the calculation of projected catch at the OFL. Whole stock status ratios were the geometric mean of the status ratios from each area. Overfished status ratios were computed as $\frac{SSB_y}{SSB_{Threshold}} = \frac{SSB_y}{0.25 SSB_0}$.

It is unlikely 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. The distributions of SSB_y and $SSB_{Threshold}$ were assumed log normal with means equal to their respective point estimates and variances equal to their delta method variances. One million draws from 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 SSB_y and $SSB_{Threshold}$ estimated in the model. 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 (Shertzer et al. 2008). The probability of the whole stock being overfished was low for all projection scenarios considered (Figure 159).

The most likely fishing scenario is probably status quo catch, because the fishery is market limited and has been catching less than the quota since 2004 (Table 2). The quota scenario with higher catches was therefore a reasonable upper bound on likely fishing pressure over the next ten years. Using the quota scenario, the maximum probability of being overfished in any one year in next five (P^*) was low (Figure 159) and the cumulative probability of being overfished at any time during the next ten years ($1 - \prod_y \{1 - p_y^*\}$) (Table 32), where p_y^* is the P^* value for each year was also low (see Shertzer et al. (2008)).

Projected fishing mortality levels are lower than the fishing mortality threshold for the entire resource under all scenarios except $F = F_{OFL}$ for each of the stock areas (Figure 158; Table 31). The cumulative probability of experiencing overfishing using the status quo catch or quota scenarios in any of the projection years was also low (Table 32).

In order to test the sensitivity of the projections to uncertainty in biomass scale, as well as model specification, quota scenario projections were conducted using the sensitivity runs with the lowest and highest biomass scale from VI ("NoQPriors" and "EstimateM" for the southern area; see Figure 136). For the northern area the sensitivity runs with the lowest scale were the runs that excluded the MCD survey and the scale was too low to be creditable. Projection sensitivities for the northern area were run with the two models with the highest and lowest creditable scales ("HighRecrVariance" and "WeightRD"; see Figure 145). Projecting forward using the status quo catch scenario with these sensitivity runs showed that probabilities of overfishing and overfished status for the southern, northern and whole stock areas were similar in projection over a wide range of initial biomass scales (Table 34). The projection sensitivity results indicate that the status of the stock over the projected time horizon is robust to uncertainty in biomass scale, when recruitment remains near time series average values.

Probability distributions of the catch at the OFL were generated by repeated draws from a lognormal distribution of catch in each year, with a mean equal to the point estimate of the catch and a cv equal to the model estimated cv for each catch value (Figures 160 - 162; Table 33).

Table 30: Projected spawning stock biomass (1000 mt) and biomass status ($\frac{SSB}{SSB_{Threshold}}$, where $SSB_{Threshold} = 0.25SSB_0$) during 2016-2025 for Atlantic surfclam in the southern, northern and combined areas. The biomass estimates from basecase models in the top panel are very uncertain and shown only to document calculation of the more reliable status ratios in the lower panel.

	Southern area			**Northern area**			**Whole stock**		
Year	Status Quo	Quota	F=FOFL	Status Quo	Quota	F=FOFL	Status Quo	Quota	F=FOFL
				SSB (1000 mt)					
2016	2937	2937	2937	396	396	396	3333	3333	3333
2017	2900	2894	2855	358	356	356	3258	3251	3212
2018	3002	2991	2914	329	325	326	3331	3316	3240
2019	2979	2963	2853	316	311	313	3295	3274	3166
2020	2983	2962	2823	309	302	305	3291	3264	3128
2021	3044	3020	2854	305	298	302	3349	3318	3156
2022	3113	3085	2897	327	319	324	3440	3404	3220
2023	3180	3149	2940	351	342	347	3531	3491	3287
2024	3243	3210	2982	375	365	371	3618	3575	3353
2025	3302	3267	3021	398	388	393	3701	3654	3414
				$\frac{SSB}{SSB_{Threshold}}$					
2016	3.24	3.24	3.24	2.04	2.04	2.04	2.57	2.57	2.57
2017	3.33	3.32	3.30	2.30	2.29	2.29	2.76	2.76	2.75
2018	3.41	3.41	3.37	2.52	2.51	2.51	2.93	2.92	2.91
2019	3.48	3.48	3.42	2.71	2.70	2.70	3.07	3.06	3.04
2020	3.55	3.54	3.47	2.87	2.86	2.86	3.19	3.18	3.15
2021	3.60	3.59	3.51	3.02	3.00	3.01	3.30	3.28	3.25
2022	3.65	3.64	3.55	3.14	3.12	3.13	3.39	3.37	3.33
2023	3.69	3.68	3.58	3.25	3.22	3.23	3.46	3.44	3.40
2024	3.73	3.71	3.60	3.34	3.31	3.32	3.53	3.50	3.46
2025	3.76	3.74	3.63	3.42	3.39	3.40	3.58	3.56	3.51

Table 31: Projected catch (landings + incidental mortality; mt) and fishing mortality status ratio $\frac{F}{F_{Threshold}}$ during 2016-2025 for Atlantic surfclam in the southern, northern and combined areas. $\frac{F}{F_{Threshold}}$ for the northern area was not possible due to a lack of the exploitation history required to generate an area specific fishing mortality threshold.

	Southern area			**Northern area**			**Whole stock**		
Year	Status Quo	Quota	F=FOFL	Status Quo	Quota	F=FOFL	Status Quo	Quota	F=FOFL
				Catch (mt)					
2016	15771	22610	68725	4562	6753	6444	20333	29363	75169
2017	15771	22610	69447	4562	6753	5917	20333	29363	75364
2018	15771	22610	69332	4562	6753	5527	20333	29363	74859
2019	15771	22610	68981	4562	6753	5279	20333	29363	74260
2020	15771	22610	68930	4562	6753	5201	20333	29363	74131
2021	15771	22610	69328	4562	6753	5288	20333	29363	74615
2022	15771	22610	70044	4562	6753	5503	20333	29363	75547
2023	15771	22610	70914	4562	6753	5793	20333	29363	76707
2024	15771	22610	71818	4562	6753	6113	20333	29363	77931
2025	15771	22610	72684	4562	6753	6431	20333	29363	79115
				$\frac{F}{F_{Threshold}}$					
2016	0.227	0.326	0.999				0.372	0.543	0.927
2017	0.222	0.319	0.999				0.382	0.560	0.927
2018	0.219	0.315	0.999				0.393	0.577	0.927
2019	0.217	0.314	0.999				0.400	0.590	0.927
2020	0.215	0.311	0.999				0.401	0.593	0.927
2021	0.212	0.307	0.999				0.395	0.585	0.927
2022	0.208	0.302	0.999				0.383	0.569	0.927
2023	0.205	0.296	0.999				0.370	0.550	0.927
2024	0.201	0.291	0.999				0.357	0.530	0.927
2025	0.198	0.286	0.999				0.345	0.513	0.927

Table 32: Cumulative probability of being in overfished status in any of the years from 2016-2025 under a variety of catch scenarios for Atlantic surfclam in the southern, northern and combined areas. Overfishing determination for the northern area was not possible due to a lack of the exploitation history required to generate an area specific fishing mortality threshold.

Catch scenario	$P[Overfished]$	$P[Overfishing]$
Southern area		
Status Quo	0.006	0.001
Quota	0.007	0.008
F=FOFL	0.010	0.526
Northern area		
Status Quo	0.107	
Quota	0.114	
F=FOFL	0.110	
Whole stock		
Status Quo	0.091	0.094
Quota	0.091	0.243
F=FOFL	0.100	0.502

Table 33: Estimated catch (landings + incidental mortality; mt) at the Over Fishing Limit (OFL) from 2016-2025 for Atlantic surfclam in the southern, northern and combined areas. OFL for the northern area was an approximation due to a lack of the exploitation history required to generate an area specific fishing mortality threshold.

Year	Mean	Median	CV
Southern area			
2016	70590	68712	0.23
2017	71339	69489	0.23
2018	71214	69302	0.24
2019	70988	68987	0.24
2020	71101	68961	0.25
2021	71646	69341	0.26
2022	72454	70045	0.26
2023	73301	70881	0.26
2024	74177	71829	0.26
2025	75017	72708	0.25
Northern area			
2016	7389	6442	0.56
2017	6787	5915	0.56
2018	6339	5526	0.56
2019	6084	5288	0.57
2020	5998	5197	0.58
2021	6112	5288	0.58
2022	6375	5508	0.58
2023	6706	5800	0.58
2024	7068	6107	0.58
2025	7425	6434	0.58
Whole stock			
2016	88105	75222	0.61
2017	88290	75435	0.61
2018	87690	74833	0.61
2019	87307	74299	0.62
2020	87541	74094	0.63
2021	88405	74554	0.64
2022	89728	75569	0.64
2023	91085	76744	0.64
2024	92360	78001	0.64
2025	93465	79109	0.63

Table 34: Projected stock status ($\frac{SSB}{SSB_{Threshold}}$ and $\frac{F}{F_{Threshold}}$) during 2016-2025 for Atlantic surfclam in the southern, northern and combined areas from projections based on the highest and lowest (in biomass scale) of credible sensitivity runs for each area. Overfishing determination for the northern area was not possible due to a lack of the exploitation history required to generate an area specific fishing mortality threshold.The results indicate that projected stock status is reasonably robust to biomass scale uncertainty.

	Southern area		**Northern area**		**Whole stock**	
Year	High Biomass	Low Biomass	High Biomass	Low Biomass	High Biomass	Low Biomass
			$\frac{SSB}{SSB_{Threshold}}$			
2016	3.072	2.954	1.611	2.532	2.225	2.735
2017	3.226	3.073	1.924	2.716	2.491	2.889
2018	3.350	3.169	2.196	2.875	2.712	3.018
2019	3.450	3.252	2.432	3.012	2.897	3.130
2020	3.531	3.323	2.636	3.130	3.051	3.225
2021	3.596	3.385	2.812	3.233	3.180	3.308
2022	3.650	3.438	2.964	3.321	3.289	3.379
2023	3.694	3.484	3.095	3.396	3.381	3.440
2024	3.730	3.524	3.209	3.461	3.460	3.492
2025	3.761	3.558	3.307	3.517	3.526	3.537
			$\frac{F}{F_{Threshold}}$			
2016	0.360	0.358			0.385	0.673
2017	0.358	0.353			0.402	0.702
2018	0.358	0.351			0.419	0.735
2019	0.357	0.348			0.431	0.766
2020	0.353	0.343			0.432	0.789
2021	0.346	0.336			0.422	0.798
2022	0.337	0.327			0.405	0.792
2023	0.329	0.319			0.385	0.779
2024	0.321	0.311			0.366	0.761
2025	0.314	0.304			0.349	0.744

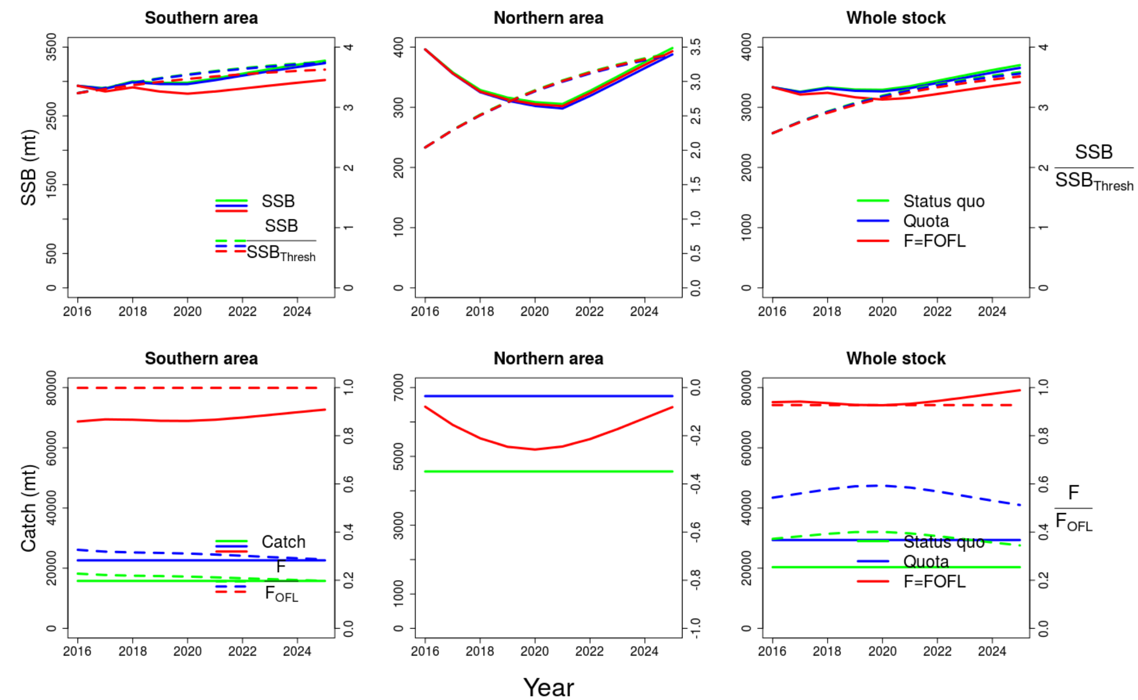

Figure 156: Projections using three different catch scenarios in the southern, northern and whole stock areas. The upper row of plots show the biomass trends over time (solid lines) and the ratio of biomass to biomass threshold (dashed lines). The lower plots show the landings (solid lines) and the ratio of F to F_{OFL}. In all plots the status quo catch scenario is green, the quota catch scenario is blue and the $F = F_{OFL}$ scenario is red. Determination of $\frac{F}{F_{OFL}}$ for the northern area was not possible due to a lack of the exploitation history required to generate an area specific fishing mortality threshold.

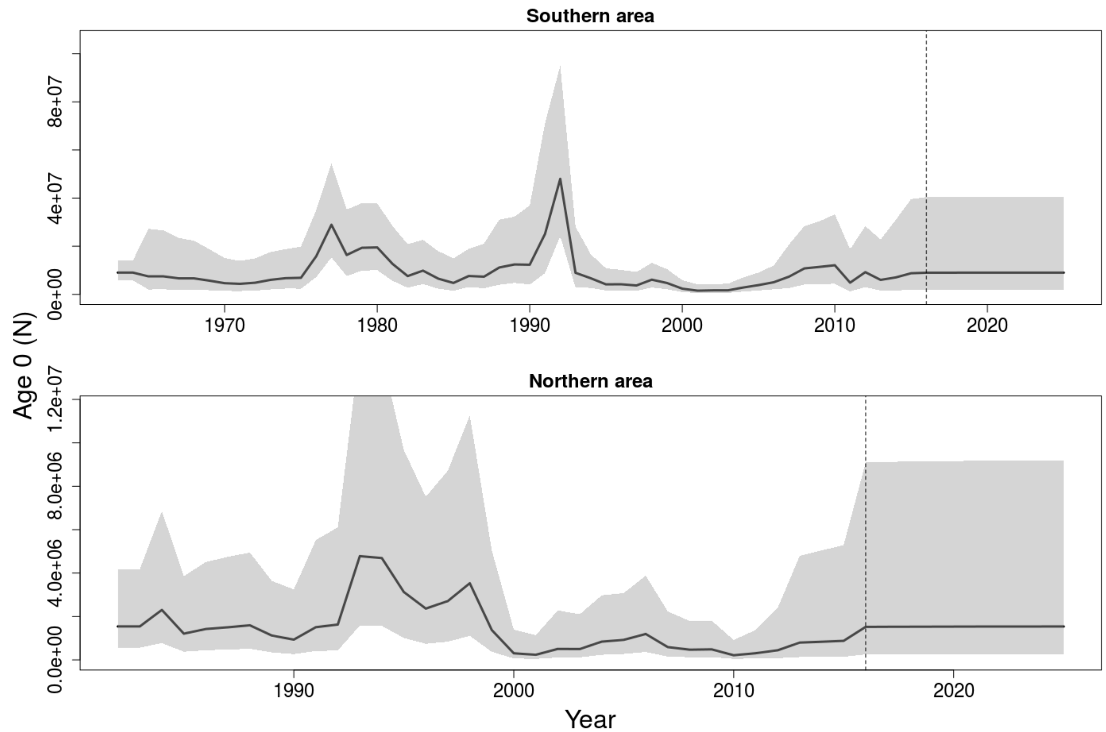

Figure 157: Forecast and time series recruitment estimates for the southern, and northern areas. Projections begin at the vertical dashed line. Note the different ranges of the vertical axes.

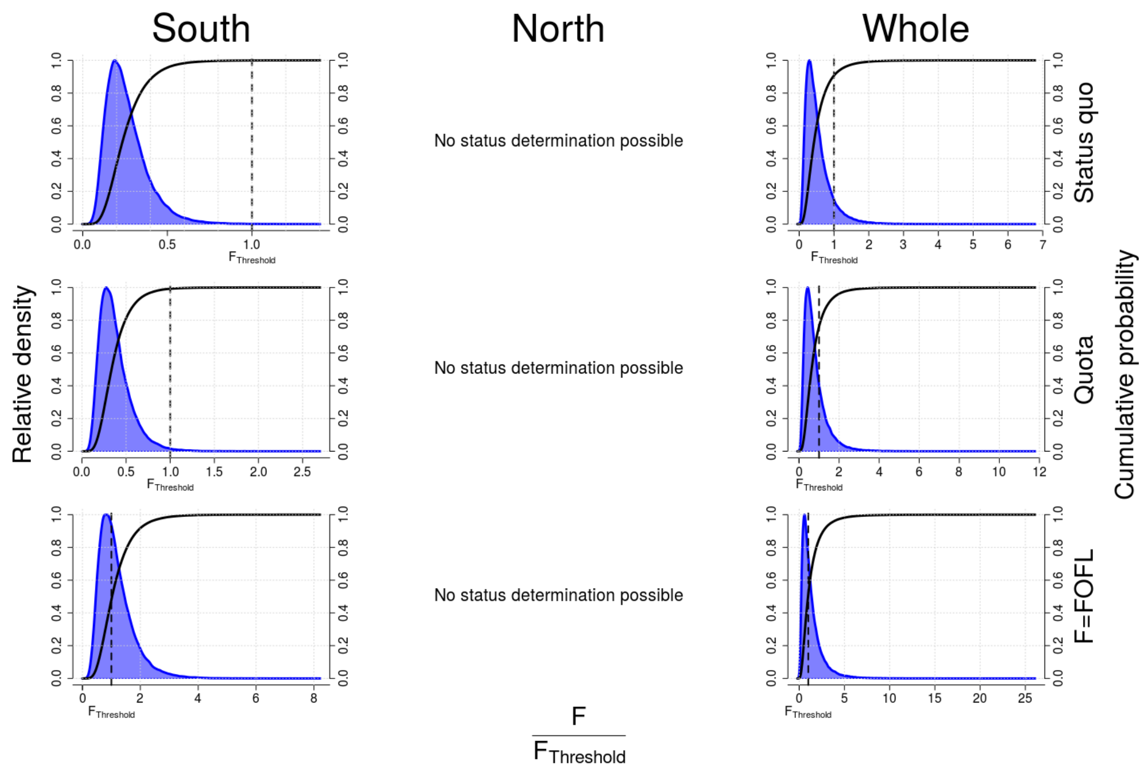

Figure 158: Probability of overfishing status for Atlantic surfclam during the projection year with the highest F from 2016-2025. The different catch scenarios are in rows and the different areas are in columns. Determination of F_{OFL} for the northern area was not possible due to a lack of the exploitation history required to generate an area specific fishing mortality threshold.

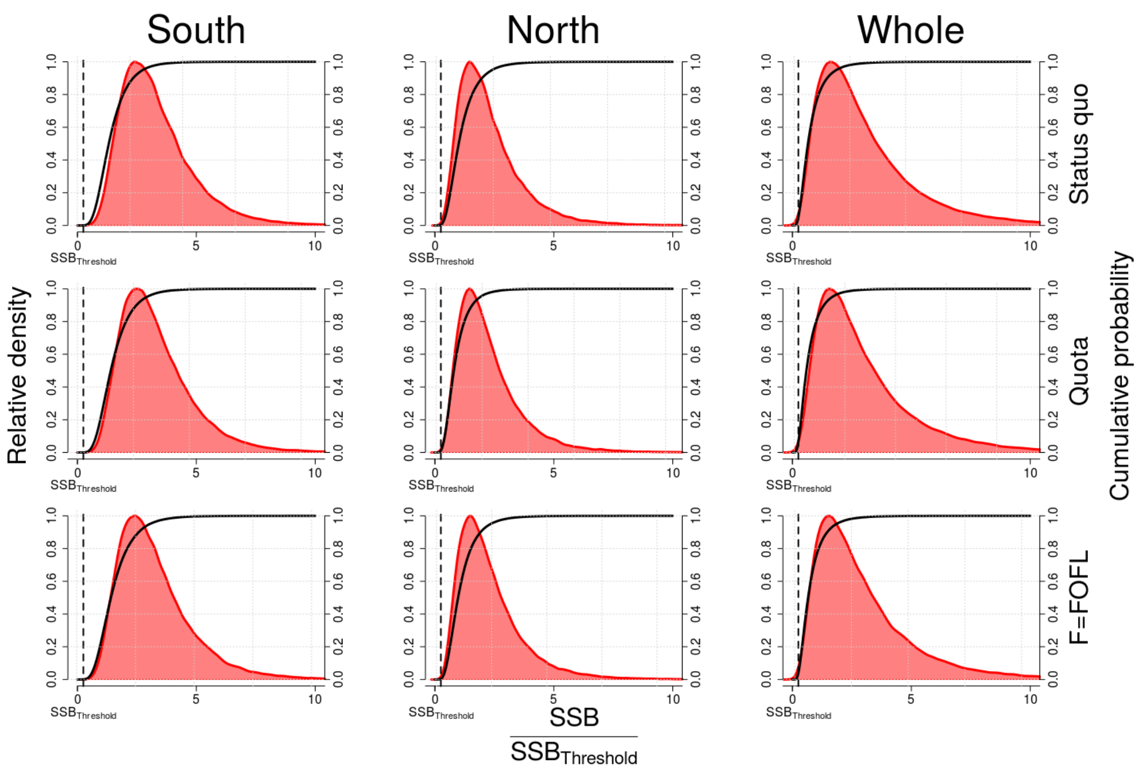

Figure 159: Probability of overfished status for Atlantic surfclam during the projection year with the lowest biomass from 2016-2025. The different catch scenarios are in rows and the different areas are in columns.

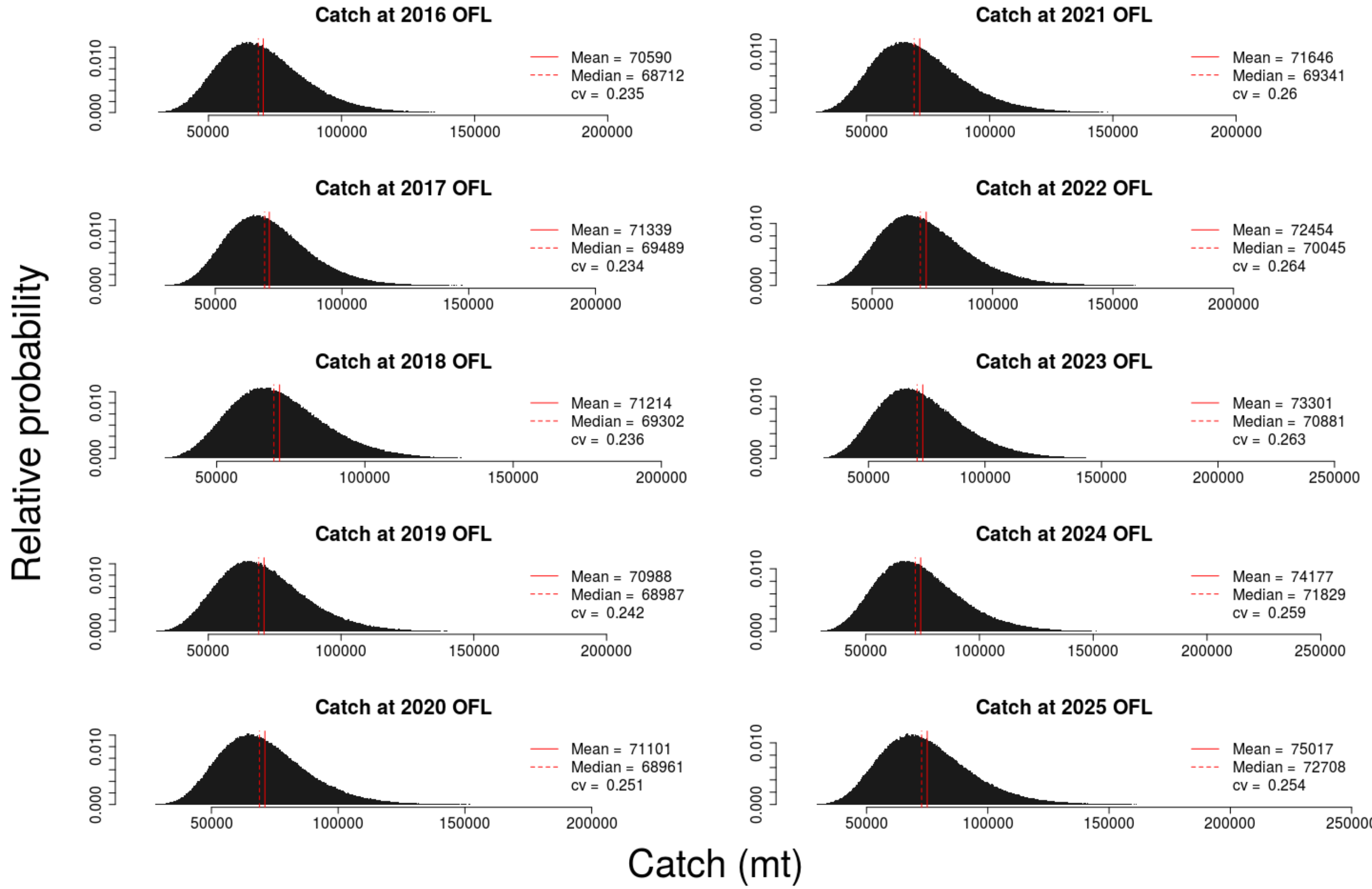

Figure 160: Distribution of catch (landings + incidental mortality) at the Over Fishing Limit (OFL) from 2016-2025 for Atlantic surfclam in the southern area.

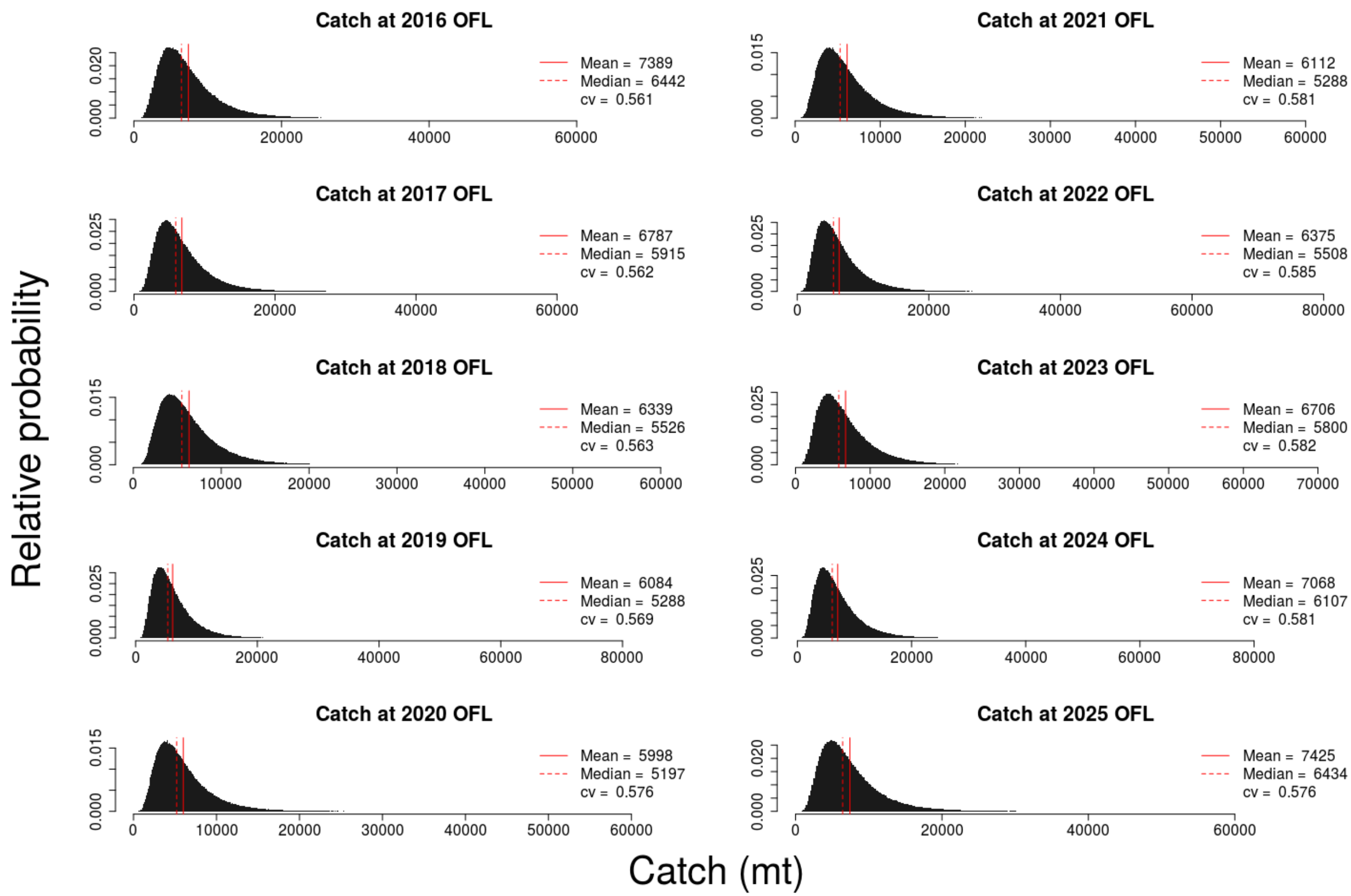

Figure 161: Distribution of catch (landings + incidental mortality) at an approximation of the Over Fishing Limit (OFL) from 2016-2025 for Atlantic surfclam in the northern area. There was not sufficient catch history to generate an OFL for the northern area, so one was approximated based on the average F during years in which fishing occurred.

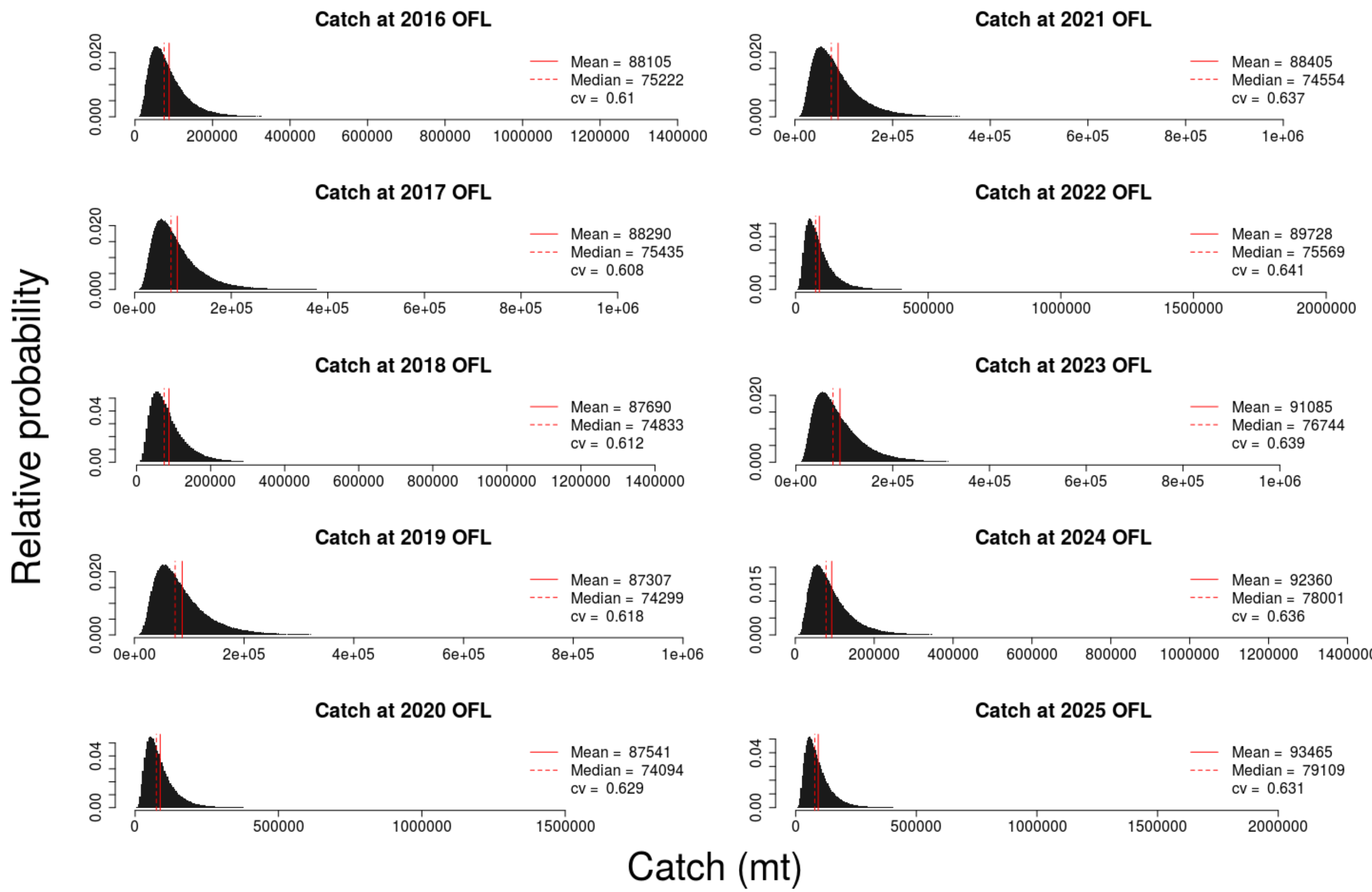

Figure 162: Distribution of catch (landings + incidental mortality) at the Over Fishing Limit (OFL) from 2016-2025 for Atlantic surfclam in the whole stock.

Part X

TOR 9: Stock definitions

Atlantic surfclam are assumed in the fishery management plan to be one unit stock throughout their range in US waters. The stock assessment workgroup discussed stock definitions of Atlantic surfclam at length during the last assessment (SAW 56) without reaching consensus. After reviewing all of the information presented, the SARC 56 review panel, "could not and did not choose to draw any conclusions as to whether a one- or two-stock definition was appropriate (SARC 56, 2013)." Ideas and arguments about Atlantic surfclam stock structure were summarized in two tables for SAW 56 which are also presented in this report (Figures 163 and 164).

The validity of the current stock definition was discussed by the working group briefly again in this assessment without reaching consensus. Opinions on this issue are strongly divided between industry-supported academic scientists and other members. As a result, the working group was unable to develop consensus recommendations as to whether there is a need to modify the current stock definition. Most of the stock definition discussion to date has focused on whether Georges Bank should be treated as a separate stock, both because it tends to be reproductively isolated due to persistent oceanographic conditions, and because it is unique based on the biological and fishery factors listed in Figure 163.

Below, the workgroup chair has summarized opinions of the assessment workgroup for purposes of addressing this TOR. Working group members agree that Atlantic surfclam consists of two or more meta-populations with different population dynamics, degrees of connectivity, fishery, exploitation, recruitment, post-settlement survival, growth rates, and shell height-meat weight patterns. However, some working group members view these differences as clinal and suggest that stock distinctions could be drawn in other places or not at all. They suggest that flexibility and lack of potential constraints on fishing activity are the most important benefits from the one stock approach. The multi-stock approach could lead to management constraints on the fishery that might not be necessary.

Other workgroup members noted that reference points like F_{MSY} and B_{MSY} are not well defined for heterogeneous stocks with independent population dynamics. Proxy reference points might not protect either population unit or maximize yield when used by the Council's SSC to set catch and landings limits intended to prevent Atlantic surfclam from being overfished, or overfishing from occurring. Stock conditions may suffer overall because problems in one area will be masked by conditions in the other. As shown in MSE analyses for Atlantic surfclam in this assessment (see XIX) and in other studies, yield is reduced at F_{MSY} because productive areas in good condition may be fished too lightly while unproductive areas in poor condition may be fished too hard. These disadvantages are pronounced and likely to be important if fishing mortality rates approach or exceed F_{MSY}.

All members of the workgroup agree that stock definitions are unlikely to affect management, yield, or biological risk in the near term as long as fishing mortality rates remain low and overall abundance and biomass are relatively high.

The single stock assumption complicates and adds uncertainty to stock status determinations based on current and recommended reference points because biomass trend estimates for the whole stock are sensitive to independent errors in estimating scale for each area. Stock status conclusions in this assessment were robust to this problem because stock size was relatively high in both areas such that overfished status and overfishing were unlikely in either.

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)

Figure 163: Points made to support splitting the Atlantic surfclam into two stocks with counterpoints (Copied directly from Table A17 in (Northeast Fisheries Science Center 2013)). 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 stock in the north would be separated from the rest of the resource in the south. Points made to support the status quo and counterpoints are listed in Figure 164. The tables presented here have not been updated with any new information since the last assessment.

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.

Figure 163 cont.

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.	

Figure 163 cont.

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

Figure 164: . Points made to support maintaining the status-quo (single) stock definition for Atlantic surfclam, with counterpoints (copied from Table A18 in (Northeast Fisheries Science Center 2013)). The status quo is a single stock and the alternative is two stocks with the break just southwest of Georges Bank.

Part XI

TOR 10: Research recommendations

The following are research recommendations from the previous assessment, in no particular order:

1. Determine the best spatial and temporal distribution to use for Atlantic surfclam assessment models.

   There have been no changes in stock definition, but the consensus of the assessment working group is that two areas modeled independently (northern area and southern area) with the results combined is the best configuration for stock assessment.

2. Biomass reference points need to be reconsidered.

   The SS3 model used for the assessment estimates B_0 for both southern and northern areas upon which biomass reference points can be based. See discussion of reference points in VII.

3. Has Atlantic surfclam biomass shifted offshore into deeper water over time?

   Sections XXII and XXIII address this question analytically.

4. Look into a better way to implement regime change into the SS3 model. Look into patterns which may match other species and climate indices.

   Model sensitivity runs for the southern area were done with two possible growth stanzas. The model did estimate decreased growth in the second stanza, but the differences in outcome were negligible. See VI for details.

5. Look at habitat on Georges Bank

   Section XXIV lists methods explored in order to better determine the Atlantic surfclam habitat in the northern area that can be sampled effectively with a hydraulic clam dredge. These approaches will become available when stratification of the survey is reconsidered in the coming year. The working group agreed that the current approach was adequate for now.

New research recommendations, in no priority order:

1. Include Nantucket Shoals in the surveyed area for Atlantic surfclam.
2. Re-stratify northern area to make the survey more efficient and effective.
3. Examine coefficients used to convert commercial catches in bushels to meat weights.

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Part XII

Appendix: Atlantic surfclam assessment working group members

The working group met February 1-3, March 28-30 and May 31-June 2 at the NEFSC in Woods Hole, MA to work on the Atlantic surfclam stock assessment. Members, contributors and attendees are listed alphabetically below.

Working group:

Jessica Coakley (MAFMC)
Bob Glenn (Mass. DMR)
Dan Hennen (NEFSC, Assessment Lead)
Tom Hoff (Wallace and Associates)
Larry Jacobson (NEFSC, Subcommittee Chair)
Roger Mann (VIMS)
Daphne Munroe (Rutgers)
Eric Powell (University of Southern Mississippi)

Contributors/attendees:

Tom Alspach (SeaWatch International)
Nicole Charriere (NEFSC)
Toni Chute (NEFSC)
Wendy Gabriel (MAFMC SSC, NEFSC)
Scott Gallagher (WHOI)
Jon Hare (NEFSC)
Deborah Hart (NEFSC)
Robert Johnston (NEFSC)
Chris Legault (NEFSC)
Michael Martin (NEFSC)
Vic Nordahl (NEFSC)
Jeff Normant (NJ DFW)
Loretta O'Brien (NEFSC)
Jennifer O'Dwyer (NY DEC)
Doug Potts (GARFO)
Mark Terceiro (NEFSC)
Dave Wallace (Wallace and Associates)
Jim Weinberg (NEFSC)

Part XIII

Appendix: Changes to assessment inputs

Commercial

The commercial length compositions were altered from the last assessment. The length compositions come from samples taken from landed catch (port samples). Each port samples consists of approximately 25 lengths (selected randomly) per landed catch from a single boat (trip). Boats are randomly selected from the vessels available on the day of sampling. Port samples are designed to be roughly proportional to the landings from each region. Port samples are systematic relative to time (evenly distributed over each quarter). The port sampler also collects information from the vessel landings sampled, including the approximate location of the area fished and the weight of the total landings.

In the 2013 assessment (Northeast Fisheries Science Center 2013), each port sample was attributed to a region (using the location data) and then the pooled proportion at length (averaging over all samples) from each region were expanded by the total landings from that region in that year.

$$\hat{P}_{r,y,l} = P_{r,y,l} C_{r,y}$$

where $\hat{P}_{r,y,l}$ was the expanded proportion at length (l), in region (r) and year (y), $P_{r,y,l}$ was the unexpanded proportion and $C_{r,y}$ was the catch by region and year. In order to get the length composition for the southern area, the $\hat{P}_{r,y,l}$ were summed over the regions that compose the southern area (SVA to SNE). The length compositions did not sum to one but that is not important for the assessment model which requires relative, but not true proportions.

The implied assumption of expanding the length composition by total landings in a region is that the port samples are randomly distributed in time and space relative to the landings from a region (random stratified sampling where the strata are the regions). Because the vessels selected for port sampling are randomly selected, random selection relative to space within a region is probably a reasonable assumption. Port samples are systematic relative to time however (they are stratified by quarter year), which is a violation of random selection relative to time. Therefore, it may be better to use cluster sampling techniques (see Cochran (1977)). Port samples are subsamples of samples (a single trip of many trips taken that quarter and landed at that port). They can be considered as 2 stage cluster samples (Cochran 1977). The estimate of the population mean is unbiased when the second stage sampling units are chosen with equal probability. The estimate of the population mean consists of a simple ratio based expansion, where the subsample is expanded to reflect the size of total sample from which it was drawn.

In the new assessment, the $P_{r,y,l}$ were expanded by the weight of the haul from which they came and then summed over each region and year (similar to the process for calculating a weighted average).

$$\hat{P}_{r,y,l} = \sum_{y} \sum_{r} P_{v,l} C_v$$

where $P_{v,l}$ and C_v are the vessel specific proportions and landings, respectively. Weight was the unit of measure chosen because the total number of animals landed was not recorded.

The change had the strongest effect on commercial catch at length during 1995 - 1999 and very little effect in most other years (Figure 165). 1995 - 1999 were years with relatively few port samples taken from relatively few regions.

Survey

The change to a cooperative survey using the *FV Pursuit* beginning in 2012 affected the way random tows from adjacent years were borrowed to fill holes (strata with no random tows) during 2011 and 2013 for calculation of abundance indices. In particular, it was not possible to use 2011 tows to fill 2012 holes or vice-versa because different vessels, gear and protocols were used starting in 2012. In addition, the new survey in 2012 and 2015 was meant to exclude the northern area while the survey in 2013 was meant to be on the northern area only. The 2014 survey was used primarily for gear testing and only a few strata were sampled in random survey mode. Survey data for 2012 and 2015 were therefore used to calculate abundance indices only for the southern area while survey data for 2013 was used to calculate abundance indices for the northern area only. No 2014 abundance indices were calculated. Therefore, northern area tows during 2013 were not borrowed to fill the intentional northern area 2012 holes although 2013 tows in other areas were used to fill 2012 holes. Northern area tows in 2014 tows were used to fill 2013 the northern area holes where necessary. The plan to survey areas south of the northern area in year one, survey the northern area in year two and take year three off was not followed perfectly during 2012-2014. It was followed in 2015 and is expected to be followed in future to the extent possible so that borrowing imputation and other approaches to filling holes are not necessary.

The ageing error vector in the assessment model was updated. The previous values could not be reproduced and the method used to generate them was unclear. The new values were based on the same data (with additional years added). The new ageing error vector was generated as a linear model fit to

$$\epsilon_a = sd(a_{prod,i,a} - a_{check,i,a})$$

where ϵ_a is the standard deviation of the ageing error for age a, $a_{prod,i}$ is the production age for individual i at age a and $a_{check,i,a}$ is the re-age of the same individual.

The standard deviation of ageing error increased with production age (Figure 166). The ageing error vector used in the assessment model was the linear fit to all of the non-zero ϵ_a. Because all zero values of ϵ_a had low sample sizes (Figure 167).

Figures

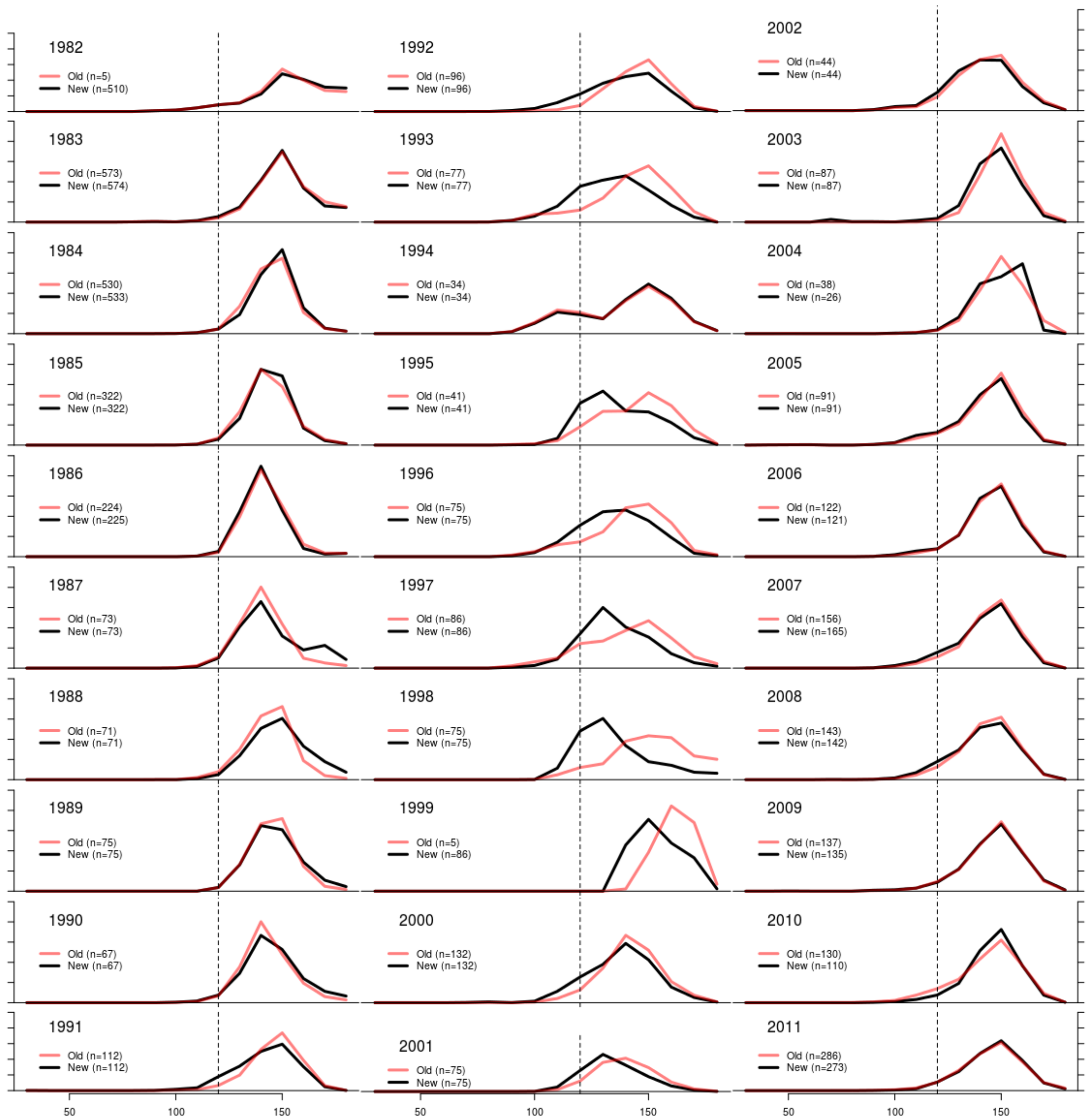


Figure 165: A comparison of the length compositions used on the surfclam assessment model in the last assessment (Old) vs. the current assessment (New). The x axis shows the shell length in mm and the y axis shows the relative frequency at each shell length. The sample sizes (n=) in the previous assessment are not the number of trips sampled (as in the current assessment). The sample sizes in the old assessment are the values used for data weighting of each component in the assessment. The vertical line at 120 mm is for reference only.

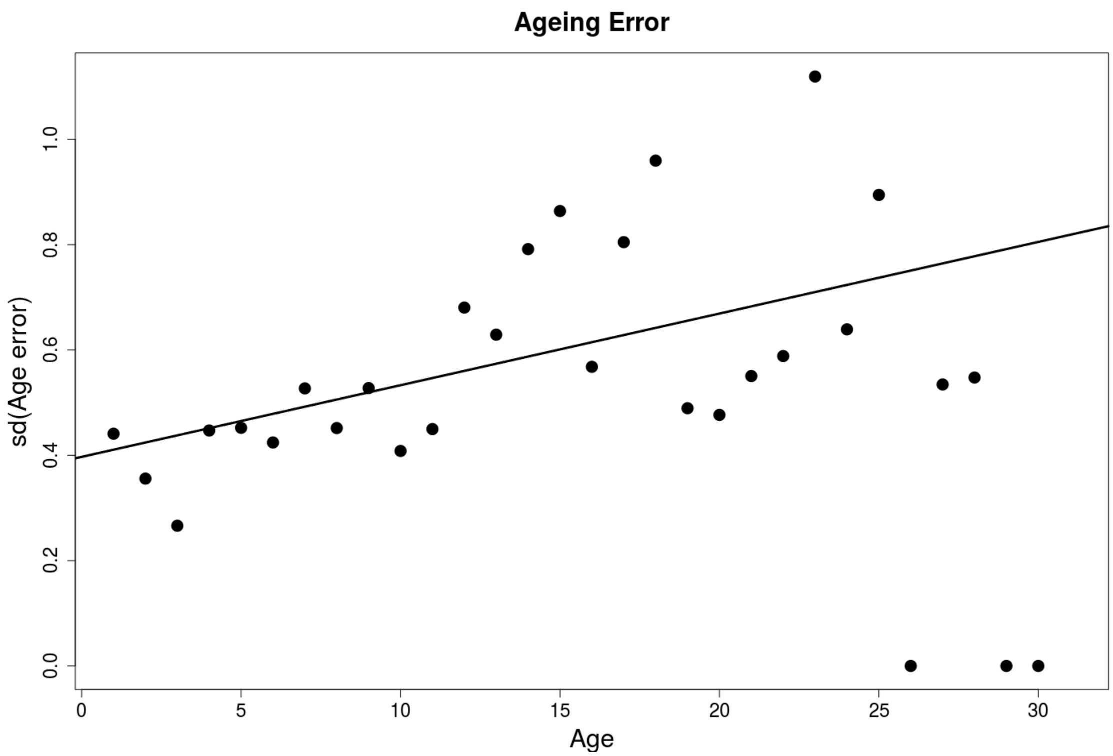


Figure 166: The standard deviation of the difference between production age and the re-age done to test ageing error against a linear fit.

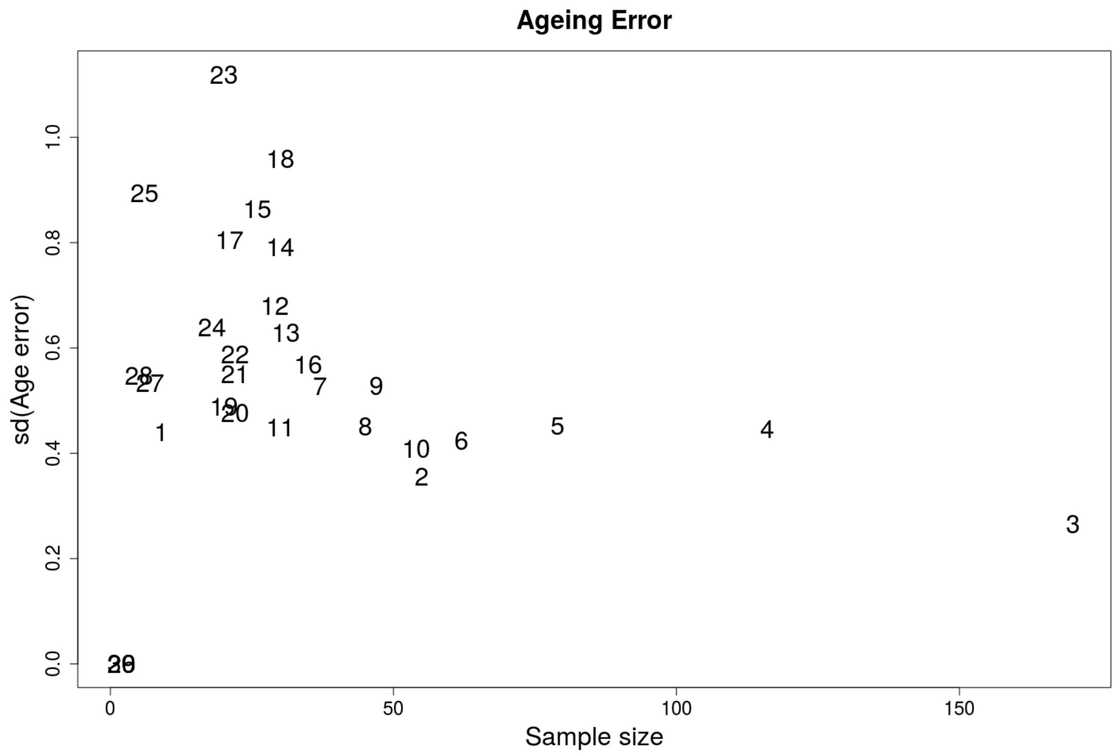


Figure 167: The sample size at age for standard deviation of the difference between production age and the re-age done to check ageing error. Each age is plotted as a numeral.

Part XIV

Appendix: Selectivity and assessment model performance

Introduction

In 2012 NMFS moved the clam survey from a research platform to a commercial one. All surveys previous to 2012 used a specially designed research dredge (RD). In 2012 the survey was conducted with a commercial dredge modified to retain smaller animals (MCD). The two dredges differ in selectivity (Figure 168) and efficiency (Figure 169). The MCD retains small animals at a reduced relative rate (lower selectivity at small sizes), and there was concern about loss of important information in future assessments.

Preliminary investigations of the data from the partial survey (4 of 6 regions were sampled) conducted with the MCD in 2012 show length composition similar to what would be expected based on selectivity. Comparing the length composition of the animals sampled by the MCD and RD reveal some differences between them (Figure 170).

The age composition of the animals surveyed with the MCD should not be as different from the age composition of those sampled with the RD (compared to length composition). The animals used for aging are stratified by length, which will mask selectivity differences because each length has representation in both dredges. Animals from the 2012 survey have not been aged so comparisons must be made based on the length of the animals that will be aged. So far, there appears to be some undersampling of small animals in the aging subsample (Figure 171). This issue bears watching as the survey continues in 2013.

There is no *apriori* reason to believe that the MCD will be less useful than the RD in providing informative data to the assessment. A reduced sample of a particular length should not theoretically pose a problem for the assessment model as long as the sample is representative of the general population and can be scaled up to population level values through selectivity. In fact, we expect that the increase in survey catchability should make the MCD a much more reliable tool for surveys.

Here, we examine the probable effects of changing dredges by comparing the results of the 2013 Atlantic surfclam assessment model (NEFSC 2013) with a mock model run using simulated MCD survey data. This exercise is intended to show how much the results of the current assessment would have differed had we conducted the survey from a commercial platform and used the MCD throughout the time series.

Methods

A SS3 model for the southern area (all regions south of GBK) was run using data from the 2013 Atlantic surfclam assessment, which was modified to simulate the MCD sampling properties as follows: 1) the selectivity of the survey index was altered, 2) the length composition data was altered and 3) the prior distribution on survey catchability was altered. All three of these changes represent likely differences in both data and model configuration corresponding to the shift in survey platform.

Selectivity

The assessment model used in the 2013 Atlantic surfclam assessment fixed (RD) selectivity at values estimated in a series of field experiments. Because we conducted selectivity experiments on the MCD simultaneously, we were able to substitute the field values estimated using the MCD for the values estimated using the RD (Figure 168).

Length composition data

Length composition data were altered as

$$L_{i,new} = L_{i,old} + (D_{s,i} * L_{i,old}) * c \tag{5}$$

where $L_{i,new}$ is the altered proportion at length for length bin i, $L_{i,old}$ is the proportion at length for length bin i used in the assessment, $D_{s,i}$ is the difference between the MCD selectivity, and RD selectivity for length bin i and c is a constant scaler used to increase the effect of the alterations (Table 35). The value of $c = 2$ was chosen to maximize the simulated effect of switching dredges. It would not be possible to increase the effect much further without losing some length classes entirely. It should be noted that (5) allows for both increases and decreases in the number of clams caught within a length bin. That is, for length bins in which the MCD catches clams at a higher rate than the RD, the number of animals in that length bin was increased. The opposite was true for length bins in which the MCD was less efficient than the RD (Table 35).

Prior on survey catchability

The prior on survey catchability was based on a log normal fit to variance weighted bootstrapped estimates of MCD efficiency (Figure 172). The estimates came from patch model analysis of depletion experiments. The methods used in patch model analysis are explained in Rago et al. (2006) and Hennen et al. (2012). The methods used in generating the prior distribution are explained in detail in Northeast Fisheries Science Center (2013).

Projections

The projection run examined here assumes that total catch will be equal to the average catch over the last 5 years. It also assumes that approximately 0.3 of the total catch will be fished in GBK and not the southern area. This scenario is identical to the "status quo" fishing scenario in the 2013 Atlantic surfclam assessment (Northeast Fisheries Science Center (2013)).

Results

The SS3 model using altered inputs converged and diagnostics did not indicate any problems. Differences between the model used in the 2013 Atlantic surfclam assessment and the current exercise in selectivity (Figure **??**), and fits to length composition data (Figures 170 and 175) were relatively minor. The scale, trend and terminal year status of estimated biomass was preserved with the altered inputs (Figures 176 and 177). Precision of the estimates improved with the altered data (Table 36). Conclusions about stock status with regard to fishing mortality were unchanged (Figures 176 and 177). Projections were somewhat more precise, but generally similar in trend, scale and probable stock status, to the projections from the 2013 Atlantic surfclam assessment (Table 36).

Discussion

The results of this exercise show that using data similar to what would have been observed had the survey always been conducted with the MCD produced assessment results that were similar to what was seen in the 2013 Atlantic surfclam assessment.

The expected effect of switching to the MCD on length composition was exaggerated in this study to make it a stringent test. In some cases, the length bin relative proportions were reduced by as much as 95% (Table 35). If the scaler c from 5 was increased much further we would have lost length classes all together, which would have made modeling difficult and reduced the comparability of the results. Setting $c = 2$ was considered to be a reasonable upper bound on the likely effects of switching dredges.

The increase in precision of this model over the 2013 assessment model is potentially spurious and may result from the somewhat artificial agreement between the selectivity and the length composition data (because length composition was adjusted using selectivity). It is likely however that the increase in precision is largely due to the reduction in the variance of the prior distribution on survey catchability and therefore a real result and an endorsement of the new dredge.

The results of this study indicate that switching to the MCD is not likely to diminish the performance of the assessment model, and may in fact increase the precision of model estimates.

Tables

Table 35: Size composition (cm) comparison between 2013 surfclam assessment and a size composition similar to what would have come from the survey using the MCD.

N	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
RD																
138	0.15	0.04	0.18	0.38	0.88	2.35	13.92	18.19	11.15	5.52	4.05	2.17	1.64	1.80	1.07	1.01
144	0.00	0.02	0.12	0.32	0.49	0.61	1.36	4.37	8.42	7.21	3.00	1.78	1.59	1.61	0.99	0.35
10	0.02	0.17	0.37	1.34	10.09	21.00	5.11	4.98	6.50	6.59	5.94	3.88	2.28	1.90	0.98	0.24
156	0.01	0.06	0.16	0.33	0.71	0.75	1.45	2.97	10.88	13.31	8.02	3.68	2.04	1.58	1.06	0.45
158	0.01	0.05	0.10	0.30	0.52	0.71	0.99	1.94	2.98	4.49	5.70	4.18	2.30	1.06	0.53	0.19
168	0.00	0.05	0.14	0.50	0.75	1.18	1.22	2.46	5.11	4.63	4.33	2.95	1.90	1.05	0.45	0.26
193	1.75	3.28	6.67	3.73	3.78	3.93	4.31	7.11	11.74	10.45	9.92	8.75	5.55	2.28	0.83	0.30
190	0.68	2.14	0.56	0.56	1.32	3.00	4.40	5.73	9.68	10.50	8.99	8.63	5.65	2.47	0.96	0.35
186	0.64	2.10	0.53	0.37	0.71	0.81	0.98	2.36	5.52	5.88	5.10	4.81	3.67	1.65	0.66	0.10
182	0.02	0.05	0.11	0.41	1.10	2.06	1.72	1.49	1.93	2.57	3.09	3.99	3.78	2.89	0.92	0.17
150	0.06	0.28	0.20	0.18	0.39	0.64	0.88	1.28	1.11	1.20	1.58	2.52	2.41	1.10	0.31	0.04
189	0.04	0.24	0.34	0.68	1.14	1.37	1.19	0.97	0.84	1.09	1.23	1.73	1.69	1.00	0.45	0.04
135	0.14	0.27	0.69	1.64	2.77	2.89	2.99	3.19	2.59	2.43	1.52	1.58	1.72	0.96	0.33	0.05
Conversion Factor (2.0)																
selx change	-0.03	-0.16	-0.46	-0.81	-0.95	-0.76	-0.45	-0.21	-0.07	-0.03	-0.05	-0.05	0.03	0.23	0.53	0.88
MCD																
138	0.15	0.03	0.10	0.07	0.05	0.57	7.69	14.45	10.32	5.33	3.86	2.07	1.69	2.20	1.64	1.90
144	0.00	0.02	0.06	0.06	0.03	0.15	0.75	3.47	7.79	6.96	2.86	1.70	1.64	1.98	1.51	0.66
10	0.02	0.14	0.20	0.25	0.54	5.10	2.82	3.95	6.01	6.36	5.67	3.70	2.35	2.33	1.50	0.45
156	0.01	0.05	0.09	0.06	0.04	0.18	0.80	2.36	10.07	12.84	7.66	3.51	2.10	1.94	1.63	0.85
158	0.01	0.04	0.05	0.06	0.03	0.17	0.55	1.54	2.76	4.33	5.44	3.99	2.37	1.31	0.82	0.36
168	0.00	0.04	0.08	0.09	0.04	0.29	0.68	1.96	4.73	4.47	4.14	2.82	1.96	1.28	0.69	0.48
193	1.69	2.74	3.60	0.69	0.20	0.96	2.38	5.65	10.87	10.09	9.47	8.35	5.72	2.80	1.28	0.56
190	0.65	1.79	0.30	0.10	0.07	0.73	2.43	4.55	8.96	10.14	8.58	8.24	5.83	3.03	1.47	0.66
186	0.62	1.75	0.29	0.07	0.04	0.20	0.54	1.87	5.11	5.68	4.86	4.59	3.78	2.03	1.01	0.19
182	0.01	0.04	0.06	0.08	0.06	0.50	0.95	1.18	1.78	2.48	2.95	3.81	3.89	3.55	1.41	0.31
150	0.05	0.23	0.11	0.03	0.02	0.15	0.49	1.02	1.03	1.16	1.51	2.41	2.48	1.35	0.48	0.08
189	0.04	0.20	0.18	0.13	0.06	0.33	0.66	0.77	0.78	1.05	1.17	1.65	1.74	1.23	0.69	0.07
135	0.13	0.23	0.37	0.31	0.15	0.70	1.65	2.53	2.39	2.34	1.45	1.50	1.77	1.18	0.50	0.10

Table 36: Biomass precision comparison between the 2013 surfclam assessment and the modified assessment presented here.

Year	Biomass	cv	lci	uci	Biomass	cv	lci	uci
1963	1250	0.14	955	1636	1200	0.08	1030	1398
1964	1160	0.14	879	1531	1112	0.08	950	1302
1965	1160	0.14	879	1531	1112	0.08	950	1302
1966	1157	0.14	878	1523	1109	0.08	947	1298
1967	1154	0.14	879	1515	1106	0.08	945	1295
1968	1155	0.14	881	1513	1107	0.08	945	1297
1969	1157	0.14	884	1515	1110	0.08	947	1300
1970	1162	0.14	887	1521	1114	0.08	950	1306
1971	1135	0.14	866	1487	1083	0.08	923	1270
1972	1101	0.14	837	1448	1045	0.08	888	1229
1973	1044	0.14	790	1379	986	0.08	836	1163
1974	990	0.15	745	1317	931	0.09	786	1102
1975	922	0.15	689	1233	863	0.09	726	1025
1976	856	0.15	638	1148	798	0.09	670	950
1977	794	0.15	591	1068	739	0.09	620	880
1978	746	0.15	555	1003	692	0.09	581	823
1979	733	0.15	545	985	677	0.09	570	806
1980	738	0.15	549	992	682	0.09	574	810
1981	768	0.15	572	1031	708	0.09	596	840
1982	950	0.15	707	1277	877	0.09	740	1040
1983	1277	0.15	950	1717	1182	0.09	997	1402
1984	1484	0.15	1103	1996	1375	0.09	1160	1630
1985	1684	0.15	1251	2266	1564	0.09	1320	1854
1986	1929	0.15	1432	2598	1802	0.09	1521	2135
1987	1974	0.15	1464	2662	1849	0.09	1561	2191
1988	1967	0.15	1457	2656	1848	0.09	1561	2188
1989	1956	0.15	1446	2645	1844	0.09	1557	2183
1990	1880	0.16	1388	2547	1777	0.09	1501	2104
1991	1789	0.16	1318	2430	1696	0.09	1432	2009
1992	1756	0.16	1290	2390	1674	0.09	1413	1983
1993	1696	0.16	1243	2314	1624	0.09	1371	1925
1994	1634	0.16	1194	2236	1573	0.09	1327	1865
1995	1608	0.16	1172	2206	1557	0.09	1312	1847
1996	1539	0.16	1119	2116	1496	0.09	1260	1776
1997	1490	0.17	1081	2053	1455	0.09	1224	1728
1998	1511	0.17	1093	2088	1484	0.09	1248	1765
1999	1488	0.17	1073	2063	1469	0.09	1234	1748
2000	1399	0.17	1006	1947	1386	0.09	1163	1651
2001	1294	0.17	926	1807	1285	0.09	1076	1534
2002	1207	0.17	861	1692	1205	0.09	1007	1441
2003	1128	0.18	801	1589	1132	0.09	945	1358
2004	1104	0.18	779	1564	1119	0.09	931	1345
2005	1079	0.18	758	1537	1102	0.10	915	1329

2006	1013	0.18	707	1450	1040	0.10	860	1257
2007	912	0.19	633	1314	940	0.10	773	1142
2008	827	0.19	571	1197	856	0.10	700	1046
2009	750	0.19	516	1091	781	0.10	635	959
2010	706	0.20	483	1032	740	0.11	597	916
2011	703	0.20	481	1028	740	0.12	589	929
2012	699	0.20	476	1027	735	0.13	572	945
2013	691	0.20	464	1029	728	0.14	551	962
2014	678	0.22	441	1042	709	0.16	515	976
2015	687	0.23	439	1073	698	0.18	495	983
2016	731	0.23	464	1152	732	0.18	514	1044
2017	726	0.24	459	1147	729	0.18	508	1045
2018	761	0.24	481	1204	759	0.19	528	1092
2019	800	0.24	506	1265	793	0.19	551	1142
2020	838	0.24	531	1322	826	0.19	574	1189
2021	873	0.23	555	1375	857	0.19	596	1232

Figures

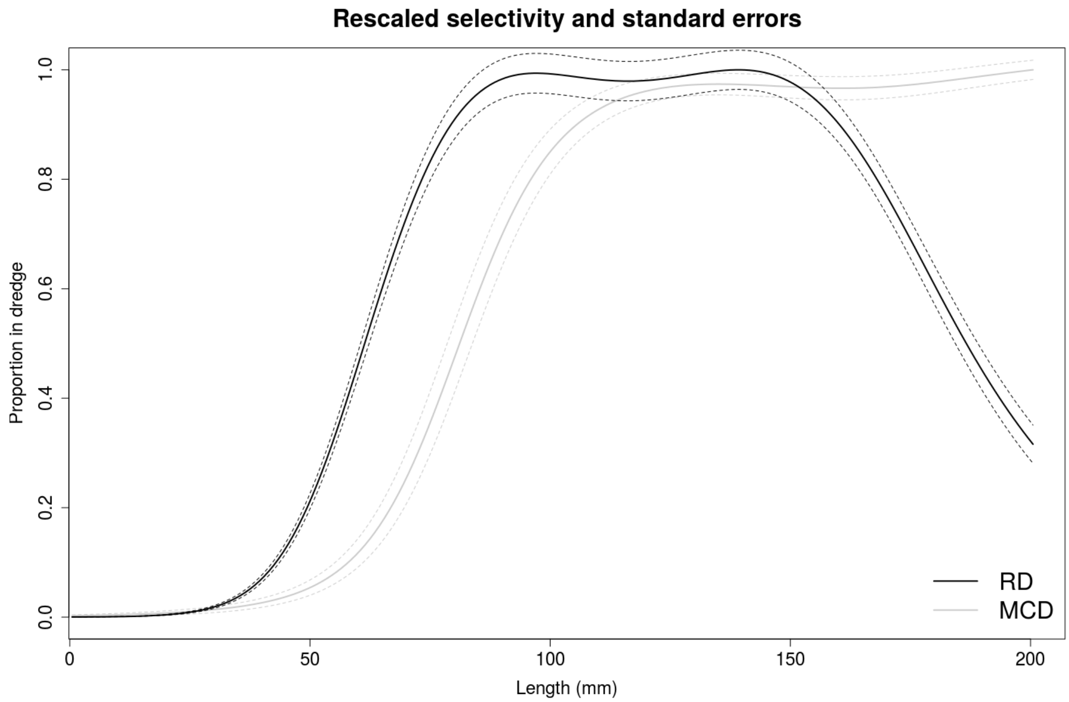


Figure 168: Selectivity differences between the MCD and RD. Curves have been rescaled so that the maximum selectivity for each curve is 1.

