7-1-2006

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

William D. DuPaul
Virginia Institute of Marine Science

David Rudders
Virginia Institute of Marine Science

Recommended Citation

DuPaul, W. D., & Rudders, D. (2006) An Assessment of Sea Scallop Abundance and Distribution in Selected Areas of Georges Bank and the Mid-Atlantic. Marine Resource Report No. 2006-2. Virginia Institute of Marine Science, William & Mary. http://dx.doi.org/doi:10.21220/m2-6yr3-2f70

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

---

Submitted to:

Sea Scallop Plan Development Team
Falmouth, MA

William D. DuPaul
David B. Rudders

Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA 23062

VIMS Marine Resource Report No. 2006-2

May 8, 2006

Revised: July 10, 2006

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.

<u>Data Analysis</u>

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:

$$TotalBiomass = \sum_{j}\left(\frac{\left(\dfrac{CatchWtperTowinSubarea_{j}}{AreaSweptperTow}\right)}{Efficiency}\right)SubArea_{j}$$

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

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

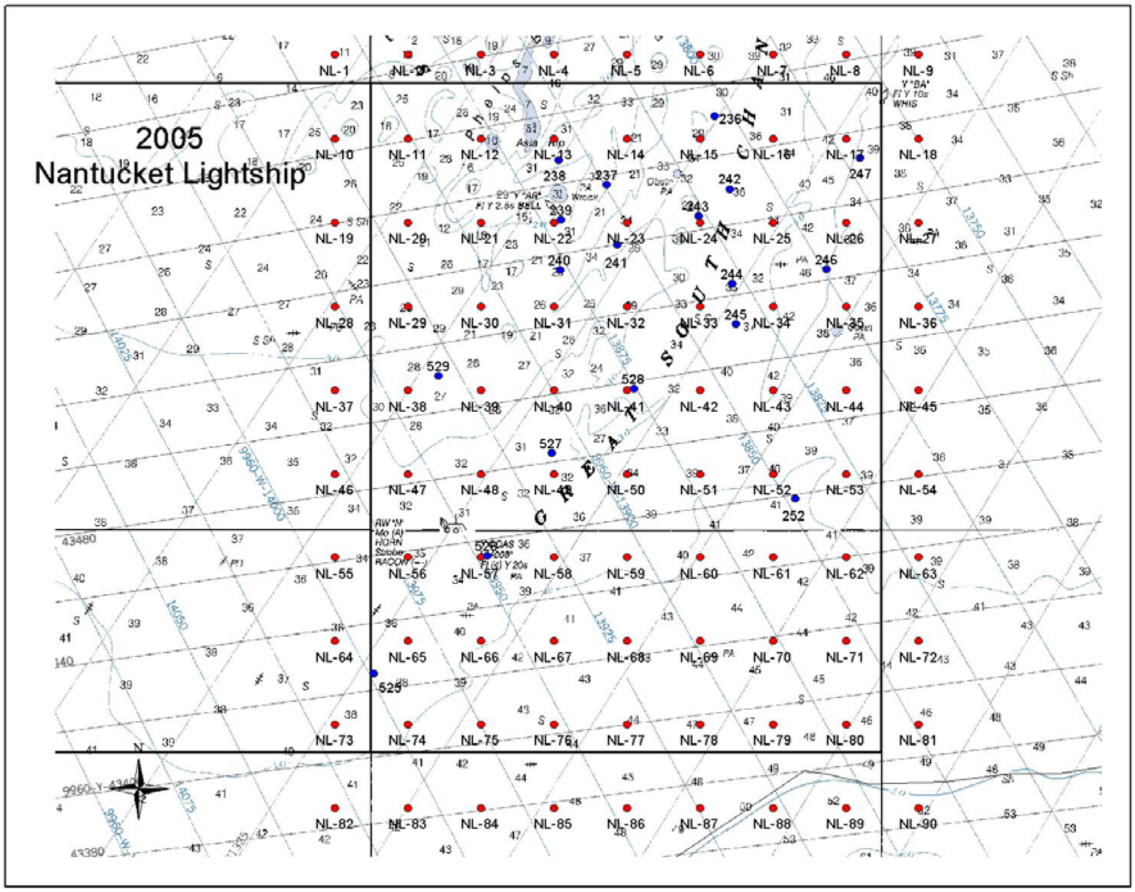


Figure 2 Locations of sampling stations in Closed Area II survey by the F/V *Celtic* during the cruise conducted during September 2005.

