FINAL REPORT

An Assessment of Sea Scallop Abundance and Distribution in Selected Areas of Georges Bank and the Mid-Atlantic

Part I: Abundance, Distribution and Biomass
Part II: Selectivity of a New Bedford Style Sea Scallop Dredge

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Part I: Abundance, Distribution and Biomass

An Assessment of Sea Scallop Abundance and Distribution in Selected Areas of Georges Bank and the Mid-Atlantic

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Project Summary

As the spatial and temporal dynamics of marine ecosystems have recently become better understood, the concept of entirely closing or limiting activities in certain areas has gained support as a method to conserve and enhance marine resources. In the last decade, the sea scallop resource has benefited from measures that have closed specific areas to fishing effort. As a result of closures on both Georges Bank and in the mid-Atlantic region, biomass of scallops in those areas has expanded. As the time approaches for the fishery to harvest scallops from the closed areas, quality, timely and detailed stock assessment information is required for managers to make informed decisions about the re-opening.

During August through October of 2005, three experimental cruises were conducted aboard commercial sea scallop vessels. At pre-determined sampling stations within the exemption areas of Closed Area II (CAII) and Nantucket Lightship Closed Area (NLCA) and the entire Elephant Trunk Closed Area (ETCA) both a NMFS survey dredge and a standard commercial dredge were simultaneously towed. From these cruises, fine scale survey data was used to assess scallop abundance and distribution in the closed areas and will also provide a comparison of the utility of using two different gears as survey tools in the context of industry based surveys. The results of this study will provide additional information in support of upcoming openings of closed areas within the context of rotational area management.

Project Background

The sea scallop, *Placopecten magellanicus,* supports a fishery that in 2004 landed 64.7 million pounds of meats with an ex-vessel value of US $321.9 million. These landings resulted in the sea scallop fishery being the most lucrative fishery along the East Coast of the United States (Van Voorhees, 2004). While historically subject to extreme cycles of productivity, the fishery has benefited from recent management measures intended to bring stability and sustainability. These measures included: limiting the number of participants, total effort (days-at-sea), gear and crew restrictions and most recently, a strategy to improve yield by protecting scallops through rotational area closures.

Amendment #10 to the Sea Scallop Fishery Management Plan officially introduced the concept of area rotation to the fishery. This strategy seeks to increase the yield and reproductive potential of the sea scallop resource by identifying and protecting discrete areas of high densities of juvenile scallops from fishing mortality. By delaying capture, the rapid growth rate of scallops is exploited to realize substantial gains in yield over short time periods. In addition to the formal attempts found in Amendment #10 to manage discrete areas of scallops for improved yield, specific areas on Georges Bank are also subject to area closures. In 1994, 17,000 km^2 of bottom were closed to any fishing gears capable of capturing groundfish. This closure was an attempt to aid in the rebuilding of severely depleted species in the groundfish complex. Since scallop dredges are capable of capturing groundfish, scallopers were also excluded from these areas. Since 1999, however, limited access to the three closed areas on Georges Bank has been allowed to harvest the dense beds of scallops that have accumulated in the absence of fishing pressure.

In order to effectively regulate the fishery and carry out a robust rotational area management strategy, current and detailed information regarding the abundance and distribution of sea scallops is essential. Currently, abundance and distribution information gathered by surveys comes from a variety of sources. The annual NMFS sea scallop survey provides a comprehensive and synoptic view of the resource from Georges Bank to Virginia. In contrast to the NMFS survey that utilizes a dredge as the sampling gear, the resource is also surveyed photographically. Researchers from the School for Marine Science and Technology (SMAST) are able to enumerate sea scallop abundance and distribution from images taken by a camera system mounted on a tripod lowered to the substrate (Stokesbury, 2002). Prior to the utilization of the camera survey and in addition to the annual information supplied by the NMFS annual survey, commercial vessels were contracted to perform surveys. Dredge surveys of the following closed areas have been successfully completed by the cooperative involvement of industry, academic and governmental partners: CAII was surveyed in 1998, Georges Bank Closed

Area I (CAI), NLCA, Hudson Canyon Closed Area (HCCA) and Virginia Beach Closed Area (VBCA) in 1999, HCCA and VBCA in 2000, NLCA, CAII and the ETCA in 2005. This additional information was vital in the determination of appropriate Total Allowable Catches (TAC) in the subsequent re-openings of the closed areas. This type of survey, using commercial fishing vessels, provides an excellent opportunity to gather required information and also involve stakeholders in the management of the resource.

The recent passing of Amendment #10 has set into motion changes to the sea scallop fishery that are designed to ultimately improve yield and create stability. This stability is an expected result of a spatially explicit rotational area management strategy where areas of juvenile scallops are identified and protected from harvest until they reach an optimum size. Implicit to the institution of the new strategy, is the highlighted need for further information to both assess the efficacy of an area management strategy and provide that management program with current and comprehensive information. In addition to rotational management areas, access to the scallop biomass encompassed by the Georges Bank Closed Areas is vital to the continued prosperity of the fishery.

The survey cruises conducted during the late summer/early fall of 2005 supported effective area management by providing a timely and detailed assessment of the abundance and distribution of sea scallops in the access areas of CAII, NLCA and the entire ETCA. The information gathered on these survey cruises will augment information gathered by the annual NMFS sea scallop survey which provides a comprehensive and synoptic view of the resource from Georges Bank to Virginia. The breadth of this sampling, however, precludes the collection of fine scale information. Due to the patchy nature of scallop aggregations, inference regarding smaller resource subunits may be uncertain. Therefore, fine scale information from this survey will be used to assess the distribution and biomass of exploitable size scallops in the CAII Access Area, NLSA Access Area and the ETCA.

Methods

Survey Areas and Experimental Design

Three closed areas were surveyed during the course of this project: two areas on Georges Bank and one area in the Mid-Atlantic. The exemption areas of CAII and NLSA and the entire ETCA were sampled. The coordinates of the surveyed areas can be found in Table 1.

The sampling stations for this study were selected within the context of a systematic random grid. With the patchy distribution of sea scallops determined by some unknown combination of environmental gradients (i.e. latitude, depth, hydrographic features, etc.), a systematic selection of survey stations results in an even dispersion of samples across the entire sampling domain. The systematic grid design was successfully implemented during surveys of CAII in 1998, and CAI, NLCA and the Mid-Atlantic closed areas in 1999. This design has also been utilized for the execution of a trawl survey in the Bering Sea (Gunderson, 1993). In addition to stations that were selected within the context of a systematic random grid, a subset of stations that were initially sampled aboard the R/V *Albatross* during the 2005 sea scallop survey were re-occupied.

The methodology to generate the systematic random grid entailed the decomposition of the domain (in this case a closed area) into smaller sampling cells. The dimensions of the sampling cells were primarily determined by a maximum number of stations that could be occupied during the time allotted for the survey. Since the three closed areas were different dimensions, the distance between the stations varied. Once the cell dimensions were set, a point within the most northwestern cell was randomly selected. This point served as the starting point and all of the other stations in the grid were based on its coordinates. The station locations for the three closed areas surveyed are shown in Figures 1-3.

Sampling Gear

While at sea, the vessels simultaneously towed two dredges. A NMFS compliant survey dredge, 8 feet in width equipped with 2-inch rings, 4-inch diamond twine top and a 1.5 inch diamond mesh liner was towed on one side of the vessel. On the other side of the vessel, a 15-foot commercial scallop dredge equipped with 4-inch rings, a 10-inch diamond mesh twine top and no liner was utilized. Position of twine top within the dredge bag was standardized throughout the study and rock chains were used in configurations as dictated by the area surveyed and current regulations. In this paired design, it is assumed that the dredges cover a similar area of substrate and sample from the same population of scallops. The dredges were switched to opposites sides of the vessel mid way throughout the trip to help minimize bias.

For each paired tow, the dredges were fished for 15 minutes with a towing speed of approximately 3.8-4.0 kts. An inclinometer was used to determine dredge bottom contact time and high-resolution navigational logging equipment was used to accurately determine vessel position. Time stamps for both the inclinometer and the navigational log were used to determine both the location and duration fished by the dredges. Bottom contact time and vessel location were integrated to estimate area swept by the gear.

Sampling of the catch was performed using the protocols established by DuPaul and Kirkley, 1995 and DuPaul *et. al.* 1989. For each paired tow, the entire scallop catch was placed in baskets. A fraction of these baskets were measured to estimate length frequency. The shell height of each scallop in the sampled fraction was measured in 5 mm intervals. This protocol allows for the determination of the size frequency of the entire catch by expanding the catch at each shell height by the fraction of total number of baskets sampled. Finfish and invertebrate bycatch were quantified, with finfish being sorted by species and measured to the nearest 1 cm.

Samples were taken to determine area specific shell height-meat weight relationships. At 10 to15 randomly selected stations the shell height of a sample of 15 scallops was measured to the nearest 0.1 mm. The scallops were then carefully shucked and the adductor muscle individually packaged and frozen at sea. Upon return, the adductor muscle was weighed to the nearest 0.1 gram. The relationship between shell height and meat weight was estimated in log-log space using linear regression procedures in SAS v. 9.0. with the model:

$$\ln MW = \ln a + b*\ln SH$$

where MW=meat weight (grams), SH=shell height (millimeters), a=intercept and b=slope.

The standard data sheets used since the 1998 Georges Bank survey were used. The bridge log maintained by the captain/mate recorded location, time, tow-time (break-set/haul-back), tow speed, water depth, catch, bearing, weather and comments relative to the quality of the tow. The deck log maintained by the scientific personnel recorded detailed catch information on scallops, finfish, invertebrates and trash.

Data Analysis

The catch, navigation and gear mensuration data was used to estimate swept area biomass within the areas surveyed. The methodology to estimate biomass is similar to that used in analyzing the data from the 1998 survey of CAII and the 1999-2000 survey of the Mid-Atlantic closed areas. It is calculated by the following:

$$TotalBiomass = \sum_j \left(\frac{\left(\frac{CatchWtperTowinSubarea_j}{AreaSweptperTow} \right)}{Efficiency} \right) SubArea_j$$

Catch weight per tow

Catch weight per tow of exploitable size scallops (≥ 80 mm) was calculated from the raw catch data as an expanded size frequency distribution with an area appropriate shell height-meat weight relationship applied (length-weight relationships were obtained from SARC 39 document, and actual relationships taken during the cruise) ((NEFSC, 2004).

The catch data was adjusted to reflect gear performance issues of the two gear configurations. Based on a paired comparison between a NMFS survey dredge equipped with a liner and one without a liner, an adjustment factor of 1.428 for scallops greater than 70 mm shell height is used to adjust the catches of a lined dredge (Serchuk and Smolowitz, 1980). To estimate the numbers of scallops greater than 80 mm shell height the catches of the commercial dredge were adjusted to account for selectivity of the 4.0" rings. This adjustment takes into account only the animals that enter the dredge and subsequently pass through the rings or inter-ring spaces. Since no direct estimate of selectivity of a 4.0 inch ring dredge exists in the literature, the adjustment was accomplished in a stepwise fashion based on prior relative efficiency studies. Results from DuPaul and Kirkley (1989) indicate that the retention of an 80 mm scallop by a 3.0" ring dredge is close to 100%. Using the 3.0" ring as a benchmark and adjusting the catches of the 4.0 inch ring commercial dredge by the relative efficiencies obtained for comparisons of a 4.0 inch ring dredge vs. a 3.5 inch ring dredge (Goff, 2002) and the relative efficiencies obtained for comparisons of a 3.5 inch ring dredge vs. a 3.0 inch ring dredge (DuPaul and Kirkley, 1989), catches can be adjusted to account for contact selectivity.

For this analysis, only the catch data from tows that were designated as generated by the systematic random grid were included in the analysis of biomass. With the exception of NLCA, all of the areas were treated as a single stratum in the analysis. In the NLCA the distribution of scallops was such that there was an area of very high concentration in the northeast corner of the area (Asia Rip). The remainder of the area had drastically lower abundances of scallops. The data from this trip was post-stratified in an attempt to reduce the overall variance in the catches. For comparative purposes, the boundaries of the northeast corner were identical to those used by NMFS to define that area of NLCA (east of 69° 20', and north of 40° 38') (D. Hart, pers. comm., 2006).

Area Swept per tow

Utilizing the information obtained from the inclinometer and the high resolution GPS, an estimate of area swept per tow was calculated. The inclinometer which measures dredge angle was utilized to delineate the beginning and end of a survey tow. Inclinometer records were interpreted based on video ground truth efforts conducted by NMFS (Nordahl, pers. comm., 2005). An internal clock aboard the inclinometer is set to a common time based on data obtained from the GPS satellites. The internal clock on the inclinometer is updated every time data is downloaded (after the completion of every survey tow). The time stamp allows for the linkage of datasets (navigation and inclinometer) and provides an estimate of the disposition of the dredge in both time and space. Throughout the cruises the location of the ship was logged every three seconds. By determining the start and end of each tow based on inclinometer records, a survey tow can be represented by a series of consecutive coordinates (latitude, longitude). The linear distance of the tow is calculated by:

$$TowDist = \sum_{i=1}^{n} \sqrt{(long_2 - long_1)^2 + (lat_2 - lat_1)^2}$$

The linear distance of the tow is multiplied by the width of the gear to result in an estimate of the area swept by the gear during a given survey tow.

Efficiency and Domain

The final two components of the estimation of biomass are constants and not determined from experimental data obtained on these cruises. Estimates of gear efficiency have been calculated from prior experiments using a variety of approaches (Gedamke *et. al.,* 2005, Gedamke *et. al.,* 2004, D. Hart, pers. comm.). Based on those experiments and consultations with NEFSC an efficiency value of 45 % was used for the trips on Georges Bank (NLCA and CAII) and 50% was used in the mid-Atlantic (ETCA). The total area each closed area sampled was calculated in ArcView v. 3.3. This area was applied to scale the mean catch per survey tow to the appropriate area of interest.

Results

Three survey cruises were completed between August and October of 2005. Summary statistics for each cruise are shown in Table 2. Catch information is shown in Table 3 and length frequency distributions for each trip are shown in Figures 4-6. The interpolated catch data for scallops greater than 80 mm shell height for each trip is shown in Figures 7-9. Based on the catch data, estimates of scallop density for each area is shown in Table 4 and estimated biomass using two different sets of shell height meat weight parameters are shown in Tables 5-6. Shell height:meat weight relationships were generated for all areas. The resulting parameters are shown in Table 7. Graphical comparisons between the fitted curves from the data from the survey cruises and the parameters for the mid-Atlantic and Georges Bank contained in SARC 39 are shown in Figures 10-11 (NEFSC, 2004).

Discussion

Fine scale surveys of closed areas area an important endeavor. These surveys provide information about subsets of the resource that may not have been subject to intensive sampling by other efforts. Additionally, the timing of industry based surveys can be tailored to give managers current information to guide important management decisions. This information can help time access to closed areas and help set Total Allowable Catches (TAC) for the re-opening. Finally, this type of survey is important in that it involves the stakeholders of the fishery in the management of the resource.

The use of commercial scallop vessels in a project of this magnitude presents some interesting challenges. One such challenge is the use of the commercial gear. This gear is not designed to be a survey gear; it is designed to be efficient in a commercial setting. The design of this current experiment however provides insight into the utility of using a commercial gear as a survey tool. The concurrent use of two different dredge configurations provides an excellent test for agreement of results. With a paired design, it is assumed that the two gears cover the same bottom and sample from the same population of scallops. The expectation that after applying the appropriate adjustment factors to compensate for gear performance issues the estimates of biomass for the two gears will be comparable.