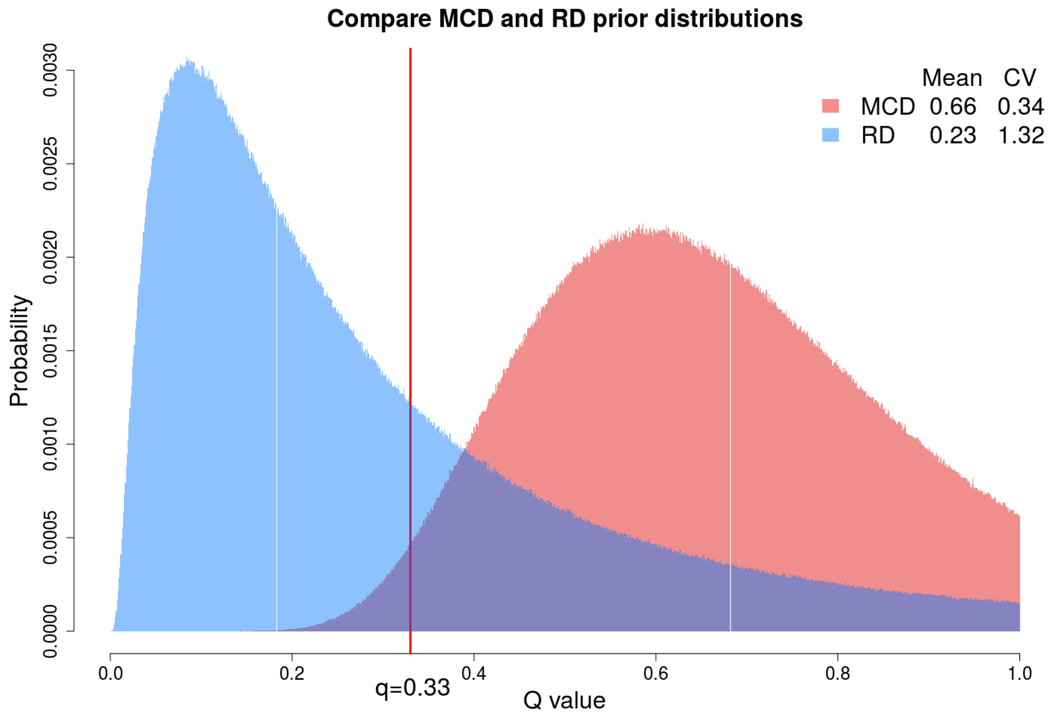


Figure 169: Differences in dredge efficiency between the MCD and RD, with the current dredge efficiency estimated in the assessment ($q = 0.33$) shown.

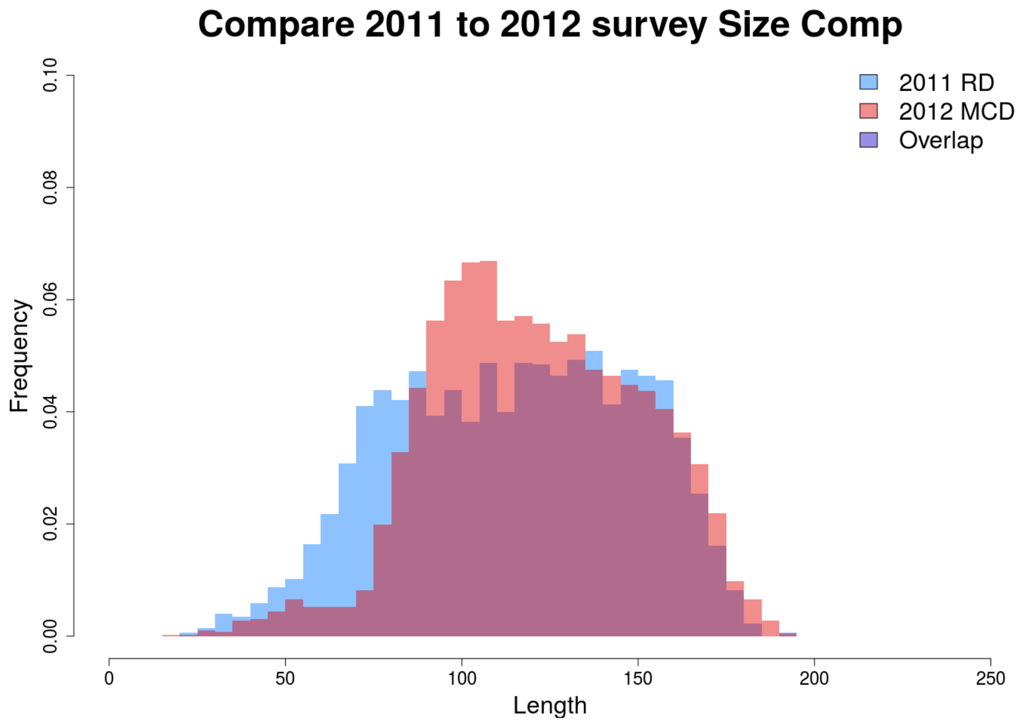


Figure 170: Length composition of survey samples from MCD and RD. Because the 2012 survey did not cover SNE or GBK, only samples from regions that were covered in both surveys are shown here.

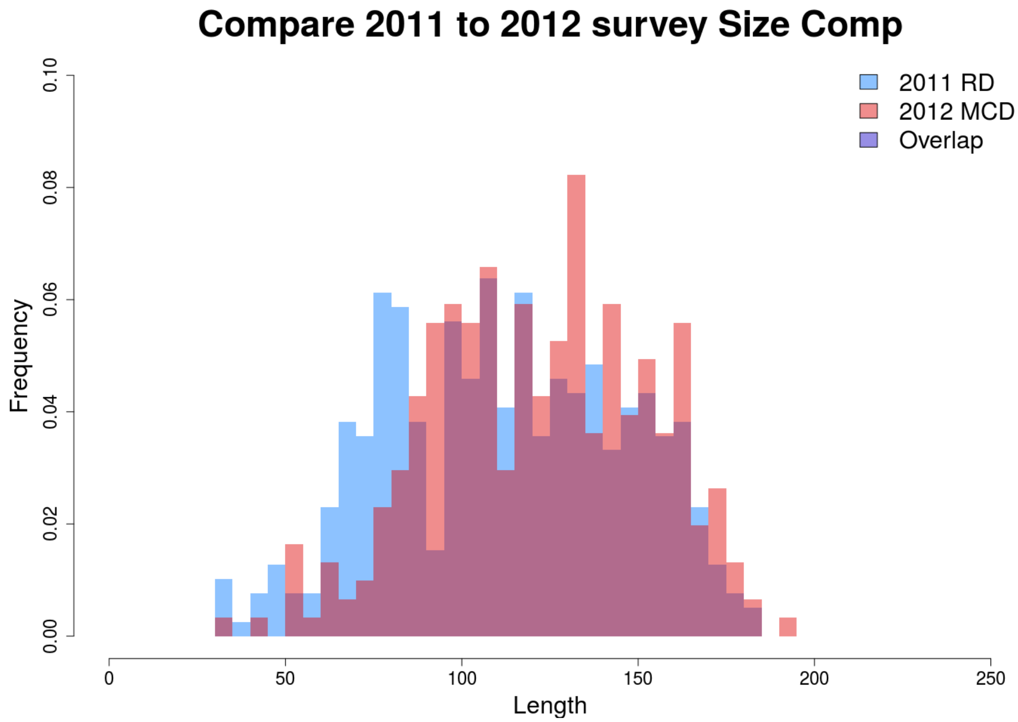


Figure 171: Length composition of survey samples that will eventually be aged from MCD and RD. Because the 2012 survey did not cover SNE or GBK, only samples from regions that were covered in both surveys are shown here.

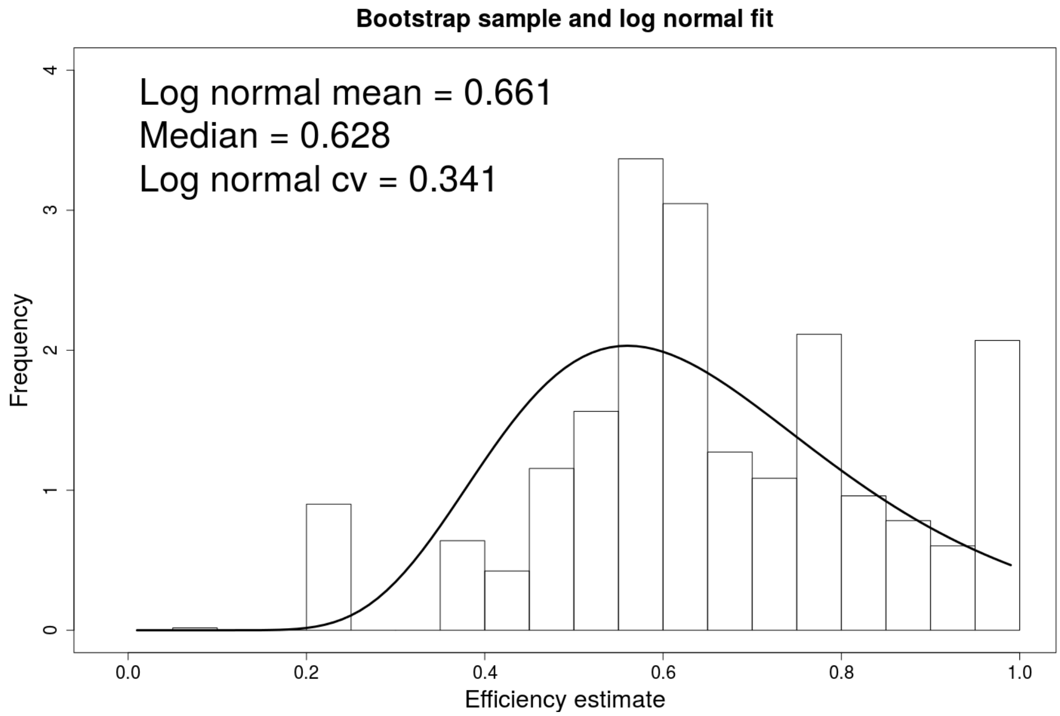
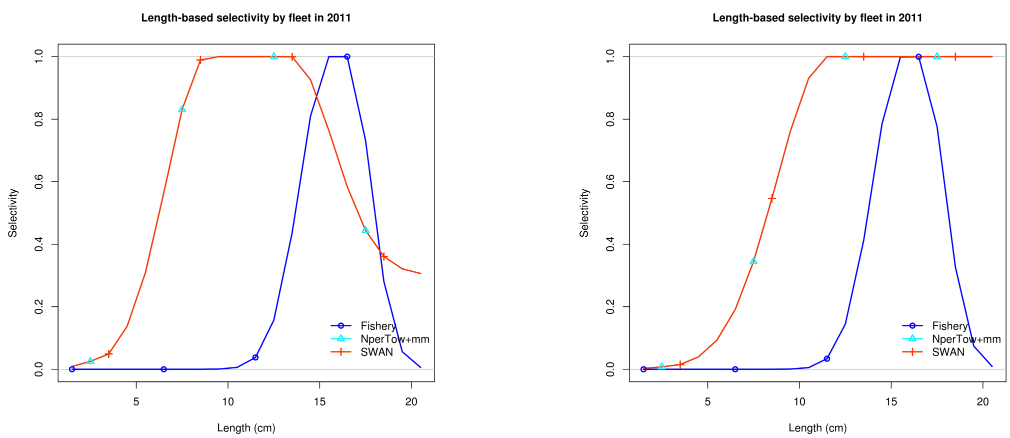


Figure 172: Log normal fit to a variance weighted bootstrap of MCD efficiency from field depletion studies.



(a) RD selectivity

(b) MCD selectivity

Figure 173: SS3 output plots showing the different selectivities used in the 2013 Atlantic surfclam assessment (a) and in this exercise (b). The red line shows the comparison between the RD and MCD.

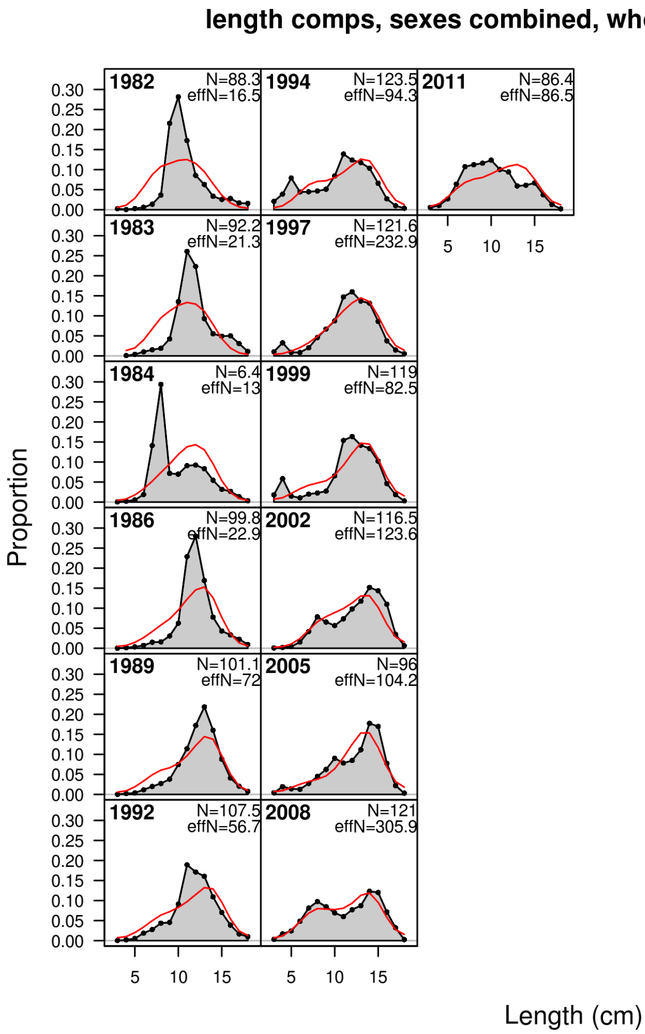


Figure 174: 2013 Atlantic surfclam assessment model fits to length composition data.

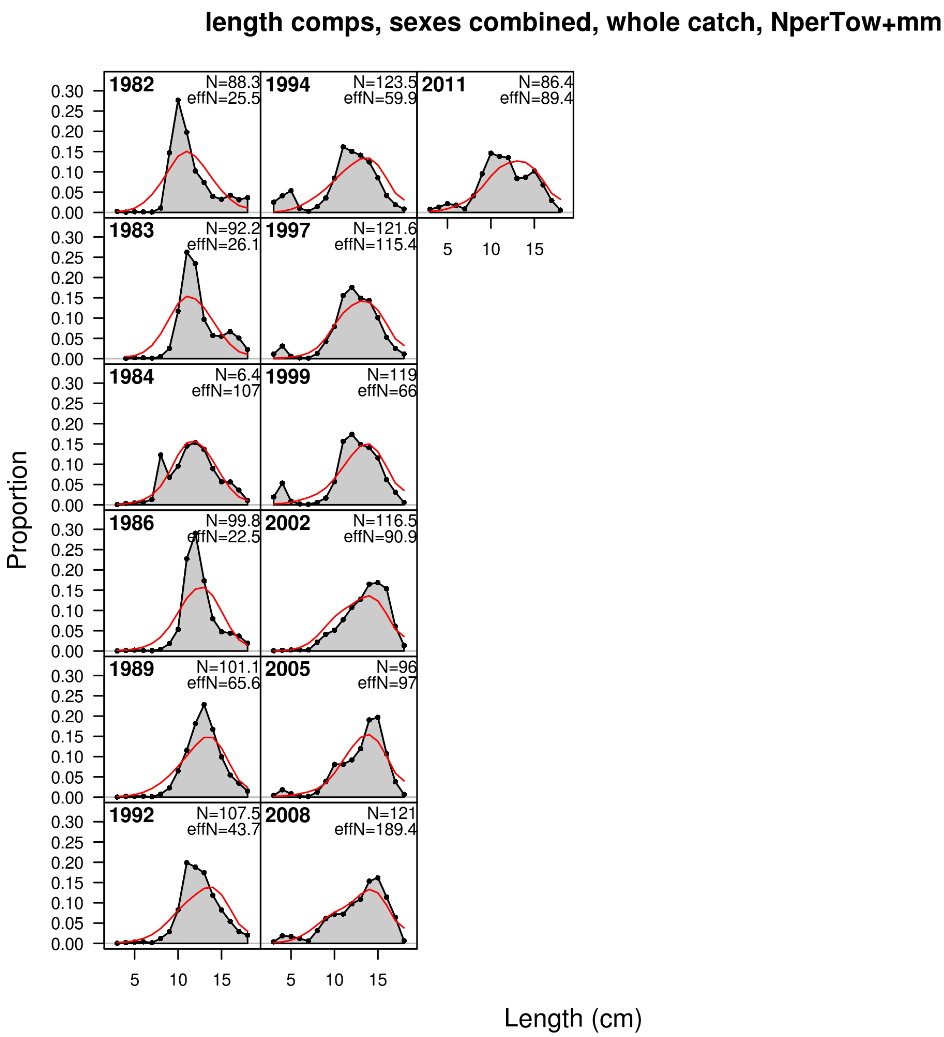


Figure 175: Fits to length composition data using modified selectivity, length composition and survey catchability prior.

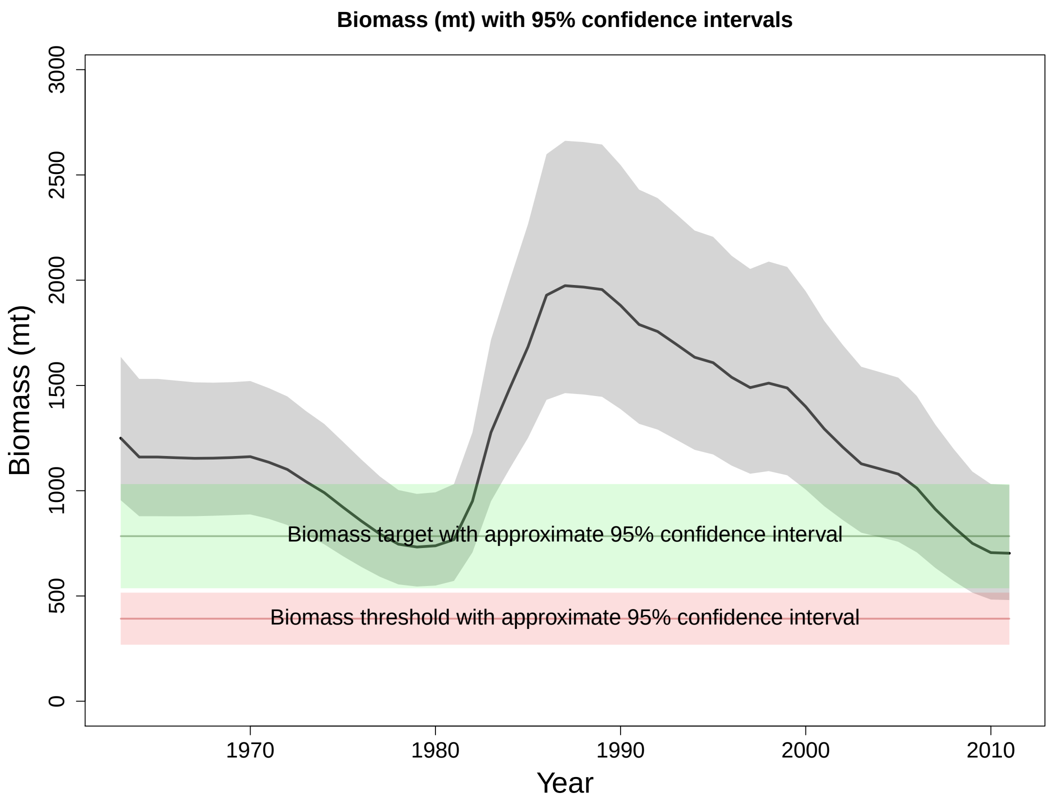


Figure 176: Biomass (1000 mt) trajectory and status estimated in the 2013 Atlantic surfclam assessment.

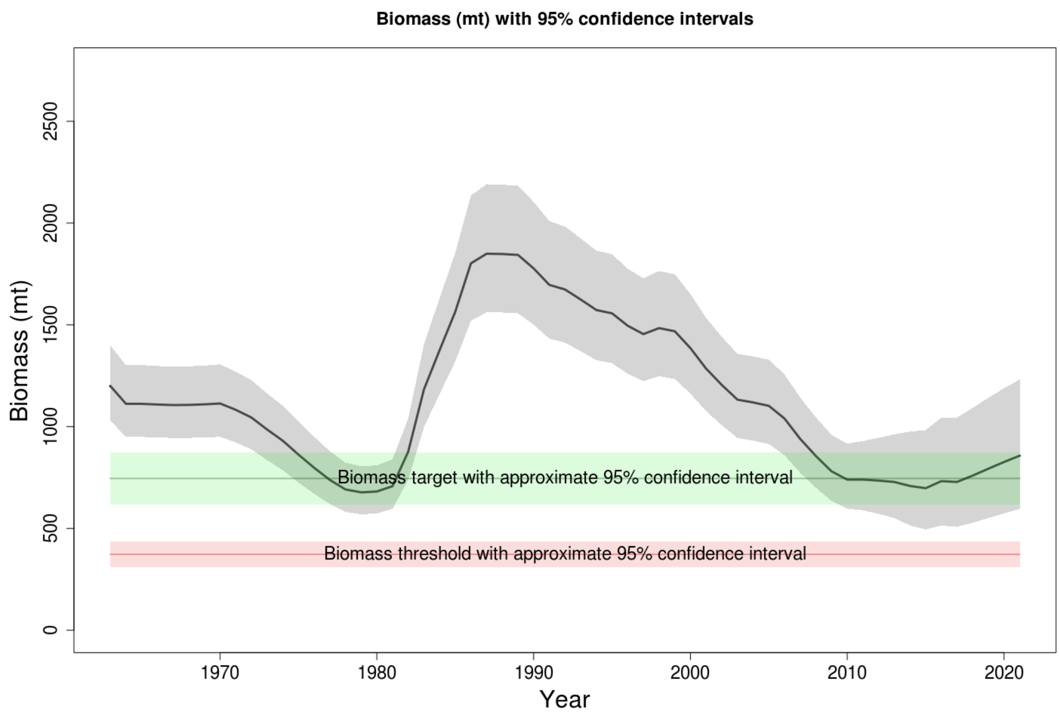


Figure 177: Biomass (1000 mt) trajectory using modified selectivity, length composition and survey catchability prior. The projection results assume status quo fishing.

Part XV

Appendix: Survey dredge efficiency

Increasing survey dredge efficiency, defined as the probability of capturing an animal if the dredge is towed over the bottom where that animal is buried, was an important consideration in switching to a commercial vessel as a platform for the NEFSC clam survey. The relatively small survey dredge deployed by the *RV Delaware II* had an estimated mean efficiency of approximately 0.23 and high variability in performance, with an estimated cv for efficiency of 1.32. A low mean dredge efficiency coupled with high variability resulted in high variance catches, which in turn increased the variability in estimates of mean abundance for survey strata, and ultimately for estimated biomass in the assessment.

The complex process for estimating survey dredge efficiency (described in detail in Northeast Fisheries Science Center (2013)) included 27 direct estimates of the efficiency of modified commercial dredges (MCD) similar to those that have been used in the NEFSC clam survey since 2012, including 8 estimates using the actual MCD used for the post-2012 surveys (Table 37). The efficiency of the MCD and the Pursuit dredge are substantially higher and more precisely estimated than the RD (Figure 178).

The depletion experiments have thus far been conducted in the southern area, with the most effort concentrated in the NJ region (Figure 179)

Tables

Table 37: Estimated dredge capture efficiency from depletion experiments. These estimates were conducted using a modified commercial dredge similar to the dredge that has been used for the NEFSC clam survey since 2012.

Experiment	Efficiency	St. dev.
1997.2	0.224	0.069
1997.3	0.641	0.138
1997.4	0.917	0.198
1997.6	0.528	0.171
1999.2	0.589	0.263
1999.5	0.211	0.058
1999.7	0.480	0.073
2002.2	0.805	0.109
2002.3	0.446	0.139
2004.1	0.552	0.105
2004.2	0.628	0.078
2004.3	0.606	0.111
2005.2	0.666	0.068
2005.3	0.569	0.068
2005.4	0.389	0.079
2005.5	0.781	0.145
2005.6	0.535	0.140
2008.1	0.966	0.142
2008.2	0.957	0.103
2008.3	0.610	0.119
2008.4	0.485	0.212
2008.6	0.882	0.143
2011.3	0.571	0.162
2011.2	0.556	0.088
2011.1	0.738	0.090

Figures

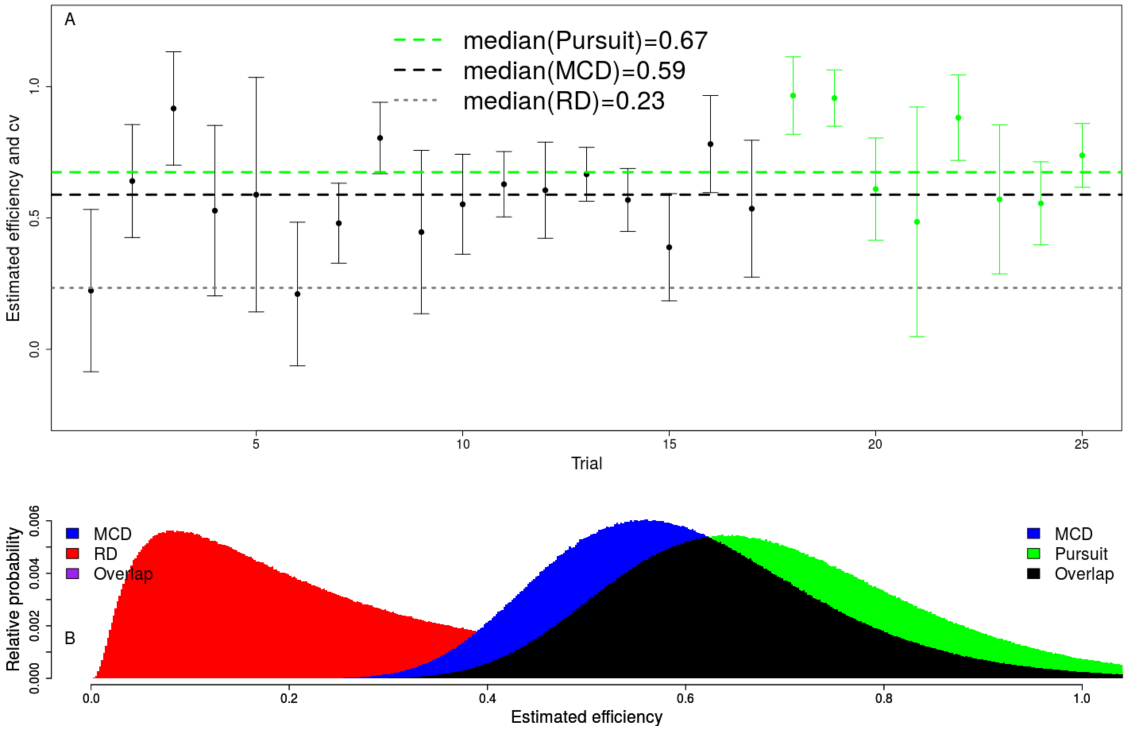


Figure 178: Panel A) Modified commercial dredge (MCD) capture efficiency estimates (all vessels) compared to median values for the survey dredge (RD) as well as the specific dredge used on the current survey (Pursuit). Panel B) A comparison of the distributions of capture efficiency for each dredge where each is shown as a truncated lognormal distribution based on the medians and confidence intervals shown in panel A. The MCD and Pursuit dredge had higher and more precisely estimated capture efficiency than the RD.

Figures

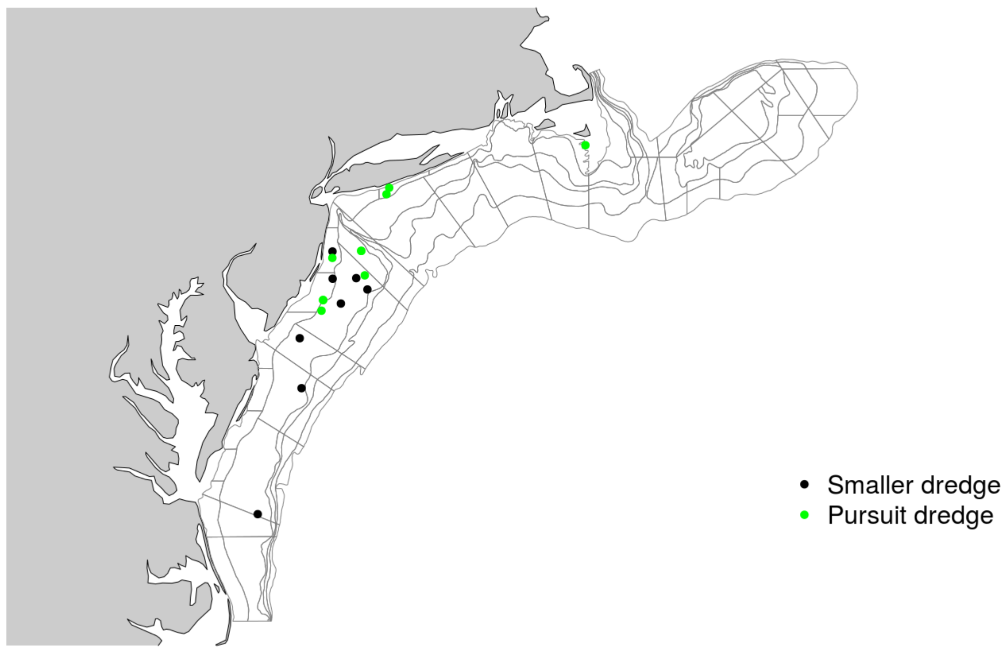


Figure 179: Position of each depletion experiment. The different colors represent the depletion experiments done with different dredges. The green dots are the experiments done with the dredge being used currently on the NEFSC clam survey.

Part XVI

Appendix: Are broken clams a problem?

The mechanical sorting equipment employed on the ESS Pursuit results in higher sampling efficiency in terms of the number of animals processed per unit time, but also tends to increase breakage. The volume, mass and approximate length of broken clams is routinely recorded, but there has been concern that a size bias in the tendency to break could skew the size composition of the survey catch. A simple size composition comparison indicates that if there is size bias in the broken clams, it is unlikely to bias the size composition. Plots of length compositions (Figures 180 - 181) demonstrate that there is very little difference between compositions composed of whole animals and those composed of whole and broken animals. All survey analyses currently include both whole and broken clams.

There is also the possibility that clams are broken more often in smaller catches, as there would be less detritus to cushion the clams as they dropped from the dredge into the hopper for sorting. This could potentially bias the survey if the length composition of clams in "clean" habitat with less detritus were skewed by a high proportion of broken animals. Bias produced by this affect would probably not be very important to the assessment unless there was some reason to suspect that clean bottom resulted in some inherent difference in the length composition of clams caught there (e.g. clams grow more slowly on clean bottom). Nonetheless it may be worth evaluating, to determine if more clams are broken in smaller catches.

Although "trash" volume is no longer recorded on the NEFSC clam survey, we can compare the proportion of broken clams to the total number of clams caught in each tow. The relationship was weakly negative (Figure 182) implying that smaller catches do indeed produce a slightly higher proportion of broken clams. The effect was small enough however, to be unlikely to warrant much concern.

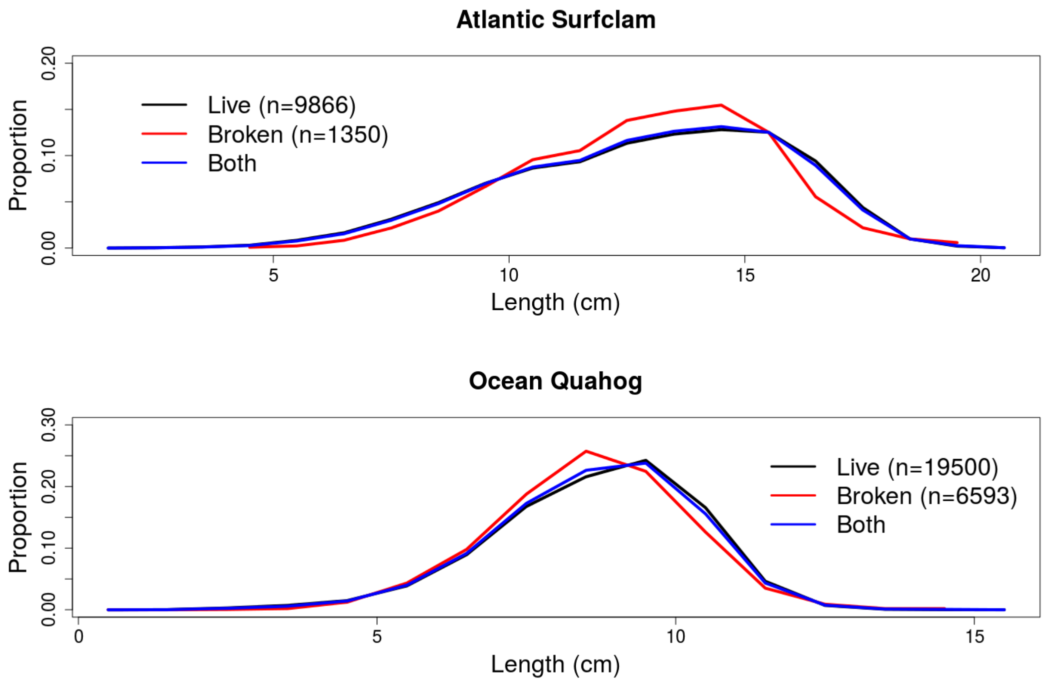


Figure 180: Length compositions from clam surveys on the ESS Pursuit through 2014. Proportion at length using only live (whole) clams, only broken clams, and live and broken clams together. There is very little difference between the length composition based only on live animals and the length composition using both whole and broken animals for both Atlantic surfclam and ocean quahog.

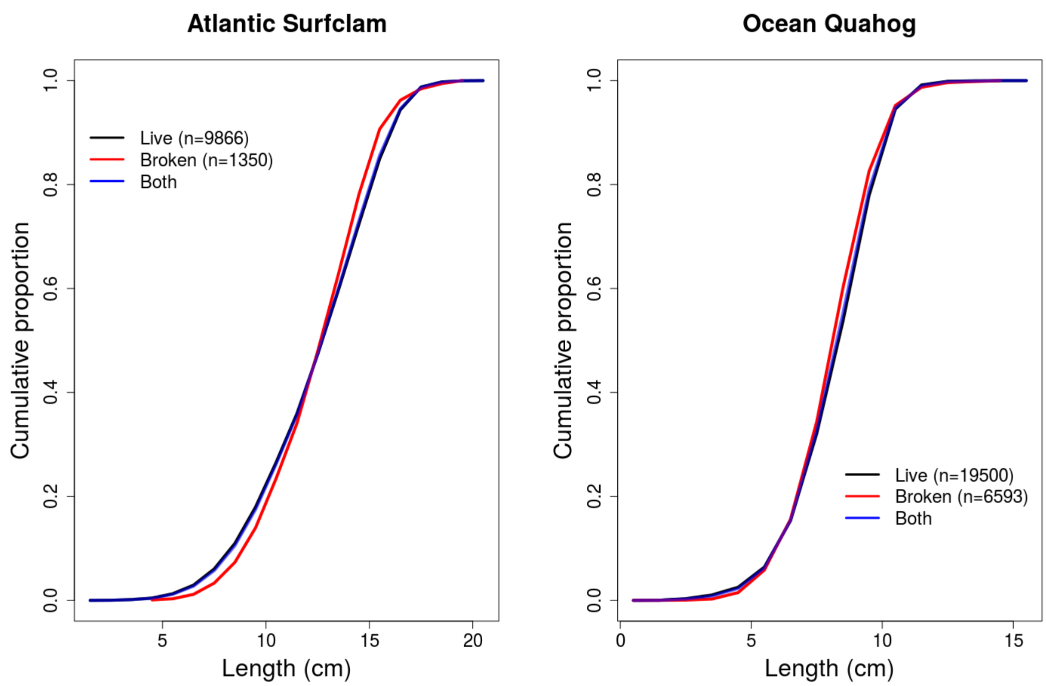


Figure 181: Cumulative length compositions from clam surveys on the ESS Pursuit through 2014. Cumulative proportion at length using only live (whole) clams, only broken clams, and live and broken clams together. There is very little difference between the cumulative length composition based only on live animals and the length composition using both whole and broken animals for both Atlantic surfclam and ocean quahog.

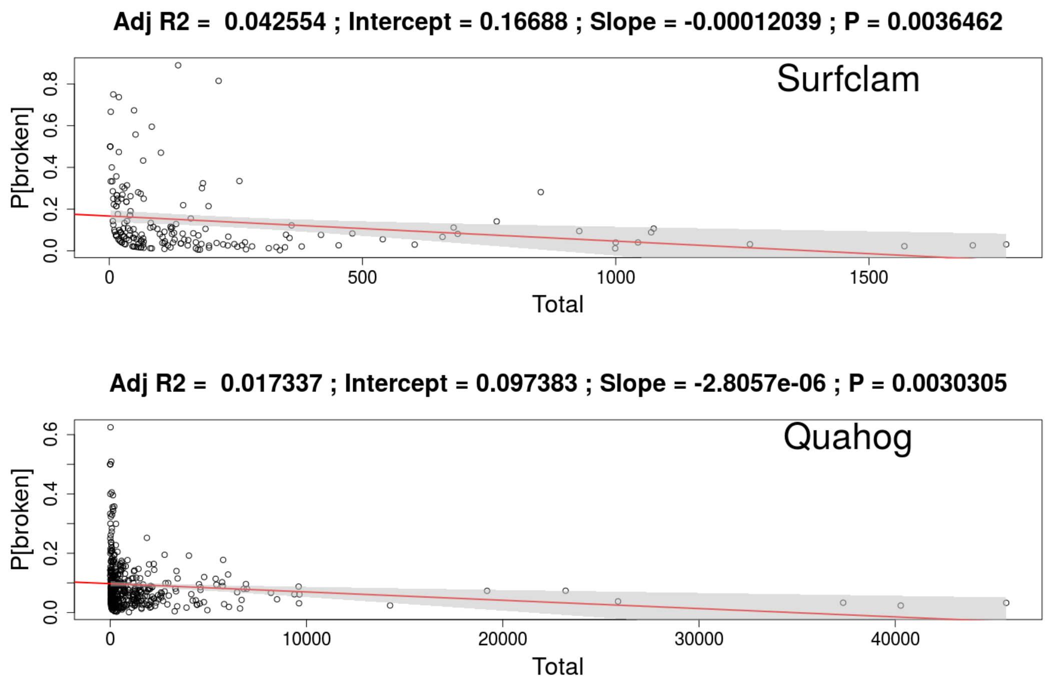


Figure 182: Correlation between the proportion of broken clams to the total clams caught in each tow from clam survey on the ESS Pursuit through 2014. The relationship was weak for both Atlantic surfclam and ocean quahog.

Part XVII

Appendix: Build a bridge

Southern area

The current assessment model for the southern area was based on the configuration of the assessment model for the southern area from the previous assessment (Northeast Fisheries Science Center (2013)). The alterations listed below illustrate step wise changes to the previous assessment model that result in the current assessment model. The sequence of these steps is not important, nor is it the actual sequence in which the changes occurred.

The first change was to incorporate new data (Figure 183). This required the addition of several new parameters (not estimated here, and left for illustrative purposes at previous values) because the new data came from a new survey (MCD). The MCD survey used a different dredge and required different selectivity parameters (Figure 184). The MCD also required a different prior probability distribution on catchability (Figure 185). The error around the growth curve was adjusted to follow a constant cv rather than a constant standard deviation (Figure 186). The relative weighting, in terms of assumed variance, of the composition data was decremented. This implicitly increased the weighting associated with the survey data and caused a shift in the trend in biomass (Figure 187) as the model began to fit the survey more closely. The ageing error was estimated, incorporating precision data from recent surveys (Figure 188). The cv of growth for young and old animals was estimated, rather than assumed (Figure 189). The number of recruitment deviations being estimated was increased to account for the additional years of data in the model, and the recruitment bias adjustment curve was altered to better fit the current data (Figure 190). The selectivity parameters for the MCD were adjusted in order to make the curve more flat topped and thus have higher selectivity for larger animals (Figure 191). Finally, the prior distribution for catchability on the RD was adjusted slightly to bring it more in line with the values estimated in the previous assessment ((Northeast Fisheries Science Center 2013); Figure 192). All of these adjustments together describe the sum of the changes made to the previous assessment model and build a bridge to the current model (Figure 193).

Northern area

The current assessment model for the northern area was based on the configuration of the assessment model for the northern area from the previous assessment (Northeast Fisheries Science Center (2013)). The alterations listed below illustrate step wise changes to the previous assessment model that result in the current assessment model. The sequence of these steps is not important, nor is it the actual sequence in which the changes occurred.

The first change was to incorporate new data (Figure 194). This required the addition of several new parameters (not estimated here, and left for illustrative purposes at previous values) because the new data came from a new survey (MCD). The previous assessment mistakenly allowed the swept area number per tow survey (SWAN) to contribute to the likelihood for estimating trend, that was corrected in this assessment (Figure 195). The MCD required a different prior probability distribution on catchability (Figure 196). The number of recruitment deviations being estimated was increased to account for the additional years of data in the model, the recruitment bias adjustment curve was altered to better fit the current data, and the variance around the recruitment deviations was fixed rather than estimated (Figure 197). The relative weighting, in terms of assumed variance, of the composition data was decremented. This implicitly increased the weighting associated with the survey data and caused a shift in the trend in biomass (Figure 198) as the model began to fit the survey more closely. The error around the growth curve was adjusted to follow a constant cv rather than a constant standard deviation (Figure 199). The MCD survey used a different dredge and required different selectivity parameters (Figure 200). The cv of growth for young and old animals was reduced to field estimated values (Figure 201). All of these adjustments together describe the sum of the changes made to the previous assessment model and build a bridge to the current model (Figure 202).

Figures

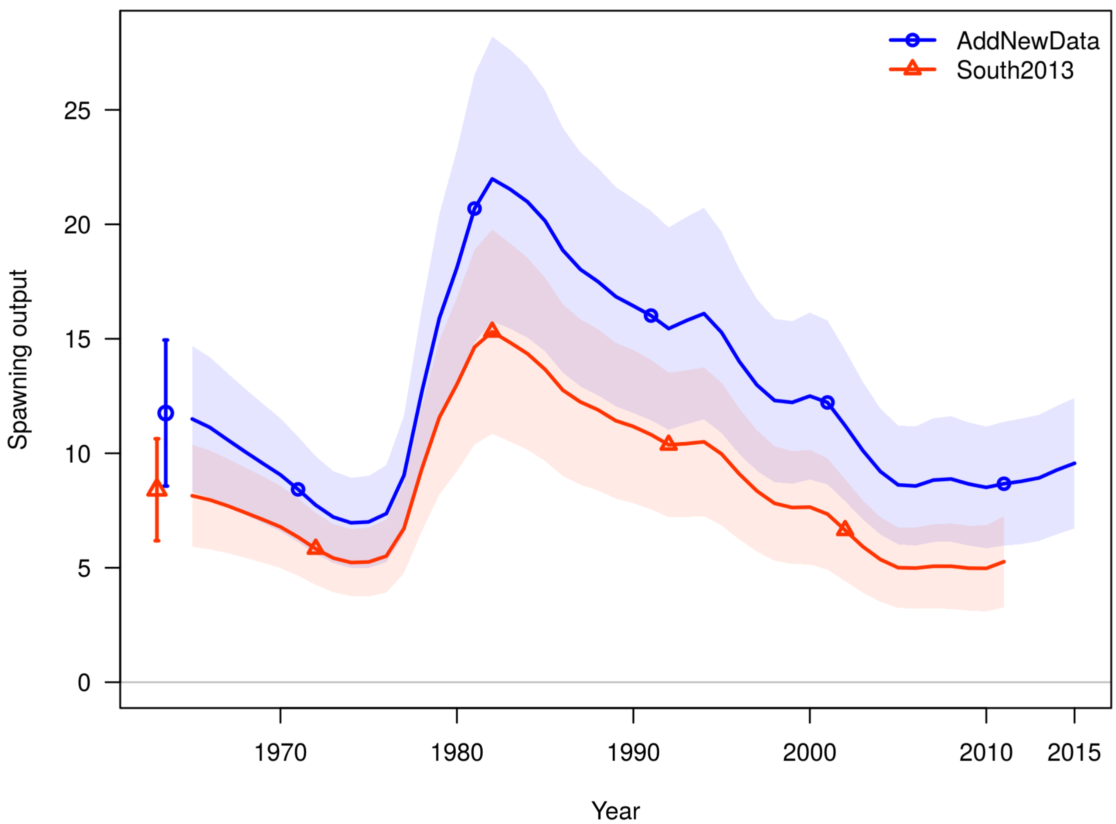


Figure 183: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model with identical configuration, but incorporating data from additional years (AddNewData).

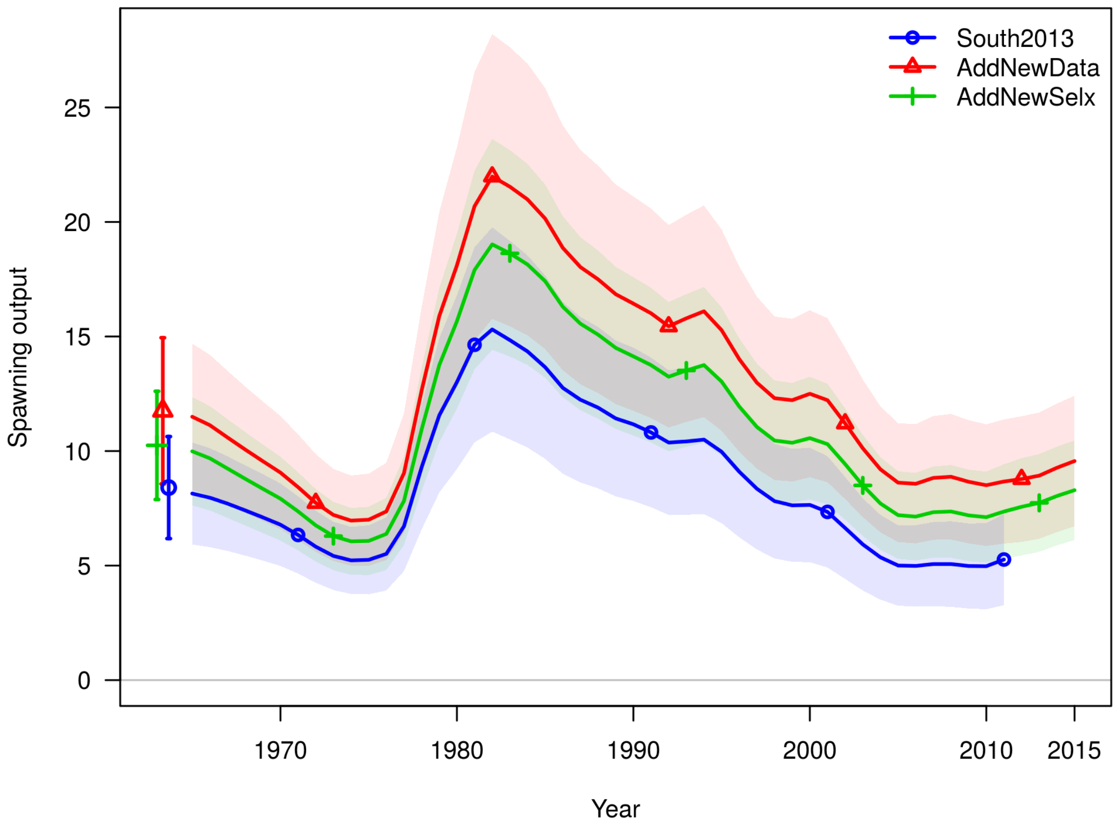


Figure 184: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model incorporating the selectivity of the new survey (AddNewSelx), as well as the previous model iteration (AddNewData).

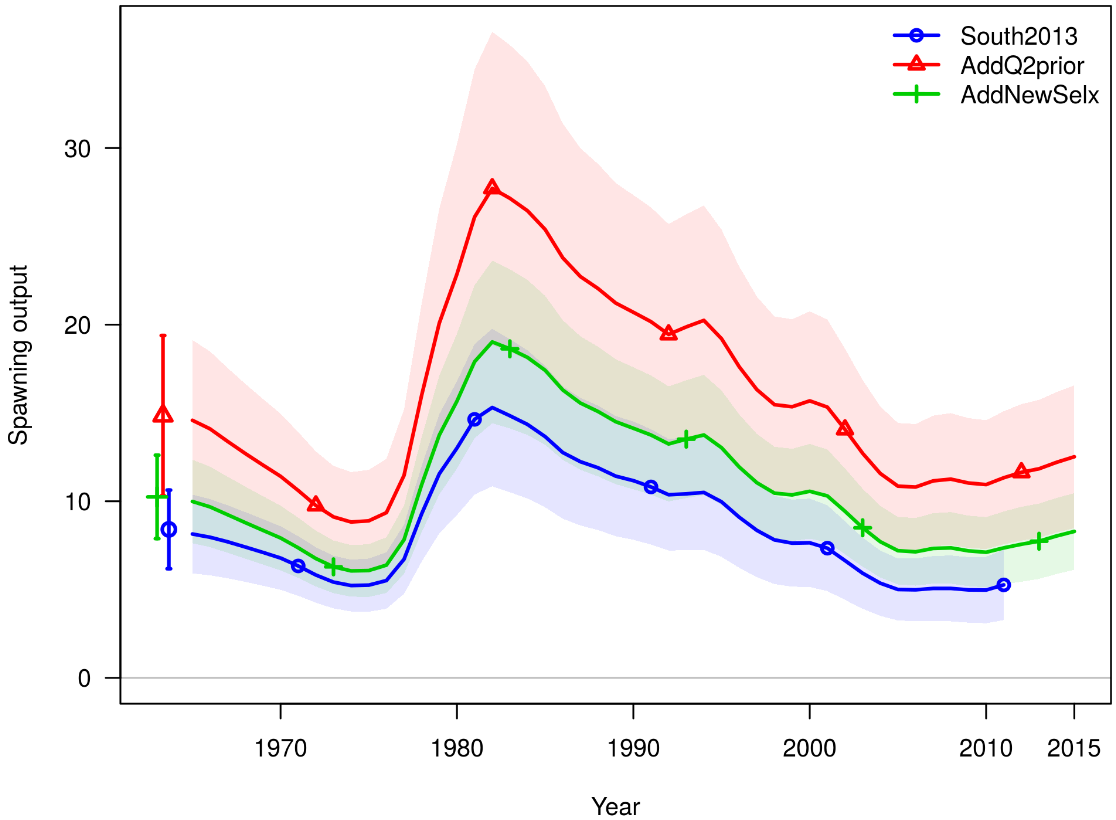


Figure 185: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model incorporating the prior on catchability for the MCD (AddQ2prior), as well as the previous model iteration (AddNewSelx).

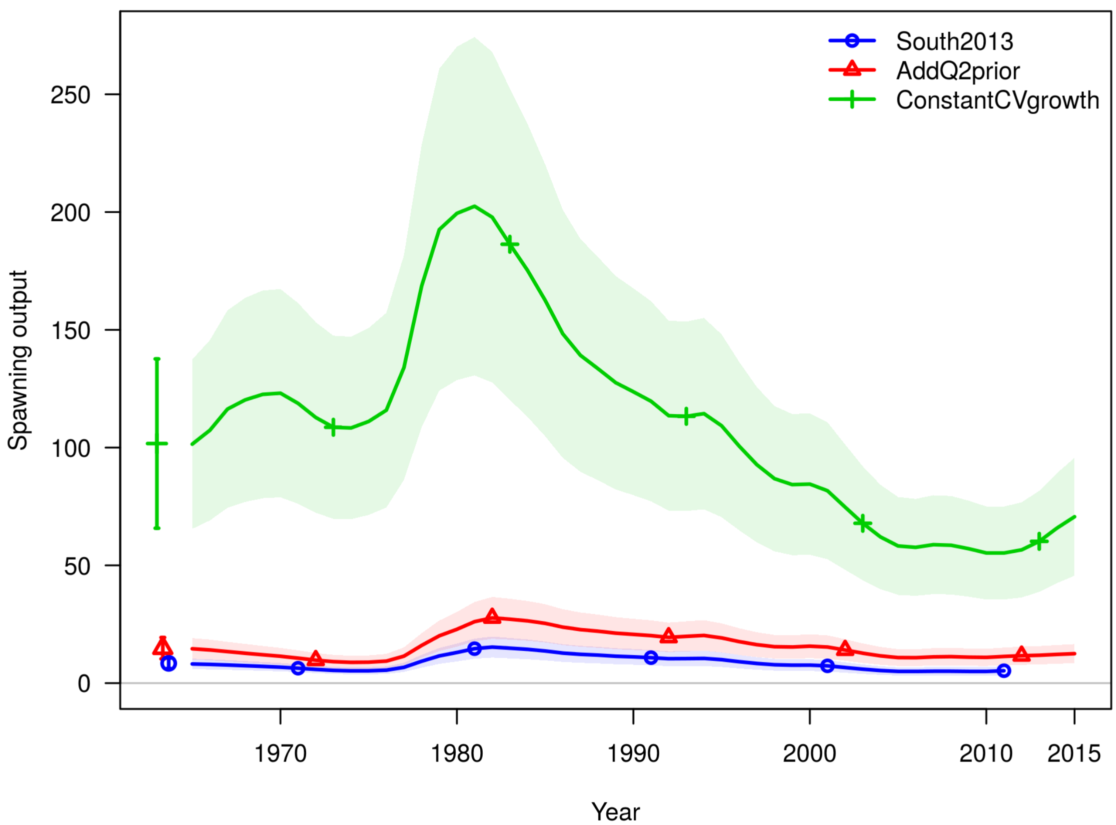


Figure 186: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model where the error around the growth curve has a constant cv rather a constant standard deviation (ConstantCVgrowth), as well as the previous model iteration (AddQ2prior).

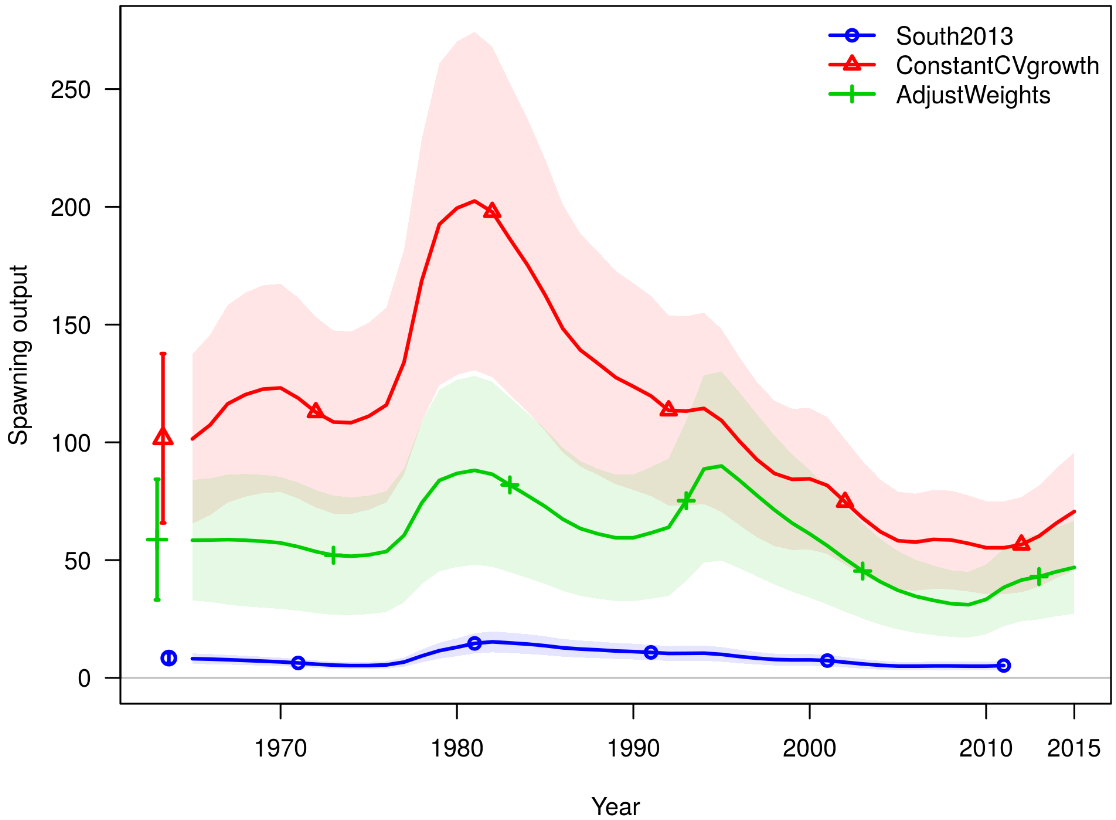


Figure 187: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model where relative weightings of the data sources has been adjusted so that the information content of the composition data is decremented (AdjustWeights), as well as the previous model iteration (ConstantCVgrowth).

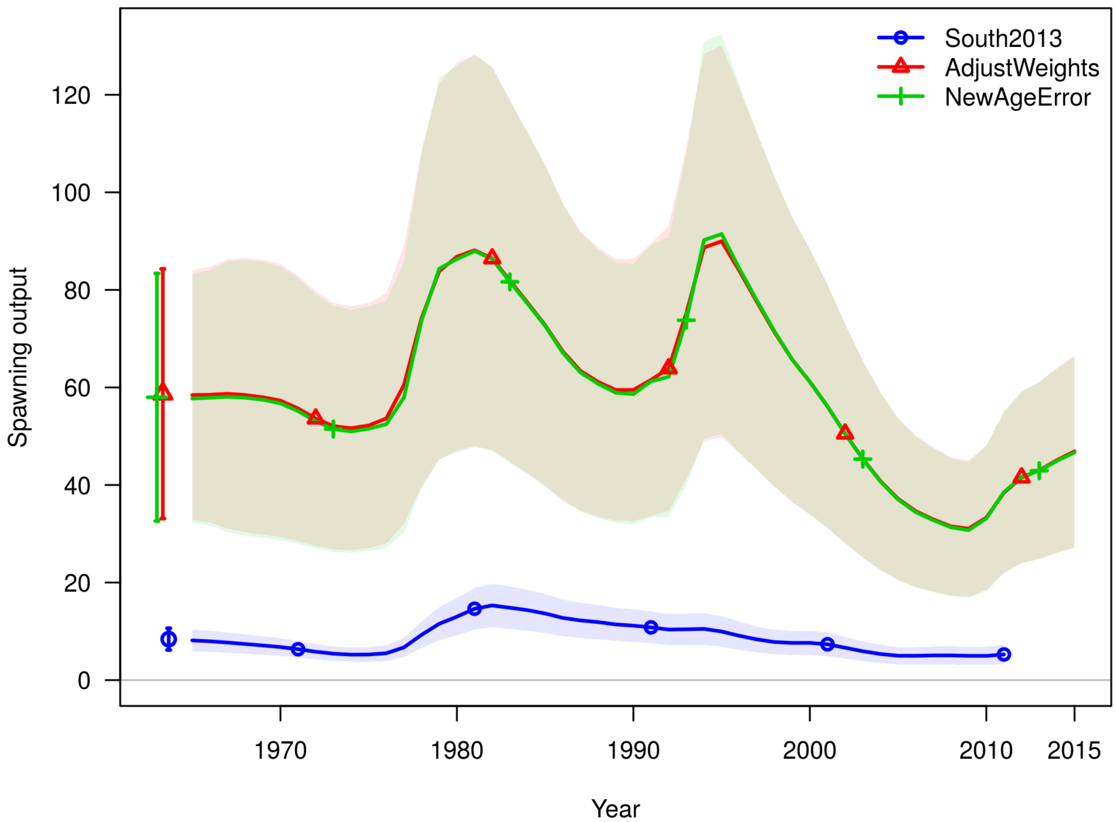


Figure 188: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model incorporating the new ageing error vector (NewAgeError), as well as the previous model iteration (AdjustWeights).

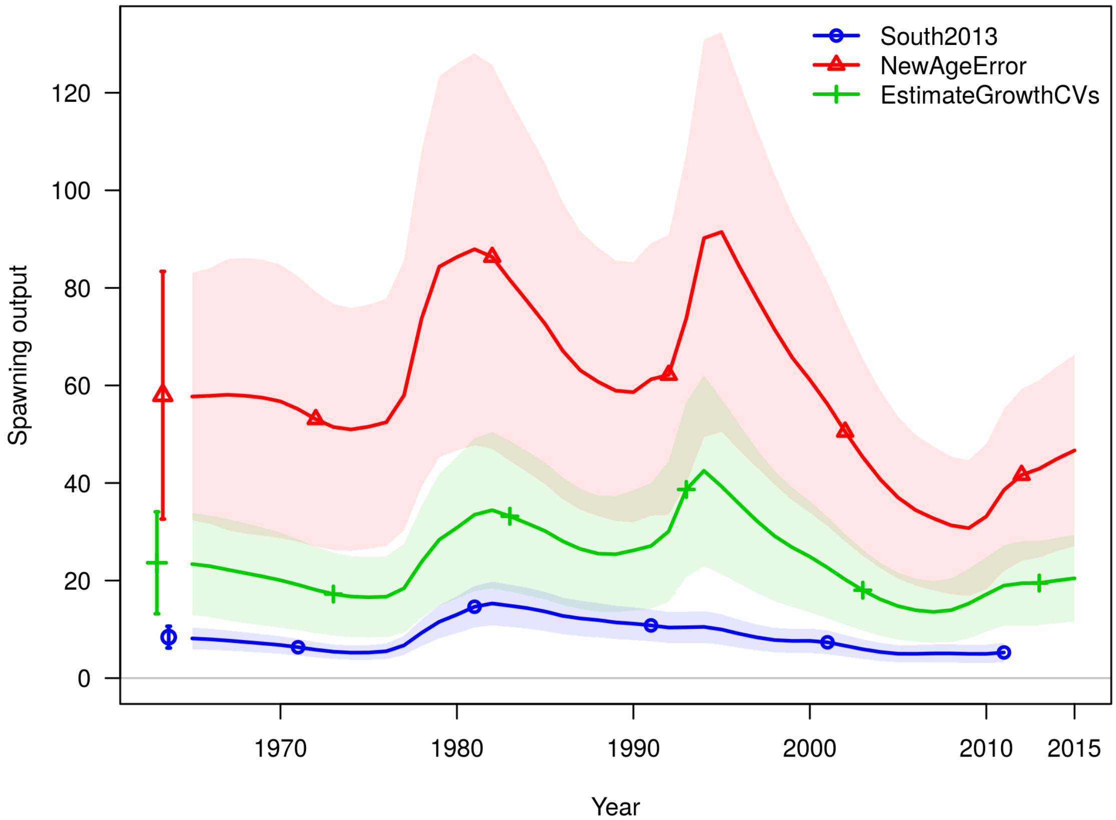


Figure 189: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model that estimates the cv of growth at the oldest and youngest ages (EstimateGrowthCVs), as well as the previous model iteration (NewAgeError).

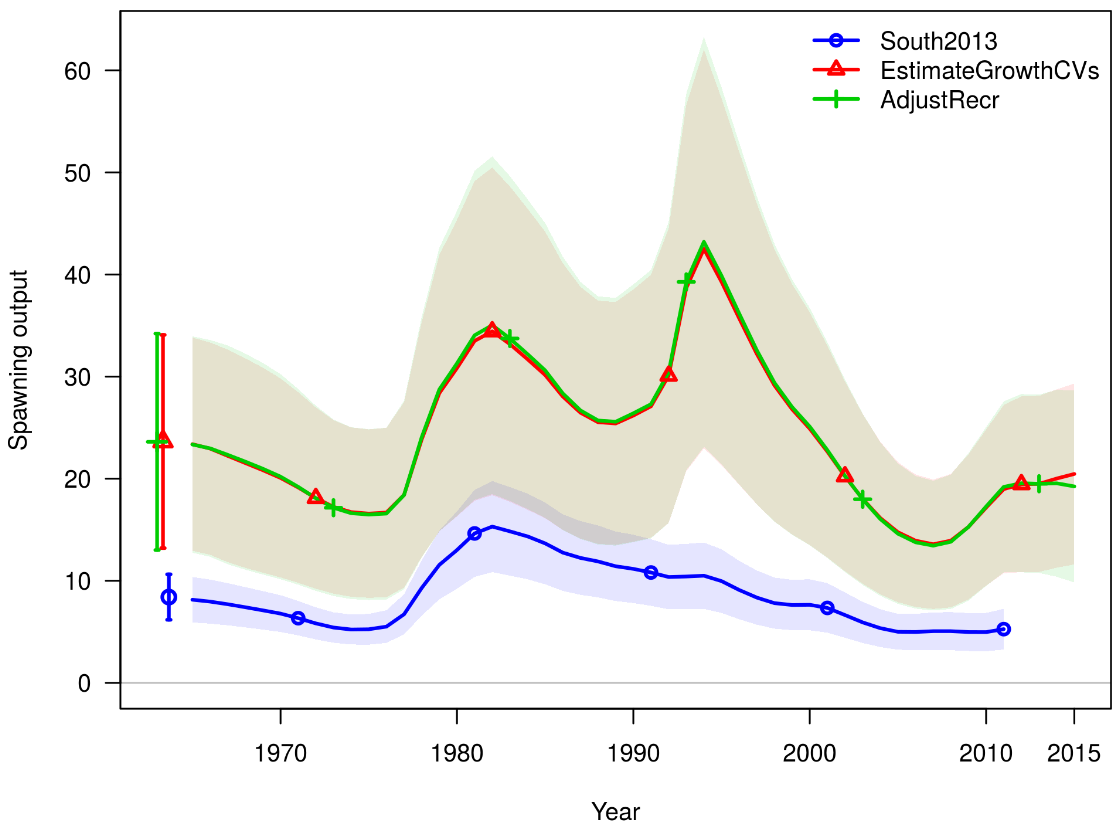


Figure 190: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model that estimates additional recruitment deviations and adjusts the parameters of the recruitment bias curve (AdjustRecr), as well as the previous model iteration (EstimateGrowthCVs).

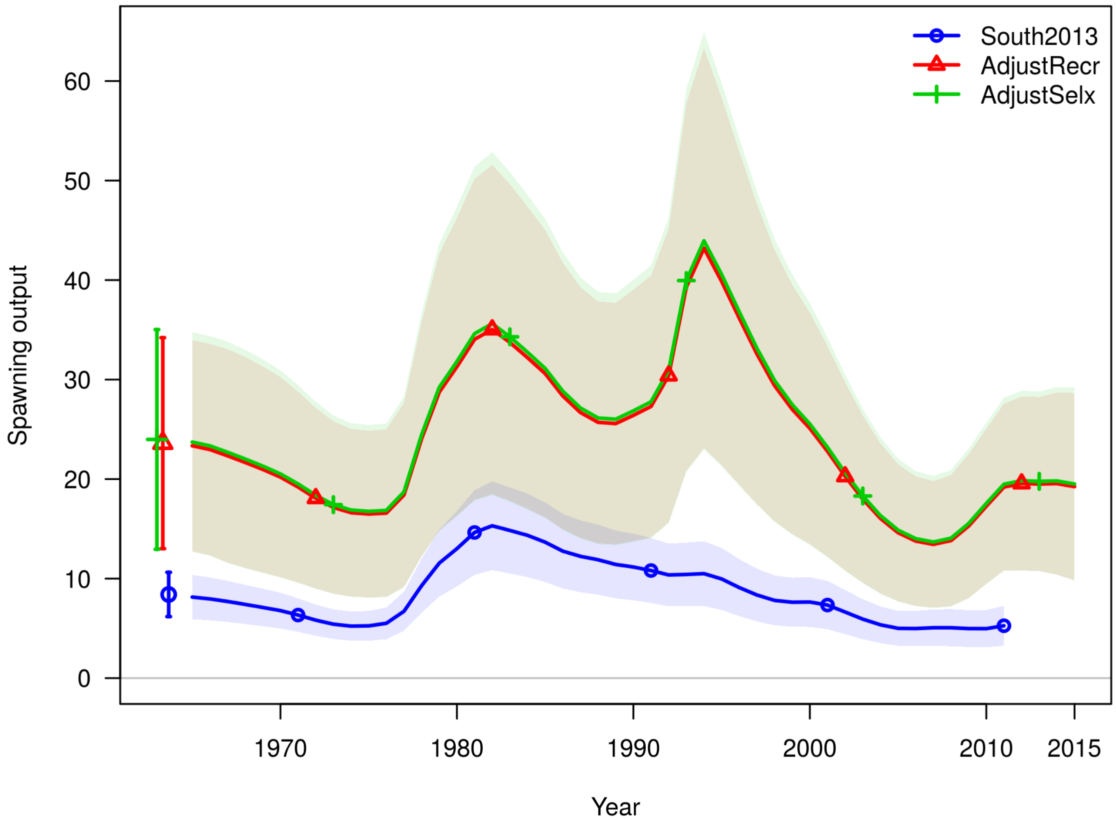


Figure 191: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model that estimates additional selectivity parameters and adjusts the right side of the MCD selectivity curve (AdjustSelx), as well as the previous model iteration (AdjustRecr).

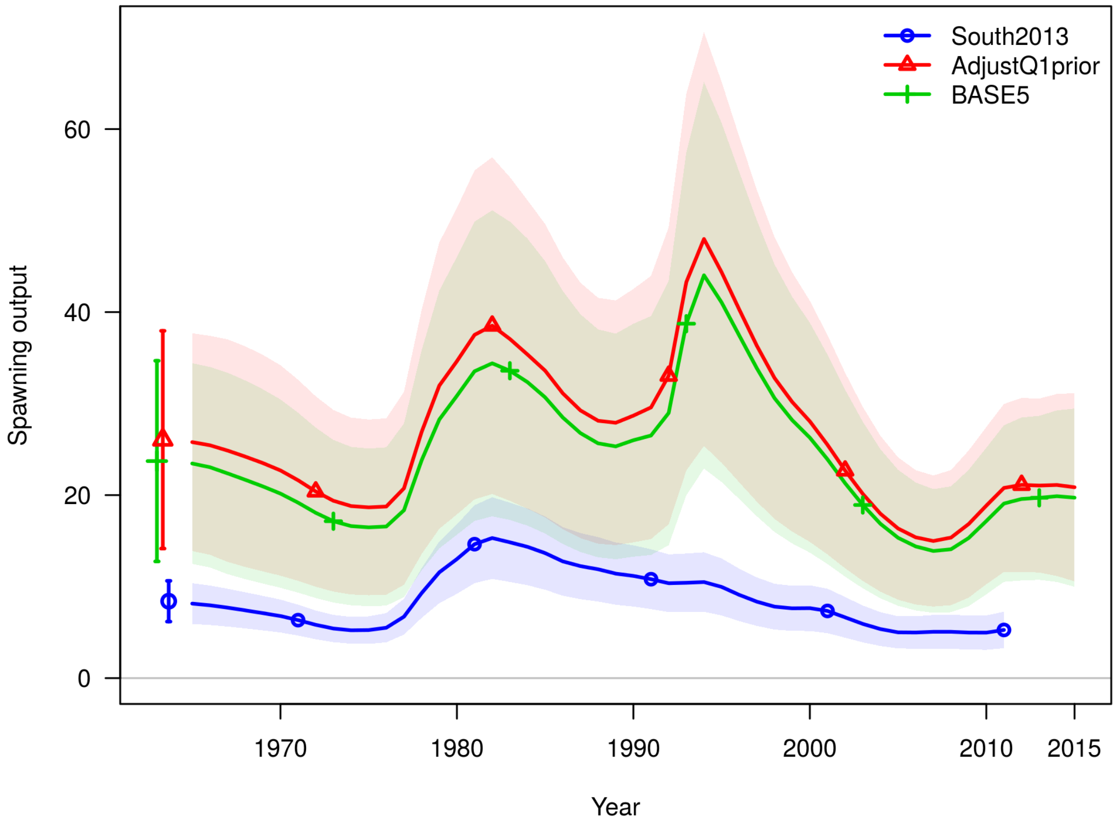


Figure 192: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model that includes a small adjustment to the prior distribution for the RD that brings it in line with the field prior distribution described in the last assessment (AdjustQ1prior), as well as the base model from the current assessment (BASE5).

