Appendix 1 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)
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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)
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Appendix 2 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 170). 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 171). 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 172).

Figures

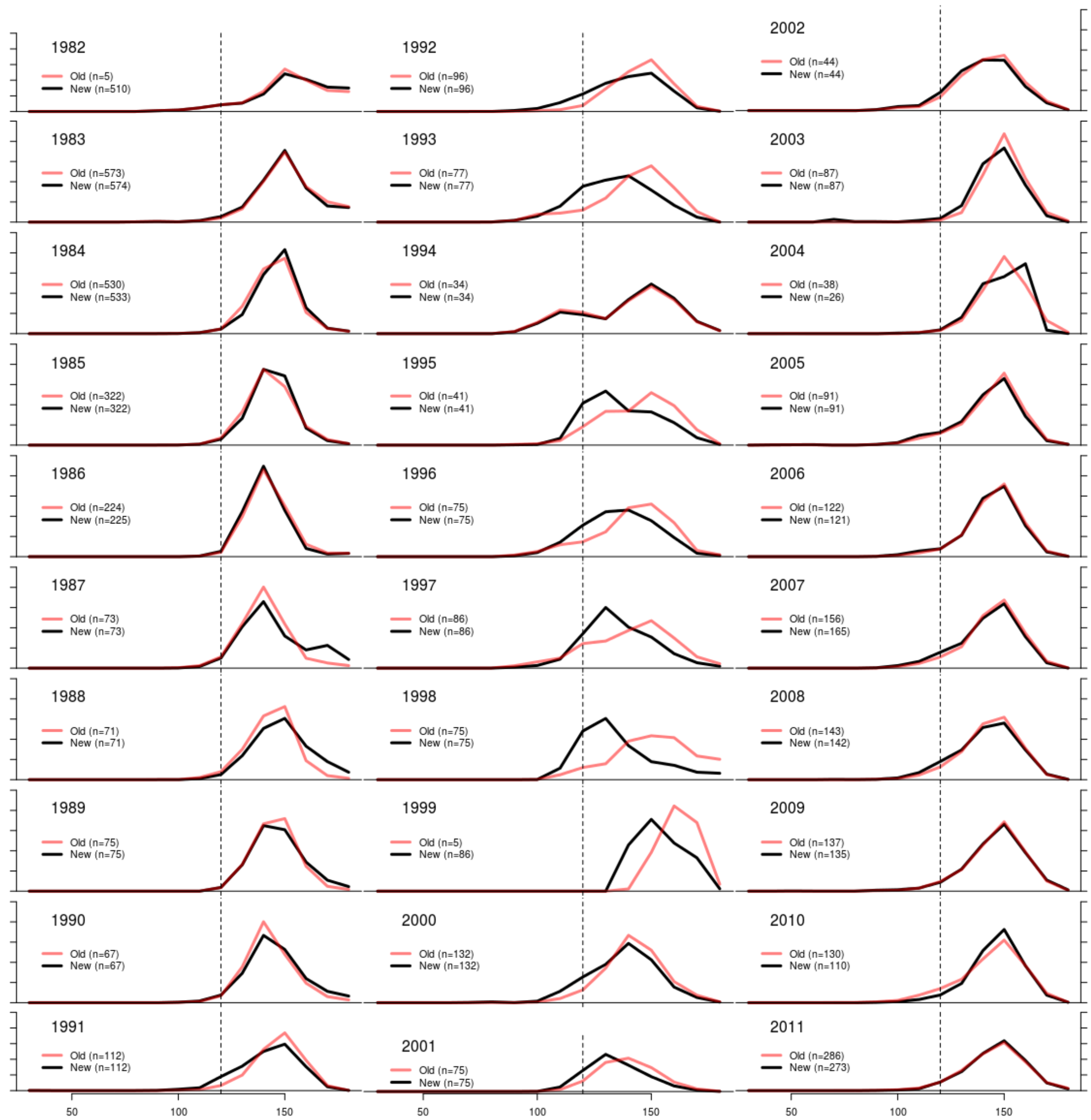


Figure 170: A comparison of the length compositions used on the surfclam assessment model in the last assessment (Old) vs. the current assessment (New). The x axis shows the shell length in mm and the y axis shows the relative frequency at each shell length. The sample sizes (n=) in the previous assessment 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.

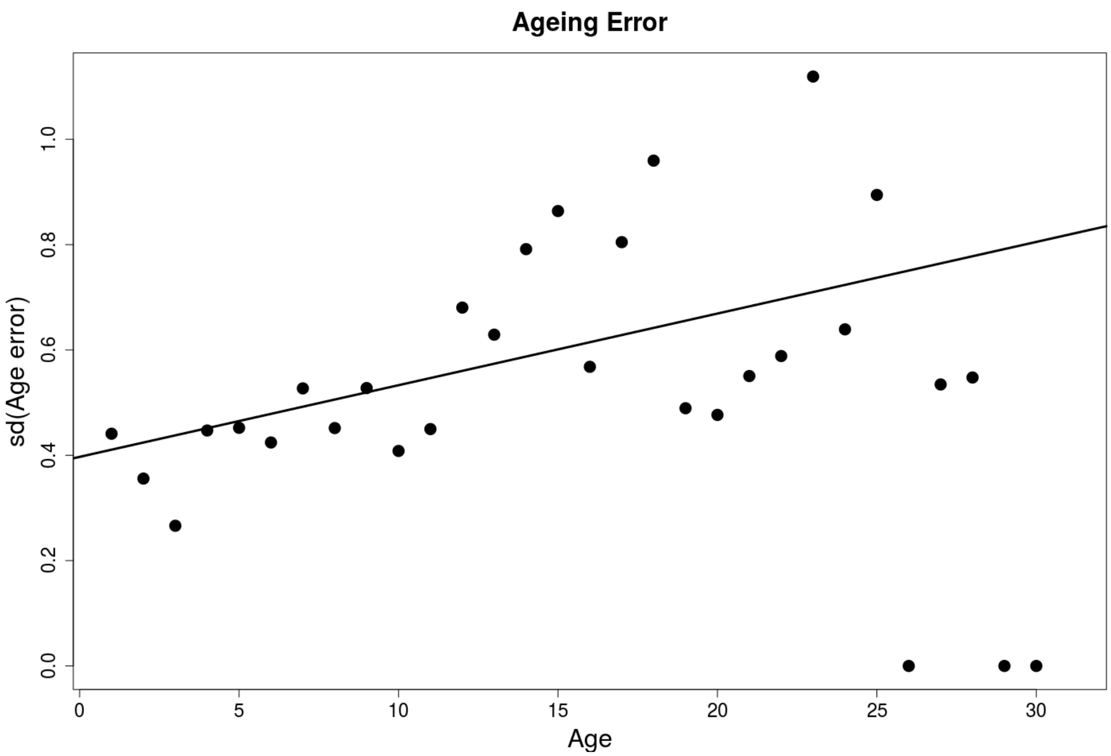


Figure 171: The standard deviation of the difference between production age and the re-age done to test ageing error against a linear fit.

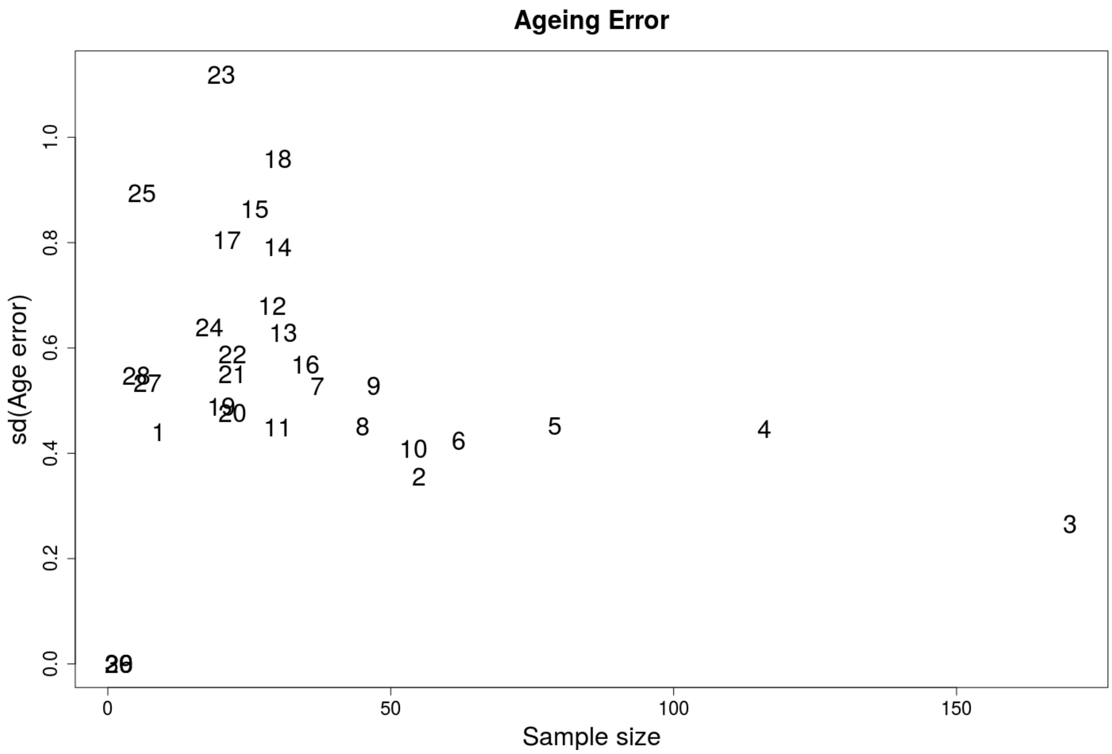


Figure 172: The sample size at age for standard deviation of the difference between production age and the re-age done to check ageing error. Each age is plotted as a numeral.

Appendix 3 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 173) and efficiency (Figure 174). 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 175).

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 176). 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 173).

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 177). 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 173), and fits to length composition data (Figures 175 and 180) were relatively minor. The scale, trend and terminal year status of estimated biomass was preserved with the altered inputs (Figures 181 and 182). Precision of the estimates improved with the altered data (Table 36). Conclusions about stock status with regard to fishing mortality were unchanged (Figures 181 and 182). 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

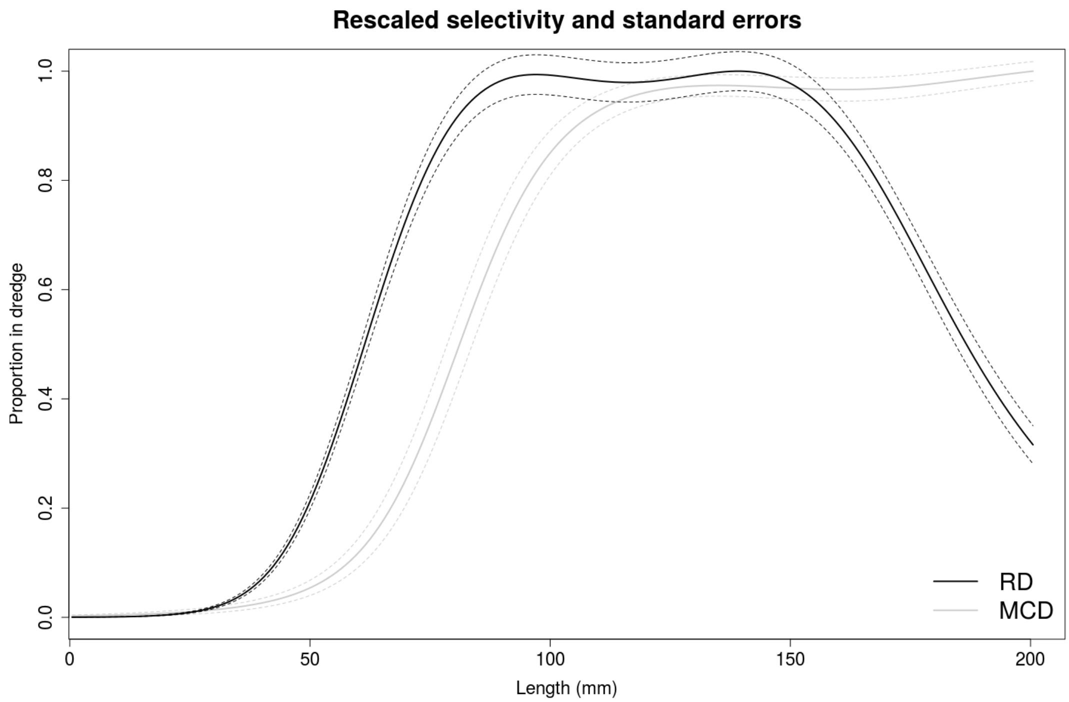


Figure 173: Selectivity differences between the MCD and RD. Curves have been rescaled so that the maximum selectivity for each curve is 1.

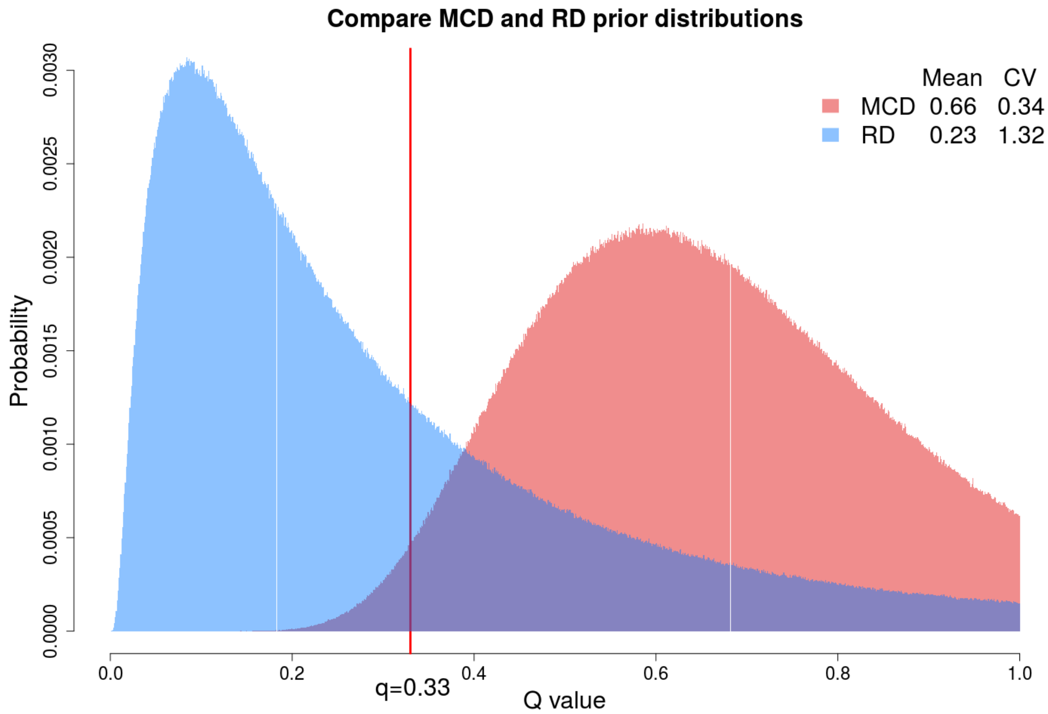


Figure 174: Differences in dredge efficiency between the MCD and RD, with the current dredge efficiency estimated in the assessment ($q = 0.33$) shown.

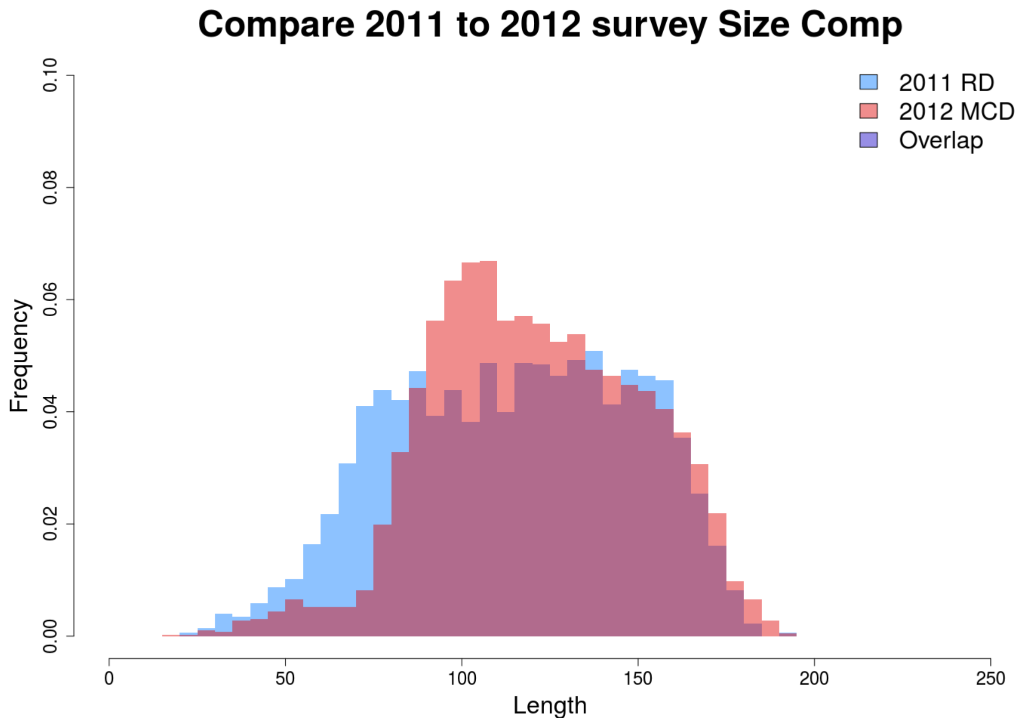


Figure 175: Length composition of survey samples from MCD and RD. Because the 2012 survey did not cover SNE or GBK, only samples from regions that were covered in both surveys are shown here.

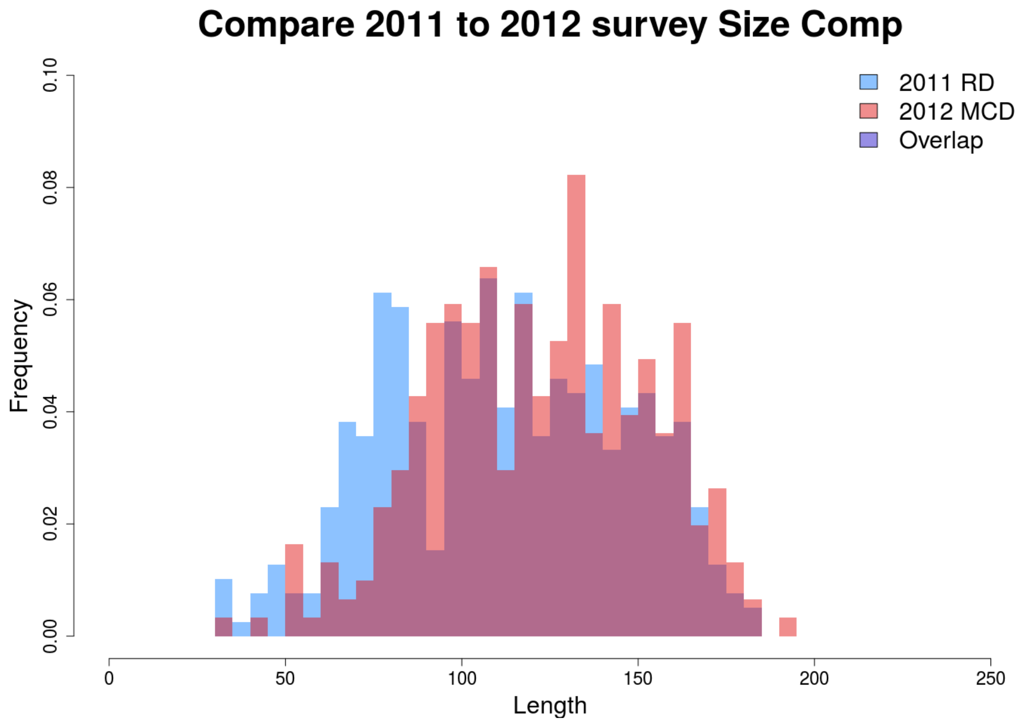


Figure 176: Length composition of survey samples that will eventually be aged from MCD and RD. Because the 2012 survey did not cover SNE or GBK, only samples from regions that were covered in both surveys are shown here.

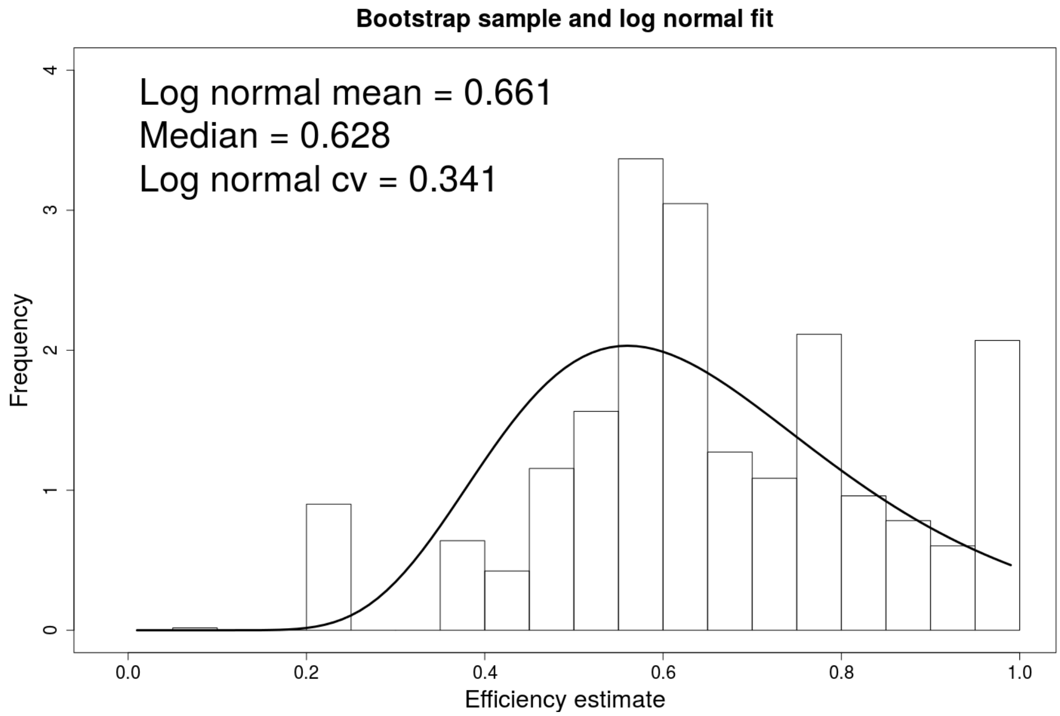
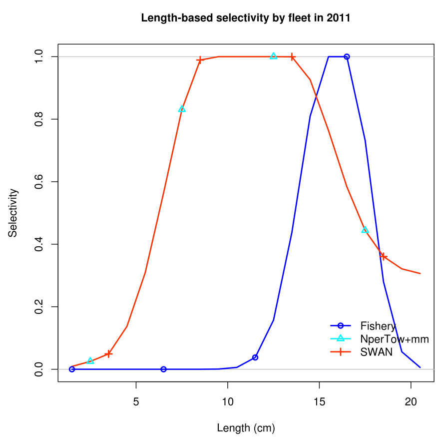
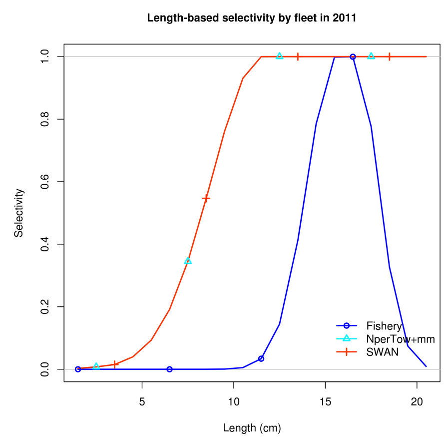


Figure 177: Log normal fit to a variance weighted bootstrap of MCD efficiency from field depletion studies.



(a) RD selectivity



(b) MCD selectivity

Figure 178: 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.

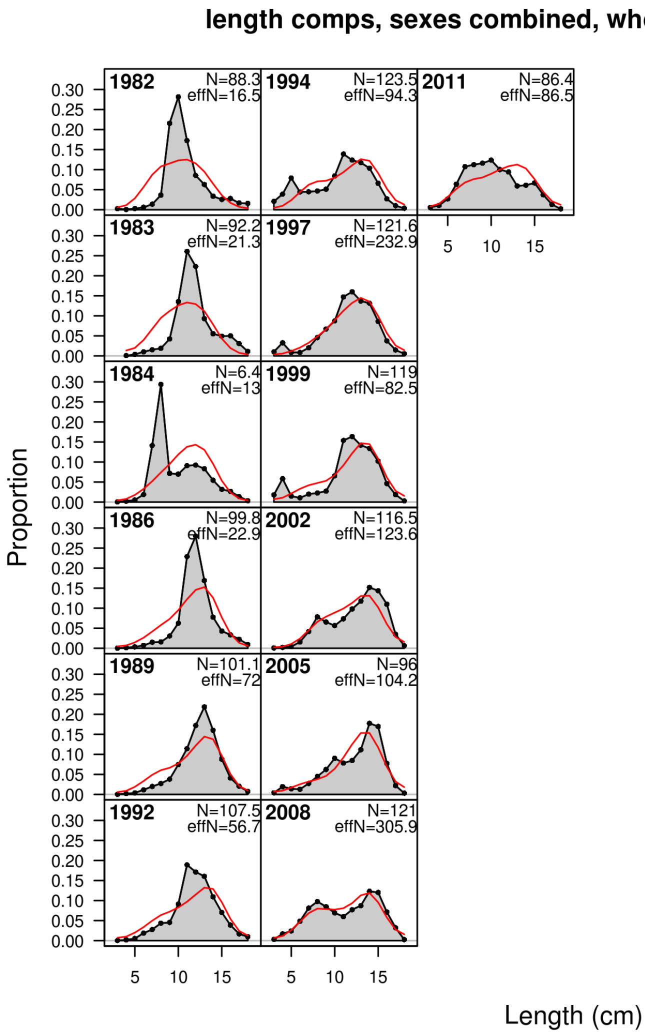


Figure 179: 2013 Atlantic surfclam assessment model fits to length composition data.

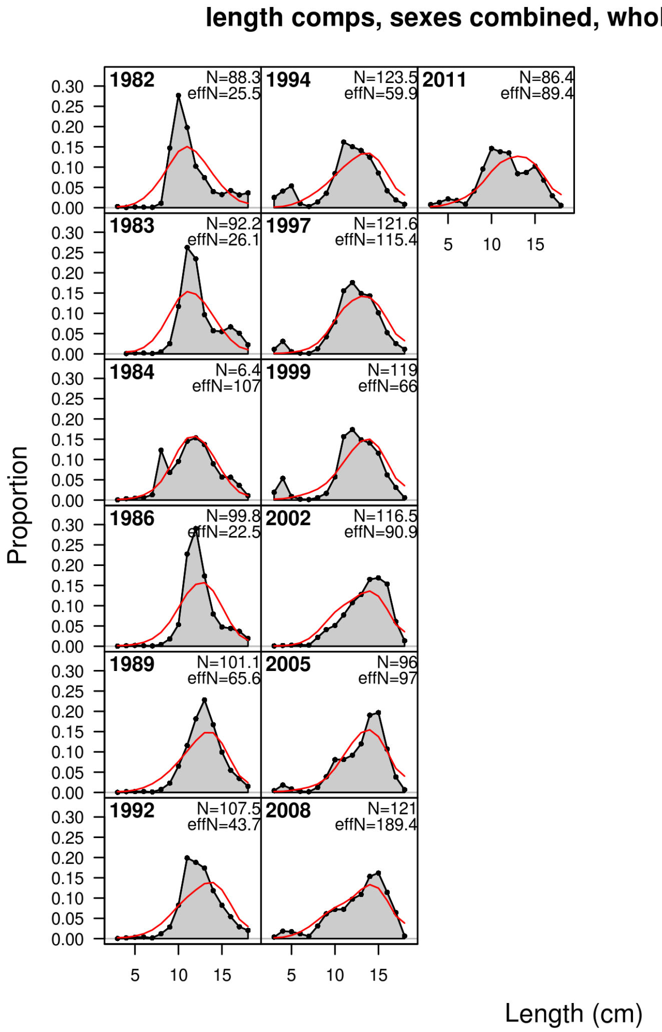


Figure 180: Fits to length composition data using modified selectivity, length composition and survey catchability prior.

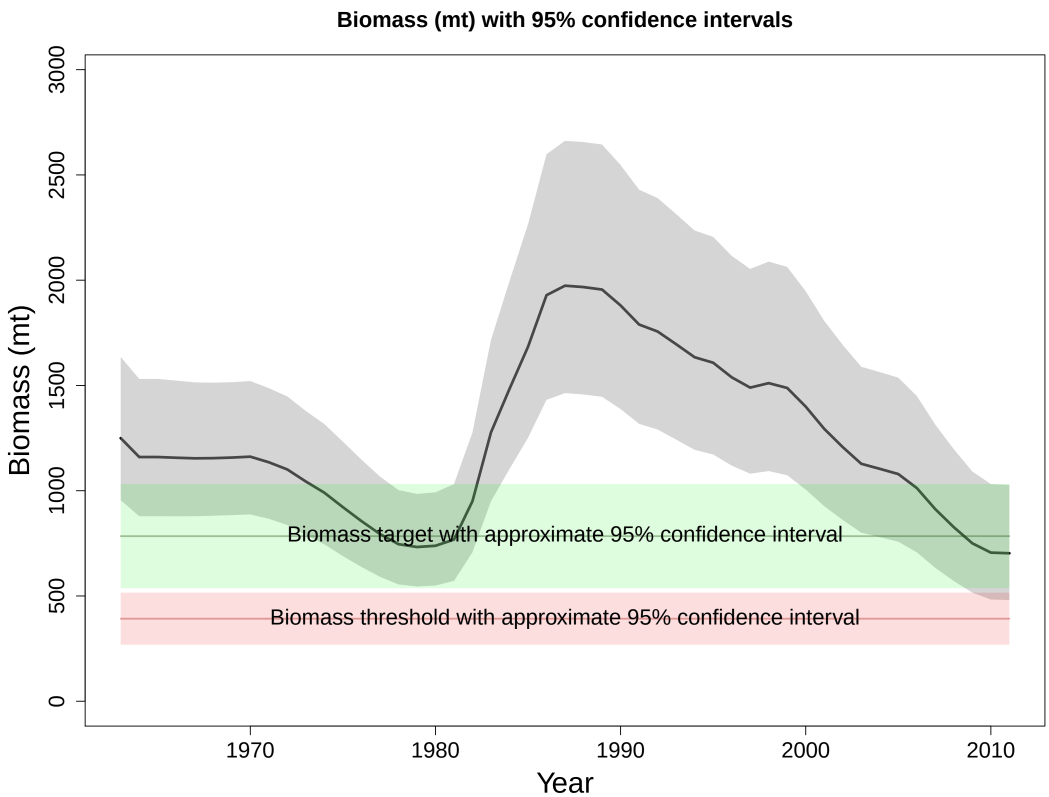


Figure 181: Biomass (1000 mt) trajectory and status estimated in the 2013 Atlantic surfclam assessment.

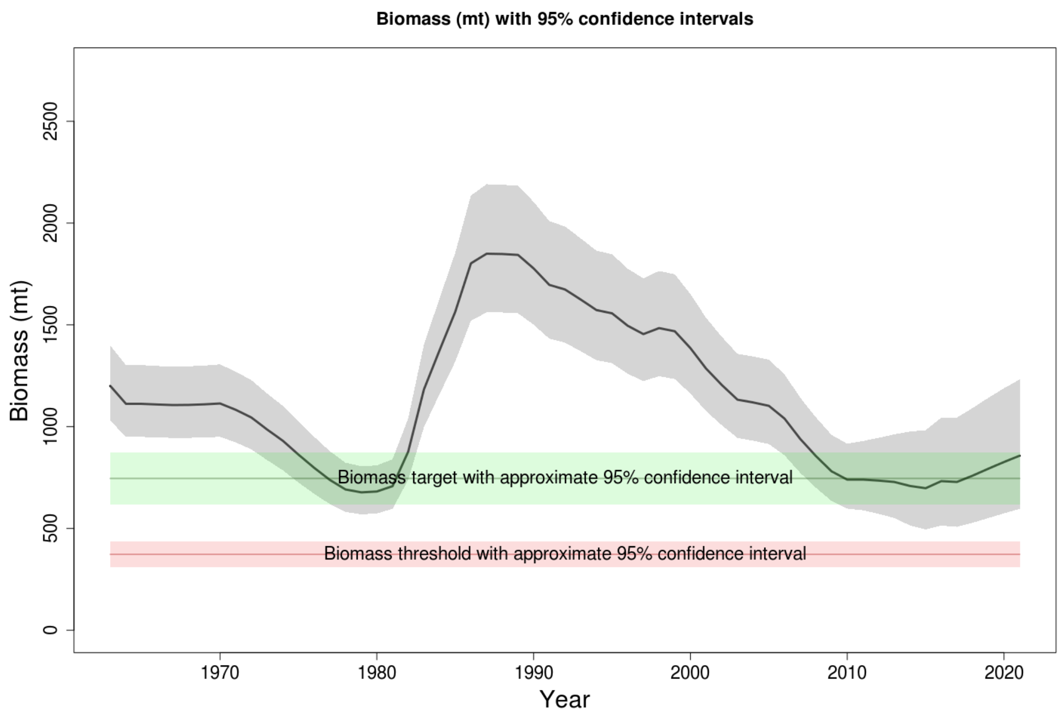


Figure 182: Biomass (1000 mt) trajectory using modified selectivity, length composition and survey catchability prior. The projection results assume status quo fishing.

Appendix 4 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 53).

The depletion experiments have thus far been conducted in the southern area, with the most effort concentrated in the NJ region (Figure 183)

Tables

Table 37: Estimated dredge capture efficiency from depletion experiments. All experiments were conducted using a modified commercial dredge similar to, though somewhat smaller than the dredge that has been used for the NEFSC clam survey since 2012. Experiments after 2007 were conducted using the same dredge used in the survey.

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

Figures

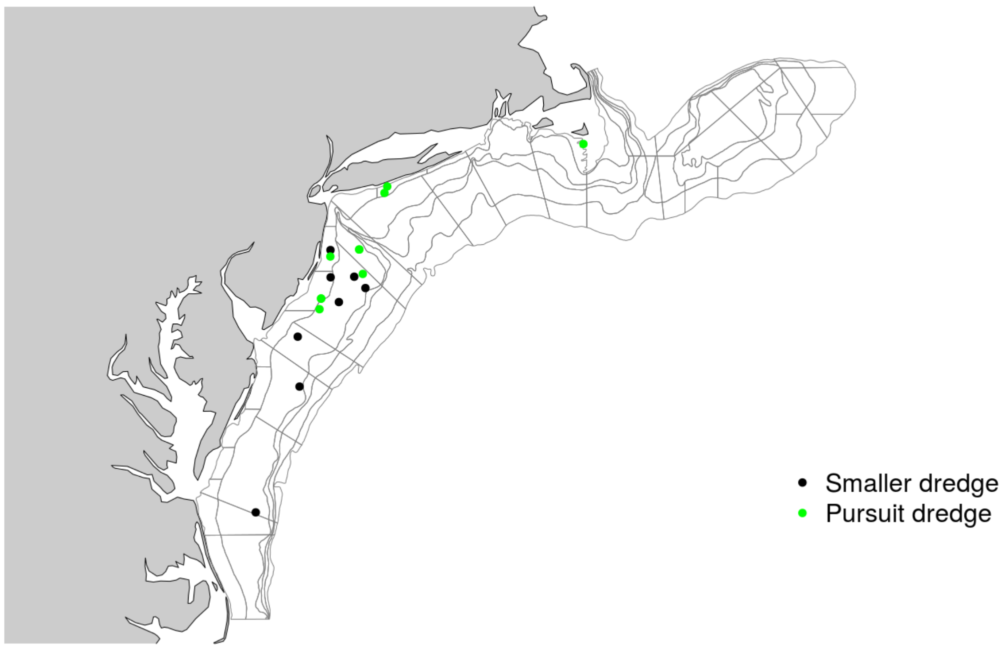


Figure 183: Position of each depletion experiment. The different colors represent the depletion experiments done with different dredges. The green dots are the experiments done with the dredge being used currently on the NEFSC clam survey.

Appendix 5 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 184 - 185) 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 186) 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.

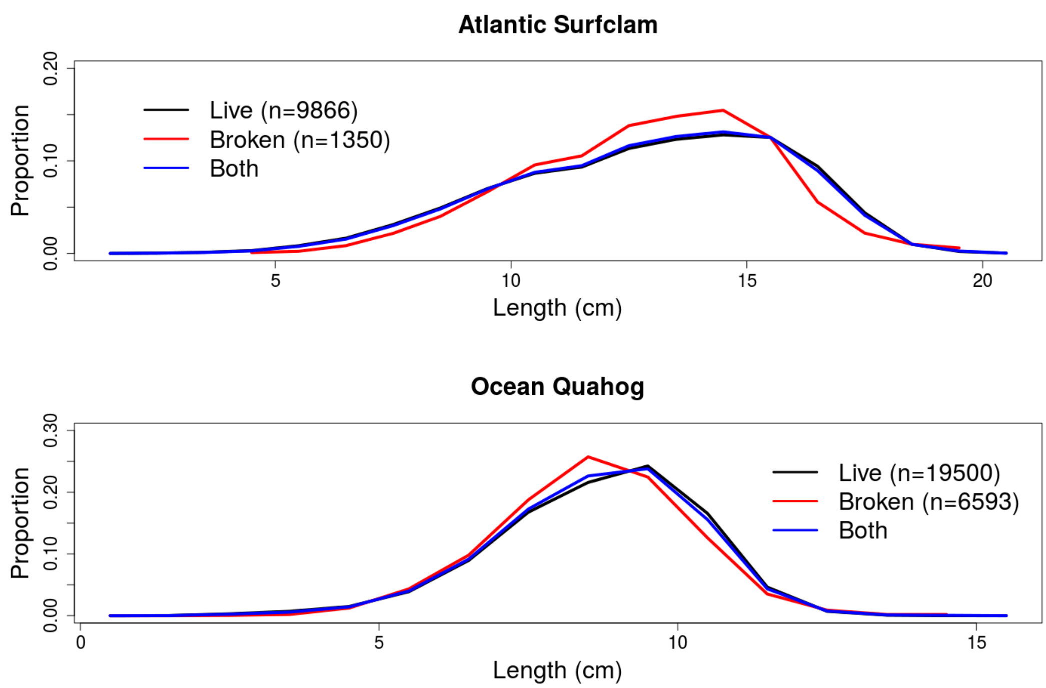


Figure 184: Length compositions from clam surveys on the ESS Pursuit through 2014. Proportion at length using only live (whole) clams, only broken clams, and live and broken clams together. There is very little difference between the length composition based only on live animals and the length composition using both whole and broken animals for both Atlantic surfclam and ocean quahog.

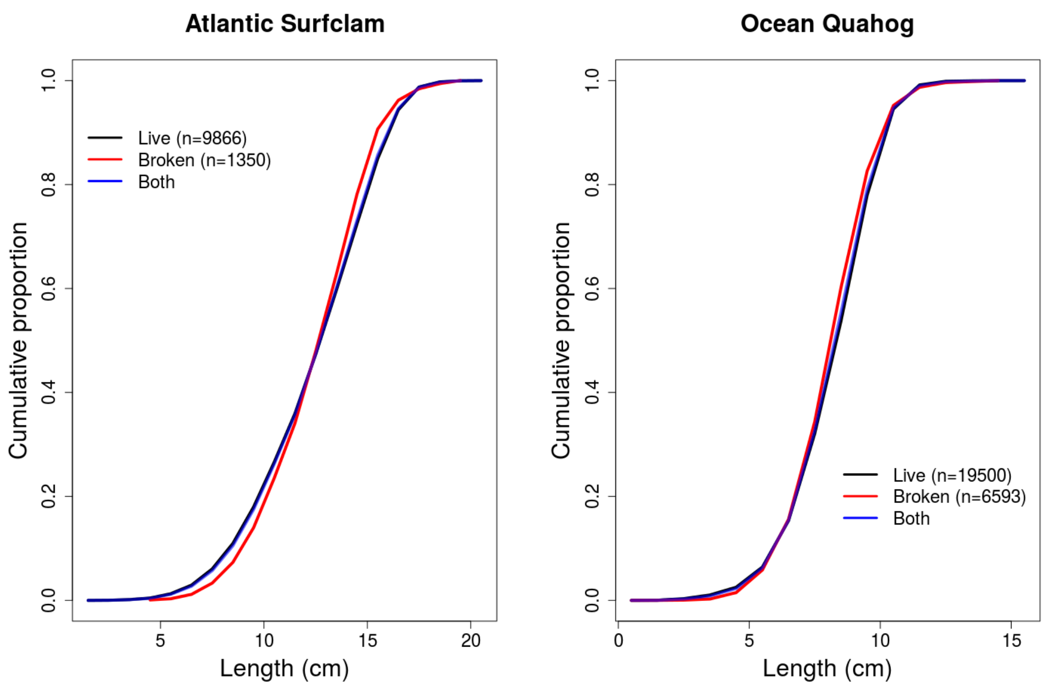


Figure 185: Cumulative length compositions from clam surveys on the ESS Pursuit through 2014. Cumulative proportion at length using only live (whole) clams, only broken clams, and live and broken clams together. There is very little difference between the cumulative length composition based only on live animals and the length composition using both whole and broken animals for both Atlantic surfclam and ocean quahog.

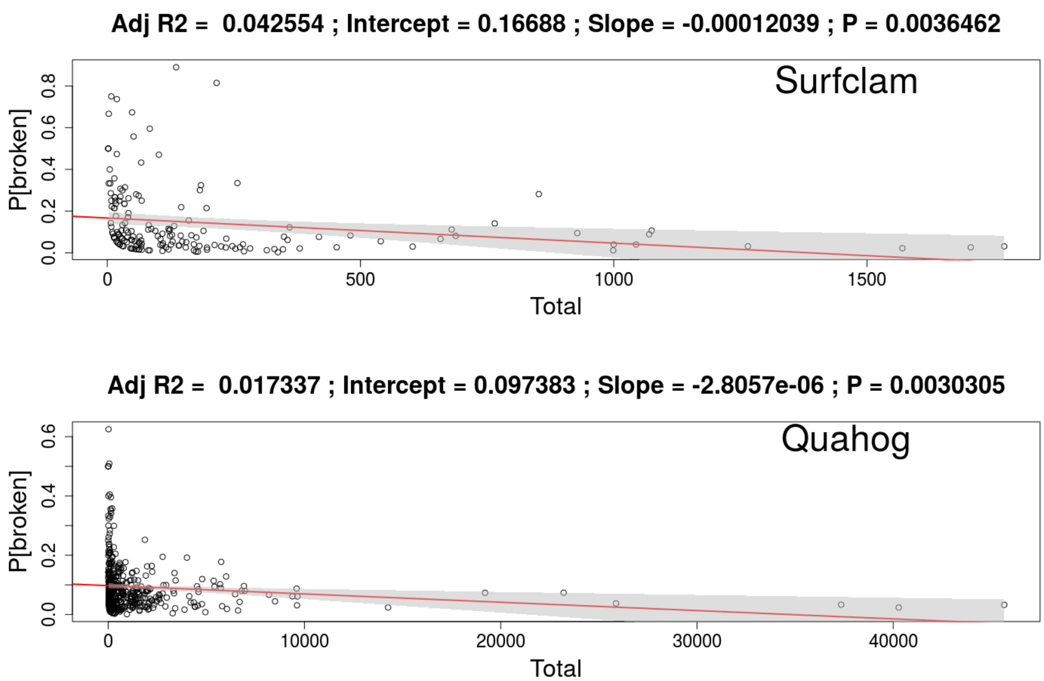


Figure 186: Correlation between the proportion of broken clams to the total clams caught in each tow from clam survey on the ESS Pursuit through 2014. The relationship was weak for both Atlantic surfclam and ocean quahog.

Appendix 6 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 187). 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 188). The MCD also required a different prior probability distribution on catchability (Figure 189). The error around the growth curve was adjusted to follow a constant cv rather than a constant standard deviation (Figure 190). 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 191) as the model began to fit the survey more closely. The ageing error was estimated, incorporating precision data from recent surveys (Figure 192). The cv of growth for young and old animals was estimated, rather than assumed (Figure 193). 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 194). 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 195). 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 196). 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 197).