This was the case in our study for two of the three areas surveyed. In the NLCA there was a disparity in the biomass estimates. This disparity may have stemmed from a problem encountered with the NMFS survey dredge. On the second day of the second trip, an inconsistency was discovered between the specifications for the NMFS survey dredge and the gear itself. The twine top on the dredge was of different dimensions than specified in the schematics of the dredge. This disparity may have causes gear performance issues for the first trip, affecting the point estimates and ultimately impacting biomass estimates. While comparative tows between the two twine top configurations were completed and are still in the process of being analyzed, another explanation for the disparities in the results from the NLCA cruise is the size of the scallops. In general scallops from that area are very large and this average size may have been a factor in the reduced efficiency of the NMFS survey dredge in that area. The inconsistency, upon discovery was changed to match given dredge specifications and the stations in CAII that had been completed were re-occupied. All of the stations for the surveys of both CAII and ETCA were completed with a NMFS survey dredge that was consistent with given specification for that piece of gear.

Based on the results of this study, the commercial gear has the potential to be an effective sampling gear under some circumstances. Due to the selective properties of a dredge equipped with 4.0 inch rings, it will never be an effective tool for sampling small scallops. Its strength lies in sampling exploitable size scallops (> 80 mm shell height). The utility of this dredge configuration will be bolstered after the completion of a formal selectivity analysis of the commercial dredge. The design of this survey also provided a comparison to accomplish this, although that analysis is pending. Upon completion of the selectivity analysis a length-based probability of capture profile will be available to adjust catches of the 4.0 inch ring dredge to compensate for contact selectivity.

Biomass estimates are sensitive to other assumptions made about both gear performance and the characteristics of the resource. Gear efficiency, or the probability that a scallop enters the gear given it encounters the gear is a major factor influencing estimates of biomass. While much work has been done to estimate efficiency for scallop dredges, it is still a topic that merits consideration due to the important role it plays in the analysis of total biomass. Another important factor that became a consideration in the study was the use of appropriate shell height meat weight parameters. Parameters generated from data collected during the course of the study were appropriate for the area and time sampled. In the case of the ETCA, samples were taken in October. This month is traditionally when the somatic tissue of the scallop is still recovering from the annual spawning event and is at some of their lowest levels relative to shell size (Serchuk and Smolowitz, 1989). So while accurately representative for the month of the survey, biomass will be underestimated relative to other times of the year. For comparative purposes, our results were also shown using the parameters from SARC 39 (NEFSC, 2004). This allowed a comparison of biomass estimates with other data sources. Area and time specific shell height: meat weight parameters are another topic that merits consideration.

The survey of the three closed areas during the summer/fall of 2005 provided a high resolution view of the resource in those discrete areas. These closed areas are unique in that they play varied roles in the spatial management of the sea scallop resource. While the data and subsequent analyses provide an additional source of information on which to base management decisions, it also highlights the need for further refinement of some of the components of industry based surveys. The use of industry based cooperative surveys provides an excellent mechanism to obtain the vital information to effectively regulate the sea scallop fishery in the context of an area management strategy

Table 1 Boundary coordinates of the closed areas sampled during the 2005 surveys.

Nantucket Lightship	**Latitude**	**Longitude**
NLCA-1	40° 50’	69° 30’
NLCA-2	40° 50’	69° 0’
NLCA-3	40° 20’	69° 0’
NLCA-4	40° 20’	69° 30’
Closed Area II		
CAII-1	41° 0	67° 20’
CAII-2	41° 0	66° 35.8’
CAII-3	41° 18.6’	66° 24.8’
CAII-4	41° 30’	66° 34.8’
CAII-5	41° 30’	67° 20’
Elephant Trunk		
ET-1	38° 50’	74° 20’
ET-2	38° 10’	74° 20’
ET-3	38° 10’	73° 30’
ET-4	38° 50’	73° 30’

Table 2 Summary statistics for the three survey cruises.

Area	**Cruise dates**	**Number of stations sampled**	**Number of stations included in biomass estimate**
Nantucket Lightship	Aug 19-24, 2006	68	56
Closed Area II	Sept. 17-24, 2006	109	57
Elephant Trunk	Oct. 10-12, 2006 Oct. 18-23,2006	71	54

Table 3 Catch information for the three survey cruises. For the Nantucket Lightship cruise, strata 1 represents the northeast corner of the area delineated as an area east of 69° 20', and north of 40° 38'. Strata 2 is the remainder of the NLCA exemption area west of 69° 20', and south of 40° 38'. The other surveyed closed areas were not stratified and treated as a single resource area.

Area	Gear	Strata	Area (km^2)	Samples	Mean (g/tow)	Std. Dev.	CV %
Nantucket Lightship							
	Commercial	1	626.79	15	107,399.3	78,926.4	18.9
	Commercial	2	1,723.68	41	14,479.7	32,713.6	35.3
	Survey	1	626.79	15	47,401.6	36,571.0	19.9
	Survey	2	1,723.68	41	5,426.2	12,616.4	36.3
Closed Area II							
	Commercial		3,865.00	57	24,278.2	36,651.5	19.9
	Survey		3,865.00	57	12,210.0	18,388.5	19.9
Elephant Trunk							
	Commercial		4,546.00	54	52,410.8	59,869.9	15.5
	Survey		4,546.00	54	26,956.6	26,108.4	13.2

Table 4 Estimated density of exploitable scallops (≥ 80 mm) by gear (commercial, survey) for the three closed areas surveyed during the summer/fall of 2005. Gear efficiency values of 45% were used for the two Georges Bank area and 50% for the Elephant Trunk.

Area	Gear	Strata	Area (km^2)	Samples	Density (scallops/m^2)	Std. Dev.	CV %
Nantucket Lightship							
	Commercial	1	626.79	15	0.7194	0.5309	19.1
	Commercial	2	1,723.68	41	0.1021	0.2264	34.6
	Survey	1	626.79	15	0.6232	0.4849	20.1
	Survey	2	1,723.68	41	0.0734	0.1648	35.0
Closed Area II							
	Commercial		3,865.00	57	0.1818	0.2800	20.4
	Survey		3,865.00	57	0.1767	0.2744	20.6
Elephant Trunk							
	Commercial		4,546.00	54	0.5565	0.6617	16.2
	Survey		4,546.00	54	0.5620	0.5367	12.9

Table 5 Estimated biomass of exploitable scallops (≥ 80 mm) by gear (commercial, survey) for the three closed areas surveyed during the summer/fall of 2005. Only scallop greater than or equal to 80 mm shell height were included in the analysis. Shell height meat weight parameters from SARC 39 document (NEFSC, 2004). Gear efficiency values of 45% were used for the two Georges Bank area and 50% for the Elephant Trunk. 95% confidence intervals (CI) were calculated as ±1.96*(variance of biomass)$^{1/2}$ (Gunderson, 1993).

Area	Gear	Biomass (mt)	Lower bound 95% CI	Upper Bound 95% CI
Nantucket Lightship				
	Commercial	25,500	19,870	31,130
	Survey	20,257	15,605	24,908
Closed Area II				
	Commercial	23,483	17,309	29,657
	Survey	22,144	16,336	27,951
Elephant Trunk				
	Commercial	57,603	45,193	70,013
	Survey	55,551	45,403	65,698

Table 6 Estimated biomass of exploitable scallops (≥ 80 mm) by gear (commercial, survey) for the three closed areas surveyed during the summer/fall of 2005. Only scallop greater than or equal to 80 mm shell height were included in the analysis. Shell height meat weight parameters from samples taken during each cruise. Gear efficiency values of 45% were used for the two Georges Bank area and 50% for the Elephant Trunk. 95% confidence intervals (CI) were calculated as ±1.96*(variance of biomass)$^{1/2}$ (Gunderson, 1993).

Area	Gear	Biomass (mt)	Lower bound 95% CI	Upper Bound 95% CI
Nantucket Lightship				
	Commercial	25,167	19,615	30,720
	Survey	20,019	15,427	24,610
Closed Area II				
	Commercial	21,790	16,069	27,511
	Survey	20,521	15,148	25,895
Elephant Trunk				
	Commercial	47,041	36,926	57,156
	Survey	45,207	36,907	53,508

Table 7 Summary of shell height-meat weight parameters for the three closed areas sampled during the course of the survey and the parameters from SARC 39 (NEFSC, 2004).

Area surveyed	**Month**	**N**	**a**	**b**
Survey data				
Nantucket Lightship	August	186	-10.7232	2.9403
Closed Area II	September	202	-12.4463	3.2800
Elephant Trunk	October	121	-13.8128	3.5512
SARC 39				
Georges Bank	-	-	-11.6038	3.1221
Mid-Atlantic	-	-	-12.2484	3.2641

Figure 1 Locations of sampling stations in the Nantucket Lightship Closed Area survey by the F/V *Westport* during the cruise conducted during August 2005.

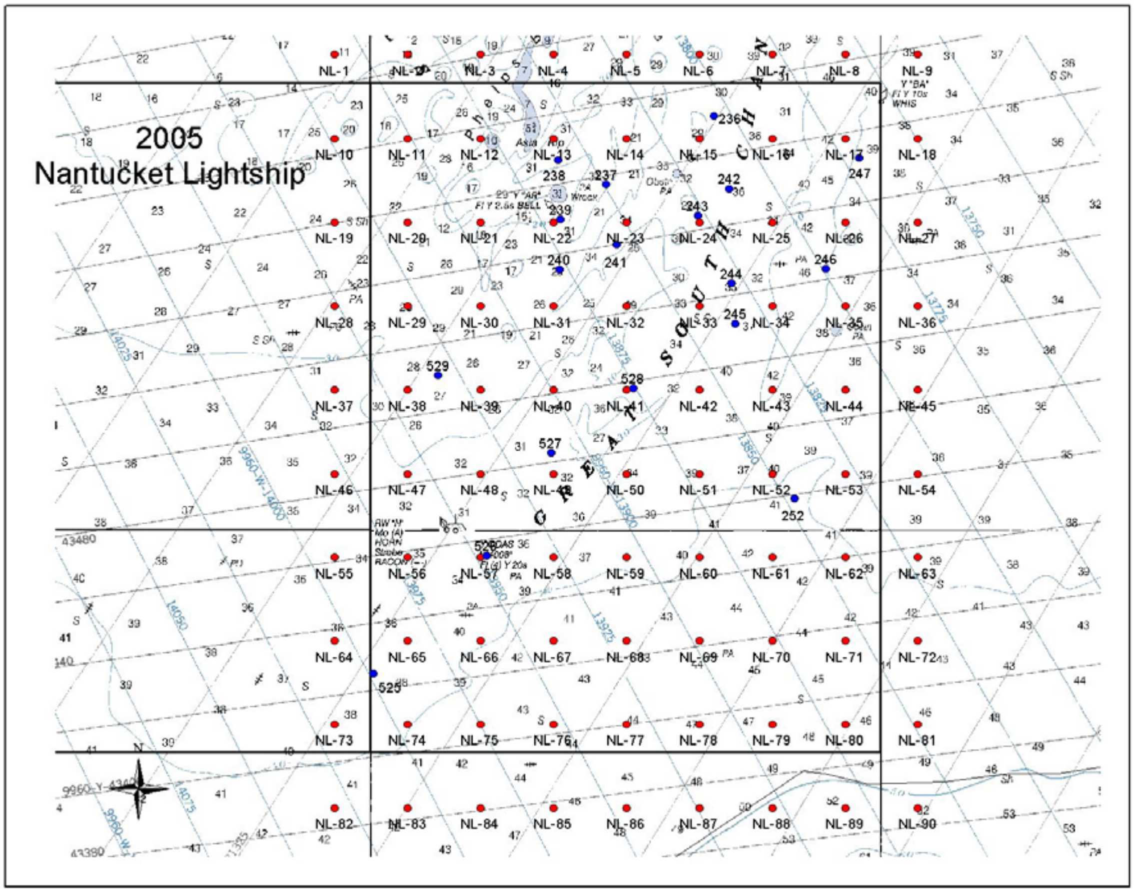


Figure 2 Locations of sampling stations in Closed Area II survey by the F/V *Celtic* during the cruise conducted during September 2005.

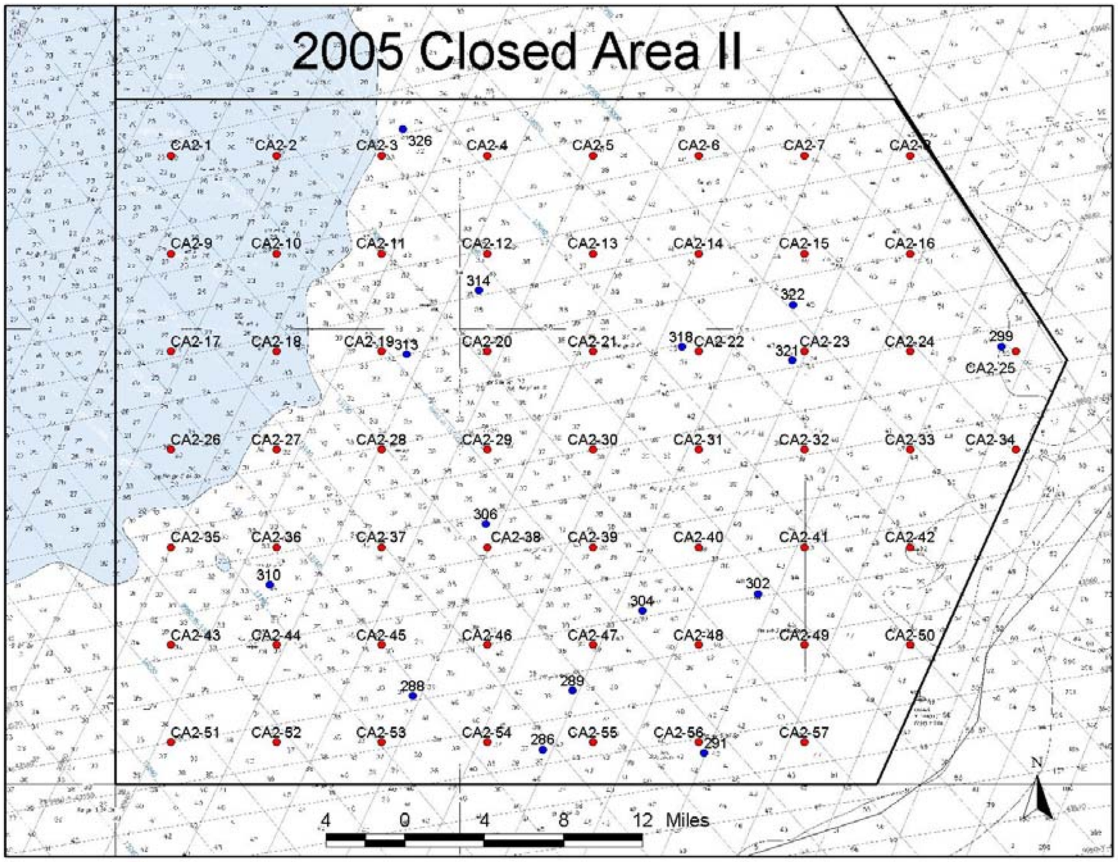


Figure 3 Locations of sampling stations in the Nantucket Lightship Closed Area survey by the F/V *Carolina Boy* during the cruise conducted during October 2005.

