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David Rudders
Virginia Institute of Marine Science

William D. DuPaul
Virginia Institute of Marine Science

Jessica Bergeron
Virginia Institute of Marine Science

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Final Report

An Inventory of the Sea Scallop Resource in the Georges Bank Closed Area II and Surrounds

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166 Water Street
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Submitted by:

David B. Rudders
William D. DuPaul
Jessica Bergeron

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 1994, large areas on Georges Bank were closed to fishing in an effort to protect and rebuild depleted stocks in the groundfish complex. Central to these efforts wa the protection of the critical habitat that these species depend on during various phases of their life history. The Georges Bank Closed Areas also contained traditional scallop fishing grounds and over time a large portion of the standing scallop stock accumulated in these areas. While in some of these areas, controlled access has been made available to the scallop fleet, there are still regions where bottom tending mobile gear is not allowed. Over the last decade, spatial management in the region has been re-evaluated in light of greater understanding of the environment, species requirements and the impact that fishing has on the habitat. As the time draws near to make decisions about the specific alternatives in a habitat action, managers need to consider a wide range of data to make an informed decision.

Northeast Georges Bank (NEG) is one such area that has been essentially closed since 1994, but its status may be reconsidered in the near future. NEG is a broad geographic term and within this area there are portions that are currently closed and also open to fishing. The entire area has been identified for possible future habitat closure. These future decisions include whether or not to re-open closed areas and if opened how to manage those areas to afford the greatest protection in the context of habitat and groundfish. A tangential issue relates to the access of the scallop fleet to these areas. It was with these issues in mind that a survey of the NEG area was conducted during July of 2012. The objective of this survey was to comprehensively evaluate the scallop resource in this area as well as species encountered as bycatch in the fishery. During this experiment as series of subareas within the NEG area were surveyed. They included the sub-areas of Northern Closed Area II (CAII), Georges Shoals/No Edge (GSNE), and the Cod Habitat Area of Particular Concern (HAPC). At pre-determined sampling stations within each subarea, both a NMFS survey dredge and a Coonamessett Farm Turtle Deflector Dredge (CFTDD) were simultaneously towed from a commercial sea scallop vessel. From these survey tows, fine scale survey data were used to assess scallop and finfish abundance and distribution in the area. This effort also provided an opportunity to document the length:weight relationship for scallops in these areas as well as assess the product quality of scallops that had essentially not been fished in 20 years. These data will also provide a

comparison of the utility of using two different gears as survey tools in the context of industry based surveys.

Results indicate that the overall resource in the NEG area is abundant, especially in the HAPC and to some extent GSNE. Of concern was the lack of observed recruitment that has the potential to impact the abundance of the resource in that area during subsequent years, especially if access is made available. Also of concern was the observation of some spatially explicit areas of poor scallop meat quality. Gear comparison analyses provided an interesting insight into the effect that large catches have on the relative performance of sea scallop dredges.

Project Background

The sea scallop, *Placopecten magellanicus,* supports a fishery that in the 2011 fishing year landed 58.7 million pounds of meats with an ex-vessel value of over US $581 million (Lowther, 2012). 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 in NEG were also subject to area closures. In 1994, 17,000 km^2 of bottom on Georges Bank 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 of Georges Bank has been allowed to harvest the dense beds of scallops that have accumulated in the absence of fishing pressure.

Over the past 10 years, approaches to spatially manage Georges Bank have been reevaluated. The Habitat Omnibus Amendment #2 has taken a comprehensive approach to the management of Georges Bank habitat in light of new data, analytical approaches and a better understanding of the requirements of the fauna on Georges Bank as well as the impact that fishing has on benthic communities. As the time draws near to reconcile these analyses and make subsequent recommendations with respect to their impact on a broad swath of human activities, current information relating to the scallop resource in that general area is informative for managers tasked with making decisions about this difficult and complex issue. From a scallop perspective, the possibility exists that this area will be a candidate for a rotational access area.

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 are 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. If some form of access is deemed appropriate for the NEG, the biomass in this area has both short term and longer term impacts on the fishery as this area not only contains large numbers of scallops, but is traditionally one of the most productive areas throughout the range of the resource. This work allowed for the examination of a scallop population that has essentially been un-fished for 20 years.

In addition to collecting data to assess the abundance and distribution of sea scallops in the NEG, 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 length based relative efficiency values of the CFTDD equipped with turtle excluder chains. Gear performance (i.e. size selectivity and relative efficiency) information is limited 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.

A stated advantage of a dredge sea scallop survey is that one can access and directly sample the target species. One attribute routinely measured is the shell height:meat weight relationship. While this relationship 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 and other factors. 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. In addition, we hypothesized that the population of scallops especially in the HAPC contained large numbers of animals in excess of 10 years old. Concerns have been raised regarding the product quality of animals in that age class. We were able to quantify the marketability of scallops from the three sub-areas based on a qualitative evaluation of meat color and texture attributes.

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 sub-areas of the NEG. Utilizing the same catch data with different analytical approaches, we estimated the length based efficiency characteristics of the commercial sea scallop dredge relative to the NMFS Survey dredge. As a third objective of this study, we collected biological samples to estimate time and area specific shell height:meat weight relationships and assess product quality metrics.

Methods

Survey Area and Sampling Design

Three sub-areas within the NEG were 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. This sampling design has been successfully implemented during industry-based surveys since 1998.

The methodology to generate the systematic random grid entailed the decomposition of the defined domain of interest 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 sampling domains 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. Due to the higher level of interest in the HAPC, a denser sampling grid was generated there. The GSNE and CAII have the same grid spacing. The station locations for the 2012 NEG survey is 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 15 foot Coonamessett Farm Turtle Deflector Dredge (CFTDD) equipped with 4-inch rings, a 10-inch diamond mesh twine top and no liner was utilized. Turtle chains/rock 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 and 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 35 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 models:

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

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

During the course of obtaining shell height:meat weight samples, we also evaluated product quality based on a qualitative assessment of meat color and texture attributes. The sampled animal was given a marketability score of 1 or 0 based upon levels of non-typical color and texture/tearing characteristics. Grey meats as well as stringy meats that tear upon shucking were the focus of the concern surrounding undesirable product quality. These data were then used to calculate a percent marketability score for the sub-area sampled.

The standard data sheets in service 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:

$$TotalBiomass = \sum_{j} \left(\frac{\left(\frac{CatchWtperTowinSubarea_{j}}{AreaSweptperTow} \right)}{Efficiency} \right) SubArea_{j} \tag{1}$$

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:

$$TowDist = \sum_{i=1}^{n} \sqrt{\left(long_{2} - long_{1}\right)^{2} + \left(lat_{2} - lat_{1}\right)^{2}} \tag{2}$$

The linear distance of the tow is multiplied by the width of the gear (either 15 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 prior surveys on Georges Bank; an efficiency value of 60% was used for the NEG survey area. To scale the estimated mean scallop catch to the full domain, the total area of each access area was calculated in ArcGIS v. 10.0.

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) were compared to the non-selective gear via the SELECT method (Millar, 1992). With this analytical approach, the selective properties (i.e. the length based probability of retention) of the commercial dredge were 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 38%), 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 dredge 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).

$$\Phi_c(l) = \frac{p_c r_c(l)}{p_c r_c(l) + (1 - p_c)} \qquad (3)$$

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:

$$r(l) = \left(\frac{\exp(a + bl)}{1 + \exp(a + bl)} \right) \qquad (4)$$

by substitution:

$$\Phi(L) = \frac{pr(L)}{(1-p) + pr(L)} = \frac{p\dfrac{e^{a+bL}}{1+e^{a+bL}}}{(1-p) + p\dfrac{e^{a+bL}}{1+e^{a+bL}}} = \frac{pe^{a+bL}}{(1-p) + e^{ea+bL}} \qquad (5)$$

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.

$$L_{50} = \frac{-a}{b} \qquad (6) \qquad\qquad SR = \frac{2 * \ln(3)}{b} \qquad (7)$$

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 uncertainty 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.

$$REP = \frac{Q}{d} \qquad (8)$$

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 $\sqrt{REP}$. This correction is only performed when the data is not overdispersed (Millar, 1993).

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).

$$RE = \frac{p/(1-p)}{p_0/(1-p_0)} \qquad (9)$$

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 15 ft. commercial dredge was used with expected split parameter of 0.6521. The computed relative efficiency values were then used to scale the estimate of the NMFS survey dredge efficiency obtained from the optical comparisons (38%). 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 (Mid-Atlantic Bight) where dredge efficiency is expected to be higher. 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.

While typically the gear comparisons between a lined survey dredge and a commercial dredge generate paired tow data that are appropriate for the SELECT model, occasionally this modeling approach does not work. This was the case with the data from this project. Large catches and tows with high catches of substrate resulted in the rings of the commercial dredge becoming occluded and not allowing small scallops to escape. Given the rigidity of fitting the resulting proportion to the logistic function, data sets where the selective gear retains large numbers of small animals resulted in the model not converging on a solution or returning unrealistic parameter values. At this point we did not abandon attempting to estimate relative efficiency, but looked to a similar analytical approach that has more flexibility with respect to the functional form.

Catch data from the paired tows provided the information to estimate differences in the relative efficiency for the gear combinations tested. This analysis is based on the analytical approach in Cadigan et al. 2006. Assume that each gear combination tested in this experiment has a unique catchability. Let q_r equal the catchability of the CFTDD and q_f equal the catchability of the NMFS Survey dredge used in the study. The efficiency of the CFTDD relative to the NMFS will be equivalent to the ratio of the two catchabilities:

$$\rho_l = \frac{q_r}{q_f} \qquad (10)$$

The catchabilities of each gear are not measured directly. However, within the context of the paired design, assuming that spatial heterogeneity in scallop/fish and fish density is minimized, observed differences in scallop/fish catch for each vessel will reflect differences in the catchabilities of the gear combinations tested.

Let C_{iv} represent the scallop/fish catch at station i by dredge v, where $v=r$ denotes the CFTDD dredge and $v=f$ denotes the NMFS dredge. Let λ_{ir} represent the scallop/fish density for the i^{th} station by the CFTDD dredge and λ_{if} the scallop/fish density encountered by the NMFS dredge. We assume that due to random, small scale variability in animal density as well as the vagaries of gear performance at tow i, the densities encountered by the two gears may vary as a result of small-scale spatial heterogeneity as reflected by the relationship between scallop/fish patch size and coverage by a paired tow. The probability that a scallop/fish is captured during a standardized tow is given as q_r and q_f. These probabilities can be different for each vessel, but are expected to be constant across stations. Assuming that capture is a Poisson process with mean equal to variance, then the expected catch by the CFTDD dredge is given by:

$$E(C_{if}) = q_f \lambda_{if} = \mu_i \tag{11}$$

The catch by the NMFS dredge is also a Poisson random variable with:

$$E(C_{ir}) = q_r \lambda_{ir} = \rho \mu_i \exp(\delta_i) \tag{12}$$

where $\delta_i = \log(\lambda_{ir} / \lambda_{if})$. For each station, if the standardized density of scallops /fish encountered by both dredges is the same, then $\delta_i=0$.

If the dredges encounter the same scallop/fish density for a given tow, (i.e. $\lambda_{ir} = \lambda_{if}$), then ρ can be estimated via a Poisson generalized linear model (GLM). This approach, however, can be complicated especially if there are large numbers of stations and scallop/fish lengths (Cadigan et al. 2006). The preferred approach is to use the conditional distribution of the catch by the CFTDD at station i, given the total non-zero catch of both vessels at that station. Let c_i represent the observed value of the total catch. The conditional distribution of C_{ir} given $C_i=c_i$ is binomial with:

$$\Pr(C_{ic} = x \mid C_i = c_i) = \binom{c_i}{x} p^x (1-p)^{r_i - x} \tag{13}$$

where $p=\rho/(1+\rho)$ is the probability that a scallop/fish captured by the CFTDD dredge. In this approach, the only unknown parameter is ρ and the requirement to estimate μ for each station is eliminated as would be required in the direct GLM approach (equations 11 &12). For the binomial distribution $E(C_{ir})=c_i p$ and $Var(C_i r)=c_i p/(1-p)$. Therefore:

$$\log\left(\frac{p}{1-p}\right) = \log(\rho) = \beta \qquad (14)$$

The model in equation 14, however, does not account for spatial heterogeneity in the densities encountered by the two gears for a given tow. If such heterogeneity does exist then the model becomes:

$$\log\left(\frac{p}{1-p}\right) = \beta + \delta_i \qquad (15)$$

where δ_i is a random effect assumed to be normally distributed with a mean=0 and variance=σ^2. This model is the formulation used to estimate the gear effect $exp(\beta_0)$ when catch per tow is pooled over lengths.

Often, gear modifications can result in changes to the length based relative efficiency of the two gears. In those instances, the potential exists for the catchability at length (l) to vary. Models to describe length effects are extensions of the models in the previous section to describe the total scallop catch per tow. Again, assuming that between-pair differences in standardized animal density exist, a binomial logistic regression GLMM for a range of length groups would be:

$$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \delta_i + \beta_1 l, \delta_i \sim N(0,\sigma^2), i = 1...n. \qquad (16)$$

In this model, the intercept (β_0) is allowed to vary randomly with respect to station (Cadigan and Dowden 2009)..Orthogonal polynomial terms can be added to the length effect to capture any curvilinear properties of the relationship between the observed proportion and length (Holst and Revill, 2009).

Adjustments for sub-sampling of the catch

Additional adjustments to the models were required to account for sub-sampling of the catch and the difference in area covered by the respective dredges for a given tow. In most instances, due to high scallop catch volume, particular tows were sub-sampled. This is accomplished by randomly selecting a proportional volumetric sample for length frequency analysis. Finfish were always sampled without subsampling. One approach to accounting for this practice is to use the expanded catches. For example, if half of the total catch was measured for length frequency, multiplying the observed catch by two would result in an estimate of the total catch at length for the tow. This approach would overinflate the sample size resulting in an underestimate of the variance, increasing the chances of spurious statistical inference (Millar et al. 2004; Holst and Revill 2009). In our experiment, the proportion sub-sampled was not consistent between tows and varied as a function of catch size. This difference must be accounted for in the analysis to ensure that common units of effort are compared. Differences in tow length(area) are handled in a similar manner and the relative areal coverage are included in the offset term.

Let q_{ir} equal the sub-sampling fraction at station *i* for the vessel *r*. Let q_{if} equal the sub-sampling fraction at station *i* for the vessel *f*. Let d_{ir}=area covered at station *i* for vessel r and let d_{if} equal the area covered at station *i* for vessel *f*. This adjustment results in a modification to the logistic regression model:

$$\log\left(\frac{p_i}{1+p_i}\right) = \beta_0 + \delta_i + (\beta_1 * l_i) + \log\left(\frac{d_{ir} * q_{ir}}{d_{if} * q_{if}}\right), \delta_{ij} \sim N(0, \sigma_j^2), i = 1...n. \quad (18)$$

The last term in the model represents an offset in the logistic regression (Littell et al. 2006). We used SAS/STAT® PROC GLIMMIX v. 9.2 to fit the generalized linear mixed effects models.