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 198). 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 199). The MCD required a different prior probability distribution on catchability (Figure 200). 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 201). 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 202) 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 203). The MCD survey used a different dredge and required different selectivity parameters (Figure 204). The cv of growth for young and old animals was reduced to field estimated values (Figure 205). 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 206).

Figures

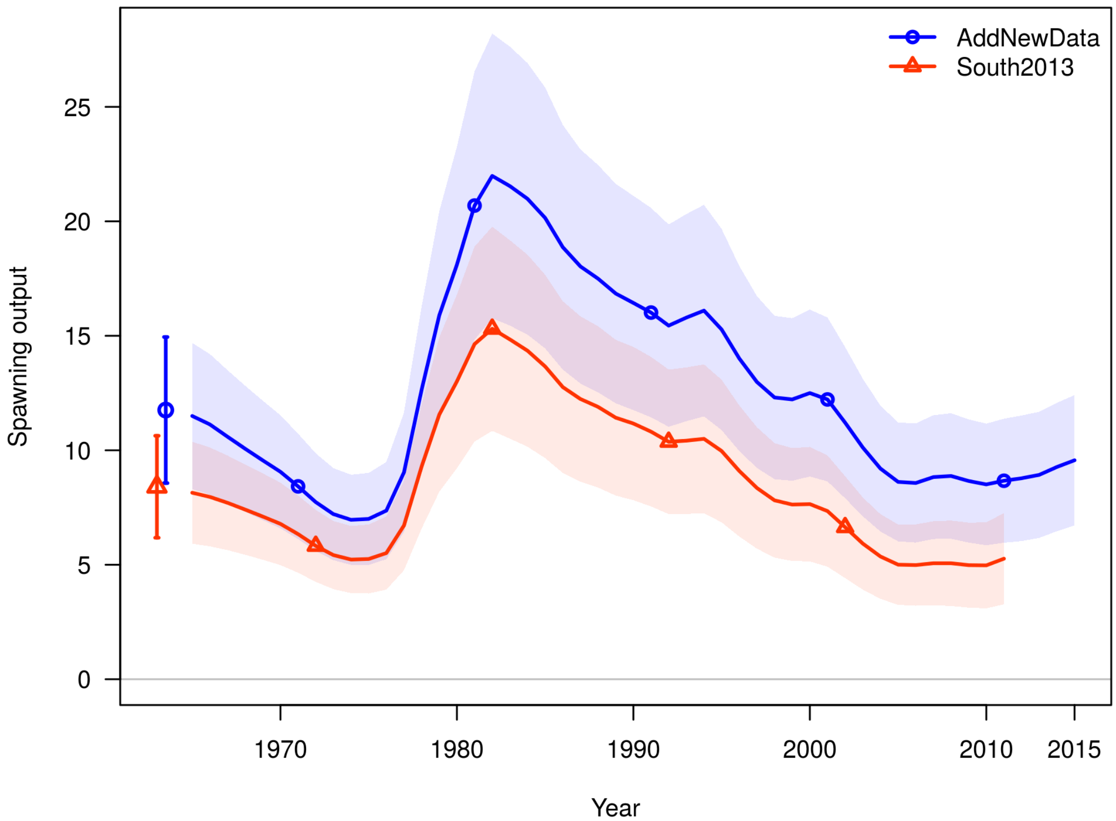


Figure 187: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model with identical configuration, but incorporating data from additional years (AddNewData).

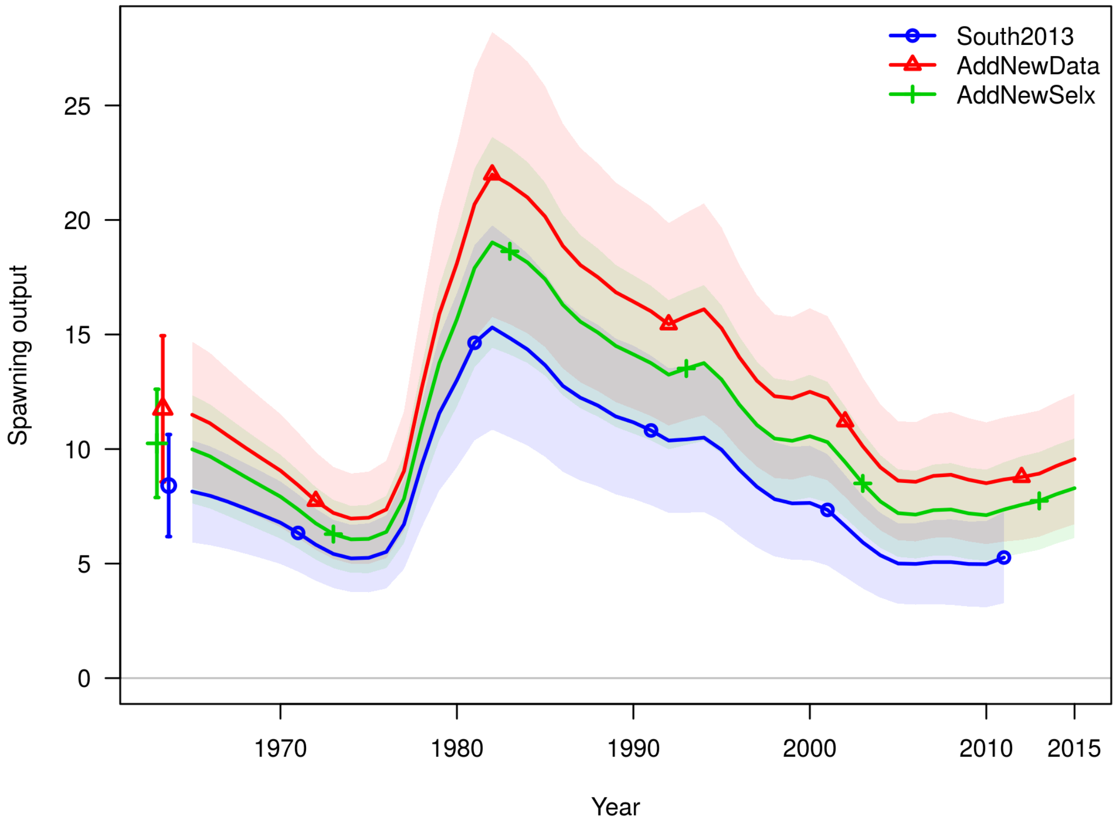


Figure 188: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model incorporating the selectivity of the new survey (AddNewSelx), as well as the previous model iteration (AddNewData).

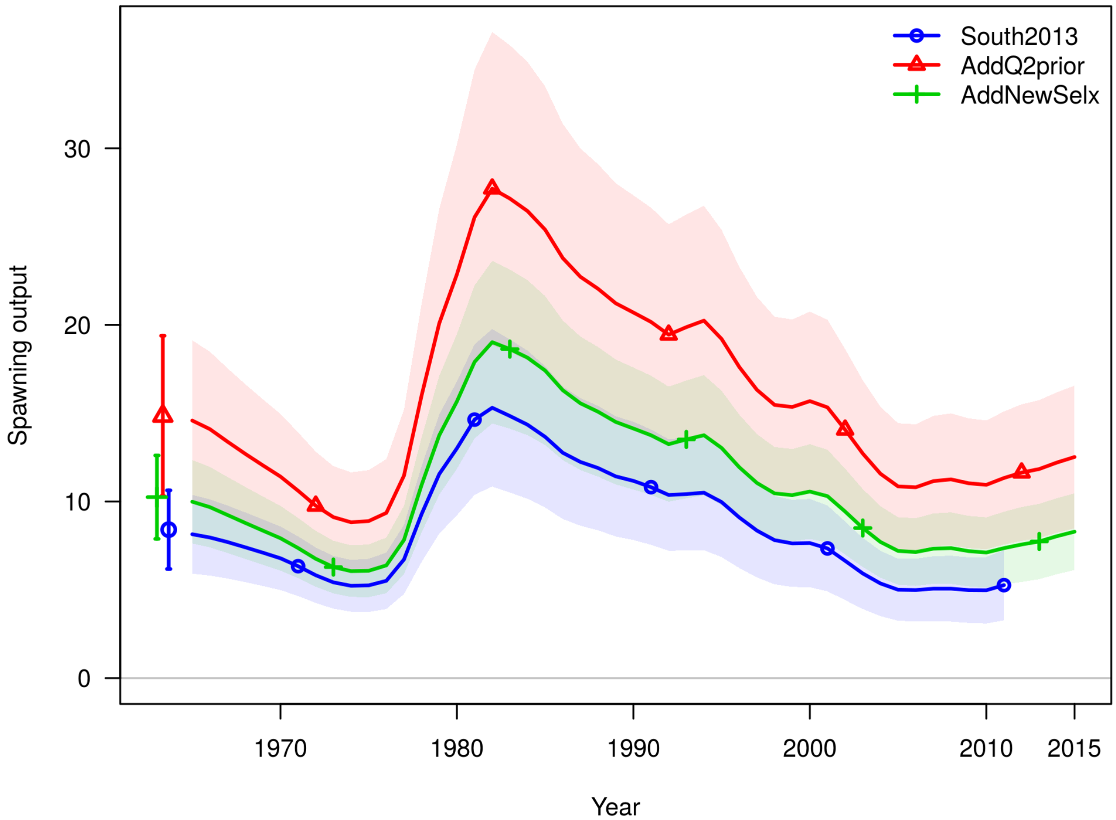


Figure 189: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model incorporating the prior on catchability for the MCD (AddQ2prior), as well as the previous model iteration (AddNewSelx).

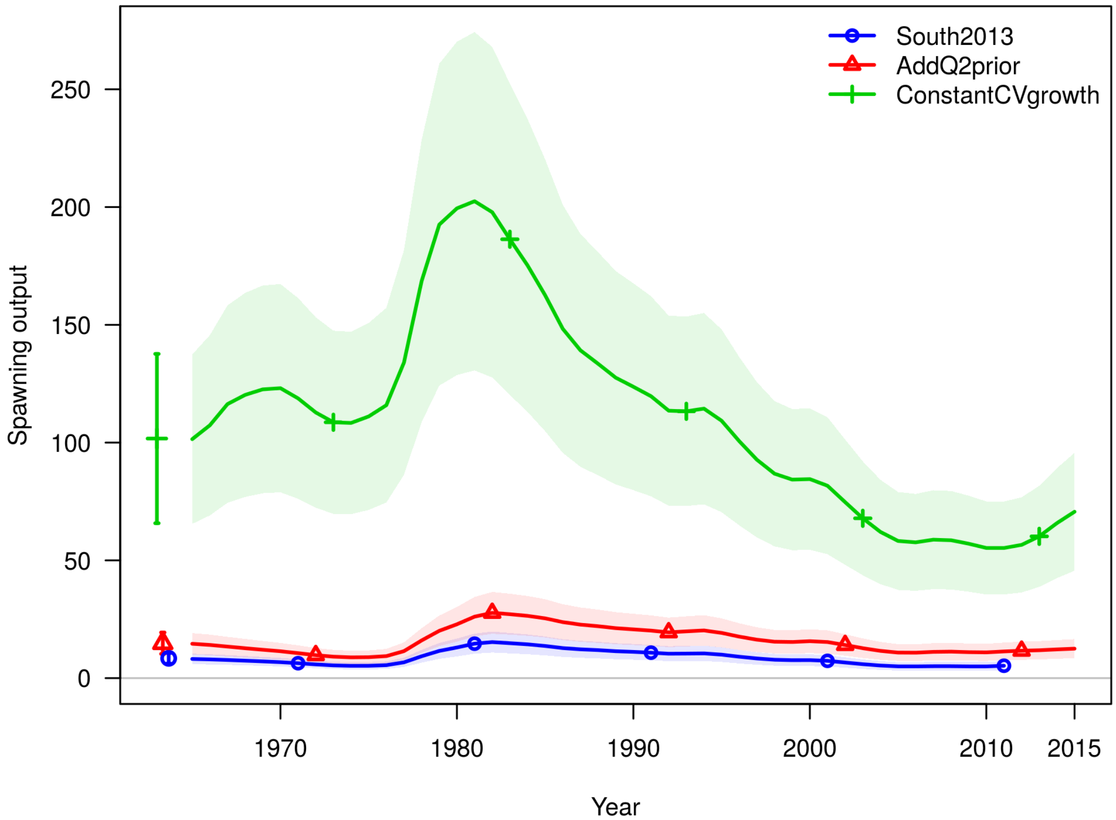


Figure 190: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model where the error around the growth curve has a constant cv rather a constant standard deviation (ConstantCVgrowth), as well as the previous model iteration (AddQ2prior).

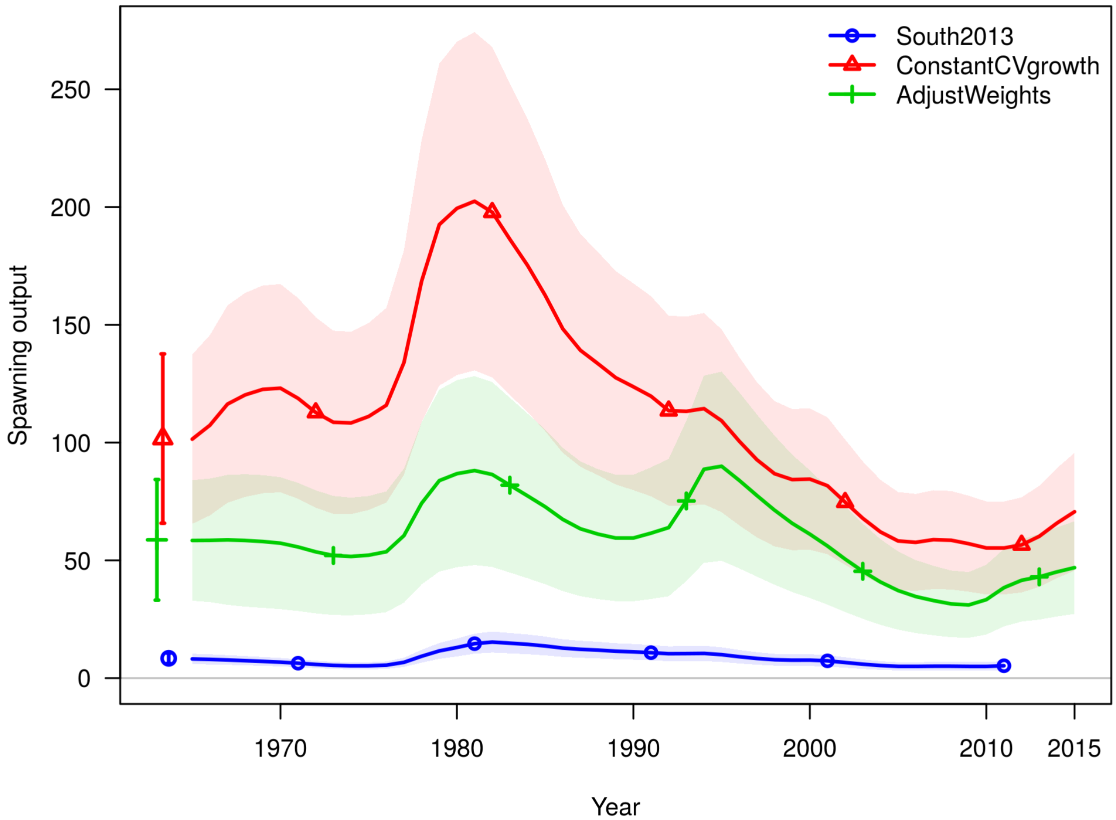


Figure 191: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model where relative weightings of the data sources has been adjusted so that the information content of the composition data is decremented (AdjustWeights), as well as the previous model iteration (ConstantCVgrowth).

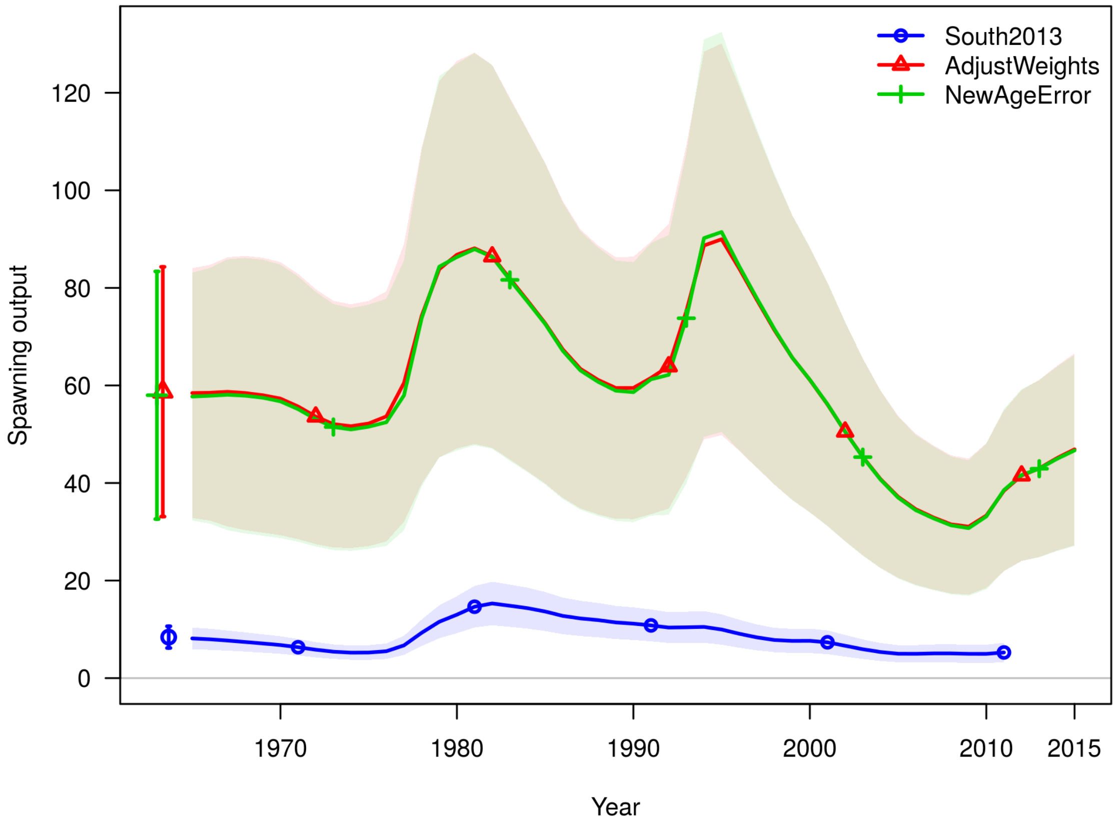


Figure 192: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model incorporating the new ageing error vector (NewAgeError), as well as the previous model iteration (AdjustWeights).

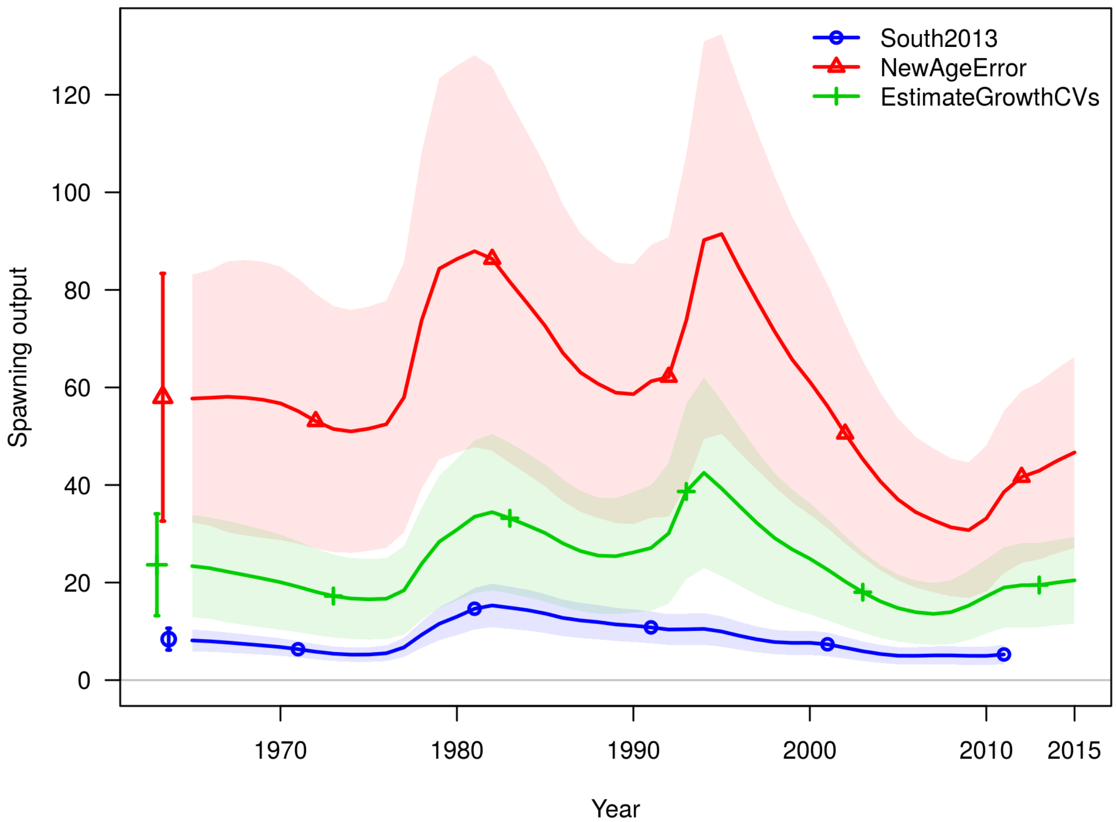


Figure 193: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model that estimates the cv of growth at the oldest and youngest ages (EstimateGrowthCVs), as well as the previous model iteration (NewAgeError).

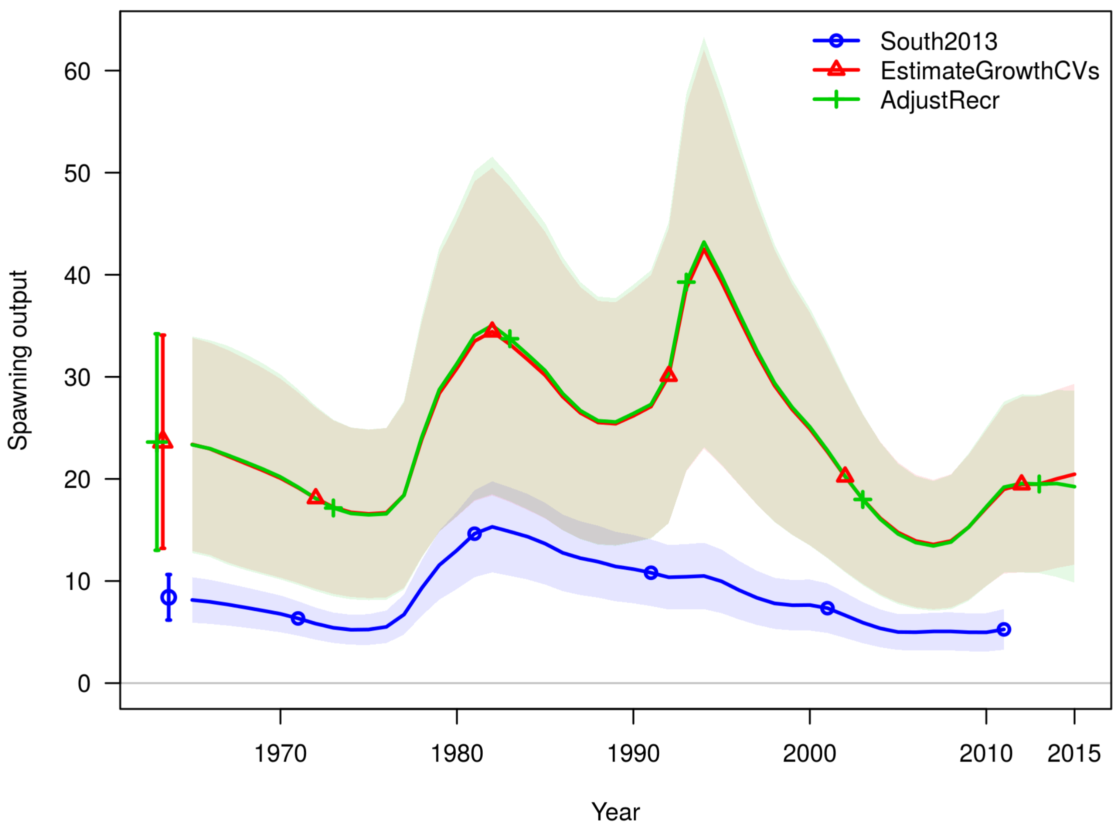


Figure 194: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model that estimates additional recruitment deviations and adjusts the parameters of the recruitment bias curve (AdjustRecr), as well as the previous model iteration (EstimateGrowthCVs).

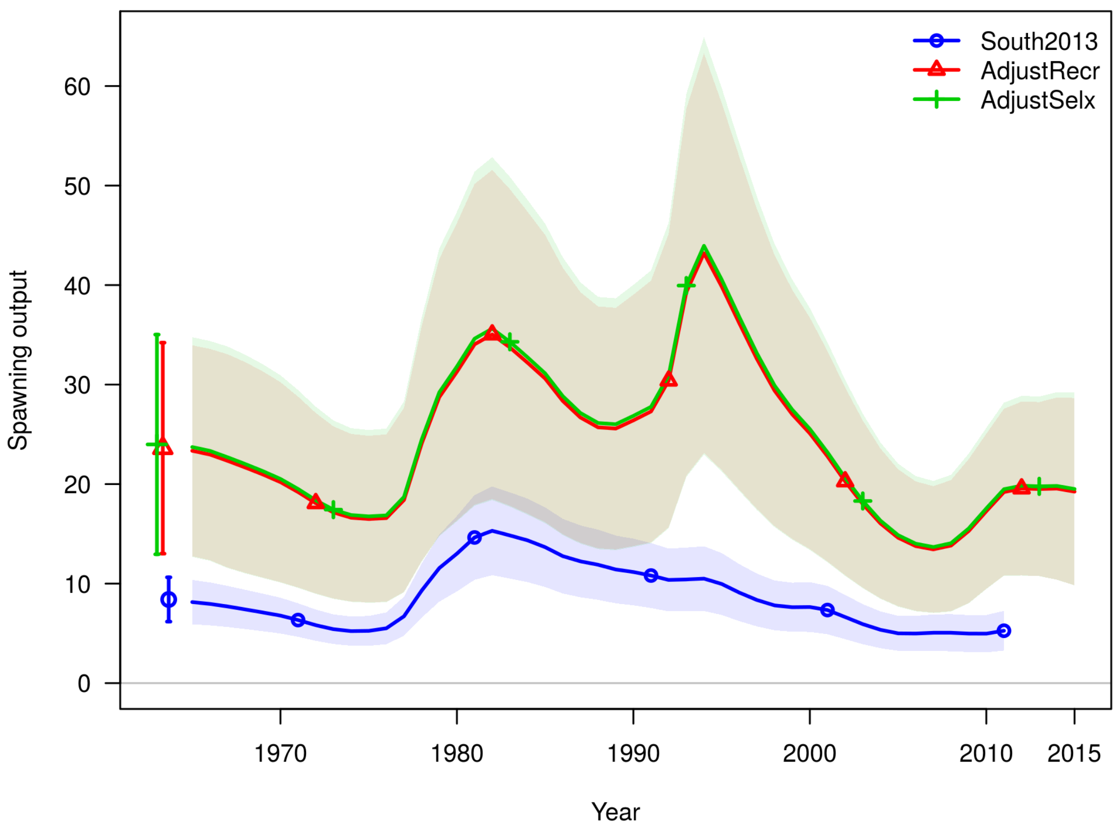


Figure 195: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model that estimates additional selectivity parameters and adjusts the right side of the MCD selectivity curve (AdjustSelx), as well as the previous model iteration (AdjustRecr).

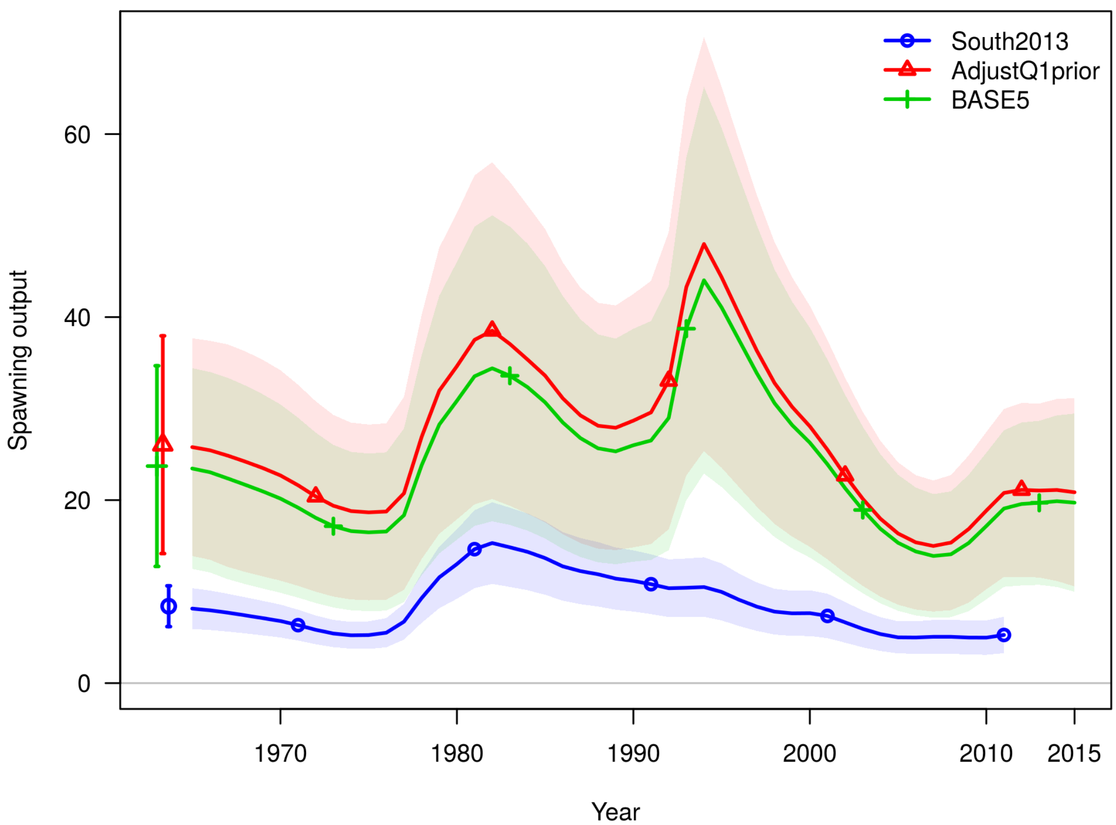


Figure 196: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model that includes a small adjustment to the prior distribution for the RD that brings it in line with the field prior distribution described in the last assessment (AdjustQ1prior), as well as the base model from the current assessment (BASE5).

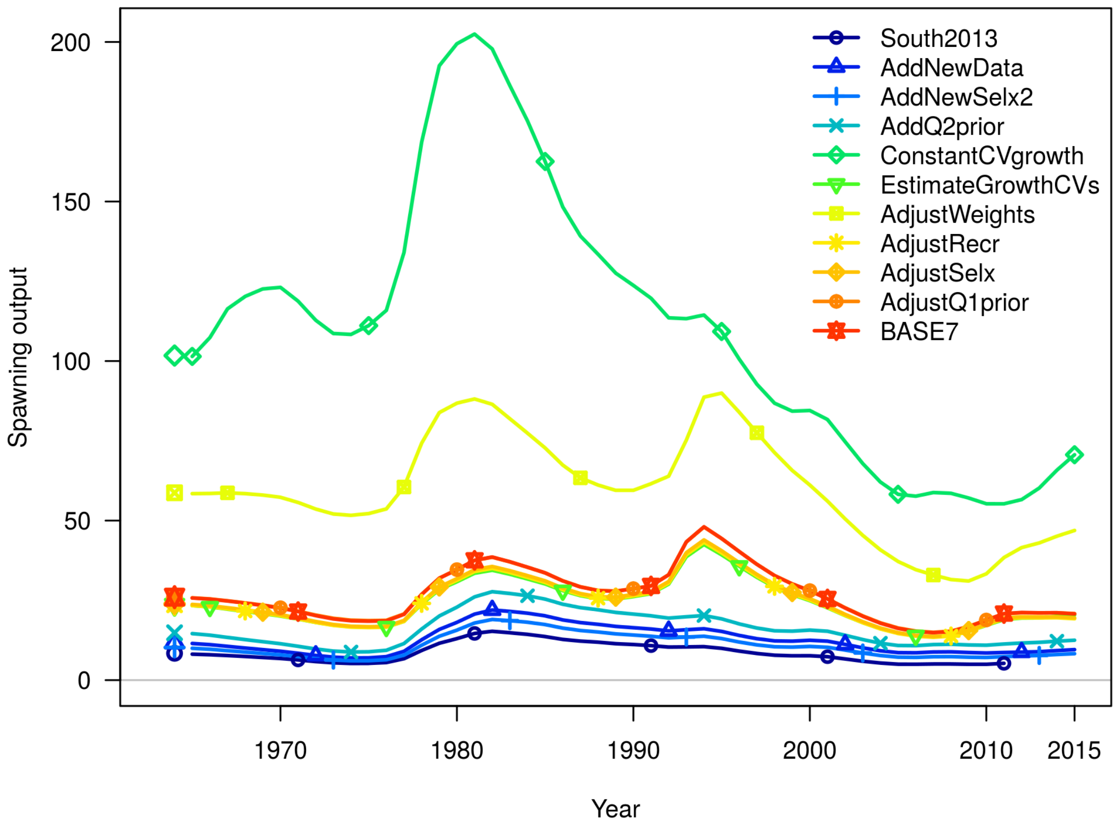


Figure 197: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to each iteration in the sequence of model changes, as well as the base model from the current assessment (BASE7).

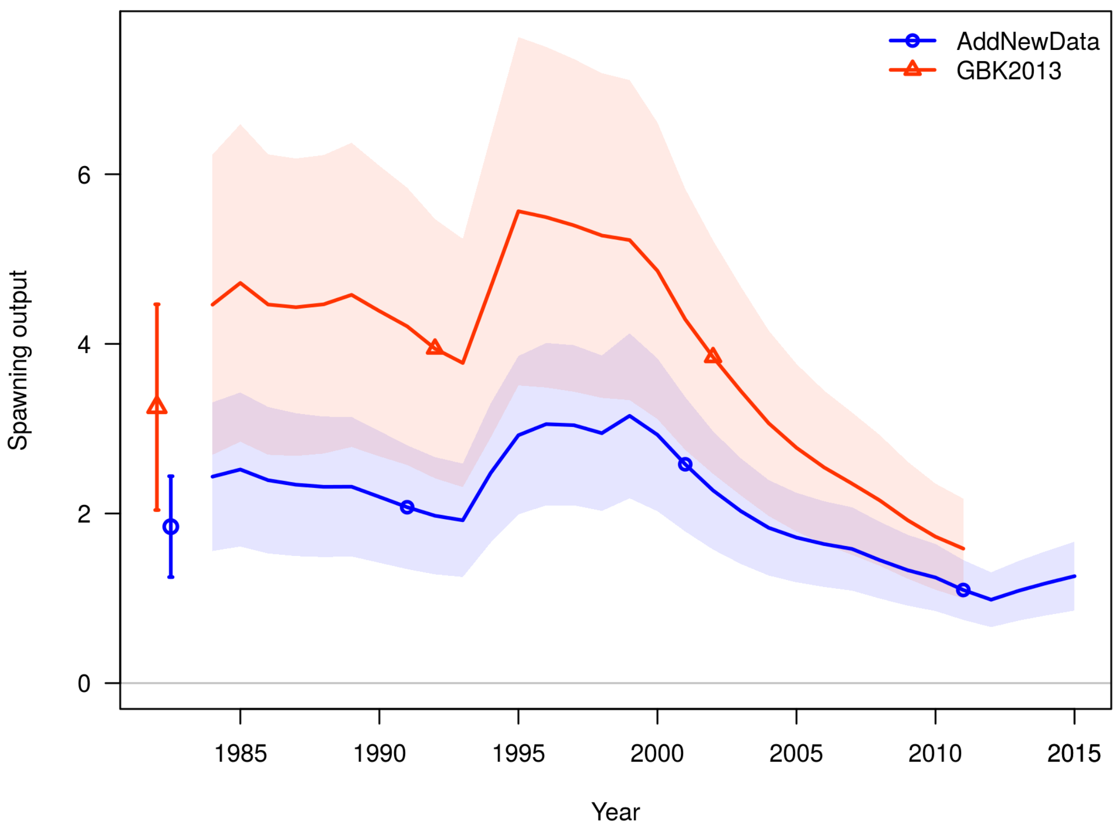


Figure 198: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model with identical configuration, but incorporating data from additional years (AddNewData).

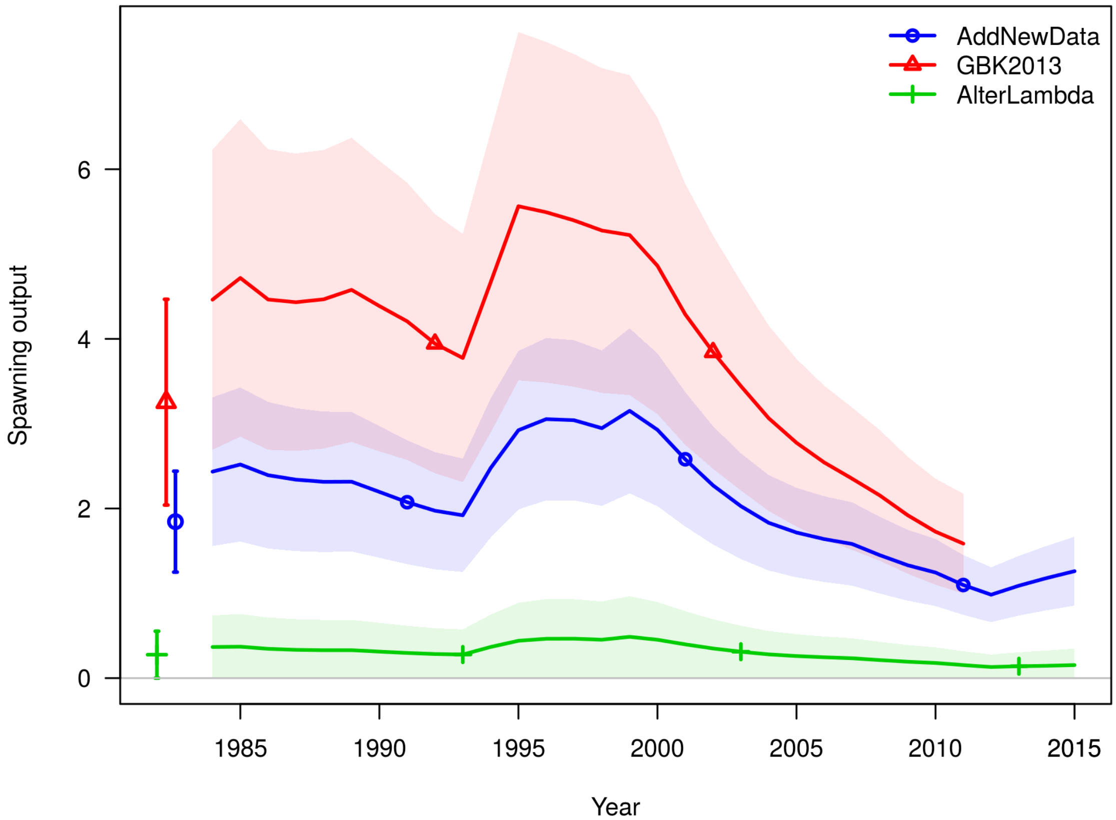


Figure 199: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model run where the likelihood component corresponding to the swept area number per tow in the survey was removed from the model solution (AlterLambda), as well as the previous model iteration (AddNewData).

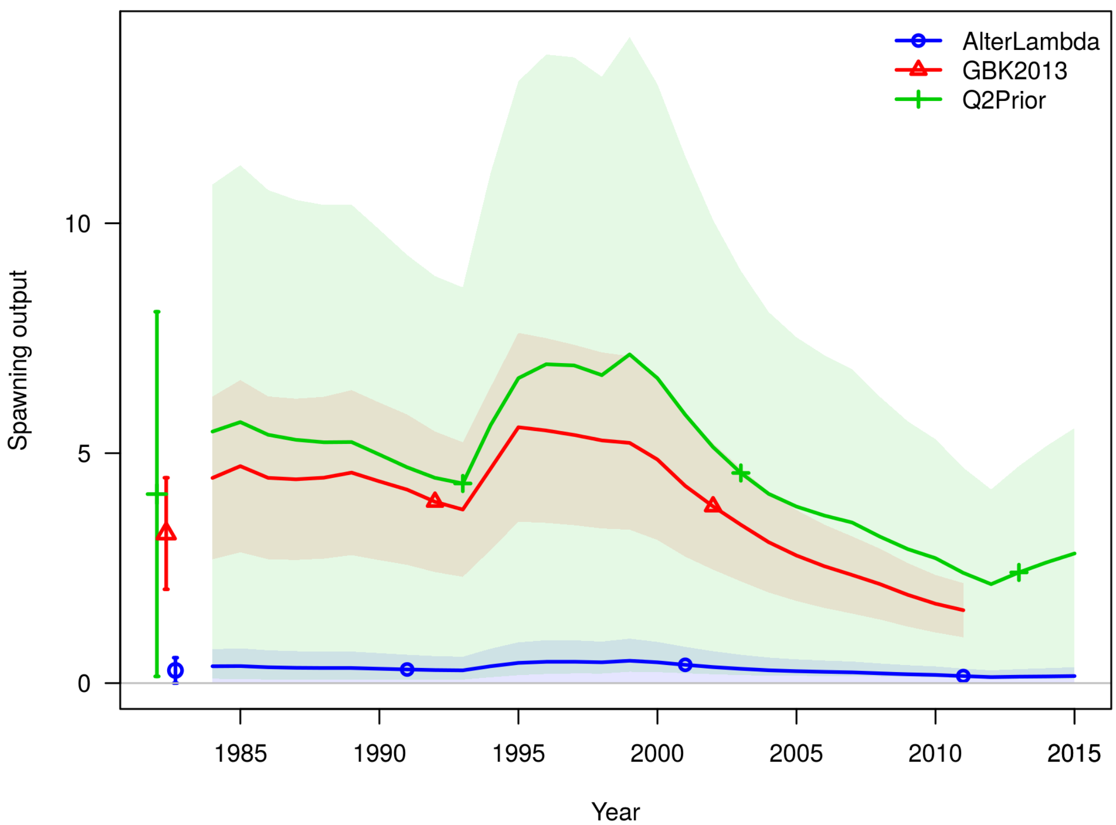


Figure 200: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model incorporating the prior on catchability for the MCD (Q2Prior), as well as the previous model iteration (AlterLambda). A comparison model run did not converge so the uncertainty associated with each spawning output trajectory could not be estimated.

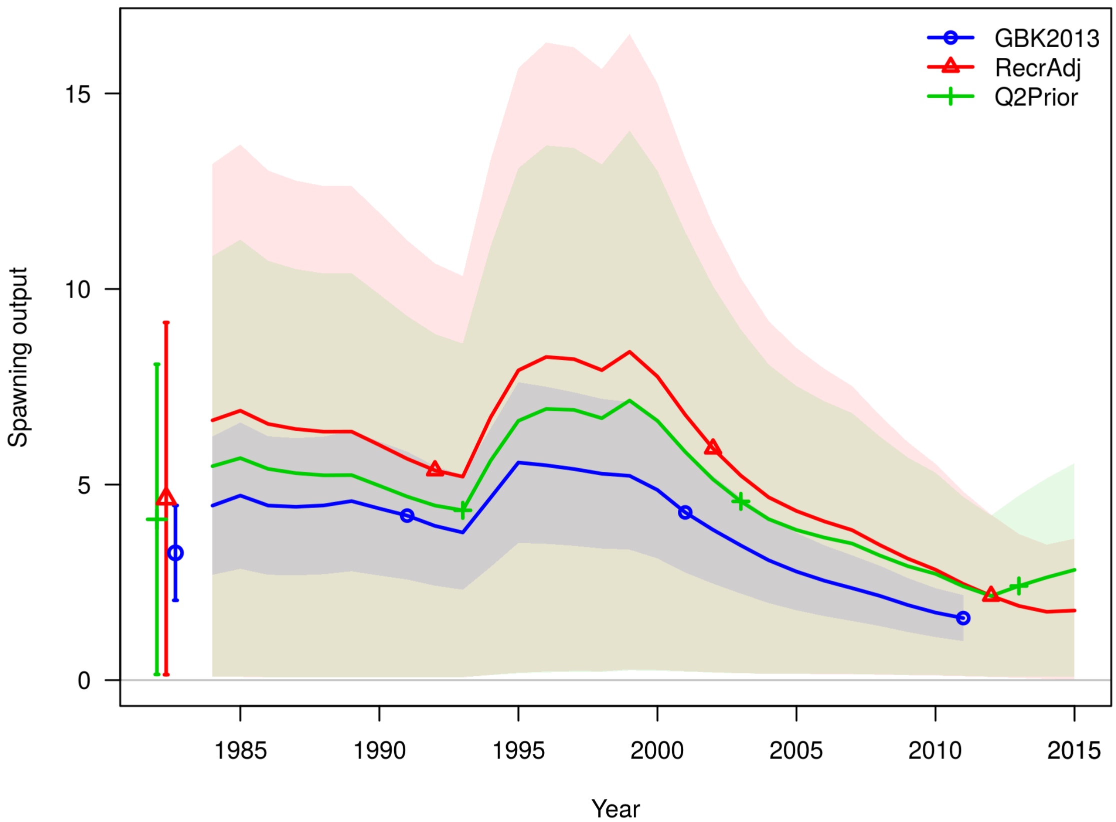


Figure 201: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where several recruitment parameters were adjusted (RecrAdj), including the number of recruitment deviations being estimated, the recruitment bias adjustment curve parameters, and the variance in recruitment was fixed rather than estimated. These runs were also compared with the previous model iteration (Q2Prior).

