Northeast Fisheries Science Center Scallop Dredge Surveys

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by

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Term of Reference 1 – Statistical design and data collection procedures

Early surveys

Regular sea scallop surveys by NEFSC (known as Bureau of Commercial Fisheries, Woods Hole Lab prior to 1970) commenced in 1960 (Table 1). Early surveys used 3.048 m (10') unlined New Bedford-style (toothless) scallop dredges with 51 mm (2") rings (except the 1960 Mid-Atlantic survey, which used 76 mm (3") rings). The surveys prior to 1975 did not always cover the same areas. Nonetheless, these surveys show a clear trend on Georges Bank, with high abundance in the early 1960s, followed by a period of low abundance, and then increases in the late 1970s (Fig 1.1). The high abundances observed in the early 1960s and late 1970s, when adjusted for dredge area swept and gear efficiency, are comparable to those observed in the last fifteen years.

Survey gear

Unlined dredges do not fully select for incoming two year old recruits (~35-75 mm). In order to more reliably observe two year olds, 2.44 m dredges with 51 mm rings and 38 mm polypropylene mesh liners have been used since 1979. Serchuk and Smolowitz (1980) conducted 88 paired tows comparing 2.44 m lined and unlined dredges, both with 51 mm rings. These data were reanalyzed in NEFSC (2004) using the method of Millar (1992). The lined gear was 72% as efficient as the lined dredge (split parameter = 0.5815) on large scallops, but retained smaller scallops more effectively (Fig 1.2). In 1999, 104 paired tows were conducted on the *F/V Tradition*, which completed the NEFSC scallop survey that year, between the lined survey dredge and standard commercial dredges in use at that time with 89 mm rings. Later, Yochum and DuPaul (2008) conducted similar work comparing the lined survey dredge to commercial dredges with 102 mm rings that have been used in the fishery since 2004. Both these studies also found that the unlined commercial dredges were more efficient on large scallops than the lined survey dredge, but were more selective than either the lined or unlined survey dredge (Fig 1.2).

The original lined survey dredge design was used from 1979-2007. At the advice of fishermen, the dredges employed since 2008 have a slightly modified design, but still have the same dimensions and liner as was used previously (see NEFSC 2015). Any differences in catches between the two designs would be captured in the calibration between the *R/V Albatross IV* and the *R/V Hugh Sharp*.

Rock excluder chains have been used on NEFSC sea scallop survey dredge since 2004 in certain hard bottom strata (strata 49-52 and in the portions of strata 651, 661, 71 and 74 within Closed Area II) to enhance safety at sea and increase reliability. Based on paired tow trials with and without excluders, the best overall estimate was that rock chains increased survey catches on hard grounds by a factor of 1.31 (CV = 0.2, NEFSC 2004, Nordahl 2004). To accommodate rock chain effects in hard bottom areas, survey data collected prior to 2004 from the strata where rock chains are now deployed, were multiplied by 1.31 prior to calculating stratified random means. Variance calculations in these strata include a term to account for the uncertainty in the adjustment factor (NEFSC 2007).

Survey vessels

The *R/V Albatross IV* was used for all NEFSC scallop surveys from 1963-2007, except during 1990-1993, when the *R/V Oregon II* was used instead (Table 1.1). Surveys by the *R/V Albatross IV* during 1989 and 1999 were incomplete on Georges Bank. In 1989, the *R/V Oregon II* and *R/V Chapman* were used to sample Georges Bank. All three vessels sampled the relatively small stratum 34 off of Long Island with 13-14 valid tows. Comparisons of the catches of the three vessels in this stratum showed no significant difference (Serchuk and Wigley 1989). The *F/V Tradition* was used to complete the 1999 survey on Georges Bank. NEFSC (2001) found no statistically significant differences in catch rates between the *F/V Tradition and R/V Albatross IV* from 21 comparison stations that were sampled by both vessels, after adjustments were made for tow path length. Therefore, survey dredge tows from these other vessels were used without adjustment except for normalizing for tow distance as discussed below.

The northern edge of Georges Bank was not covered by the NEFSC survey until 1982. Data from the Canadian scallop survey during 1979-1981, which used the same gear as the NEFSC survey, was used to cover the northern edge of Georges Bank in those years (NEFSC 2010). Comparisons between the Canadian vessel, the *R/V E. E. Prince*, with the *R/V Albatross IV* indicated that catches from the two vessels were comparable after adjusting for tow distance (Serchuk and Wigley 1986).

In 2008-2014, the NEFSC scallop survey was conducted on the *R/V Hugh Sharp*. Direct and indirect comparisons between the catches by the *R/V Hugh Sharp*, *R/V Albatross IV* and commercial vessels towing the lined survey dredge were not significantly different (NEFSC 2010, Rudders 2010). However, average catches were slightly greater on the *R/V Hugh Sharp*; this is likely due to differences in tow length.

Estimation of dredge tow length

As discussed above, all evidence suggests that vessel effects for scallop dredge surveys are small, and that catches with the same gear on different vessels is proportional to the tow length. In recent years, the survey dredges have been equipped with inclinometer sensors that measure the tilt of the dredge during its deployment. The most recent sensor, manufactured by Star-Oddi and used since 2009, also collects pressure and temperature data as well as tilt along all three axes. In addition, cable tension data from the *Sharp* are available for the last several years. In order to interpret the data from these sensors, several tows where a video camera was mounted on the dredge were conducted both on the *R/V Albatross IV* and on the *R/V Hugh Sharp*.

Example sensor data showing the determination of tow start and end is given in Fig 1.3. These data were combined with recorded vessel speeds to estimate tow length. Because full sensor data are available on only a subset of tows, regression equations were developed based on tows where the sensor data is available to predict tow distance using nominal tow distance and depth as predictors (NEFSC 2014). Nominal tow distance is the nominal tow time (i.e., the time elapsed after the winch is locked at the beginning of the tow to the time when haul back begins) times the mean vessel speed between these times. Separate relationships were developed for the *R/V Albatross IV* (which was assumed to also apply to the other vessels used from 1989-1993 and in 1999), and the *R/V Hugh Sharp:*

Tow length = -0.0388 + 0.001484*Depth + 1.061*Nominal length (*R/V Hugh Sharp)*

Tow length = 0.0864 – 0.000444*Depth + 0.972*Nominal length (*R/V Albatross IV)*

where tow length is in nautical miles and depth is in meters.

Survey stratification

A random stratified design has been used for the dredge survey since 1977 using the NEFSC shellfish strata (Fig 1.4). Stratified means and variances are calculated using standard methods (Cochran 1977, Smith 1997). These strata were defined by bathymetry and area. During the 2014 scallop stock assessment (NEFSC 2014), two large strata on Georges Bank (strata 72 and 74) were modified. Very low abundances of scallops were observed in most of these two strata, but small portions were more productive (Fig 1.5). These strata were modified to include only the more productive areas, which will be the only ones to be sampled in the future; previous years' data has been post-stratified to include only those tows within the new strata boundaries.

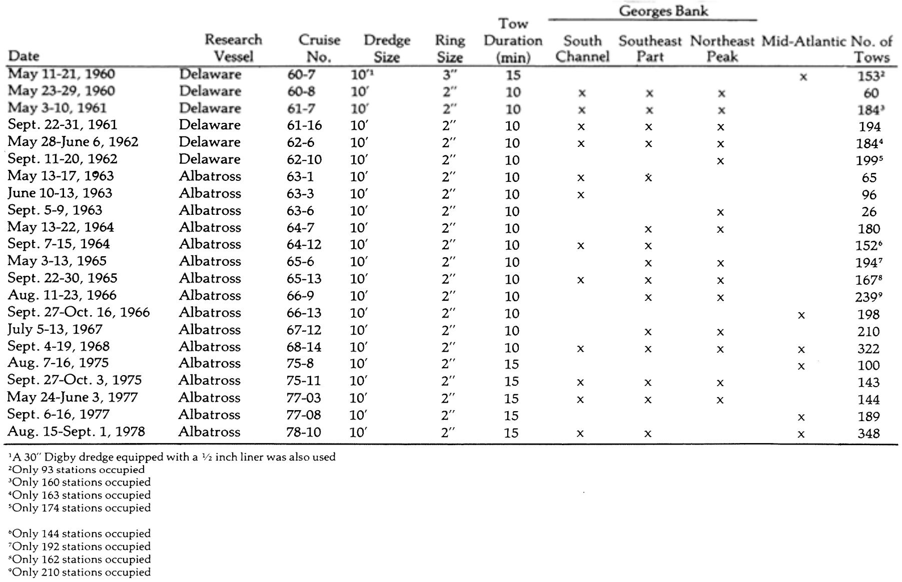
The initial surveyed strata set included numerous strata where scallop abundance was relatively low (Fig 1.6). In 1989 and 1990, a number of strata were dropped from the regularly surveyed strata in order to concentrate effort on the areas of higher abundance (Fig 1.4).

In December, 1994, three large areas on Georges Bank were closed to fishing for scallops and groundfish (Figs 1.4, 1.6). Since 1998, four rotational areas have been implemented in the Mid-Atlantic. One area in the far south (Virginia Beach) was not successful, and was in existence for only between 1998-2002; thus there are three Mid-Atlantic rotational areas in existence today. The closed/rotational area boundaries cut several strata, so that parts of these strata are inside and parts outside a closed/rotational area. Because scallops were often at much higher densities inside these areas, these strata were split into "open" and "closed" portions. The stratification using the open/closed divisions is used for all years; data from previous years were post-stratified. In addition, the northeast corner of the Nantucket Lightship Closed Area generally has much higher scallop biomass than the rest of this area. This area is covered by portions of survey strata 46 and 47. These strata were split into the portion in the northeast corner of the Lightship area (bounded by -69 and -69.3 longitude, and 40.6333 and 40.8333 latitude and merged into a single strata, see Fig 1.6) and the area outside this rectangle; previous years' data were post-stratified.

The Virginia Institute of Marine Science (VIMS) has conducted intensive dredge surveys of selected regions on commercial vessels since 2005 using partially randomized grid designs. These surveys use two dredges fished side-by-side; a lined survey dredge, identical to those used on the NEFSC survey, is deployed on one side while a commercial dredge is used on the other side. Comparisons between commercial vessels and the *R/V Albatross IV* indicate suggest that the survey dredge has the same fishing power on these vessels (NEFSC 2010, Rudders 2010 and the VIMS documents from this review). In the last several years, VIMS has conducted several hundred tows per year. All VIMS data for fully covered strata (original or split into open/closed) were treated in the same way as NEFSC tows. The partially randomized grid design was treated as random when calculating variances. This likely slightly overstates the true sample variance.

In some years, a few strata, typically those with lower scallop abundance, were unsurveyed. These unsurveyed strata were filled by imputation (NEFSC 2007, Appendix 6). In brief, GLM models were fit to predict catch rates over time for individual survey strata based on other strata neighboring the unsurveyed strata. Length composition data for missing strata was estimated by the stratified mean length composition for other strata in the same subregion.

Allocation of stations to strata were generally proportional to strata area prior to 2000, although marginal strata were given reduced allocations. Since then, allocations have varied among years, based on a compromise between the Neyman optimal allocation (Cochran 1977) using variances from previous year's survey data, and the need to have some coverage of all areas. Figure 1.7 gives a plot of the mean number of stations in each strata as a function of the product of stratum area and its standard deviation among the tows in the stratum, averaged over all years. It indicates that the allocation is fairly close to optimal, while still giving some coverage to low abundance strata.



Date	Research Vessel	Cruise No.	Dredge Size	Ring Size	Tow Duration (min)	Georges Bank			Mid-Atlantic	No. of Tows
						South Channel	Southeast Part	Northeast Peak		
May 11-21, 1960	Delaware	60-7	10′[1]	3″	15				x	153[2]
May 23-29, 1960	Delaware	60-8	10′	2″	10	x	x	x		60
May 3-10, 1961	Delaware	61-7	10′	2″	10	x	x	x		184[3]
Sept. 22-31, 1961	Delaware	61-16	10′	2″	10	x	x	x		194
May 28-June 6, 1962	Delaware	62-6	10′	2″	10	x	x	x		184[4]
Sept. 11-20, 1962	Delaware	62-10	10′	2″	10			x		199[5]
May 13-17, 1963	Albatross	63-1	10′	2″	10	x	x			65
June 10-13, 1963	Albatross	63-3	10′	2″	10	x				96
Sept. 5-9, 1963	Albatross	63-6	10′	2″	10			x		26
May 13-22, 1964	Albatross	64-7	10′	2″	10		x	x		180
Sept. 7-15, 1964	Albatross	64-12	10′	2″	10	x	x			152[6]
May 3-13, 1965	Albatross	65-6	10′	2″	10		x	x		194[7]
Sept. 22-30, 1965	Albatross	65-13	10′	2″	10	x	x	x		167[8]
Aug. 11-23, 1966	Albatross	66-9	10′	2″	10		x	x		239[9]
Sept. 27-Oct. 16, 1966	Albatross	66-13	10′	2″	10				x	198
July 5-13, 1967	Albatross	67-12	10′	2″	10		x	x		210
Sept. 4-19, 1968	Albatross	68-14	10′	2″	10	x	x	x	x	322
Aug. 7-16, 1975	Albatross	75-8	10′	2″	15				x	100
Sept. 27-Oct. 3, 1975	Albatross	75-11	10′	2″	15	x	x	x		143
May 24-June 3, 1977	Albatross	77-03	10′	2″	15	x	x	x		144
Sept. 6-16, 1977	Albatross	77-08	10′	2″	15				x	189
Aug. 15-Sept. 1, 1978	Albatross	78-10	10′	2″	15	x	x		x	348

[1] A 30″ Digby dredge equipped with a ½ inch liner was also used
[2] Only 93 stations occupied
[3] Only 160 stations occupied
[4] Only 163 stations occupied
[5] Only 174 stations occupied

[6] Only 144 stations occupied
[7] Only 192 stations occupied
[8] Only 162 stations occupied
[9] Only 210 stations occupied