Results

Abundance and distribution

The survey cruises to NEG were completed in July 2012. Summary statistics for the cruises are shown in Table 2. Length frequency distributions for the scallops captured during the NEG surveys are shown in Figure 4-6. Maps depicting the spatial distribution of the scallop 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 7-10. 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 NEG 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 four 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 for the CFTDD 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 (both an area specific (Northeast Peak) as well as a general Georges Bank relationship) are shown in Table 9. A comparative plot of the curves is shown in Figure 11. Total catch and catch per unit of effort for finfish and bycatch is shown in Table 10. Length distributions for the major bycatch species are shown in Figures 12-15 and their spatial distribution is shown in Figures 16-23.

Product quality observations were collated and partitioned by sub-area to give a general sense of the magnitude of unmarketable scallops in each sub-area. For the CAII area, unmarketable meats were rare and from the samples an average of 75% of the animals were marketable. In the GSNE area the results were even better and this area yielded a 90% marketability value. The area of most concern was the HAPC where some tows were totally unmarketable and overall the samples yielded an estimate of 55% marketability. (see Figure 24 for examples of marketable/unmarketable meats)

Size selectivity/relative efficiency

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 no variants of the logistic function were appropriate for the structure of the data. There were simply too many small animals captured by CFTDD. This resulted in model runs not converging or values that were totally unrealistic. Partitioning the data into subareas also did not help and the SELECT model was abandoned for a method that allows a more flexible functional form. Results of the mixed model evaluation are shown in Table 11 and Figure 12. This approach was able to accommodate higher proportion retention by the CFTDD at smaller sizes and returned a reasonable estimate of the observed relative efficiency of the two gears tested.

As part of the outreach component of this project, a special data presentation was given to the joint Habitat PDT/ Closed Area Technical Team on January 17, 2013. This presentation detailed the results from this survey and provided them with additional data on scallop and finfish distribution in this area. It was hoped that by distributing this information, current data on the resources in the NEG could help guide the decision making process for the Habitat Amendment. That presentation is included as an attachment 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. This especially true of the HAPC and CAII that have been closed for 20 years. Additionally, the timing of industry-based surveys can be tailored to give managers current information to guide important management decisions. This information can help establish spatial management areas, time access to those areas and help set Total Allowable Catches (TAC). Finally, this type of survey is important in that it involves the stakeholders of the fishery in the management of the resource.

Our results help delineate the scallop resource in the surveyed area and give a baseline estimate of biomass for the three sub-areas. The CA2 area was virtually devoid of scallops. We estimate that only 2-3 million pounds of exploitable scallops were present in that area. The abundance of scallops in GSNE was higher with an estimated 6.4-9.2 million lbs of exploitable scallops. With respect to the HAPC, roughly 20-25 million pounds of meats from exploitable size scallops were observed in that area. One concern in that area relates to the high percentage of unmarketable meats the have the potential to drive down the effective biomass in that area. A similar situation currently exists in CAI where many more animals have been killed to reach a catch limit due to the unmarketable meats that can only be discovered upon shucking. For an area that is dominated by a large size class, there appears to have been limited recent recruitment in the area. This mirrors general observations across Georges Bank over the past couple of years. The recruits that we did observe were spatially limited and their overall extent and magnitude 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 and a lined survey dredge is used, 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/relative efficiency experiments. In this instance, our experiment provided information regarding a recently mandated 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 attempt to use the SELECT model was unsuccessful, but a method that accommodates a flexible functional form was able to capture the relationship between the length distributions of the two gears. These results need to be taken in a broader context that includes different vessels, seasons and geographic regions. Given the major role that dredge relative efficiency plays in understanding gear performance, it is clear that this topic is of critical importance and 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 (Northeast Peak and Georges Bank overall) 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 NEG during the July 2012 provided a high-resolution view of the resource in this area. Northeast Georges is unique in that it may play a critical role in the spatial management strategy of the sea scallop resource on Georges Bank. The Habitat Omnibus Amendment may set the stage for new approaches to spatial scallop management on Georges Bank. If this becomes a reality, the NEG region will surely become a cornerstone. 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 the surveyed areas of Northern Closed Area II, Georges Shoals/Northern Edge, and the Habitat Area of Particular Concern. All coordinates are shown in decimal degrees. The northern border of the GSNE follows the depth contour, but is in a general straight line between GSNE-1 and GSNE-2.

Area	Latitude	Longitude
CAII -1	41.500 N	66.580 W
CAII -2	41.500 N	67.334 W
CAII -3	41.833 N	67.334 W
CAII -4	41.833 N	67.167 W
CAII -5	42.000 N	67.167 W
CAII -6	42.000’ N	67.010 W
HAPC-1	41.833 N	67.334 W
HAPC-2	41.833 N	67.167 W
HAPC-3	42.000 N	67.167 W
HAPC-4	42.000’ N	67.010 W
HAPC-5	42.167’ N	67.334 W
HAPC-6	42.167’ N	67.157 W
GSNE-1	42.047 N	67.667 W
GSNE-2	42.142 N	67.334 W
GSNE-3	41.800 N	67.334 W
GSNE-4	41.800 N	67.667 W

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)
NEG	July 15-25, 2012	133	133

Table 3 Mean total and mean exploitable scallop densities observed during the 2012 cooperative sea scallop surveys of Northeast Georges.

Area	Efficiency	Average Total Density (scallops/m^2)	SE	Average Density of Exploitable Scallops (scallops/m^2)	SE
CAII					
Commercial	60%			0.011	0.006
Survey	38%	0.014	0.005	0.010	0.004
GSNE					
Commercial	60%			0.104	0.027
Survey	38%	0.110	0.028	0.086	0.022
HAPC					
Commercial	60%			0.511	0.110
Survey	38%	0.538	0.108	0.416	0.087

Table 4 Estimated number of scallops in the area surveyed. The estimate is based upon the estimated density of scallops at commercial dredge efficiency of 60% and survey dredge efficiency of 38%. The total area surveyed in NEG was estimated at 3,796 km^2 (CAII 2,258 km^2, GSNE 924.5 km^2, and HAPC 613.6 km^2).

	Efficiency	Estimated Total	Estimated Total Exploitable
CAII			
Commercial	60%		26,524,908
Survey	38%	31,690,222	24,501,330
GSNE			
Commercial	60%		96,776,991
Survey	38%	102,223,196	80,054,068
HAPC			
Commercial	60%		313,700,302
Survey	38%	330,632,583	255,771,614

Table 5 Estimated average scallop meat weights for the area surveyed. 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. Length:weight relationships from both SARC 50 as well as that observed from the cruise are shown.

CAII	SH:MW	Mean Meat Weight (g) Total scallops	Mean Meat Weight (g) Exploitable scallops
Commercial	SARC 50 NEP		45.93
Survey	SARC 50 NEP	37.91	46.35
Commercial	SARC 50 W/ LAT		46.66
Survey	SARC 50 W/ LAT	38.87	47.54
Commercial	VIMS DEPTH WEIGHTED		59.14
Survey	VIMS DEPTH WEIGHTED	50.30	60.02
Commercial	VIMS		51.83
Survey	VIMS	44.22	52.99

GSNE	SH:MW	Mean Meat Weight (g) Total scallops	Mean Meat Weight (g) Exploitable scallops
Commercial	SARC 50 NEP		37.20
Survey	SARC 50 NEP	33.21	35.89
Commercial	SARC 50 W/ LAT		36.93
Survey	SARC 50 W/ LAT	32.99	35.66
Commercial	VIMS DEPTH WEIGHTED		42.28
Survey	VIMS DEPTH WEIGHTED	39.31	41.74
Commercial	VIMS		38.47
Survey	VIMS	35.79	38.09

HAPC	SH:MW	Mean Meat Weight (g) Total scallops	Mean Meat Weight (g) Exploitable scallops
Commercial	SARC 50 NEP		35.83
Survey	SARC 50 NEP	32.43	36.51
Commercial	SARC 50 W/ LAT		35.47
Survey	SARC 50 W/ LAT	32.43	36.52
Commercial	VIMS DEPTH WEIGHTED		39.67
Survey	VIMS DEPTH WEIGHTED	37.14	40.63
Commercial	VIMS		35.81
Survey	VIMS	33.41	36.69

Table 6 Mean catch of sea scallops observed during the 2012 VIMS-Industry cooperative surveys. Mean catch is depicted as a function of various shell height meat weight relationships, either an area specific relationships derived from samples taken during the survey, or relationships from SARC 50. The top table depicts mean grams per tow of all scallops caught by the survey dredge. The bottom table depicts mean grams per tow for exploitable scallops caught by each gear.

CAII	Samples	SH:MW	Mean Total (grams/tow)	Standard Error
Survey	67	SARC 50 NEP	671.08	280.77
Survey	67	SARC 50 W/ LAT	688.02	284.77
Survey	67	VIMS DEPTH WEIGHTED	890.39	313.57
Survey	67	VIMS	782.64	357.73

GSNE	Samples	SH:MW	Mean Total (grams/tow)	Standard Error
Survey	28	SARC 50 NEP	6,476.46	1,640.65
Survey	28	SARC 50 W/ LAT	6,433.61	1,621.93
Survey	28	VIMS DEPTH WEIGHTED	7,688.16	1,898.67
Survey	28	VIMS	6,981.05	1,712.70

HAPC	Samples	SH:MW	Mean Total (grams/tow)	Standard Error
Survey	38	SARC 50 NEP	27,760.17	5,320.50
Survey	38	SARC 50 W/ LAT	27,470.04	5,264.88
Survey	38	VIMS DEPTH WEIGHTED	31,457.60	6,304.83
Survey	38	VIMS	28,301.90	5,761.75

Table 6 Continued

CAII	**Samples**	**SH:MW**	**Mean Exploitable (grams/tow)**	**Standard Error**
Commercial	67	SARC 50 NEP	2,116.69	1,198.57
Survey	67	SARC 50 NEP	671.08	280.77
Commercial	67	SARC 50 W/ LAT	2,150.31	1,207.33
Survey	67	SARC 50 W/ LAT	688.01	284.76
Commercial	67	VIMS DEPTH WEIGHTED	2,725.35	1,518.25
Survey	67	VIMS DEPTH WEIGHTED	890.39	357.72
Commercial	67	VIMS	2,388.81	1,325.19
Survey	67	VIMS	782.63	313.56

GSNE	**Samples**	**SH:MW**	**Mean Exploitable (grams/tow)**	**Standard Error**
Commercial	28	SARC 50 NEP	20,683.44	5,218.33
Survey	28	SARC 50 NEP	6,476.46	1,640.64
Commercial	28	SARC 50 W/ LAT	20,530.99	5,154.66
Survey	28	SARC 50 W/ LAT	6,433.61	1,621.93
Commercial	28	VIMS DEPTH WEIGHTED	23,508.75	5,803.00
Survey	28	VIMS DEPTH WEIGHTED	7668,15	1898.7
Commercial	28	VIMS	21,387.21	5,223.98
Survey	28	VIMS	6,981.04	1,898.67

HAPC	**Samples**	**SH:MW**	**Mean Exploitable (grams/tow)**	**Standard Error**
Commercial	38	SARC 50 NEP	86,255.82	17,121.2
Survey	38	SARC 50 NEP	27,760.03	5,320.50
Commercial	38	SARC 50 W/ LAT	85,385.71	16,950.43
Survey	38	SARC 50 W/ LAT	27470.03	5,264.87
Commercial	38	VIMS DEPTH WEIGHTED	95,505.47	20,308.96
Survey	38	VIMS DEPTH WEIGHTED	31,457.59	6,304.83
Commercial	38	VIMS	86,214.95	18672.49
Survey	38	VIMS	28,301.90	5,761.75

Table 7 Estimated total biomass of sea scallops observed during the 2012 VIMS-Industry cooperative survey. Biomass is presented as a function of different shell height meat weight relationships, either an area specific relationships derived from samples taken during the actual survey or relationships from SARC 50.

CAII	**SH:MW**	**Efficiency**	**Total Biomass (mt)**	**95% CI**	**Lower Bound 95% CI**	**Upper Bound 95%CI**
Survey	SARC 50 NEP	38%	944.71	477.55	467.16	1,422.26
Survey	SARC 50 W/ LAT	38%	968.55	484.35	484.19	1,452.90
Survey	VIMS DEPTH WEIGHTED	38%	1,253.44	608.45	644.99	1,861.90
Survey	VIMS	38%	1,101.75	533.34	568.42	1,635.09

GSNE	**SH:MW**	**Efficiency**	**Total Biomass (mt)**	**95% CI**	**Lower Bound 95% CI**	**Upper Bound 95%CI**
Survey	SARC 50 NEP	38%	3,437.67	1,052.18	2,385.49	4,489.85
Survey	SARC 50 W/ LAT	38%	3,414.92	1,040.18	2,374.75	4,455.10
Survey	VIMS DEPTH WEIGHTED	38%	4,070.21	1,217.65	2,852.56	5,287.87
Survey	VIMS	38%	3,705.50	1,098.39	2,607.11	4,803.89

HAPC	**SH:MW**	**Efficiency**	**Total Biomass (mt)**	**95% CI**	**Lower Bound 95% CI**	**Upper Bound 95%CI**
Survey	SARC 50 NEP	38%	10,115.60	2,342.45	7,773.15	12,458.04
Survey	SARC 50 W/ LAT	38%	10,009.88	2,317.96	7,691.92	12,327.83
Survey	VIMS DEPTH WEIGHTED	38%	11,462.91	2,775.82	8,687.10	14,238.73
Survey	VIMS	38%	10,313.00	2,536.72	7,776.28	12,849.72

Table 8 Estimated exploitable biomass of sea scallops observed during the 2012 VIMS-Industry cooperative survey. Biomass is presented as a function of different shell height meat weight relationships, either an area specific relationship derived from samples taken during the actual survey or relationships from SARC 50.

CAII	**SH:MW**	**Efficiency**	**Exploitable Biomass (mt)**	**95% CI**	**Lower Bound 95% CI**	**Upper Bound 95%CI**
Commercial	SARC 50 CAII	60%	1,006.49	865.26	141.23	1,871.75
Survey	SARC 50 CAII	38%	898.76	464.15	434.61	1,362.90
Commercial	SARC 50 W/ LAT	60%	1,022.48	871.59	150.89	1,894.07
Survey	SARC 50 W/ LAT	38%	921.95	470.87	451.08	1,392.81
Commercial	VIMS DEPTH WEIGHTED	60%	1,295.91	1,096.04	199.87	2,391.96
Survey	VIMS DEPTH WEIGHTED	38%	1,163.97	587.60	576.37	1,751.57
Commercial	VIMS	60%	1,135.89	956.68	179.21	2,092.56
Survey	VIMS	38%	1,027.62	515.65	511.97	1,543.26

GSNE	**SH:MW**	**Efficiency**	**Exploitable Biomass (mt)**	**95% CI**	**Lower Bound 95% CI**	**Upper Bound 95%CI**
Commercial	SARC 50 GSNE	60%	3,708.34	1,420.43	2,287.91	5,128.78
Survey	SARC 50GSNE	38%	2,940.27	896.96	2,043.31	3,837.23
Commercial	SARC 50 W/ LAT	60%	3,681.01	1,403.10	2,277.91	5,084.11
Survey	SARC 50 W/ LAT	38%	2,921.48	886.94	2,034.54	3,808.42
Commercial	VIMS DEPTH WEIGHTED	60%	4,214.90	1,579.58	2,635.32	5,794.48
Survey	VIMS DEPTH WEIGHTED	38%	3,419.88	1,023.41	2,396.47	4,443.29
Commercial	VIMS	60%	3,834.53	1,421.97	2,412.55	5,256.50
Survey	VIMS	38%	3,120.89	924.94	2,195.95	4,045.83

Table 8 Continued

HAPC	**SH:MW**	**Efficiency**	**Exploitable Biomass (mt)**	**95% CI**	**Lower Bound 95% CI**	**Upper Bound 95%CI**
Commercial	SARC 50 HAPC	60%	10616.68	3,199.38	7,417.29	13,816.07
Survey	SARC 50 HAPC	38%	8,768.80	2,045.19	6,723.61	10,813.99
Commercial	SARC 50 W/ LAT	60%	10509.58	3,167.47	7,342.11	13,677.06
Survey	SARC 50 W/ LAT	38%	8,679.17	2,024.08	6,655.08	10,703.25
Commercial	VIMS DEPTH WEIGHTED	60%	11,755.16	3,795.07	7,960.09	15,550.23
Survey	VIMS DEPTH WEIGHTED	38%	9,656.74	2,363.97	7,292.77	12,020.71
Commercial	VIMS	60%	10,611.65	3,795.07	7,960.09	15,550.23
Survey	VIMS	38%	8,721.85	2,169.31	6,552.54	10,891.15

Table 9 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, and (2) SARC 50 (NEFSC, 2010).

