Final Report

An Assessment of Sea Scallop Abundance and Distribution in a Selected Closed Area: Hudson Canyon Closed Area

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166 Water Street
Woods Hole, Massachusetts 02543-1026

Submitted by:

David B. Rudders
William D. DuPaul

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

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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 July 2010, a survey was conducted in the Hudson Canyon Closed Area (HCCA) aboard a commercial sea scallop vessel. At pre-determined sampling stations within the HCCA, both a NMFS survey dredge and a Coonamessett Farm Turtle Deflector Dredge (CFTDD) were simultaneously towed. From this trip, fine scale survey data was used to assess scallop abundance and distribution in the closed area. This data 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 the 2009 fishing year landed 58 million pounds of meats with an ex-vessel value of over US $382 (Pritchard, 2010). These landings resulted in the sea scallop fishery being the most valuable single species fishery along the East Coast of the United States. While historically subject to extreme cycles of productivity, the fishery has benefited from recent management measures intended to bring stability and sustainability. These measures include: 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 optically. Researchers from the School for Marine Science and Technology (SMAST) and the Woods Hole Oceanographic Institute (WHOI) are able to enumerate sea scallop abundance and distribution from images taken by both a still camera and a towed camera system (Stokesbury, *et. al.,* 2004;

Stokesbury, 2002). Prior to the utilization of the optical surveys and in addition to the annual information supplied by the NMFS annual survey, commercial vessels were contracted to perform surveys. Dredge surveys of the scallop access areas have been successfully completed by the cooperative involvement of industry, academic and governmental partners. The additional information provided by these surveys 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 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.

In addition to collecting data to assess the abundance and distribution of sea scallops in the HCCA, the operational characteristics of commercial scallop vessels allow for the simultaneous towing of two dredges. As in past surveys, we towed two dredges at each station. One dredge was a NMFS sea scallop survey dredge and the other was a Coonamessett Farm Turtle Deflector Dredge (CFTDD). This paired design allowed for the estimation of the size selective characteristics of CFTDD equipped with turtle excluder chains. Gear performance information does not exist for this dredge design and understanding how this dredge impacts the scallop resource will be beneficial for two reasons. First, it will be an important consideration for the stock assessment for scallops in that it provides the size selectivity characteristics of the most recent gear configuration and second, this information will support the use of this gear configuration to sample closed areas prior to re-openings. In addition, selectivity analyses using the SELECT method provide insight to the relative efficiency of the two gears used in the study (Millar, 1992). The relative efficiency measure from this experiment can be used to refine existing absolute efficiency estimates for the New Bedford style scallop dredge.

One of the stated advantages of a dredge sea scallop survey is that one can access and sample the target species. One parameter routinely measured is the shell height:meat weight relationship. While this parameter is used to determine swept area biomass for the area surveyed at that time, it can also be used as an indicator of seasonal shifts in biomass due to the influence of spawning. For this reason, data on the shell height:meat weight relationship is routinely gathered by both the NMFS and VIMS scallop surveys. While this relationship may not be a direct indicator of animal health in and of itself, long term data sets may be useful in evaluating changing environmental conditions, food availability and density dependent interactions.

For this study, we pursued multiple objectives. The primary objective was to collect information to characterize the abundance and distribution of sea scallops within the access area of HCCA. Utilizing the same catch data with a different analytical approach, we estimated the size selectivity characteristics of the commercial sea scallop dredge. In addition, an additional component of the selectivity analysis allows for supplementary information regarding the efficiency of the commercial dredge relative to the NMFS survey dredge. As a third objective of this study, we collected biological samples to estimate a time and area specific shell height:meat weight relationship.

Methods

Survey Area and Sampling Design

The HCCA was surveyed during the course of this project. The boundary coordinates of the surveyed areas can be found in Table 1. 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 industry-based surveys since 1998.

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 sample size analysis conducted using the catch data from survey trips conducted in the same areas during prior years. Since closed areas are of different dimensions and the total number of stations sampled per survey remains fairly constant, the distance between the stations varies. Generally, the distance between stations is roughly 3-4 nautical miles. 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 2010 HCCA survey are shown in Figure 1.

Sampling Protocols

While at sea, the vessels simultaneously towed two dredges. A NMFS 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 14 foot Coonamessett Farm Turtle Deflector Dredge (CFTDD) 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 turtle 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 opposite sides of the vessel mid-way throughout the trip to help minimize any bias.

For each survey tow, the dredges were fished for 15 minutes with a towing speed of approximately 3.8-4.0 kts. High-resolution navigational logging equipment was used to accurately determine and record vessel position. A Star-Oddi™ DST sensor was used on the dredge to measure and record dredge tilt angle as well as depth (Figure 2). With these measurements, the start and end of each tow was estimated. Synchronous time stamps on both the navigational log and DST sensor were used to estimate the linear distance for each tow. A histogram depicting the estimated linear distances covered per tow over the entire survey is shown in Figure 3.

Sampling of the catch was performed using the protocols established by DuPaul and Kirkley, 1995 and DuPaul *et. al.* 1989. For each survey tow, the entire scallop catch was placed in baskets. Depending on the total volume of the catch, a fraction of these baskets were measured for sea scallop length frequency. The shell height of each scallop in the sampled fraction was measured on NMFS sea scallop measuring boards in 5 mm intervals. This protocol allows for the estimation of the size frequency for 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 roughly 25 randomly selected stations the shell height of 10 randomly selected scallops were measured to the nearest 0.1 mm. These 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 using a generalized linear mixed model (gamma distribution, log link) incorporating depth as an explanatory variable using PROC GLIMMIX in SAS v. 9.2. The relationship was estimated with the following model:

$$\ln MW = \ln\alpha + \beta * \ln SH + \gamma * \ln Depth$$

where MW=meat weight (grams), SH=shell height (millimeters), Depth=depth (meters). α, β and γ are parameters to be estimated.

The standard data sheets used since the 1998 Georges Bank survey were used. Data recorded on the bridge log included GPS location, 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 and navigation data were used to estimate swept area biomass within the area surveyed. The methodology to estimate biomass is similar to that used in previous survey work by VIMS. In essence, we estimate a mean abundance from the point estimates and scale that value up to the entire area of the domain sampled. This calculation is given:

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

Catch weight per tow of exploitable scallops was calculated from the raw catch data as an expanded size frequency distribution with an area and depth appropriate shell height-meat weight relationship applied (length-weight relationships were obtained from SARC 50 document as well as the actual relationship taken during the cruise) (NEFSC, 2010). Exploitable biomass, defined as that fraction of the population vulnerable to capture by the currently regulated commercial gear, was calculated using two approaches. The observed catch at length data from the NMFS survey dredge (assumed to be non size selective) was adjusted based upon the size selectivity characteristics of the commercial gear (Yochum and DuPaul, 2008). The observed catch-at-length data from the commercial dredge was not adjusted due to the fact that these data already represent that fraction of the population that is subject to exploitation by the currently regulated commercial gear.

Utilizing the information obtained from the high resolution GPS, an estimate of area swept per tow was calculated. Throughout the cruise, the location of the ship was logged every three seconds. By determining the start and end of each tow based on the recorded times as delineated by the tilt sensor data, 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 (either 14 or 8 ft.) to result in an estimate of the area swept during a given survey tow.

The final two components of the estimation of biomass are constants and not determined from experimental data obtained on these cruises. Estimates of survey dredge gear efficiency have been calculated from a prior experiment using a comparison of optical and dredge catches (NEFSC, 2010). Based on this experiment, an efficiency value for the NMFS survey dredge of 38% was estimated for the rocky substrate areas on Georges Bank and a value of 44% was estimated for the smoother (sand, silt) substrates of some portions of Georges Bank and the entire mid-Atlantic. Estimates of commercial sea scallop dredge 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.). The efficiency of the commercial dredge is generally considered to be higher and based on the prior work as well as the relative efficiency from the data generated from this study; an efficiency value of 65% was used for the

HCCA. To scale the estimated mean scallop catch to the full domain, the total area of the HCCA was calculated in ArcGIS v. 9.0.

