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A Cooperative High Precision Dredge Survey to Assess the Mid-Atlantic Sea Scallop Resource Area in 2019 and 2020: Final Report

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Final Report

A Cooperative High Precision Dredge Survey to Assess the Mid-Atlantic Sea Scallop Resource Area in 2019 and 2020

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Project Summary

For the sea scallop, *Placopecten magellanicus*, current and accurate information related to the abundance and distribution of adult and juvenile scallops is essential for effective management of the resource. Scallop management is a combination of input and output controls, with a focus on spatial area management. The continued prosperity of the scallop resource and fishery is dependent on both periodic and large incoming year classes, as well as a mechanism to delineate the scale of a recruitment event and subsequently monitor the growth and abundance of these scallops over time.

Acknowledging the importance of accurate, timely, and meaningful information necessary to meet the management objectives and support the fishery, the Virginia Institute of Marine Science (VIMS) conducted a synoptic high resolution stratified random survey of the Mid-Atlantic Bight (MAB) scallop resource from the VA/NC border to Block Island, RI encompassing the Mid-Atlantic Access Area (MAAA), as well as the open areas of the MAB resource area during the spring/summer of 2019 and 2020. The primary objective of these surveys was to assess the abundance and distribution of sea scallops in this area, culminating with spatially explicit annual estimates of total and exploitable biomass by Scallop Area Management Simulator (SAMS) Area. Secondary project objectives for each survey year included: 1. Finfish bycatch species composition and catch rates, 2. Scallop biological sampling (length:weight relationship, disease, product quality parameters, and shell samples for ageing), and 3. Sea scallop dredge performance (commercial and survey dredges).

Survey results were presented to the Sea Scallop Plan Development Team (PDT) to inform management decisions for fishing years (FY) 2019 and 2020 (i.e., access area access and catch allocation). Survey data were also provided to the Northeast Fisheries Science Center (NEFSC) in 2019 and 2020 for use in projections for the annual specification process for FY 2019 and 2020 and for use in upcoming stock assessments. Results indicated that the exploitable biomass in the traditional access areas and open area off of Long Island remained high in both years, although recruitment was limited. Analysis of relative gear performance for the Coonamessett Farm Turtle Deflector Dredge (TDD) suggested that this dredge is more efficient than the New Bedford style dredge.

Project Background

The sea scallop, *Placopecten magellanicus*, supports a fishery that landed over 48 million pounds of meats with an ex-vessel value in excess of US $475 million in 2020 (NOAA, 2021). These landings resulted in the sea scallop fishery being one of the most valuable single species fisheries along the U.S East Coast. While historically subject to extreme cycles of productivity, the fishery has benefited from management measures intended to bring stability and sustainability. These measures include: limited entry, total effort (days-at-sea), gear and crew restrictions, and a strategy to improve yield by protecting scallops through rotational area management.

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 recent years, spatial management of the scallop resource has become more adaptive and conducted at finer spatial scales to provide protection for observed recruitment events to meet management and fishery objectives. Examples of this adaptive management in the MAB include the division of the traditional Elephant Truck Access Area into two discrete areas, as well as reverting the more southern Virginia Beach and Delmarva Access Areas to open area.

In order to effectively manage the fishery and carry out a robust rotational area management strategy, current and detailed information regarding the abundance and distribution of sea scallops in the MAB resource area is essential. This information forms the basis for assessment of the species and specifications for the next fishing year, as well as the potential establishment of additional closed areas. Amendment #10 specifies that an area is a candidate to be closed when the annual growth potential in that area is greater than 30%. Additionally, when the annual growth rate is reduced to less than 15% the area is available for a controlled re-opening. Certain other criteria exist regarding the spatial requirements for a closed area, but growth rates which are determined by the age structure of the population within that area is a key component of that determination. The collection of abundance and age distribution information from discrete areas is a major component of this strategy, and the use of commercial vessels provides a flexible and efficient platform to collect the required information.

Cooperative dredge surveys have been successfully completed with the involvement of industry, academic, and governmental partners since 2000 through funding from the Sea Scallop Research Set-Aside Program (RSA). The additional information provided by these surveys has been vital in the determination of appropriate Total Allowable Catches (TAC) in the subsequent re-openings of closed areas, and determination of the number of open area days-at-sea (DAS). 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.

In addition to collecting data to assess the abundance and distribution of sea scallops in the areas surveyed, the operational characteristics of commercial scallop vessels allow for the simultaneous towing of two dredges. As in past surveys, two dredges were towed at each survey station. One dredge was a standard sea scallop survey dredge used by the National Marine Fisheries Service (NMFS) since the 1970s and modified in 2008 (NEFSC, 2015). The other dredge was a commercial dredge, which consisted of one of two general configurations commonly used in the fishery (New Bedford style (NBD) or Coonamessett Farm Turtle Deflector Dredge). This paired design, using one non- size selective gear (NMFS survey dredge) and one size selective commercial gear, allowed for the estimation of the size selectivity characteristics of the commercial dredge. While gear performance (i.e., size selectivity and relative efficiency) information for both commercial dredges have been documented (Yochum and DuPaul, 2008; NEFSC 2018; Roman and Rudders, 2019), continuing to evaluate the performance of the gear will allow for changes in selectivity and efficiency to be monitored and quantified. Understanding time varying changes for the commercial dredges is beneficial for two reasons. First, it could be an important consideration for the scallop stock assessment in that it provides the current size selectivity characteristics for the most recent and commonly used gear configuration. In addition, size 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 commercial dredges.

An advantage of a sea scallop dredge survey is that one can access and sample the target species. This has a number of advantages including accurate measurement of animal length and the ability to collect biological specimens. One such attribute that is 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 to document seasonal shifts in the relationship due to environmental and biological 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.

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 MAB resource area, ultimately culminating in estimates of scallop biomass that were used as the basis for subsequent fishery management actions. Utilizing the same catch data with a different analytical approach, we estimated both the size selectivity characteristics and relative efficiency of the commercial sea scallop dredge. A third objective of this study resulted in the collection of biological samples to estimate time and area specific shell height:meat weight relationships, assess product quality and to monitor spatio-temporal patterns in scallop diseases/parasites. Sea scallop shells were also collected to supplement the NMFS shell collection for ageing.

Methods

Survey Area and Sampling Design

Sampling stations for the surveys were selected using a stratified random sampling design, with strata based on those used by NMFS since the 1970 for sea scallops, surf clams (*Spisula solidissima*) and ocean quahogs (*Arctica islandica*). Station locations were determined using a hybrid approach consisting of both proportional and optimal allocation techniques based on stratum area, the biomass (weight) of scallops, and number of animals observed during the VIMS 2018 and 2019 surveys of the same area. To assure all strata were sampled, a minimum of two stations were allocated to each stratum to allow for the calculation of mean catch and variance. A fraction of the total pool of samples is allocated proportionally based on stratum area with the remaining samples allocated using the Neyman approach that allocates samples based upon the biomass and number of animals observed in the prior year's survey. In both years a total of 450 stations were allocated in the survey domain.

Sampling Protocols

While at sea, the vessels simultaneously towed two dredges. A NMFS sea scallop survey dredge, 8 ft. in width equipped with 2-inch rings, 3.5-inch diamond mesh 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 ft. TDD, equipped with 4-inch rings, a 10-inch diamond mesh twine top, and no liner was utilized. In this paired design, it is assumed that the dredges cover a similar area of substrate and sample from the same population of scallops.

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 affixed to the dredge measured and recorded dredge tilt angle, as well as depth and temperature (Figure 1). Dredge angle data from the DST sensor were used to estimate the start and end of each tow by evaluating the angle of attack . Synchronous time stamps on both the navigational log and DST sensor were used to estimate the linear distance for each tow and ultimately provide a representative characterization of area swept by the dredges.

Sampling of the catch was conducted in the same manner described by DuPaul and Kirkley (1995), which has been utilized during all of our scallop surveys since 2005. For each station, the entire scallop catch from both the survey and commercial dredges was kept separate and placed in traditional scallop baskets to quantify total catch. Total scallop catch or a subsample, depending upon the volume of the catch, was measured to the nearest mm to determine size frequency. This protocol allows for the determination of the size frequency of the entire catch by expanding the catch at each shell height by the fraction of total number of baskets sampled. This calculation results in an estimate of the total number and size of the scallops caught for each dredge at each station. These catch data were also used to calculate biomass for both dredges and to estimate the commercial gear selectivity.

Finfish and invertebrate bycatch were also quantified at each station for each gear, with commercially important finfish and barndoor skates being sorted by species and measured to the nearest mm (total length (TL)). All other skate species (consisting predominantly of little (*Leucoraja erinacea*) and winter skates (*Leucoraja ocellata*)) were grouped into an unclassified category and enumerated. A systematic sampling approach was used to sample sea scallop predators. At every fifth station predators were enumerated and weighed. These predators, which included mainly crabs and starfish, were identified to the genus or species level and enumerated. Depending on catch volume either a full bushel basket or subsample was taken to sample predators.

Samples from sea scallops were taken to determine area specific shell height:meat weight relationships, as well as monitor animal health and product quality. At every station with scallop catch, 15 animals encompassing the size distribution observed at the station were selected for sampling. First, shell height was measured to the nearest mm. Each scallop was then carefully shucked and the adductor muscle and gonad were separated from the remaining soft tissue. Both the adductor muscle and gonad were individually weighed at sea with a Marel™ M2200 motion compensating scale to the nearest 0.01 gram. In addition to shell height and meat weight data collected, biological characteristics and product quality information were collected. Biological data included sex and reproductive stage. Sex was identified based on gonad color as either female (red gonad) or male (white gonad). An additional unknown category is used for immature scallops, where sex cannot be determined, or for hermaphrodite scallops, where the gonad is white and red. Seven reproductive stages were assessed by visual examination of the gonad. The stages include immature, resting, rebuilding, mature, spawning, spent, and unknown. Product quality was evaluated through visual inspection of each adductor muscle and shell using a semi-qualitative ordinal coding scheme for each characteristic assessed. Characteristics evaluated included overall market condition, color, texture, and the presence of blister disease. The presence/absence and number of nematode (*Sulcascaris sulcata*) lesions observed on each adductor muscle was also quantified through gross observation.

Up to 15 scallop shells were collected at every fifth station from samples selected for shell height:meat weight assessment for ageing purposes. Shells were selected if there was no shell damage (i.e., broken shell, damaged margin of shell or deformed). Shells were aged using the external ring method described in Hart and Chute (2009), as well as a novel method involving the resilium, which is being developed at VIMS by Dr. Roger Mann's lab (Mann and Rudders, 2019). A subset of shells was added to the archived collection housed at VIMS.

Station level catch and location information were entered into FEED (Fisheries Environment for Electronic Data), a data acquisition program developed by Chris Bonzek at VIMS. Time-stamped location data from the bridge were entered into FEED using an integrated GPS input. Station level data included location, time, tow-time (brake-set/brake-release), tow speed, water depth, weather, and comments relative to the quality of the tow. FEED was also used to record detailed catch information at the station level for scallops, finfish, and predator sampling. Catch by species was entered into FEED as either the number of baskets caught and measured (scallops) or number of animals (finfish, skates, etc.) caught. Length measurements were recorded using the Ichthystick measuring board input to the FEED program that allows for automatic recording of length measurements. Shell height:meat weight and product quality data were also recorded using FEED. The Marel scale was connected to FEED to allow for automatic recording of adductor muscle and gonad weight data.

Data Analysis

Absolute swept area biomass within the area surveyed was estimated by Scallop Area Management Simulator (SAMS) Area (Figure 2). The methodology to estimate biomass is similar to that used in previous survey work by VIMS. In essence, we estimate a stratified mean catch weight of either all scallops or the fraction available to the commercial gear (exploitable) from the point estimates and scale that value up to the entire area of the domain sampled following methods from Cochran (1977) for calculating a stratified random size of a population. These calculations are given as:

Stratified mean biomass per tow in stratum and subarea of interest:

$$\bar{C}_h = \frac{1}{n_h}\sum_{i=1}^{h} C_{i,h} \qquad (1)$$

Variance Equation 1

$$Var(\bar{C}_h) = \frac{1}{n_h(n_h-1)}\sum_{i=1}^{n_h}(C_{i,h}-\bar{C}_h)^2$$

Stratified mean biomass per tow in subarea of interest:

$$\bar{C}_s = \sum_{h=1}^{L} W_h \cdot \bar{C}_h \qquad (2)$$

Variance Equation 2

$$Var(\bar{C}_s) = \sum_{h=1}^{L} W_h^2 \cdot Var(\bar{C}_h)$$

Total biomass in subarea of interest:

$$\widehat{B_s} = \left(\frac{\left(\frac{\bar{C}_s}{\bar{a}_s}\right)}{E_s}\right) A_s \qquad (3)$$

Variance Equation 3

$$Var\left(\widehat{B_s}\right) = Var(\bar{C}_s) \cdot \left(\frac{A_s}{\bar{a}_s}\right)^2$$

where:

L = # of strata
n = # of stations in stratum *h*
h = stratum
i = station *i* in stratum *h*
s = subarea *s* in survey of interest
A_s = area of survey of interest in subarea *s*
E_s = gear efficiency estimate for subarea *s*
$\bar{a}_s$ = mean area swept per tow in subarea s
$\hat{B}_s$ = total biomass in subarea s
$\bar{C}_s$ = stratified mean biomass caught per tow for subarea s
$\bar{C}_{h,s}$ = mean biomass caught per tow in stratum h for subarea s
W_h = proportion of survey/subarea area in stratum h

Stratified mean catch weight per tow of exploitable scallops was calculated from the raw catch data as an expanded size frequency distribution with a SARC 65 or SAMS Area appropriate shell height:meat weight relationship applied (NEFSC, 2018). Shell height:meat weight relationships used to convert the number of scallops to weight were determined by the Scallop PDT. In both 2019 and 2020, SARC 65 shell height:meat weight relationships were used for all SAMS Areas (NEFSC, 2018). Exploitable biomass, defined as the 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 survey dredge (assumed to be non-size selective) was adjusted based upon the size selectivity characteristics of the commercial gear (Roman and Rudders, 2019). The observed catch at length data from the commercial dredge was not adjusted due to the fact that these data already represent the 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 second. By determining the start and end of each tow based on the recorded times as delineated by the DST 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 (14 ft. for the commercial dredge and 8 ft. for the survey dredge.) for 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 during the cruises. The Miller et al. (2019) and SARC 65 (NEFSC, 2018) efficiency (q) estimates for the NMFS survey dredge (40%) and the commercial dredge (65%) were used to scale relative biomass to absolute biomass. To scale the estimated stratified mean scallop catch to the full domain, the total area of each resource subunit within the survey domain was calculated in ArcGIS v. 10.1. Biomass estimates were calculated for the SAMS Areas for the entire survey domain, including area outside of the SAMS Areas that were surveyed (Figure 2). Area surveyed outside the pre-determined SAMS Areas were included with the adjacent SAMS Areas within the survey domain. SAMS Areas were consistent between years.

Shell Height:Meat Weight

The relationship between shell height and meat weight was estimated using a generalized linear mixed effects model (gamma distribution, log link, and a random effect of station) using the glmer function in the lme4 package in R v. 4.1 (Bates et al., 2015; R Core Team, 2021). The relationship was estimated with the following general model:

$$\mu = X'\beta + Z\gamma + \varepsilon$$

where μ is the predicted weight (grams), X' is a design matrix of covariates, β is a vector of coefficients, Z is a design matrix of random effects, γ is a vector of random effect parameters and ε is the error term.

Models were developed with forward selection and variables were retained in the model if the Akaike Information Criterion (AIC) was reduced by three or more units. Variables were added to the model based on individual model AIC values. SAMS Area was included in all models to allow for the estimation of a SAMS Area effect. The model with the lowest AIC was selected as the preferred model and used to predict shell height:meat weight relationships by SAMS Area. If models had AIC values within three units of each other, a likelihood ratio test was used to test for a significant difference between models. If there was no significant difference between the candidate models, the more parsimonious model was selected as the preferred model. Variables considered were: ln shell height, ln depth (average depth of a tow), SAMS Area (retained in all models), latitude (beginning latitude of a tow), and an interaction term of shell height and depth. Since 2020 surveys were delayed due to COVID19 travel restrictions, additional models incorporating maturity stage were developed to assess the impact of survey timing on shell height:meat weight relationships, as spawning cycle has been shown to impact meat height (Sarro and Stokesbury, 2009; NEFSC, 2018). Models with maturity stage were developed following similar model development as described above. If maturity stage was in the preferred model, a Tukey's honest significance test (HSD) was used to conduct *post hoc* pairwise comparisons to test for significant differences between maturity stage factor levels (Miller, 1981). The glht function in the multcomp R package was used to carry out the post-hoc tests (Hothorn et al., 2008). Statistical significance (α) was equal to 0.05 for all analyses. Models with and without maturity stage were also compared by examining parameter estimates and predicted shell height:meat weight relationships.

Size Selectivity

Size selectivity for the commercial dredge was estimated 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) was 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 40%), insight into the efficiency of the other gear (commercial dredge) can be obtained.

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 or less than 20 scallops were captured by both dredges were also removed (Yochum and DuPaul, 2008; Roman and Rudders, 2019). The remaining tow pairs were then used to analyze the size selective properties of the commercial dredge. The TDD was fished during the MAB survey in both 2019 and 2020. A TDD was also used by two other VIMS surveys completed in 2020 and 2021 on Georges Bank (GB) in the Nantucket Lightship (NL) and in 2021 in Closed Area I and Closed Area II (referred to as CA I II). Data from the TDD for all three surveys was analyzed collectively with the SELECT method to examine for an area effect and to compare findings to those published by Roman and Rudders (2019) for the TDD. Initially, individual cruises were analyzed separately, subsequently tows were aggregated by survey areas (MAB, NL, and CA I&II), with a final aggregation at the resource area level (MAB and GB) to determine if data from all three surveys could be combined. Combining data was determined by visually assessing if 95% confidence intervals overlapped for L_{50} estimates. Ninety-five percent confidence intervals for the split parameter were also plotted for comparison. These methods are similar to those used by both Yochum and DuPaul (2008) and Roman and Rudders (2019).

The SELECT method is a preferred method to analyze size-selectivity studies encompassing a wide array of fishing gears and experimental designs (Millar and Fryer, 1999). The SELECT model conditions the catch from the selective gear at length *l* to the total catch (from both the selective gear variant and non-selective 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, a functional form with symmetrical tails. In certain cases, other functional forms have been utilized to describe size selectivity of fishing gears. Examples of alternative 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 AIC (Xu and Millar, 1993, Sala, et al., 2008). For towed fishing gears; however, the logistic function is the most common functional form observed and was the only form assessed for this analysis. Given the logistic function:

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

by substitution:

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

where *a*, *b*, and *p* are parameters estimated via maximum likelihood. Based on the parameter estimates, L_{50} and the selection range (SR) can be calculated as:

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

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-hauls approach may be more appropriate (Millar et al., 2004).

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 $\sqrt{REP}$. This correction is only performed when the data are 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 with the following formula:

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

where p is equal to the observed value (estimated p value) and p_0 represents the expected value of the split parameter based upon the dredge widths in the study (Park et al., 2007). For this study, a 14 ft. commercial dredge was used with expected split parameter of 0.652. Models with a fixed split parameter and models that were allowed to estimate the split parameter were developed for this analysis. The preferred model was selected by comparing AIC values, as well as model fit. Computing efficiency for the estimated p value from Yochum and DuPaul (2008) yields a commercial dredge efficiency of 65% for a New Bedford style dredge.

Meat Quality and Shell Blisters

During the survey, shell blister and meat quality observations were made for all scallops sampled at shell height:meat weight stations. Adductor meats were assessed for quality issues pertaining to color, texture, and overall marketability. The presence and severity of shell blisters were scored as well. All assessments were done using a semi-qualitative scoring index (Table 1).

Nematode Monitoring

All scallops sampled at shell height:meat weight stations were also visually examined for the presence and incidence of the parasitic nematode. Gross observation was used to identify scallop meats that were infected with the parasite and the number of parasites was enumerated (incidence) by counting the number of rust colored lesions present on the adductor muscle.

Data on nematode distribution and prevalence from the VIMS 2015-2020 surveys of the MAB resource area were mapped to understand the spatial extent of infections and data were also compared across survey years to assess shifts in the spatial distribution of infected scallops. Analyses for the comparison between years included mapping the distribution and intensity of nematode infected scallops throughout the survey domain by year, as well as by size class. Spatial distribution maps were created using the inverse distance weighting method.

Results

Survey Characteristics

The MAB resource area was surveyed in May of 2019. The first survey leg was conducted onboard the F/V *Italian Princess* (CruiseID 201905) from 5/10/2019-5/19/2019 out of Seaford, VA and 225 stations were occupied. The F/V *Carolina Capes* II (CruiseID 201906) completed the second leg from 5/22/2019-6/2/2019 and also surveyed 225 stations. A third reduced survey trip was conducted in August (8/12/2019-8/15/2019) onboard the F/V *Anticipation* out of Cape May, NJ to reoccupy stations sampled during the first leg of the survey. This additional leg was completed after VIMS staff realized 39 stations of data had not been saved from the original cruise (Figure 3). Our 2020 survey was delayed due to COVID19 pandemic travel restrictions issued by the Governor of the Commonwealth of Virginia for state employees. The F/V *Carolina Capes II* (CruiseID 202003) completed the first survey leg from 7/10/2020-7/20/2020 and the F/V *Italian Princess* (CruiseID 202004) completed the second leg from 7/30/2020-8/11/2020. All proposed 450 stations were occupied over the two legs (Figure 4). Boxplots depicting the estimated linear distances covered per tow by survey leg (excluding the third make-up trip in 2019) are shown in Figure 5. The mean tow length in 2019 for CruiseID 201905 was 1,535.84 m with a standard deviation of 152.48 m. The mean tow length in 2019 for CruiseID 201906 was 1,654.99 m with a standard deviation of 78.43 m. The mean tow length in 2020 for CruiseID 202003 was 1,807.92 m with a standard deviation of 46.74 m. The mean tow length in 2020 for CruiseID 202004 was 1,849 m with a standard deviation of 72.70 m.

Abundance and Distribution

Length frequency distributions for scallops captured by the survey dredge during the survey by SAMS area and year are shown in Figures 6-7. Maps depicting the spatial distribution of the catches partitioned into three size classes of scallops (<35 mm, 35-75 mm, and >75mm shell height) are shown in Figure 8-9. Total and exploitable biomass calculated using the SARC 65 area-specific shell height:meat weight coefficients and total number of animals by year, gear type, and SAMS area are shown in Tables 2-5 (total biomass and number of animals from the commercial dredge are not estimated due to the selective properties of the commercial gear).

Shell Height Meat Weight

Shell height:meat weight relationships were estimated by SAMS Area within the survey domain by year. In 2019, a total of 5,510 scallops from 375 stations were included in the analysis. The preferred model showed shell height, depth, and SAMS Area were significant predictors of meat weight (Table 6). The parameters estimated are shown in Table 7. The predicted shell height:meat weight relationships by SAMS Areas are shown in Figure 10.

In 2020, data collected from 4,761 scallops at 377 stations were used for predicting shell height:meat weight relationships. Models examining the impact of maturity stage on observed shell height:meat weight relationships collected in 2020 indicated the delay in survey timing did not affect predicted relationships for any SAMS Area. When including maturity stage, predictors in the preferred model were an interaction term of shell height and depth, SAMS Area, and maturity stage (Table 8). The interaction term and SAMS Area were significant predictors, while maturity stage did not have a significant effect on meat weight (Table 9). The only maturity stage that was significantly different from the reference level was the unknown stage, which made up two percent of the sampled scallops. Tukey's HSD tests for the preferred model showed that the only significant difference between maturity stage factors levels (n = 6) was between the unknown and spawning stage (p-value = 0.03) and the unknown and resting stage (p-value = 0.04). There were no significant differences detected between the other five maturity stages (p-value ranged from 0.07-1). Parameters estimates from the preferred model with maturity stage were similar to the preferred model excluding maturity stage in terms of direction and magnitude (Table 9), the effect size of maturity level factors was small (Table 9), and predicted shell height:meat weight relationships by SAMS Area and maturity stage were similar to those without maturity stage (Figure 11). Models developed excluding maturity stage are provided in Table 10. The preferred model from this analysis was considered the appropriate model to represent the shell height:meat weight relationship for MAB and was presented to the NEFMC Scallop PDT. The preferred model indicated the interaction term of shell height and depth along with SAMS Area had significant impacts on meat weight. The resulting parameters estimated for the preferred model in 2020 are shown in Table 9. The predicted shell height:meat weight relationships by SAMS Areas are shown in Figure 12. The impact of the timing difference for the 2020 survey should not have a substantial impact on long term average shell height:meat weight relationships. Overall, the shell height:meat weight relationships observed in 2019 and 2020 followed the latitudinal and depth gradients that have persisted for this resource area over time.

Bycatch

Catch per unit of effort for finfish bycatch for the survey is shown in Table 11. Length frequency distributions for finfish bycatch with sufficient sample sizes are shown in Figures 13 and 14 by gear and year.

Predator Sampling

The spatial distribution and number of animals counted by species or genus for 2019 and 2020 predator sampling stations are provided in Figures 15 and 16. The number of animals represents either the number enumerated in the subsample or the entire sample taken at a given station. Subsampled counts have not been expanded.

Size Selectivity

Summary information by cruise for the selectivity analysis is provided in Table 12 and include CruiseID, surveyed area, year, and sample sizes. For the TDD survey level analysis, 474 stations and 34 five mm length bins were used for the MAB survey. For the NL survey, 117 stations and 36 length bins were included; the CA I II survey had 81 stations and 36 length bins. For the resource area analysis, the MAB had the same number of stations and length bins. The GB resource area included 198 stations and 36 length bins. A total of 127 stations were removed because no scallops were caught and 565 stations were excluded because less than 20 scallops were caught in either dredge.

Models that estimated the split parameter were preferred over the fixed split parameter models for all analyses. Visual examination of residuals and AIC values indicated the models with an estimated split parameter provided the best fit to the data. Selectivity parameter estimates by cruise are shown in Table 13, estimates by survey are in Table 14, and estimates by resource area are in Table 15. Predicted length based retention probabilities with observed values and deviance residuals by survey are shown in Figure 17. Split parameter and L_{50} estimates with 95 percent confidence intervals are shown in Figure 18 for each survey. The predicted length based retention probabilities and observed values with deviance residuals by resource area are shown in Figures 19, with split parameter and L_{50} estimates with 95 percent confidence intervals in Figure 20. Predicted selectivity curves by survey and resource area are shown in Figures 21 and 22.

The analysis for the MAB data indicated the several parameter estimates were unrealistic compared to the observed data despite model convergence. For example, for Cruise 201905, the L_{25} estimate was 163 mm, L_{50} value was 179 mm, and L_{75} parameter was 197 mm (Table 13). A similar pattern of overestimation was also observed for the MAB survey and resource area L_{50} estimate of 109 mm, although the magnitude of overestimation was reduced (Tables 13 and 14 and Figures 17 and 19). Residuals indicated the model was overestimating the retention probability for scallops from 90 to 100 mm (Figures 17 and 19). This issue with the L_{50} estimate for the MAB is likely driving the significant difference observed between the MAB and either GB survey (NL and CA I II) and the MAB and GB resource area L_{50} estimates, where 95 percent confidence intervals did not overlap (Figures 18 and 20). This significant difference indicated that combining data from all three surveys and both resource areas was not valid, but the issue with parameter estimates for the MAB needs to be investigated. There were no differences between the L_{50} or split parameter estimates between the two GB surveys (NL and CA I & II), so data from both surveys was combined for a GB resource TDD selectivity analysis (Figure 18). Split parameter estimates from all three surveys and the two resource areas were comparable (Figures 18 and 20). All estimated split parameters (0.81 – 0.87) were greater than reported in Yochum and DuPaul (2008) for the New Bedford Style dredge (0.77), suggesting that the TDD is more efficient than the New Bedford Style dredge. The estimated split parameters were similar to the value of 0.83 reported in Roman and Rudders (2019). The GB L_{50} estimate of 98.2 mm is lower than the 100.1 mm estimated by Yochum and DuPaul for the New Bedford style dredge (2008) and 107.4 mm estimated by Roman and Rudders for the TDD (2019).

Meat Quality and Shell Blisters

A total of 10,251 scallops were sampled at shell height:meat weight stations over the two-year period. In 2019, a total of 5,489 scallops were sampled, with 2,894 scallops sampled on the first cruise and 2,595 sampled on the second cruise. In 2020, 2,352 were sampled on the first cruise and 2,410 were sampled on the second cruise, for a total of 4,762 scallops processed. Summary information on sex, market category, color, texture and blister disease stage are provided in Table 16. Table 1 provides the classifications for market category, color, texture and blister codes. The majority of scallops were classified as marketable with no texture or color deviations. Scallops with observed nematode lesions were assigned a lower overall market classification. Approximately six percent of scallops regardless of sex were observed to have some form of shell blister disease in 2019. This increased to 9 percent in 2020.

Nematode Monitoring

All scallops assessed for meat quality and shell blisters were also assessed for nematode infections. In both 2019 and 2020, 10 percent of scallops were observed to be infected. This is a decrease compared to previous years, where the percentage of scallops infected ranged from 21 to 16 percent. The average number of lesions observed in a scallop ranged from 1 to 11 scallops.

The spatial distribution of infected scallops from 2015 through 2020 showed some shifts in the distribution of scallops infected for both prevalence and intensity (Figures 23-24). Prevalence is defined as the number of scallops observed to be infected out of all scallops sampled. Intensity is defined as the number of lesions observed in infected scallops. In 2015, the majority of infected scallops were located in the Delmarva. In 2016, there was a northward shift into the Elephant Trunk and the extent to which infected scallops were observed was the largest. The range of infected scallops extended from the most southern portion of the resource area to the northern boundary of the Hudson Canyon (Figure 23). We observed a contraction in the range of infected scallops in 2017, with the locus of the observations in the northern portion of the Delmarva and Elephant Trunk. In 2018, the majority of infected scallops were again observed in the Delmarva. The least number of infected scallops was observed in 2019 and in 2020 there was an increase in the number of infected scallops, with a hotspot identified in the Elephant Trunk. The trend in the spatial distribution for intensity was similar to that for prevalence (Figure 24).

Scallop Shells

A total of 2,175 scallop shells were collected and aged in 2019. In 2020, 1,611 shells were collected and aged. A subset of shell samples were archived at VIMS. For the 2020 operational stock assessment, age data from 2016-2019 were provided to the NEFSC assessment scientists.

Outreach

As part of the outreach component of this project, a presentation detailing the annual results of each survey was compiled. These presentations were delivered to the Sea Scallop PDT in Woods Hole, MA in August 2019 and at their virtual meeting in October 2020. Presentations are included as Appendices A and B, respectively. At the same meetings, presentations were also given to the Sea Scallop PDT summarizing disease prevalence for nematode infected scallops and shell blister disease (Appendices C and D). As requested by the NEFMC staff, a short report summarizing survey results was also drafted for each year. These reports were submitted to the NEFMC for distribution to the Sea Scallop PDT, Scallop Advisory Panel, and Scallop Committee. An annual industry report was generated to summarize results from the VIMS 2019 and 2020 survey efforts and distributed to stakeholders. Industry reports can be downloaded from: https://www.vims.edu/research/units/centerspartners/map/comfish/scallop/publications/industryreports/index.php.

Graduate Student Involvement

Ms. Kaitlyn Clark, a Ph.D. candidate under Dr. Rudders, participated in both surveys.