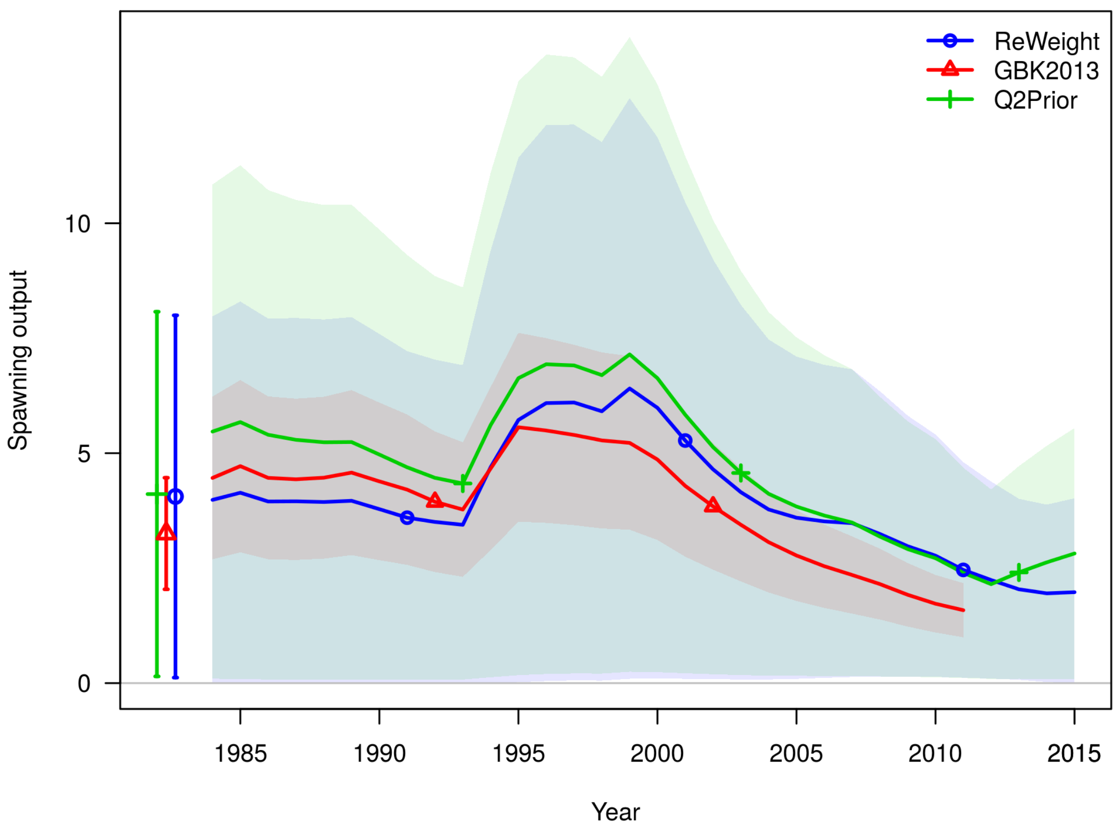


Figure 202: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where relative weightings of the data sources has been adjusted so that the information content of the composition data is decremented (ReWeight), as well as the previous model iteration (RecrAdj).

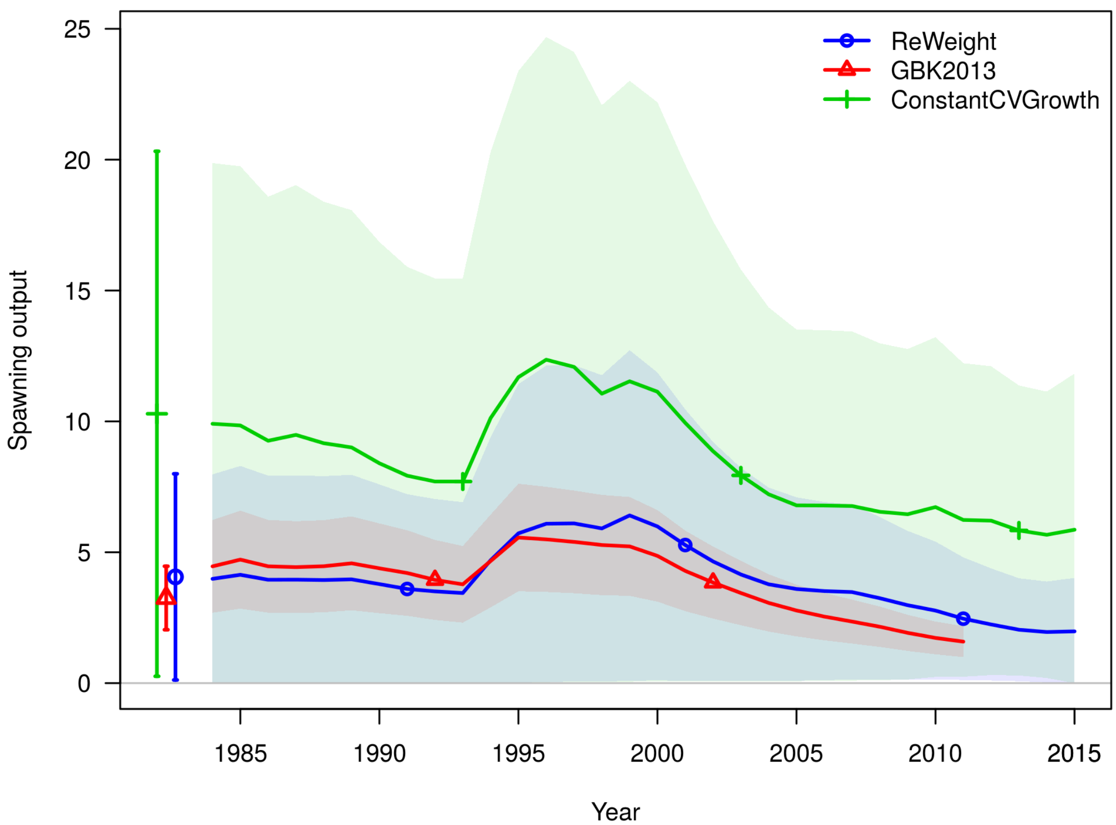


Figure 203: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where the error around the growth curve has a constant cv rather a constant standard deviation (ConstantCVGrowth), as well as the previous model iteration (ReWeight).

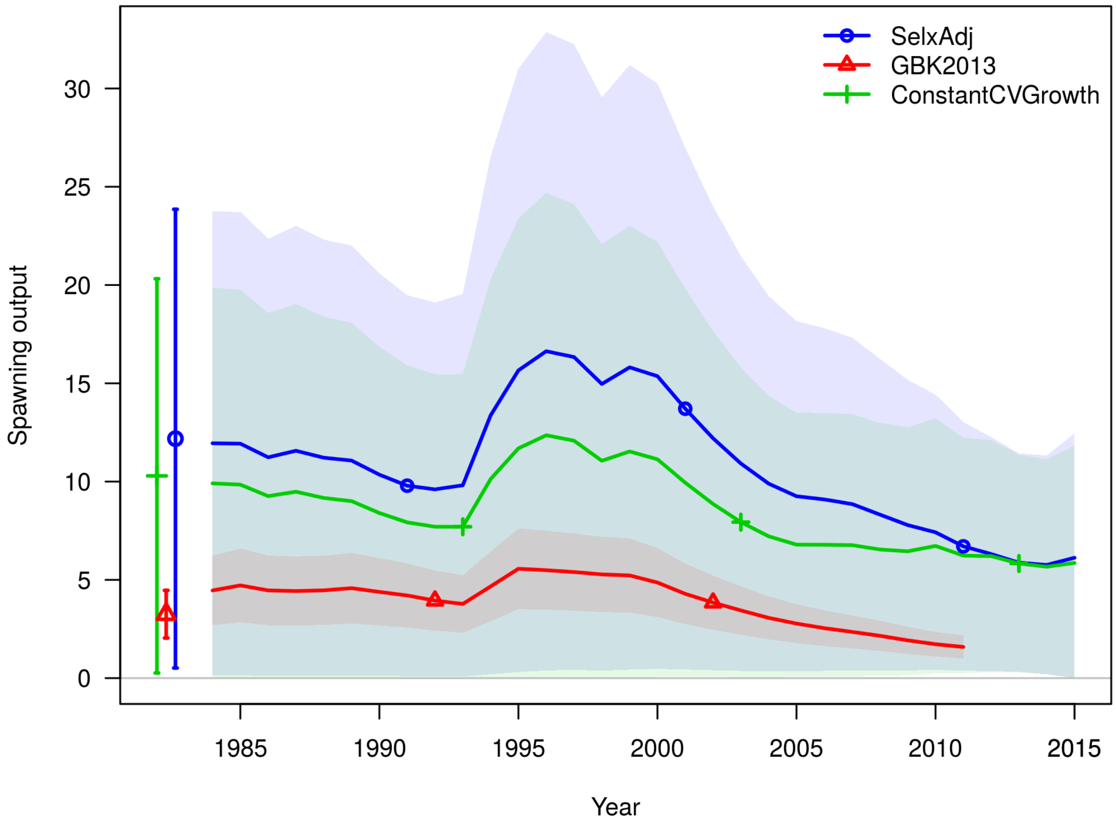


Figure 204: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where several selectivity parameters were estimated rather than fixed (SelxAdj), as well as the previous model iteration (ConstantCVGrowth).

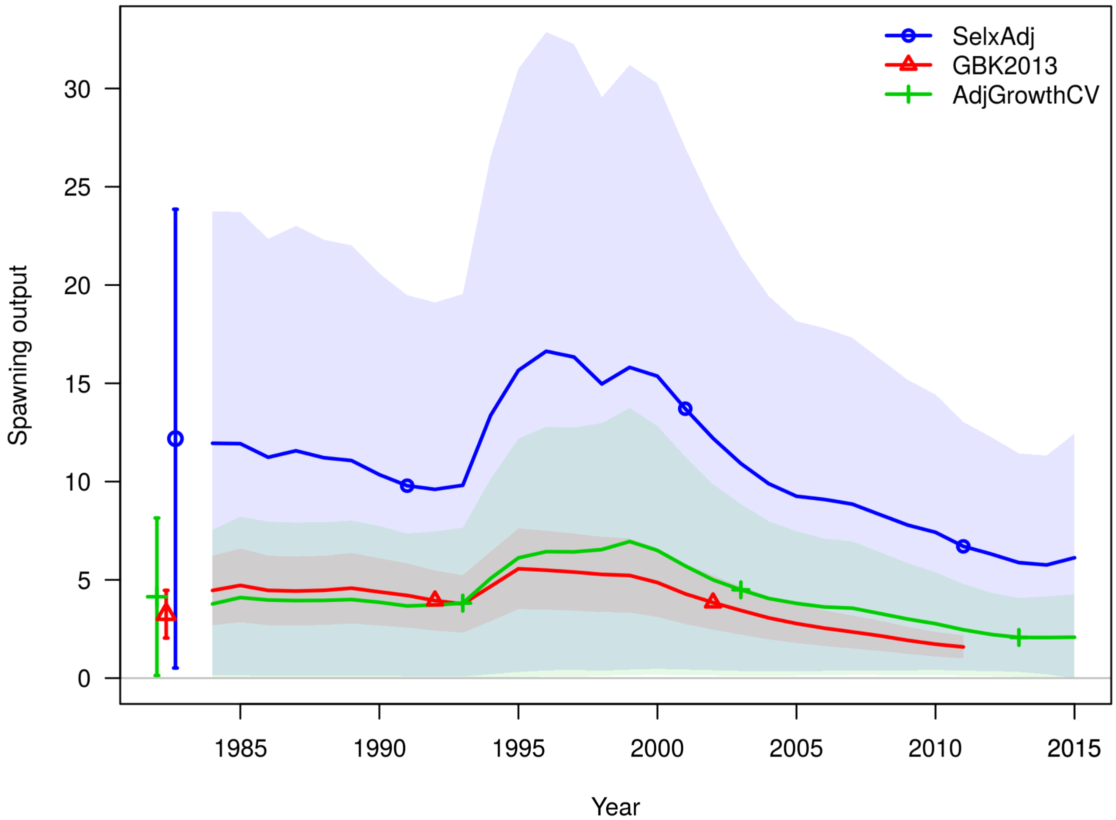


Figure 205: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where the cv around growth was adjusted to field estimated values (AdjGrowthCV), as well as the previous model iteration (SelxAdj).

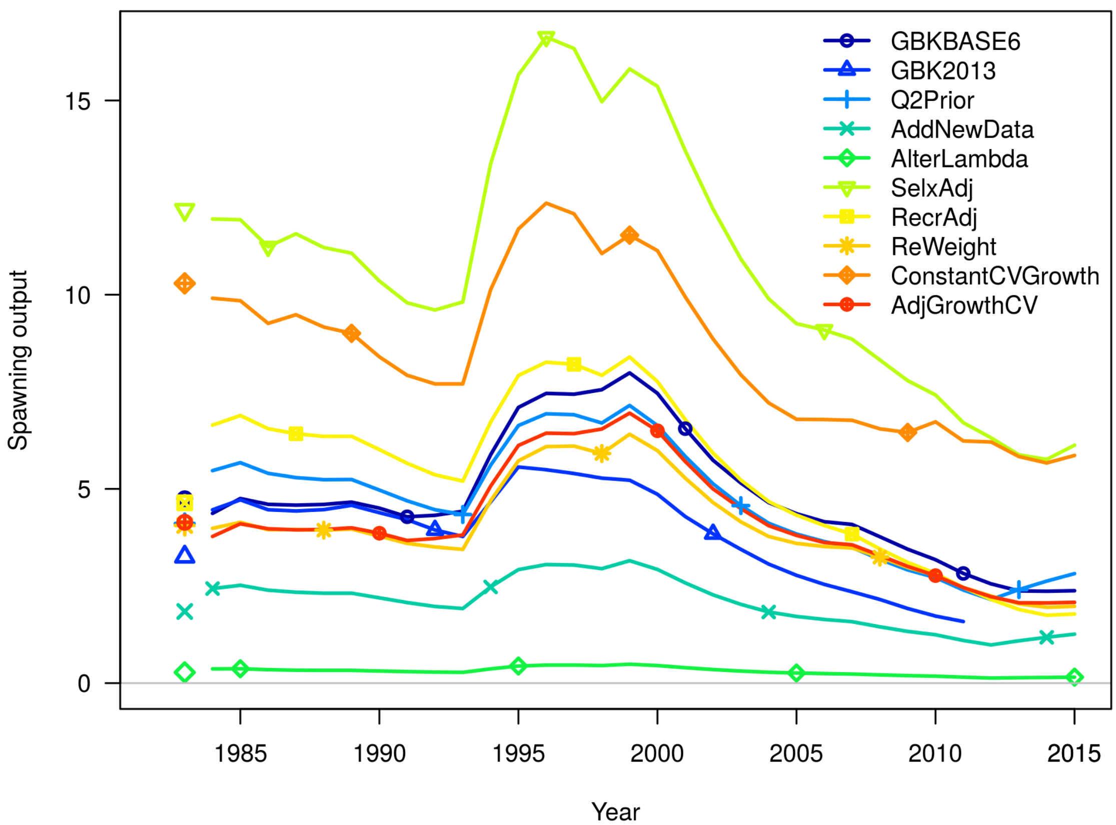


Figure 206: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (GBK2013) to each iteration in the sequence of model changes, as well as the base model from the current assessment (GBKBASE6).

Appendix 7 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 207). 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 208 - 209). 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 210). 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 211). 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 212). Grab sample data collected regularly since 1994 from the area of the survey show that juvenile Atlantic surfclam are consistently setting successfully (Figure 213). 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 214). Since 2008 the percentage of estimated Atlantic surfclam standing stock in prohibited waters has varied from 5 to 26 percent (Figure 215). 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 216). 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 217), 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 218). 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 219). 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 220), 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 221). The percentage of seed taken in the survey in years since has been falling. Survey length frequencies also indicate poor recruitment (Figure 222). Length at age plots do not seem to suggest New York Atlantic surfclam are growing more slowly in recent years (Figure 223), 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 224). 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 225). 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 226). 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 227). Even then much data remain confidential (Figure 228).

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 229).

Figures

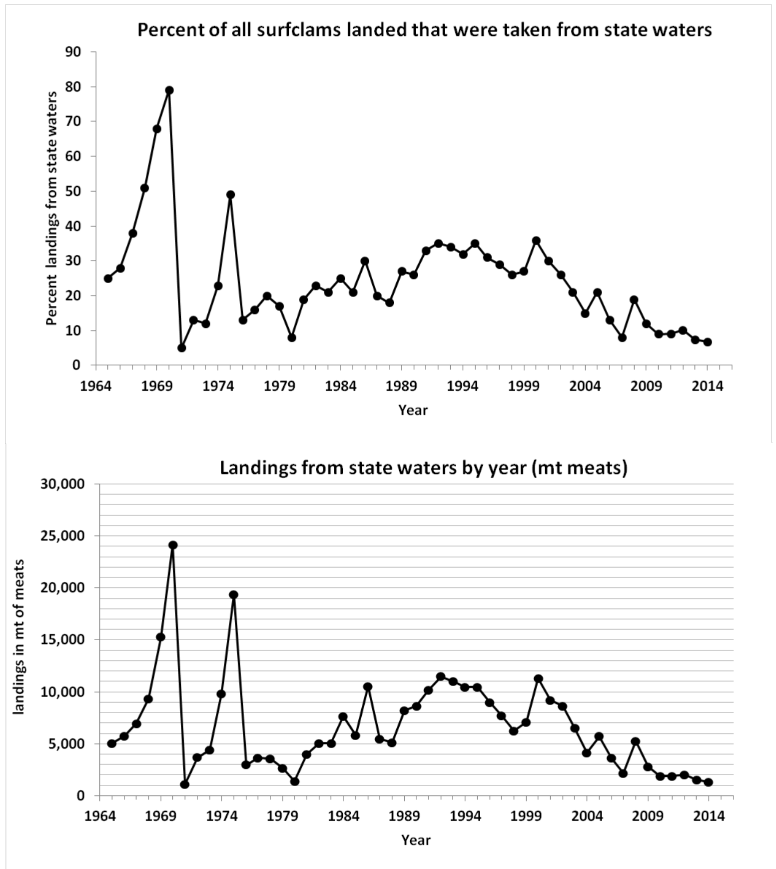


Figure 207: Percentage of total Atlantic surfclam landings harvested from state waters, almost entirely from New York, New Jersey and Massachusetts (top), and landings from state waters in metric tons of meats by year (bottom). There may be differences between the landings shown above and landings attributed 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.

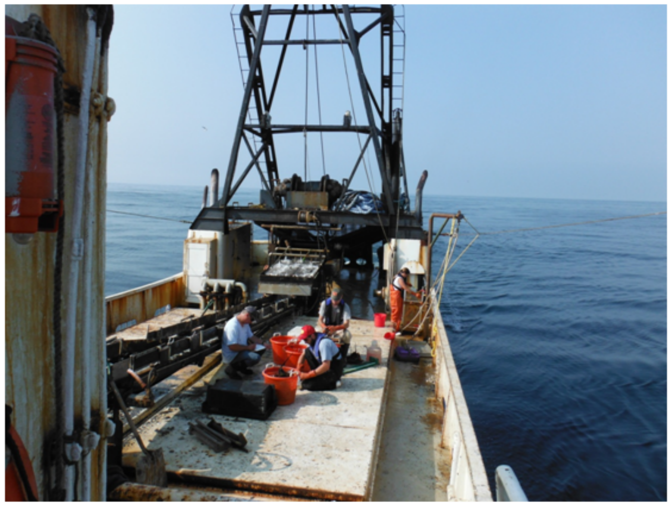


Figure 208: The New Jersey state survey under way aboard the FV Jersey Girl.

Figure 209: Results of a tow from the New Jersey state survey.

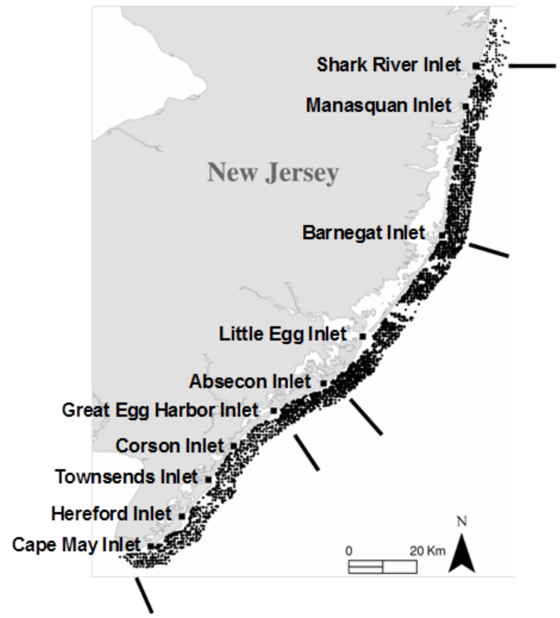


Figure 210: Map showing the sampling regions for the NJ state survey, and station locations 1988-2008. Within each region there are three along-shore depth strata one mile wide. Map courtesy of Jeff Normant.

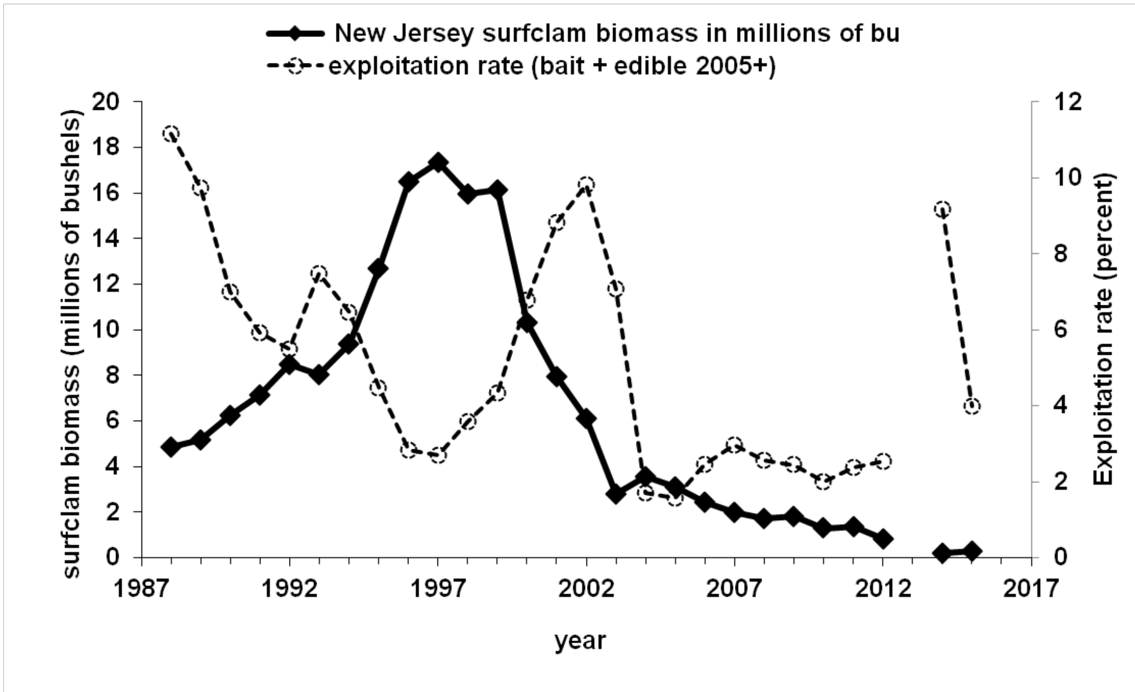


Figure 211: Exploitation rates (expressed as landings as a percentage of estimated biomass) and population biomass for New Jersey state Atlantic surfclam.

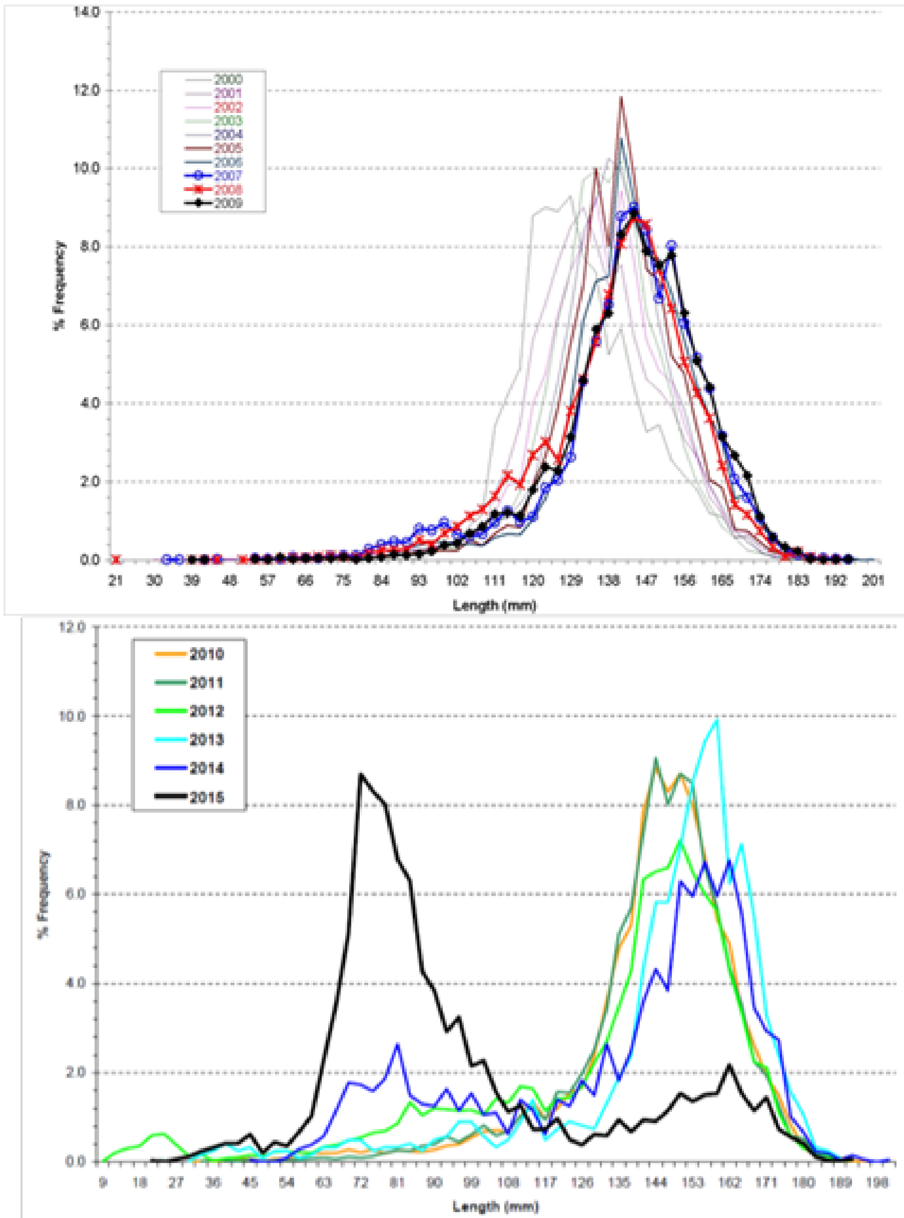


Figure 212: Length frequencies from the 2000-2009 (top) and 2010-2015 (bottom) New Jersey state Atlantic surfclam surveys. Not all strata were sampled in 2013 and 2014 but the most populous ones were. Note scales are different on both axes. Plots courtesy of Jeff Normant.

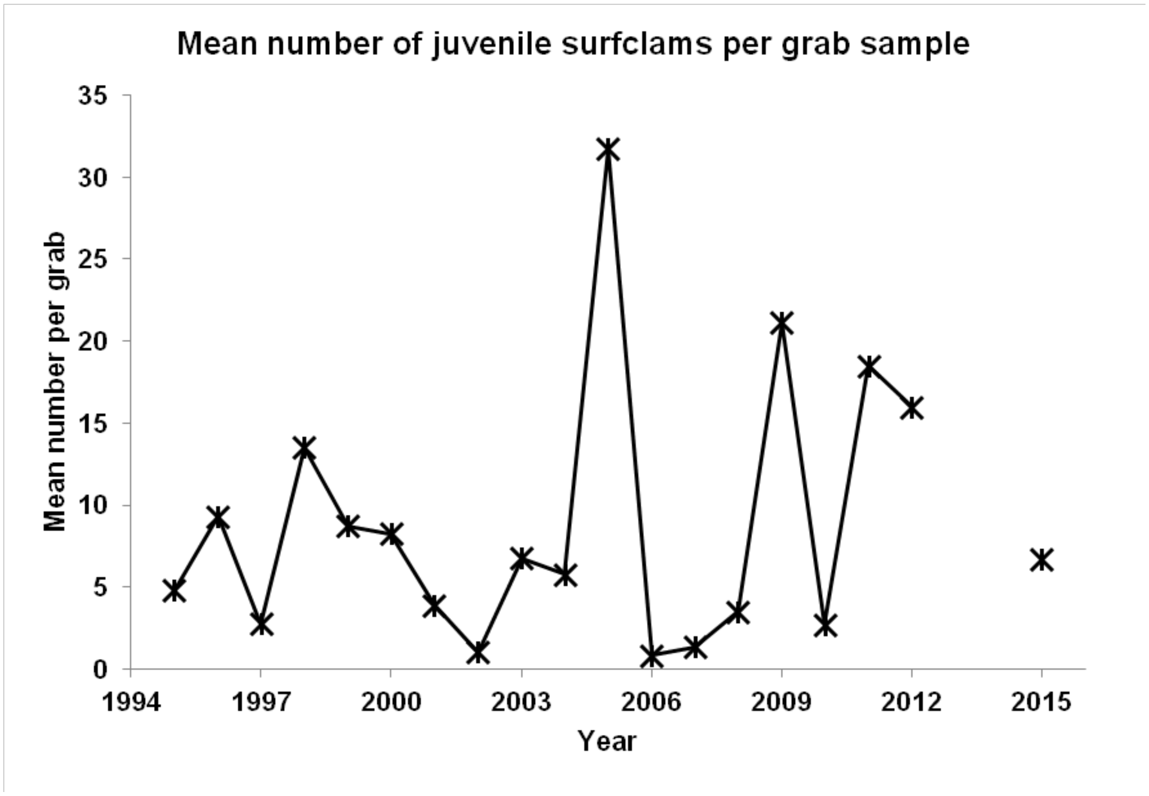


Figure 213: As part of the Atlantic surfclam survey, the state of New Jersey takes sediment grab samples, which contain juvenile Atlantic surfclam too small to be retained in the survey dredge. The clams are generally less than 10mm. About 300 grab samples were taken each year up until 2012, in 2013 and 2014 there were no grabs done, and 186 grabs were done in 2015. The area sampled is 1/10 of a square meter.

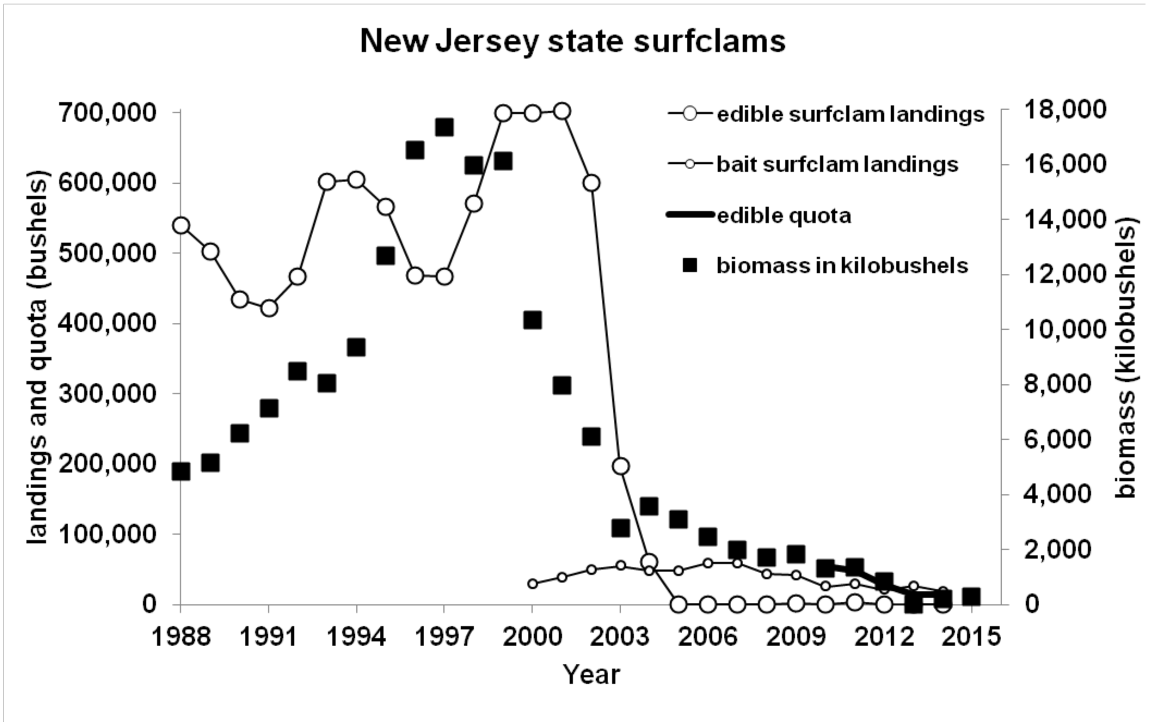


Figure 214: Landings of both edible and bait Atlantic surfclam, quota for edible Atlantic surfclam and survey-based Atlantic surfclam population estimates in New Jersey state waters. Landings and quota are scaled to the left axis and population is scaled to the right axis. There are no quotas or restrictions on harvest of bait clams at this time.

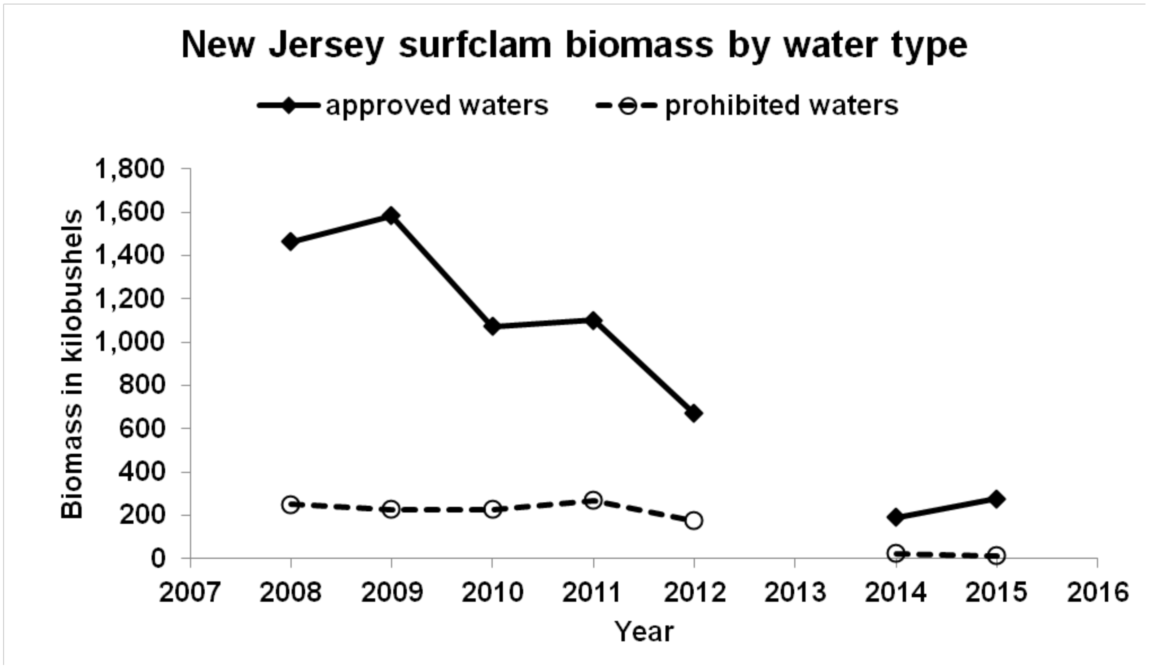


Figure 215: Standing stock in industry bushels from New Jersey state waters. Clams from approved waters can be sold for human consumption, while clams from prohibited waters are sold for bait only.

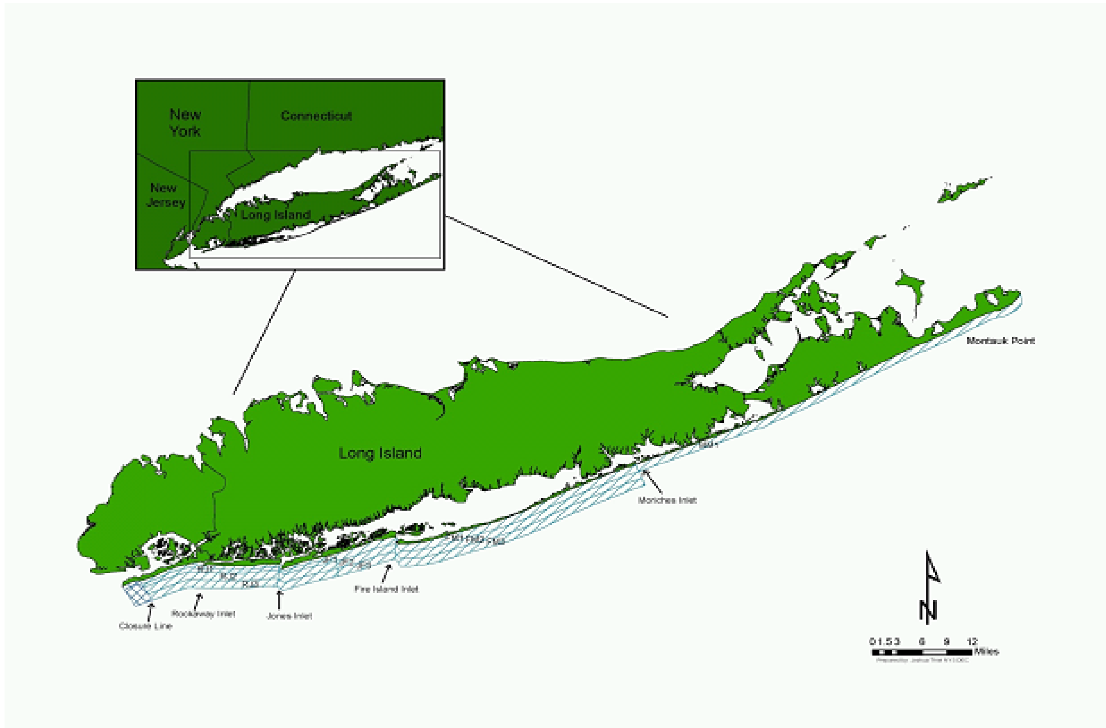


Figure 216: Map showing New York state sampling regions from west to east: RJ, JF and FM, which each have 3 depth strata, and MM which has one depth stratum. Map courtesy of New York State Department of Environmental Conservation.

Figure 217: The commercial clam vessel FV Ocean Girl, used for the New York state surveys, with dredge deployed. Photo courtesy of Jennifer O'Dwyer.

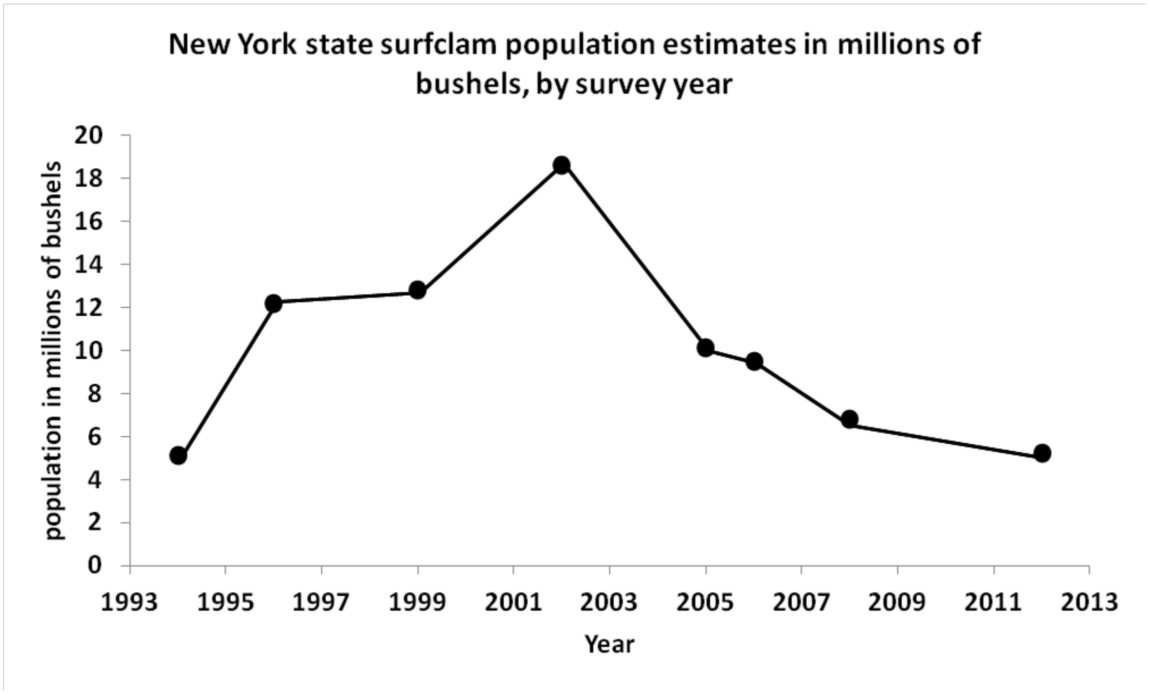


Figure 218: Atlantic surfclam population estimates for the surveyed area in New York state waters since 1994, in millions of bushels.

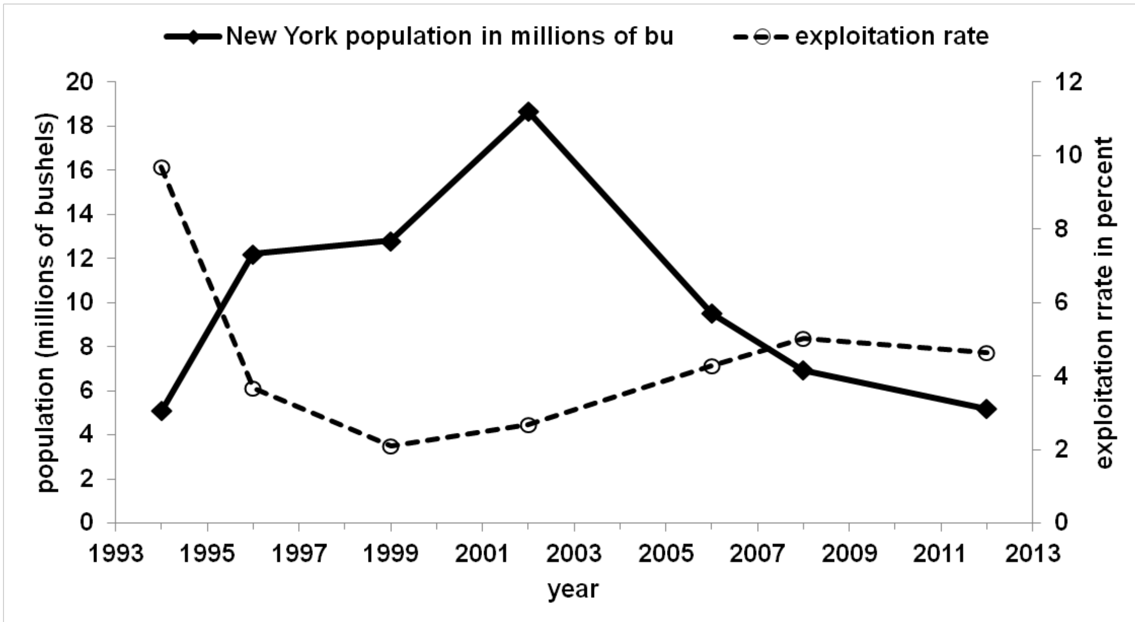


Figure 219: Exploitation rates (expressed as landings as a percentage of estimated biomass) and population biomass for New York state Atlantic surfclam.