	Date	**α**	**β**	**γ**	**δ**
VIMS 2 Parameter					
	July, 2012	-6.1377	2.1171	0.1625	
	July, 2012	-6.1377	2.1171	0.1165	
	July, 2012	-6.1377	2.1171	0	
VIMS Depth Weighted					
Northern CAII	July, 2012	-5.0491	1.9131	-0.1300	0.2050
GSNE	July, 2012	-5.0491	1.9131	-0.1300	0.07866
HAPC	July, 2012	-5.0491	1.9131	-0.1300	0
SARC 50					
Northeast Peak	-	-7.9335	2.8325	-0.5477	
Northeast Georges W/ Latitude	-	9.6771	2.8387	-0.5084	-4.7629

The length weight relationship for sea scallops from data collected on the cruise as well as SARC 50 is modeled as:

$$W=\exp(\alpha+ \beta*\ln(L) + \gamma_{subarea})$$

$$W=\exp(\alpha+ \beta*\ln(L) + \gamma*\ln(D) + \delta_{subarea})$$

For SARC 50 (Georges Bank) depth and latitude term are included in the model as follows:

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

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

Where *W* is meat weight in grams, *SH* is scallop shell height in millimeters (measured from the umbo to the ventral margin) and *L* is latitude in decimal degrees.

Table 10 Catch per unit effort (a unit of effort is represented by one standard survey tow of 15 minute duration at 3.8 kts.) and total catch of finfish bycatch encountered during the survey of Northeast Georges during July 2012.

Northern CAII	**Commercial Dredge**		**NMFS Survey Dredge**	
Species	**total caught**	**CPUE**	**total caught**	**CPUE**
Spiny Dogfish	0	0.00	55	0.82
Unclassified Skates	890	13.28	952	14.21
Barndoor Skate	4	0.06	2	0.03
Atlantic Cod	1	0.01	1	0.01
Haddock	1	0.01	66	0.99
Summer Flounder	2	0.03	9	0.13
Fourspot Flounder	11	0.16	26	0.39
Yellowtail Flounder	27	0.40	62	0.93
Winter Flounder	61	0.91	61	0.91
Windowpane Flounder	145	2.16	454	6.78
Monkfish	15	0.22	19	0.28

Georges Shoal/ No. Edge	**Commercial Dredge**		**NMFS Survey Dredge**	
Species	**total caught**	**CPUE**	**total caught**	**CPUE**
Unclassified Skates	377	13.46	192	6.86
Barndoor Skate	7	0.25	1	0.04
Haddock	4	0.14	0	0.00
Summer Flounder	8	0.29	13	0.46
Fourspot Flounder	13	0.46	12	0.43
Yellowtail Flounder	7	0.25	14	0.50
Winter Flounder	9	0.32	20	0.71
Windowpane Flounder	77	2.75	96	3.43
Monkfish	4	0.14	2	0.07

HAPC	**Commercial Dredge**		**NMFS Survey Dredge**	
Species	**total caught**	**CPUE**	**total caught**	**CPUE**
Unclassified Skates	921	24.24	553	14.55
Barndoor Skate	13	0.34	4	0.11
Atlantic Cod	1	0.03	1	0.03
Haddock	0	0.00	2	0.05
Summer Flounder	1	0.03	3	0.08
Fourspot Flounder	5	0.13	4	0.11
Yellowtail Flounder	15	0.39	21	0.55
Winter Flounder	70	1.84	94	2.47
Windowpane Flounder	83	2.18	110	2.89
Monkfish	33	0.87	15	0.39

Table 11 Mixed effects model results using the unpooled scallop catch data . Results are for from the model that provided the best fit (intercept and length, length^2 and length^3) to the data as supported by model comparison (minimum AIC value). Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale.

Effect	**Estimate**	**SE**	**DF**	**t-value**	**p-value**	**LCI**	**UCI**
Intercept	2.389187	0.7497	1123	3.1868	0.0015	0.9182	3.8602
Length	-0.123413	0.0232	1123	-5.3300	0.0000	-0.1688	-0.0780
Length^2	0.001457	0.0002	1123	6.3527	0.0000	0.0010	0.0019
Length^3	-0.000005	0.0000	1123				

Figure 1 Locations of stations sampled during the Northeast Georges survey by the F/V *Regulus* during the cruise conducted in July, 2012.

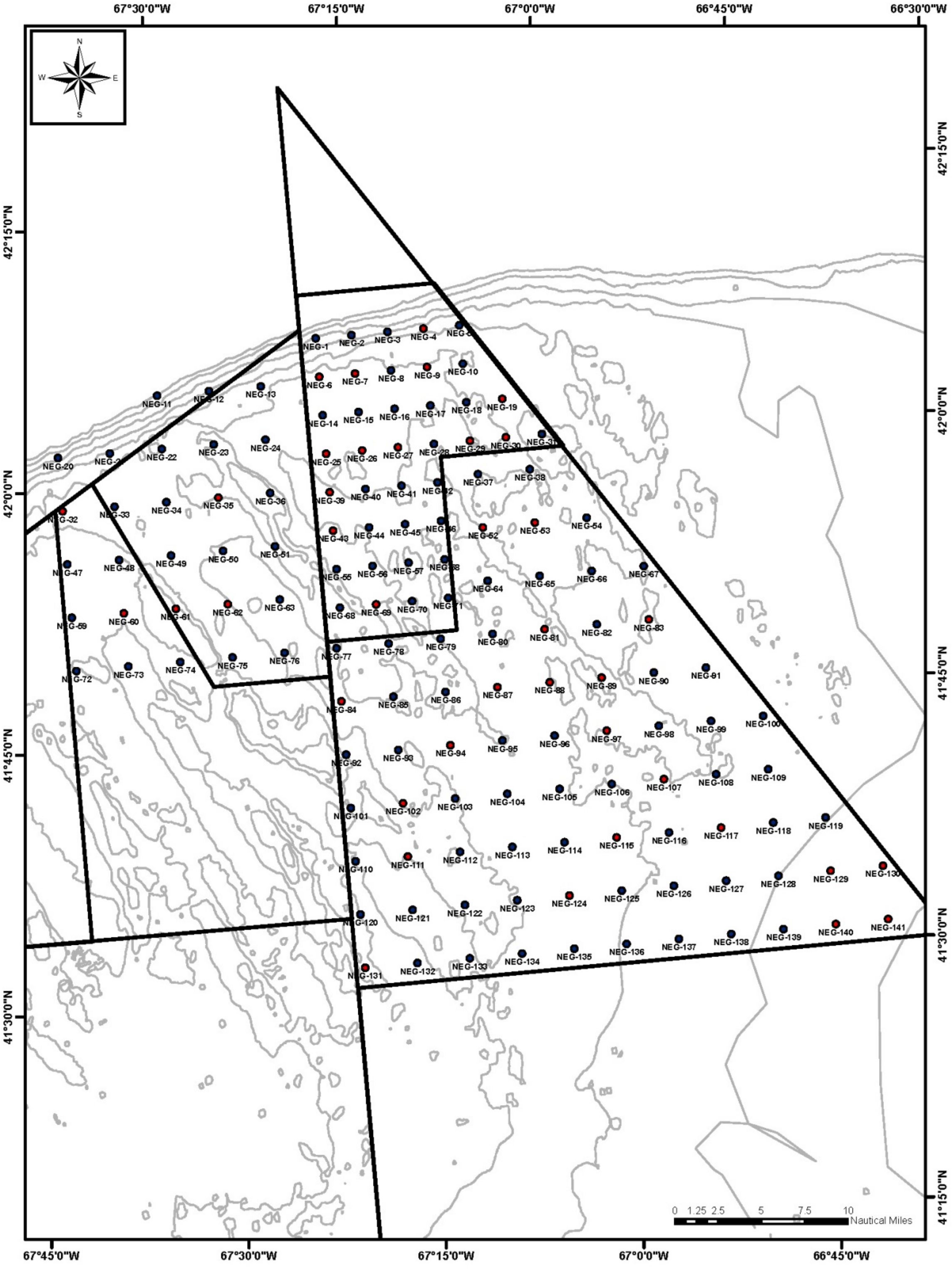


Figure 2 An example of the output Star-Oddi™ DST sensor. Arrows indicate the interpretation of the start and end of the dredge tow

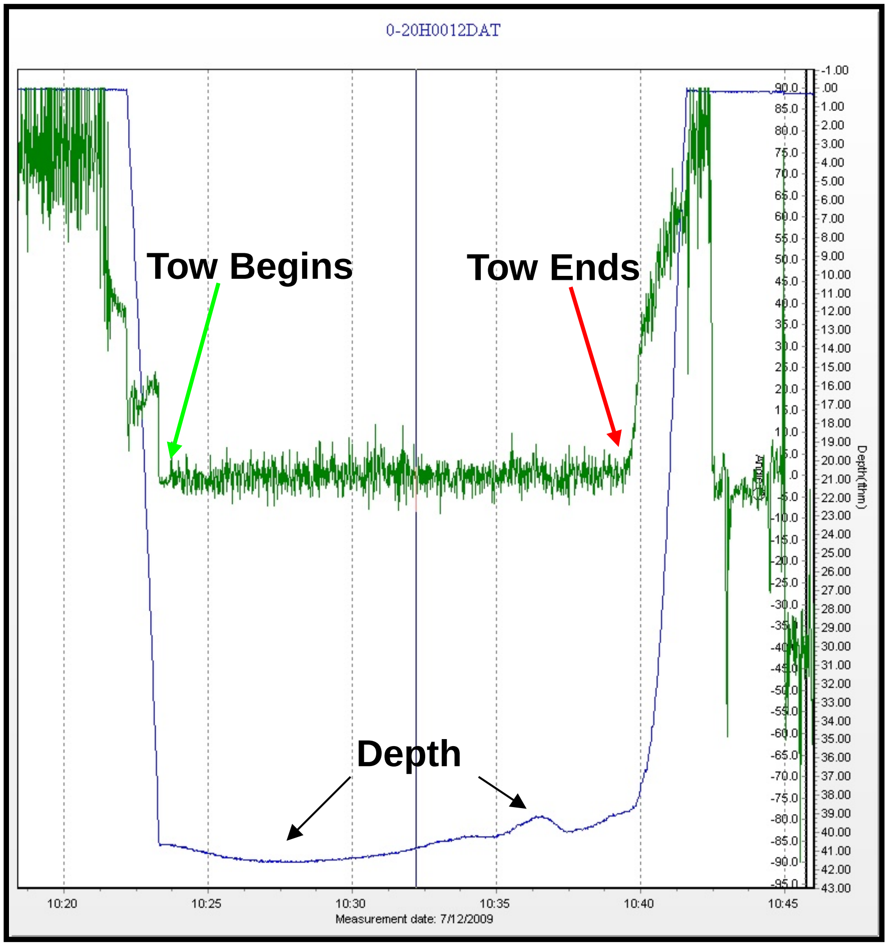


Figure 3 Histogram of calculated tow lengths from the 2012 survey of Northeast Georges. Mean tow length was 1851.8 m with a standard deviation of 68.6 m.

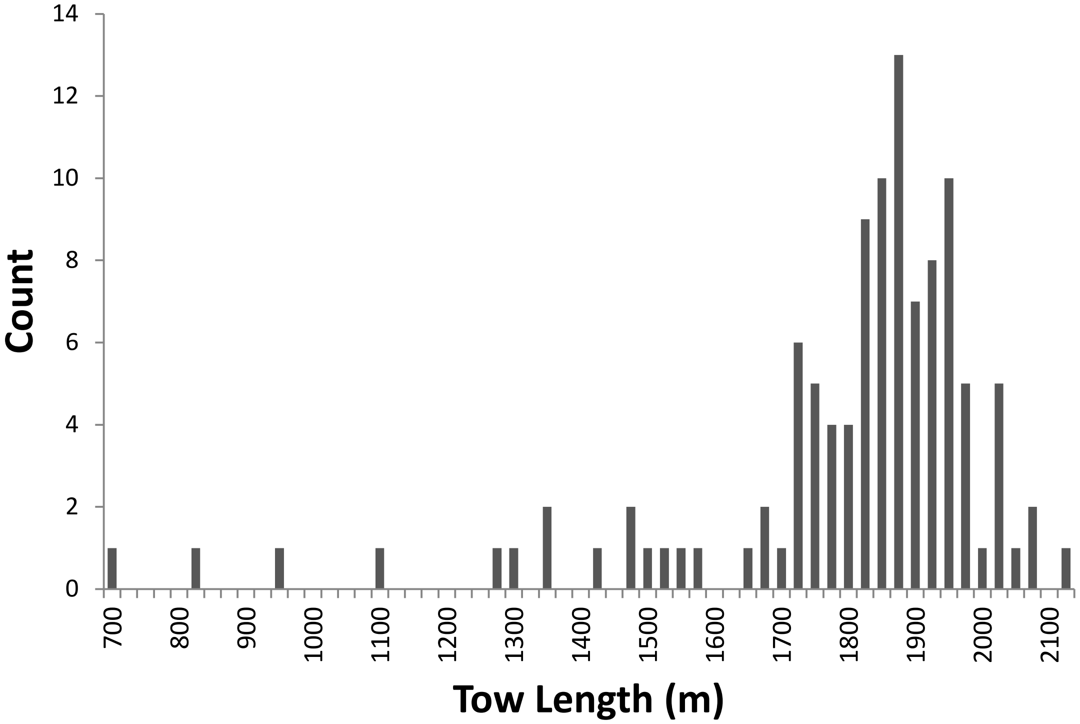


Figure 4 Shell height frequencies for the two dredge configurations used to survey Northern Closed Area II during July, 2012. The frequencies represent the expanded but unadjusted catches of the two gears for all sampled tows.