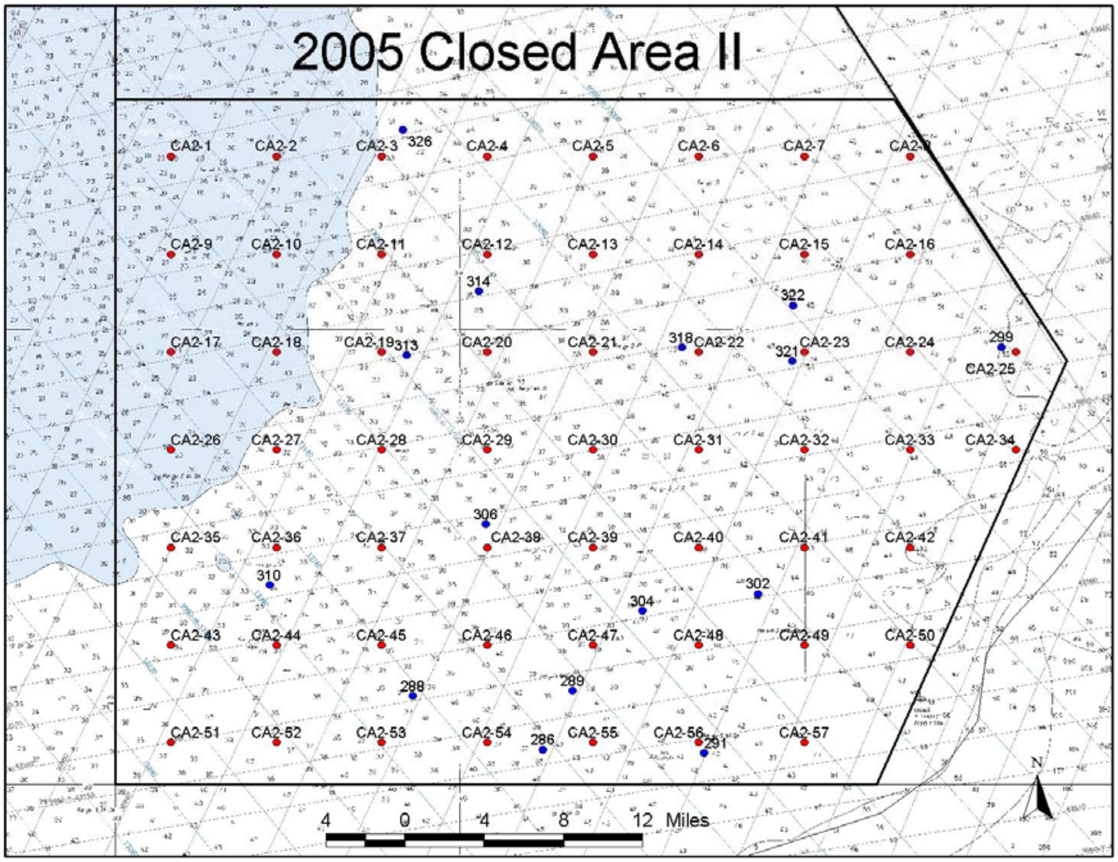


Figure 3 Locations of sampling stations in the Nantucket Lightship Closed Area survey by the F/V *Carolina Boy* during the cruise conducted during October 2005.