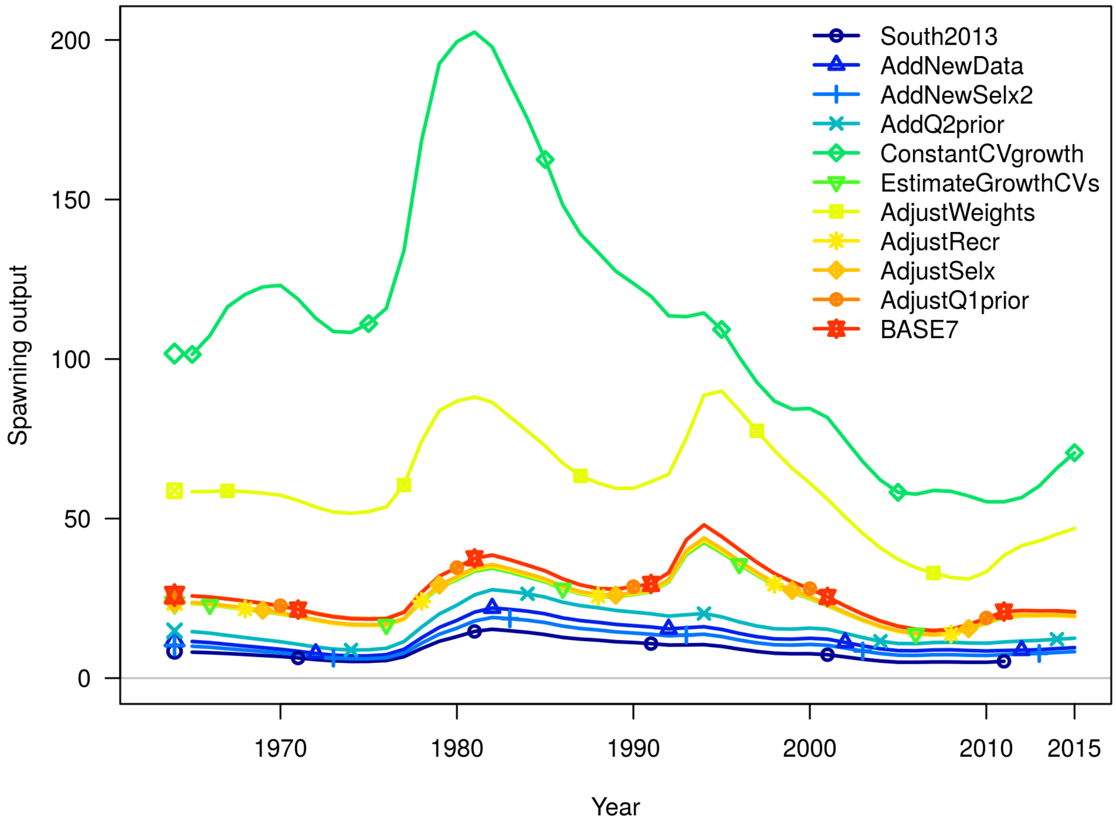


Figure 193: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to each iteration in the sequence of model changes, as well as the base model from the current assessment (BASE7).

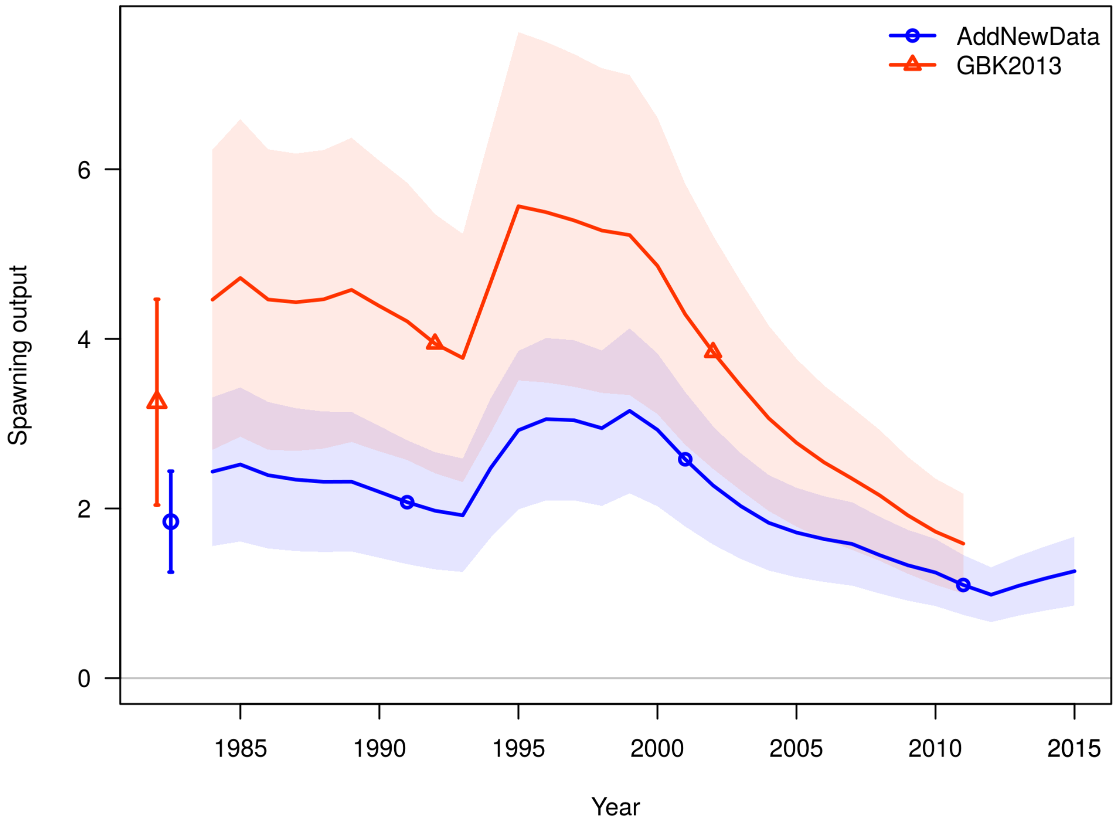


Figure 194: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model with identical configuration, but incorporating data from additional years (AddNewData).

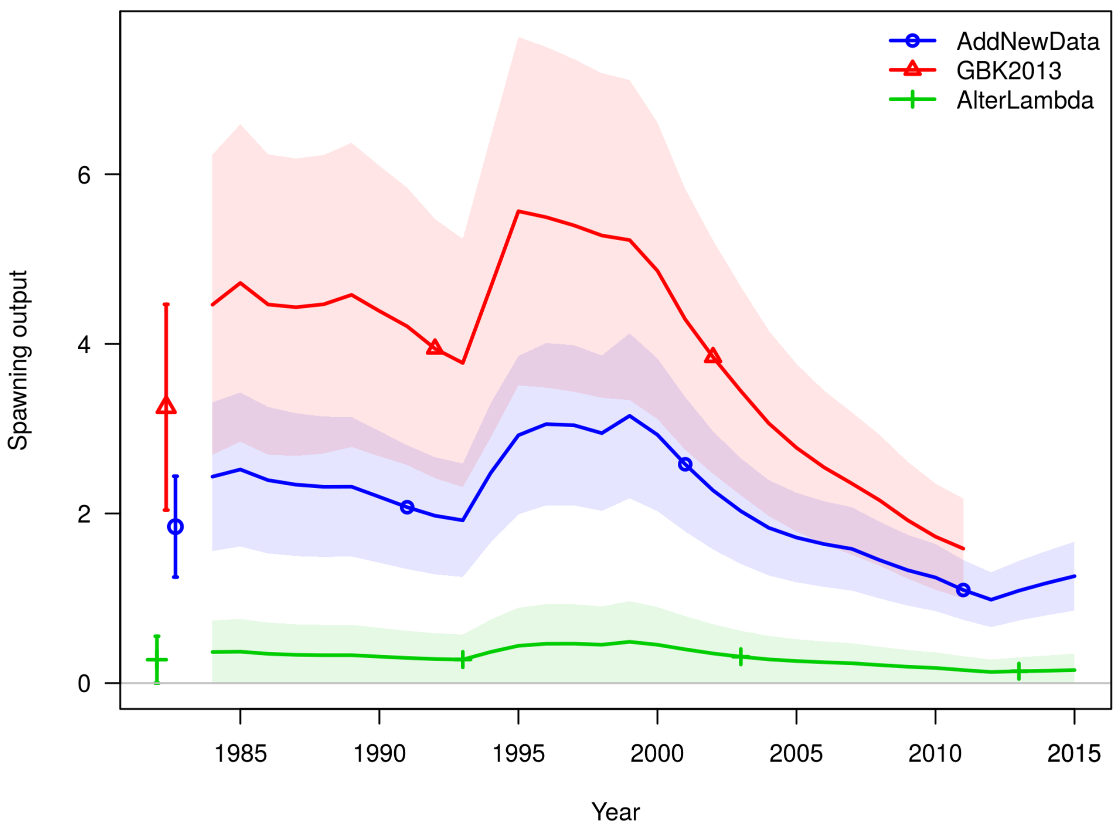


Figure 195: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model run where the likelihood component corresponding to the swept area number per tow in the survey was removed from the model solution (AlterLambda), as well as the previous model iteration (AddNewData).

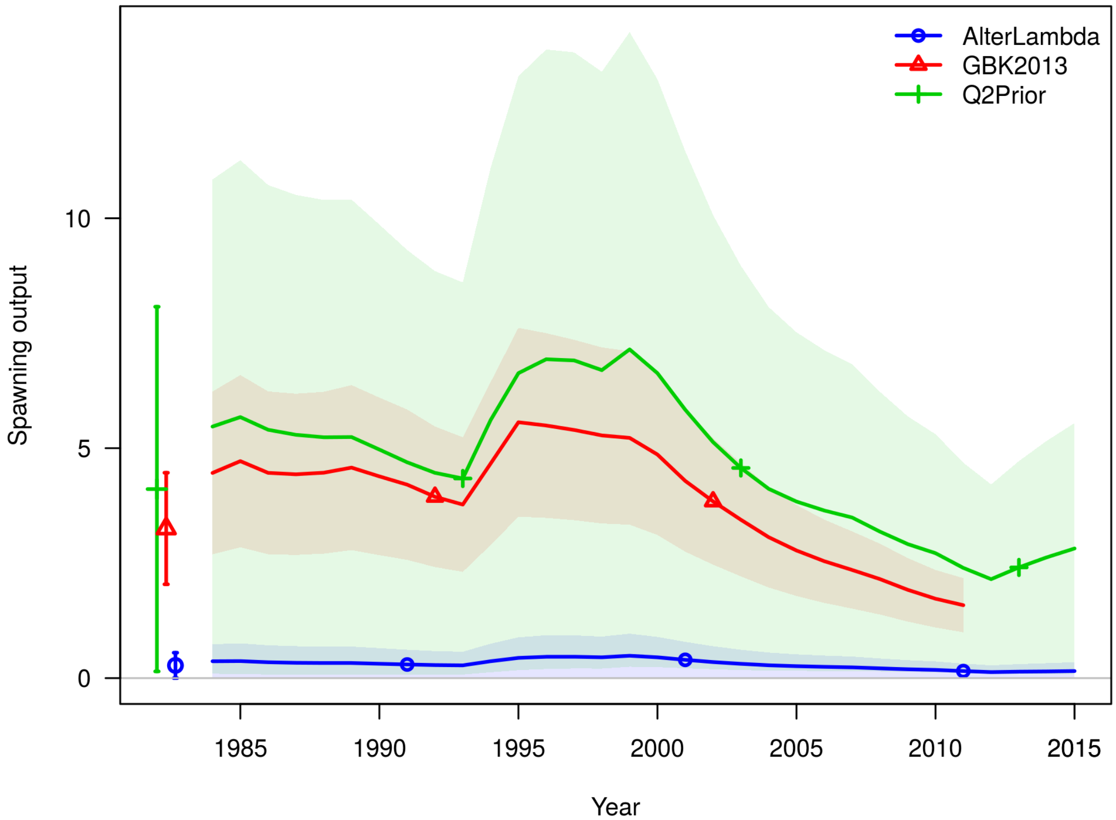


Figure 196: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model incorporating the prior on catchability for the MCD (Q2Prior), as well as the previous model iteration (AlterLambda). A comparison model run did not converge so the uncertainty associated with each spawning output trajectory could not be estimated.

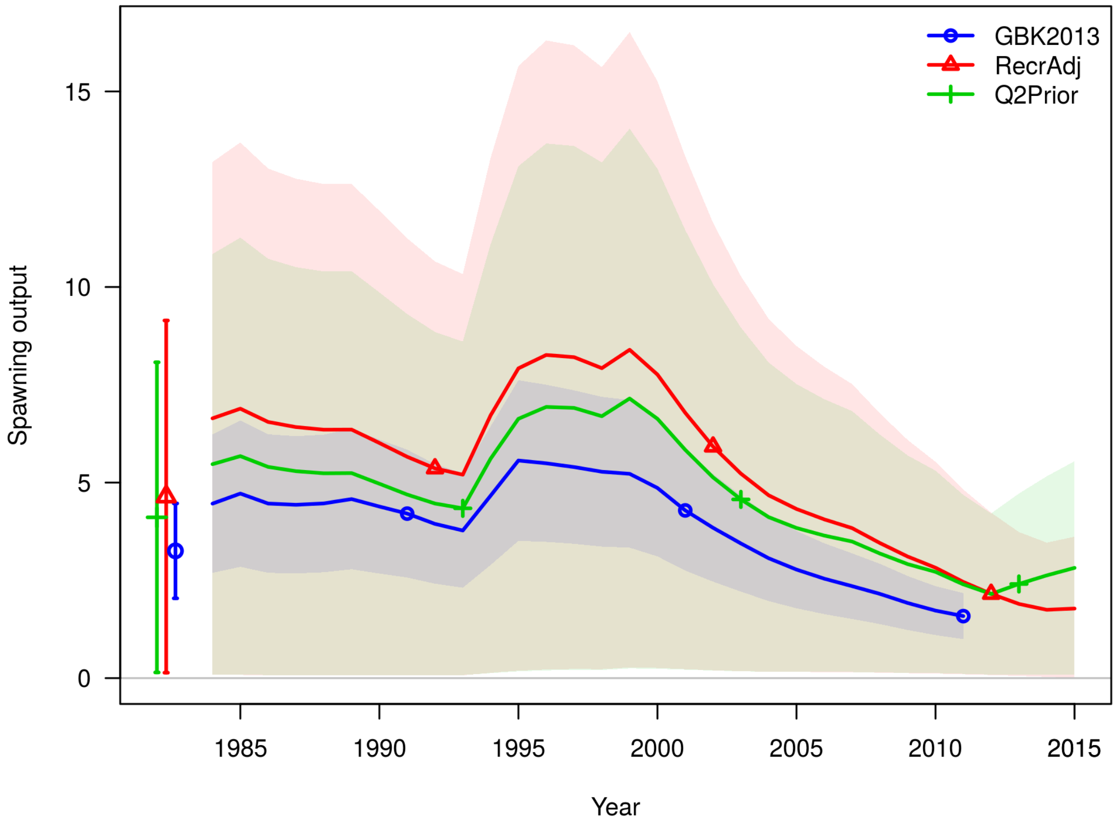


Figure 197: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where several recruitment parameters were adjusted (RecrAdj), including the number of recruitment deviations being estimated, the recruitment bias adjustment curve parameters, and the variance in recruitment was fixed rather than estimated. These runs were also compared with the previous model iteration (Q2Prior).

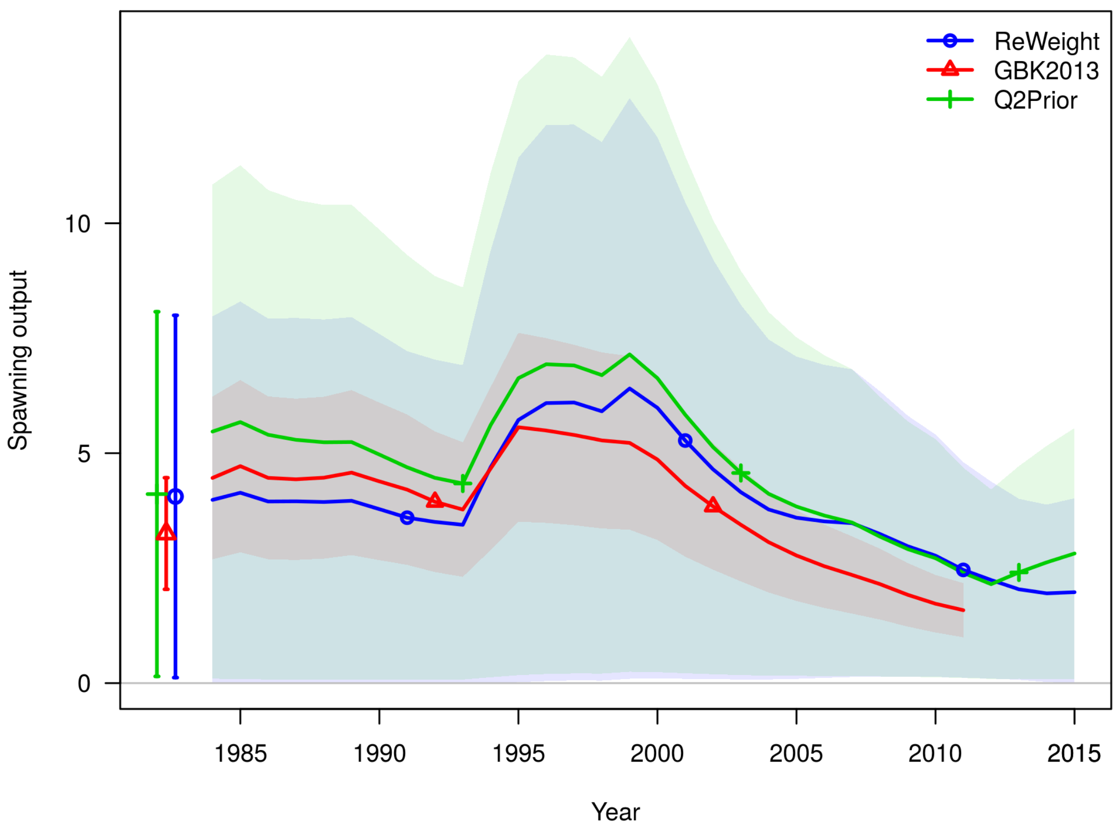


Figure 198: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where relative weightings of the data sources has been adjusted so that the information content of the composition data is decremented (ReWeight), as well as the previous model iteration (RecrAdj).

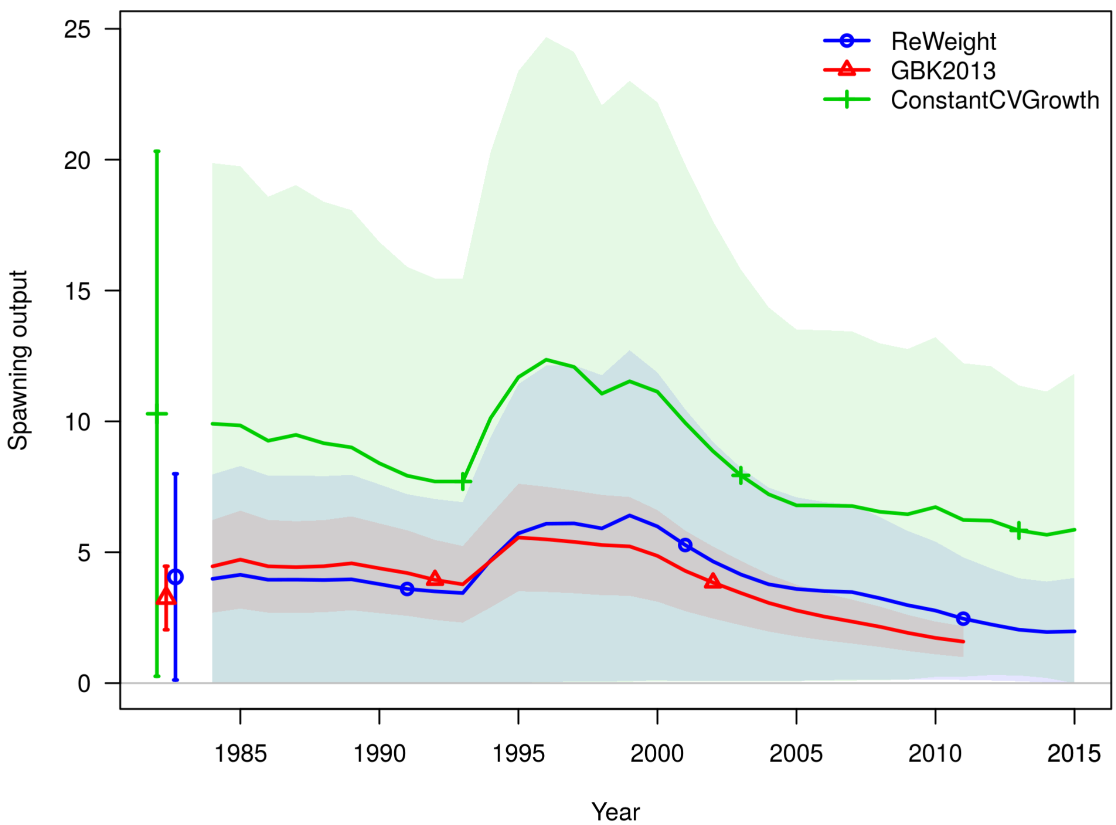


Figure 199: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where the error around the growth curve has a constant cv rather a constant standard deviation (ConstantCVGrowth), as well as the previous model iteration (ReWeight).

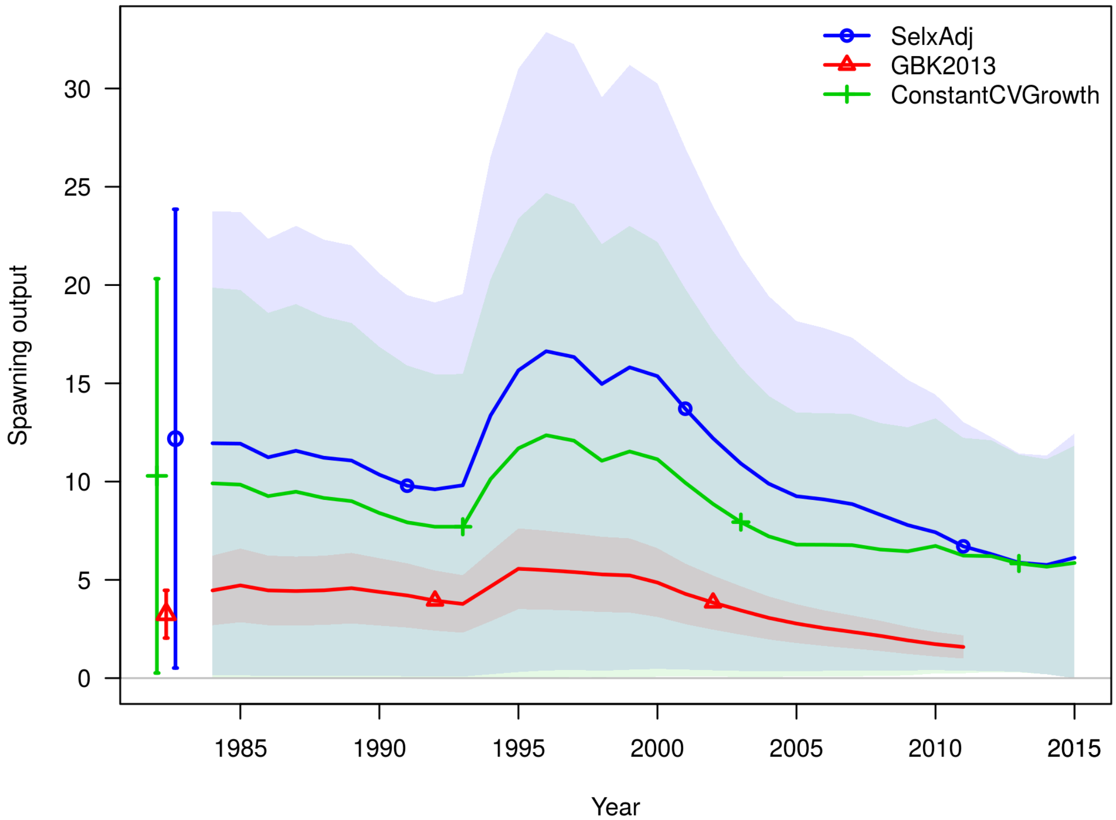


Figure 200: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where several selectivity parameters were estimated rather than fixed (SelxAdj), as well as the previous model iteration (ConstantCVGrowth).

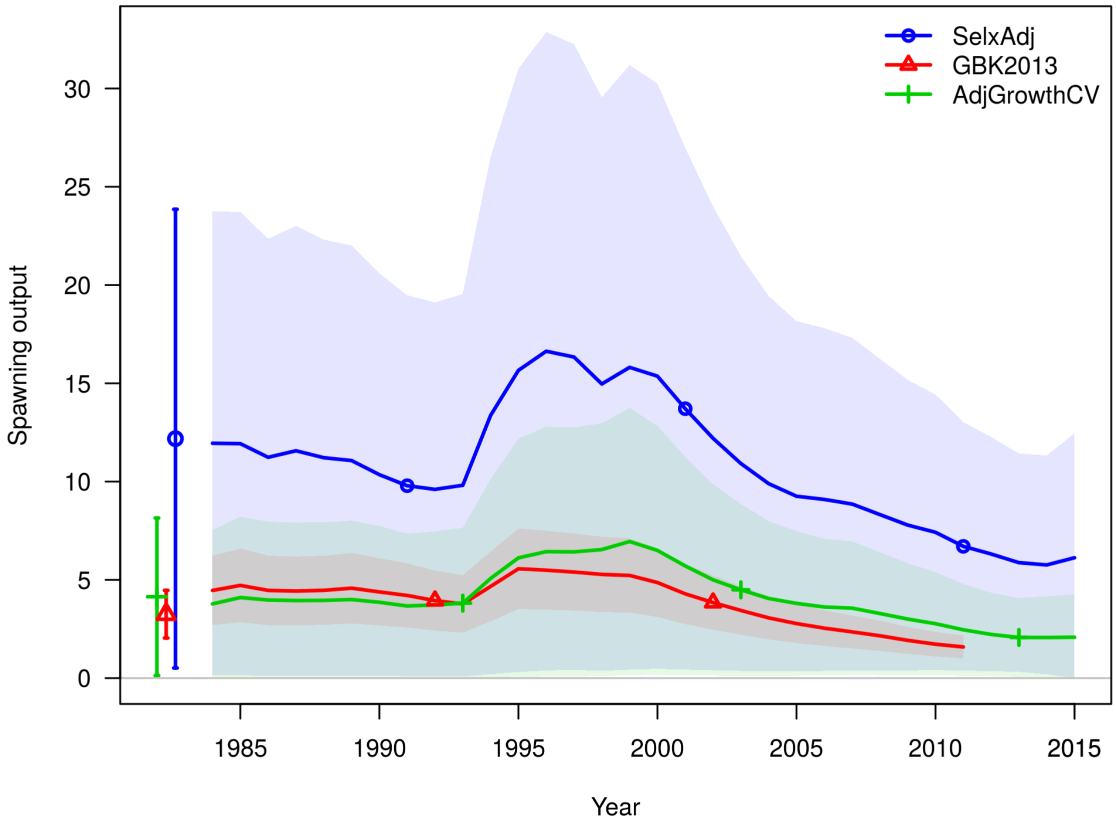


Figure 201: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where the cv around growth was adjusted to field estimated values (AdjGrowthCV), as well as the previous model iteration (SelxAdj).

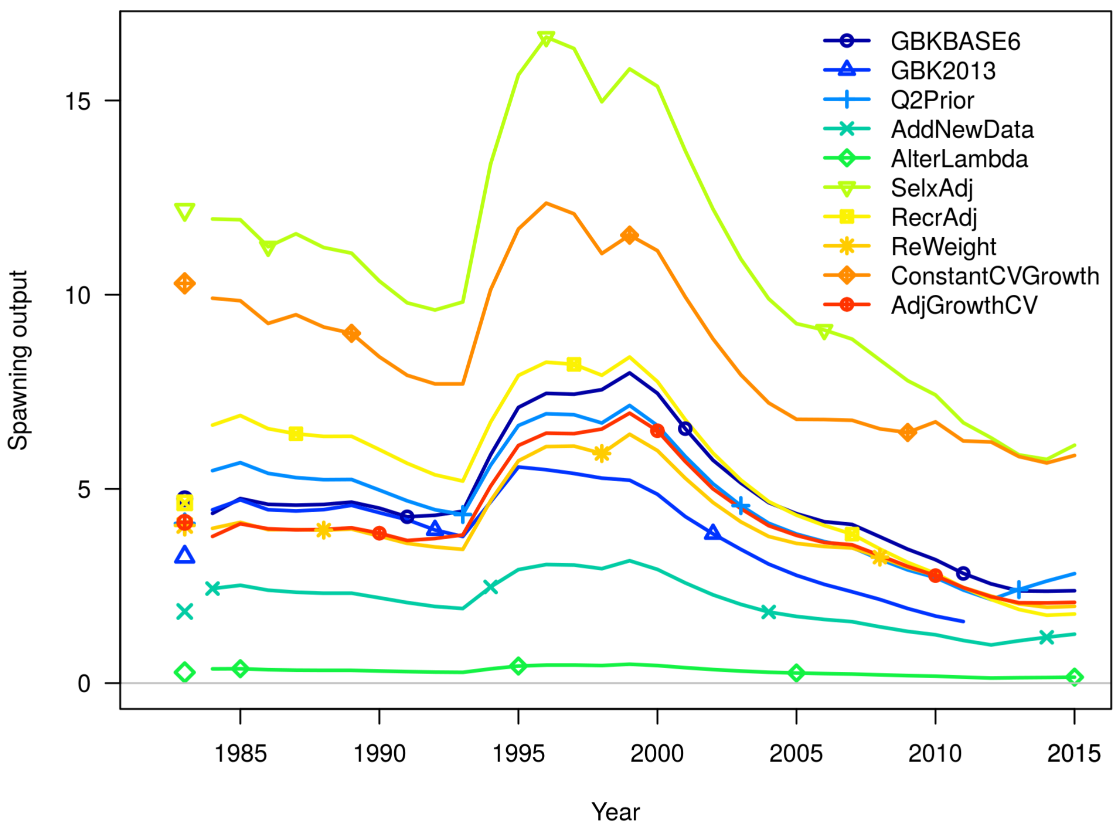


Figure 202: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (GBK2013) to each iteration in the sequence of model changes, as well as the base model from the current assessment (GBKBASE6).

Part XVIII

Appendix: Atlantic surfclam in Massachusetts, New York and New Jersey state waters

Thanks to Robert Glenn of the Massachusetts Division of Marine Fisheries, Jeff Normant of the New Jersey Division of Fish and Wildlife Bureau of Shellfisheries, and Jennifer O'Dwyer of the New York State Department of Environmental Conservation for data and assistance with this report.

The states of Massachusetts, New York, and New Jersey support and manage commercial Atlantic surfclam fisheries in their territorial waters (defined as from the shoreline to three nautical miles offshore) not covered by the NEFSC clam survey or assessment process. Commercial and survey data from state waters complement the assessment of the Federally managed EEZ stock given the biological linkage between state waters and the EEZ, and the possibility that environmental effects in inshore Atlantic surfclam habitat will be mirrored in the offshore population or vice versa.

Massachusetts, New Jersey and New York state waters have historically been excellent habitat for Atlantic surfclam and supported robust fisheries. In recent years, however, there is evidence of declining recruitment to the fishable population and mortality of large clams in New Jersey and New York based on size frequencies and total biomass estimates. This could be happening for any number of reasons including not enough successful spawning leading to reduced larval supply, or because newly settled Atlantic surfclam are not surviving due to predation, environmental conditions, or disease.

The percentage of total Atlantic surfclam landings (EEZ plus state waters) harvested from within state waters has been falling since the late 1980s (Figure 203). Commercial landings have also fallen dramatically in each of the three states. As recently as the 1990s, landings from state waters were around 500,000 bushels per year from New Jersey (all along the coast), 400,000 bushels per year from New York (off the south side of Long Island) and 260,000 bushels from Massachusetts (mostly from around Cape Cod Bay, Martha's Vineyard, and Nantucket). Since then, landings have been down about 90% in New Jersey, 70% in New York, and 75% in Massachusetts.

Each state has a shellfish management plan in place involving various methods of assessing the population. New Jersey and New York conduct annual or semi-annual surveys of the Atlantic surfclam resource in their territorial waters and track landings by subarea. Massachusetts has tracked Atlantic surfclam landings from subareas within its state waters since 1994. For details and results from each state see below.

New Jersey

The New Jersey State Atlantic surfclam survey has been conducted each summer by the New Jersey Bureau of Shellfisheries since 1988. The survey platform is a commercial clam vessel using a hydraulic dredge lined with 2x2 inch steel mesh; since 2010 either the F/V Ocean Bird or the FV Jersey Girl (Figures 204 - 205). The survey has followed a stratified random sampling protocol since 1994. The survey area includes the New Jersey territorial waters off the whole east coast of the state facing the Atlantic Ocean. The survey area is divided into 5 regions, and each region is divided into three one-mile-wide strata running parallel to the coast, covering Atlantic surfclam habitat out to the 3-mile limit of state waters (Figure 206). Surveys have generally completed between 250 and 330 five minute tows each year.

In preparation for the 2013 field season, a new survey station allocation plan was established to deliver the information needed for less money and time by emphasizing key strata. Unfortunately, hurricane Sandy struck in the fall of 2012, disrupting the coast to such a degree that there were virtually no Atlantic surfclam left in the reduced strata set, and the newly streamlined survey could not be considered a viable part of the time series. During the summer of 2014 the survey resumed sampling almost the whole strata set with a reduced number of stations.

After each survey tow, the volume of the total Atlantic surfclam catch is measured in bushels, and all the clams from one bushel are counted and measured for calculation of population estimates and length frequencies. For swept-area biomass estimates, the dredge efficiency is assumed to be 1.0, which yields a conservative population estimate. Abundance estimates are made using the mean number of clams per bushel from any given stratum multiplied by the biomass estimate in bushels. Grab samples of the sediment are also taken and juvenile Atlantic surfclam too small to be retained by the dredge are sorted out and counted.

Data from the state of New Jersey available for this appendix include survey biomass estimates, survey length frequencies, an index of juveniles from sediment grab samples through 2015, and landings from 1988 through the 2014-2015 fishing year (October 1 through May 31). The survey data from 2015 are considered preliminary.

Estimates of Atlantic surfclam biomass for all the survey strata combined since the first survey year rose to a peak in 1997, then fell to the lowest estimate of the time series in 2014. Rough estimates of exploitation rate (landings over biomass estimate for the year) in New Jersey state waters have been between about 2 and 12 percent (Figure 207). Whether overexploitation contributed to the biomass decline is unclear, but the population did recover from a time of high exploitation in the 1980s. The impact of Hurricane Sandy can be seen in the estimates following 2012.

In the 2000s, the length composition of Atlantic surfclam in New Jersey was narrow and composed of only larger Atlantic surfclam, indicating a lack of new recruitment. However, recent survey data shows some smaller clams recruiting to the population (Figure 208). Grab sample data collected regularly since 1994 from the area of the survey show that juvenile Atlantic surfclam are consistently setting successfully (Figure 209). Some years have been better than others with occasional larger sets such as the ones seen in 2005 and 2009, a typical pattern for bivalve recruitment. These data do not show any downward trend in production of juvenile Atlantic surfclam that might occur as the result of unsuccessful spawning due to a decline in spawning stock.

Atlantic surfclam landings for human consumption from New Jersey state waters have fallen from a high of about 700,000 bushels in 2003 to less than 100,000 in 2005 and to zero or near-zero levels since 2006. Since the early 2000s, a small fraction of landings came from "prohibited waters" - fishing areas where landings can only be sold as bait due to contamination (Figure 210). Since 2008 the percentage of estimated Atlantic surfclam standing stock in prohibited waters has varied from 5 to 26 percent (Figure 211). As of 2005 the landings of bait Atlantic surfclam surpassed edible Atlantic surfclam, and during the 2014-2015 season the only Atlantic surfclam harvested were less than 300 bushels for bait. As the standing stock of edible Atlantic surfclam has declined, the quota has been cut to levels prohibitive to fishing. There is no quota for bait Atlantic surfclam harvested from prohibited waters.

Temperature change may be at least partly to blame for the rapid decline in adult Atlantic surfclam off New Jersey, whether directly or indirectly (such as changes in the timing, location or type of phytoplankton blooms). Increased predation on juvenile clams may also be occurring as the result of temperature-driven changes in predator species or densities.

New York

The New York state Atlantic surfclam surveys are conducted by the New York Department of Environmental Conservation. Surveys took place in 1992, 1993, 1996, 1999, 2002, 2005, 2006, 2008 and 2012. Plans for running the survey in 2014, and then plans for 2015, were set aside due to problems with contracting the survey vessel. The surveys from 1992-1996 were conducted and analyzed using different methods than the later surveys, so the results may not be directly comparable to more recent surveys and thus are usually not included in plots and summaries in this report.

The survey area comprises four regions spanning the southern shore of Long Island. The three westernmost regions are subdivided into three mile-wide strata running parallel to the coast, reaching the limit of state waters. The remaining easternmost region consists of a single stratum from the shore to one mile out (Figure 212). The area further offshore in this region is not surveyed as the bottom is extremely rocky and incompatible with hydraulic clam dredges.

The survey is conducted using a commercial clam vessel, most recently the FV Ocean Girl (Figure 213), using a hydraulic dredge lined with 1 in. inch plastic mesh to retain smaller clams. The 1999-2012 surveys were conducted in the summer or fall, had an average of 236 stations, and used a random stratified sampling technique. Survey tows are three minutes long, the total volume of Atlantic surfclam from each tow is measured in bushels, and half a bushel of Atlantic surfclam from each tow is measured and counted for population estimates and length frequencies.

Data from the New York State surveys include total numbers, densities and length frequencies for all surveys and ages from all surveys except 2012. Atlantic surfclam landings from New York state waters are available through 2015 (although not all 2015 reports were in when we received these data so they are considered preliminary).

Population estimates from the survey years show that the Atlantic surfclam abundance increased through the 1990s and peaked in the early 2000s. After that begins a decline that is just as fast as the increase, and in 2012 the population was estimated to be about what is was in 1994 (Figure 214). The decline has been especially pronounced in the inshore and western strata. The simple catch/biomass exploitation rate has been less than 6% since the population increase so it does not seem like overfishing is responsible for the decrease (Figure 215). Just like New Jersey but to a lesser degree, it seems that New York Atlantic surfclam are declining mostly as the result of environmental stress.

Recruitment to the population has declined, but the 2008 and 2012 survey age frequencies both suggest there were more young clams than the two previous surveys (Figure 216), but many fewer than in 2002. There has also been an increase in very old Atlantic surfclam over the time series, so even though there are fewer clams overall the old ones do not seem to be dying disproportionally. The three main cohorts seen in the age frequency plots can all be followed from 2002 through 2012 but no new cohorts of any size seem to be making it past the age of five or six. The percentage of the Atlantic surfclam less than 100mm shell length caught (considered seed) caught on the survey is also a measure of recruitment. Many seed Atlantic surfclam were caught in the 2002 survey, especially in the western strata where up to 54% of clams caught were seed (Figure 217). The percentage of seed taken in the survey in years since has been falling. Survey length frequencies also indicate poor recruitment (Figure 218). Length at age plots do not seem to suggest New York Atlantic surfclam are growing more slowly in recent years (Figure 219), although all regions and strata were lumped together so spatial changes may be masked.

Despite the decline, Atlantic surfclam continue to be harvested in New York state waters at about 33 percent of the 1994-2014 mean (Figure 220). There was a very large harvest limit set in 2004 (930,000 bushels) and it was almost reached, making the landings from New York from that year almost double what they had been the year before, and since then there has been a downward trend. The harvest limit based on the results of the 2012 state survey is the lowest since 1994.

The Atlantic surfclam fishery in New York state waters has been limited entry since 1993 when 25 boats qualified, and as of 2015 there were 17 vessels still fishing. In 2003 an FMP was implemented, requiring the harvest limit not to exceed 5% of the biomass estimated by the most recent survey, and dividing it into equal quotas for each permitted vessel.

Massachusetts

The Massachusetts Department of Marine Fisheries has been logging total Atlantic surfclam landings from state waters since 1994, and since 2008, the location harvested. Landings are recorded as having been harvested in one of over 75 contiguous Designated Shellfish Growing Areas (DSGAs) surrounding the Massachusetts coast including Boston Harbor, Cape Cod, Buzzards Bay and the islands of Marthas Vineyard and Nantucket (Figure 221). Because there are so many small areas, these data give the DMF an overview of how both the resource and the fishing are distributed and where the particularly productive areas are (Figure 222). The data are also used to calculate landings per unit effort and track fishing effort and its impact in specific areas. The numeric data per DSGA are often confidential due to a small number of harvesters using the area and not available for publication, so they are reported by the larger statistical reporting areas SRAs (Figure 223). Even then much data remain confidential (Figure 224).

There is a cap on the number of commercial permits issued, a daily harvest limit of 200 bushels and a minimum size of 5.0 in. shell length. Catches must be reported using daily trip reports. Some of the Atlantic surfclam harvested are from contaminated areas and are only used for bait. A special permit must be issued for this and only 50 bushels can be landed per day. Landings of all Atlantic surfclam from Massachusetts have declined since the early 1990s and have varied without trend since 1997 (Figure 225).

Figures

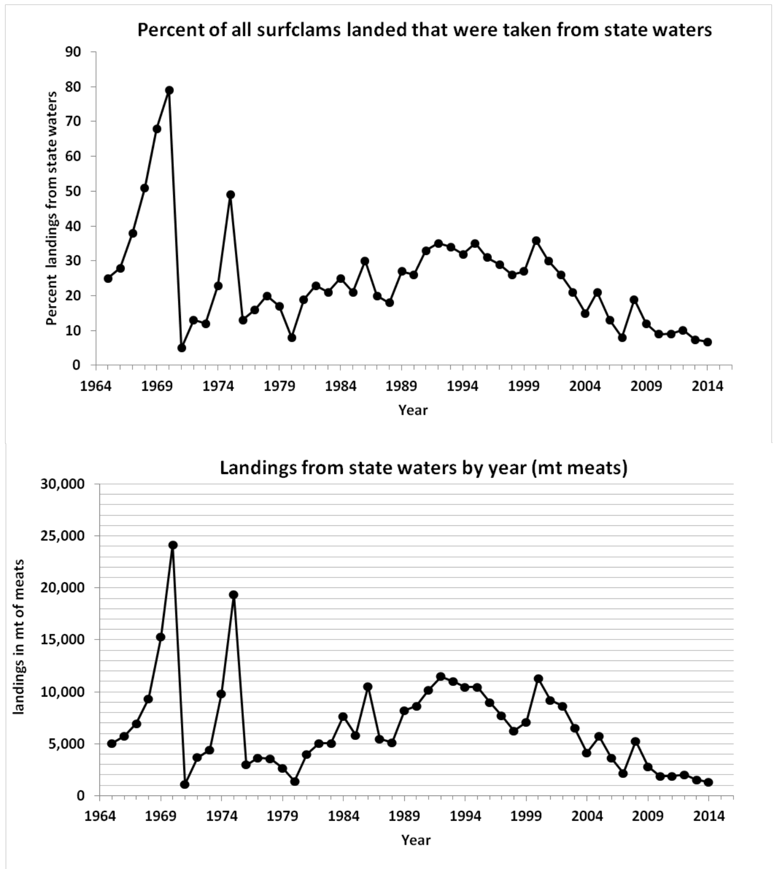


Figure 203: Percentage of total Atlantic surfclam landings harvested from state waters, almost entirely from New York, New Jersey and Massachusetts (top), and landings from state waters in metric tons of meats by year (bottom). There may be differences between the landings shown above and landings attributed to state waters in the main assessment report. The report has historically used dealer-reported landings minus logbook-reported landings (from EEZ - permitted vessels) to estimate state landings, which is not as accurate as the landings reported directly from the states. However, the assessment time series begins well before the states were keeping track of their landings and the subtraction method is still used for consistency.

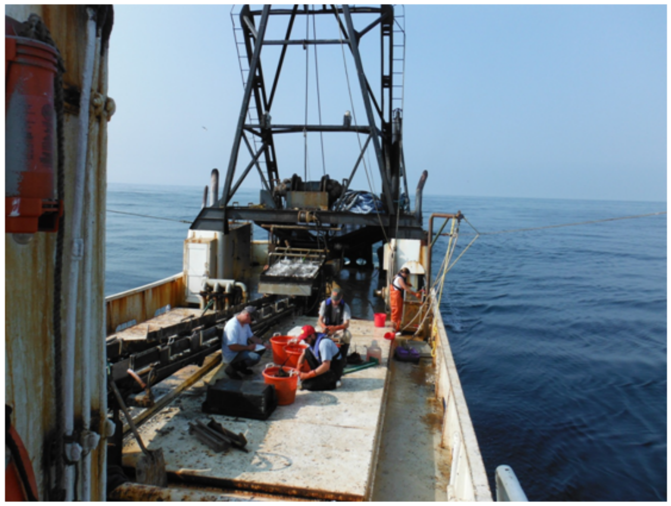


Figure 204: The New Jersey state survey under way aboard the FV Jersey Girl.

Figure 205: Results of a tow from the New Jersey state survey.

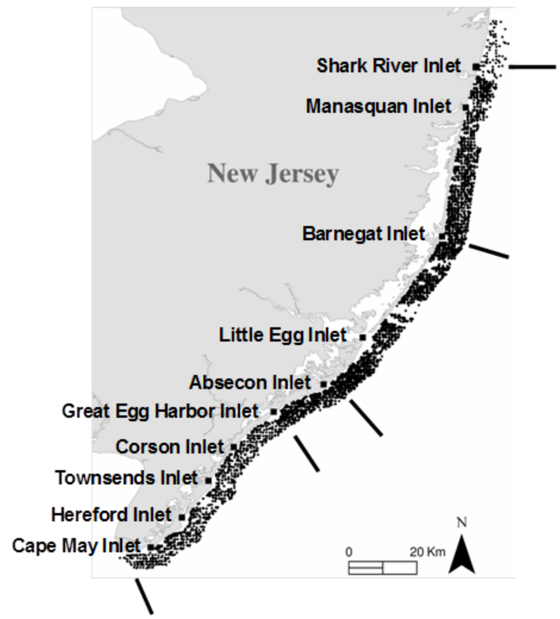


Figure 206: Map showing the sampling regions for the NJ state survey, and station locations 1988-2008. Within each region there are three along-shore depth strata one mile wide. Map courtesy of Jeff Normant.

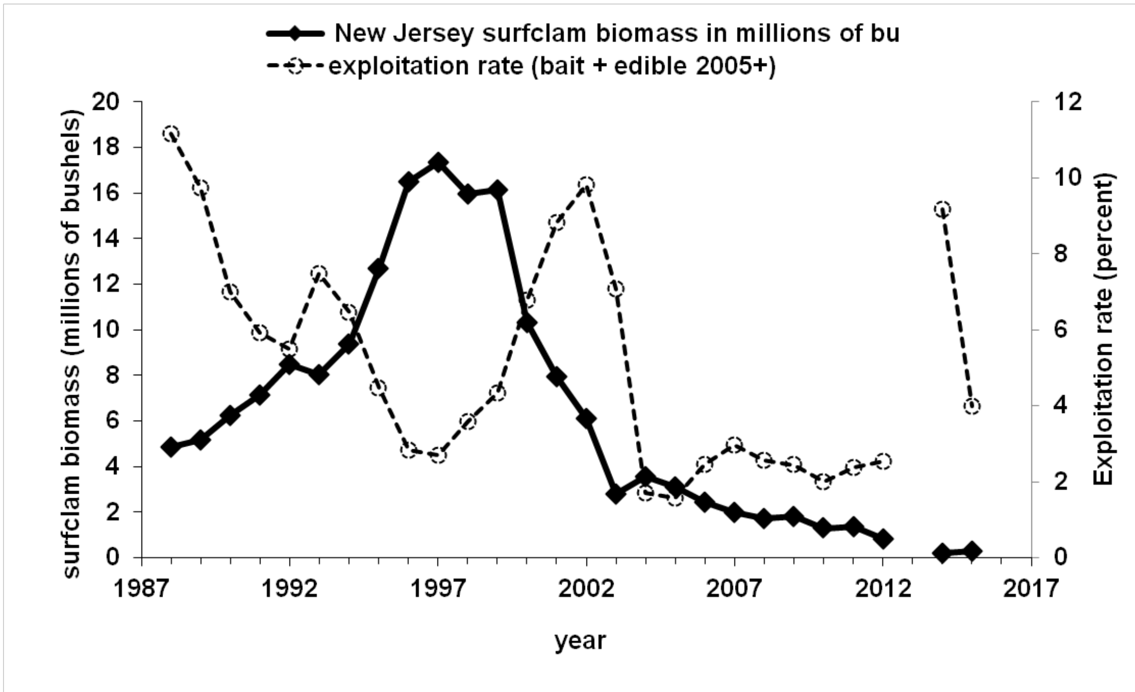


Figure 207: Exploitation rates (expressed as landings as a percentage of estimated biomass) and population biomass for New Jersey state Atlantic surfclam.

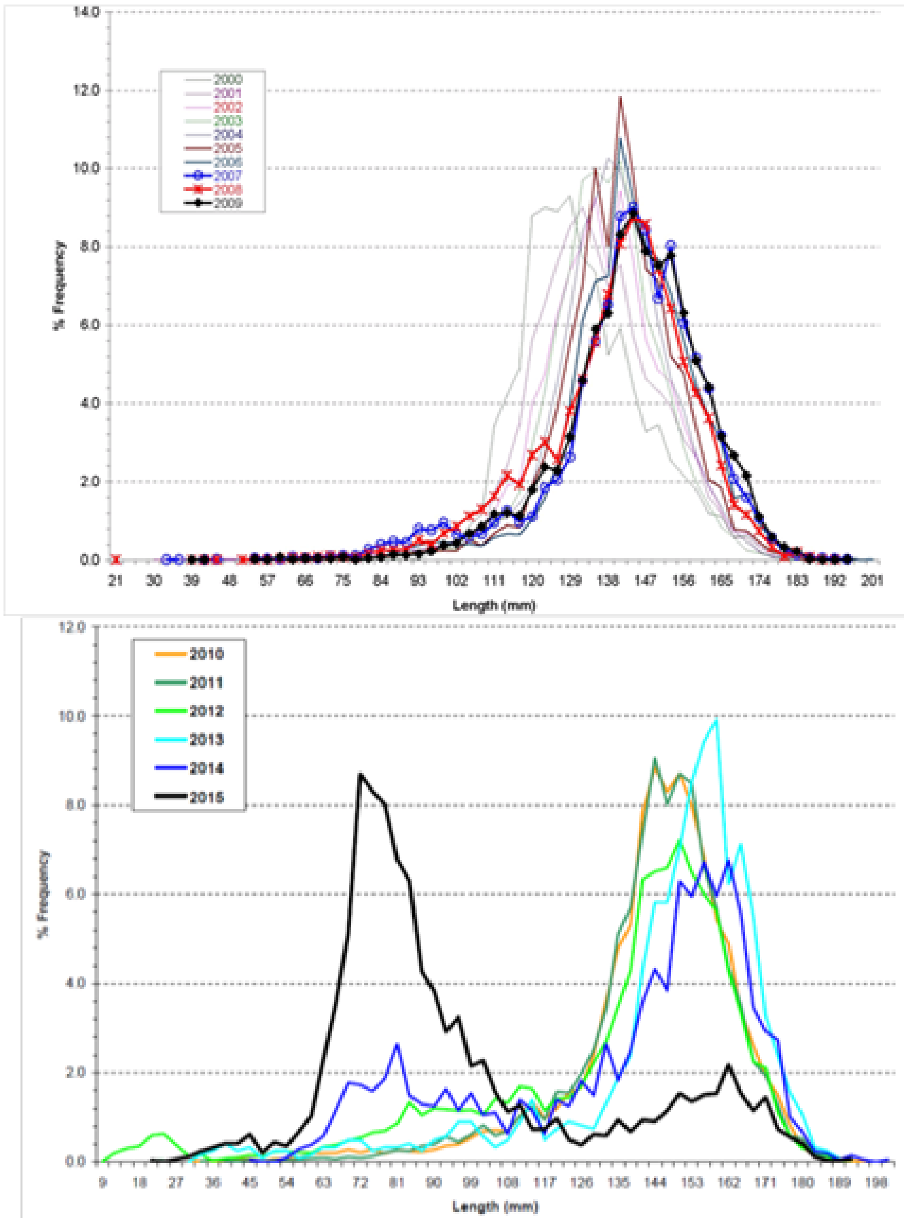


Figure 208: Length frequencies from the 2000-2009 (top) and 2010-2015 (bottom) New Jersey state Atlantic surfclam surveys. Not all strata were sampled in 2013 and 2014 but the most populous ones were. Note scales are different on both axes. Plots courtesy of Jeff Normant.

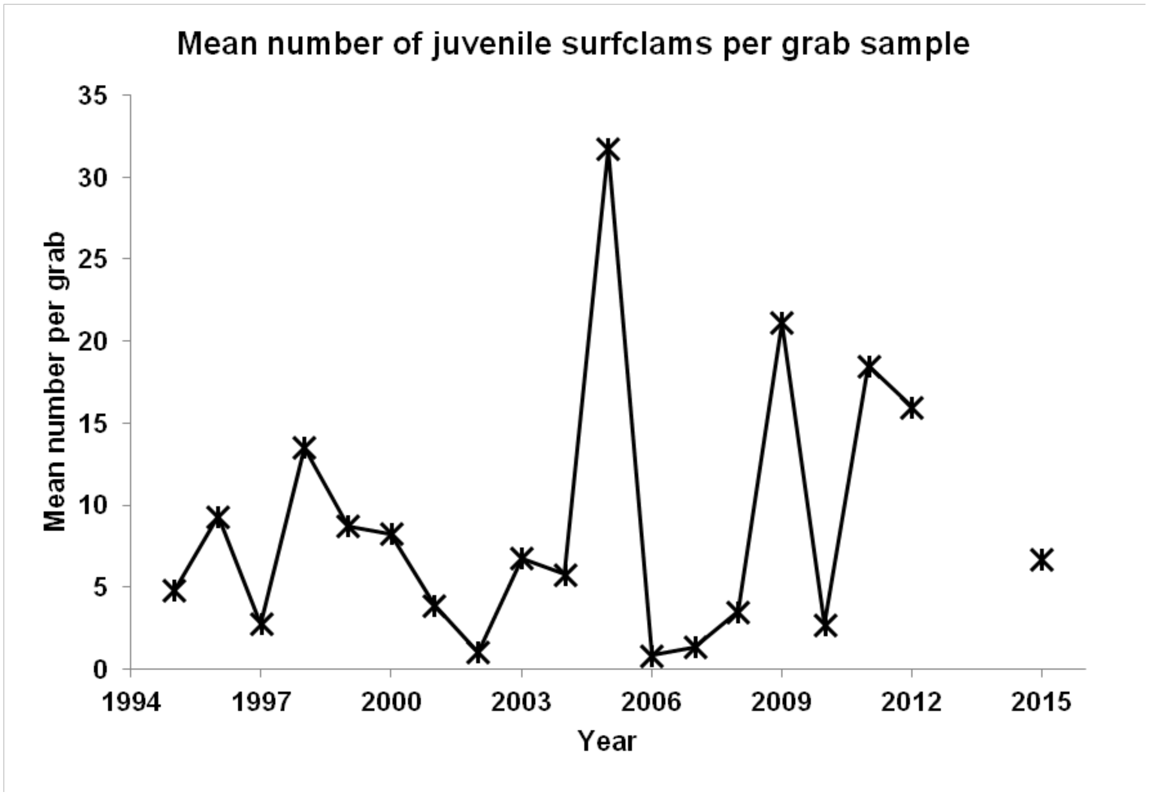


Figure 209: As part of the Atlantic surfclam survey, the state of New Jersey takes sediment grab samples, which contain juvenile Atlantic surfclam too small to be retained in the survey dredge. The clams are generally less than 10mm. About 300 grab samples were taken each year up until 2012, in 2013 and 2014 there were no grabs done, and 186 grabs were done in 2015. The area sampled is 1/10 of a square meter.

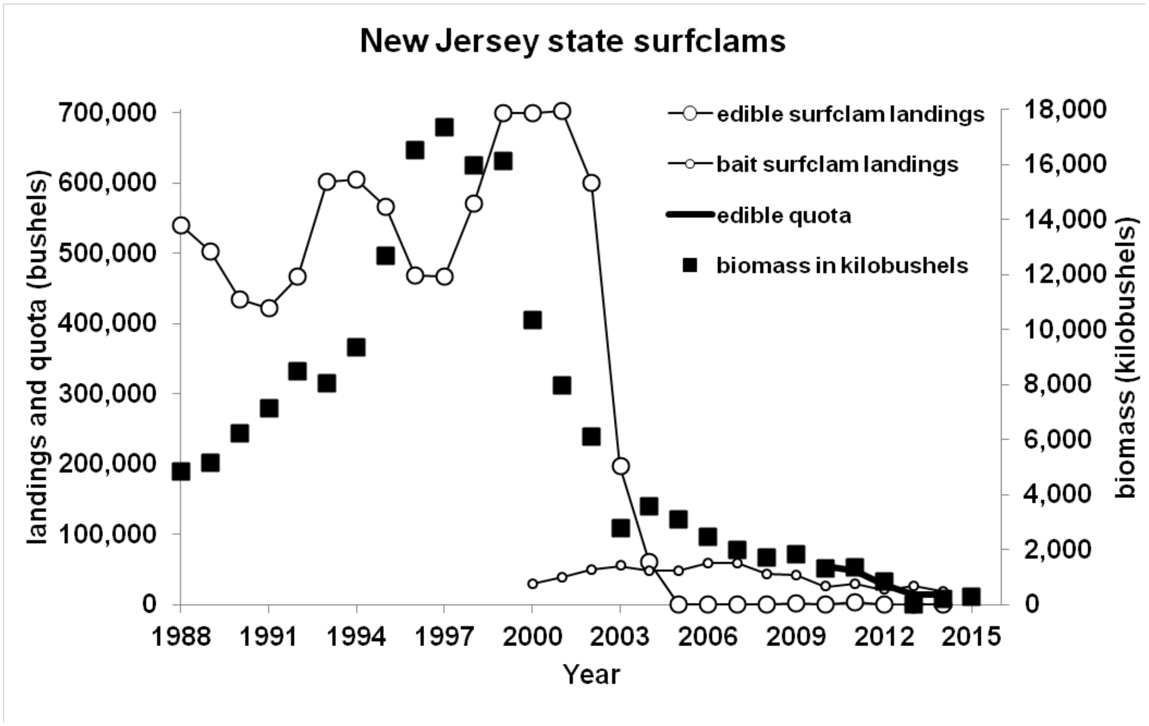


Figure 210: Landings of both edible and bait Atlantic surfclam, quota for edible Atlantic surfclam and survey-based Atlantic surfclam population estimates in New Jersey state waters. Landings and quota are scaled to the left axis and population is scaled to the right axis. There are no quotas or restrictions on harvest of bait clams at this time.

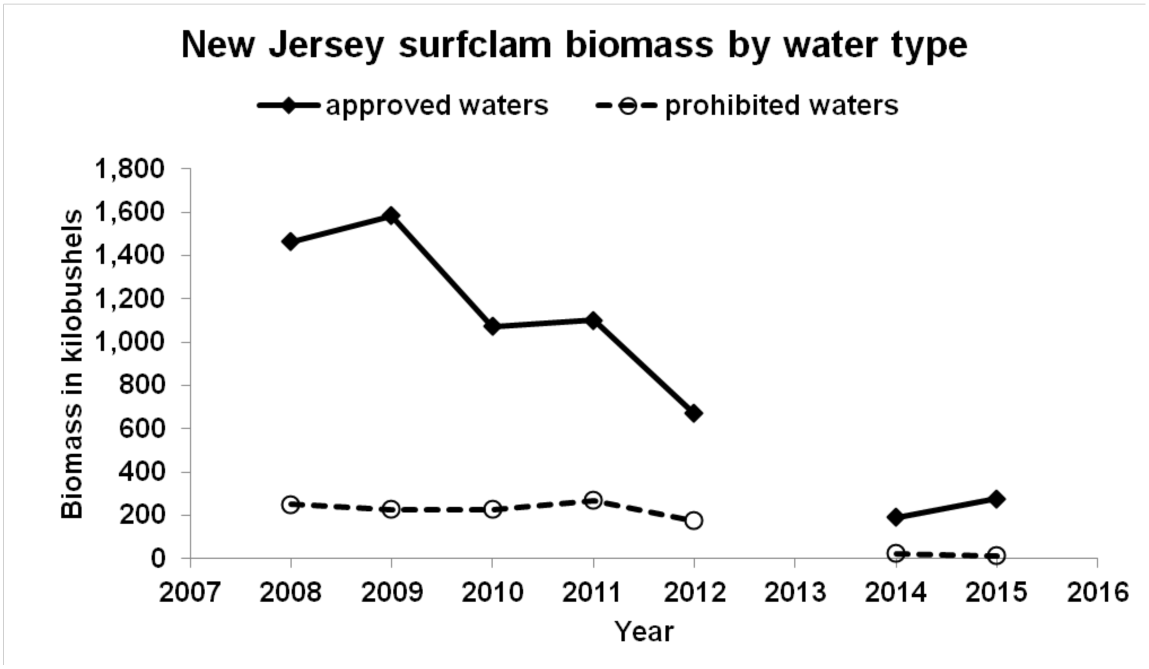


Figure 211: Standing stock in industry bushels from New Jersey state waters. Clams from approved waters can be sold for human consumption, while clams from prohibited waters are sold for bait only.

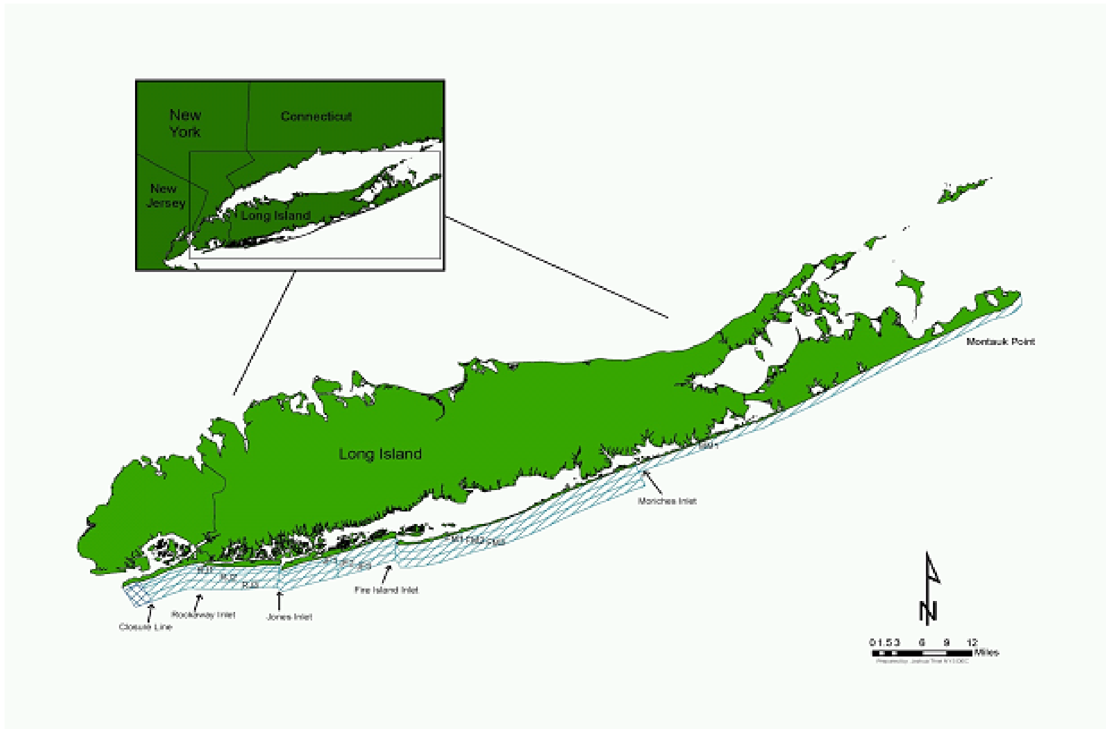


Figure 212: Map showing New York state sampling regions from west to east: RJ, JF and FM, which each have 3 depth strata, and MM which has one depth stratum. Map courtesy of New York State Department of Environmental Conservation.

Figure 213: The commercial clam vessel FV Ocean Girl, used for the New York state surveys, with dredge deployed. Photo courtesy of Jennifer O'Dwyer.

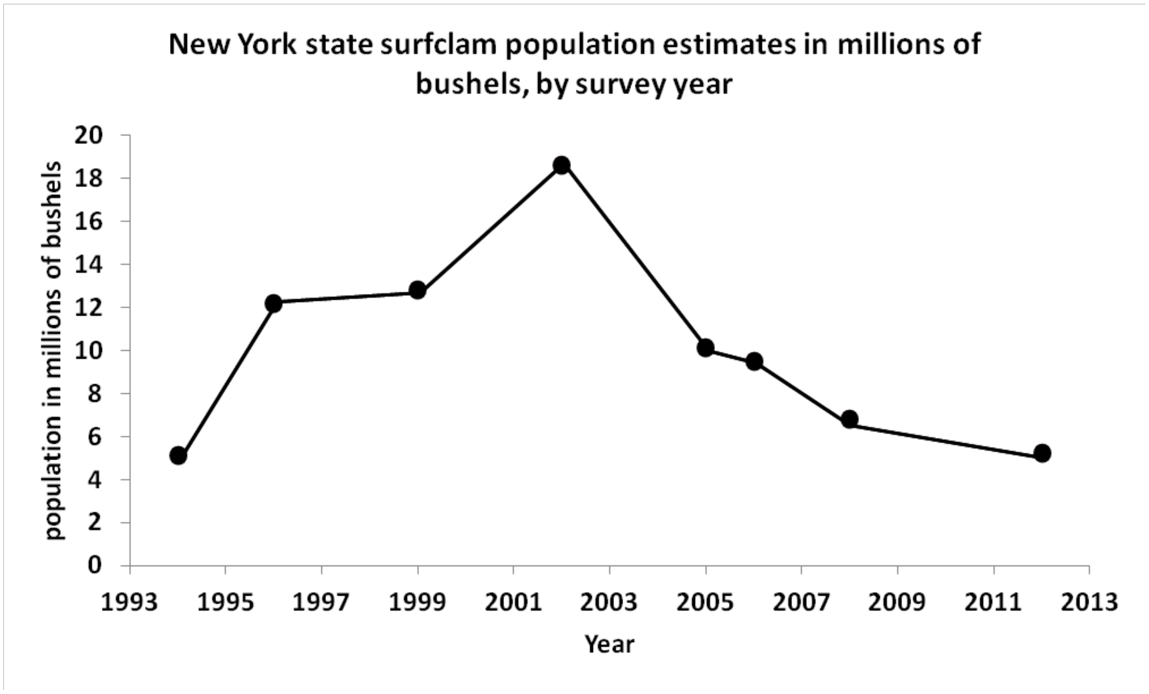


Figure 214: Atlantic surfclam population estimates for the surveyed area in New York state waters since 1994, in millions of bushels.

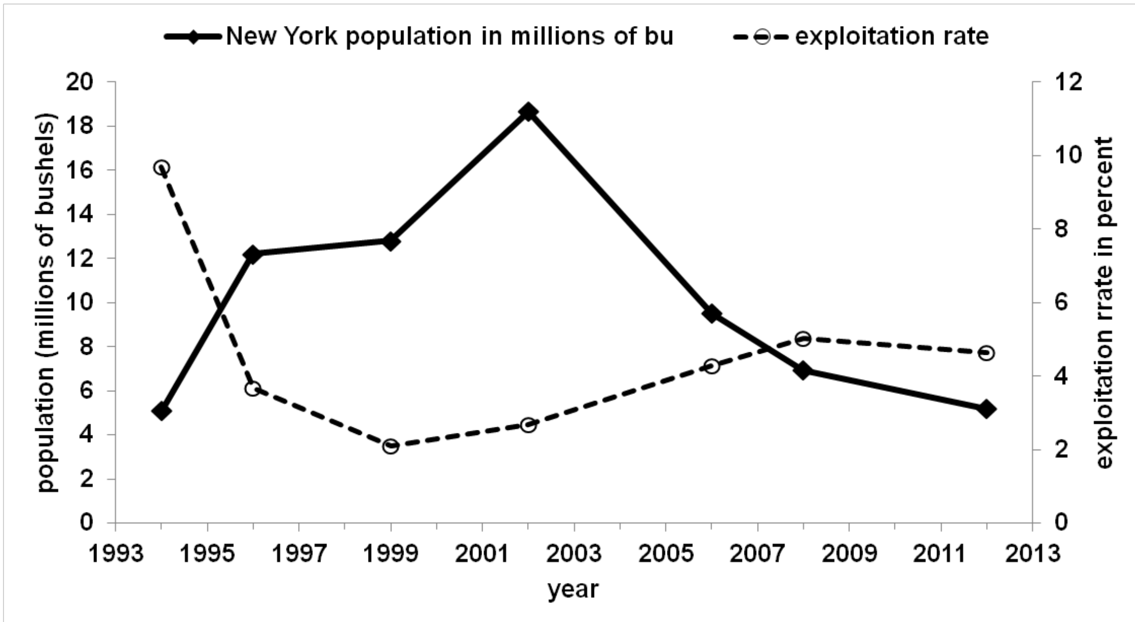


Figure 215: Exploitation rates (expressed as landings as a percentage of estimated biomass) and population biomass for New York state Atlantic surfclam.

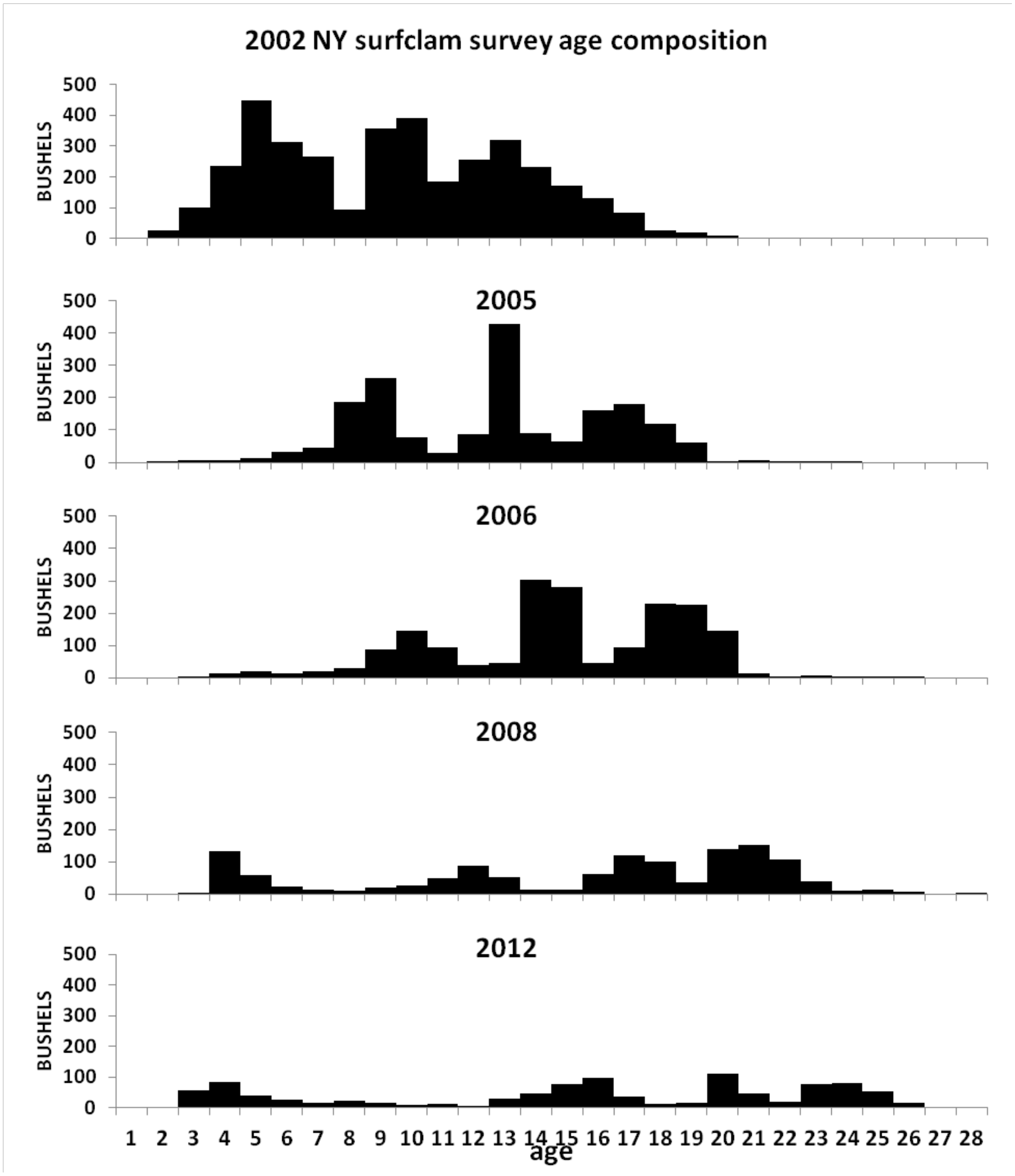


Figure 216: Age compositions from the 2002, 2005, 2006, 2008 and 2012 New York State Atlantic surfclam surveys, in bushels at age.