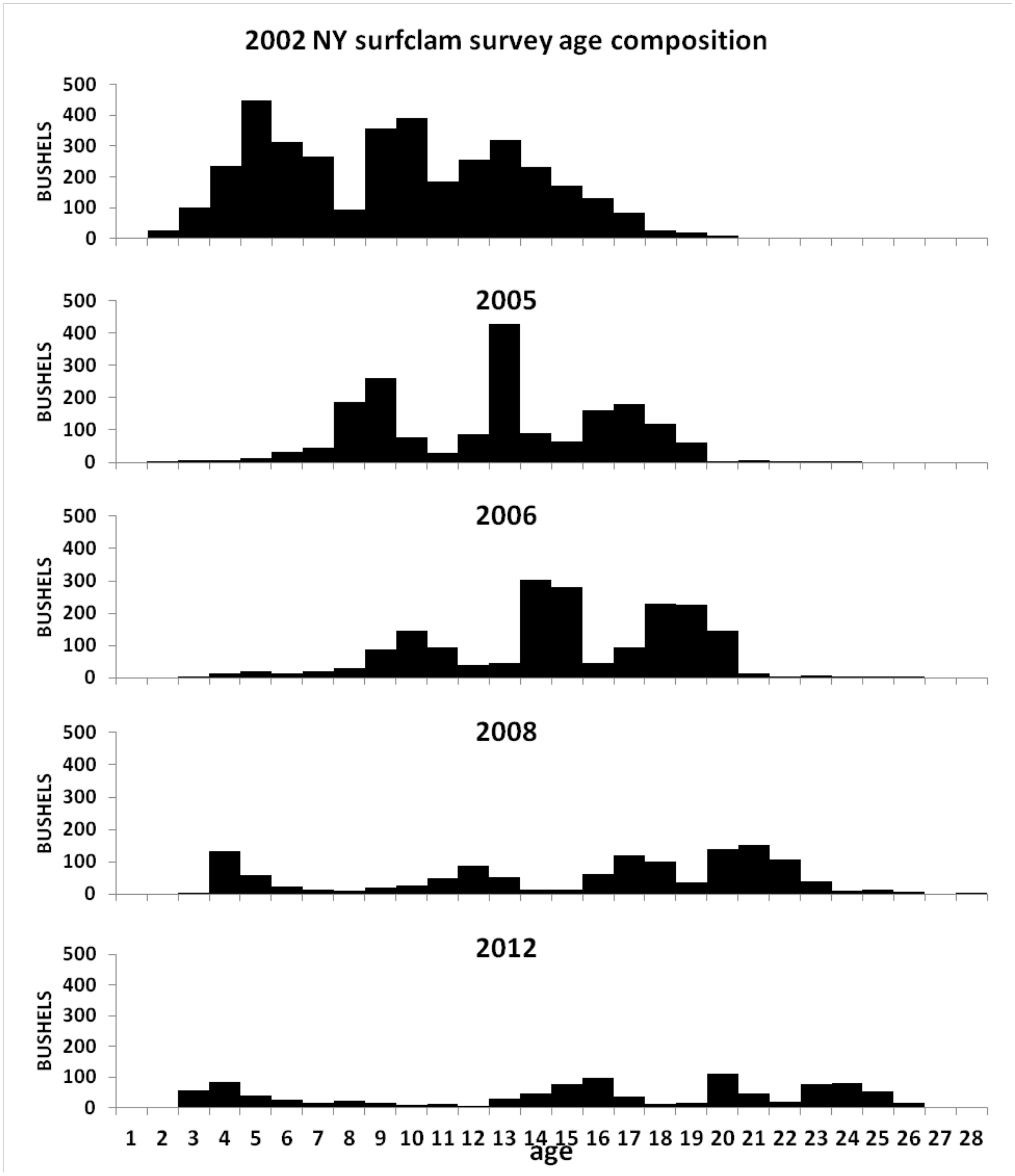


Figure 220: Age compositions from the 2002, 2005, 2006, 2008 and 2012 New York State Atlantic surfclam surveys, in bushels at age.

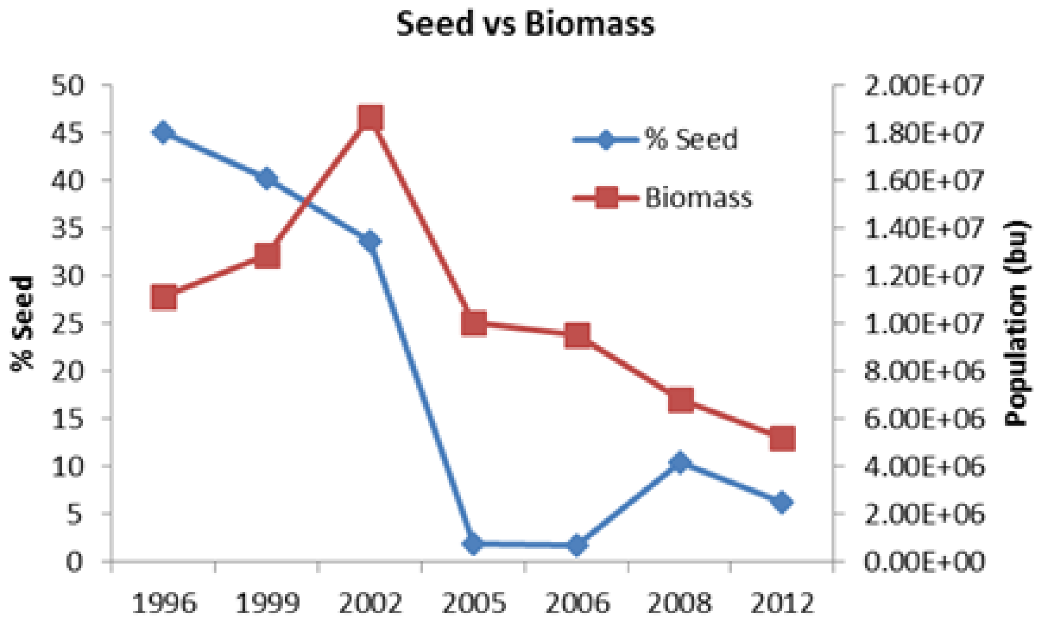


Figure 221: Population estimates for Atlantic surfclam in New York state waters and the percentage of the population considered seed clams (less than 100mm SL) by survey year. Plot courtesy of Jennifer O'Dwyer, NYDEC.

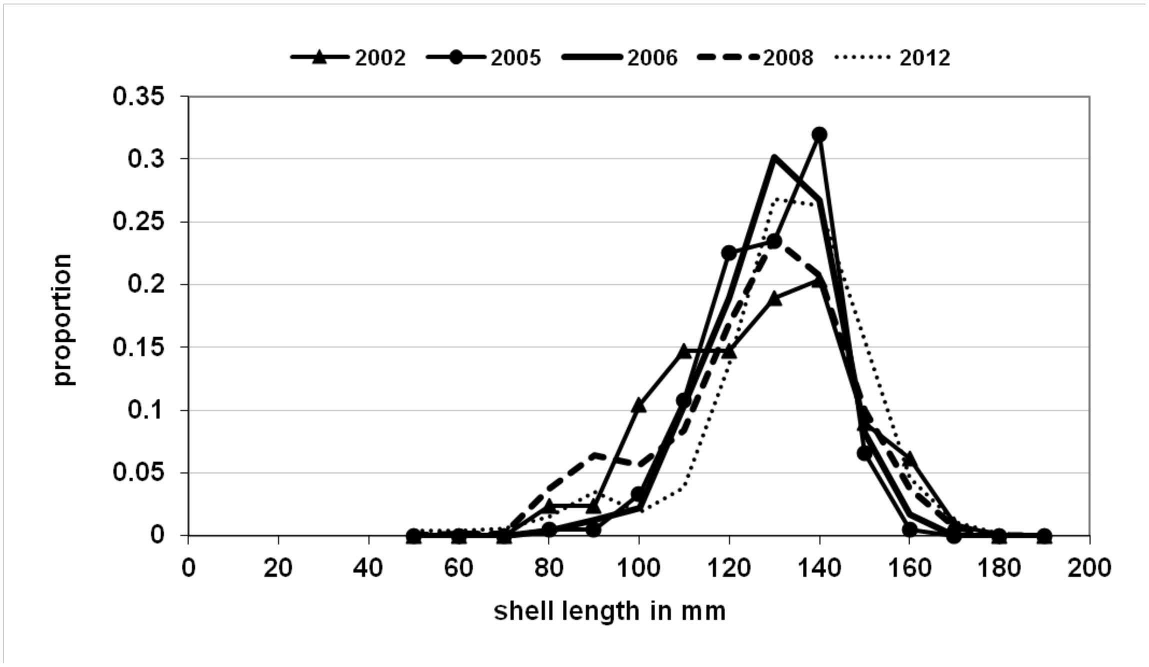


Figure 222: Length frequencies from the 2002, 2005, 2006, 2008 and 2012 New York state Atlantic surfclam survey.

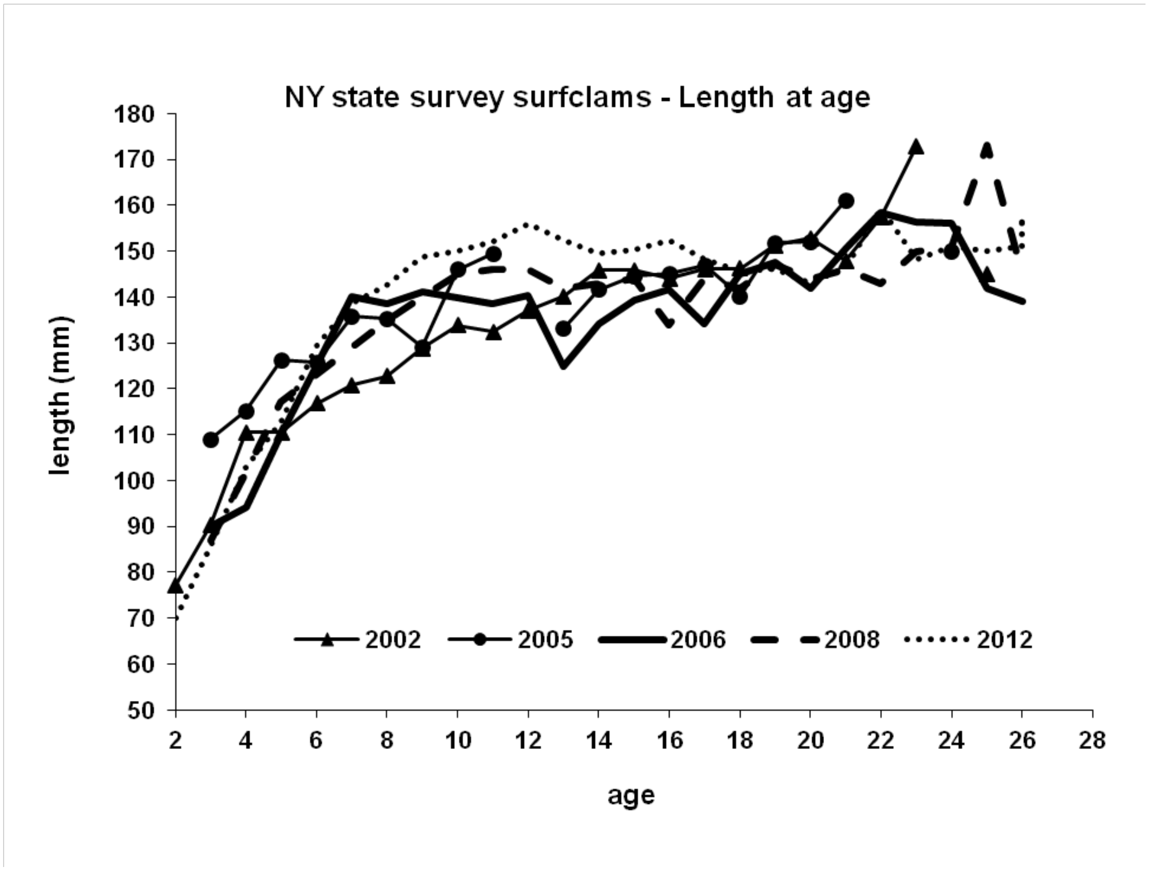


Figure 223: Atlantic surfclam length at age from the 2002, 2005, 2006, 2008 and 2012 New York state surveys.

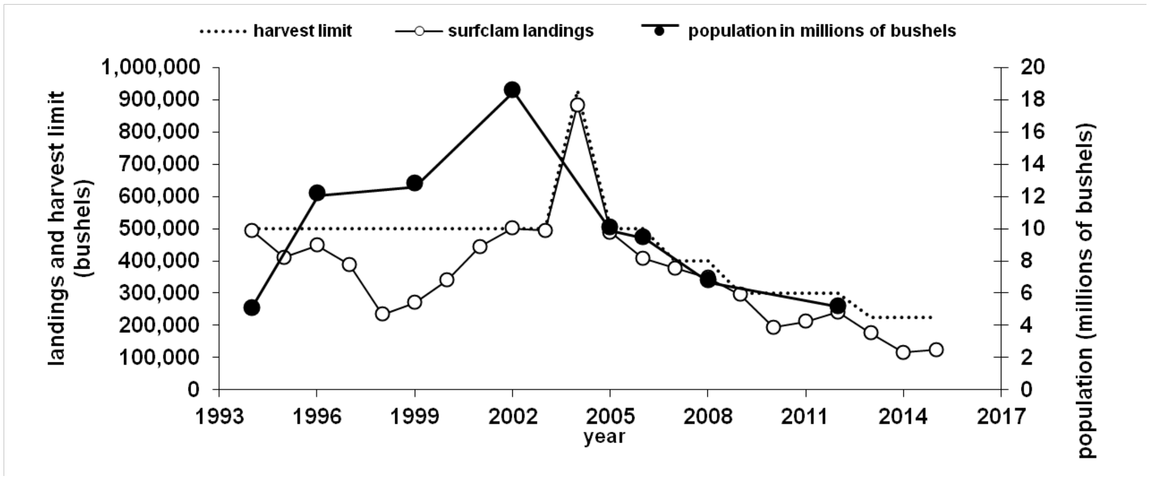


Figure 224: Landings, harvest limit and survey-based population estimates of Atlantic surfclam in New York state waters. Landings and harvest limit are scaled to the left axis and population is scaled to the right axis. The harvest limit was raised to 890,000 bushels for one year in 2004. Landings for 2015 are considered preliminary and an underestimate as not all catch reports were in.

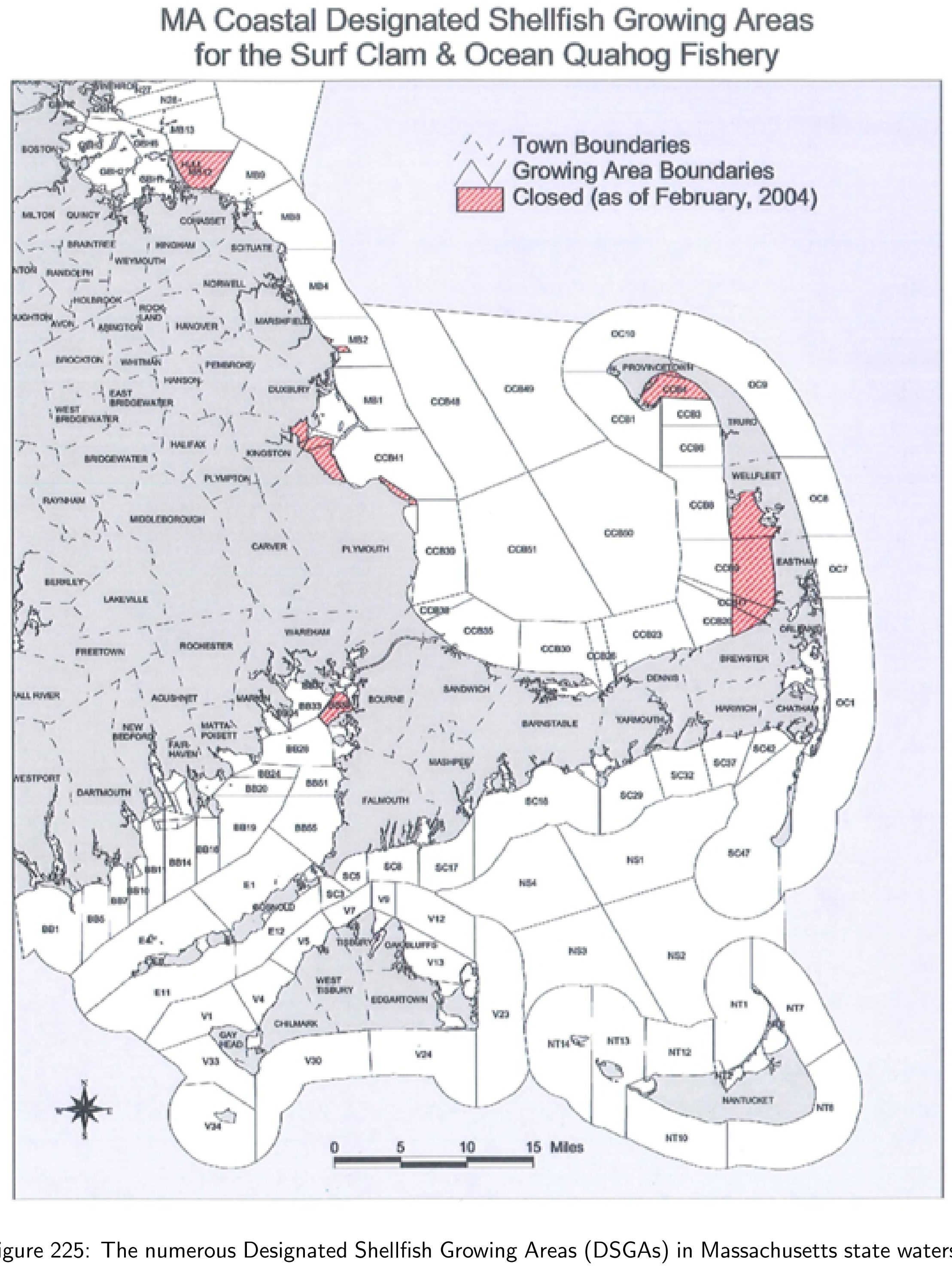


Figure 225: The numerous Designated Shellfish Growing Areas (DSGAs) in Massachusetts state waters.

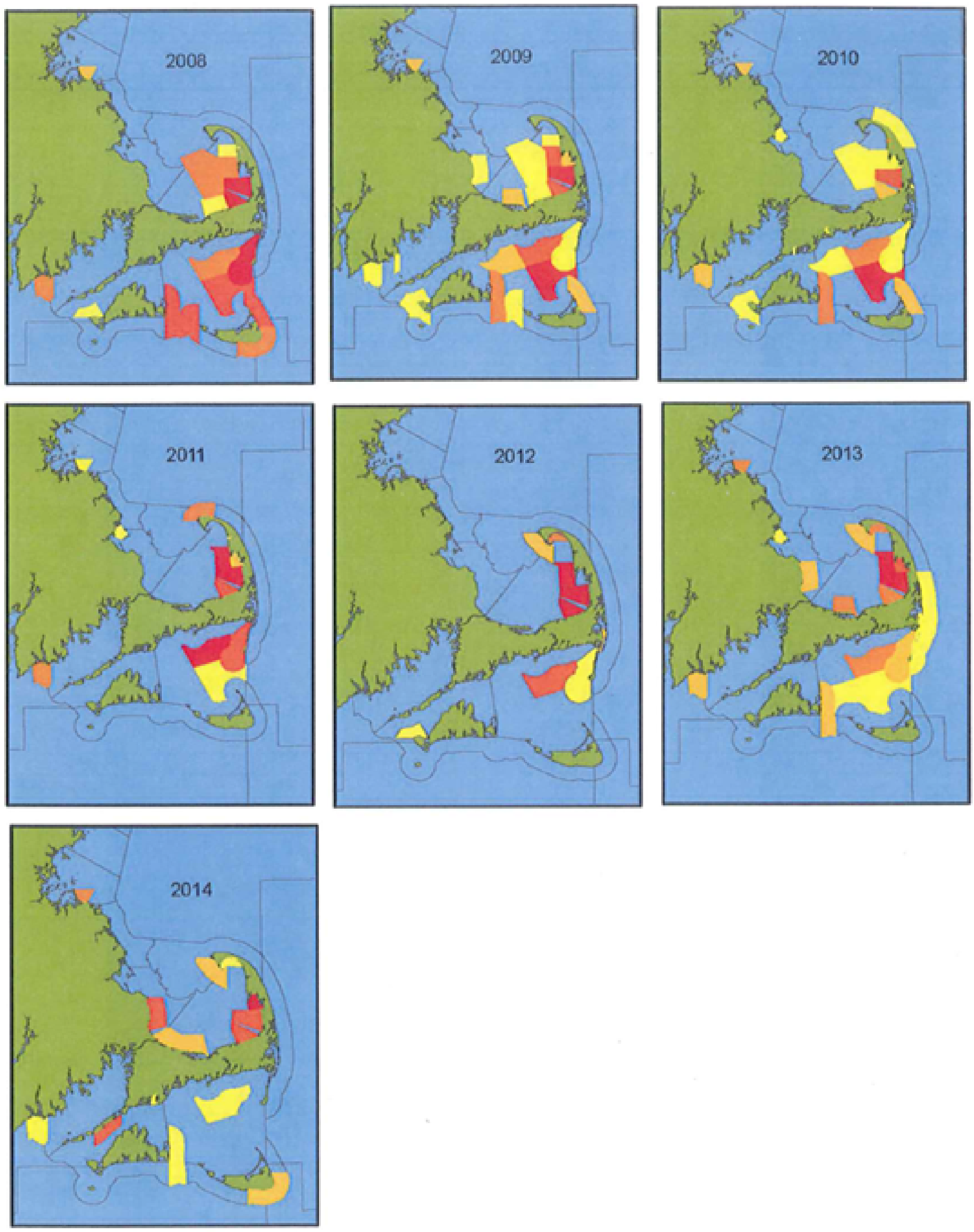


Figure 226: Massachusetts state waters Atlantic surfclam landings from each of the states' multiple Designated Shellfish Growing Areas, or DSGAs. There are more than 75 DSGAs in the waters surrounding the state. Red designates the areas with highest landings and yellow the lowest landings.

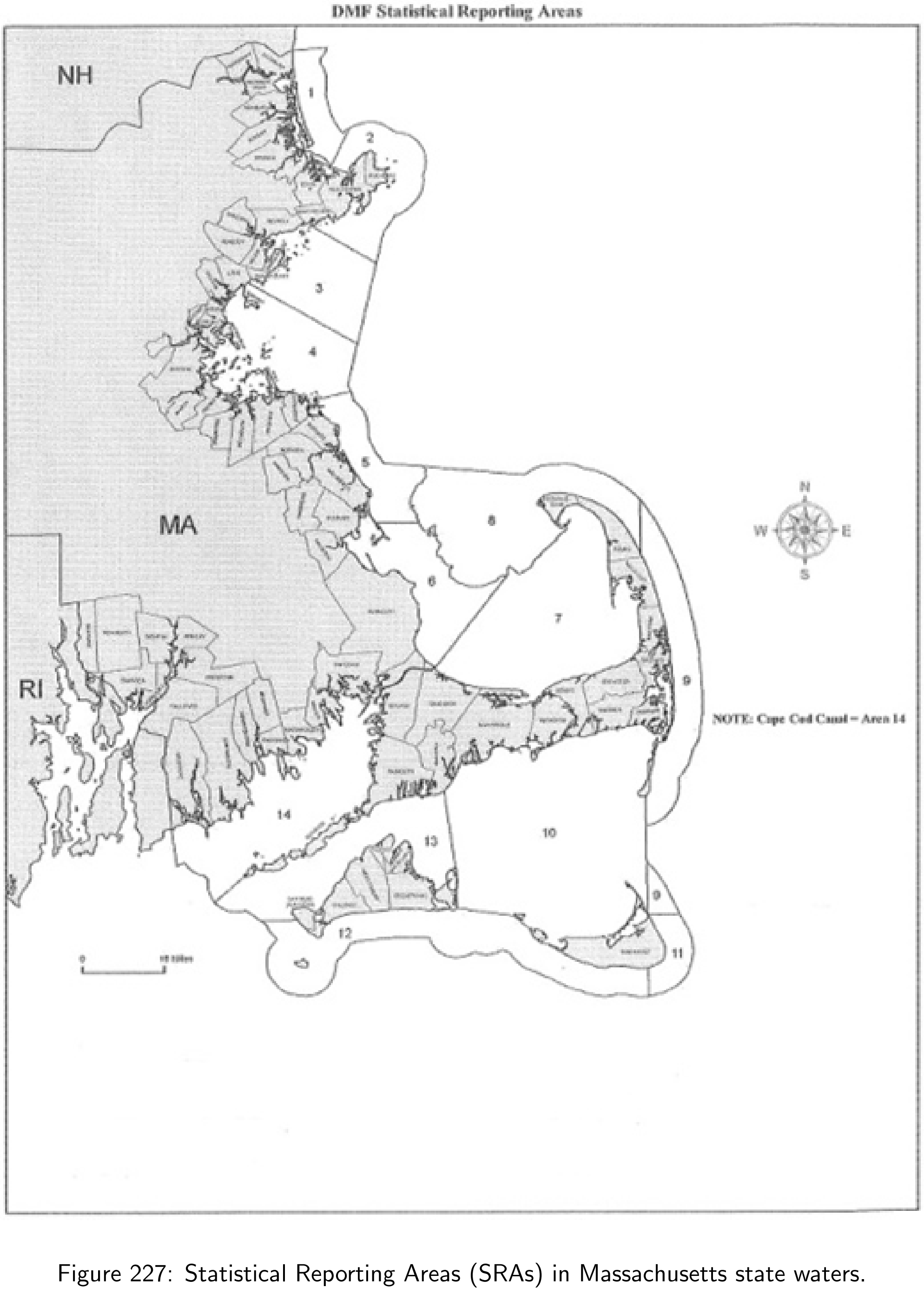


Figure 227: Statistical Reporting Areas (SRAs) in Massachusetts state waters.

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 228: 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.

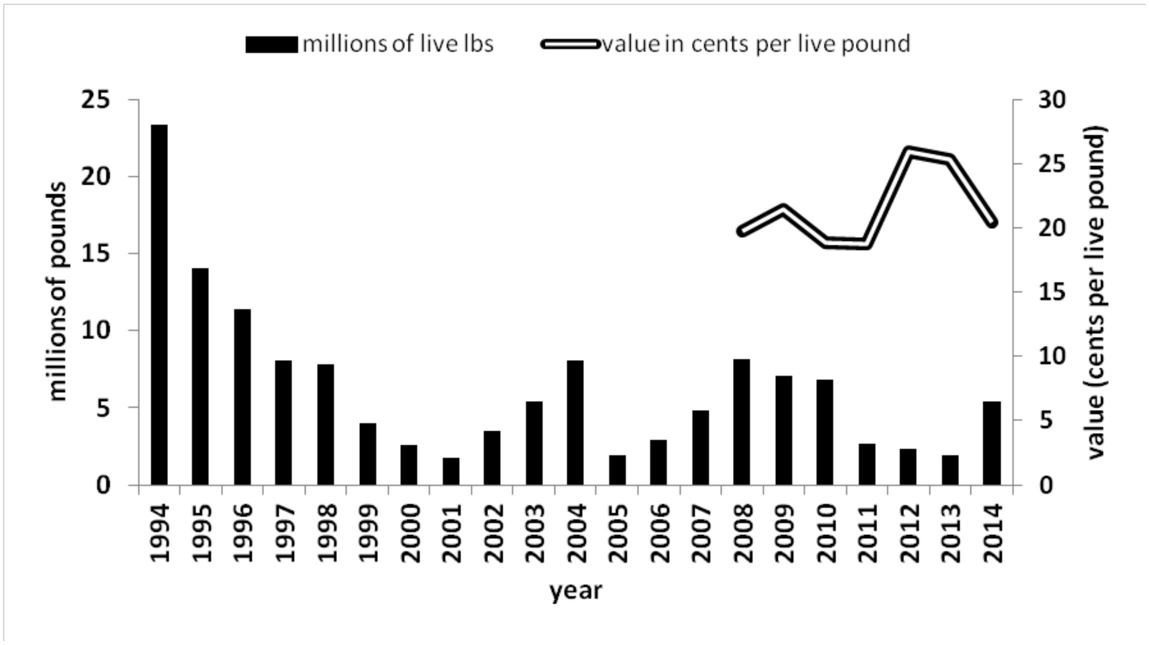


Figure 229: Total landings of Atlantic surfclam from Massachusetts state waters 1994-2014. The landings are shown in millions of live pounds and the values are cents per live pound.

Appendix 8 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 230). 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[5]. 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.

[5] 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 231). 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

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

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

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 $S\hat{S}B_t$ 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

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

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 232 – 233). 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 234).

Simulated management over different spatial scales

The effect of spatial scale on management was substantial on average across most of the response variables tested (Table 40). Mean biomass was greater when the stocks were managed separately, but mean yield was greater under single stock management (Figure 235). 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 236 - 237). 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 1.3). 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.

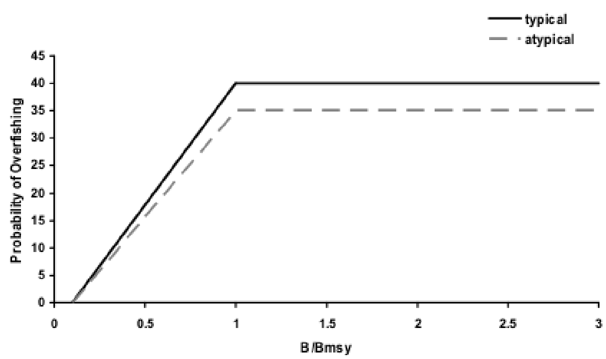


Figure 230: Mid-Atlantic Fisheries Management Council risk policy MAFMC 2011 (p. 51).

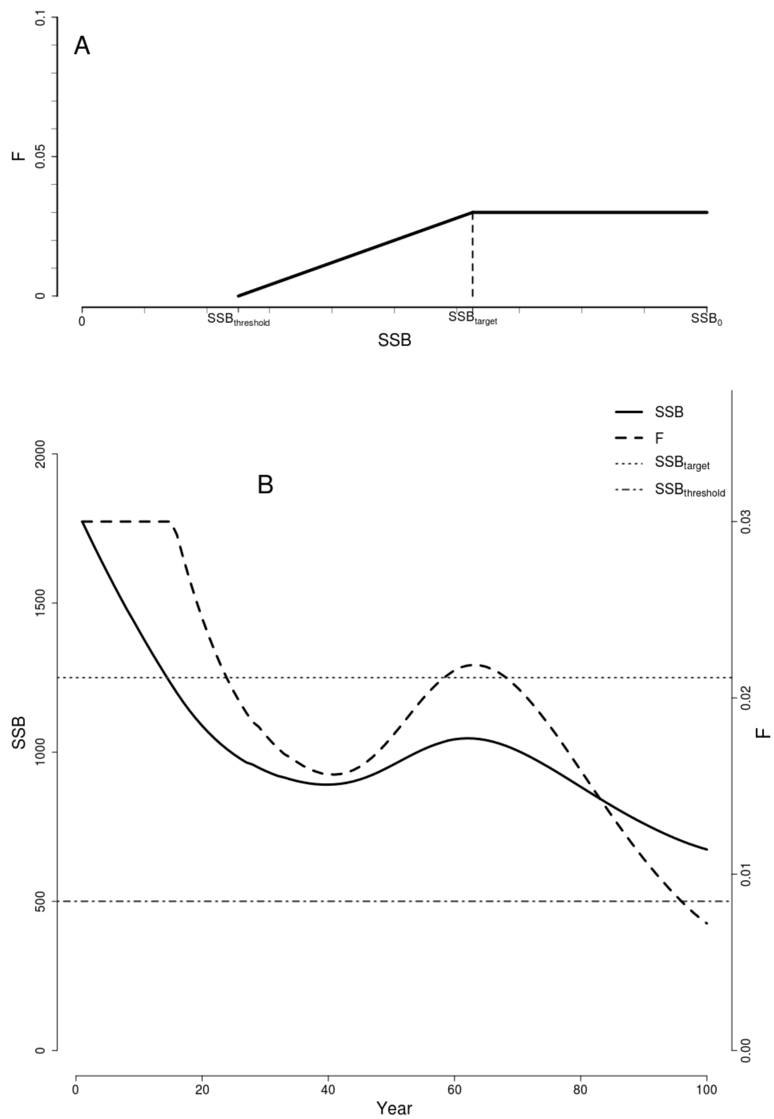


Figure 231: Panel (A) Control rule for Atlantic surfclam in terms of F and SSB. Fishing mortality is constant unless SSB drops below SSB_{target}, it then declines linearly until it reaches 0 at $SSB_{threshold}$. Panel (B) The control rule applied in a simulation run. Fishing mortality was constant when $SSB_t > SSB_{target}$, and was reduced when $SSB_t < SSB_{target}$. Simulated SSB units are 000 mt.

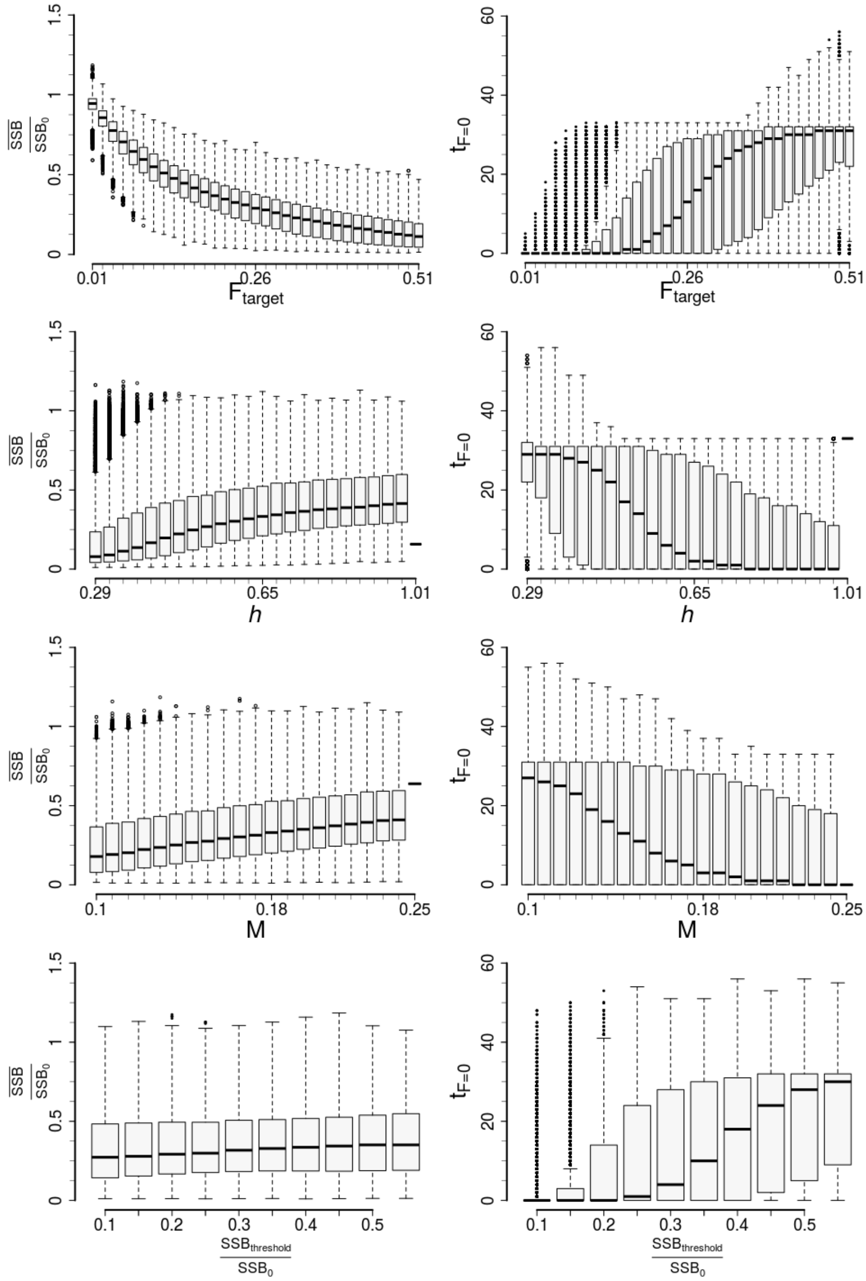


Figure 232: Mean biomass ($\frac{\overline{SSB}}{SSB_0}$), and time not fished due to management intervention ($t_{F=0}$) in 100 year simulations, by values of target fishing mortality (F_{target}), steepness (h), assessment error (σ_{At}), natural mortality (M) and the fraction of SSB_0 that corresponds 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 ($n = 500000$).

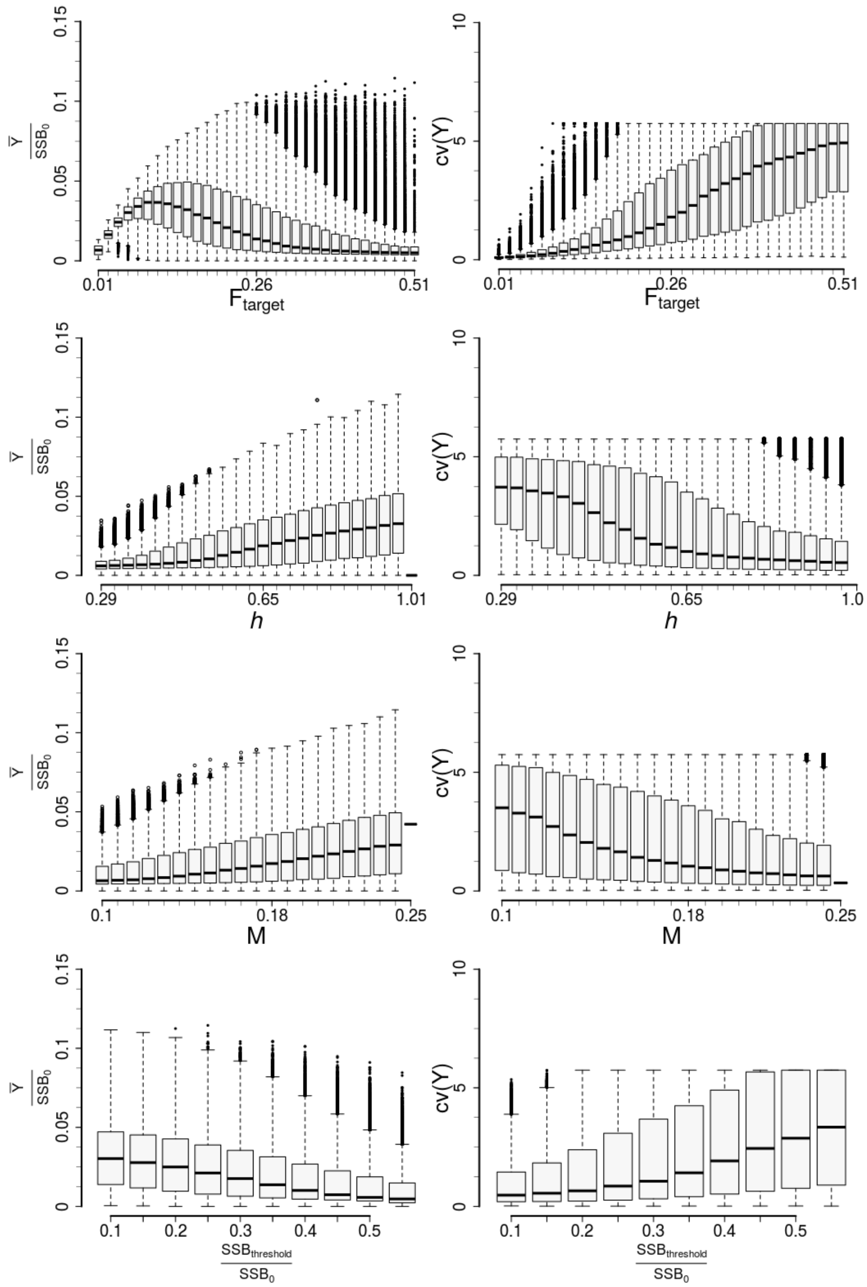


Figure 233: Mean yield ($\frac{\overline{Y}}{SSB_0}$) and cv yield in 100 year simulations, by values of target fishing mortality (F_{target}), steepness (h), natural mortality (M) and the fraction of SSB_0 that corresponds to the control rule (stock replenishment) threshold ($\frac{SSB_{threshold}}{SSB_0}$) ($n = 500000$).

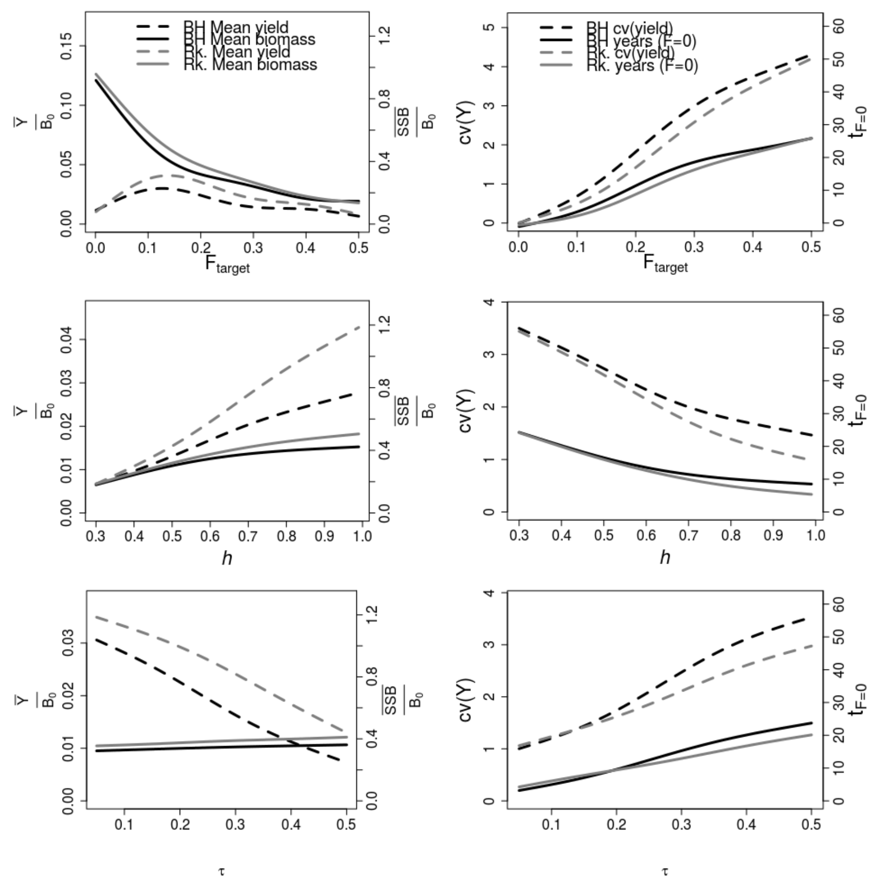


Figure 234: Mean yield, mean biomass, cv yield and years without fishing by F_{target}, h and $\frac{SSB_{threshold}}{SSB_0}$ from 100 year simulations for simulations where recruitment was driven by Beverton Holt (BH; $n = 60000$ for each) or Ricker (Rk) dynamics. The solid and dashed lines are fits to simple univariate generalized additive models (splines with basis dimension, $k = 5$). These are used to illustrate trends only.