Year	Vessel	Start Date	End Date	MA Sta	GB Sta	GOM Sta	Total Sta	Scallops Caught
1979	*Albatross IV*	15-May-79	1-Jun-79	217	89	0	306	16175
1980	*Albatross IV*	19-May-80	12-Jun-80	300	69	0	369	22573
1981	*Albatross IV*	9-Jun-81	2-Jul-81	251	93	0	344	10982
1982	*Albatross IV*	1-Jun-82	6-Aug-82	248	189	0	437	61378
1983	*Albatross IV*	26-Jul-83	2-Sep-83	262	274	52	588	87631
1984	*Albatross IV*	24-Jul-84	31-Aug-84	275	219	171	665	77523
1985	*Albatross IV*	22-Jul-85	31-Aug-85	269	267	0	536	63941
1986	*Albatross IV*	29-Jul-86	29-Aug-86	287	199	0	486	67349
1987	*Albatross IV*	6-Jul-87	13-Aug-87	290	302	9	601	116281
1988	*Albatross IV*	7-Jul-88	10-Aug-88	296	305	0	601	92077
1989	*Albatross IV*	9-Jun-89	19-Jun-89	259	0	0	259	69180
1989	*Chapman*	6-Jul-89	14-Jul-89	13	54	0	67	5438
1989	*Oregon II*	1-Aug-89	9-Aug-89	14	84	0	98	5576
1990	*Oregon II*	26-Jul-90	20-Aug-90	216	240	0	456	80212
1991	*Oregon II*	28-Jul-91	21-Aug-91	228	208	0	436	128213
1992	*Oregon II*	1-Aug-92	22-Aug-92	229	191	0	420	155565
1993	*Oregon II*	31-Jul-93	25-Aug-93	214	230	0	444	77402
1994	*Albatross IV*	22-Jun-94	18-Jul-94	227	242	0	469	58246
1995	*Albatross IV*	19-Jun-95	30-Jun-95	227	241	0	468	64512
1995	*Albatross IV*	24-Jul-95	6-Aug-95	227	241	0	468	137799
1996	*Albatross IV*	29-Jul-96	26-Aug-96	211	218	0	429	117211
1997	*Albatross IV*	21-Jul-97	17-Aug-97	225	249	0	474	85163
1998	*Albatross IV*	21-Jul-98	16-Aug-98	230	286	0	516	227765
1999	*Albatross IV*	16-Jul-99	6-Aug-99	247	131	0	378	138046
1999	*Tradition*	26-Sep-99	4-Oct-99	0	104	0	104	54519
2000	*Albatross IV*	6-Jul-00	18-Aug-00	251	221	0	472	263128
2001	*Albatross IV*	27-Jun-01	16-Aug-01	229	293	0	522	283473
2002	*Albatross IV*	15-Jul-02	16-Aug-02	216	284	0	500	253283
2003	*Albatross IV*	1-Jul-03	6-Sep-03	211	247	0	458	366926
2004	*Albatross IV*	6-Jul-04	5-Aug-04	262	299	0	561	390478
2005	*Albatross IV*	5-Jul-05	11-Aug-05	256	256	0	512	316387
2006	*Albatross IV*	10-Jul-06	11-Aug-06	243	278	0	521	285880
2007	*Albatross IV*	9-Jul-07	16-Aug-07	253	316	0	569	296110
2008	*Sharp*	21-Jun-08	6-Aug-08	263	178	0	441	339418
2009	*Sharp*	9-May-09	3-Jul-09	213	193	0	406	327347
2010	*Sharp*	11-May-10	2-Jul-10	213	243	0	456	393490
2011	*Sharp*	9-May-11	1-Jul-11	153	146	0	299	115773
2012	*Sharp*	9-May-12	6-Jul-12	88	115	0	203	91420
2013	*Sharp*	13-Jun-13	20-Jul-13	65	117	0	182	173487
2014	*Sharp*	8-Jun-14	16-Jul-14	6	116	0	122	108854

Table 1.1. NEFSC survey cruises, 1960-1978 (above, from Serchuk et al. 1979), and 1979-2014 (below), showing the number of stations in the Mid-Atlantic, Georges Bank, Gulf of Maine and combined. Note that surveys since 2011 have been a combination of Habcam and dredge surveys.

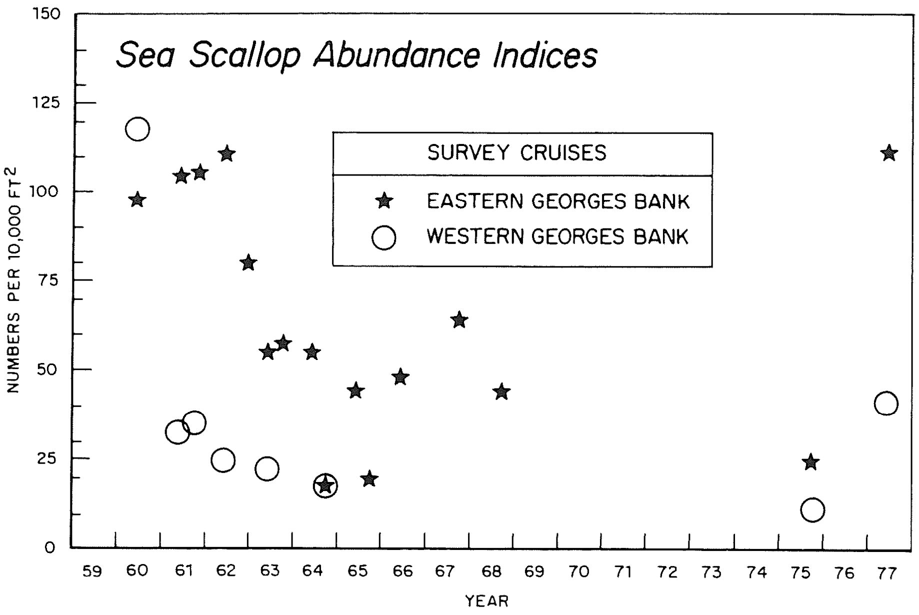


Figure 1.1. Unlined dredge survey mean abundance on Georges Bank, 1960-1977, from Serchuk et al. (1979).

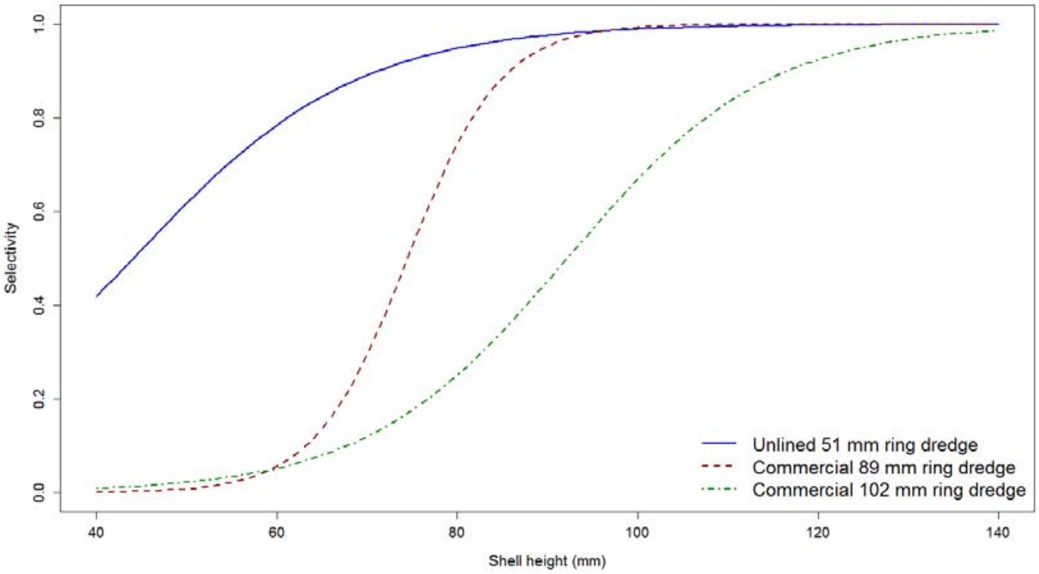
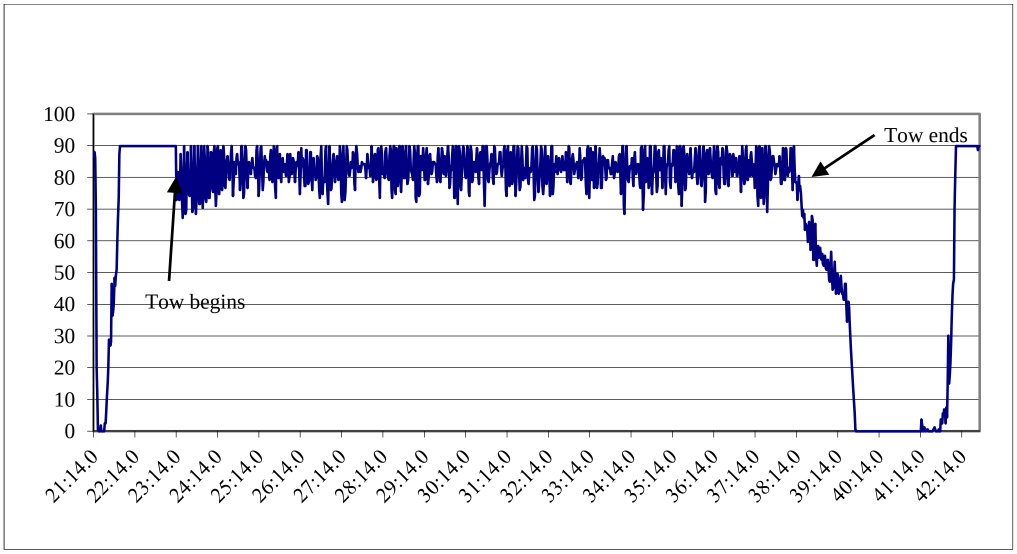


Figure 1.2. Estimated selectivity of unlined scallop dredges relative to the lined survey dredge, based on paired tow experiments.



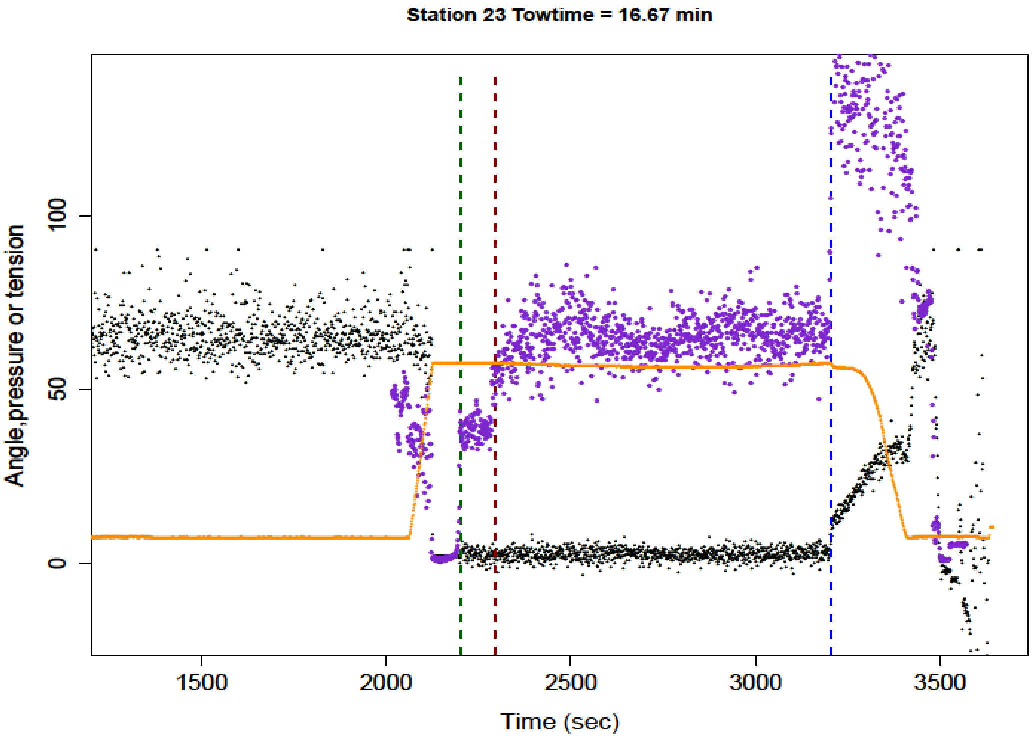


Figure 1.3. Example sensor data from the *R/V Albatross IV* (above), and the *R/V Hugh Sharp* (below). The green line for the *Sharp* tow shows where the dredge began to fish, the blue line indicates the end of the tow, and the red line is the nominal tow start, when the winch was locked. The black dots indicate tow angle, the purple gives cable tension, and the orange line is pressure.

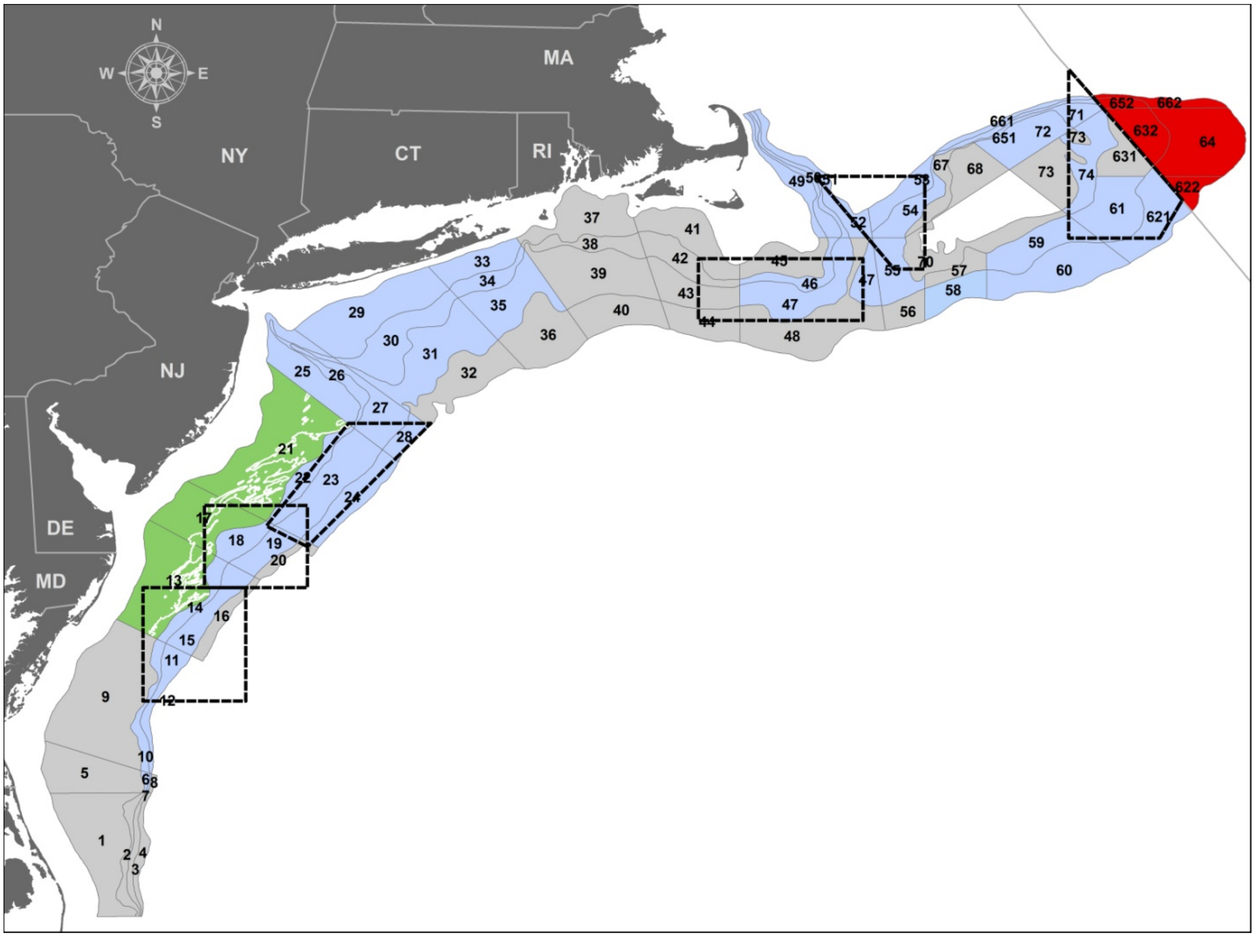


Figure 1.4. The NEFSC shellfish strata used for scallop surveys. The regularly surveyed strata are shown in blue, while the gray strata are ones that were regularly surveyed prior to 1989. In some years, the Canadian side of Georges Bank has been surveyed (red). The strata shown in green were regularly surveyed prior to 1989, and the portions deeper than 40m (the white lines give the 40m isobath) have been regularly sampled since 2000. The polygons with the black dashed outlines are the closed or rotational areas: from southwest to northeast, they are Delmarva, Elephant Trunk, Hudson Canyon South, Nantucket Lightship Area, Closed Area I and Closed Area II.