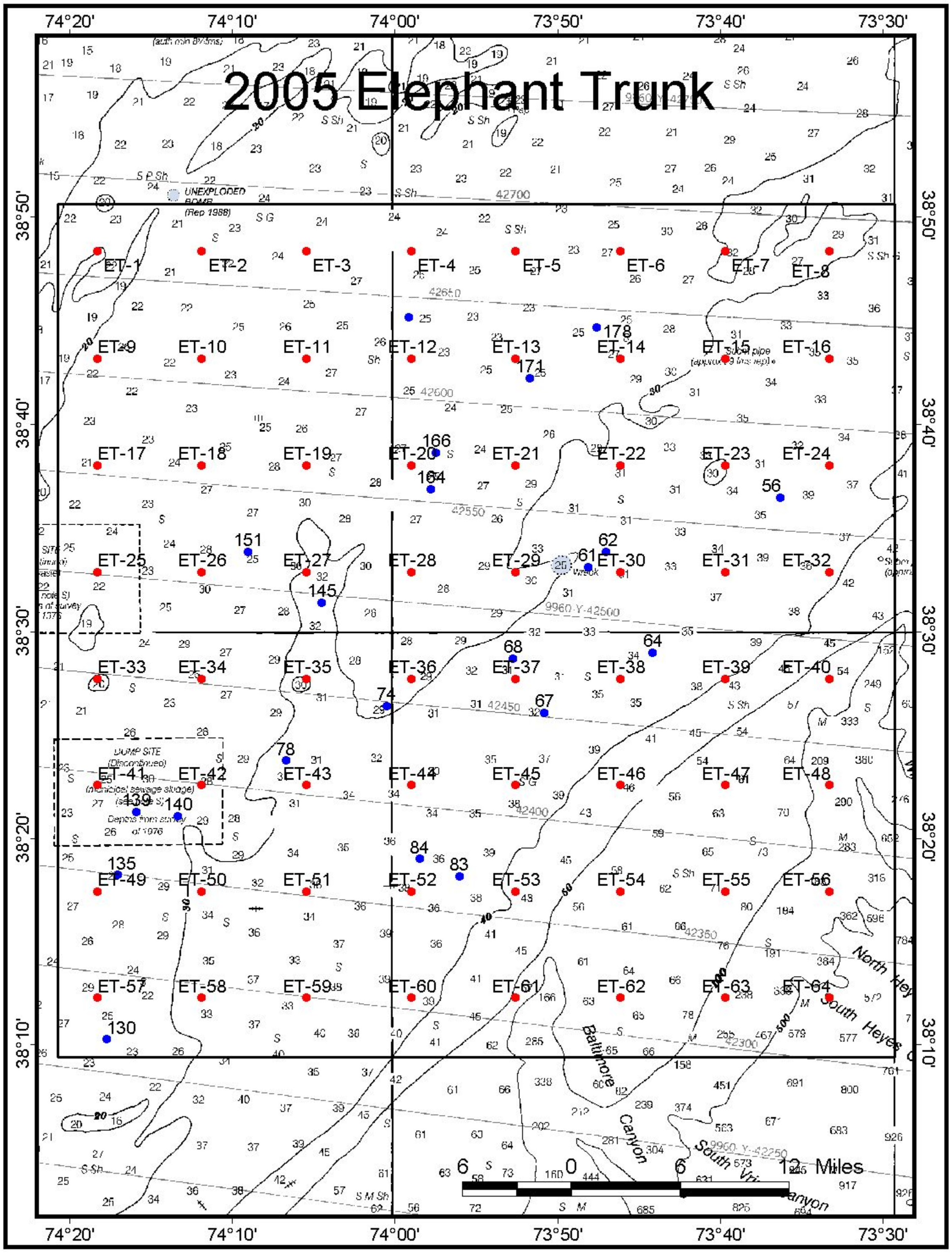
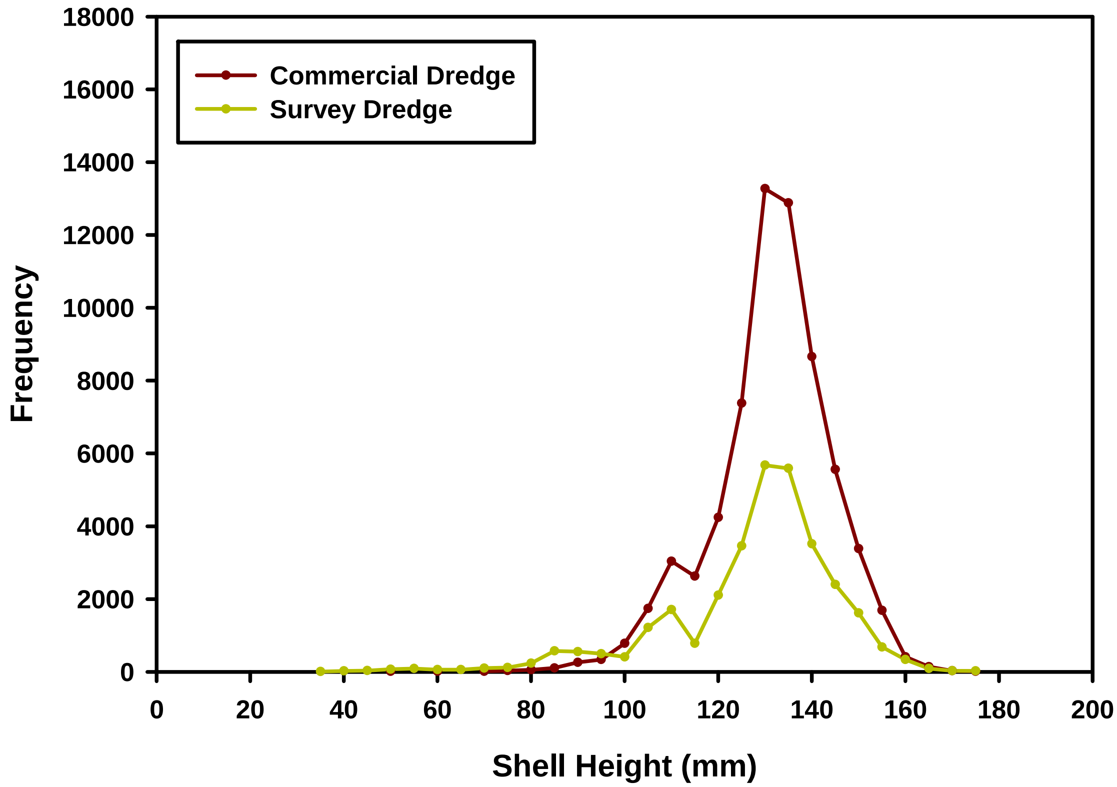


Figure 4 Shell height frequency for the cooperative survey of the Nantucket Lightship Closed Area aboard the F/V W*estport* conducted August 2005. The two frequencies represent the unadjusted catches from the two gears used during the survey.



<u>Figure 5</u> Shell height frequency for the cooperative survey of Closed Area II aboard the F/V *Celtic* conducted September 2005. The two frequencies represent the unadjusted catches from the two gears used during the survey.

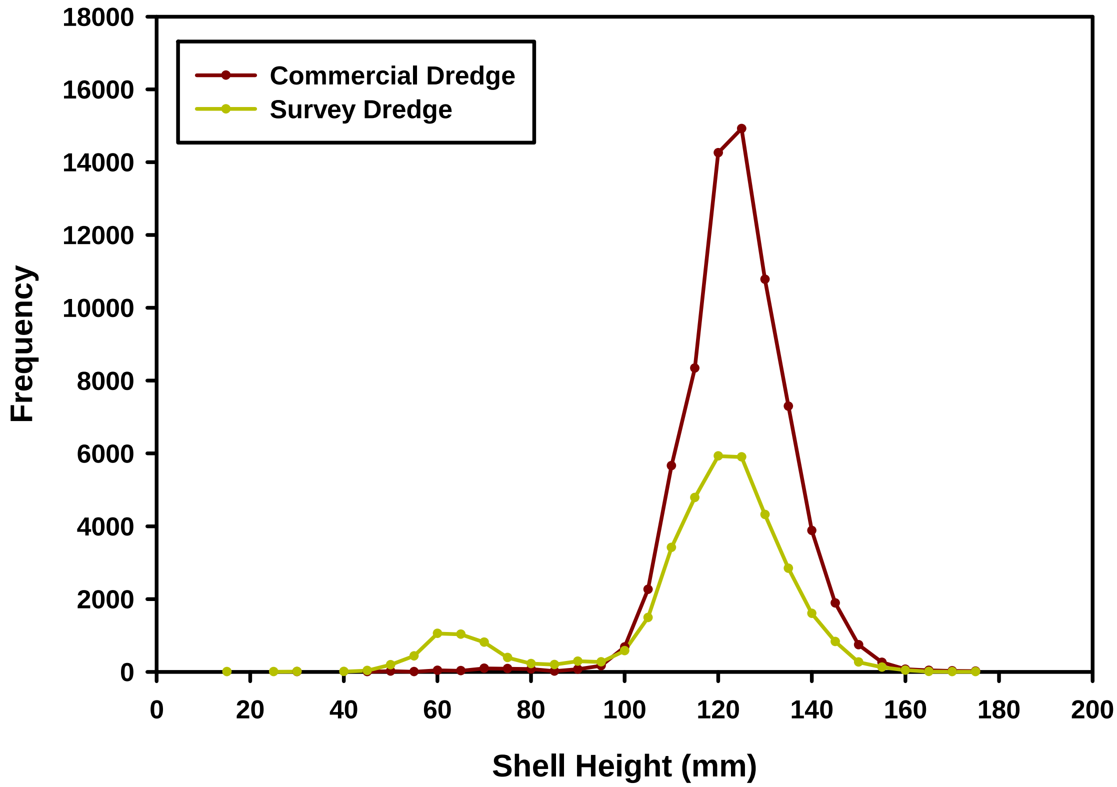


Figure 6 Shell height frequency for the cooperative survey of the Elephant Trunk Closed Area aboard the F/V *Carolina Boy* conducted October 2005. The two frequencies represent the unadjusted catches from the two gears used during the survey.

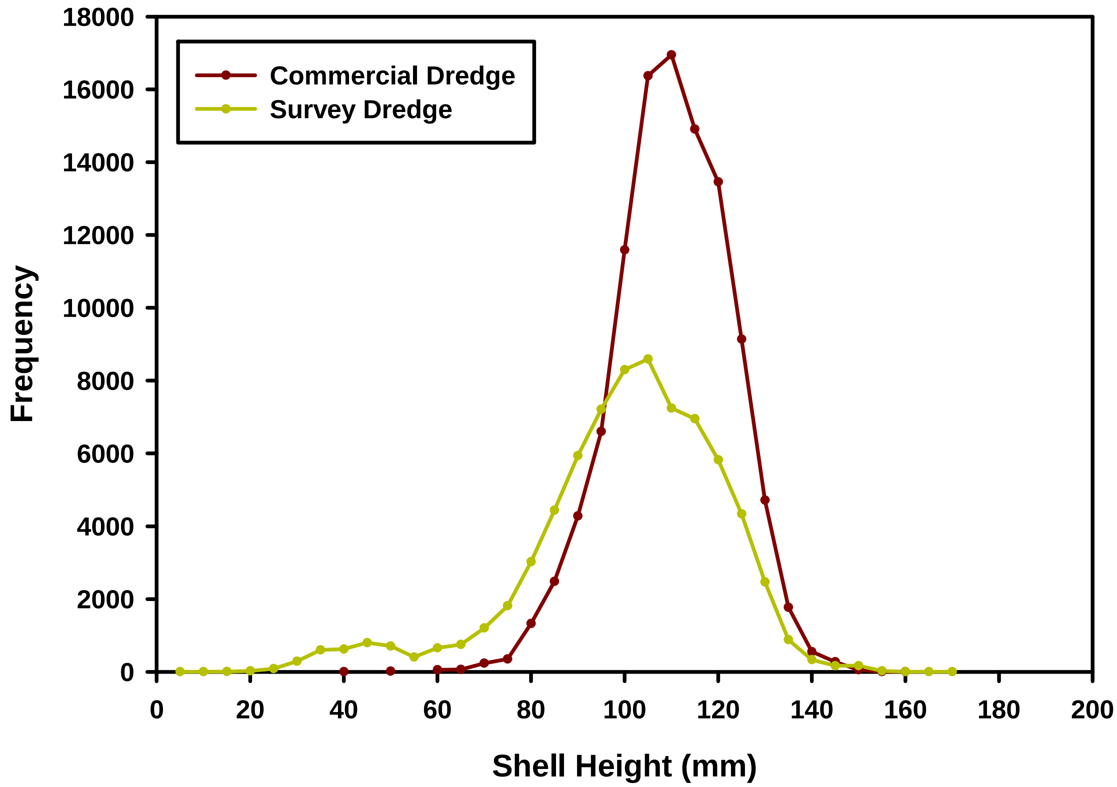


Figure 7 Interpolated catches for the Nantucket Lightship Closed Area derived from survey data obtained aboard the F/V *Westport* during August 2005.