Size Selectivity

The estimation of size selectivity of the CFTDD equipped with 4” rings, a 10” twine top and turtle chains was based on a comparative analysis of the catches from the two dredges used in the survey. For this analysis, the NMFS survey dredge is assumed to be non-selective (i.e. a scallop that enters the dredge is retained by the dredge). Catch at length from the selective gear (commercial dredge) are compared to the non-selective gear via the SELECT method (Millar, 1992).   The selective properties (i.e. the length based probability of retention) of the commercial dredge are estimated. In addition to estimates of the length based probabilities of capture by the commercial dredge, the SELECT method characterizes a measure of relative fishing intensity. Assuming a known quantity of efficiency for one of the two gears (in this case the survey dredge at 44%), insight into the efficiency of the other gear (commercial dredge) can be attained.

Prior to analysis, all comparative tows were evaluated. Any tows that were deemed to have had problems during deployment or at any point during the tow (flipped, hangs, crossed towing wires, etc.) were removed from the analysis. In addition, tows where zero scallops were captured by both dredges were also removed from the analysis. The remaining tow pairs were then used to analyze the size selective properties of the commercial with the SELECT method.

The SELECT method has become the preferred method to analyze size-selectivity studies encompassing a wide array of fishing gears and experimental designs (Millar and Fryer, 1999). This analytical approach conditions the catch of the selective gear at length *l* to the total catch (from both the selective gear variant and small mesh control).

$$\Phi_c(l) = \frac{p_c r_c(l)}{p_c r_c(l) + (1 - p_c)}$$

Where r(l) is the probability of a fish at length l being retained by the gear given contact and p is the split parameter, (measure of relative efficiency). Traditionally selectivity curves have been described by the logistic function. This functional form has symmetric tails. In certain cases, other functional forms have been utilized to describe size selectivity of fishing gears. Examples of different functional forms include Richards, log-log and complimentary log-log. Model selection is determined by an examination of model deviance (the likelihood ratio statistic for model goodness of fit) as well as Akaike Information Criterion (AIC) (Xu and Millar, 1993, Sala, *et. al.*, 2008). For towed gears, however, the logistic function is the most common functional form observed in towed fishing gears. Given the logistic function:

$$r(l) = \left(\frac{\exp(a + bl)}{1 + \exp(a + bl)} \right)$$

by substitution:

$$\Phi(L) = \frac{pr(L)}{(1-p) + pr(L)} = \frac{p\frac{e^{a+bL}}{1+e^{a+bL}}}{(1-p) + p\frac{e^{a+bL}}{1+e^{a+bL}}} = \frac{pe^{a+bL}}{(1-p) + e^{ea+bL}}$$

Where a, b, and p are parameters estimated via maximum likelihood. Based on the parameter estimates, L_{50} and the selection range (SR) are calculated.

$$L_{50} = \frac{-a}{b} \qquad\qquad SR = \frac{2 * \ln(3)}{b}$$

Where L_{50} defines the length at which an animal has a 50% probability of being retained, given contact with the gear and SR represents the difference between L_{75} and L_{25} which is a measure of the slope of the ascending portion of the logistic curve.

In situations where catch at length data from multiple comparative tows is pooled to estimate an average selectivity curve for the experiment, tow by tow variation is often ignored. Millar *et al.* (2004) developed an analytical technique to address this between-haul variation and incorporate that error into the standard error of the parameter estimates. Due to the inherently variable environment that characterizes the operation of fishing gears, replicate tows typically show high levels of between-haul variation. This variation manifests itself with respect to estimated selectivity curves for a given gear configuration (Fryer 1991, Millar *et. al.*, 2004). If not accounted for, this between-haul variation may result in an underestimate of the uncertainty surrounding estimated parameters increasing the probability of spurious statistical significance (Millar *et. al.,* 2004).

Approaches developed by Fryer (1991) and Millar *et. al.,* (2004) address the issue of between-haul variability. One approach formally models the between-haul variability using a hierarchical mixed effects model (Fryer 1991). This approach quantifies the variability in the selectivity parameters for each haul estimated individually and may be more appropriate for complex experimental designs or experiments involving more than one gear. For more straightforward experimental designs, or studies that involve a single gear, a more intuitive combined-haul approach may be more appropriate.

This combined-hauls approach characterizes and then calculates an overdispersion correction for the selectivity curve estimated from the catch data summed over all tows, which is identical to a curve calculated simultaneously to all individual tows. Given this identity, a replication estimate of between-haul variation (REP) can be calculated and used to evaluate how well the expected catch using the selectivity curve calculated from the combined hauls fits the observed catches for each individual haul (Millar *et. al.* 2004).

REP is calculated as the Pearson chi-square statistic for model goodness of fit divided by the degrees of freedom.

$$REP = \frac{Q}{d}$$

Where Q is equal to the Pearson chi-square statistic for model goodness of fit and d is equal to the degrees of freedom. The degrees of freedom are calculated as the number of terms in the summation, minus the number of estimated parameters. The calculated replicate estimate of between-haul variation was used to calculate observed levels of extra Poisson variation by multiplying the estimated standard errors by $\sqrt{REP}$.

A significant contribution of the SELECT model is the estimation of the split parameter which estimates the probability of an animal “choosing” one gear over another (Holst and Revill, 2009). This measure of relative efficiency, while not directly describing the size selectivity properties of the gear, is insightful relative to both the experimental design of the study as well as the characteristics of the gears used. A measure of relative efficiency (on the observational scale) can be calculated in instances where the sampling intensity is unequal. In this case, the sampling intensity is unequal due to differences in dredge width. Relative efficiency can be computed for each individual trip (Park *et. al.*, 2007).

$$RE = \frac{p/(1-p)}{p_0/(1-p_0)}$$

Where p is equal to the observed (estimated p value) and p_0 represents the expected value of the split parameter based upon the dredge widths in the study. For this study, a 14 ft. commercial dredge was used with expected split parameter of 0.6363. The computed relative efficiency values were then used to scale the estimate of the NMFS survey dredge efficiency obtained from the optical comparisons (44%). Computing efficiency for the estimated p value from Yochum and DuPaul (2008) yields a commercial dredge efficiency of 64%. That work was conducted throughout the range of the scallop in areas (Georges Bank) where dredge efficiency is expected to be lower. Preliminary observations suggest a slightly higher efficiency of the CFTDD relative to the standard New Bedford style scallop dredge. This selectivity analysis will provide an additional piece of evidence related to the efficiency of the CFTDD.

Results

Abundance and distribution

The survey cruise to the HCCA was completed in July 2010. Summary statistics for the cruise is shown in Table 2. Length frequency distributions for the scallops captured during the HCCA survey is shown in Figure 4. Maps depicting the spatial distribution of the catches of pre-recruit (<90 mm shell height), and fully recruited (≥90mm shell height) scallops from both the commercial and survey dredges are shown in Figures 5-8. Mean total and mean exploitable scallop densities for both the survey and commercial dredge is shown in Table 3. This information expanded to the area of the entire HCCA and representing an estimate of the total number of animals in the area is shown in Table 4. The mean estimated scallop meat weight for both the commercial and survey dredges for both of the shell height:meat weight relationships used is shown in Table 5. Mean catch (in grams of scallop meat) for the two dredge configurations as well as the two shell height: meat weight relationships are shown in Table 6. Total and exploitable biomass for both shell height:meat weight relationships and levels of assumed gear efficiency are shown in Tables 7-8 (total biomass is not estimated due to the selective properties of the commercial gear). Shell height-meat weight relationships were generated for the area. The resulting parameters as well as the parameters from SARC 50 are shown in Table 9. A comparative plot of the two curves are shown in Figure 9 CPUE of finfish and invertebrate bycatch is shown in Table10.