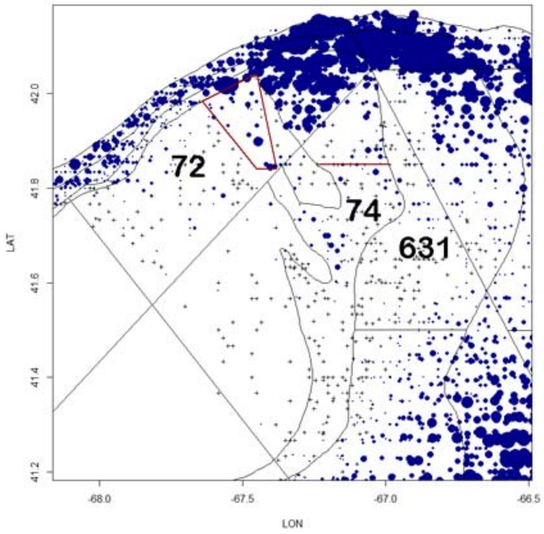


Figure 1.5. NEFSC dredge survey tows on the northeast portions of Georges Bank, showing the divisions of strata 72 and 74.

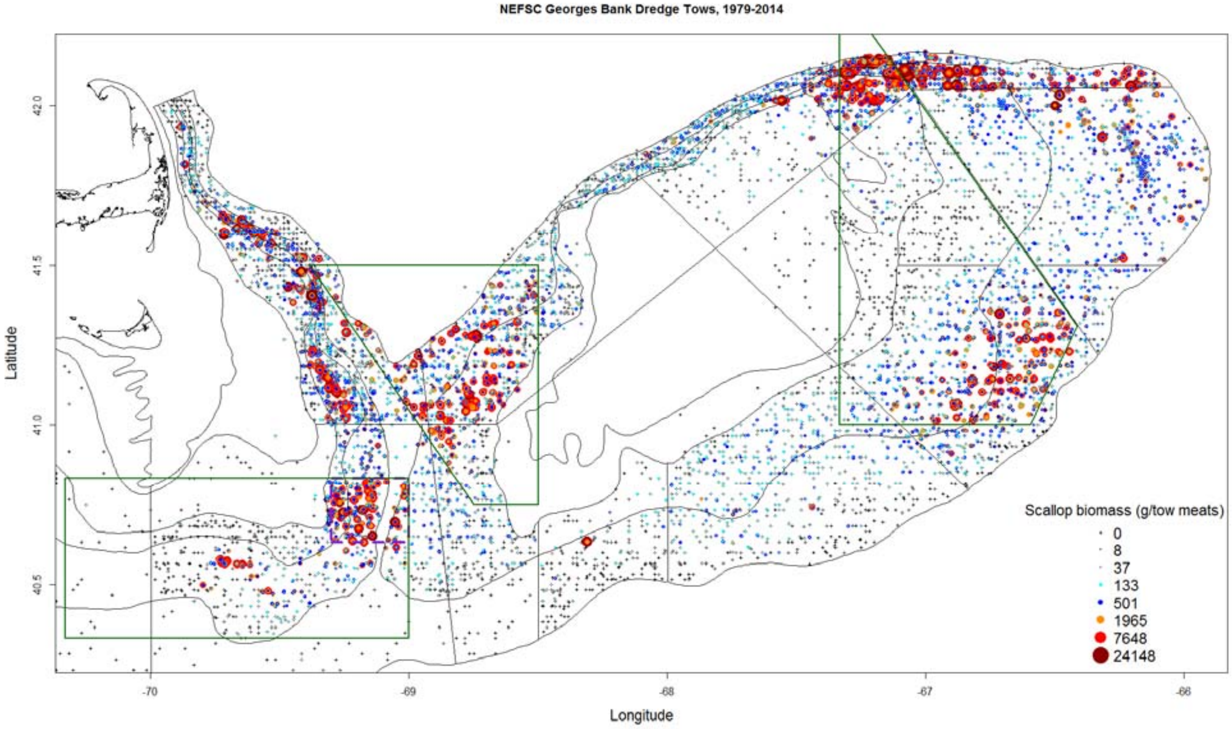


Figure 1.6 (a) Biomass of NEFSC scallop survey catches on Georges Bank, 1979-2014. The green polygons are the three closed areas. The purple dashed lines delineate the northeast corner of the Nantucket Lightship Closed Area.

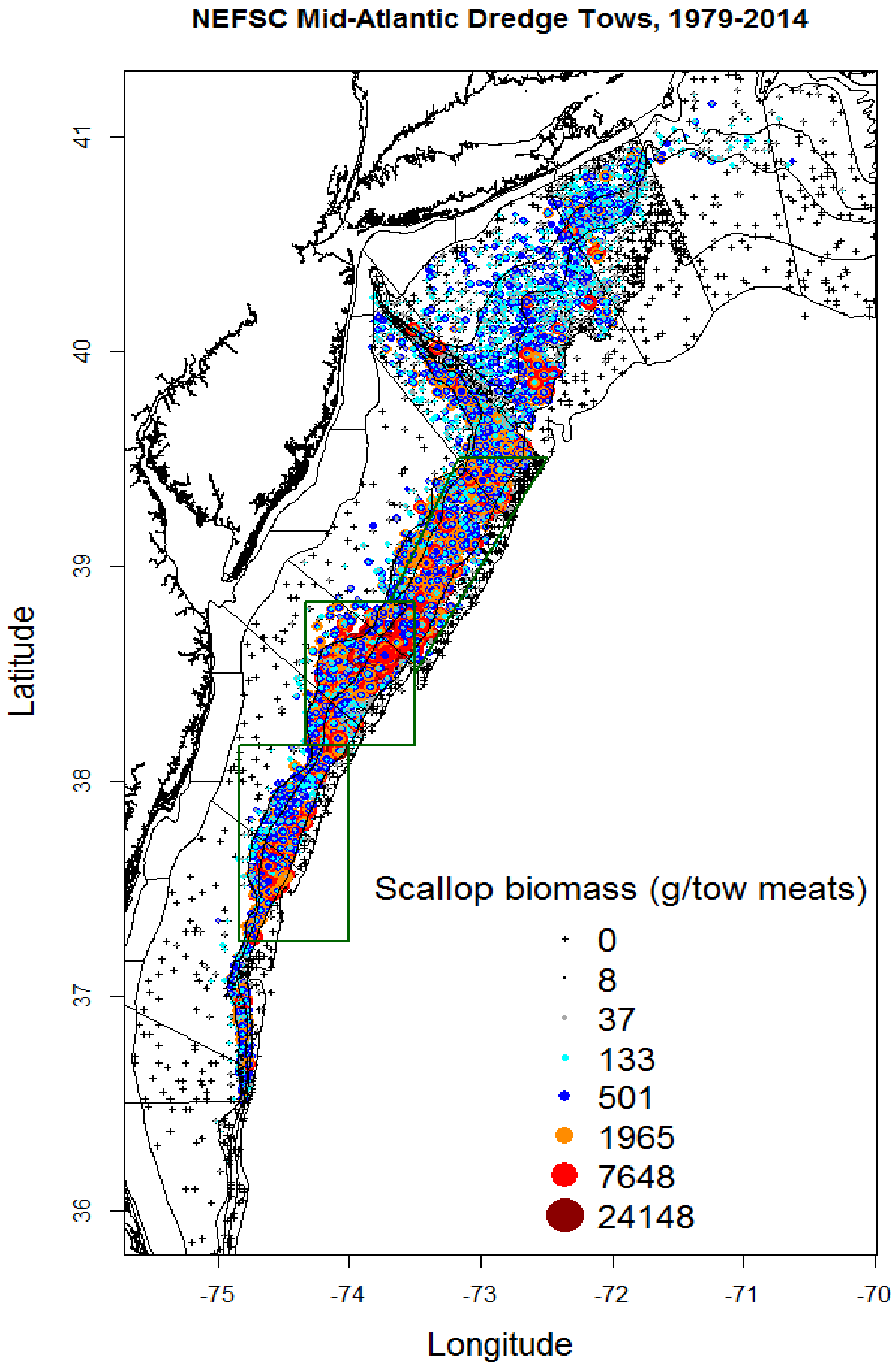


Figure 1.6 (b) Biomass of NEFSC scallop survey catches in the Mid-Atlantic Bight, 1979-2014. The green polygons are the three rotational management areas.

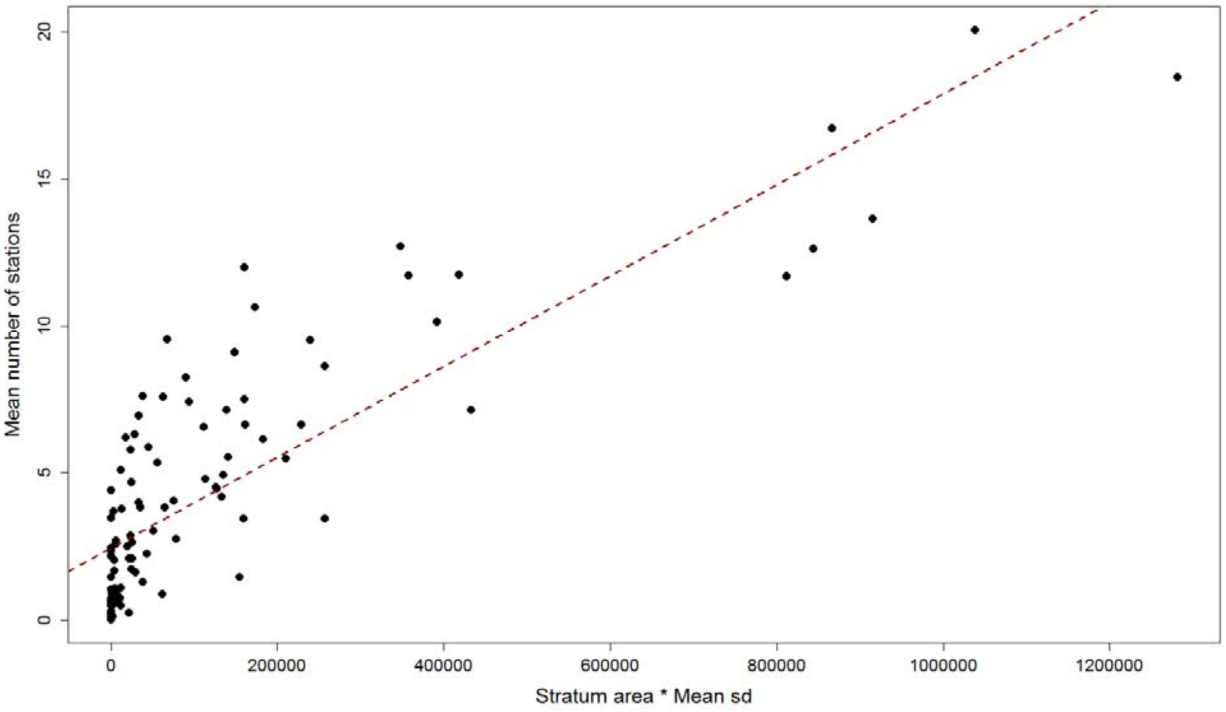


Figure 1.7. Mean number of stations per stratum vs. product of stratum area times the mean standard deviation of scallop catch numbers in that stratum (which is proportional to the Neyman optimal allocation).

Terms of Reference 2 – Measurement errors, gear selectivity, and other potential confounding factors

Shell height measurement error

Scallop shell heights were measured on mechanical measuring boards prior to 2005, and electronic boards thereafter. The mechanical boards binned the measurements into 5 mm size groups, whereas the electronic boards measure scallops to the nearest millimeter.

Measurement errors due to the mechanical measuring boards were reported in Jacobson et al. (2010). The shell heights of 344 scallops were measured with calipers and with the mechanical measuring boards. Relative to the caliper measurements, the mechanical measuring boards had a mean bias of -0.6 mm, a standard deviation of 1.7 mm, skewness of -0.044, and kurtosis of -0.85.

In order to investigate the measurement error of the electronic measuring boards used since 2005, shell heights measured with calipers when aging scallop shells on land were compared to those from the electronic measuring boards on the same scallops at sea (n=7460). Each shell saved for aging is numbered, and that number in principle corresponds to that entered into the database. While that is true for vast majority of the scallops, a few shells were misnumbered, or their numbers became obscure, which induced possible mismatches on a small numbers of scallops, with large discrepancies between the calipers and the measuring board shell heights (up to 80 mm). As a first pass, any case where the difference between calipers and measuring board was more than 20 mm was discarded (n=55). Of the remaining 7406 shells, the differences between the measuring board and the calipers had a mean of 0.33 mm, a standard deviation of 2.8 mm, a skewness of 0.15, and kurtosis of 7.6 (Fig 2.1a). The high kurtosis indicates that there are many more high error measurements than would be expected from a normal distribution. A normal quantile-quantile plot confirms this (Fig 2.1b), and indicates strong deviations from a normal distribution when more than about 2.5 standard deviations from the mean. This suggests than most differences greater than about 7 mm may be due to mismatched shells rather than random error. If all observations with differences more than 7 mm are removed (n = 203), the difference between the measuring board and the calipers of the remaining 7202 shells had a mean of 0.24 mm, standard deviation of 2.2 mm, a skewness of 0.18 and kurtosis of -0.08. It is likely that shell edge breakage occurs in some shells when they are bagged and transported to shore, which may explain the slight bias.

It can be concluded that the shell height measurement error using either the mechanical or the electronic boards is about 2 mm.

Effects of Sea State

Generalized Additive Models (GAMs) were used to evaluate possible effects of sea state on dredge catches. Most tows were conducted when wave heights were less than 1 m, but there were some tows conducted with waves as high as 5 m (Fig 2.2). For Georges Bank, catch in numbers or biomass were predicted from s(year), s(depth), s(lat,lon) and wave height, where the s function denotes a spline smoother. Because the distribution of the catches is zero-inflated, the GAMs were done in two stages: first, a GAM was done for presence/absence using the binomial family and a logit link, followed by a GAM predicting log-transformed abundance or biomass of the catch for positive tows only, assuming Gaussian errors. The presence/absence GAM explained 35.5% of the deviance, but wave height was not significant (p=0.11). Removing wave height from the GAM reduced the percent deviance explained by 0.1%, to 35.4%. For prediction of catch numbers, wave height was significant ($p<0.001$), but removing wave height from the GAM only reduced the deviance explained from 48.8% to 48.6%. Similarly, wave height was significant for predicting catch weight ($p < 0.001$), but removing it from the GAM only reduced the explained deviance from 22.6% to 22.5%.

In the Mid-Atlantic, longitude and depth are strongly correlated, so longitude was dropped as a predictor variable. Instead, predictors were s(lat,depth), s(year) and wave height. For Mid-Atlantic presence/absence GAM, wave height was a marginally significant predictor ($p = 0.03$), but removing it only reduced the explained deviance from 34.7% to 34.6%. Similarly, wave height was a significant predictor of catch number for positive tows ($p < 0.01$), but only reduced the explained deviance from 29.2% to 29% for abundance. The GAM for biomass that included wave height did not converge when wave height was included.

It is most likely that the small apparent explanatory value of wave height is an artifact. Certain areas (e.g., the northern edge of Georges Bank) tend to have both high scallop catches and rough seas. With 6000-7000 tows in both regions, and limited number of tows in rough seas, even a very weak correlation between sea state and area would be translated into a statistically significant result. It can be concluded that sea state has little or no effect on scallop catches.

Quantification of Dead Scallop Shells

Any “clappers” (dead scallops with the two valves still attached at the hinge) are measured and recorded with their own “species” code to distinguish them from the live scallops used in the abundance indices. The ratio of live scallops to clappers is an indicator of natural mortality, and under certain assumptions, can be used to estimate natural mortality (Merrill and Posgay 1964). In addition, the presence or dominance of (dead, non-clapper) scallop shells in the catch is noted qualitatively (see TOR-6).