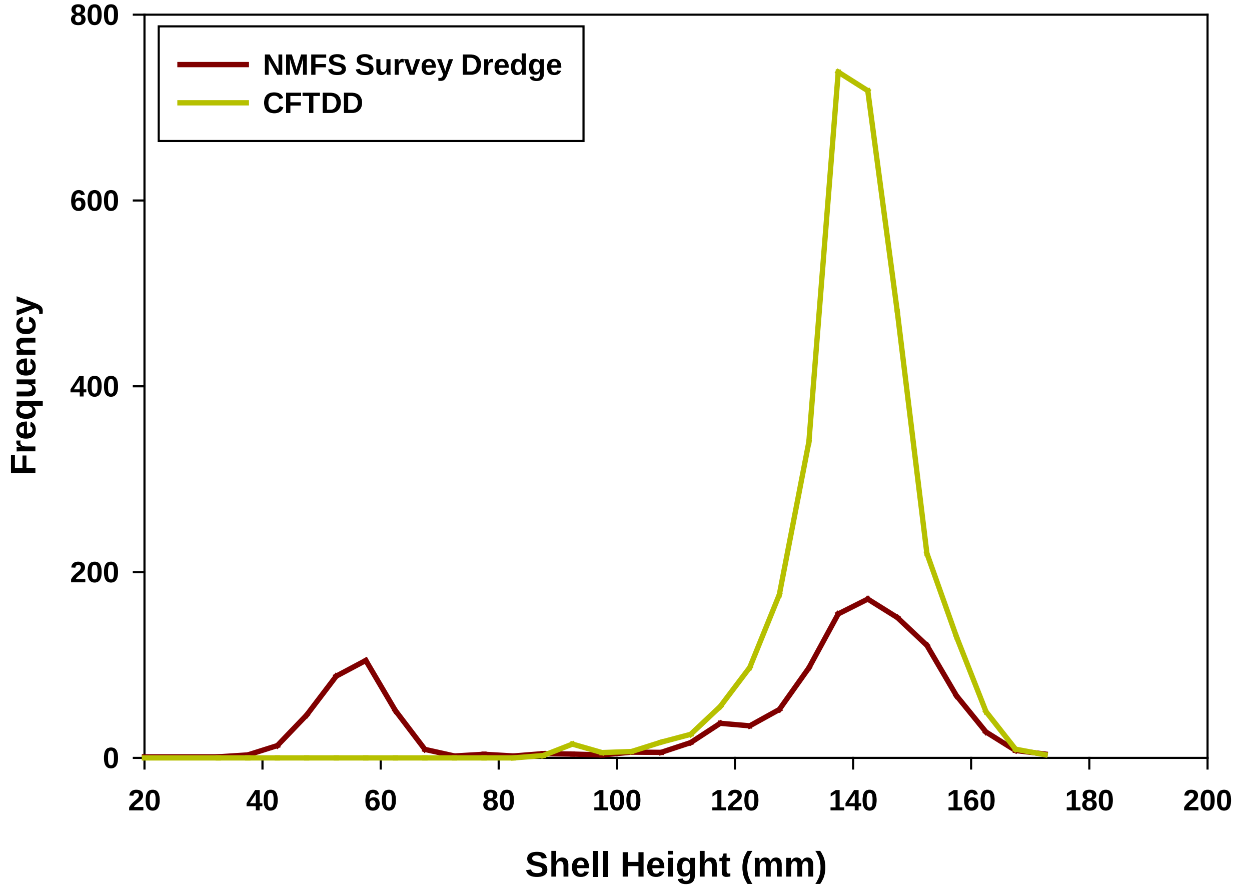


Figure 5 Shell height frequencies for the two dredge configurations used to survey Georges Shoal/Northern Edge during July, 2012. The frequencies represent the expanded but unadjusted catches of the two gears for all sampled tows.

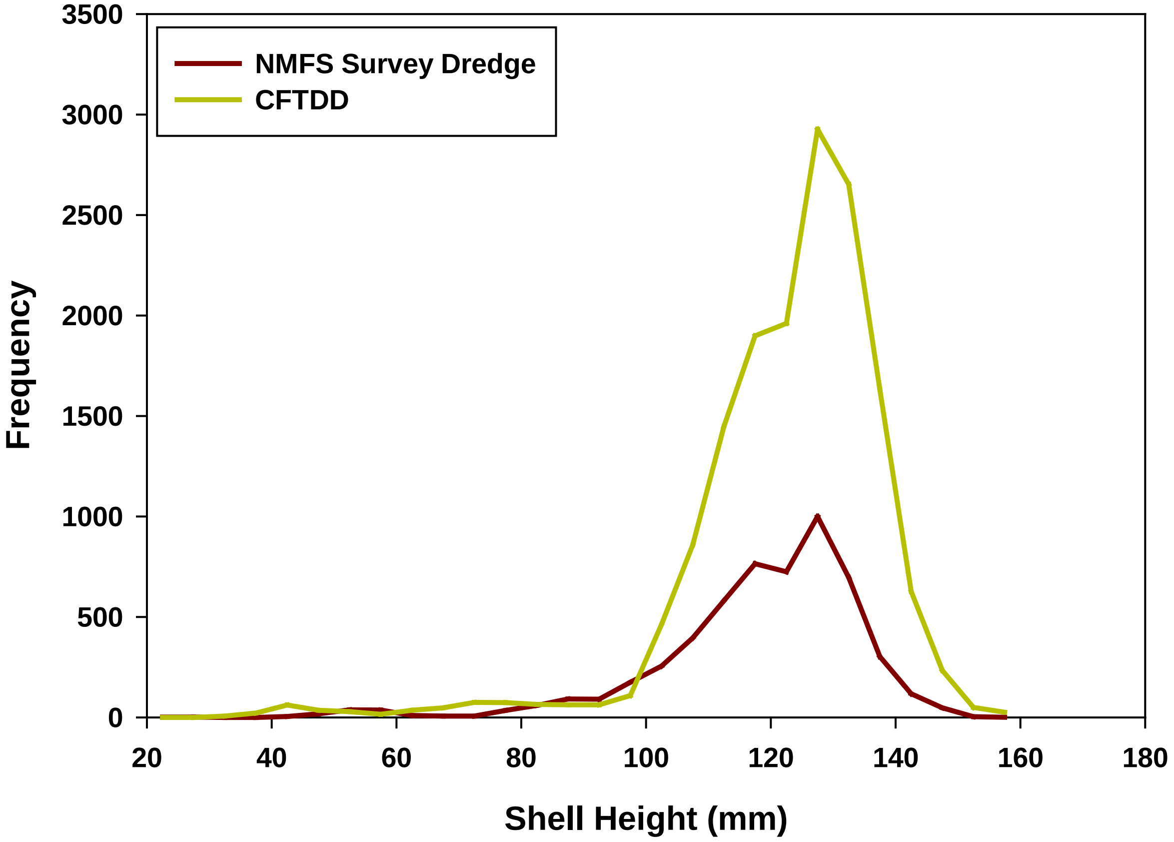


Figure 6 Shell height frequencies for the two dredge configurations used to survey the HAPC during July, 2012. The frequencies represent the expanded but unadjusted catches of the two gears for all sampled tows.

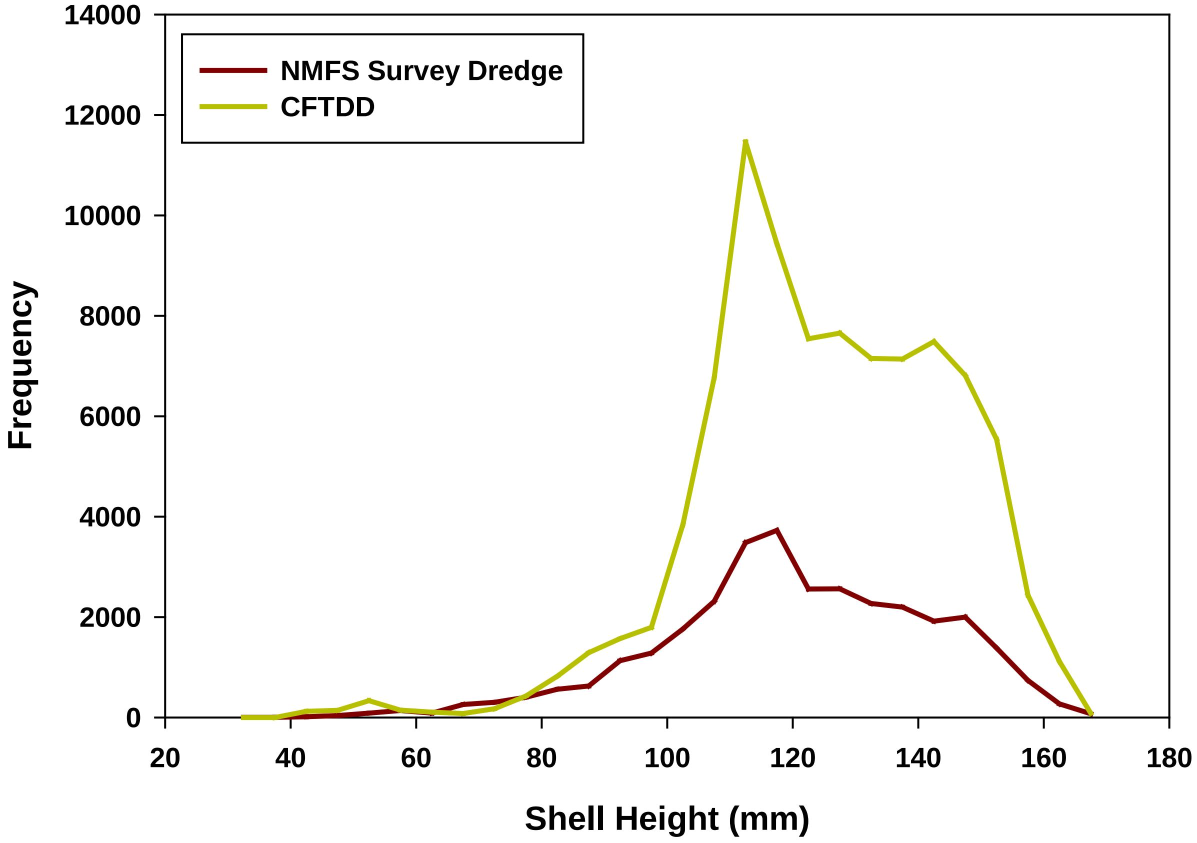


Figure 7 Spatial distribution of sea scallop catches on the survey cruise of the Northeast Georges Closed Area during July, 2012 by the NMFS survey dredge. This figure represents the catch of pre-recruit sea scallops (<90mm).

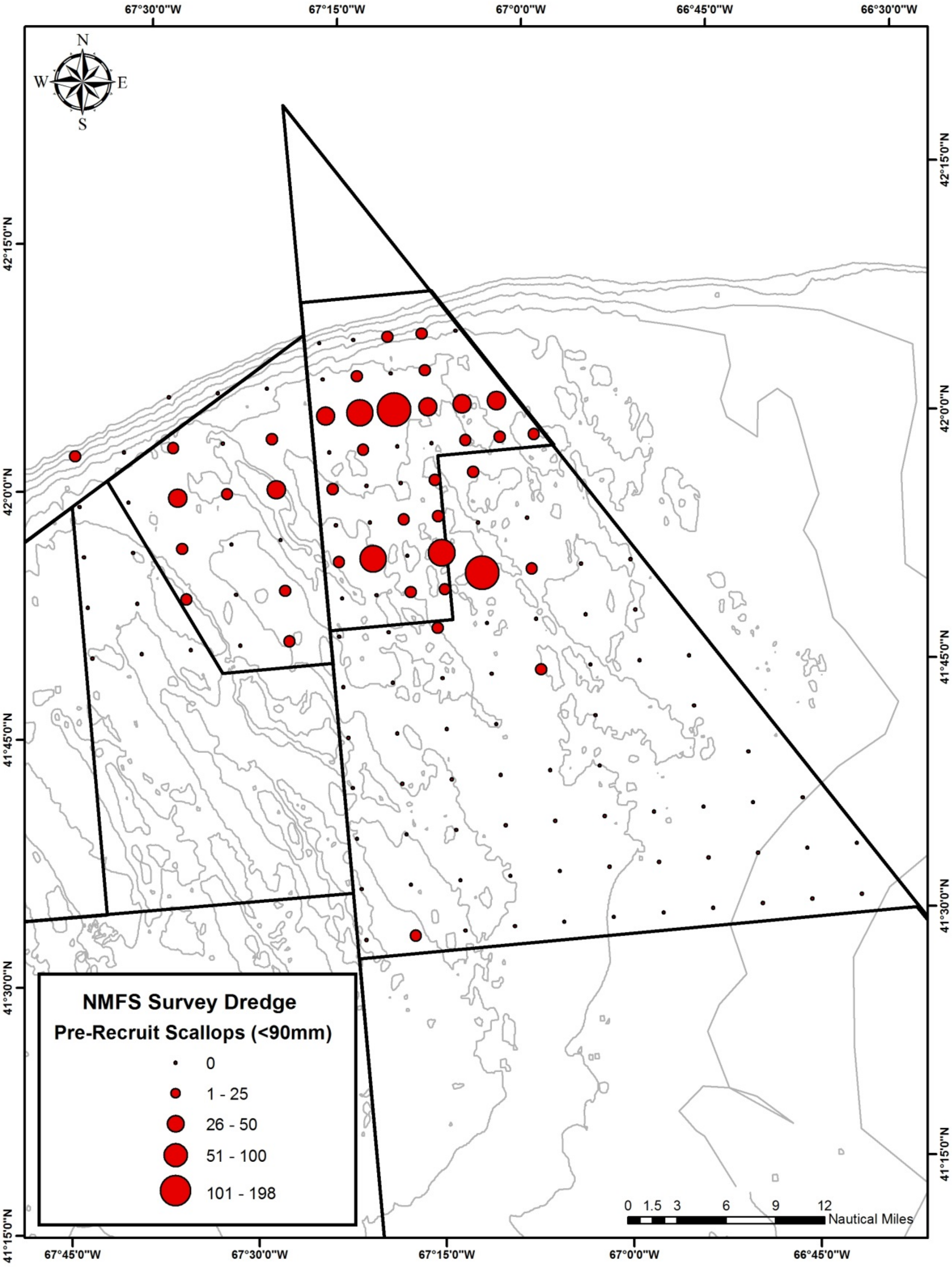


Figure 8 Spatial distribution of sea scallop catches on the survey cruise of the Northeast Georges Closed Area during July, 2012 by the NMFS survey dredge. This figure represents the catch of recruit sea scallops (>90 mm).