<u>Discussion</u>

Surveys of important resource areas like the MAB resource area are an important endeavor. These surveys provide information about a critical component of the resource unit that includes rotational access areas and open area. 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, set TACs for re-opening of access areas, and determine the number of allowable DAS for open area fishing. 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 significant biomass existed in the traditional access areas of MAB resource area in 2019 and 2020. Biomass in the open areas off of Long Island was also high and will be able to support open DAS fishing in both years. The high density aggregation of scallops in the southern portion of the Elephant Truck Flex area that had been exhibiting slower growth compared to scallops in the same area in lower densities to the north had improved growth in 2019 and 2020. This improved growth should be able to support harvest for the next fishing year. No large recruitment events were observed in the resource area in either year. Nematode infected scallops in 2019 and 2020 were largely constrained to the ET, but the impact on the fishery in terms of limiting effort in the southern portion of the MAB may continue as a result of the persistent presence of nematode infected scallops. Biomass in the Delmarva and Virginia SAMS Areas continues to decline. The cause of the decline in biomass in this portion of the MAB should be investigated.

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 represents 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 the TDD based on information collected from 2019 to 2021. Selectivity of the New Bedford style dredge was estimated by Yochum and DuPaul (2008) and for the TDD by Roman and Rudders (2019). Our results indicated the TDD is slightly more efficient than the New Bedford style dredge. This information is useful for managers and assessment scientists to understand the selectivity and relative efficiency of this dredge type.

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. Also, there was no indication that a delayed 2020 survey will have an impact on the long-term average shell height:meat weight data used for assessment and management purposes. 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. Area and time specific shell height:meat weight parameters are another topic that merits continued study.

Data generated from the surveys were used to support fishery management decisions for fishing years 2020 and 2021, as well as for the 2020 operational stock assessment. Other data collected from the surveys were submitted to the NEFSC for monkfish.

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Figure 1. An example of the output from the Star-Oddi™ DST sensor. Arrows indicate the interpretation of the start and end of the dredge tow.

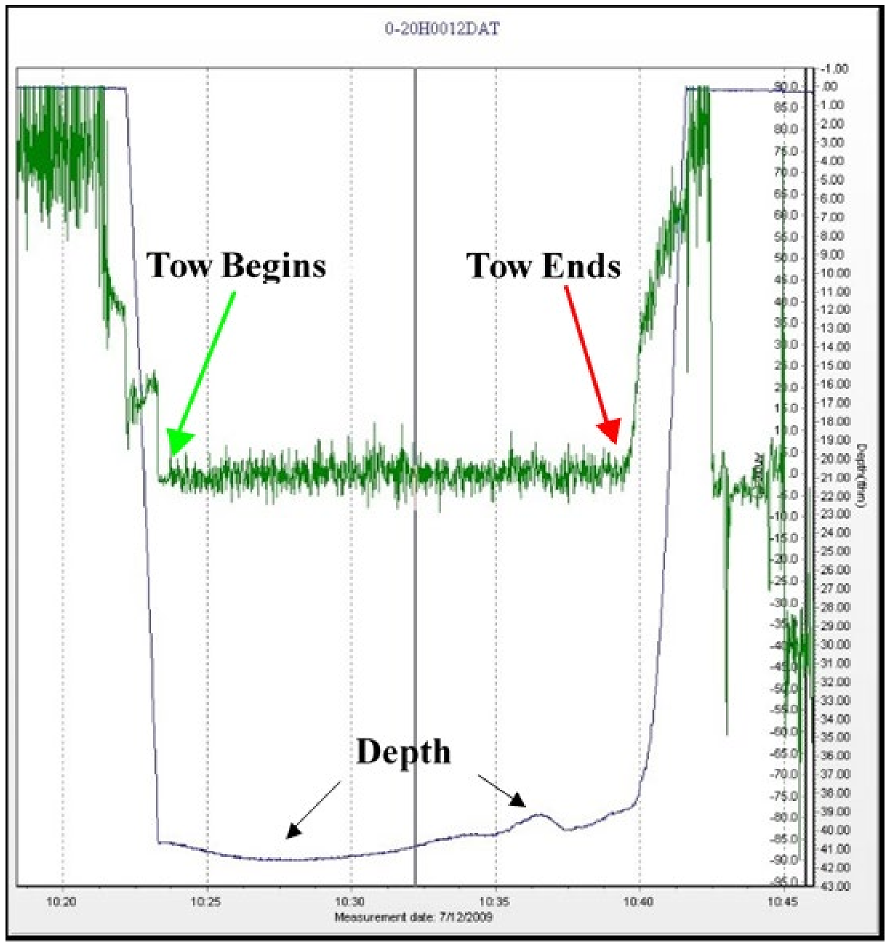


Figure 2. Map of the 2019 and 2020 survey domain for the survey of the Mid-Atlantic Bight resource area with the SAMS Area designations.

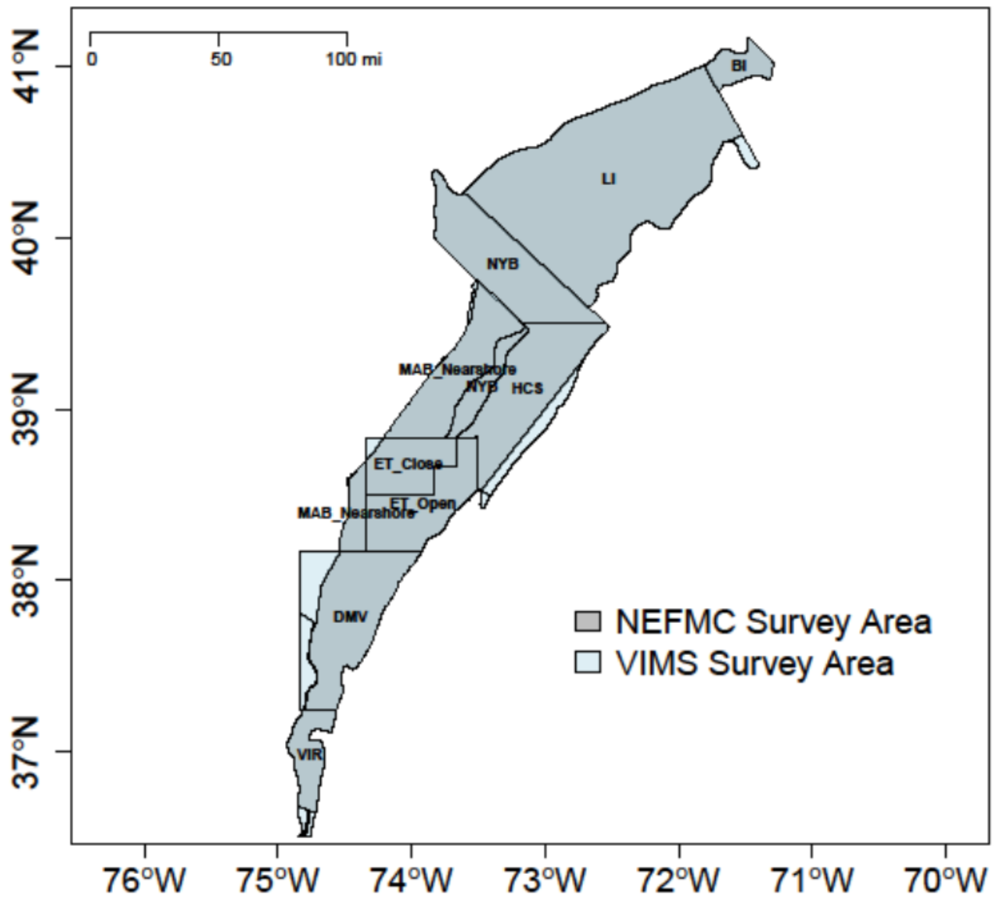


Figure 3. Locations of sampling stations for the 2019 survey of the Mid-Atlantic Bight resource area by survey leg.

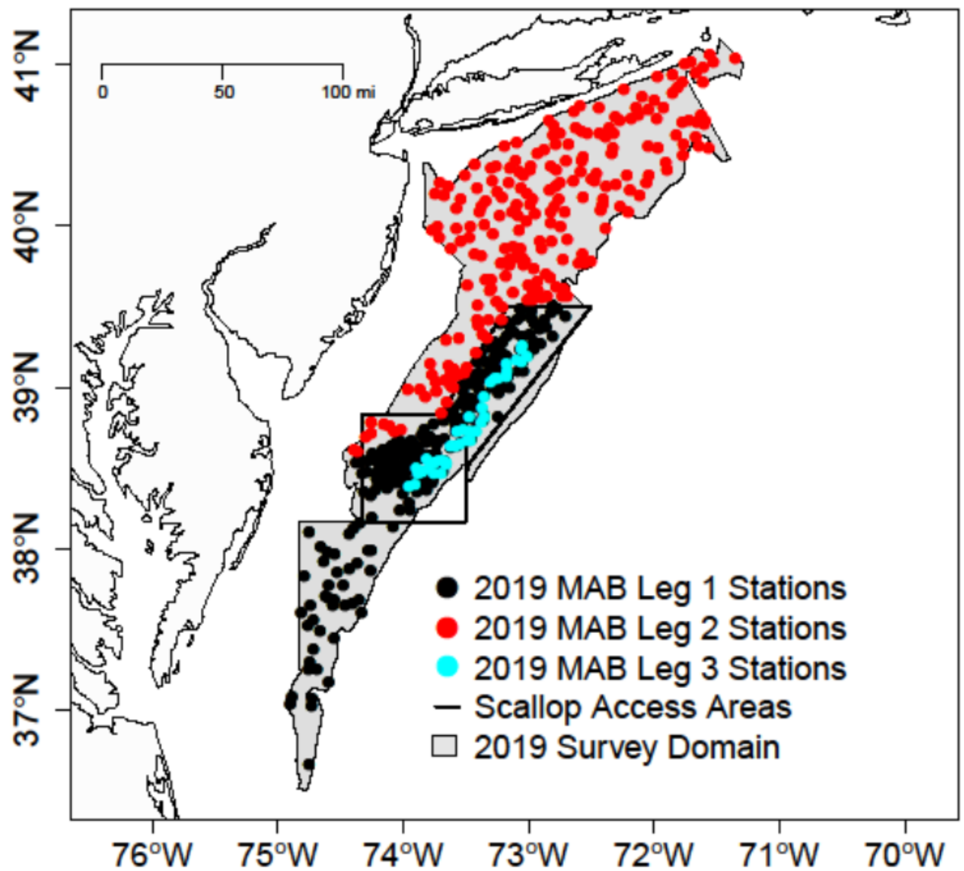


Figure 4. Locations of sampling stations for the 2020 survey of the Mid-Atlantic Bight resource area by survey leg.

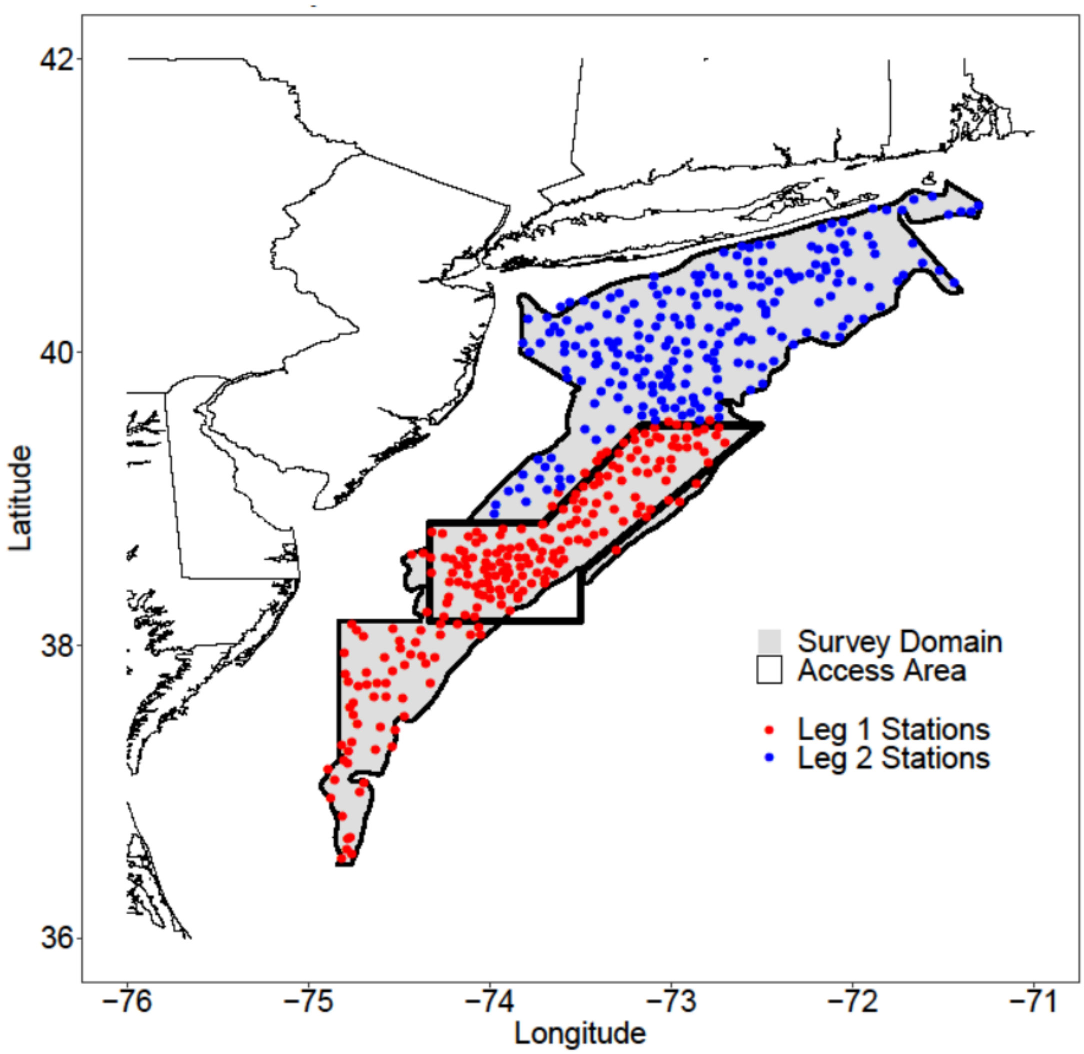


Figure 5. Boxplots of calculated tow lengths from the 2019 and 2020 surveys by CruiseID for the Mid-Atlantic Bight resource area survey.

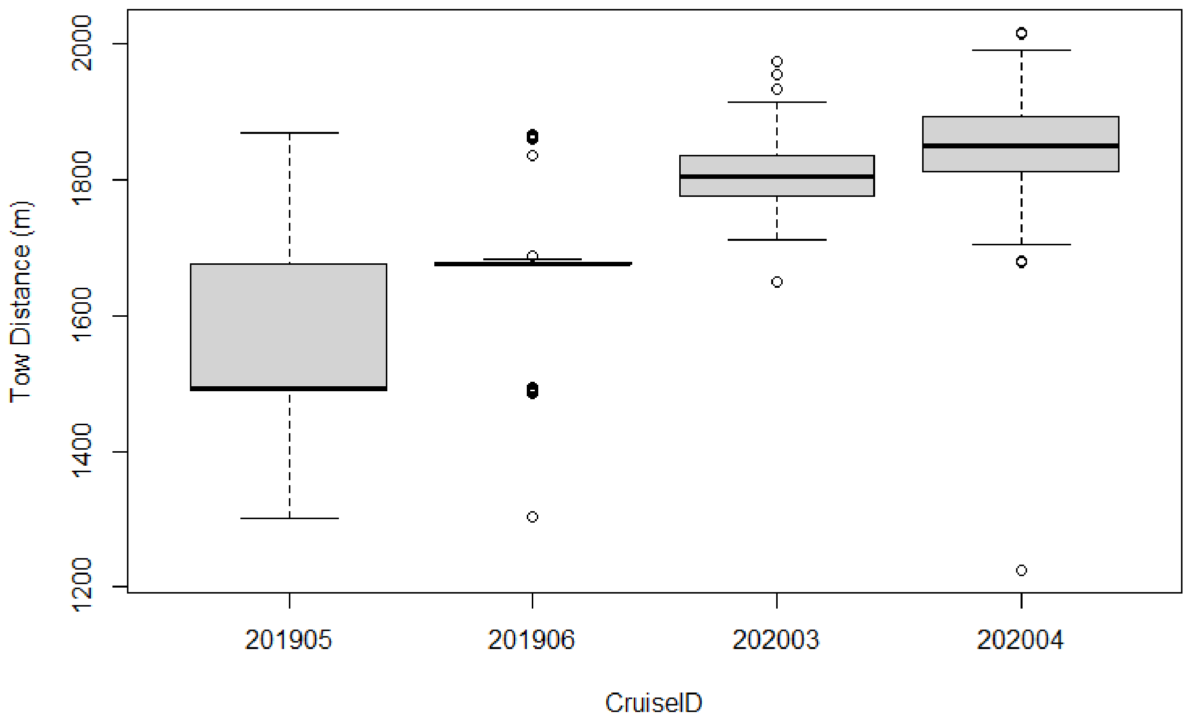


Figure 6. Scallop relative length frequency distributions generated from catch data obtained from both the survey and the commercial dredges during the VIMS/Industry cooperative survey of the Mid-Atlantic Bight resource area in 2019 by SAMS Area. Number of scallops (n) measured and mean length by gear are also included.

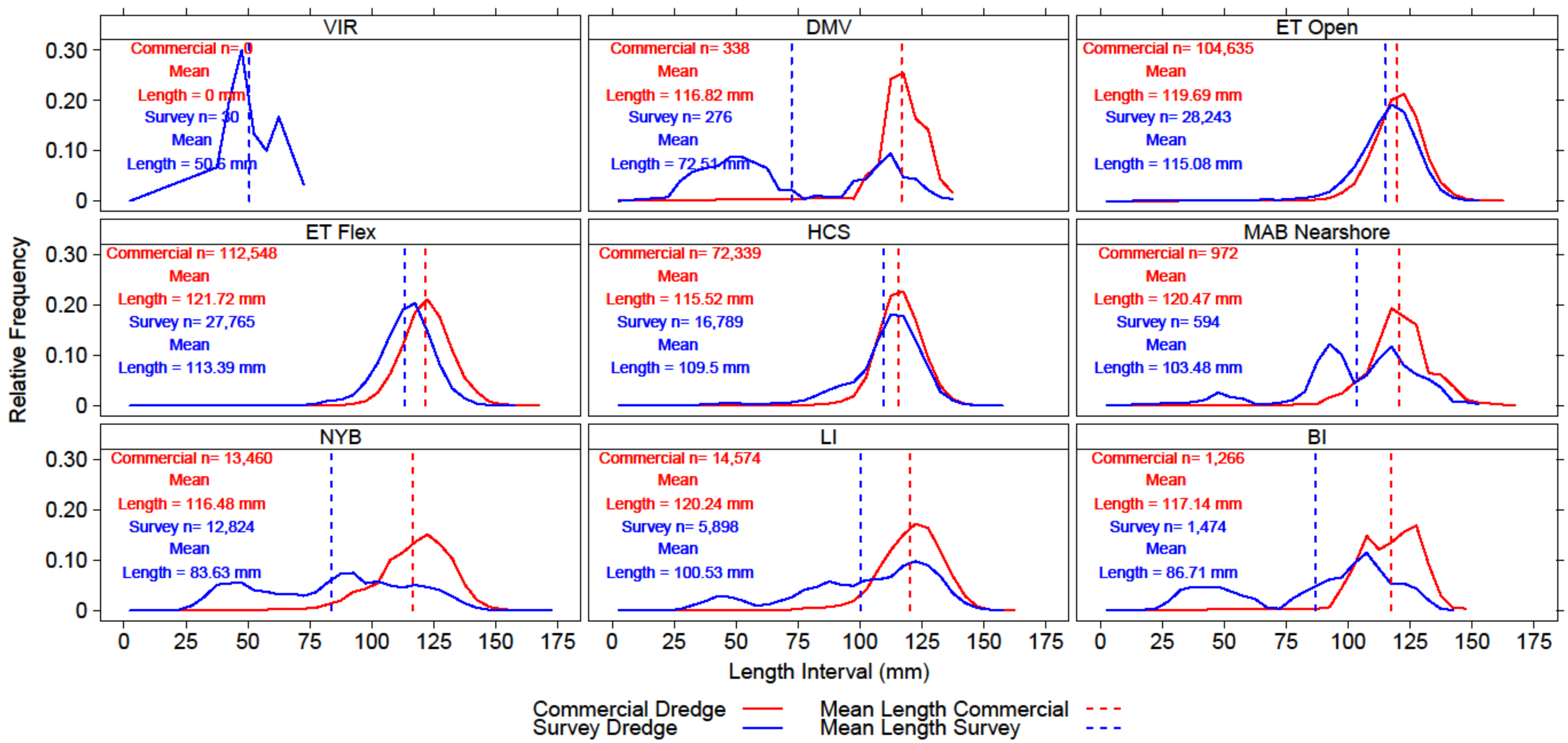


Figure 7. Scallop relative length frequency distributions generated from catch data obtained from both the survey and the commercial dredges during the VIMS/Industry cooperative survey of the Mid-Atlantic Bight resource area in 2020 by SAMS Area. Number of scallops (n) measured and mean length by gear are also included.

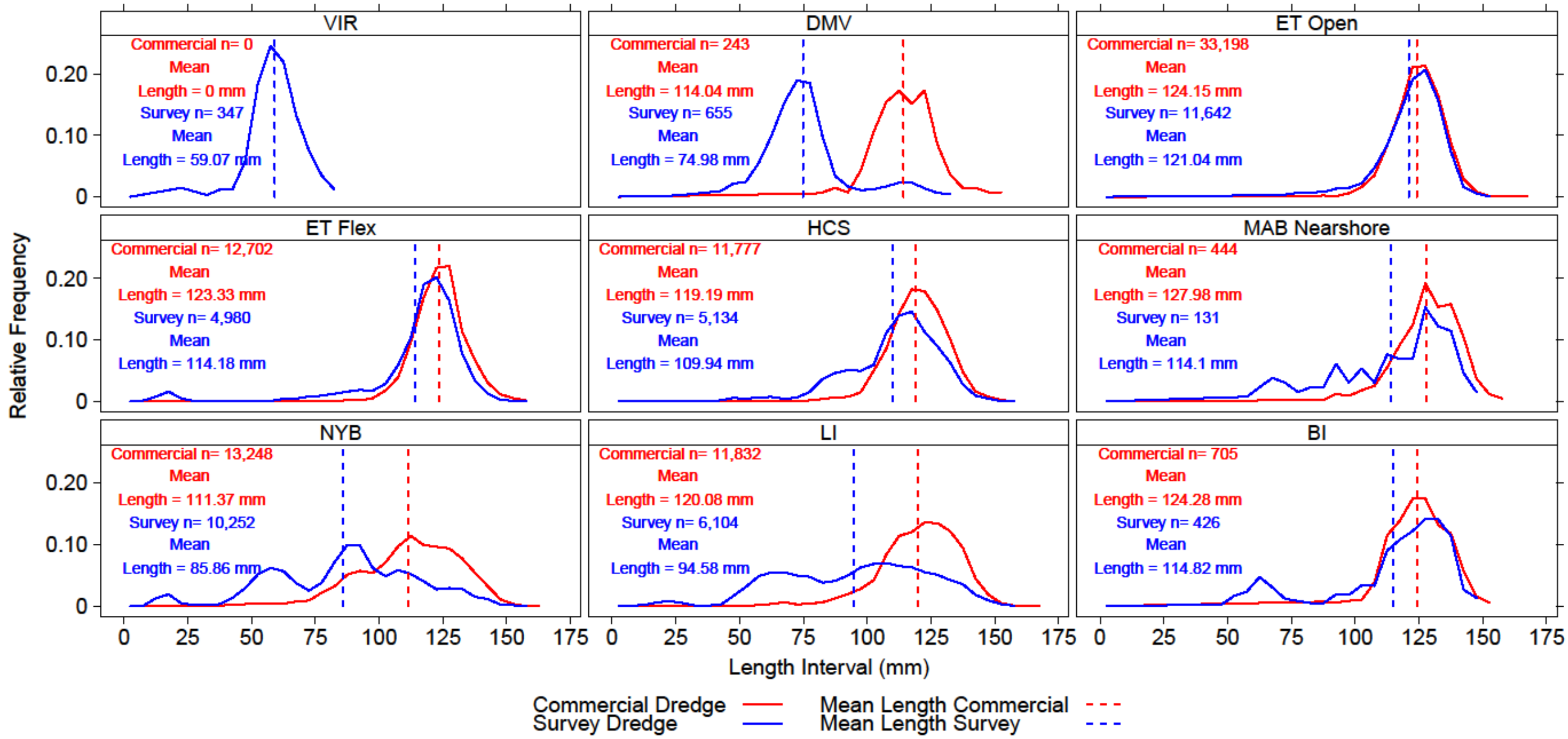
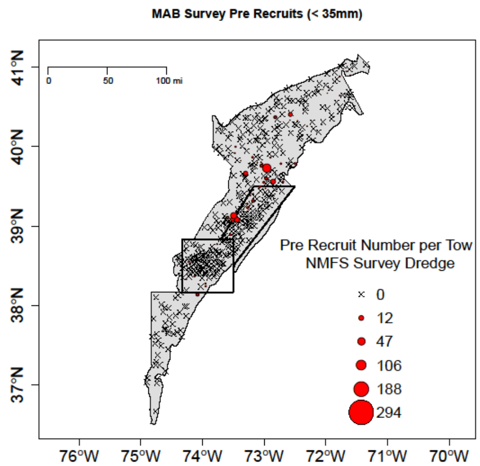
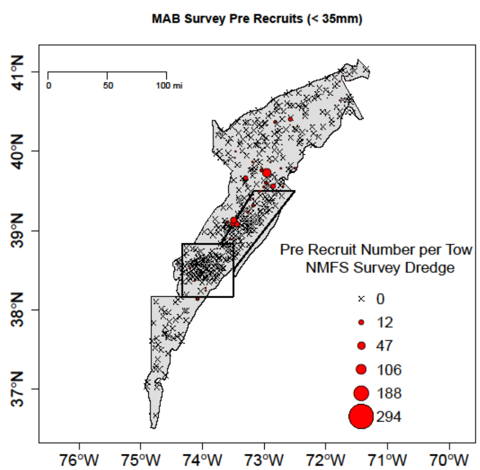


Figure 8. Spatial distribution of the number of sea scallops caught per m^2 in the NMFS survey dredge during the VIMS/Industry cooperative survey of the Mid-Atlantic Bight resource area in 2019. This figure represents the catch of three size classes of sea scallops (<35mm (top), 35mm-75mm (middle), and >75mm (bottom)).





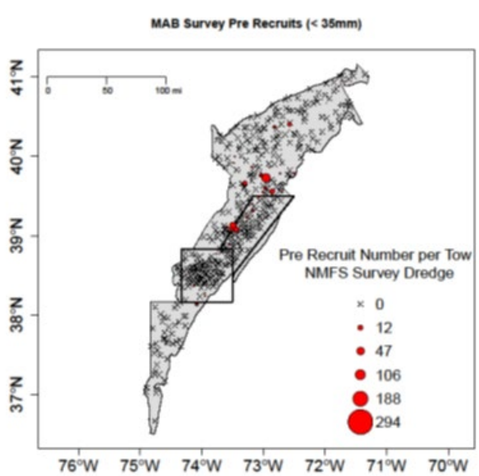


Figure 9. Spatial distribution of the number of sea scallops caught per m^2 in the NMFS survey dredge during the VIMS/Industry cooperative survey of the Mid-Atlantic Bight resource area in 2020. This figure represents the catch of three size classes of sea scallops (<35mm (top), 35mm-75mm (middle), and >75mm (bottom)).

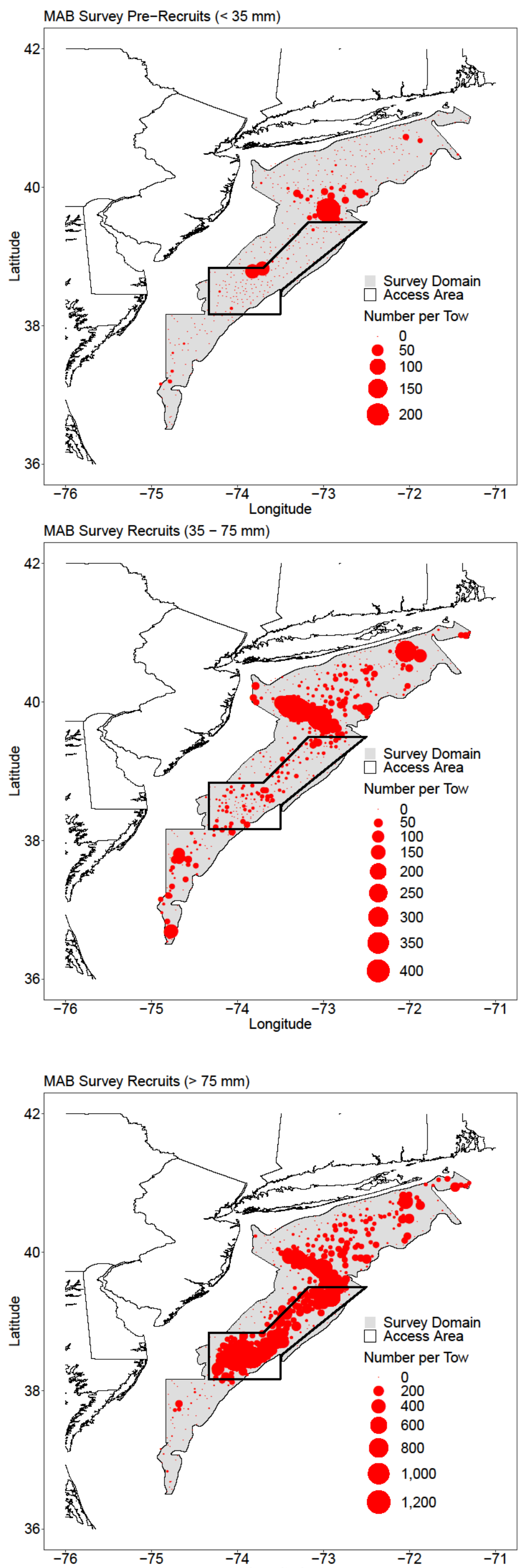


Figure 10. Predicted shell height:meat weight relationships by SAMS Area estimated from scallops sampled in the Mid-Atlantic Bight resource area in 2019.

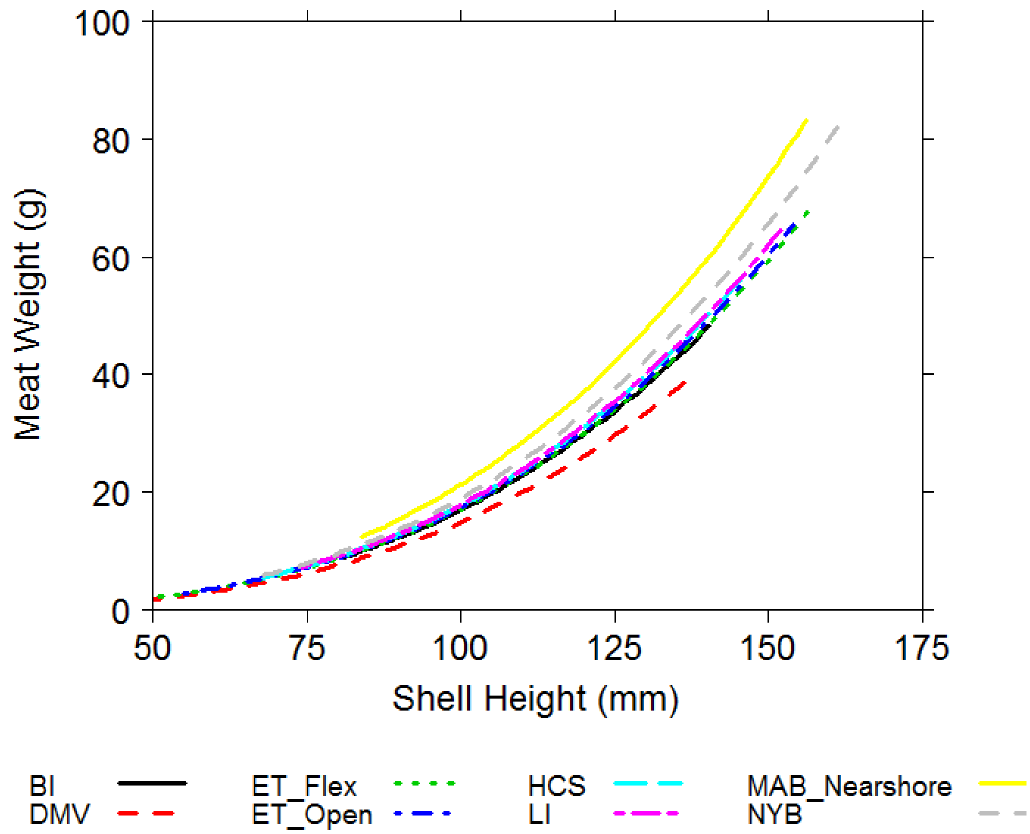


Figure 11. Predicted shell height:meat weight relationships by SAMS Area and maturity stage estimated from scallops sampled in the Mid-Atlantic Bight resource area in 2020 including maturity stage.