Size selectivity

The catch data was evaluated by the SELECT method with a variety of functional forms (logistic, Richards, log-log) in an attempt to characterize the most appropriate model. Examination of residual patterns model deviance and AIC values indicated that for all cruises the logistic curve provided the best fit to the data. An additional model run was conducted to determine whether the hypotheses of equal fishing intensity (i.e. the two gears fished with equally) were supported. Output for model runs for the logistic function with the split parameter (*p*) both held fixed at the expected value based on gear width and with *p* being estimated is shown in Table 11. Visual examination of residuals and values of model deviance and AIC indicated that in all cases, the model with an estimated split parameter provided the best fit to the data. Fitted curves and deviance residuals for the HCCA cruise is shown in Figure 10. Estimated parameters for the final model run excluding tows with less than 50 total scallop caught and with a correction to account for between haul variation is shown in Table 12. The estimated L_{50} value was 98.56 mm and the selection range was 20.03 mm. A final selectivity curve for this data set is shown in Figure 11.

The analysis that estimated the relative efficiency of the two gears based upon the expected and observed split parameter values resulted in an estimate relative efficiency value of 1.5887. Assuming the survey dredge operates with a 44% efficiency, the expected value for the efficiency of the commercial dredge was 69.9%. These results justify the inclusion of the 65% efficiency value in the previously calculated estimates of total and exploitable biomass.

As part of the outreach component of this project, a special data report detailing the spatial distribution of scallops and bycatch species in HCCA was compiled. The objective of this report was to inform the sea scallop industry about the abundance and distribution of scallops in the area as well as potential areas of high finfish bycatch concentrations in an effort to direct effort away from these areas. It was hoped that by distributing this information, effort could be focused on areas that contained high densities of scallops while minimizing finfish bycatch. This is one potential strategy to reduce the rate of finfish bycatch. This data is included as a supporting document to this report.

Discussion

Fine scale surveys of closed areas are 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.

Our results suggest that for the HCCA sufficient biomass exists to support an opening in 2011. For an area that had been dominated by a large size class, there appears to have been some recruitment in the area and that the age distribution of the resource is broader relative to prior years. These pre-recruits represent an important size class and have the ability of realize year over year increases in growth as well as the potential to sustain openings in subsequent years. These animals, however, were spatially limited and their overall extent was not remarkable.

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. One advantage of the use of this gear is that the catch from this dredge represent exploitable biomass and no further correction is needed. A disadvantage lies in the fact that there is very little ability of this gear to detect recruitment events. However, since this survey is designed to estimate exploitable biomass, this is not a critical issue.

The concurrent use of two different dredge configurations provides a means to not only test for agreement of results between the two gears, but also simultaneously conduct size selectivity experiments. In this instance, our experiment provided information regarding a potential change to the commercial gear (CFTDD). While the expectation was that these changes should not affect the size selectivity characteristics of the gear (i.e. L_{50} and SR), as these characteristics are primarily determined by ring and mesh sizes, the possibility exists that the overall efficiency will be altered by different dredge frame design. Our results were indeed very similar to those of Yochum and DuPaul (2008) with respect to L_{50} and SR. Our estimated *p* value was slightly higher than what was reported in Yochum and DuPaul (2008). This suggests an increase in relative efficiency as a result of the modified dredge frame especially in the smoother substrate of the mid-Atlantic. Given the major role that dredge efficiency plays in the estimates of biomass from dredge surveys, it is clear that this topic is of critical importance its refinement be a high priority.

Biomass estimates are sensitive to other assumptions made about the biological characteristics of the resource; specifically, 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. There is however, a large variation in this relationship as a result of many factors. Seasonal and inter-annual variation can result in some of the largest differences in shell height-meat weight values. Traditionally, when the sea scallop undergoes its annual spawning cycle, metabolic energy is directed toward the production of gametes and the somatic tissue of the scallop is still recovering and is at some of their lowest levels relative to shell size (Serchuk and Smolowitz, 1989). While accurately representative for the month of the survey, biomass has the potential to be different relative to other times of the year. For comparative purposes, our results were also shown using the parameters from SARC 50 (NEFSC, 2010). These parameters reflect larger geographic regions (mid-Atlantic) and are collected during the summer months. This allowed a comparison of results that may be reflective of some of the variations in biomass due to the fluctuations in the relationship between shell height and adductor muscle weight. Area and time specific shell height-meat weight parameters are another topic that merits consideration.

The survey of the HCCA during the summer of 2010 provided a high-resolution view of the resource in this area. The HCCA is unique in that it will play a critical role in the spatial management strategy of the sea scallop resource over the next few years. With the other closed area of the mid-Atlantic (Elephant Trunk and DelMarVa) nearing the end of their rotational cycles, the HCCA may have to carry some additional fishing pressure. 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.

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Table 1 Boundary coordinates of Hudson Canyon Closed Area sampled during 2010.

Hudson Canyon Closed Area	Latitude	Longitude
HCCA-1	39°30’	73°10’
HCCA-2	39°30’	72°30’
HCCA-3	38°30’	73°30’
HCCA-4	39°50’	73°30’
HCCA-5	39°50’	73°42’

Table 2 Summary statistics for the survey cruise.

Area	**Cruise dates**	**Number of stations included in biomass estimate (survey dredge)**	**Number of stations included in biomass estimate (comm. dredge)**
Hudson Canyon Closed Area	July 24-30, 2010	97	97

Table 3 Mean total and mean exploitable scallop densities observed during the July 2010 cooperative sea scallop surveys.

Gear	Efficiency	Average Total Density (scallops/m^2)	SE	Average Density of Exploitable Scallops (scallops/m^2)	SE
HCCA					
Commercial	65%			0.138	0.020
Survey	44%	0.242	0.036	0.128	0.015

Table 4 Estimated number of scallops in the Hudson Canyon Closed Area. The estimate is based upon the estimated density of scallops at a commercial dredge efficiency of 65% and a survey dredge efficiency of 44%. The total area surveyed was estimated at 4,356 km^2. July 2010.

Gear	Efficiency	Estimated Total	Estimated Total Exploitable
HCCA			
Commercial	65%		595,726,870
Survey	44%	1,052,060,925	557,723,459

Table 5 Estimated average scallop meat weights for the access area of the Hudson Canyon Closed Area. Estimated weights are for the total size distribution of animals as represented by the catch from the NMFS survey dredge as well as the mean weight of exploitable scallops in the area as represented by the catches from both the survey and commercial dredge.

Gear	SH:MW	Mean Meat Weight (g) Total scallops	Mean Meat Weight (g) Exploitable scallops
HCCA			
Commercial	SARC 50		23.58
Survey	SARC 50	17.71	23.45
Commercial	July, 2010		26.20
Survey	July, 2010	19.35	25.96

Table 6 Mean catch of sea scallops observed during the 2010 VIMS-Industry cooperative closed area survey of the Hudson Canyon Closed Area. Mean catch is depicted as a function of various shell height meat weight relationships, either an area specific relationship derived from samples taken during the survey, or a relationship from SARC 50.

Gear	Samples	SH:MW	Mean (grams/tow)	Standard Error
HCCA				
Commercial	97	SARC 50	18,193.7	2,541.5
Survey	97	SARC 50	6,120.1	692.8
Commercial	97	July, 2010	20,215.64	2,836.1
Survey	97	July, 2010	9,562,8	1,123.8

Table 7 Estimated total biomass of sea scallops observed during the July 2010 VIMS-Industry cooperative closed area survey of the Hudson Canyon Closed Area. Biomass is presented as a function of two different shell height meat weight relationships, either an area specific relationship derived from samples taken during the actual survey or a regional relationship from SARC 50.

Gear	SH:MW	Efficiency	Total Biomass (mt)	95% CI	Lower Bound 95% CI	Upper Bound 95%CI
HCCA						
Survey	SARC 50	44%	18,678.7	2,868.3	15,810.4	21,546.9
Survey	July, 2010	44%	25,320.8	3,118.8	17,292.8	23,530.0

Table 8 Estimated exploitable biomass of sea scallops observed during the 2010 VIMS-Industry cooperative closed area survey of the Hudson Canyon Closed. Biomass is depicted as a function of various shell height-meat weight relationships, either an area specific relationship derived from samples taken during the survey, or a regional relationship from SARC 50.