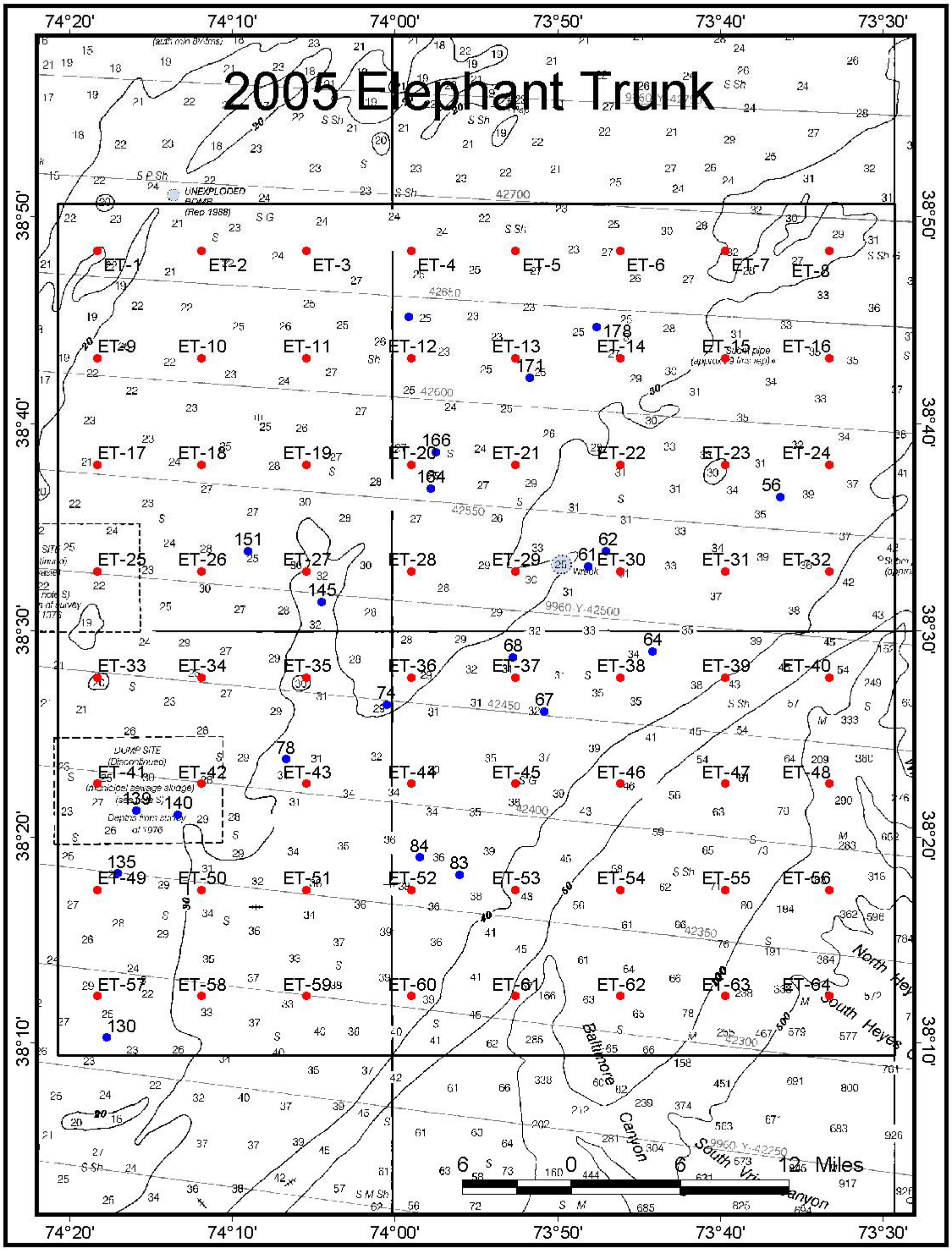
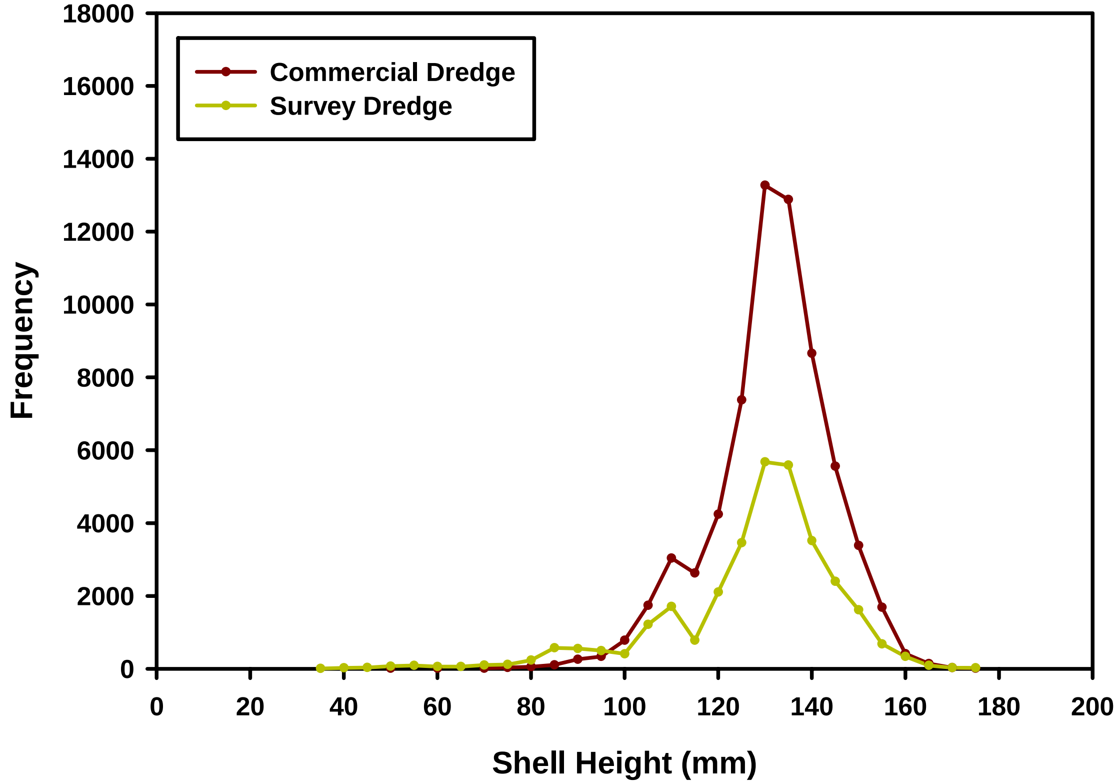


Figure 4 Shell height frequency for the cooperative survey of the Nantucket Lightship Closed Area aboard the F/V W*estport* conducted August 2005. The two frequencies represent the unadjusted catches from the two gears used during the survey.



Draft document-for Scallop PDT use only
Do not circulate, copy or cite

<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.