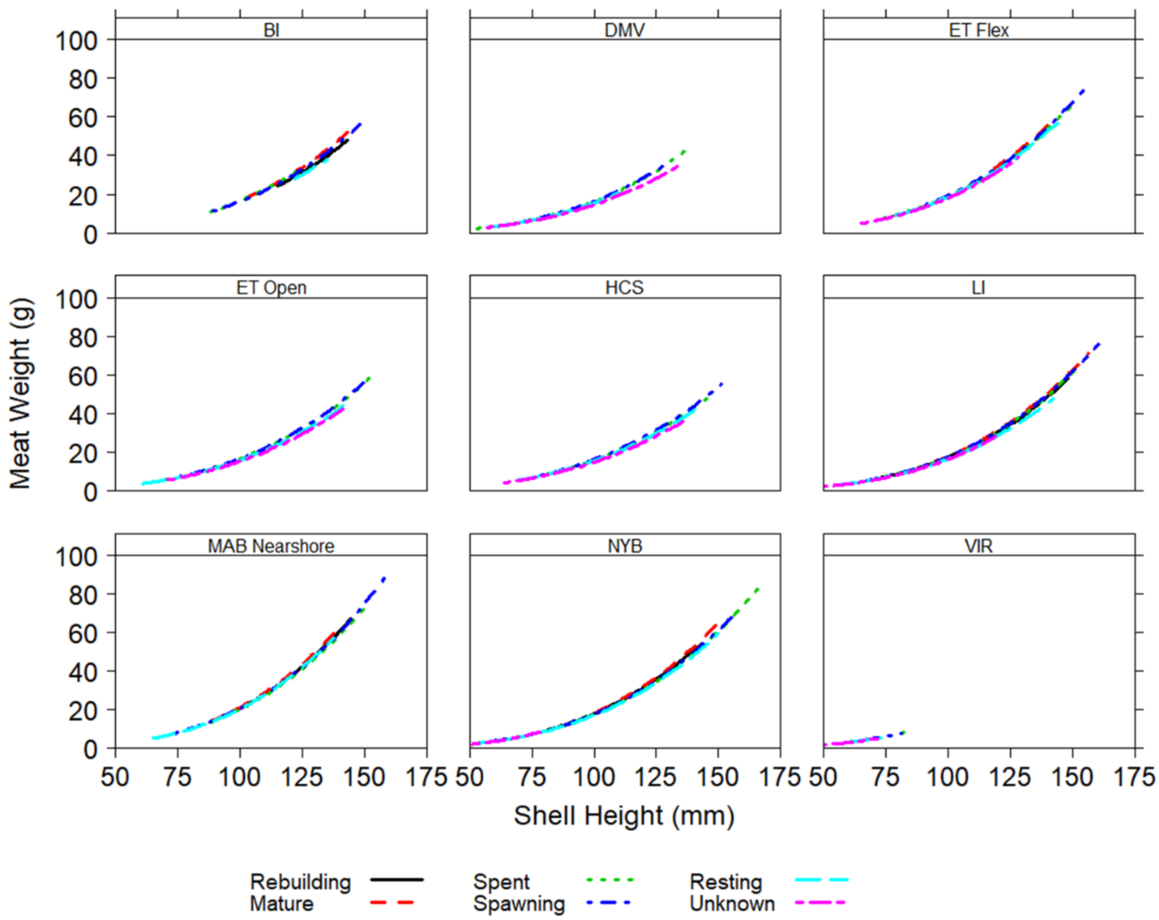


Figure 12. Predicted shell height:meat weight relationships by SAMS Area estimated from scallops sampled in the Mid-Atlantic Bight 2020 excluding maturity stage.

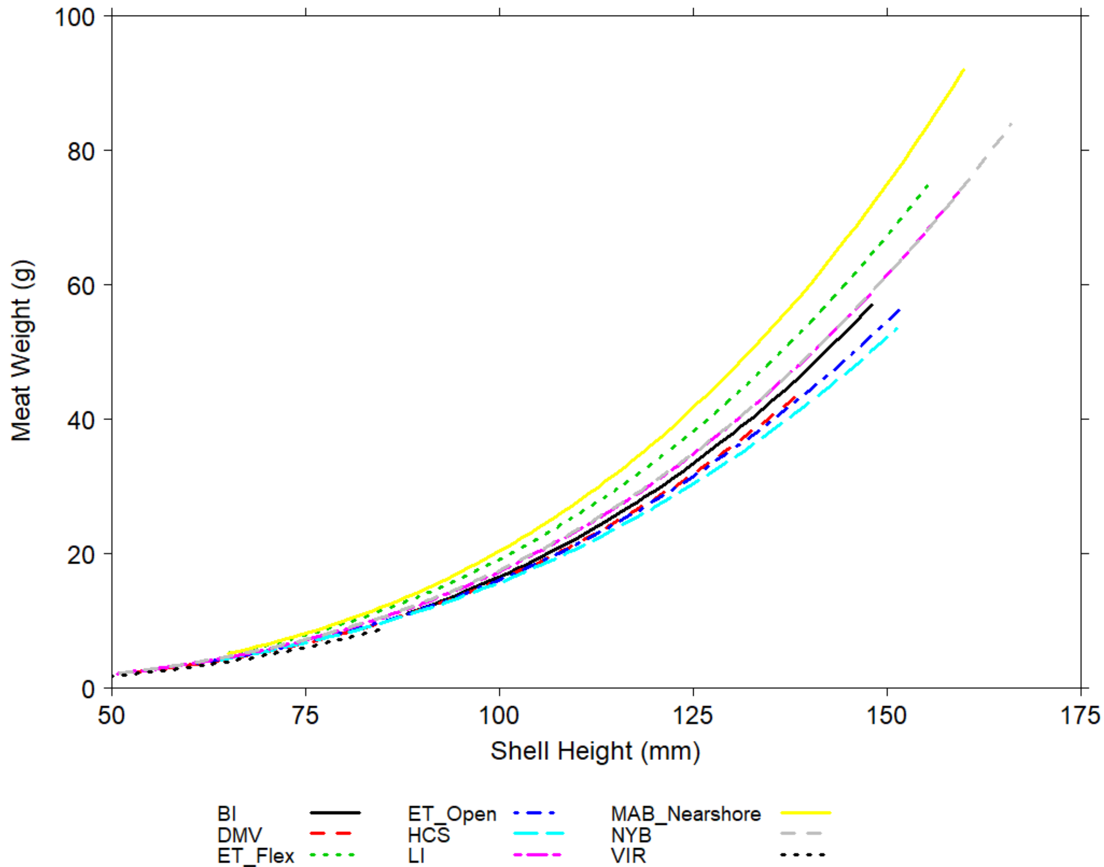


Figure 13. Length frequency distributions of bycatch for the NMFS survey dredge with sufficient sample sizes for the Mid-Atlantic Bight resource area in 2019 (top row) and 2020 (bottom row).

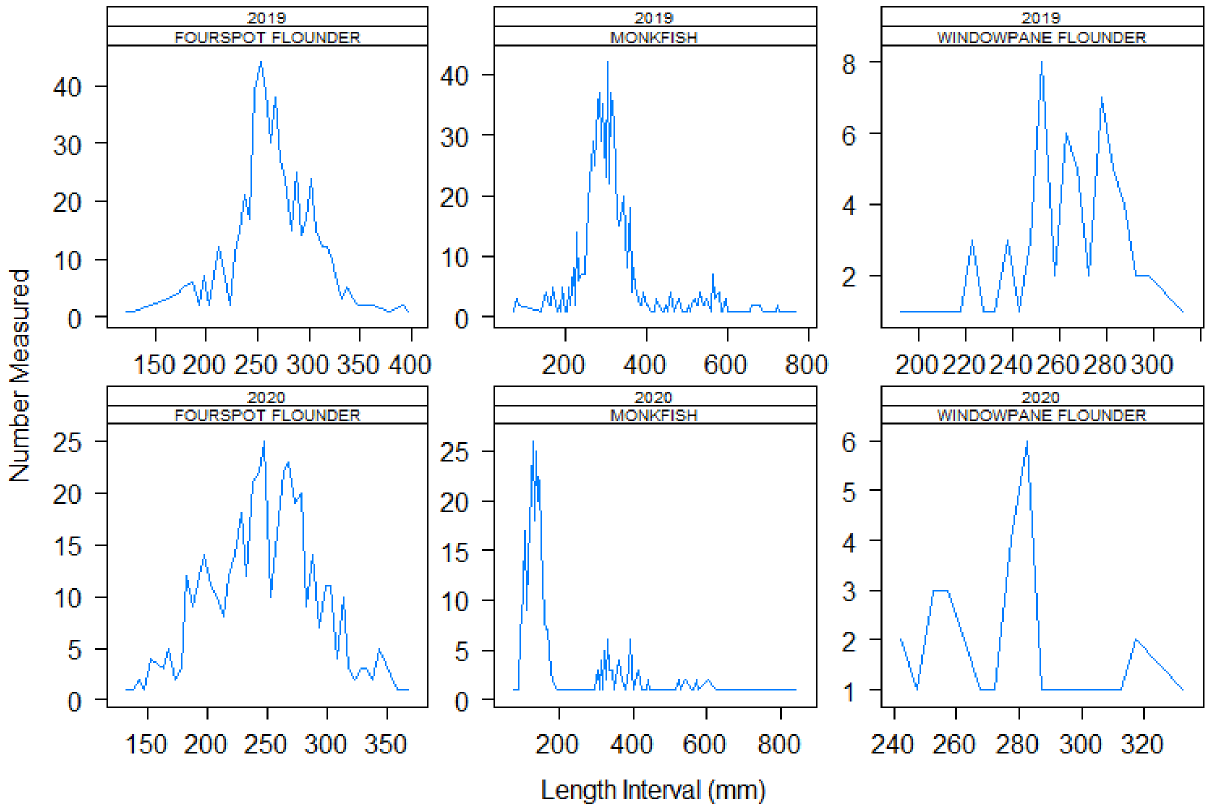


Figure 14. Length frequency distributions of bycatch for the commercial dredge with sufficient sample sizes for the Mid-Atlantic Bight resource area in 2019 (top row) and 2020 (bottom row).

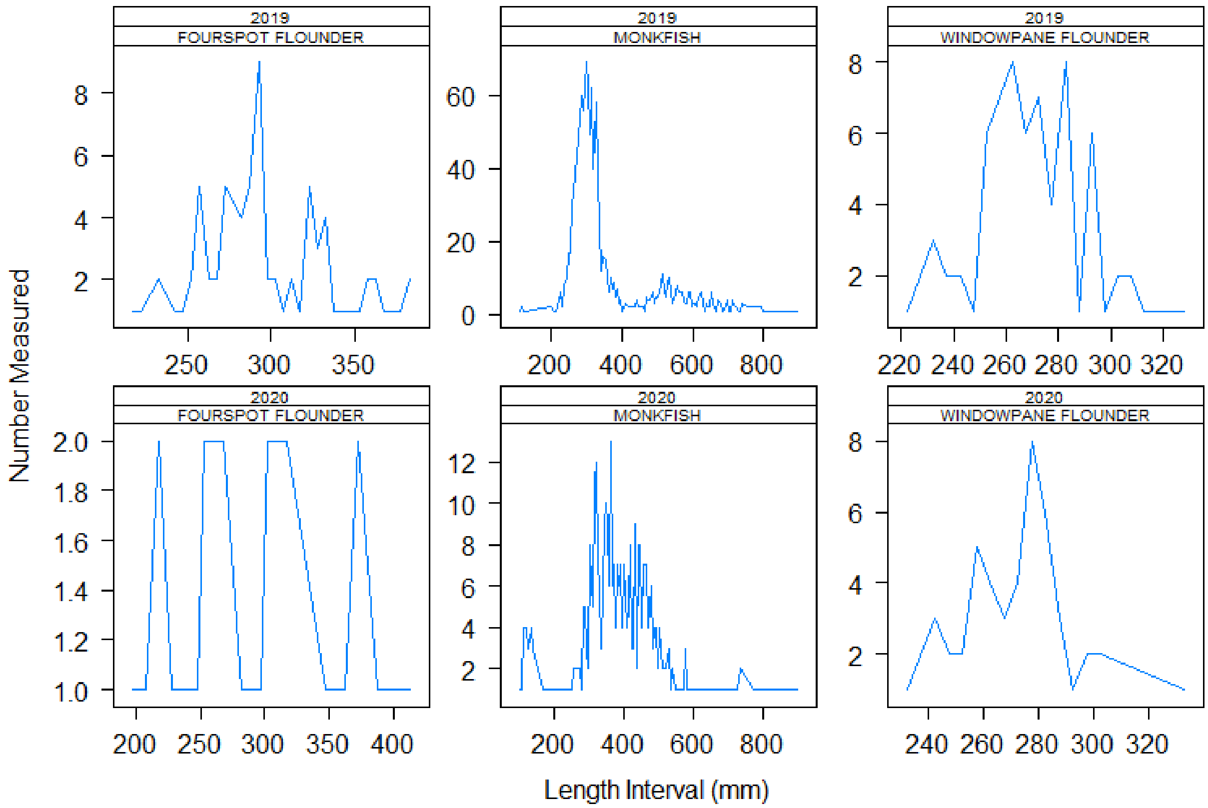


Figure 15. Spatial distribution and number of predators counted by species or genus for the 2019 MAB resource survey predator sampling stations. The number of animals represents either the number enumerated in the subsample or entire sample taken at a given station. Subsampled counts are not expanded.

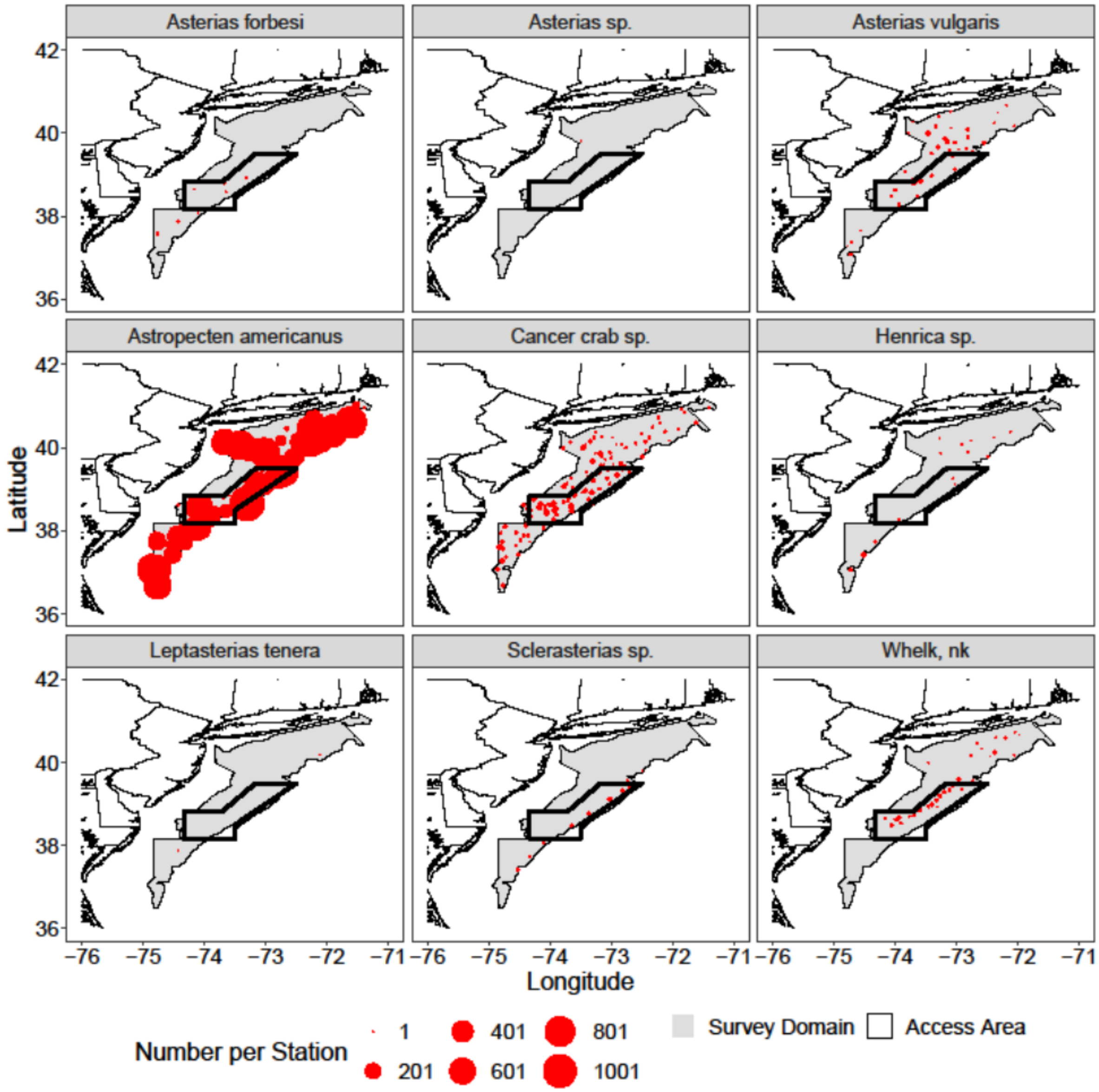


Figure 16. Spatial distribution and number of predators counted by species or genus for the 2020 MAB resource survey predator sampling stations. The number of animals

represents either the number enumerated in the subsample or entire sample taken at a given station. Subsampled counts are not expanded.

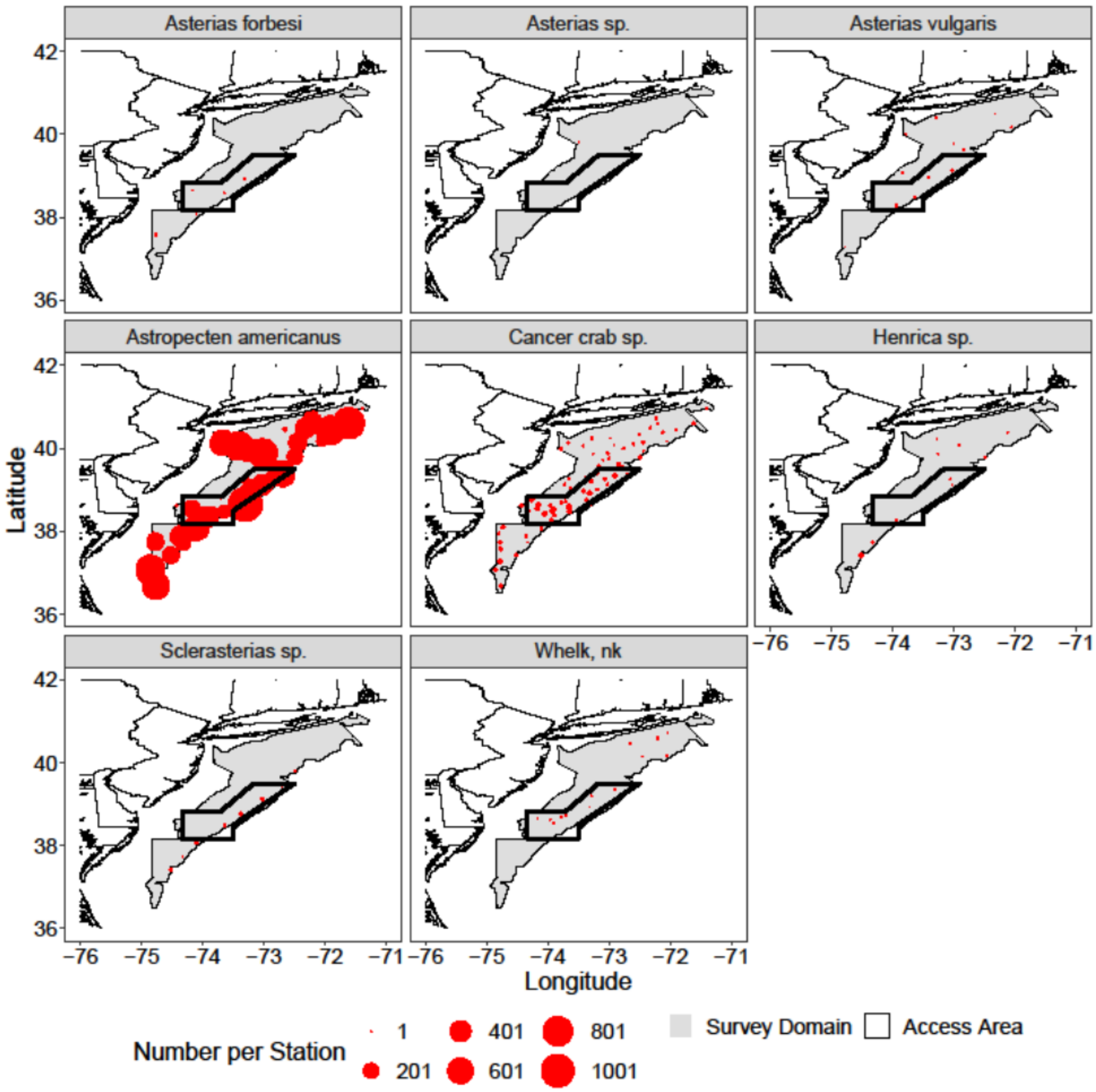


Figure 17. Predicted and observed retention probabilities and deviance residuals by survey for the Mid-Atlantic Bight (A), Nantucket Lightship (B), and Closed Area I II (C) surveys for the turtle deflector dredge estimated with the SELECT method.

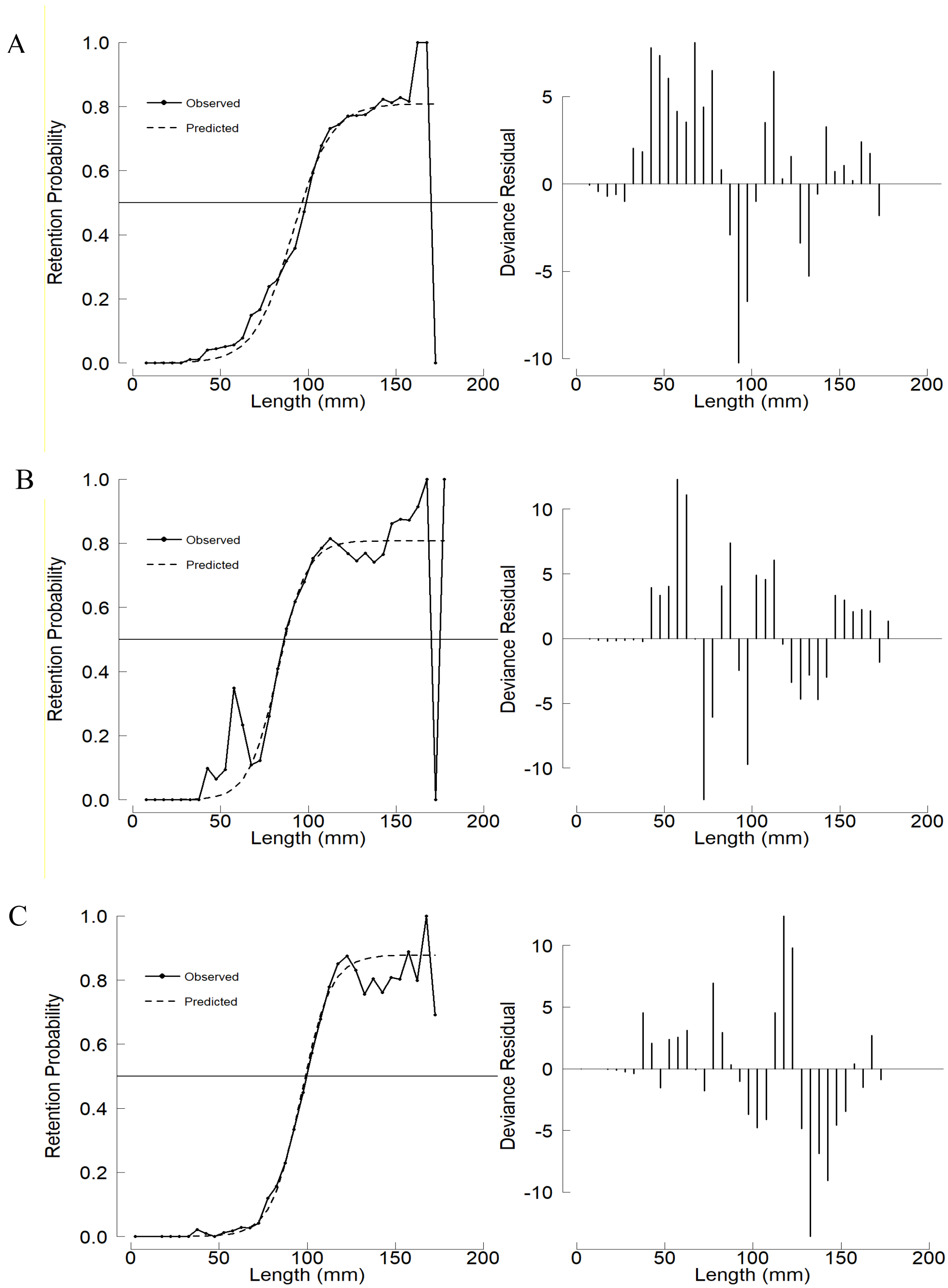

A
B
C
Observed
Predicted
Retention Probability
Deviance Residual
Length (mm)
1.0
0.8
0.6
0.4
0.2
0.0
10
5
0
-5
-10
0
50
100
150
200

Figure 18. Split parameter (left) and L50 (right) estimates with 95 percent confidence intervals by survey estimated with the SELECT method.

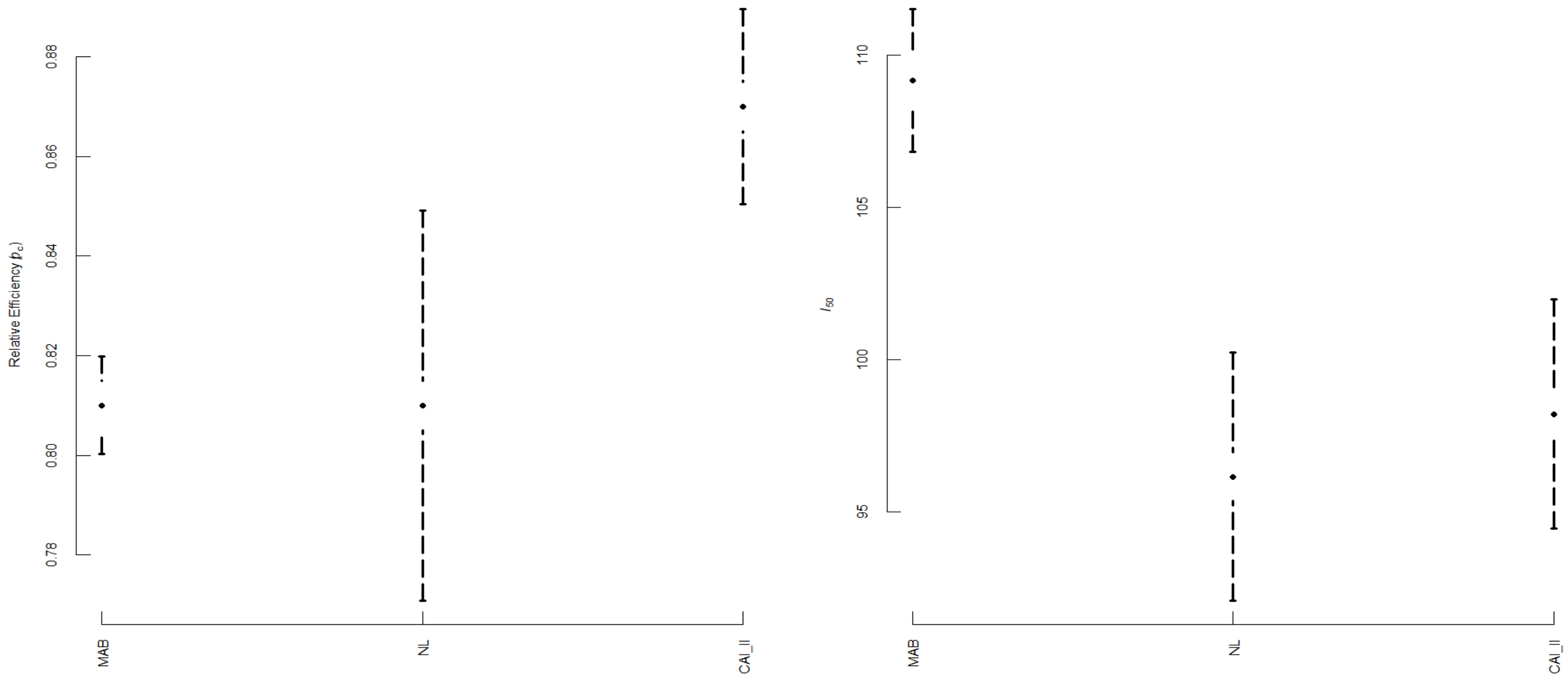


Figure 19. Predicted and observed retention probabilities and deviance residuals by resource area for the Mid-Atlantic Bight (A) and Georges Bank (B) for the turtle deflector dredge estimated with the SELECT method.

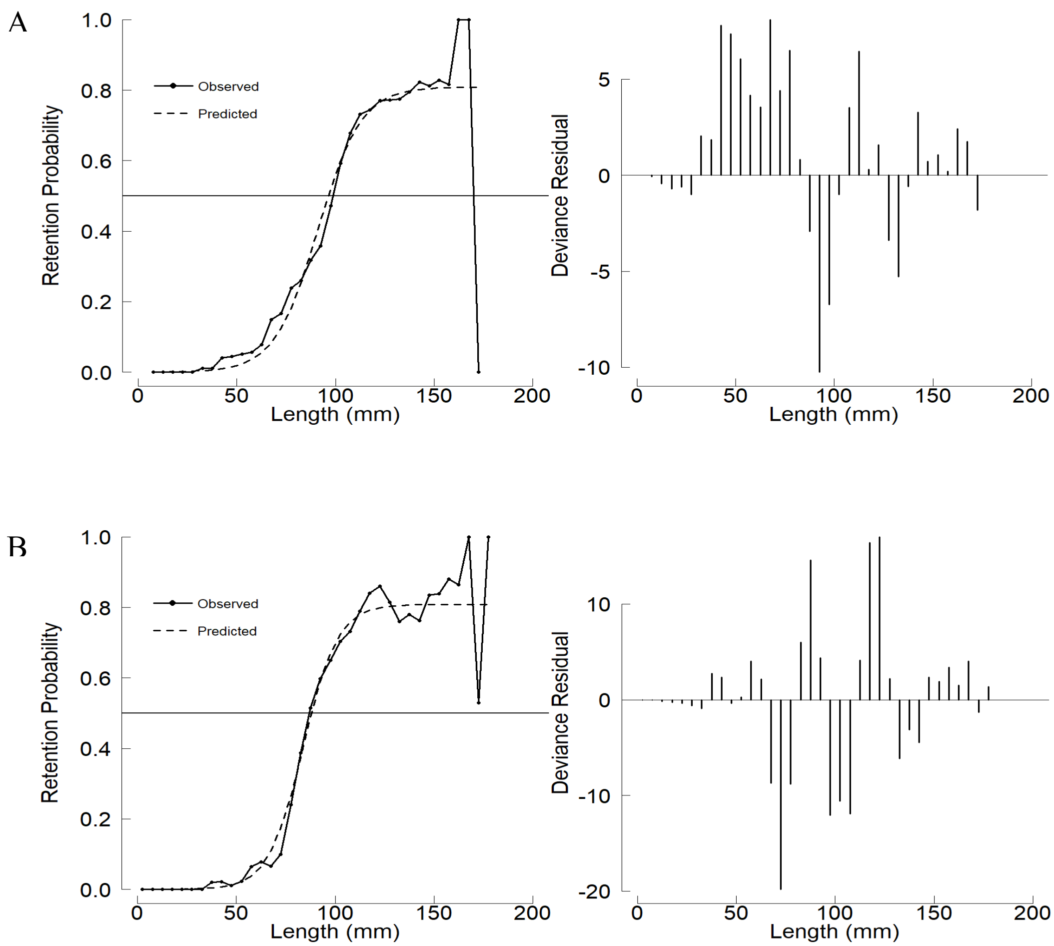


Figure 20. Split parameter (left) and L_{50} (right) estimates with 95 percent confidence intervals by resource area estimated with the SELECT method.