Gear	SH:MW	Efficiency	Exploitable Biomass (mt)	95% CI	Lower Bound 95% CI	Upper Bound 95%CI
HCCA						
Commercial	SARC 50	65%	15,021.6	3,315.8	11,705.7	18,337.4
Survey	SARC 50	44%	13,063.2	1,922.2	11,140.4	14,986.0
Commercial	July, 2010	65%	16,690.4	3,700.2	12,990.6	20,391.1
Survey	July, 2010	44%	14,459.1	2,130.2	12,328.9	16,589.3

<u>Table 9</u> Summary of area specific shell height-meat weight parameters used in the analyses. Parameters were obtained from two sources: (1) samples collected during the course of the surveys (July of 2010), and (2) SARC 50 (NEFSC, 2010)*.

	Date	α	β	γ	δ
Survey Data					
	July, 2009	-8.7372	3.1413	-0.6967	
SARC 45					
		-16.88	4.64	1.57	-0.43

*The length weight relationship for sea scallops from data collected on the cruise is modeled as:

$$W=\exp(\alpha+ \beta*\ln(L) + \gamma*\ln(D))$$

For SARC 50 (mid-Atlantic) an interaction term is included in the model as follows:

$$W=\exp(\alpha+ \beta*\ln(L) + \gamma*\ln(D) + \delta*\ln(L)*\ln(D))$$

Where W is meat weight in grams, L is scallop shell height in millimeters (measured from the umbo to the ventral margin) and D is depth in meters.

<u>Table 10</u> Catch per unit effort (a unit of effort is represented by one standard survey tow of 15 minute duration at 3.8 kts.) of finfish and invertebrate bycatch encountered during the survey of the Hudson Canyon Closed Area during July 2010. In total, finfish and invertebrate bycatch was measured and recorded for 97 survey tows.

Common Name	Scientific Name	Commercial Dredge	Survey Dredge
Unclassified Skates	Raja spp.	11.48	3.18
Fourspot Flounder	Paralichtys oblongotus	0.01	0.05
Monkfish	Lophius americanus	1.41	0.95

Table 11 Selection curve parameter estimates and hypotheses test. Selectivity data for each cruise was evaluated by a logistic curve with and without the split parameter (p) estimated. Improvements with respect to model fit were assessed by an examination of model deviance and AIC values.

	HCCA	
	Fixed p	**Estimated p**
a	-12.7072	-10.8271
b	0.1444	0.1097
p	.6364	0.7354
L_{25}	80.407	88.647
L_{50}	88.017	98.675
L_{75}	95.627	108.670
Selection Range (SR)	15.219	20.021
Model Deviance	23.195	1.787
Degrees of Freedom	28	28
AIC	112.66	91.26

<u>Table 12</u> Estimated logistic SELECT model fit for tows with total catch of greater than 50 scallops . Estimated parameters *a*, *b* and *p* as well as the length at 50% retention (L_{50}) and Selection Range (SR) are shown. The number of valid tows, as well as the replication estimate of between-haul variation (REP) is shown. Standard error estimates have been multiplied by square root of the REP estimate to reflect the observed levels of between-haul variation

	HCCA	
Length Classes	22.5-157.5	
a	-10.8208	1.44
b	0.1097	0.017
p	0.7355	0.027
L_{50}	98.565	20.30
Selection Range	20.033	3.139
REP	6.27	
# of tows in analysis	75	

Figure 1 Locations of sampling stations in the exemption area of the Hudson Canyon Closed Area surveyed by the F/V *Pursuit* during the cruise conducted during July, 2010. Stations in red represent randomly selected stations designated for the collection of shell height:meat weight samples. Stations at depths of greater than 50 fathoms were excluded from the survey.

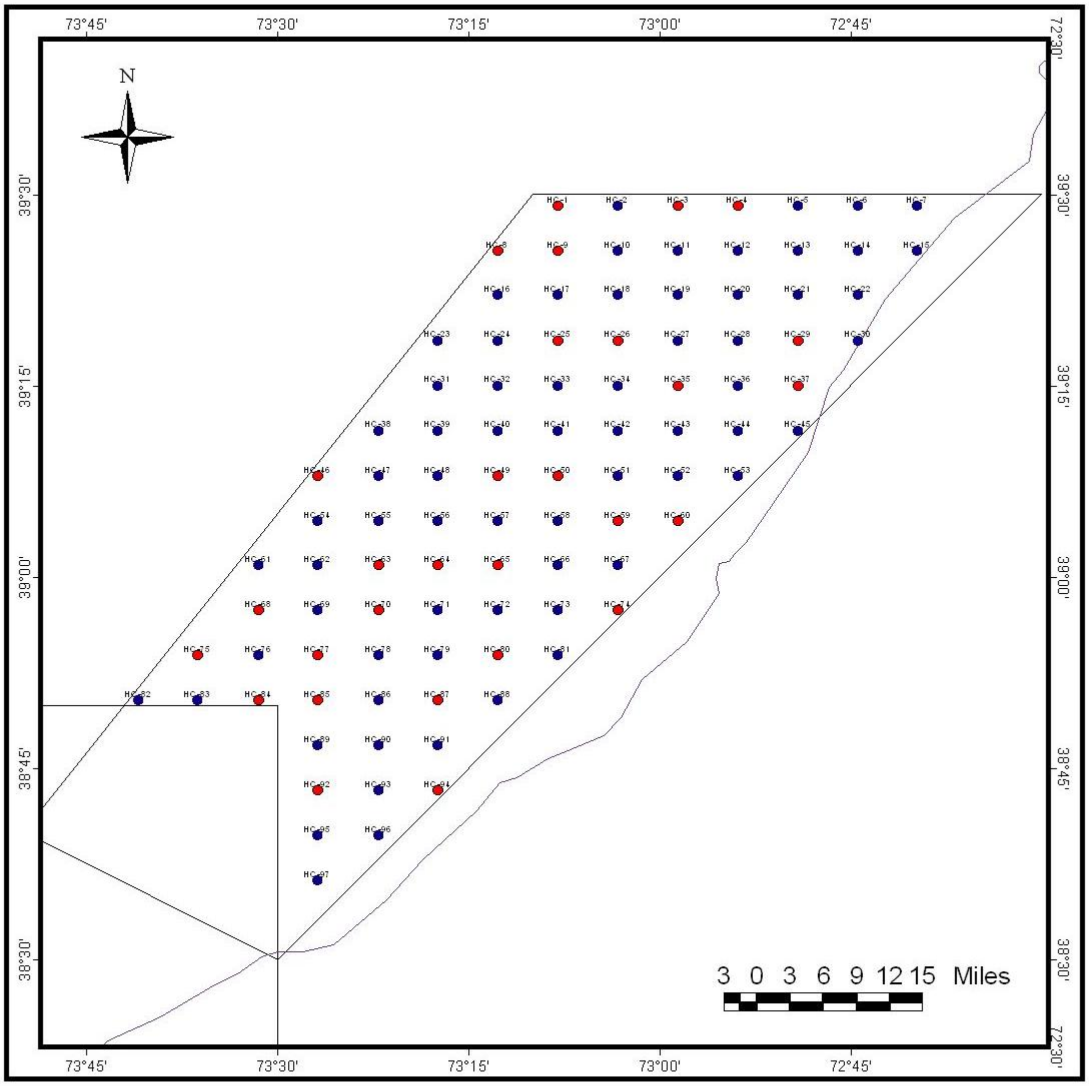
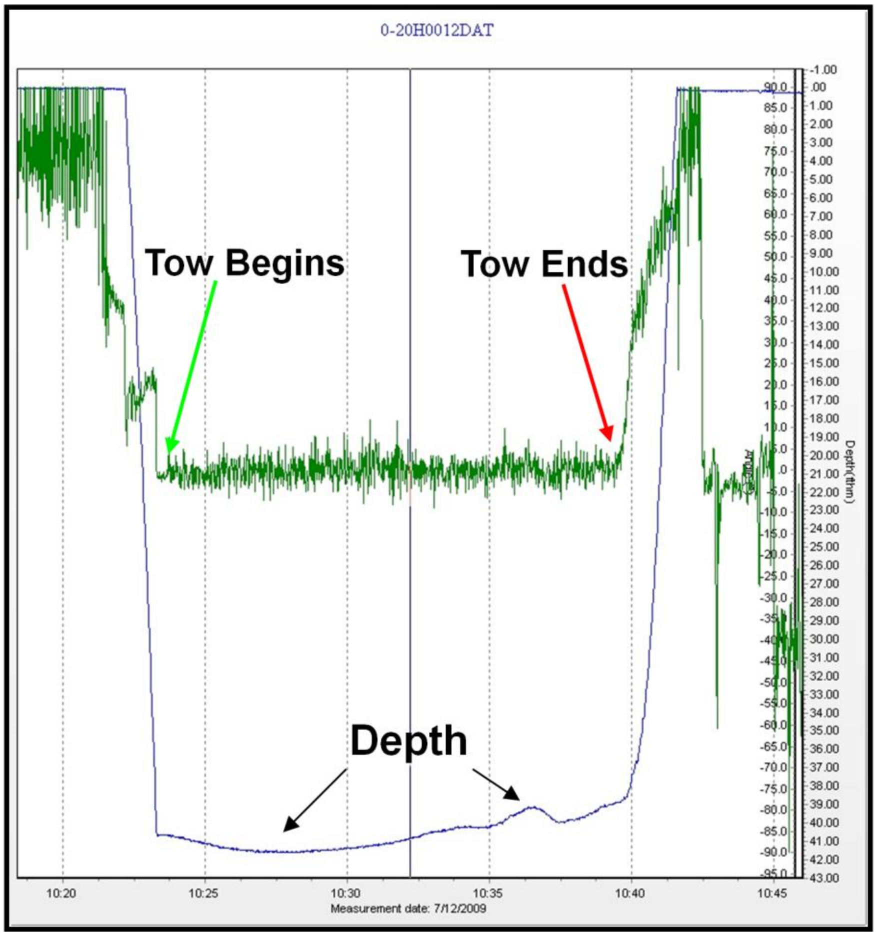