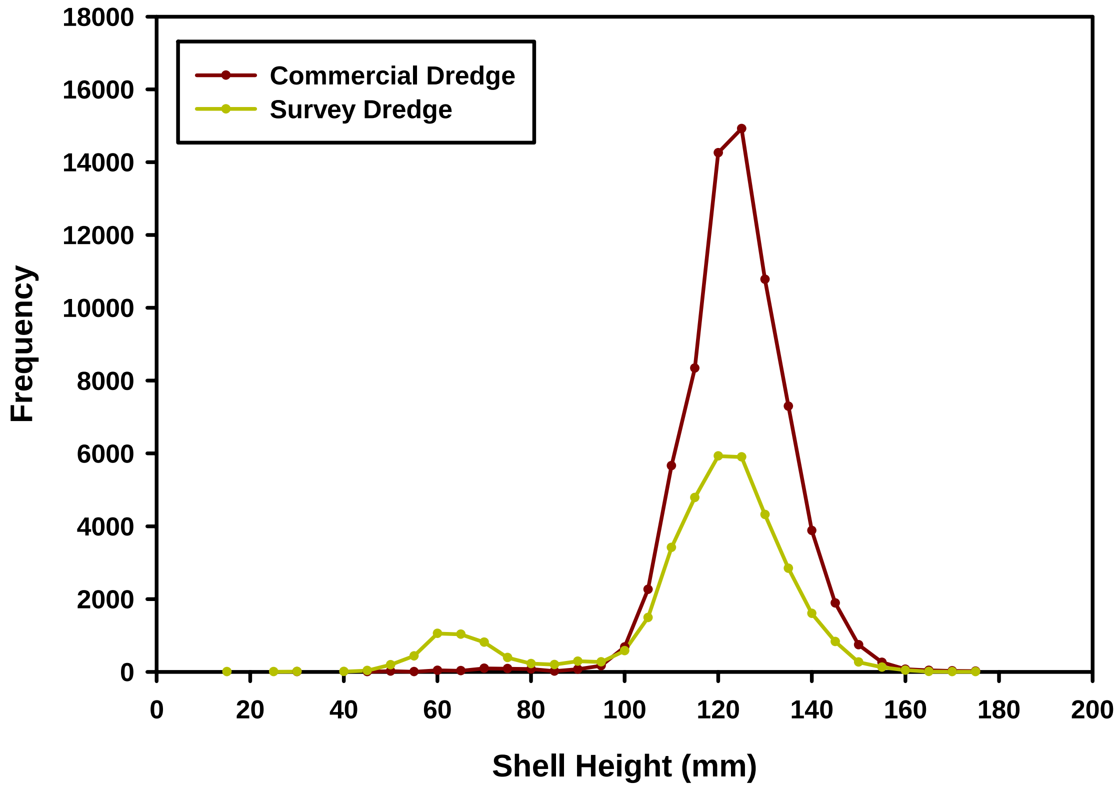


Figure 6 Shell height frequency for the cooperative survey of the Elephant Trunk Closed Area aboard the F/V *Carolina Boy* conducted October 2005. The two frequencies represent the unadjusted catches from the two gears used during the survey.

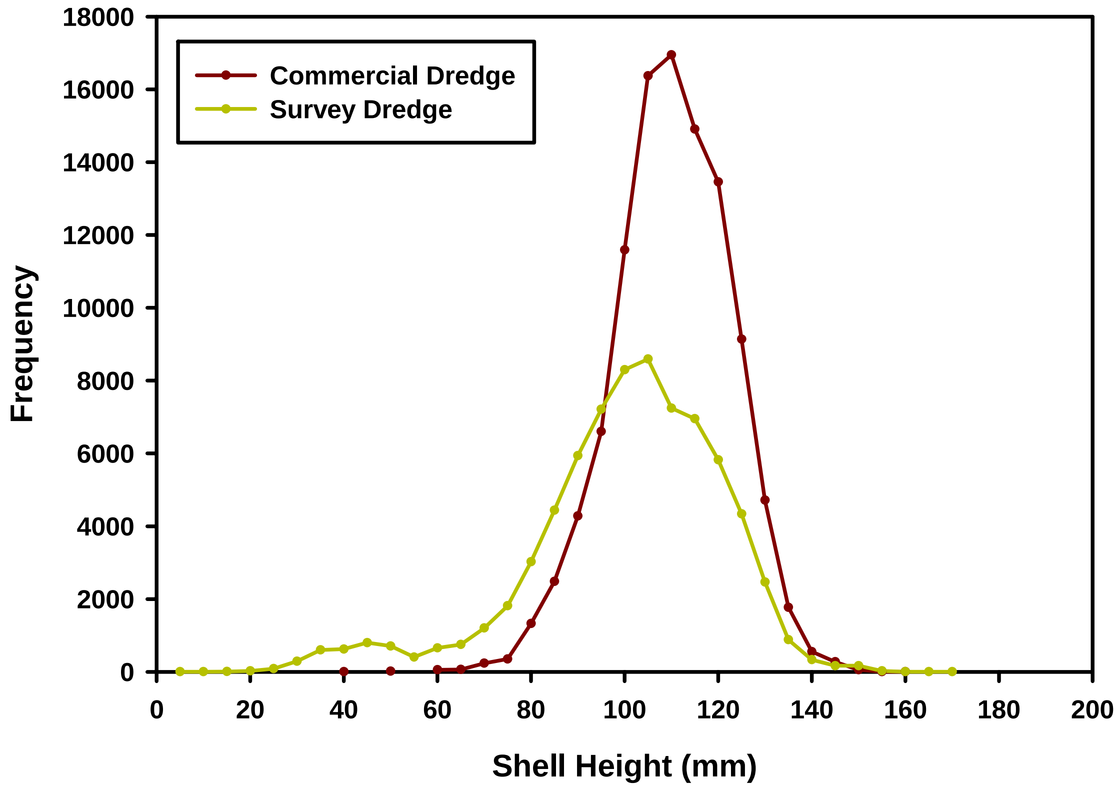


Figure 7 Interpolated catches for the Nantucket Lightship Closed Area derived from survey data obtained aboard the F/V *Westport* during August 2005.