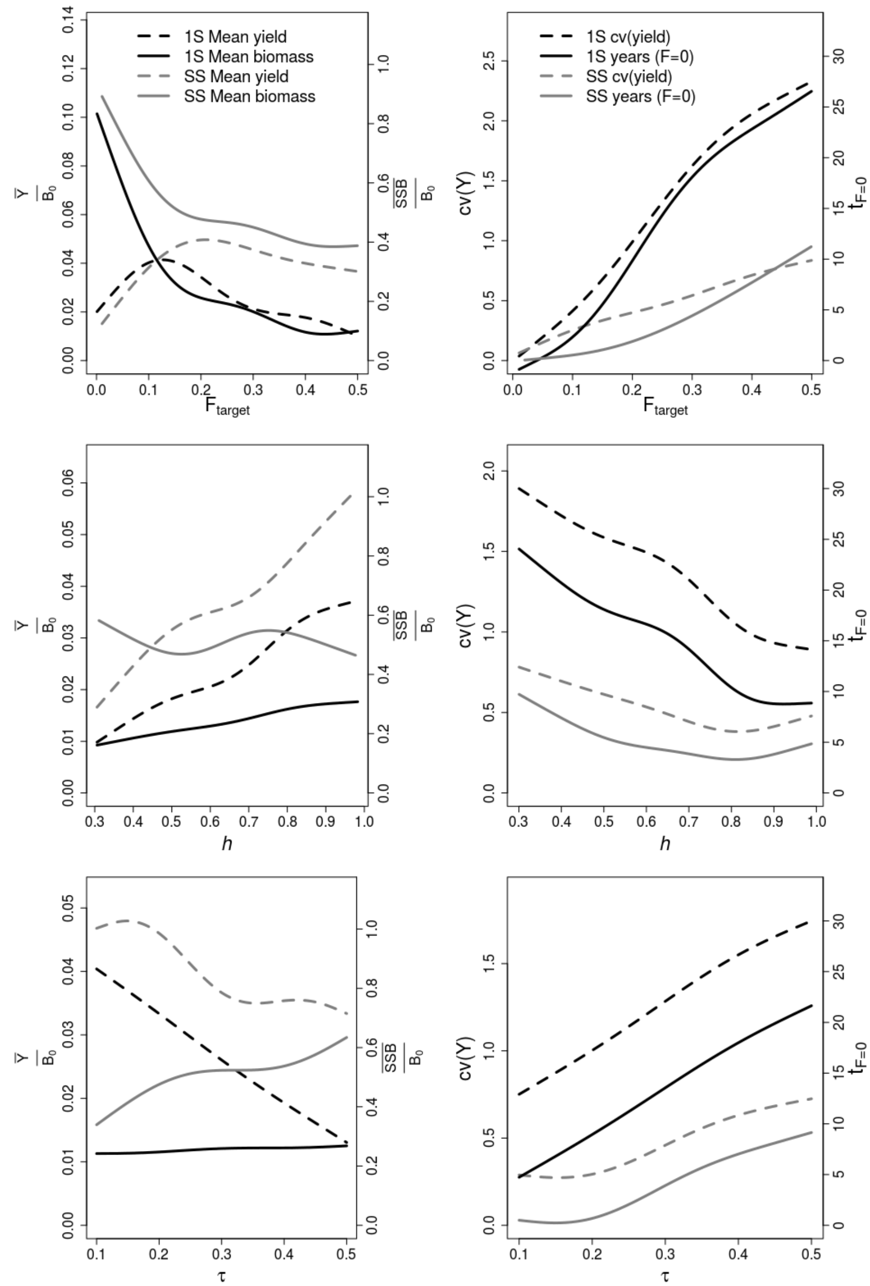


Figure 235: Mean yield, mean biomass, cv yield and years without fishing by F_{target}, h and $\frac{SSB_{threshold}}{SSB_0}$ from 100 year simulations for two regions with independent recruitment managed together, either as separate stocks (SS) or as a single stock ($1S$; $n = 60000$ for each). Both 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.

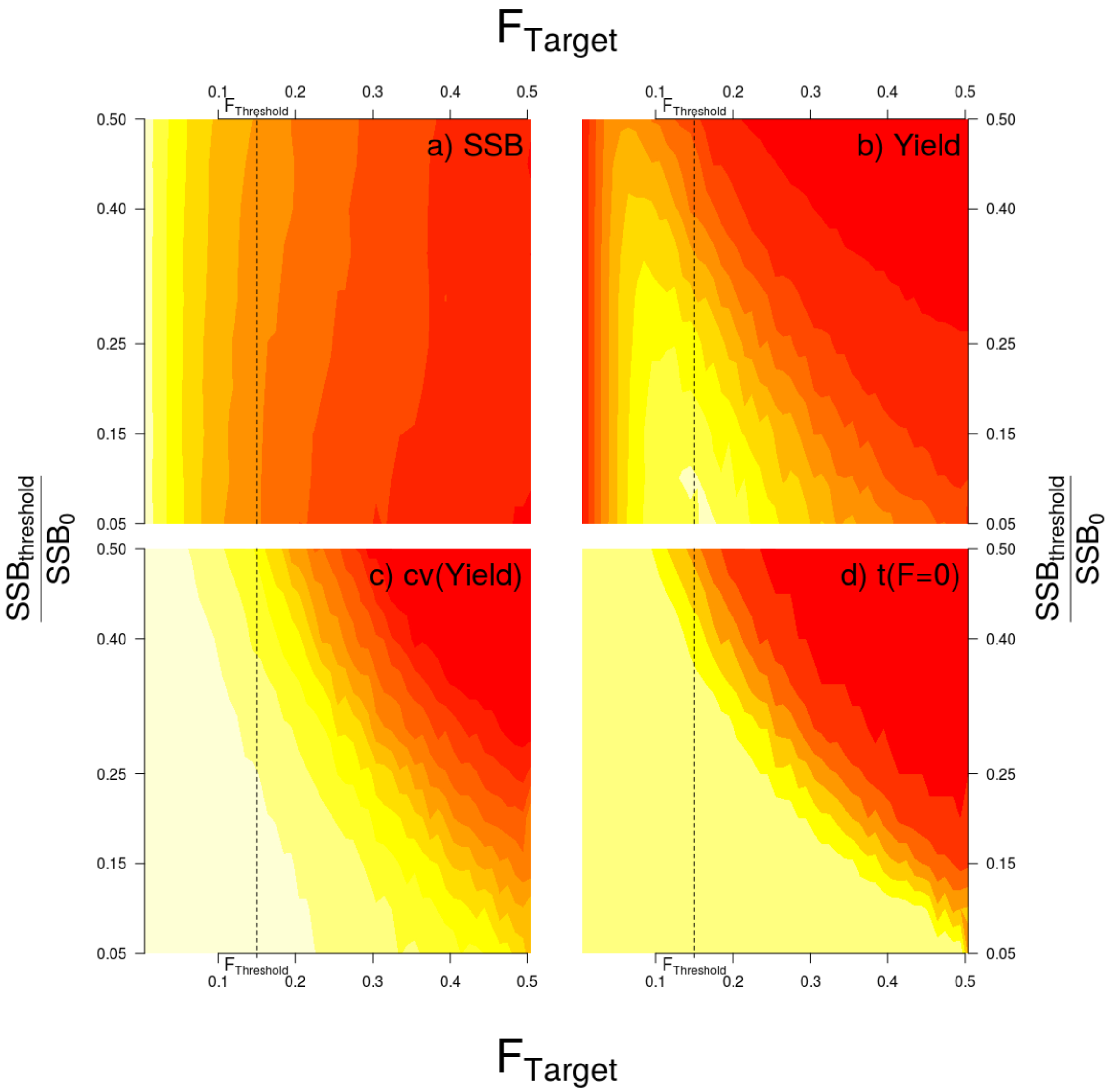


Figure 236: Contour plots showing the combined effects of F_{target} and the fraction of SSB_0 that corresponds to the control rule (stock replenishment) threshold ($\frac{SSB_{threshold}}{SSB_0}$) on: (a) $\frac{\overline{SSB}}{SSB_0}$, (b) $\frac{\overline{Y}}{SSB_0}$, (c) cv(Y) and (d) $t_{F=0}$. 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.

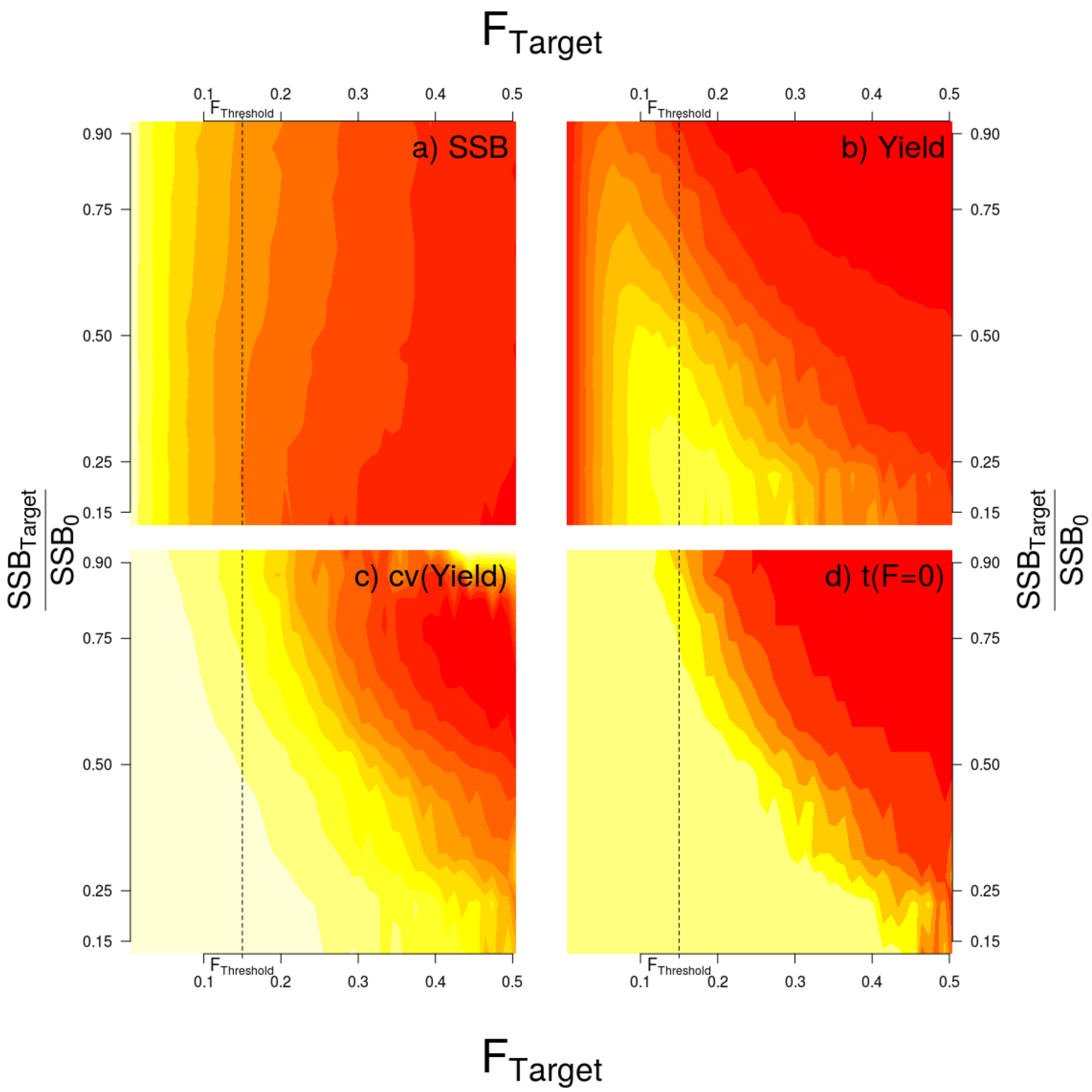


Figure 237: Contour plots showing the combined effects of F_{target} and the fraction of SSB_0 that corresponds to the control rule target ($\frac{SSB_{targer}}{SSB_0}$) on: (a) $\frac{\overline{SSB}}{SSB_0}$, (b) $\frac{\overline{Y}}{SSB_0}$, (c) cv(Y) and (d) $t_{F=0}$. In each plot the darker colors 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 9 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 238). $\widehat{F_{W,wt}}$ 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 239). 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.

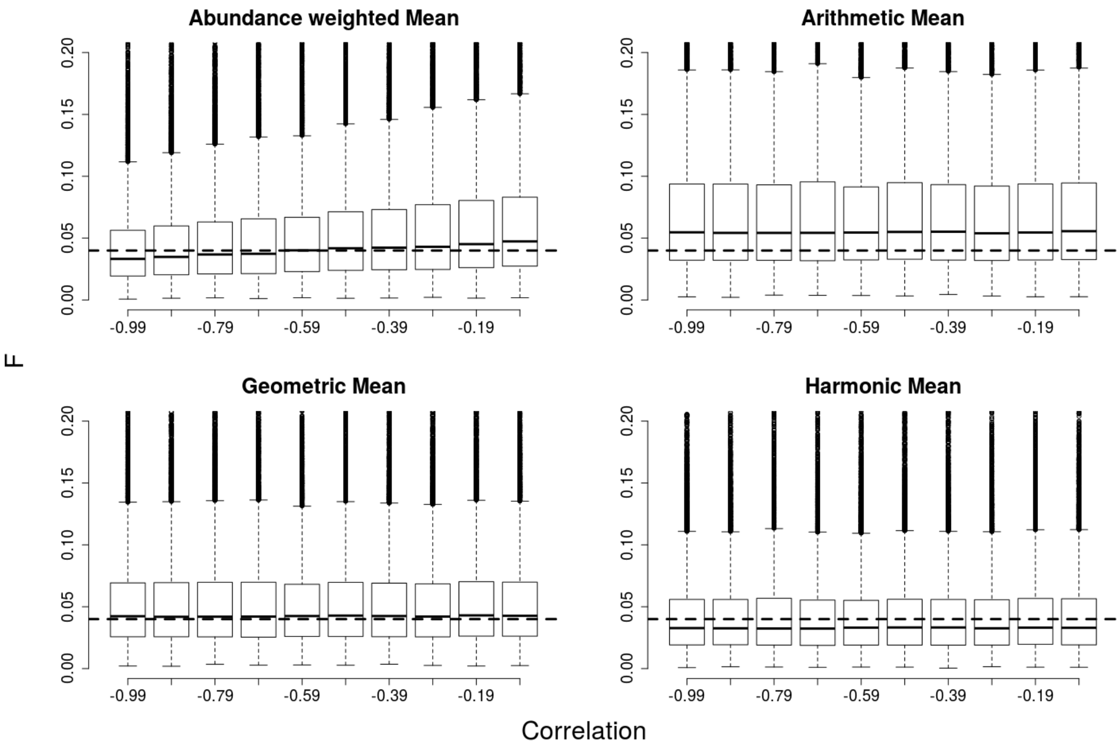


Figure 238: The distribution of estimates of the combined fishing mortality from two regions at varying levels of correlation between abundance and F, compared to the true combined fishing mortality (dashed line). The geometric mean was nearly unbiased at all correlation levels, while the bias in abundance weighted mean depended on the correlation between F and abundance.

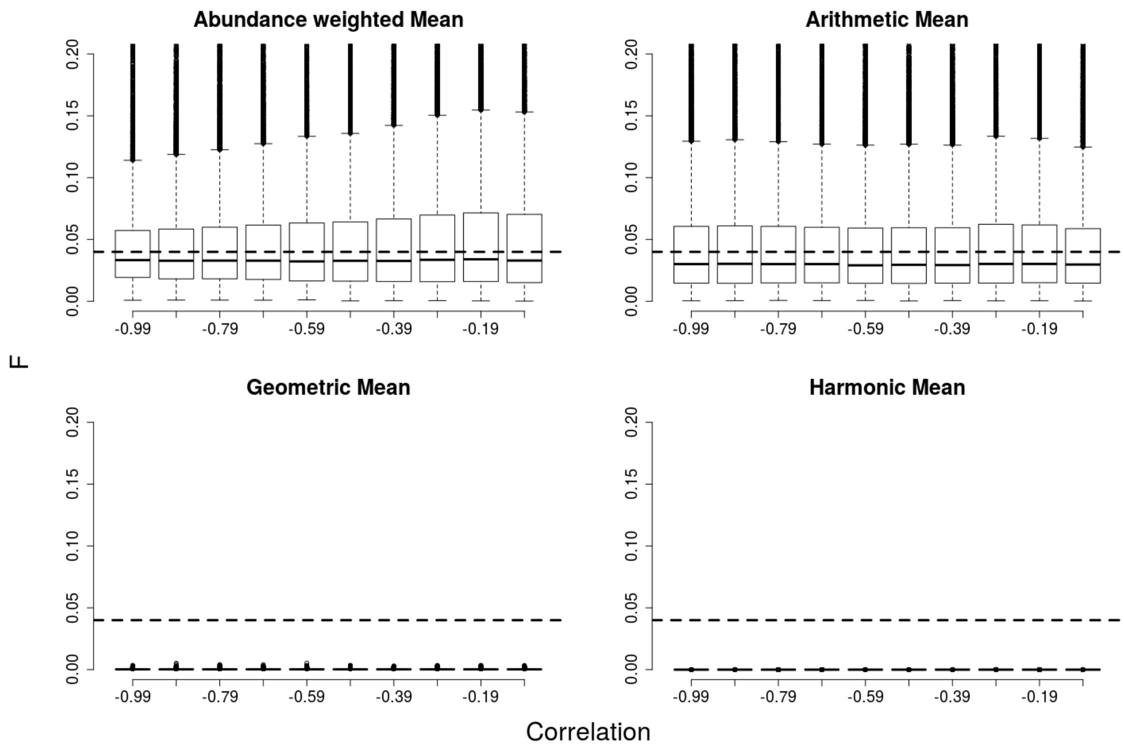


Figure 239: The distribution of estimates of the combined fishing mortality from two regions at varying levels of correlation between abundance and F, compared to the true combined fishing mortality (dashed line), when one the true F values is near 0 ($F = 0.00001$). In this case the geometric and harmonic means were strongly negatively biased and the abundance weighted average was the preferred method

Appendix 10 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 240; Weinberg et al. (2002)). 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:

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

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:

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

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:

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

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 45). 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 45). 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 45 and Figures 241-242). 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 240). 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 45).

Table 45: 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

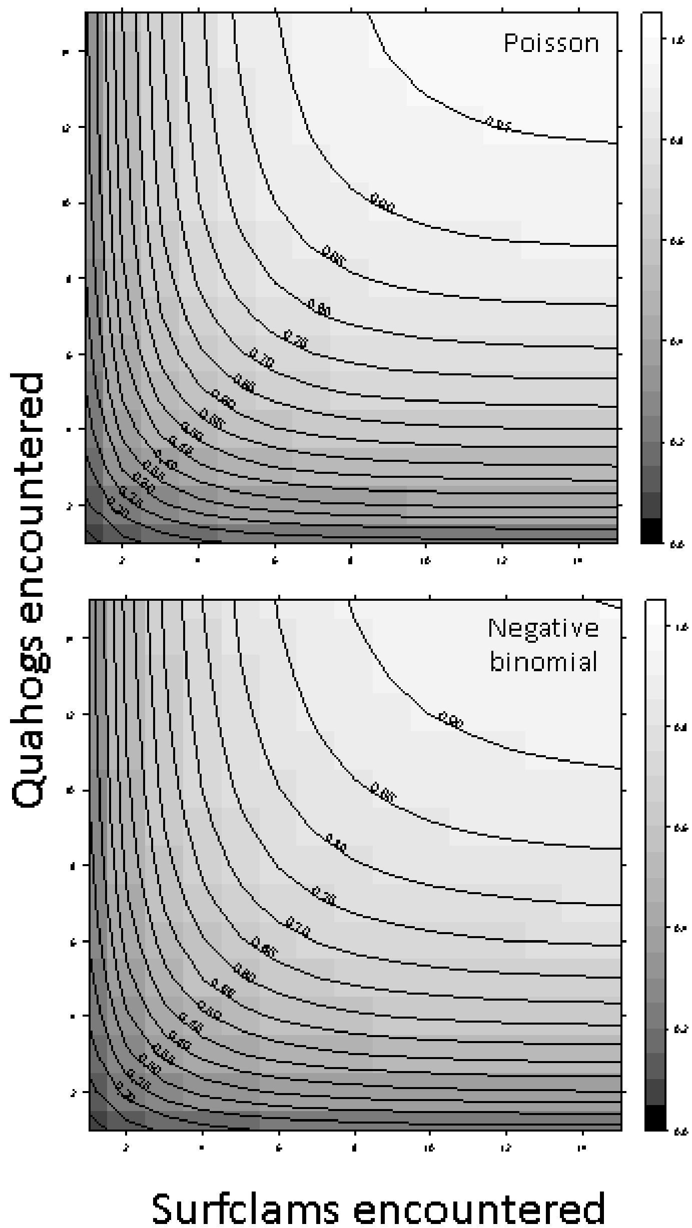


Figure 240: Isopleths for the probability of co-occurrence (at least one Atlantic surfclam and one ocean quahog in a hypothetical survey tow) given the number of Atlantic surfclam and ocean quahogs encountered.

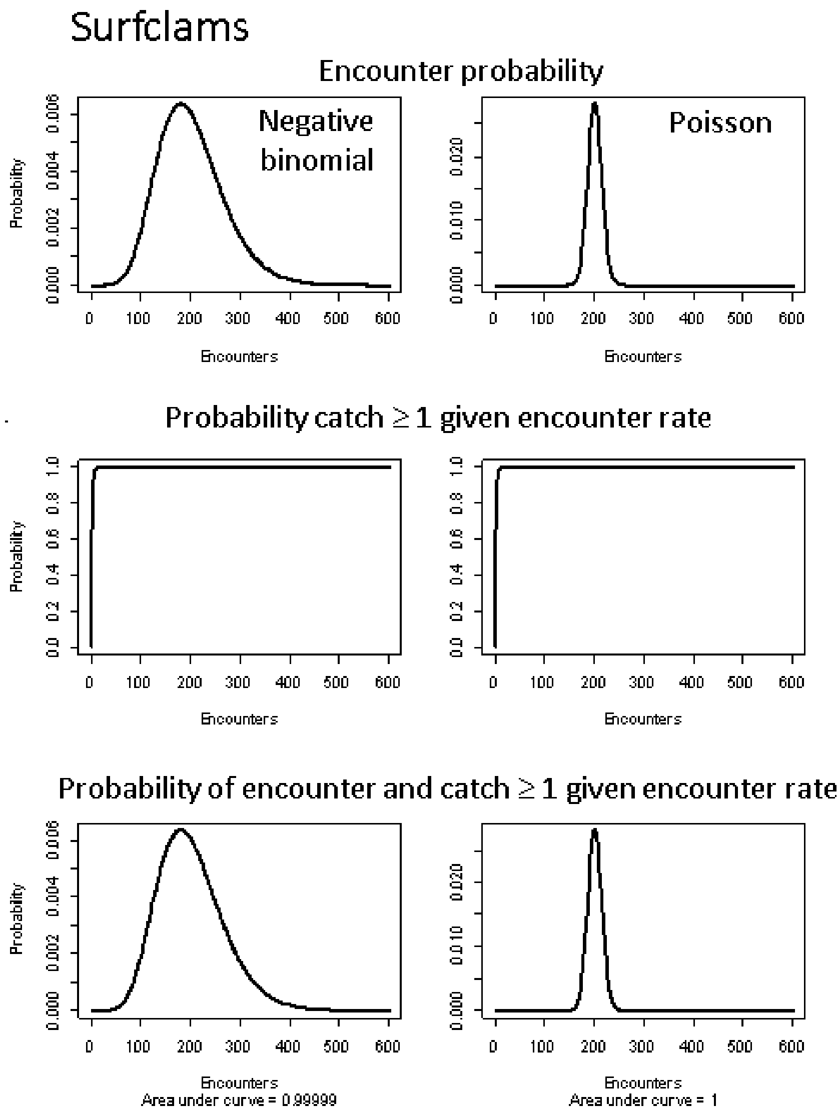


Figure 241: Intermediate calculations in calculating the probability that at least one individual is captured in a hypothetical survey tow assuming typical parameter values and either a negative binomial (left) or Poisson (right) distribution for encounter probability. The top row gives the probability 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.

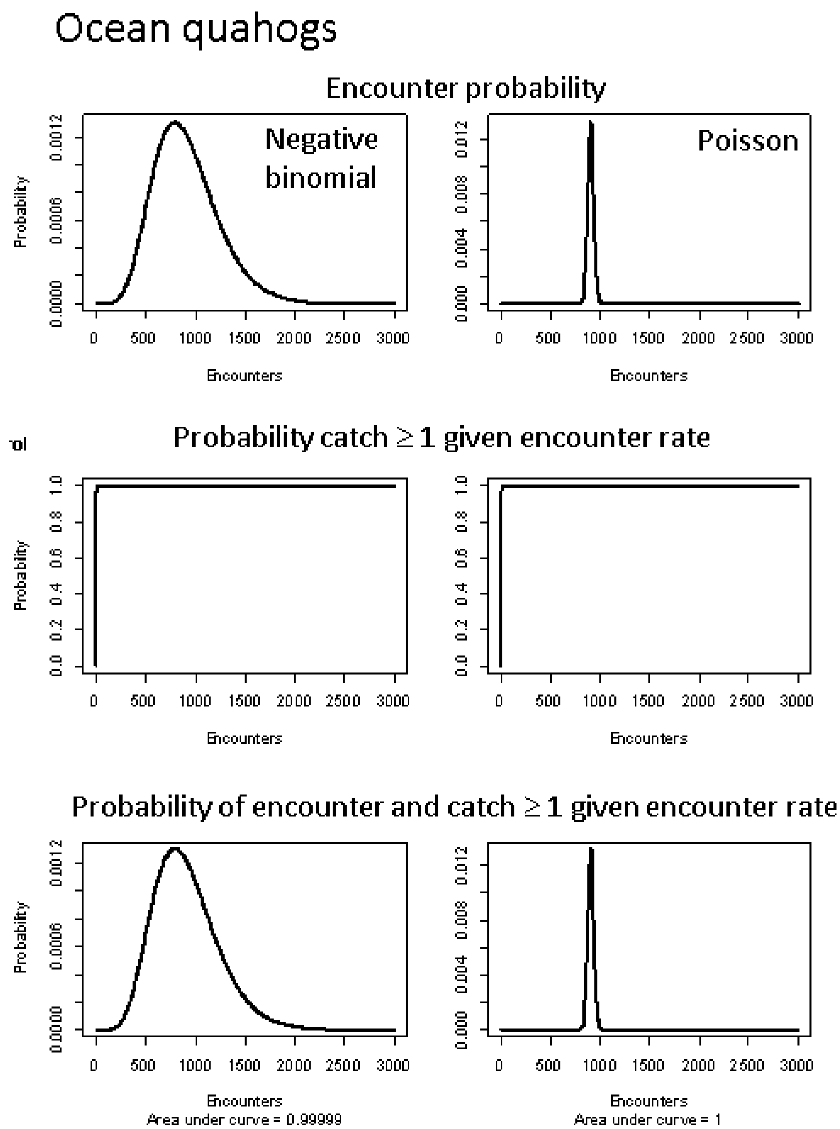


Figure 242: Intermediate calculations in calculating the probability that at least one individual is captured in a hypothetical survey tow assuming typical parameter values and either a negative binomial (left) or Poisson (right) distribution for encounter probability. The top row gives the probability 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.

Appendix 11 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 10), 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 243). Significant trends were detected for individual survey strata within each region except SNE (Table 46).

Table 46: 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

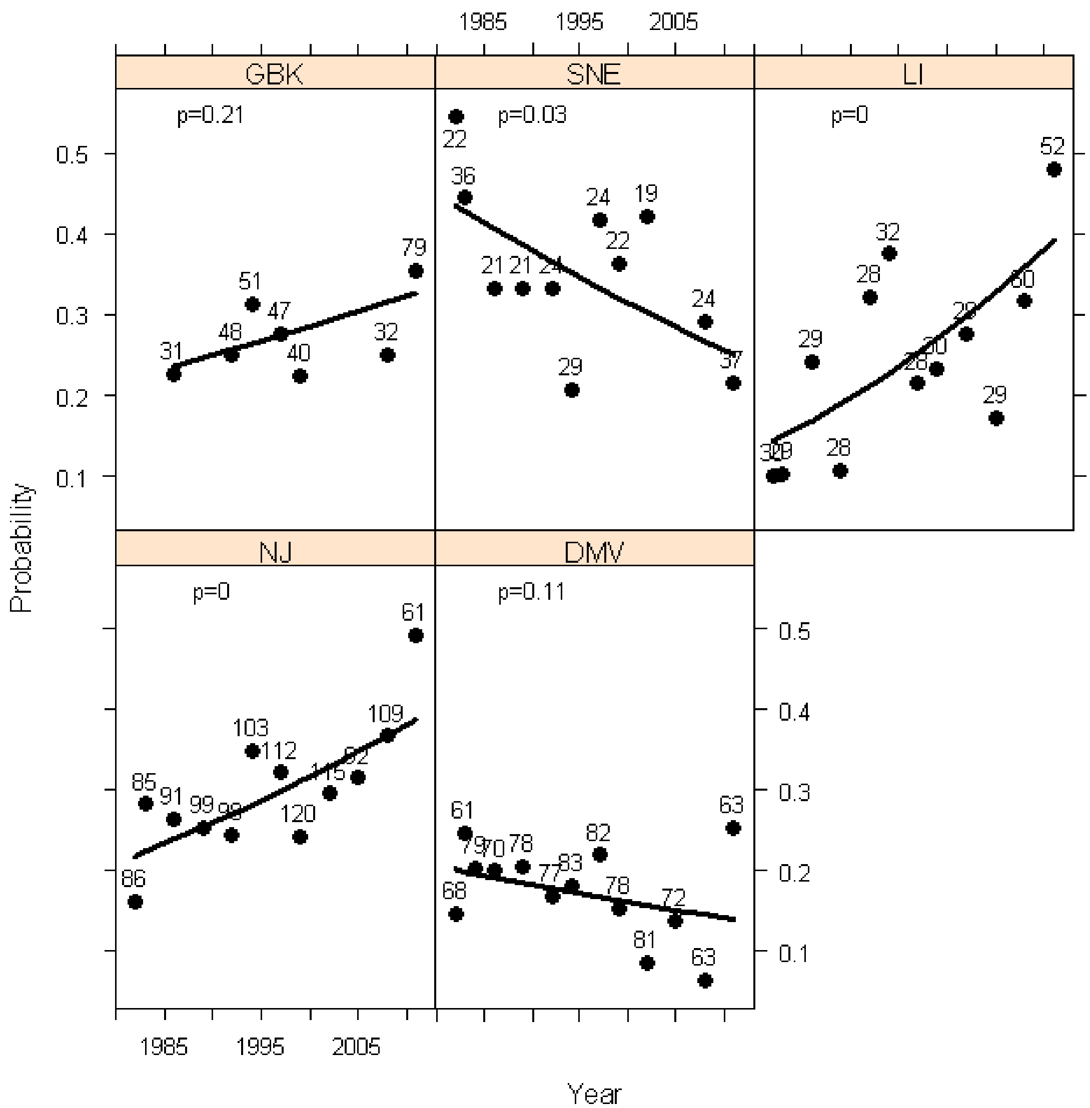


Figure 243: Trends in co-occurrence of Atlantic surfclam and ocean quahogs by region with p-values (top of each panel) and sample sizes in each year.

Appendix 12 Changes in habitat area for Atlantic surfclam 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 10). 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 47, Figure 244 and Appendix 10). 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 245). 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 48). 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 246-250) .

Trends in total habitat were calculated by summing the predicted probabilities for each year and cell from the best model (Figures 246-250). 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 48 and Figure 250). 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 246-250) 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 248-249). The best model for trends in DMV suggests that habitat area declined due to losses in shallow coastal areas (Figure 250).

Table 47: 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 48: 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

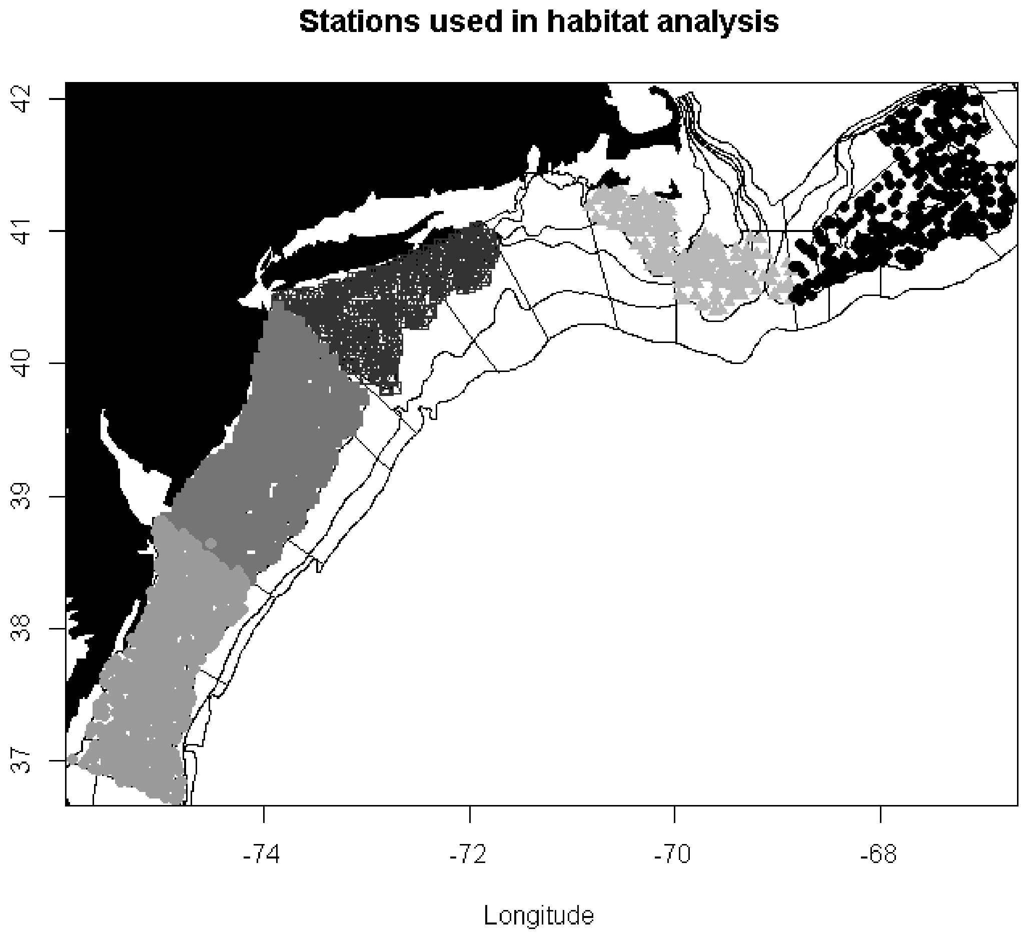


Figure 244: Location of survey stations used to measure Atlantic surfclam habitat area. Regions are identified using shades of grey. The regions from north to south are GBK, SNE, LI, NJ and DMV.

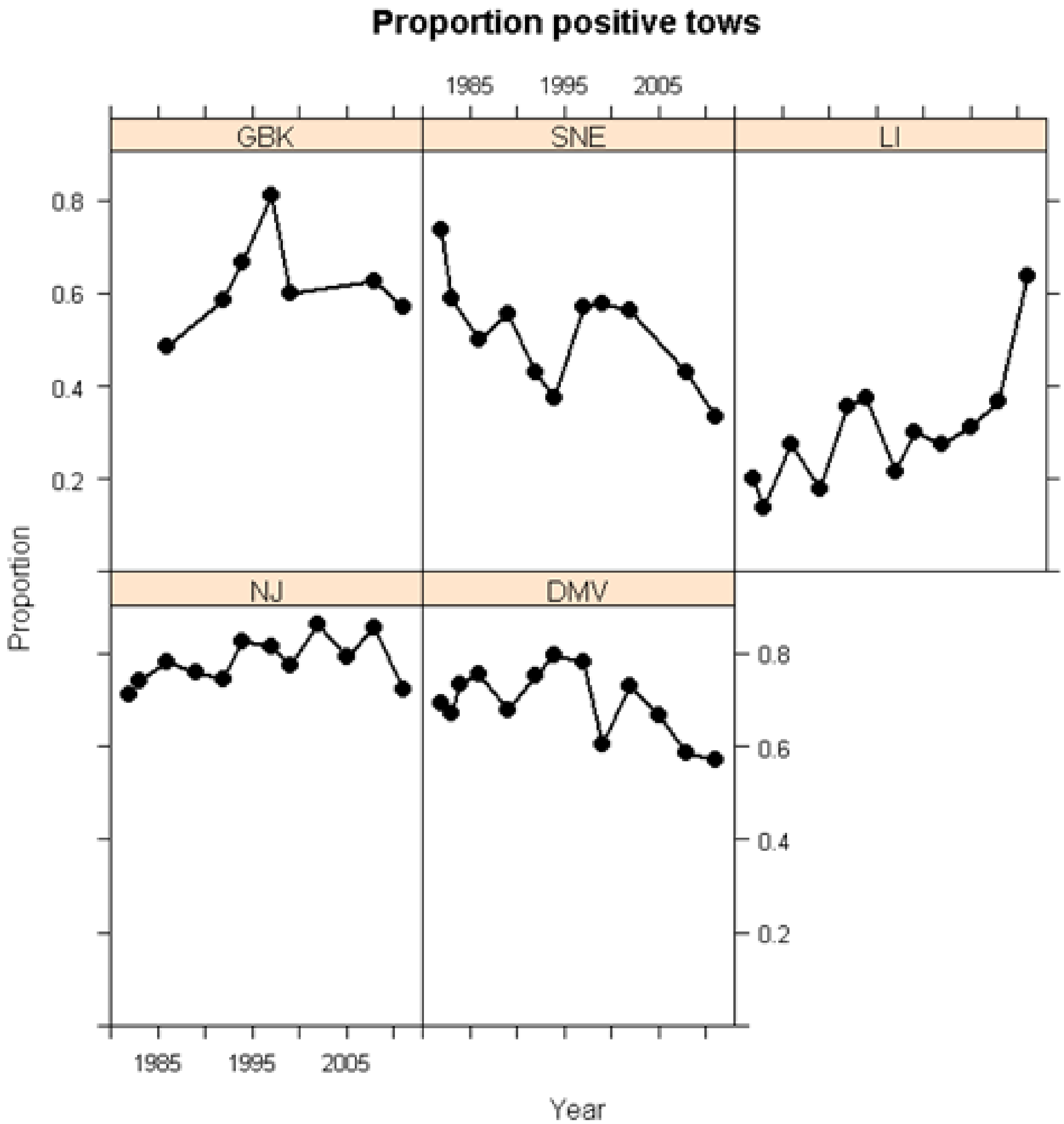


Figure 245: Trends in proportion positive tows based on raw survey data by region.

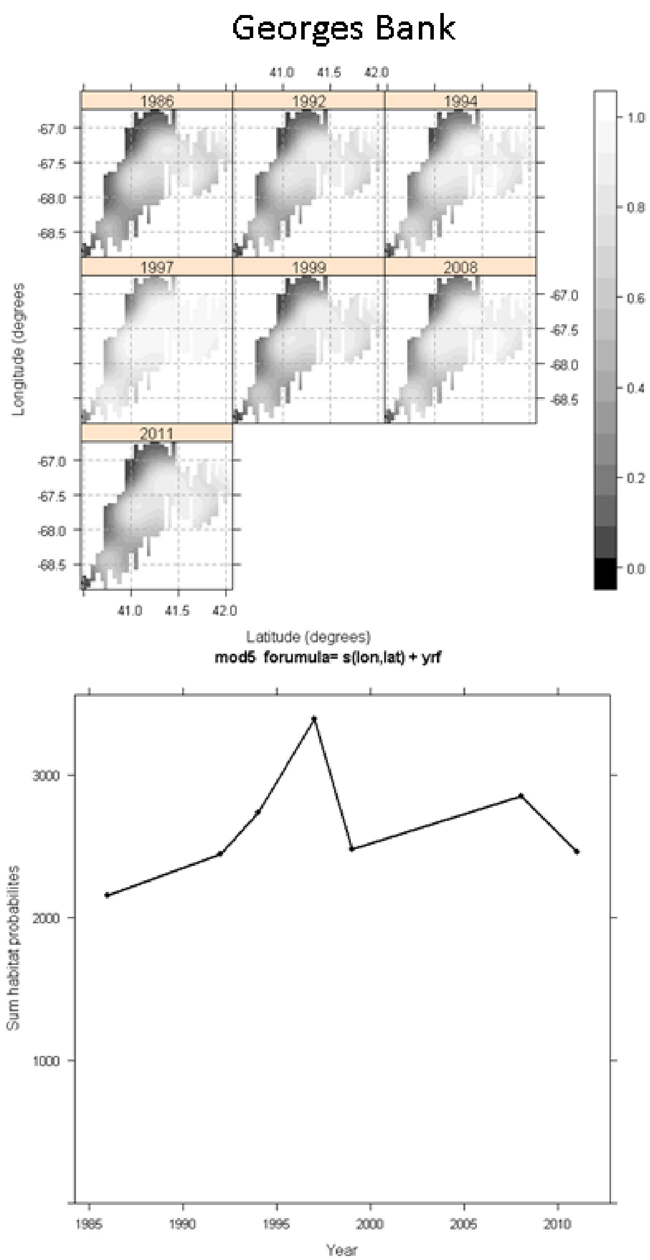


Figure 246: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The "Best for trends" model for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

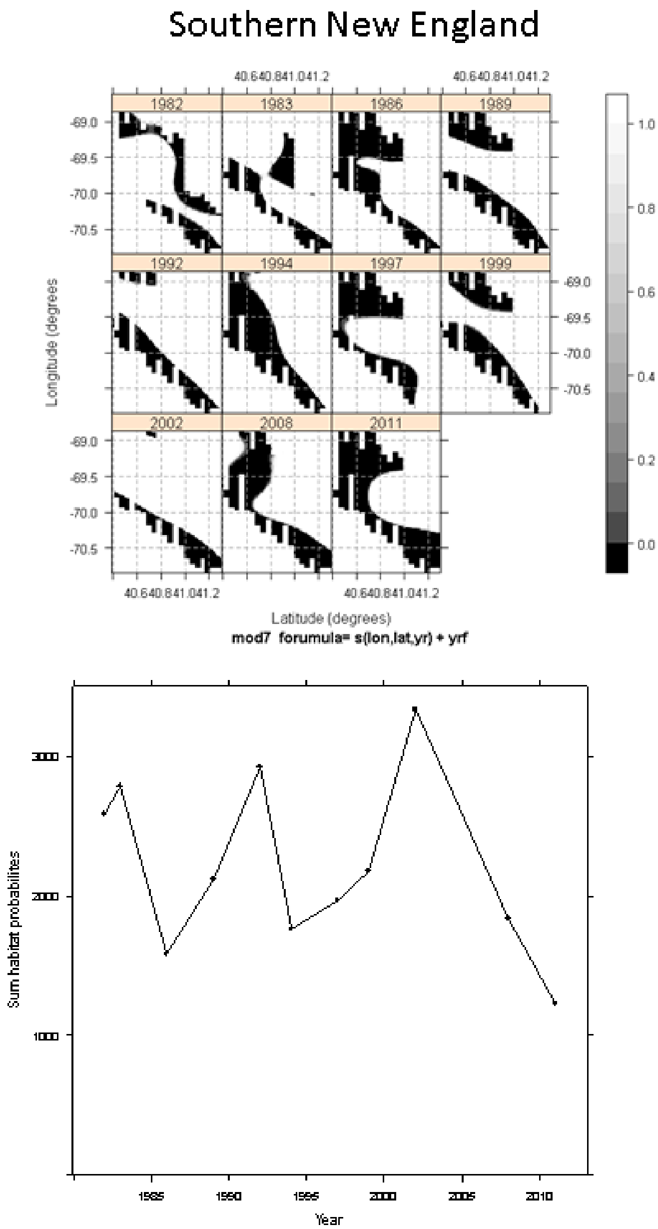


Figure 247: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The "Best for trends" model for DMV is different from the best model based on AIC although the two models had nearly identical AIC scores (see text).