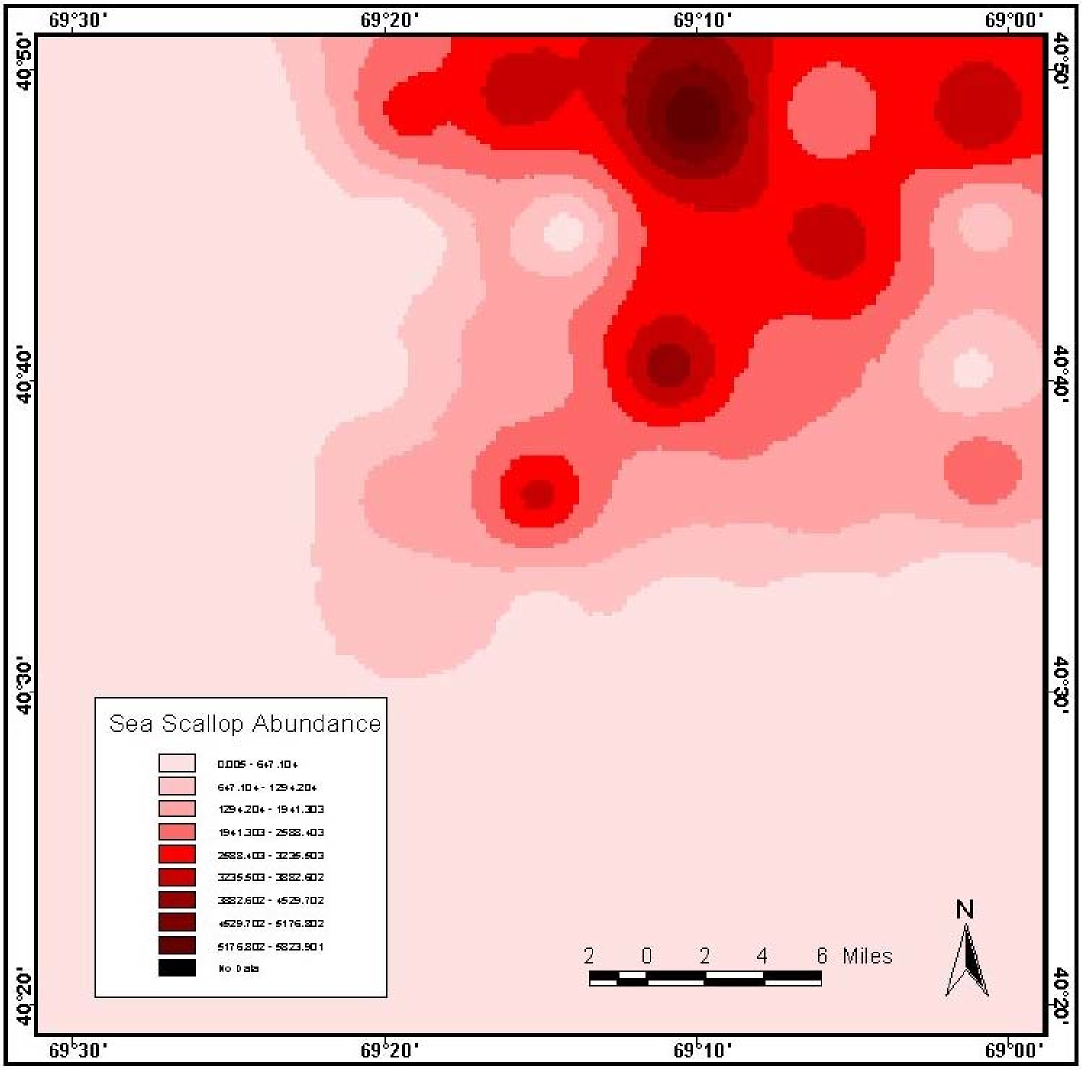
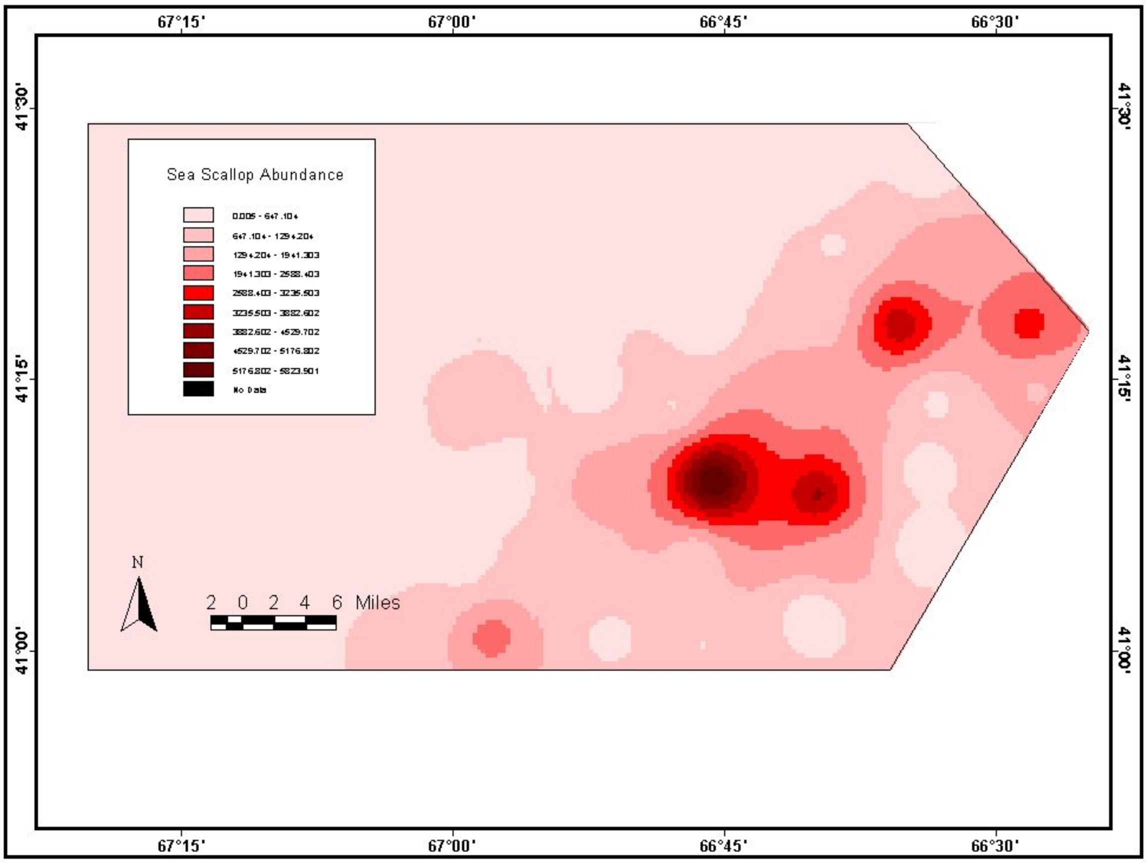


Figure 8 Interpolated catches for the Closed Area II derived from survey data obtained aboard the F/V *Celtic* during September 2005.



<u>Figure 9</u> Interpolated catches for the Elephant Trunk Closed Area derived from survey data obtained aboard the F/V *Carolina Boy* during October 2005.

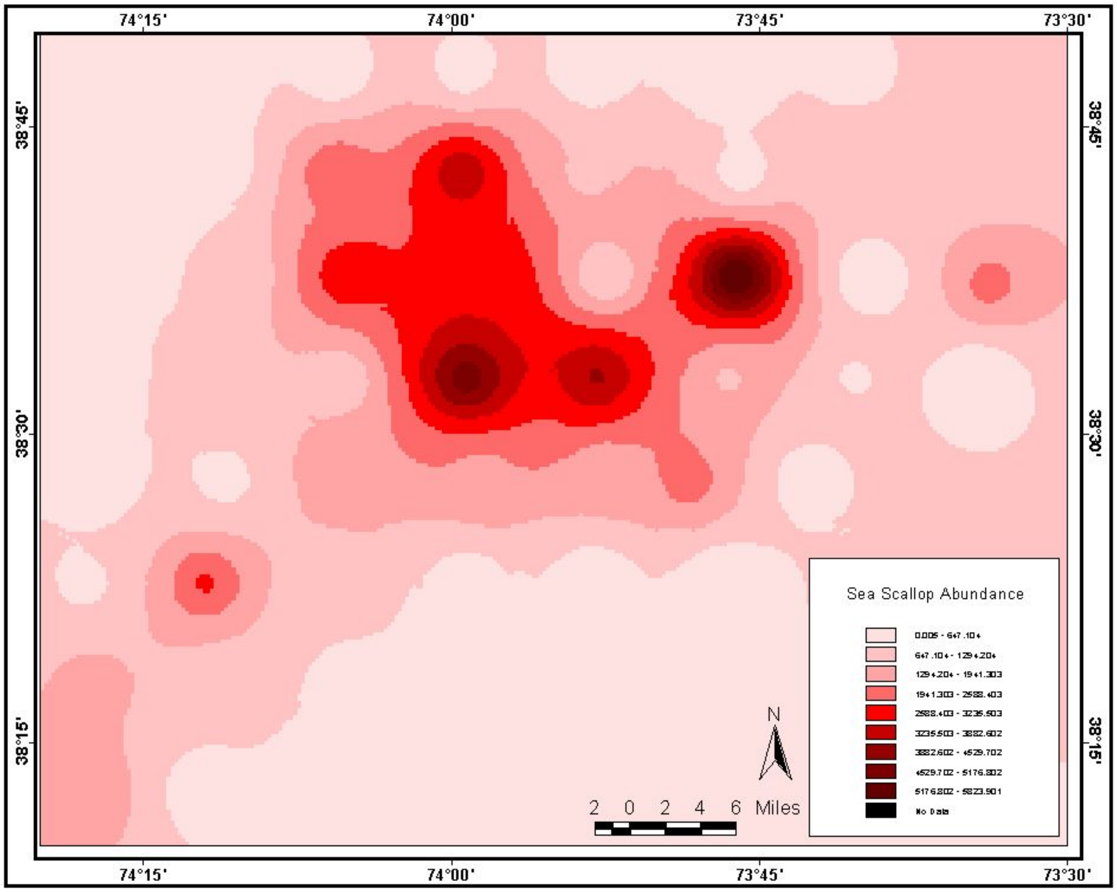
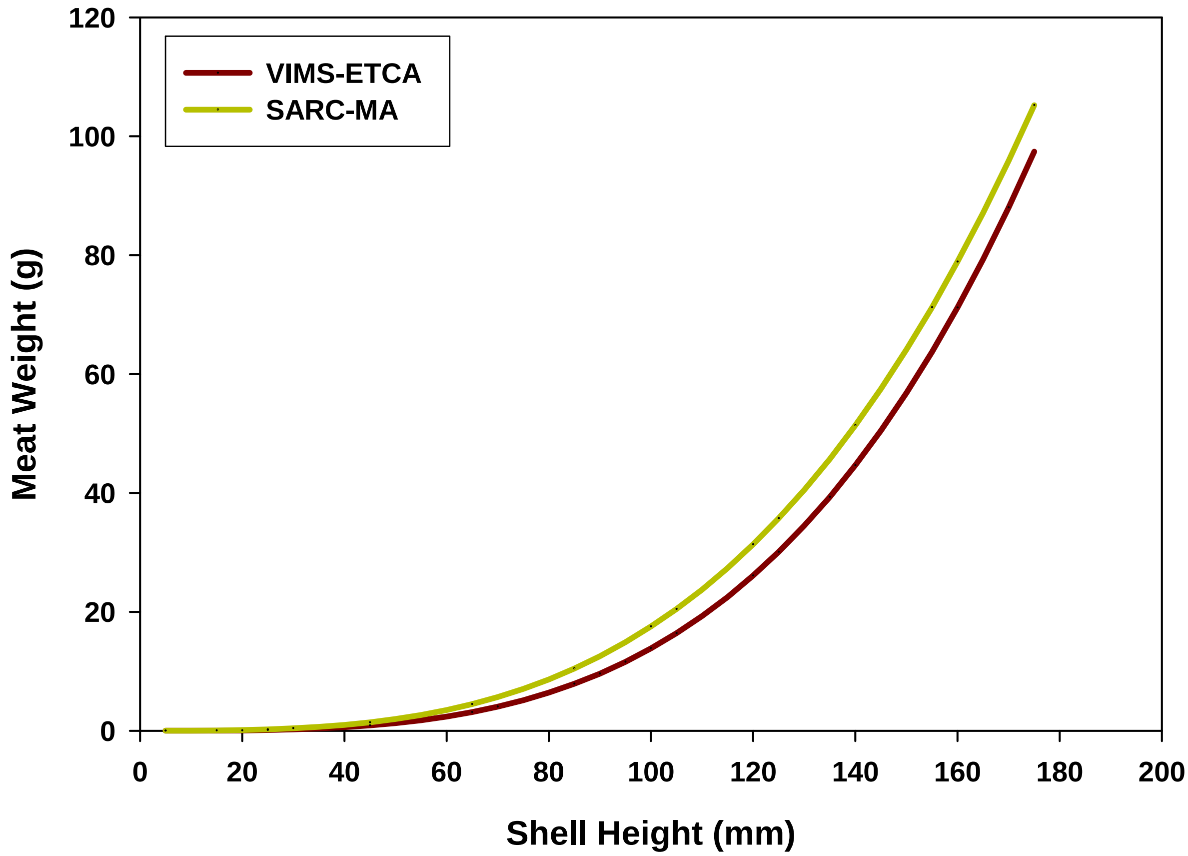
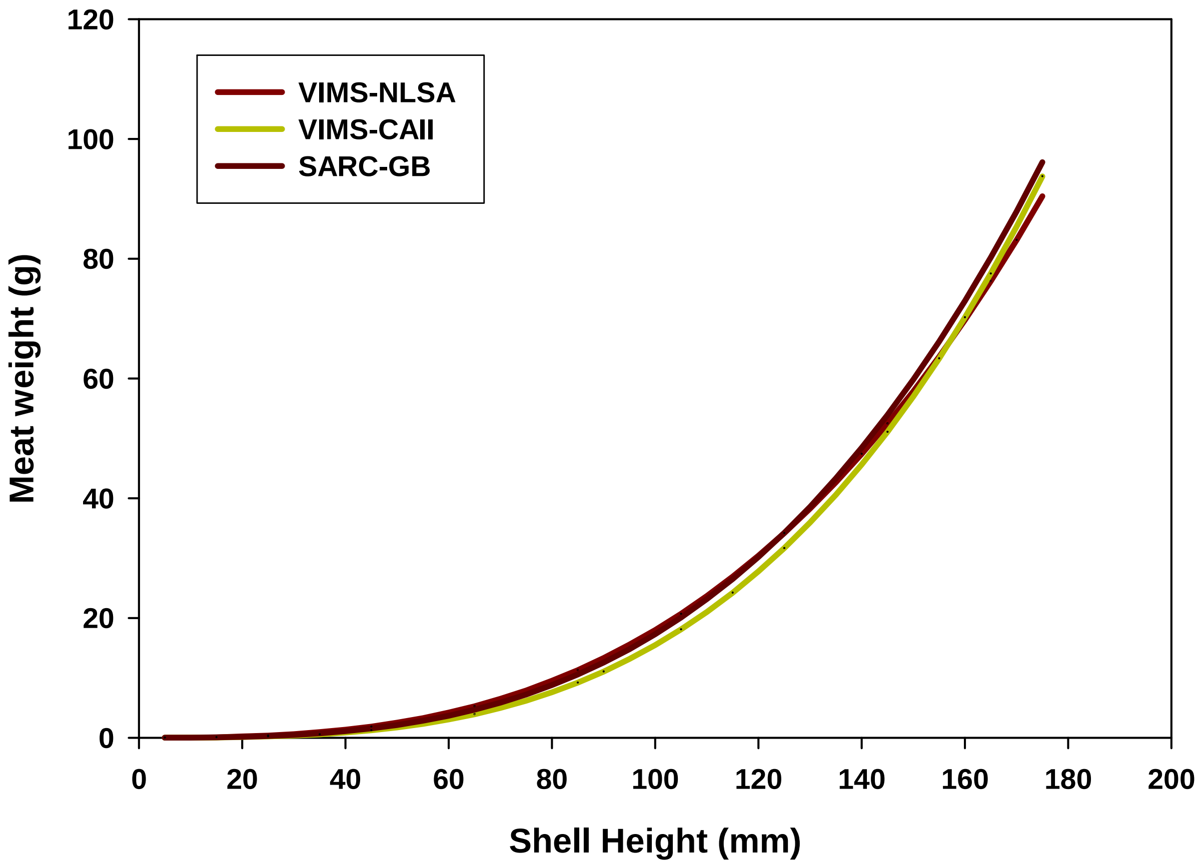


Figure 10 Comparison between fitted shell height-meat weight relationships. The two curves are the product of parameters generated from different sources. The curve labeled VIMS-ETCA was generated from data collected during the survey cruise conducted aboard the F/V *Carolina Boy* during October 2006. The curve labeled SARC-MA was generated from parameters contained SARC 39 (NEFSC, 2004).



<u>Figure 11</u> Comparison between fitted shell height-meat weight relationships. The three curves are the product of parameters generated from different sources. The curves labeled VIMS-NLCA and VIMS-CAII were generated from data collected during survey cruises conducted aboard the F/V *Westport* and F/V *Celtic* during August and September 2006. The curve labeled SARC-GB was generated from parameters for the entire Georges Bank region contained SARC 39 (NEFSC, 2004).



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Addendum to Part 1

This addendum will serve as a supplement to the report entitled, "An Assessment of Sea Scallop Abundance and Distribution in Selected Areas of Georges Bank and the Mid-Atlantic Part I: Abundance, Distribution and Biomass". The aforementioned report was submitted to the Sea Scallop Plan Development Team on May 8, 2006. At that time the priority analysis focused on sea scallops and as a result, information regarding the capture of finfish during the survey was not included. This addendum will present the CPUE (a unit of effort is represented by one standard survey tow of 15 minute duration at 3.8 kts.) of both finfish and invertebrate bycatch for each closed area surveyed.

Table 1 Catch per unit effort of finfish and invertebrate bycatch encountered during the VIMS-Industry cooperative study of Nantucket Lightship Closed Area during August of 2005. In total, finfish and invertebrate bycatch was measured and recorded for 63 survey tows.