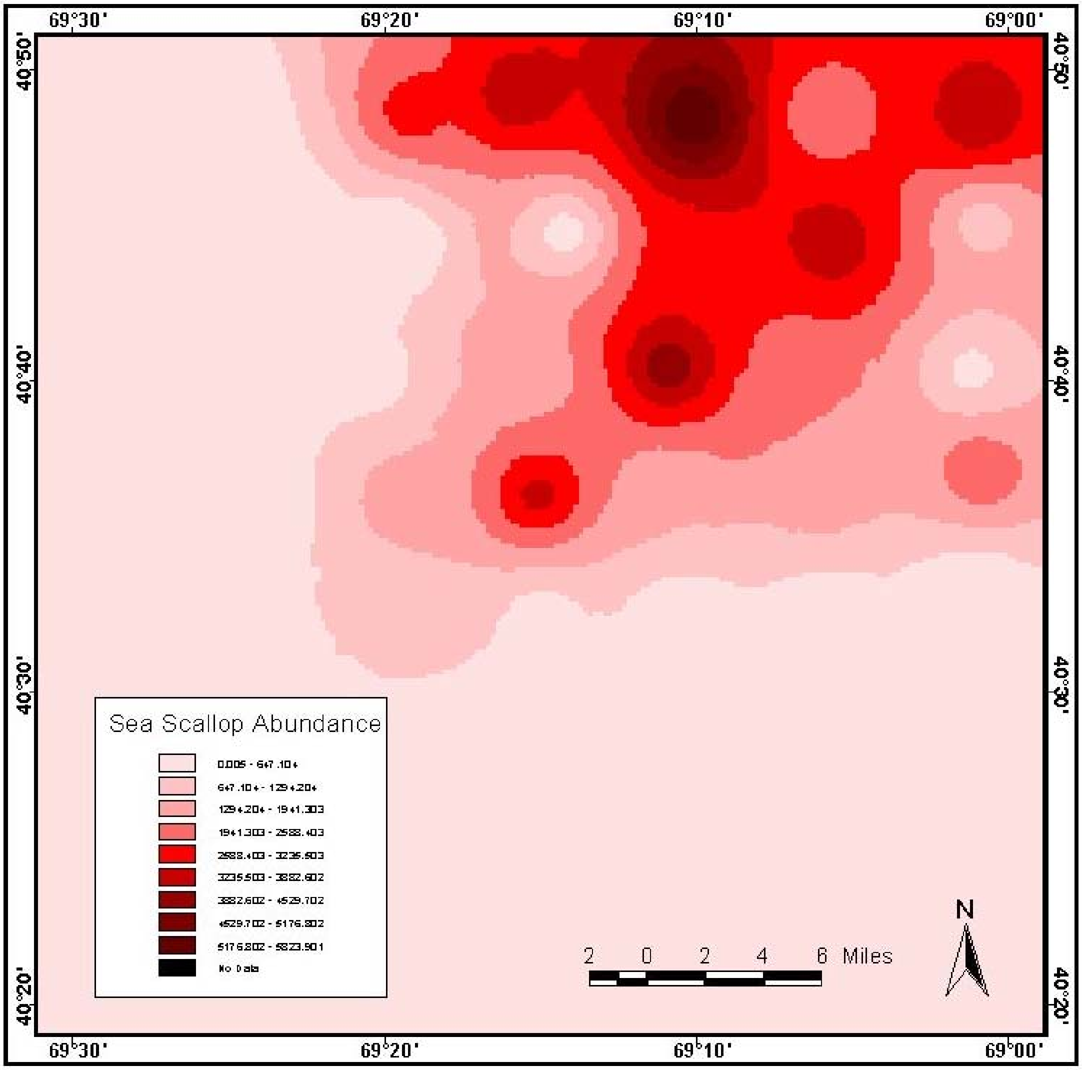


Figure 8 Interpolated catches for the Closed Area II derived from survey data obtained aboard the F/V *Celtic* during September 2005.