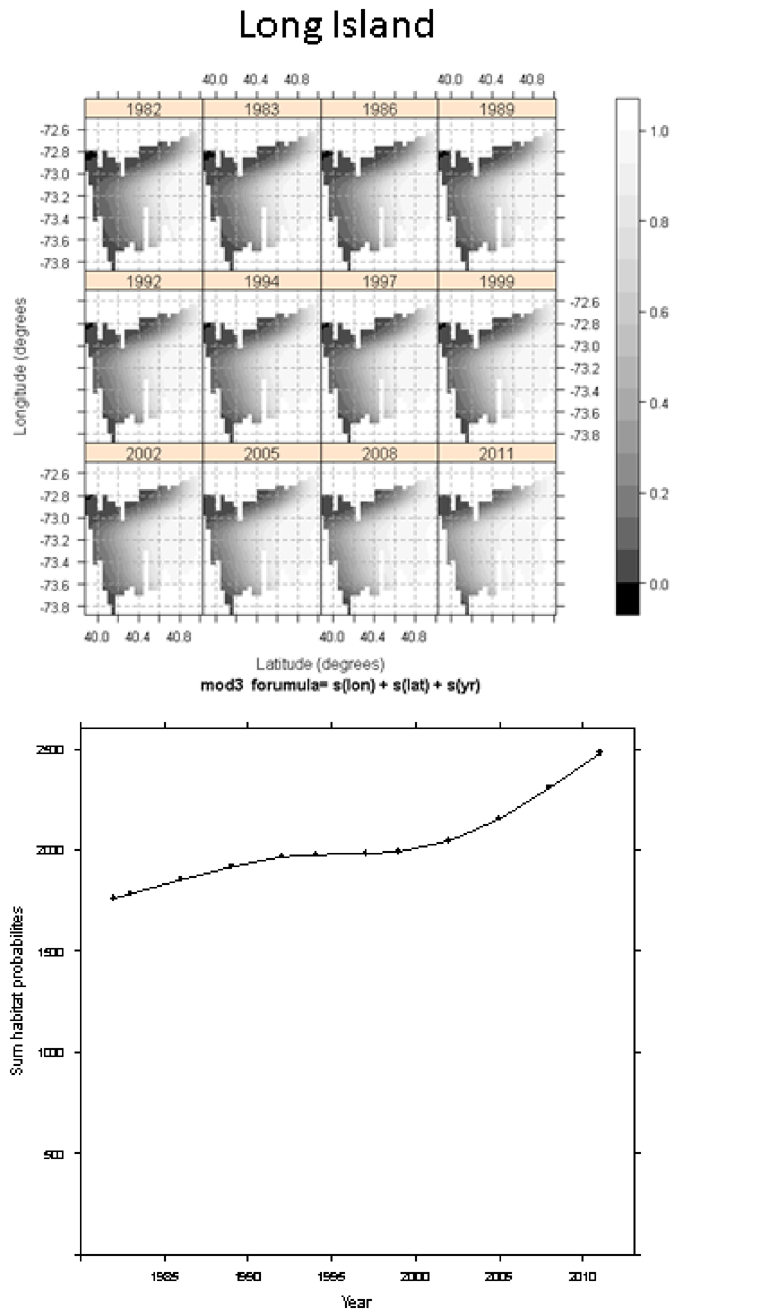


Figure 248: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The “Best for trends” model for DMV is different from the best model based on AIC although the two models had nearly identical AIC scores (see text).

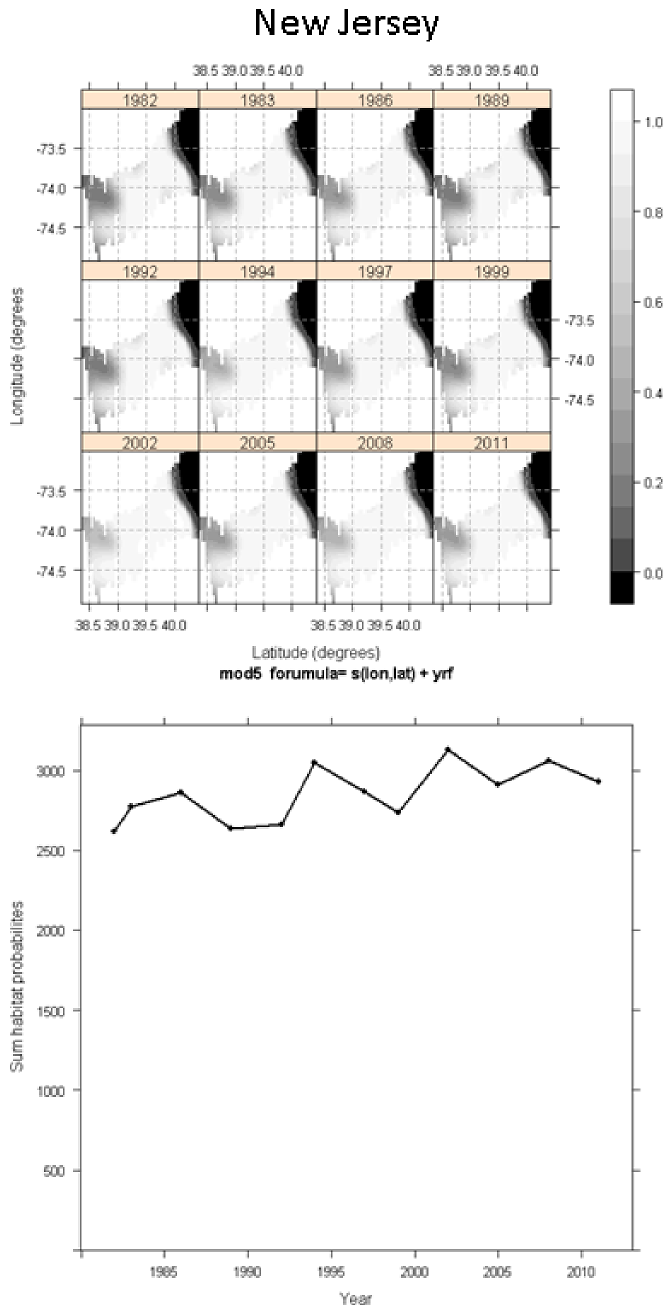


Figure 249: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The "Best for trends" model for DMV is different from the best model based on AIC although the two models had nearly identical AIC scores (see text).

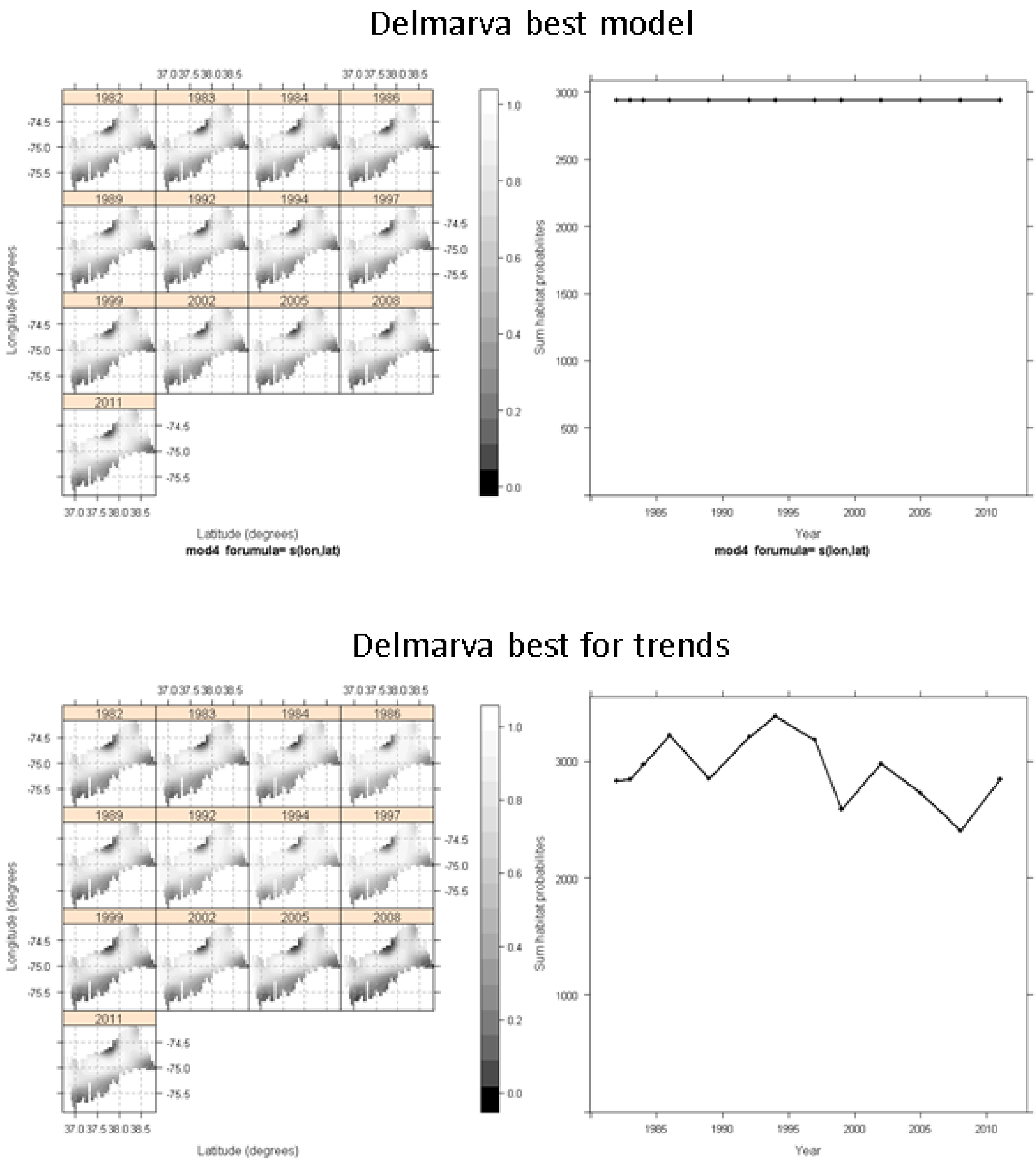


Figure 250: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The "Best for trends" model for DMV is different from the best model based on AIC although the two models had nearly identical AIC scores (see text).

Appendix 13 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[6]

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 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.

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

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 251 and 252).

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 253 and 254).

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 255, 256, 257, 258.

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 259 and 260 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 261).

As can be seen in Figure 261, 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 262 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 263). 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 264 - 266. 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 267 - 270). 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 270), 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 271). 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

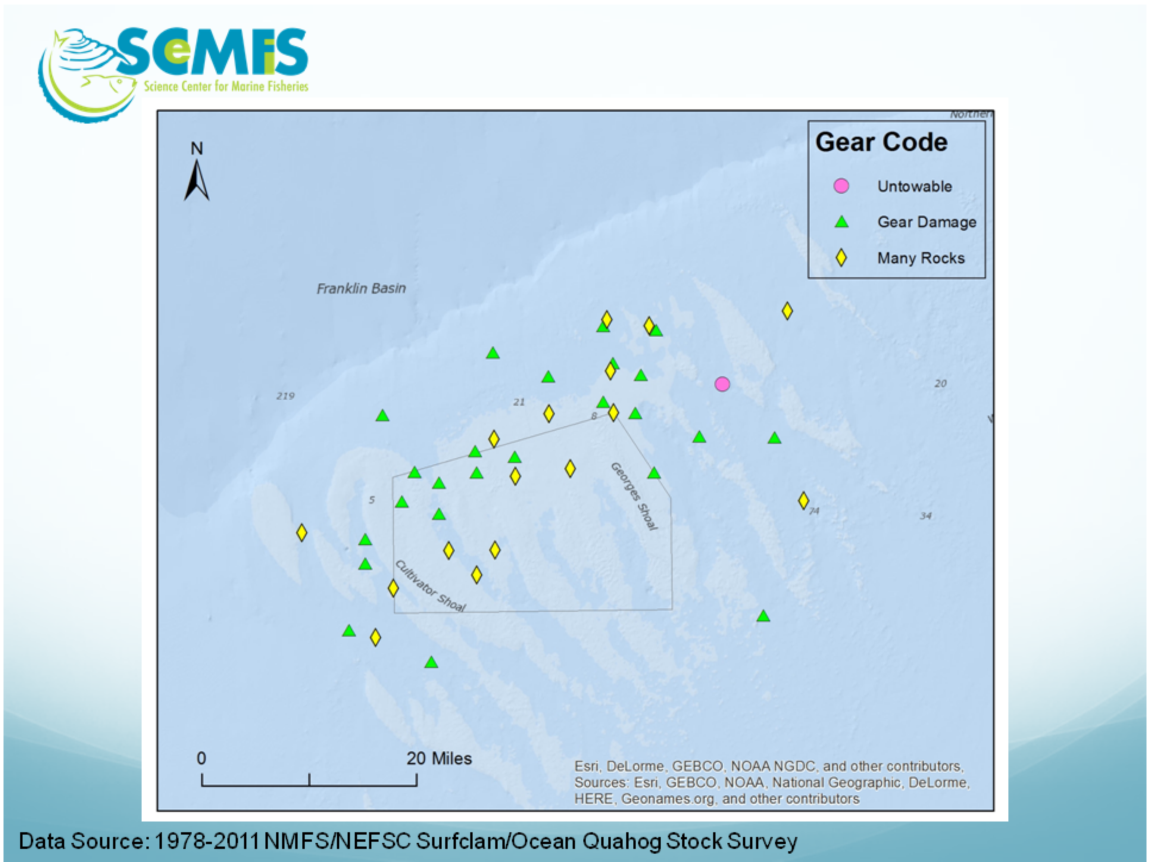


Figure 251: Locations on Georges Shoal and Cultivator Shoal (on Georges Bank) where gear codes or station comments from the NEFSC clam survey indicated untowble or rough ground.

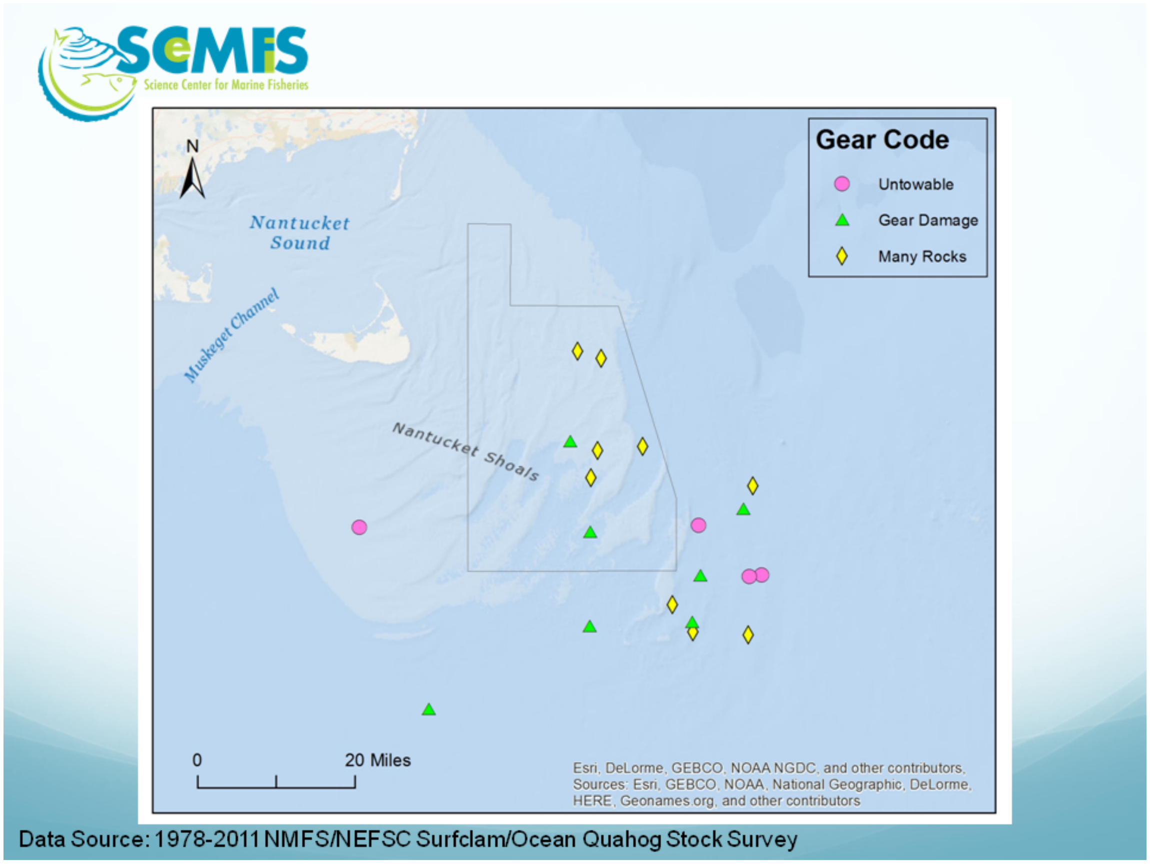


Figure 252: Locations on Nantucket Shoals where gear codes or station comments from the NEFSC clam survey indicated untowble or rough ground.

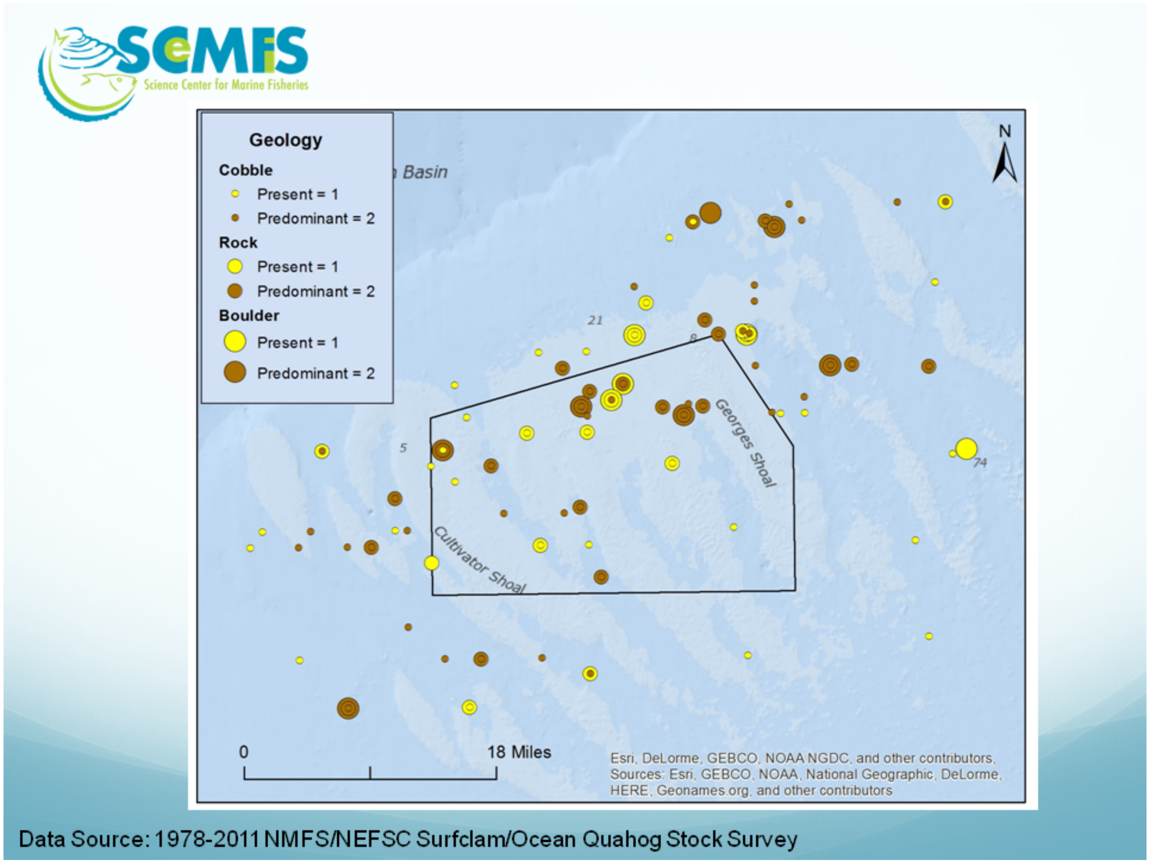


Figure 253: Locations where substrate bycatch data from the NEFSC clam survey included cobbles, rocks and boulders on Georges Shoal and Cultivator Shoal on Georges Bank.

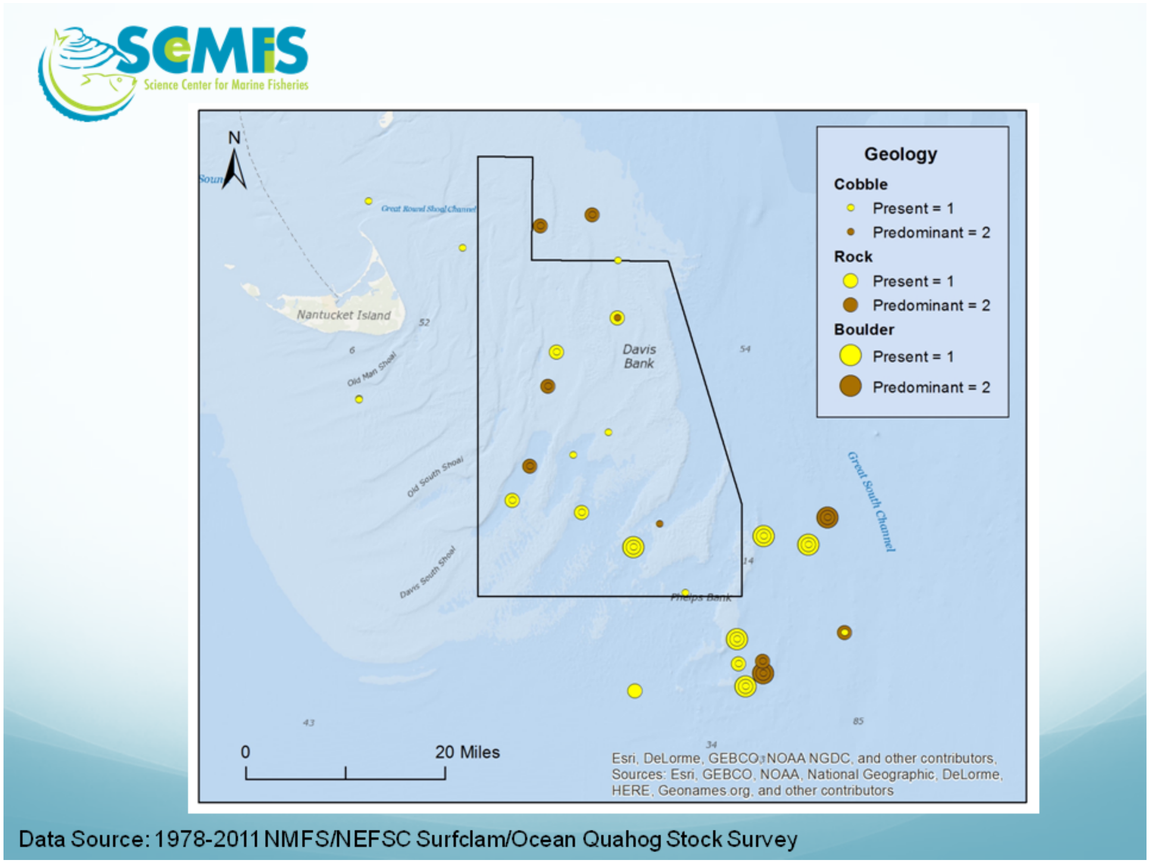


Figure 254: Locations where substrate bycatch data from the NEFSC clam survey included cobbles, rocks and boulders on Nantucket Shoals.

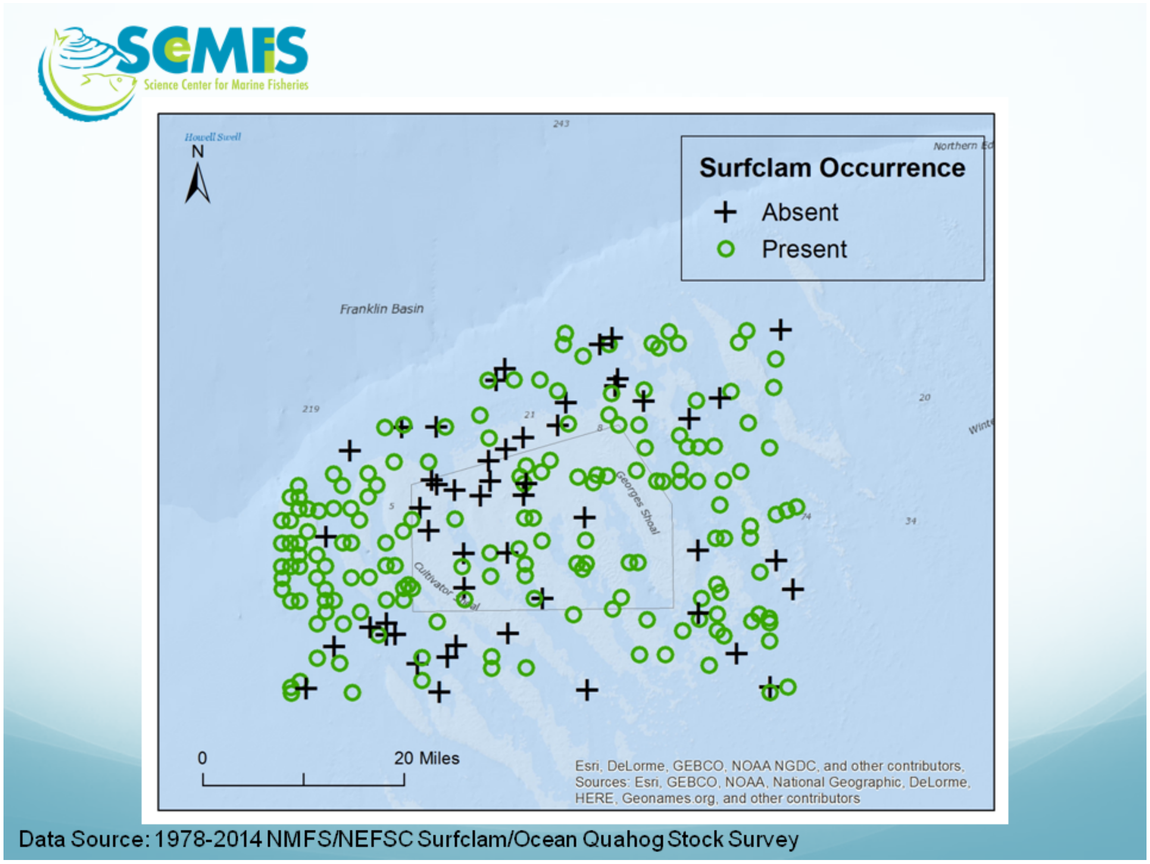


Figure 255: Locations where NEFSC clam survey tow results indicated the presence or absence of live Atlantic surfclam on Georges Shoal and Cultivator Shoal on Georges Bank.

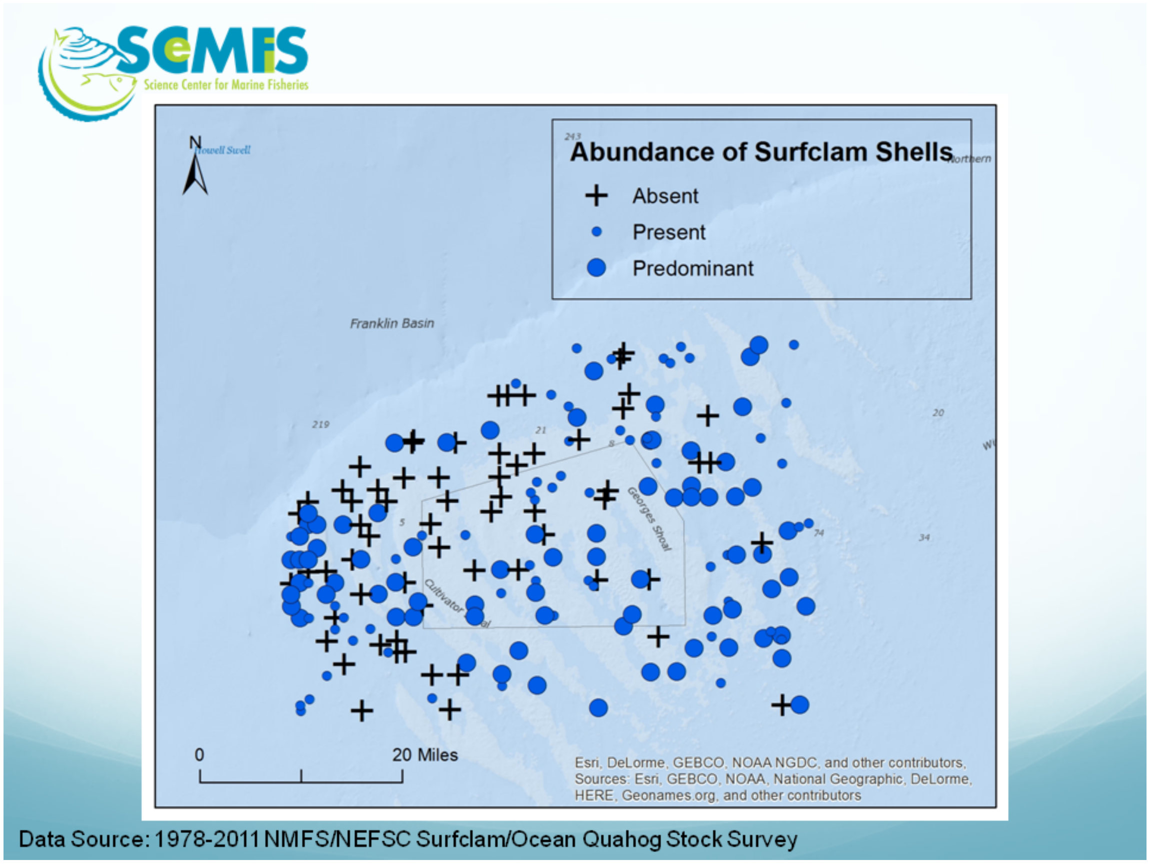


Figure 256: Locations where NEFSC clam survey bycatch data indicated the presence, dominance or absence of Atlantic surfclam dead shell on Georges Shoal and Cultivator Shoal on Georges Bank.

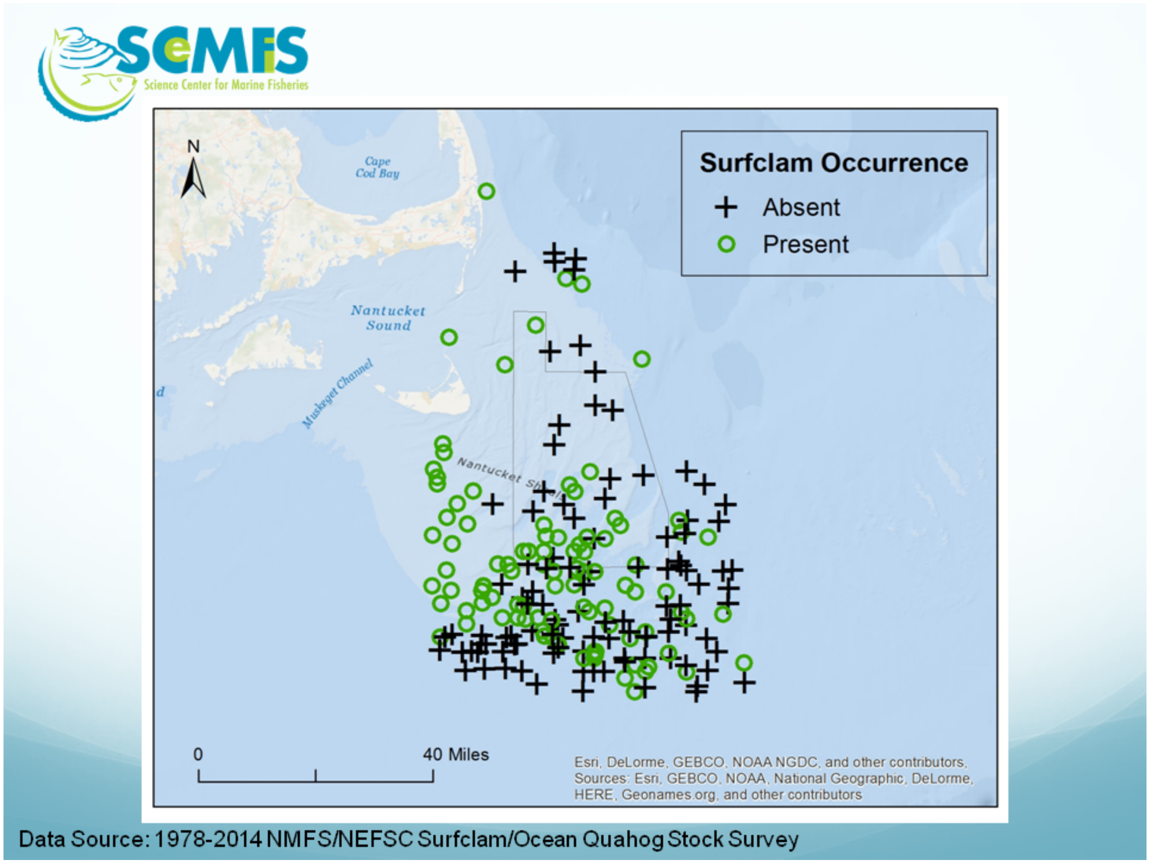


Figure 257: Locations where NEFSC clam survey tow results indicated the presence or absence of live Atlantic surfclam on Nantucket Shoals.

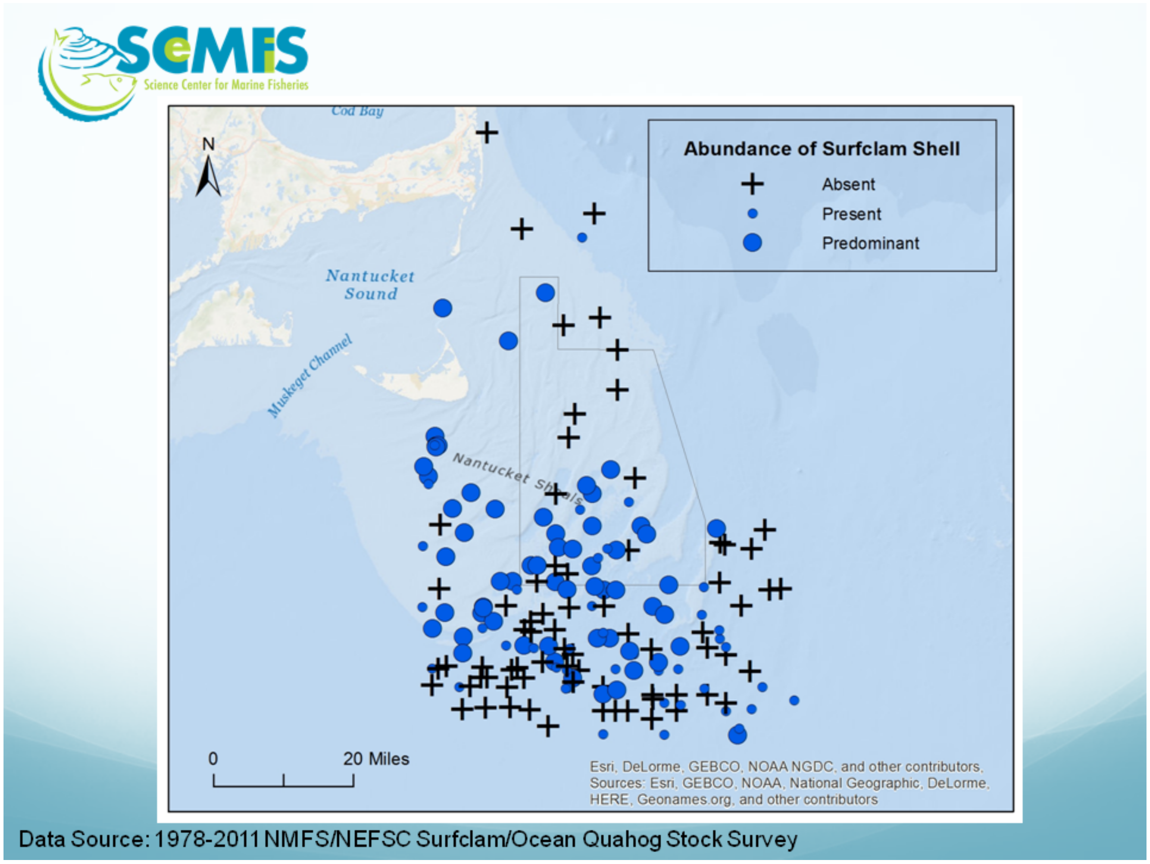


Figure 258: Locations where NEFSC clam survey bycatch data indicated the presence, dominance or absence of Atlantic surfclam dead shell on Nantucket Shoals.

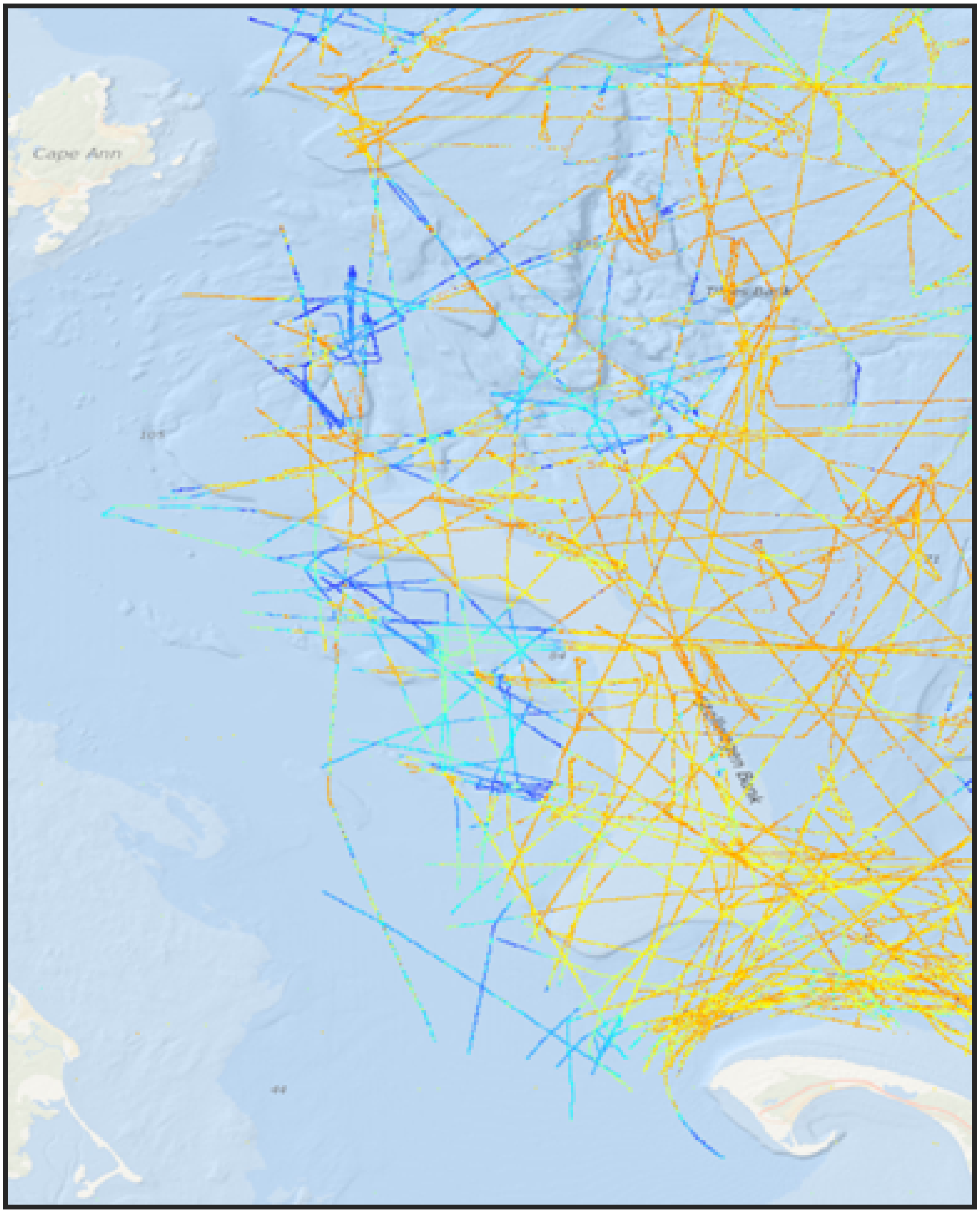


Figure 259: Hardness in the western Gulf of Maine estimated from mutlifrequency acoustic data collected along the tracks of NOAA ships. The data are displayed on a blue to red scale where redder colors are harder and bluer colors are less hard.

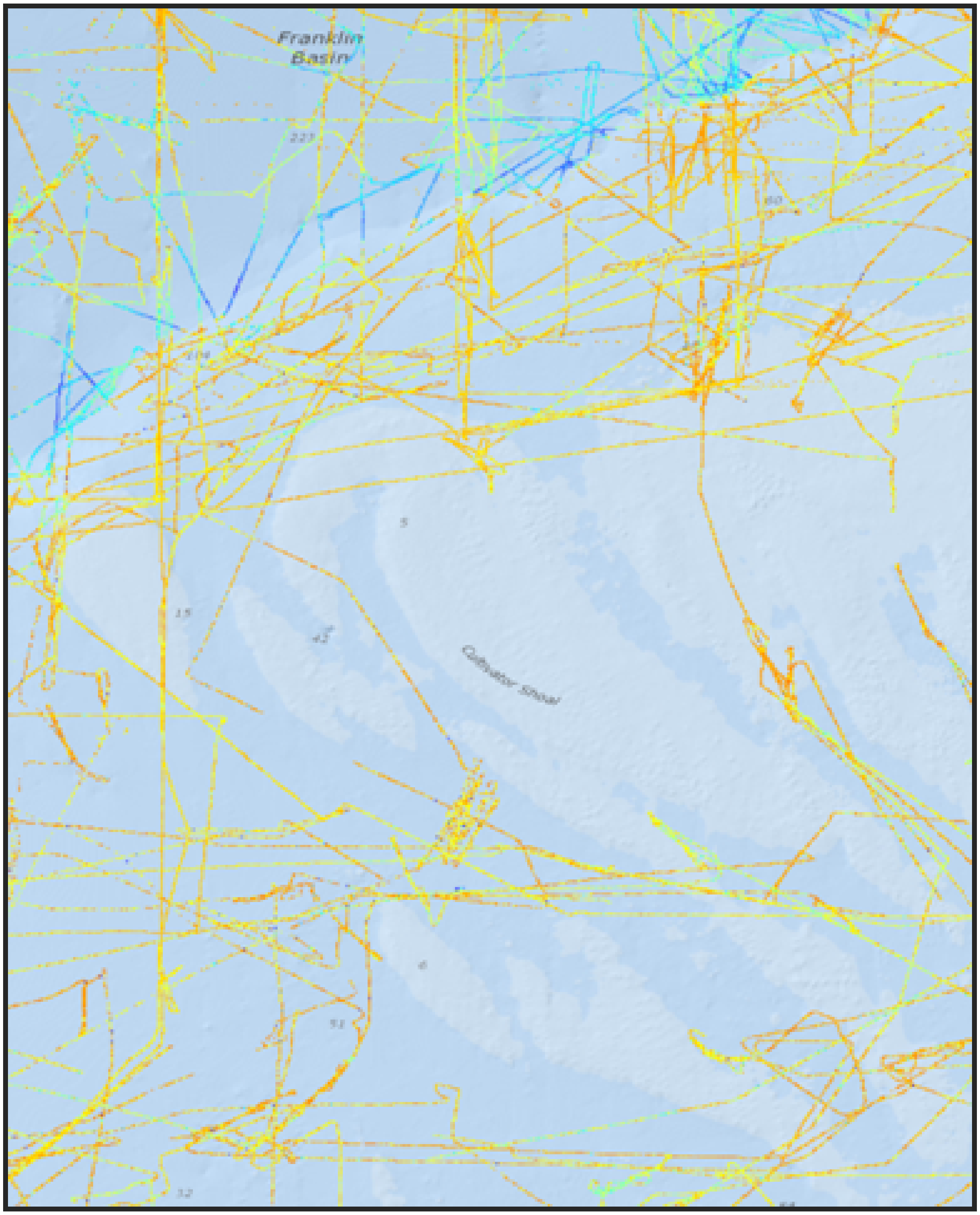


Figure 260: Hardness on Cultivator shoals, Georges Bank as estimated from mutlifrequency acoustic data collected along the tracks of NOAA ships. The data are displayed on a blue to red scale where redder colors are harder and bluer colors are less hard.