Figure 2 An example of the output Star-Oddi™ DST sensor. Arrows indicate the interpretation of the start and end of the dredge tow



<u>Figure 3</u> Histogram of calculated tow lengths from the 2010 survey of the HCCA. Mean tow length was 1901.6 m with a standard deviation of 61.1 m.

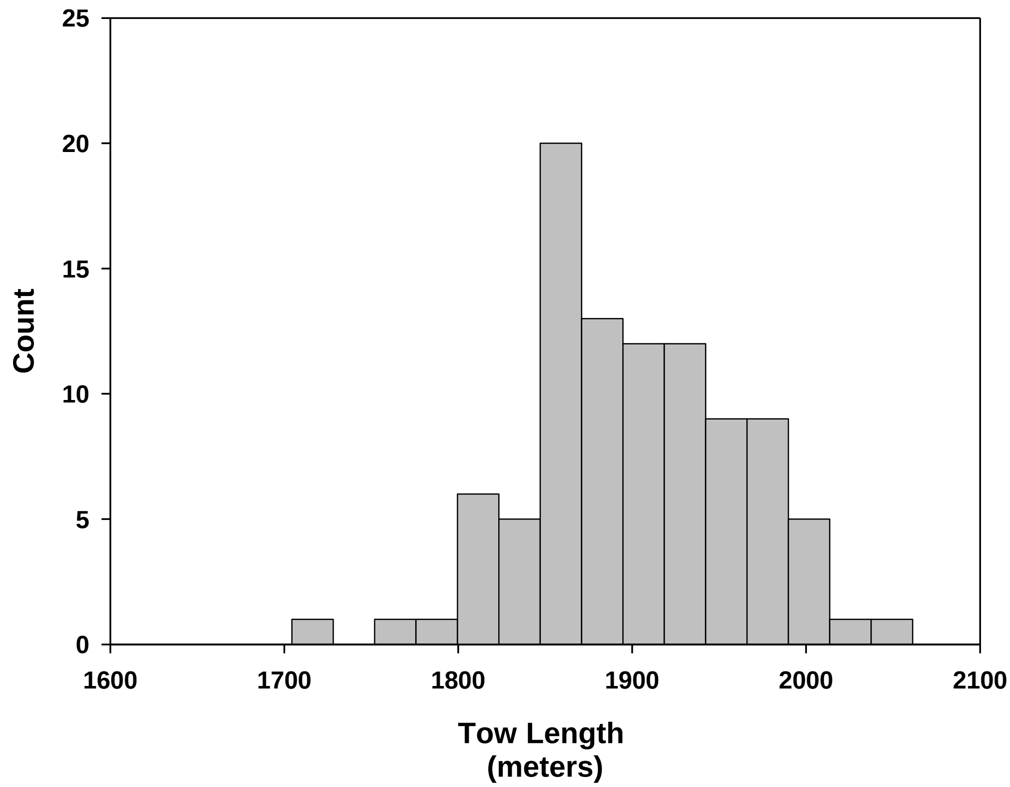


Figure 4 Shell height frequencies for the two dredge configurations used to survey the exemption area of the Hudson Canyon Closed Area during July, 2010. The frequencies represent the expanded but unadjusted catches of the two gears for all sampled tows.

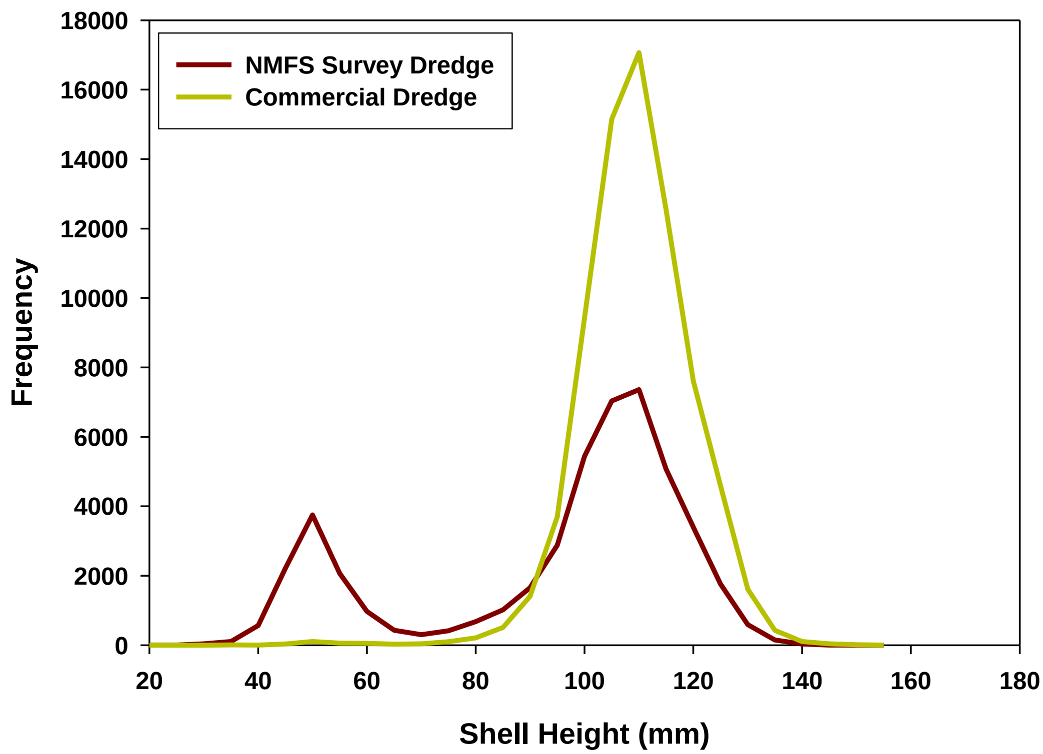


Figure 5 Spatial distribution of sea scallop catches on survey cruise to Hudson Canyon Closed Area during July, 2010 by the commercial dredge. This figure represents the catch of pre-recruit sea scallops (<90mm).