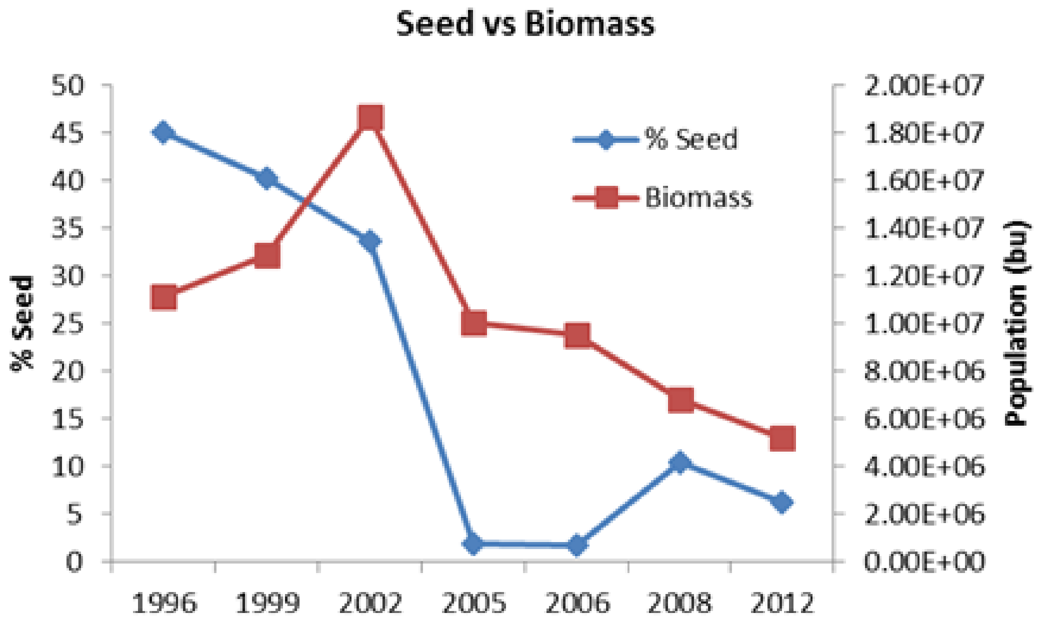


Figure 217: Population estimates for Atlantic surfclam in New York state waters and the percentage of the population considered seed clams (less than 100mm SL) by survey year. Plot courtesy of Jennifer O'Dwyer, NYDEC.

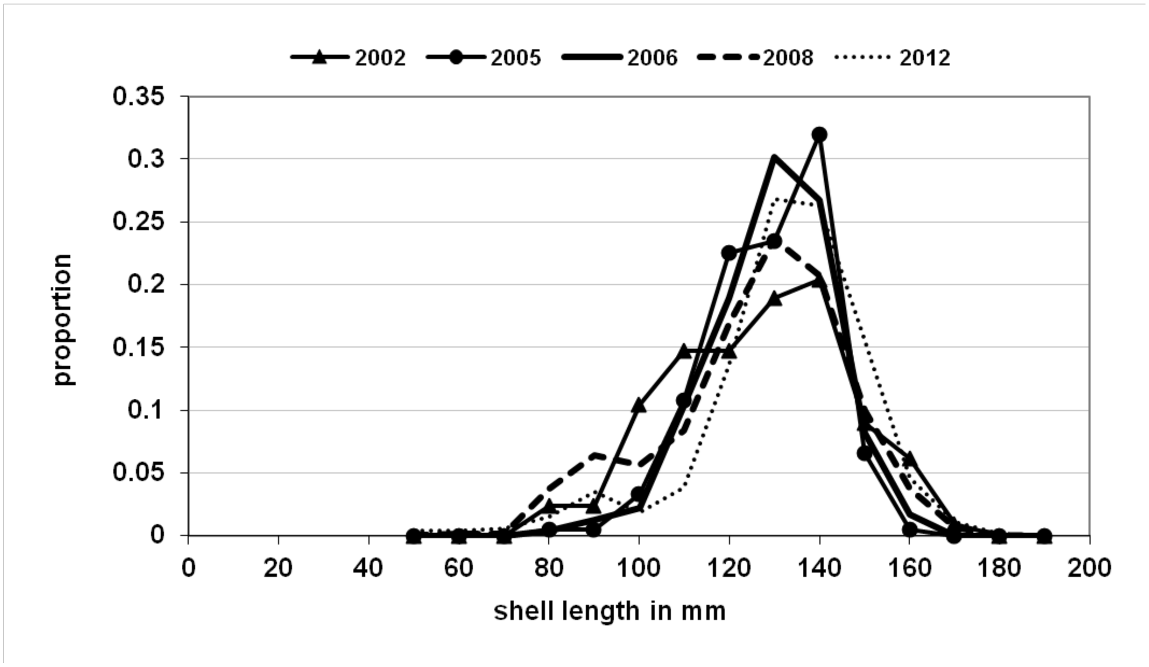


Figure 218: Length frequencies from the 2002, 2005, 2006, 2008 and 2012 New York state Atlantic surfclam survey.

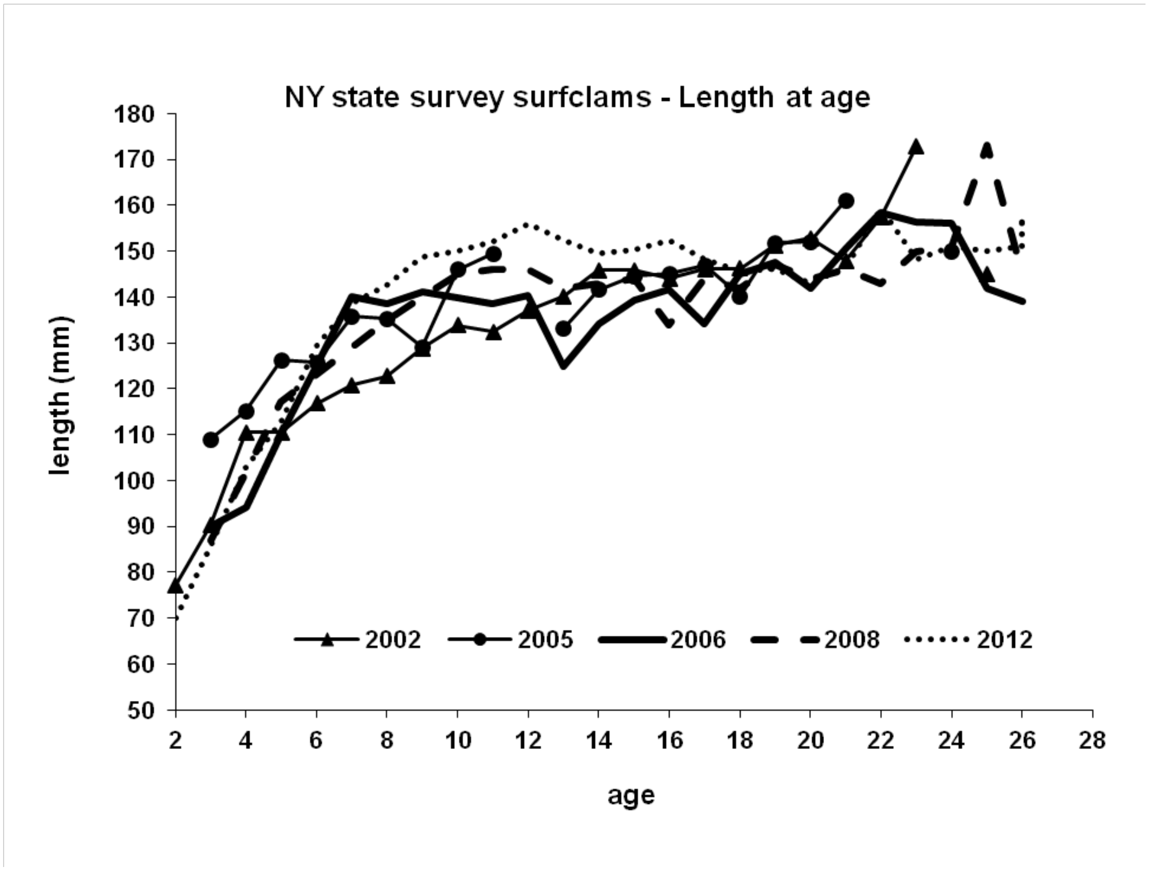


Figure 219: Atlantic surfclam length at age from the 2002, 2005, 2006, 2008 and 2012 New York state surveys.

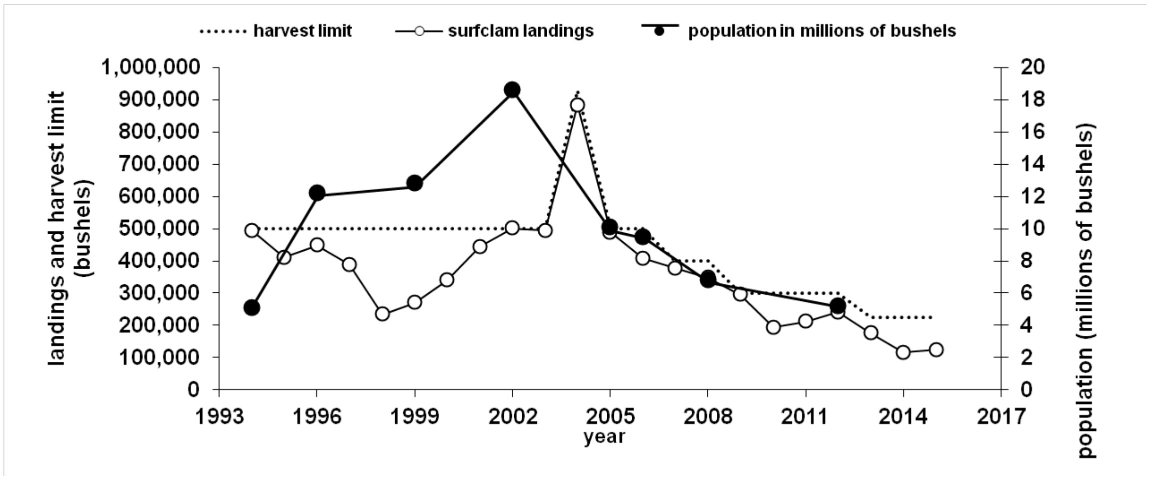


Figure 220: Landings, harvest limit and survey-based population estimates of Atlantic surfclam in New York state waters. Landings and harvest limit are scaled to the left axis and population is scaled to the right axis. The harvest limit was raised to 890,000 bushels for one year in 2004. Landings for 2015 are considered preliminary and an underestimate as not all catch reports were in.

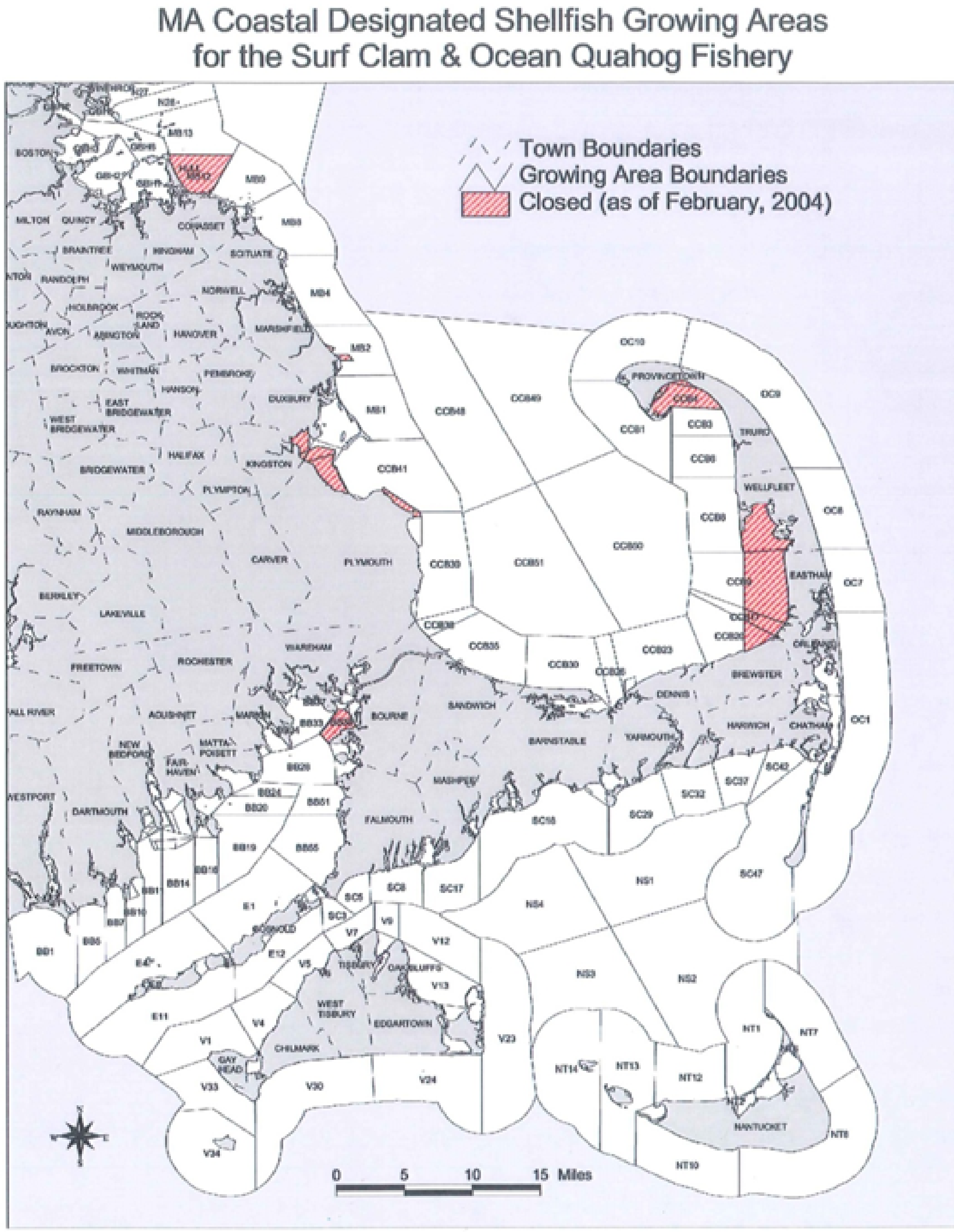


Figure 221: The numerous Designated Shellfish Growing Areas (DSGAs) in Massachusetts state waters.

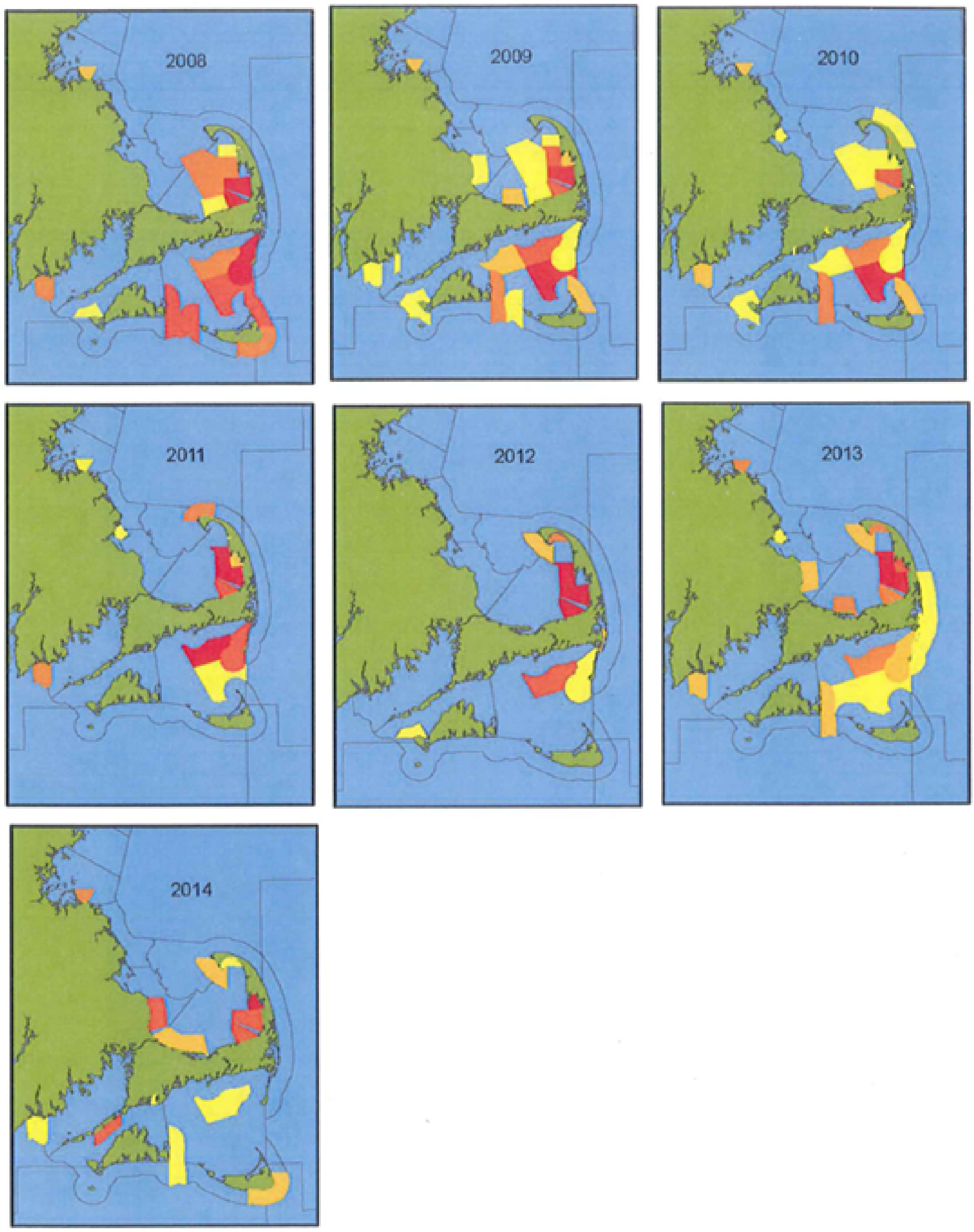


Figure 222: Massachusetts state waters Atlantic surfclam landings from each of the states' multiple Designated Shellfish Growing Areas, or DSGAs. There are more than 75 DSGAs in the waters surrounding the state. Red designates the areas with highest landings and yellow the lowest landings.

DMF Statistical Reporting Areas

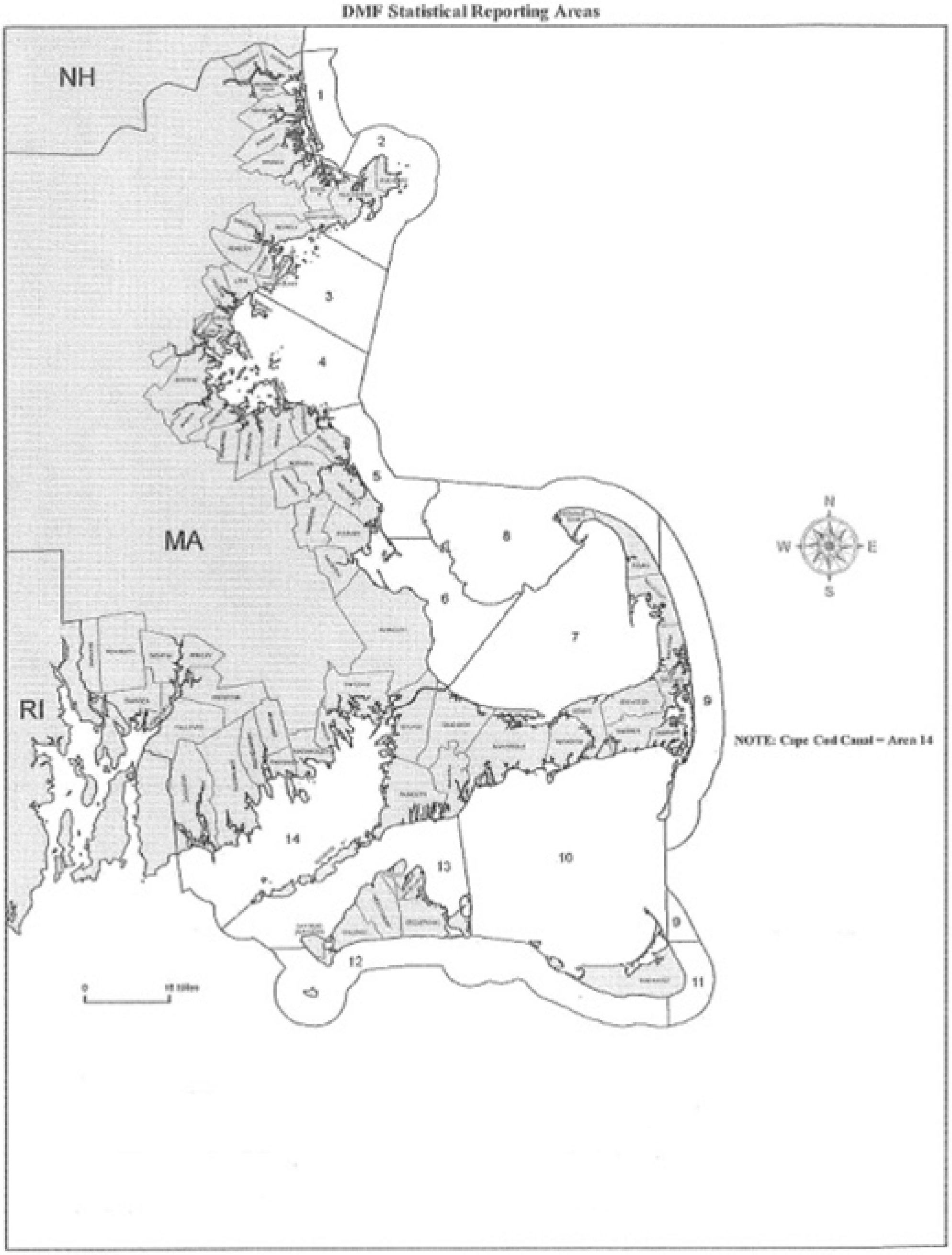


Figure 223: Statistical Reporting Areas (SRAs) in Massachusetts state waters.

SRA	2008	2009	2010	2011	2012	2013	2014
1			C		C	0.002	0.09
2			0.002				
3							
4	C	0.09	C	C		C	C
5							
6	C	C				C	C
7	3.62	2.85	2.02	1.43	2.20	1.78	0.65
8			C	C	C		
9					0.009	0.0004	
10	3.25	3.88	4.32	1.15	0.11	0.07	C
12	0.83	C	C				C
13	C	C	C		C		C
14	0.39	C	C	0.03		C	C

Figure 224: Landings of Atlantic surfclam from Massachusetts state waters by Statistical Reporting Area since 2008. Landings are in millions of live pounds. Information for SRA 11 was not available.

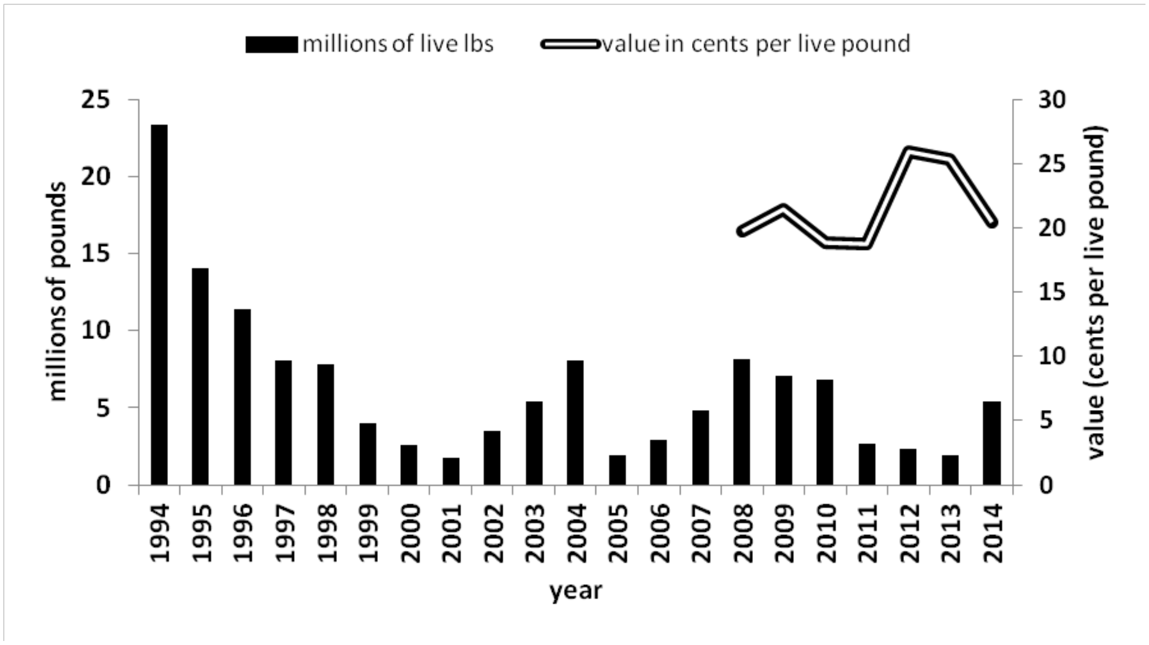


Figure 225: Total landings of Atlantic surfclam from Massachusetts state waters 1994-2014. The landings are shown in millions of live pounds and the values are cents per live pound.

Part XIX

Appendix: Management strategy evaluation

Introduction

The Atlantic surfclam (*Spissula solidissima*) has supported an important US fishery for many years (Northeast Fisheries Science Center 2010). There are, however, outstanding questions regarding the optimal biological targets and thresholds for Atlantic surfclam management, which warrant additional exploration through this management strategy evaluation.

The current maximum fishing mortality rate threshold is $F = 0.15$, which is a proxy for F_{MSY} and was derived by setting it equal to the current estimate of natural mortality (M). The Atlantic surfclam fishery has historically been lightly fished; therefore, the dynamics of the resource under fishing pressure near threshold intensity are unknown. There are also regional dynamics to the fishery and biology (*i.e.*, recruitment, growth, and M), and changes in fishing pressure across regions over time. Given the levels of exploitation and what is known about the dynamics of this resource, is $F = 0.15$ an appropriate overfishing threshold for Atlantic surfclam? The current control rule biomass target, also a proxy, is a fraction (0.5) of the biomass estimated in an earlier year (1999), and the minimum stock size threshold is set at a fraction (0.5) of the current control rule target. The current control rule applies to the entire stock in the US EEZ, but the biomass for a segment of the population called the southern area, which runs from Southern Virginia to Southern New England, is below target (as of the last assessment Northeast Fisheries Science Center (2013)), while the remainder of the population, the northern area located on Georges Bank is above target. Are these control rule reference points appropriate for Atlantic surfclam?

The current stock assessment models the two segments of the population separately (southern and northern areas), and then combines them for management purposes. The basis for separating the stocks were differences in exploitation patterns, growth, recruitment and the timing of surveys. Given the differences between areas, would the management of the resource be improved if the stocks were also managed separately? These questions have not been formally evaluated.

Methods

Simulation model

The population simulation model was age structured, such that for ages a

$$N_{t,a} = \begin{cases} R_t & \text{if } a=1 \\ N_{(t-1),(a-1)} * e^{-Z_{(t-1),(a-1)}} & \text{if } 1 < a < a_{max} \\ N_{(t-1),a_{max-1}} * e^{-Z_{(t-1),a_{max-1}}} + N_{(t-1),a_{max}} * e^{-Z_{(t-1),a_{max}}} & \text{if } a = a_{max} \end{cases} \quad (6)$$

where $a_{max} = 30$, $N_{t,a}$ was the number of animals in year t at age a, R_t was the number of recruits in year t (see below). $Z_{t,a}$ was the instantaneous total mortality defined by

$$Z_{t,a} = F_t * S_a + M \tag{7}$$

where F_t was the fully selected fishing mortality, S_a was the fishery selectivity in age a, converted from selectivity at length (see below) and M was the natural mortality rate, which was constant over time and age.

The spawning stock biomass for each age in each year $SSB_{t,a}$ was determined by

$$SSB_{t,a} = N_{t,a} * Mat_{t,a} * W_{t,a} \tag{8}$$

Maturity $Mat_{t,a}$ was 0.5 at age 1 and 1 at all other ages.

Weight at age was modelled as a function of mean length and age

$$W_a = \begin{cases} e^{-9.27} L_a^{2.73} & \text{southern area} \quad (9) \\ e^{-9.16} L_a^{2.73} & \text{northern area} \quad (10) \end{cases}$$

where W is the weight (g) and L_a is the predicted mean length at age a (mm) such that

$$L_a = \begin{cases} 162.6(1 - e^{(-0.23(a+0.14))}) & \text{southern area} \quad (11) \\ 145(1 - e^{(-0.29(a-0.64))}) & \text{northern area} \quad (12) \end{cases}$$

The parameters used in eq. (9 and 11) were averaged values for each region derived as in Northeast Fisheries Science Center (2013). W_a and L_a refer to weight and length at age a, respectively.

Fishery selectivity at age (S_a) measures the relative impact of fishing on different age groups. It was defined as the relative proportion of age a animals in the population encountered and caught. The selectivity curve was logistic and taken directly from the previous Atlantic surfclam assessment for the northern area (Northeast Fisheries Science Center 2013).

The yield from the fishery was calculated as

$$Y_t = \sum_a \frac{F_{t,a}}{F_{t,a} + M} * N_{t,a} * W_a * (1 - e^{-(F_{t,a}+M)}) \tag{13}$$

where $F_{t,a} = F_t * S_a$ (Baranov 1918).

Recruitment (R_t) followed Beverton Holt (Beverton and Holt 1957)

$$R_t = \frac{SSB_{t-1}}{\frac{SSBR_{f=0}(1-h)}{4h} + \frac{5h-1}{4hR_0} * SSB_{t-1}} \tag{14}$$

or Ricker (Ricker 1954) dynamics.

$$R_t = \alpha SSB_{t-1} e^{-\beta SSB_{t-1}} \tag{15}$$

where

$$\alpha = \frac{log(h) - log(0.2)}{0.8 R_0 SSBR_{f=0}} \tag{16}$$

$$\beta = \frac{e^{\alpha R_0 SSBR_{f=0}}}{SSBR_{f=0}} \tag{17}$$

and $SSBR_{f=0}$ was the equilibrium unfished spawning stock biomass per recruit, R_0 was equilibrium unfished recruitment and steepness (h) was a simulation specific random variable (Table 38). The bounds on h were based on He et al. (2006) and further modified based on the results of sensitivity testing in the assessment model. Half of the total simulation runs used Beverton Holt stock recruitment dynamics and the other half used Ricker.

Control rule

The current process for setting catch and associated landings limits (i.e., quotas) for the Atlantic surfclam fishery is complicated. For Mid-Atlantic Fishery Management Council (Council) managed stocks, acceptable biological catch limits (ABC) are set at a level less than the catch associated with the maximum fishing mortality threshold rate ($F = 0.15$) using a control rule that is a combination of the predetermined Councils risk policy (i.e., maximum tolerance for overfishing under specific conditions) and Scientific and Statistical Committee (SSC) decisions on the degree of uncertainty associated with the stock assessment. Because setting these catch limits involves a committee decision on the degree of uncertainty in the assessment, and is not a purely formulaic control rule, it is difficult to apply directly and requires some simplification for simulation in this MSE. The Councils risk policy which is used in the derivation of the Atlantic surfclam ABC is described on page 51 of Amendment 16 to the fishery management plan (MAFMC 2011; Figure 226). The risk policy is conditioned on the ratio of current stock biomass relative to the control rule (stock replenishment) threshold, and whether the life history is considered to be typical or atypical[4]. The policy includes a stock replenishment threshold defined as the ratio of $\frac{B}{BMSY} = 0.10$, to ensure the stock does not reach low levels from which it cannot recover. The probability of overfishing is 0 percent at $\frac{B}{BMSY} = 0.10$ and increases linearly until the inflection point of $\frac{B}{BMSY} = 1.0$, where a 40 percent probability of overfishing is utilized for stocks defined as typical, and a 35 percent probability for those defined as atypical. In addition, the risk policy has associated regulations that govern setting ABC for stocks under rebuilding plans and in instances where no maximum fishing mortality rate threshold has been identified. Neither of these cases apply to Atlantic surfclam.

[4]An atypical stock has a life history strategy that results in greater vulnerability to exploitation, and whose life history has not been fully addressed through the stock assessment and biological reference point development process.

Simulation set up

Simulations of a managed population like Atlantic surfclam must account for management actions, because the actions of managers will affect population dynamics. Management actions were simulated by including a simple control rule (based on a simplified version of the current Atlantic surfclam control rule) with target (the control rule inflection point described above) and stock replenishment threshold levels of SSB in the base simulation routine. The target was the desired level of SSB. The threshold was the minimum acceptable SSB. If SSB_t fell below SSB_{target}, F_{target} was reduced linearly, finally reaching 0 where $SSB_t = SSB_{threshold}$ (Restrepo and Powers 1999; Figure 227). This framework allowed a comparison of various candidate control rule reference points ($SSB_{threshold}$ and SSB_{target}) as well as an examination of the response of the population to management. Control rule reference points were $\frac{SSB_{target}}{SSB_0}$ and $\frac{SSB_{threshold}}{SSB_0}$, the fraction of unfished biomass (SSB_0) that correspond to target and threshold biomass levels respectively. $\frac{SSB_{threshold}}{SSB_0}$ levels between 0.05 and 0.5 and $\frac{SSB_{target}}{SSB_0}$ levels between 0.1 and 1.0 (in increments of 0.05) were tested by drawing randomly with replacement from the candidate values (Table 38).

Although the true Atlantic surfclam control rule is based on the probability of overfishing, rather than the fraction of SSB_0 remaining, and acts on the ABC, rather than the F_{target}, the functional response of the stock to management is similar. In both cases, the catch will be reduced in proportion to biomass, when biomass drops below a target value (the probability of overfishing depends on F_{target} and biomass; when biomass is low, F_{target} must be reduced proportionately to reduce the probability of overfishing). In both cases, fishing will no longer be allowed when the biomass drops below a threshold value.

All simulations included lognormal autocorrelated assessment error. Assessment error was included to mimic the uncertainty around biomass estimates from an assessment, and that error was autocorrelated to reflect a situation where an error in the assessment in one year was more likely to produce an error in the following assessment(s) (Deroba and Bence 2008). Assessment error was described by

$$\hat{SSB}_t = SSB_t * e^{\epsilon_t - \frac{\sigma^2_{At}}{2}} \tag{18}$$

$$\epsilon_t = \epsilon_{t-1} * \varphi * \eta + \sqrt{1 - \varphi^2} \tag{19}$$

where $\eta \sim N(0, \sigma^2_{At})$ was the assessment error, φ was the autocorrelation coefficient, and ϵ_t was the year specific autocorrelated random deviation. The parameterization of eq. 19 makes $\hat{SSB}_t$ an unbiased estimate of SSB_t (Deroba and Bence 2012).

A manager may decide on a particular F_{target} for a fishery, but that F_{target} may not be achieved exactly. This discrepancy is often referred to as implementation error. Implementation error was included by modifying F_t (where $F_1 = F_{target}$) such that

$$\hat{F}_t = F_t * e^{\epsilon_{Ft} - \frac{\sigma^2_{Ft}}{2}} \tag{20}$$

where $\hat{F}_t$ was an unbiased estimate of F_t, including lognormal implementation error ϵ_{Ft} with error variance σ^2_{Ft}.

Simulated management included an "assessment" at the end of each 3 years. That is, a decision to reduce F_t from it's initial value (F_{target}) was made at the end of each 3 year period depending on the value of $S\hat{S}B_t$ relative to SSB_{target} and $SSB_{threshold}$. The actual fishing mortality experienced by the simulated population ($\hat{F}_t$) was then based on the (potentially) reduced F_t using eq. 20.

Simulated management over different spatial scales

Recruitment, growth, and natural mortality in the US Atlantic surfclam population are not uniform across space. Simulation results might be altered by combining the results from independently recruiting areas experiencing different life history parameters. Because the Atlantic surfclam stock is assessed using two distinct areas, simulations were set up to mimic the biological parameters measured in each area. Simulations combined the two regions, which had independent growth, weight at age, steepness, and natural mortality parameters, using two contrasting spatial management scenarios. In all cases, recruitment events occurred separately in each region according to eq. 15. Growth in each region was determined by

$$L_a = \begin{cases} (162.6 + N(0, \sigma_{L\infty,S})) * & (21) \\ (1 - e^{((-0.23+N(0.0,\sigma_{k,S}))(a+(0.14+N(0.0,\sigma_{t0,S}))))}) & \text{southern area} \\ (145.6 + N(0, \sigma_{L\infty,N})) * & (22) \\ (1 - e^{((-0.29+N(0.0,\sigma_{k,N}))(a+(-0.64+N(0.0,\sigma_{t0,N}))))}) & \text{northern area} \end{cases}$$

where N were normally distributed random variables with parameters (0,$\sigma_{x,a}$), where x represents either k, $t0$ or $L\infty$, the growth parameters describing the curvature, location and asymptote (respectively) of the growth curve (von Bertalanffy 1938), and the subscript a represents the southern area (S) or the northern area (N). Simulation specific regional growth and natural mortality parameters were selected from the distributions described in Table 38 and then held constant for each region over that simulation. All other parameters (F_{target}, φ, σ_t^{A2}, σ^2_{Ft}, $\frac{SSB_{threshold}}{SSB_0}$ and $\frac{SSB_{target}}{SSB_0}$; Table 38) were simulation specific, but shared between the regions.

In the first management scenario, each region was managed separately (separate stocks, SS). Under SS, each region had its own assessment in which the biomass in that region was compared to the control rule reference points ($\frac{SSB_{threshold}}{SSB_0}$ equal for each region, though the SSB_0 for each might be somewhat different depending on regional life history parameters and stochastic recruitment variability during the unfished portion of each simulation) and then the F_t for that region was adjusted from F_{target} if necessary. SS regions were then fished according to their individual $\hat{F}_t$ after application of eq. (20). In the second management scenario (one stock, 1S), the sum of the biomasses from each region was compared to the control rule reference points ($\frac{SSB_{threshold}}{SSB_0}$ multiplied by the sum of the SSB_0 in the case of $B_{threshold}$), and F_t for all regions was adjusted if necessary. 1S regions were all fished according to the resulting $\hat{F}_t$ and yield was extracted from each according to eq. (13), but using the region specific M, $N_{t,a}$ and W_a. SS and 1S total yield and total biomass were the sum of the yield and biomass in each region, and the cv of yield was the mean of the cv of yield in each region. In both scenarios the period between assessments, and subsequent adjustments to fishing mortality rates, were 5 years to mimic a realistic assessment interval.

Simulation

Some parameters in the model had unknown true values, such as steepness (h) and natural mortality (M). Other parameters, such as potential values for management quantities like F_{target} or $\frac{SSB_{threshold}}{SSB_0}$, had unknown affects on biomass and yield. To understand how these parameters affected the outcome of simulations, a range of values for each was examined.

In each new simulation run a random variable was drawn for: h, M, F_{target}, φ, σ^2_{At}, σ^2_{Ft}, $\frac{SSB_{threshold}}{SSB_0}$ and $\frac{SSB_{target}}{SSB_0}$ (Table 38). These were constant for the duration of the run. The simulation was initialized by running a cohort based on the simulation specific M out to a_{max}. The proportion at age was then multiplied by R_0. All simulations included a period of 100 years without fishing intended to allow the population to stabilize. The simulation continued through 100 years with fishing and then new values were drawn for 49,999 subsequent runs.

Results from simulations (both with and without spatial complexity) were compared to values of F_{target}, $\frac{SSB_{threshold}}{SSB_0}$ and $\frac{SSB_{target}}{SSB_0}$, while considering the effects of φ, σ^{A2}_t, σ^2_{Ft}, M and h, to determine how reference points affected biomass and yield.

Analysis

To understand how the stochastic parameters affected simulation results, mean scaled biomass ($\frac{\overline{SSB}}{SSB_0}$), mean scaled yield ($\frac{\overline{Y}}{SSB_0}$), coefficient of variation in yield $cv(Y)$ and time without fishing due to implementation of the control rule ($t_{F=0}$) were compared to natural mortality M, steepness (h), target fishing mortality (F_{target}), $\frac{SSB_{threshold}}{SSB_0}$, $\frac{SSB_{target}}{SSB_0}$, φ, σ^2_{At}, and σ^2_{Ft}. Interactions and main effects were examined with generalized linear models (McCullagh and Nelder 1989). In an example predicting mean biomass, the saturated model contained all the main effects and selected interactions between the predictor variables as

$$(\frac{\overline{SSB}}{SSB_0}) = f(\overrightarrow{b}(1 + (h * F_{target} * \frac{SSB_{threshold}}{SSB_0} * M) + \sigma^2_{At} + \varphi + \sigma^2_{Ft}) \quad (23)$$

where f represents the link function and $\overrightarrow{b}$ is the vector of coefficients estimated in the model. Models predicting biomass and yield were overdispersed relative to the Poisson distribution so the error structure for the models described generally by eq. 23, was quasipoisson with a log link function (R Core Team 2013; McCullagh and Nelder 1989). This distribution includes a dispersion parameter for variance and reduces the degrees of freedom for estimation accordingly.

The relative importance of predictors (e.g. h, F_{target}, and M) was determined using deviance tables. The number of simulations was large and simulation results are not data in the traditional sense. Therefore model selection approaches based on AIC would result in very complicated models in which nearly all covariates and interactions tested would be significant. The deviance table approach may also be better than conventional χ^2 tests, which are more sensitive to the order in which explanatory variables are tested (Ortiz and Arocha 2004).

Variables tested included each categorical and continuous predictor variable, and several interactions between them. Linear models for deviance table analyses were fitted by sequentially adding main effects and interactions. Explanatory variables were judged statistically significant as they entered the model if they reduced model deviance by at least 5% of the deviance associated with the null (intercept only) model. This allowed the exclusion of the explanatory variables that least affected the response variables of interest from further consideration.

Simulation results were also plotted and inspected visually for indications of nonlinearity. In particular after initial results showed that steepness was not an important predictor of biomass or yield, results were binned over steepness values to determine if the effects of steepness were being masked by the stronger effects such as fishing mortality.

Results

Simulations

Because $\frac{SSB_{target}}{SSB_0}$ and $\frac{SSB_{threshold}}{SSB_0}$ were highly correlated, results using each were similar and results showing $\frac{SSB_{threshold}}{SSB_0}$ only are discussed here for simplicity.

Deviance tables show that the effects of F_{target}, steepness (h), control rule (stock replenishment) threshold ($\frac{SSB_{threshold}}{SSB_0}$) and M were better predictors of mean biomass, yield, variation in yield and time without fishing than any of the other candidate predictors and interactions tested (Table 39). Biomass tended to decrease with F_{target}, while variation in yield and time without fishing tended to increase (Figures 228 – 229). Yield increased initially with F_{target} before decreasing at higher values of F_{target}. Increasing natural mortality resulted in higher yields, more variation in yield and less time without fishing. Higher steepness resulted in higher biomass and yield and less variation in yield and time without fishing. Higher control rule (stock replenishment) thresholds produced higher biomass, more time without fishing, and more variation around less yield.

An interactions involving $\frac{SSB_{threshold}}{SSB_0}$ and steepness was an important predictor time without fishing (Table 39). At high $\frac{SSB_{threshold}}{SSB_0}$ and low h, the population was not productive enough to trigger recovery and a cessation of the management actions that shut down the fishery. At low $\frac{SSB_{threshold}}{SSB_0}$ and high h, the population was productive enough and the control rule (stock replenishment) threshold low enough to never trigger a shut down.

Stock recruitment dynamics

The stock was more productive at higher F when recruitment dynamics were driven by the Ricker curve (Figure 230).

Simulated management over different spatial scales

The effect of spatial scale on management was substantial on average across most of the response variables tested. Mean biomass was greater when the stocks were managed separately, but mean yield was greater under single stock management (Figure 231). The higher yields however, resulted in a tendency to over-harvest and a higher probability of fishery closures due to management intervention, as well as higher variability in yield.

Discussion

Management strategy evaluation can be a useful tool for determining reference points that work well for a variety of life history traits and possible states of nature. Currently, there are many aspects of Atlantic surfclam biology that are poorly understood. The response of the Atlantic surfclam stock to ocean warming is unknown, and the behavior of the fishery may change over time as well. This management strategy evaluation used a broad distribution of possible values intended to capture both the unknown biological parameters and a reasonable suite of potential fishery conditions. The F_{Target} and control rule reference points were simulated over 100 years using random combinations of important biological and fishery parameters. Therefore the results of these simulations should describe management quantities that will work well under many possible combinations of life history traits and fishery conditions.

Simulation

The simulations demonstrate the utility of potential reference points relative to metrics of fishery performance. For example, SSB is maximized at low F regardless of the control rule (stock replenishment) threshold or target used, while yield is maximized at intermediate levels of F and lower values of $\frac{SSB_{threshold}}{SSB_0}$ or $\frac{SSB_{target}}{SSB_0}$ (Figures 232 - 233). Examination of the relative SSB and yield at various F_{Target} and B_{Target} or $B_{Threshold}$ (Tables 41 - 44) allow for comparison of the likely performance of competing reference points.

Variation in yield and time without fishing due to closures were near minimum at all the values of $\frac{SSB_{threshold}}{SSB_0}$ or $\frac{SSB_{target}}{SSB_0}$ tested when $F < 0.15$. The current $F_{Threshold} = 0.15$. If we consider only $F_{Threshold} <= 0.15$ then there is no further need to concern ourselves with variation in yield or the probability of fishery closures.

The current $B_{Threshold}$ is $0.25 * B_{0,proxy}$ and the current B_{Target} is $0.5 * B_{0,proxy}$. Using these values, yield is maximized at $F_{Target} = 0.12$, while $SSB = 0.5 * B_0$ at $F_{Target} = 0.11$.

The Atlantic surfclam fishery is market limited and currently fished under quota (see II). Therefore there is little interest from either industry or management to increase yield. Under these conditions, it might be advantageous to weight SSB somewhat more than yield when deciding on reference points.

Simulated management over different spatial scales

There does appear to be an advantage to managing the Atlantic surfclam population as separate stocks. In general it results in higher yield and biomass, less variability in yield, less fishery closures over all values of h and $\frac{SSB_{threshold}}{SSB_0}$. Managing for separate stocks also results in higher biomass over all values of F, but higher yield only when F is over approximately 0.12, a high value, relative to what the fishery is currently experiencing. The advantages in variation in yield and time without fishing due to closures also appear to accrue only at values of F that are somewhat higher than the Atlantic surfclam population is currently experiencing. Therefore, while it appears to be advantageous to manage the population as separate stocks, those advantages are less clear at low F and the switch to management as separate stocks may not be important unless the fishing mortality rate increases relative to its current state.

Tables

Table 38: Sampling distributions of random variables used in simulation. The variable h was steepness, M was natural mortality, F_{target} was fully selected fishing mortality target, φ was the autocorrelation coefficient for assessment error, σ_{At}, σ_{Ft} were the standard deviation of annual assessment and implementation error, respectively, $\sigma^S_{L\infty}$, $\sigma^{GBK}_{L\infty}$, σ^S_k, σ^{GBK}_k, σ^S_{t0}, σ^{GBK}_{t0} were standard deviations of the growth parameters for each area, $\frac{SSB_{threshold}}{SSB_0}$ was the control rule (stock replenishment) threshold, and $\frac{SSB_{target}}{SSB_0}$ was the control rule target for fishery management. A random value for each variable was drawn from the sampling distributions shown for each simulation run.

Variable	Sampling distribution
	Continuous
h	$Unif(0.3, 0.99)$
M	$Unif(0.1, 0.25)$
F_{target}	$Unif(0.0001, 0.5)$
φ	$Unif(0.0, 0.5)$
σ_{At}	$Unif(0.0, 0.25)$
σ_{Ft}	$Unif(0.0, 0.5)$
$\sigma^S_{L\infty}$	$Unif(0.0, 1.95)$
$\sigma^{GBK}_{L\infty}$	$Unif(0.0, 3.9)$
σ^S_k	$Unif(0.0, 0.025)$
σ^{GBK}_k	$Unif(0.0, 0.061)$
σ^S_{t0}	$Unif(0.0, 0.249)$
σ^{GBK}_{t0}	$Unif(0.0, 0.59)$
	Discrete
$\frac{SSB_{threshold}}{SSB_0}$	$\{0.05, 0.1, 0.15, 0.2, \ldots, 0.5\}$
$\frac{SSB_{target}}{SSB_0}$	$\{0.1, 0.15, 0.2, 0.25, \ldots, 1.0\}$
SR	Ricker or Beverton-Holt

Table 39: Deviance table results for models predicting mean Atlantic surfclam biomass ($\frac{\overline{SSB}}{SSB_0}$), mean ($\frac{\overline{Y}}{SSB_0}$), and cv of yield ($cv(Y)$) and years without fishing due to management ($t_{F=0}$), over ($n = 50,000$) 100 year simulations. The candidate predictors were fishing mortality target (F_{target}), steepness (h), natural mortality (M), the fraction of SSB_0 that corresponds to the control rule (stock replenishment) threshold ($\frac{SSB_{threshold}}{SSB_0}$), assessment error ($\sigma_{At}$), amount of auto correlation in assessment error (φ), implementation error (σ_{Ft}) as well as interactions of potential interest. Only predictors that explained $\geq 5\%$ of the deviance relative to the null model are shown.

Response	Significant predictors (% dev. explained)
	Biomass
$\frac{\overline{SSB}}{B_0}$	F_{target} (43.5), h (27.5), M (11.0)
	Yield
$\frac{\overline{Y}}{B_0}$	h (36.0), $\frac{SSB_{threshold}}{SSB_0}$ (22.9), M (20.4), SR (5.6)
$cv(Y)$	F_{target} (57.4), $\frac{SSB_{threshold}}{SSB_0}$ (10.4), h (11.8), M (7.9)
	Years without fishing
$t_{F=0}$	F_{target} (48.3), h (13.6), $\frac{SSB_{threshold}}{SSB_0}$ (14.2), h:$\frac{SSB_{threshold}}{SSB_0}$ (5.8)

Table 40: Deviance table results from simulations testing possible spatial structures of management. Inputs were models predicting mean Atlantic surfclam biomass, mean, and cv of yield and years without fishing due to management, over ($n = 50,000$) 100 year simulations. The total biomass and yield were based on summed values from two separately managed stocks and from two regions managed as one, each assessed every five years. The candidate predictors were fishing mortality target (F_{target}), steepness (h), natural mortality (M), the fraction of SSB_0 that corresponds to the control rule (stock replenishment) threshold ($\frac{SSB_{threshold}}{SSB_0}$), assessment error ($\sigma_{At}$), amount of auto correlation in assessment error (φ), implementation error (σ_{Ft}) and several interactions between them.

Response	Significant predictors (% dev. explained)
	Separate stocks
	Biomass
$\frac{\overline{SSB}}{B_0}$	F_{target} (89.7)
	Yield
$\frac{\overline{Y}}{B_0}$	F_{target} (24.4), $\frac{SSB_{threshold}}{SSB_0}$ (26.8), M (18.2), h (15.4)
$cv(F)$	F_{target} (66.0), $\frac{SSB_{threshold}}{SSB_0}$ (12.6), M (9.5), h (7.0)
	Years without fishing
$t_{F=0}$	F_{target} (55.8), $\frac{SSB_{threshold}}{SSB_0}$ (17.4), M (7.7), h (7.7)
	Single stock
	Biomass
$\frac{\overline{SSB}}{B_0}$	F_{target} (16.6), h (5.4), $\frac{SSB_{threshold}}{SSB_0}$ (54.1), F:$\frac{SSB_{threshold}}{SSB_0}$ (18.4)
	Yield
$\frac{\overline{Y}}{B_0}$	F_{target} (64.4), h (22.5)
$cv(F)$	F_{target} (55.7), $\frac{SSB_{threshold}}{SSB_0}$ (23.6), h (9.5), M (5.6)
	Years without fishing
$t_{F=0}$	F_{target} (55.1), $\frac{SSB_{threshold}}{SSB_0}$ (24.5), $\frac{SSB_{threshold}}{SSB_0}$ (6.7)

Table 41: Average biomass ($\frac{S\hat{S}B}{SSB_0}$) over 100 years of managed fishing simulations at different levels of biomass threshold (columns) and target fishing mortality (rows).

	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0	0.96	0.96	0.96	0.97	0.96	0.96	0.96	0.96	0.96	0.96
0.01	0.91	0.90	0.91	0.90	0.90	0.90	0.90	0.91	0.90	0.91
0.02	0.85	0.84	0.85	0.84	0.85	0.84	0.85	0.85	0.85	0.85
0.03	0.80	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.80	0.81
0.04	0.74	0.75	0.74	0.74	0.74	0.75	0.75	0.75	0.75	0.76
0.05	0.70	0.70	0.69	0.70	0.70	0.70	0.70	0.71	0.71	0.73
0.06	0.66	0.66	0.66	0.66	0.66	0.66	0.65	0.67	0.68	0.67
0.07	0.60	0.62	0.62	0.61	0.62	0.63	0.63	0.64	0.63	0.65
0.08	0.59	0.58	0.59	0.59	0.59	0.60	0.60	0.61	0.61	0.63
0.09	0.55	0.56	0.56	0.56	0.56	0.56	0.57	0.58	0.58	0.59
0.1	0.51	0.53	0.53	0.52	0.53	0.53	0.55	0.55	0.57	0.57
0.11	0.48	0.50	0.49	0.51	0.50	0.50	0.52	0.53	0.54	0.55
0.12	0.45	0.47	0.47	0.49	0.49	0.50	0.50	0.51	0.52	0.53
0.13	0.41	0.45	0.45	0.44	0.45	0.46	0.48	0.49	0.50	0.52
0.14	0.40	0.44	0.43	0.43	0.45	0.45	0.46	0.46	0.48	0.50
0.15	0.40	0.40	0.40	0.42	0.43	0.43	0.44	0.45	0.48	0.47
0.16	0.39	0.38	0.39	0.39	0.40	0.42	0.43	0.44	0.46	0.46
0.17	0.36	0.35	0.36	0.38	0.39	0.41	0.42	0.42	0.43	0.44
0.18	0.34	0.34	0.36	0.36	0.38	0.38	0.40	0.40	0.42	0.43
0.19	0.33	0.34	0.35	0.35	0.36	0.38	0.38	0.40	0.40	0.40
0.2	0.30	0.31	0.32	0.34	0.35	0.36	0.38	0.39	0.40	0.39
0.21	0.30	0.31	0.31	0.32	0.33	0.34	0.36	0.38	0.38	0.37
0.22	0.28	0.29	0.30	0.32	0.32	0.34	0.35	0.36	0.36	0.36
0.23	0.26	0.28	0.29	0.30	0.31	0.33	0.34	0.33	0.35	0.35
0.24	0.25	0.27	0.29	0.29	0.31	0.32	0.33	0.34	0.34	0.34
0.25	0.25	0.26	0.26	0.28	0.28	0.30	0.31	0.33	0.33	0.34
0.26	0.23	0.24	0.26	0.27	0.28	0.30	0.31	0.31	0.31	0.32
0.27	0.24	0.24	0.26	0.27	0.28	0.29	0.29	0.29	0.31	0.31

0.28	0.22	0.24	0.25	0.25	0.26	0.28	0.29	0.28	0.29	0.30
0.29	0.21	0.22	0.23	0.25	0.26	0.27	0.28	0.28	0.28	0.27
0.3	0.19	0.21	0.22	0.24	0.25	0.25	0.26	0.27	0.27	0.25
0.31	0.20	0.21	0.21	0.23	0.25	0.24	0.25	0.25	0.25	0.25
0.32	0.19	0.20	0.21	0.23	0.24	0.23	0.25	0.24	0.24	0.25
0.33	0.17	0.18	0.20	0.22	0.23	0.23	0.24	0.23	0.24	0.23
0.34	0.17	0.18	0.20	0.21	0.22	0.22	0.23	0.22	0.24	0.22
0.35	0.18	0.18	0.20	0.20	0.21	0.21	0.23	0.20	0.22	0.22
0.36	0.16	0.17	0.19	0.20	0.21	0.21	0.21	0.21	0.21	0.21
0.37	0.15	0.17	0.18	0.19	0.20	0.20	0.19	0.19	0.20	0.20
0.38	0.15	0.16	0.18	0.19	0.19	0.19	0.20	0.18	0.19	0.20
0.39	0.16	0.16	0.16	0.18	0.18	0.20	0.19	0.19	0.19	0.18
0.4	0.15	0.15	0.16	0.18	0.17	0.19	0.18	0.18	0.18	0.18
0.41	0.13	0.15	0.16	0.16	0.16	0.17	0.17	0.17	0.18	0.18
0.42	0.13	0.14	0.16	0.16	0.16	0.17	0.17	0.17	0.16	0.18
0.43	0.13	0.14	0.14	0.16	0.16	0.17	0.15	0.16	0.16	0.17
0.44	0.12	0.14	0.14	0.14	0.15	0.16	0.16	0.14	0.14	0.15
0.45	0.11	0.13	0.14	0.14	0.14	0.16	0.15	0.14	0.15	0.15
0.46	0.11	0.11	0.13	0.14	0.14	0.14	0.15	0.15	0.12	0.15
0.47	0.11	0.12	0.13	0.12	0.13	0.13	0.13	0.13	0.15	0.14
0.48	0.09	0.11	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13
0.49	0.09	0.11	0.11	0.12	0.13	0.12	0.11	0.12	0.13	0.13
0.5	0.07	0.11	0.11	0.15	0.11	0.12	0.10	0.14	0.08	0.12

Table 42: Average biomass ($\frac{S\hat{S}B}{SSB_0}$) over 100 years of managed fishing simulations at different levels of biomass target (columns) and target fishing mortality (rows).

	0.125	0.225	0.275	0.325	0.425	0.475	0.525	0.575	0.675	0.775	0.825	0.875	0.925
0.005	0.96	0.96	0.96	0.97	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.97
0.015	0.90	0.90	0.90	0.90	0.91	0.90	0.90	0.90	0.91	0.91	0.91	0.91	0.91
0.025	0.84	0.86	0.84	0.84	0.85	0.85	0.85	0.84	0.85	0.84	0.85	0.85	0.85
0.035	0.80	0.79	0.79	0.79	0.80	0.79	0.79	0.79	0.79	0.80	0.80	0.79	0.80
0.045	0.75	0.75	0.74	0.73	0.74	0.75	0.74	0.75	0.75	0.76	0.77	0.75	0.76
0.055	0.70	0.70	0.69	0.70	0.71	0.70	0.70	0.70	0.71	0.71	0.72	0.72	0.72
0.065	0.66	0.66	0.66	0.66	0.66	0.66	0.65	0.66	0.66	0.67	0.69	0.69	0.70
0.075	0.62	0.60	0.62	0.60	0.62	0.61	0.61	0.63	0.64	0.65	0.64	0.66	0.65
0.085	0.58	0.60	0.58	0.59	0.59	0.58	0.58	0.60	0.61	0.63	0.62	0.61	0.63
0.095	0.55	0.55	0.55	0.55	0.55	0.55	0.56	0.57	0.58	0.59	0.60	0.59	0.61
0.105	0.53	0.52	0.52	0.51	0.53	0.52	0.53	0.55	0.55	0.56	0.58	0.58	0.58
0.115	0.48	0.50	0.50	0.50	0.49	0.50	0.50	0.52	0.54	0.54	0.54	0.55	0.57
0.125	0.45	0.47	0.47	0.46	0.47	0.49	0.48	0.50	0.51	0.53	0.53	0.53	0.53
0.135	0.44	0.43	0.43	0.45	0.43	0.45	0.46	0.48	0.49	0.50	0.50	0.51	0.52
0.145	0.43	0.40	0.42	0.42	0.42	0.43	0.45	0.46	0.48	0.49	0.50	0.48	0.49
0.155	0.40	0.38	0.40	0.40	0.40	0.41	0.44	0.44	0.46	0.46	0.47	0.48	0.47
0.165	0.38	0.37	0.37	0.38	0.39	0.40	0.42	0.42	0.44	0.46	0.45	0.44	0.46
0.175	0.35	0.34	0.36	0.37	0.37	0.38	0.41	0.41	0.42	0.44	0.42	0.43	0.46
0.185	0.31	0.31	0.34	0.36	0.36	0.37	0.39	0.40	0.40	0.42	0.42	0.40	0.43
0.195	0.33	0.32	0.33	0.34	0.35	0.37	0.37	0.38	0.39	0.41	0.41	0.39	0.42
0.205	0.28	0.31	0.30	0.33	0.33	0.35	0.36	0.37	0.37	0.38	0.40	0.39	0.40
0.215	0.30	0.29	0.29	0.32	0.32	0.33	0.34	0.35	0.37	0.36	0.37	0.38	0.38
0.225	0.26	0.27	0.29	0.31	0.32	0.32	0.33	0.34	0.36	0.36	0.34	0.37	0.35
0.235	0.25	0.25	0.27	0.29	0.30	0.31	0.32	0.33	0.34	0.34	0.33	0.32	0.34
0.245	0.25	0.24	0.27	0.28	0.30	0.29	0.31	0.32	0.33	0.33	0.35	0.32	0.34
0.254	0.22	0.23	0.25	0.28	0.28	0.28	0.31	0.30	0.32	0.33	0.33	0.33	0.32
0.264	0.19	0.24	0.24	0.27	0.27	0.28	0.29	0.30	0.32	0.30	0.31	0.32	0.34
0.274	0.21	0.24	0.24	0.26	0.27	0.28	0.28	0.30	0.30	0.29	0.30	0.29	0.30

0.284	0.19	0.22	0.23	0.25	0.25	0.27	0.28	0.28	0.29	0.27	0.30	0.27	0.29
0.294	0.21	0.21	0.22	0.24	0.24	0.26	0.27	0.27	0.28	0.27	0.28	0.29	0.27
0.304	0.16	0.19	0.22	0.22	0.23	0.24	0.25	0.25	0.25	0.28	0.26	0.25	0.28
0.314	0.18	0.18	0.21	0.23	0.23	0.23	0.24	0.24	0.26	0.25	0.26	0.25	0.22
0.324	0.17	0.18	0.20	0.22	0.23	0.23	0.24	0.24	0.24	0.25	0.25	0.24	0.24
0.334	0.14	0.17	0.19	0.20	0.22	0.22	0.23	0.23	0.23	0.23	0.24	0.23	0.22
0.344	0.16	0.16	0.19	0.21	0.21	0.21	0.22	0.22	0.23	0.21	0.24	0.23	0.26
0.354	0.15	0.17	0.19	0.20	0.20	0.20	0.22	0.21	0.22	0.21	0.22	0.22	0.23
0.364	0.13	0.15	0.17	0.19	0.20	0.20	0.21	0.21	0.21	0.20	0.20	0.23	0.21
0.374	0.14	0.17	0.17	0.19	0.18	0.18	0.19	0.20	0.20	0.18	0.20	0.22	0.19
0.384	0.13	0.16	0.17	0.18	0.17	0.17	0.20	0.20	0.19	0.17	0.19	0.18	0.19
0.394	0.13	0.16	0.16	0.16	0.18	0.17	0.18	0.19	0.19	0.19	0.19	0.19	0.20
0.404	0.14	0.15	0.16	0.17	0.16	0.17	0.18	0.17	0.18	0.18	0.17	0.18	0.17
0.414	0.13	0.13	0.16	0.15	0.15	0.16	0.16	0.17	0.17	0.16	0.16	0.16	0.18
0.424	0.12	0.14	0.14	0.16	0.16	0.16	0.16	0.16	0.17	0.17	0.19	0.19	0.15
0.434	0.12	0.12	0.15	0.15	0.14	0.16	0.15	0.16	0.16	0.16	0.16	0.17	0.17
0.444	0.11	0.12	0.14	0.15	0.14	0.14	0.14	0.15	0.16	0.14	0.15	0.12	0.14
0.454	0.11	0.12	0.14	0.13	0.14	0.14	0.14	0.15	0.14	0.14	0.15	0.16	0.15
0.464	0.08	0.12	0.13	0.14	0.11	0.14	0.14	0.14	0.15	0.14	0.13	0.14	0.12
0.474	0.10	0.12	0.12	0.12	0.13	0.13	0.14	0.13	0.13	0.13	0.15	0.14	0.15
0.484	0.09	0.10	0.11	0.13	0.13	0.13	0.12	0.12	0.13	0.12	0.12	0.13	0.13
0.494	0.10	0.10	0.11	0.12	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13
0.504	0.09	0.05	0.12	0.15	0.11	0.09	0.12	0.12	0.10	0.16	0.07	0.15	0.11

Table 43: Relative average yield over 100 years of managed fishing simulations at different levels of biomass threshold (columns) and target fishing mortality (rows).

	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0	0.09	0.10	0.09	0.09	0.10	0.09	0.10	0.10	0.09	0.09
0.01	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.23	0.22
0.02	0.38	0.37	0.37	0.37	0.38	0.37	0.37	0.36	0.35	0.34
0.03	0.49	0.48	0.48	0.48	0.48	0.48	0.47	0.46	0.45	0.43
0.04	0.59	0.59	0.58	0.58	0.58	0.57	0.57	0.54	0.52	0.47
0.05	0.67	0.66	0.66	0.66	0.66	0.65	0.63	0.60	0.57	0.50
0.06	0.75	0.74	0.73	0.73	0.71	0.70	0.66	0.64	0.60	0.50
0.07	0.78	0.79	0.79	0.77	0.75	0.74	0.71	0.65	0.55	0.51
0.08	0.85	0.83	0.84	0.81	0.80	0.78	0.72	0.65	0.55	0.48
0.09	0.87	0.88	0.87	0.86	0.82	0.77	0.70	0.65	0.53	0.41
0.1	0.88	0.92	0.89	0.86	0.82	0.75	0.69	0.61	0.53	0.40
0.11	0.92	0.93	0.89	0.90	0.82	0.74	0.66	0.62	0.46	0.36
0.12	0.91	0.93	0.91	0.90	0.83	0.76	0.67	0.53	0.45	0.31
0.13	0.88	0.95	0.91	0.83	0.79	0.67	0.58	0.50	0.39	0.29
0.14	0.92	0.96	0.90	0.84	0.80	0.67	0.55	0.41	0.36	0.29
0.15	0.94	0.94	0.90	0.81	0.77	0.61	0.51	0.39	0.34	0.22
0.16	1.00	0.91	0.88	0.76	0.69	0.63	0.49	0.36	0.26	0.19
0.17	0.96	0.86	0.82	0.79	0.69	0.59	0.45	0.32	0.21	0.18
0.18	0.92	0.84	0.80	0.73	0.66	0.50	0.39	0.28	0.21	0.14
0.19	0.91	0.89	0.83	0.70	0.59	0.50	0.34	0.28	0.18	0.12
0.2	0.88	0.81	0.74	0.71	0.56	0.43	0.33	0.23	0.16	0.11
0.21	0.88	0.84	0.73	0.56	0.51	0.37	0.29	0.20	0.14	0.10
0.22	0.82	0.77	0.70	0.62	0.47	0.40	0.25	0.17	0.13	0.10
0.23	0.76	0.76	0.66	0.54	0.41	0.35	0.24	0.14	0.12	0.09
0.24	0.80	0.68	0.70	0.53	0.43	0.32	0.21	0.15	0.11	0.09
0.25	0.76	0.69	0.61	0.47	0.35	0.25	0.17	0.15	0.11	0.09
0.26	0.71	0.62	0.56	0.48	0.33	0.24	0.18	0.13	0.10	0.08
0.27	0.73	0.64	0.59	0.45	0.33	0.25	0.16	0.12	0.09	0.08

0.28	0.70	0.63	0.53	0.41	0.27	0.22	0.15	0.11	0.09	0.08
0.29	0.68	0.57	0.48	0.39	0.29	0.18	0.14	0.11	0.09	0.08
0.3	0.59	0.52	0.41	0.31	0.23	0.17	0.13	0.10	0.09	0.08
0.31	0.63	0.54	0.42	0.29	0.23	0.16	0.12	0.10	0.09	0.08
0.32	0.62	0.50	0.37	0.30	0.23	0.15	0.12	0.10	0.08	0.08
0.33	0.50	0.42	0.35	0.28	0.19	0.14	0.12	0.09	0.09	0.07
0.34	0.53	0.42	0.32	0.24	0.20	0.14	0.11	0.09	0.08	0.07
0.35	0.55	0.42	0.35	0.23	0.16	0.13	0.11	0.09	0.08	0.08
0.36	0.50	0.38	0.28	0.22	0.16	0.13	0.10	0.09	0.08	0.07
0.37	0.48	0.41	0.30	0.19	0.15	0.12	0.10	0.09	0.08	0.07
0.38	0.47	0.36	0.27	0.20	0.14	0.11	0.10	0.09	0.08	0.07
0.39	0.45	0.32	0.23	0.19	0.14	0.11	0.10	0.09	0.08	0.06
0.4	0.46	0.30	0.23	0.17	0.13	0.11	0.09	0.09	0.08	0.06
0.41	0.35	0.30	0.22	0.16	0.12	0.11	0.10	0.09	0.08	0.06
0.42	0.38	0.27	0.22	0.15	0.13	0.10	0.10	0.09	0.08	0.07
0.43	0.38	0.26	0.19	0.15	0.12	0.11	0.09	0.09	0.08	0.06
0.44	0.36	0.27	0.18	0.15	0.11	0.10	0.09	0.09	0.07	0.05
0.45	0.34	0.25	0.18	0.14	0.11	0.10	0.09	0.08	0.08	0.04
0.46	0.31	0.21	0.17	0.14	0.11	0.10	0.09	0.08	0.07	0.05
0.47	0.32	0.21	0.17	0.13	0.11	0.10	0.09	0.08	0.08	0.04
0.48	0.27	0.20	0.15	0.13	0.11	0.10	0.09	0.08	0.07	0.04
0.49	0.25	0.20	0.15	0.13	0.11	0.10	0.09	0.08	0.06	0.03
0.5	0.19	0.21	0.14	0.14	0.11	0.09	0.09	0.08	0.07	0.03

Table 44: Relative average yield over 100 years of managed fishing simulations at different levels of biomass target (columns) and target fishing mortality (rows).