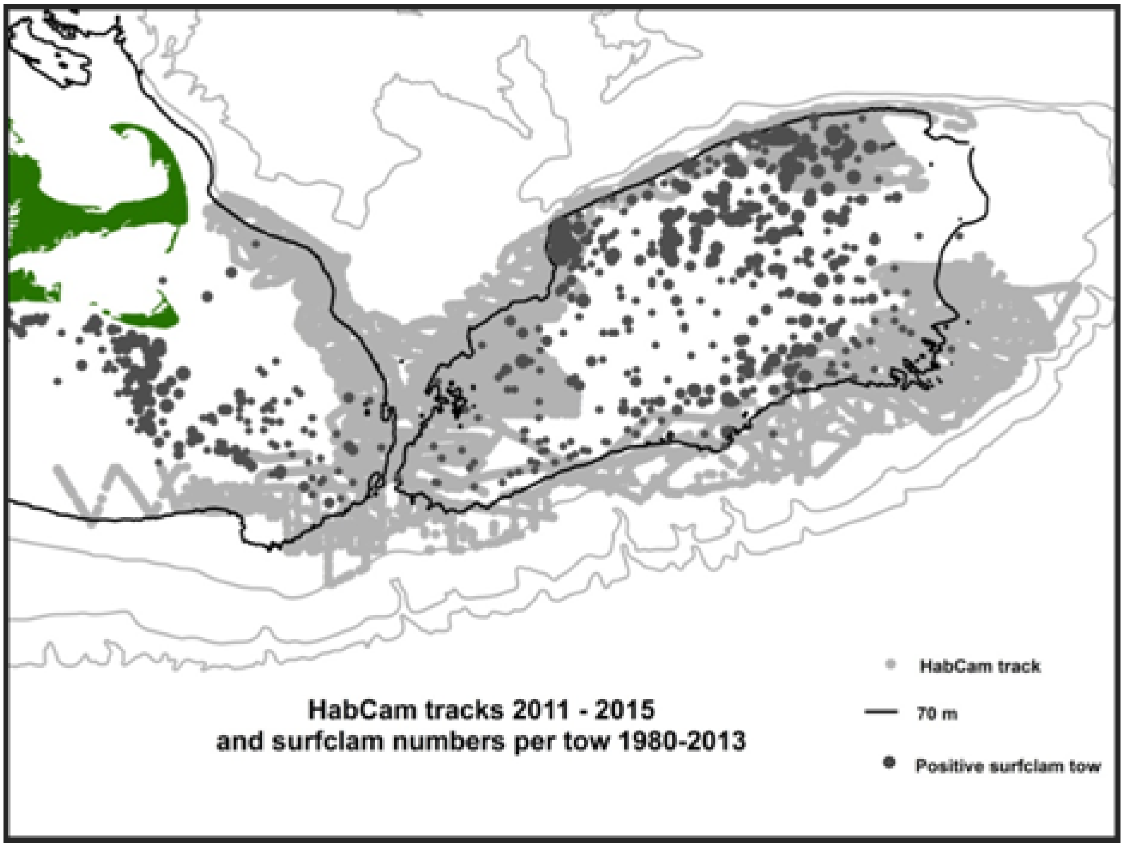


Figure 261: Tracklines of the HabCam towed by the NEFSC scallop survey vessel (gray shading) with the NEFSC clam survey Atlantic surfclam catches overlaid (black dots) and the 70 m isobath. In reality the tracklines are only about 1 meter wide.

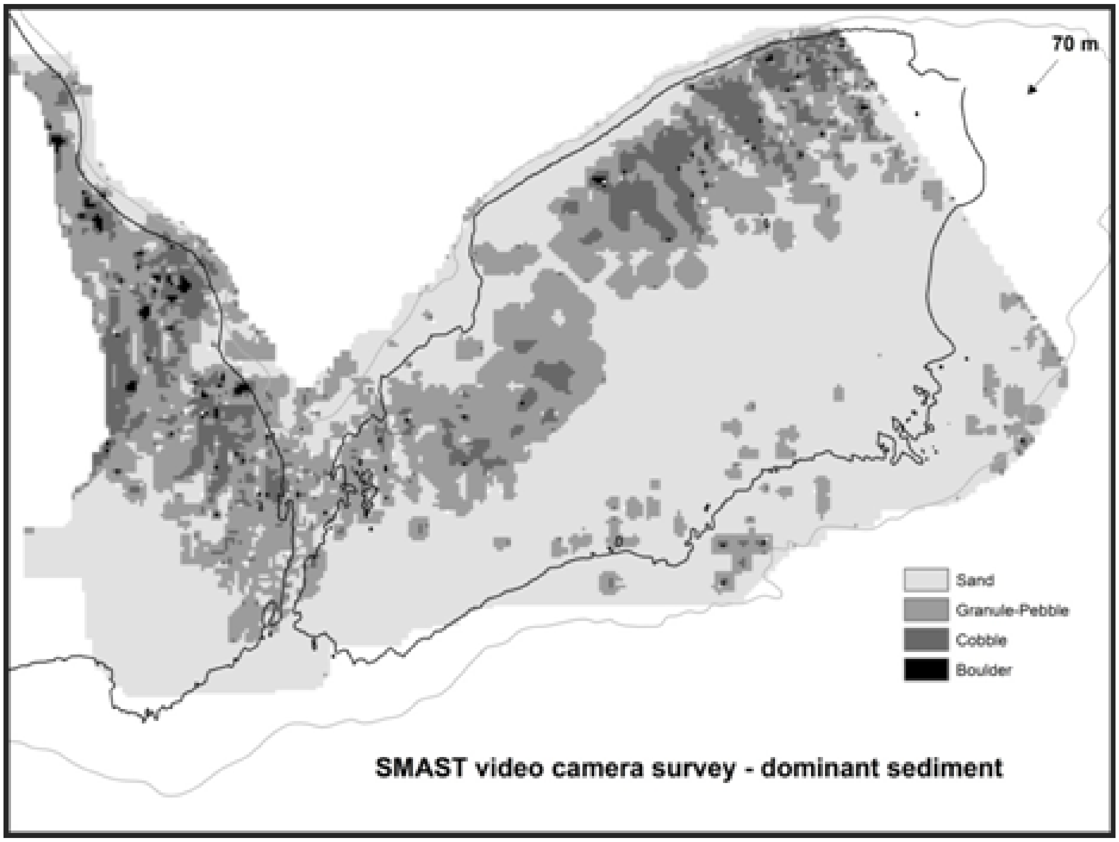


Figure 262: A map of the maximum sediment size visible from the underwater video at each station.

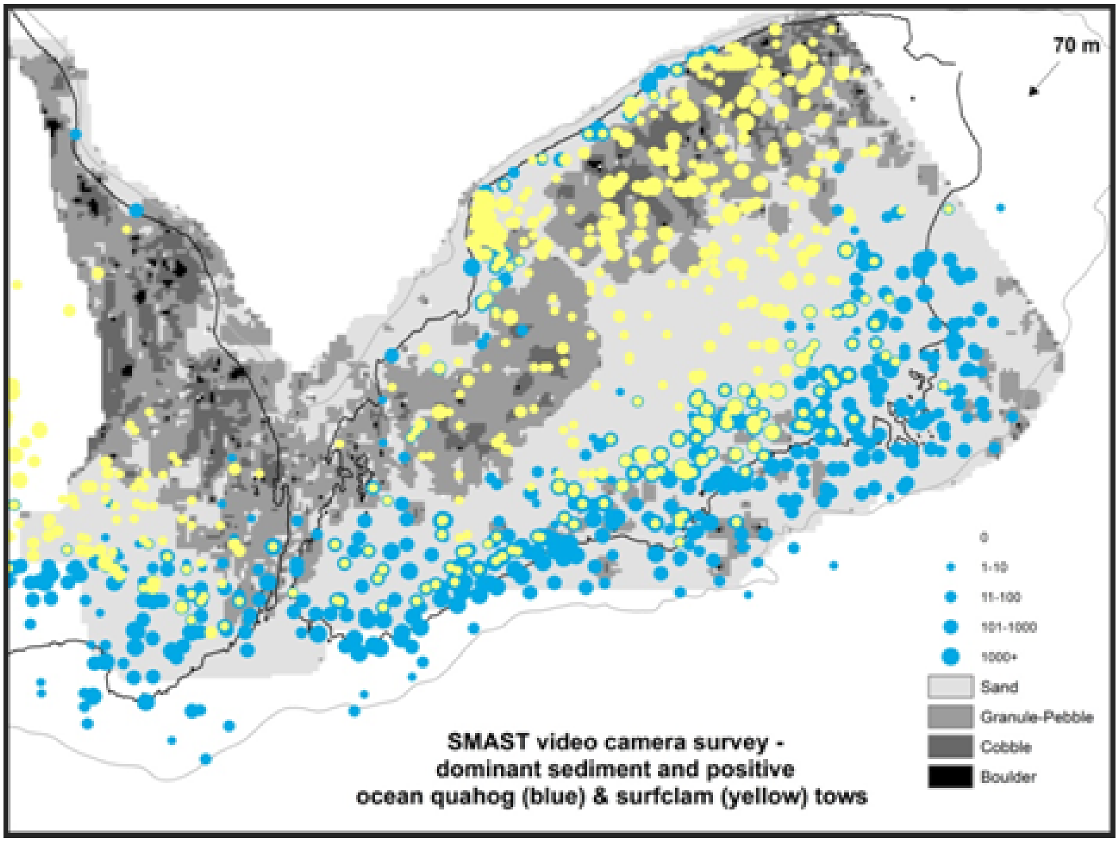


Figure 263: A map of the maximum sediment size visible from the underwater video at each station with positive tows for Atlantic surfclam (yellow dots) and ocean quahogs (blue dots) overlaid.

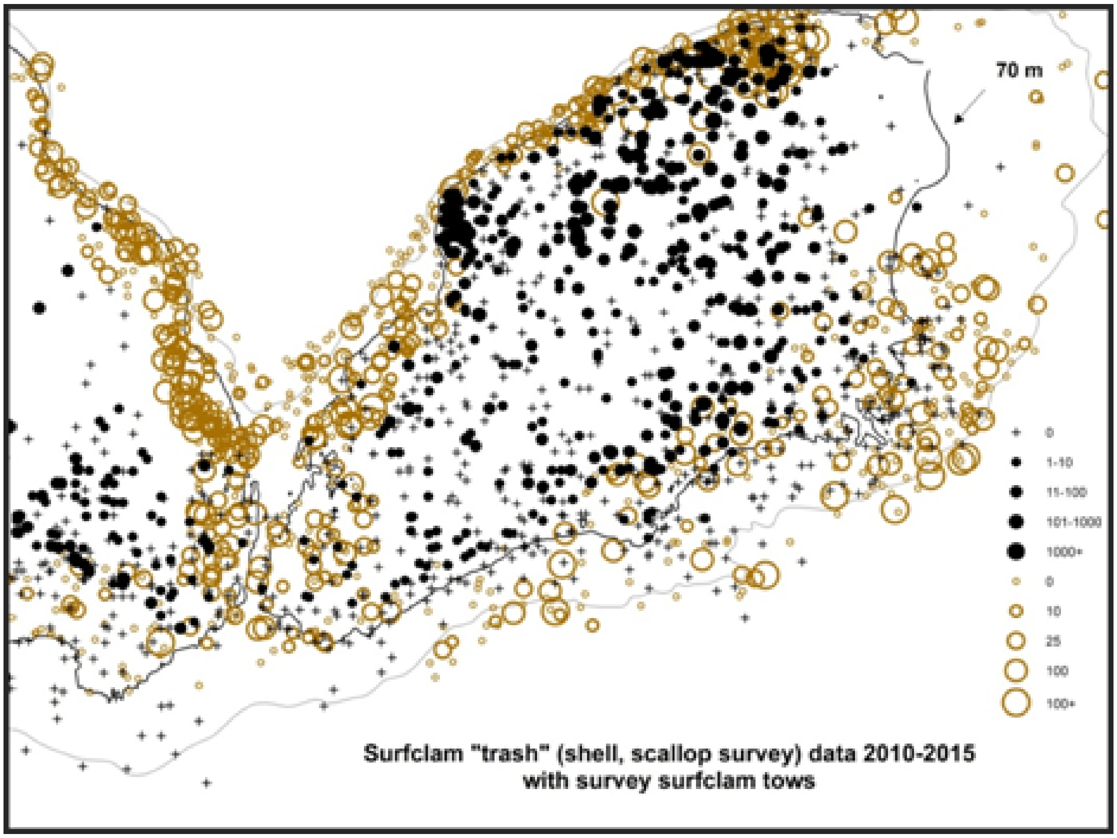


Figure 264: Brown circles represent Atlantic surfclam shell trash brought up in the NEFSC scallop survey dredge, in roughly-estimated liters. Black dots are positive tows for Atlantic surfclam from the NEFSC clam surveys 1980-2013.

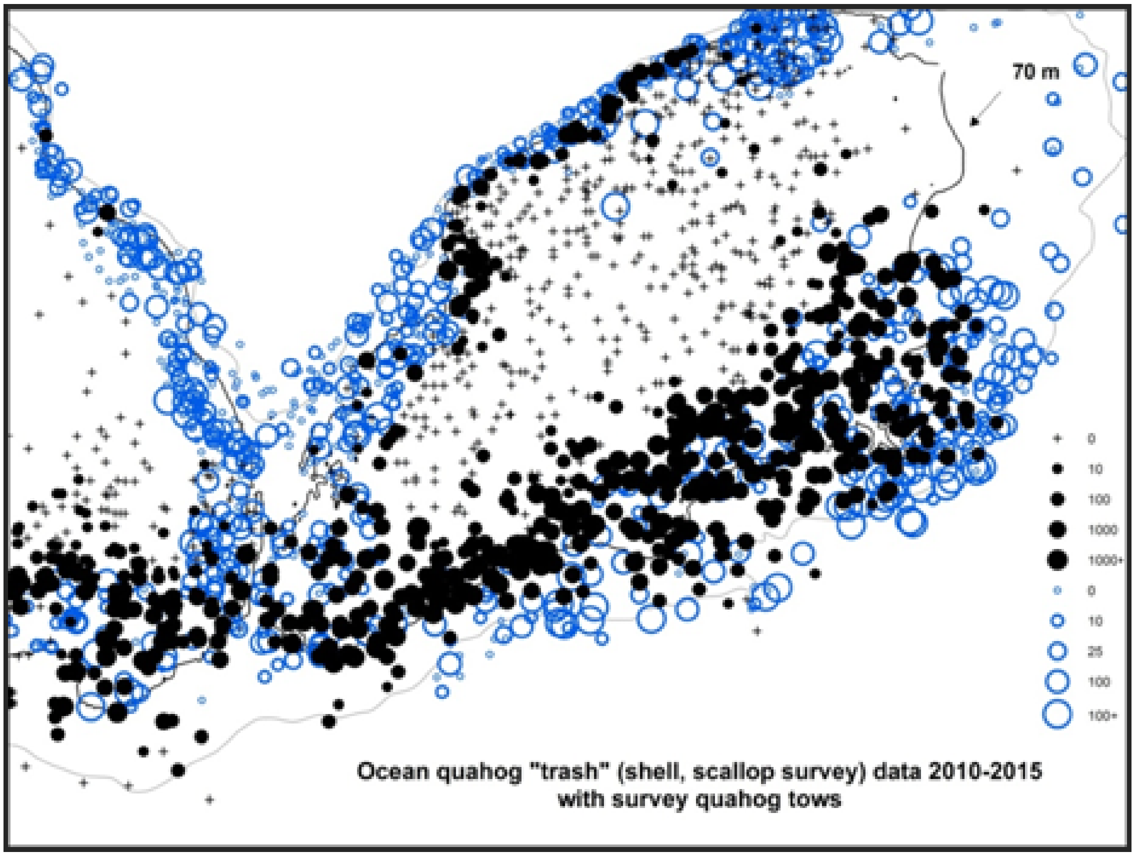


Figure 265: Blue circles represent ocean quahog shell trash brought up in the NEFSC scallop survey dredge, in roughly-estimated liters. Black dots are positive tows for ocean quahogs from the NEFSC clam surveys 1980-2013.

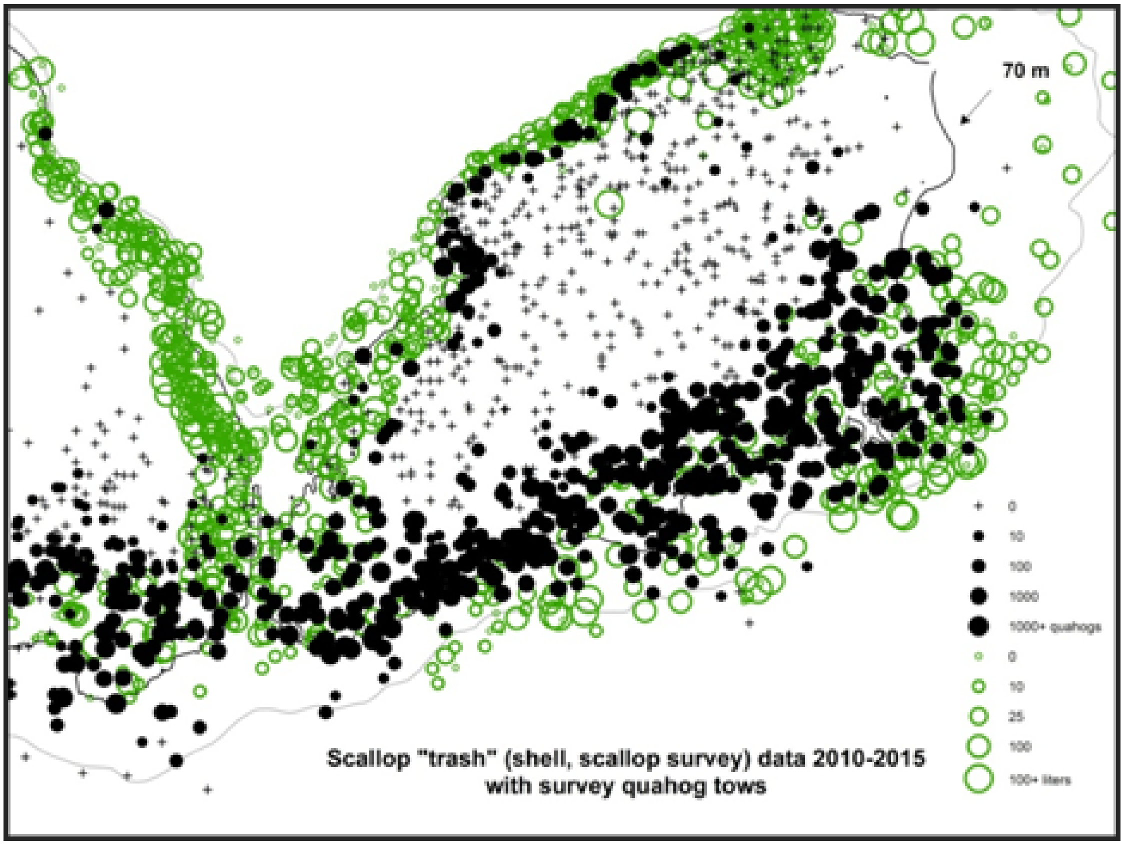


Figure 266: Green circles represent sea scallop shell trash brought up in the NEFSC scallop survey dredge, in roughly-estimated liters. Black dots are positive tows for ocean quahogs from the NEFSC clam surveys 1980-2013.

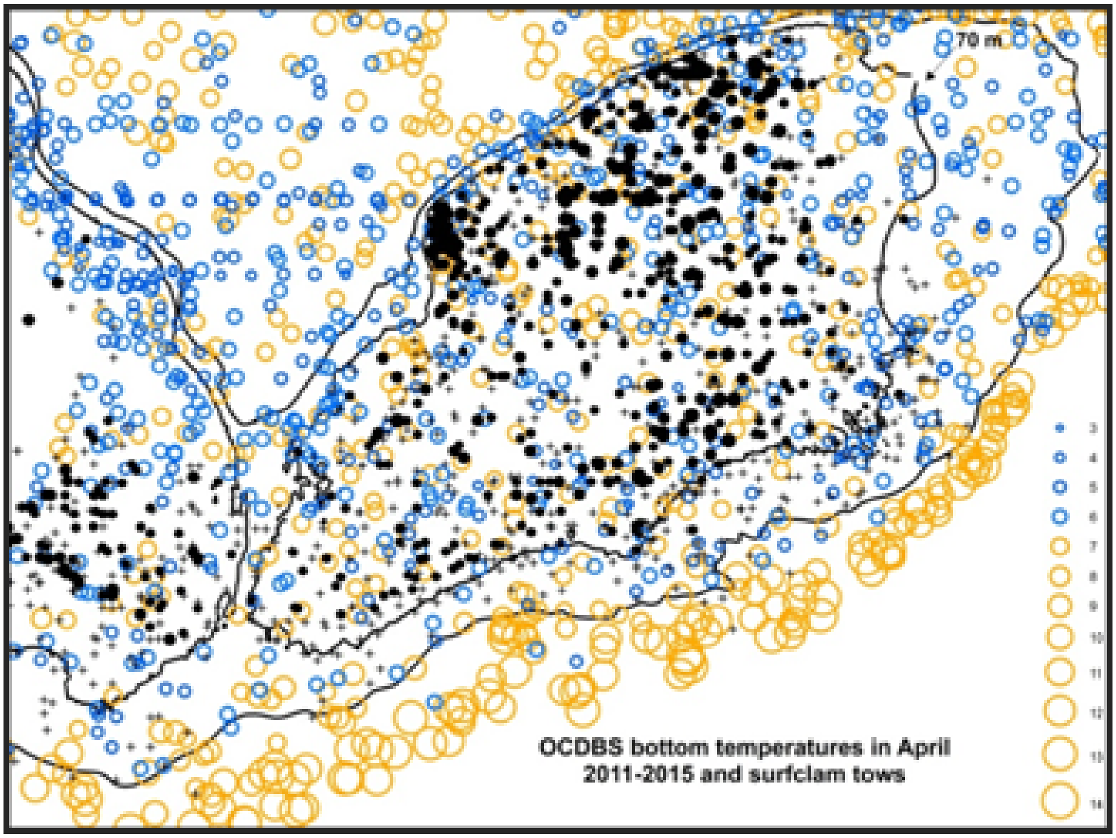


Figure 267: April bottom temperatures on Georges Bank plotted with NEFSC survey Atlantic surfclam catches 1980-2013.

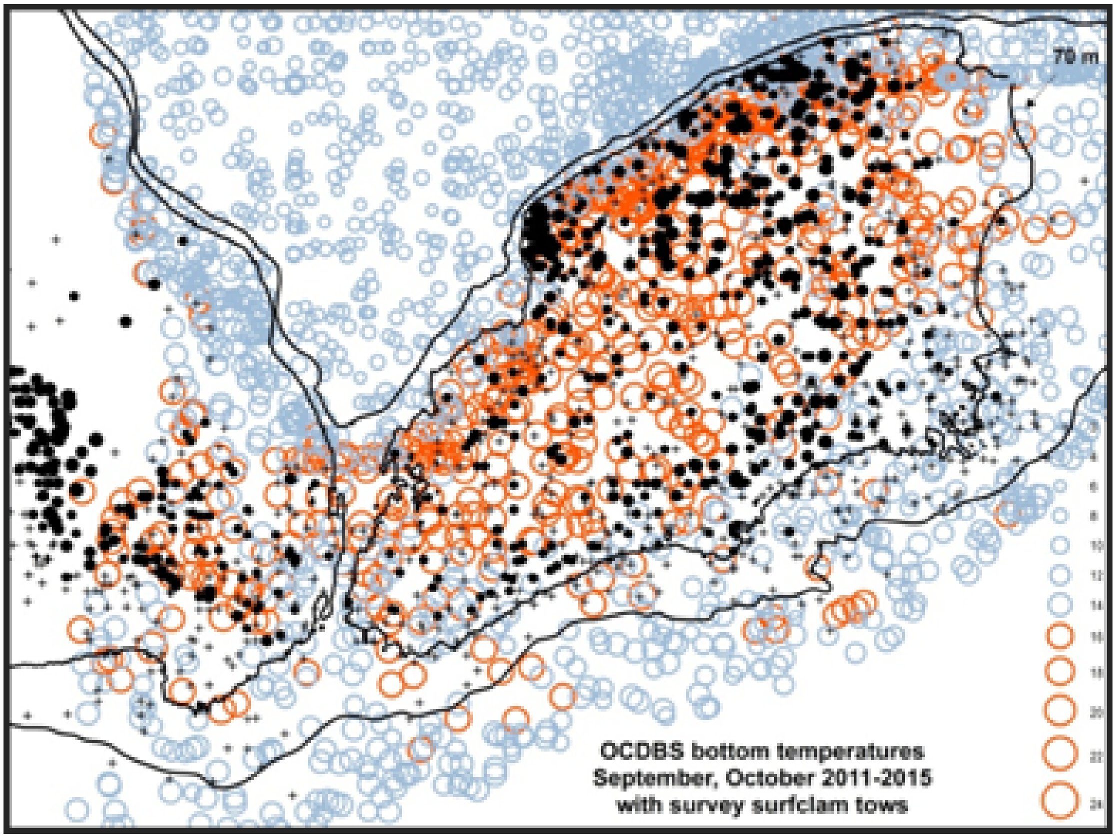


Figure 268: September-October bottom temperatures on Georges Bank plotted with NEFSC survey Atlantic surfclam catches 1980-2013.

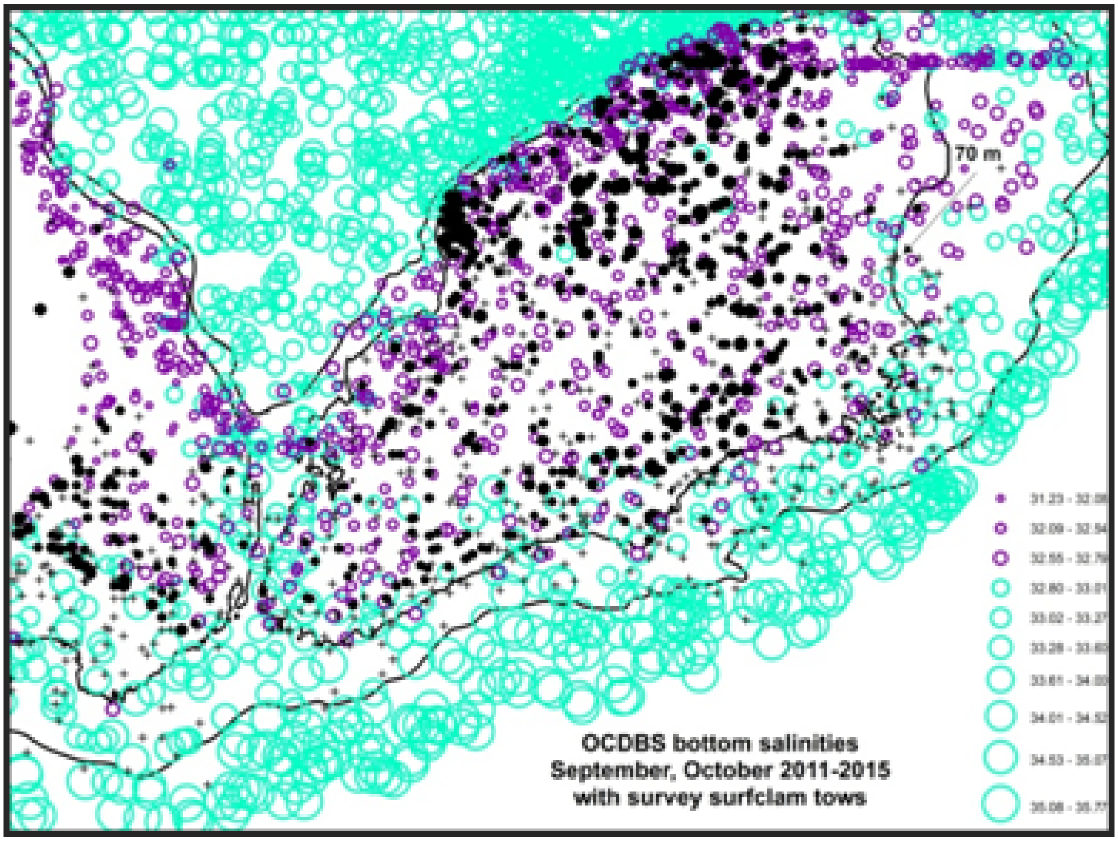


Figure 269: September-October bottom salinities on Georges Bank plotted with NEFSC survey Atlantic surfclam catches 1980-2013.

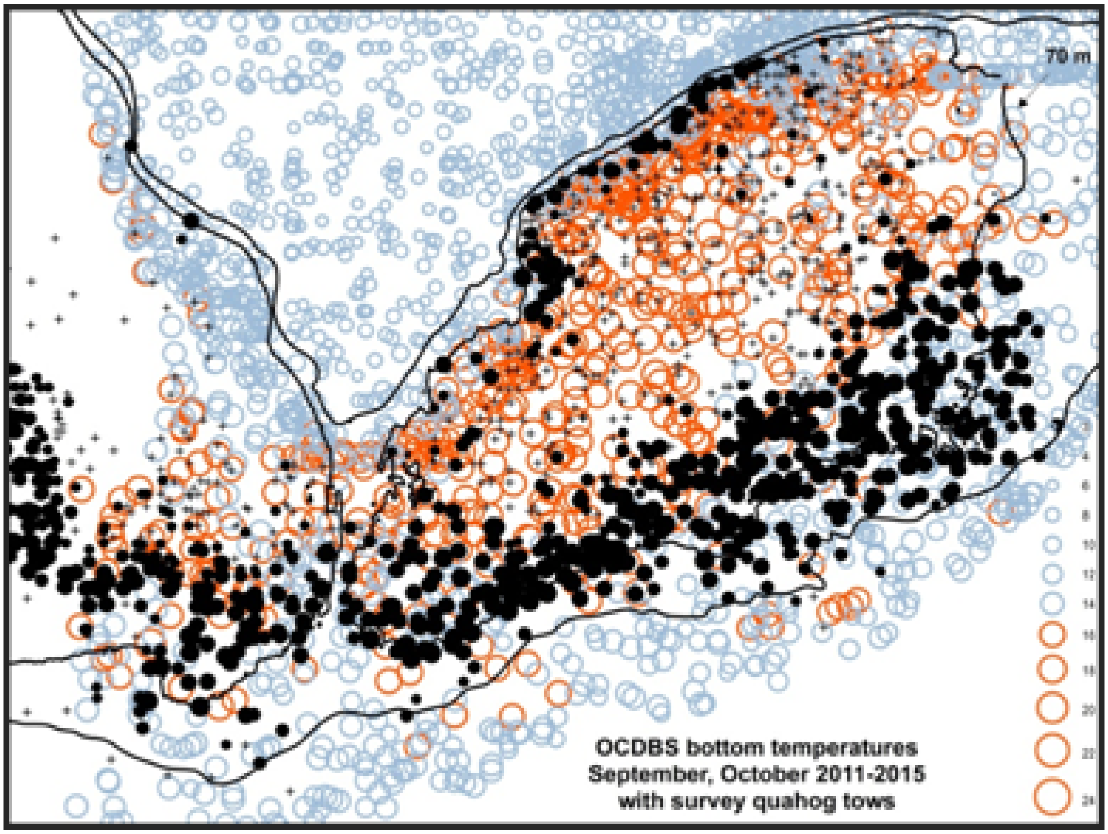


Figure 270: September-October bottom temperatures on Georges Bank plotted with NEFSC survey ocean quahog catches 1980-2013.

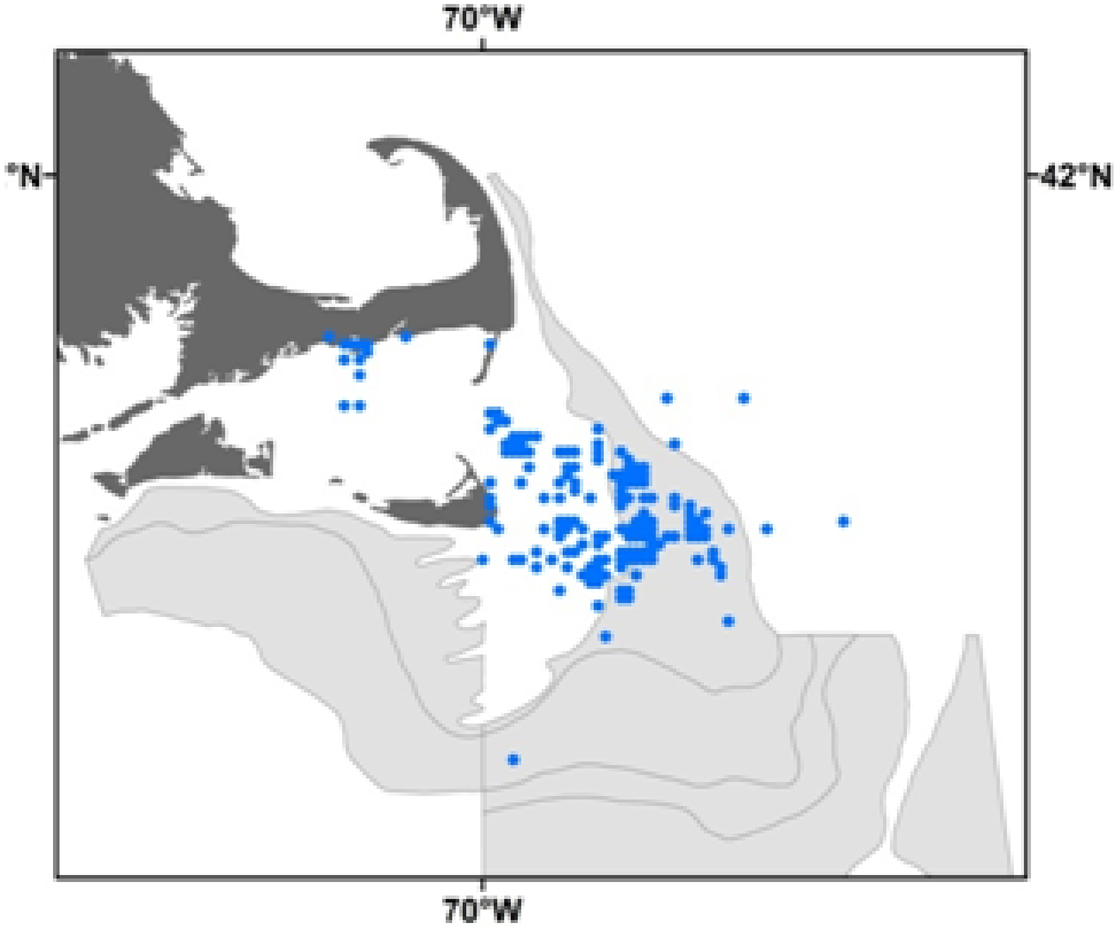


Figure 271: Locations of Atlantic surfclam fishing trips as reported in the clam logbooks from 2003 to 2012 (blue dots). The shaded areas are the strata surveyed and used to determine Atlantic surfclam biomass in the area.

Appendix 14   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 272-274). 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 275).

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 275–276). 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 275–276). Results indicate that recruit abundance was relatively high in the south during 2015 and about average in the northern area during 2012 (Figures 278-279).

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 272). 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 273). 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 274). 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 276-275). 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 278-279).

Figures

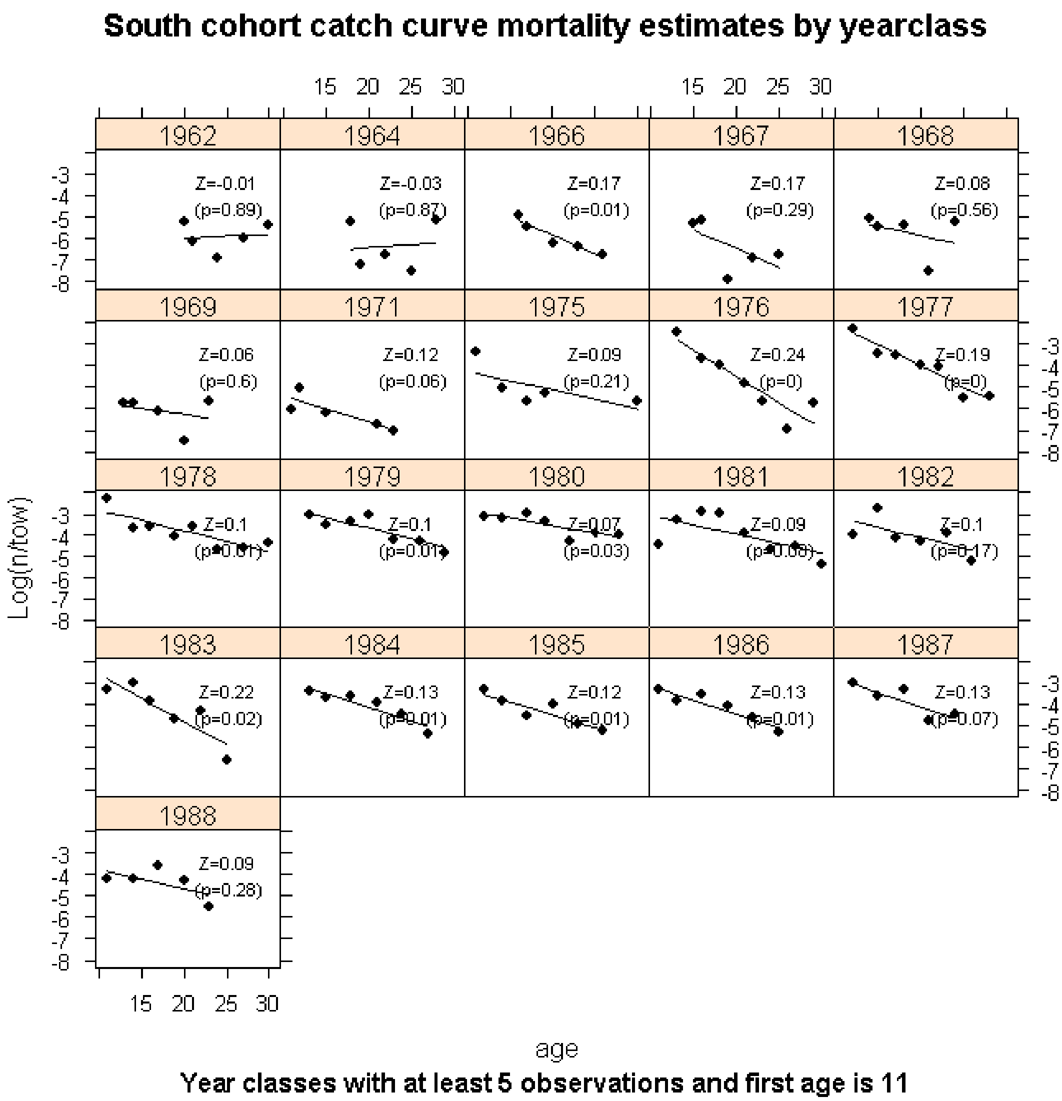


Figure 272: Cohort catch curves (one panel for each cohort) based on survey age composition data for Atlantic surfclam 15+ y in the southern area and omitting cohorts with fewer than five observations.

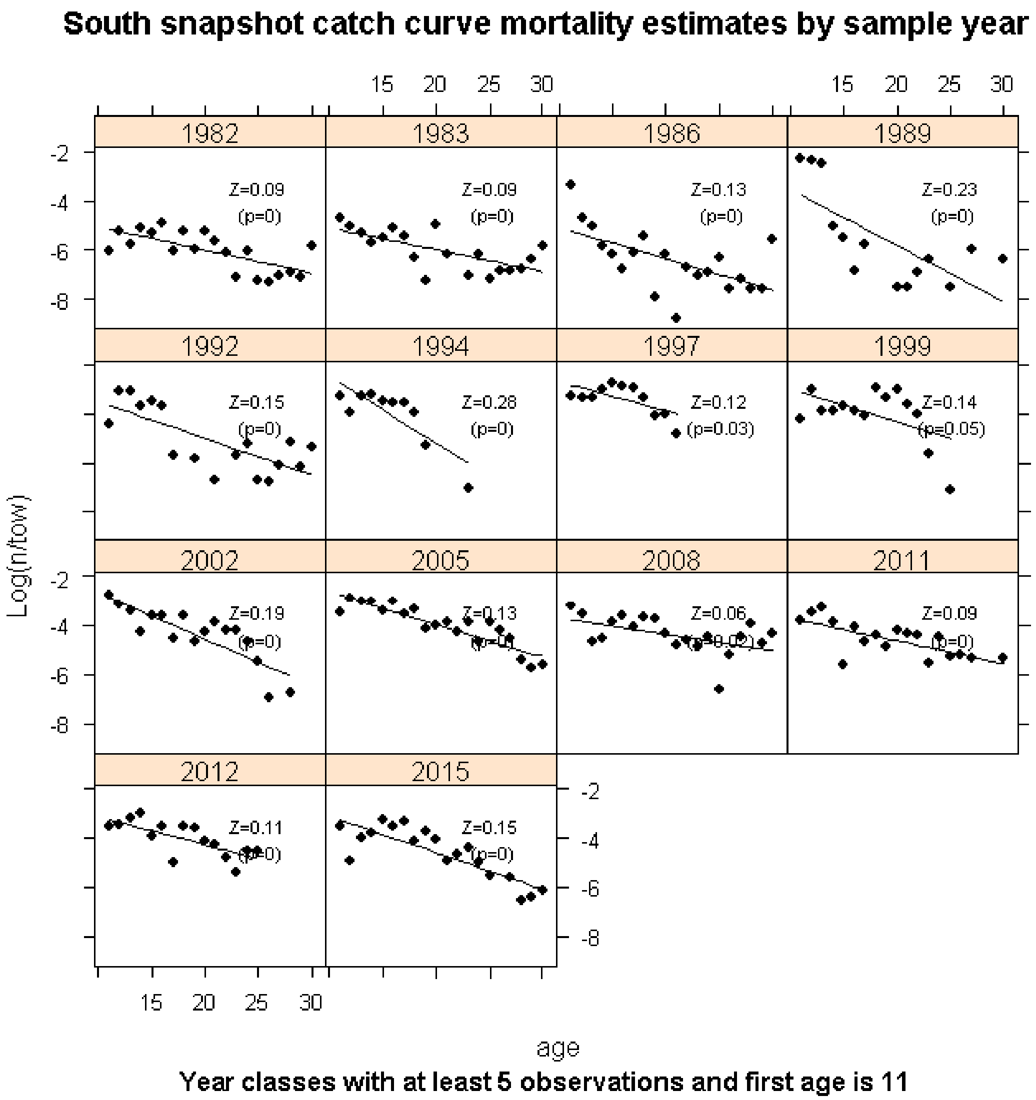


Figure 273: Snapshot catch curves (one panel for each cohort) based on survey age composition data for Atlantic surfclam 15+ y in the southern area and omitting cohorts with fewer than five observations.

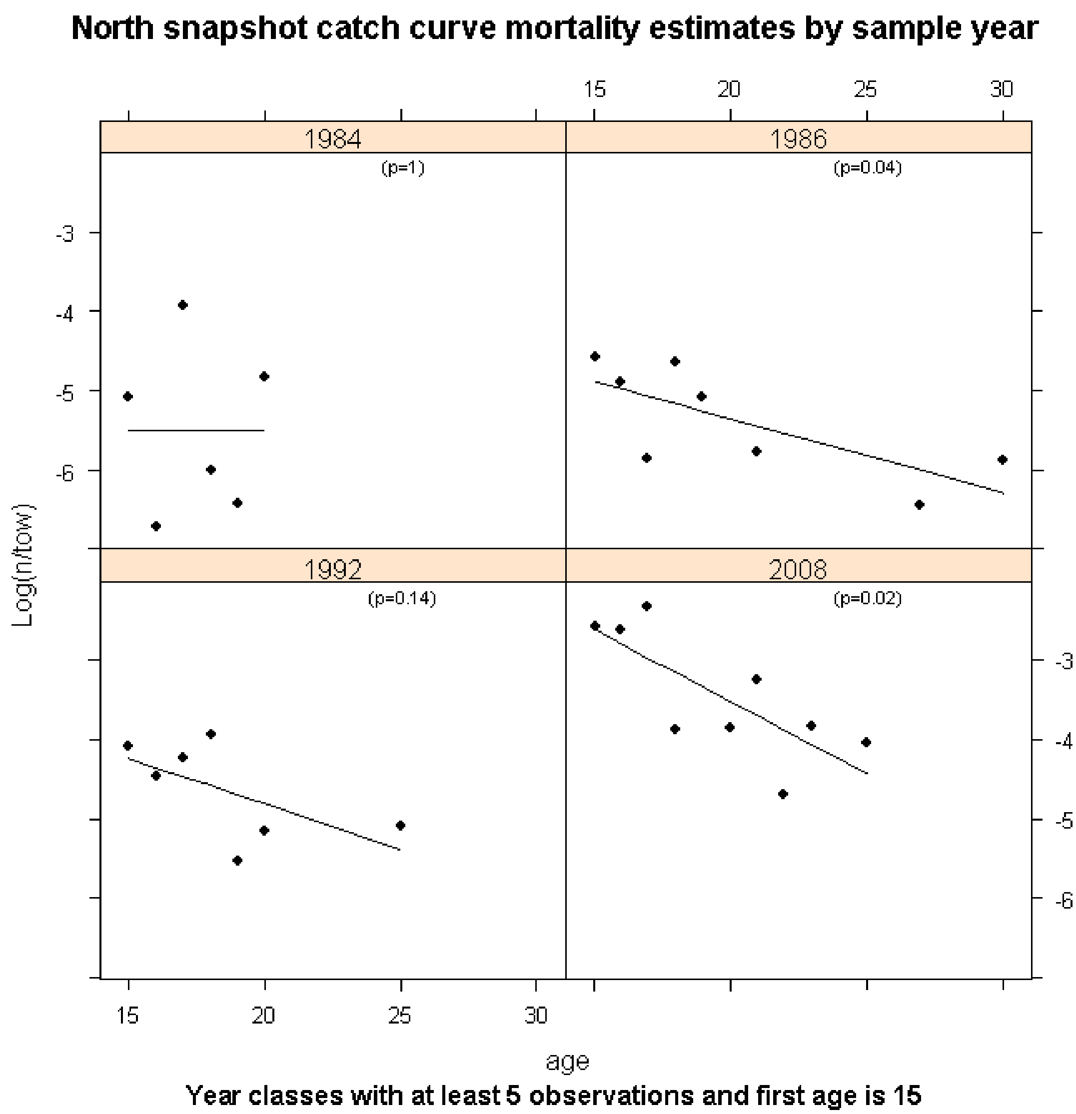


Figure 274: Snapshot catch curves (one panel for each cohort) based on survey age composition data for Atlantic surfclam 15+ y in the northern area and omitting cohorts with fewer than five observations.