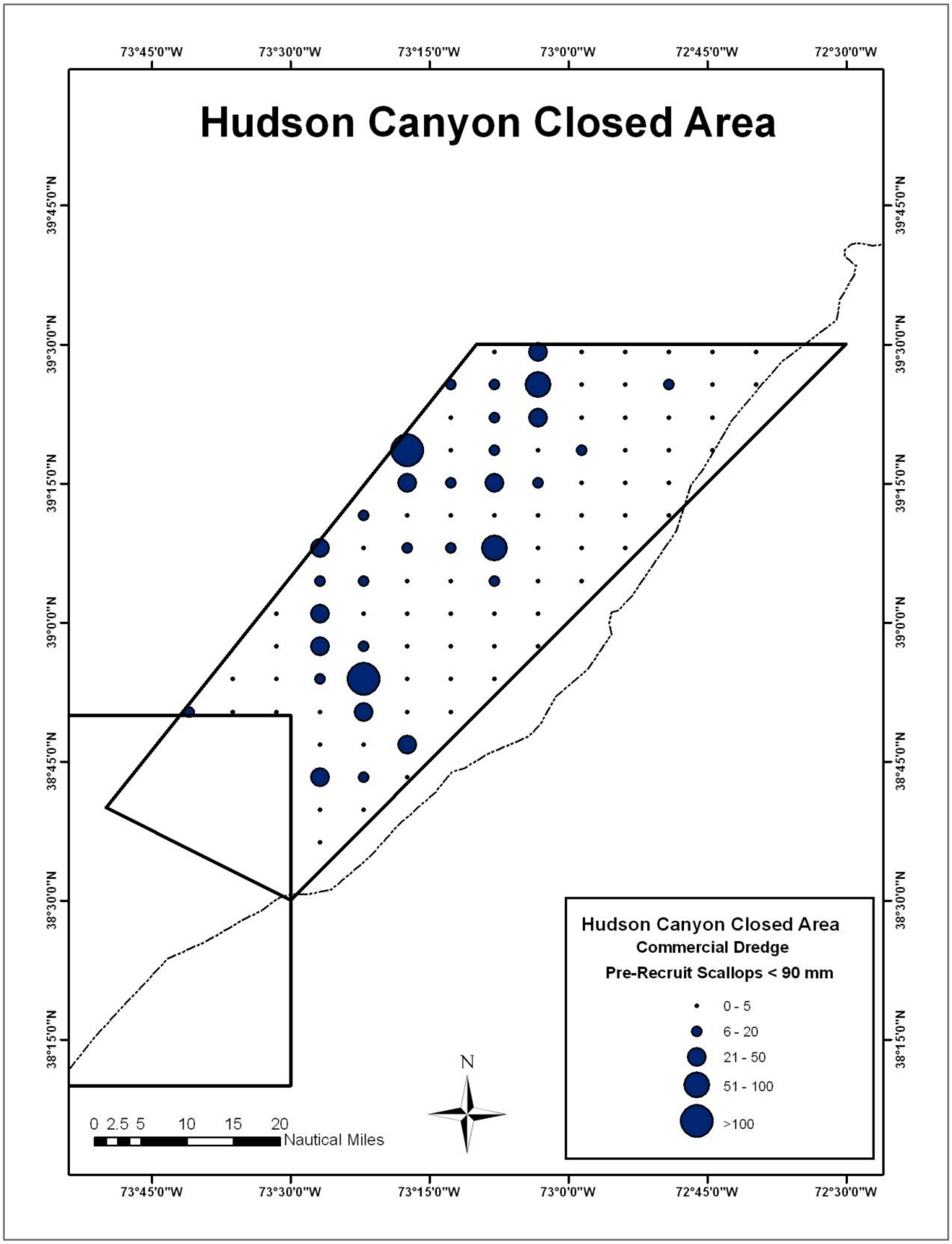


Figure 6 Spatial distribution of sea scallop catches on survey cruise to Hudson Canyon Closed Area during July, 2010 by the commercial dredge. This figure represents the catch of fully recruited sea scallops (>90mm).

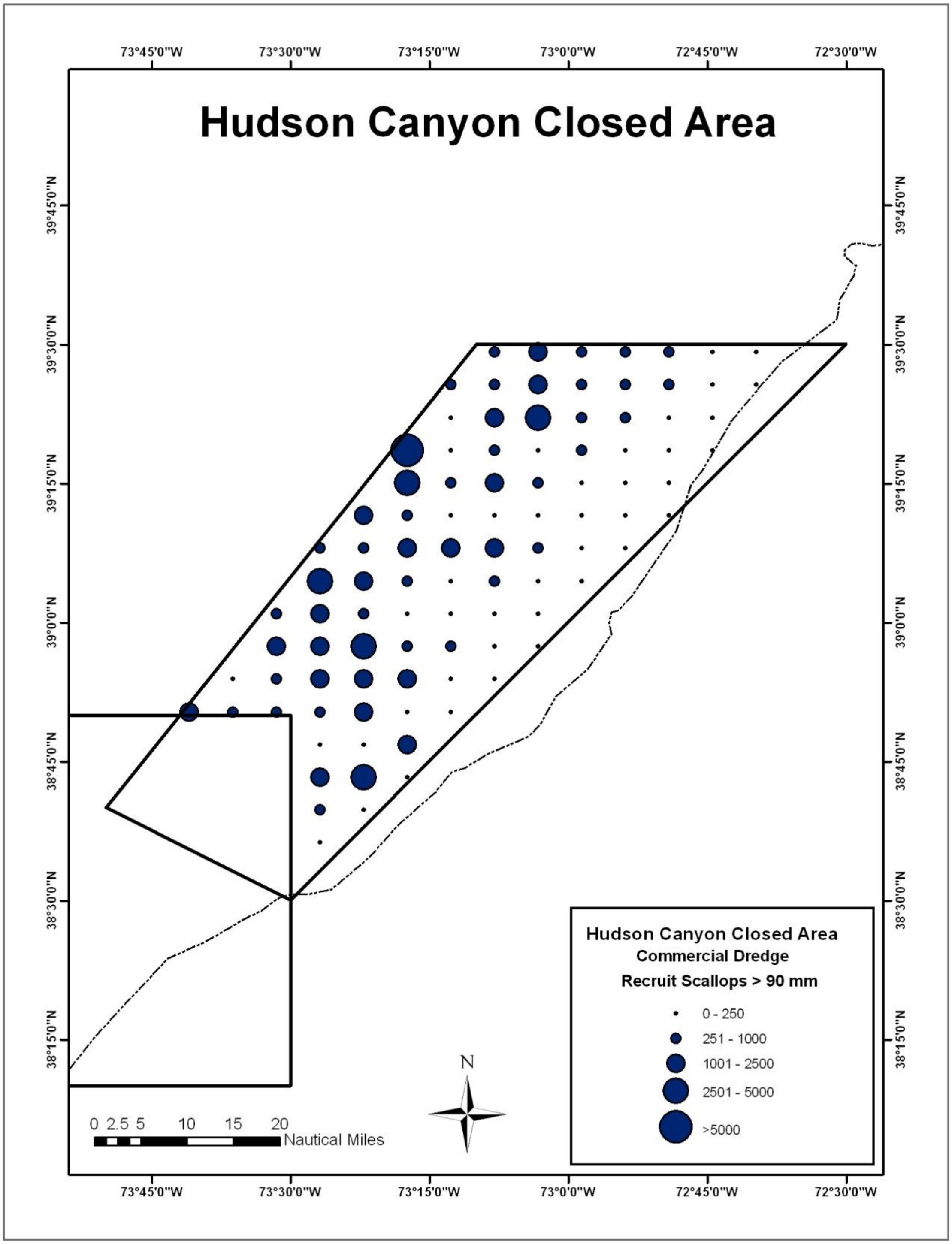


Figure 7 Spatial distribution of sea scallop catches on survey cruise to Hudson Canyon Closed Area during July, 2010 by the NMFS survey dredge. This figure represents the catch of pre-recruit sea scallops (<90mm).