Common Name	**Scientific Name**	**Commercial Dredge**	Survey Dredge
Unclassified Skates	Raja sp.	40.143	19.683
Barndoor Skates	Raja laevis	0.619	0.190
Silver Hake	Merluccius bilinearis	0.333	2.841
Haddock	Melanogrammus aeglefinus	0.016	0.016
Red Hake	Urophycis chuss	0.143	17.810
American Plaice	Hippglossoides platessoides	0.016	0.000
Summer Flounder	Paralichthys dentatus	0.063	0.000
Fourspot Flounder	Paralichthys oblongus	0.762	5.302
Yellowtail Flounder	Limanda ferruginea	1.302	3.794
Blackback Flounder	Psuedopleuronectes americana	0.397	0.222
Witch Flounder	Glyptocephalus cynoglossus	0.016	0.127
Windowpane Flounder	Scophthalmus aquasus	2.651	2.556
Gulfstream Flounder	Citharichthys arctifrons	0.000	1.476
Unclassified Sculpin	Cottidae	0.667	3.587
Sea Raven	Hemitripterus americanus	0.063	0.063
Fawn Cusk Eel	Lepophidium profundorum	0.000	0.032
Monkfish	Lophius americanus	2.952	1.698
Eelpout uncl.	Zoarcidae	0.111	2.000
American Lobster	Homarus americanus	0.048	0.032

Table 2 Catch per unit effort of finfish and invertebrate bycatch encountered during the VIMS-Industry cooperative study of Georges Bank Closed Area II during September of 2005. In total, finfish and invertebrate bycatch was measured and recorded for 103 survey tows.

Species	**Scientific Name**	**Commercial Dredge**	**Survey Dredge**
Unclassified Skates	Raja sp.	16.010	7.466
Barndoor Skates	Raja laevis	0.631	0.214
Silver Hake	Merluccius bilinearis	0.243	7.233
Haddock	Melanogrammus aeglefinus	0.019	0.553
Red Hake	Urophycis chuss	0.816	16.825
Summer Flounder	Paralichthys dentatus	0.136	0.029
Fourspot Flounder	Paralichthys oblongus	0.796	6.534
Yellowtail Flounder	Limanda ferruginea	6.553	8.981
Blackback Flounder	Psuedopleuronectes americana	0.146	0.058
Witch Flounder	Glyptocephalus cynoglossus	0.175	0.107
Windowpane Flounder	Scophthalmus aquasus	0.553	0.398
Unclassified Sculpin	Cottidae	0.175	2.476
Sea Raven	Hemitripterus americanus	0.058	0.087
Monkfish	Lophius americanus	3.524	1.913
Eelpout uncl.	Zoarcidae	0.010	0.340
American Lobster	Homarus americanus	0.039	0.029
Lesser Electric Ray	Narcine brasiliensis	0.010	0.000
Unclassified Squid	Cephalopoda	0.029	0.000
Northern Shortfin Squid	Illex illecebrosus	0.000	0.019

Table 3 Catch per unit effort of finfish and invertebrate bycatch encountered during the VIMS-Industry cooperative study of Elephant Trunk Closed Area during October of 2005. In total, finfish and invertebrate bycatch was measured and recorded for 69 survey tows.

Species	**Scientific Name**	**Commercial Dredge**	**Survey Dredge**
Spiny Dogfish	Squalus acanthias	0.014	0.000
Unclassified Skates	Raja sp.	16.203	8.522
Silver Hake	Merluccius bilinearis	0.014	0.130
Red Hake	Urophycis chuss	0.087	3.406
Summer Flounder	Paralichthys dentatus	0.043	0.014
Fourspot Flounder	Paralichthys oblongus	0.130	3.014
Yellowtail Flounder	Limanda ferruginea	0.000	0.130
Blackback Flounder	Psuedopleuronectes americana	0.000	0.029
Witch Flounder	Glyptocephalus cynoglossus	0.000	0.029
Windowpane Flounder	Scophthalmus aquasus	0.101	0.043
Gulfstream Flounder	Citharichthys arctifrons	0.000	0.696
Butterfish	Peprilus triacanthus	0.000	0.014
Armored Searobin	Peristedion miniatum	0.101	0.652
Monkfish	Lophius americanus	1.812	1.812
Gray Triggerfish	Balistes capriscus	0.000	0.014
Eelpout uncl.	Zoarcidae	0.000	0.072
Unclassified Squid	Cephalopoda	0.029	0.232

An Assessment of Sea Scallop Abundance and Distribution in Selected Areas of Georges Bank and the Mid-Atlantic

Part II: Selectivity of a New Bedford Style Sea Scallop Dredge

Award Number: NA05NMF4541294

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VIMS Marine Resource Report No. 2006-8

October 27, 2006

Project Summary

A size-selectivity curve was constructed to characterize the performance of the New Bedford style Atlantic sea scallop (*Placopecten magellanicus)* dredge, configured to meet the requirements of Amendment #10 to the Sea Scallop Fishery Management Plan. The curve was generated using the SELECT model on catch-at-length data obtained by simultaneously towing the New Bedford style dredge and the non-selective National Marine Fisheries Service sea scallop survey dredge from commercial sea scallop vessels. Data was collected during three cruises in the Northwest Atlantic between 2005 and 2006. One cruise was completed in Georges Bank (Groundfish Closed Area II) and two cruises were completed in the Mid-Atlantic Bight (both in the Elephant Trunk Closed Area) [Results from data collected in an additional cruise in the Nantucket Lightship Closed Area will be presented separately.] The resulting selectivity curve for all cruises combined yielded a 50% retention length (l_{50}) of 97. 6 mm, a selection range of 23.6 mm and a relative efficiency value of 0.77. A l_{50} value of 97.6 mm corresponds to an age of approximately 4 ½ years in Georges Bank and 5 ½ years in the Mid-Atlantic. This implies that sea scallops are being recruited into the fishery after they have taken advantage of their substantial growth potential in their early years of life and after they have increased their spawning potential. The selectivity curve can serve to assist fisheries managers with stock assessments, mortality calculations and with the interpretation of catch data from government and industry-based surveys. Additionally, the selection curve can be used as a foundation for evaluating the effect of future changes to sea scallop dredge design.

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Project Background

The Atlantic sea scallop (*Placopecten magellanicus*) population supports the most lucrative fishery along the east coast of the United States (Van Voorhees 2005). In order to ensure the longevity of this industry, management strategies such as effort controls, closed area rotation and gear configuration requirements are used to promote a healthy sea scallop resource. By modifying the gear used to harvest sea scallops, fishing pressure can be reduced on young animals and the age at entry into the fishery can be increased. This results in a potential increase in both the yield-per-recruit and the total reproductive output of the population.

Under Amendment #10 to the Sea Scallop Fishery Management Plan, New Bedford style dredges (the principal offshore commercial fishing gear, “commercial”) are required to have twine tops with a minimum mesh size of 10-inches (25.4 cm), restrict chafing gear to the bottom of the dredge, have rings with a minimum internal diameter of 4-inches (102 mm) and use no more than double links between rings, except on the dredge bottom where a maximum of triple links may be used (NEFMC 2003). With the passing of this amendment in 2003, it becomes necessary to determine whether or not a dredge configured with these specifications will attain the goal of selecting against smaller scallops. Additionally, it becomes imperative to evaluate this gear configuration so that comparisons can be made when future alterations are attempted.

Size-selectivity curves have the potential to address both of these concerns by modeling the probability that a sea scallop of length *l*, if contacting the gear, will be retained (Millar 1992). A curve of this nature can also assist fisheries managers translate survey abundance into expected yield and can provide insight into how the gear is interacting with scallops of a given length. Additionally, because gear selectivity measurements are used in connection with fishing mortality calculations, this information can assist fisheries managers in making stock assessments (Wileman 1996). Furthermore, a selection curve can provide insight into incidental morality and assist with yield-per-recruit analysis and the estimation of population length frequency (Millar and Fryer 1999).

In order to construct an absolute size-selectivity curve, the commercial (experimental) gear must be compared to a non-selective (control) gear. The National Marine Fisheries Service (NMFS) survey dredge (“survey”) served as the control gear in this study. The survey dredge is assumed to be non-selective because there is a liner sewn into the dredge bag which prohibits scallops from escaping. With the catch-at-length data from the two dredges, the Share Each LEngth’s Catch Total (SELECT) model developed by Millar (1992) was used to generate the curve. This is preferential to other methods because the SELECT model is biologically meaningful, does not require knowledge of the actual population length distribution, and, because the model conditions on the total catch, it avoids the problem of dividing by zero and it allows the data to be modeled as binary data. Additionally, the SELECT model incorporates a parameter that denotes relative fishing intensity between the two gears (experimental and control). This is the split parameter, p_j, which factors in how catch between gears (j=1,…, n) will vary due to differential fishing effort, fish avoidance behavior and localized fish concentrations (Millar 1992). It is the probability that a fish entered gear j, given that it entered the combined gear. In addition to estimating p_j, the SELECT model calculates two other factors often used to characterize selection. These are: 1. the 50% retention length (l_{50}), the length at which a scallop has a 50% probability of escaping and of being retained (above this length most of the scallops will be retained) and 2. the selection range (SR), the difference between the 75 and 25% retention lengths (l_{75}- l_{25}), which is a measure of how quickly the 100% retention length is approached, i.e., the steepness of the curve.

Methods

Data Collection

In August, September and October of 2005 and in June of 2006, four cruises were completed aboard commercial sea scallop vessels. During these cruises, three closed areas were sampled, two in Georges Bank (Nantucket Lightship Closed Area, NLCA, and Groundfish Closed Area II, CA2) and one in the Mid-Atlantic Bight (Elephant Trunk Closed Area, ETCA) (Figure 1, Table 1) [Because the gears used in the NLCA were not configured in the same way as in the other areas, the results from this cruise will be presented separately.] Within each area, pre-determined stations (Figure 2), selected within a systematic random grid, were sampled. At each station, a standard NMFS survey dredge was towed simultaneously with a New Bedford style commercial sea scallop dredge. The survey dredge was 8-feet (2.4 m) in width, was configured with 2-inch (51 mm) rings, a 3.5-inch (89 mm) diamond twine top, and a 1.5-inch (3.8 cm) diamond mesh liner and the commercial dredges were 15-feet (4.6 m) in width, had 4-inch (102mm) rings, a 10-inch twine top and no liner. Certain aspects of the commercial gear configuration varied on the different vessels used for this study, but this is advantageous since this variation exists within the actual commercial fleet. Rock chains and chafing gear were used on both dredges as dictated by the area surveyed and current regulations. Simultaneously towing the two dredges from the same vessel allowed for similar area of substrate and population of scallops to be sampled. The duration of each tow was approximately 15 minutes and towing speed was 3.8 knots. Depth range varied in each area; however a 3:1 wire scope (scope being the ratio of the amount of wire out to the vertical distance from the boat to the seafloor) was attempted for all tows (Table 2). During each cruise the survey dredge was towed from the port side of the vessel for the first half of the stations and from the starboard side for the remainder in order to counteract any random effect associated with fishing from a particular side. In order to determine bottom contact time and to ensure that the gear was fishing correctly, an inclinometer was attached to the survey dredge. Also, high-resolution navigational logging equipment was used to document tow time, vessel position, speed over ground and bearing.

Upon completion of each tow, the entire catch from both gears was emptied on deck. Scallops (live and clappers) were then sorted out of the catch and placed into baskets. The number of baskets from each side was counted and a fraction of these was measured. Measurements of the scallops were made in 5 mm increments (shell height measured as the longest distance between the umbo and the outer margin of the shell) on counting boards. Additionally, all bycatch was quantified, trash from both gears was counted in baskets and, at 15 randomly selected stations for each cruise, 15 individual scallops were measured to the nearest millimeter and the meat was frozen and taken back to the lab where it was weighed to the nearest kilogram in order to generate shell height-meat weight curves.

Data Analysis

Data for all valid tows was entered into both Excel and Access data bases and the number of scallops caught per length class, from each gear, was multiplied by an expansion factor equivalent to the number of baskets caught during the tow divided by the number of baskets measured. The tows were then combined by cruise, closed area, year and all tows together. Following this, for each tow and combination of tows, a plot was made of the ratio of the number of scallops at each length in the commercial dredge to the total in both dredges (Commercial/Total) in order to determine if the commercial gear was behaving selectively. This assessment validated proceeding with analysis.

The catch-at-length data from all valid tows was multiplied by an expansion factor equivalent to the number of baskets of scallops caught during the tow divided by the number measured. The tows were then combined by cruise, closed area, year and all tows together and the resulting data was analyzed with the SELECT model. Historically, selectivity, r(*l*), (the probability that a fish of length *l* will be retained given that it enters the gear), for a dredge has taken a logistic form because of the fact that as fish increase in length the probability of retention asymptotically approaches 100% due to the fact that at larger sizes there is no opportunity for escape. If selection of the commercial gear is logistic, the SELECT model equates the proportion ($\Phi(l)$) of scallops (of length *l*) that are caught in the commercial gear out of the total catch from both gears to:

$$\Phi(l) = \frac{p_c \exp(a+bl)}{(1-p_c)+\exp(a+bl)}$$

Where *a* and *b* are the logistic parameters and p_c is the split-parameter, which describes the relative fishing intensity or efficiency of the commercial dredge (the relative efficiency of the survey dredge is $1- p_c$) (Millar 1992). These three parameters (*a, b* and p_c) are estimated by maximizing the likelihood:

$$L(a,b,p_c|data) = \prod_{l=5}^{175} \left(\frac{p_c \exp(a+bl)}{(1-p_c)+\exp(a+bl)}\right)^{C_C} \left(1-\frac{p_c \exp(a+bl)}{(1-p_c)+\exp(a+bl)}\right)^{C_S}$$

In this equation, the length classes are taken from 5 to 175 mm (a *l* of “5 mm” equates to the length class “5-10 mm”), C_C is the number of length *l* scallops in the commercial gear and C_S is the number of length *l* scallops in the survey gear. To generate the selectivity curve, values for *a* and *b* are reinserted into the logistic equation. The resultant curve is symmetric about l_{50} and the shape is determined by the selection range. The data was evaluated using the R-Statistical Program for Windows (R). Code to facilitate this analysis was written by Dr. Russell Millar and can be found on his website (http://www.stat.auckland.ac.nz/~millar/). For verification, the analysis was also completed in Excel using the Solver function.

Due to variation in wind speed, water depth, sea state, scallop density and other factors that cannot be controlled by the experiment, there is variation in the selectivity from one tow to the next. This variation must be considered. The replication estimate of between-haul variation (REP) is able to evaluate this as well as account for the effect of inflated sample sizes due to scaling up the data. The combined hauls approach discussed in Millar et al. 2004 was used in this analysis to account for these effects. In order to avoid over-inflating the degrees of freedom for this analysis, only length classes where, when all tows are combined, one dredge has caught at least 20 scallops were used.

Results

The catch-at-length data obtained during this study was evaluated with the SELECT model using the Logistic as well as Richards, Log-Log and C-Log-Log curves. The resulting residuals from the Logistic curve showed no considerable trends and the curve sufficiently fit the data. The other three curves did not significantly improve the fit of the curve and, therefore, the results will be presented for the Logistic SELECT model. Additionally, in order to avoid over-inflating the sample size, only length classes where there were at least 20 scallops in one of the two dredges were used in the analysis. In order to determine if this affected the estimated parameters, the model was run under this criterion as well as under the criteria that, for each length class: 1) at least one dredge had more than zero scallops, 2) at least one dredge had more than 60 scallops and 3) at least one dredge had more than 1,000 scallops. In general, with fewer length classes used in the analysis, the 50% retention length, selection range, split parameter and likelihood values all increased. However, as seen in Table 3, these changes were not substantial.