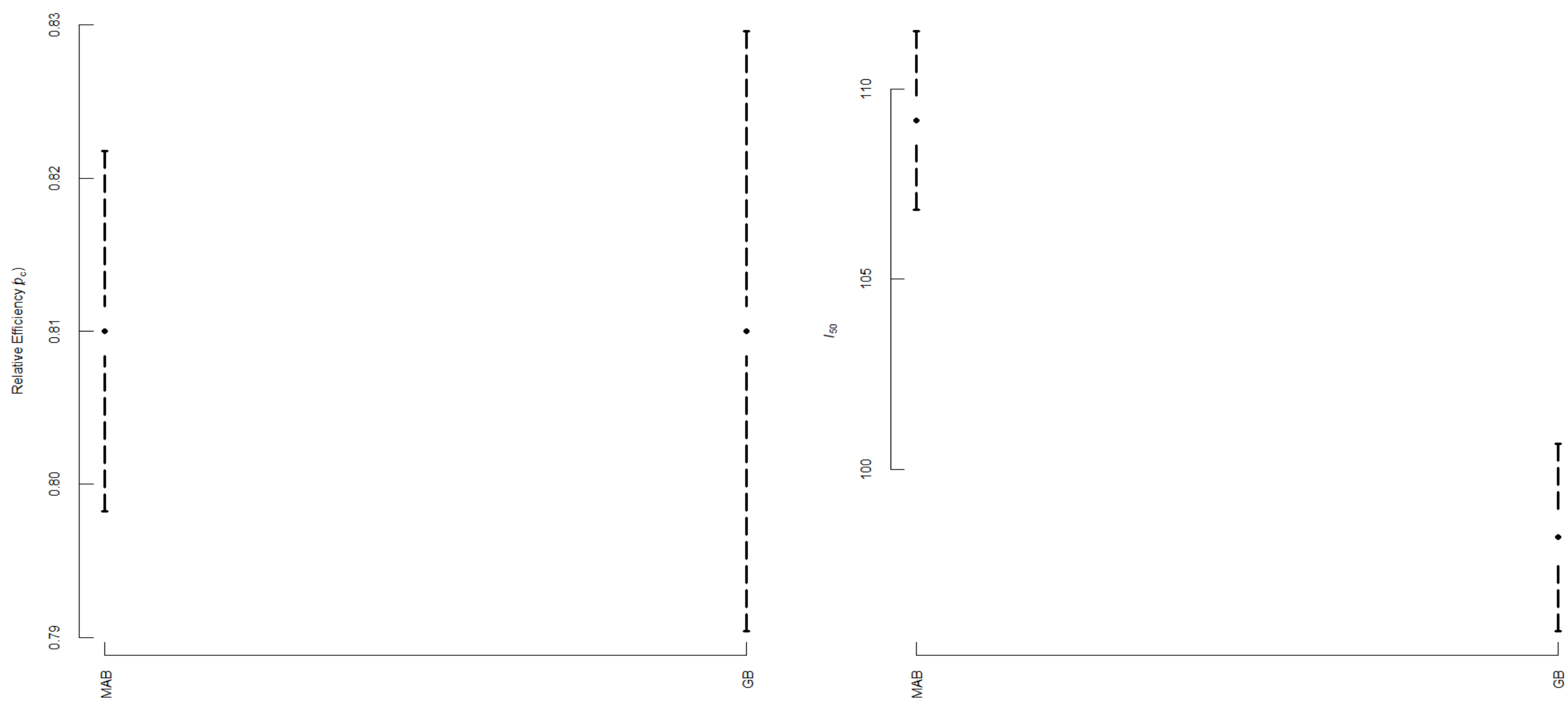


Figure 21. Predicted selectivity curves estimated with the SELECT method by survey for the Mid-Atlantic Bight (A), Nantucket Lightship (B), and Closed Area I II (C) surveys for the turtle deflector dredge.

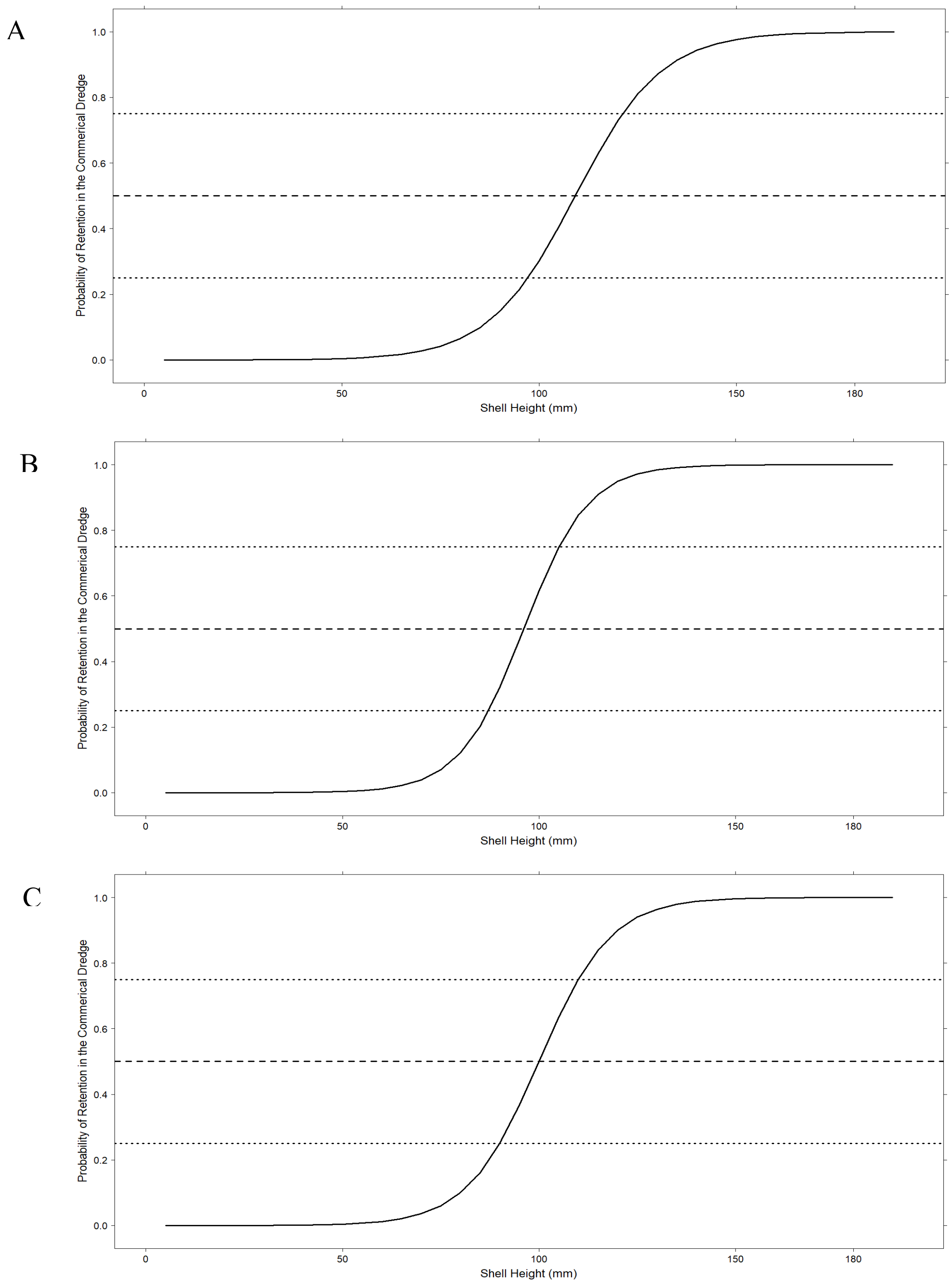


Figure 22. Predicted selectivity curves estimated with the SELECT method by resource area for the Mid-Atlantic Bight (A) and Georges Bank (B) for the turtle deflector dredge.

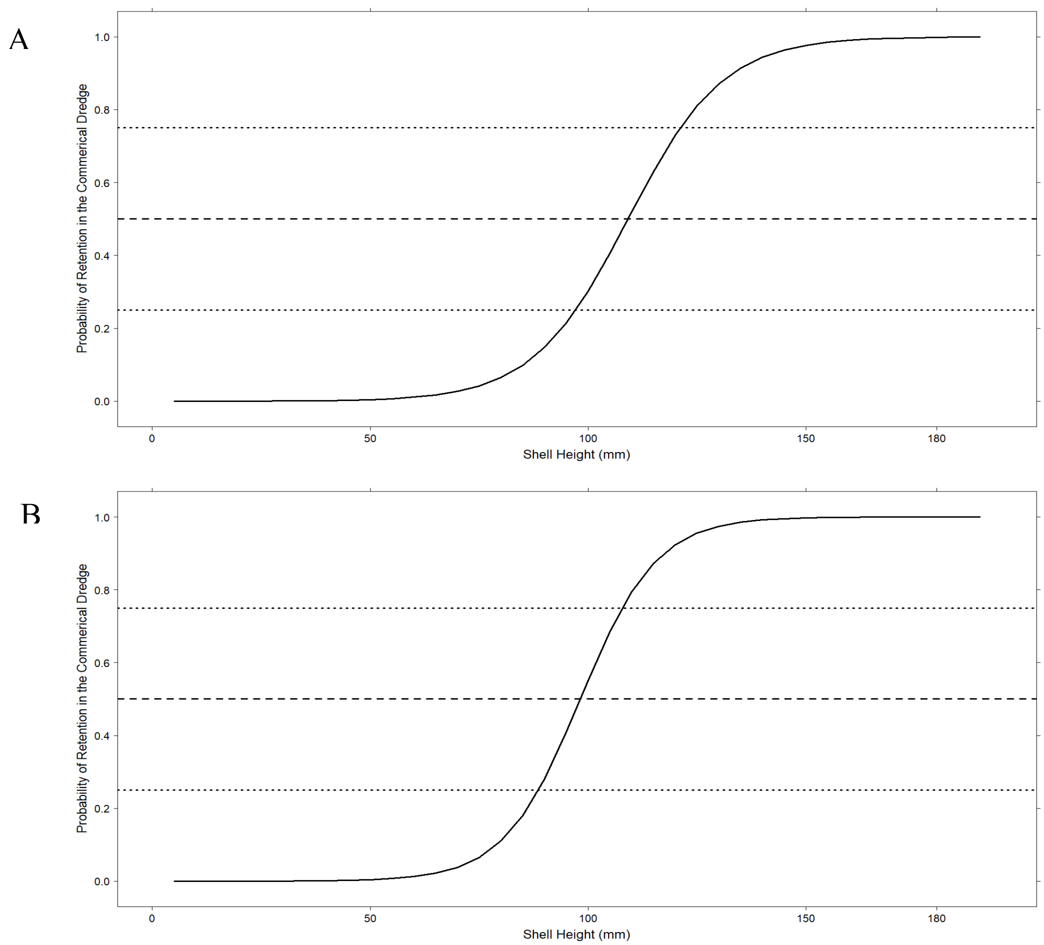


Figure 23. Percentage of scallops infected with the nematode parasite (prevalence) observed in the MAB resource area from 2015-2020.

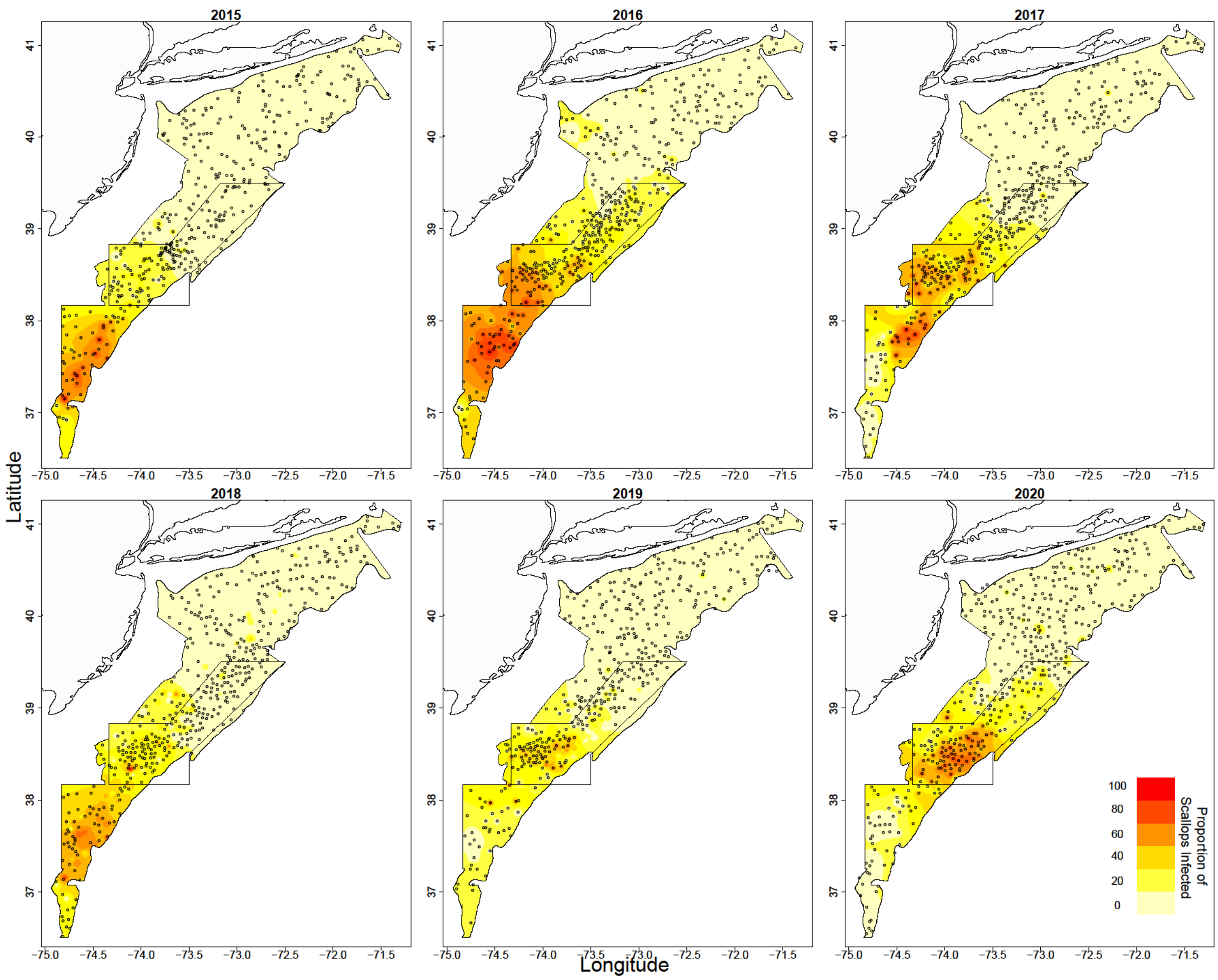


Figure 24. Average number of nematodes observed in infected scallops (intensity) in the MAB resource area from 2015-2020.

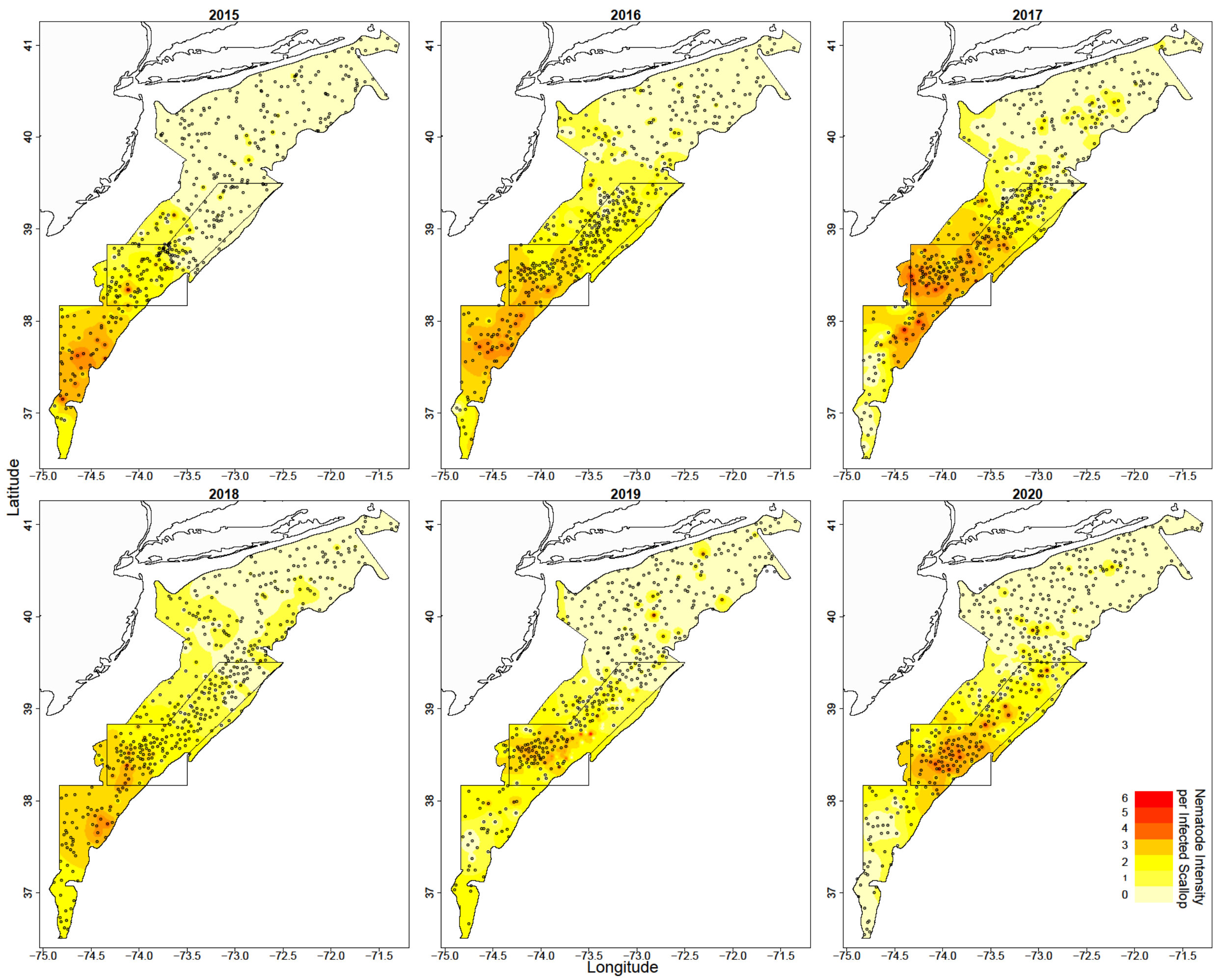


Table 1. Description of marketability, color, texture, and blister codes.

Classification	Color	Texture	Marketability	Blister
1	Extreme color deviation	Extreme stringiness, tearing, flaccid	Unmarketable	Blister in advanced stage
2	Noticeable color deviation	Noticeable stringiness, tearing, flaccid	Marginally marketable	Moderate blister severity
3	Slight color deviation	Slight stringiness, tearing, flaccid	Slightly inferior marketability	Blister in early stage
4	No color deviation	No texture concern	Marketable	No blister present

Table 2. Estimated total and exploitable biomass for the NMFS survey dredge for the survey domain in 2019 by SAMS Area. Standard error (SE), coefficient of variation (CV), average density (scallops/m^2), average meat weight (grams), and number of scallops are also provided.

	SAMS Area	Total Biomass (mt)	SE	CV	Density (scal/m^2)	Avg MW (g)	Total Number
Total	BI	1,515	254	42	0.11	17.33	94,885,840
	DMV	203	43	53	0.01	10.48	20,305,939
	ET_Flex	13,529	1,174	22	0.44	25.46	523,603,853
	ET_Open	15,105	897	15	0.3	25.84	592,011,891
	HCS	8,621	791	23	0.13	22.67	382,732,206
	LI	9,078	350	10	0.03	22.44	407,273,485
	MAB_Nearshore	1,048	168	40	0.02	23.67	43,934,548
	NYB	7,504	527	18	0.12	15.15	543,317,040
	VIR	14	1	20	0	2.98	4,182,976
Exploitable	BI	952	153	40	0.047	26.76	35,511,021
	DMV	120	30	64	0.002	22.79	5,286,765
	ET_Flex	10,652	933	22	0.329	26.85	389,225,489
	ET_Open	12,108	675	14	0.23	27.37	441,797,615
	HCS	6,503	580	22	0.091	24.96	262,255,237
	LI	6,767	259	10	0.016	30.38	223,912,256
	MAB_Nearshore	741	118	40	0.009	29.63	25,180,547
	NYB	4,184	203	12	0.042	26.12	168,627,098
	VIR	0	0	0	0	0	0

Table 3. Estimated exploitable biomass for the Turtle Deflector style commercial dredge in the survey domain in 2019 by SAMS Area. Standard error (SE), coefficient of variation (CV), average density (scallops/m2), average meat weight (grams), and number of scallops are also provided.

	SAMS Area	Exp Biomass (mt)	SE	CV	Density (scal/m^2)	Avg MW (g)	Exp Number
Exploitable	BI	706	128	28	0.03	32.26	21,781,182
	DMV	174	67	59	0	26.38	6,574,359
	ET_Flex	23,037	4,424	30	0.61	31.34	745,473,176
	ET_Open	18,884	1,438	12	0.37	29.1	639,647,357
	HCS	11,355	1,162	16	0.16	25.67	444,822,639
	LI	9,436	547	9	0.02	33.51	282,690,480
	MAB_Nearshore	733	184	39	0.01	34.06	21,786,935
	NYB	3,920	269	11	0.03	31.27	128,778,829
	VIR	0	0	0	0	0	0

Table 4. Estimated total and exploitable biomass for the NMFS survey dredge for the survey domain in 2020 by SAMS Area. Standard error (SE), coefficient of variation (CV), average density (scallops/m^2), average meat weight (grams), and number of scallops are also provided.

	SAMS Area	Total Biomass (mt)	SE	CV	Density (scal/m^2)	Avg MW (g)	Total Number
Total	BI	809	117.8	36	0.03	31.29	25,306,075
	DMV	351	60.5	43	0.01	9.52	36,976,500
	ET_Flex	3,208	282.5	22	0.08	28.34	113,945,394
	ET_Open	7,811	369.5	12	0.12	29.63	265,744,949
	HCS	4,095	232.8	14	0.06	23.33	174,733,150
	LI	6,151	338	14	0.02	20.32	294,927,147
	MAB_Nearshore	309	45.5	37	0	30.47	10,113,305
	NYB	4,007	229.9	14	0.07	16.04	256,377,427
	VIR	71	11.1	39	0.01	4.71	16,057,046
Exploitable	BI	711	109	38	0.03	35.98	19,630,845
	DMV	120	21	44	0.002	15.43	7,787,590
	ET_Flex	2,732	244	22	0.06	29.91	90,048,253
	ET_Open	6,908	337	12	0.10	30.9	223,223,434
	HCS	3,269	186	14	0.04	26.02	124,751,173
	LI	4,507	220	12	0.01	28.44	157,273,548
	MAB_Nearshore	263	40	38	0.002	35.4	7,427,941
	NYB	2,451	119	12	0.03	23.71	103,794,798
	VIR	5	1	31	0.001	5.77	937,183

Table 5. Estimated exploitable biomass for the Turtle Deflector style commercial dredge in the survey domain in 2020 by SAMS Area. Standard error (SE), coefficient of variation (CV), average density (scallops/m2), average meat weight (grams), and number of scallops are also provided.

	SAMS Area	Exp Biomass (mt)	SE	CV	Density (scal/m^2)	Avg MW (g)	Exp Number
Exploitable	BI	498	90.9	28	0.02	36.68	13,631,037
	DMV	89	46.1	80	0	26.34	3,360,604
	ET_Flex	3,081	372	19	0.06	32.37	92,208,708
	ET_Open	7,443	622	13	0.11	31.74	233,926,657
	HCS	3,601	384	16	0.04	28.68	124,068,373
	LI	6,082	426	11	0.01	34.4	176,077,048
	MAB_Nearshore	430	118	42	0	39.43	10,912,934
	NYB	2,566	176	11	0.02	29.76	85,181,778
	VIR	0	0	0	0	0	0

Table 6. Shell height:meat weight models for the 2019 VIMS survey data for the Mid-Atlantic resource area. Bold variables indicate significant terms. The model in red was selected as the preferred model based on AIC value and model selection criteria. The number of parameters (K), AIC, ΔAIC, and Deviance explained are also included.

Model	Parameters	K	AIC	ΔAIC	Deviance
mab1	~ 1 + shell height*depth + SAMS Area	13	34,390.82	0	77.09
mab3	**~ 1 + shell height + depth + SAMS Area**	**12**	**34,390.90**	**0.08**	**77.08**
mab2	~ 1 + shell height + SAMS Area + latitude	12	34,421.61	30.79	77.08

Table 7. Shell height:meat weight parameters estimated from the preferred model for the 2019 VIMS survey data for the Mid-Atlantic resource area. Predictor variables in bold indicate terms are significant.

Parameter	Estimate
Intercept	-10.14
log shell height	**3.07**
log depth	-0.31
DMV	-0.02
ET_Flex	0.05
ET_Open	0.12
HCS	**0.17**
LI	0.08
MAB_Nearshore	**0.20**
NYB	**0.17**

Table 8. Shell height:meat weight models for the 2020 VIMS survey data for the Mid-Atlantic resource area including maturity stage as a predictor. Bold variables indicate significant terms. The model in red was selected as the preferred model based on AIC value and model selection criteria. The number of parameters (K), AIC, ΔAIC, and Deviance explained are also included.

Model	Parameters	K	AIC	ΔAIC	Deviance
mab2	**~ 1 + shell height*depth + SAMS Area + Maturity Stage**	**19**	**29,230.19**	**0**	**81.14**
mab3	~ 1 + shell height *depth + SAMS Area + Maturity Stage + Latitude	20	29,232.20	2.01	81.14
mab1	~ 1 + shell height*depth + SAMS Area	14	29,234.75	4.56	81.12
mab4	~ 1 + shell height*depth + SAMS Area + Latitude	15	29,236.70	6.51	81.12
mab6	~ 1 + shell height + depth + SAMS Area + Maturity Stage	18	29,265.99	35.80	80.99
mab5	~ 1 + shell height + depth + SAMS Area	13	29,270.80	40.61	80.96
mab7	~ 1 + shell height + depth + SAMS Area + Latitude	14	29,272.09	41.9	80.96

Table 9. Shell height:meat weight parameters estimated from the preferred models with and without maturity stage as a predictor variable for the 2020 VIMS survey data for the Mid-Atlantic resource area. Predictor variables in bold indicate terms are significant.

Parameter	Maturity Stage Excluded	Maturity Stage Included
Intercept	-19.41	-19.22
log shell height	**5.04**	**4.99**
log depth	**2.02**	**1.99**
DMV	**0.02**	**0.03**
ET_Flex	0.18	0.19
ET_Open	0.05	0.08
HCS	0.05	0.08
LI	0.08	0.09
MAB_Nearshore	**0.18**	**0.19**
NYB	0.10	0.11
VIR	-0.08	-0.07
Mature		0.01
Spent		0.00
Spawning		0.01
Resting		-0.03
Unknown		**-0.05**
log shell height:log depth	**-0.5**	**-0.49**

Table10. Shell height:meat weight models for the 2020 VIMS survey data for the Mid-Atlantic resource area excluding maturity stage as a predictor. Bold variables indicate significant terms. The model in red was selected as the preferred model based on AIC value and model selection criteria. The number of parameters (K), AIC, ΔAIC, and Deviance explained are also included.

Model	Parameters	K	AIC	ΔAIC	Deviance
mab1	**~ 1 + shell height*depth + SAMS Area**	**14**	**29,234.75**	**0**	**81.12**
mab2	~ 1 + shell height *depth + SAMS Area + Latitude	15	29,236.70	1.95	81.12
mab4	~ 1 + shell height + depth + SAMS Area	13	29,270.80	36.05	80.97
mab3	~ 1 + shell height + depth + SAMS Area + Latitude	14	29,272.09	37.34	80.96

Table 11. Total catch (number of animals) and catch per unit effort for bycatch for the 2019 and 2020 surveys for the NMFS survey dredge and the commercial dredges.

Survey	Common Name	Commercial Gear Catch (Number)	Commercial Gear CPUE	Survey Gear Catch (Number)	Survey Gear CPUE
2019	SPINY DOGFISH	3	0.01	2	0.01
2019	CHAIN DOGFISH	1	0	19	0.05
2019	BARNDOOR SKATE	8	0.02	1	0
2019	YELLOWTAIL FLOUNDER	2	0.01	0	0
2019	BLACK SEA BASS	7	0.02	59	0.14
2019	GULFSTREAM FLOUNDER	2	0.01	539	1.31
2019	MONKFISH	1,235	3.01	752	1.83
2019	SCUP	2	0.01	43	0.11
2019	RED HAKE	2	0.01	812	1.98
2019	NORTHERN SEAROBIN	282	0.69	2,109	5.13
2019	SILVER HAKE	7	0.02	848	2.06
2019	SPOTTED HAKE	5	0.01	1,759	4.28
2019	HORSESHOE CRAB	167	0.41	84	0.20
2019	UNCLASSIFIED SKATES	4,737	11.53	1,740	4.23
2019	BLACKBACK FLOUNDER	2	0.01	14	0.03
2019	SUMMER FLOUNDER	74	0.18	45	0.11
2019	WINDOWPANE FLOUNDER	70	0.17	60	0.15
2019	FOURSPOT FLOUNDER	71	0.17	532	1.29
2019	GREY SOLE	9	0.02	22	0.05
2019	AMERICAN LOBSTER	0	0	1	0
2019	WHITE HAKE	0	0	1	0
2019	STRIPED SEAROBIN	0	0	6	0.02
2019	ILLEX SQUID	0	0	3	0.01
2019	BUTTERFISH	0	0	12	0.03
2019	OCEAN POUT	0	0	60	0.15
2019	LOLIGO SQUID	0	0	66	0.16
2019	SMOOTH DOGFISH	0	0	2	0.01
2019	LONGHORN SCULPIN	0	0	1	0
2020	BLACK SEA BASS	6	0.01	40	0.09
2020	GULFSTREAM FLOUNDER	12	0.03	1,685	3.74
2020	MONKFISH	315	0.70	351	0.78
2020	BLACKBACK FLOUNDER	2	0	6	0.01
2020	HORSESHOE CRAB	2	0	0	0
2020	NORTHERN SEAROBIN	99	0.22	147	0.33
2020	BARNDOOR SKATE	2	0	0	0
2020	RED HAKE	8	0.02	1,077	2.39
2020	LOLIGO SQUID	1	0	58	0.13
2020	SUMMER FLOUNDER	4	0.01	4	0.01
2020	SPOTTED HAKE	153	0.34	14,171	31.49
2020	CHAIN DOGFISH	1	0	11	0.02
2020	FOURSPOT FLOUNDER	41	0.09	421	0.94
2020	UNCLASSIFIED SKATES	4,802	10.67	2,020	4.49
2020	SILVER HAKE	4	0.01	169	0.38
2020	WINDOWPANE FLOUNDER	47	0.10	31	0.07
2020	SQUID UNCL	1	0	2	0
2020	SMOOTH DOGFISH	1	0	0	0
2020	AMERICAN LOBSTER	0	0	5	0.01
2020	WHITE HAKE	0	0	1	0
2020	BUTTERFISH	0	0	4	0.01
2020	SCUP	0	0	1	0
2020	ILLEX SQUID	0	0	20	0.04
2020	OCEAN POUT	0	0	22	0.05
2020	SPINY DOGFISH	0	0	2	0
2020	STRIPED SEAROBIN	0	0	3	0.01

Table 12. Selectivity analysis summary information for each cruise included in the analysis along with resource area, commercial dredge information, number of stations, and number of five mm length bins.