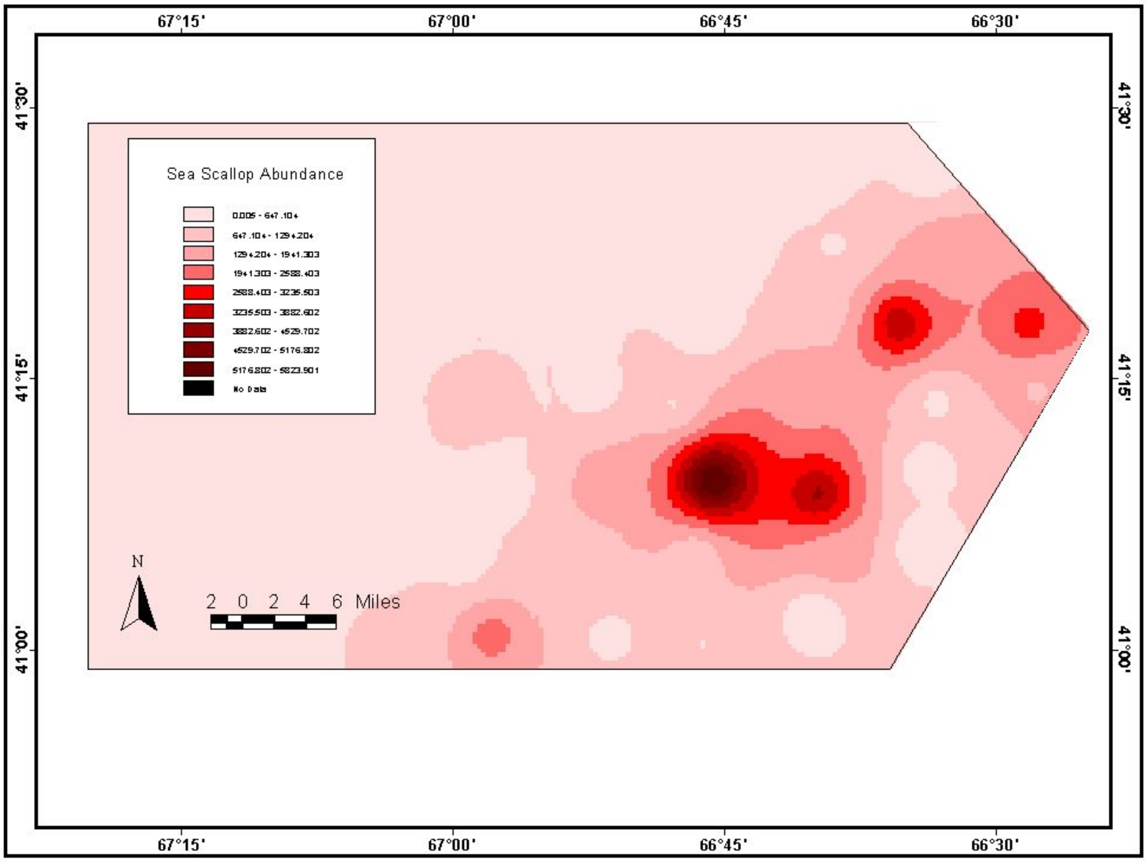


Figure 9 Interpolated catches for the Elephant Trunk Closed Area derived from survey data obtained aboard the F/V *Carolina Boy* during October 2005.