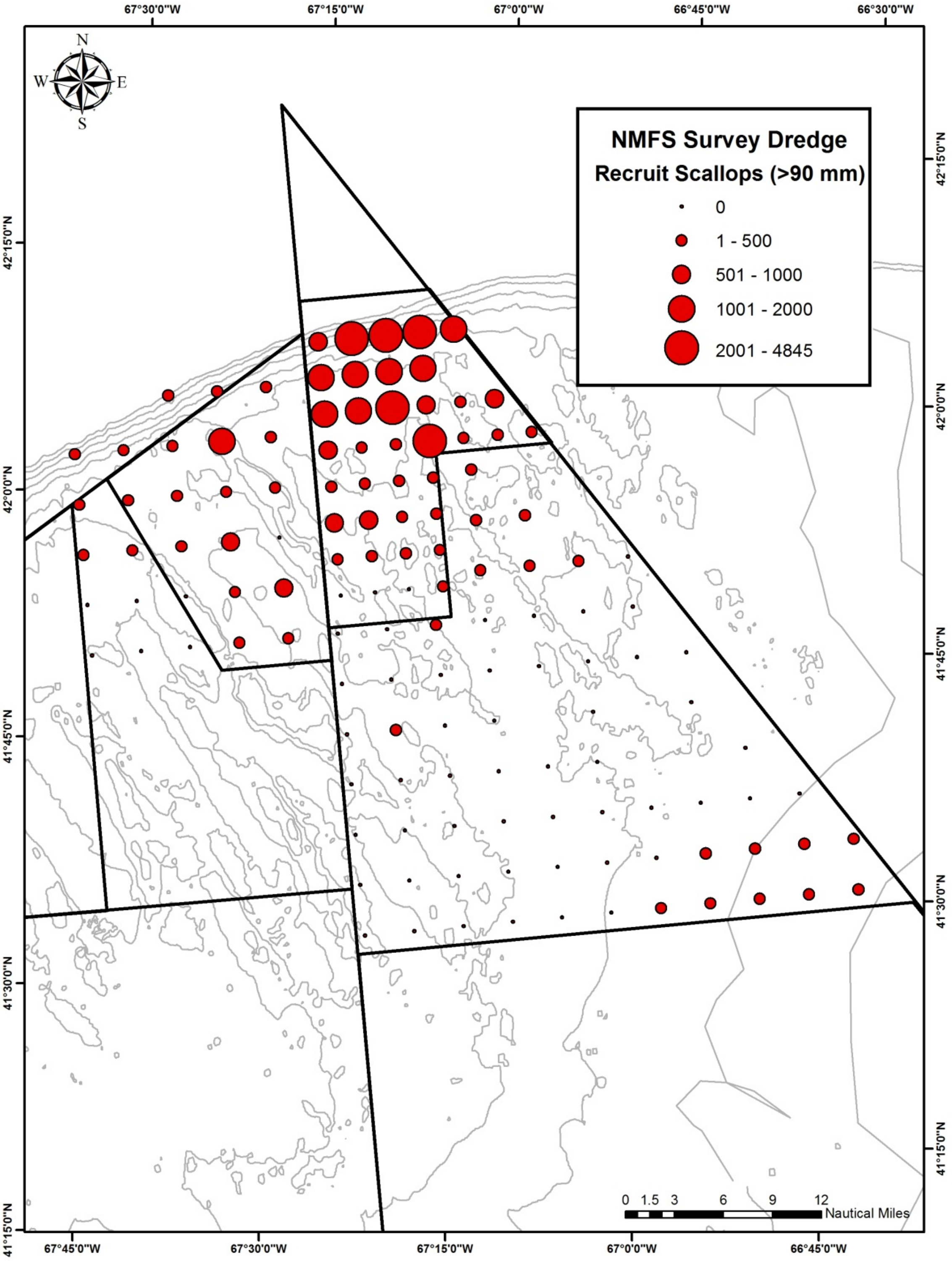


Figure 9 Spatial distribution of sea scallop catches on the survey cruise of the Northeast Georges Closed Area during July, 2012 by the CFTDD. This figure represents the catch of pre-recruit sea scallops (<90mm).

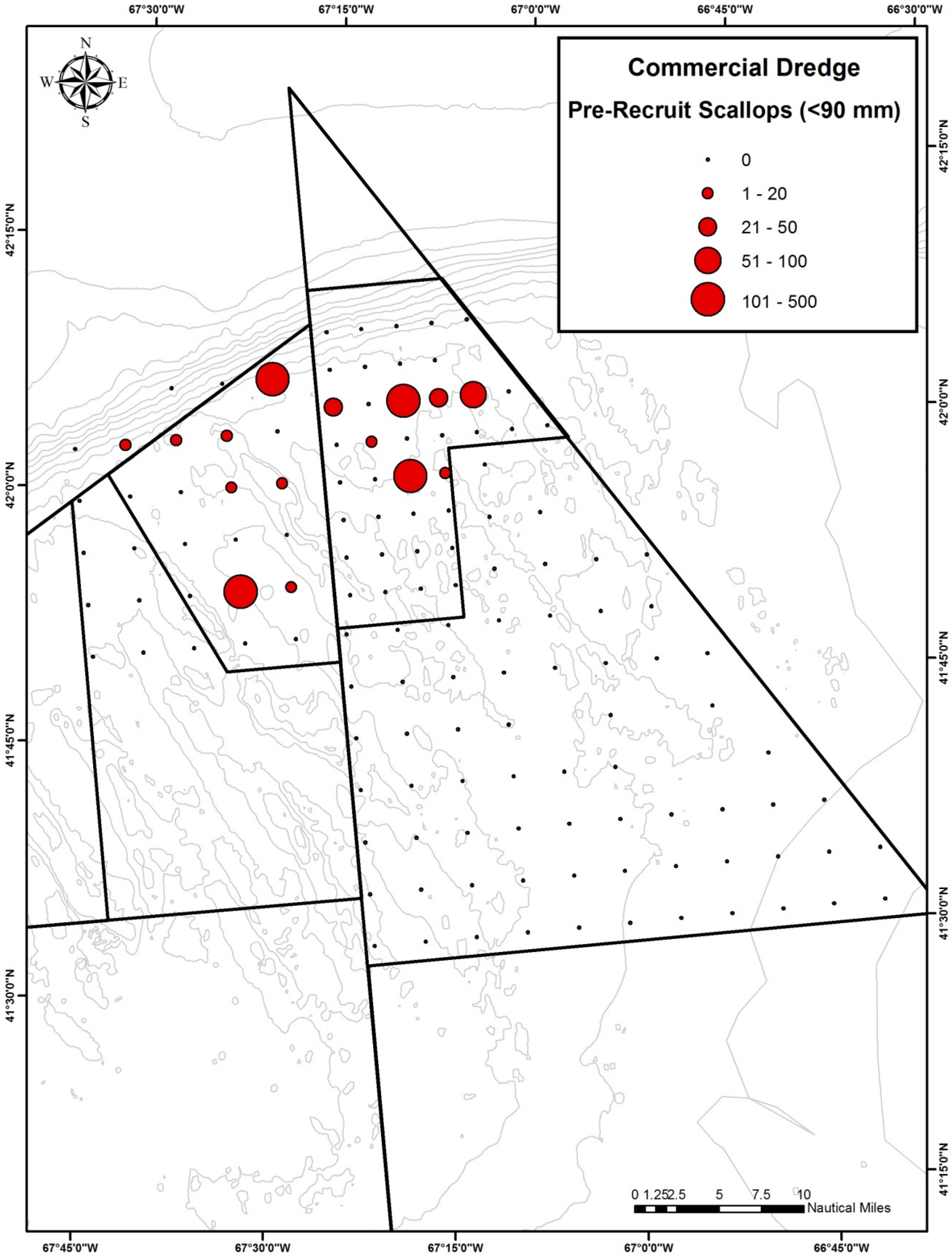


Figure 10 Spatial distribution of sea scallop catches on the survey cruise of the Northeast Georges Closed Area during July, 2012 by the CFTDD. This figure represents the catch of recruit sea scallops (>90 mm).

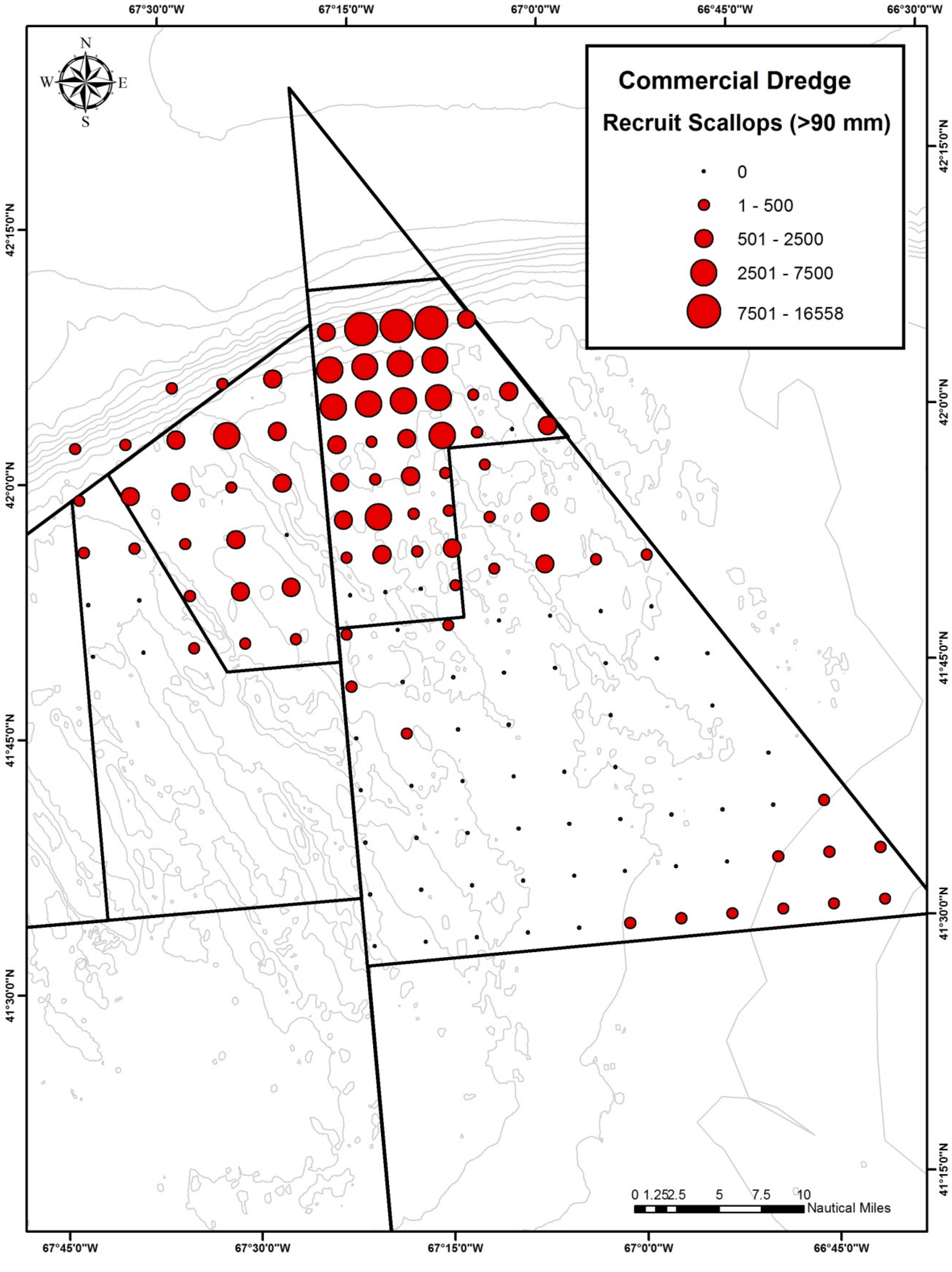
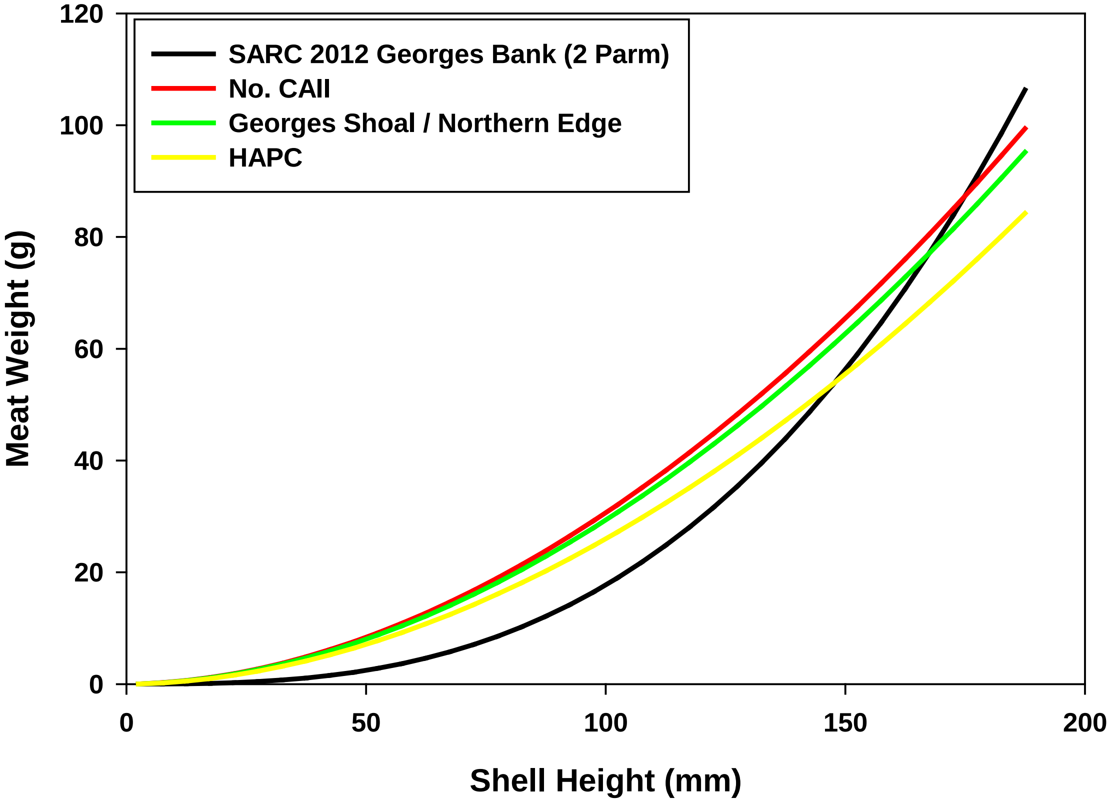


Figure 11 Shell height:meat weight relationships used in the study. The SARC-50 curve is a general relationship for the Northeast Georges. The VIMS-2012 curve is based on samples taken during the survey and is specific for the NEG during July 2012.



<u>Figure 12</u> Yellowtail flounder length frequencies for the two dredge configurations used to survey Northeast Georges during July, 2012. The frequencies represent observations pooled across all sub areas.