CruiseID	Area	Year	Dredge	Dredge Width	Number of Stations	Number of 5 mm Length Bins
201905	MAB	2019	Turtle	14 ft	115	31
201906	MAB	2019	Turtle	14 ft	124	32
202003	MAB	2020	Turtle	14 ft	130	33
202004	MAB	2020	Turtle	14 ft	105	33
202103	CA II	2021	Turtle	14 ft	81	33
202006	NL	2020	Turtle	14 ft	57	28
202104	NL	2021	Turtle	14 ft	60	33

Table 13. Selectivity analysis parameter values estimated with a logistic curve and estimated split parameter (*p*) by cruise.

Trip	Parameter	Parameter Estimate	SE
CruiseID 201905	a	-11.81	-
	b	0.06	-
	p	0.99	0.01
	L_{25}	163.13	57.07
	L_{50}	179.86	58.02
	L_{75}	196.59	58.97
	SR	33.46	2.16
	REP Factor	20.17	
CruiseID 201906	a	-11.42	-
	b	0.1	-
	p	0.83	0.01
	L_{25}	101.31	1.07
	L_{50}	112.09	1.39
	L_{75}	122.86	1.76
	SR	21.55	0.86
	REP Factor	4.16	
CruiseID 202003	a	-10.52	-
	b	0.1	-
	p	0.79	0.003
	L_{25}	96.69	1.01
	L_{50}	107.97	1.43
	L_{75}	119.25	2.03
	SR	22.56	1.46
	REP Factor	5.52	
CruiseID 202004	a	-7.88	-
	b	0.07	-
	p	0.86	0.02
	L_{25}	100.72	4.12
	L_{50}	117.05	4.13
	L_{75}	133.36	4.99
	SR	32.63	1.94
	REP Factor	6.76	

CruiseID 202005	a	-9.83	-
	b	0.09	-
	p	0.75	0.02
	L_{25}	94.05	2.17
	L_{50}	105.88	2.74
	L_{75}	117.72	3.41
	SR	23.67	1.56
	REP Factor	29.81	
CruiseID 202006	a	-16.04	-
	b	0.16	-
	p	0.87	0.02
	L_{25}	91.08	1.81
	L_{50}	97.78	2.25
	L_{75}	104.47	2.74
	SR	13.4	1.1
	REP Factor	81	
CruiseID 202103	a	-13.52	-
	b	0.12	-
	p	0.88	0.01
	L_{25}	104.94	1.59
	L_{50}	114.22	1.94
	L_{75}	123.5	2.32
	SR	18.56	0.88
	REP Factor	19.61	
CruiseID 202104	a	-4.77	-
	b	0.04	-
	p	0.86	0.09
	L_{25}	94.77	27.49
	L_{50}	123.09	35.1
	L_{75}	151.41	42.9
	SR	56.63	16.23
	REP Factor	34.88	

Table 14. Selectivity analysis parameter values estimated with a logistic curve and estimated split parameter (*p*) by survey area.

Area	Parameter	Parameter Estimate	SE
MAB	a	-9.99	-
	b	0.09	-
	p	0.81	0.005
	L_{25}	97.18	0.9
	L_{50}	109.17	1.2
	L_{75}	121.18	1.54
	SR	24	0.78
	REP Factor	5.41	
NL	a	-11.26	-
	b	0.12	-
	p	0.81	0.02
	L_{25}	87.2	1.5
	L_{50}	96.15	2.08
	L_{75}	105.11	1.39
	SR	17.9	1.39
	REP Factor	57.81	
CA I II	a	-13.52	-
	b	0.11	-
	p	0.87	0.01
	L_{25}	88.63	1.58
	L_{50}	98.21	1.92
	L_{75}	107.79	2.3
	SR	19.16	0.87
	REP Factor	19.34	

Table 15. Selectivity analysis parameter values estimated with a logistic curve and estimated split parameter (*p*) by resource area.

Area	Parameter	Parameter Estimate	SE
MAB	a	-9.99	-
	b	0.09	-
	p	0.81	0.002
	L_{25}	97.18	0.9
	L_{50}	109.17	1.2
	L_{75}	121.18	1.54
	SR	24	0.78
	REP Factor	5.42	
GB	a	-11.26	-
	b	0.11	-
	p	0.81	0.01
	L_{25}	88.63	0.92
	L_{50}	98.21	1.26
	L_{75}	107.79	1.68
	SR	19.16	0.91
	REP Factor	37.91	

Table 16. Summary for scallops assessed for marketability, color, texture, and blister disease at shell height:meat weight stations by sex during the 2019 and 2020 surveys by year.

Year	Sex	Market Classification			
		1	2	3	4
2019	Female	20	224	504	1,997
	Male	12	192	494	2,041
	Unknown	1	1	1	2
2020	Female	195	86	319	1,701
	Male	152	80	325	1,790
	Unknown	4	6	22	82
		Color Classification			
		1	2	3	4
2019	Female	14	39	313	2,379
	Male	5	34	290	2,410
	Unknown	1	0	0	4
2020	Female	17	64	310	1,910
	Male	19	66	262	2,000
	Unknown	4	6	18	86
		Texture Classification			
		1	2	3	4
2019	Female	16	86	466	2,177
	Male	7	76	449	2,207
	Unknown	1	0	1	3
2020	Female	24	113	361	1,803
	Male	22	104	373	1,848
	Unknown	4	8	23	79
		Disease Classification			
		1	2	3	4
2019	Female	19	53	116	2,557
	Male	16	32	117	2,574
	Unknown	1	0	0	4
2020	Female	38	107	100	2,056
	Male	40	98	91	2,118
	Unknown	5	4	5	100

Appendix A

An Assessment of Sea Scallop Abundance and Distribution in the Mid-Atlantic Bight, Nantucket Lightship, Closed Area I and Closed Area II

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August 27-28, 2019

Preliminary – PDT use only.

2019 VIMS-Industry Cooperative Surveys
Project Objectives

Primary Objectives

- Assess the abundance and distribution of scallops in the Mid-Atlantic Bight, NL, CAI & CAII by SAMS Area
- Estimate total & exploitable biomass

Secondary Objectives

- Gear performance
  - Selectivity of commercial gear
- Scallop Biology & Product Quality
  - Assess marketability, growth, disease & SHMW
- Finfish Bycatch
- Scallop Predators

2019 VIMS-Industry Cooperative Surveys

- Sampling design
  - Stratified random design
    - NMFS shellfish strata plus SAMS areas included in survey domains
  - Allocation
    - Area, prior year catch data (biomass, number)
- Automated Data acquisition system
- Survey dredge performance monitored
- All other protocols remained the same
  - Tow a survey dredge & commercial dredge simultaneously
    - Survey dredge – 8 ft in width, 2 in rings & 1.5 in diamond mesh liner
    - Commercial dredge – varies by vessel and area

Biomass Estimation

- Swept area method is used to calculate biomass estimates (Cochran, 1997)
- Area swept per tow (a_s)
  - Navigational info
  - Tilt sensor
- Catch weight per tow (C_h)
  - Expanded length frequencies
  - Length-weight relationship (SARC 65 or determined by PDT)
  - Selectivity (Yochum and DuPaul, 2008)
- Efficiency (E_s)
  - Values from SARC 2014
    - 65%Commercial Dredge
    - 40% NMFS Survey Dredge

Stratified mean biomass per tow in stratum and subarea of interest

$$\bar{C}_{h,s} = \frac{1}{n_h} \sum_{i=1}^{h} C_{i,h,s}$$

$$Var(\bar{C}_{h,s}) = \frac{1}{n_h(n_h - 1)} \sum_{i=1}^{n_h} (C_{i,h,s} - \bar{C}_{h,s})^2$$

Stratified mean biomass per tow in subarea of interest

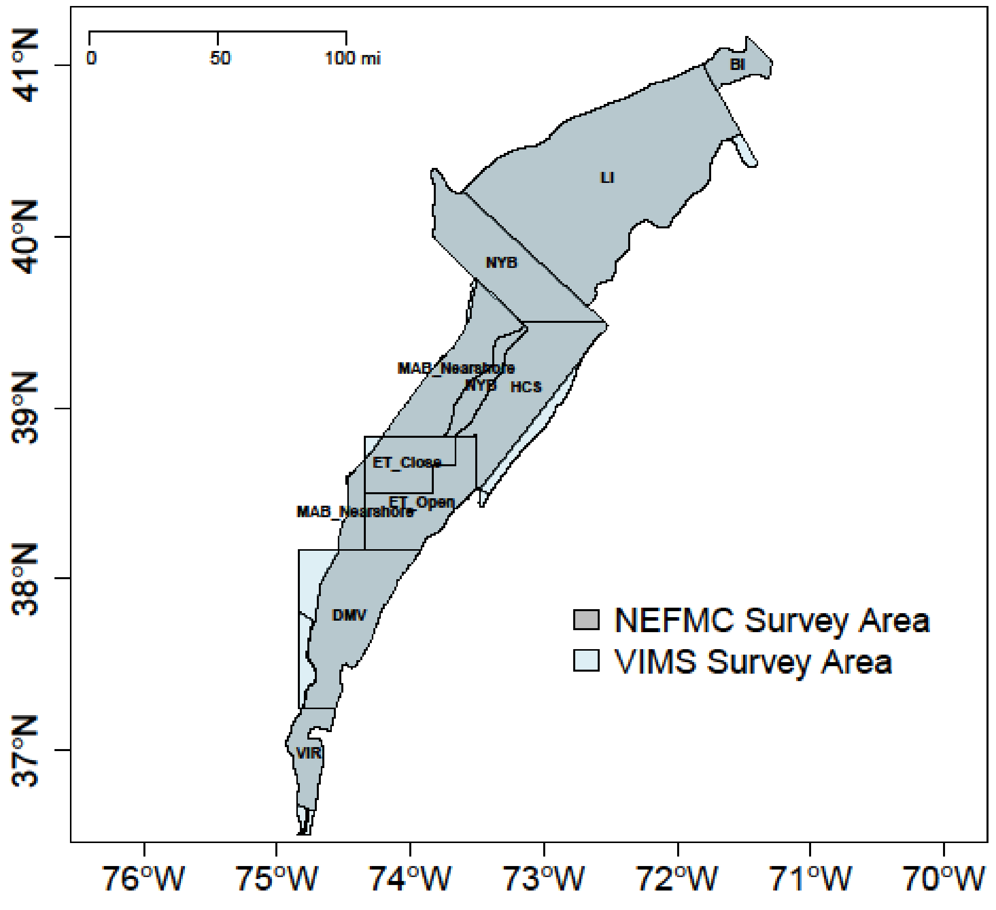
$$\bar{C}_s = \sum_{h=1}^{L} W_h \cdot \bar{C}_{h,s} \quad Var(\bar{C}_s) = \sum_{h=1}^{L} W_h^2 \cdot Var(\bar{C}_h)$$

Total biomass in subarea of interest

$$\widehat{B_s} = \left(\frac{\left(\frac{\bar{C}_s}{\bar{a}_s} \right)}{E_s} \right) A_s \quad Var(\widehat{B_s}) = Var(\bar{C}_s) \cdot \left(\frac{A_s}{\bar{a}_s} \right)^2$$

L = # of strata
n = # of stations in stratum h
h = stratum
i = station i in stratum h
s = subarea s in survey of interest
A_s = area of survey of interest in subarea s
E_s = gear efficiency estimate for subarea s
$\bar{a}_s$ = mean area swept per tow in subarea s
$\hat{B}_s$ = total biomass in subarea s
$\bar{C}_s$ = stratified mean biomass caught per tow for subarea s
$\bar{C}_{h,s}$ = mean biomass caught per tow in stratum h for subarea s
W_h = proportion of survey/subarea in stratum h

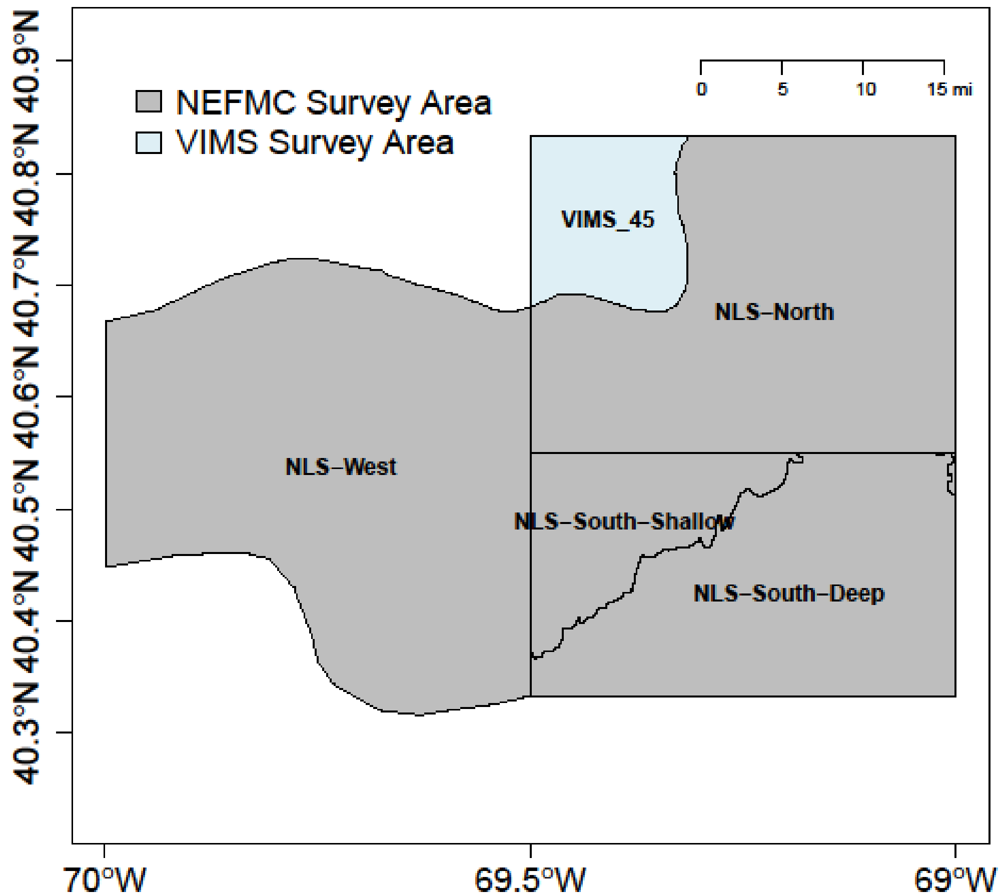
2019 SAMS Areas



MAB Survey

- 9 SAMS Areas
- Only minor changes to some area names
- VIMS surveys outside of areas & biomass in VIMS areas is included in the closest SAMS Area

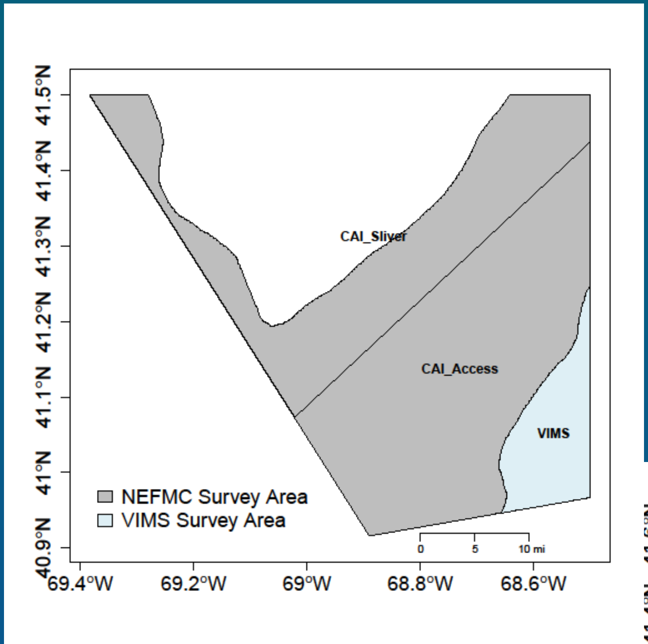
2019 SAMS Areas

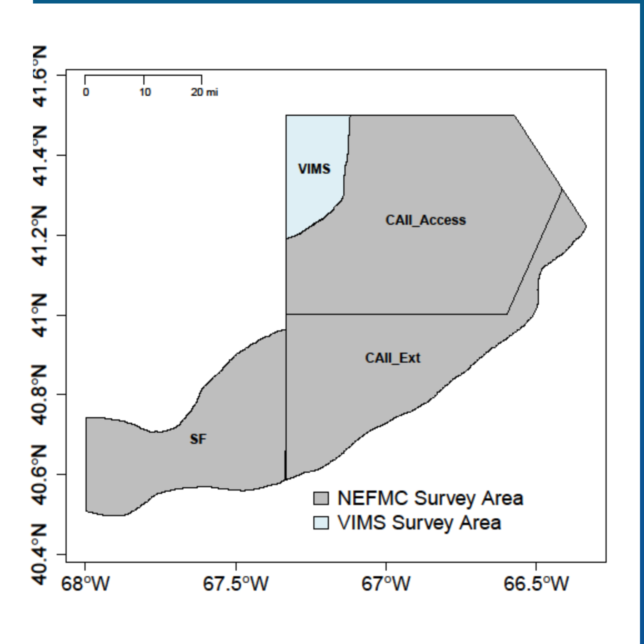


NL Survey

- 4 SAMS Areas
- 2018 Ext SAMS Area included in GSC
- VIMS surveys outside of areas & biomass in VIMS areas is calculated as a separate area

2019 SAMS Areas





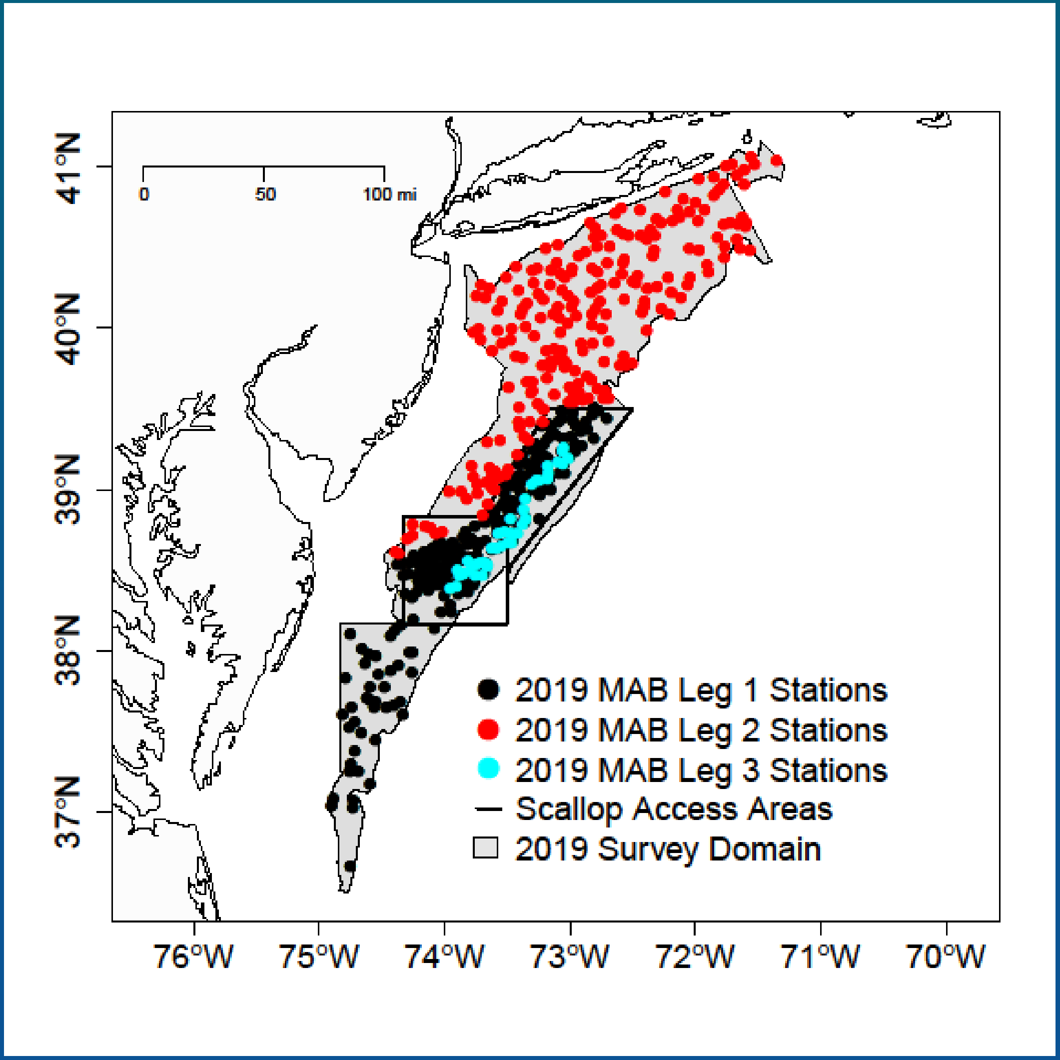
CAI II Survey

- CAI - 2 SAMS Areas
- CAII - 3 SAMS Areas

- Only changes to names

- VIMS surveys outside of areas & biomass in VIMS areas is calculated as separate areas

2019 VIMS-Industry Cooperative Surveys
MAB



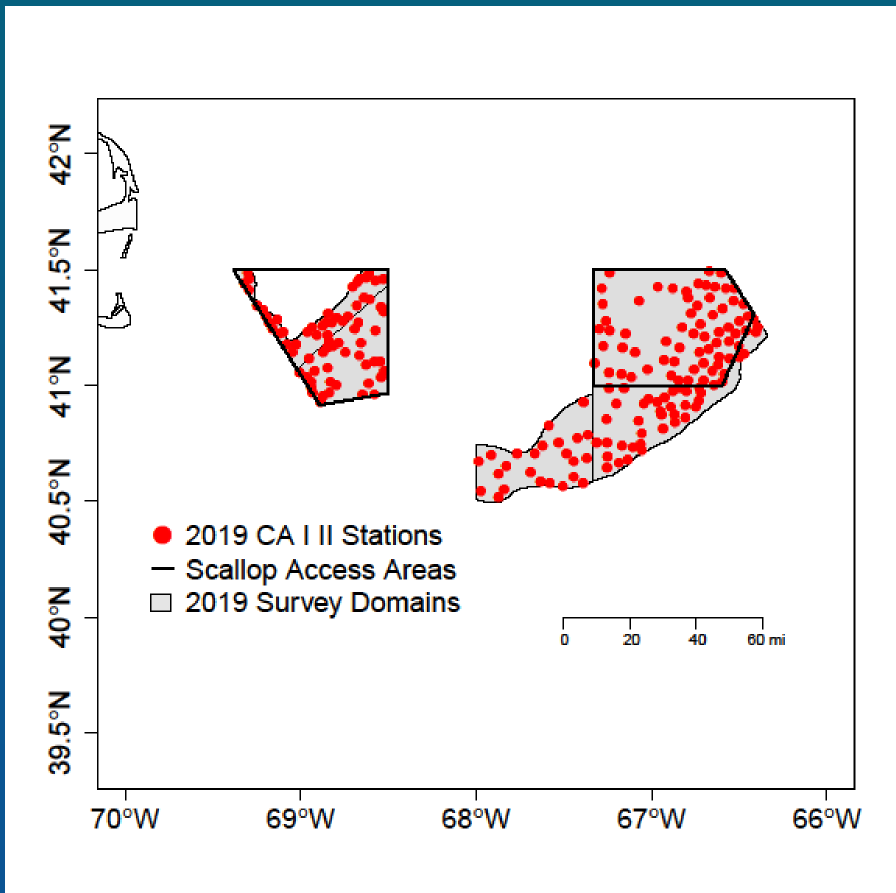
First Leg
- F/V Italian Princess
- 5/10/19 – 5/19/19
- 225 Stations

Second Leg
- F/V Carolina Capes II
- 5/22/19 – 6/2/19
- 225 Stations

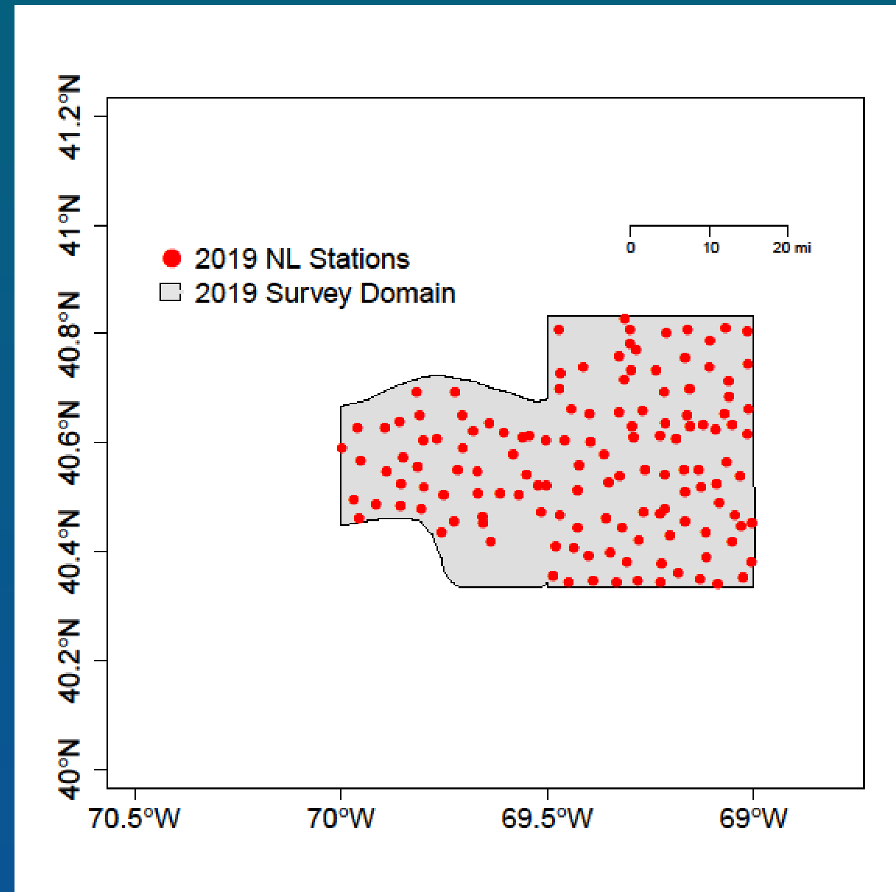
Third Leg
- F/V Anticipation
- 8/12/19 – 8/15/19
- 39 Stations reoccupied from Leg 1

Total
- 450 Stations

2019 VIMS-Industry Cooperative Surveys
CA I II and NL

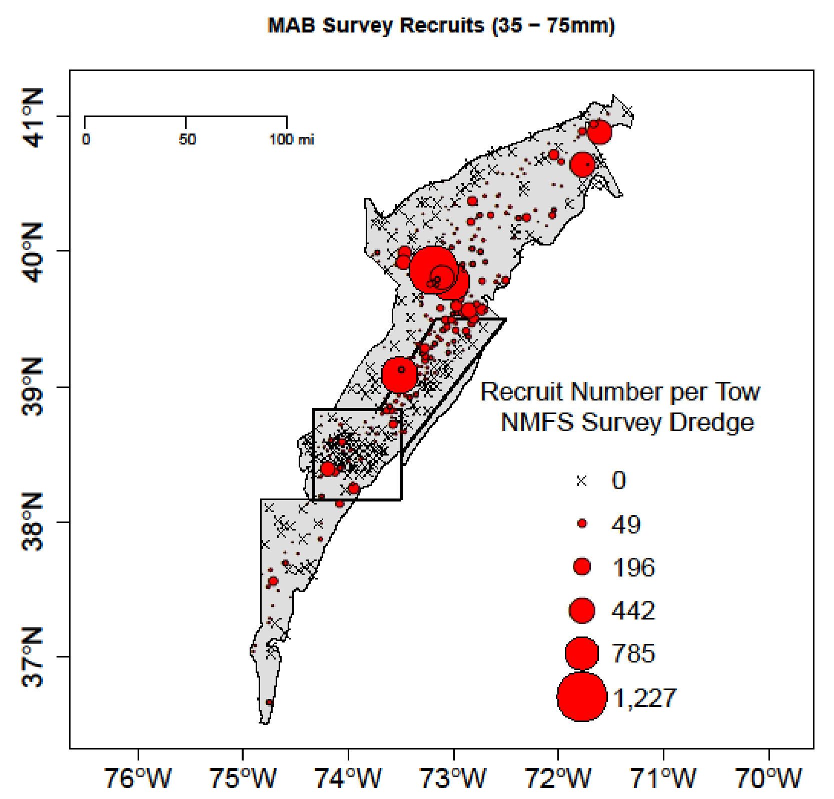


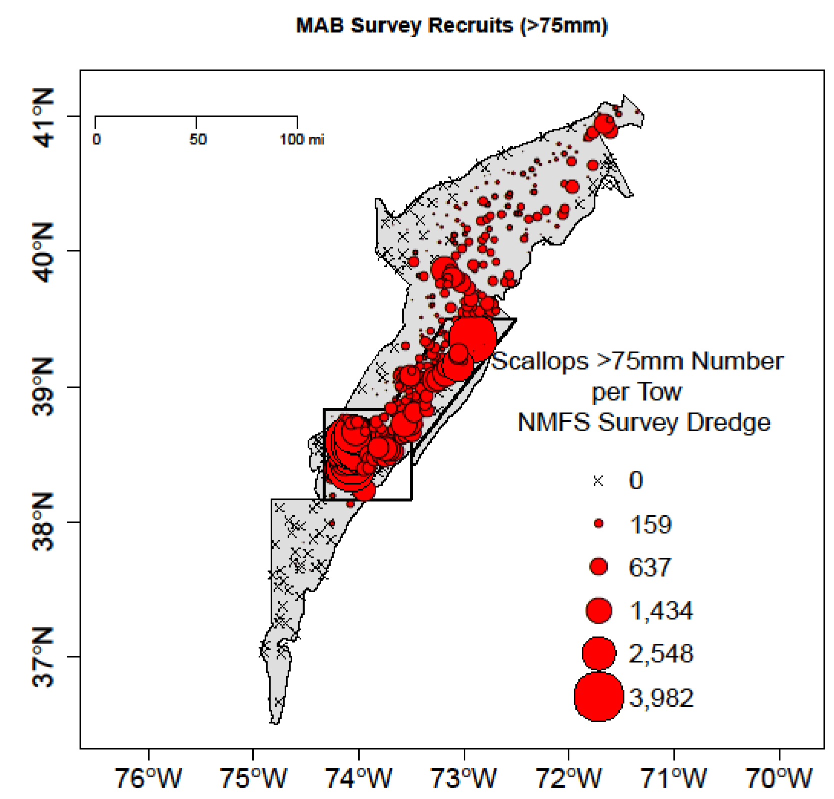
- F/V Polaris
- 6/7/19 - 6/14/19
- 200 Stations