	0.075	0.175	0.225	0.275	0.375	0.425	0.475	0.525	0.625	0.725	0.775	0.825	0.875
0	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08
0.01	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.22	0.22	0.20	0.20
0.02	0.35	0.36	0.36	0.36	0.36	0.36	0.35	0.35	0.35	0.33	0.32	0.30	0.29
0.03	0.46	0.47	0.46	0.46	0.47	0.46	0.46	0.46	0.45	0.43	0.40	0.36	0.34
0.04	0.56	0.57	0.56	0.55	0.55	0.56	0.56	0.55	0.52	0.49	0.47	0.42	0.37
0.05	0.63	0.64	0.63	0.63	0.64	0.63	0.63	0.62	0.58	0.51	0.49	0.45	0.38
0.06	0.72	0.70	0.70	0.71	0.70	0.70	0.68	0.67	0.61	0.54	0.52	0.45	0.41
0.07	0.77	0.75	0.76	0.74	0.76	0.75	0.73	0.71	0.63	0.54	0.49	0.45	0.35
0.08	0.81	0.82	0.80	0.82	0.81	0.79	0.76	0.73	0.63	0.57	0.47	0.36	0.35
0.09	0.83	0.83	0.84	0.85	0.83	0.83	0.80	0.73	0.61	0.53	0.46	0.38	0.32
0.1	0.89	0.88	0.88	0.86	0.87	0.83	0.79	0.72	0.58	0.46	0.45	0.37	0.35
0.11	0.88	0.90	0.91	0.90	0.87	0.82	0.77	0.69	0.54	0.45	0.39	0.35	0.32
0.12	0.89	0.91	0.92	0.89	0.88	0.86	0.77	0.68	0.54	0.42	0.40	0.27	0.26
0.13	0.93	0.90	0.92	0.92	0.83	0.80	0.73	0.63	0.51	0.38	0.35	0.28	0.23
0.14	0.95	0.92	0.93	0.91	0.85	0.81	0.70	0.59	0.47	0.36	0.33	0.25	0.16
0.15	0.95	0.93	0.94	0.87	0.82	0.74	0.72	0.56	0.43	0.32	0.26	0.25	0.16
0.16	0.97	0.95	0.92	0.83	0.81	0.71	0.67	0.52	0.38	0.32	0.24	0.17	0.15
0.17	0.96	0.93	0.90	0.87	0.76	0.66	0.65	0.50	0.34	0.31	0.18	0.16	0.15
0.18	0.86	0.91	0.90	0.84	0.73	0.64	0.57	0.45	0.30	0.22	0.19	0.12	0.10
0.19	1.00	0.91	0.91	0.78	0.72	0.67	0.57	0.41	0.27	0.21	0.18	0.10	0.09
0.2	0.88	0.93	0.82	0.82	0.67	0.62	0.52	0.39	0.24	0.18	0.14	0.09	0.08
0.21	0.98	0.89	0.82	0.74	0.61	0.53	0.45	0.33	0.24	0.15	0.12	0.09	0.07
0.22	0.86	0.87	0.77	0.69	0.65	0.54	0.37	0.33	0.22	0.15	0.09	0.08	0.05
0.23	0.84	0.83	0.73	0.63	0.55	0.48	0.41	0.29	0.19	0.13	0.10	0.08	0.05
0.24	0.91	0.81	0.76	0.63	0.54	0.45	0.37	0.28	0.17	0.11	0.11	0.06	0.03
0.25	0.80	0.78	0.68	0.61	0.44	0.37	0.32	0.23	0.15	0.12	0.09	0.08	0.03
0.26	0.71	0.80	0.62	0.54	0.41	0.37	0.30	0.21	0.15	0.10	0.09	0.05	0.04
0.27	0.77	0.83	0.63	0.53	0.48	0.36	0.27	0.22	0.13	0.10	0.08	0.05	0.03

0.28	0.78	0.79	0.59	0.46	0.35	0.32	0.28	0.17	0.12	0.09	0.09	0.05	0.02
0.29	0.89	0.72	0.52	0.37	0.32	0.32	0.25	0.17	0.12	0.09	0.08	0.06	0.03
0.3	0.56	0.63	0.55	0.36	0.28	0.26	0.21	0.15	0.11	0.09	0.08	0.03	0.02
0.31	0.73	0.59	0.49	0.43	0.30	0.24	0.19	0.15	0.11	0.09	0.07	0.03	0.01
0.32	0.63	0.59	0.47	0.33	0.32	0.25	0.19	0.14	0.10	0.08	0.07	0.03	0.01
0.33	0.42	0.47	0.44	0.33	0.27	0.21	0.17	0.13	0.10	0.08	0.07	0.03	0.01
0.34	0.58	0.53	0.40	0.34	0.23	0.20	0.16	0.13	0.10	0.08	0.07	0.02	0.01
0.35	0.59	0.54	0.40	0.34	0.24	0.18	0.16	0.12	0.09	0.08	0.06	0.03	0.01
0.36	0.48	0.44	0.35	0.29	0.23	0.19	0.14	0.12	0.10	0.07	0.05	0.02	0.01
0.37	0.45	0.52	0.30	0.27	0.20	0.16	0.14	0.11	0.09	0.07	0.05	0.03	0.01
0.38	0.48	0.46	0.32	0.22	0.16	0.15	0.13	0.11	0.09	0.07	0.05	0.02	0.01
0.39	0.50	0.49	0.28	0.20	0.18	0.15	0.13	0.11	0.09	0.07	0.05	0.02	0.01
0.4	0.57	0.44	0.26	0.20	0.17	0.15	0.12	0.10	0.09	0.07	0.04	0.02	0.00
0.41	0.41	0.27	0.29	0.18	0.16	0.14	0.12	0.10	0.09	0.07	0.04	0.02	0.00
0.42	0.45	0.36	0.25	0.17	0.16	0.14	0.12	0.10	0.09	0.07	0.05	0.01	0.00
0.43	0.41	0.25	0.28	0.17	0.15	0.13	0.11	0.10	0.09	0.06	0.04	0.01	0.00
0.44	0.37	0.28	0.23	0.18	0.14	0.13	0.11	0.10	0.08	0.06	0.03	0.00	0.00
0.45	0.36	0.31	0.21	0.15	0.15	0.12	0.11	0.10	0.08	0.06	0.03	0.01	0.00
0.46	0.22	0.28	0.18	0.16	0.13	0.12	0.11	0.10	0.08	0.06	0.03	0.01	0.00
0.47	0.26	0.31	0.19	0.15	0.14	0.12	0.11	0.10	0.08	0.05	0.03	0.00	0.00
0.48	0.23	0.22	0.17	0.14	0.13	0.12	0.11	0.10	0.08	0.05	0.03	0.00	0.00
0.49	0.29	0.21	0.16	0.15	0.12	0.12	0.10	0.10	0.08	0.05	0.01	0.00	0.00
0.5	0.26	0.15	0.20	0.16	0.12	0.10	0.10	0.09	0.08	0.07	0.01	0.00	0.00

Figures

Alternative Risk-G (Council-Preferred): Stock Status/Life History, Inflection at B/B_{MSY} = 1.0

Under this alternative, a stock replenishment threshold defined as the ratio of B/B_{MSY} = 0.10, will be utilized to ensure the stock does not reach low levels from which it cannot recover. The probability of overfishing will be 0 percent if the ratio of B/B_{MSY} is less than or equal to 0.10. Probability of overfishing increases linearly for stock defined as typical as the ratio of B/B_{MSY} increases, until the inflection point of B/B_{MSY} = 1.0 is reached and a 40 percent probability of overfishing is utilized for ratios equal to or greater than 1.0. Probability of overfishing increases linearly for stock defined as atypical as the ratio of B/B_{MSY} increases, until the inflection point of B/B_{MSY} = 1.0 is reached and a 35 percent probability of overfishing is utilized for ratios equal to or greater than 1.0. The SSC will determine whether a stock is typical or atypical each time an ABC is recommended. Generally speaking, an atypical stock has a life history strategy that results in greater vulnerability to exploitation, and whose life history has not been fully addressed through the stock assessment and biological reference point development process.

In addition, under this alternative for managed resources that are under rebuilding plans, the upper limit on the probability of exceeding $F_{REBUILD}$ would be 50 percent unless modified to a lesser value (i.e., higher probability of not exceeding $F_{REBUILD}$) through a rebuilding plan amendment. In instances where the SSC derives a more restrictive ABC recommendation, based on the application of the ABC control rule methods framework and risk policy, than the ABC derived from the use of $F_{REBUILD}$ at the MAFMC-specified overfishing risk level, the SSC shall recommend to the MAFMC the lower of the ABC values.

In addition, if no OFL is available (i.e., No F_{MSY} or F_{MSY} proxy provided through the stock assessment to identify it) and no OFL proxy is provided by the SSC at the time of ABC recommendations, then an upper limit (cap) on allowable increases in ABC will be established. ABC may not be increased until an OFL has been identified.

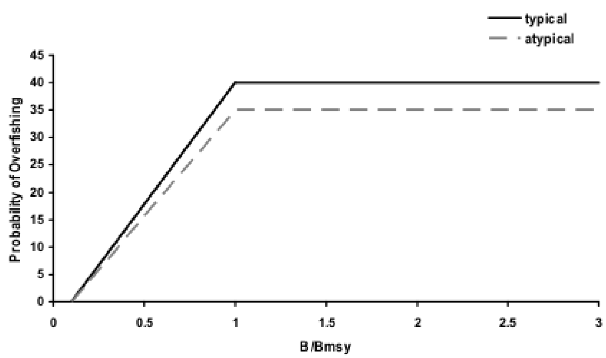


Figure 226: Mid-Atlantic Fisheries Management Council risk policy MAFMC 2011 (p. 51).

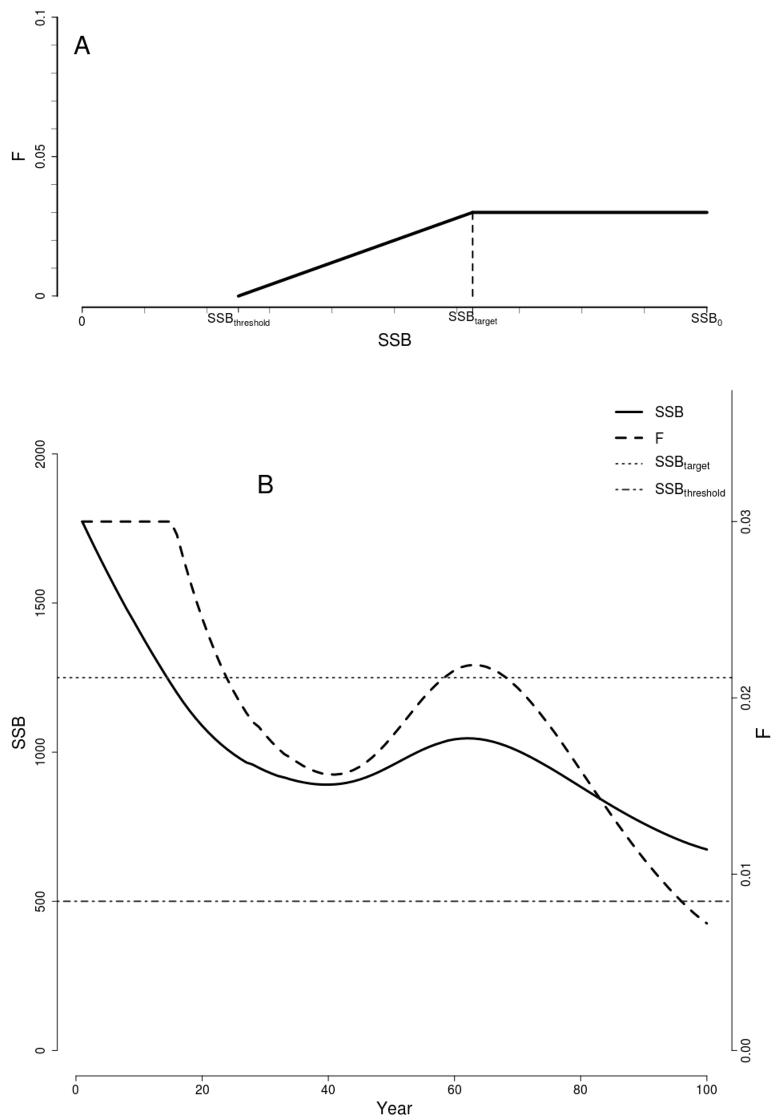


Figure 227: Panel (A) Control rule for Atlantic surfclam in terms of F and SSB. Fishing mortality is constant unless SSB drops below SSB_{target}, it then declines linearly until it reaches 0 at $SSB_{threshold}$. Panel (B) The control rule applied in a simulation run. Fishing mortality was constant when $SSB_t > SSB_{target}$, and was reduced when $SSB_t < SSB_{target}$. Simulated SSB units are 000 mt.

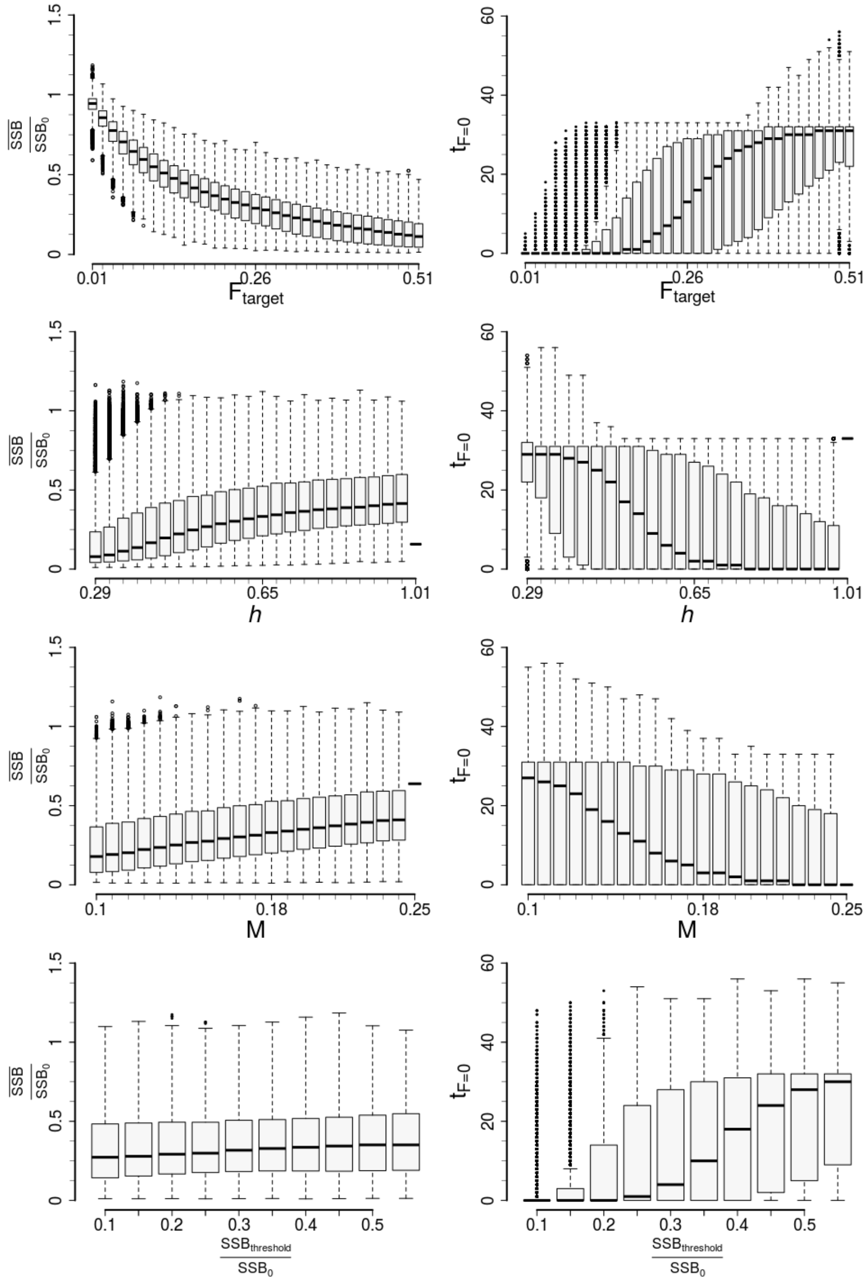


Figure 228: Mean biomass ($\frac{\overline{SSB}}{SSB_0}$), and time not fished due to management intervention ($t_{F=0}$) in 100 year simulations, by values of target fishing mortality (F_{target}), steepness (h), assessment error (σ_{At}), natural mortality (M) and the fraction of SSB_0 that corresponds to the control rule (stock replenishment) threshold ($SSB_{threshold}$). The boxes represent interquartile range, solid horizontal lines in each box are the medians, and the whiskers indicate the range between the 0.025 and 0.975 quanitles ($n = 500000$).

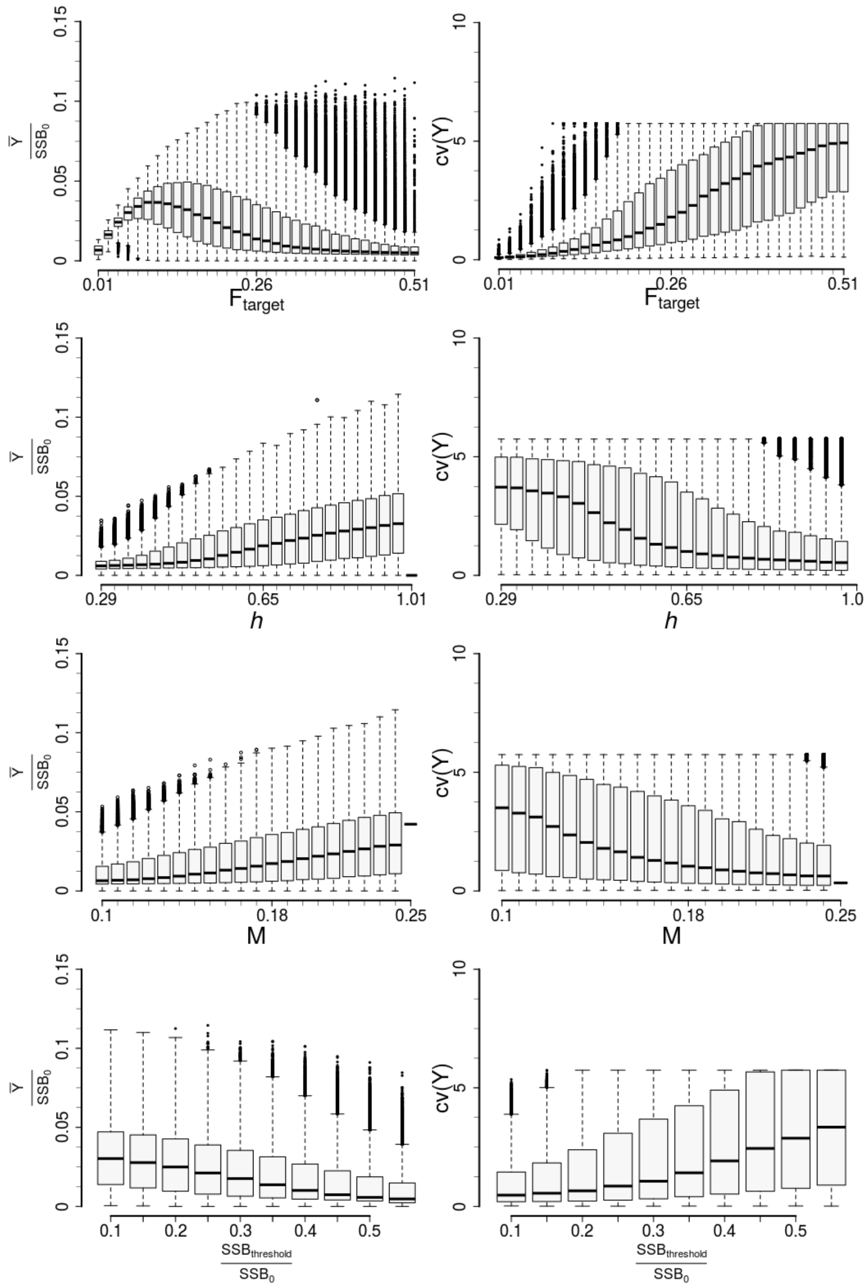


Figure 229: Mean yield ($\frac{\overline{Y}}{SSB_0}$) and cv yield in 100 year simulations, by values of target fishing mortality (F_{target}), steepness (h), natural mortality (M) and the fraction of SSB_0 that corresponds to the control rule (stock replenishment) threshold ($\frac{SSB_{threshold}}{SSB_0}$) ($n = 500000$).

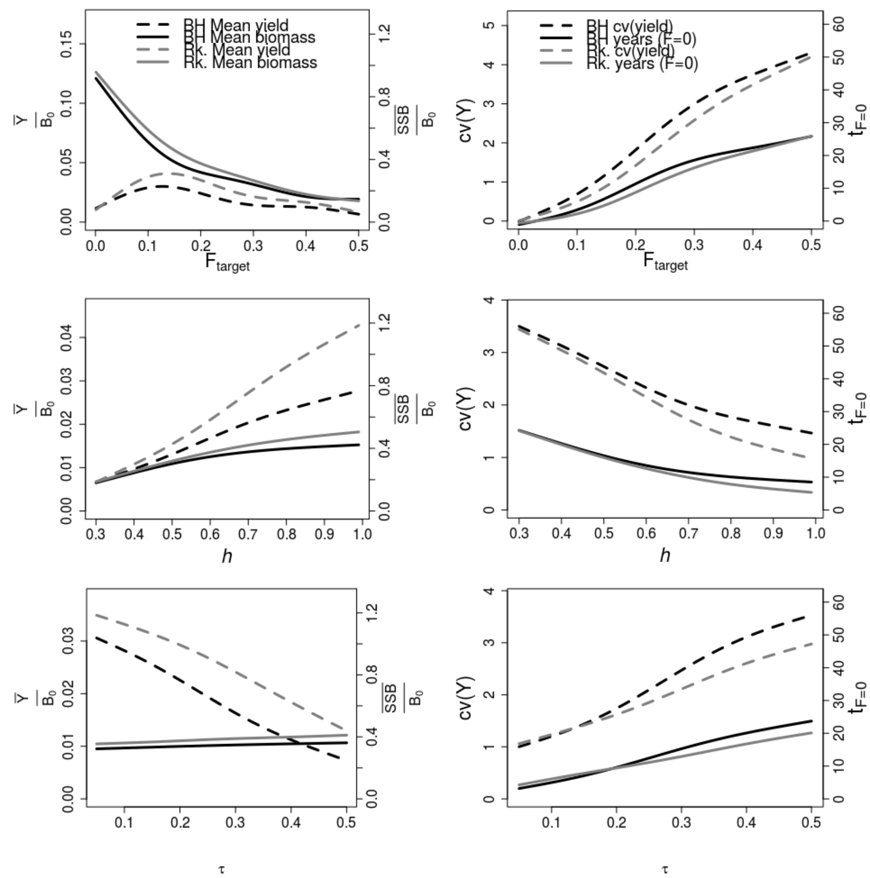


Figure 230: Mean yield, mean biomass, cv yield and years without fishing by F_{target}, h and $\frac{SSB_{threshold}}{SSB_0}$ from 100 year simulations for simulations where recruitment was driven by Beverton Holt (BH; $n = 60000$ for each) or Ricker (Rk) dynamics. The solid and dashed lines are fits to simple univariate generalized additive models (splines with basis dimension, $k = 5$). These are used to illustrate trends only.

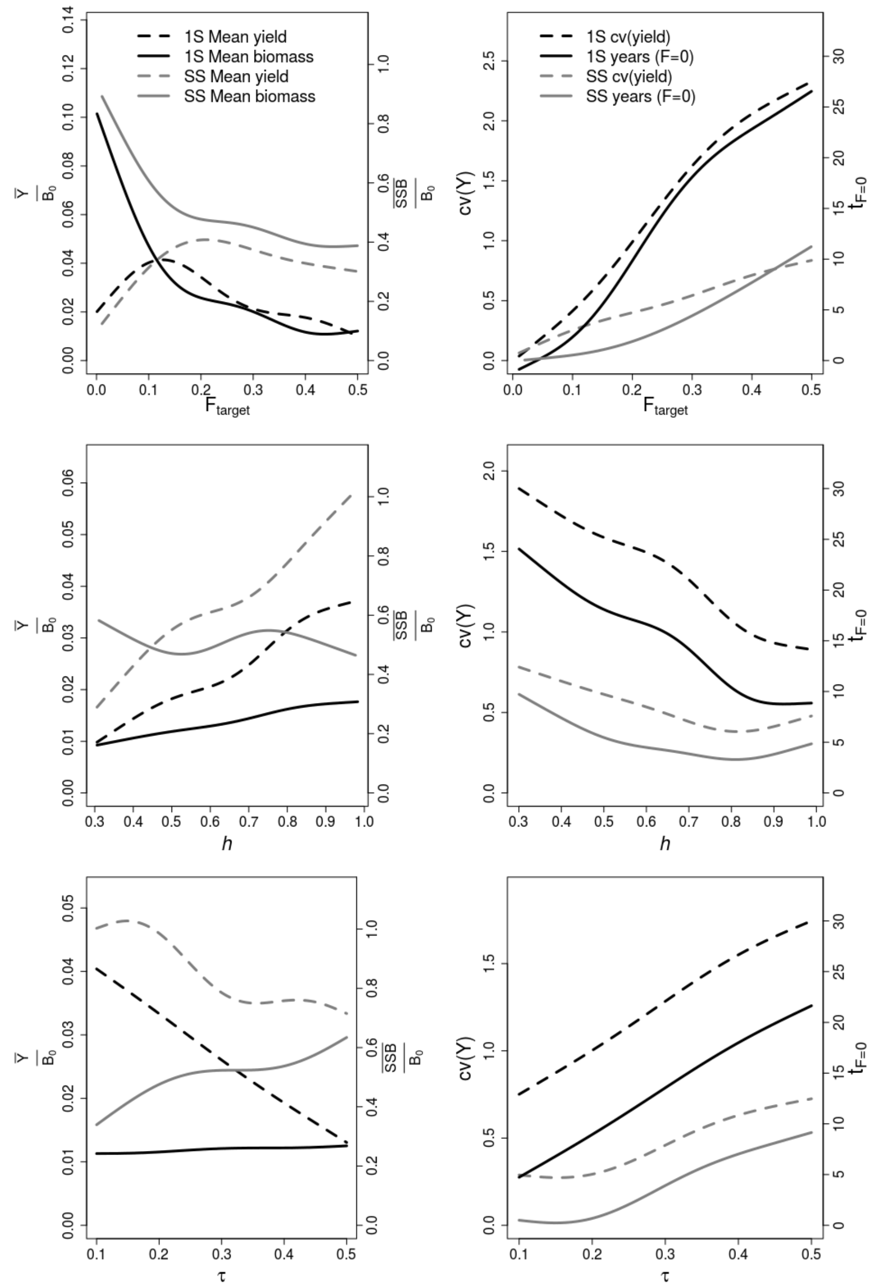


Figure 231: Mean yield, mean biomass, cv yield and years without fishing by F_{target}, h and $\frac{SSB_{threshold}}{SSB_0}$ from 100 year simulations for two regions with independent recruitment managed together, either as separate stocks (SS) or as a single stock ($1S$; $n = 60000$ for each). Both stocks were assessed every five years. The solid and dashed lines are fits to simple univariate generalized additive models (splines with basis dimension, $k = 5$). These are used to illustrate trends only.

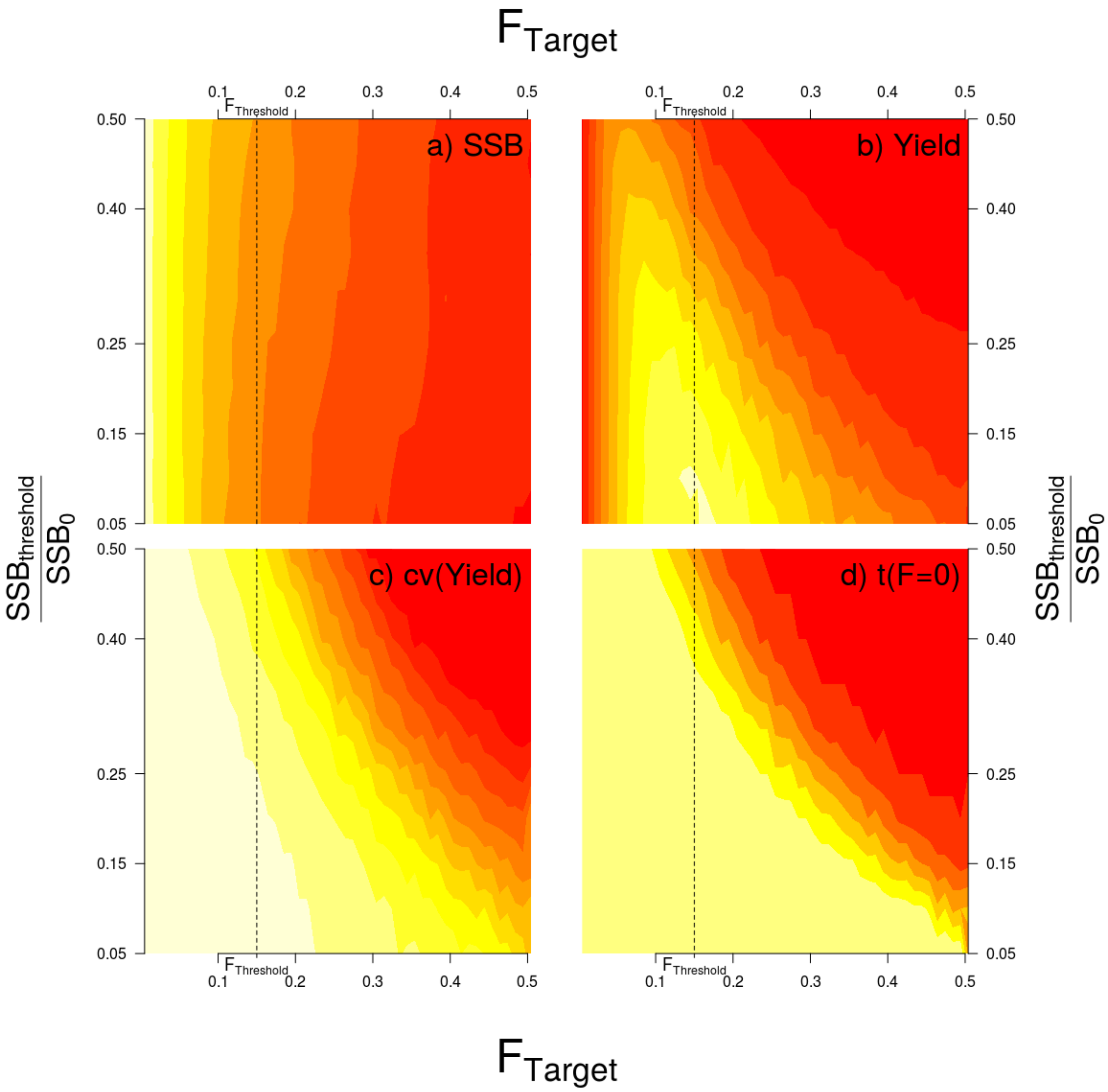


Figure 232: Contour plots showing the combined effects of F_{target} and the fraction of SSB_0 that corresponds to the control rule (stock replenishment) threshold ($\frac{SSB_{threshold}}{SSB_0}$) on: (a) $\frac{\overline{SSB}}{SSB_0}$, (b) $\frac{\overline{Y}}{SSB_0}$, (c) cv(Y) and (d) $t_{F=0}$. In each plot the darker colors are associated with less preferred values (*e.g.* in plot (a) the lowest $\frac{\overline{SSB}}{SSB_0}$ occurs on the right side, where F_{target} is high, and in plot (c) the highest variation in yield occurs on the right side, where F_{target} is high). The current $F_{threshold}$ (0.15; Northeast Fisheries Science Center 2013) is marked with a dashed line. These simulations were based on a single stock where recruitment followed either Beverton Holt or Ricker stock recruitment dynamics.

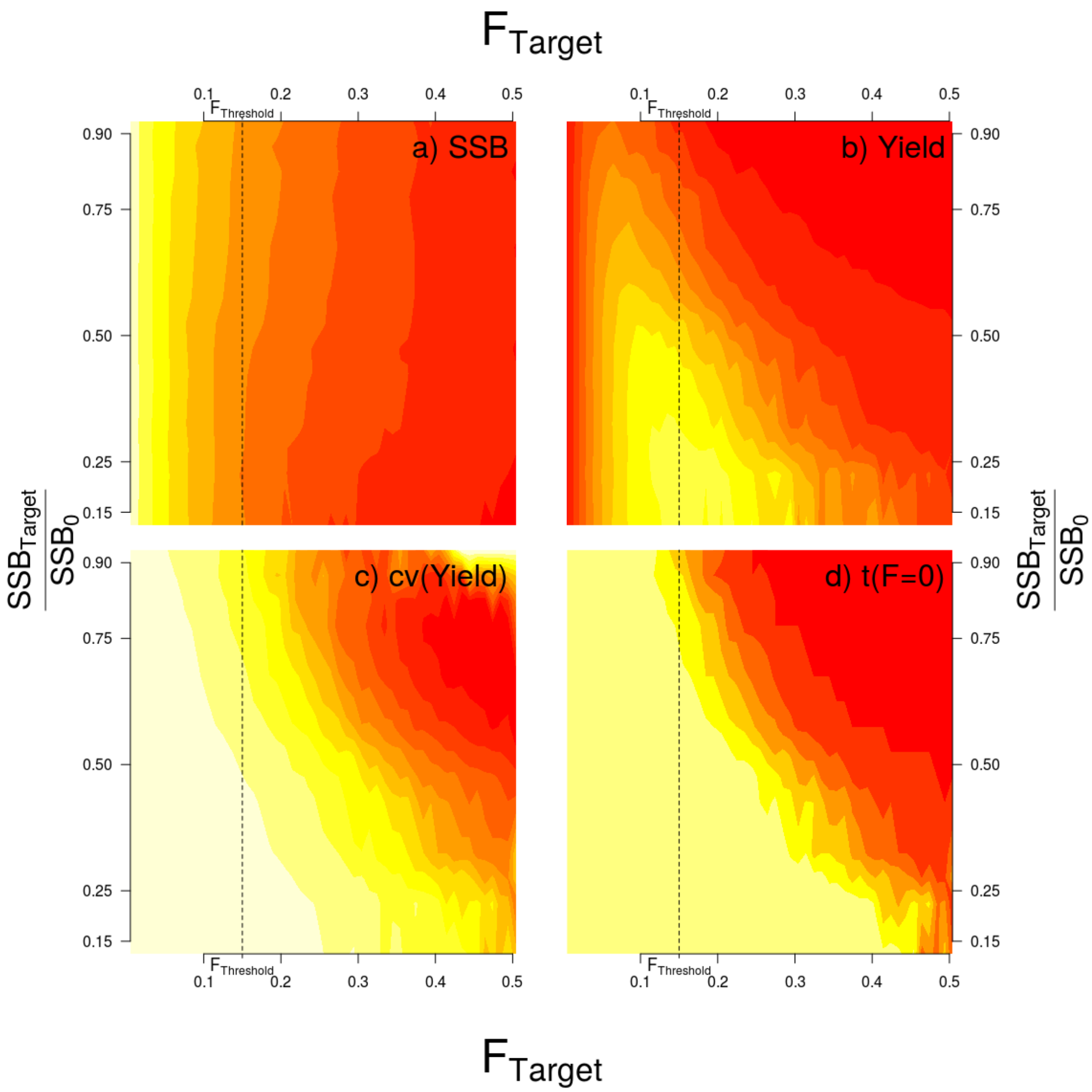


Figure 233: Contour plots showing the combined effects of F_{target} and the fraction of SSB_0 that corresponds to the control rule target ($\frac{SSB_{targer}}{SSB_0}$) on: (a) $\frac{\overline{SSB}}{SSB_0}$, (b) $\frac{\overline{Y}}{SSB_0}$, (c) cv(Y) and (d) $t_{F=0}$. In each plot the darker colors are associated with less preferred values (*e.g.* in plot (a) the lowest $\frac{\overline{SSB}}{SSB_0}$ occurs on the right side, where F_{target} is high, and in plot (c) the highest variation in yield occurs on the right side, where F_{target} is high). The current $F_{threshold}$ (0.15; Northeast Fisheries Science Center 2013) is marked with a dashed line. These simulations were based on a single stock where recruitment followed either Beverton Holt or Ricker stock recruitment dynamics.

Appendix: Deviance Tables

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	5.98e+04			
2	F	3.71e+04	2.26e+04	43.45	**
3	steepness	2.28e+04	1.43e+04	27.54	**
4	B_thresh	2.21e+04	6.53e+02	1.25	
5	M	1.64e+04	5.74e+03	11.03	**
6	Ass_err	1.64e+04	1.32e+01	0.03	
7	Auto_cor	1.64e+04	3.16e-02	0.00	
8	F_err	1.64e+04	4.57e-01	0.00	
9	SR	1.59e+04	5.05e+02	0.97	
10	F:steepness	9.97e+03	5.90e+03	11.34	**
11	F:B_thresh	9.82e+03	1.52e+02	0.29	
12	steepness:B_thresh	9.80e+03	1.83e+01	0.04	
13	F:M	8.09e+03	1.72e+03	3.30	
14	steepness:M	7.80e+03	2.84e+02	0.55	
15	B_thresh:M	7.79e+03	1.33e+01	0.03	
16	F:steepness:B_thresh	7.79e+03	1.84e-01	0.00	
17	F:steepness:M	7.69e+03	1.01e+02	0.19	
18	F:B_thresh:M	7.69e+03	4.26e-01	0.00	
19	steepness:B_thresh:M	7.69e+03	1.12e+00	0.00	
20	F:steepness:B_thresh:M	7.69e+03	5.21e-01	0.00	

Table 45: Deviance table for a model predicting mean Atlantic surfclam biomass over 453834 100 year simulations. The candidate predictors were F, mean(recruitment), biomass threshold, assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	5.98e+04			
2	F	3.71e+04	2.26e+04	43.13	**
3	steepness	2.28e+04	1.43e+04	27.33	**
4	B_targ	2.18e+04	9.50e+02	1.81	
5	M	1.61e+04	5.74e+03	10.94	**
6	Ass_err	1.61e+04	1.32e+01	0.03	
7	Auto_cor	1.61e+04	5.18e-02	0.00	
8	F_err	1.61e+04	3.95e-01	0.00	
9	SR	1.56e+04	5.07e+02	0.97	
10	F:steepness	9.67e+03	5.91e+03	11.27	**
11	F:B_targ	9.44e+03	2.31e+02	0.44	
12	steepness:B_targ	9.41e+03	2.61e+01	0.05	
13	F:M	7.70e+03	1.71e+03	3.26	
14	steepness:M	7.42e+03	2.86e+02	0.55	
15	B_targ:M	7.39e+03	2.27e+01	0.04	
16	F:steepness:B_targ	7.39e+03	2.31e-02	0.00	
17	F:steepness:M	7.29e+03	1.01e+02	0.19	
18	F:B_targ:M	7.29e+03	3.84e-02	0.00	
19	steepness:B_targ:M	7.29e+03	1.62e+00	0.00	
20	F:steepness:B_targ:M	7.29e+03	3.42e-01	0.00	

Table 46: Deviance table for a model predicting mean Atlantic surfclam biomass over 453834 100 year simulations. The candidate predictors were F, mean(recruitment), biomass target, assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	1.04e+04			
2	F	1.01e+04	2.32e+02	3.31	
3	steepness	7.63e+03	2.52e+03	36.04	**
4	B_thresh	6.02e+03	1.61e+03	22.94	**
5	M	4.59e+03	1.43e+03	20.37	**
6	Ass_err	4.59e+03	5.46e-01	0.01	
7	Auto_cor	4.59e+03	6.58e-04	0.00	
8	F_err	4.59e+03	6.21e-02	0.00	
9	SR	4.20e+03	3.91e+02	5.59	*
10	F:steepness	4.00e+03	1.97e+02	2.81	
11	F:B_thresh	3.68e+03	3.26e+02	4.66	.
12	steepness:B_thresh	3.68e+03	4.68e-01	0.01	
13	F:M	3.48e+03	2.00e+02	2.86	
14	steepness:M	3.47e+03	6.61e+00	0.09	
15	B_thresh:M	3.45e+03	1.53e+01	0.22	
16	F:steepness:B_thresh	3.45e+03	8.13e+00	0.12	
17	F:steepness:M	3.40e+03	4.44e+01	0.63	
18	F:B_thresh:M	3.40e+03	3.23e-01	0.00	
19	steepness:B_thresh:M	3.39e+03	1.39e+01	0.20	
20	F:steepness:B_thresh:M	3.38e+03	9.46e+00	0.14	

Table 47: Deviance table for a model predicting mean Atlantic surfclam yield over 453834 100 year simulations. The candidate predictors were F, mean(recruitment), biomass threshold, assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	1.00e+06			
2	F	5.89e+05	4.13e+05	57.37	**
3	steepness	5.04e+05	8.47e+04	11.76	**
4	B_thresh	4.30e+05	7.48e+04	10.38	**
5	M	3.73e+05	5.70e+04	7.92	*
6	Ass_err	3.71e+05	2.12e+03	0.29	
7	Auto_cor	3.71e+05	1.21e+00	0.00	
8	F_err	3.71e+05	5.88e+00	0.00	
9	SR	3.66e+05	4.43e+03	0.61	
10	F:steepness	3.51e+05	1.46e+04	2.03	
11	F:B_thresh	3.43e+05	8.95e+03	1.24	
12	steepness:B_thresh	3.20e+05	2.24e+04	3.11	
13	F:M	3.16e+05	4.52e+03	0.63	
14	steepness:M	2.97e+05	1.87e+04	2.60	
15	B_thresh:M	2.85e+05	1.22e+04	1.69	
16	F:steepness:B_thresh	2.85e+05	2.89e+01	0.00	
17	F:steepness:M	2.85e+05	2.03e-01	0.00	
18	F:B_thresh:M	2.84e+05	5.13e+02	0.07	
19	steepness:B_thresh:M	2.82e+05	1.75e+03	0.24	
20	F:steepness:B_thresh:M	2.82e+05	3.76e+02	0.05	

Table 48: Deviance table for a model predicting coefficient of variation in Atlantic surfclam yield over 453834 100 year simulations. The candidate predictors were F, mean(recruitment), biomass threshold, assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	2.07e+06			
2	F	1.35e+06	7.17e+05	48.28	**
3	steepness	1.15e+06	2.02e+05	13.61	**
4	B_thresh	9.40e+05	2.11e+05	14.20	**
5	M	8.42e+05	9.73e+04	6.55	*
6	Ass_err	8.41e+05	1.07e+03	0.07	
7	Auto_cor	8.41e+05	8.52e+00	0.00	
8	F_err	8.41e+05	1.91e-01	0.00	
9	SR	8.35e+05	6.73e+03	0.45	
10	F:steepness	7.94e+05	4.09e+04	2.75	
11	F:B_thresh	7.67e+05	2.68e+04	1.80	
12	steepness:B_thresh	6.81e+05	8.56e+04	5.76	*
13	F:M	6.70e+05	1.14e+04	0.77	
14	steepness:M	6.40e+05	3.00e+04	2.02	
15	B_thresh:M	6.05e+05	3.45e+04	2.33	
16	F:steepness:B_thresh	6.00e+05	5.29e+03	0.36	
17	F:steepness:M	5.99e+05	1.22e+03	0.08	
18	F:B_thresh:M	5.99e+05	1.49e+02	0.01	
19	steepness:B_thresh:M	5.85e+05	1.38e+04	0.93	
20	F:steepness:B_thresh:M	5.85e+05	2.24e+02	0.02	

Table 49: Deviance table for a model predicting years without fishing in Atlantic surfclam yield over 453834 100 year simulations of managed populations. The candidate predictors were F, mean(recruitment), biomass threshold , assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

Spatial management: one stock

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	4.26e+03			
2	F	3.00e+03	1.26e+03	40.06	**
3	steepness	2.90e+03	9.09e+01	2.89	
4	B_thresh	1.53e+03	1.37e+03	43.69	**
5	M	1.52e+03	8.51e+00	0.27	
6	Ass_err	1.52e+03	1.91e-01	0.01	
7	Auto_cor	1.52e+03	5.22e-02	0.00	
8	F_err	1.52e+03	2.65e-01	0.01	
9	SR	1.46e+03	5.99e+01	1.90	
10	F:steepness	1.46e+03	5.52e-01	0.02	
11	F:B_thresh	1.18e+03	2.83e+02	9.01	*
12	steepness:B_thresh	1.17e+03	5.01e+00	0.16	
13	F:M	1.15e+03	2.54e+01	0.81	
14	steepness:M	1.15e+03	1.48e+00	0.05	
15	B_thresh:M	1.13e+03	1.20e+01	0.38	
16	F:steepness:B_thresh	1.13e+03	1.72e+00	0.05	
17	F:steepness:M	1.12e+03	1.09e+01	0.35	
18	F:B_thresh:M	1.12e+03	4.04e+00	0.13	
19	steepness:B_thresh:M	1.11e+03	6.80e+00	0.22	
20	F:steepness:B_thresh:M	1.11e+03	2.10e-01	0.01	

Table 50: Deviance table for a model predicting mean Atlantic surfclam biomass over 62768 100 year simulations of two populations managed as a single stock and assessed every three years. The candidate predictors were F, mean(recruitment), biomass threshold, assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	4.26e+03			
2	F	3.00e+03	1.26e+03	40.04	**
3	steepness	2.90e+03	9.09e+01	2.89	
4	B_targ	1.43e+03	1.48e+03	46.98	**
5	M	1.42e+03	4.26e+00	0.14	
6	Ass_err	1.42e+03	6.13e-02	0.00	
7	Auto_cor	1.42e+03	2.46e-01	0.01	
8	F_err	1.41e+03	1.51e+01	0.48	
9	SR	1.37e+03	3.16e+01	1.00	
10	F:steepness	1.37e+03	3.12e+00	0.10	
11	F:B_targ	1.15e+03	2.24e+02	7.13	*
12	steepness:B_targ	1.15e+03	4.26e-01	0.01	
13	F:M	1.13e+03	1.58e+01	0.50	
14	steepness:M	1.13e+03	2.78e+00	0.09	
15	B_targ:M	1.13e+03	4.42e-03	0.00	
16	F:steepness:B_targ	1.13e+03	6.18e-01	0.02	
17	F:steepness:M	1.12e+03	9.20e+00	0.29	
18	F:B_targ:M	1.11e+03	4.09e+00	0.13	
19	steepness:B_targ:M	1.11e+03	1.46e+00	0.05	
20	F:steepness:B_targ:M	1.11e+03	4.70e+00	0.15	

Table 51: Deviance table for a model predicting mean Atlantic surfclam biomass over 62768 100 year simulations of two populations managed as a single stock and assessed every three years. The candidate predictors were F, mean(recruitment), biomass target, assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	1.42e+03			
2	F	5.90e+02	8.28e+02	69.99	**
3	steepness	3.93e+02	1.97e+02	16.66	**
4	B_thresh	3.35e+02	5.80e+01	4.90	.
5	M	3.04e+02	3.11e+01	2.63	
6	Ass_err	2.99e+02	4.78e+00	0.40	
7	Auto_cor	2.95e+02	3.93e+00	0.33	
8	F_err	2.93e+02	2.17e+00	0.18	
9	SR	2.47e+02	4.61e+01	3.90	
10	F:steepness	2.45e+02	1.56e+00	0.13	
11	F:B_thresh	2.44e+02	7.08e-01	0.06	
12	steepness:B_thresh	2.44e+02	6.10e-03	0.00	
13	F:M	2.44e+02	4.51e-01	0.04	
14	steepness:M	2.44e+02	1.25e-04	0.00	
15	B_thresh:M	2.43e+02	1.22e+00	0.10	
16	F:steepness:B_thresh	2.42e+02	2.65e-01	0.02	
17	F:steepness:M	2.36e+02	6.48e+00	0.55	
18	F:B_thresh:M	2.35e+02	9.51e-01	0.08	
19	steepness:B_thresh:M	2.35e+02	1.18e-02	0.00	
20	F:steepness:B_thresh:M	2.35e+02	2.09e-01	0.02	

Table 52: Deviance table for a model predicting mean Atlantic surfclam yield over 62768 100 year simulations of two populations managed as a single stock and assessed every three years. The candidate predictors were F, mean(recruitment), biomass threshold , assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	1.70e+04			
2	F	9.81e+03	7.23e+03	55.68	**
3	steepness	8.58e+03	1.23e+03	9.46	*
4	B_thresh	5.53e+03	3.06e+03	23.55	**
5	M	4.81e+03	7.21e+02	5.55	*
6	Ass_err	4.55e+03	2.55e+02	1.96	
7	Auto_cor	4.52e+03	2.99e+01	0.23	
8	F_err	4.52e+03	2.80e+00	0.02	
9	SR	4.41e+03	1.06e+02	0.81	
10	F:steepness	4.41e+03	2.09e-01	0.00	
11	F:B_thresh	4.41e+03	3.68e-01	0.00	
12	steepness:B_thresh	4.27e+03	1.36e+02	1.05	
13	F:M	4.27e+03	1.29e-01	0.00	
14	steepness:M	4.27e+03	3.00e+00	0.02	
15	B_thresh:M	4.20e+03	7.36e+01	0.57	
16	F:steepness:B_thresh	4.18e+03	1.70e+01	0.13	
17	F:steepness:M	4.18e+03	2.40e-01	0.00	
18	F:B_thresh:M	4.16e+03	2.42e+01	0.19	
19	steepness:B_thresh:M	4.06e+03	9.68e+01	0.74	
20	F:steepness:B_thresh:M	4.06e+03	3.41e+00	0.03	

Table 53: Deviance table for a model predicting coefficient of variation in Atlantic surfclam yield over 62768 100 year simulations of two populations managed as a single stock and assessed every three years. The candidate predictors were F, mean(recruitment), biomass threshold , assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	6.02e+05			
2	F	4.14e+05	1.88e+05	47.69	**
3	steepness	3.99e+05	1.45e+04	3.68	
4	B_thresh	2.56e+05	1.43e+05	36.15	**
5	M	2.38e+05	1.81e+04	4.58	.
6	Ass_err	2.35e+05	3.43e+03	0.87	
7	Auto_cor	2.30e+05	4.71e+03	1.19	
8	F_err	2.28e+05	1.93e+03	0.49	
9	SR	2.27e+05	8.37e+02	0.21	
10	F:steepness	2.27e+05	4.87e+02	0.12	
11	F:B_thresh	2.22e+05	4.77e+03	1.21	
12	steepness:B_thresh	2.21e+05	1.37e+03	0.35	
13	F:M	2.20e+05	3.95e+02	0.10	
14	steepness:M	2.20e+05	6.18e+02	0.16	
15	B_thresh:M	2.14e+05	5.33e+03	1.35	
16	F:steepness:B_thresh	2.14e+05	4.60e+02	0.12	
17	F:steepness:M	2.14e+05	4.95e+02	0.13	
18	F:B_thresh:M	2.13e+05	4.24e+02	0.11	
19	steepness:B_thresh:M	2.07e+05	5.88e+03	1.49	
20	F:steepness:B_thresh:M	2.07e+05	9.41e+00	0.00	

Table 54: Deviance table for a model predicting years without fishing in Atlantic surfclam yield over 62768 100 year simulations of two populations managed as a single stock and assessed every three years. The candidate predictors were F, mean(recruitment), biomass threshold , assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

Spatial management: separate stocks

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	7.39e+03			
2	F	1.31e+03	6.08e+03	89.74	**
3	steepness	1.08e+03	2.32e+02	3.42	
4	B_thresh	1.07e+03	1.21e+01	0.18	
5	M	8.86e+02	1.82e+02	2.69	
6	Ass_err	8.86e+02	2.38e-01	0.00	
7	Auto_cor	8.86e+02	2.13e-03	0.00	
8	F_err	8.86e+02	4.11e-04	0.00	
9	SR	8.66e+02	2.01e+01	0.30	
10	F:steepness	7.32e+02	1.33e+02	1.97	
11	F:B_thresh	7.31e+02	1.37e+00	0.02	
12	steepness:B_thresh	7.31e+02	5.62e-02	0.00	
13	F:M	6.21e+02	1.10e+02	1.62	
14	steepness:M	6.19e+02	2.55e+00	0.04	
15	B_thresh:M	6.19e+02	9.57e-03	0.00	
16	F:steepness:B_thresh	6.19e+02	1.14e-01	0.00	
17	F:steepness:M	6.17e+02	1.49e+00	0.02	
18	F:B_thresh:M	6.17e+02	8.50e-02	0.00	
19	steepness:B_thresh:M	6.17e+02	1.48e-01	0.00	
20	F:steepness:B_thresh:M	6.17e+02	6.42e-02	0.00	

Table 55: Deviance table for a model predicting mean Atlantic surfclam biomass over 52745 100 year simulations of two populations managed as separate stocks and assessed every three years. The candidate predictors were F, mean(recruitment), biomass threshold, assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	7.39e+03			
2	F	1.31e+03	6.08e+03	89.78	**
3	steepness	1.08e+03	2.32e+02	3.42	
4	B_targ	1.07e+03	8.75e+00	0.13	
5	M	8.89e+02	1.82e+02	2.69	
6	Ass_err	8.89e+02	2.32e-01	0.00	
7	Auto_cor	8.89e+02	1.00e-03	0.00	
8	F_err	8.89e+02	6.84e-04	0.00	
9	SR	8.68e+02	2.04e+01	0.30	
10	F:steepness	7.35e+02	1.34e+02	1.98	
11	F:B_targ	7.34e+02	6.01e-01	0.01	
12	steepness:B_targ	7.34e+02	5.10e-05	0.00	
13	F:M	6.25e+02	1.10e+02	1.62	
14	steepness:M	6.22e+02	2.53e+00	0.04	
15	B_targ:M	6.22e+02	3.13e-05	0.00	
16	F:steepness:B_targ	6.22e+02	7.20e-02	0.00	
17	F:steepness:M	6.20e+02	1.45e+00	0.02	
18	F:B_targ:M	6.20e+02	3.96e-01	0.01	
19	steepness:B_targ:M	6.20e+02	1.18e-01	0.00	
20	F:steepness:B_targ:M	6.20e+02	1.09e-01	0.00	

Table 56: Deviance table for a model predicting mean Atlantic surfclam biomass over 52745 100 year simulations of two populations managed as separate stocks and assessed every three years. The candidate predictors were F, mean(recruitment), biomass target, assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	8.35e+02			
2	F	7.15e+02	1.20e+02	24.36	**
3	steepness	6.39e+02	7.59e+01	15.42	**
4	B_thresh	5.07e+02	1.32e+02	26.81	**
5	M	4.18e+02	8.93e+01	18.15	**
6	Ass_err	4.17e+02	5.35e-01	0.11	
7	Auto_cor	4.17e+02	1.05e-02	0.00	
8	F_err	4.17e+02	1.83e-02	0.00	
9	SR	3.90e+02	2.72e+01	5.53	*
10	F:steepness	3.84e+02	6.34e+00	1.29	
11	F:B_thresh	3.64e+02	2.02e+01	4.10	
12	steepness:B_thresh	3.64e+02	3.52e-02	0.01	
13	F:M	3.47e+02	1.63e+01	3.31	
14	steepness:M	3.47e+02	3.89e-01	0.08	
15	B_thresh:M	3.46e+02	9.67e-01	0.20	
16	F:steepness:B_thresh	3.45e+02	5.08e-01	0.10	
17	F:steepness:M	3.43e+02	1.98e+00	0.40	
18	F:B_thresh:M	3.43e+02	9.96e-02	0.02	
19	steepness:B_thresh:M	3.43e+02	3.61e-01	0.07	
20	F:steepness:B_thresh:M	3.43e+02	1.70e-01	0.03	

Table 57: Deviance table for a model predicting mean Atlantic surfclam yield over 52745 100 year simulations of two populations managed as separate stocks and assessed every three years. The candidate predictors were F, mean(recruitment), biomass threshold , assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	4.50e+04			
2	F	2.27e+04	2.24e+04	66.05	**
3	steepness	2.03e+04	2.37e+03	6.99	*
4	B_thresh	1.60e+04	4.27e+03	12.58	**
5	M	1.28e+04	3.21e+03	9.46	*
6	Ass_err	1.28e+04	4.23e+01	0.12	
7	Auto_cor	1.28e+04	5.56e-01	0.00	
8	F_err	1.28e+04	2.03e+00	0.01	
9	SR	1.24e+04	3.41e+02	1.00	
10	F:steepness	1.23e+04	1.66e+02	0.49	
11	F:B_thresh	1.22e+04	7.90e+01	0.23	
12	steepness:B_thresh	1.19e+04	2.56e+02	0.76	
13	F:M	1.19e+04	6.66e+01	0.20	
14	steepness:M	1.14e+04	4.36e+02	1.29	
15	B_thresh:M	1.13e+04	1.67e+02	0.49	
16	F:steepness:B_thresh	1.12e+04	8.28e+00	0.02	
17	F:steepness:M	1.12e+04	1.70e+01	0.05	
18	F:B_thresh:M	1.12e+04	4.58e+01	0.14	
19	steepness:B_thresh:M	1.12e+04	1.15e+01	0.03	
20	F:steepness:B_thresh:M	1.11e+04	2.79e+01	0.08	

Table 58: Deviance table for a model predicting coefficient of variation in Atlantic surfclam yield over 52745 100 year simulations of two populations managed as separate stocks and assessed every three years. The candidate predictors were F, mean(recruitment), biomass threshold , assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

	Model	Residual dev.	Delta dev.	% dev. explained	signif.
1	NULL	2.35e+05			
2	F	1.52e+05	8.28e+04	55.79	**
3	steepness	1.41e+05	1.15e+04	7.72	*
4	B_thresh	1.15e+05	2.59e+04	17.43	**
5	M	1.03e+05	1.14e+04	7.66	*
6	Ass_err	1.03e+05	7.63e+01	0.05	
7	Auto_cor	1.03e+05	1.33e-01	0.00	
8	F_err	1.03e+05	5.51e+00	0.00	
9	SR	1.03e+05	7.49e+02	0.50	
10	F:steepness	1.01e+05	1.97e+03	1.33	
11	F:B_thresh	9.75e+04	3.13e+03	2.11	
12	steepness:B_thresh	9.30e+04	4.45e+03	3.00	
13	F:M	9.18e+04	1.19e+03	0.80	
14	steepness:M	9.01e+04	1.72e+03	1.16	
15	B_thresh:M	8.71e+04	2.99e+03	2.02	
16	F:steepness:B_thresh	8.71e+04	7.48e+01	0.05	
17	F:steepness:M	8.70e+04	1.27e+01	0.01	
18	F:B_thresh:M	8.70e+04	3.55e+00	0.00	
19	steepness:B_thresh:M	8.65e+04	5.20e+02	0.35	
20	F:steepness:B_thresh:M	8.65e+04	2.60e+01	0.02	

Table 59: Deviance table for a model predicting years without fishing in Atlantic surfclam yield over 50,000 100 year simulations of two populations managed as separate stocks and assessed every three years. The candidate predictors were F, mean(recruitment), biomass threshold , assessment error, amount of auto correlation in assessment error, implementation error, natural mortality, stock recruit function type and all two, three, four, five, six and seven way interactions between them. Only predictors that explained 5 percent of the deviance relative to the null model were considered significant.

Part XX

Appendix: Comparing methods for combining F from different areas

Four different methods for combining estimates of fishing mortality from different areas were compared. The methods were: the arithmetic mean

$$\widehat{F_{W,arith}} = E[F_S + F_N] \tag{24}$$

where F_W is the whole stock fishing fishing mortality and F_S and F_N are the F form the southern and northern areas, respectively. The geometric mean

$$\widehat{F_{W,geo}} = e^{E[log(F_S)+lof(F_N)]} \tag{25}$$

the harmonic mean

$$\widehat{F_{W,har}} = \frac{2}{F_S^{-1} + F_N^{-1}} \tag{26}$$

and the abundance weighted mean

$$\widehat{F_{W,wt}} = \frac{N_S}{N_S + N_N} F_S + \frac{N_S}{N_S + N_N} F_N \tag{27}$$

where N_S and N_N are the abundances form the southern and northern areas, respectively.

Correlated lognormal random variables (n=10000) were drawn for F and N for each of two areas where

$$F_a \sim lognormal(\mu_{F,a}, \sigma_{S,a}) \tag{28}$$

$$N_a \sim lognormal(\mu_{N,a}, \sigma_{N,a}) \tag{29}$$

$\mu_{i,a}$ and $\sigma_{i,a}$ were the mean and variance of the parameter i (N or F) and simulated area a. The correlation between F_a and N_a (ρ) was varied experimentally. The distribution of each of $\widehat{F_{W,method}}$ from each of the different methods for combining F was compared to the true combined $F_W = E[\mu_{F,a}\mu_{N,a}]$.

The simulations showed that $\widehat{F_{W,arith}}$ is biased high and $\widehat{F_{W,har}}$ is biased low at all values of ρ (Figure 234). $\widehat{F_{W,wt}}$ was biased low when $\rho < -0.6$ and biased high when $\rho > -0.4$. $\widehat{F_{W,geo}}$ was close to F_W at all values of ρ and deemed the best choice for the combining the F in the Atlantic surfclam assessment where the correlation between biomass (and abundance) and fishing mortality is high (for example, from the base run for the southern area $\rho_{max} = -0.78$ and $\rho_{min} = -0.97$).

The results depended on the level of F. In particular when $F \cong 0.0$, the geometric and harmonic means were strongly negatively biased (Figure 235). When $F \cong 0.0$, the preferred method for combining F from different areas was the abundance weighted mean, based on less bias at all levels of correlation between F and abundance.

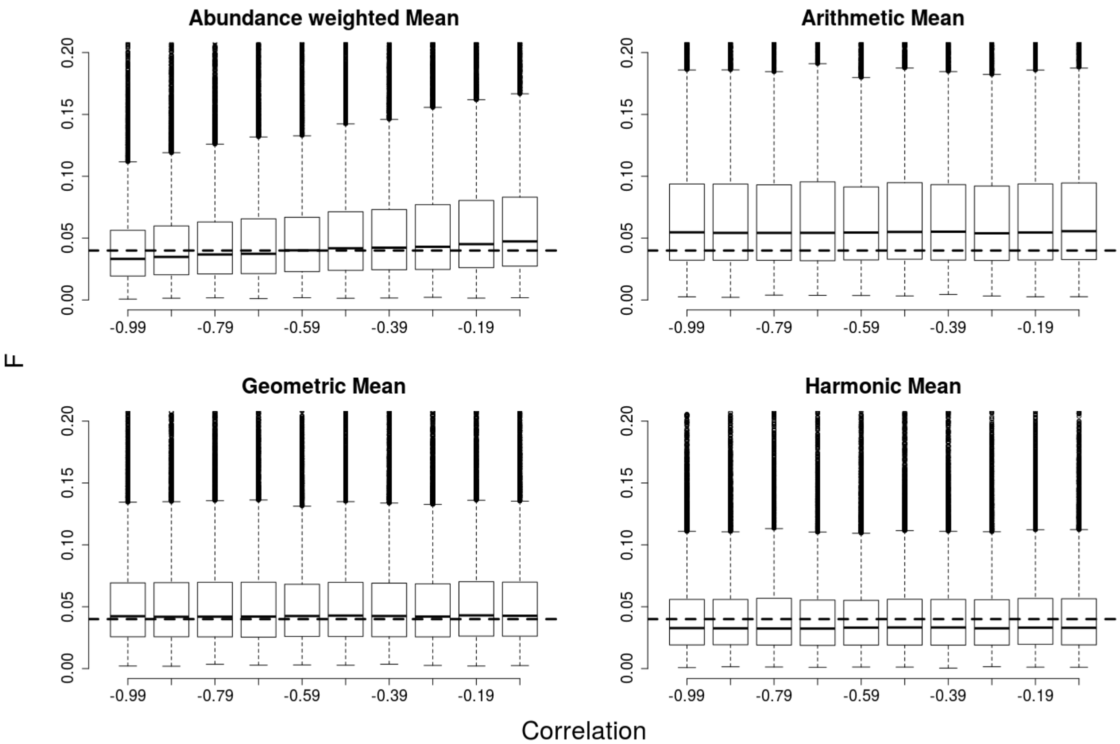


Figure 234: The distribution of estimates of the combined fishing mortality from two regions at varying levels of correlation between abundance and F, compared to the true combined fishing mortality (dashed line). The geometric mean was nearly unbiased at all correlation levels, while the bias in abundance weighted mean depended on the correlation between F and abundance.

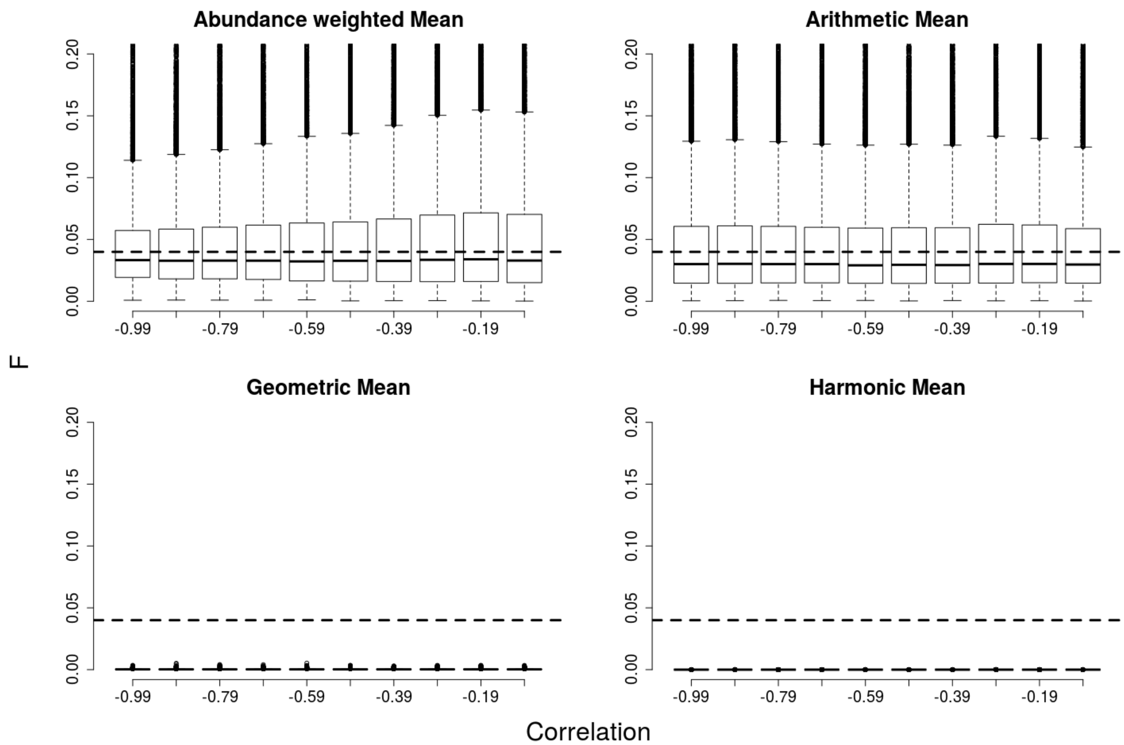


Figure 235: The distribution of estimates of the combined fishing mortality from two regions at varying levels of correlation between abundance and F, compared to the true combined fishing mortality (dashed line), when one the true F values is near 0 ($F = 0.00001$). In this case the geometric and harmonic means were strongly negatively biased and the abundance weighted average was the preferred method

Part XXI

Appendix: Sampling properties of presence-absence data for from NEFSC clam surveys

Changes in habitat overlap and co-occurrence of Atlantic surfclam and ocean quahogs affect the fisheries for both species because mixed catches are harder and more expensive to process for sale. Co-occurrence may be a simple metric for tracking climate change effects on habitat for both species. Here, we develop some mathematics that describe occurrence and co-occurrence of Atlantic surfclam and ocean quahogs in dredge survey tows as a function of individual densities using the RD clam survey as an example. In summary, occurrence and co-occurrence are sensitive indicators that one or both species are found in an area. However, they are insensitive to changes in density once encounter rates for both species reach about 15 individuals per tow (roughly 0.013 per m^2). Calculations are based on the RD, but the overall result applies to the MCD, which has higher capture efficiency for both species and sweeps a larger area, so that it is even more sensitive to the presence of either species and less useful as a measure of density (in the context of presence-absence).

The data used in this analysis are from random tows during NEFSC clam surveys during 1982-2011. The nominal area swept is 423 m^2 per tow, but varies with depth. We assume that the area swept by the survey dredge (1.82 m or 5 ft wide) is about 1140 m^2 per tow, based on a tow distance of about 700 m, where both species might be found (see Figure 238; citeweinberg2002estimation). This crude approximation aids interpretation but does not affect the overall conclusion.

The probability of catching at least one Atlantic surfclam and one ocean quahog in the same tow depends on depth, species, and/or time dependent factors including: 1) capture efficiency of the gear, 2) area swept (tow distance x dredge width, m^2), 3) encounter rate and density (individuals per tow or m^2) and 4) the statistical distributions of the number of clams encountered in a tow (with parameters for the mean, variance and, implicitly, patchiness). The probability of catching at least one Atlantic surfclam (s) and one quahog (q) in a dredge tow is:

$$p(s, q \mid d) = p(s \mid d)p(q \mid d) \tag{30}$$

where $p(s \mid d)$ and $p(q \mid d)$ are the conditional probabilities of catching at least one Atlantic surfclam or quahog at depth d as independent events. These probabilities might depend on time, region, etc. but subscripts for such factors are not included. Using Atlantic surfclam as an example:

$$p(s \mid d) = \sum_{n=1}^{\infty} \left[P(E_s = n \mid d) \sum_{m=1}^{n} \binom{n}{m} e_s^m (1 - e_s)^{n-m} \right] \tag{31}$$

where $p(E_s = n \mid d)$ is the probability that the dredge encounters n individual Atlantic surfclam, e_s is capture efficiency ($0 < e_s < 1$), $\binom{n}{m}$ are binomial coefficients giving the number of ways to catch m clams if n are encountered, and $e_s^m(1-e_s)^{n-m}$ is the probability of catching m and missing

$n - m$ individuals in the path of the dredge when n clams are encountered. The formula can be simplified because the

$$\sum_{m=1}^{n} \binom{n}{m} e_s^m (1 - e_s)^{n-m}$$

used to calculate the probability of catching at least one clam is the complement of the probability of catching none with probability $(1 - e_s)^n$, so that:

$$p(s \mid d) = \sum_{n=0}^{\infty} P(E_s = n \mid d)[1 - (1 - e_s)^n] \tag{32}$$

Note that the possibility that the dredge will not encounter any clams (even though they may be in the general area) is included. Such an event does not contribute to the probability of any catch because $1 - (1 - e_s)^0 = 0$. Thus, the probability of catching no clams could be omitted from the calculation without changing the results.

The encounter probability $P(E_s = n \mid d)$ is from an unknown statistical distribution with mean ($\mu_{s,d}$) and variance ($\sigma^2_{s,d}$) parameters that may depend on any of the factors listed above. Patchiness is an inherent property of the statistical distribution that also affects the encounter probability because patchy organisms are captured less frequently than randomly distributed ones. The mean number of encounters per tow depends directly on the density of Atlantic surfclam (and overall abundance) and the area swept by the tow.

Using the Poisson distribution with parameters $\lambda_{s,d} = \mu_{s,d} = \sigma^2_{s,d}$, the probability distribution for encountering n individuals would be:

$$P(E_s = n \mid d) = \frac{\lambda_{s,d}^n e^(-\lambda_{s,d})}{n!} \tag{33}$$

The negative binomial distribution is another candidate distribution which may be appropriate given that Atlantic surfclam and ocean quahog catches during depletion experiments have been modeled successfully based on the distribution:

$$P(E_s = n \mid d) = \frac{\Gamma(n + k_{s.d})}{n!\Gamma(k_{s.d})} \left(\frac{k_{s.d}}{\mu_{s,d} + k_{s.d}} \right)^{k_{s.d}} \left(\frac{\mu_{s,d}}{\mu_{s,d} + k_{s.d}} \right)^{n} \tag{34}$$

where $k_{s.d}$ is a dispersion parameter and $\sigma^2_{s,d} = \mu_{s,d} + \frac{\mu^2_{s,d}}{k}$. By the method of moments, $k_{s.d} = \frac{\mu_{s,d}}{\left[\frac{\sigma^2_{s,d}}{(\mu_{s,d} - 1)}\right]}$.