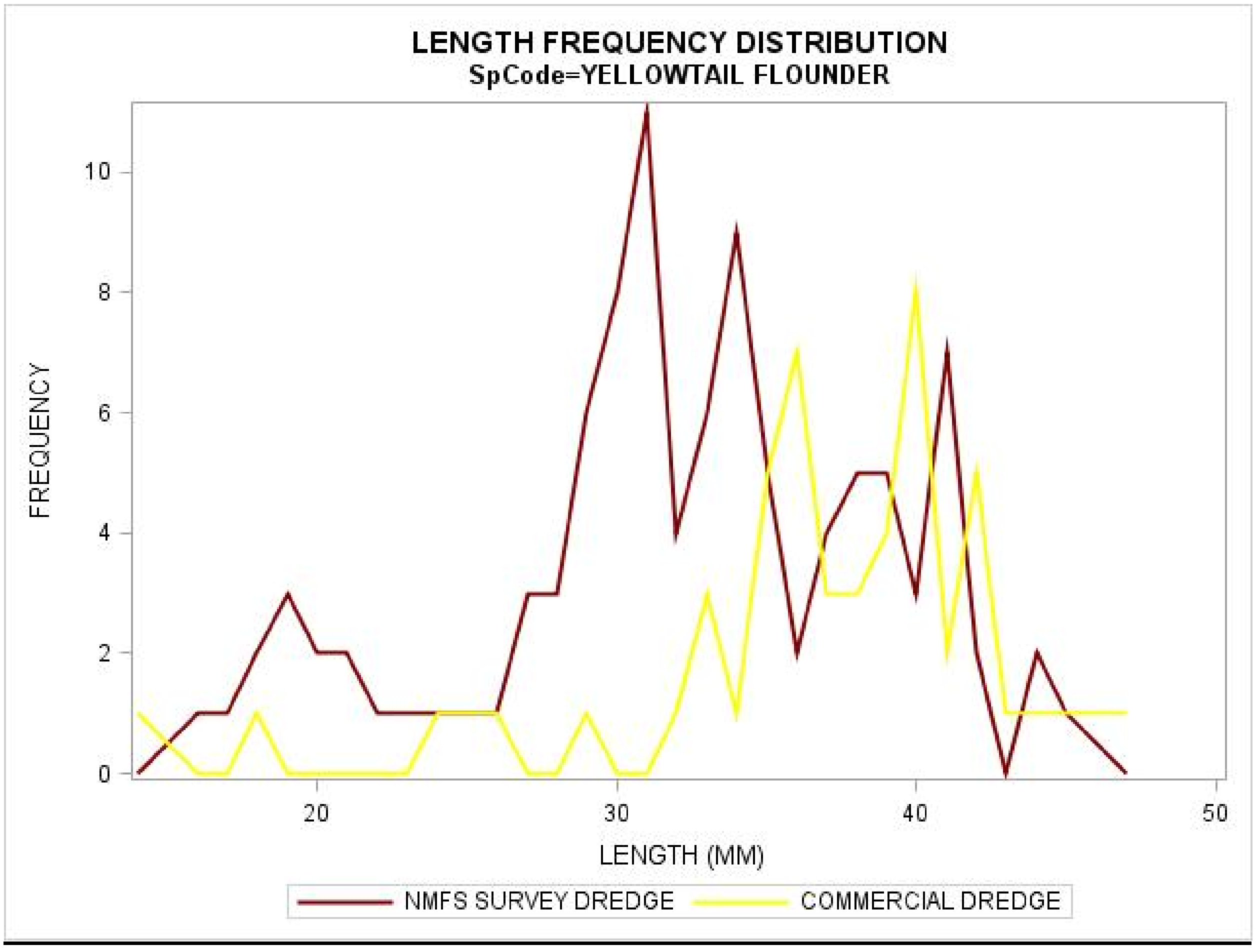


Figure 13 Winter flounder length frequencies for the two dredge configurations used to survey Northeast Georges during July, 2012. The frequencies represent observations pooled across all sub areas.

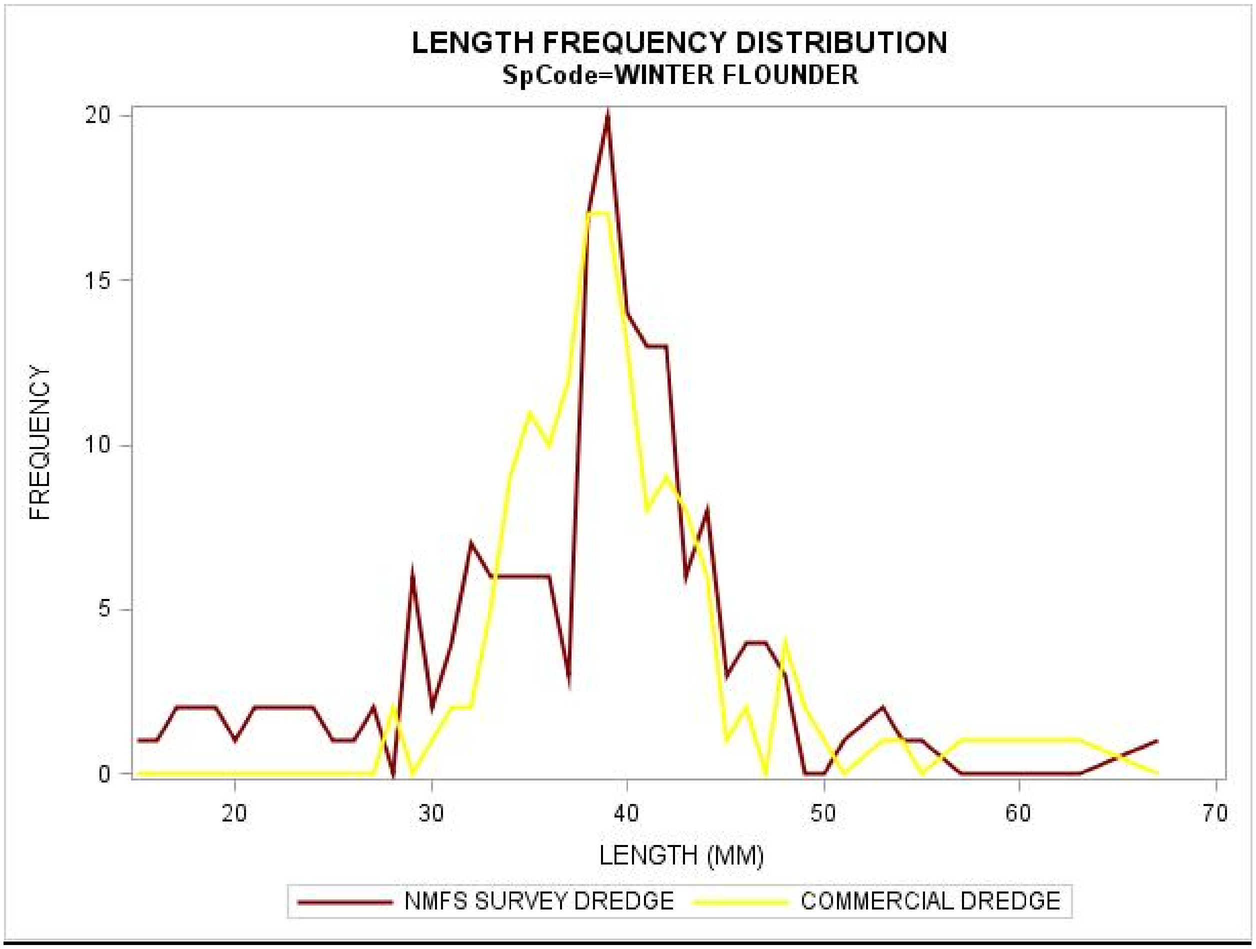


Figure 14 Windowpane flounder length frequencies for the two dredge configurations used to survey Northeast Georges during July, 2012. The frequencies represent observations pooled across all sub areas.

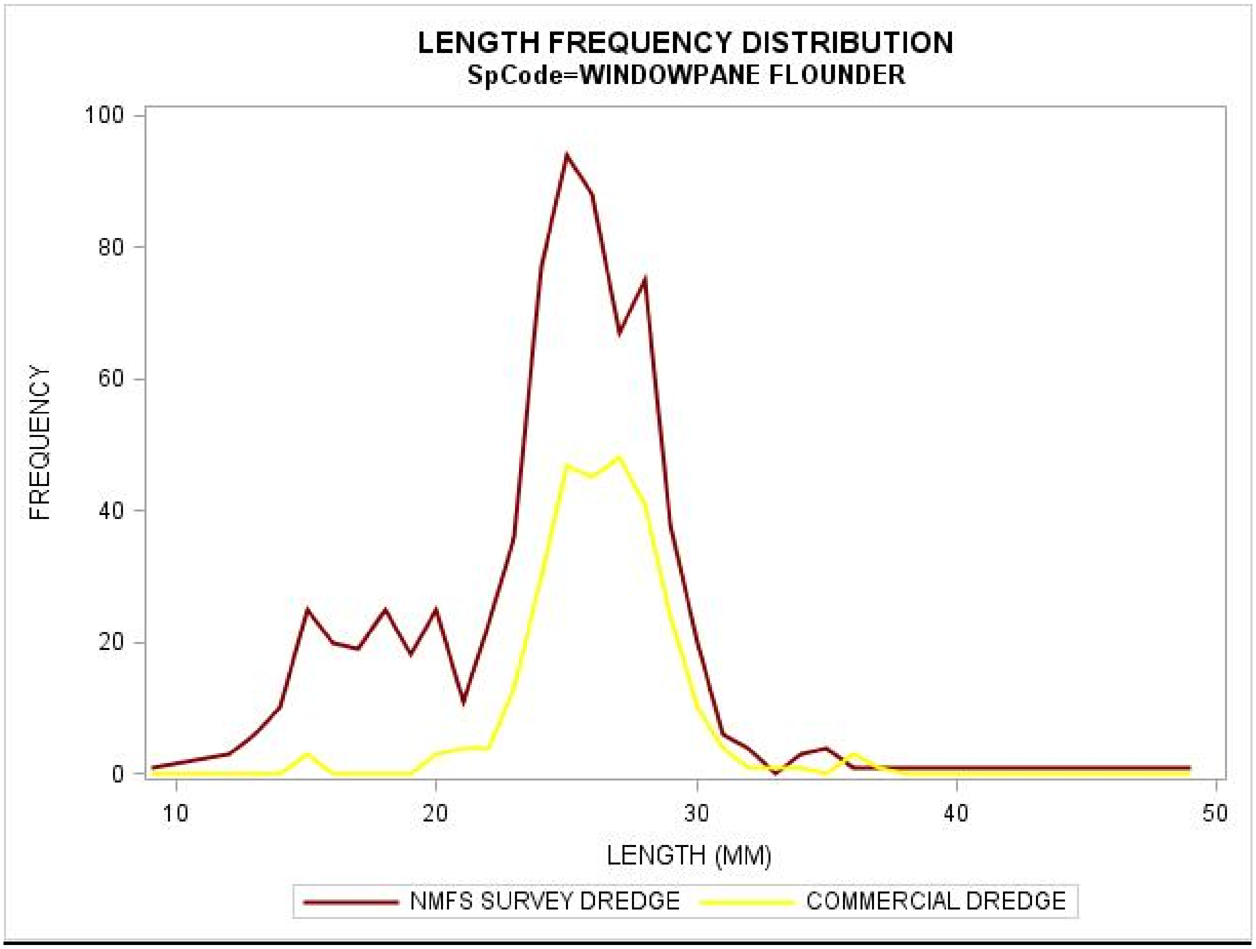


Figure 15 Monkfish length frequencies for the two dredge configurations used to survey Northeast Georges during July, 2012. The frequencies represent observations pooled across all sub areas.

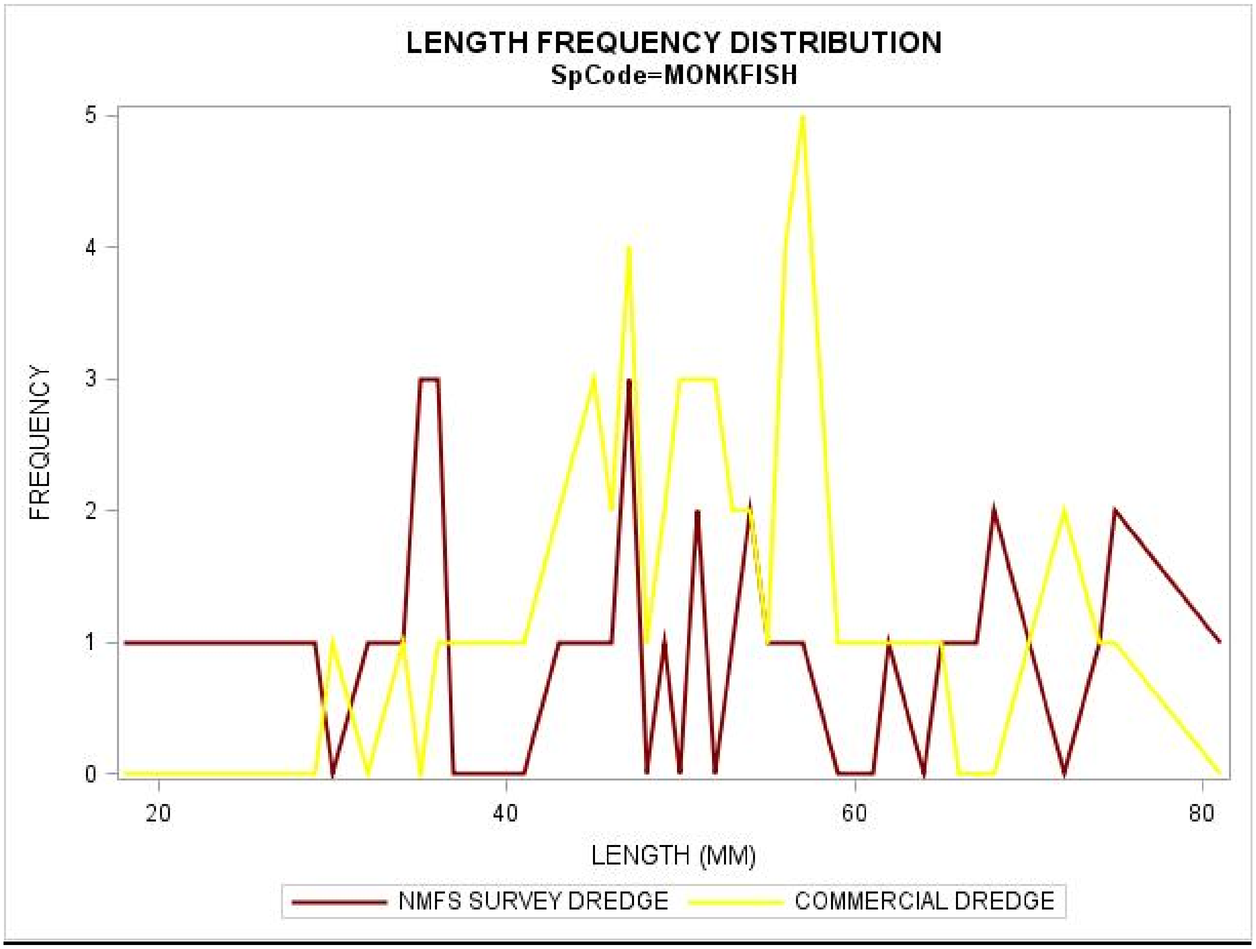


Figure 16 Spatial distribution of yellowtail flounder catches on the survey cruise of the Northeast Georges Closed Area during July, 2012 by the NMFS Survey Dredge.