An assessment of the potential overdispersion from combining the tows indicated that there was extra Poisson variation and, therefore, the standard errors for the estimated parameters from the SELECT analysis were multiplied by the square root of REP. These parameters are given in Table 4 and the fitted curves and deviance residuals are in Figure 3. A common feature for all tow combinations is that at the largest sizes the proportion caught in the commercial dredge decreases. This causes a pattern in the residuals, namely that residuals at the larger lengths are negative. This is not of great concern since the data points for these sizes are influenced by only a handful of tows which makes them susceptible to outlying information. For example, the 150 mm data point for the ETCA 2005 SELECT fitted curve is influenced primarily by two tows where there were a few scallops at 150 mm in the survey dredge and none in the commercial. When this data was multiplied by the expansion factor the discrepancy between the two dredges was exaggerated. Additionally, patterns in the residuals attributed to this are not significant since, when these outlying length classes were removed, as seen in Table 3, there is not a significant change in the estimated parameter values.

The a and b parameters estimated for each combination of tows were inserted into the logistic selectivity curve equation (Figure 4). The range of l_{50} values from the different combinations of data was 95.6 -102.7 mm, a small difference of 7.1 mm. Also, there is variation in the selection range for the different tow combinations; however the resultant curves are relatively similar.

The final results are those that were estimated for tows combined for the CA2 2005, ETCA 2005 and ETCA 2006 cruises since an evaluation of the resulting parameters and confidence intervals from all other combinations of data (by cruise, area and year) revealed little significant difference (Figure 5). Additionally, by including tows from multiple cruises the selectivity curve becomes more representative of the commercial fleet. The resulting SR for this analysis was 23.6 mm and the l_{50} was 97.6 mm, which indicates that sea scallops larger than this are likely to be retained by the commercial dredge. The split parameter (p_c) indicates that the commercial dredge is fishing more efficiently than the survey dredge. If the two gears were equally efficient, then the difference in the number of scallops entering the dredges would merely be a function of the width of the gears and the split parameter value for the commercial dredge would be equal to $\frac{15}{(15+8)}$ or 0.65. However, the resulting value, 0.77, indicates that other factors are affecting efficiency. An additional analysis was done to evaluate how increasing number of baskets of scallops and trash caught in the commercial gear might affect these values. The results indicated that the estimated parameters sufficiently represent the selective properties of the commercial gear regardless of these two variables.

Discussion

Using the Von Bertalanffy growth model and the parameters from Serchuk et al. 1979, the resultant l_{50} value of 97.6 mm indicates that sea scallops that have a 50% probability of retention are 4.5 years old in Georges Bank and are 5.6 years old in the Mid-Atlantic. Also, using the resulting curves from the shell height-meat weight analysis on the data obtained during this study, a shell height of 97.6 mm would yield a meat weight (on average) of 12.04 g. [Using the NEFSC 2001 shell height-meat weight parameters this shell height would yield a meat weight of 14.86 g in Georges Bank and 14.94 g in the Mid-Atlantic. It must also be noted that shell height-meat weight relationships vary seasonally and by location (Smolowitz and Serchuk 1987).]

These results imply that scallops are being able to take advantage of their substantial growth potential in their early years of life before being recruited into the fishery and that the current commercial gear being used in sea scallop harvest is promoting higher yield-per-recruit. Additionally, scallops being recruited into the fishery have been able to maximize their spawning potential, based on the findings of Langton et al. that somatic production steadily increases to and levels off at age 5 (1987).

Nantucket Lightship Closed Area 2005 Cruise

In order to combine the tows from two or more different cruises for the analysis it is imperative that the gears remain the same throughout. Gear configuration was consistent for the Closed Area II (CA2) cruise in 2005 and for the cruises in the Elephant Trunk Closed Area (ETCA) in 2005 and 2006. The dredges used during the cruise in the

Nantucket Lightship Closed Area (NLCA), however, were not equivalent. To begin with, the hanging ratio and the size of the twine top on the survey dredge used in the NLCA were different from those used on the other cruises. The hanging ratio changed since, while the number of rings along the frame of the dredge remained the same for all cruises, the size of the twine top was 25 x 17 meshes for the NLCA cruise and was 40 x 15 meshes for the others. Additionally, there was a reduced surface area, and hence a tighter fit, in the NLCA survey dredge twine top because the dimensions 25x17 equates to a total of 425 meshes where a twine top with 40x15 has 600. Furthermore, the commercial dredge in the NLCA differed in that it had a shorter twine top and a longer sweep chain. Because of these differences, analysis for the data from the NLCA cruise is presented separately and is not included in the final results.

The catch-at-length data from the NLCA cruise was analyzed in the same manner as the other cruises. The estimated parameters for the NLCA cruise yielded a 50% retention length of 99.14 mm, a selection range of 17.63 mm and a split parameter value of 0.76. Standard errors for the estimated parameters were multiplied by the square root of REP because the data were overdispersed. Results from the NLCA are comparable to the results from the other cruises (Figures 6 and 7, Table 5). The split parameter values are similar and there is less than a two millimeter difference between the 50% retention lengths for the NLCA cruise and the other cruises combined. However, the selection ranges differ in that the curve for the NLCA cruise is steeper, indicating that fewer small and more large scallops will be retained. Additionally, the ratio of number of baskets of scallops in the survey dredge to the commercial dredge (Survey/Commercial) for the NLCA cruise was smaller than for all other cruises. The ratios for the NLCA cruise, CA2 cruise, ETCA cruise in 2005 and ETCA cruise in 2006 were 0.34, 0.44, 0.54 (0.45 if one outlying point is excluded), and 0.47 respectively. This potentially implies that the difference in the survey gear configuration affected the number of baskets of scallops caught in the survey dredge, but further investigation is needed to confirm this hypothesis.

Figure 1. **Closed areas surveyed in this study.**

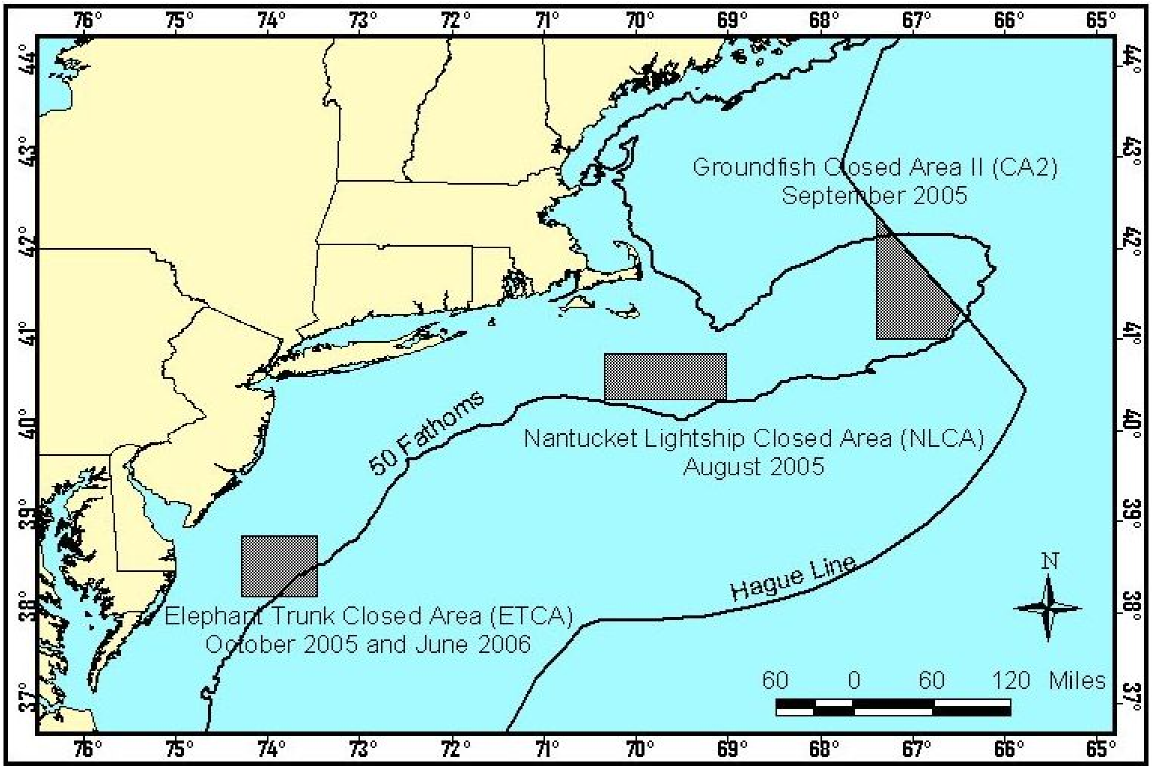
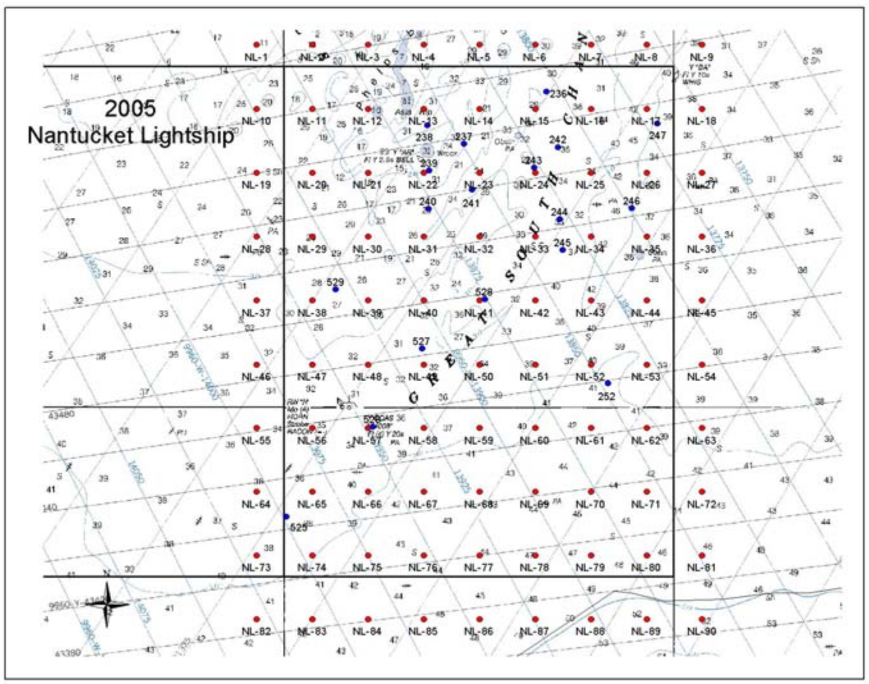
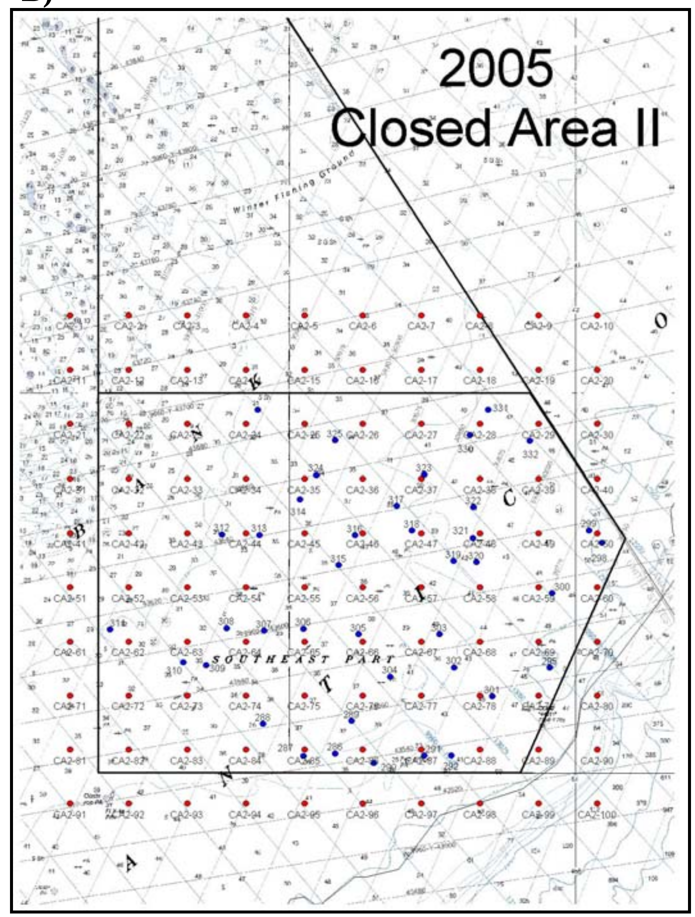


Figure 2. Systematic random stations generated for this study. All stations within the closed area boundary were surveyed for cruises: a) Nantucket Lightship Closed Area 2005, b) Groundfish Closed Area II 2005, c) Elephant Trunk Closed Area 2005, and d) Elephant Trunk Closed Area 2006.

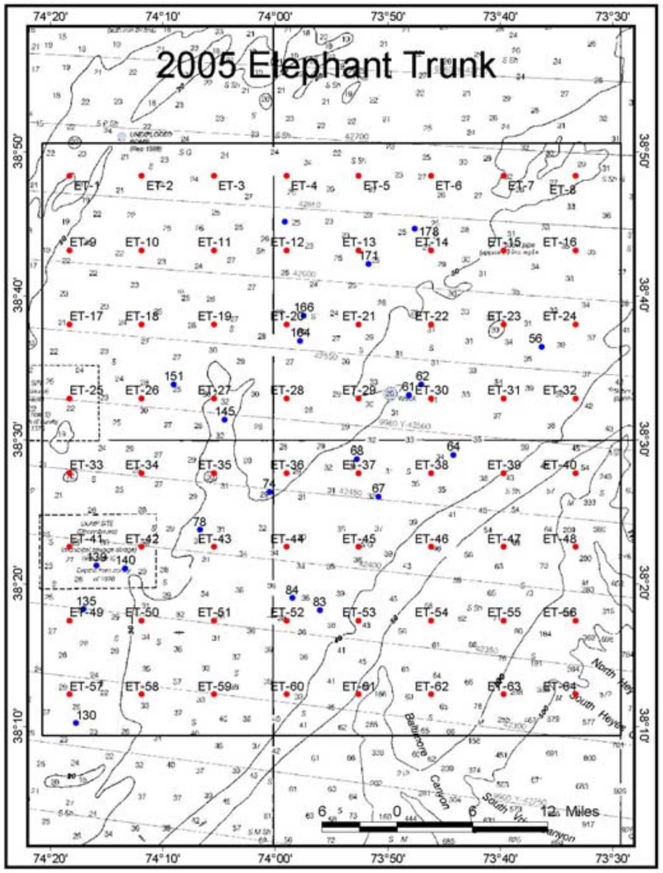
A)



B)



C)



D)