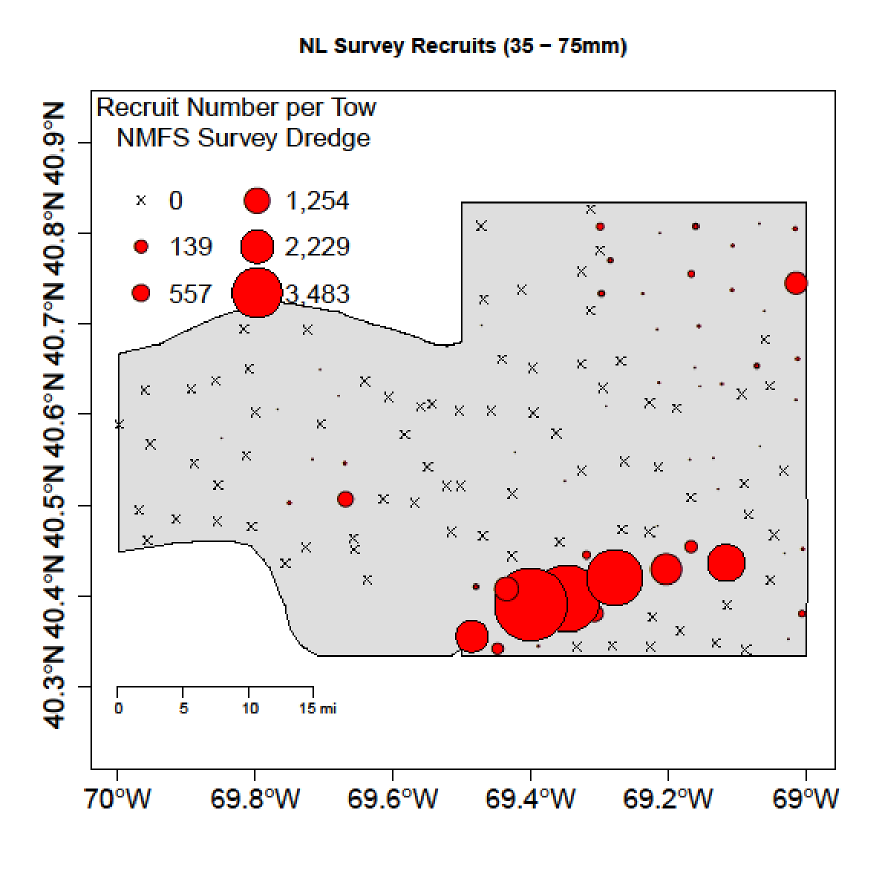
- F/V Socetean
- 7/24/19 - 7/31/19
- 135 Stations

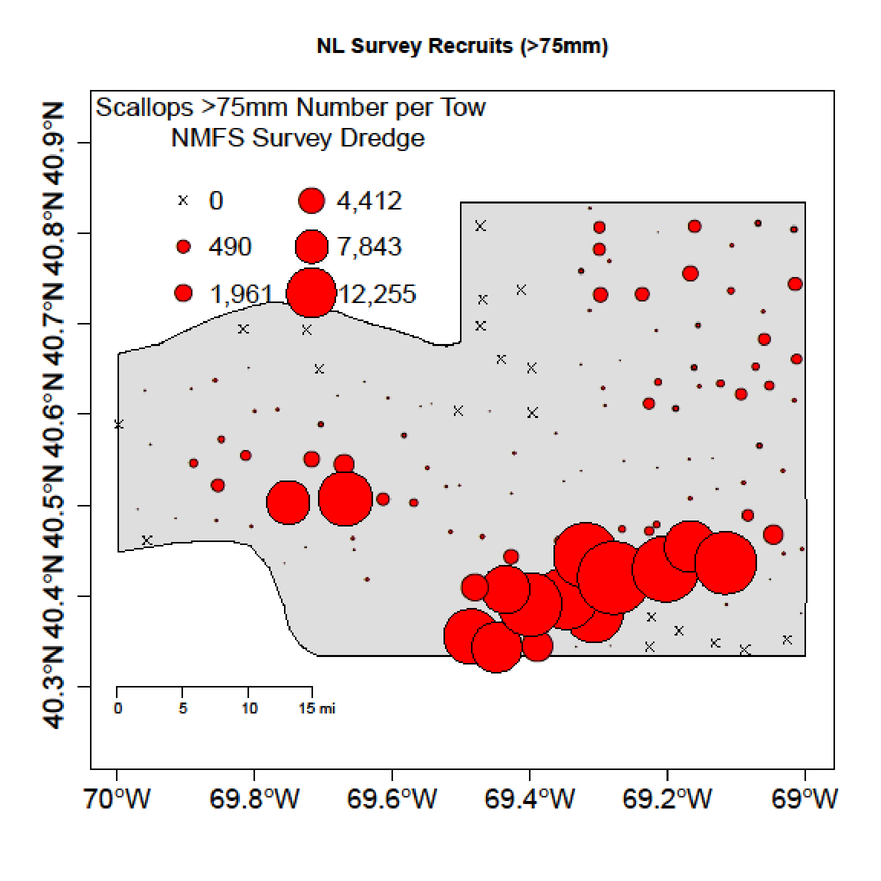
2019 MAB Survey
Scallop Distribution



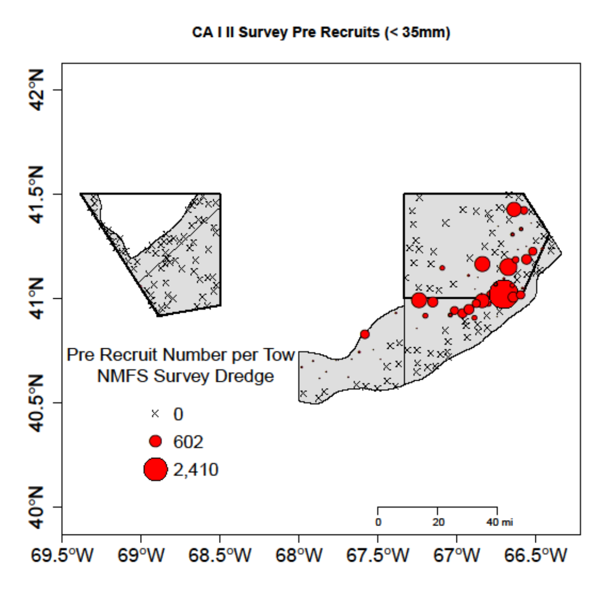


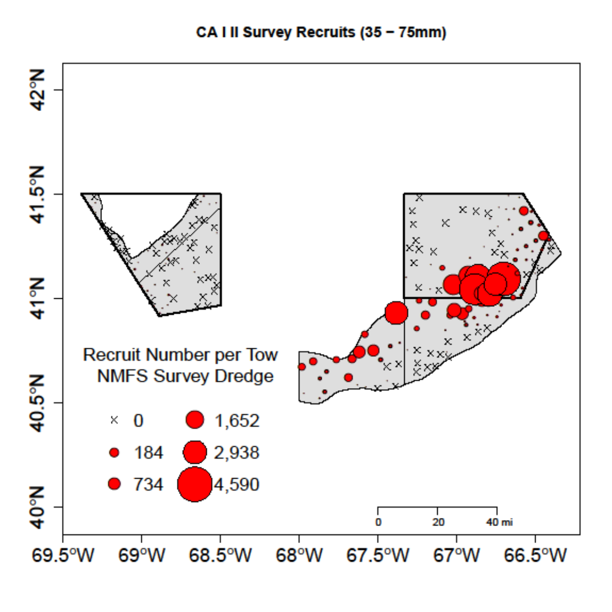
2019 NL Survey
Scallop Distribution

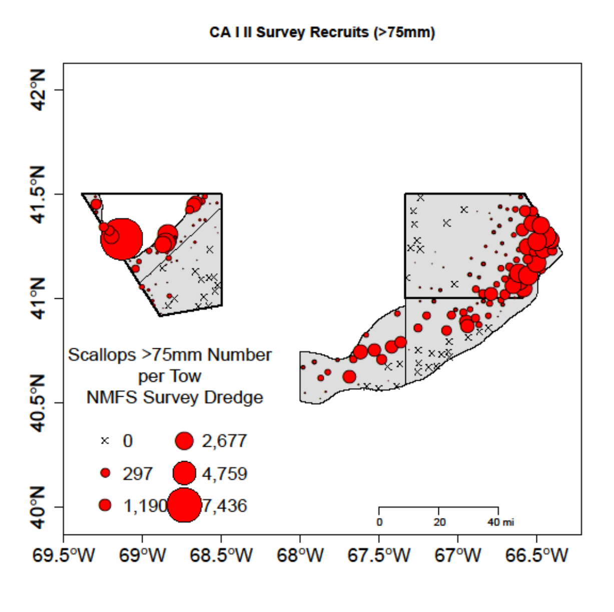




2019 CA I II Survey
Scallop Distribution



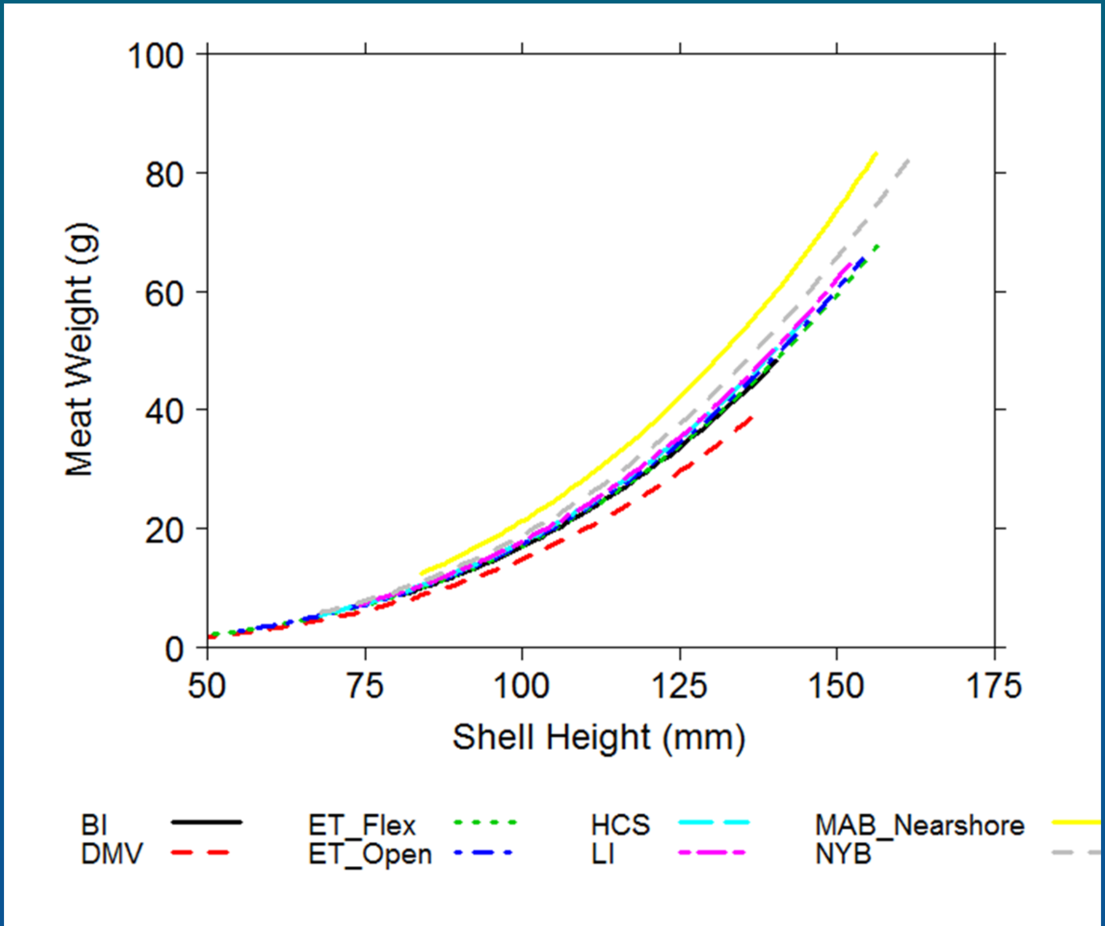




SHMW Relationship

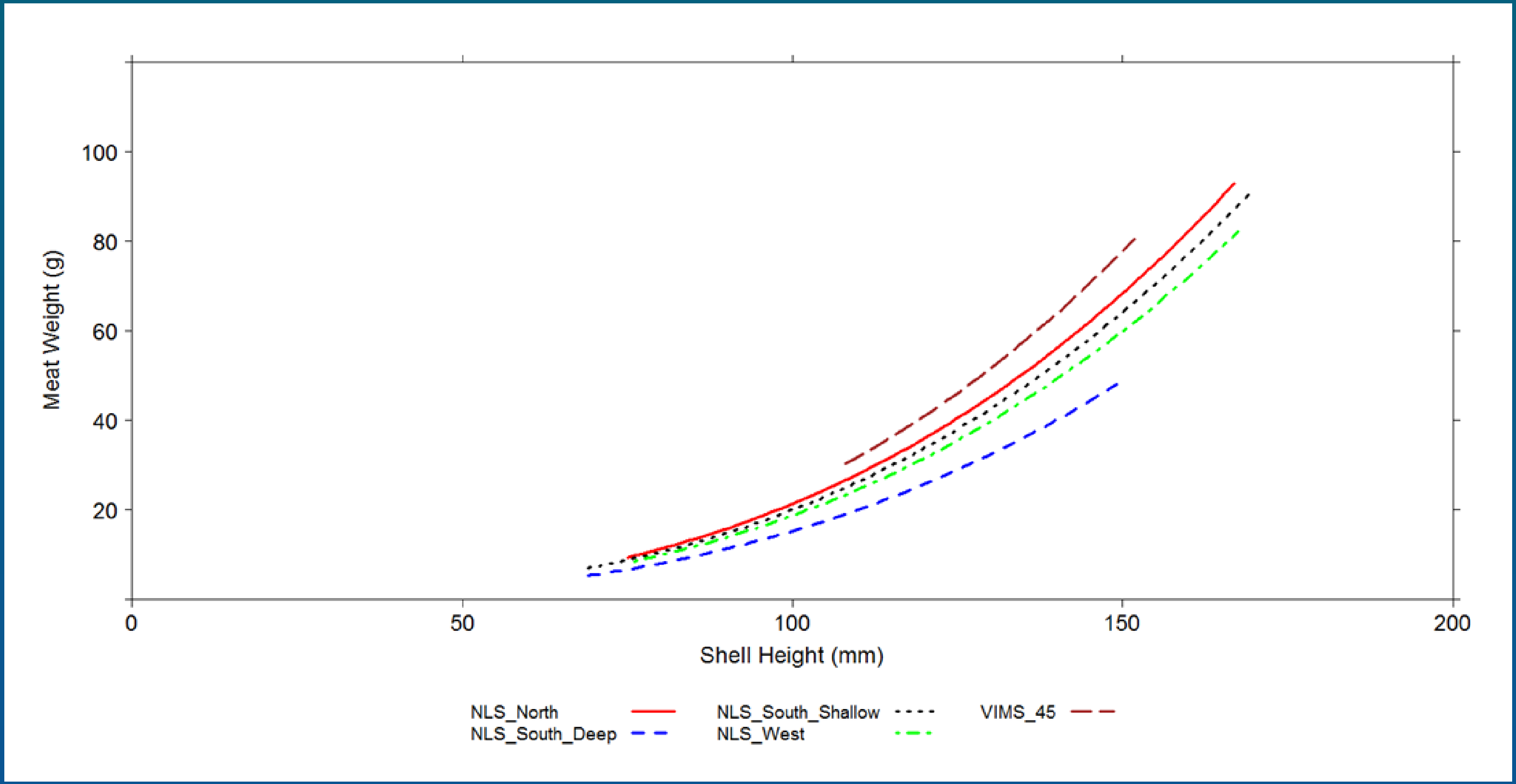
- SHMW samples (meat & gonad weight) were taken from all stations that had scallops (15/station):
  - MAB Survey: 5,510 (377 stations)
  - CA I II Survey: 2,350 (174 stations)
  - NL Survey: 1,989 (124 stations)
- The objective is to construct a model to predict meat weight based on a suite of potential covariates (i.e. shell height, depth, SAMS area, sex, disease…)
- Average depth was calculated for each tow from tilt sensor
- A GLMM was used to fit model (Gamma distribution, log link, random effect at the station level) with R v 3.3.1 Package lme4

2019 MAB Survey
SHMW Results



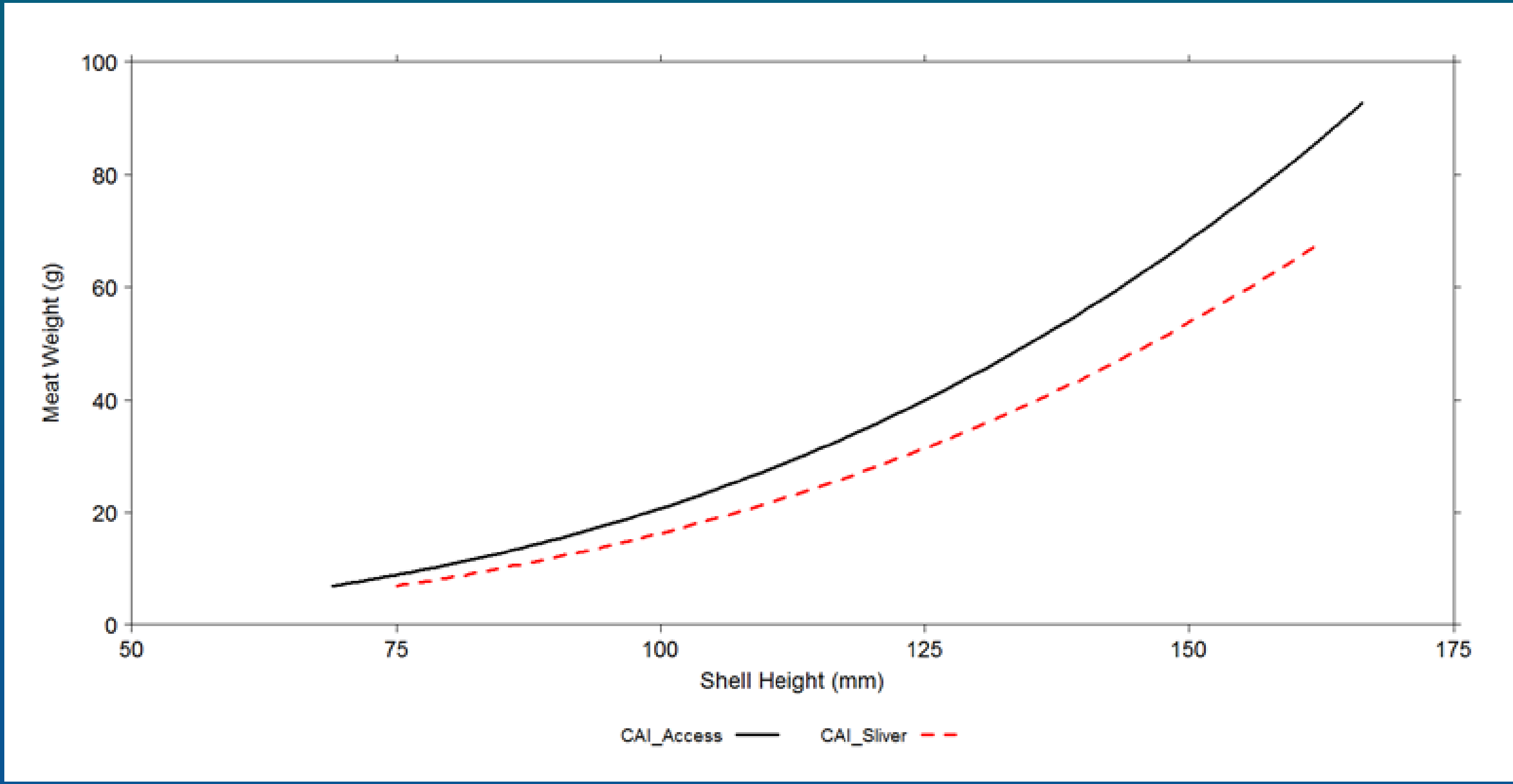
- **Majority of SAMS Areas have similar SHMW relationship**
- **DMV has the smallest meat weight at a given shell height**

2019 NL Survey
SHMW Results



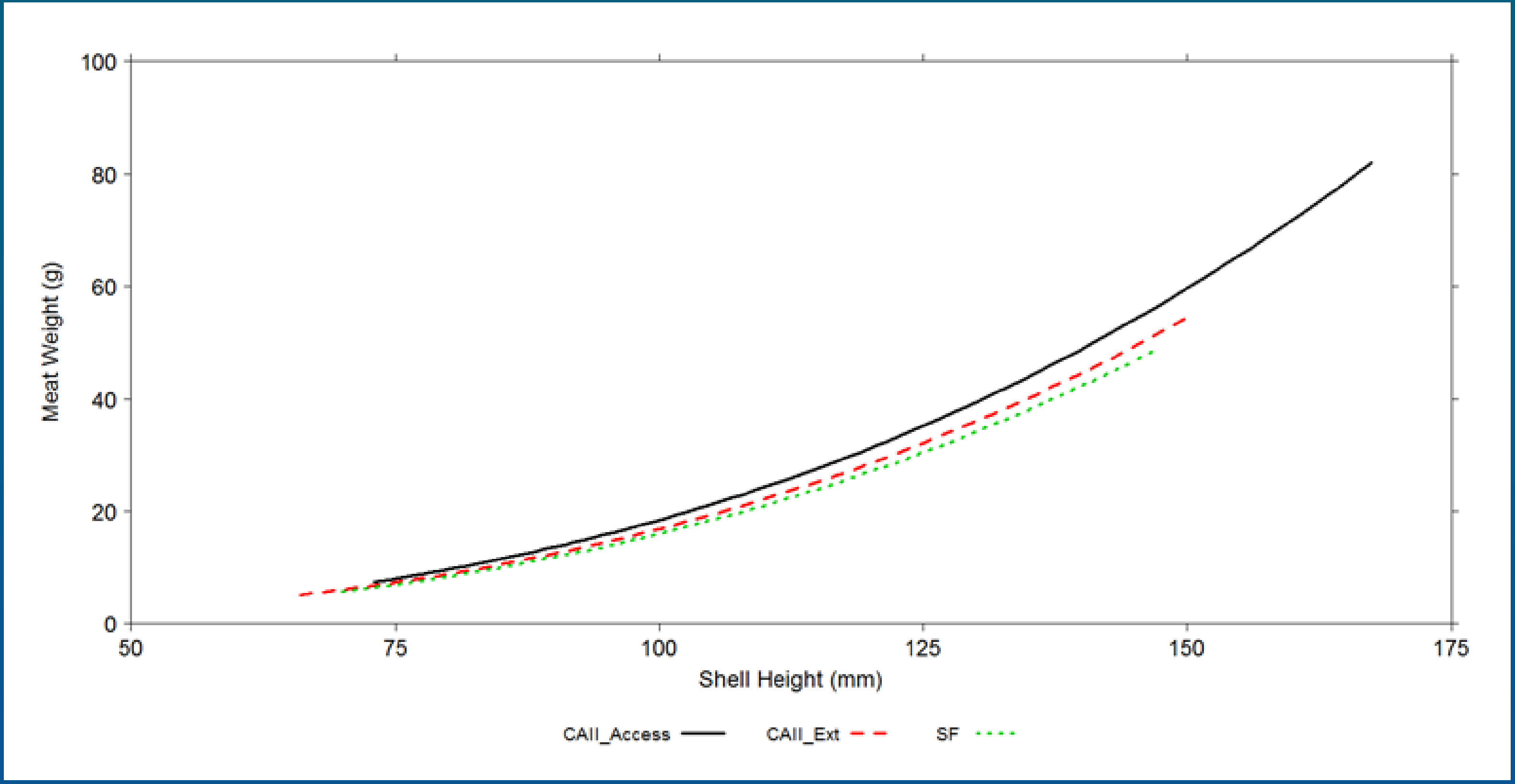
- **Similar trend to previous years for the South Deep SAMS Area having the lowest meat weight at shell height**
- **South Deep SAMS only area significantly different than reference area: NLS-North**

2019 CA I Survey
SHMW Results



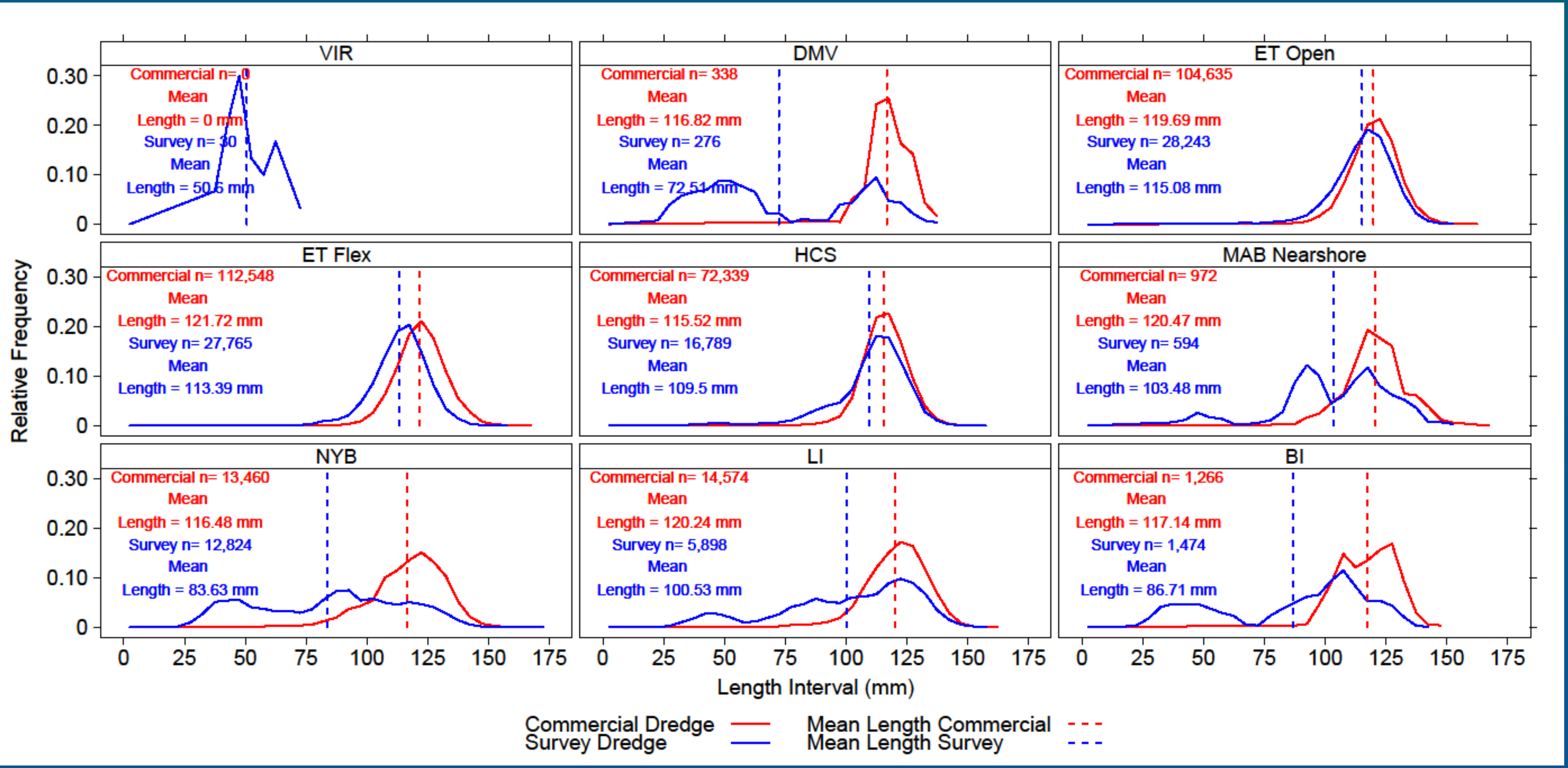
- **CAI Access SAMS Areas significantly different from Sliver SAMS Area**
- **Likely a function of average depths for each subarea, as well as the temporal spread of the sampling**

2019 CAII Survey
SHMW Results

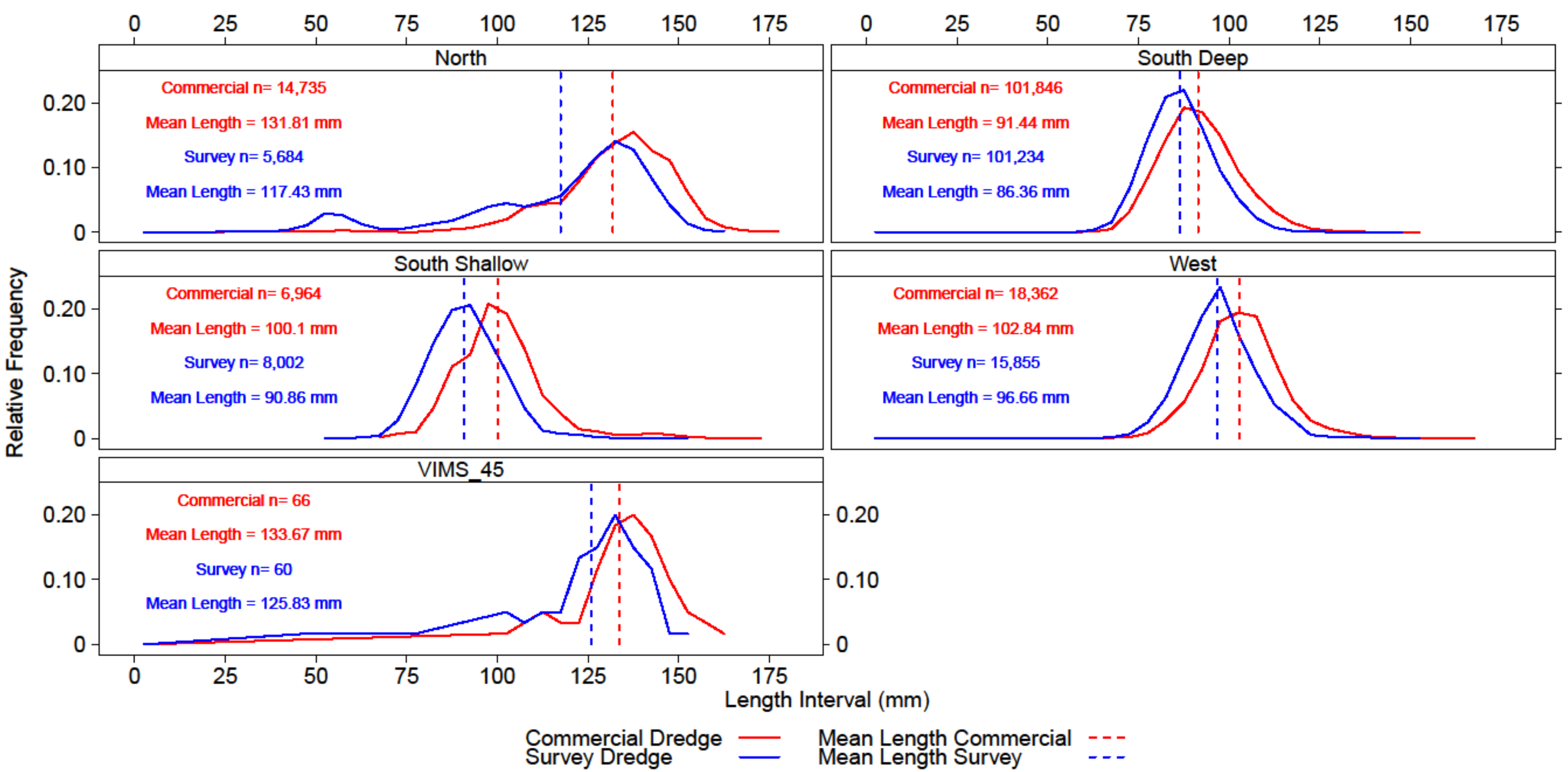


- **Extension and Open Area SF SHMW curves are lower than the Northern Access Area**