Dredge selectivity

The relative selectivity of the lined survey dredge with respect to unlined gear is given in Fig 1.2. Optical surveys give an opportunity to evaluate the selectivity of the lined dredge for scallops greater than 40 mm shell height. When making such comparisons, it needs to be taken into account that optical surveys have larger measurement errors than the dredge (typically, with a standard deviation of 1 cm or more, NEFSC 2014). Figure 2.3 illustrates the effects of measurement error on size-frequency distributions. A true size-frequency distribution (based on the 2008 Mid-Atlantic dredge shell heights) was convolved with a Gaussian kernel with mean 0 and standard deviations of either 5, 10, or 15 mm to simulate measurement error. The resulting distributions were renormalized to sum to 1 for 40+ mm scallops. The resulting distributions that include measurement error have more large scallops that the true distribution, as well as more in the trough between the two modes, and less at the peaks of the modes. In addition, it should be kept in mind that the SMAST large camera data does not fully select scallops less than about 70-80 mm, and the small camera data tend to be noisy because of limited sample size. Finally, the surveys in some cases may have modestly different spatial footprints, and were not all conducted at the same time. In particular, there were several months between Mid-Atlantic surveys with the different methods in recent years. Considerable growth can occur during that intervals, particularly with smaller scallops.

Comparisons of the regional size-frequencies for the dredge surveys, SMAST small and large camera, and Habcam are shown for the Mid-Atlantic (Fig 2.4) and Georges Bank (Fig 2.5). While the effects discussed above are apparent in many of these plots, there is no evidence that the dredge size-frequencies are systematically biased compared to the optical surveys (excluding the SMAST large camera at small shell heights). It can be concluded that the lined dredge selectivity is approximately flat for shell heights greater than 40 mm.

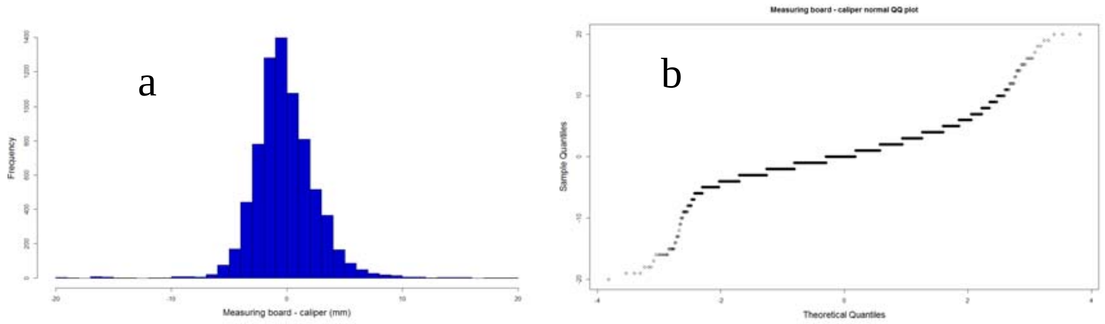


Figure 2.1. (a) Histogram of differences between caliper and electronic measuring board measured shell heights. (b) Normal quantile-quantile plot of the differences between the caliper and electronic measuring board.

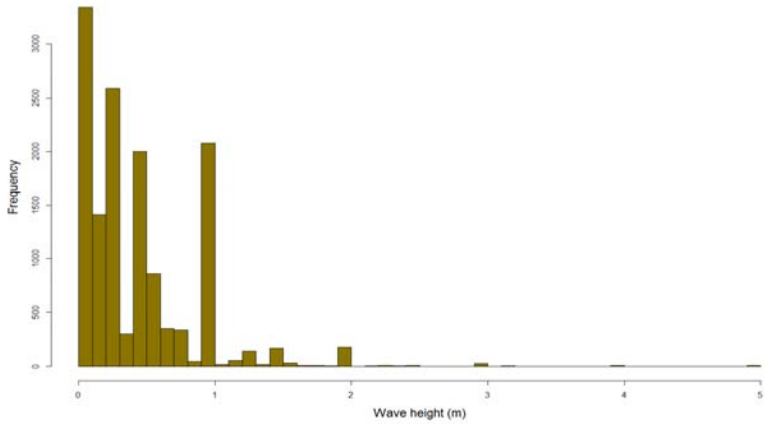


Figure 2.2. Histogram of wave heights during dredge tows, 1979-2014.

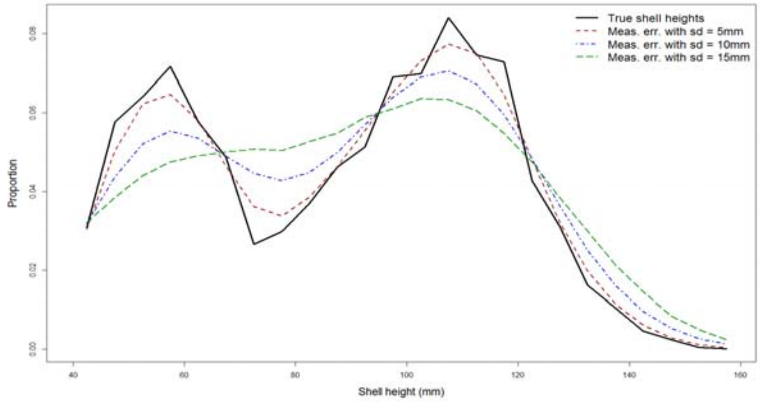


Figure 2.3. Example plot showing the effects of measurement error on size-frequencies. Gaussian kernels with mean zero and standard deviations 5, 10, or 15 mm (red, blue and green lines) were convolved with the true shell heights (black line). Note that measurement error tends to erode peaks and fill in valleys, and adds a tail to the right.

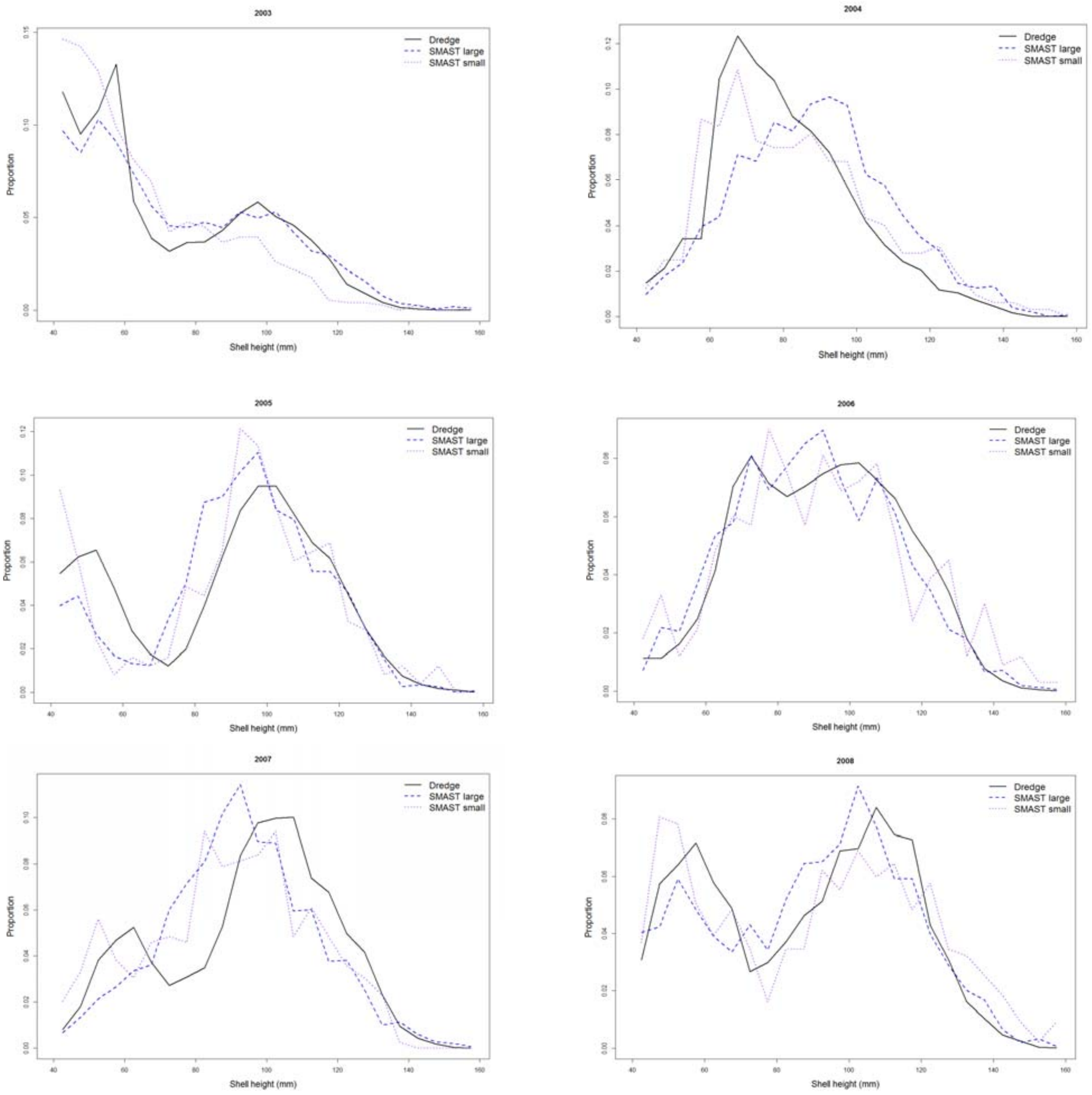


Figure 2.4. Comparison of size frequencies from Mid-Atlantic surveys (continued on next page).

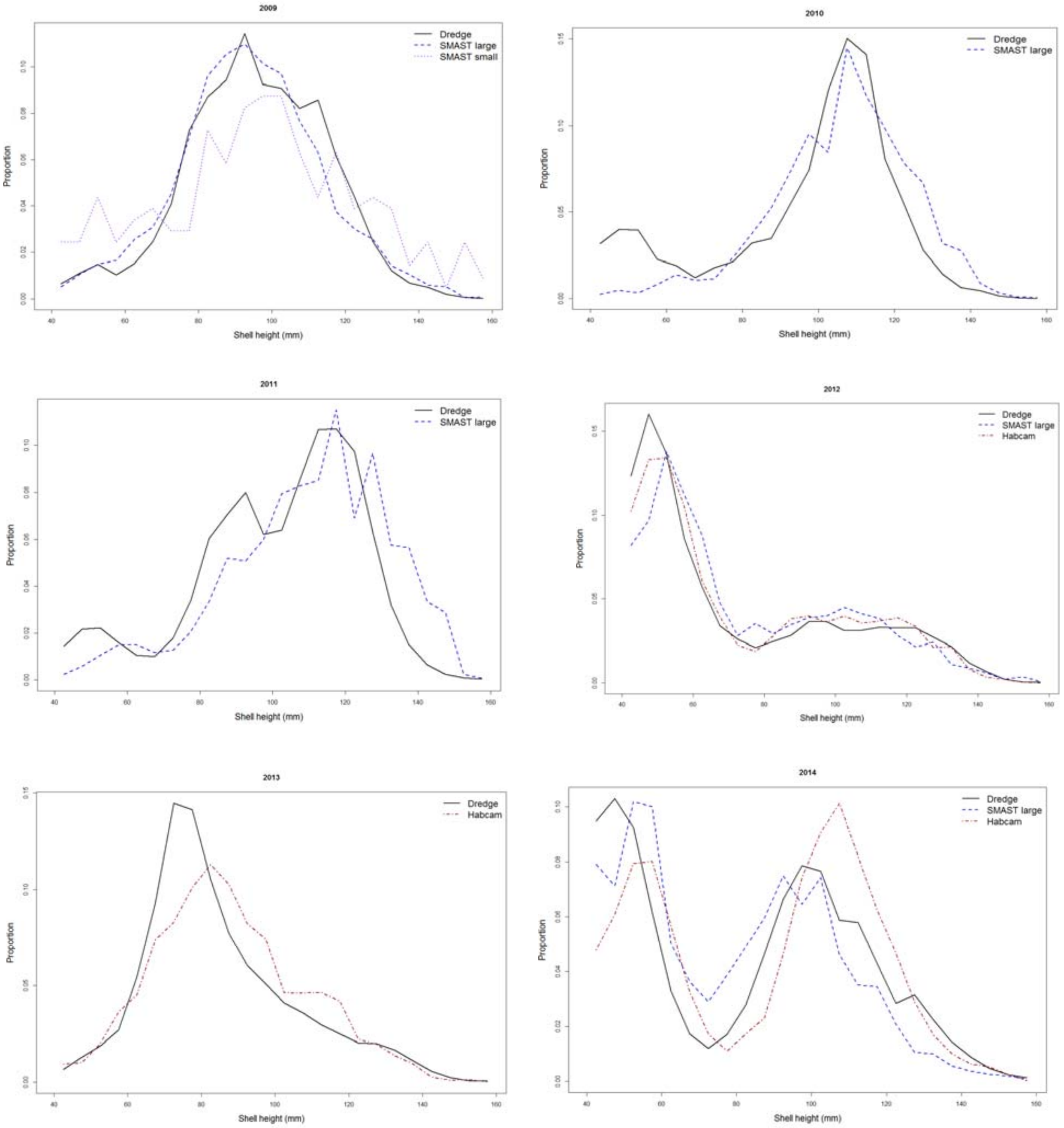


Figure 2.4. Comparison of size frequencies from Mid-Atlantic surveys (continued from last page).

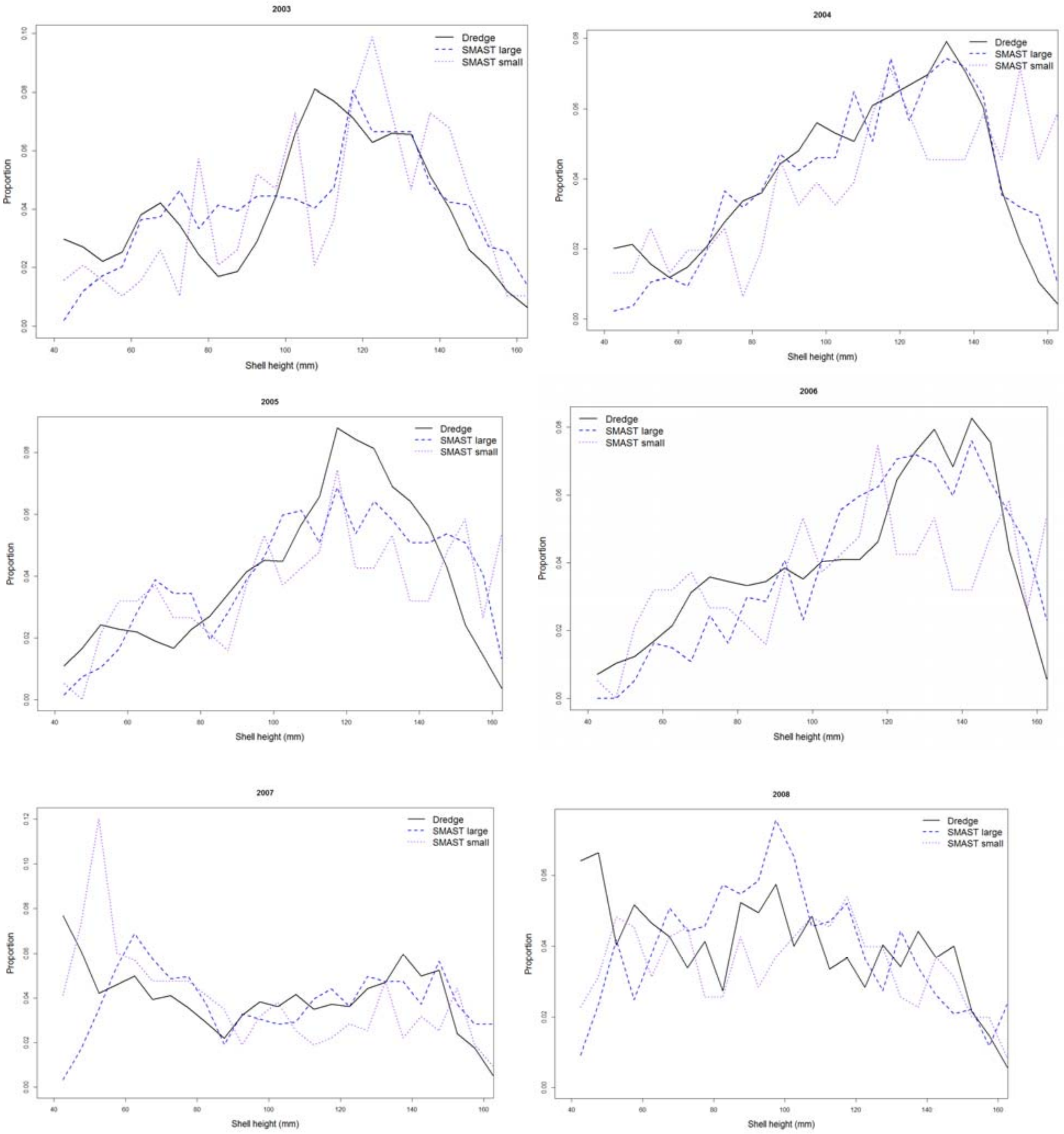


Figure 2.5. Comparison of size frequencies from Georges Bank surveys (continued next page).