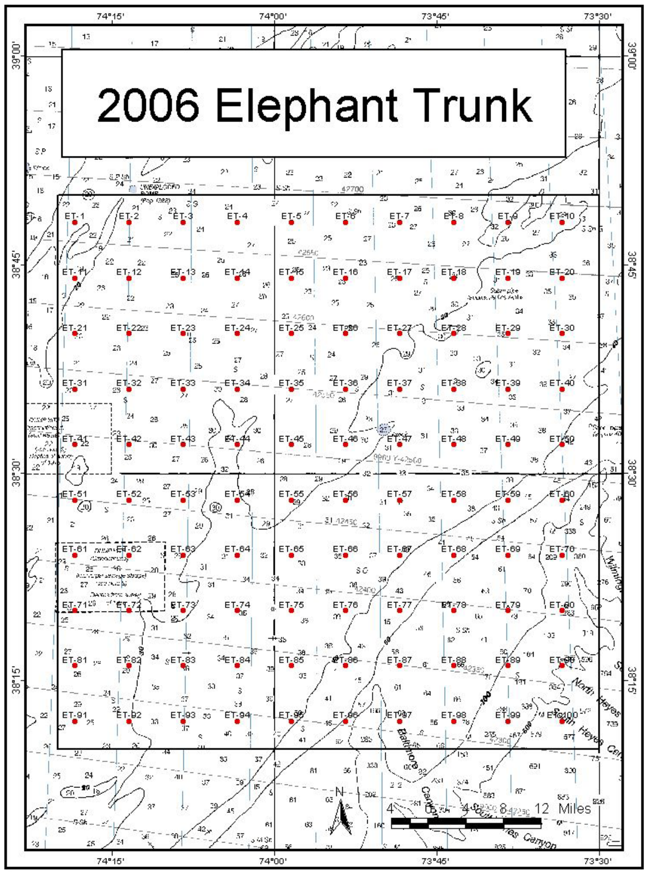
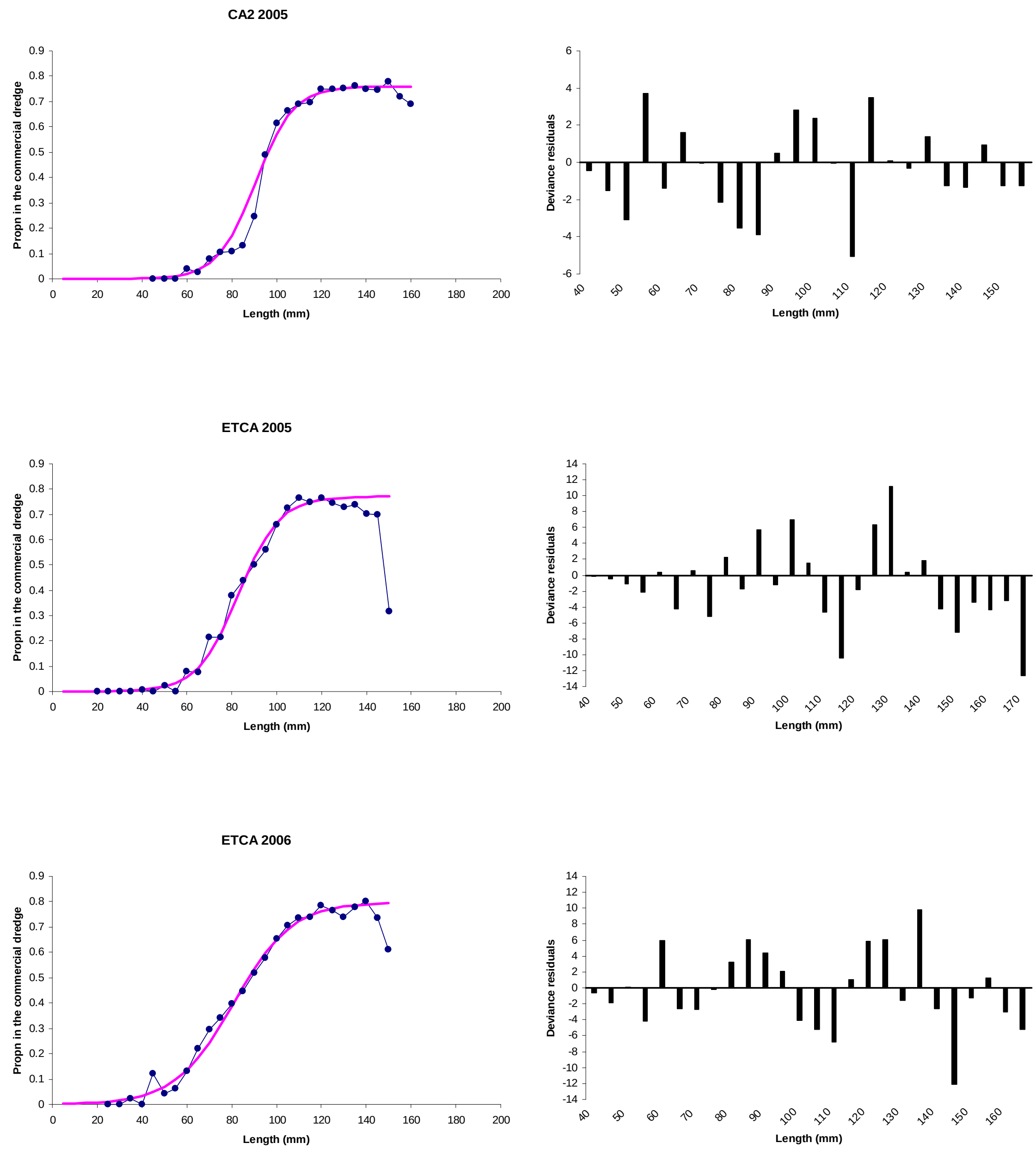
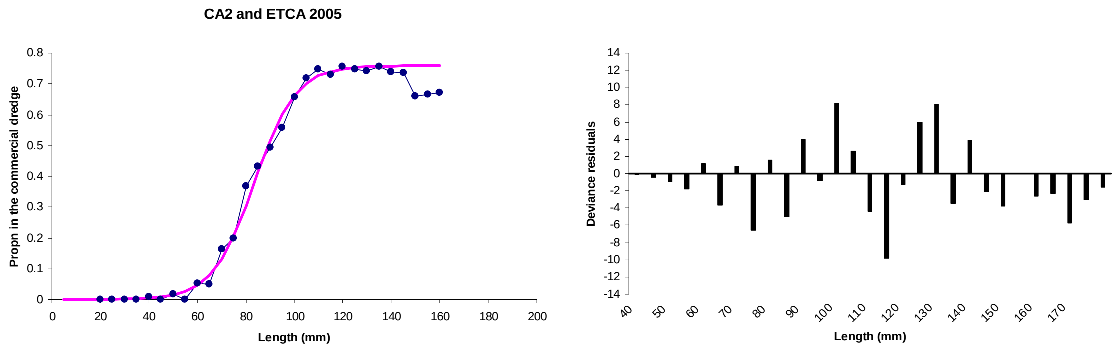
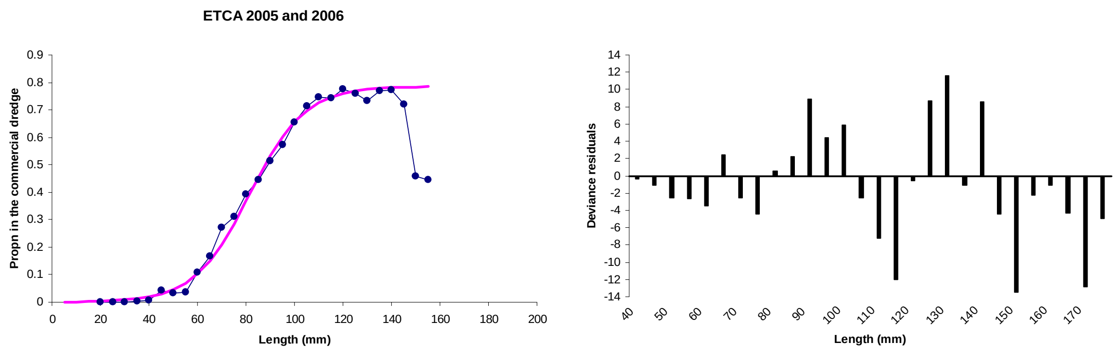


Figure 3. Logistic SELECT curves fit to the proportion of the total catch in the commercial gear and deviance residuals for a) Groundfish Closed Area II 2005 (CA2 2005), b) Elephant Trunk Closed Area 2005 (ETCA 2005), c) Elephant Trunk Closed Area 2006 (ETCA 2006), d) CA2 2005 and ETCA 2005 combined, e) ETCA 2005 and ETCA 2006 combined, and f) CA2 2005, ETCA 2005 and ETCA 2006 combined.




CA2 and ETCA 2005
Propn in the commercial dredge
Length (mm)
Deviance residuals
Length (mm)


ETCA 2005 and 2006
Propn in the commercial dredge
Length (mm)
Deviance residuals
Length (mm)

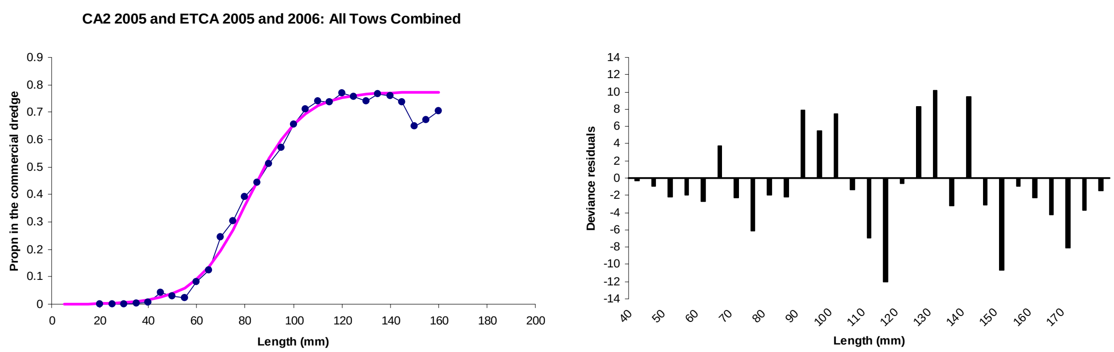

CA2 2005 and ETCA 2005 and 2006: All Tows Combined
Propn in the commercial dredge
Length (mm)
Deviance residuals
Length (mm)

Figure 4. **Size-selection curves from the estimated logistic parameters for Groundfish Closed Area II 2005 (CA2 2005), Elephant Trunk Closed Area 2005 (ETCA 2005), Elephant Trunk Closed Area 2006 (ETCA 2006), CA2 2005 and ETCA 2005 combined, ETCA 2005 and ETCA 2006 combined, and CA2 2005, ETCA 2005 and ETCA 2006 combined.**

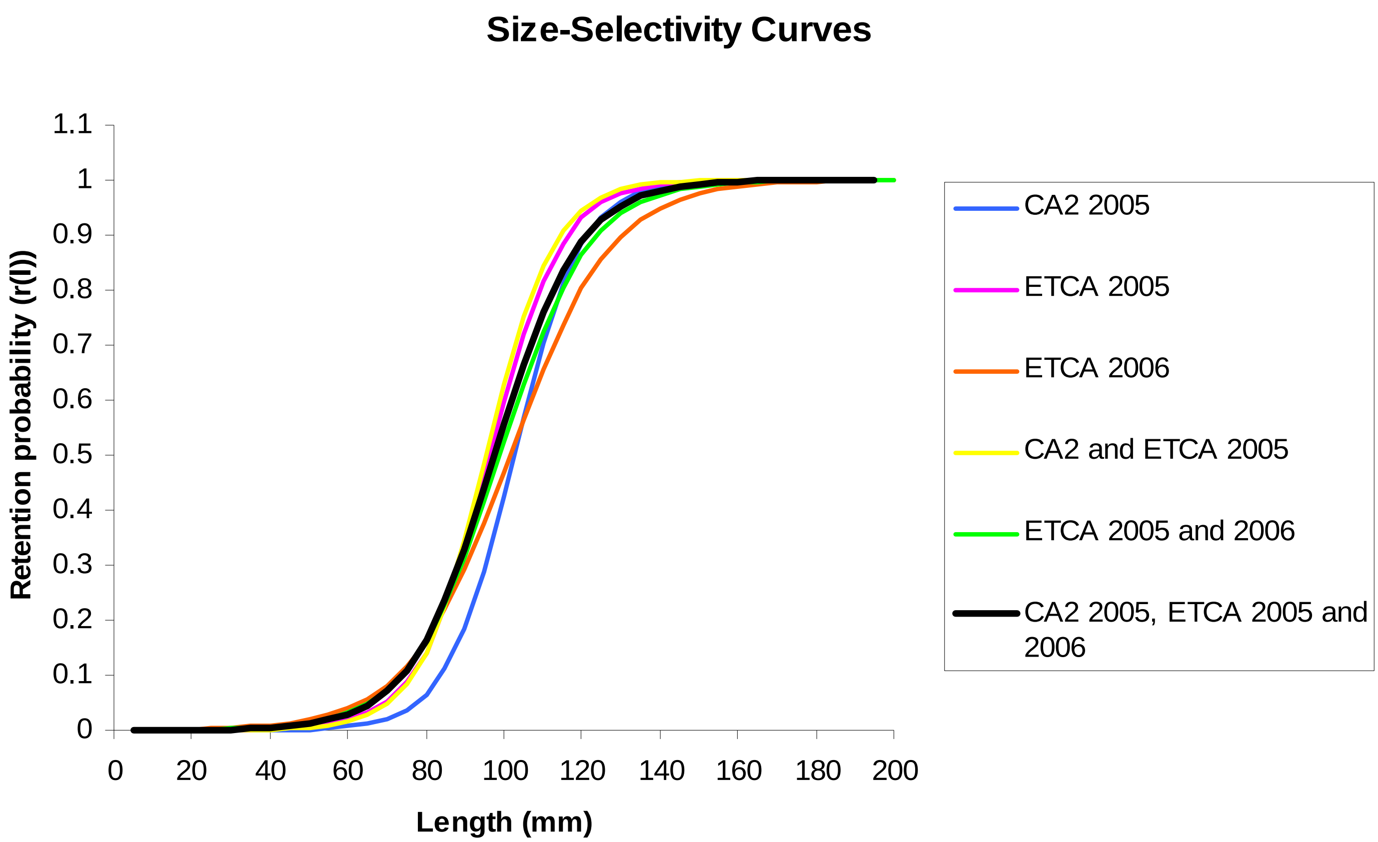
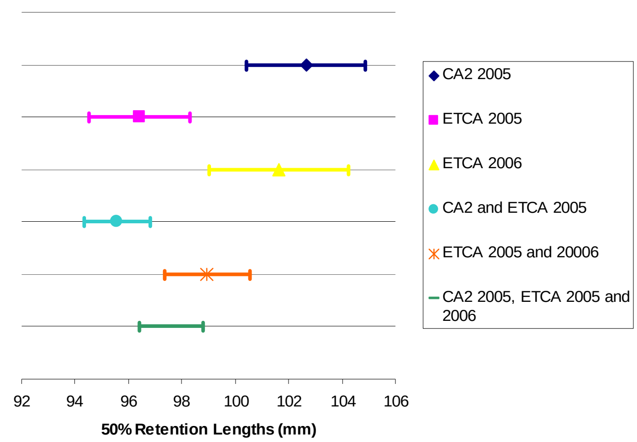
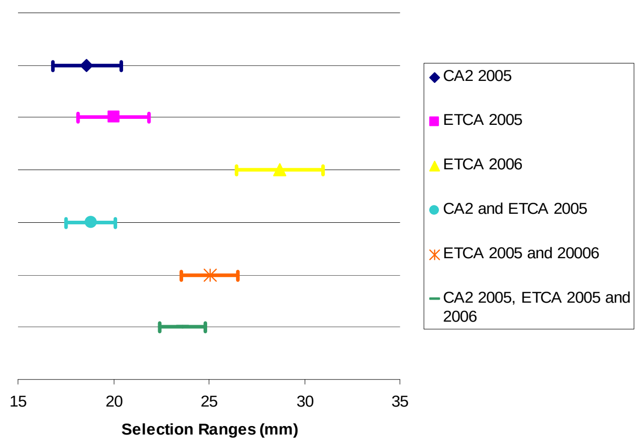


Figure 5. Estimated parameters for the different combinations of data with their confidence intervals.