It is important to remember that the probability density function for co-occurrence $p(s, q \mid d)$ can decline, for example, if either or both of $p(s \mid d)$ and $p(q \mid d)$ decline, if $p(s \mid d)$ declines substantially while $p(q \mid d)$ increases slightly, or if $p(s \mid d)$ increases substantially while $p(q \mid d)$ declines slightly. The probability may remain constant despite large ecological changes if a decline in density of Atlantic surfclam, for example, is offset by an increase in density of ocean quahogs. Very small changes in $p(s \mid d)$ are possible despite large changes in density if $(s \mid d)$ is close to one initially (and vice-versa). The probability of co-occurrence is therefore nearly the same as the probability of occurrence for a species at low density in a habitat where the other species is at high density.

The sampling characteristics of co-occurrence data can be evaluated using eq. (32) with assumed statistical distributions and parameter values (Table 60). The mean of 21 Delaware II dredge capture efficiency estimates in NEFSC (2013) for Atlantic surfclam 150+ mm SL was 0.413 (SE 0.098). The mean of 15 Delaware II dredge capture efficiency estimates in NEFSC (2009) for ocean quahogs 90+ mm SL was 0.263 (SE 0.057). The mean dispersion parameter (k) for catches in depletion studies was 9.83 (SD 11.6, SE 2.37) for Atlantic surfclam and 8.00 (SD 4.03, SE 0.88) for ocean quahogs.

The mean Atlantic surfclam catch (all sizes) was 83 (SD 237, SE 7.13) and the mean quahog catch was 239 (SD 895, SE 26.9) in random survey tows that caught both species during 1982-2011 (Table 60). The distributions of observed catches were highly skewed for both species. Based on catch and capture efficiency, the mean number of Atlantic surfclam encountered in tows that caught both species was mean catch/efficiency=83/0.413=201 (about 0.18 Atlantic surfclam per m^2) and the mean number of quahogs encountered was 239/0.263=909 (about 0.8 quahogs per m^2). These figures are under-estimates because of reduced capture efficiency for Atlantic surfclam < 150 mm SL and for quahogs < 90 mm SL.

The probabilities of catching at least one Atlantic surfclam, one ocean quahog or at least one of each species in a hypothetical survey tow is nearly one given the typical values described above using either the negative binomial or Poisson distribution (Table 60 and Figures 236-237). The probabilities are high because numbers encountered tend to be high (> 100) for both species based on typical values and particularly because the probability of catching at least one clam is high for even modest numbers of encounters. Considering Atlantic surfclam with capture efficiency $e_{s.d} = 0.413$, the probability of capturing at least one individual with only five encounters (0.01 m^2) is $1-(1-0.413)^5 = 0.93$. For ocean quahogs, the corresponding probability is $1-(1-0.263)^5 = 0.78$.

The calculations above show that the probability of capture for both species and for co-occurrence is likely to be high at relatively low densities for both species and suggest that co-occurrence is a sensitive indicator that both species are present. To test this hypothesis, we calculated the probability catching at least one individual of both species, and the probability of co-occurrence for mean encounter rates ranging from 1 to 15 clams of each species per tow (0.0009 to 0.013 per m^2). Results indicate that the probability of co-occurrence is 0.10-0.15 when only one Atlantic surfclam and ocean quahog are encountered, 0.55-0.65 for five individuals of both species and at least 0.85 for ten individuals per tow (0.009 per m^2) of both species (Figure 238). However, the results also show that co-occurrence is insensitive to changes in encounter rates and density beyond fifteen individuals per tow. Average co-occurrence over many tows is unlikely to be useful for tracking trends in density of either species because typical catches in tows that caught both species were usually above 15 clams per tow for both Atlantic surfclam and ocean quahogs (Table 60).

Table 60: Typical parameters used in simulating occurrence and co-occurrence of Atlantic surfclam and ocean quahogs in survey tows. The probability of capturing at least one individual from eq. (32) under conditions in the table is shown in the last row. Statistic.

Statistic	Atlantic surfclam	Ocean quahogs
Mean number encountered	201	909
Approximate density assuming 500 m^2 per tow (see text)	0.40 per m^2	1.8 per m^2
Dispersion parameter	9.83	8.00
Capture efficiency	0.413	0.263
P(catch > 0)	1	1

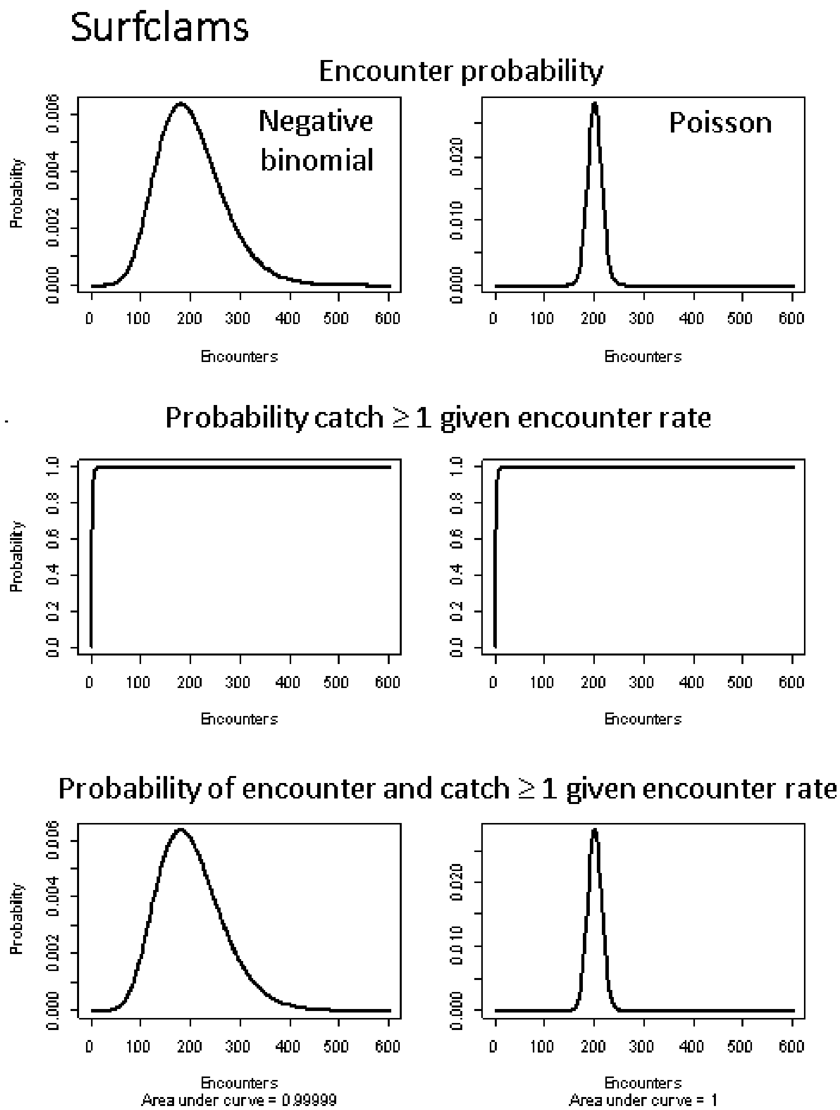


Figure 236: Intermediate calculations in calculating the probability that at least one individual is captured in a hypothetical survey tow assuming typical parameter values and either a negative binomial (left) or Poisson (right) distribution for encounter probability. The top row gives the probability density functions $P(E_s = n \mid d)$ for the number of clams encountered by the dredge given the assumed mean encounter rate (density) and statistical distribution. The middle row (same on left and right) shows the conditional probability $[1-(1-e_s)^n]$ that at least one clam is captured given the number of encounters on the x-axis. The bottom row shows the joint probability of the encounter rate and capture of at least one clam (the product of the curves in the top and middle rows). The area under the bottom curve is the total probability of catching at least one clam. The range of encounters on the x-axis differs markedly for the two species because ocean quahog densities are higher than Atlantic surfclam densities based on survey catches and because of capture efficiency assumptions.

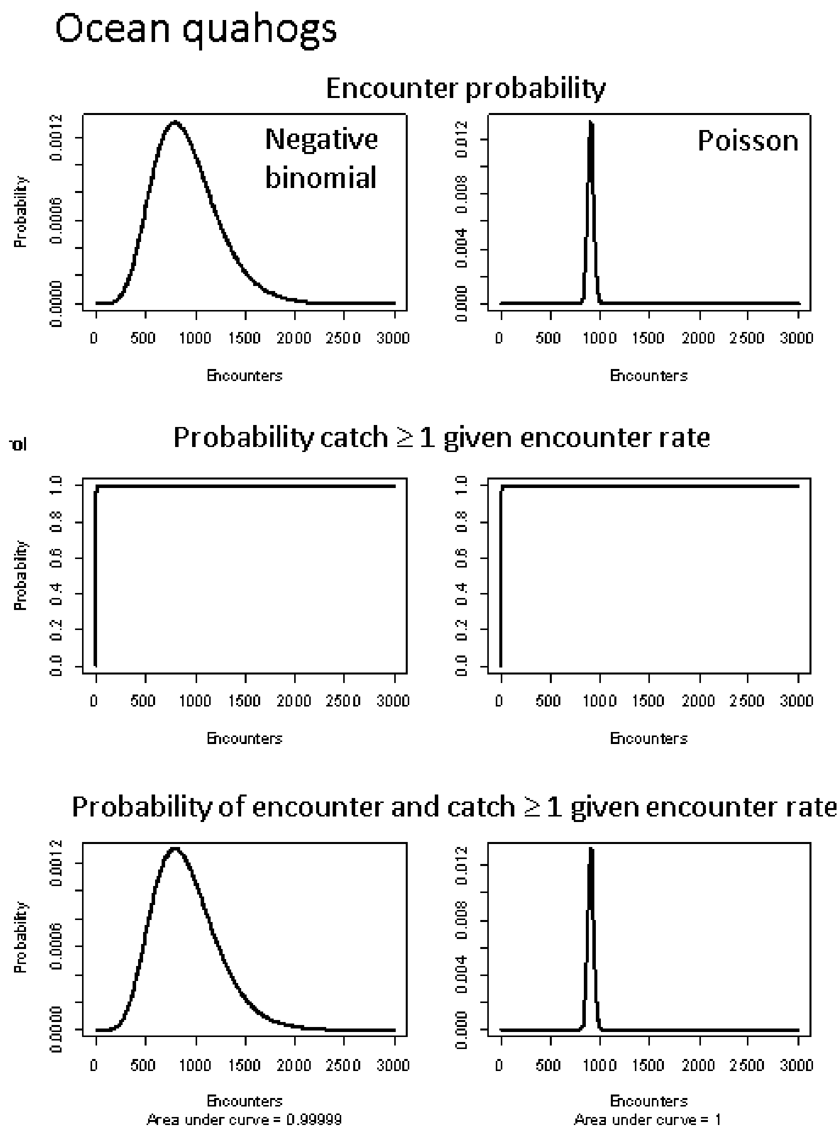


Figure 237: Intermediate calculations in calculating the probability that at least one individual is captured in a hypothetical survey tow assuming typical parameter values and either a negative binomial (left) or Poisson (right) distribution for encounter probability. The top row gives the probability density functions $P(E_s = n \mid d)$ for the number of clams encountered by the dredge given the assumed mean encounter rate (density) and statistical distribution. The middle row (same on left and right) shows the conditional probability $[1 - (1 - e_s)^n]$ that at least one clam is captured given the number of encounters on the x-axis. The bottom row shows the joint probability of the encounter rate and capture of at least one clam (the product of the curves in the top and middle rows). The area under the bottom curve is the total probability of catching at least one clam. The range of encounters on the x-axis differs markedly for the two species because ocean quahog densities are higher than Atlantic surfclam densities based on survey catches and because of capture efficiency assumptions.

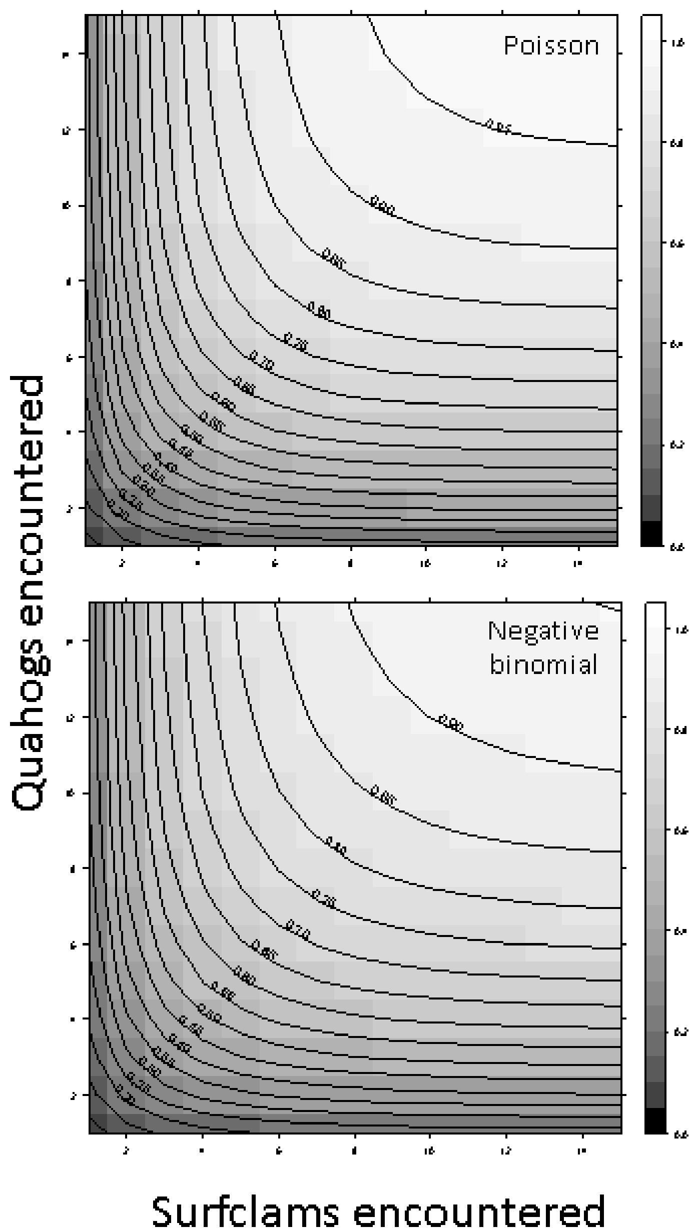


Figure 238: Isopleths for the probability of co-occurrence (at least one Atlantic surfclam and one ocean quahog in a hypothetical survey tow) given the number of Atlantic surfclam and ocean quahogs encountered.

Part XXII

Appendix: Trends in probability of Atlantic surfclam-ocean quahog co-occurrence in NEFSC clam surveys

Logistic regression models were used to detect trends in the probability of co-occurrence (Atlantic surfclam and ocean quahogs taken in the same tow) in NEFSC clam surveys during 1982-2011. Survey data collected after 2011 were not included because they involved different survey gear, were not comparable (Appendix XXI), and because too few survey years were available for independent use. Only data from successful random tows were used. Poorly sampled strata with > 2 missing years were omitted. The dependent variable for each tow was a dummy variable for co-occurrence (1 if both Atlantic surfclam and ocean quahogs were captured and zero otherwise). In the R programming language, the models were specified $glm(d \sim y, family = binomial)$ where d is the dummy variable and y is year. The null hypothesis of no trend was rejected if $p \leq 0.1$.

Results show that the probability of co-occurrence decreased almost linearly during 1982-2011 in SNE while increasing almost linearly in the LI and NJ regions (Figure 239). Significant trends were detected for individual survey strata within each region except SNE (Table 61).

Table 61: Summary of strata with significant trends ($p \leq 0.1$) in co-occurrence of Atlantic surfclam and ocean quahogs in NEFSC clam surveys during 1982-2011.

Region	Stratum	Direction of trend	p-value	Strata depth range (m)	Area (nm2)
GBK	55	decline	0.08	55-73	364
GBK	69	increase	0.1	0-46	938
LI	29	increase	0.01	27-46	1096
LI	33	increase	0.01	27-46	363
NJ	22	increase	< 0.01	46-55	312
NJ	25	increase	0.01	27-46	648
DMV	9	decline	< 0.01	27-46	2171
SVA	6	decline	0.08	46-55	62

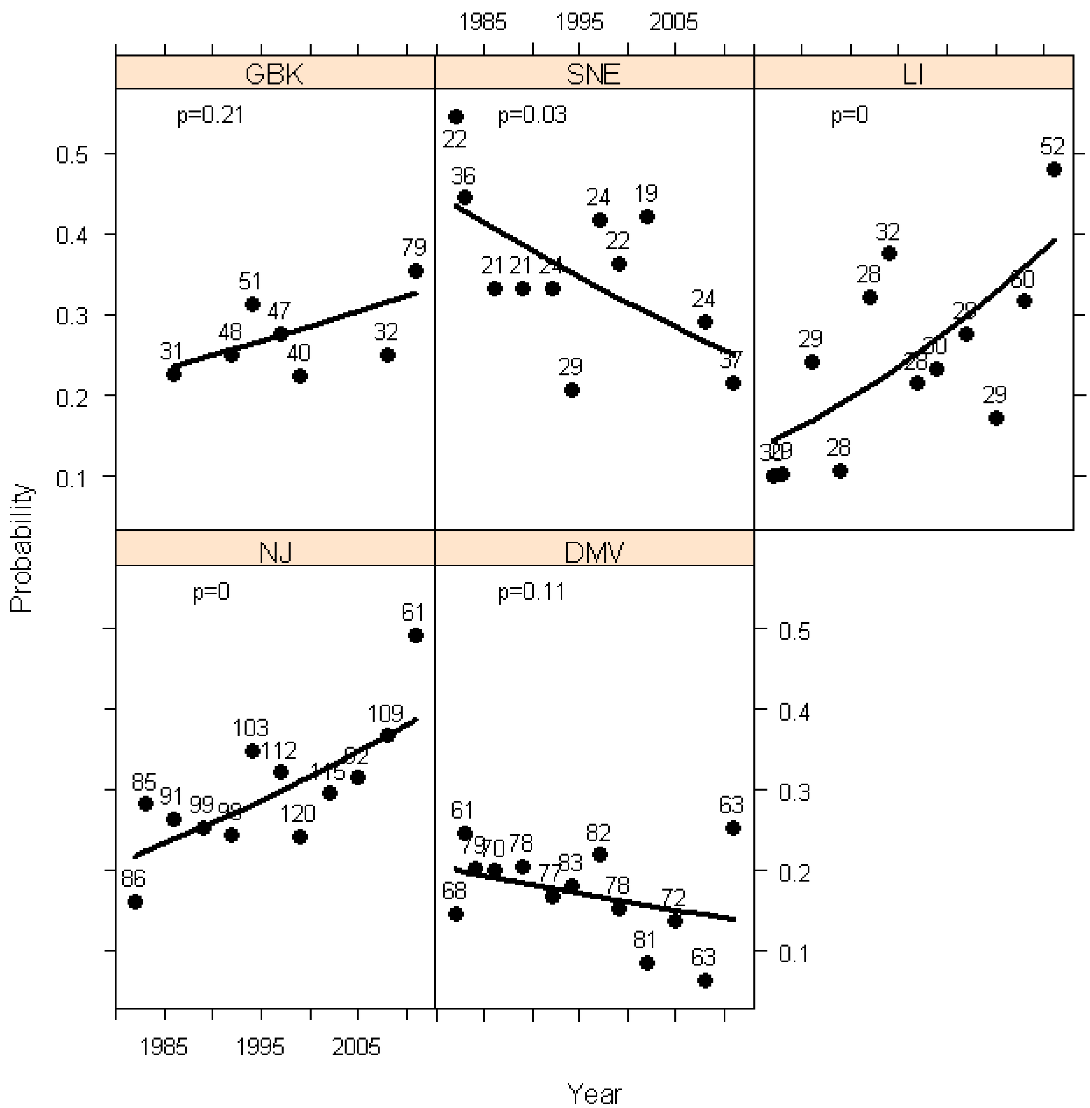


Figure 239: Trends in co-occurrence of Atlantic surfclam and ocean quahogs by region with p-values (top of each panel) and sample sizes in each year.

Part XXIII

Appendix:Changes in habitat area for Spp in the Mid-Atlantic and GBK regions based on NEFSC clam survey data and presence-absence modeling

Survey data and model results suggest that habitat area declined in the south off DMV area due to losses in shallow water, increased along the central Mid-Atlantic Bight (NJ and LI areas) due to increases in deep water and varied without trend in the north (SNE and GBK areas). These changes were likely due to water temperatures increasing above the preferred range for Spp in nearshore coastal areas off DMV and above the lower bound of the preferred range in deep offshore waters off NJ and LI.

Presence-absence data for Spp in NEFSC clam survey tows are a sensitive indicator of whether clams exist in an area (Appendix XXI). If clam habitat is defined as areas where clams are present, then statistical analysis and mapping based on presence-absence data can be used to study changes in habitat size over time. Habitat area estimates from presence-absence data amount to estimates of the total area in which Atlantic surfclam are found with almost no adjustment for differences in density or habitat quality. For example, carrying capacity in terms of abundance might change dramatically without changing the total habitat area based on presence-absence data as long as Atlantic surfclam were found on the same grounds in both cases.

Separate modeling analyses were carried out for each region. Only well sampled years and strata were used in the analysis (Table 62, Figure 240 and Appendix XXI). Tows at locations beyond depths where Atlantic surfclam were observed were omitted in each region. The maximum depths used for each region were GBK=75 m, SNE=70 m, LI=60 m, and DMV=55 m.

The proportion of positive tows in each year and area were plotted as a rough check on model based trends (Figure 241). Trends in this simple measure of habitat area are variable or ambiguous for GBK and SNE in the north, increasing for LI Sound and NJ along the middle of the Mid-Atlantic Bight and decreasing off DMV in the south. Three coordinate systems were used to specify the location of survey stations for modeling, including one system that used depth to measure position across shelf. However, only results for latitude and longitude (decimal degrees) are shown because results were similar and because latitude and longitude are easy to visualize.

Seven logistic regression type GAM models (dependent variable 0/1 for presence/absence of Atlantic surfclam, logit link, binomial maximum likelihood) were tested for each region (Table 63). Models with and without year effects were included and there would be evidence of changes in habitat area over time if the best model chosen by AIC included year effects. Preliminary analyses showed that sample sizes were too low to reliably estimate spatial patterns for each year independently. It was therefore necessary to “borrow” data from adjacent surveys by smoothing over years. Thus, all models with year effects included spatial patterns that were the same every year or smoothed over time. Location effects in models were smooth functions with different levels of interaction between latitude and longitude.

Maps and trends in habitat area were made by constructing a "large" grid made up of cells which combined the full range of coordinates across each region (all possible combinations of the cells for each coordinate). Cells for latitude and longitude were about 0.45o on a side. Next, the coordinates of the stations actually sampled (years combined) were gridded in the same way to produce a list of the first and last longitude cell actually sampled along each row of latitude cells. The list was used to omit cells from the large grid outside of the range sampled. The best GAM model was then used to predict the probability of a positive tow across the remaining grid cells. The predictions at each cell were plotted to produce maps (Figures 242-246) .

Trends in total habitat were calculated by summing the predicted probabilities for each year and cell from the best model (Figures 242-246). Habitat area computed in this way is essentially a sum of cell areas weighted by the predicted probability.

The best models for each region and coordinate system included year effects with the exception of DMV where Model 4 (with a two dimensional smooth on latitude and longitude but no year effects) had the lowest AIC indicating insignificant changes in habitat over time (Table 63 and Figure 246). However, Model 5 (with year effects) had nearly the same AIC score (878.1 vs 877.8). We therefore chose to identify Model 4 as the best model and Model 5 as the best model for trends in the DMV region. Spatial patterns in results from the two models with latitude and longitude for DMV were similar.

Trends in habitat area estimates from GAM models (Figures 242-246) were similar to trends in proportion positive tows (Figure 2). Trends for Atlantic surfclam on GBK (where sampling was relatively sporadic) and in SNE were variable. Estimated habitat area increased dramatically in LI after 1986 and steadily in NJ after 1982 based on model estimates. Maps indicate that the increases were due to increasing utilization of offshore areas, probably due to warming (Figures 244-245). The best model for trends in DMV suggests that habitat area declined due to losses in shallow coastal areas (Figure 246).

Table 62: Sample size (number of survey tows) used to measure Atlantic surfclam habitat area.

Region	1982	1983	1984	1986	1989	1992	1994	1999	2002	2005	2008	2011	
GBK				31		48	51	47	40			32	79
SNE	19	34		18	18	21	24	21	19	16		21	30
LI	30	29		29	28	28	32	28	30	29	29	60	52
NJ	86	85		91	99	98	103	112	120	115	92	109	61
DMV	68	61	79	70	78	77	83	82	78	81	72	63	63

Table 63: AIC for models used to predict the probability of a positive tow and estimate habitat area for Atlantic surfclam. Bold font identifies the best model (lowest AIC) for each region. Terms in the formulas for each model (column 2) are "yr" for year as a continuous covariate, "yrf" for year as a categorical factor, "lat" for latitude and "lon" for longitude. The term "s()" is a smooth one- or two dimensional nonlinear spline function of the variables inside the brackets.

ID	Model	GBK	SNE	LI	NJ	DMV
1	s(lon) + s(lat)	625	228	361	760	971
2	s(lon) + s(lat) + yrf	614	223	359	757	974
3	s(lon) + s(lat) + s(yr)	608	221	349	753	966
4	s(lon,lat)	621	210	356	727	877.8
5	s(lon,lat) + yrf	603	201	357	721	878.1
6	s(lon,lat,yr)	625	245	392	910	993
7	s(lon,lat,yr) + yrf	631	124	399	915	1,004

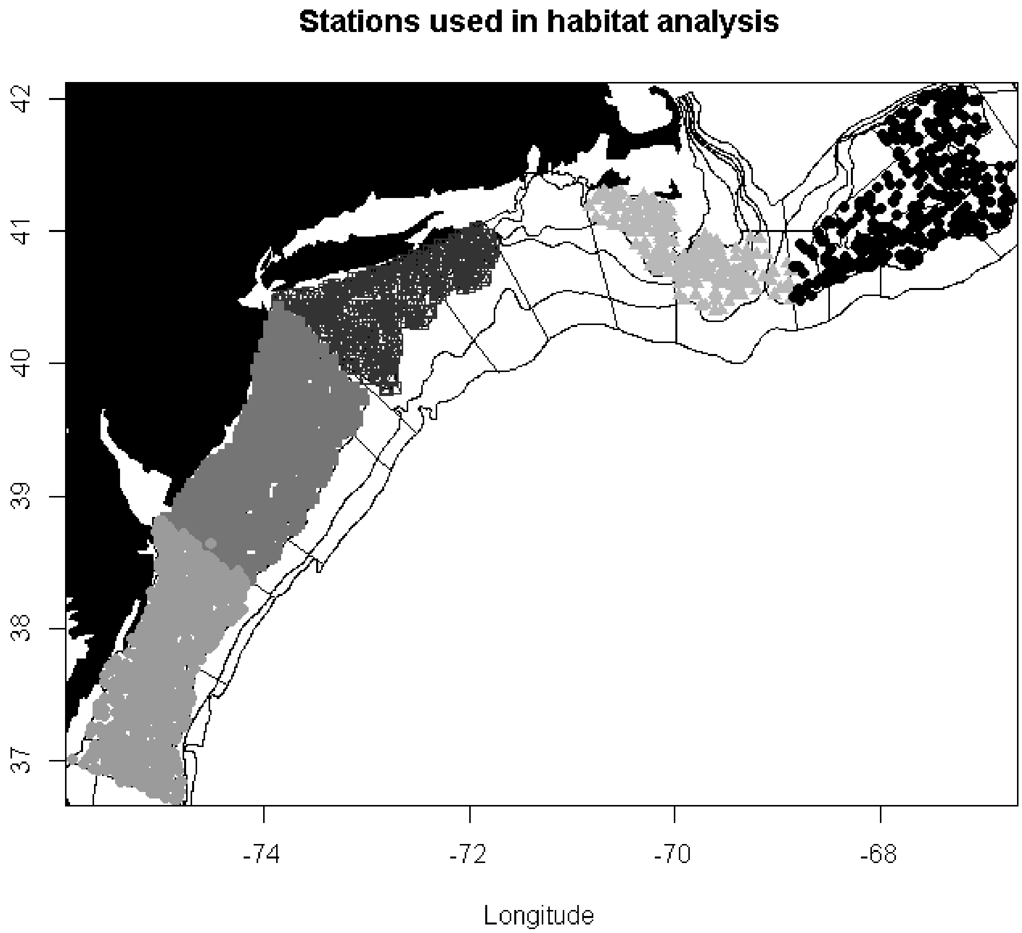


Figure 240: Location of survey stations used to measure Atlantic surfclam habitat area. Regions are identified using shades of grey. The regions from north to south are GBK, SNE, LI, NJ and DMV.

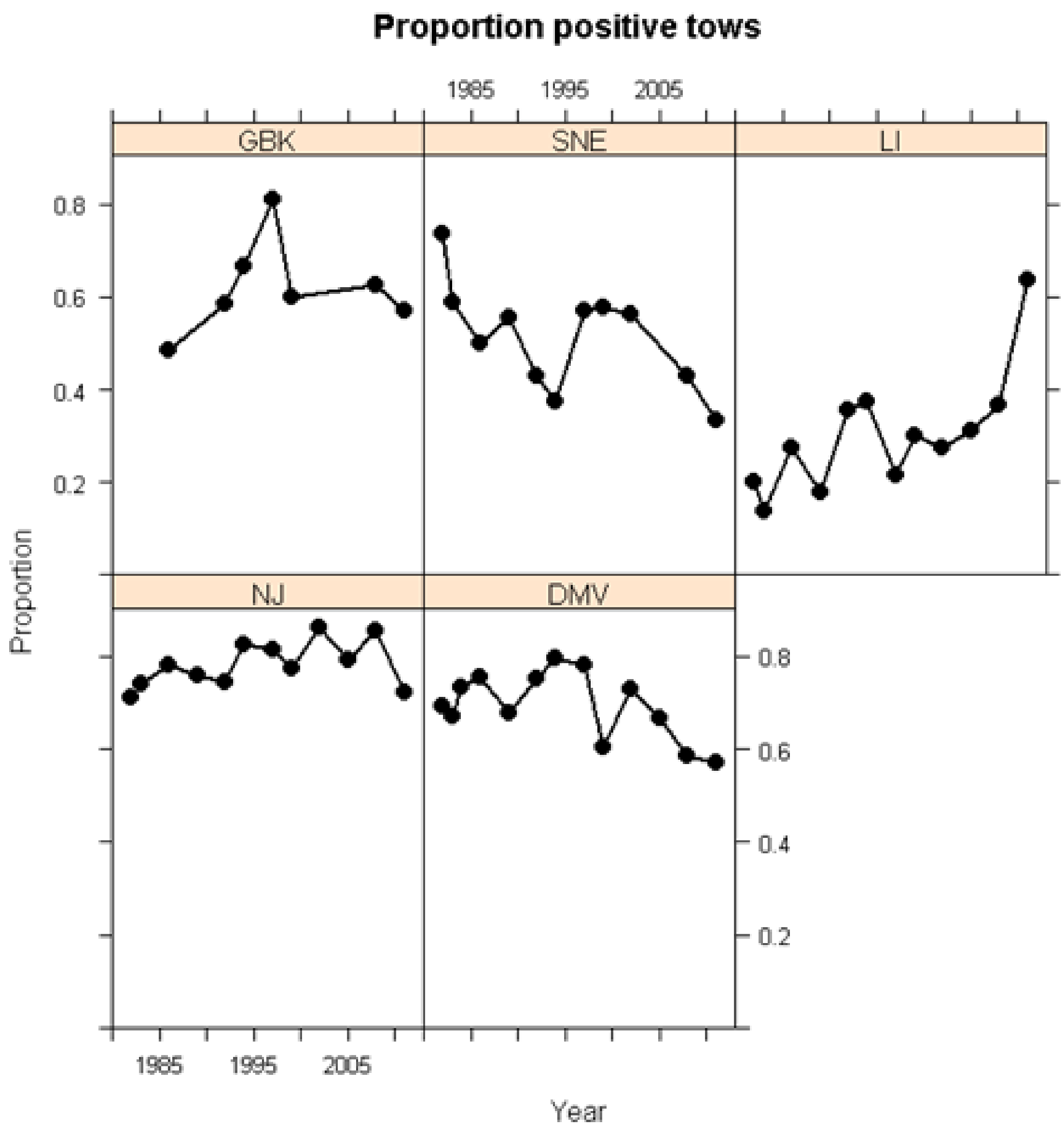


Figure 241: Trends in proportion positive tows based on raw survey data by region.

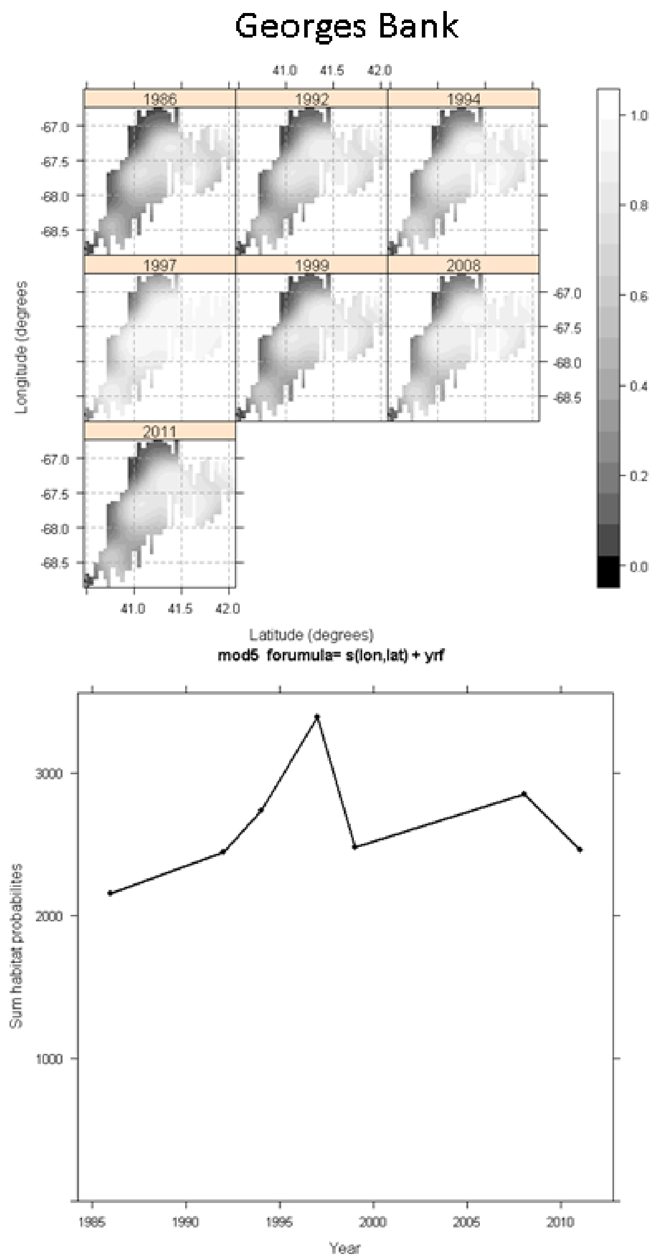


Figure 242: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The "Best for trends" model for DMV is different from the best model based on AIC although the two models had nearly identical AIC scores (see text).

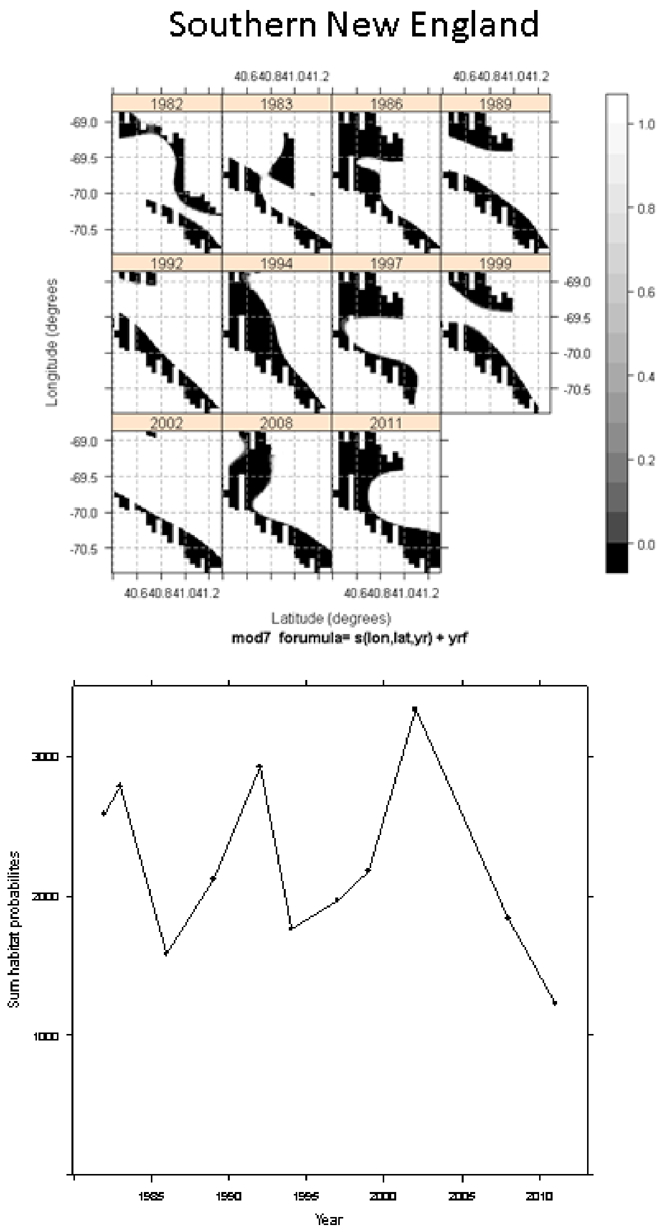


Figure 243: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The "Best for trends" model for DMV is different from the best model based on AIC although the two models had nearly identical AIC scores (see text).

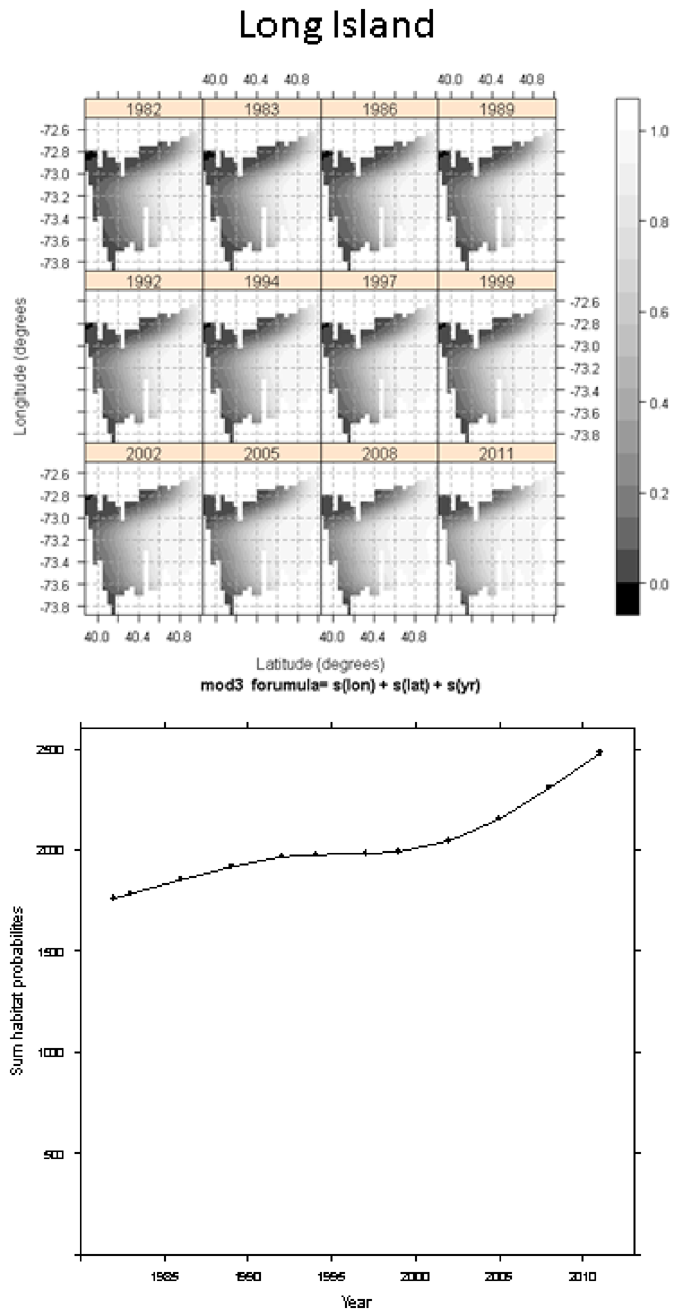


Figure 244: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The "Best for trends" model for DMV is different from the best model based on AIC although the two models had nearly identical AIC scores (see text).

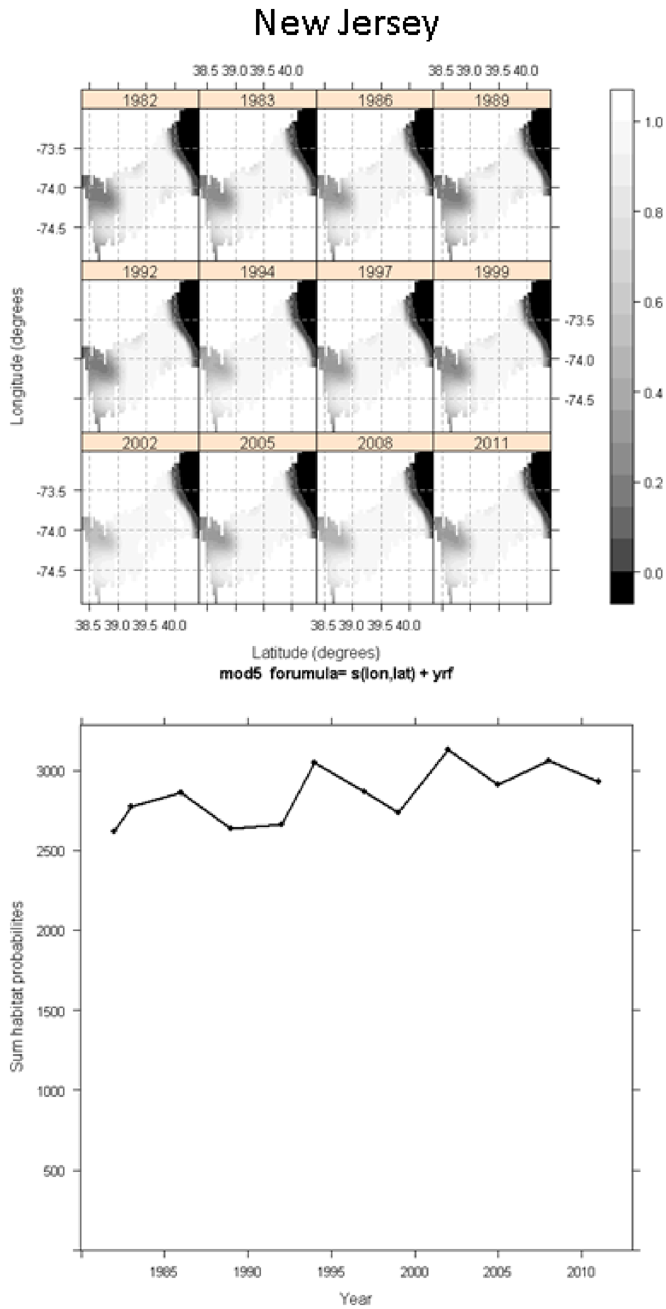
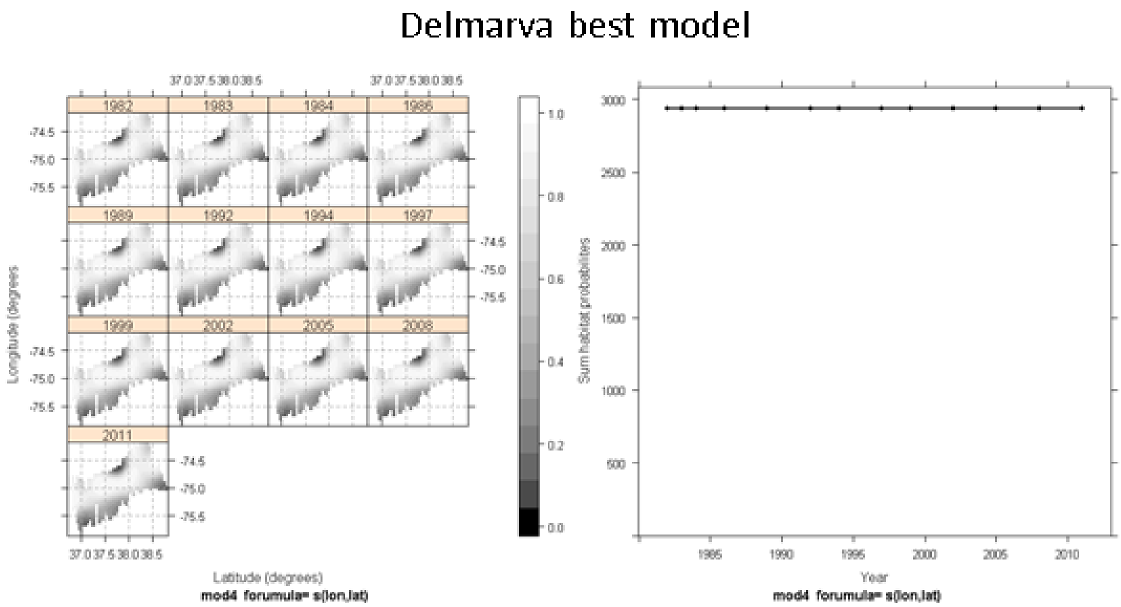


Figure 245: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The "Best for trends" model for DMV is different from the best model based on AIC although the two models had nearly identical AIC scores (see text).



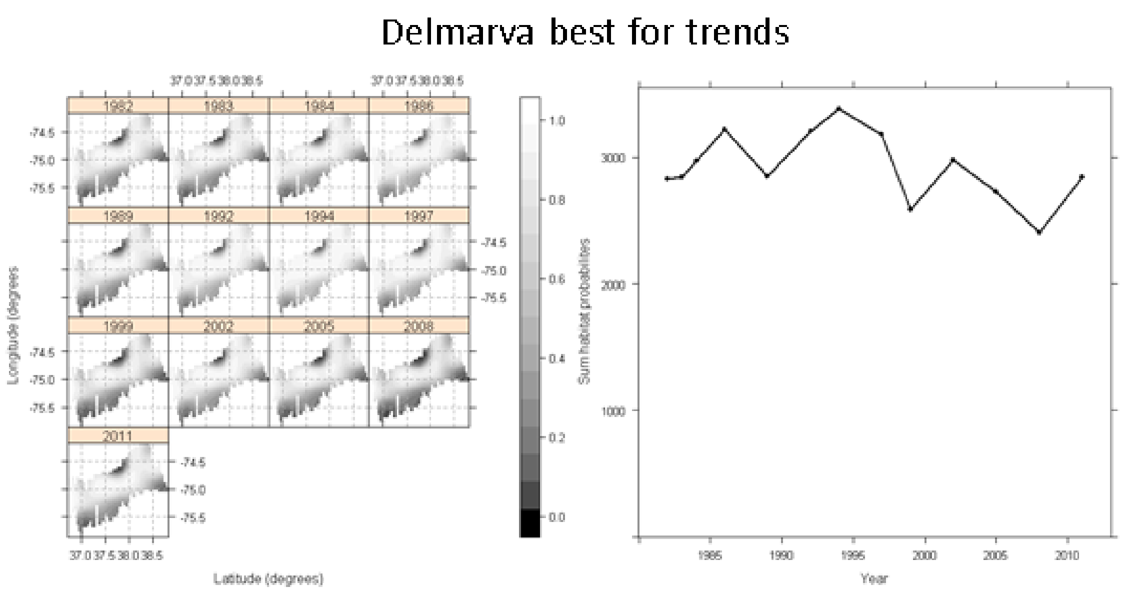


Figure 246: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The “Best for trends” model for DMV is different from the best model based on AIC although the two models had nearly identical AIC scores (see text).

Part XXIV

Appendix: Potential methods for locating and quantifying good Atlantic surfclam habitat and untowable ground/poor Atlantic surfclam habitat on Georges Bank

With the planned redesign of the NEFSC clam survey, the working group spent time discussing how to improve the survey in general and especially on Georges Bank. With Atlantic surfclam vessels now regularly fishing on Georges Bank after a hiatus of many years due to closures for health concerns, it is of renewed importance to estimate biomass as accurately as possible and monitor the affects of the fishery.

Unlike the mid-Atlantic, Georges Bank is a patchwork of sand, gravel, cobble and boulder bottom. This presents a challenge as the sandy areas are considered good Atlantic surfclam habitat, but patches of rough, rocky bottom, considered “untowable” and probably marginal habitat, often occur within the same strata. The new survey design will likely include some restratification of these areas into units of similar bottom. Areas composed of sandy substrate are more likely to contain higher densities of Atlantic surfclam, than areas composed of harder substrate. In order to increase the efficiency of the survey and the accuracy and precision of abundance estimates, good habitat should be sampled more frequently. Restratifying by substrate should result in fewer “untowable” survey stations and a more precise and accurate estimate of abundance, as well as a more targeted and perhaps less expensive survey.

An additional aspect of improving the survey on Georges Bank is determining what overall area is inhabited by Atlantic surfclam, and the fraction that is untowable (and probably poor clam habitat) and should be discounted when estimating swept-area biomass. For instance, if the overall Atlantic surfclam habitat area on Georges Bank is found to be 100 nm2 and there are 20 nm2 of untowable rocky bottom within that area, then the swept-area biomass would be extrapolated to 80% of the overall Atlantic surfclam area for a more accurate estimate.

To demarcate the overall area inhabited by Atlantic surfclam it is desirable to identify the limits of the population on Georges Bank, whether physical (temperature, depth, substrate) or ecological (food, predators, competition for habitat). An indicator of the presence of Atlantic surfclam would also serve to define habitat both in and outside the surveyed areas. Simply mapping survey catches is helpful, but the region analyzed needs to encompass areas outside the current Atlantic surfclam strata set as well, in case there is significant Atlantic surfclam habitat that should be added to the surveyed area. An example of this (although not on Georges Bank) is northern Nantucket shoals (see Part H).

Years of experience surveying the bank with a clam dredge has led to general knowledge of where there are boulder fields, and how to read the ship's depthfinder before a tow and know to move on to a new location. This hit or miss method can waste time and potentially damage equipment. However, detailed maps of the bottom have not been available to actually quantify the number of square miles inhospitable to both Atlantic surfclam and dredges. Today, with constantly improving technology and a new emphasis on habitat, the sea floor on Georges Bank is becoming known in more and more detail. It should be possible to bound the zones of bad bottom and calculate their areas for both restratification and biomass estimation.

In anticipation of the survey redesign the assessment working group reviewed several potential methods of evaluating habitat for the presence of Atlantic surfclam and for the delineation of areas of rough bottom, and they are summarized below. Some methods might work best in conjunction with others, and there will likely be suggestions of other techniques. This work is ongoing, and a formal committee experienced with survey design will be formed to make final decisions on any improvements or changes to the NEFSC clam survey.

Analysis of ancillary survey data for the Georges Shoals and Cultivator Shoals area of Georges Bank[5]

The following is a near-final analysis of ancillary survey data for the region of Georges Bank encompassing Cultivator Shoals and Georges Shoals. The analysis was funded by the NSF I/UCRC Science Center for Marine Fisheries (SCeMFiS). SCeMFiS has also funded a full analysis of Georges Bank. This update will be available some time in September.

Data Resources

Atlantic surfclam and ocean quahog survey data from 1982 to 2014 were obtained from the NMFS-NEFSC assessment database. These data included standardized catch of Atlantic surfclam, haul and gear codes, and, for years after 1999, comments for each tow with a non-zero haul and gear code. Additional information was obtained from survey data sheets for Atlantic surfclam and ocean quahog surveys from 1978 to 1999. All of these data sheets were digitized into PDF documents and the data obtained were entered into excel spreadsheets. Additional data from 2002 to 2014 were obtained from NEFSC survey electronic archives.

Analytical approach

Mapping the locations of various variables was carried out at the scale of an *ESS Pursuit* survey tow. This is a distance of approximately 0.29 minutes of latitude or 0.39 minutes of longitude. Survey tows within this distance apart were considered to be replicates even if taken in different years. In general, the most extreme value amongst replicates was taken for further analysis. Most non-living variables can be considered to be stable constituents over much, if not all, of the entirety

[5]Contributed by: Eric Powell, University of Southern Mississippi

of the survey time series. For shells, for example, taphonomic loss rates are low for Atlantic surfclam and ocean quahog shells and likely to be low for lesser clam constituents. Stability over time would not be the case for live animals, all but one of which has a life span less than the survey time series. These temporally more ephemeral variables should be interpreted to indicate the potential for occupation of a site. Regardless, no temporal variations have been tracked in this analysis.

Haul and Gear Codes

These codes encompass a range of incidents that might have compromised the tow. Generally, these incidents fell into two broad categories: issues associated with the proper functioning of the dredge itself and issues associated with bottom type that might compromise a successful tow. Our focus was on the latter set of incidences. Unfortunately, the haul and gear codes used by NMFS-NEFSC were developed for the trawl survey; thus, an analysis was required to determine how these codes were applied to clam dredge hauls and the degree of consistency in that application across surveys. This analysis relied on annotations for each of these tows in the survey database for the period 2002-2014. Unfortunately, no annotations occur in the survey database prior to 2002. In order to investigate the consistency and meaning of haul and gear codes, the data for 2002-2014 were sorted by haul and gear code combination and comments were examined. A total of nine combinations of haul and gear codes indicated problems with the tows stemming from bottom obstruction (e.g. damage to the dredge or location dropped from the survey after scouting bottom). These tows were consolidated into one of three categories: 1.) locations where "bad bottom" was identified, such that the dredge was not deployed; 2.) locations where dredge damage occurred, including broken nipples, broken or bent knife blades, torn hoses, or damage to the dredge frame; and 3.) locations where rocks were caught by the dredge in sufficient number to be judged to have compromised the tow, but which did not cause significant/any damage to the dredge.

Tows for surveys from 2002-2014 could be assigned to these three categories without qualification. Unfortunately, with a few exceptions, haul and gear codes were not used predictably over the survey time series and often tows influenced by non-bottom-contact events (e.g., clogged pump, power supply issues) were given haul and gear codes also used for bottom contact events. Thus, earlier tows (1982-1999) with haul and gear codes could rarely be assigned to one of the three categories without qualification. However, for essentially all of these tows, annotations were recorded on the original data sheets. Accordingly, the raw data sheets were examined for tows prior to 2002, for which haul and gear comments were missing. Comments recorded on the raw data sheets permitted extraction of tows falling into the 3 afore-mentioned categories, so that the entire survey time series was assembled. Plots of these data identify the locations where each of the three incident types occurred (Figures 247 and 248).

Bycatch data - substrate

The term "bycatch" was used in a general way on the 1978-1999 data sheets to apply to a series of materials obtained in the dredge including substrate, shell, and a selection of live animals. Some species of live animals were not included in the bycatch category. Bycatch data from 1978 to 1999 was present on each digitized data sheet. Electronic data were available in the FSCS database.

Terminology and category were relatively consistent between 1978 and 1982 and essentially identical from 1982 to 2011. Data ceased to be collected at the end of the 2011 survey.

The bycatch data comprise three categories: shell, substrate, and other invertebrates. Information regarding tows where gravel, rocks, cobbles, and boulders were present in the haul was extracted into a common database. The category “cobbles” encompassed anything smaller than six inches and larger than gravel, the size of which, however, was not specified. The category “rocks” encompassed material between six and twelve inches and “boulders” were anything larger than twelve inches. Over the history of the survey, the annotations regarding substrate varied considerably. From 1978 to 1980 substrate data were recorded in either liters or bushels. The survey dredge used during this time period was considerably smaller than the dredge used from 1982 to 2011. Due to the extreme variability of recorded data from 1978 to 1980, presence and predominance values were assigned to the data. A value of 0 indicates an absence of a particular substrate (e.g., cobbles). A value of 1 was given to volumes =1 bushel or where presence was indicated without a volume given (e.g., “trace” was recorded in the place of a numerical value). A value of 2 was given to any volume > 1 bushel.

From 1982 to 1999 substrate data were recorded on the data sheet in terms of check marks (1 check for present and 2 checks for predominant) and categories include gravel as well as finer-grained substrates such as sand, mud, and clay; however, these substrate types are not further defined. The categories “cobble”, “rock”, and “boulder” were defined by the same sizes as used on the 1978-1980 data sheets. The survey dredge for this time period was larger than the dredge used from 1978 to 1980. Volume of bycatch was routinely recorded, as was the percent composition of the various components. In order to provide more quantitative and consistent values for substrate, the total volume of substrate in bushels was calculated for each tow for the period 1982 to 1999 from the percent of total volume. The total substrate volume was then divided equally by the sum of presence and predominance values (i.e. number of checks) in order to estimate a number of bushels of gravel, cobble, rocks, and boulders. For instances where the percent composition for substrate or total bycatch volume was not recorded, the data were entered as presence and predominance values (i.e. number of checks seen on datasheet) because a total substrate volume could not be calculated. These instances were relatively rare, however. In most cases, a volumetric estimate could be made. The data were then coded as 0 for absence or < 1 bushel, 1 where the volume of a particular category was < 30 bushels, and 2 where the volume was =30 bushels. For 2002-2011, the data were entered into FSCS as 0, 1, or 2. Substrate volumes were given in bushels (2002) or liters (post-2002) and percent composition was recorded in each case. An assumption was made initially that the criteria for presence and predominance were consistent across the transition from data sheets to FSCS files. However, subsequent statistical analysis showed that the substrate volumes recorded in the FSCS database were consistently lower per tow than those values on the pre-2002 data sheets, by a factor of 10. Further investigation, including interviews with people who participated in the survey across the 1999-2002 transition, did not elucidate an explanation for the differential, but evaluation across a series of surveys showed that the differential coincided with the transition from data sheet to FSCS files and that the differential was relatively consistent forwards and backwards in time from that point. To standardize the data, the FSCS substrate volumes were increased by a factor of 10.

The divisions at 0 and 1 bushel and 29 and 30 bushels used to distinguish absent, present, and predominant were obtained by examining the FSCS data from 2002-2011 where the tows for the entire survey could be analyzed as they were already in electronic format . The median and 75th percentile for all tows was 0 (no substrate larger than gravel collected) for these tows. That is, cobbles, rocks, and boulders were rarely encountered by the survey. The value of 30 fell between the 95th and 99th percentiles of all tows for these substrate types. The value 1 fell at or above the 90th percentile of all tows for these substrate types. Thus, we include as present all tows where at least one bushel of material was obtained and list as predominant the rare tows where 30 or more bushels were obtained. (See Figures 249 and 250).

Bycatch data - shell and miscellaneous invertebrates

For shell and other invertebrates, abundance data were entered as presence and predominance values. This information was also recorded by check marks on the pre-2002 data sheets. Abundance of shell was recorded in either liters or bushels from 1978 to 1980. Presence and predominance values were then assigned where 0 indicated absence, 1 indicated presence of =50% of the total shell volume, and 2 indicated presence of > 50% of the total shell volume. From 1982 to 1999, each of the shell types of concern were listed separately and given presence and predominance values seen as checks on the datasheets. For 2002-2011, the data were entered into FSCS as 0, 1, or 2. An assumption was made that the criteria for presence and predominance were consistent across the transition from data sheets to FSCS files. Interviews of survey personnel were confirmatory.

Generally, shell volume as a percentage of total bycatch was recorded for each tow. The afore-described analysis for substrate could be recapitulated for shell. However, our approach was to focus on the relative importance of shell types at each location rather than comparing the absolute quantity across all tows; thus, we relied on the number of check marks to assign values of 0, 1, and 2 for absent, present, and predominant within-tow. Shells of a series of miscellaneous clams were tracked (e.g. Astarte, Pitar). For presentation, we took the maximum value amongst these species (0, 1, 2) and assigned that to the "Clam shell" category.

The four species selected from the "Other Invertebrates" category are epibionts that indicate presence of substrate that is of a size that might be colonized (i.e. anything gravel sized or larger). These four were sponges, tunicates, anemones, and barnacles. Specific species are not identified on the data sheets. As with the shells, a volumetric conversion is present for most tows; however, our focus once again was on real presence and a within-tow evaluation of predominance. Thus, values are assigned based on check marks as 1 for present and 2 for predominant within-tow. A value for total bionts was calculated as the sum of the four values. See Figures 251, 252, 253, 254.

Species data - live animals

The numbers per tow for a suite of clams, asteroids, crabs, and gastropods were also recorded by survey species code. For 1978 to 1999, data were recorded and entered into a common database as the number of individuals. For 2002 to 2011, data regarding the number of individuals were obtained from the NMFS-NEFSC survey database. The number of individuals of asteroid species, spider crabs and hermit crabs, and gastropods were placed in three bins and data were entered as the sum of individuals from each of the three categories. Placopecten and Modiolus were retained as separate species. Total numbers per category were converted into a qualitative scale of 0, 1, 2, and 3 using 0 for absent, 1-2 for 1 (present), 3-10 for 2 (some), and > 10 for 3 (many).

Interpretation Relative to Re-stratification

Re-stratification of Georges Bank focuses on the need to limit the survey abundance estimates to areas inhabited by Atlantic surfclam and to limit the incidence of dredge damage on the bottom. The following are likely to be of most importance in assigning specific locations to a Atlantic surfclam and non-Atlantic surfclam stratum, wherein we use the term "non-Atlantic surfclam" to indicate areas where Atlantic surfclam are likely to be uncommon or where the catch of Atlantic surfclam with routine efficiency by the dredge is compromised.

1. The haul and gear code analysis has generated a comprehensive and consistent database establishing four bottom types.
a. No haul and gear code indicates a substrate potentially habitable by Atlantic surfclam (or ocean quahogs).
b. Untowable bottom or locations where gear damage occurred indicate regions of potentially complex habitat that very likely either do not harbor Atlantic surfclam or for which abundances are low due to the presence of substrate types that preclude Atlantic surfclam (e.g., boulders). In addition, continuing to sample these location risks dredge damage. However, these locations are spotty, that is, patches of sand clearly containing Atlantic surfclam exist within e.g., boulder fields.
c. The retention of many rocks in the dredge is a common occurrence and may permit allocation of the site to a non-Atlantic surfclam stratum.

2. Of the live animals recorded, the one that may provide additional guidance is the horse mussel Modiolus. It is unlikely that horse mussels are found in areas harboring large numbers of Atlantic surfclam. Thus, the large catches of horse mussels might provide additional assignment of sites to a non-Atlantic surfclam stratum.

3. The absence of abundant Atlantic surfclam shells may also indicate locations assignable to a non-Atlantic surfclam stratum.

4. Perusal of the plots of these variables shows that low abundance of Atlantic surfclam, presence of tows with haul and gear codes, presence of tows with high catches of rocks and boulders, and locations where horse mussel catches were high are not randomly distributed. Rather, there is a strong tendency for all of these tow types to group together, and this grouping might provide the basis for re-stratification.

One suggestion is that the survey database might be used to compare Atlantic surfclam catches in tows with few Atlantic surfclam shells, high catches of rocks or boulders, high mussel catches, and non-zero haul and gear codes to tows without any of these four conditions to see if Atlantic surfclam are differentially abundant in these two tow types. A consideration is that dredge efficiency is also likely to differ between these two groups of tows, but, of course, this would be true regardless of how the "non-Atlantic surfclam" locations are incorporated into strata. If a similar analysis for the entirety of Georges Bank continues to demonstrate some coherency in the location of indicators of habitat conducive to and disfavoring the presence of abundant Atlantic surfclam, then strata might be defined thusly and a biased allocation of tows to the Atlantic surfclam stratum might be considered.

For the Georges Shoals/Cultivator Shoals plots provided, the domain which encompasses the area as shown contains 206 survey tow cells (defined by the length of an F/V Pursuit tow) of which 71 recovered some combination of predominant catches of horse mussels, cobbles, rocks, or boulders, or for which gear damage occurred. Reducing the cell size to the length of an R/V Delaware II tow modestly increases both counts (210 and 74, respectively) as a few "replicates" occur in the database. Replicates are tows taken at the same or nearly the same location as defined by the cell size. Accordingly, 34.5% of the tows occurred in potentially complex habitat.

Using split-beam multi-frequency acoustic data to calculate hardness, roughness and slope of the bottom to help determine the extent of untowable areas on Georges Bank

This is data which could be used in conjunction with optical information to map the size and shape of boulder fields and allow them to be measured more precisely.

Michael Martin, NEFSC: Split-beam multi-frequency data from NOAA ships is used to estimate the hardness, roughness and slope of the seafloor in the Gulf of Maine and Georges Bank using interferometric techniques. Split-beam tranducers allow the user to infer the direction from which the sound reflected from the seafloor is returning. This information, when used with the estimated range, allows the slope of the seafloor over the ensonified area to be estimated. As the slope increases, less reflected sound energy is returned from the seafloor. The properties of the reflected sound returned from the bottom also allow inference about the hardness and roughness of the bottom as different seafloor sediments exhibit differential properties when interacting with sound waves at different frequencies (see Figures 255 and 256 for examples of the plotted data). Depth of the water will affect the interaction as more area is ensonified, so the same level of response does not necessarily mean the same kind of bottom. Up to 5 frequencies (18, 38, 70, 120, 200 Khz) are available aboard the latest class of NOAA ships. The data examined were collected on the FRVs Bigelow, Delaware II, and Pisces between 2007 and 2015.

It is hoped that these estimates can be used to help with stratification issues in both the Georges Bank clam survey and the Gulf of Maine longline survey. This data set is attractive for this purpose because of its geographical extent, which covers all the areas of interest. Approximately 4 million records were generated over these areas. Acoustic noise or interference was a prominent feature of much of the data and prevented estimation in approximately 25% of cases.

The next step is to perform quality assurance checks, and attempt to ground truth this information using other data sources. Here some of the optical or bad tow data we have could help to verify the acoustic data (it is not always possible to determine the bottom type from acoustic data only) while the acoustic data could help determine the size of particular patches of boulders and rough ground since a similar signal at similar depth usually indicates the same bottom type.

Using HabCam to provide optical information on the extent of untowable ground

The HabCam (Habitat Characterization Camera System) is an underwater system that (among other things) takes high-resolution photographs of the ocean floor as it is towed behind a survey ship. The vehicle flies close to the bottom and photographs an area approximately a meter wide at a rate that allows the individual photographs to overlap and create an unbroken photographic record of what the ship has passed over. The images yield a wealth of fish, invertebrate and substrate data. The images are currently processed by people but the goal is to have an automated system be able to pick out features such as scallops independently. The HabCam has been deployed as part of the NEFSC scallop survey on Georges Bank for several years (Figure 257).

As can be seen in Figure 257, there are HabCam data from Atlantic surfclam habitat on Georges Bank which could provide information on the size and shape of the untowable areas within the overall Atlantic surfclam habitat. Some of the images have already been processed and substrate information has been recorded. If one image is found that contains rough bottom, then surrounding images can be viewed to measure the width of the feature in the direction of travel of the HabCam.

Using HabCam data to create a Habitat Suitability model

Expecting content from: Scott Gallagher, WHOI

HabCam data can also be used to model the extent of Atlantic surfclam habitat based on substrate characteristics and other variables measured by the HabCam such as depth and temperature. Known as a Habitat Suitability Model, it uses the presence or absence of the target organism under certain conditions to predict the extent of the population. The model has been used for other species and has potential to help define suitable habitat for Atlantic surfclam on Georges Bank.

Using surficial sediment data from Harris and Stokesbury (2010) to locate untowable ground

Using underwater video camera data collected during numerous different surveys over 11 years, Harris and Stokesbury created composite substrate maps of all of Georges Bank, which they published in 2010 (see reference below for details of methods). The maps use sediment size and dominance characteristics determined from video footage taken by a camera facing down from the peak of a pyramid-shaped frame. The frame rests on the bottom as the video records movement of fish and invertebrates as well as sediment type. Maximum sediment size, dominant sediment type, average coarseness (mean size of types present) and sediment heterogeneity data were collected at each station. Data from each station were interpolated onto a 1 km grid and Figure 258 shows a resulting map of maximum size sediment (GIS files to make this map can be found with the electronic version of the Harris and Stokesbury paper).

The positive Atlantic surfclam tows overlaid on the sediment map show the need to enlarge the figure and look to see if there is a relationship between predicted sediment size and Atlantic surfclam catch or if the map is too low resolution to catch the untowable areas, which is helpful in itself for determining scale (Figure 259). However, if the areas with large boulders that are not available to the survey are located, and together with another source of optical data, a more precise extent of the boulder areas may be calculated, and the resulting areas discounted, from the Atlantic surfclam survey total swept area.

Harris, B. P. and Stokesbury, K. D. E. 2010. The spatial structure of local surficial sediment characteristics on Georges Bank, USA. Continental Shelf Research 30:1840-1853.

Using presence of dead shell to delineate habitat

We used NEFSC scallop survey data from 2010 through 2015 to map areas where dead shell has collected to see if that would be a marker for the presence of the live Atlantic surfclam or ocean quahogs. The scallop dredge often retains shell substrate, and the type and estimated amount of dead shell is recorded in the station log. It is not an exact measure: the total volume of trash (non-living matter brought up in the tow) is recorded, then an estimated percent of the volume comprising shell is made, and finally which species of shell were present and which species was dominant are noted. We found stations where Atlantic surfclam, ocean quahog or scallop (scallop just for comparison of distribution) shell was present, then estimated a rough volume by multiplying the total amount of trash by the proportion that was shell, then assuming the species marked "dominant" was 50% of the shell volume and any other species present were 25%. We mapped where shells of the three species were found over where the live animals were found, and the results can be seen in Figures 262 - 262. The maps of the three species of dead shell looked very similar and did not appear to designate where the species were, but instead where shell was concentrated by oceanographic processes. However, the estimation of shell volume by species was not very accurate and it may be worth another look at the trash data in more detail.

Using oceanographic data to delineate the extent of Atlantic surfclam habitat on Georges Bank

Temperature and salinity data from the NEFSC oceanography database were plotted with positive tows for Atlantic surfclam and ocean quahogs. The database contains all the CTD results from NOAA ships and NOAA cruises over many years. All the bottom temperature and bottom salinity data points (elevation less than 10 m) from 2011-2015 available for the month of April (representing the usual thermal minimum) and the months of September and October combined (representing the usual thermal maximum) were plotted on separate maps. Much of Georges Bank is known as a well-mixed, dynamic system, but there were gradients evident between different parts. Salinity was lower and temperature was higher on top of the Bank (in the shallower areas) at both times of year (Figures 263 - 266). Temperature and salinity were plotted using two colors to show the pattern.

With some additional data from other times of year and analysis of more specific temperature ranges, we may be able to plot isotherms that bound the Atlantic surfclam area on the bank and provide support for a designated Atlantic surfclam habitat area. Temperature is well known to limit populations, and with evidence Atlantic surfclam are moving into deeper waters in the MAB we understand it plays a role in the distribution of Atlantic surfclam and ocean quahogs. For instance, it looks like ocean quahogs on Georges Bank are limited by temperature maxima exceeding $\sim 16^o$ C (Figure 266), which is not new information, but supports the existence of the pattern on Georges Bank.

Increasing the footprint of the NEFSC clam survey to cover more of Nantucket shoals

Nantucket Shoals is an area not completely covered by the NEFSC clam survey that is densely populated with Atlantic surfclam, and supports a productive local Atlantic surfclam fishery (Figure 267). As part of the survey redesign, it has been suggested that there be an additional stratum added here to fill in the gap in the survey. How this will be accomplished and folded into the survey time series is yet to be determined, but areas where Atlantic surfclam fishing occur are not always stable over time and there should be a mechanism in place, or at least a process, to add new ground to the survey.