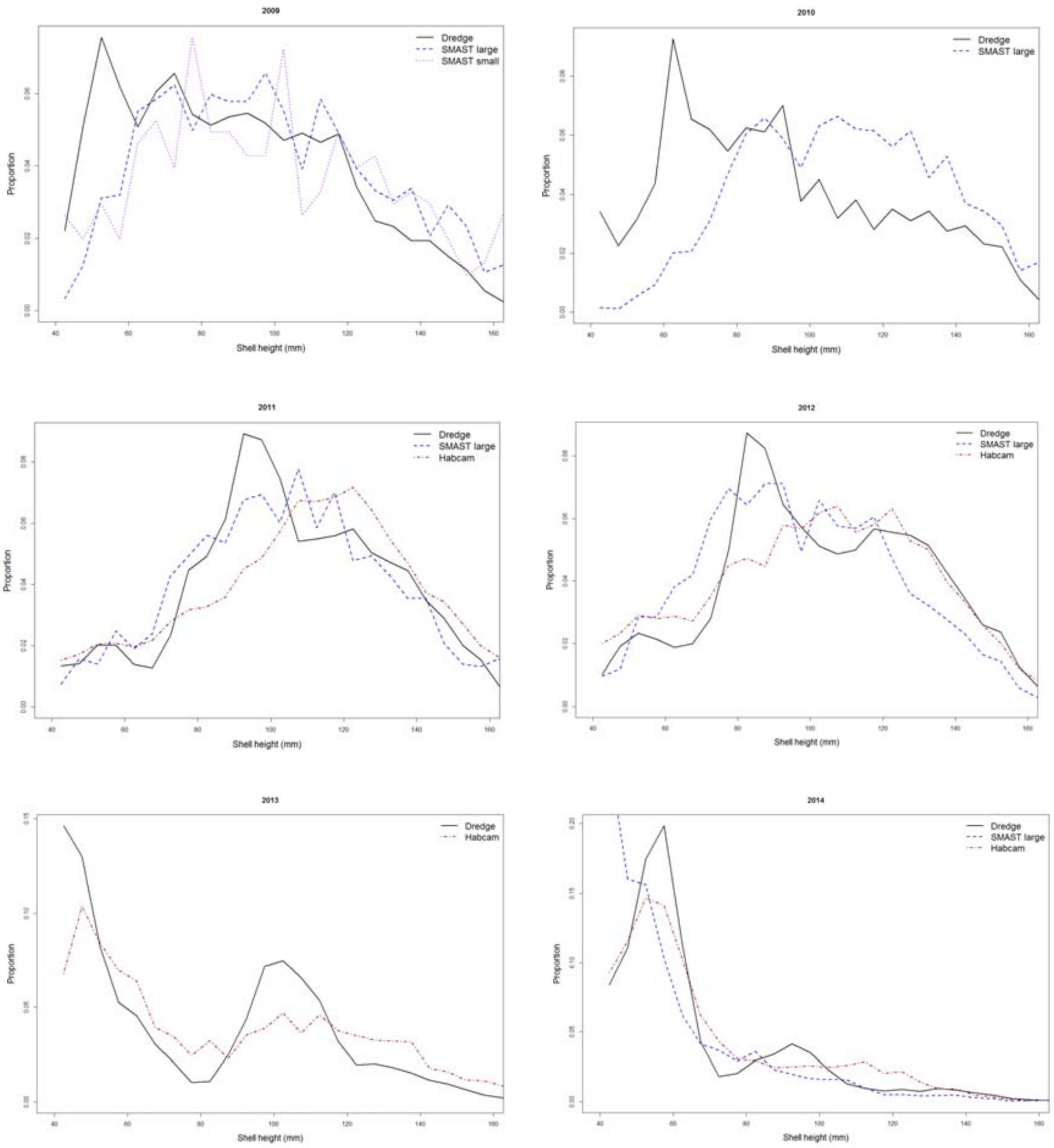


Figure 2.5. Comparison of size frequencies from Georges Bank surveys (continued from last page).

Terms of Reference 3 – Biological sampling, subsampling, fine-scale ecology

Subsampling

In most tows, all scallops are measured. However, when catches are very large, only a subsample of the scallops are measured, and these measurements are expanded to the entire catch. In most such cases, the scallops are placed into baskets, the baskets are counted, and a random sample of the baskets are measured. Of the 5414 tows conducted between 2001-2014, scallops were subsampled on 1338 stations; the mean expansion factor was 4.9 and the median was 3.5. Further details of the sampling procedures are discussed in NEFSC (2015).

Detection of recruitment

Two year old “recruits” are typically 35-75 mm shell height during the survey season, and thus mostly or completely recruited to the survey dredge with its 38 mm liner. One year old “pre-recruits” are about 10-25 mm when the surveys are conducted, so that most of these pass through the liner and are not caught. However, very large numbers of one year old scallops have been caught upon occasion, and these observations are good predictors of a strong year class. For example, very large numbers of one year old scallops were observed in the Elephant Trunk area in the Mid-Atlantic Bight in 2002, and even larger numbers of two year olds were observed the next year (Fig 3.1). From this plot, it is evident that one year olds are not fully recruited to the gear, but can be used as a qualitative predictor of future recruitment. Similarly, very large catches of one year olds were observed in 2013 on the southern portions of Nantucket Shoals and Georges Bank. In one station, over 60,000 small (most < 20 mm) scallops were caught. Some nearby HabCam photos show scallop spat density of over $100/m^2$. Very high catches of two year old recruits were observed in this area in 2014 in all the surveys.

Biological sampling

Shells from a subsample of the catch are saved for shell ring growth analysis (Fig 3.2, Hart and Chute 2009a, 2009b). Growth parameters are estimated based on the growth increments between successive rings, using a mixed-effects modeling approach (Hart and Chute 2009b). These growth estimates are in turn used to construct the growth transition matrices that are central to the CASA, SAMS and SYM sea scallop stock assessment models (NEFSC 2014). Prior to 2012, a specified number of shell samples were requested from each survey strata, with more samples requested from the higher abundance strata. Samples were taken at about half of the stations; an average of six shells were saved at the stations where samples were taken. Because the number of dredge stations has been reduced since 2012, shell samples have been taken on all stations except those where only few or no scallops were caught. Because more stations are generally allocated to higher abundance strata, there are still more shell samples taken from these strata.

Meat, gonad, and whole weights have been taken for the scallops saved for ageing since 2001 (meats only in 2001-2002). These data were analyzed in Hennen and Hart (2012) using a generalized linear mixed-effects modeling approach, and updated during the last benchmark assessment (NEFSC 2014). Prior to 2001, meat weights were sampled only in certain years (Haynes 1966, Serchuk and Rak 1983, Lai and Helser 2004).

Biological samples for finfish are also sometimes taken, especially for commonly caught species such as goosefish (*Lophius americanus*) and skates. Stomach contents and vertebrae for ageing have been obtained from the goosefish. Measurements of clasper length and cloaca depth for seven species of skate were collected on scallop surveys from 2000-2006. Stage-based maturity for skates was also collected in 2006. These data are being used, along with the same information collected on the trawl surveys, to examine spatial and temporal differences in maturity for skates.

Biological samples are taken for special purposes at the request of outside investigators. For example, in 2007-2009, scientists from the U.S. Food and Drug Administration tested the gonads and viscera of scallops for paralytic shellfish poisoning (PSP, DeGrasse et al. 2014). While PSP is not retained in the scallop meats usually consumed in the US, there is a market for “roe-on” or whole scallops where PSP toxicity may be an issue. As a second example, in 2012 and 2013, DNA samples were taken from selected stations as part of a study of the genetics of Atlantic sea scallops throughout its range (Fig 3.4, Van Wyngaarden et al. 2014). In both these cases, many of the samples were taken from the scallops already dissected for meat and gonad weights. As a final example, samples of the “trash” were collected and analyzed to determine the species composition of benthic invertebrates inside and just outside the Georges Bank closed areas to evaluate the impact of bottom fishing on the benthic community (Walker 2004).

Predator-prey relationships

Since 2000, sea scallop predators, in particular the sea stars *Astropecten americanus*, *Asterias* spp., and the crabs *Cancer* spp., have been sampled in about every third tow (and in most tows since 2012). On the pre-designated “stars and crabs” stations, all *Cancer* spp. crabs from the catch are counted and weighed. In addition, sea stars in a random subsample of the “trash” (the catch after scallops, finfish and *Cancer* spp. crabs have been removed), are identified to genus (and in some cases to species), counted and weighed. Because the total amount of trash is also quantified, these estimates can be expanded to the entire catch. Analysis of these data indicates that both *A. americanus* sea stars and *Cancer* crabs are negatively related to sea scallop recruitment (Hart 2006, Shank et al. 2012, Hart 2014b). The effects of the spat predator *A. americanus*, which is commonly at very high densities in the deeper portion of the Mid-Atlantic Bight (often >10000/tow, corresponding to several per square meter), is especially pronounced (Fig 3.3).

Allee effects

Atlantic sea scallops are dioecious broadcast spawners, and males and females must be in close proximity during spawning in order for substantial fertilization success. Smith and Rago (2004) used NEFSC dredge survey data to show that scallop aggregations were much denser after closures, and hence fertilization success likely increased substantially. The increases in fertilized egg production were therefore likely much greater than the (very substantial) increases in biomass in these areas.

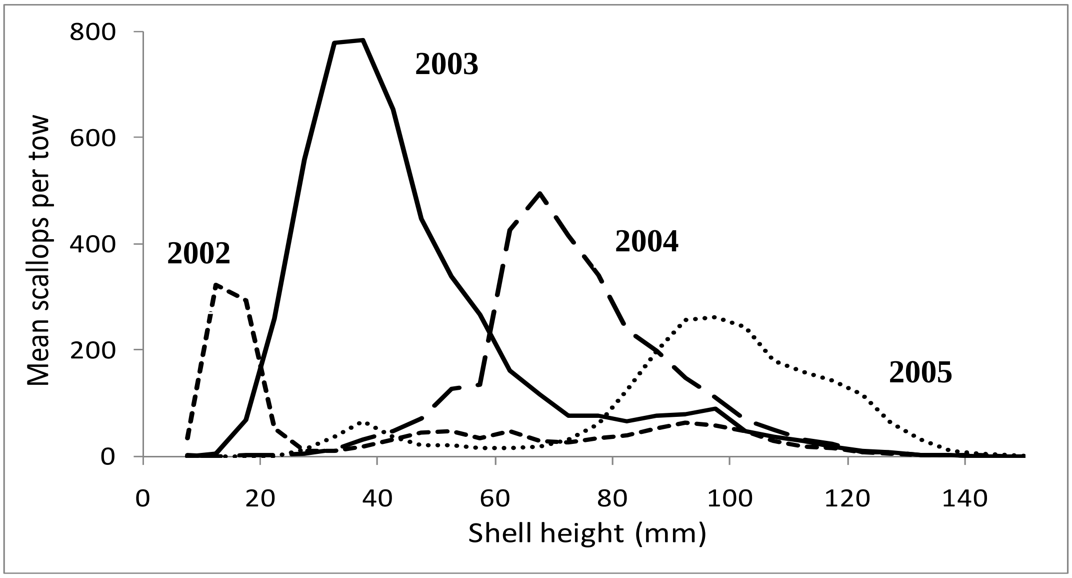


Figure 3.1. Mean stratified shell heights in the Elephant Trunk area of the Mid-Atlantic Bight, 2002-2005, showing the tracking of the large 2001 year class, from the NEFSC dredge scallop survey (from Hart and Shank 2012).

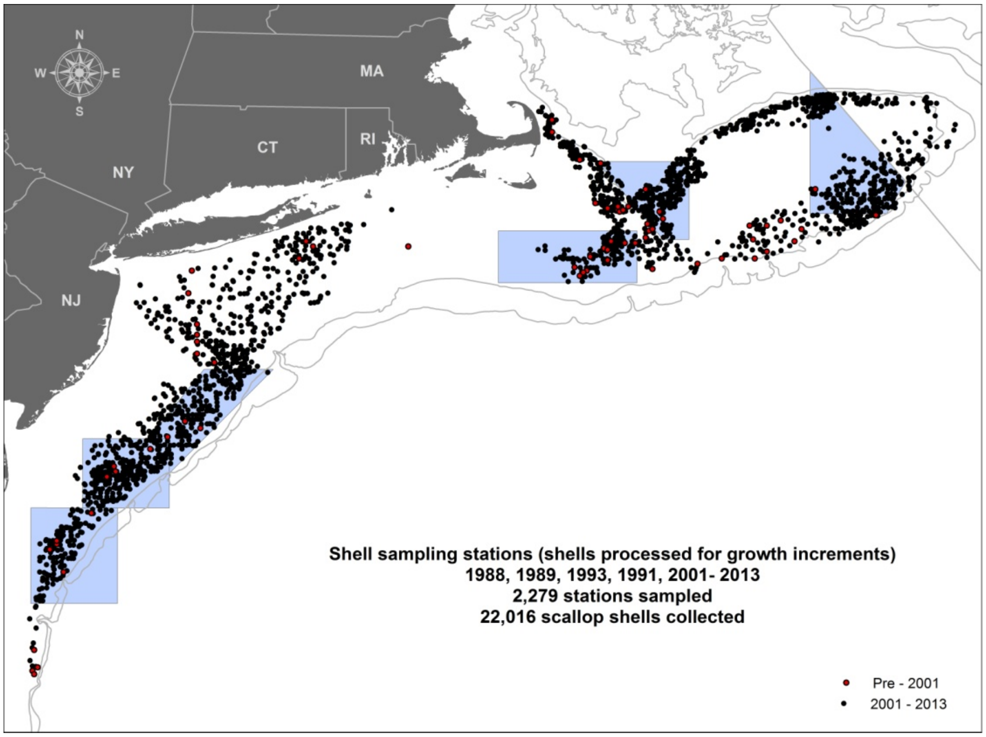


Figure 3.2. Locations where shell samples have been analyzed for growth. Samples were collected in other years prior to 2001, but have not yet been processed. Meat weights (and whole and gonad weights since 2003) were also sampled at the stations sampled since 2001.