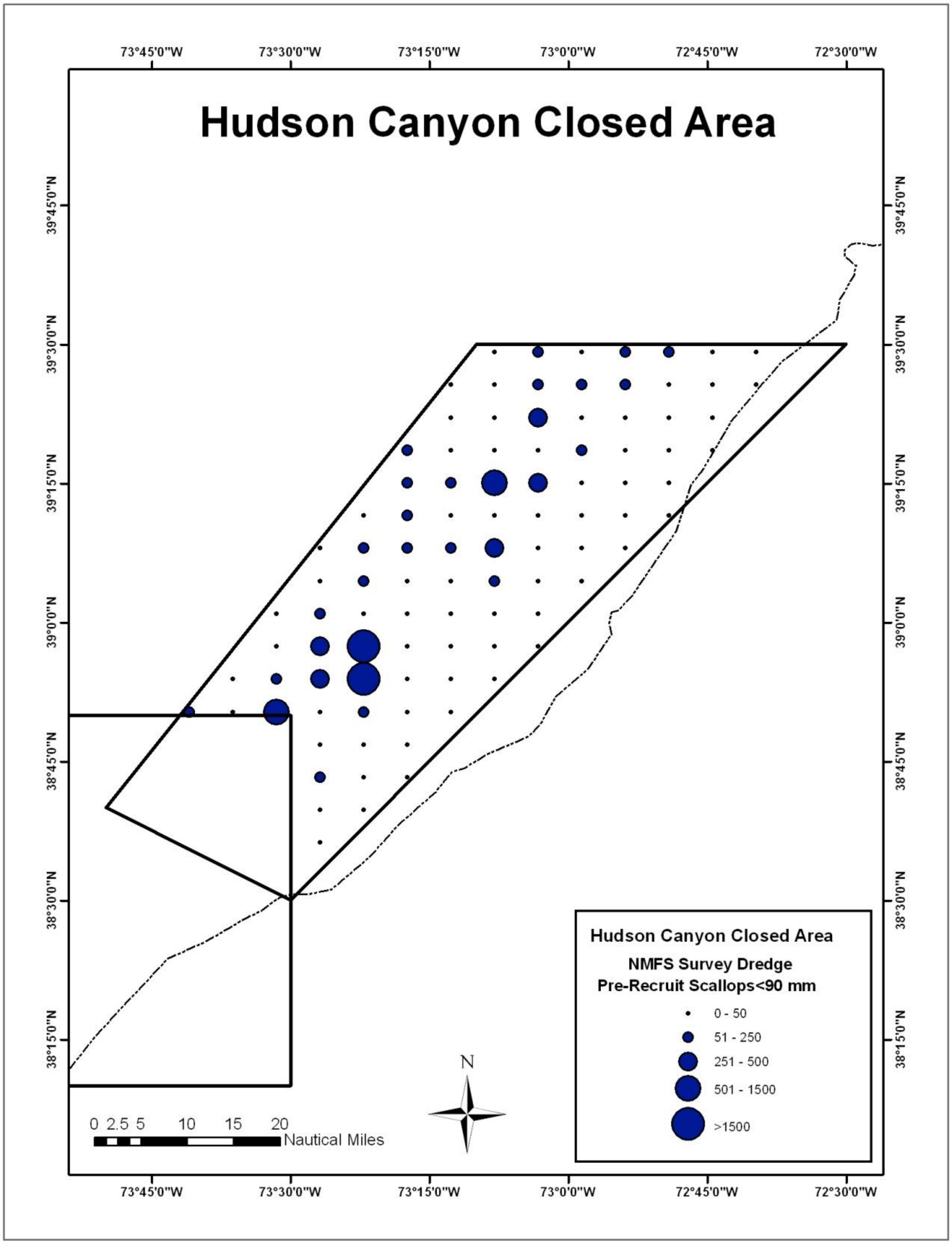


Figure 8 Spatial distribution of sea scallop catches on survey cruise to Hudson Canyon Closed Area during July, 2010 by the NMFS survey dredge. This figure represents the catch of fully recruited sea scallops (>90mm).

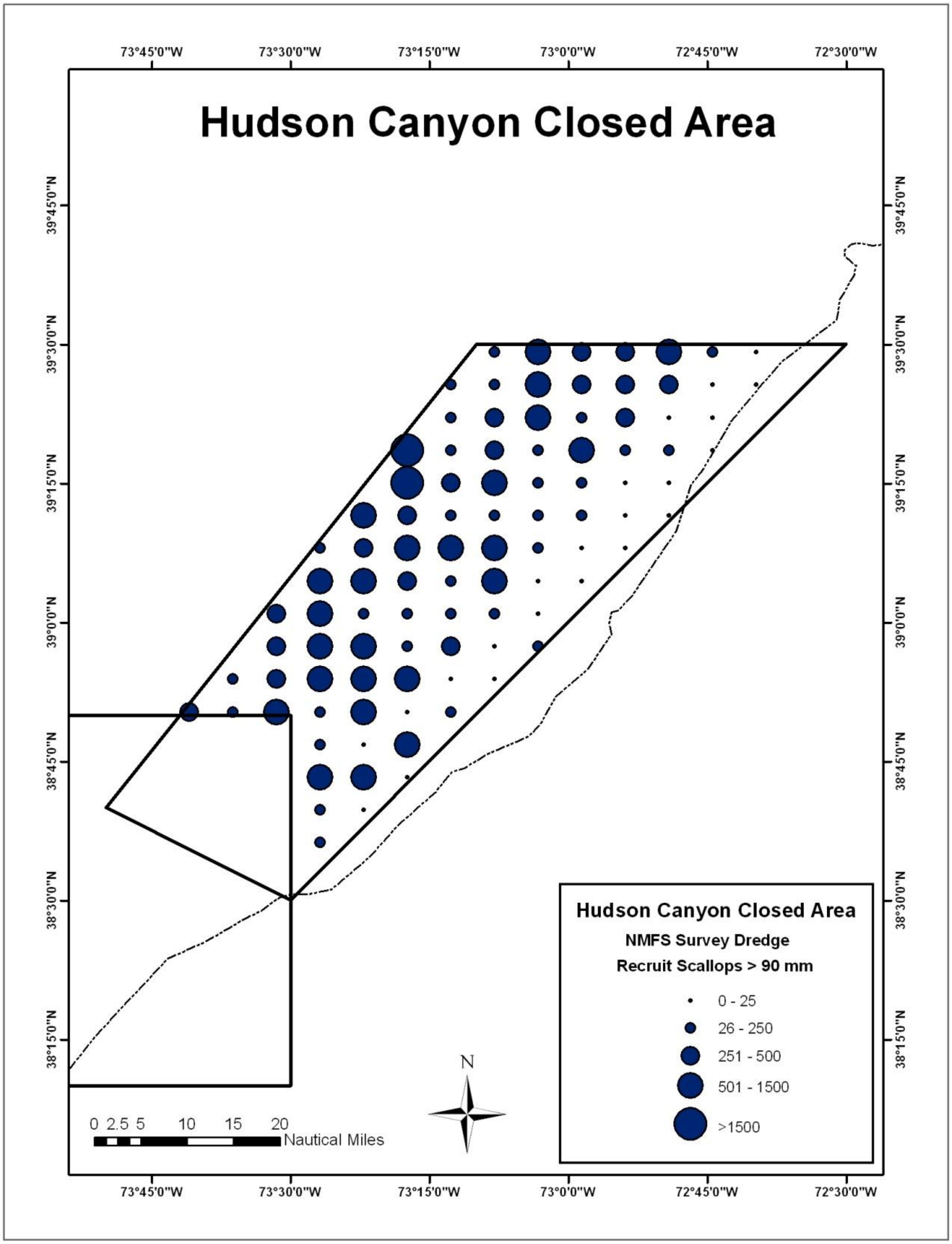


Figure 9 Shell height:meat weight relationships used in the study. The SARC-50 curve is an area specific curve for the entire mid-Atlantic area. The VIMS-2010 curve is based on samples taken during the survey and is specific for the HCCA during July 2010.