Figures

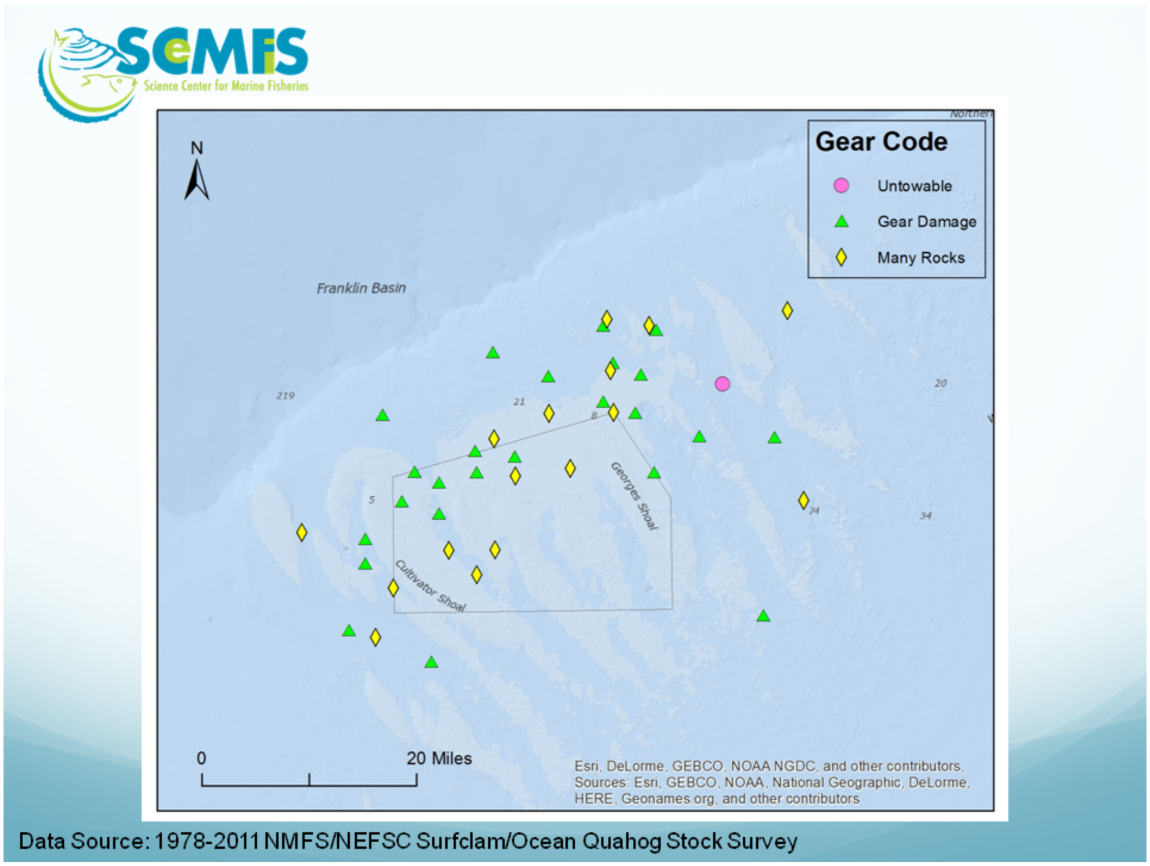


Figure 247: Locations on Georges Shoal and Cultivator Shoal (on Georges Bank) where gear codes or station comments from the NEFSC clam survey indicated untowble or rough ground.

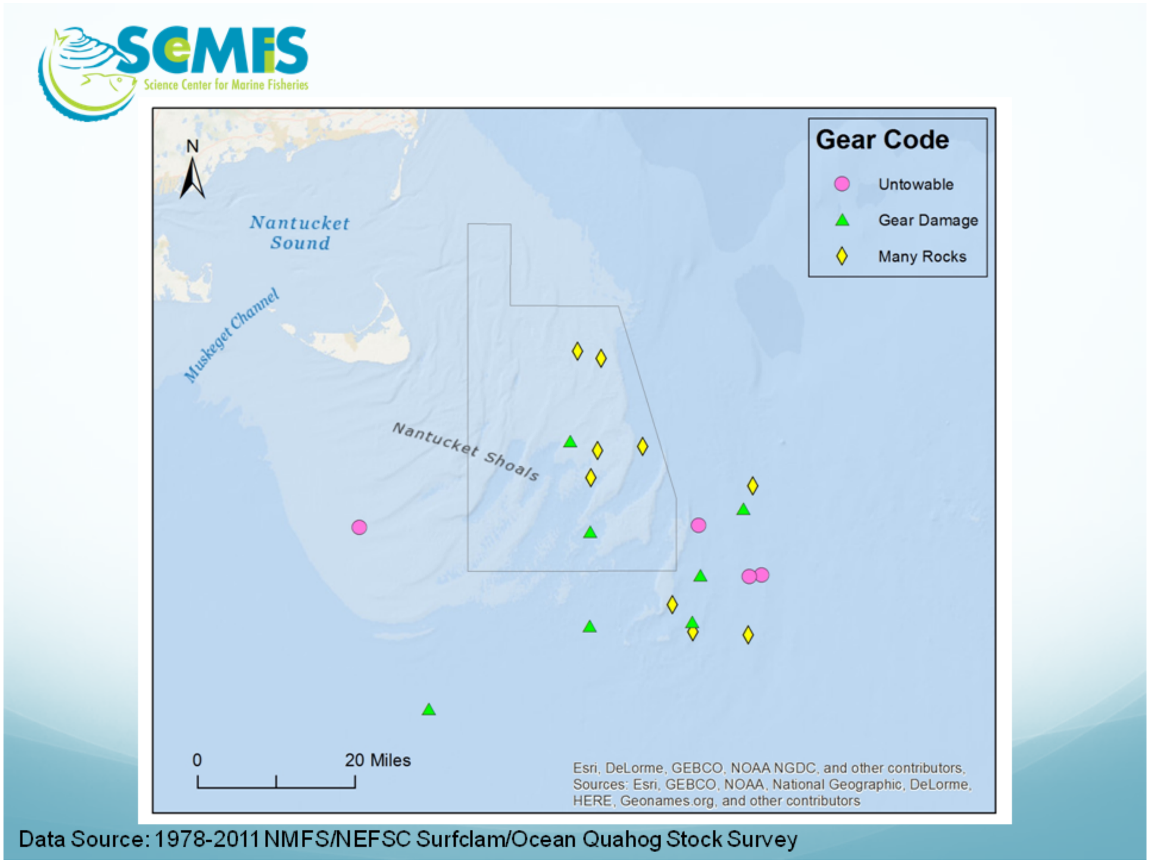


Figure 248: Locations on Nantucket Shoals where gear codes or station comments from the NEFSC clam survey indicated untowble or rough ground.

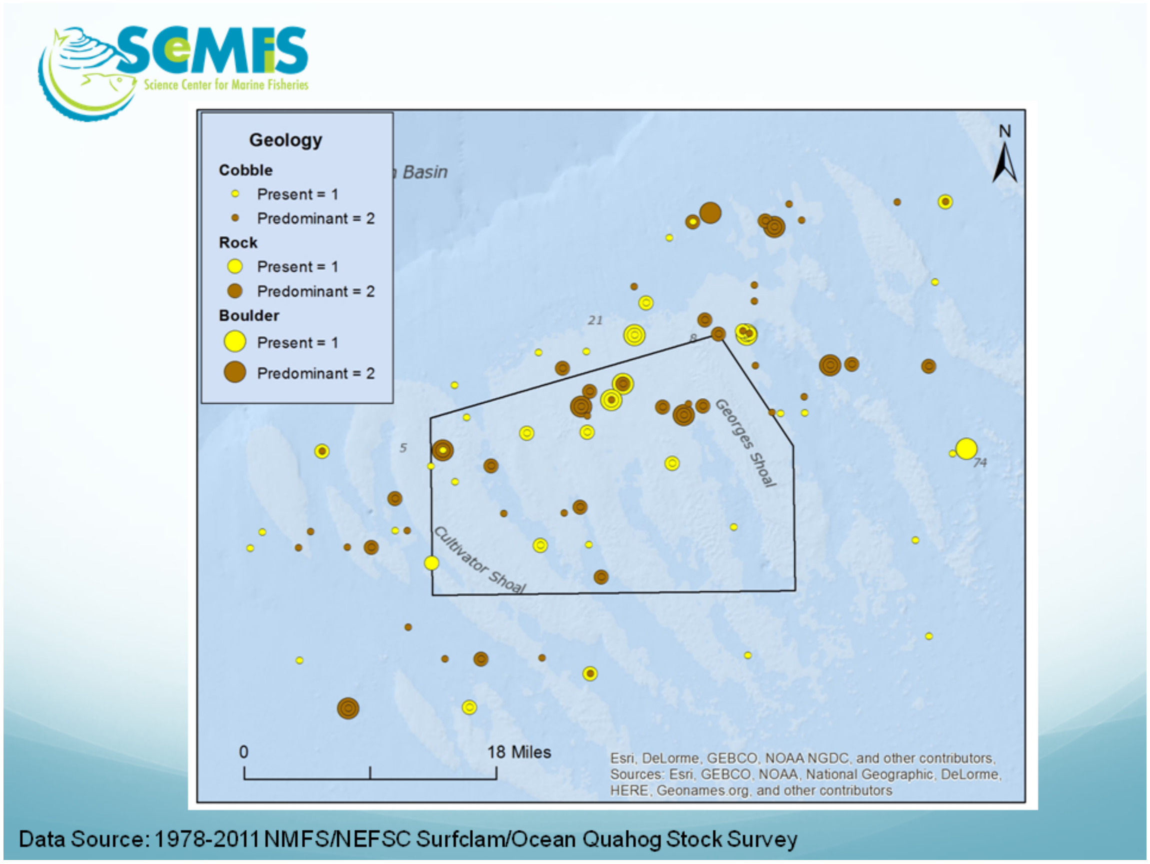


Figure 249: Locations where substrate bycatch data from the NEFSC clam survey included cobbles, rocks and boulders on Georges Shoal and Cultivator Shoal on Georges Bank.

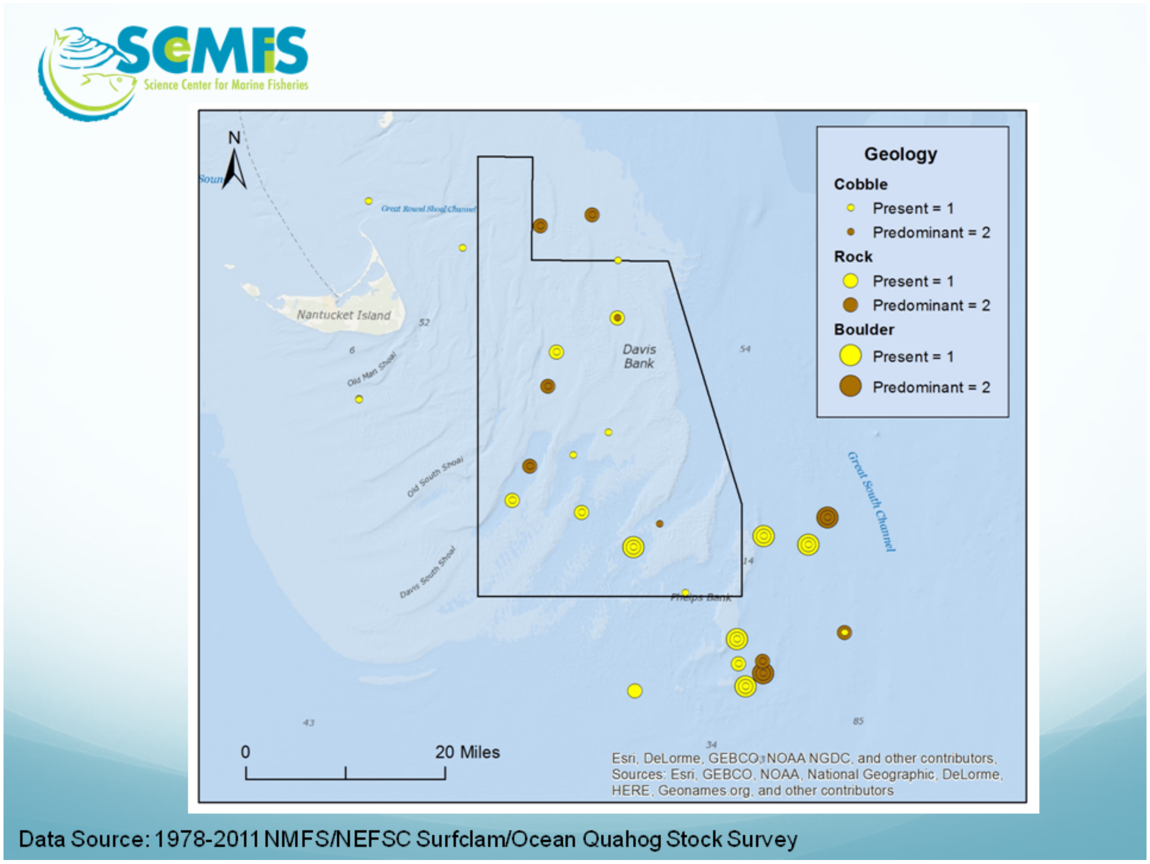


Figure 250: Locations where substrate bycatch data from the NEFSC clam survey included cobbles, rocks and boulders on Nantucket Shoals.

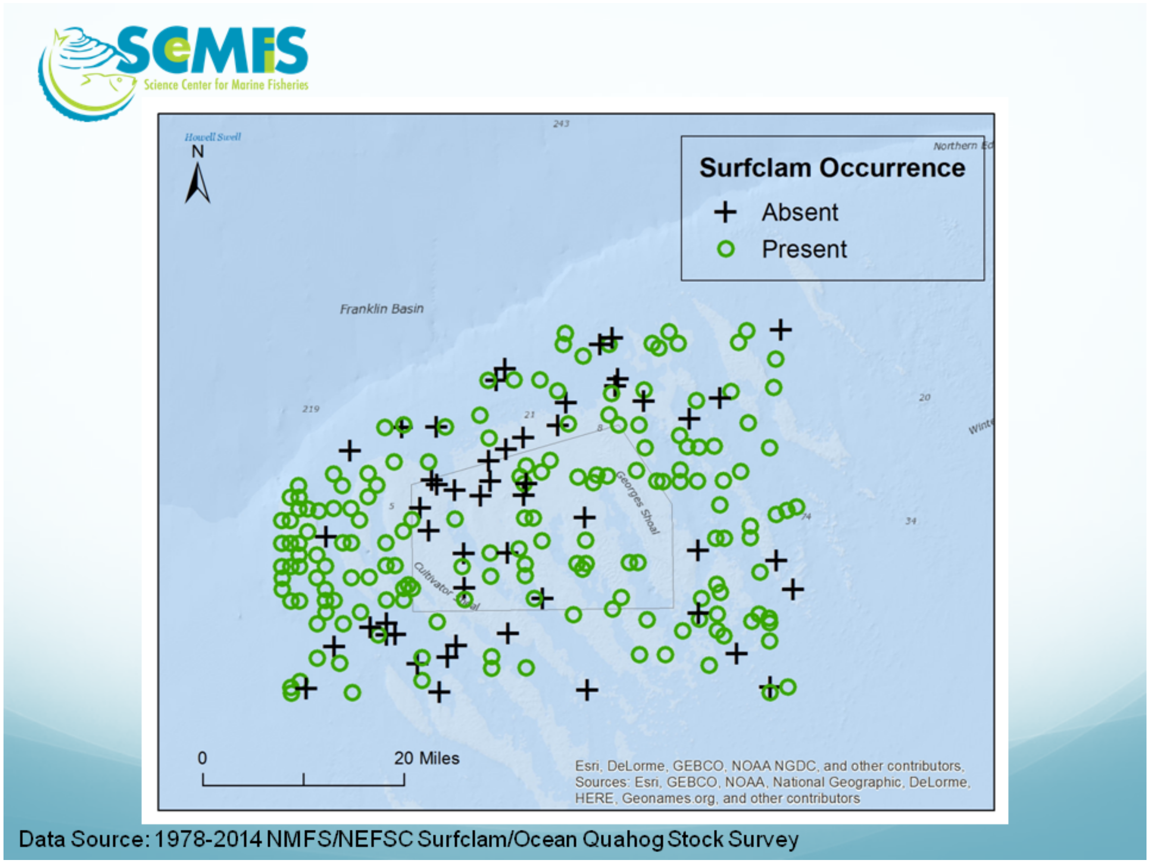


Figure 251: Locations where NEFSC clam survey tow results indicated the presence or absence of live Atlantic surfclam on Georges Shoal and Cultivator Shoal on Georges Bank.

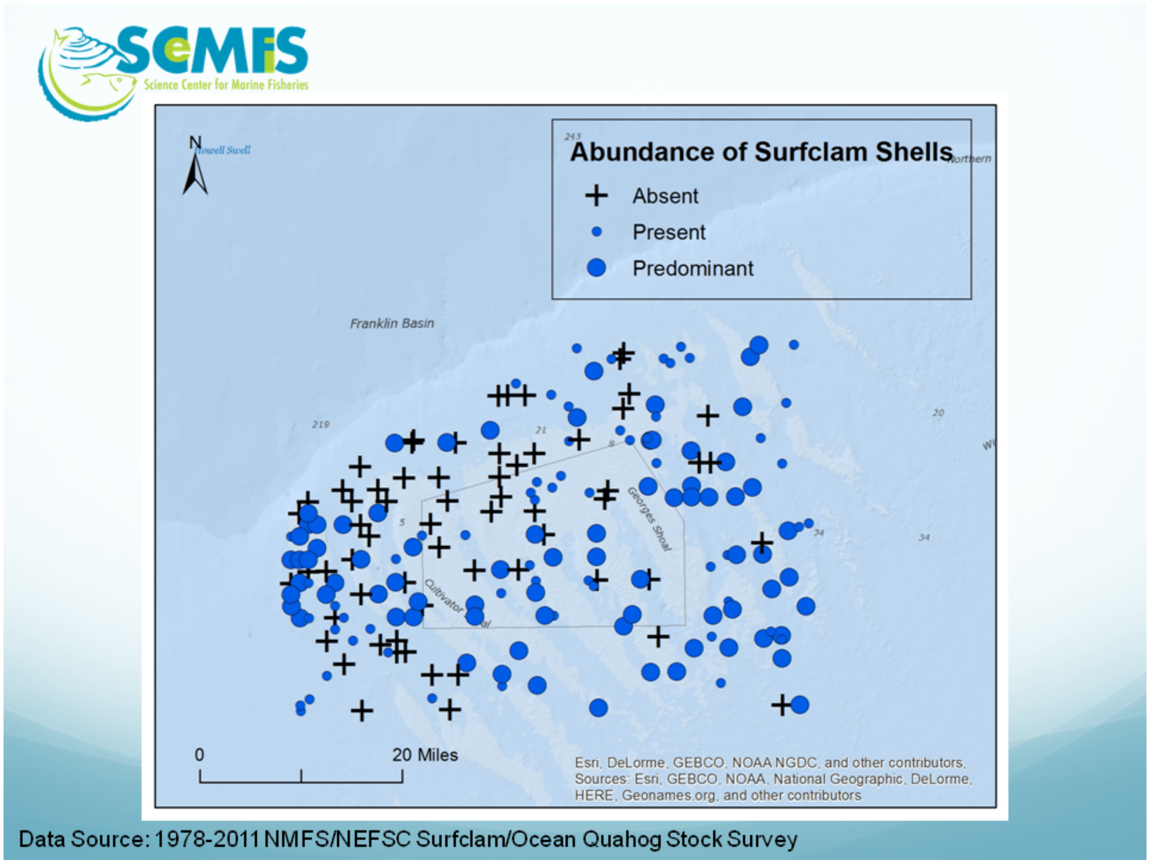


Figure 252: Locations where NEFSC clam survey bycatch data indicated the presence, dominance or absence of Atlantic surfclam dead shell on Georges Shoal and Cultivator Shoal on Georges Bank.

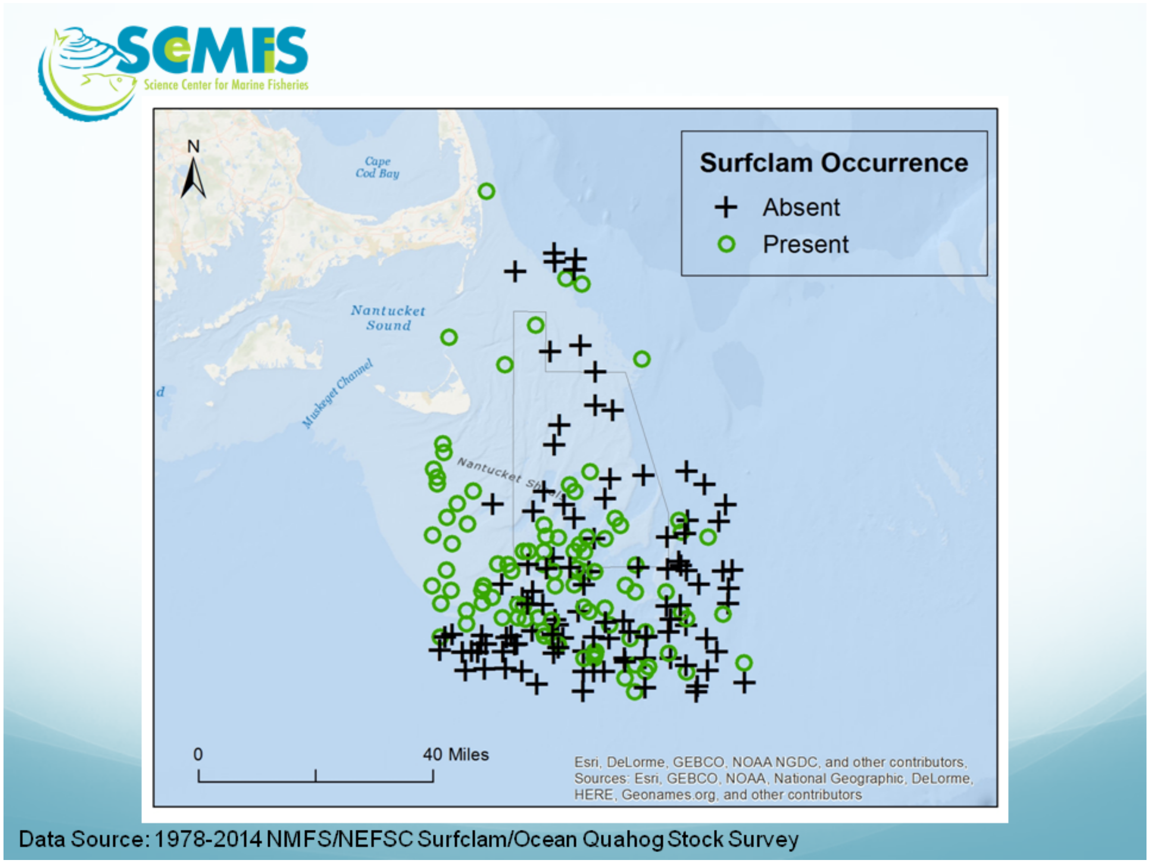


Figure 253: Locations where NEFSC clam survey tow results indicated the presence or absence of live Atlantic surfclam on Nantucket Shoals.

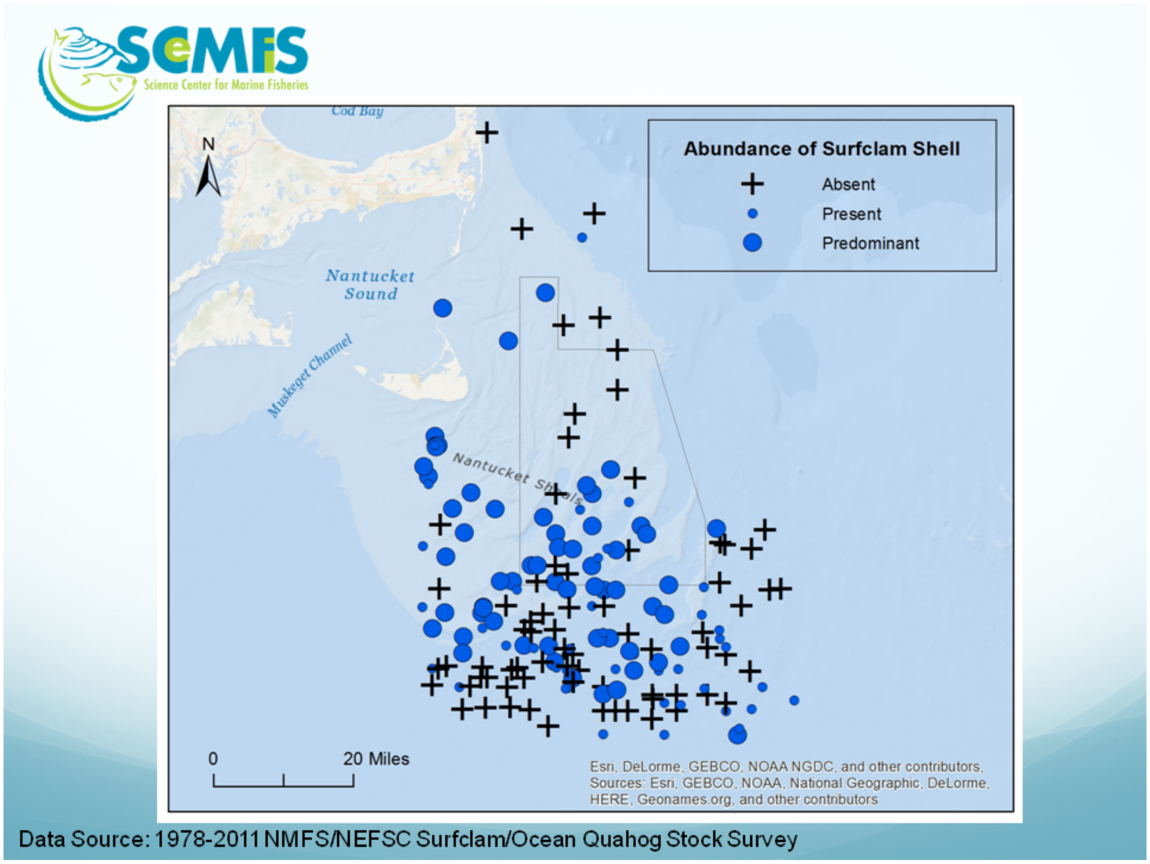


Figure 254: Locations where NEFSC clam survey bycatch data indicated the presence, dominance or absence of Atlantic surfclam dead shell on Nantucket Shoals.

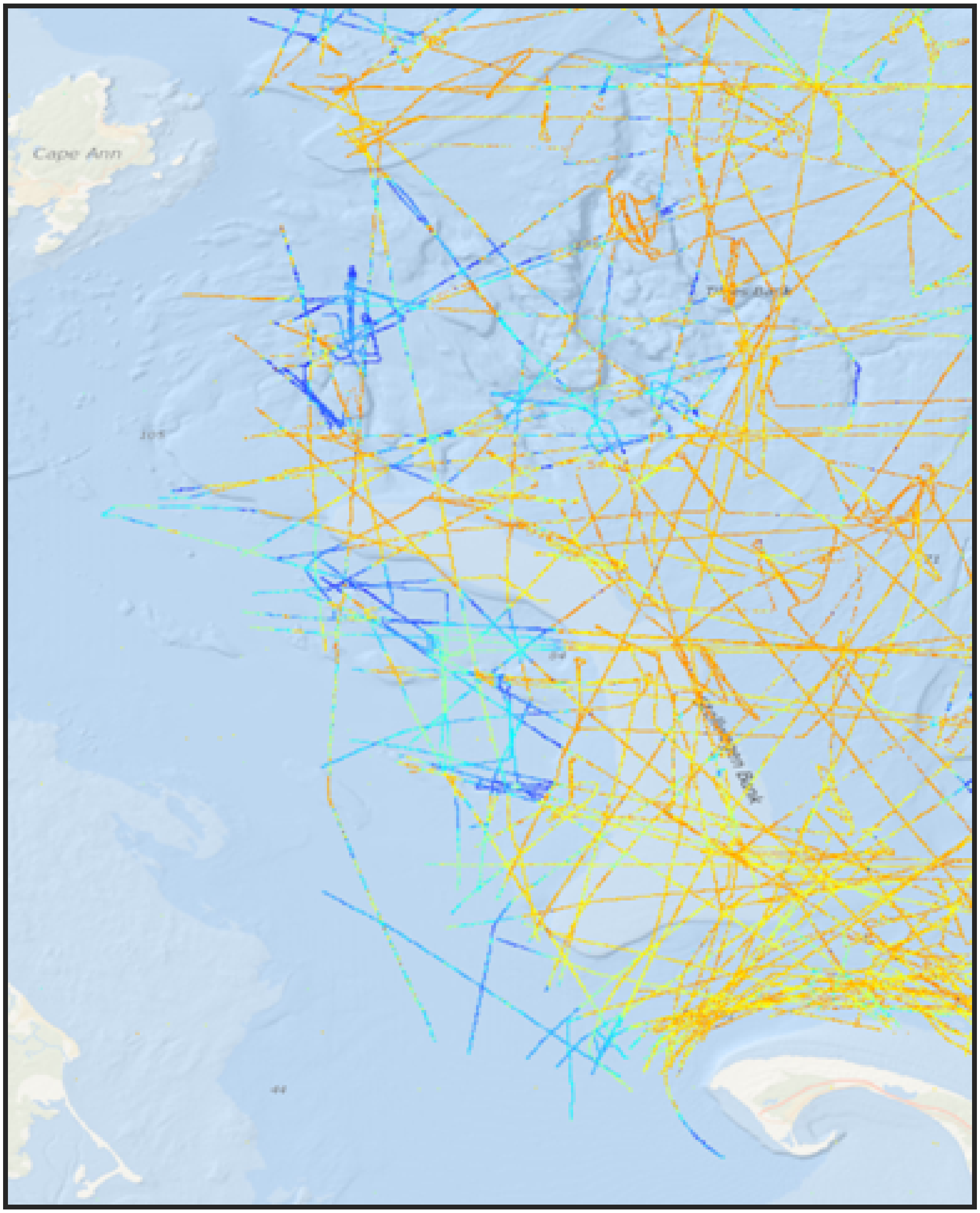


Figure 255: Hardness in the western Gulf of Maine estimated from mutlifrequency acoustic data collected along the tracks of NOAA ships. The data are displayed on a blue to red scale where redder colors are harder and bluer colors are less hard.

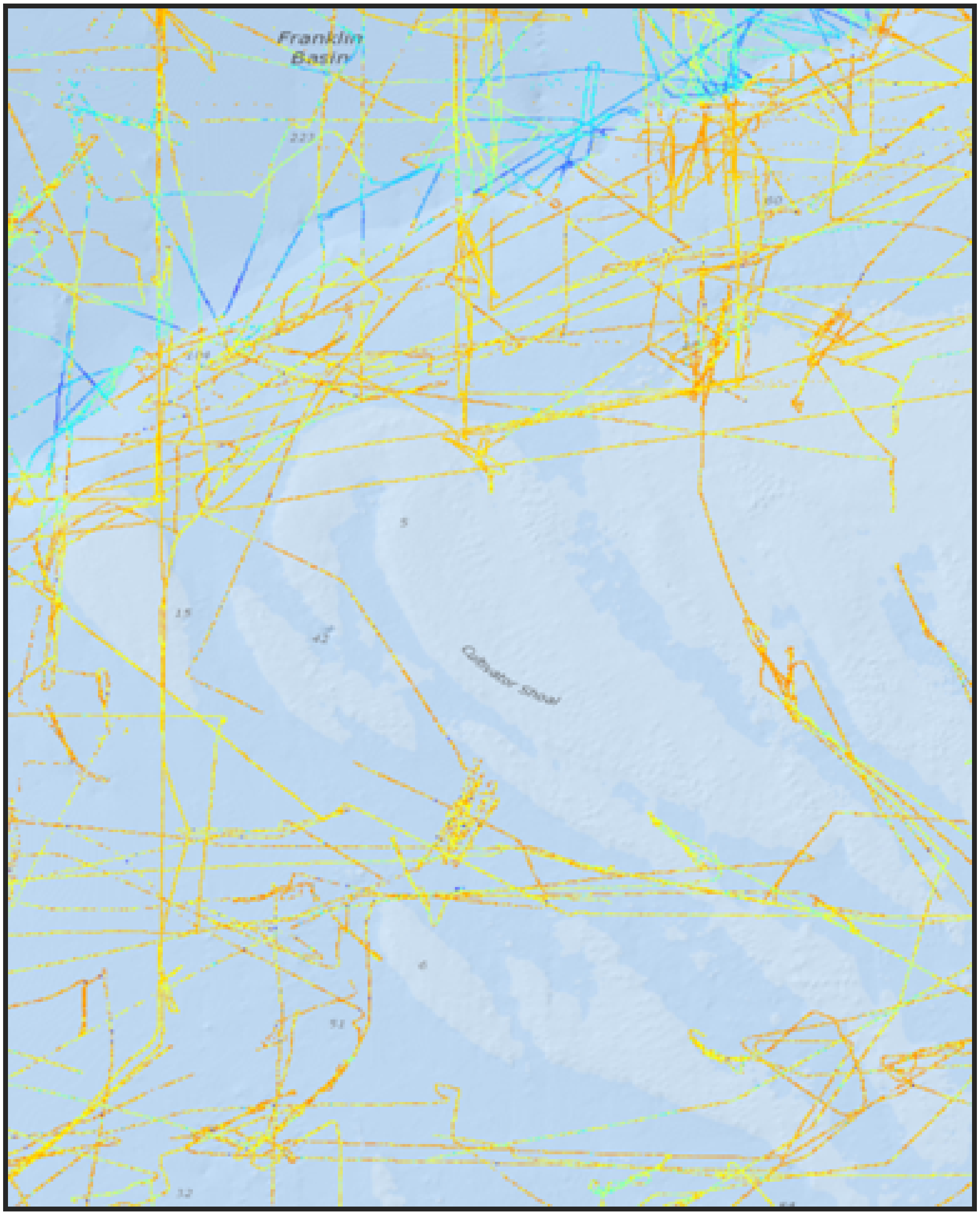


Figure 256: Hardness on Cultivator shoals, Georges Bank as estimated from mutlifrequency acoustic data collected along the tracks of NOAA ships. The data are displayed on a blue to red scale where redder colors are harder and bluer colors are less hard.

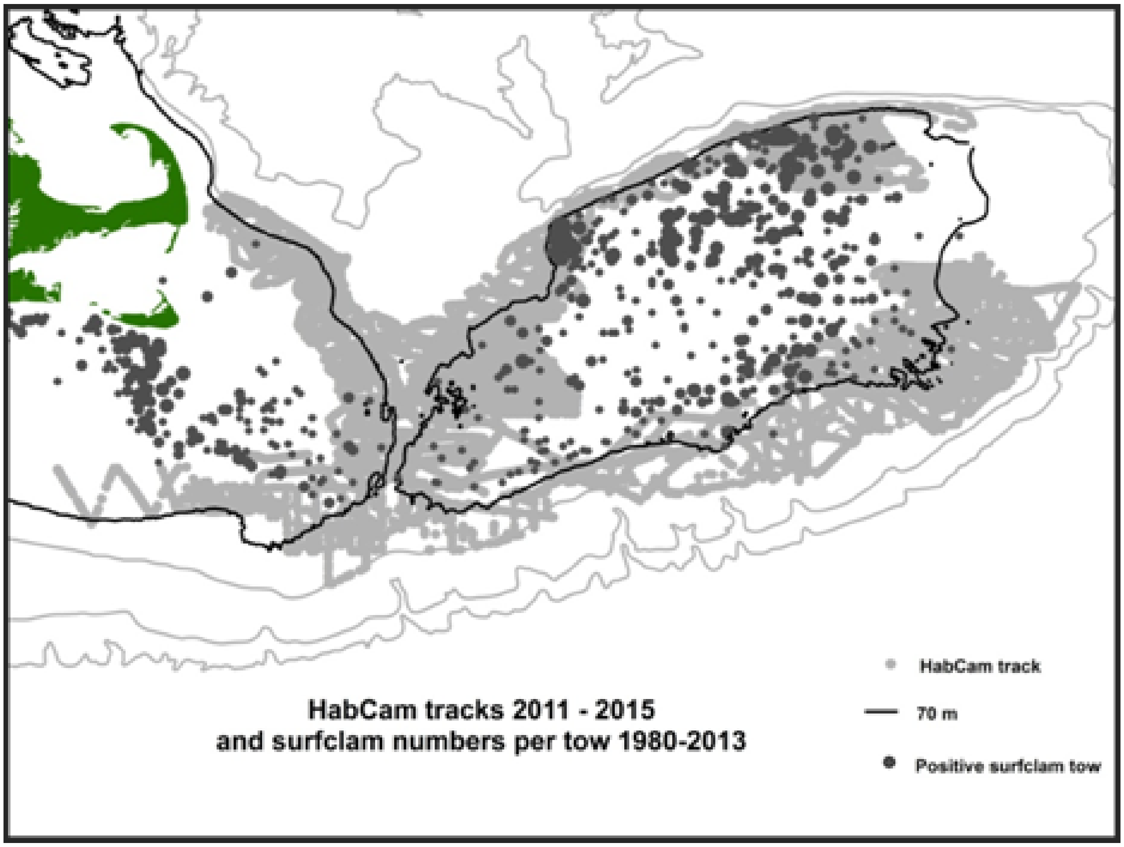


Figure 257: Tracklines of the HabCam towed by the NEFSC scallop survey vessel (gray shading) with the NEFSC clam survey Atlantic surfclam catches overlaid (black dots) and the 70 m isobath. In reality the tracklines are only about 1 meter wide.

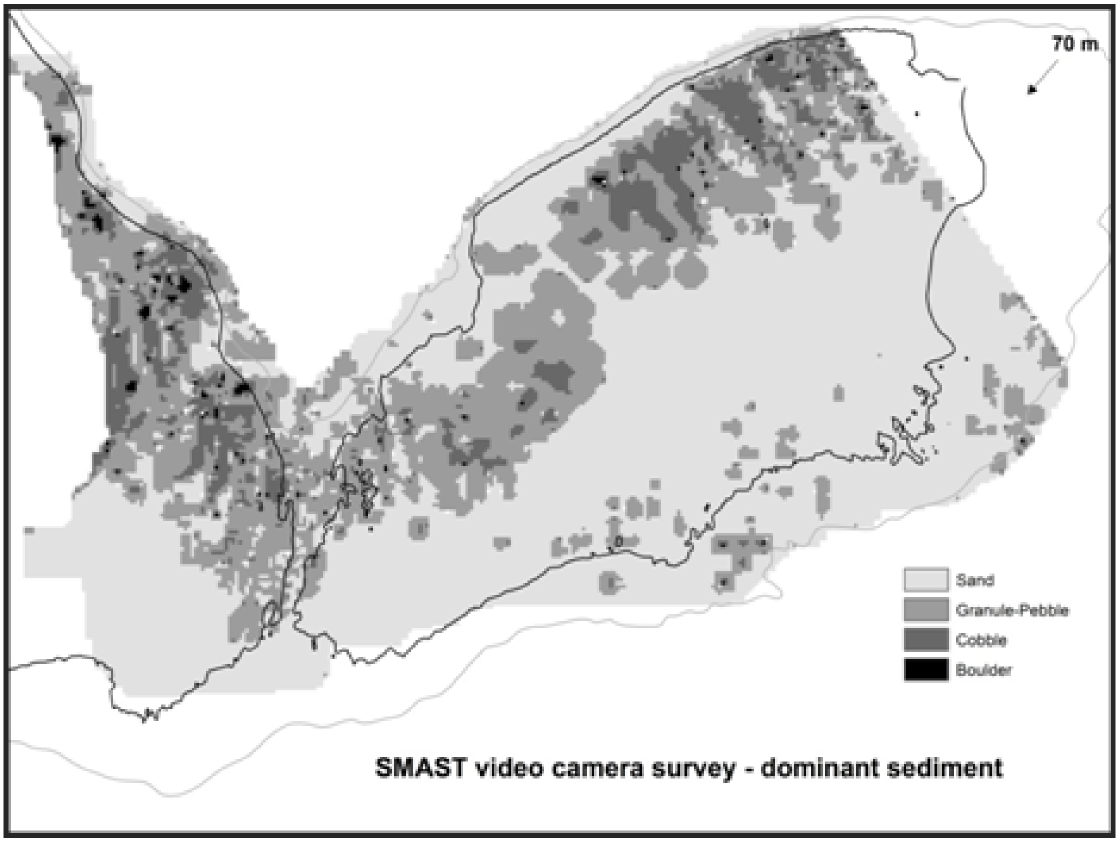


Figure 258: A map of the maximum sediment size visible from the underwater video at each station.

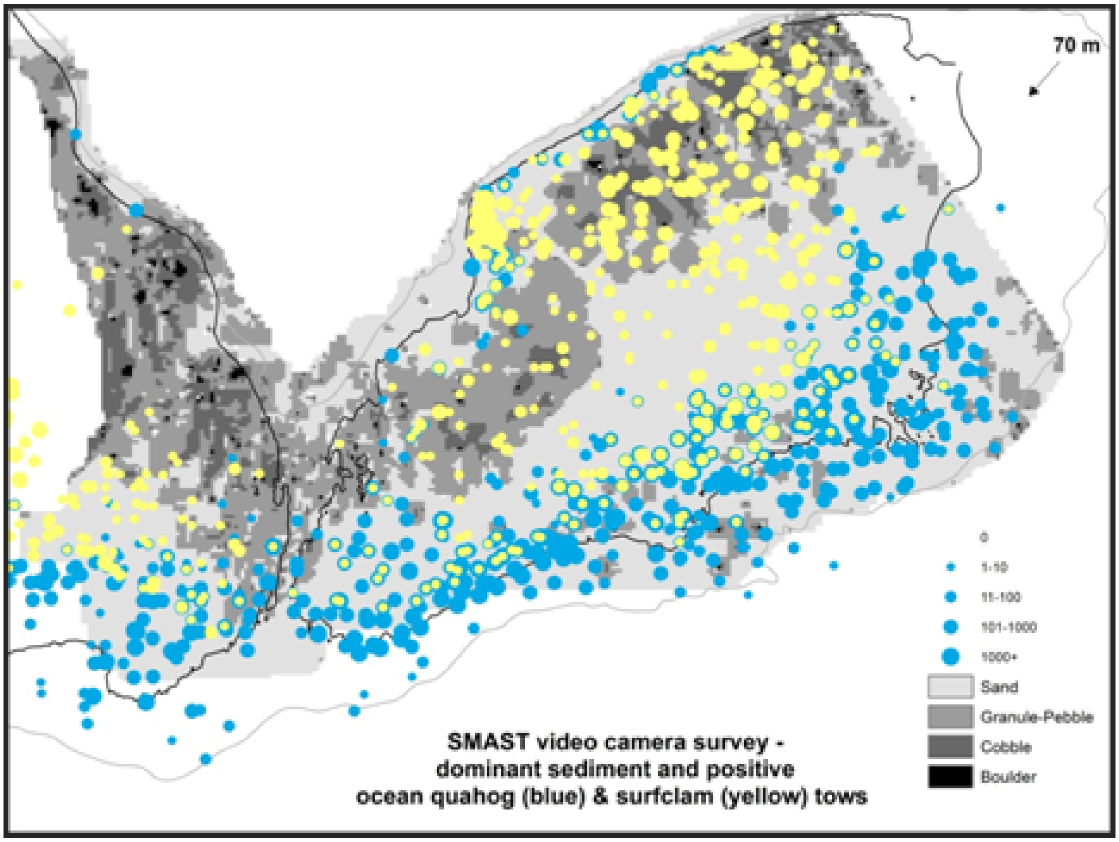


Figure 259: A map of the maximum sediment size visible from the underwater video at each station with positive tows for Atlantic surfclam (yellow dots) and ocean quahogs (blue dots) overlaid.

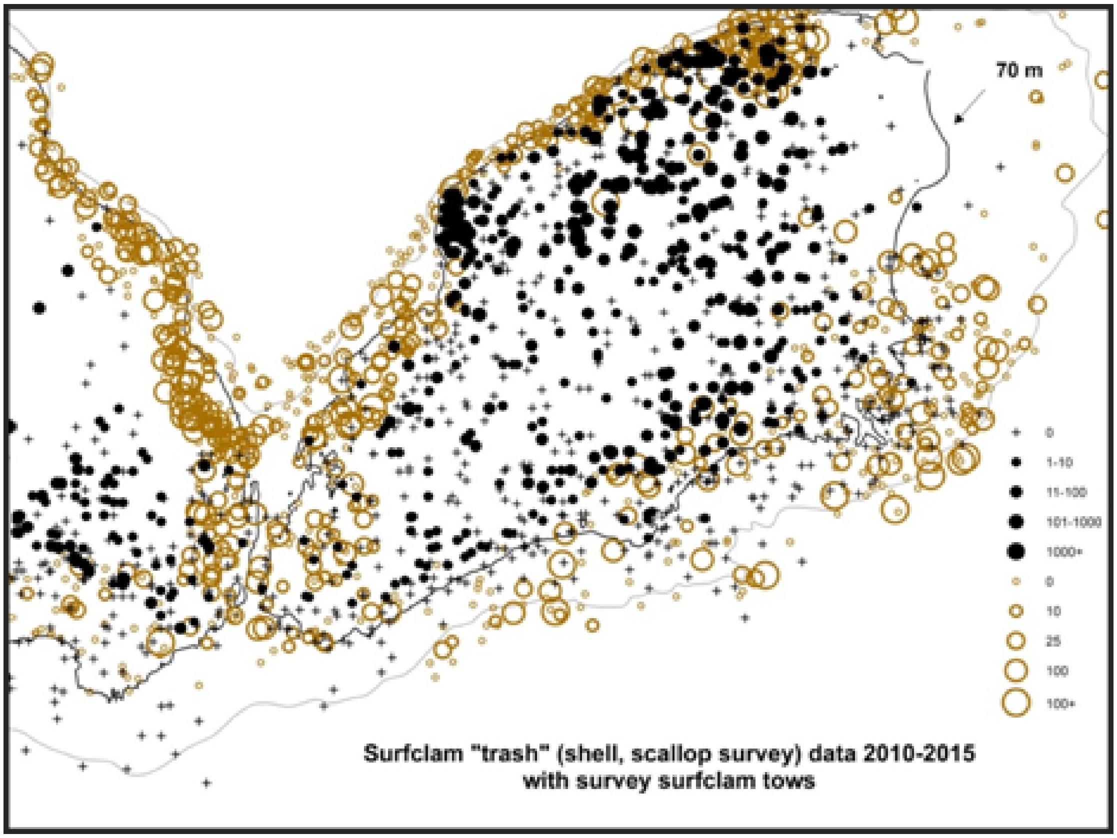


Figure 260: Brown circles represent Atlantic surfclam shell trash brought up in the NEFSC scallop survey dredge, in roughly-estimated liters. Black dots are positive tows for Atlantic surfclam from the NEFSC clam surveys 1980-2013.

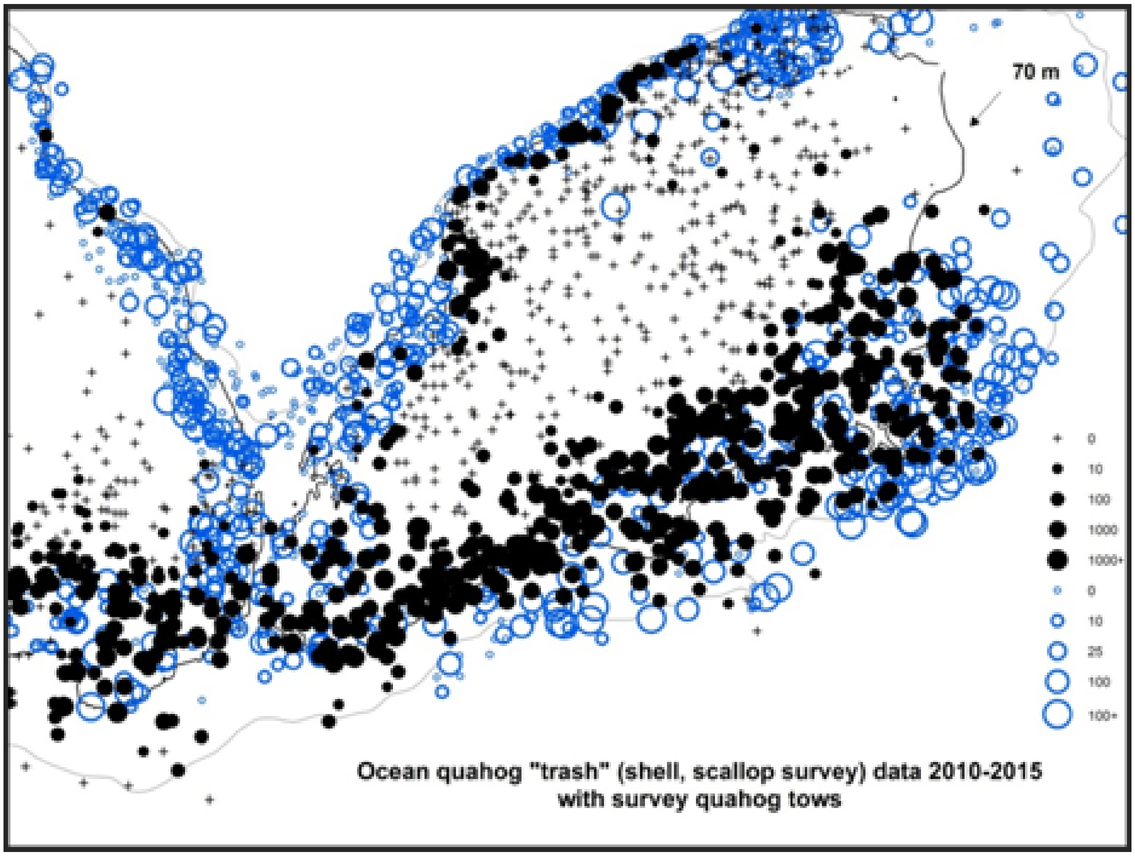


Figure 261: Blue circles represent ocean quahog shell trash brought up in the NEFSC scallop survey dredge, in roughly-estimated liters. Black dots are positive tows for ocean quahogs from the NEFSC clam surveys 1980-2013.

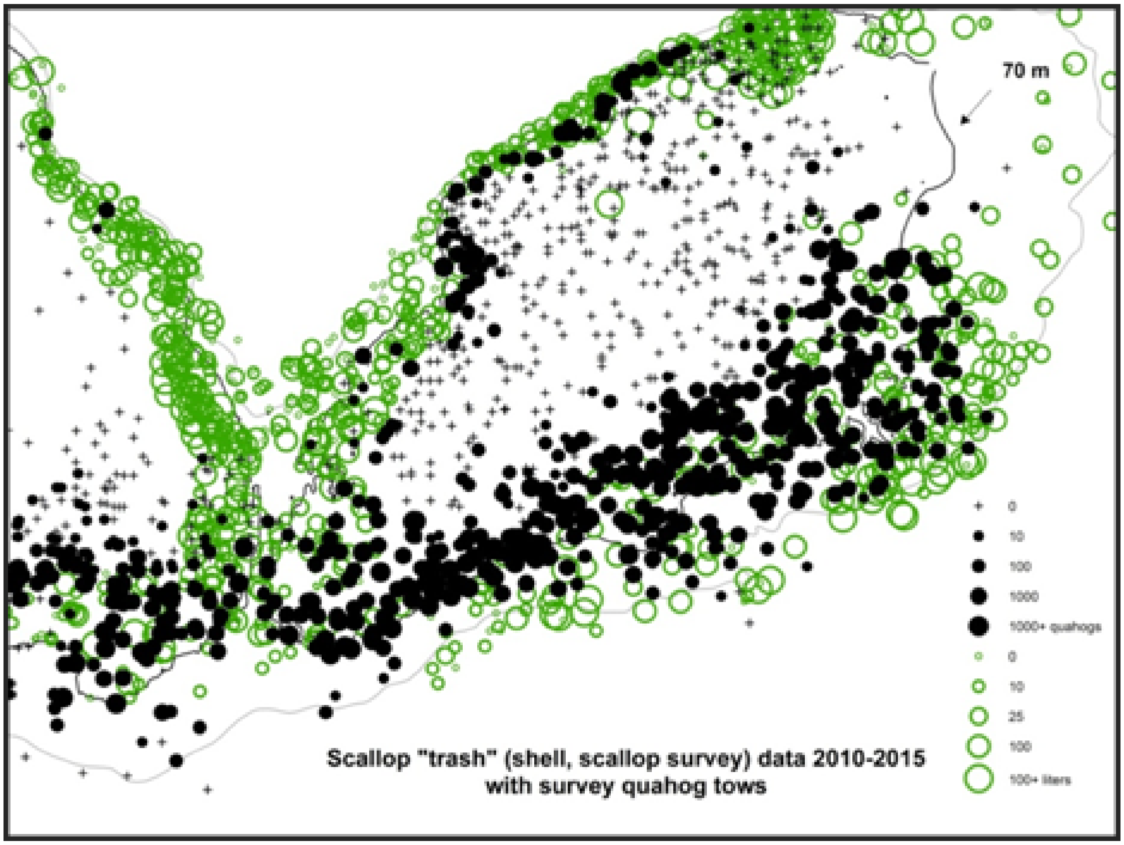


Figure 262: Green circles represent sea scallop shell trash brought up in the NEFSC scallop survey dredge, in roughly-estimated liters. Black dots are positive tows for ocean quahogs from the NEFSC clam surveys 1980-2013.

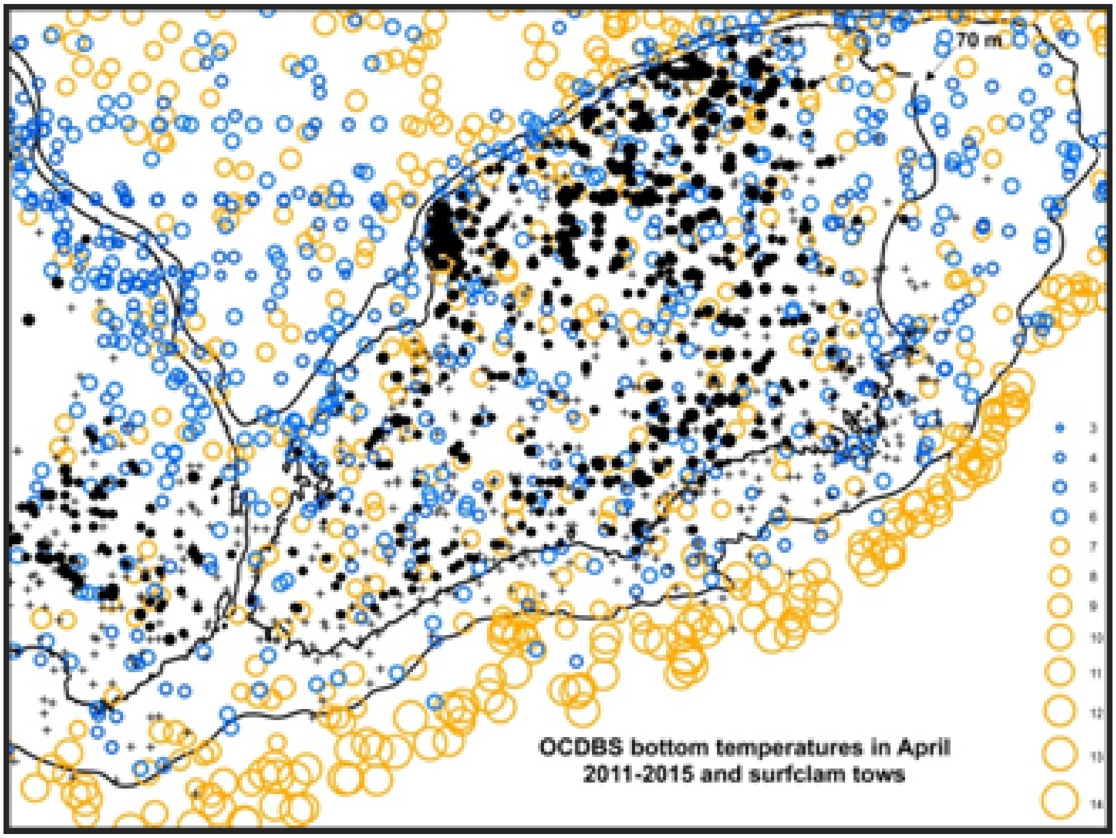


Figure 263: April bottom temperatures on Georges Bank plotted with NEFSC survey Atlantic surfclam catches 1980-2013.

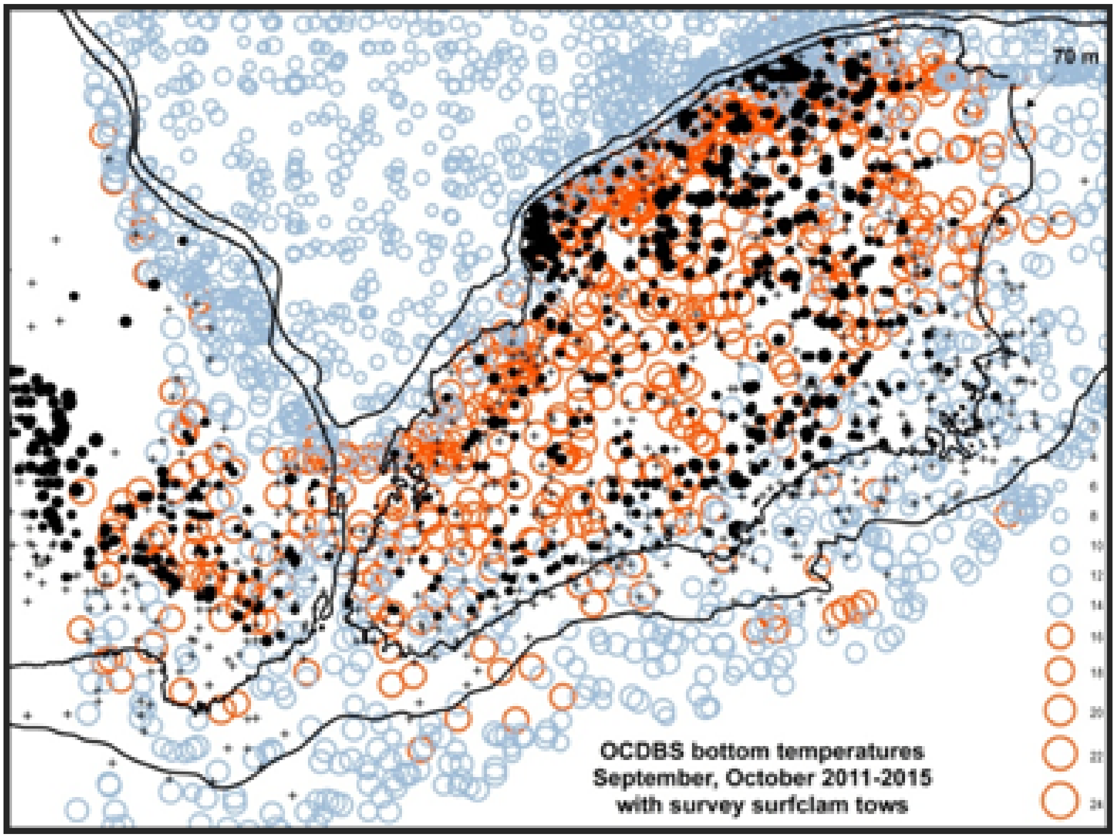


Figure 264: September-October bottom temperatures on Georges Bank plotted with NEFSC survey Atlantic surfclam catches 1980-2013.

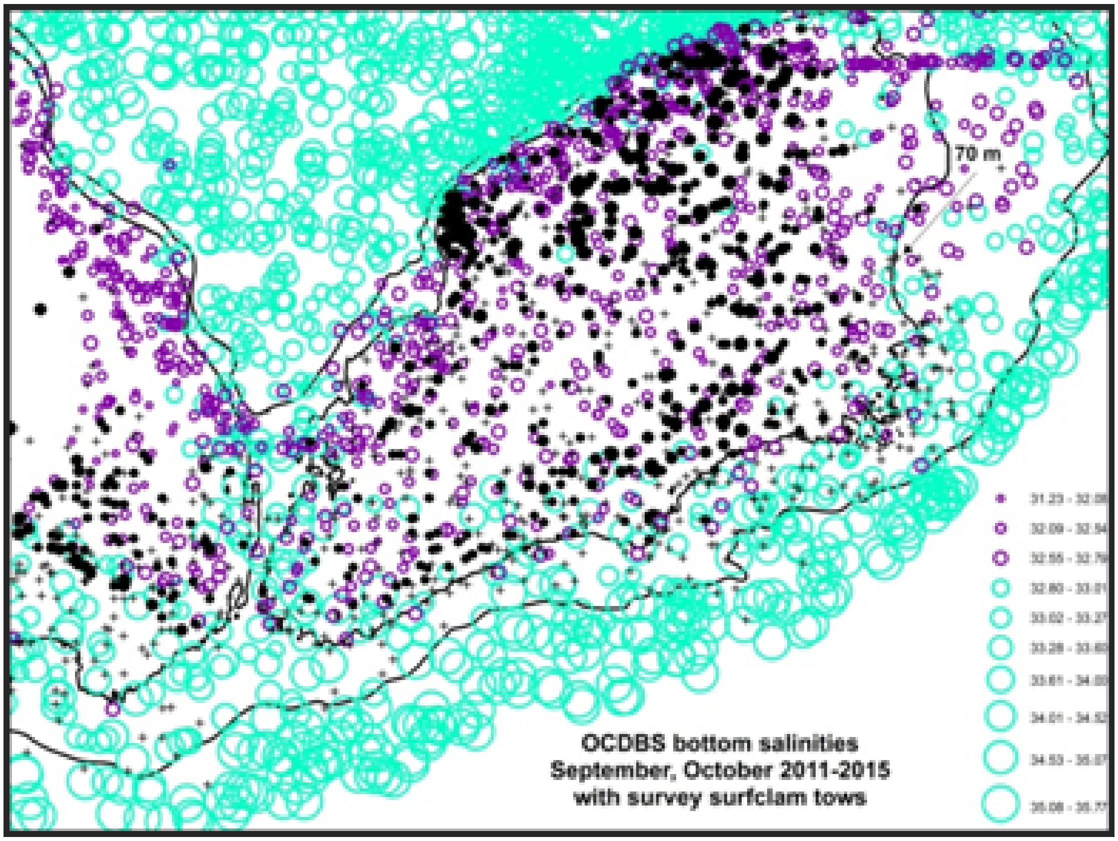


Figure 265: September-October bottom salinities on Georges Bank plotted with NEFSC survey Atlantic surfclam catches 1980-2013.

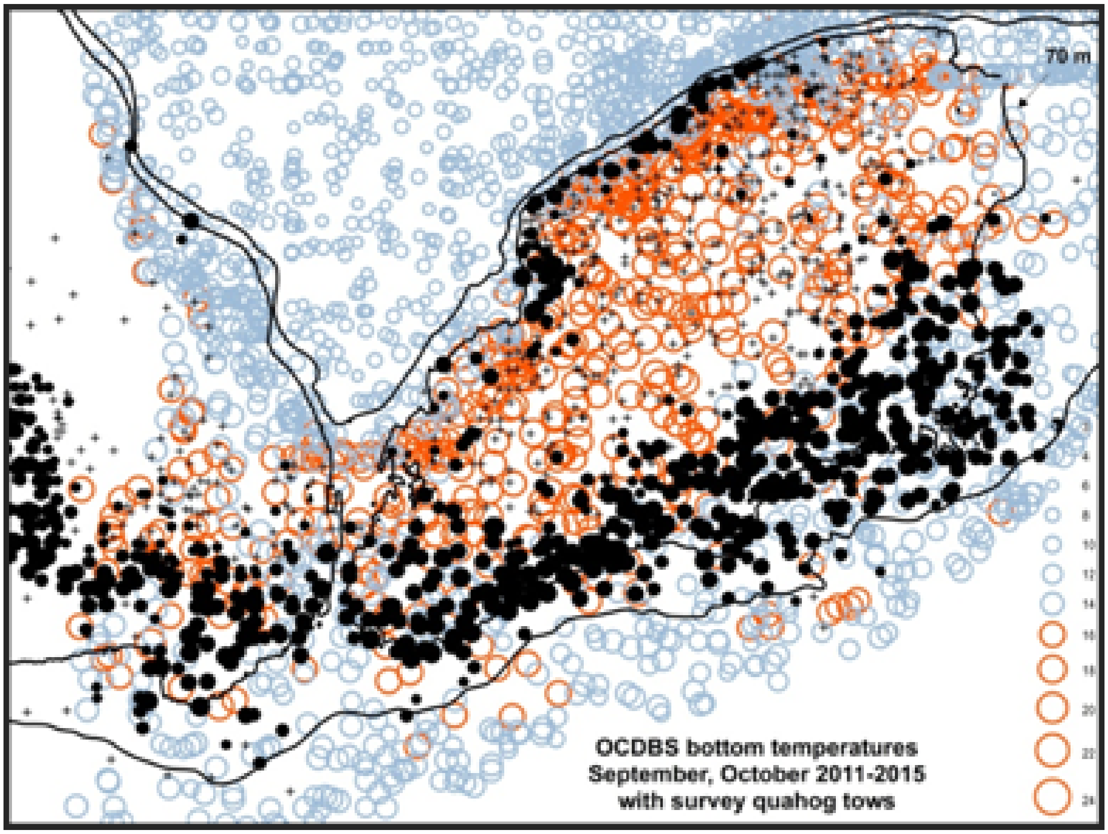


Figure 266: September-October bottom temperatures on Georges Bank plotted with NEFSC survey ocean quahog catches 1980-2013.

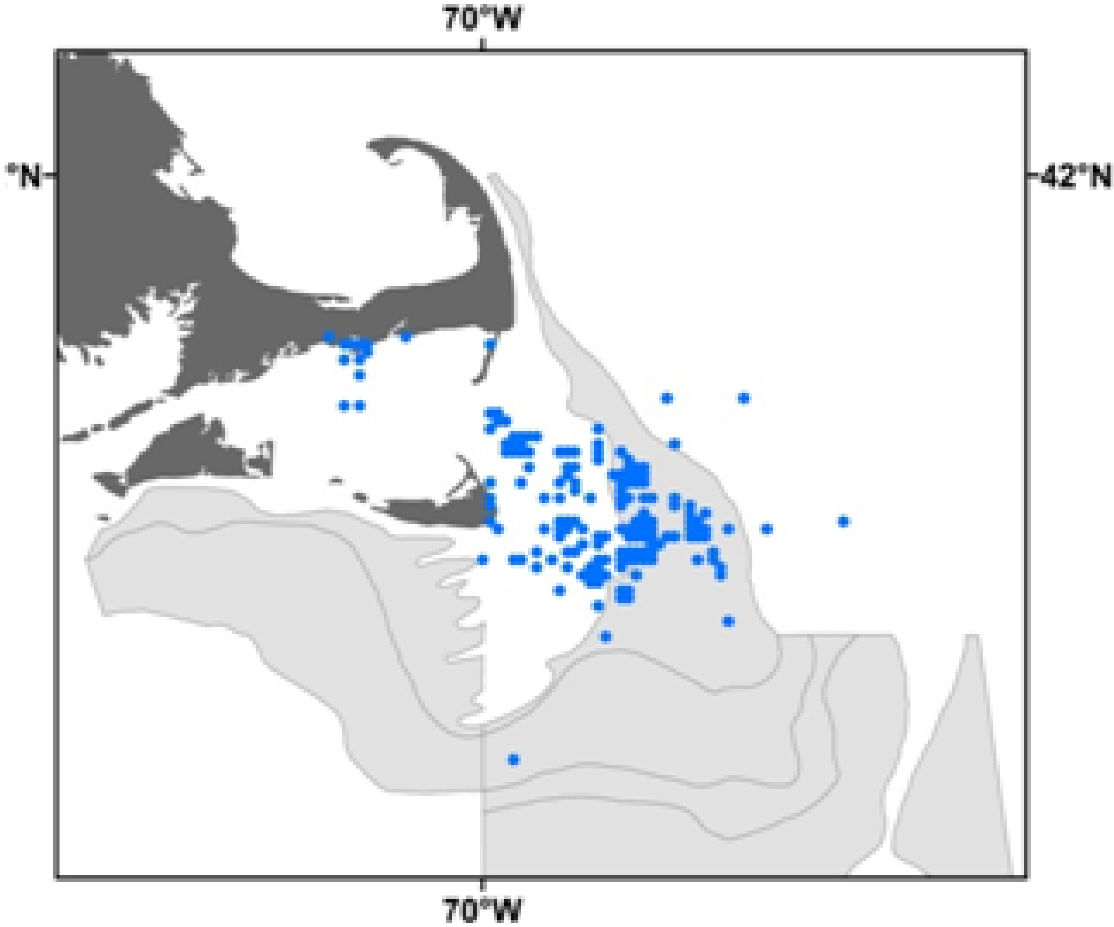


Figure 267: Locations of Atlantic surfclam fishing trips as reported in the clam logbooks from 2003 to 2012 (blue dots). The shaded areas are the strata surveyed and used to determine Atlantic surfclam biomass in the area.

Part XXV

Appendix: Empirical Atlantic surfclam assessment

Summary

Empirical stock assessment results from catch curves, exploitation rates ($E = \frac{Catch}{swept\,area\,biomass}$), and recruit abundance and biomass trends were provided for comparison to stock assessment model estimates. Empirical analyses were the main source of information about mortality, recruitment, and biomass in southern subregions (SNE, LI, NJ, DMV and SVA). Catch curve and other empirical analyses were complicated by domed survey size selectivity patterns before 2012, that caused a positive bias in mortality estimates, and survey gear changes after 2011, and low numbers of age samples for some years (particularly in the north).

Empirical results appear to support assessment model estimates. Total annual mortality estimates (probably biased high) from catch curves for the northern and southern areas averaged 0.14 y^{-1} and were near the current estimate of natural mortality (0.15 y^{-1}) indicating that fishing mortality rates were low (Figures 268-270). There was no clear evidence of trends in mortality over time. Empirical exploitation estimates for the south indicate that recent fishing mortality rates in the northern and southern areas were relatively low ($E < 0.05y^{-1}$, Figure 273).

Exploitation rates were low ($E < 0.06y^{-1}$) after 2011 in the LI NJ, DMV and SVA subregions regions but relatively high ($0.1 < E < 0.15$) in SNE (Figures 271-273). Biomass appears to be declining in in all areas south of SNE and in the south as a whole although changes in the survey complicate interpretation of trends (Figures 271-273). Results indicate that recruit abundance was relatively high in the south during 2015 and about average in the northern area during 2012 (Figures 274-275).

Catch curves

Catch curves based on survey age data were for individual cohorts (cohort catch curves) and for all of the cohorts captured during the same survey (snapshot catch curves). In both types of analyses, the logarithm of mean numbers per tow was regressed on age and the slope of the regression model was taken as an estimate of the average mortality rate (Z). Survey age composition data were based on age-length keys. Poorly sampled years with less than 300 ages per survey from the south or less than 200 ages from the north were omitted. Year classes observed less than five times in the generally triennial clam survey were omitted from cohort catch curve analyses.

Field estimates of size-selectivity for the survey dredge used during 1982-2011 are dome shaped with a broad peak from about 8 cm (about age 4 y) to 15 cm (Northeast Fisheries Science Center (2013)). The survey dredge used since 2012 has a logistic size selectivity shape with full selectivity at about

10 cm (about age 5 y). The change is survey selectivity means that 1982-2011 and 2012-2015 data cannot be combined.

The most important decision in catch curve analysis is the first age group included. Average fishery length composition data for the southern area indicate that Atlantic surfclam are fully recruited to commercial gear and should experience maximum mortality at about 15 cm SL. Based on the updated growth curve in this assessment, Atlantic surfclam in the southern area reach 15 cm at about age 11 y. It is difficult to translate 15 cm SL into age for Atlantic surfclam in the northern area because 15 cm is close to the maximum size predicted by the von Bertalanffy growth curve, but it appears that Atlantic surfclam in the northern area may be close to fully recruited at age 15 y or older. We therefore fit catch curves assuming full recruitment at age 11 y in the south and at age 15 y for the northern area. Sensitivity analyses (not shown) showed that mean mortality estimates from cohort and snapshot catch curves increased as starting age increased, probably due to the dome shaped size-selectivity in the survey.