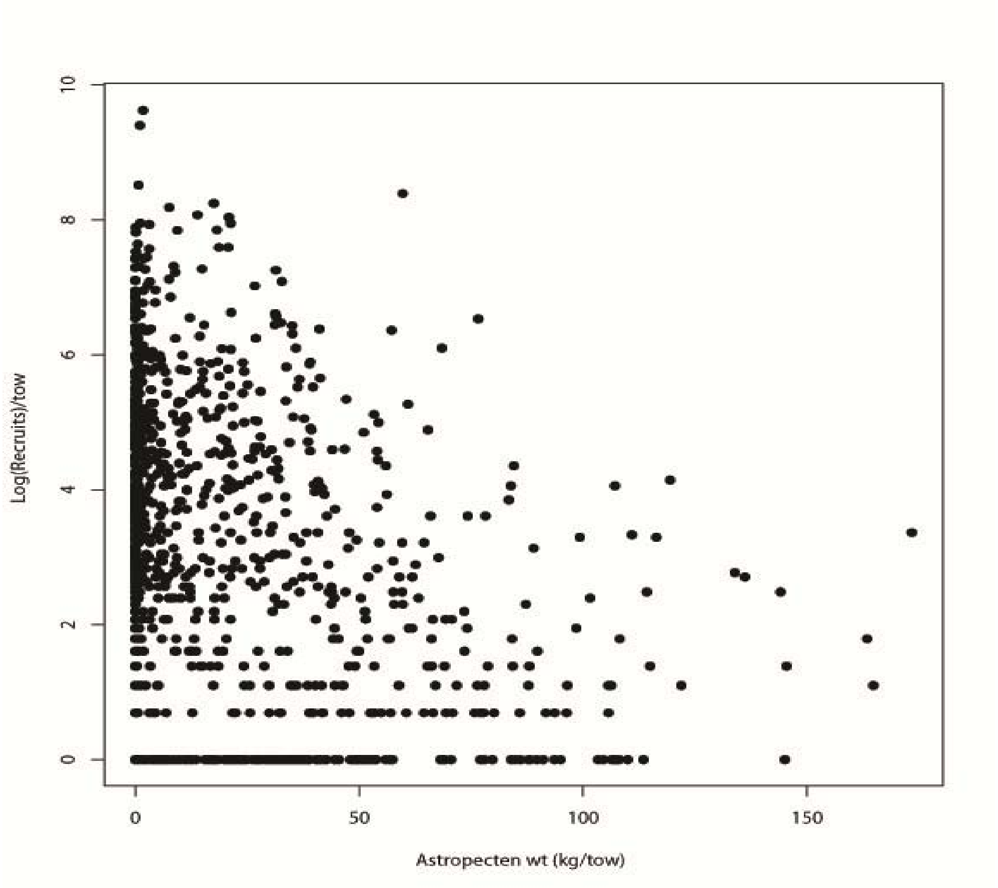


Figure 3.3. Plot of log + 1 transformed scallop recruits vs the weight of *Astropecten americanus* in all Mid-Atlantic tows from 2001-2013 where sea stars were sampled.

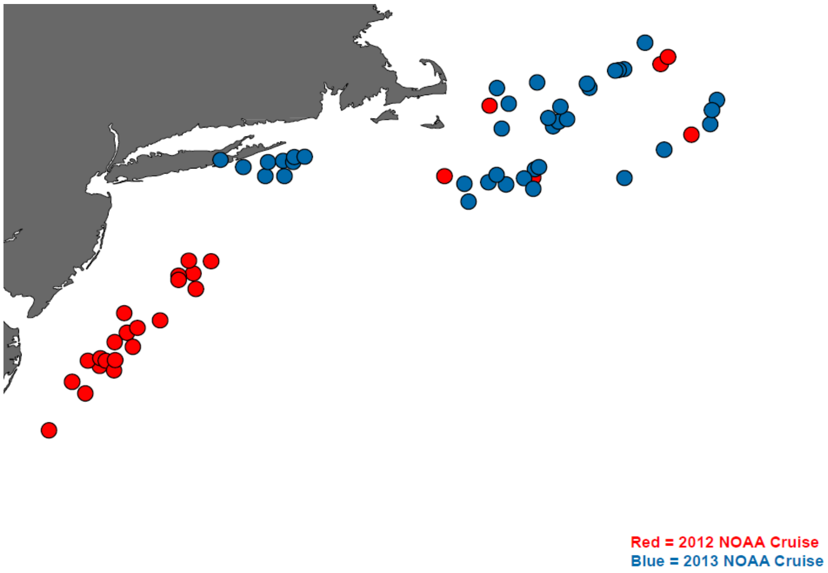


Figure 3.4. Locations of genetic samples taken on the 2012-2013 NEFSC surveys, from Van Wyngaarden et al. (2014).

Terms of Reference 4

Standardized indices of abundance and biomass (Table 4.1 and Fig 4.1) are computed for Georges Bank and the Mid-Atlantic as stratified means (Cochran 1977, Smith 1997) of the regularly surveyed strata (Fig 1.4), post-stratified as necessary to account for closed areas (see TOR-1). These indices are given in relative terms (mean number or biomass per standardized tow).

In order to expand these indices into absolute abundances, it is necessary to determine the catch efficiency *q* of the dredge, that is, the (expected) ratio of the dredge catch to the total number of scallops that were in the dredge path. Towards this goal, numerous paired tows were conducted that compared normal survey dredge tows on the R/V *Hugh Sharp*, and scallop densities observed from Habcam v2, deployed on the F/V *Kathy Marie*. An analysis of 110 such paired tows estimated the mean survey dredge efficiency to be 0.40 (SE = 0.04) on sand bottoms and 0.24 (SE = 0.07) on gravel/cobble bottoms (Miller 2014).

(A) Georges Bank

Year	Abundance index (mean N/tow)	CV	Biomass index (kg/tow)	CV	N tows	Proportion positive tows	Mean weight (g/scallop)	Expanded abundance (millions)	Expanded biomass (mt)
1979	87.4	0.41	1.697	0.34	108	0.89	19.4	1463	26137
1980	75.8	0.24	0.920	0.16	118	0.81	12.1	1152	13088
1981	61.2	0.13	1.079	0.13	82	0.83	17.6	923	15667
1982	132.9	0.46	1.080	0.32	118	0.83	8.1	2474	18379
1983	61.2	0.22	0.810	0.21	126	0.88	13.2	965	12553
1984	39.3	0.11	0.577	0.10	128	0.85	14.7	574	8039
1985	61.8	0.15	0.731	0.16	154	0.90	11.8	995	11475
1986	116.8	0.13	1.070	0.10	153	0.90	9.2	1723	15240
1987	120.1	0.17	1.173	0.16	170	0.86	9.8	1823	17705
1988	98.7	0.16	0.993	0.14	175	0.80	10.1	1423	14371
1989	63.6	0.11	0.631	0.08	120	0.78	9.9	836	8474
1990	184.1	0.24	1.511	0.22	175	0.81	8.2	2831	21941
1991	257.9	0.37	1.633	0.25	176	0.89	6.3	4314	25228
1992	232.0	0.44	2.020	0.43	171	0.89	8.7	4386	36683
1993	61.8	0.24	0.577	0.16	164	0.87	9.3	1080	9231
1994	46.7	0.20	0.518	0.16	177	0.84	11.1	683	7548
1995	111.8	0.20	0.873	0.16	176	0.88	7.8	1915	14345
1996	133.6	0.20	1.617	0.19	171	0.90	12.1	2171	25819
1997	89.4	0.15	1.606	0.17	190	0.88	18.0	1409	25154
1998	283.0	0.26	4.003	0.32	195	0.87	14.1	3750	53005
1999	193.5	0.15	3.391	0.16	173	0.98	17.5	2698	46832
2000	766.7	0.29	8.198	0.22	164	0.91	10.7	10400	111317
2001	408.9	0.13	6.761	0.13	208	0.95	16.5	5611	93561
2002	334.5	0.14	7.195	0.14	214	0.93	21.5	4495	96510
2003	277.9	0.12	6.749	0.13	207	0.94	24.3	3707	90507
2004	291.5	0.11	8.301	0.12	218	0.94	28.5	4026	112010
2005	265.6	0.12	6.792	0.09	343	0.95	25.6	3838	96667
2006	221.3	0.13	6.123	0.13	236	0.94	27.7	3271	89186
2007	224.8	0.10	4.722	0.07	363	0.97	21.0	3373	72649
2008	321.8	0.10	6.460	0.08	239	0.97	20.1	4855	97543
2009	362.7	0.15	6.151	0.11	214	0.97	17.0	5709	93294
2010	413.1	0.21	7.652	0.09	268	0.97	18.5	6846	117925
2011	279.4	0.12	6.971	0.08	225	0.96	25.0	4038	101381
2012	225.3	0.13	5.034	0.08	224	0.97	22.3	3514	77557
2013	336.5	0.23	4.856	0.14	213	0.94	14.4	4942	77254
2014	543.7	0.42	5.198	0.42	108	0.94	9.6	7002	72722

Table 4.1. (A) Sea scallop dredge survey indices for Georges Bank

(B) Mid-Atlantic

Year	Abundance index (mean N/tow)	CV	Biomass index (kg/tow)	CV	N tows	Proportion positive tows	Mean weight (g/scallop)	Expanded abundance (millions)	Expanded biomass (mt)
1979	34.7	0.10	0.665	0.10	166	0.92	19.2	550	10557
1980	42.8	0.12	0.577	0.08	167	0.94	13.5	679	9159
1981	32.1	0.16	0.457	0.13	167	0.91	14.3	509	7260
1982	33.5	0.11	0.497	0.08	185	0.91	14.8	532	7881
1983	32.3	0.10	0.458	0.08	193	0.89	14.2	512	7262
1984	32.2	0.11	0.444	0.09	204	0.91	13.8	510	7044
1985	74.1	0.12	0.739	0.09	201	0.94	10.0	1177	11724
1986	129.6	0.09	1.295	0.08	226	0.93	10.0	2056	20552
1987	131.9	0.08	1.177	0.07	226	0.93	8.9	2093	18686
1988	147.8	0.10	1.738	0.08	227	0.91	11.8	2345	27590
1989	172.8	0.09	1.553	0.07	244	0.93	9.0	2742	24648
1990	215.2	0.22	1.789	0.18	216	0.89	8.3	3415	28385
1991	81.0	0.10	0.945	0.10	228	0.92	11.7	1285	15002
1992	43.5	0.11	0.526	0.07	229	0.87	12.1	690	8345
1993	135.6	0.10	0.852	0.08	214	0.96	6.3	2152	13523
1994	145.1	0.13	1.141	0.09	227	0.94	7.9	2302	18105
1995	173.4	0.13	1.605	0.11	227	0.96	9.3	2751	25469
1996	58.8	0.08	0.747	0.07	211	0.89	12.7	933	11851
1997	43.2	0.13	0.504	0.06	225	0.93	11.7	686	8004
1998	168.4	0.15	1.343	0.12	215	0.92	8.0	2672	21312
1999	238.3	0.24	2.239	0.20	226	0.92	9.4	3782	35542
2000	292.1	0.14	3.719	0.13	229	0.88	12.7	4636	59027
2001	308.4	0.11	4.124	0.12	227	0.90	13.4	4894	65445
2002	284.0	0.10	4.224	0.11	206	0.89	14.9	4508	67044
2003	654.5	0.16	7.007	0.10	201	0.90	10.7	10387	111199
2004	471.0	0.12	6.093	0.08	248	0.89	12.9	7475	96693
2005	344.6	0.08	6.048	0.07	278	0.94	17.5	5469	95979
2006	386.6	0.09	6.917	0.07	302	0.95	17.9	6136	109774
2007	314.6	0.06	6.097	0.06	304	0.94	19.4	4994	96768
2008	373.7	0.09	6.258	0.08	259	0.97	16.7	5932	99316
2009	370.5	0.12	7.007	0.10	196	0.92	18.9	5880	111203
2010	250.3	0.08	5.115	0.07	281	0.94	20.4	3973	81183
2011	172.7	0.10	3.840	0.10	298	0.96	22.2	2740	60935
2012	260.2	0.12	3.194	0.06	269	0.94	12.3	4130	50696
2013	256.1	0.10	3.746	0.08	309	0.98	14.6	4065	59444
2014	253.4	0.15	4.069	0.10	443	0.90	16.1	4022	64577

(C) Whole stock

Year	Abundance index (mean N/tow)	CV	Biomass index (kg/tow)	CV	N tows	Proportion positive tows	Mean weight (g/scallop)	Expanded abundance (millions)	Expanded biomass (mt)
1979	57.6	0.27	1.113	0.23	274	0.91	18.2	2013	36694
1980	57.2	0.15	0.726	0.09	285	0.89	12.1	1831	22247
1981	44.7	0.10	0.727	0.09	249	0.88	16.0	1432	22926
1982	76.7	0.35	0.750	0.20	303	0.88	8.7	3006	26260
1983	44.8	0.14	0.611	0.13	319	0.88	13.4	1477	19816
1984	35.3	0.08	0.502	0.07	332	0.89	13.9	1085	15084
1985	68.8	0.09	0.735	0.08	355	0.92	10.7	2172	23199
1986	124.0	0.08	1.197	0.06	379	0.92	9.5	3779	35792
1987	126.8	0.09	1.176	0.08	396	0.90	9.3	3916	36391
1988	126.5	0.08	1.415	0.07	402	0.86	11.1	3768	41960
1989	125.3	0.07	1.153	0.06	364	0.88	9.3	3578	33122
1990	201.7	0.16	1.668	0.14	391	0.85	8.1	6246	50326
1991	157.8	0.27	1.244	0.15	404	0.91	7.2	5598	40230
1992	125.4	0.35	1.175	0.32	400	0.88	8.9	5077	45028
1993	103.6	0.10	0.733	0.08	378	0.92	7.0	3233	22754
1994	102.4	0.11	0.870	0.08	404	0.90	8.6	2985	25653
1995	146.6	0.11	1.287	0.09	403	0.92	8.5	4666	39814
1996	91.3	0.13	1.125	0.12	382	0.90	12.1	3104	37670
1997	63.3	0.10	0.983	0.12	415	0.91	15.8	2095	33158
1998	218.2	0.16	2.498	0.22	410	0.90	11.6	6422	74317
1999	218.8	0.16	2.739	0.13	399	0.95	12.7	6479	82373
2000	498.2	0.20	5.664	0.15	393	0.89	11.3	15036	170344
2001	352.0	0.09	5.269	0.09	435	0.93	15.1	10505	159006
2002	305.9	0.08	5.514	0.09	420	0.91	18.2	9003	163554
2003	490.9	0.12	6.895	0.08	408	0.92	14.3	14094	201706
2004	393.0	0.09	7.051	0.07	466	0.91	18.1	11501	208703
2005	310.3	0.07	6.371	0.05	621	0.95	20.7	9307	192647
2006	314.8	0.08	6.572	0.06	538	0.95	21.2	9407	198960
2007	275.6	0.05	5.500	0.04	667	0.95	20.3	8366	169418
2008	351.2	0.07	6.346	0.06	498	0.97	18.3	10786	196859
2009	367.1	0.09	6.635	0.08	410	0.95	17.6	11589	204497
2010	321.0	0.12	6.217	0.06	549	0.95	18.4	10819	199108
2011	219.0	0.08	5.199	0.06	523	0.96	23.9	6778	162316
2012	245.0	0.09	3.993	0.05	493	0.96	16.8	7643	128253
2013	291.0	0.12	4.228	0.08	522	0.96	15.2	9006	136698
2014	379.5	0.27	4.559	0.21	551	0.91	12.5	11024	137300

Table 4.1 (continued). Sea scallop dredge survey indices (40+ mm) for Mid-Atlantic (left) and combined (right).