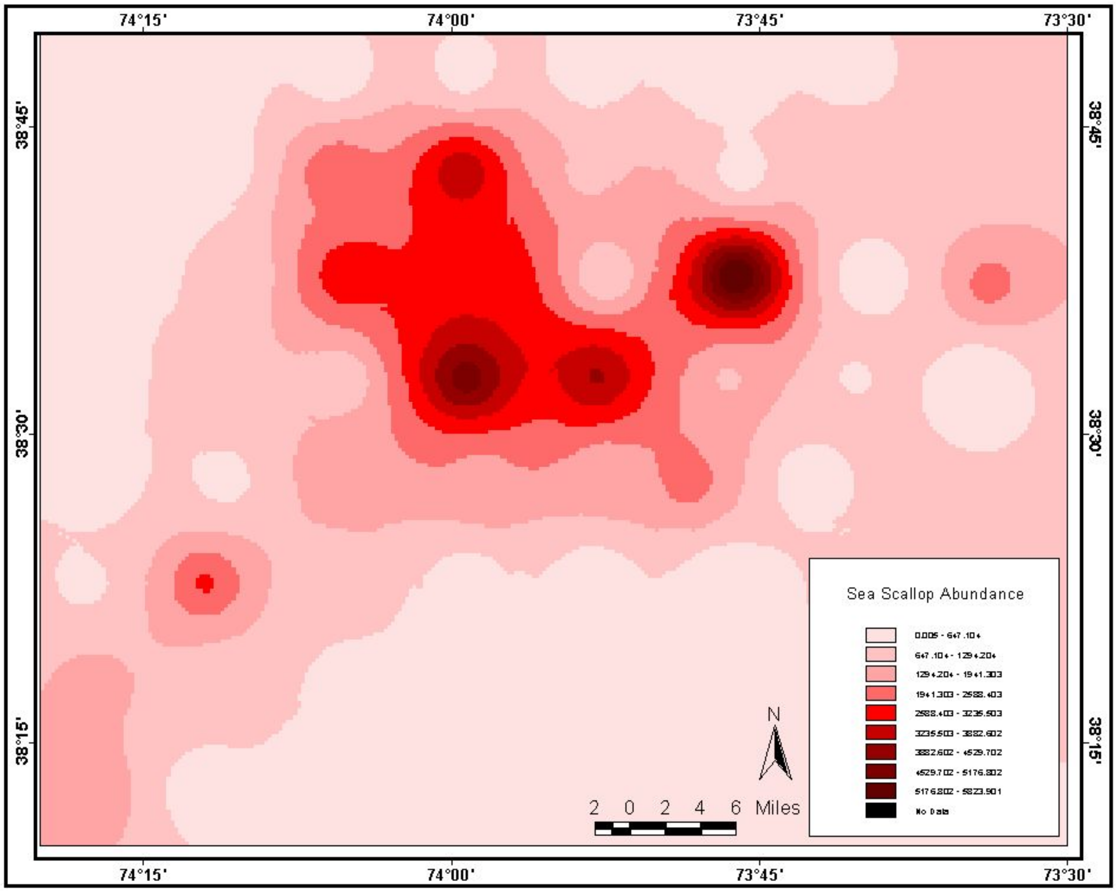
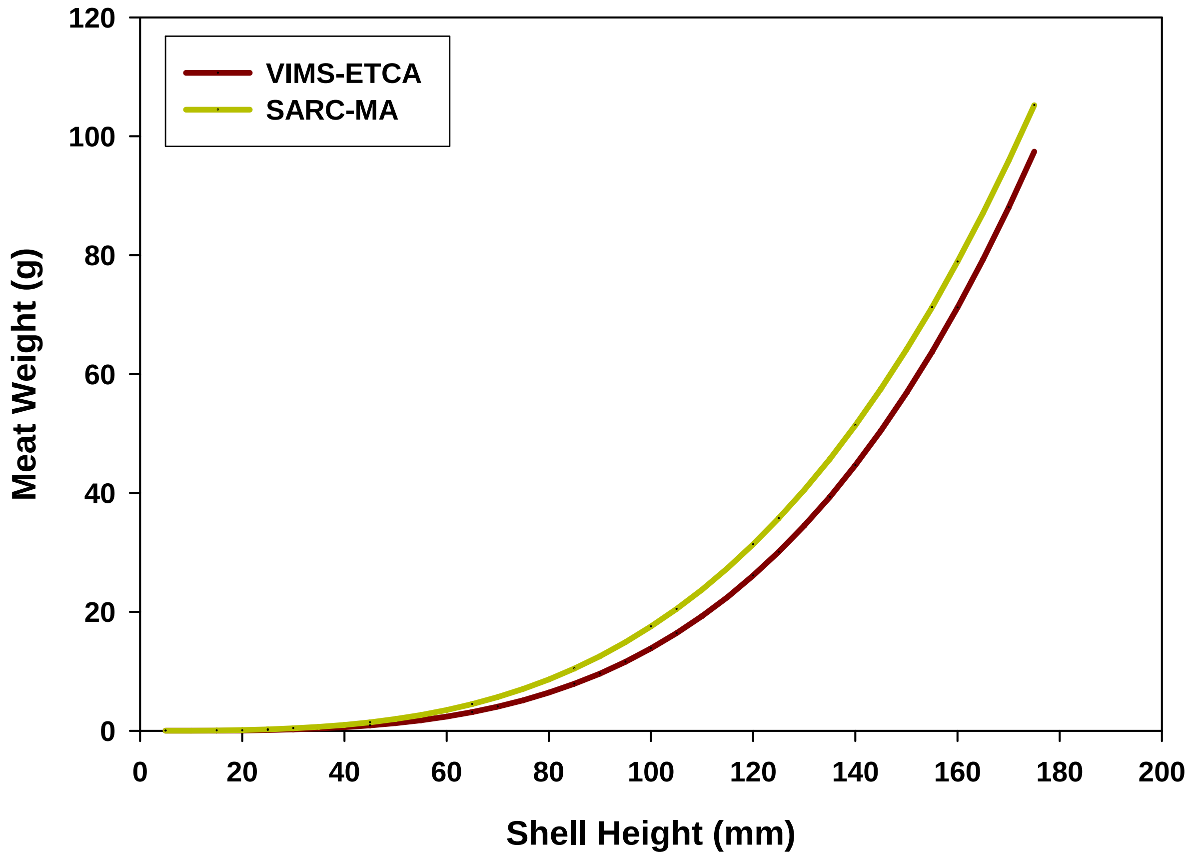
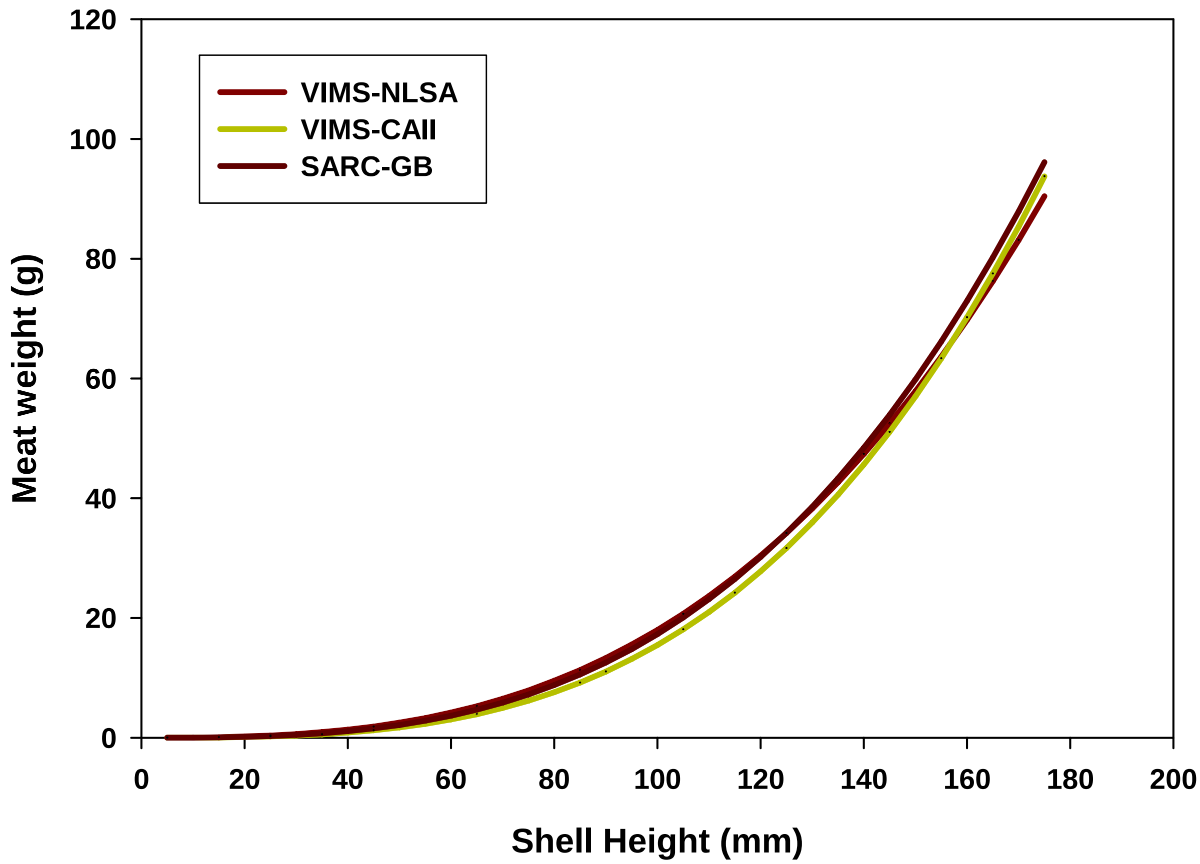