Statistically significant ($p \leq 0.1$) cohort mortality rates for the south ranged 0.07-0.24 y^{-1} and averaged 0.14 (Figure 268). There was no clear trend in mortality rate estimates over time. Statistically significant ($p \leq 0.1$) snapshot mortality rates ranged 0.06-0.28 y^{-1} and averaged 0.14 (Figure 269). There was no clear trend in mortality rate estimates over time. Runs of positive and negative residuals were noted in some cases.

It was not possible to estimate cohort catch curves for Atlantic surfclam in the northern area because of limited sampling, but the data were sufficient to fit four snapshot catch curves from data collected during 1984, 1986, 1992 and 2008 (Figure 270). Statistically significant ($p \leq 0.1$) mortality rates ranged 0.09-0.18 y^{-1} and averaged 0.14. Catch was negligible in the northern area prior to 2010 so these estimates represent natural mortality and do not include fishing mortality. There was no clear trend in mortality rate estimates over time. Runs of positive and negative residuals were noted in some cases.

Catch/swept-area biomass estimates

As in the last assessment (Appendix A8 in Northeast Fisheries Science Center (2013)), swept-area biomass and exploitation rates were computed for Atlantic surfclam 12+ cm during 1997-2015 by assessment area and smaller regions. The survey data used here were adjusted for survey selectivity to compensate for the dome shaped survey selectivity pattern in Atlantic surfclam 12+ cm in the old survey during 1982-2011. Field experiments indicate that survey selectivity was flat at 12+ cm in the new survey after 2012 so that no selectivity adjustments were required. Sensor based tow distances and updated estimates for survey selectivity, shell length-meat weight and other parameters were used in calculating survey catch weight per tow. Swept-area biomass was calculated assuming median dredge efficiency estimates of 0.23 for 1997-2011 and 0.67 for 2012-2015 based on depletion and selectivity studies to provide an approximate empirical measure of relative scale. Only one set of swept-area estimates were available for the northern area after 2011. Two sets of surveys were available after 2011 for the southern area which may reflect recent trends and should be interpreted with care.

Swept-area biomass estimates for 1997-2011 and 2012-2015 were comparable in scale suggesting that efficiency and tow distance estimates for the two survey dredges are reasonably consistent (Figure 271-273). There is substantial uncertainty in interpreting the composite time series in recent years, but it appears that SNE biomass increased during 2012-2015. Atlantic surfclam biomass in the LI and NJ regions may have declined substantially during 2012-2015 while biomass in DMV remained steady and biomass in the SVA region remained low. Exploitation rates since 2011 were low ($E < 0.06y^{-1}$) in the LI, NJ, DMV, and SVA regions but relatively high (0.1 - 0.15 y^{-1}) in SNE. The high values in SNE may be due in part to the fact that a proportion of the catch is landed in an area (northern Nantucket Shoals) that is not surveyed. Empirical exploitation estimates for the south confirm assessment model estimates which indicate recent fishing mortality rates in both areas are low ($E < 0.05y^{-1}$).

Survey recruitment trends

Long term (1982-2015, but see below) trends in abundance of recruits (5-12 cm, before recruitment to the fishery) were computed by adjusting survey catch data based on nominal tow distances (distance traveled while the dredge was on the tow rope) and dredge efficiency (0.23 for 1997-2011 and 0.67 for 2012-2015). Selectivity curves based on field studies were used to adjust for differences in size selectivity during 1982-2011 and 2012-2015. Recruit abundance trends were similar ending in 2011 and starting in 2012 indicating that dredge efficiency and selectivity estimates were consistent (Figures 274-275).

Figures

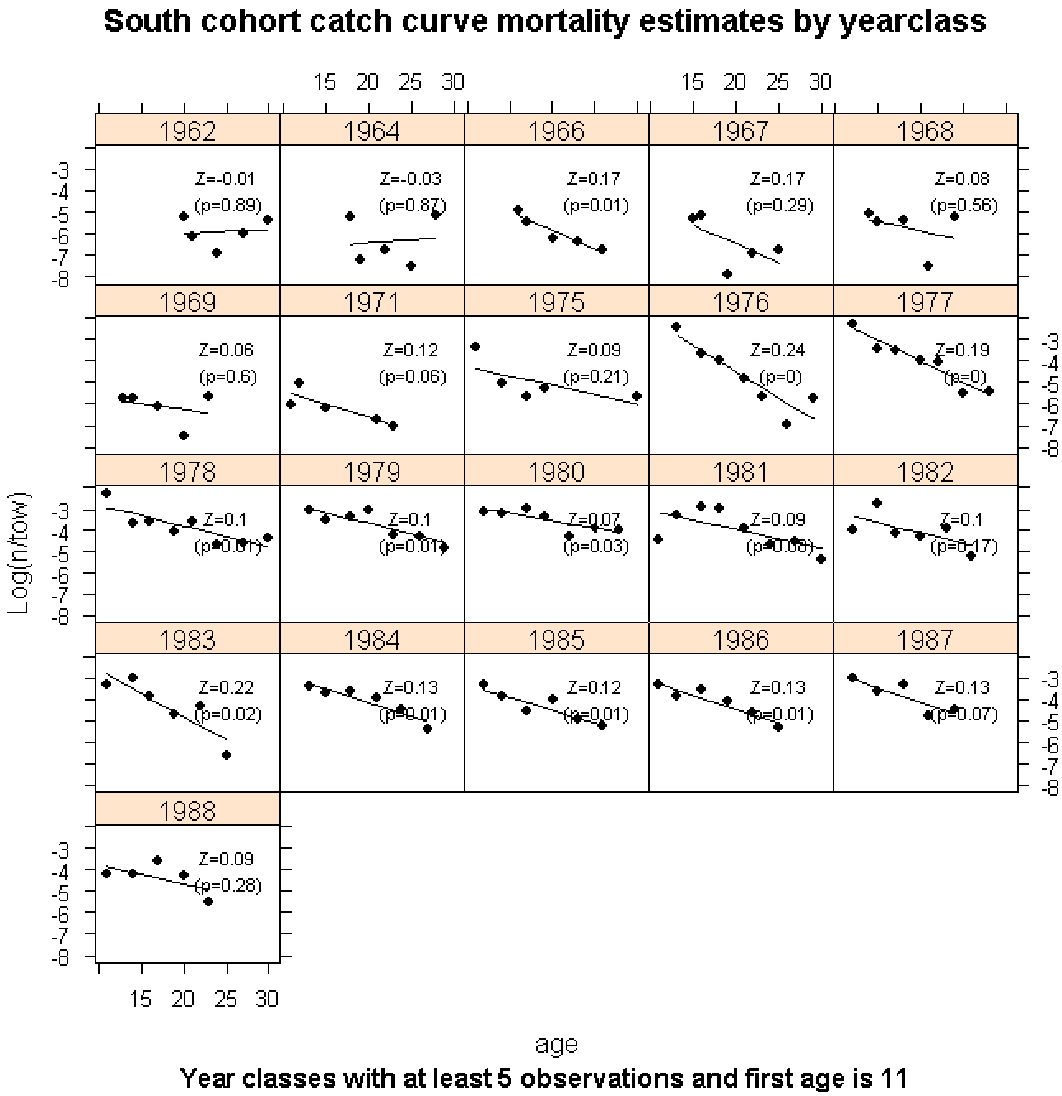


Figure 268: Cohort catch curves (one panel for each cohort) based on survey age composition data for Atlantic surfclam 15+ y in the southern area and omitting cohorts with fewer than five observations.

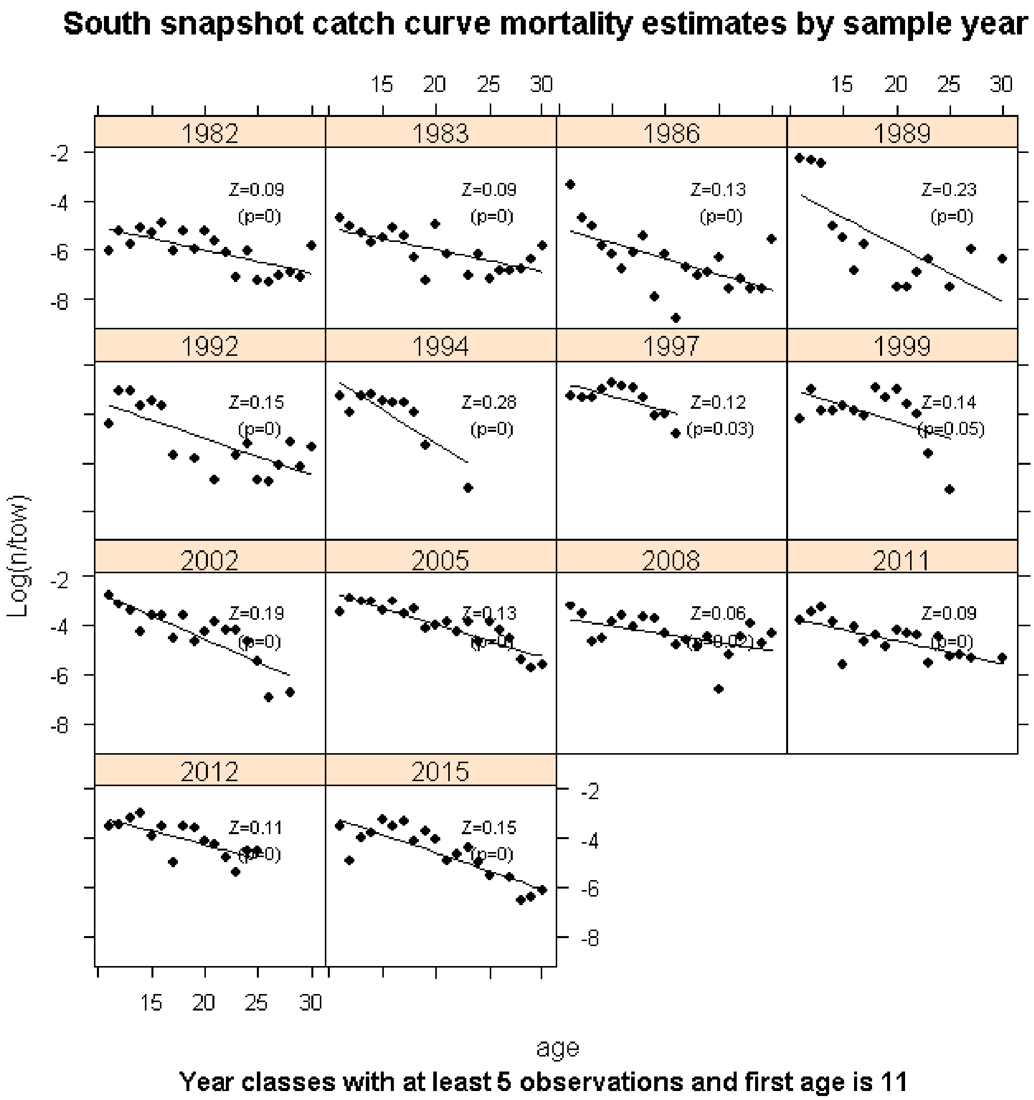


Figure 269: Snapshot catch curves (one panel for each cohort) based on survey age composition data for Atlantic surfclam 15+ y in the southern area and omitting cohorts with fewer than five observations.

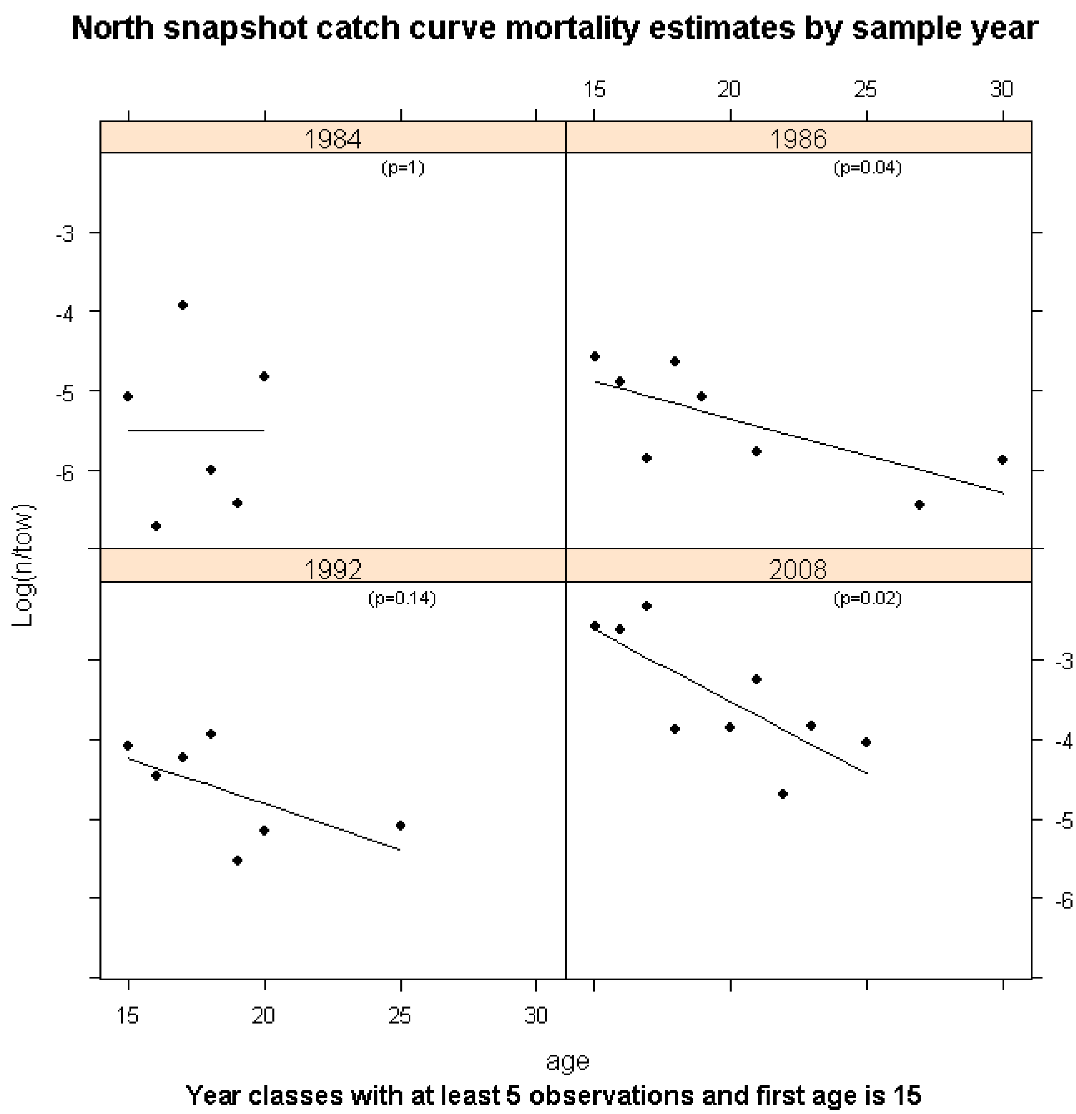


Figure 270: Snapshot catch curves (one panel for each cohort) based on survey age composition data for Atlantic surfclam 15+ y in the northern area and omitting cohorts with fewer than five observations.

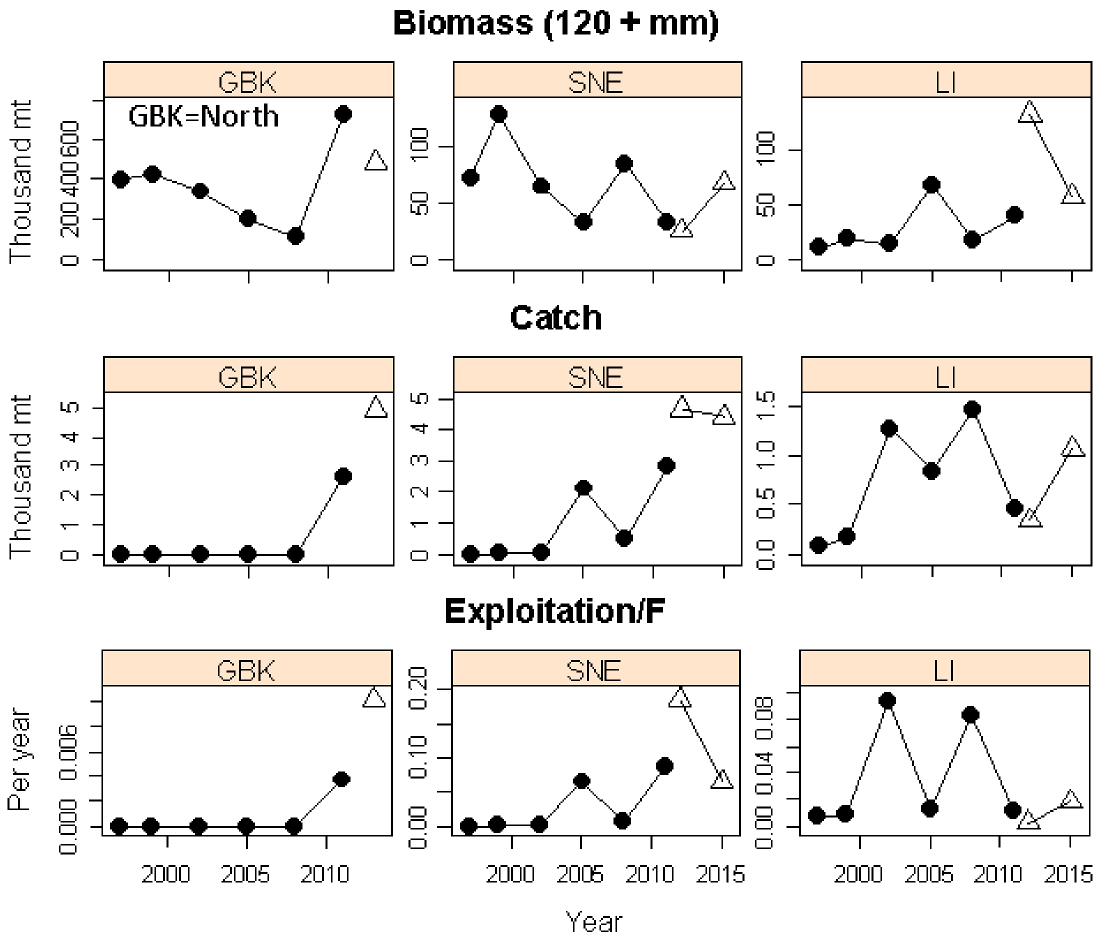


Figure 271: Swept-area biomass for Atlantic surfclam 12+ cm SL based on survey data adjusted for dome shaped selectivity (top), catch weight (landings + 12% for incidental mortality, middle) and exploitation rates (catch/biomass) for Atlantic surfclam in the Georges Bank (GBK), Southern New England (SNE) and Long Island (LI) regions (bottom). Data and results for 1997-2011 (when the original survey dredge was used) and 2012-2015 when a modified commercial survey dredge was used are shown using different symbols. Median dredge efficiency and sensor based tow distances were used in computations.

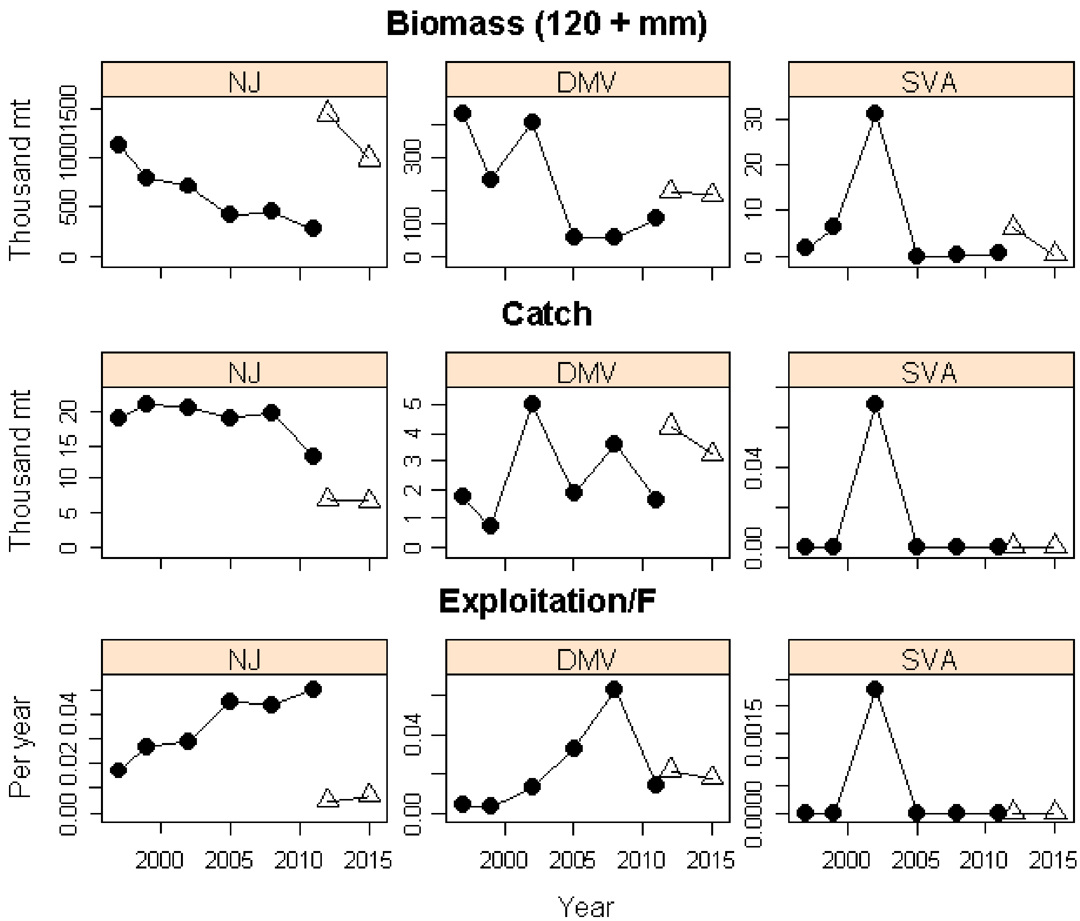


Figure 272: Swept-area biomass for Atlantic surfclam 12+ cm SL based on survey data adjusted for dome shaped selectivity (top), catch weight (landings + 12% for incidental mortality, middle) and exploitation rates (catch/biomass) for Atlantic surfclam in the New Jersey (NJ), Delmarva (DMV) , Southern Virginia (SVA) regions (bottom). Data and results for 1997-2011 (when the original survey dredge was used) and 2012-2015 when a modified commercial survey dredge was used are shown using different symbols. Median dredge efficiency and sensor based tow distances were used in computations.

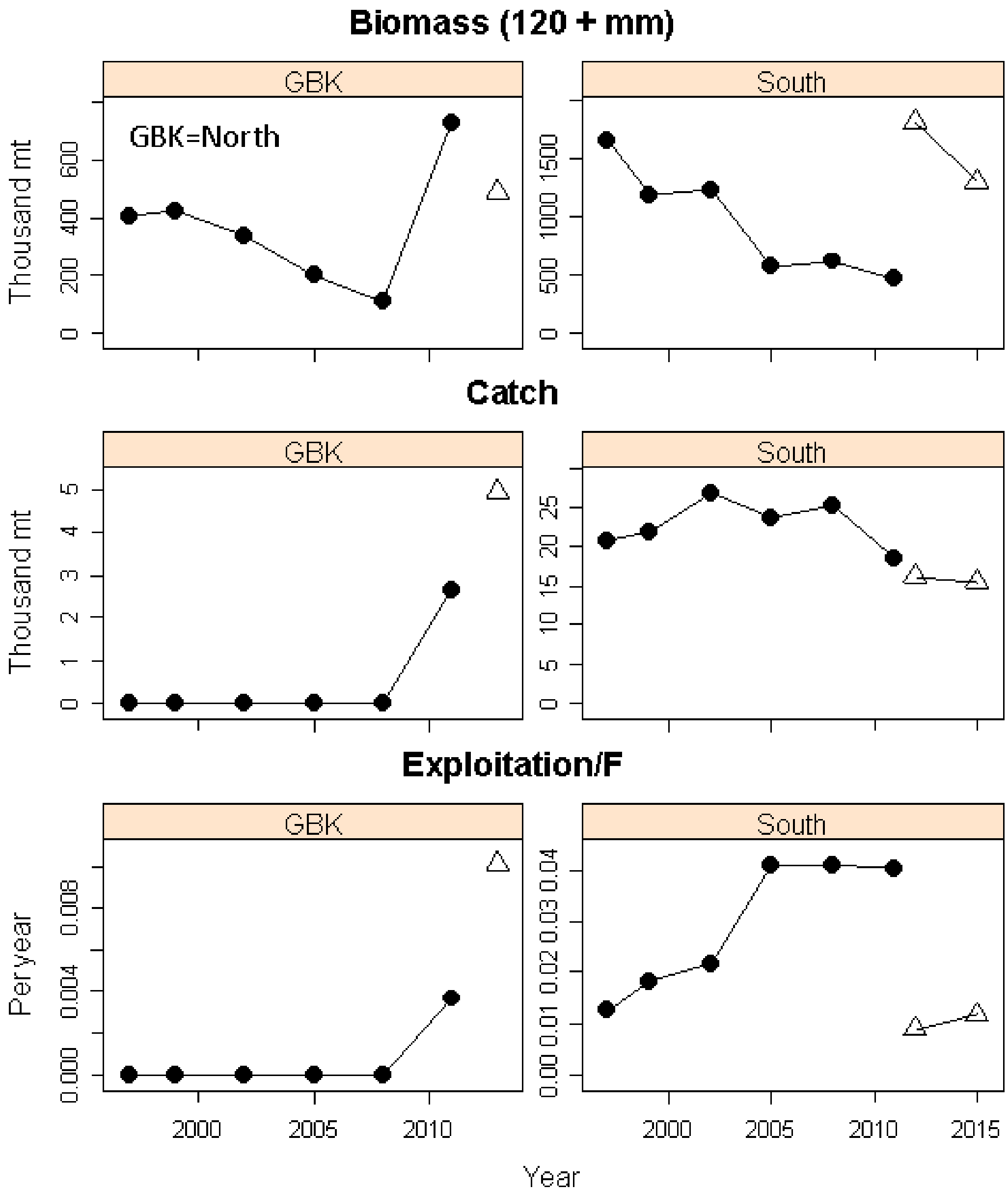


Figure 273: Swept-area biomass for Atlantic surfclam 12+ cm SL based on survey data adjusted for dome shaped selectivity (top), catch weight (landings + 12% for incidental mortality, middle) and exploitation rates (catch/biomass) for Atlantic surfclam in the Georges Bank (GBK) and Southern regions (bottom). Data and results for 1997-2011 (when the original survey dredge was used) and 2012-2015 when a modified commercial survey dredge was used are shown using different symbols. Median dredge efficiency and sensor based tow distances were used in computations.

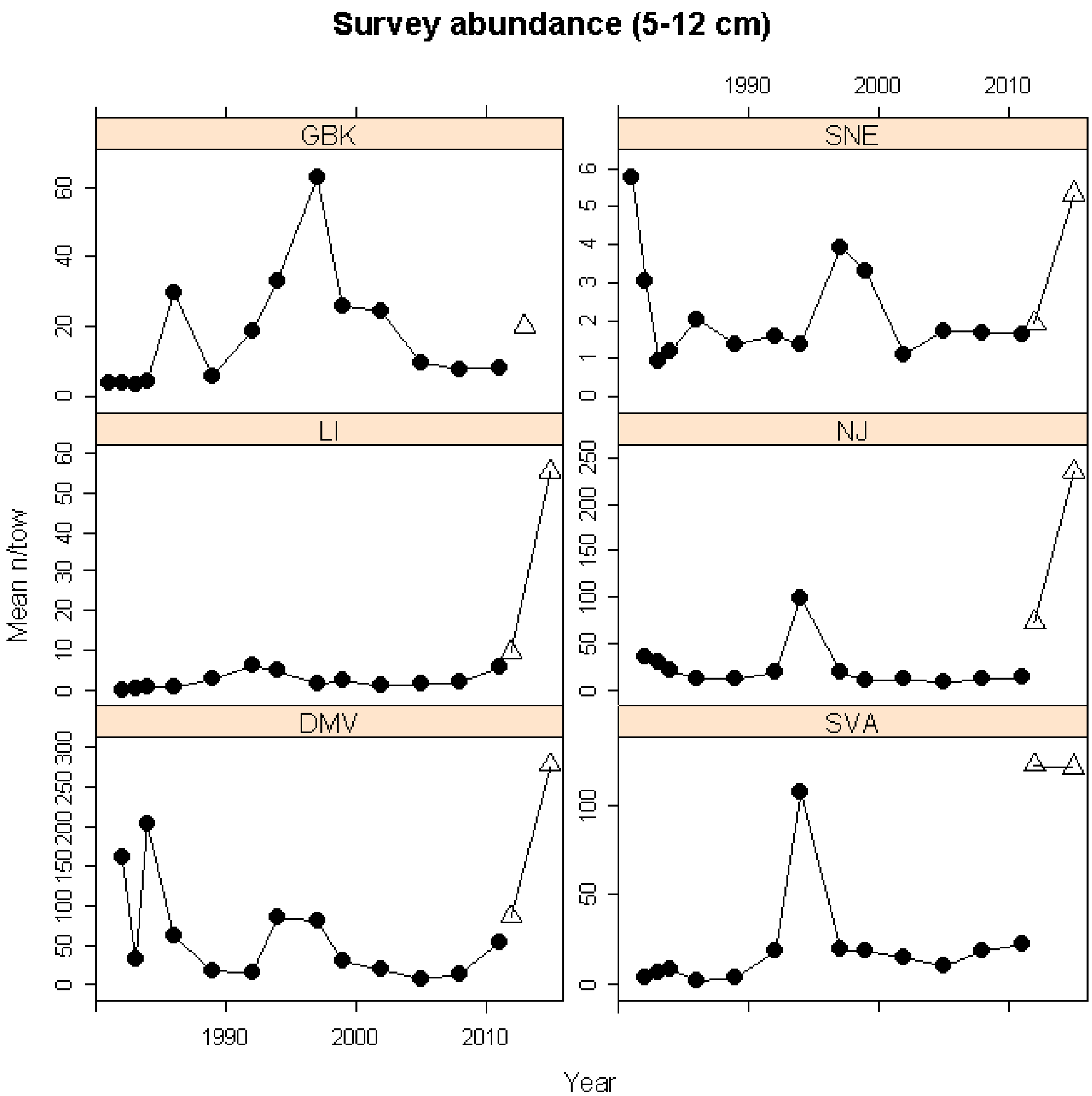


Figure 274: Trends in abundance of "recruit" Atlantic surfclam (5-12 cm SL) by area based on NEFSC clam surveys during 1982-2015. Data are adjusted for size-selectivity and dredge efficiency based field study results. Survey gear changed in 2012 so that comparison of trends up to and after 2011 may be misleading. Note that y-scales differ in each plot.

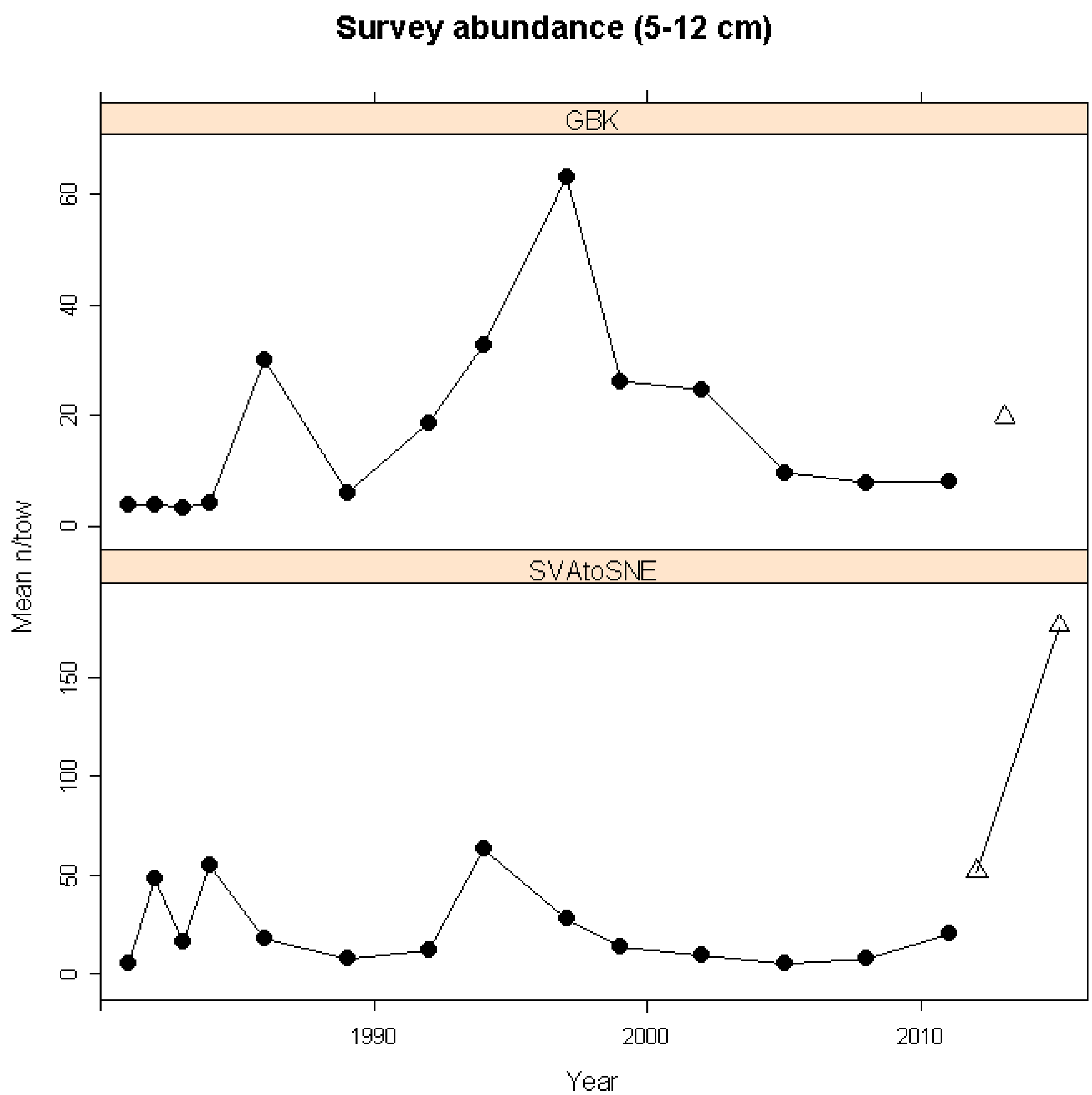


Figure 275: Trends in abundance of "recruit" Atlantic surfclam (5-12 cm SL) by stock assessment region based on NEFSC clam surveys during 1982-2015. Data are adjusted for size-selectivity and dredge efficiency based field study results. Survey gear changed in 2012 so that comparison of trends up to and after 2011 may be misleading. Note that y-scales differ in each plot.

Part XXVI

Appendix to the SAW Assessment TORs:

Clarification of Terms used in the SAW/SARC Terms of Reference

On "Acceptable Biological Catch" (DOC Nat. Stand. Guidel. Fed. Reg., v. 74, no. 11, 1-16-2009):

Acceptable biological catch (ABC) is a level of a stock or stock complex's annual catch that accounts for the scientific uncertainty in the estimate of [overfishing limit] OFL and any other scientific uncertainty..." (p. 3208) [In other words, OFL ABC.]

ABC for overfished stocks. For overfished stocks and stock complexes, a rebuilding ABC must be set to reflect the annual catch that is consistent with the schedule of fishing mortality rates in the rebuilding plan. (p. 3209)

NMFS expects that in most cases ABC will be reduced from OFL to reduce the probability that overfishing might occur in a year. (p. 3180)

ABC refers to a level of "catch" that is "acceptable" given the "biological" characteristics of the stock or stock complex. As such, [optimal yield] OY does not equate with ABC. The specification of OY is required to consider a variety of factors, including social and economic factors, and the protection of marine ecosystems, which are not part of the ABC concept. (p. 3189)

On "Vulnerability" (DOC Natl. Stand. Guidelines. Fed. Reg., v. 74, no. 11, 1-16-2009):

"Vulnerability. A stocks vulnerability is a combination of its productivity, which depends upon its life history characteristics, and its susceptibility to the fishery. Productivity refers to the capacity of the stock to produce MSY and to recover if the population is depleted, and susceptibility is the potential for the stock to be impacted by the fishery, which includes direct captures, as well as indirect impacts to the fishery (e.g., loss of habitat quality)." (p. 3205)

Participation among members of a SAW Assessment Working Group:

Anyone participating in SAW assessment working group meetings that will be running or presenting results from an assessment model is expected to supply the source code, a compiled executable, an input file with the proposed configuration, and a detailed model description in advance of the model meeting. Source code for NOAA Toolbox programs is available on request. These measures allow transparency and a fair evaluation of differences that emerge between models.

Part XXVII

Appendix: Survey performance 2013

Introduction

The 2013 survey covered a portion of the whole stock area including the SNE and most of GBK subareas. There were 149 total tows and four selectivity tows. One tow resulted in severe damage to the dredge and was aborted and eight other tows during which no sensor data was recovered. Therefore there were 136 standard survey tows on which sensors were deployed and sensor data was recorded.

The 2013 survey used a modified commercial dredge with 3 on board data recorders. There was an inclinometer (Star Oddi) and two (Madge Tech) pressure sensors: one in the pump manifold measuring the pressure in the hydraulic jets used to loosen the sediments around clams and one measuring the ambient pressure at fishing depth. The inclinometer measured the pitch roll and yaw of the dredge as it was towed and was used to determine if the dredge was in a fishing position, which was the basis for determining "time fishing" on each tow. The pressure sensors were used to make sure that the pump was achieving sufficient pressure to maintain capture efficiency.

Survey performance

Sensors deployed during the 2013 survey suggest that either the average pump pressure was some what less than 2012 (Figure 284), or the pressure sensor was mis-calibrated. The pressure sensor data was not analyzed until 2014, after the 2014 survey had been conducted and the sensors re-calibrated. Therefore there is no way to determine if the problem with the sensors was due to reduced pump pressure or sensor calibration. Speed over ground also appeared to be somewhat less than in previous years (Figure 284), but may be related to the type of substrate encountered and/or current strength. The ground fished was in some cases exceedingly rocky and difficult to dredge through, while currents on GBK and SNE are strong relative to areas further south. The tow speeds recorded were probably not sufficient in magnitude to cause concern regarding dredge efficiency and may represent the maximum advisable speed given the conditions. Neither pump pressure nor vessel speed appeared to be less than expected based on ship board instruments during operations, which may indicate problems with sensor calibration, but the discrepancy cannot be definitively resolved at this juncture.

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. Roll and yaw were relatively stable for the large modified commercial dredge and rarely fluctuated from baseline levels during fishing events. Pitch was recorded by a Star Oddi inclinometer which functioned consistently. Data from each instrument was smoothed using a 7 second moving average and then parsed for time above or below the median fishing angle for that tow.

In order to account for median pitch $> 0^o$, the determination of time fishing was based on a critical deviation from median pitch, rather than an absolute critical pitch angle. The choice of critical deviation has implications for the calculation of tow distance for each tow. When the dredge is above or below the critical deviation it is assumed to be pitched too steeply for the blade to penetrate the sediment. If the dredge is pitched within Δ_{crit} (the critical deviation) of $\tilde{\phi}_t$ (the median pitch for tow t), it assumed to be near enough to parallel to the bottom that the blade should penetrate and thus be actively fishing.

An ideal critical deviation is as close to zero as possible, but not so small that it includes poor dredge performance seconds. 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 deviation is too small, many seconds when the dredge is actually fishing would be excluded, which would tend to bias estimates of tow distance down. It is therefore important to find a critical deviation that is neither too small, nor too large.

The choice of Δ_{crit} was informed by an examination of the total and average tow distances based on different critical deviations. Total tow distance summed across all tow and average tow distance over all tows was compared when different values of Δ_{crit} were used. In general, higher values of Δ_{crit} result in longer tows because the dredge is considered to be in fishing position for a greater proportion of the tow (Figure 285). We selected a Δ_{crit} of $4°$ because it produced an average tow distance that was near the nominal tow distance (0.25 nm, a value equal to the nominal tow speed 3 kt multiplied by the nominal tow time 5 min) and because it seemed reasonable based on examination of the engineering schematic of the dredge being used (*Figure not yet available*)

Time fishing during the 2013 survey was less than the nominal tow time in most cases due to the lower average tow speed discussed above (Figure 286).

Effects of depth

Depth is typically associated with longer tows due to the scope of the towing wire that must be deployed to assure good dredge performance. Additional scope requires longer retrieval times and may result in some additional time fishing while the slack in the wire is spooled up. This effect was evident (though the data was noisy) during the 2013 survey (Figure 286).

Temperature

Temperature was recorded from the dredge and averaged over fishing seconds for all tows during the 2013 survey (Figure 287). Temperature was correlated with depth (Figure 287).

Figures

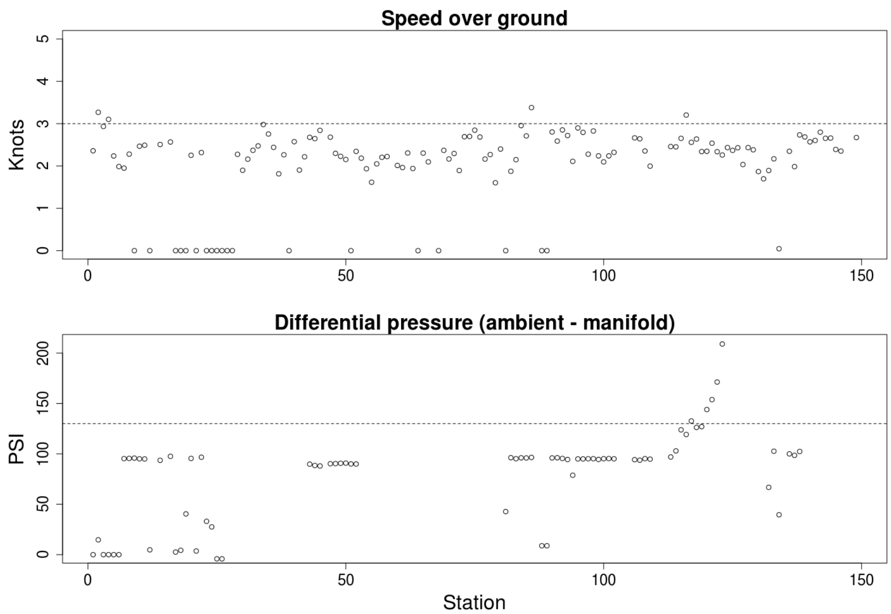


Figure 276: Speed over ground and differential pressure for each tow in the 2013 survey. The optimal speed over ground (3 kt) is marked with a horizontal dashed line. Differential pressure is the difference between the pressure in the dredge manifold, which indicates the absolute pressure realized by the dredges hydraulic jets, and the ambient pressure at fishing depth. The vertical line is plotted at 130 psi for reference only. Instrument failure or lost data are represented by differential pressure equal to 0.

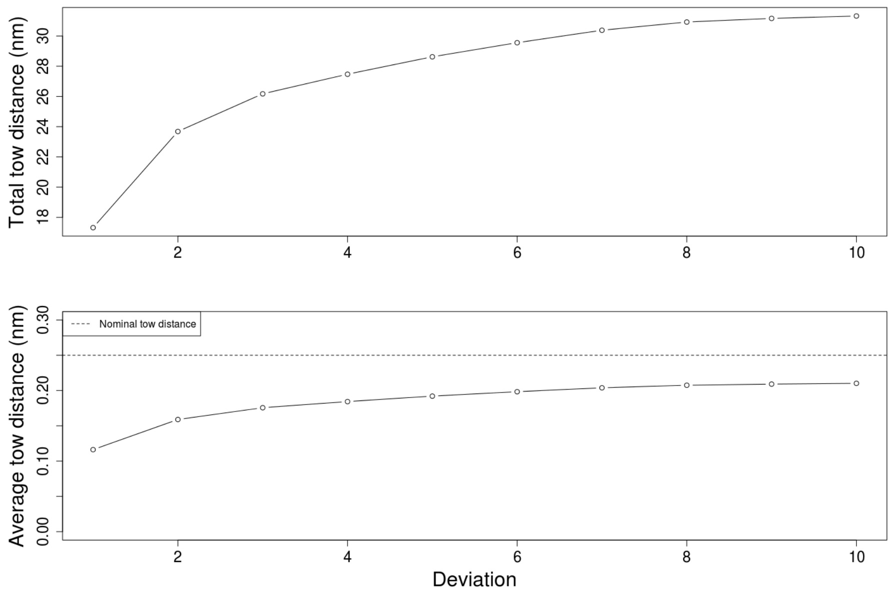


Figure 277: Average and total tow distance over all stations by critical deviation angle. The dashed line in the lower figure represents the nominal tow distance.

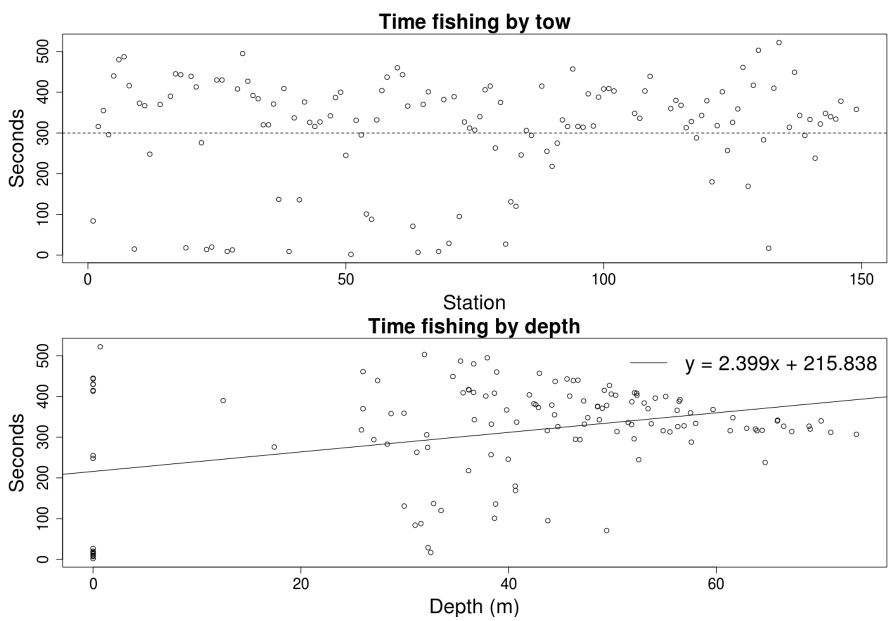


Figure 278: Time fished by station and depth. Depth significantly predicts tow time. The p value for slope was < 0.001, though the results were noisy and $R^2 < 0.14$ for the regression line shown.

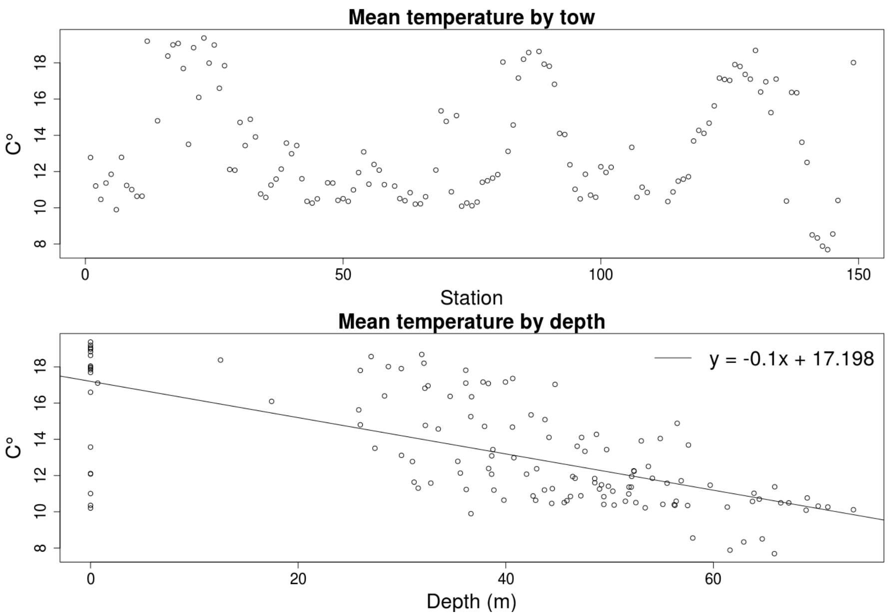


Figure 279: Temperature by station and depth. Depth significantly predicts temperature. The p value for slope was < 0.001 and $R^2 > 0.43$ for the regression line shown.

Part XXVIII

Appendix: Survey performance 2014

Introduction

The 2014 survey covered portions of the SNE and GBK areas that were not sampled in 2013. There were 79 total tows and 49 experimental tows. Some sensor data was recorded on every completed tow except one. Therefore there were 29 standard survey tows on which sensors were deployed and sensor data was recorded.

The 2014 survey used a modified commercial dredge with 3 on board data recorders. There was an inclinometer (Star Oddi) and two (Madge Tech) pressure sensors: one in the pump manifold measuring the pressure in the hydraulic jets used to loosen the sediments around clams and one measuring the ambient pressure at fishing depth. The inclinometer measured the pitch roll and yaw of the dredge as it was towed and was used to determine if the dredge was in a fishing position, which was the basis for determining ”time fishing” on each tow. The pressure sensors were used to make sure that the pump was achieving sufficient pressure to maintain capture efficiency.

Survey performance

Sensors deployed during the 2014 survey suggest that the average pump pressure was very close to the median pump pressure observed in 2012 (Figure 284). Speed over ground appeared to be somewhat less than in 2012 (Figure 284), but was well within the confidence bounds observed then and may be related to the type of substrate encountered and/or current strength. The ground fished was in some cases exceedingly rocky and difficult to dredge through, while currents on GBK and SNE are strong relative to areas durther south. The tow speeds recorded were probably not sufficient in magnitude to cause concern regarding dredge efficiency and may represent the maximum advisable speed given the conditions. Neither pump pressure nor vessel speed appeared to be less than expected based on ship board instruments during operations. The values observed are probably well within normal operating tolerance and are probably not suggestive of changes in dredge performance.

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. Roll and yaw were relatively stable for the large modified commercial dredge and rarely fluctuated from baseline levels during fishing events. Pitch was recorded by a Star Oddi inclinometer which functioned consistently. Data from each instrument was smoothed using a 7 second moving average and then parsed for time above or below the median fishing angle for that tow.

In order to account for median pitch $> 0^o$, the determination of time fishing was based on a critical deviation from median pitch, rather than an absolute critical pitch angle. The choice of critical deviation has implications for the calculation of tow distance for each tow. When the dredge is above or below the critical deviation it is assumed to be pitched too steeply for the blade to penetrate the sediment. If the dredge is pitched within Δ_{crit} (the critical deviation) of $\tilde{\phi}_t$ (the median pitch for tow t), it assumed to be near enough to parallel to the bottom that the blade should penetrate and thus be actively fishing.

An ideal critical deviation is as close to zero as possible, but not so small that it includes poor dredge performance seconds. 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 deviation is too small, many seconds when the dredge is actually fishing would be excluded, which would tend to bias estimates of tow distance down. It is therefore important to find a critical deviation that is neither too small, nor too large.

The choice of Δ_{crit} was informed by an examination of the total and average tow distances based on different critical deviations. Total tow distance summed across all tow and average tow distance over all tows was compared when different values of Δ_{crit} were used. In general higher values of Δ_{crit} result in longer tows because the dredge is considered to be in fishing position for a greater proportion of the tow (Figure 285). We selected a Δ_{crit} of $4°$ because it produced an average tow distance that was near the nominal tow distance (0.25 nm, a value equal to the nominal tow speed 3 kt multiplied by the nominal tow time 5 min) and because it seemed reasonable based on examination of the engineering schematic of the dredge being used (*Figure not yet available*)

Time fishing during the 2014 survey was less than the nominal tow time in most cases due to the lower average tow speed discussed above (Figure 286).

Effects of depth

Depth is typically associated with longer tows due to the scope of the towing wire that must be deployed to assure good dredge performance. Additional scope requires longer retrieval times and may result in some additional time fishing while the slack in the wire is spooled up. This effect was evident (though noisy) during the 2014 survey (Figure 286).

Temperature

Temperature was recorded from the dredge and averaged over fishing seconds for all tows during the 2014 survey (Figure 287). Temperature was correlated with depth (Figure 287).

Figures

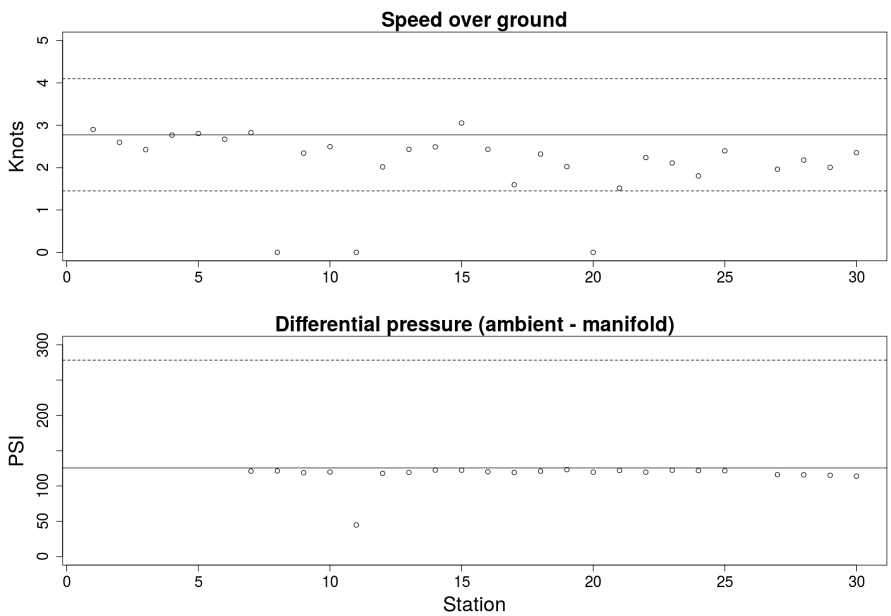


Figure 280: Speed over ground and differential pressure for each tow in the 2014 survey. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed speed over ground in 2012. Differential pressure is the difference between the pressure in the dredge manifold, which indicates the absolute pressure realized by the dredges hydraulic jets, and the ambient pressure at fishing depth. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed differential pressure in 2012. Instrument failure or lost data are represented by differential pressure equal to 0.

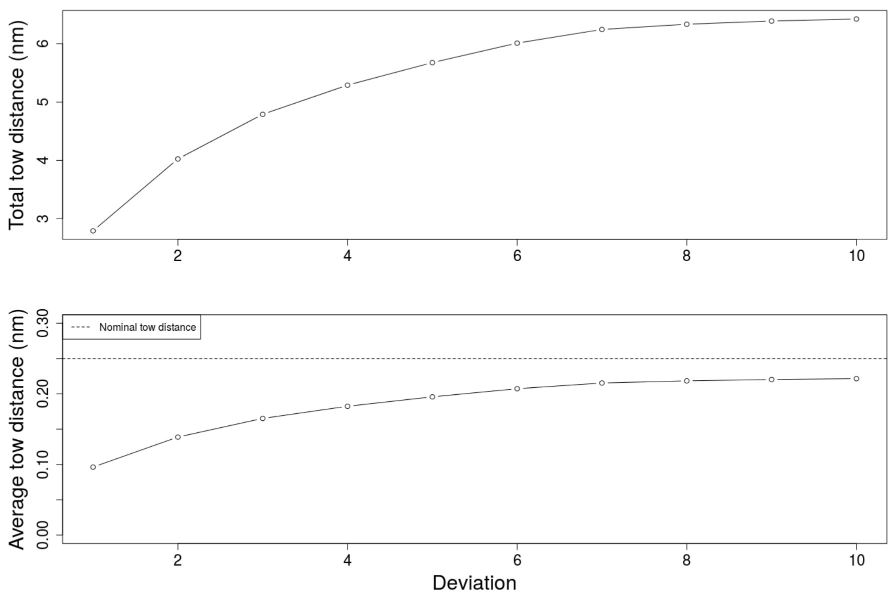


Figure 281: Average and total tow distance over all stations by critical deviation angle. The dashed line in the lower figure represents the nominal tow distance.

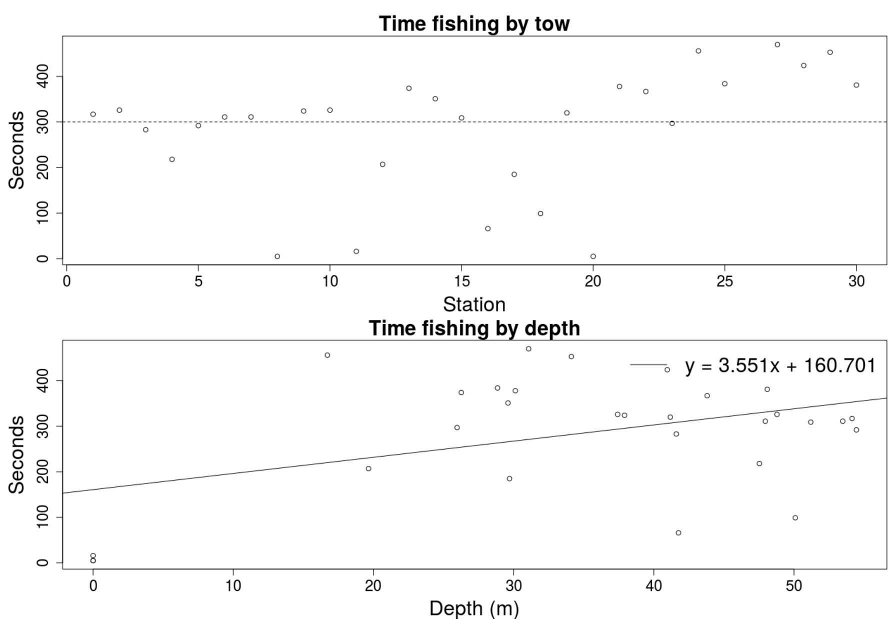


Figure 282: Time fished by station and depth. Depth significantly predicts tow time. The p value for slope was < 0.001, though the results were noisy and $R^2 < 0.14$ for the regression line shown.

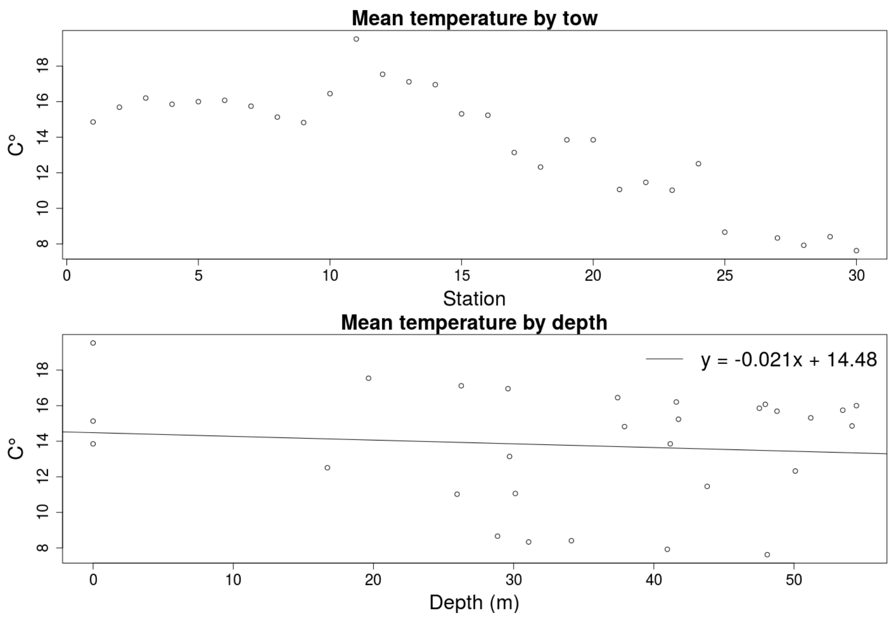


Figure 283: Temperature by station and depth. Depth significantly predicts temperature. The p value for slope was < 0.001 and $R^2 > 0.43$ for the regression line shown.

Part XXIX

Appendix: Survey performance 2015

Introduction

The 2015 survey covered a portion of the stock area including the SNE and most of GBK subareas. There were 189 total tows and two selectivity tows. At least some sensor information was recorded on every tow. Therefore there were 187 standard survey tows on which sensors were deployed and sensor data was recorded.

The 2015 survey used a modified commercial dredge with 3 on board data recorders. There was an inclinometer (Star Oddi) and two (Madge Tech) pressure sensors: one in the pump manifold measuring the pressure in the hydraulic jets used to loosen the sediments around clams and one measuring the ambient pressure at fishing depth. The inclinometer measured the pitch roll and yaw of the dredge as it was towed and was used to determine if the dredge was in a fishing position, which was the basis for determining "time fishing" on each tow. The pressure sensors were used to make sure that the pump was achieving sufficient pressure to maintain capture efficiency.

Survey performance

Sensors deployed during the 2015 survey suggest speed over ground was somewhat less than 2012, but consistent with the years since (Figure 284). Pump pressure was close to the 2012 median (Figure 284 and well within the confidence bounds observed then. Neither pump pressure nor vessel speed appeared to be less than expected based on ship board instruments during operations and the sensor data have substantial coefficients of variation. The values observed are probably well within normal operating tolerance and are probably not suggestive of changes in dredge performance.

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. Roll and yaw were relatively stable for the large modified commercial dredge and rarely fluctuated from baseline levels during fishing events. Pitch was recorded by a Star Oddi inclinometer which functioned consistently. Data from each instrument was smoothed using a 7 second moving average and then parsed for time above or below the median fishing angle for that tow.

In order to account for median pitch $> 0^o$, the determination of time fishing was based on a critical deviation from median pitch, rather than an absolute critical pitch angle. The choice of critical deviation has implications for the calculation of tow distance for each tow. When the dredge is above or below the critical deviation it is assumed to be pitched too steeply for the blade to penetrate the sediment. If the dredge is pitched within Δ_{crit} (the critical deviation) of $\tilde{\phi}_t$ (the median pitch for tow t), it assumed to be near enough to parallel to the bottom that the blade should penetrate and thus be actively fishing.

An ideal critical deviation is as close to zero as possible, but not so small that it includes poor dredge performance seconds. 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 deviation is too small, many seconds when the dredge is actually fishing would be excluded, which would tend to bias estimates of tow distance down. It is therefore important to find a critical deviation that is neither too small, nor too large.

The choice of Δ_{crit} was informed by an examination of the total and average tow distances based on different critical deviations. Total tow distance summed across all tow and average tow distance over all tows was compared when different values of Δ_{crit} were used. In general higher values of Δ_{crit} result in longer tows because the dredge is considered to be in fishing position for a greater proportion of the tow (Figure 285). We selected a Δ_{crit} of 4° because it produced an average tow distance that was near the nominal tow distance (0.25 nm, a value equal to the nominal tow speed 3 kt multiplied by the nominal tow time 5 min) and because it seemed reasonable based on examination of the engineering schematic of the dredge being used (*Figure not yet available*)

Time fishing during the 2015 survey was less than the nominal tow time in most cases due to the lower average tow speed discussed above (Figure 286).

Effects of depth

Depth is typically associated with longer tows due to the scope of the towing wire that must be deployed to assure good dredge performance. Additional scope requires longer retrieval times and may result in some additional time fishing while the slack in the wire is spooled up. This effect was evident (though noisy) during the 2015 survey (Figure 286).

Temperature

Temperature was recorded from the dredge and averaged over fishing seconds for all tows during the 2015 survey (Figure 287). Temperature was correlated with depth (Figure 287).

Figures

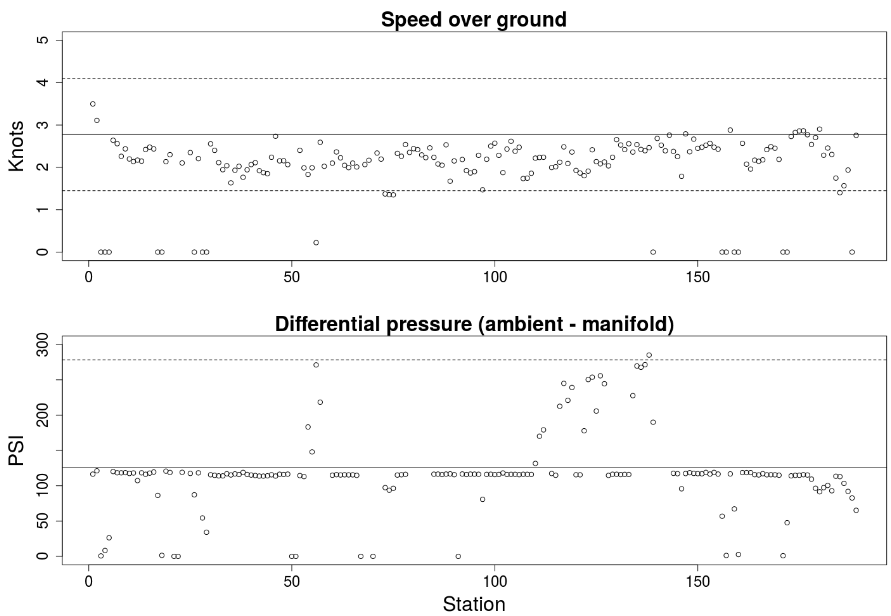


Figure 284: Speed over ground and differential pressure for each tow in the 2015 survey. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed speed over ground in 2012. Differential pressure is the difference between the pressure in the dredge manifold, which indicates the absolute pressure realized by the dredges hydraulic jets, and the ambient pressure at fishing depth. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed differential pressure in 2012. Instrument failure or lost data are represented by differential pressure equal to 0.

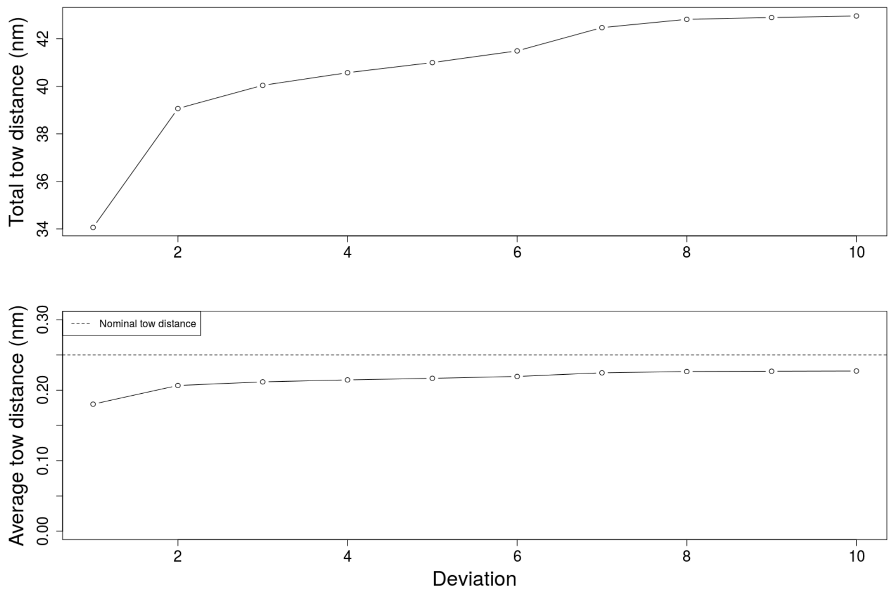


Figure 285: Average and total tow distance over all stations by critical deviation angle. The dashed line in the lower figure represents the nominal tow distance.

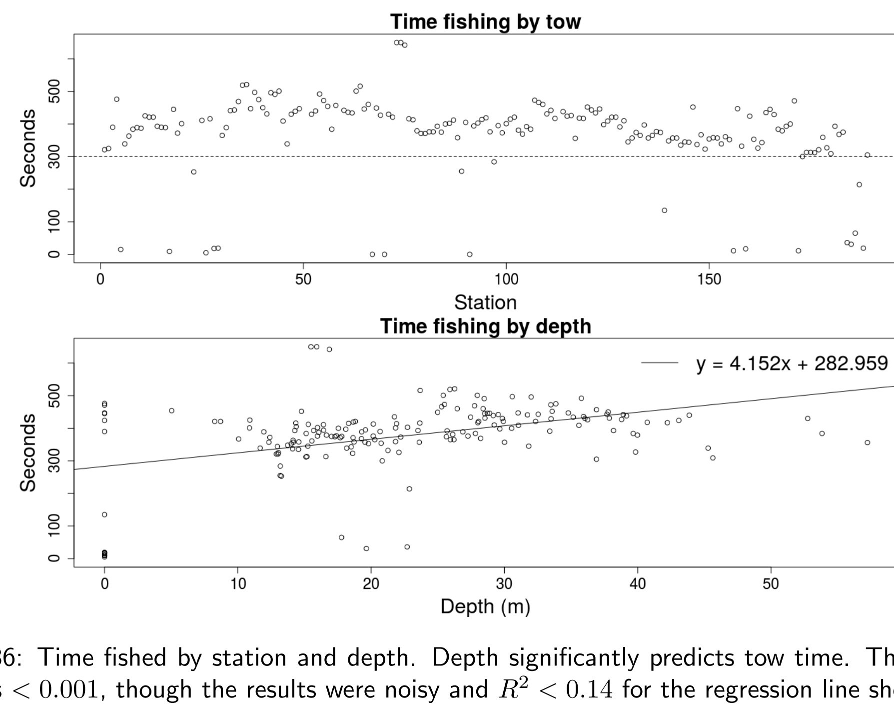


Figure 286: Time fished by station and depth. Depth significantly predicts tow time. The p value for slope was < 0.001, though the results were noisy and $R^2 < 0.14$ for the regression line shown.

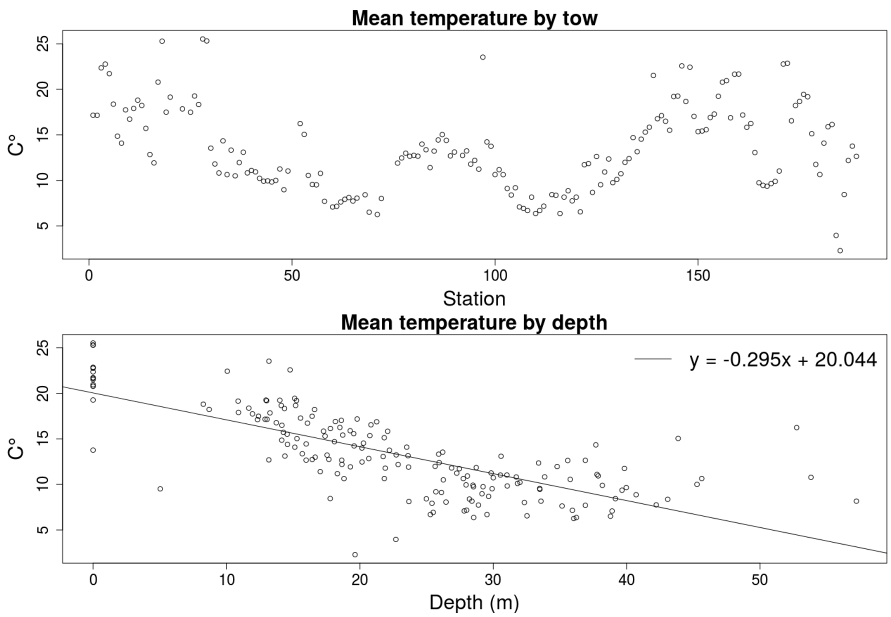


Figure 287: Temperature by station and depth. Depth significantly predicts temperature. The p value for slope was < 0.001 and $R^2 > 0.43$ for the regression line shown.