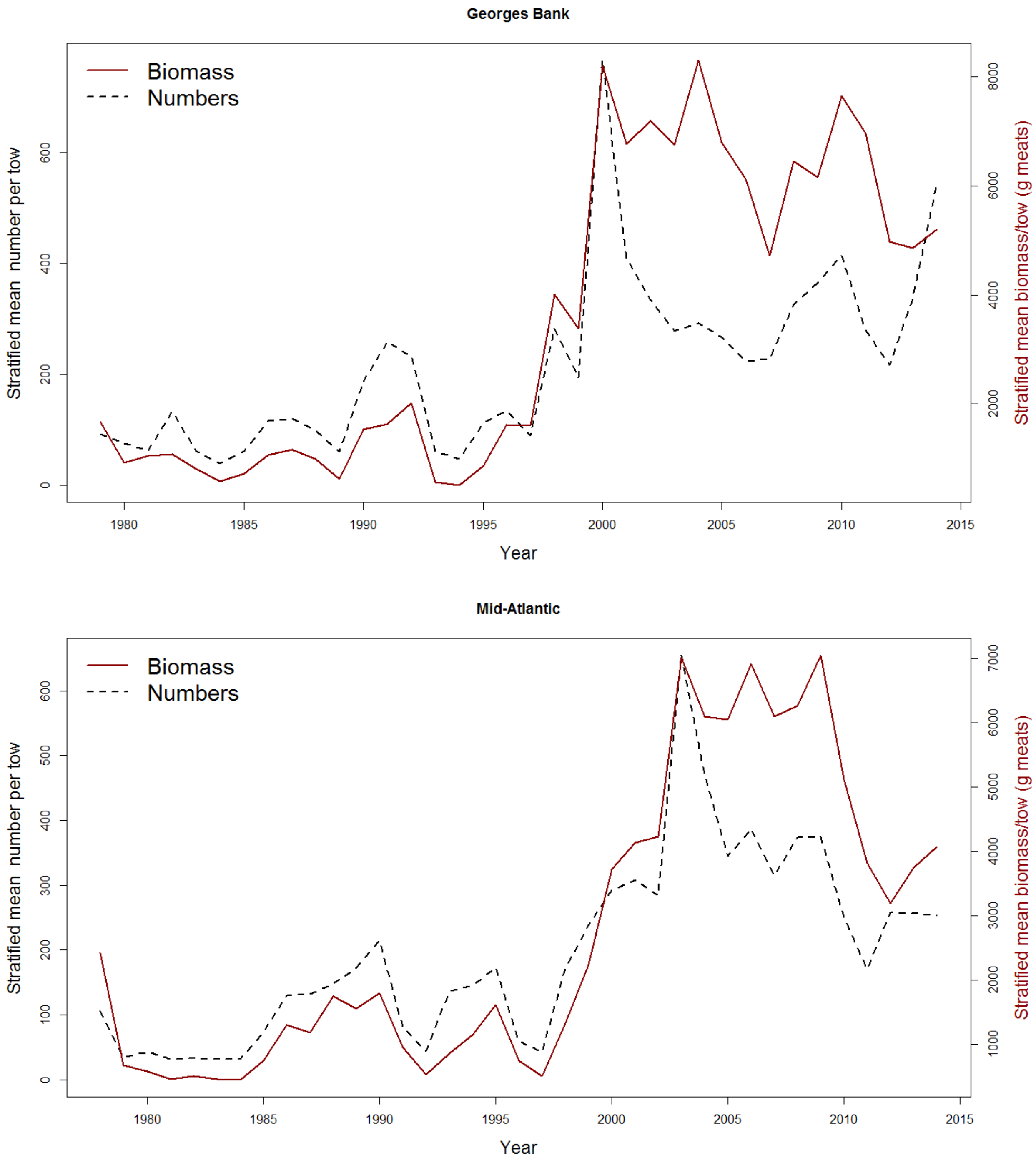


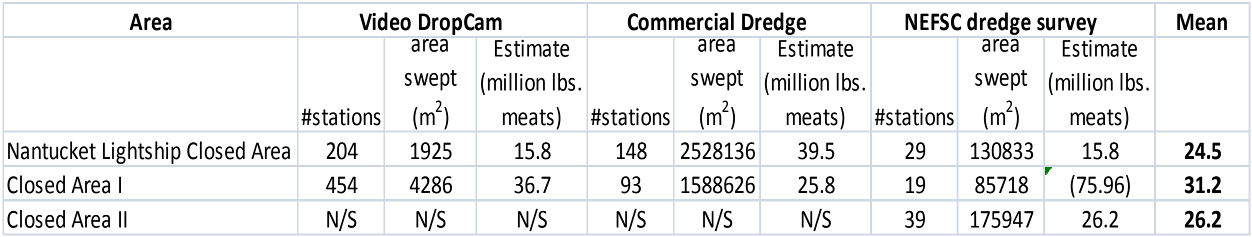
Figure 4.1. Biomass and abundance scallop dredge survey indices (40+ mm) for Georges Bank (above) and the Mid-Atlantic (below).

Term of Reference 5 – Integration of surveys

As already has been discussed (in TOR-1), the NEFSC scallop dredge survey has been integrated with the VIMS dredge surveys, using the catches from the lined survey gear on both surveys. More generally, survey data from disparate sources need to be integrated in order to be used for catch advice. Besides overall allocations (both in terms of days-at-sea and catch weight), management sets separate catch targets in access areas (formerly closed areas that have been reopened to fishing). Thus, biomass needs to be estimated spatially as well as overall.

The simplest way to integrate multiple surveys is to average the results from each survey. Examples of this method are shown from 1999 (one of the first years with multiple surveys), and the most recent years (2012-2014) (Table 1). Inverse variance weighted means (IVM) give more importance to surveys with lower standard errors, and have the lowest standard error of any weighted mean. However, IVMs are not consistent across spatial scales. For example, suppose a region is divided up into a number of subregions, and IVMs are calculated for each subregion and then summed. This sum is in general different than taking an IVM on the regional scale (see Table 1b). For that reason, simple means have been used in most years.

Finally, an alternative method is to use cokriging using all the survey data to obtain geostatistical estimate of biomass in each subregion. This method will be discussed in the HabCam documents.



Area	**Video DropCam**			**Commercial Dredge**			**NEFSC dredge survey**			**Mean**
	#stations	area swept (m^2)	Estimate (million lbs. meats)	#stations	area swept (m^2)	Estimate (million lbs. meats)	#stations	area swept (m^2)	Estimate (million lbs. meats)	
Nantucket Lightship Closed Area	204	1925	15.8	148	2528136	39.5	29	130833	15.8	**24.5**
Closed Area I	454	4286	36.7	93	1588626	25.8	19	85718	(75.96)	**31.2**
Closed Area II	N/S	N/S	N/S	N/S	N/S	N/S	39	175947	26.2	**26.2**

Table 5.1 (a). Biomass estimates for the Georges Bank groundfish closed areas in 1999, based on three survey methods (NEFMC 1999), including two intensive surveys (dropcam and commercial dredge) as well as the broadscale NEFSC sea scallop survey. The NEFSC estimate for Closed Area I was dropped because it was driven by two very large tows. Table 1 continued on next two pages.

Table 1b - Summary of 2012 Survey Results

	Dredge		SMAST Video		Habcam		Mean	SE	IVM	SE
MidAtlantic	**Bms(mt)**	**SE**	**Bms(mt)**	**SE**	**Bms(mt)**	**SE**				
Delmarva	2299	220	4762	674	3005	798	3355	356	2566	202
HCSAA	6791	530	6532	1082	7139	642	6821	455	6882	382
ET	4570	803	7021	1419	8130	847	6574	612	6366	539
VB	102	55	NS	NS	NS	NS	102	55	102	55
NYB	11803	2084	4673	810	8750	1015	8408	819	6728	606
LI	13196	1273	13053	1147	10351	185	12200	575	10476	181
Stratum21	2077	265	2632	709	1540	426	2083	290	1992	214
Block Island	NS	NS	1803	463	821	NA	1803	463	1803	463
MidAtl	**40837**	**2648**	**40476**	**2516**	**39736**	**1736**	**41346**	**1418**	**36915**	**1068**
Regional-scale IVM									**40169**	**1257**
Georges Bank										
CL1ACC	4431	716	5789	1180	3054	356	4425	475	3494	307
CL1NA	1768	729	6990	3572	10230	877	6330	1250	5266	554
CL-2(N)	11207	1233	14921	4036	8183	2240	11437	1593	10799	1044
CL-2(S)	7007	1110	6014	1000	7404	707	6808	551	6955	512
NLS-Access	8598	699	4401	722	4434	324	5811	352	5062	273
NLS-NA	23	13	2412	857	NS	NS	2412	857	2412	857
SCC	12420	1353	10873	2610	10230	877	11174	1023	10878	708
SCH	6924	1011	11370	3649	14195	1201	10830	1324	10002	757
NEP	4004	1163	3933	983	5836	481	4591	532	5291	405
SEP	1027	124	2226	390	7111	NA	2226	390	2226	390
Georges Bank	**57408**	**2916**	**68930**	**7345**	**70677**	**2994**	**65672**	**2953**	**62385**	**1988**
Regional-scale IVM									**64248**	**2009**
Total	**98246**	**3939**	**109406**	**7764**	**110413**	**3460**	**106021**	**3276**	**99299**	**2257**
Overall IVM									**104417**	**2370**

Table 1c - 2013 Surveys Summary

Mid-Atlantic Bight	**Dredge**	**SE**	**Habcam**	**SE**	**SMAST**	**SE**	**Mean**	**SE**
Hudson Canyon South	7839	1126	7528	831			7684	700
Delmarva	4559	605	6415	781	6249	803	5741	424
Elephant Trunk	14317	1758	19063	1993			16690	1329
Inshore of ET	109	421	868	825			489	463
Virginia Beach	1208	605	395	388			802	359
NYB/LI (includes str 21)	20662	2468	23497	1893			22080	1555
Block Island	N/S	N/S	1655	364			1655	364
TotalMA Rotational	26715	2173	33006	2296			29861	1581
TotalMA Open	21979	2575	24760	2101			23370	1662
Total MidAtlantic	**48694**	**3370**	**57766**	**3112**			**53230**	**2200**
Georges Bank								
Closed Area I Acc	494	108	3340	401			1917	208
Closed Area I NA	16940	5750	4553	747			10747	2899
Closed Area II Acc	5552	1042	3340	1324	5148	1049	4680	662
Closed Area II NA	9041	1220	8497	765			8769	720
NLS Acc	3271	342	4098	584			3685	338
NLS NA	90	28	N/S	N/S			90	28
S Channel	11711	2842	13496	1130			12603	1529
Southern Flank	5704	1197	11445	1946			8575	1142
Northern Edge	4425	580	3160	537			3793	395
Total GB Clsd/Acc	35389	5980	23828	1843			29608	3129
Total GB Open	21840	3138	28101	2313			24970	1949
Total Georges Bank	**57229**	**6754**	**51929**	**2958**			**54858**	**7922**
TOTAL	105923	7548	109695	4294			**108089**	**8221**

Table 1d – 2014 Survey Summary

		DREDGE			SMAST			HABCAM			TOTALS	
Area	Bms	SE	Ebms	Bms	SE	Ebms	Bms	SE		Bms	SE	Ebms
Delmarva	4707	778	2080	9626	1093	3935	10598	3665		8310	2253	3488
Elephant Trunk	16392	3426	8067	24799	2909	12938	36154	3469		25782	3278	13147
HCS	5805	1206	3044	7381	1021	3143	18041	5050		10409	3055	4884
Virginia	279	79	3	NS	NS	NS	NS	NS		279	79	3
NYB	6822	1656	4140	3609	495	2119	12756	613		10618	1059	6371
Long Island	11966	816	8438	10269	950	6402	14305	508		12950	780	8643
NYB Ext	1766	332	757	6900	867	4013	*			*		*
Block Island	939	206	535	1372	671	521	*			*		*
Mid-Atlantic Total	**48676**	**4167**	**27064**	**63956**	**3612**	**33071**	**91854**	**7184**		**68348**	**5186**	**36536**
CL-I NA	2163	649	1854	5115	3004	3091	21378	5917		9984	3850	6783
CL-1 Acc	333	59	246	962	375	190	*			*		*
CL-2 NA	8989	3190	7061	5550	2054	4191	7087	524		7209	2211	5579
CL-2 Acc	7848	2462	3642	8197	2570	929	9835	95		8627	2055	2458
NLS-NA	2240	1142	675	5211	4650	677	NS	NS		3726	3386	676
NLS-Acc	1637	327	854	30052	6534	3091	3231	626		11640	3794	1449
GSch	17689	1875	9485	11134	7849	4949	15994	4870		14939	5442	7481
SEP	15434	9833	2862	7026	1359	2476	16038	1223		12833	5775	3050
NEP	7752	9302	3837	5863	1483	2259	4330	394		5982	5443	2678
Georges Bank Total	**64085**	**14311**	**30516**	**79110**	**12246**	**21853**	**77893**	**7814**		**74938**	**11294**	**30154**
TOTALS	**112761**	**14906**	**57580**	**143066**	**12767**	**54924**	**159149**	**10614**		**143286**	**12428**	**66690**

Table 5.1. Summaries of surveys in 1999 (a), and 2012-2014 (b-d).

Terms of Reference 6 – Non-scallop species, habitat, ecology

All finfish, cephalopods and lobsters caught on the NEFSC dredge survey have been counted and recorded since 1985, and also weighed in aggregate since 2001. Individual measurements as well as counts of yellowtail flounder, goosefish, Atlantic cod, and haddock have been taken since 1981. Skates have been measured since 2000; winter flounder, summer flounder, and Atlantic halibut have been measured since 2001. Iceland and (since 2003) calico scallops are also counted, measured and, since 2001, weighed in aggregate. As discussed in TOR-3, catches of *Cancer* crabs and sea stars have been quantified on roughly every third tow since 2000 (on most tows since 2012), and these data have been used to understand the spatial-temporal patterns of sea scallop recruitment in the Mid-Atlantic Bight (Hart 2006, Shank et al. 2012, Hart 2014b, Figs 3.3, 6.1).

NEFSC scallop dredge survey indices are used as indices of abundance in the stock assessments of Georges Bank yellowtail flounder, goosefish, and the skate complex. In addition, it potentially could be used as a recruitment index for haddock; large catches of year 0 haddock have been caught during strong recruitment years such as 2003.

The NEFSC scallop survey has a higher density of tows than the trawl surveys, and therefore is useful in detecting effects due to spatial management, and in particular, effects of the closures that were imposed on Georges Bank in 1994. Hart (2014a) compared dynamics of Georges Bank yellowtail flounder in the southern portion of Closed Area II to that outside the closures. Biomass inside Closed Area II south rose markedly during the first six years after the closure (Fig 6.2). There was a directed fishery for yellowtail flounder in this area in 2004, which is reflected by a sharp decrease in the dredge survey index that year. Increases were observed in the next several years due to the strong 2005 year class, but then decreased rapidly. Examination of the length structure indicates an expansion of the length structure inside the southern portion of Closed Area II during 1995-2003, but not in recent years, even though there has been no directed fishery for yellowtail flounder in Closed Area II since 2004 (Fig 6.2). This led Hart (2014a) to conclude that natural mortality of yellowtail flounder may have increased in recent years.

For each tow, the “trash” (the remainder of the catch after the species of interest have been removed) volume is quantified by putting it into baskets, and the proportion of the trash that is substrate, shells, or biological is estimated. Qualitative information on the trash are also recorded: the absence, presence or dominance of dead shells of various species or groups, including ocean quahogs, surfclams, razor clams, *Astarte* clams, scallops, oysters, cockles, and gastropods. Live invertebrates (sand dollars, sea urchins, sponges, gastropods, anemones, barnacles, and worms) are similarly characterized (Fig 6.3). Finally any substrate (sand, gravel, mud, etc.) are also characterized as being absent, present or a dominant portion of the trash.