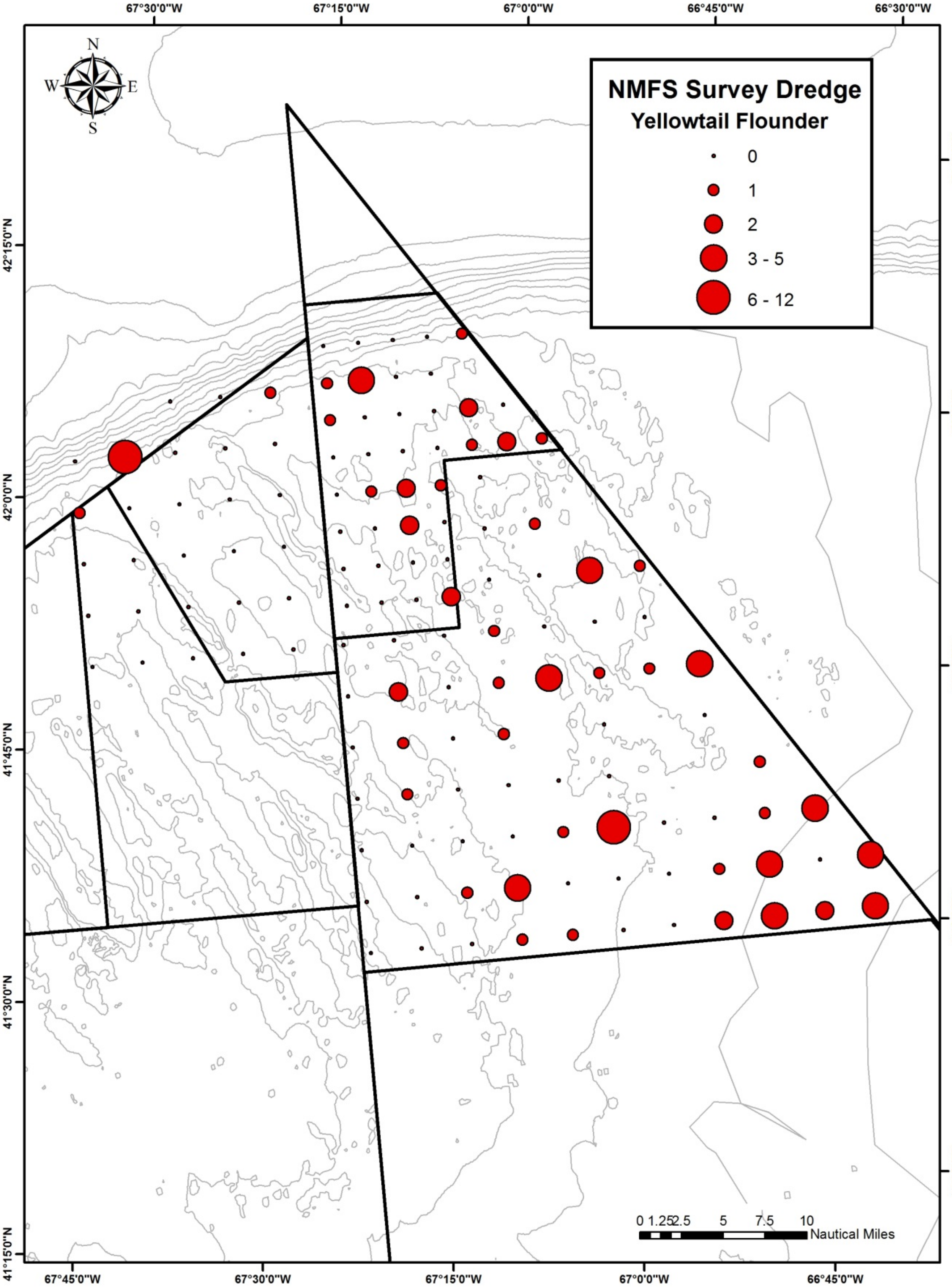


Figure 17 Spatial distribution of yellowtail flounder catches on the survey cruise of the Northeast Georges Closed Area during July, 2012 by the CFTDD.

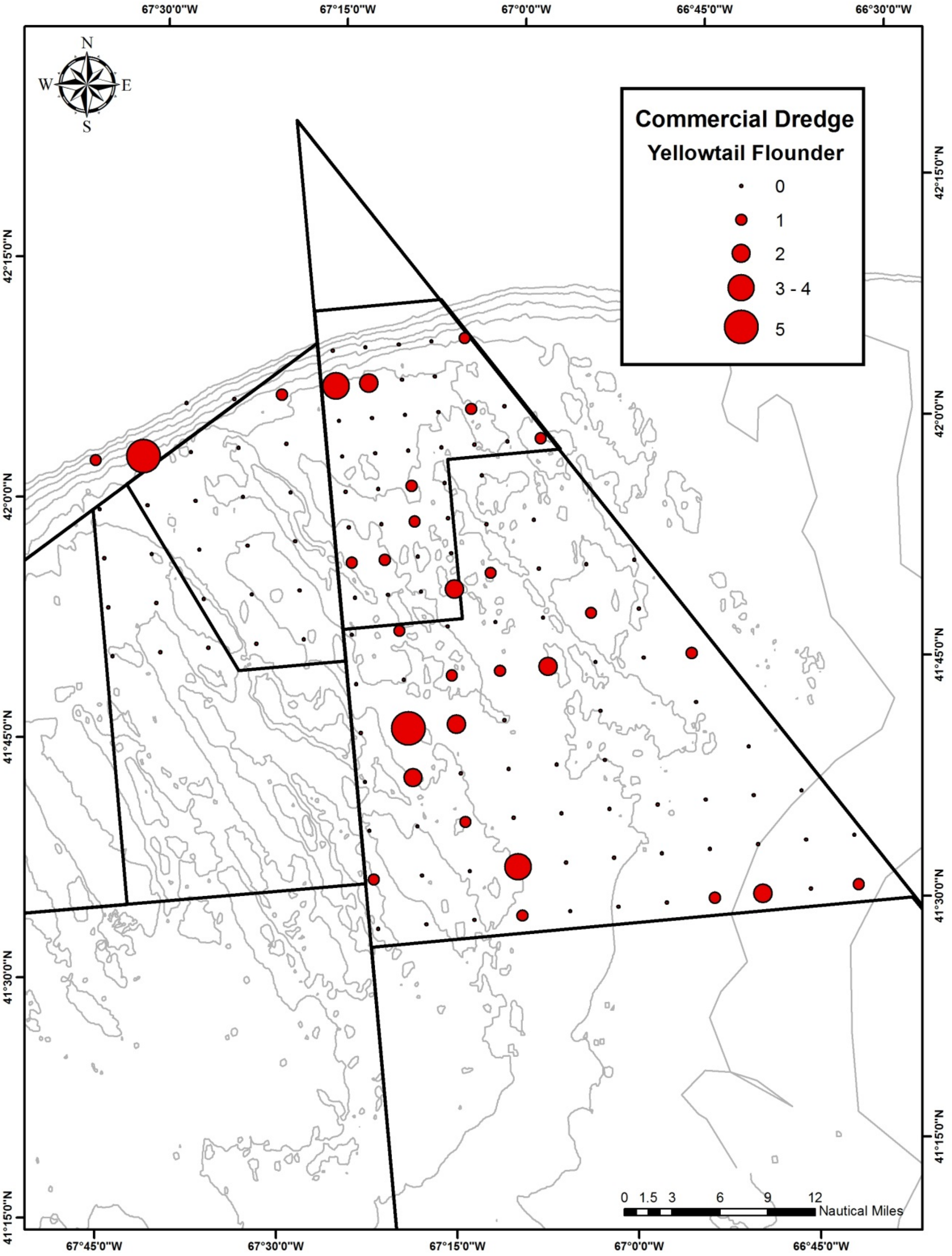


Figure 18 Spatial distribution of winter flounder catches on the survey cruise of the Northeast Georges Closed Area during July, 2012 by the NMFS Survey Dredge.

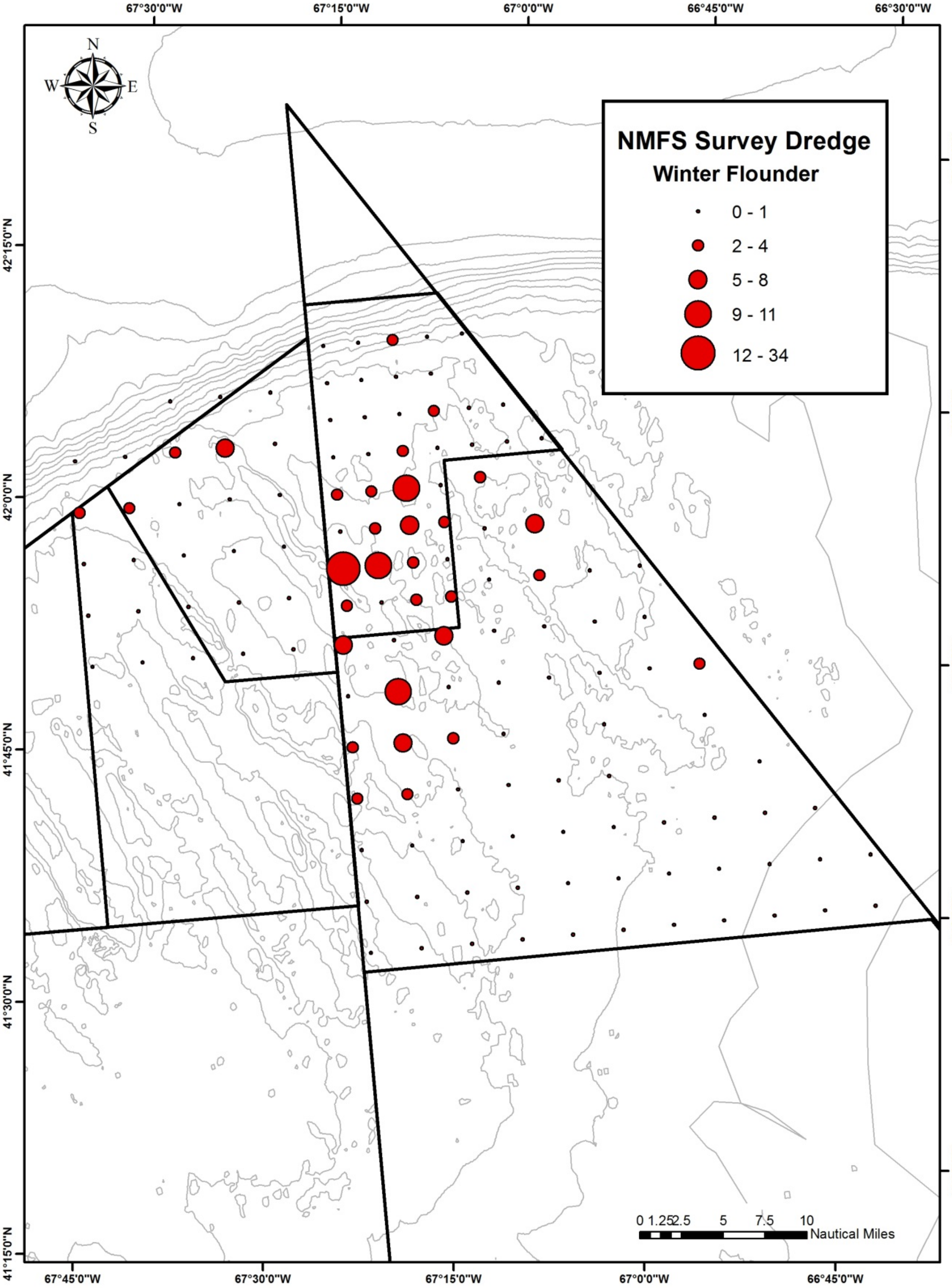


Figure 19 Spatial distribution of winter flounder catches on the survey cruise of the Northeast Georges Closed Area during July, 2012 by the CFTDD.

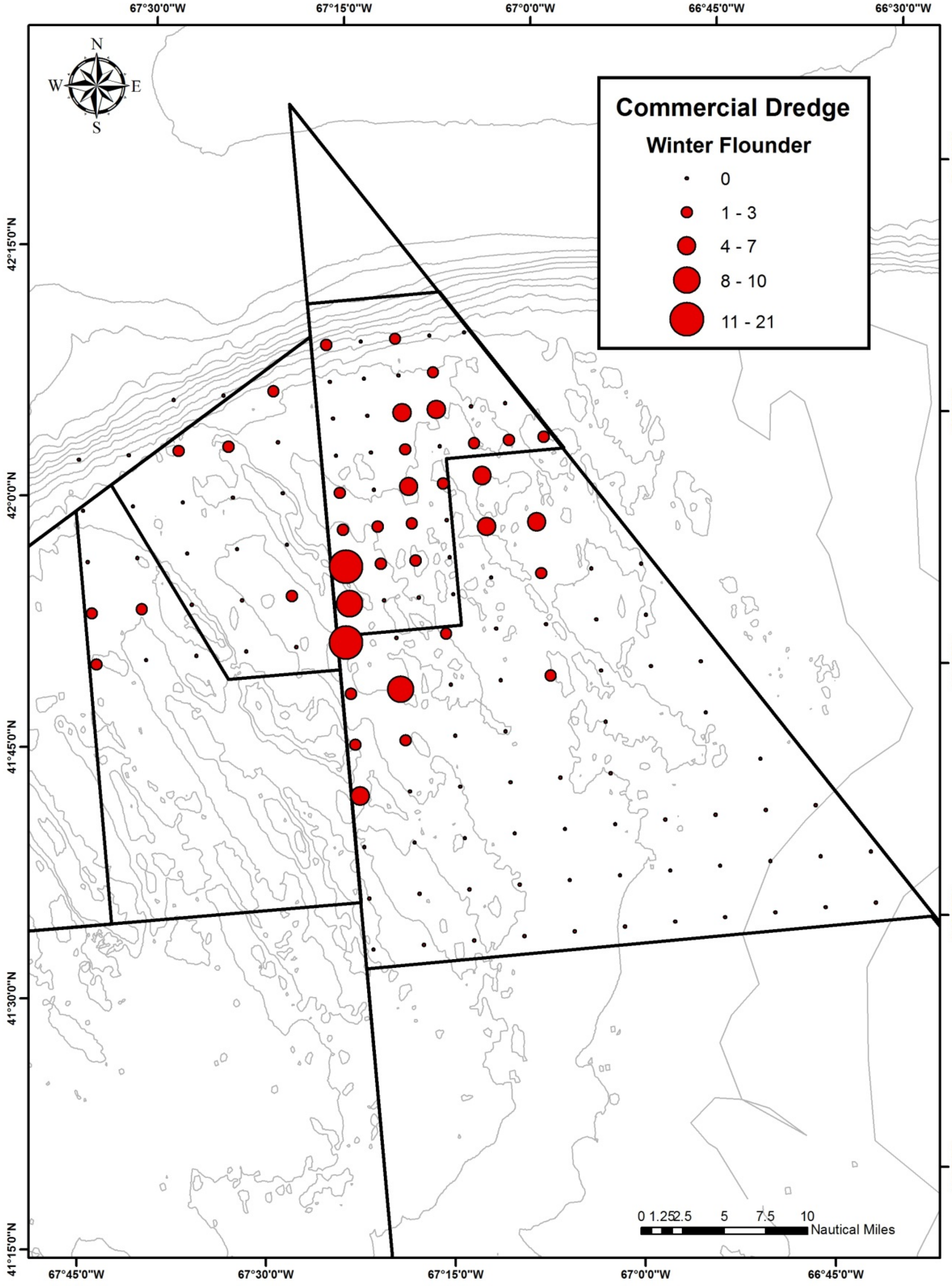


Figure 20 Spatial distribution of windowpane flounder catches on the survey cruise of the Northeast Georges Closed Area during July, 2012 by the NMFS Survey Dredge.