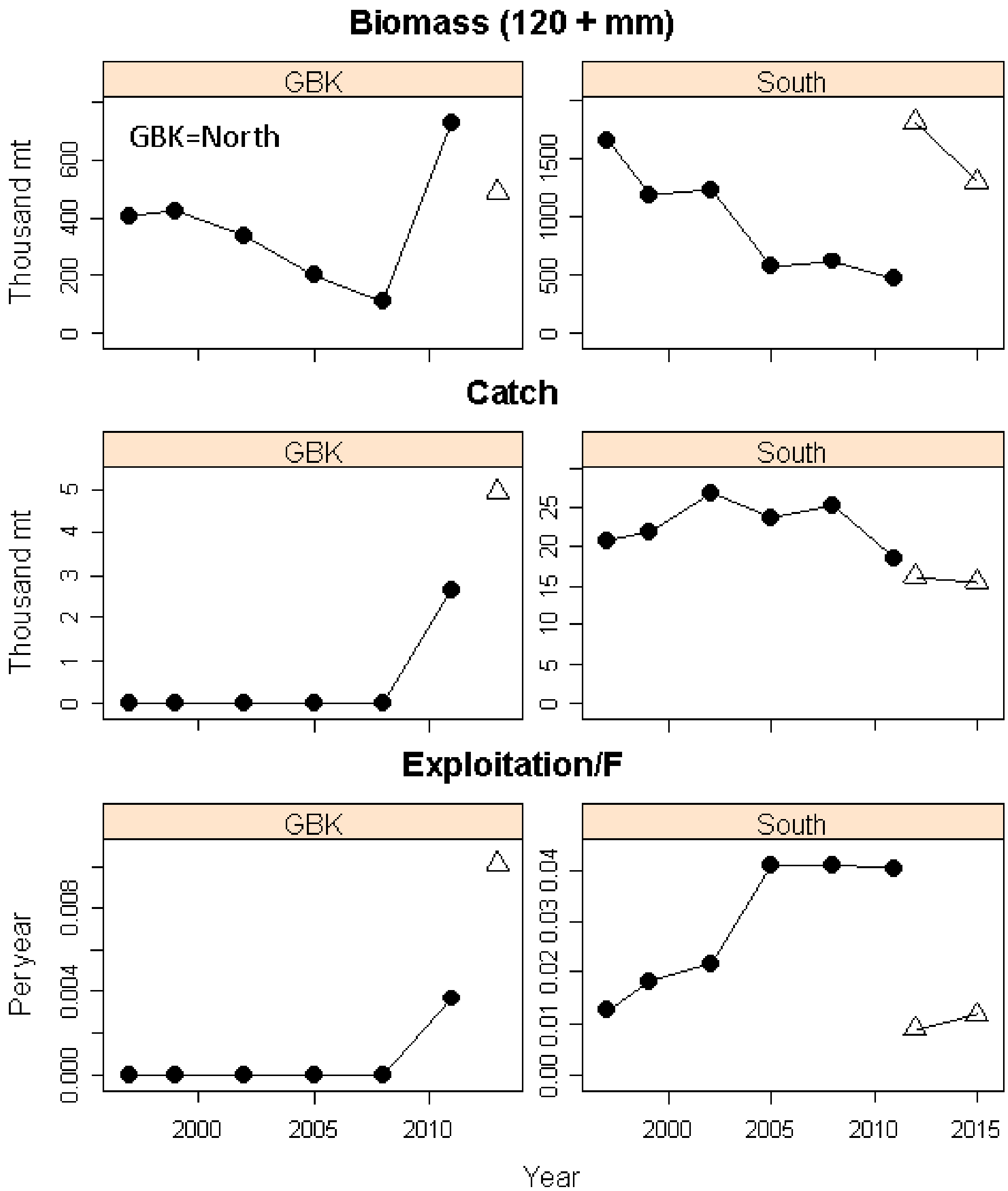


Figure 275: Swept-area biomass for Atlantic surfclam 12+ cm SL based on survey data adjusted for dome shaped selectivity (top), catch weight (landings + 12% for incidental mortality, middle) and exploitation rates (catch/biomass) for Atlantic surfclam in the Georges Bank (GBK) and Southern regions (bottom). 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.

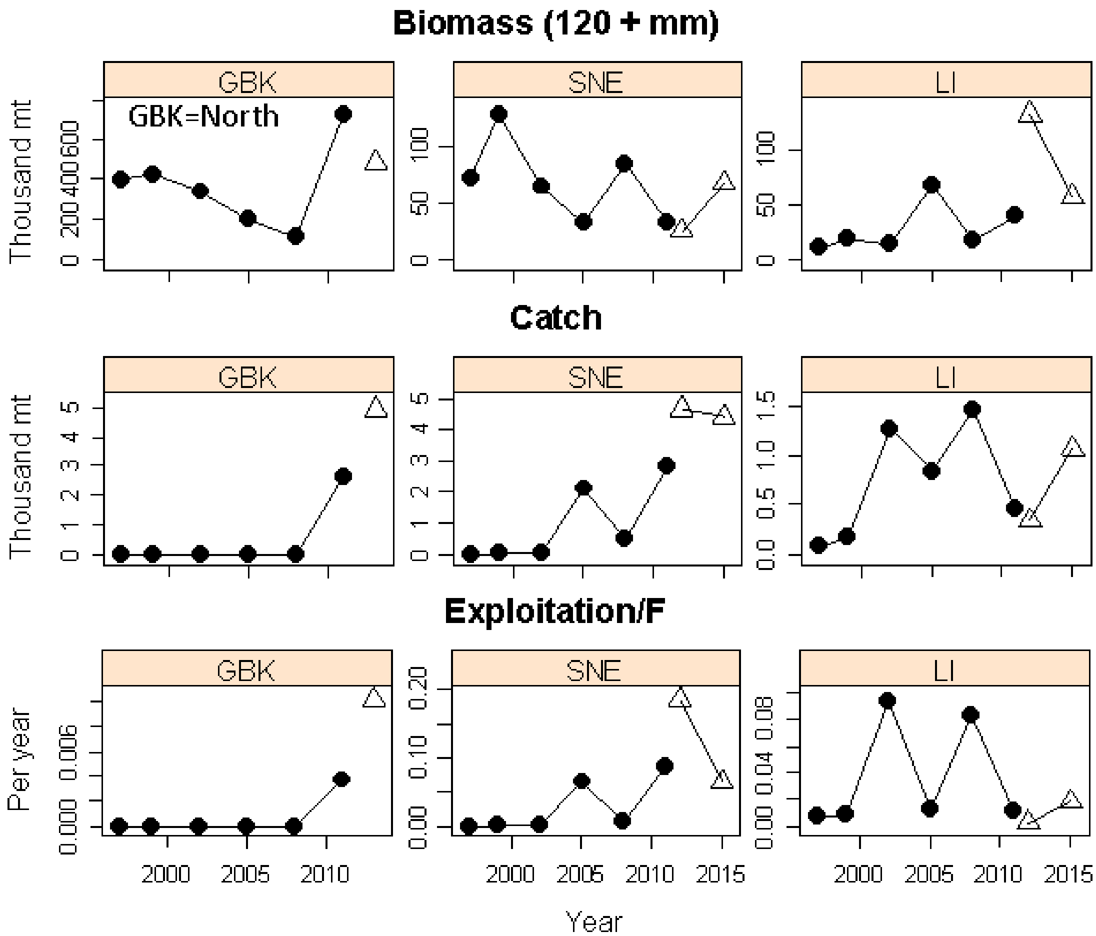


Figure 276: Swept-area biomass for Atlantic surfclam 12+ cm SL based on survey data adjusted for dome shaped selectivity (top), catch weight (landings + 12% for incidental mortality, middle) and exploitation rates (catch/biomass) for Atlantic surfclam in the Georges Bank (GBK), Southern New England (SNE) 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.

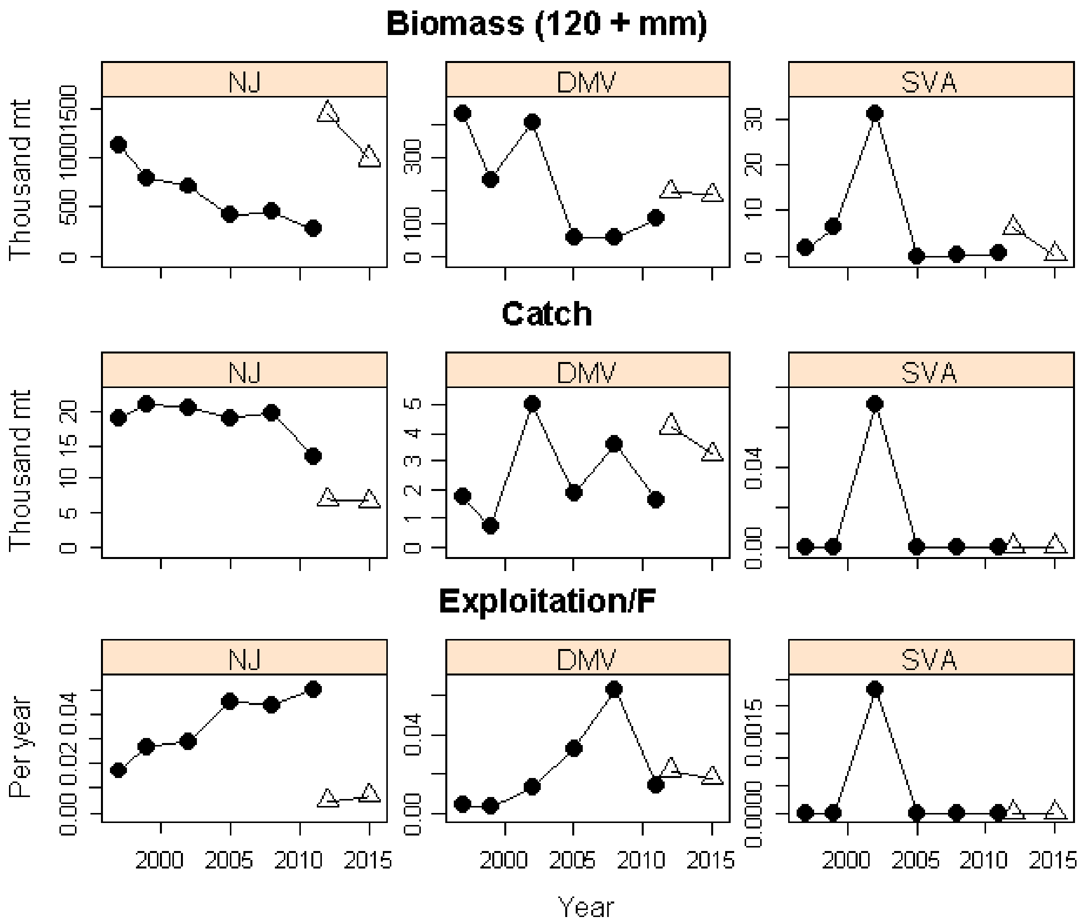


Figure 277: Swept-area biomass for Atlantic surfclam 12+ cm SL based on survey data adjusted for dome shaped selectivity (top), catch weight (landings + 12% for incidental mortality, middle) and exploitation rates (catch/biomass) for Atlantic surfclam in the New Jersey (NJ), Delmarva (DMV) , Southern 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.

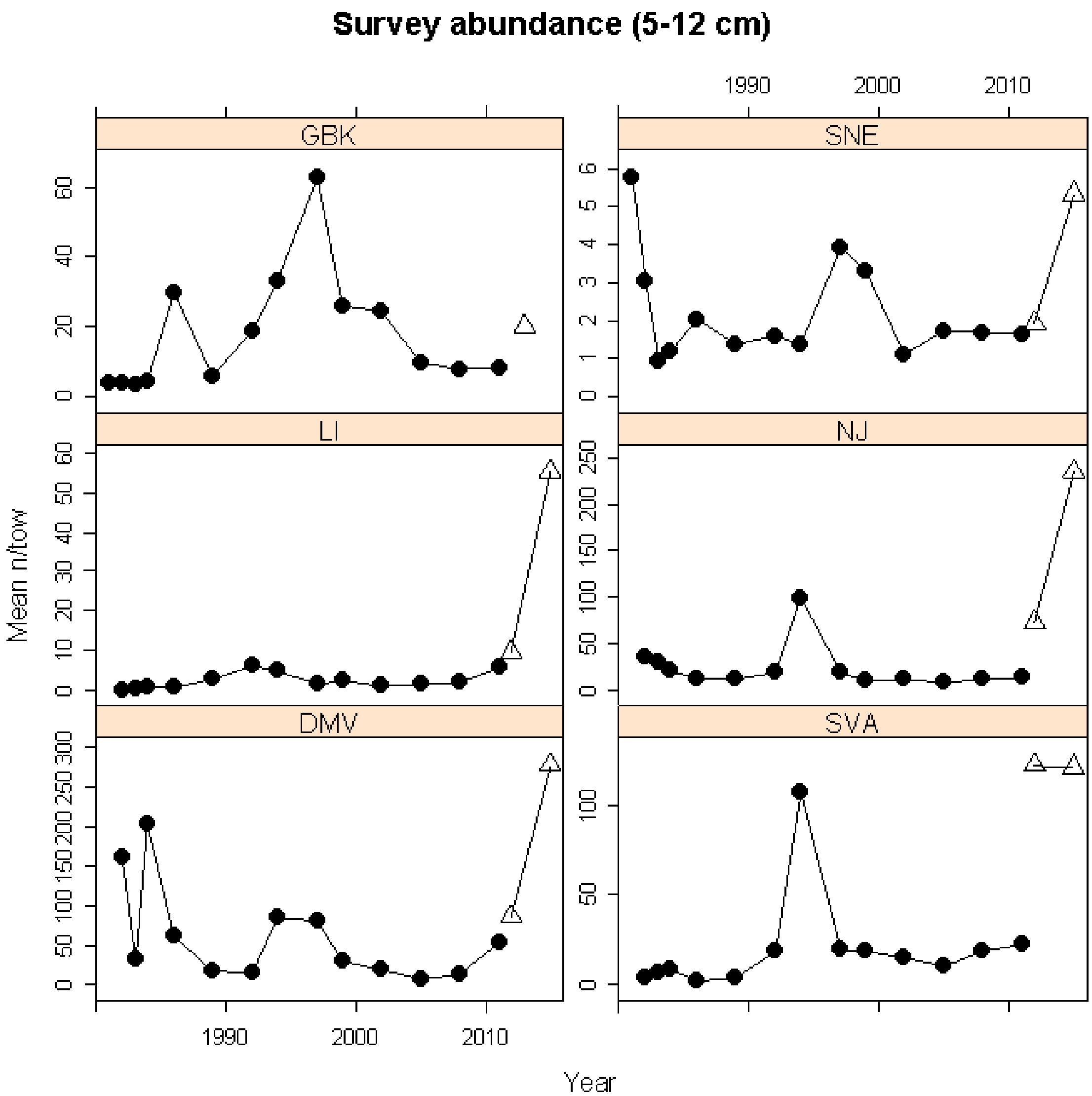


Figure 278: Trends in abundance of “recruit” Atlantic surfclam (5-12 cm SL) by area based on NEFSC clam surveys during 1982-2015. Data are adjusted for size-selectivity and dredge efficiency based field study results. Survey gear changed in 2012 so that comparison of trends up to and after 2011 may be misleading. Note that y-scales differ in each plot.

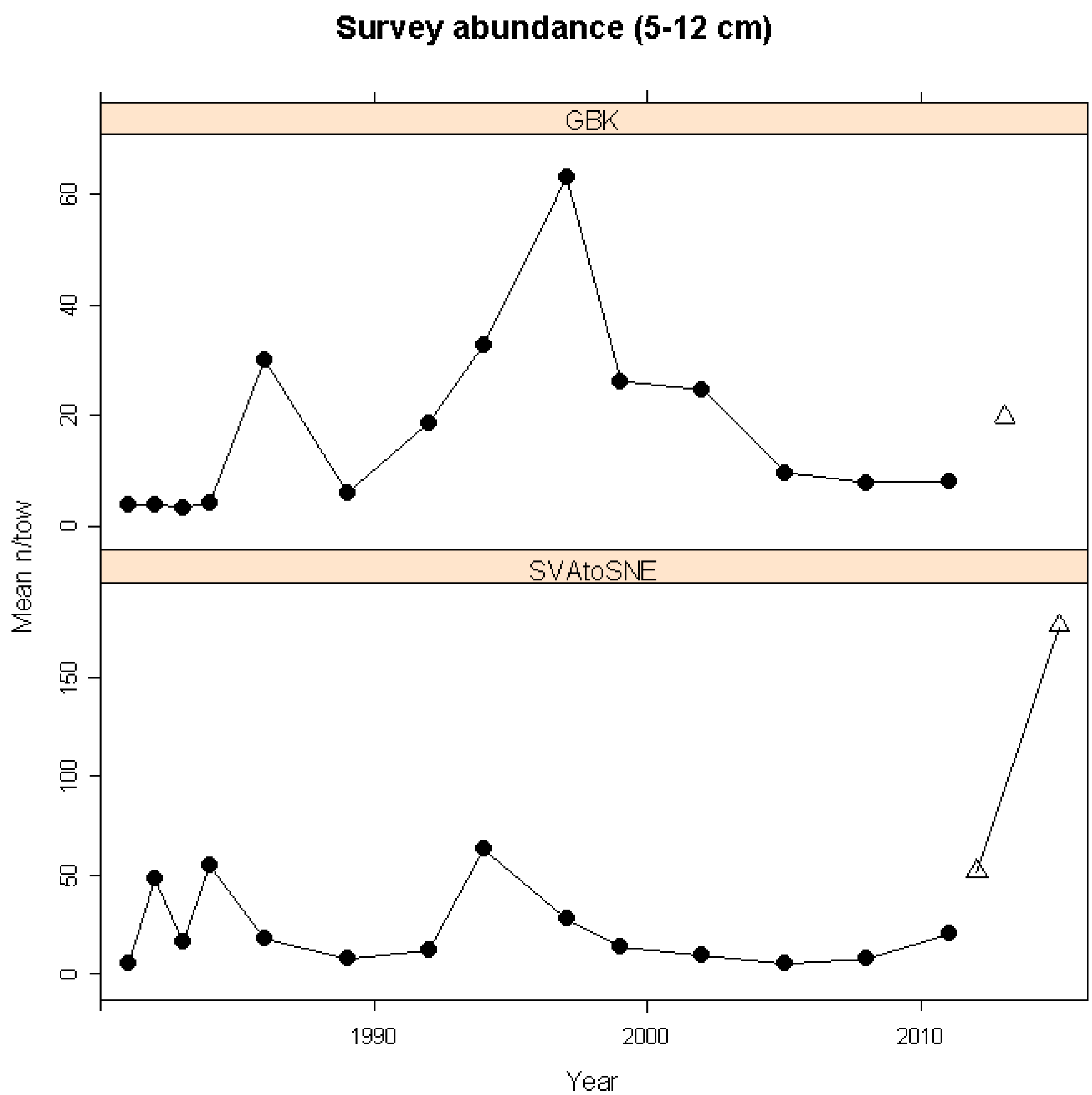


Figure 279: Trends in abundance of "recruit" Atlantic surfclam (5-12 cm SL) by stock assessment region based on NEFSC clam surveys during 1982-2015. Data are adjusted for size-selectivity and dredge efficiency based field study results. Survey gear changed in 2012 so that comparison of trends up to and after 2011 may be misleading. Note that y-scales differ in each plot.

Appendix 15 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.

Appendix 16 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 280), 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 280), 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 281). 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 282).

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 282).

Temperature

Temperature was recorded from the dredge and averaged over fishing seconds for all tows during the 2013 survey (Figure 283). Temperature was correlated with depth (Figure 283).

Figures

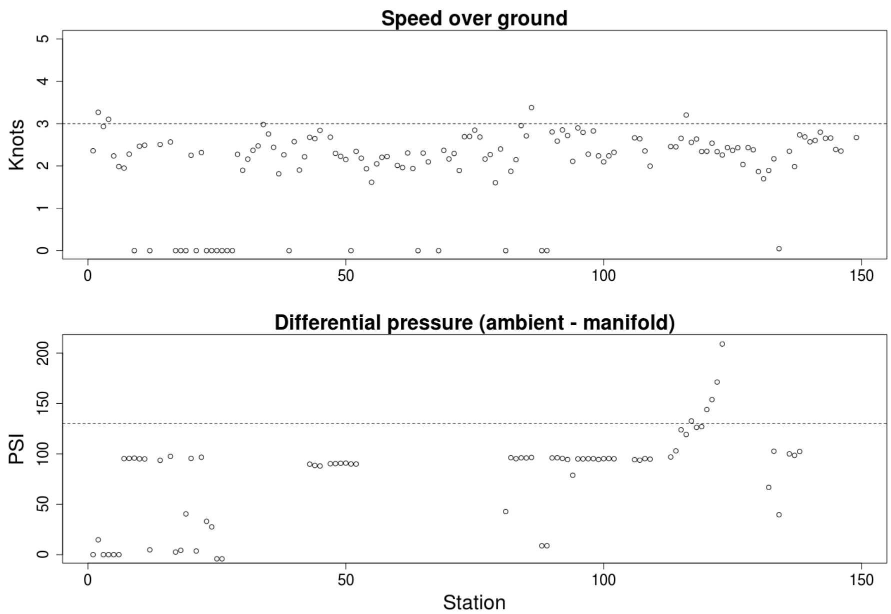


Figure 280: Speed over ground and differential pressure for each tow in the 2013 survey. The optimal speed over ground (3 kt) is marked with a horizontal dashed line. Differential pressure is the difference between the pressure in the dredge manifold, which indicates the absolute pressure realized by 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.

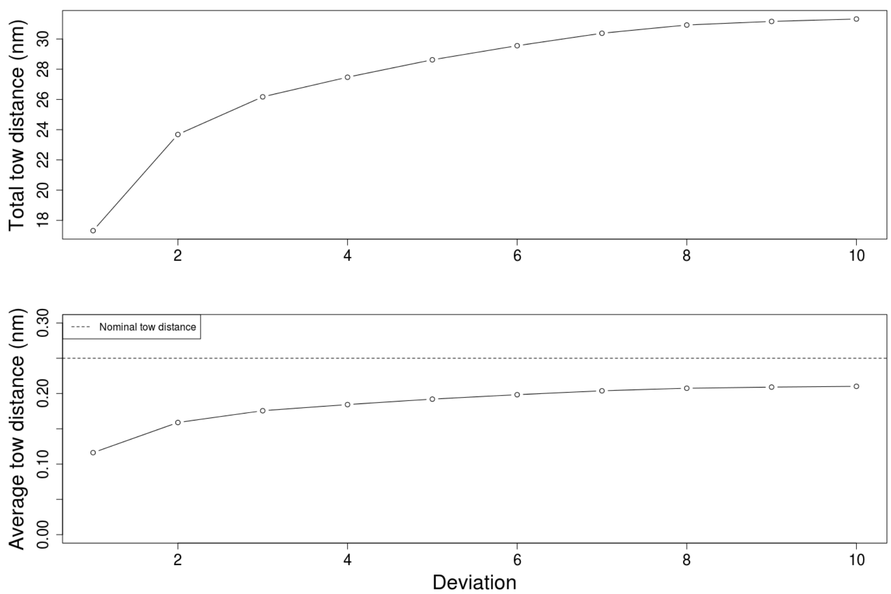


Figure 281: Average and total tow distance over all stations by critical deviation angle. The dashed line in the lower figure represents the nominal tow distance.

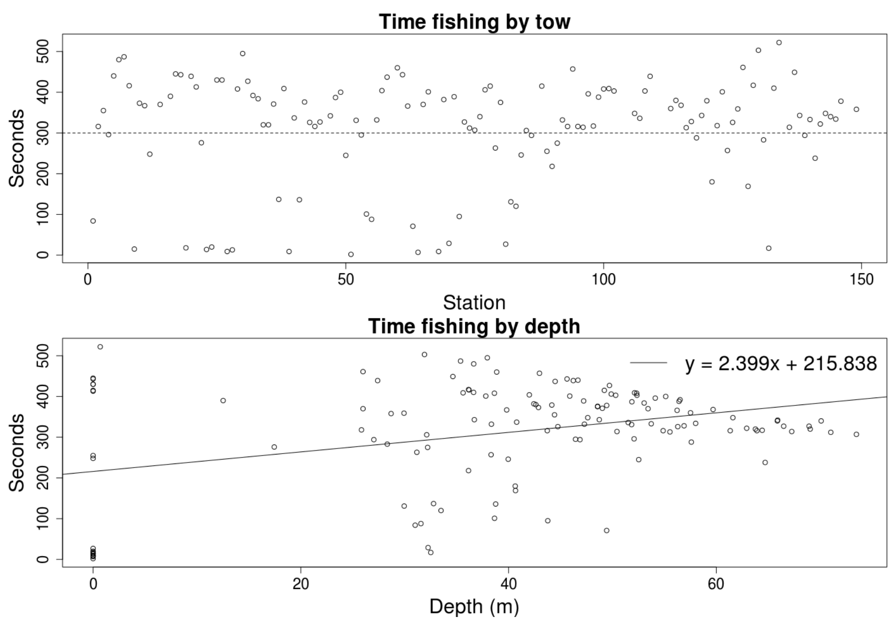


Figure 282: Time fished by station and depth. Depth significantly predicts tow time. The p value for slope was < 0.001, though the results were noisy and $R^2 < 0.14$ for the regression line shown.

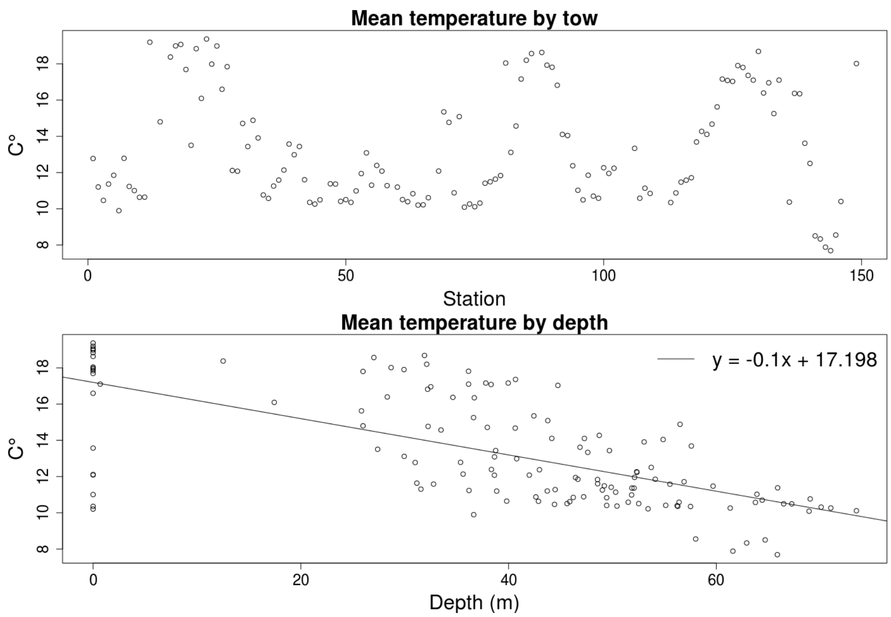


Figure 283: Temperature by station and depth. Depth significantly predicts temperature. The p value for slope was < 0.001 and $R^2 > 0.43$ for the regression line shown.

Appendix 17 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 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. 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

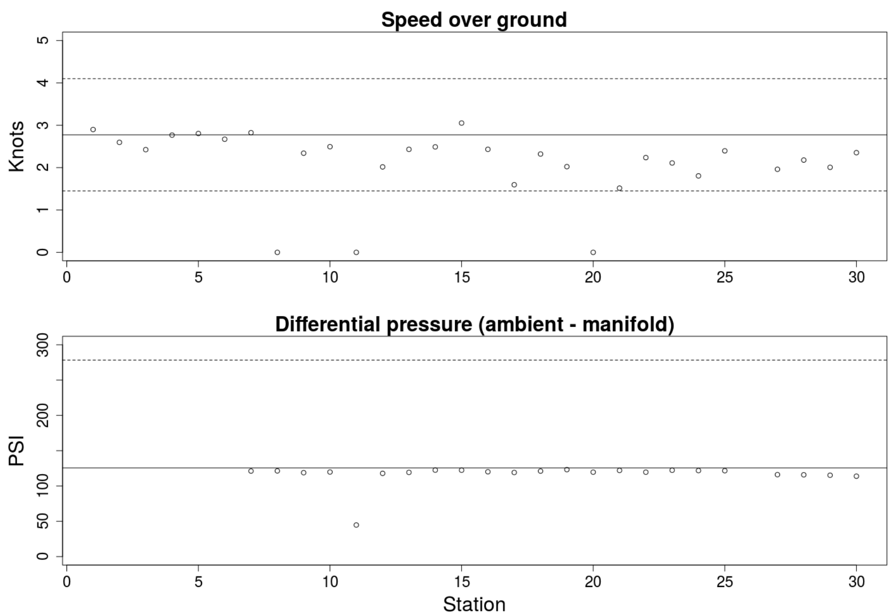


Figure 284: Speed over ground and differential pressure for each tow in the 2014 survey. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed speed over ground in 2012. Differential pressure is the difference between the pressure in the 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.

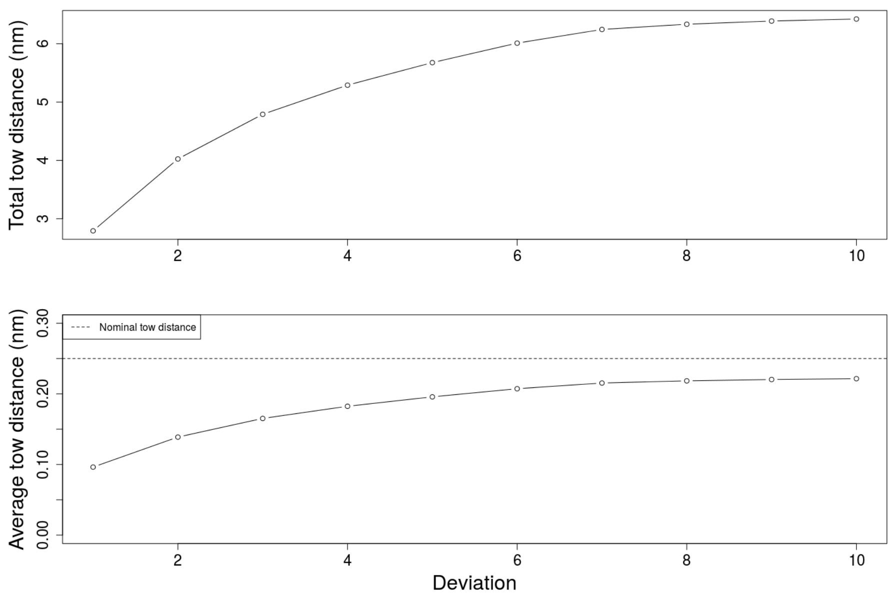


Figure 285: Average and total tow distance over all stations by critical deviation angle. The dashed line in the lower figure represents the nominal tow distance.

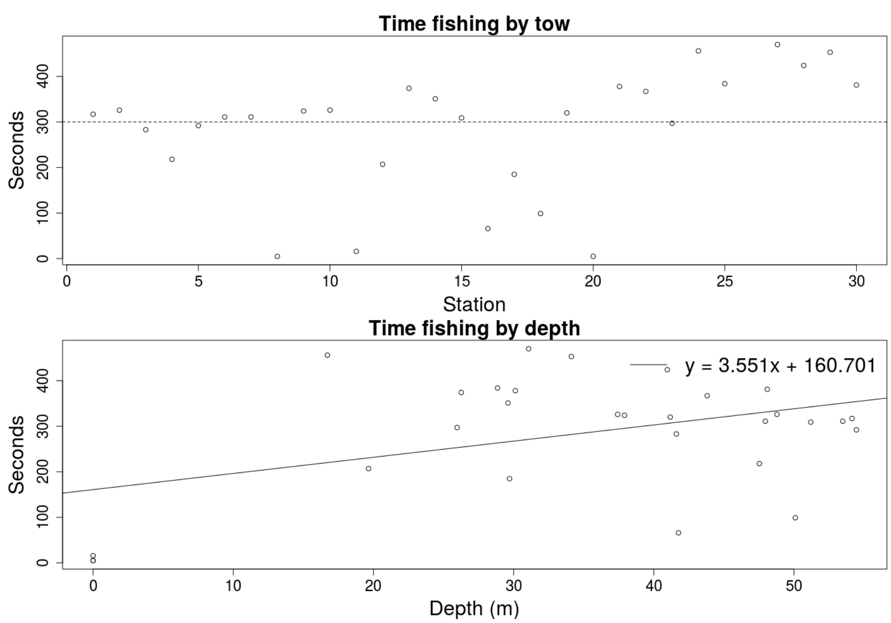


Figure 286: Time fished by station and depth. Depth significantly predicts tow time. The p value for slope was < 0.001, though the results were noisy and $R^2 < 0.14$ for the regression line shown.

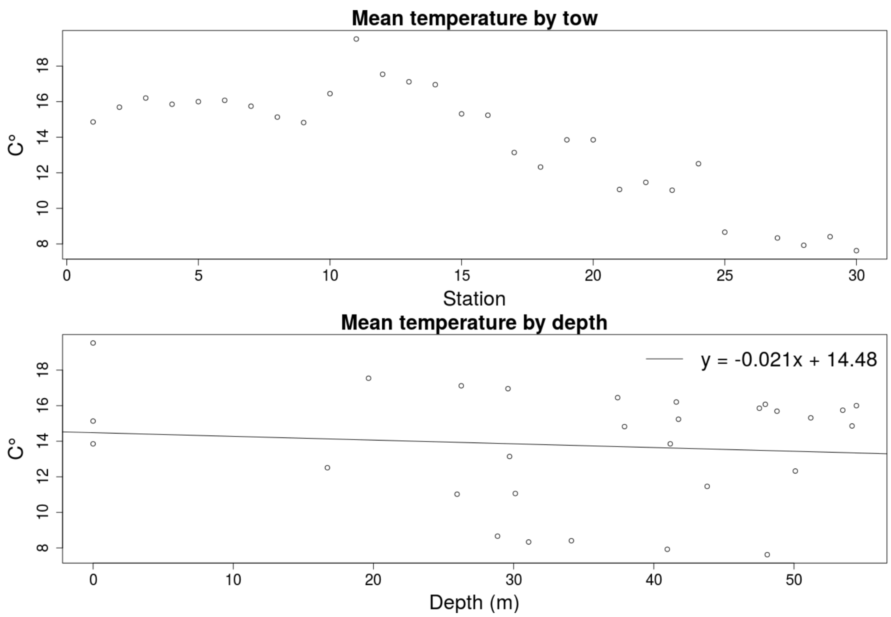


Figure 287: Temperature by station and depth. Depth significantly predicts temperature. The p value for slope was < 0.001 and $R^2 > 0.43$ for the regression line shown.

Appendix 18 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 288). Pump pressure was close to the 2012 median (Figure 288 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 289). 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 290).

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 290).

Temperature

Temperature was recorded from the dredge and averaged over fishing seconds for all tows during the 2015 survey (Figure 291). Temperature was correlated with depth (Figure 291).

Figures

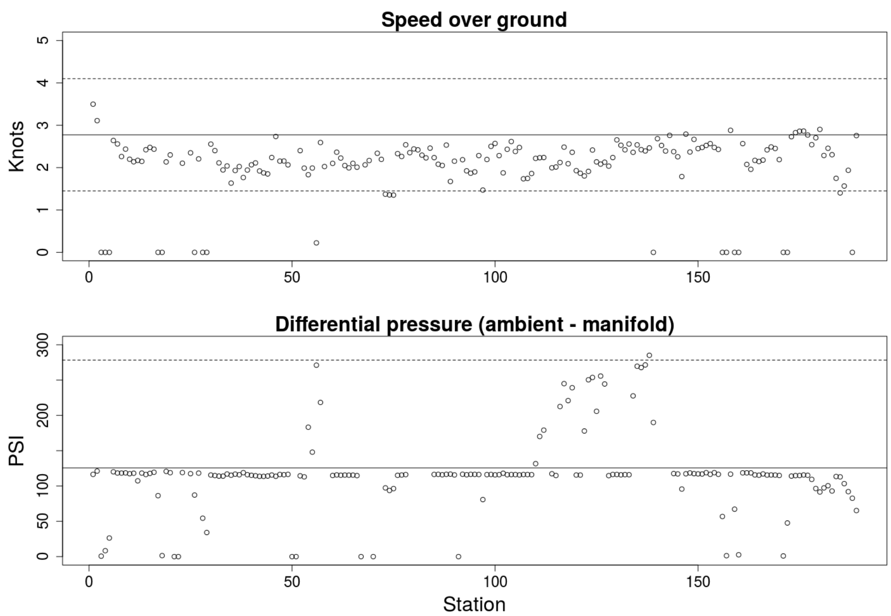


Figure 288: Speed over ground and differential pressure for each tow in the 2015 survey. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed speed over ground in 2012. Differential pressure is the difference between the pressure in the 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.

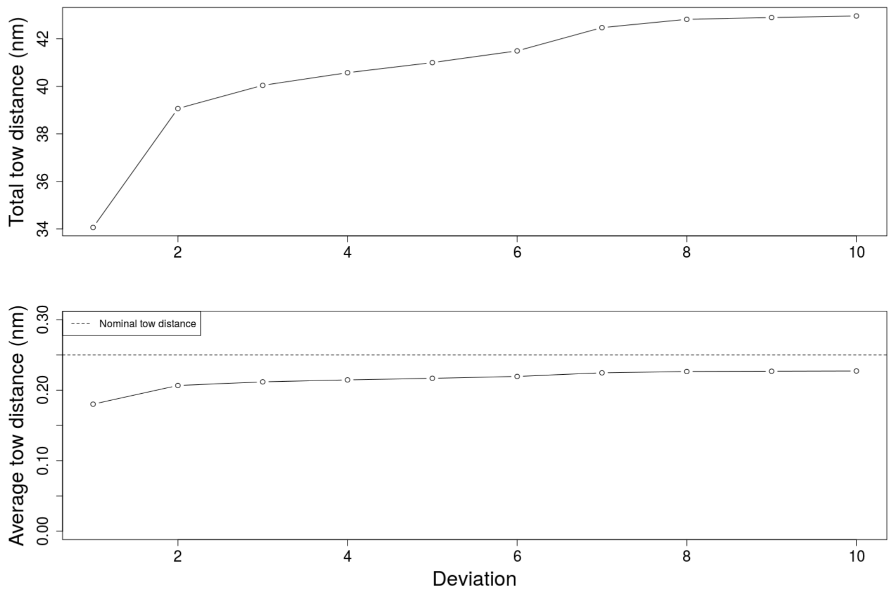


Figure 289: Average and total tow distance over all stations by critical deviation angle. The dashed line in the lower figure represents the nominal tow distance.

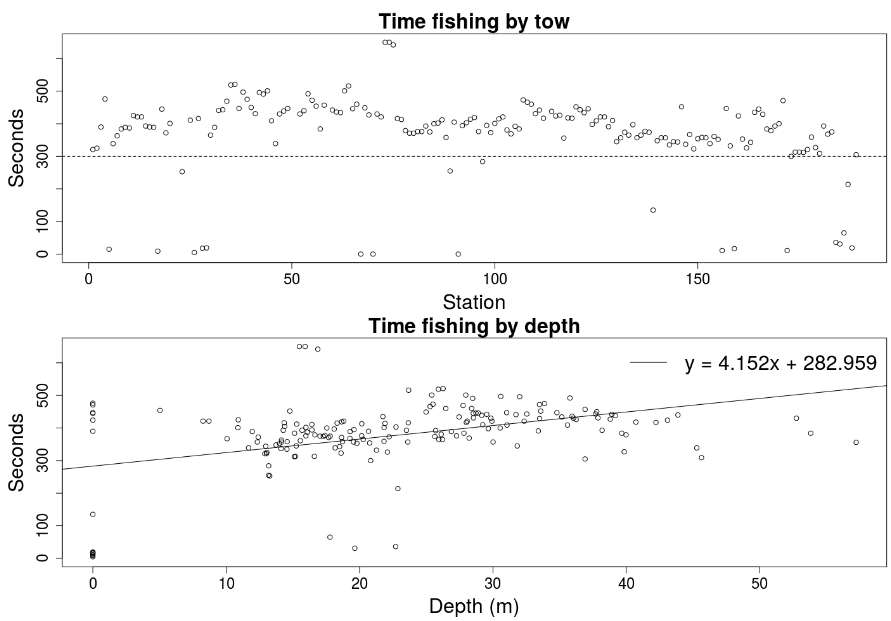


Figure 290: Time fished by station and depth. Depth significantly predicts tow time. The p value for slope was < 0.001, though the results were noisy and $R^2 < 0.14$ for the regression line shown.

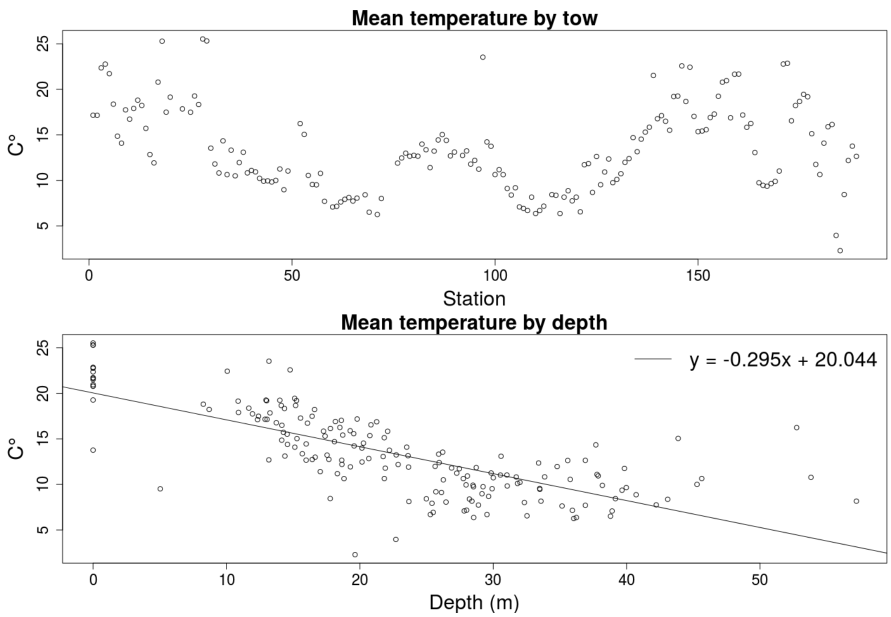


Figure 291: Temperature by station and depth. Depth significantly predicts temperature. The p value for slope was < 0.001 and $R^2 > 0.43$ for the regression line shown.