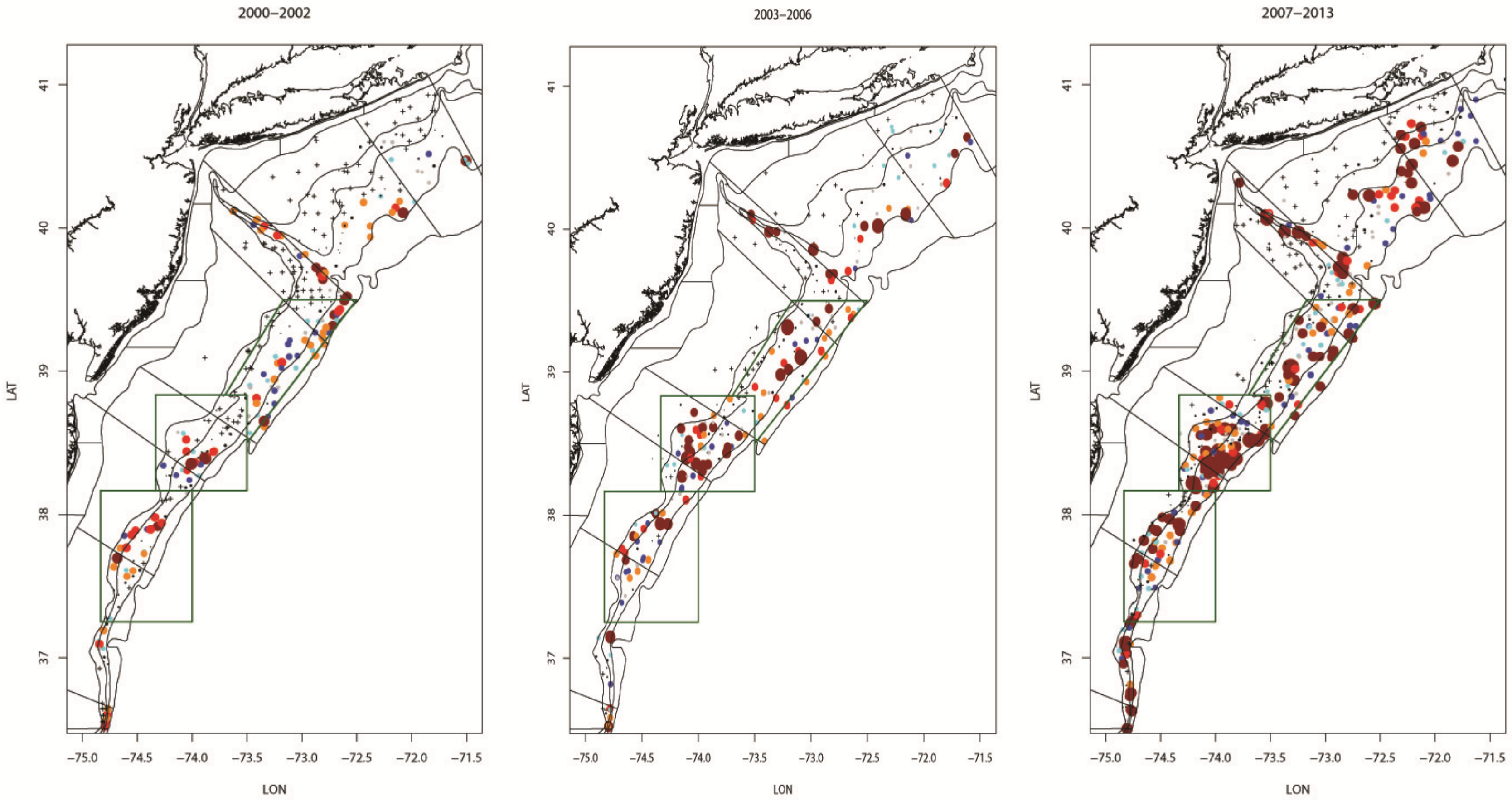
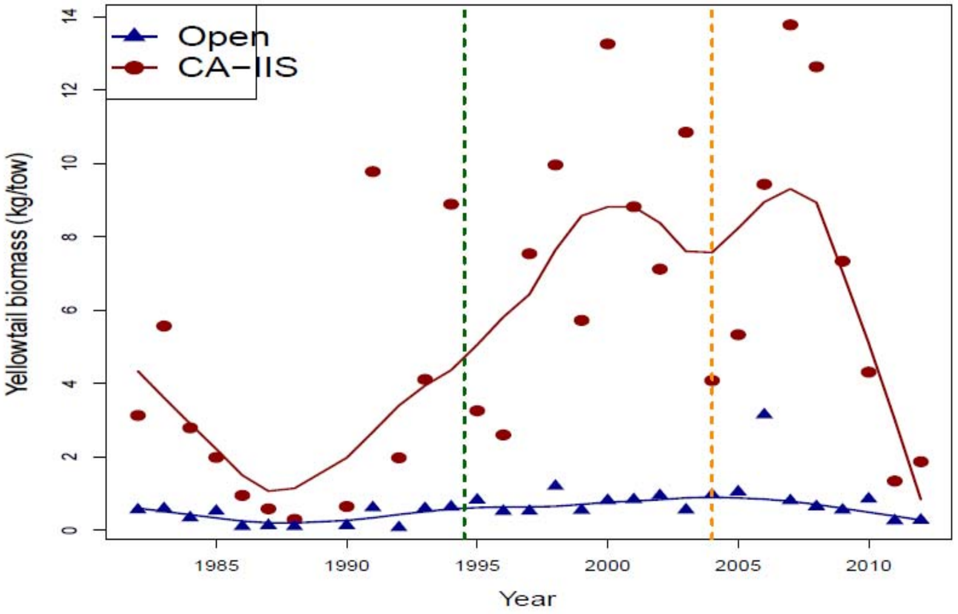


Figure 6.1. *Astropecten americanus* biomass (kg/tow) in the Mid-Atlantic Bight from NEFSC scallop survey catches during three periods of time, from Hart (2014b). Note the increases in biomass inshore, especially in the northern regions.



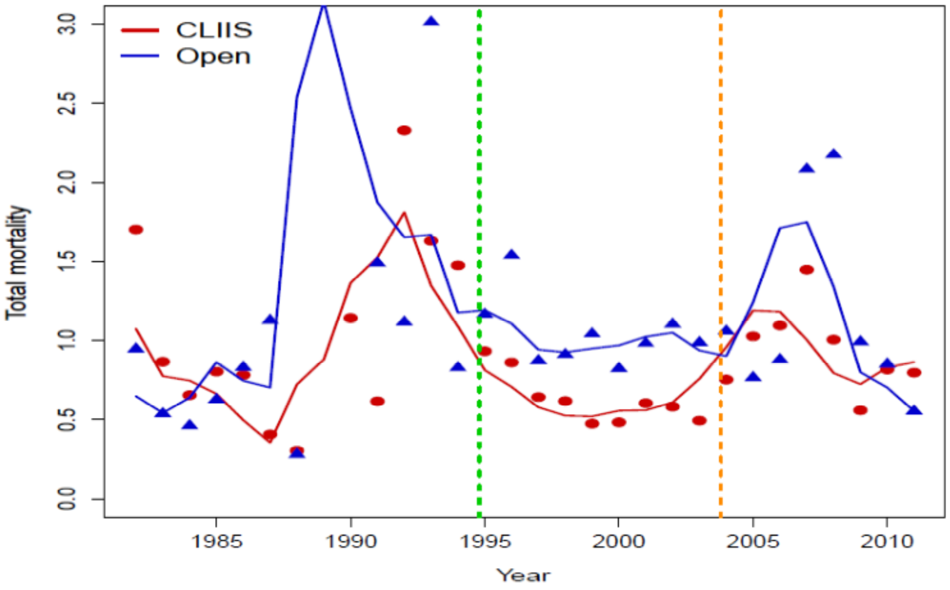


Figure 6.2. *Above*: Stratified mean biomass of yellowtail flounder in open portions of Georges Bank and in the southern portion of Closed Area II from the NFESC scallop survey. *Below*: Total mortality estimated from the Beverton-Holt equilibrium mortality estimator, with forward moving average smoothers, for the open portions of Georges Bank and in the southern portion of Closed Area II, from Hart (2014 a).

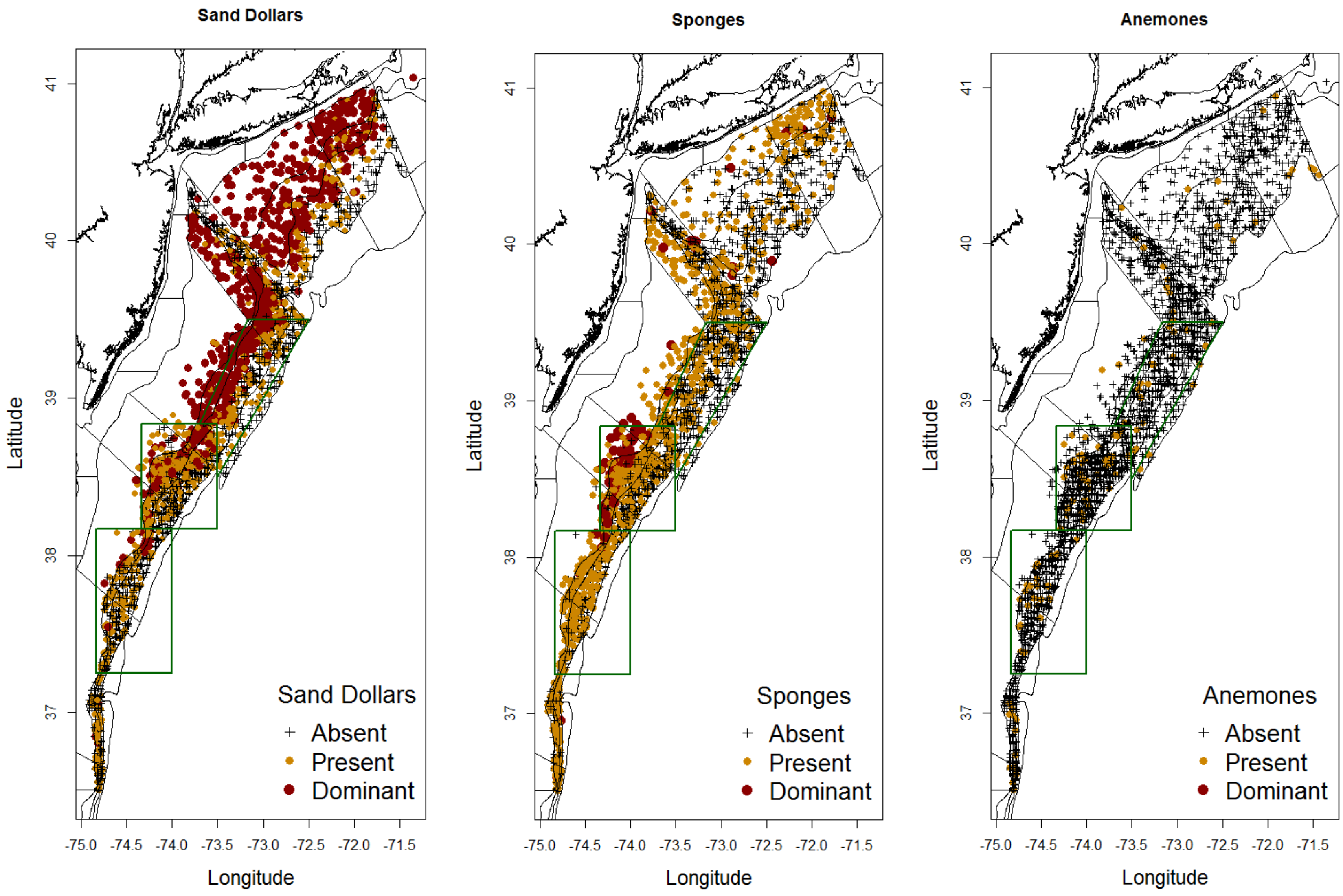


Figure 6.3. Example distribution plots for three groups based on qualitative data from the NEFSC sea scallops survey in the Mid-Atlantic, 1985-2013.

Term of Reference 7 – Frequency and combination of survey methods

The NEFSC scallop survey is currently funded for 36 sea days, which is unlikely to increase in the future. This is not sufficient time to do full dredge and HabCam surveys of both Georges Bank and the Mid-Atlantic. Not considering other surveys for the moment, the choices for allocating time between dredge and HabCam operations is somewhere on this continuum:

1. Dredge only, no HabCam
2. Dredge survey only, with HabCam used for special projects (e.g., paired tow work)
3. Dredge survey of both regions, with HabCam survey in one region (potentially alternating between years)
4. HabCam survey of both regions, with dredge survey in one region (potentially alternating between years)
5. HabCam survey only, with dredge samples used to obtain physical samples for ageing, weights, etc., and for special projects
6. HabCam survey only, with no dredge

We consider the options in the middle (e.g., option 4) to be best, as they would both allow for a continuation of the NEFSC dredge time series and allow for full use of the HabCam technology, which with software developments and other advances, will only improve over time. If the VIMS cooperative dredge survey is conducted in a whole region, as it was in 2014 in the Mid-Atlantic, option 4 would still allow for dredge surveys of both regions, thus continuing the annual time series. Note however that if the dredge survey is allocated one third of the sea days for surveying one region, it is less than the allocation in that region for a dredge only survey, resulting in less stations and greater variance in the estimates. This will likely be compensated for by having HabCam data of the same region.

Considering the broader question of the combination of survey methods, we would suggest the following principles:

1. Because dredge and optical surveys give complimentary information, it is ideal to have (at least) one dredge and one optical survey of each area.
2. Broadscale surveys such as the NEFSC surveys or the SMAST 3 nm grid survey often can give unreliable biomass estimates in small areas. For that reason, dedicated high intensity surveys of access areas, where specific quotas need to be set, are highly desirable.
3. While some coordination between surveys exists currently, most particularly between the NEFSC, VIMS, and HabCam v2, better coordination would be useful. Additionally, RSA funding is currently a grants process in which each investigator proposes surveys of specific areas with typically no coordination between groups. This often results in several proposals for surveying some areas, and none for other important areas. A mechanism to better coordinate these proposals would be desirable.

Terms of Reference 8 – Future research and collaboration

Three research recommendations with regards to dredge surveys:

1. The shellfish strata set used by the NEFSC scallop dredge survey was not specifically designed for scallops. While some of the survey strata work well, others show considerable intra-stratum spatial variability in scallop productivity. In addition, as the number of stations in the NEFSC dredge survey has been reduced to accommodate HabCam work, it may be preferable to enlarge the strata areas and reduce the total number of strata. For these reasons, it may be desirable to design new strata specifically for scallop surveys. This task would be greatly aided by the substantial amount of existing survey data.
2. Paired HabCam/dredge tows have already proved useful in estimating dredge efficiency for scallops and has some potential to do the same for at least some finfish, but more such data should be collected. The current work crudely splits bottom sediment into two groups: sand and hard bottom. Additional paired tows might benefit from acoustic data, such as the v4 HabCam sidescan sonar or ship-based multibeam, to more precisely characterize the bottom substrate. For example, dredge efficiency may be different on sand waves compared to smooth sand, or gravel/sand compared to cobble and boulders.
3. Questions have been raised as to whether clogging of the survey dredge with e.g., small scallops or sand dollars, or filling of the dredge bag, affects dredge efficiency. Paired tows, both between the survey dredge and HabCam, and between the survey and commercial dredge, could help resolve this question.

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