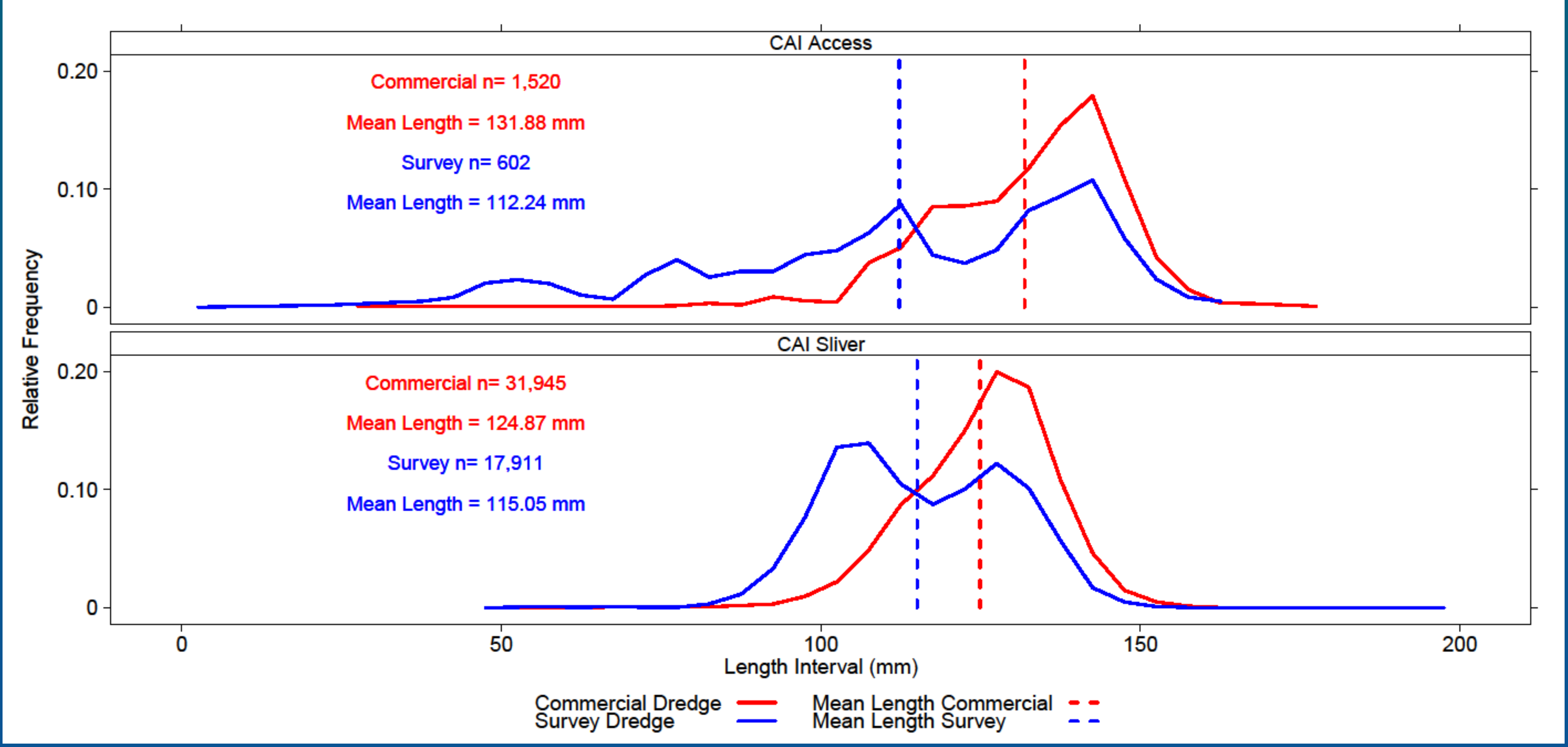
2019 MAB Survey
Length Frequency- SAMS Areas



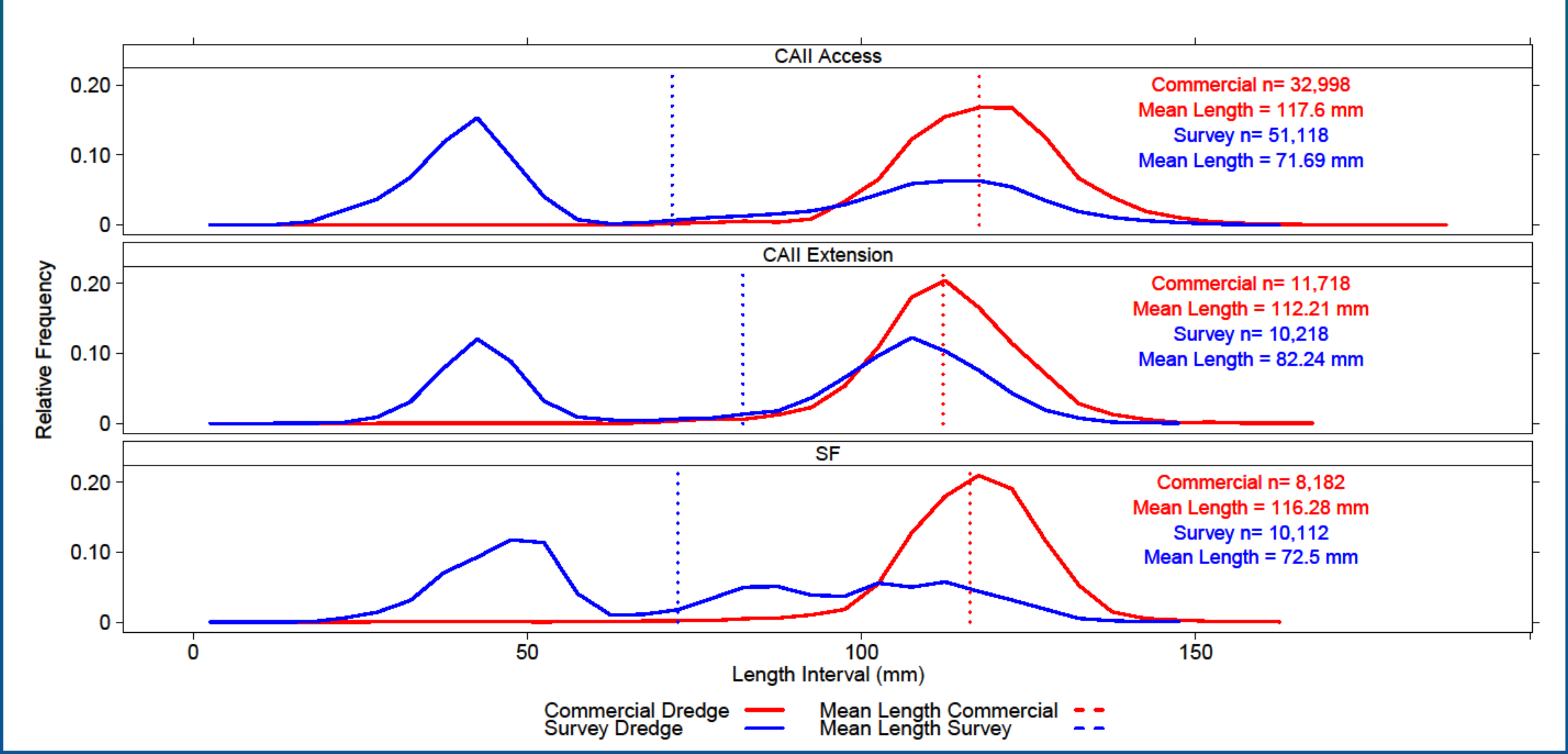
2019 NL Survey
Length Frequency- SAMS Areas



2019 CA I Survey
Length Frequency- SAMS Areas



2019 CA II Survey
Length Frequency- SAMS Areas



2019 CA II Survey

Recruitment

2019 VIMS-Industry Cooperative Surveys
Total Biomass Survey Gear – SAMS Areas

SAMS Area	Total Biomass (mt)	SE Biomass (mt)	CV Biomass (mt)	Density (scal/m^2)	Avg MW (g)	Total Number
VIR	13.76	1.12	20.29	0.00	2.98	4,182,976
DMV	203.02	43.41	53.46	0.01	10.48	20,305,939
ET Open	15,104.89	896.65	14.84	0.30	25.84	592,011,891
ET Flex	13,528.87	1,174.25	21.70	0.44	25.46	523,603,853
HCS	8,544.00	774.62	22.67	0.13	22.63	380,404,883
MAB Nearshore	1,264.53	180.52	35.69	0.02	23.67	53,427,827
NYB	7,424.97	522.70	17.60	0.12	14.84	537,825,315
LI	9,079.02	349.85	9.63	0.03	22.44	407,307,126
BI	1,514.65	254.05	41.93	0.11	17.33	94,885,840
NLS North	3,368.23	209.81	15.57	0.08	41.26	81,516,050
NLS South Deep	11,897.84	1,181.65	24.83	1.62	10.11	1,176,063,622
NLS South Shallow	1,721.07	425.60	61.82	0.40	14.64	117,563,486
NLS West	3,276.12	663.54	50.63	0.20	16.68	195,268,579
VIMS 45	82.57	29.51	89.33	0.01	49.51	1,667,620
CAI Access	693.40	83.55	30.12	0.02	35.57	18,434,122
CAI Sliver	7,856.85	911.86	29.01	0.32	29.54	258,991,330
CAII Access	20,689.43	1,129.01	13.64	0.56	15.49	1,670,993,750
CAII Ext	5,567.79	565.55	25.39	0.17	17.49	312,054,690
SF	6,437.53	646.95	25.12	0.29	12.15	529,788,692

2019 VIMS-Industry Cooperative Surveys

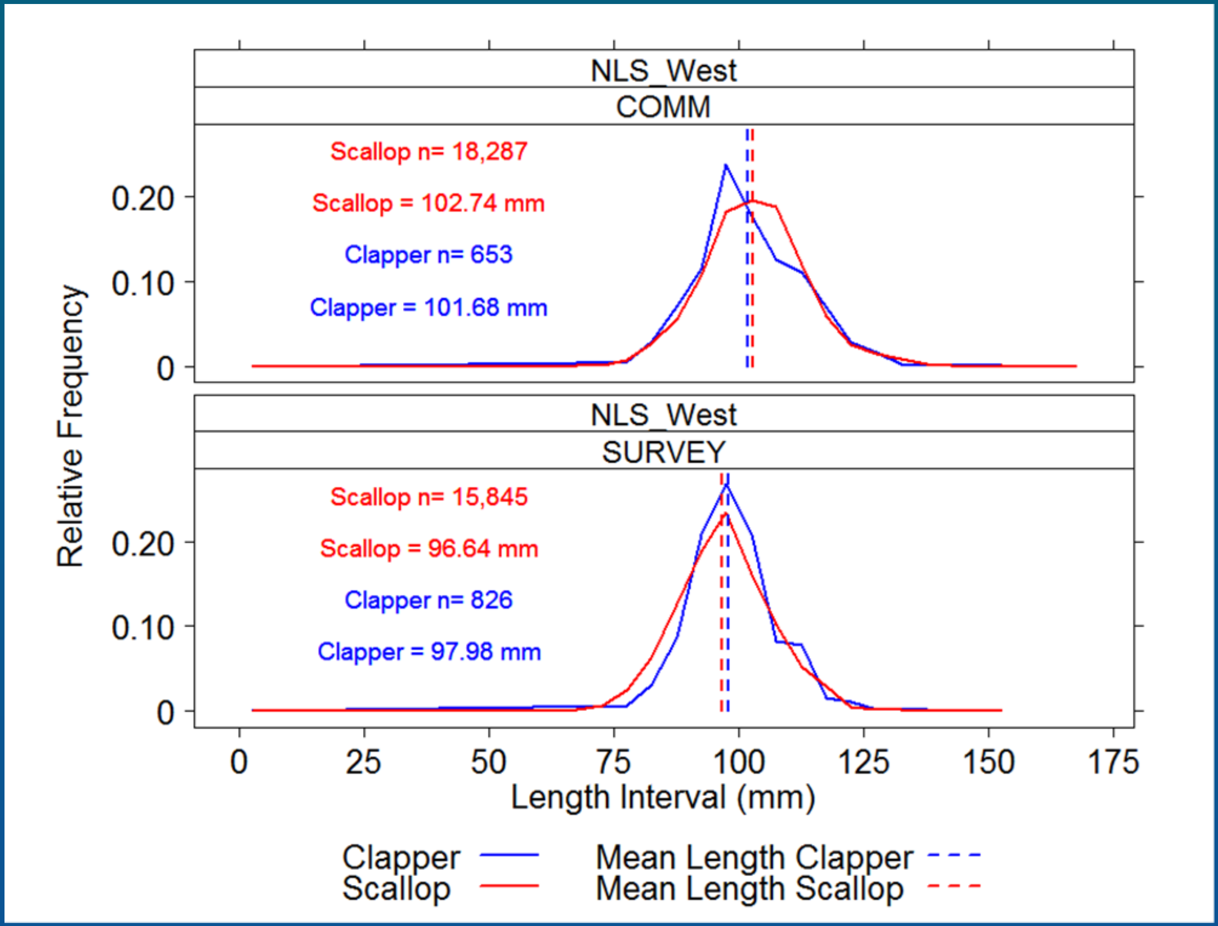
Exploitable Biomass Commercial Gear - SAMS Areas

SAMS Area	Exp Biomass (mt)	SE Biomass (mt)	CV Biomass (mt)	Density (scal/m^2)	Avg MW (g)	Exp Number
VIR	0.00	0.00	0.00	0.00	0.00	0.00
DMV	173.98	66.99	59.24	0.00	26.38	6,574,359.16
ET Open	18,883.50	1,437.89	11.71	0.37	29.10	639,647,357.29
ET Flex	18,691.29	2,682.01	22.08	0.54	31.25	601,828,611.86
HCS	10,986.92	1,122.82	15.72	0.16	25.79	428,387,241.60
MAB Nearshore	861.19	192.73	34.43	0.01	34.06	25,293,944.23
NYB	3,880.14	264.69	10.49	0.03	31.02	127,356,560.41
LI	9,437.00	546.96	8.92	0.02	33.50	282,714,230.41
BI	705.68	128.19	27.95	0.03	32.26	21,781,182.10
NLS North	4,118.83	339.75	12.69	0.07	54.68	75,192,779
NLS South Deep	2,200.75	396.60	27.73	0.21	14.63	150,332,552
NLS South Shallow	448.49	115.78	39.72	0.07	23.26	19,279,540
NLS West	1,080.04	308.25	43.91	0.05	22.19	47,986,968
VIMS_45	37.93	21.70	88.02	0.00	58.85	644,404
CAI Access	957.27	135.98	21.85	0.01	51.91	18,194,175
CAI Sliver	6,438.48	1,076.98	25.73	0.20	39.34	162,369,294
CAII Access	9,690.29	817.91	12.99	0.11	38.06	244,325,929
CAII Ext	3,258.13	486.51	22.97	0.05	32.06	100,845,369
SF	4,193.63	704.08	25.83	0.07	32.86	127,630,804

SARC 65 Total Biomass Estimates Compared to VIMS 2016-19 Estimates NL

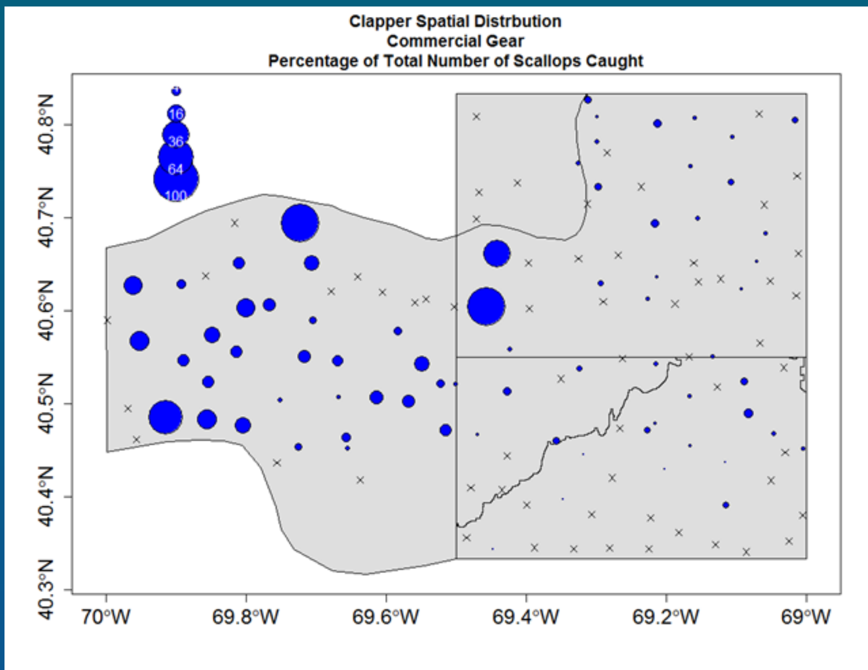
SAMS Area	Total Biomass (mt)- SARC 65	Total Biomass (mt) VIMS 2016-19
NLS North	3,613.91	3,368.23
NLS South Deep	11,955.05	11,987.84
NLS South Shallow	2,402.17	1,721.06
NLS West	4,732.83	3,276.12
VIMS 45	90.47	82.58

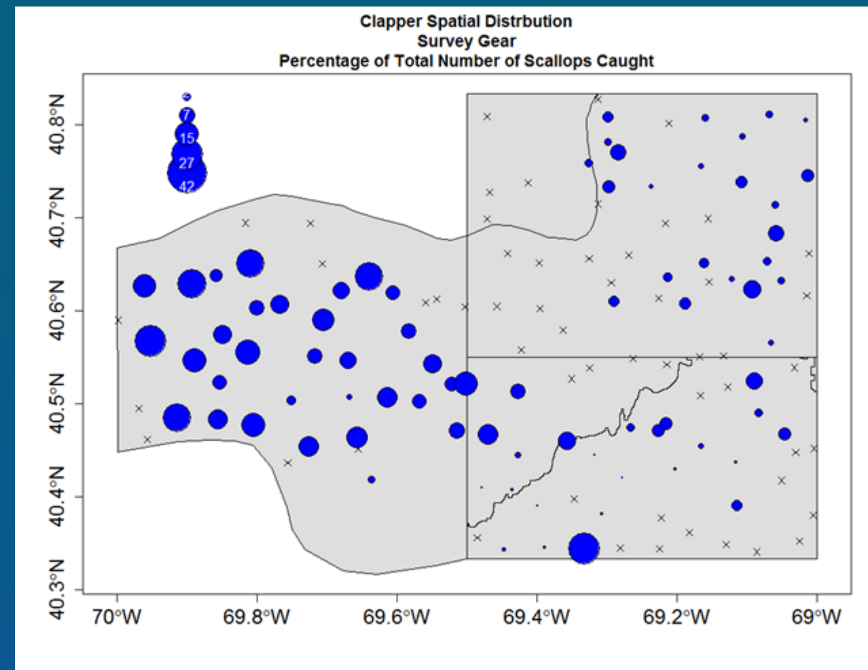
NLS West Clappers



- Observed large quantities of clappers in the NLS-West SAMS Area
- Maybe an indication of higher than expected discard and/or incidental mortality.
- This information may provide insight into potential fishery behavior in the South Deep SAMS Area in the future, due to the size range of scallops in this SAMS Area.

NLS West Clappers





- The percentage of clappers in the catch was greatest in the NLS-West SAMS Area for both gears
- Percentage of clappers in both dredges ranged from 1 to 26%.

Acknowledgements

- The owners, captains and crews:
  - *F/V Carolina Capes II*
  - *F/V Italian Princess*
  - *F/V Polaris*
  - *F/V Socetean*
- Scientific Staff:
  - Lee Rollins, Kelly Lewis, Victoria Thomas, and Sarah Borsetti
- Reidar's Manufacturing Inc.
- Support from NMFS NEFSC: Dvora Hart and Pete Chase.
- Funding through Sea Scallop RSA program.

Appendix B

An Assessment of Sea Scallop Abundance and Distribution in the Mid-Atlantic Bight, Nantucket Lightship, Great South Channel, Closed Area I and Closed Area II

Sally Roman

David B. Rudders

Russell Nicholson

Kaitlyn Clark

Virginia Institute of Marine Science

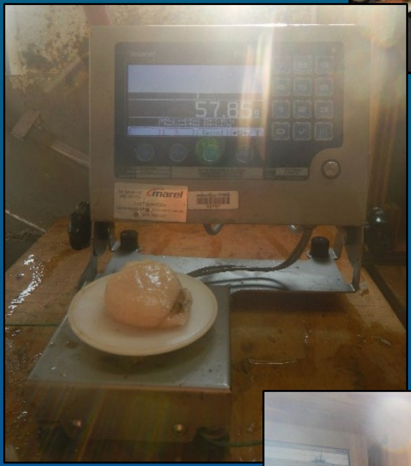
Sea Scallop Plan Development Team

Zoom Meeting

October 15, 2020

Preliminary – PDT use only.

2020 VIMS-Industry Cooperative Surveys



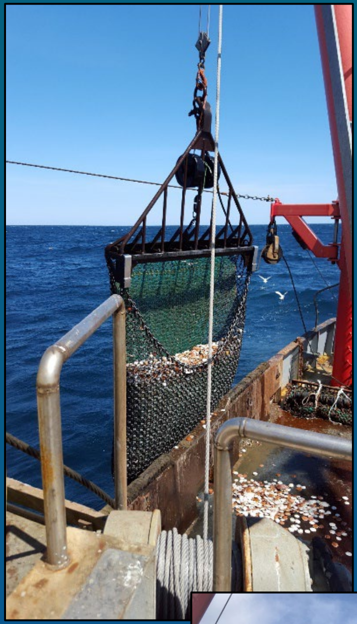
Primary Objectives

- Assess the abundance & distribution of scallops in survey domains by SAMS Areas
- Estimate total & exploitable biomass

Secondary Objectives

- Gear performance
  - Selectivity of commercial gear
- Scallop Biology & Product Quality
  - Assess marketability, growth, disease & SHMW
- Finfish Bycatch
- Scallop Predators

2020 VIMS-Industry Cooperative Surveys



- Sampling design
  - Stratified random design
    - NMFS shellfish strata
    - SAMS Areas included in survey domains
  - Station Allocation
    - Hybrid approach – stratum area & prior year catch data (biomass & number)
- Tow a survey dredge & commercial dredge simultaneously
  - Survey dredge – 8 ft in width, 2 in rings & 1.5 in diamond mesh liner
  - Rock Chains in strata 49-52 in GSC
  - Commercial dredge – varies by vessel and area
  - Survey dredge performance monitored

Biomass Estimation

- **Biomass calculated using swept area method (Cochran, 1997)**
- **Area swept per tow (a_s)**
  - **Navigational info**
  - **Tilt sensor**
- **Catch weight per tow (C_h)**
  - **Expanded length frequencies ≥ 40 mm**
  - **SHMW relationships from SARC 65 or determined by PDT**
  - **Selectivity (Roman and Rudders, 2019)**
- **Efficiency (E_s)**
  - **Values from Miller et al. (2018) for survey dredge:**
    - **.40 in soft bottom**
    - **.13 NLS South Deep**
    - **.27 in Strata 49-52 in GSC**
  - **Commercial Dredge = .65**

Stratified mean biomass per tow in stratum and SAMS Area

$$\bar{C}_{h,s} = \frac{1}{n_h}\sum_{i=1}^{h} C_{i,h,s}$$

$$Var\left(\bar{C}_{h,s}\right) = \frac{1}{n_h(n_h-1)}\sum_{i=1}^{n_h}\left(C_{i,h,s} - \bar{C}_{h,s}\right)^2$$

Stratified mean biomass per tow in SAMS Area

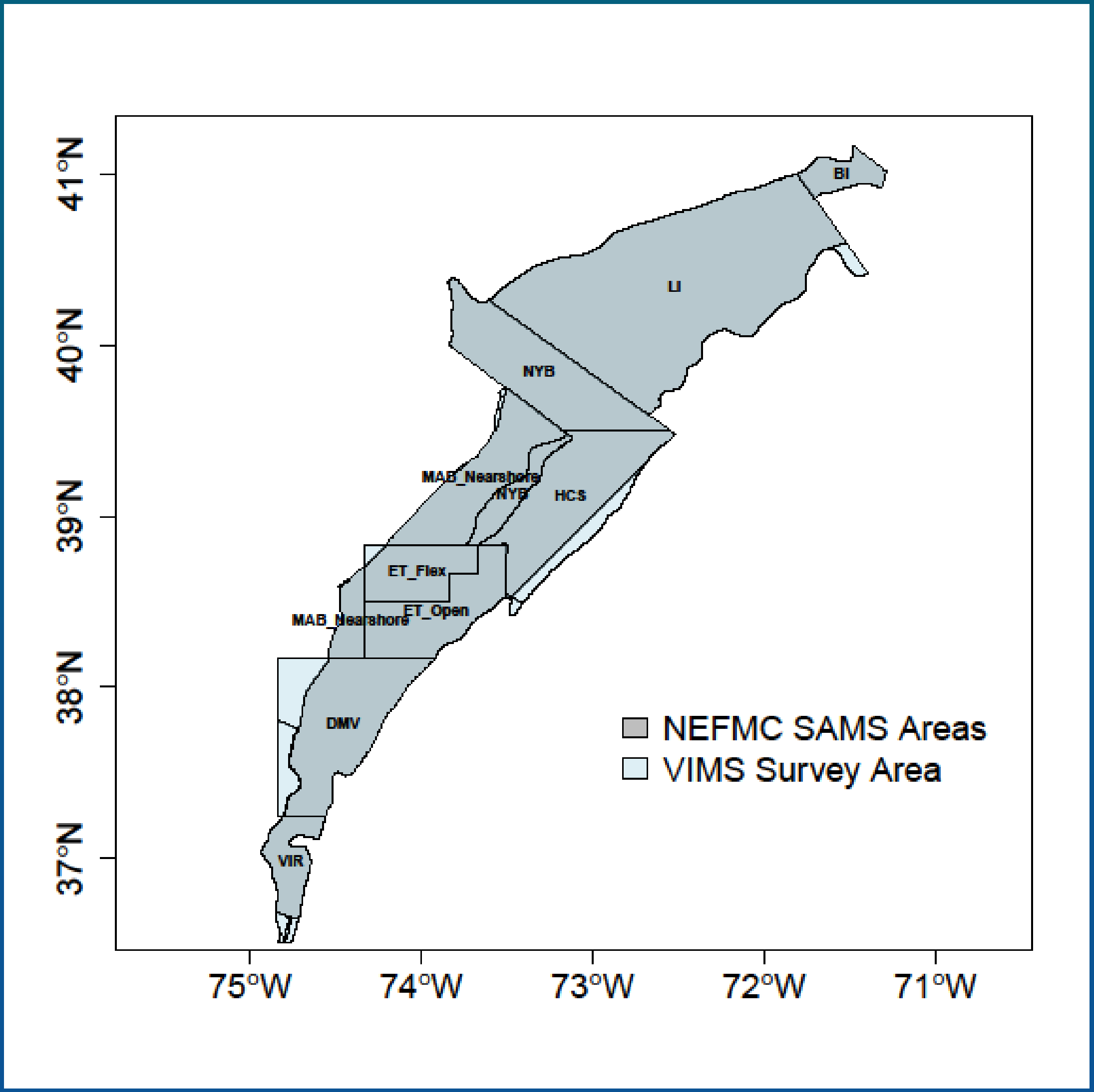
$$\bar{C}_s = \sum_{h=1}^{L} W_h \cdot \bar{C}_{h,s}$$

$$Var(\bar{C}_s) = \sum_{h=1}^{L} W_h^2 \cdot Var(\bar{C}_h)$$

Total biomass in SAMS Area

$$\widehat{B_s} = \left(\frac{\left(\frac{\bar{C}_s}{\bar{a}_s}\right)}{E_s}\right) A_s \qquad Var\left(\widehat{B_s}\right) = Var(\bar{C}_s) \cdot \left(\frac{A_s}{\bar{a}_s}\right)^2$$

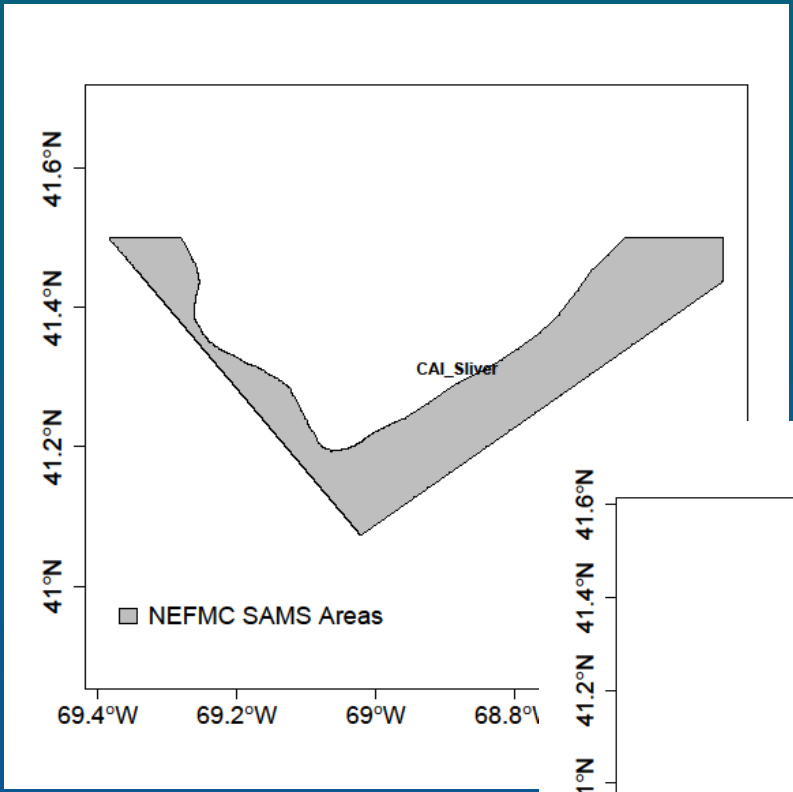
2020 SAMS Areas

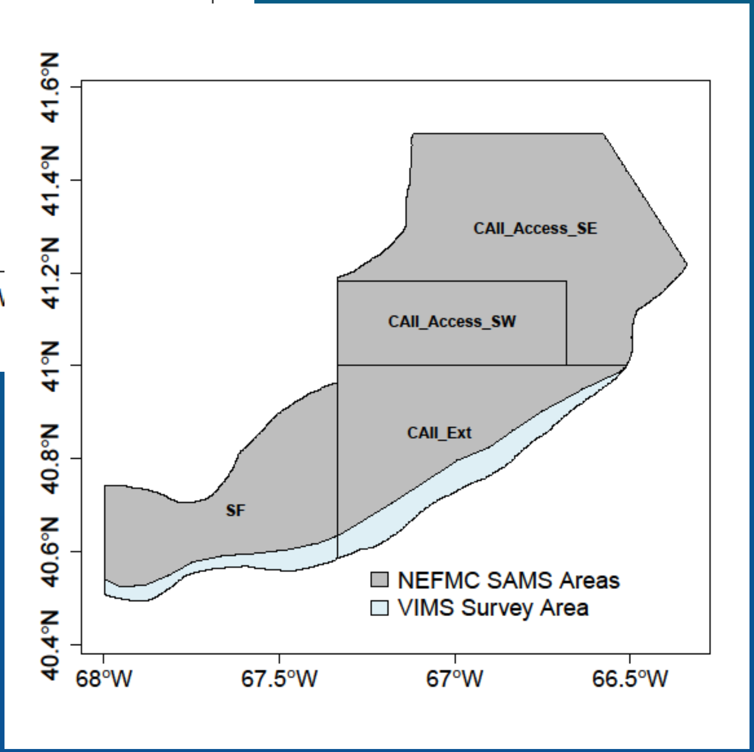


MAB Survey

- 9 SAMS Areas
- Survey outside of SAMS Areas
- Stations are included in the closest SAMS Area