A)



B)



C)

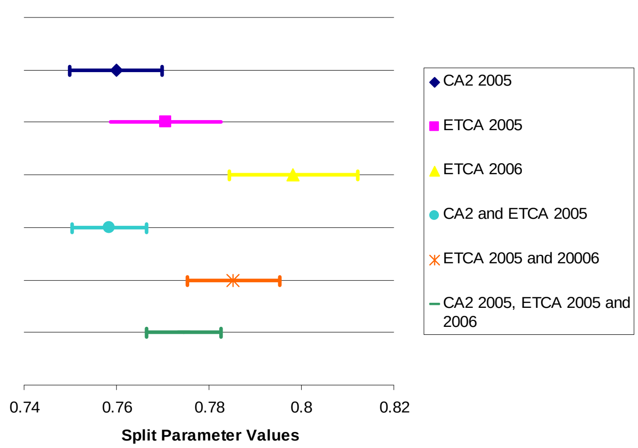


Figure 6. Logistic selection curve for the NLCA 2005 cruise and the curve for the CA2 2005, ETCA 2005 and ETCA 2006 cruises combined (final curve).

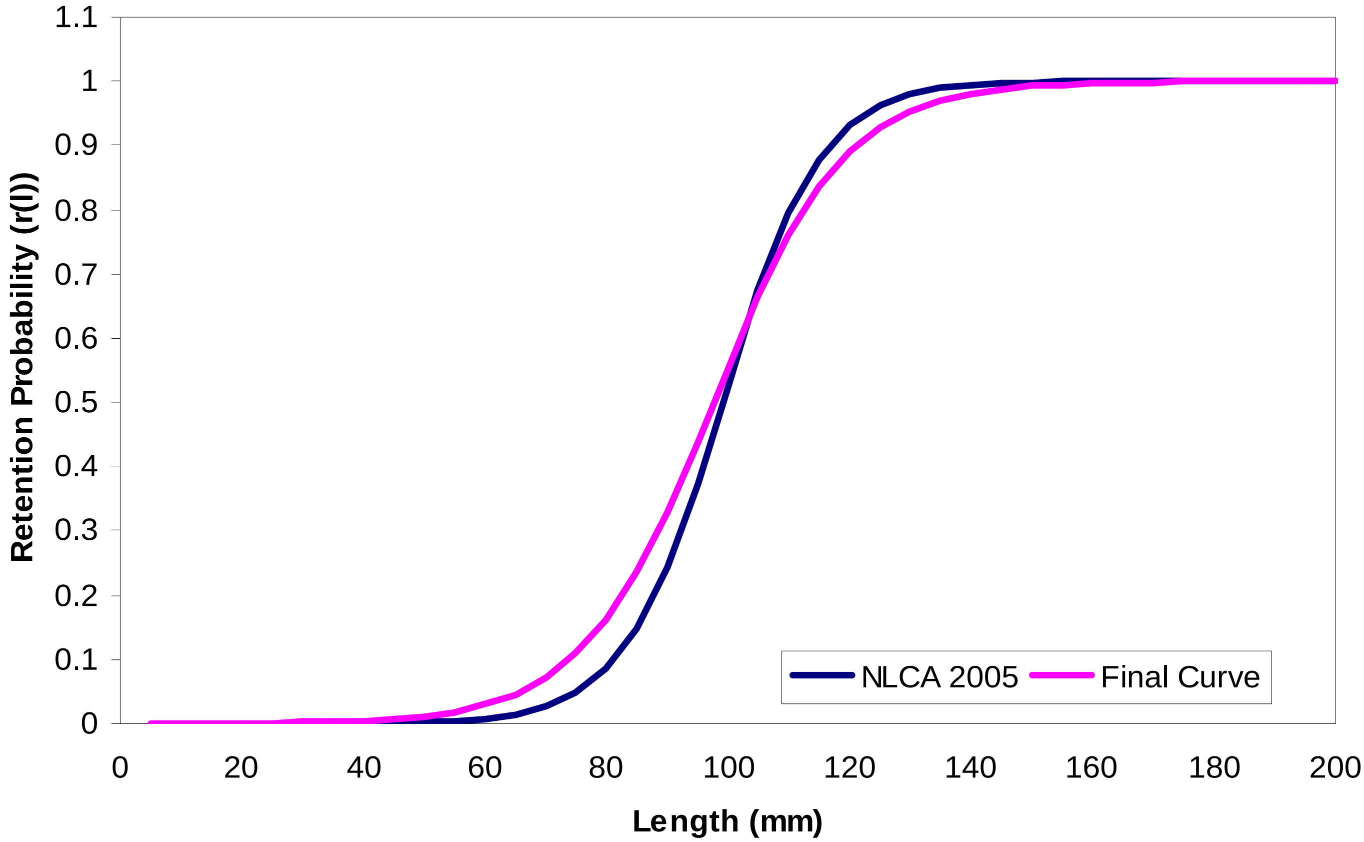
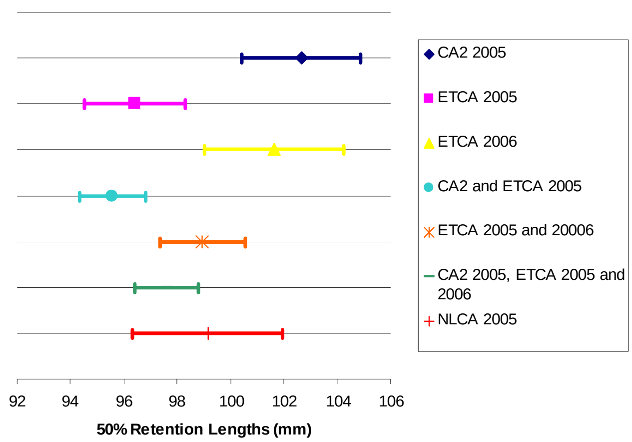
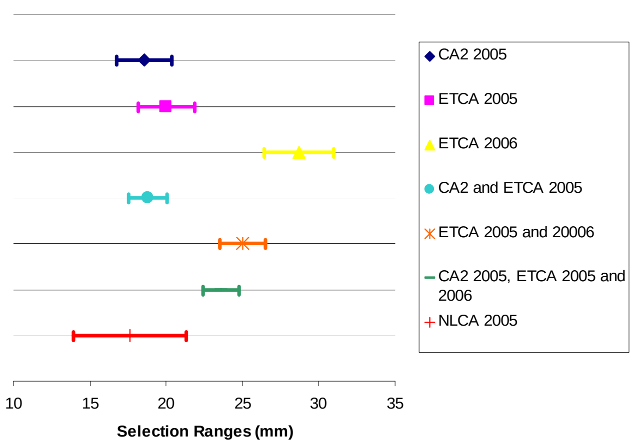


Figure 7. Estimated parameters for the different combinations of data (including the Nantucket Lightship Closed Area 2005 cruise) with their confidence intervals.

A)



B)



C)

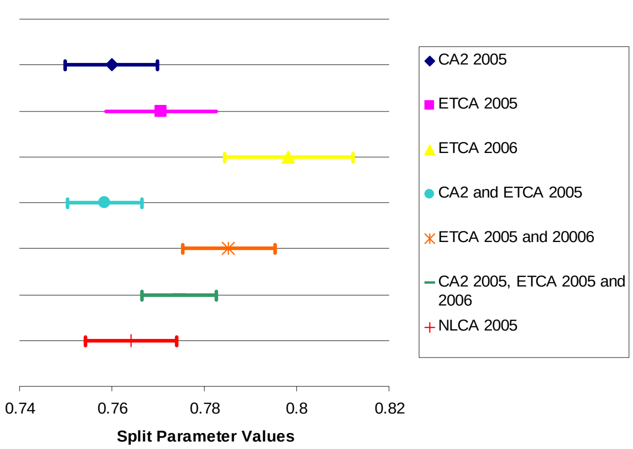


Table 1. Cruise and vessel information.

Cruise Number	**1**	**2**	**3**	**4**
Location	Nantucket Lightship Closed Area	Groundfish Closed Area II	Elephant Trunk Closed Area	Elephant Trunk Closed Area
Reference	NLCA 2005	CA2 2005	ETCA 2005	ETCA 2006
Dates of Survey	August 19-24	September 17-23	October 10-12, 18-23	June 5-12
Year	2005	2005	2005	2006
Vessel	F/V *Westport*	F/V *Celtic*	F/V *Carolina Boy*	F/V *Carolina Boy*
Length (ft)	88.1	88.1	85.3	85.3
Gross Tonnage	196	199	195	195
Captain	Edie Welch	Charlie Quinn	Rodney Watson	Rodney Watson
No. Tows Used in Analysis	35	54	50	69

Table 2. **Survey station and tow information (only the stations used in the data analysis are included in these figures).**

Cruise	NLCA 2005	CA2 2005	ETCA 2005	ETCA 2006
Average Station Depth (fathoms)	35.80	40.04	28.16	28.06
Station Depth Range (fathoms)	28-43	32-51	18-39	20-38
Average Minimum/Maximum Wind Speed	6.88/11.46	9.34/14.91	11.00/17.50	10.96/16.67
Average Minimum/Maximum Sea State	2/4.13	1.74/3.78	2.24/4.46	2.46/4.91
Average Tow Duration (hr:min)	14:37	15:47	14:42	15:39
Average Vessel Speed (knots)	3.8	3.8	3.8	3.8
Average Scope	3.11	3.06	3.01	2.97

Table 3. An assessment of how the number of length classes used in the analysis will affect the resulting parameters (the 50% retention length (l_{50}), the selection range (SR= l_{75} - l_{25}) and the relative efficiency split parameter (p_c)). The data was analyzed under the criteria that, for each length class, 1) at least one dredge had more than zero scallops, 2) at least one dredge had more than 20 scallops, 3) at least one dredge had more than 60 scallops and 4) at least one dredge had more than 1,000 scallops. The second criterion represents that which is used for this study. The length classes used under each situation and the log likelihoods (L) are also given.

Cruise(s)		>0	>20	>60	>1000
CA2 2005	Lengths	25-165	**45-160**	50-155	60-145
	l_{50} (mm)	102.65447	**102.66044**	102.68471	102.76290
	SR (mm)	18.59938	**18.60577**	18.62312	18.90600
	p_c	0.75989	**0.75992**	0.76008	0.76070
	L	-44823.84	**-44814.15**	-44773.37	-44383.55
ETCA 2005	Lengths	5-170	**20-150**	25-150	75-135
	l_{50} (mm)	96.37136	**96.41731**	96.41799	96.87916
	SR (mm)	19.99227	**20.02289**	20.02307	20.12396
	p_c	0.77034	**0.77070**	0.77071	0.77406
	L	-92431.86	**-92396.01**	-92395.99	-90342.28
ETCA 2006	Lengths	25-160	**25-150**	30-150	65-140
	l_{50} (mm)	101.64999	**101.64497**	101.65734	102.04229
	SR (mm)	28.70759	**28.70136**	28.71451	29.04931
	p_c	0.79827	**0.79825**	0.79831	0.80035
	L	-173214.64	**-173197.30**	-173197.05	-172008.06
CA2 & ETCA 2005	Lengths	5-170	**20-160**	25-155	60-145
	l_{50} (mm)	95.54761	**95.57826**	95.58805	95.84932
	SR (mm)	18.80613	**18.80661**	18.81477	19.21789
	p_c	0.75833	**0.75835**	0.75842	0.76021
	L	-137465.80	**-137451.90**	-137406.22	-136672.66
ETCA 2005 & 2006	Lengths	5-170	**20-155**	25-150	45-140
	l_{50} (mm)	98.94422	**98.94415**	98.97836	99.45376
	SR (mm)	25.03686	**25.03441**	25.06050	25.49206
	p_c	0.78522	**0.78522**	0.78544	0.78828
	L	-265847.43	**-265835.70**	-265792.77	-264889.72
CA2 2005, ETCA 2005 & ETCA 2006	Lengths	5-170	**20-160**	25-155	45-145
	l_{50} (mm)	97.60958	**97.60939**	97.62017	97.85313
	SR (mm)	23.60812	**23.60612**	23.61602	23.84986
	p_c	0.77445	**0.77445**	0.77452	0.77596
	L	-311049.03	**-311034.80**	-310986.57	-310200.04

Table 4. **Estimated parameters from the Logistic SELECT analysis on catch-at-length data for all length classes with at least 20 scallops in one of the dredges. Listed are the length classes used in the analysis' and the starting values to estimate the parameters. In addition, the estimated values (left column) for logistic parameters *a* and *b*, as well as the 50% retention length (l_{50}), the selection range (SR= l_{75}- l_{25}) and the relative efficiency split parameter (p_c) are given. The log likelihood (L) and the replication estimate of between-haul variation (REP) are specified as well as the standard errors (right column), which have been multiplied by the square root of REP.**

	CA2 2005		ETCA 2005		ETCA 2006		CA2 & ETCA 2005		ETCA 2005 & 2006		CA2 2005, ETCA 2005 & 2006	
Lengths	45-160		20-150		25-150		20-160		20-155		20-160	
Start values	(-13, 0.13, 0.8)		(-10, 0.1, 0.75)		(-12, 0.12, 0.8)		(-11, 0.11, 0.8)		(-12, 0.12, 0.8)		(-12, 0.12, 0.8)	
a	-12.1235		-10.5804		-7.7814		-11.1667		-8.6841		-9.0853	
b	0.1181		0.1097		0.0766		0.1168		0.0878		0.0931	
p_c	0.7599	0.005	0.7707	0.006	0.7983	0.007	0.7584	0.004	0.7852	0.005	0.7745	0.004
l_{50} **(mm)**	102.6604	1.112	96.4173	0.941	101.6450	1.303	95.5783	0.625	98.9442	0.799	97.6094	0.602
SR (mm)	18.6058	0.905	20.0229	0.924	28.7014	1.129	18.8066	0.638	25.0344	0.738	23.6061	0.594
L	-44814.15		-92396.01		-173197.30		-137451.90		-265835.70		-311034.80	
REP	4.5372		8.7343		8.5071		7.0850		8.7949		7.9839	

Table 5. **Estimated parameters from the Logistic SELECT analysis' on catch-at-length data for all length classes with at least 20 scallops in one of the dredges given for the NLCA 2005 cruise and for the CA2 2005, ETCA 2005 and 2006 cruises combined. Listed are the length classes used in the analysis' and the starting values to estimate the parameters. In addition, the estimated values (left column) for logistic parameters *a* and *b*, as well as the 50% retention probability length (l_{50}), the selection range (SR= l_{75}- l_{25}) and the relative efficiency split parameter (p_c) are given. The log likelihood (L) and the replication estimate of between-haul variation (REP) are specified as well as the standard errors (right column), which have been multiplied by the square root of REP.**

	NLCA 2005		CA2 2005, ETCA 2005 & 2006	
Lengths	40-170		20-160	
Start values	(-12, 0.12, 0.8)		(-12, 0.12, 0.8)	
a	-12.3559		-9.0853	
b	0.1246		0.0931	
p_c	0.7642	0.0049	0.7745	0.0035
l_{50} **(mm)**	99.1353	1.4168	97.6094	0.6020
SR (mm)	17.6290	1.8481	23.6061	0.5941
L	-50672.09		-311034.80	
REP	2.8297		7.9839	

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