Figure 10 Comparison between fitted shell height-meat weight relationships. The two curves are the product of parameters generated from different sources. The curve labeled VIMS-ETCA was generated from data collected during the survey cruise conducted aboard the F/V *Carolina Boy* during October 2006.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



Literature Cited

DuPaul, W.D., E.J. Heist, and J.E. Kirkley, 1989. Comparative analysis of sea scallop escapement/retention and resulting economic impacts. College of William & Mary, Virginia Institute of Marine Science, Gloucester Point, VA. VIMS Marine Resource Report 88-10. 70 pp.

DuPaul, W.D. and J.E. Kirkley, 1995. Evaluation of sea scallop dredge ring size. Contract report submitted to NOAA, National Marine Fisheries Service. Grant # NA36FD0131.

Gedamke, T., W.D. DuPaul, and J.M. Hoenig. 2004. A Spatially Explicit Open-Ocean DeLury Analysis to Estimate Gear Efficiency in the Dredge Fishery for Sea Scallop *Placopecten magellanicus*. North American Journal of Fisheries Management 24:335-351.

Gedamke, T., W.D. DuPaul, and J.M. Hoenig. 2005. Index-Removal Estimates of Dredge Efficiency for Sea Scallops on Georges Bank. North American Journal of Fisheries Management 25:1122-1129.

Goff, K.D. 2002. Ring Diameter and Closed Area Scallop Fisheries. The Performance of a Dredge with 4" Rings in the Atlantic Sea Scallop (*Placopecten magellanicus*) Fishery, in the Context of an Area rotation Management Scheme. Virginia Institute of Marine Science Thesis. 81 pp.

Gunderson, D.R. 1993. Surveys of Fisheries Resources. John Wiley & Sons, Inc. New York, NewYork.

Northeast Fisheries Science Center. 2004. 39th Northeast Regional Stock Assessment Workshop (39th SAW) assessment summary report. *U.S. Dep. Commer., Northeast Fish. Sci. Cent. Ref. Doc.* 04-10a; 16 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026.

Serchuk, F.M. and Smolowitz, R.J. 1980. Size Selection of Sea Scallops by an Offshore Scallop Survey Dredge. ICES C.M. K:24. 38 pp.

Serchuk, F.M. and Smolowitz, R.J. 1989. Seasonality in sea scallop somatic growth and reproductive cycles. J. Shellfish Res.. 8:435.

Stokesbury, K.D. 2002. Estimation of sea scallop abundance in closed areas of Georges Bank, USA. Trans. of the Amer. Fish. Soc. 131:1081-1092.

Van Voorhees, D. 2005. Fisheries of the United States, 2004. NMFS Office of Science and Technology, Fisheries Statistics Division.