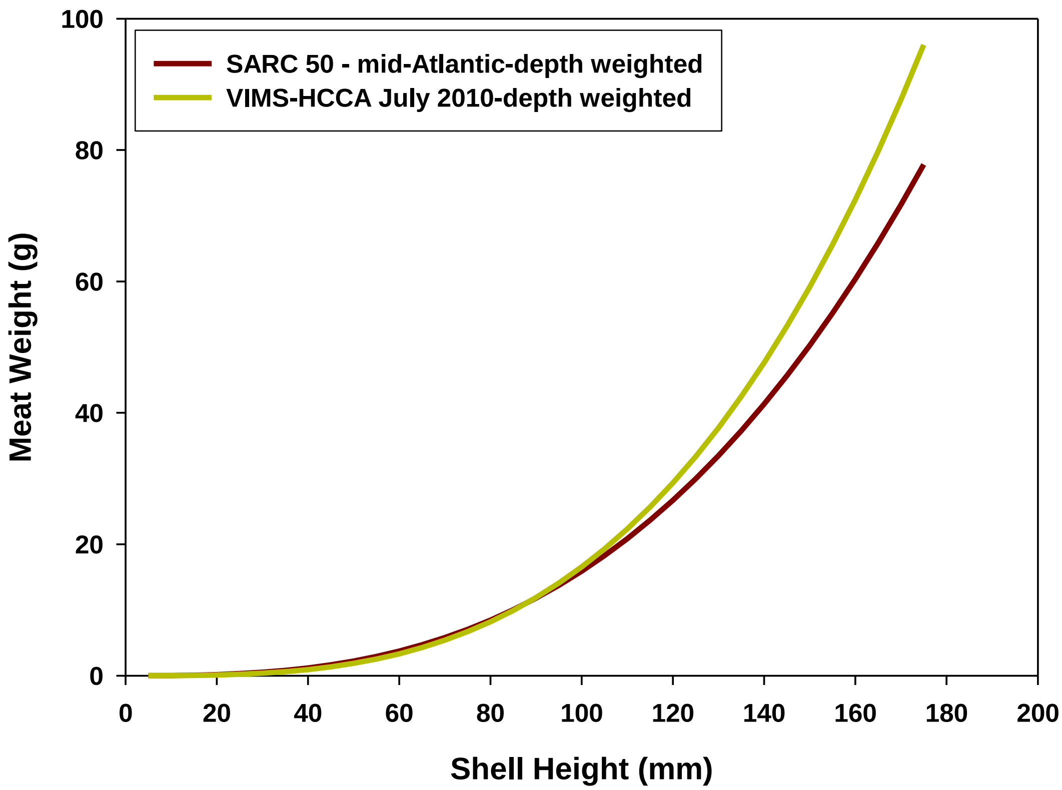
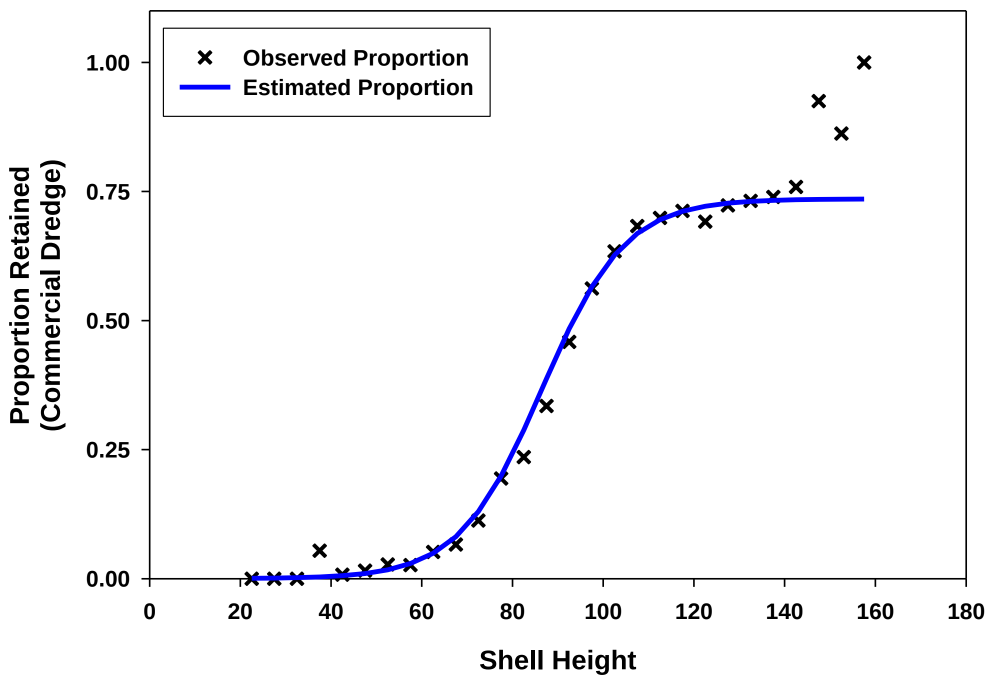


Figure 10 Top Panel: Logistic SELECT curves fit to the proportion of the total catch in the commercial dredge relative to the total catch (survey and commercial) for 2010 cruise to the Hudson Canyon Closed Area. Bottom Panel: Deviance residuals for the model fit.



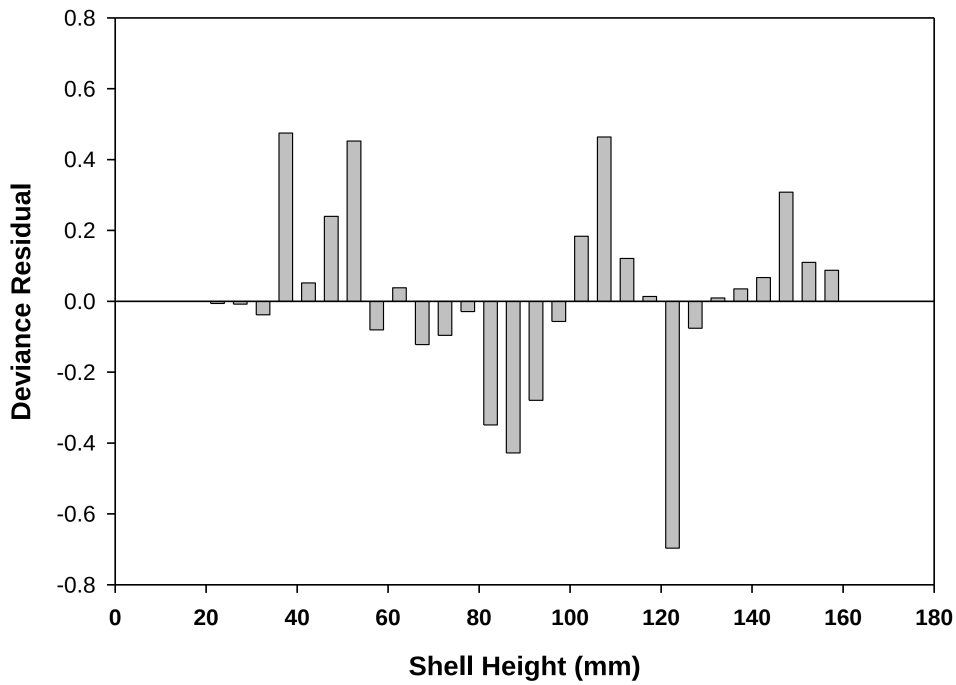


Figure 11 Estimated selectivity curve for the New Bedford style sea scallop dredge based on data from the 2010 survey of the Hudson Canyon Closed Area.