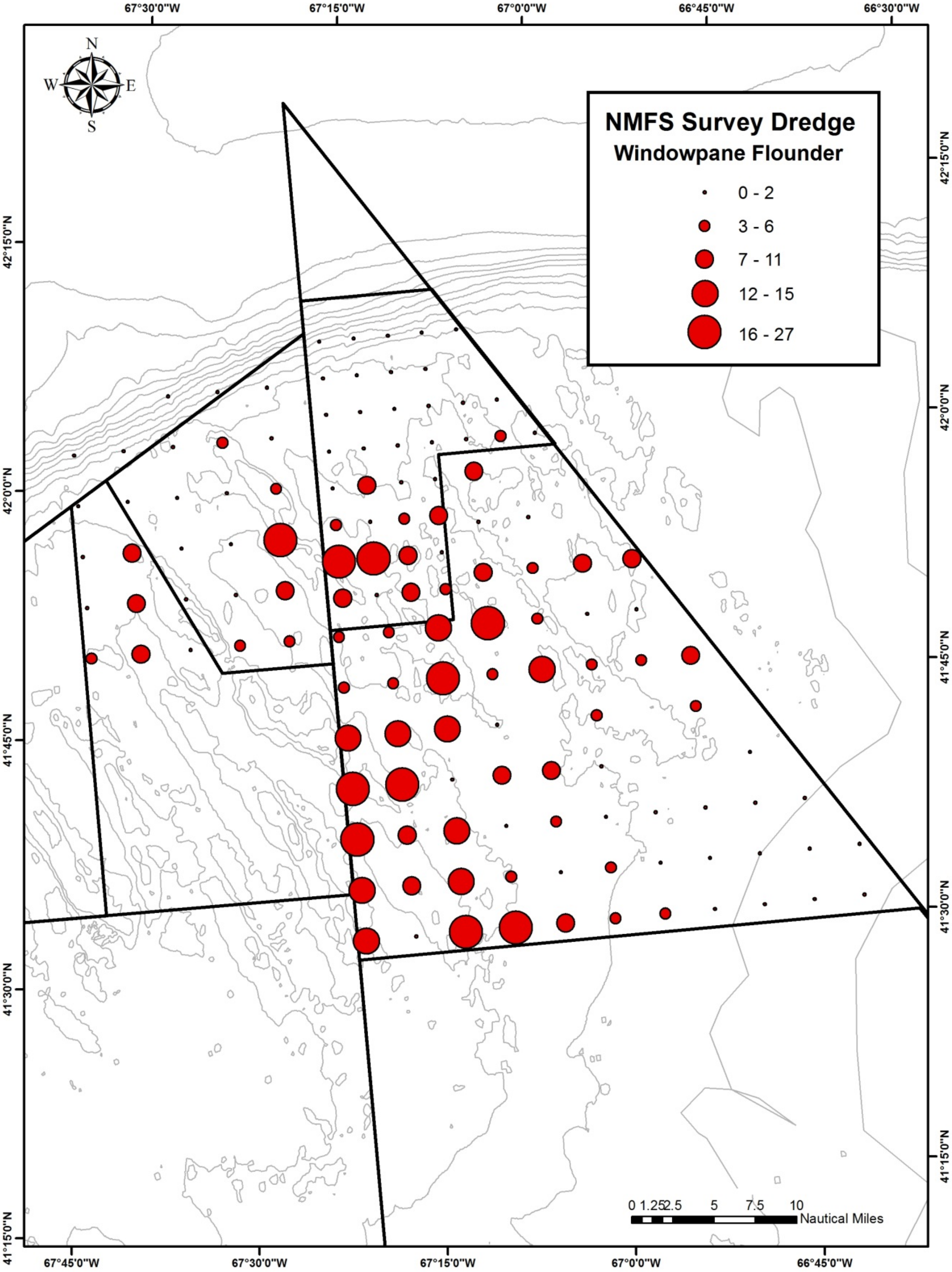


Figure 21 Spatial distribution of windowpane flounder catches on the survey cruise of the Northeast Georges Closed Area during July, 2012 by the CFTDD

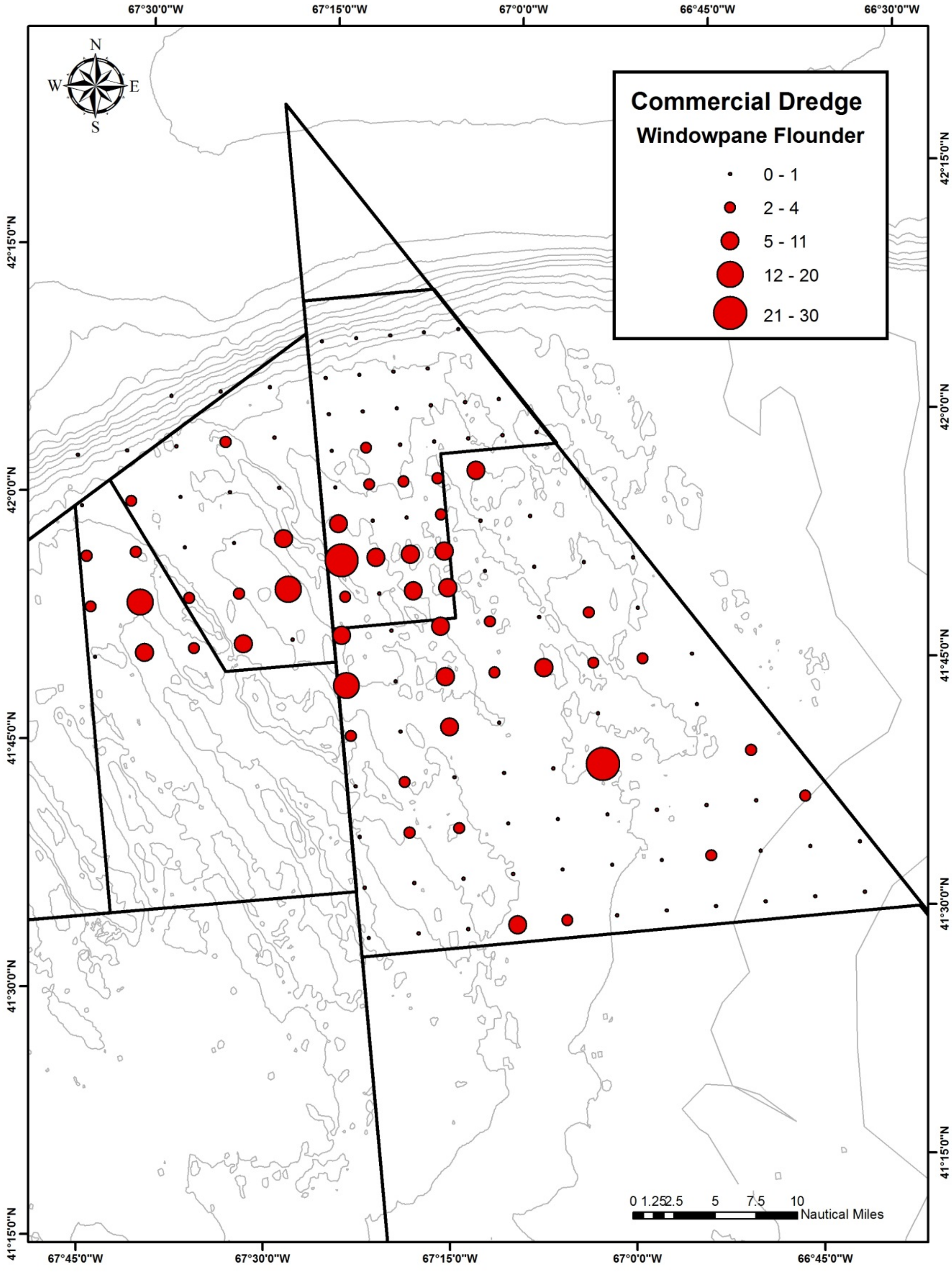


Figure 22 Spatial distribution of monkfish catches on the survey cruise of the Northeast Georges Closed Area during July, 2012 by the NMFS Survey Dredge.

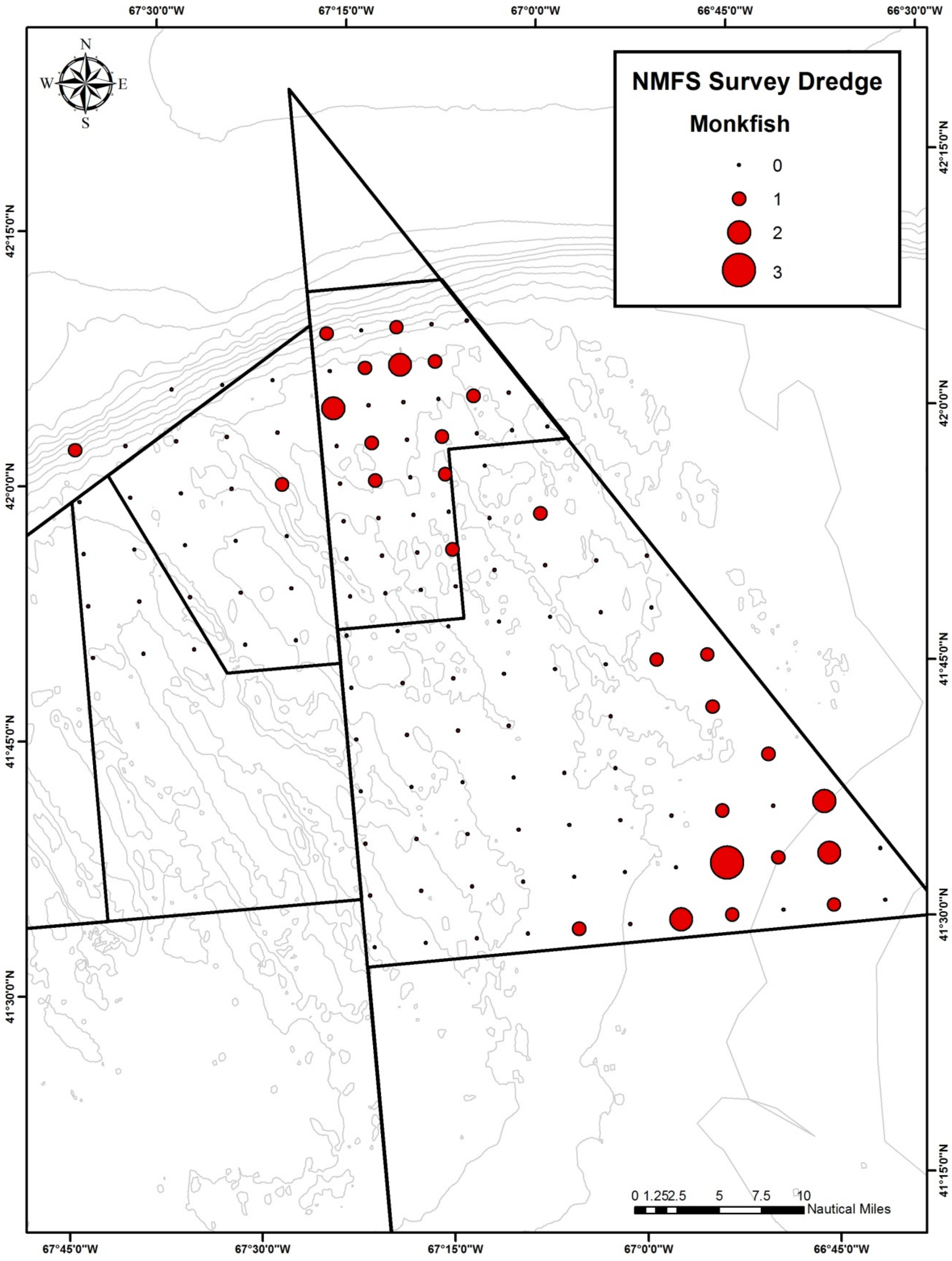


Figure 23 Spatial distribution of monkfish catches on the survey cruise of the Northeast Georges Closed Area during July, 2012 by the CFTDD.

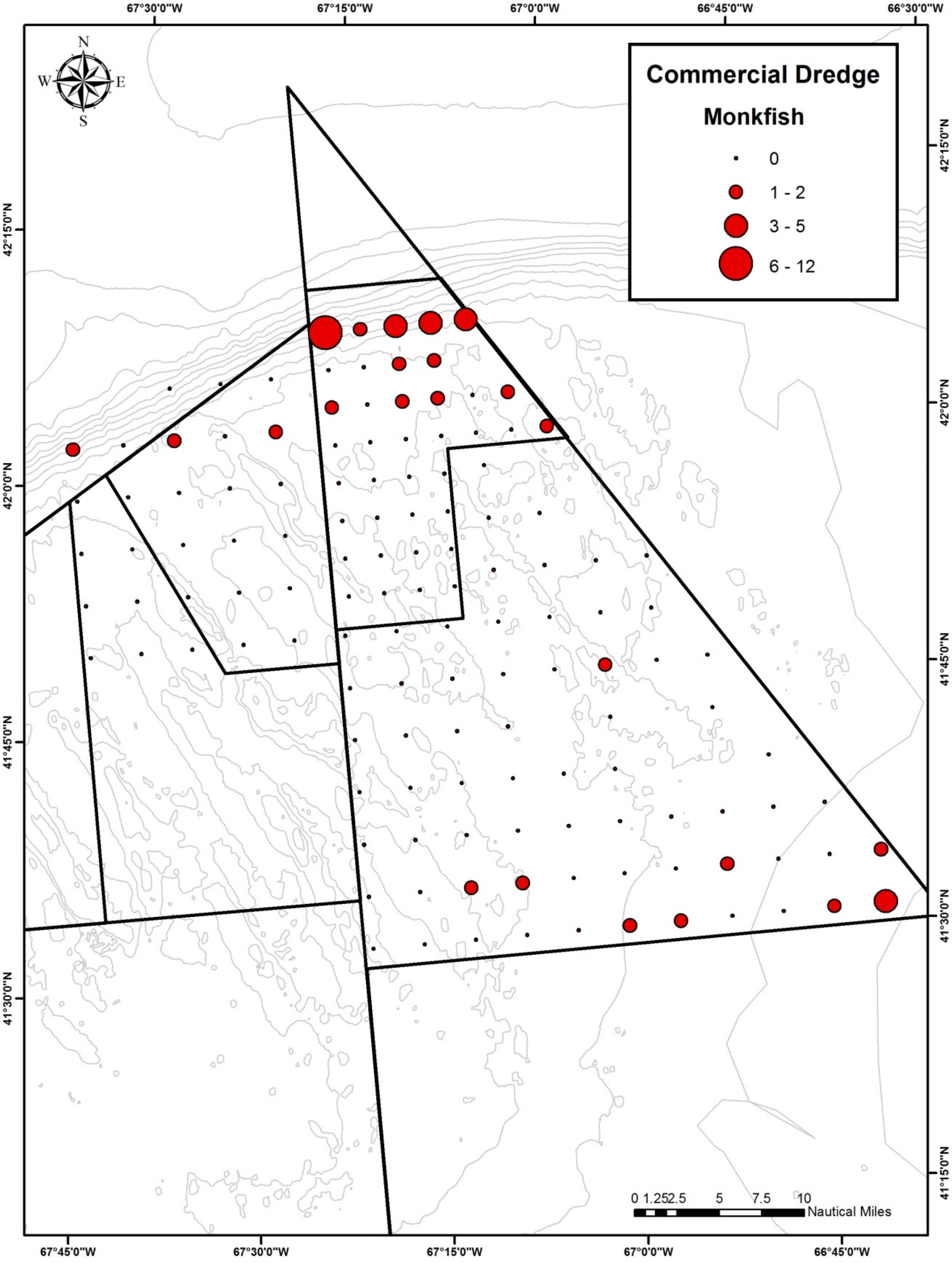


Figure 24 Examples of unmarketable (top) and marketable (bottom) scallop from the HAPC. It is interesting to note that these animals both came from the same tow. Also note the large amount of encrusting epifauna present on the shells.

Figure 25 Relative Sea Scallop catch by the two dredge configurations. The triangles represent the observed proportion at length ($Catch_c/(Catch_c + Catch_s)$), with a proportion >0.5 representing more animals at length captured by the 5R dredge. The grey area represents the 95% confidence band for the modeled proportion (solid black line).