2020 SAMS Areas

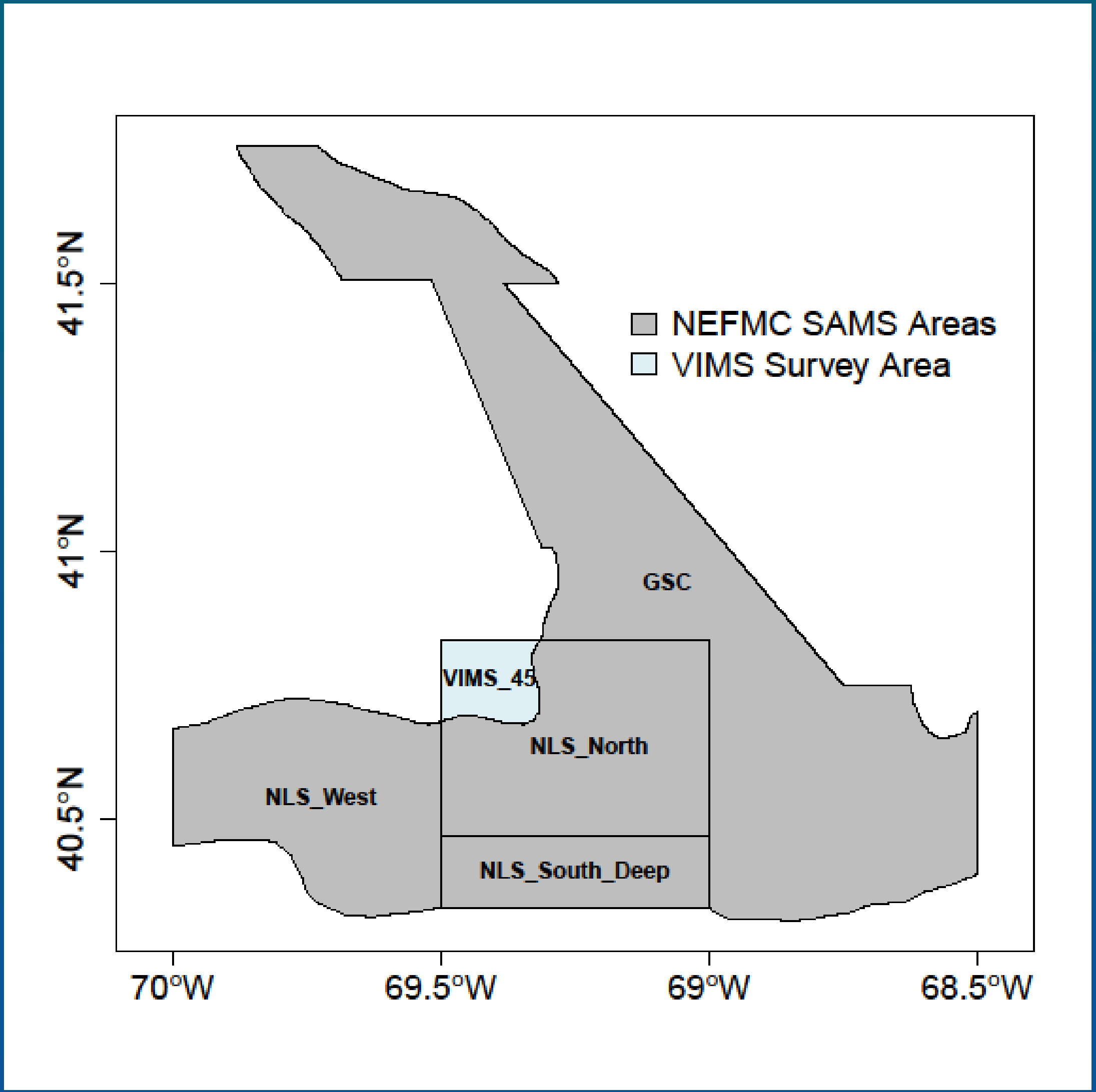




<u>CAI & CAII Survey</u>

- **CAI - 1 SAMS Areas**
- **CAII - 4 SAMS Areas**
- **CAII Access Area split into 2 SAMS Areas this year**
- **Survey outside of SAMS Areas**
- **Stations are included in the closest SAMS Area**

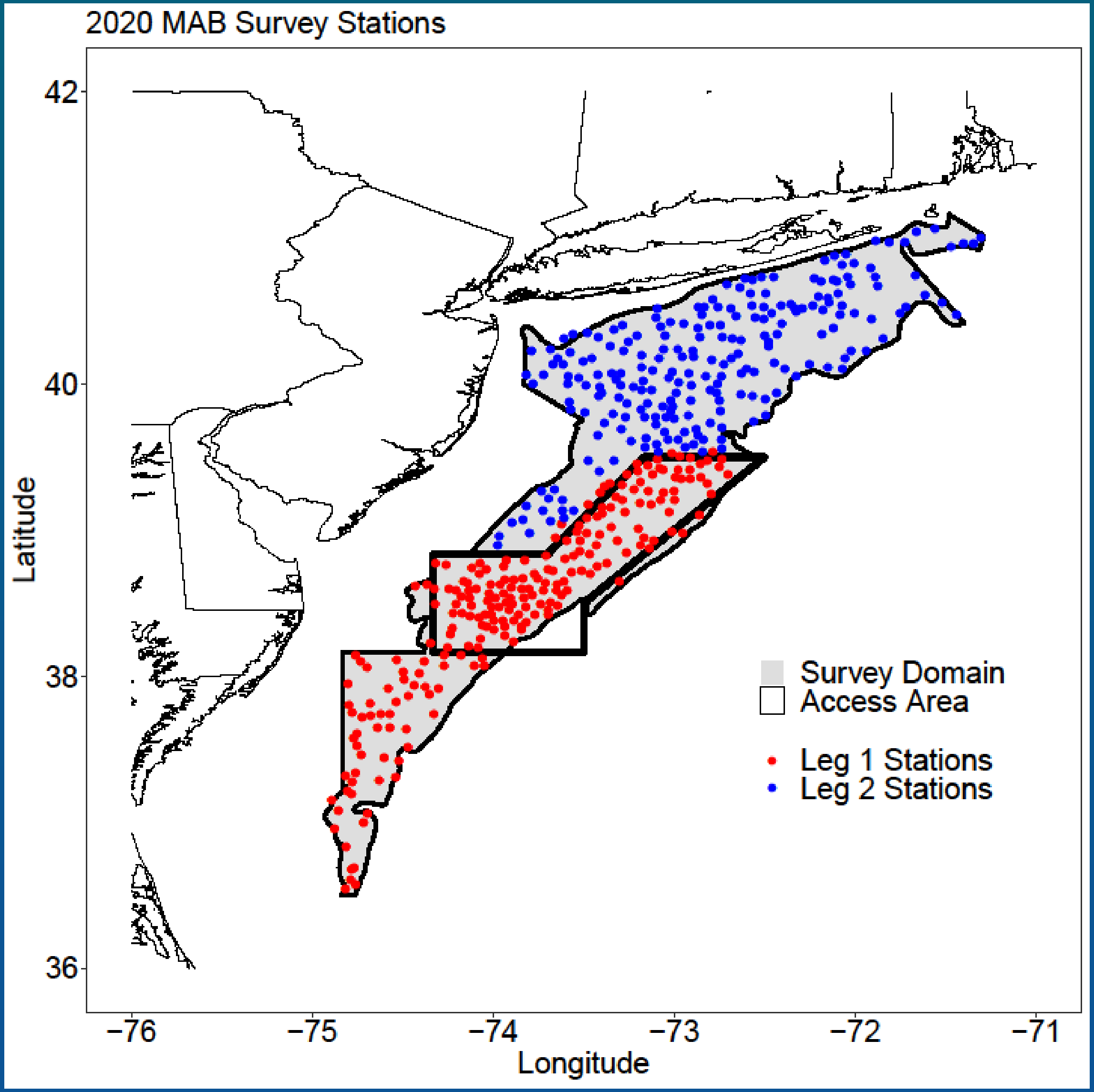
2020 SAMS Areas



NL & GSC Survey

- 4 SAMS Areas
- Survey outside of SAMS Areas
- Separate "SAMS Area" biomass estimated for VIMS_45

2020 MAB Survey

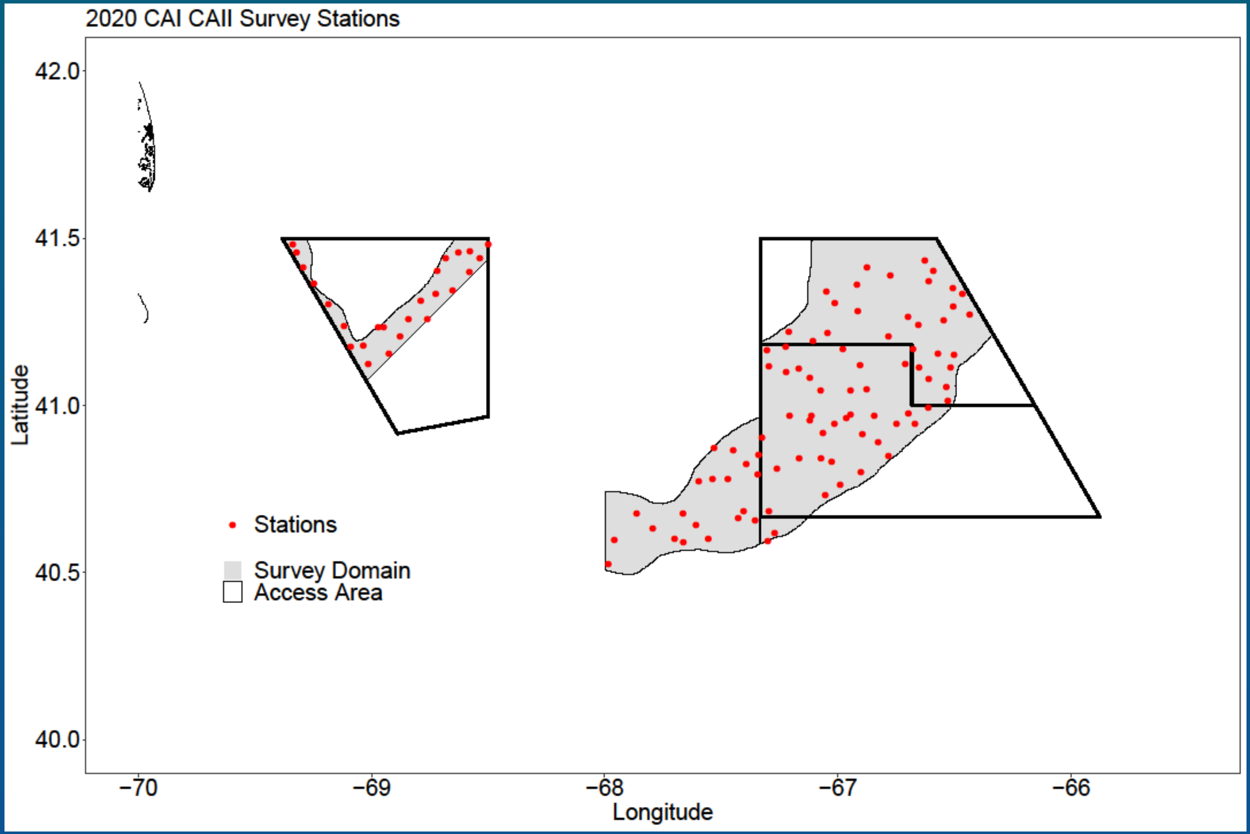


First Leg
- F/V Carolina Capes II
  - 7/10 – 7/20/2020

Second Leg
- F/V Italian Princess
  - 7/30 – 8/11/2020

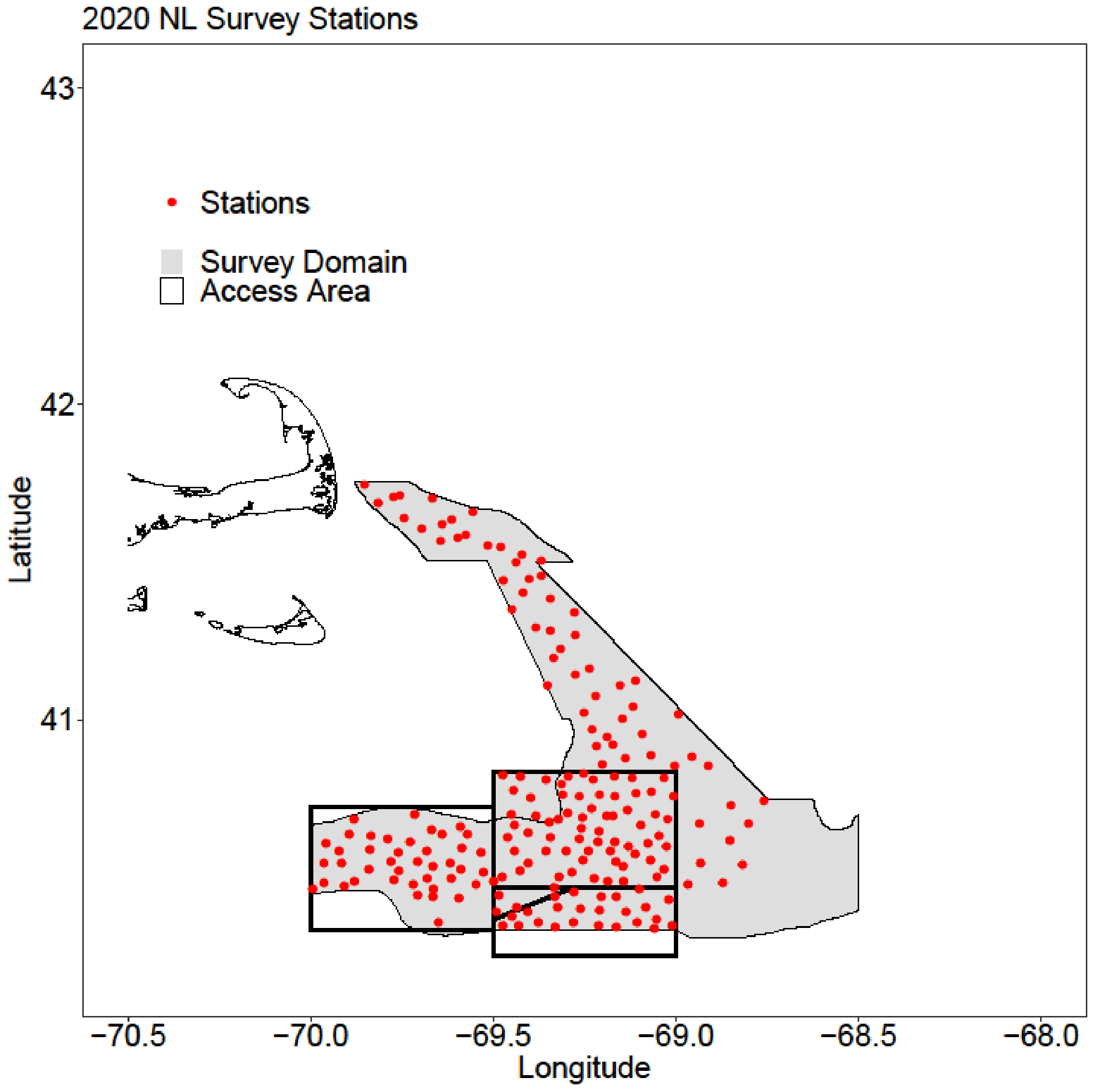
- Completed 450 Stations

2020 CAI & CAII Survey



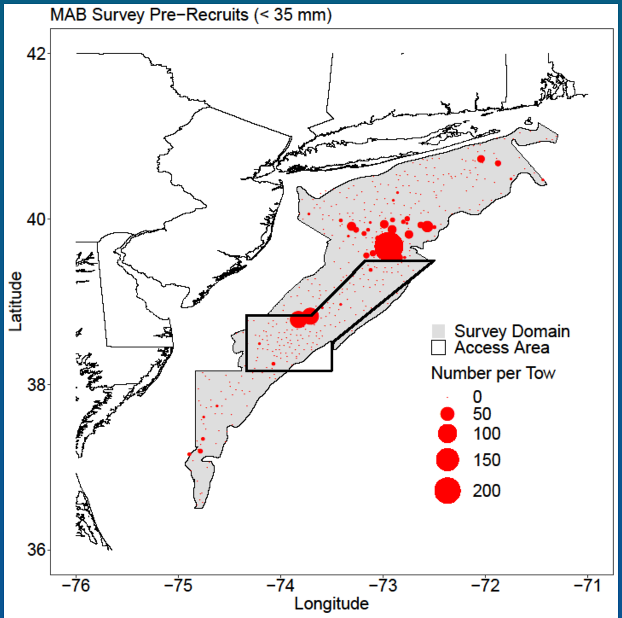
- F/V Pyxis
- 8/24 – 8/31/2020
- 125 Stations planned
- Completed 111 stations
- Dropped 14 stations in the northern portion of the CAII Access SE SAMS Area due to lobster gear

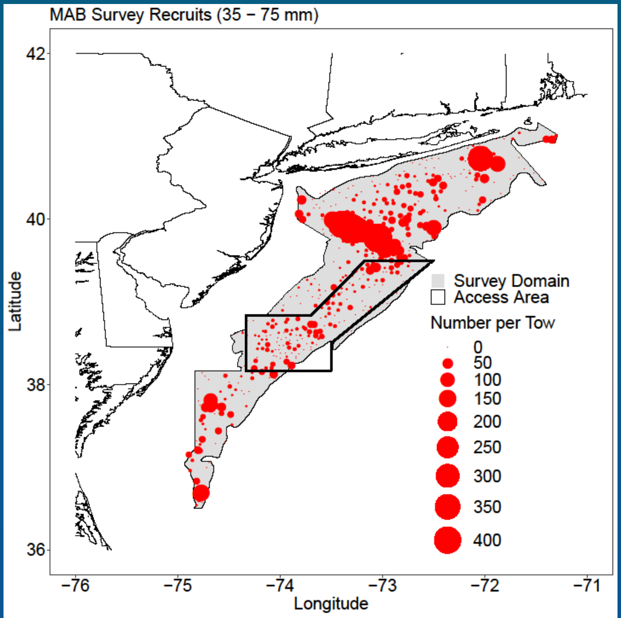
2020 NL & GSC Survey

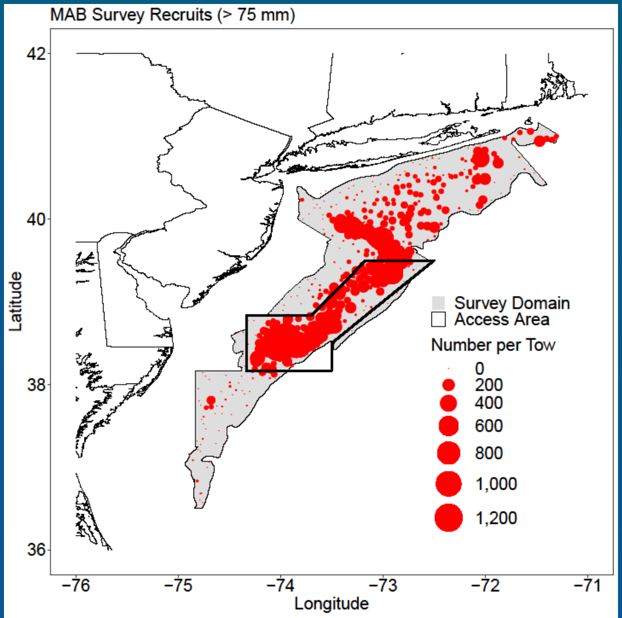


- F/V Celtic
- 9/1 – 9/8/2020
- Completed 195 stations with the survey dredge
- 119 stations completed with commercial dredge – excludes majority of GSC & northern portion of the North SAMS Area

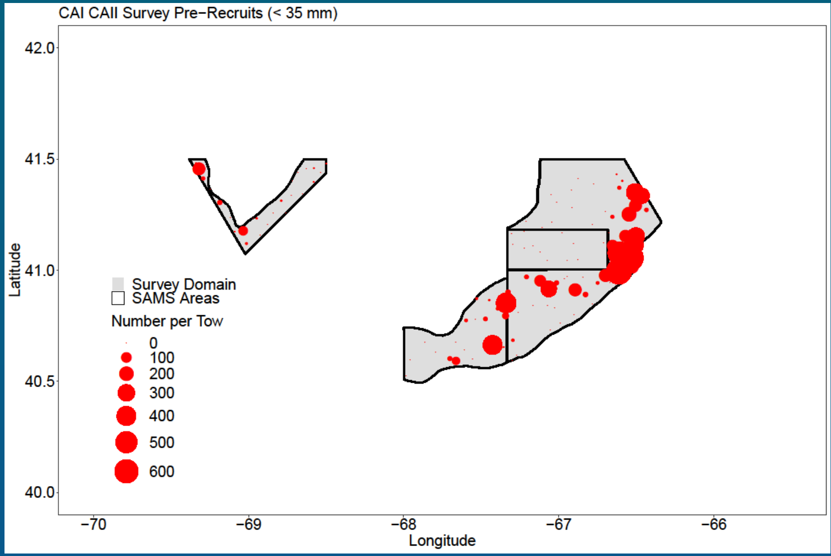
2020 MAB Survey
Scallop Distribution – Number per Tow

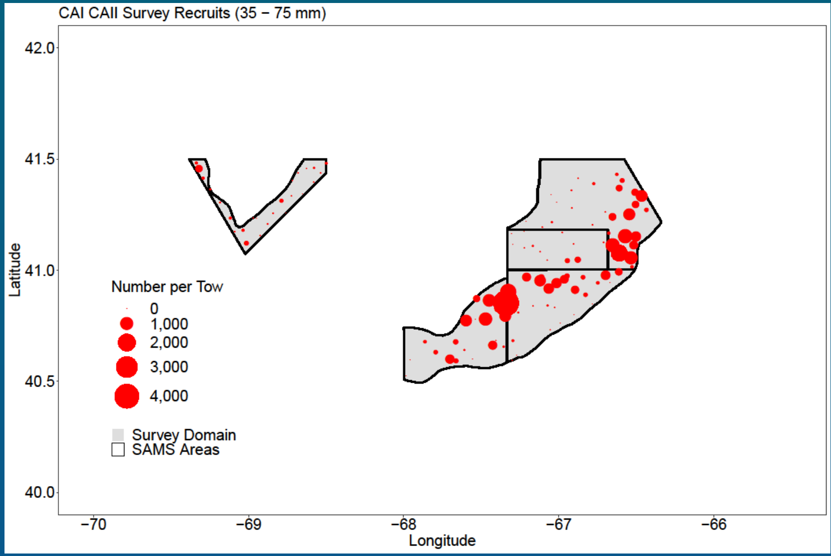


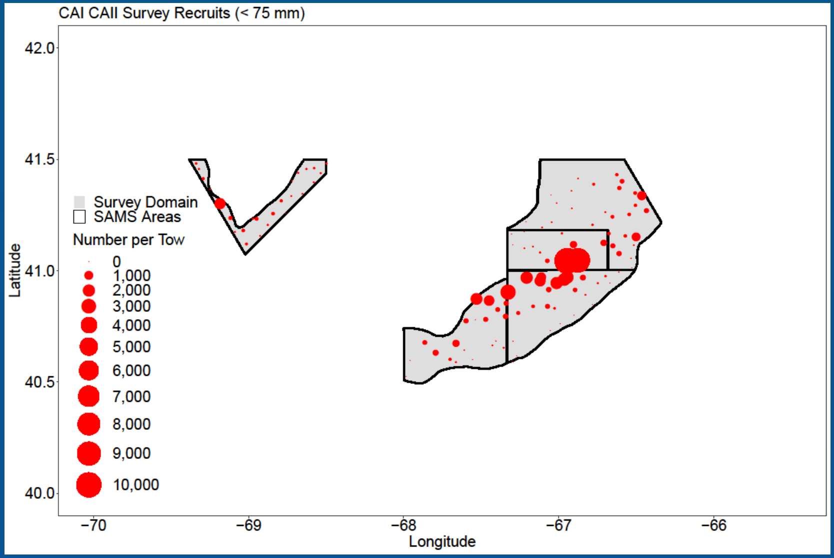




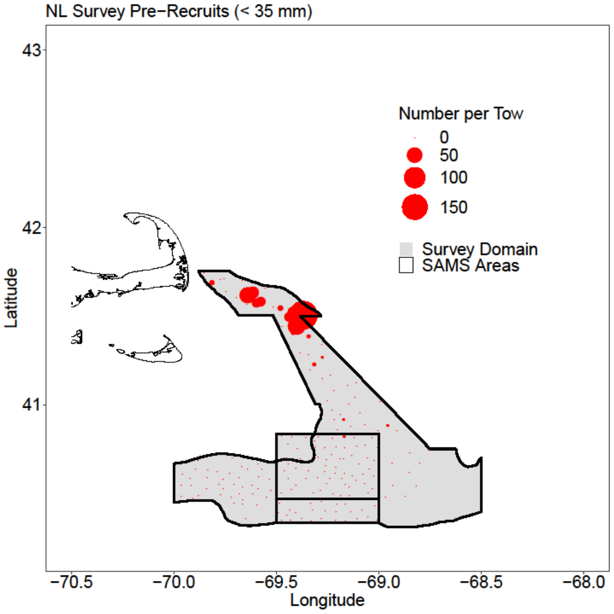
2020 CA I & CAII Survey
Scallop Distribution – Number per Tow

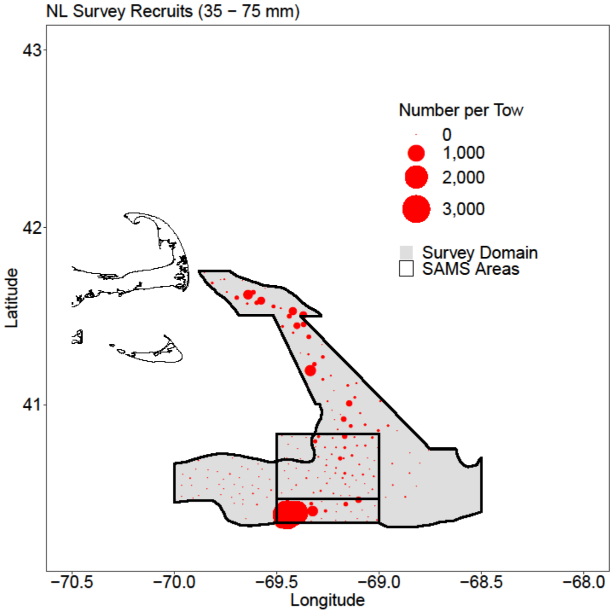


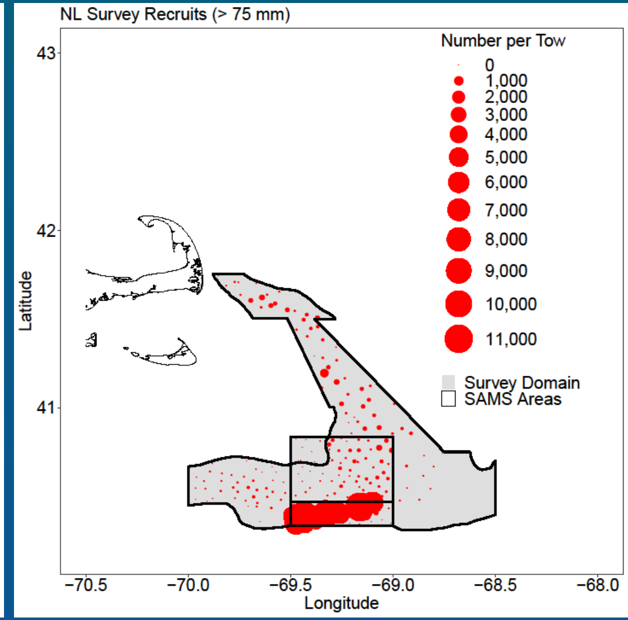




2020 NL & GSC Survey
Scallop Distribution – Number per Tow





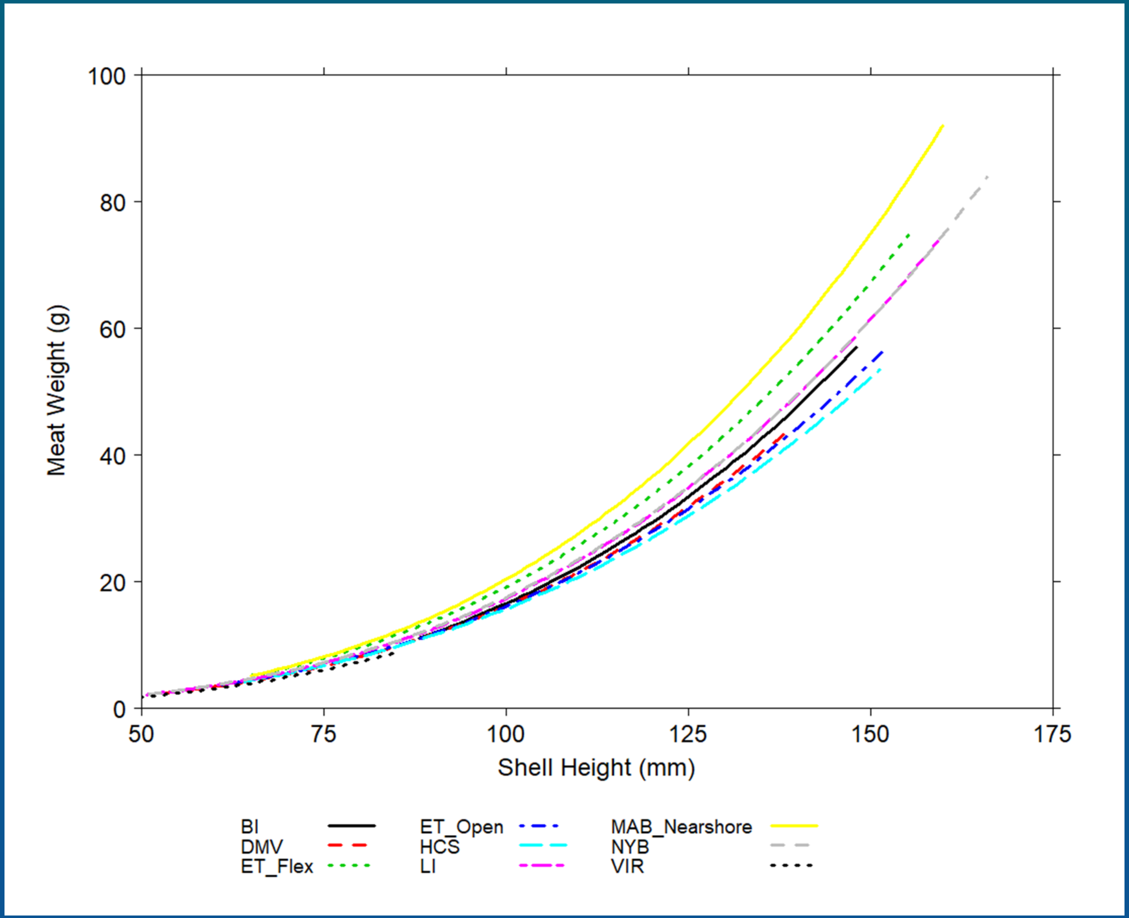


Number per tow shown calculated with reduced q = .13 for South Deep SAMS Area

SHMW Relationship

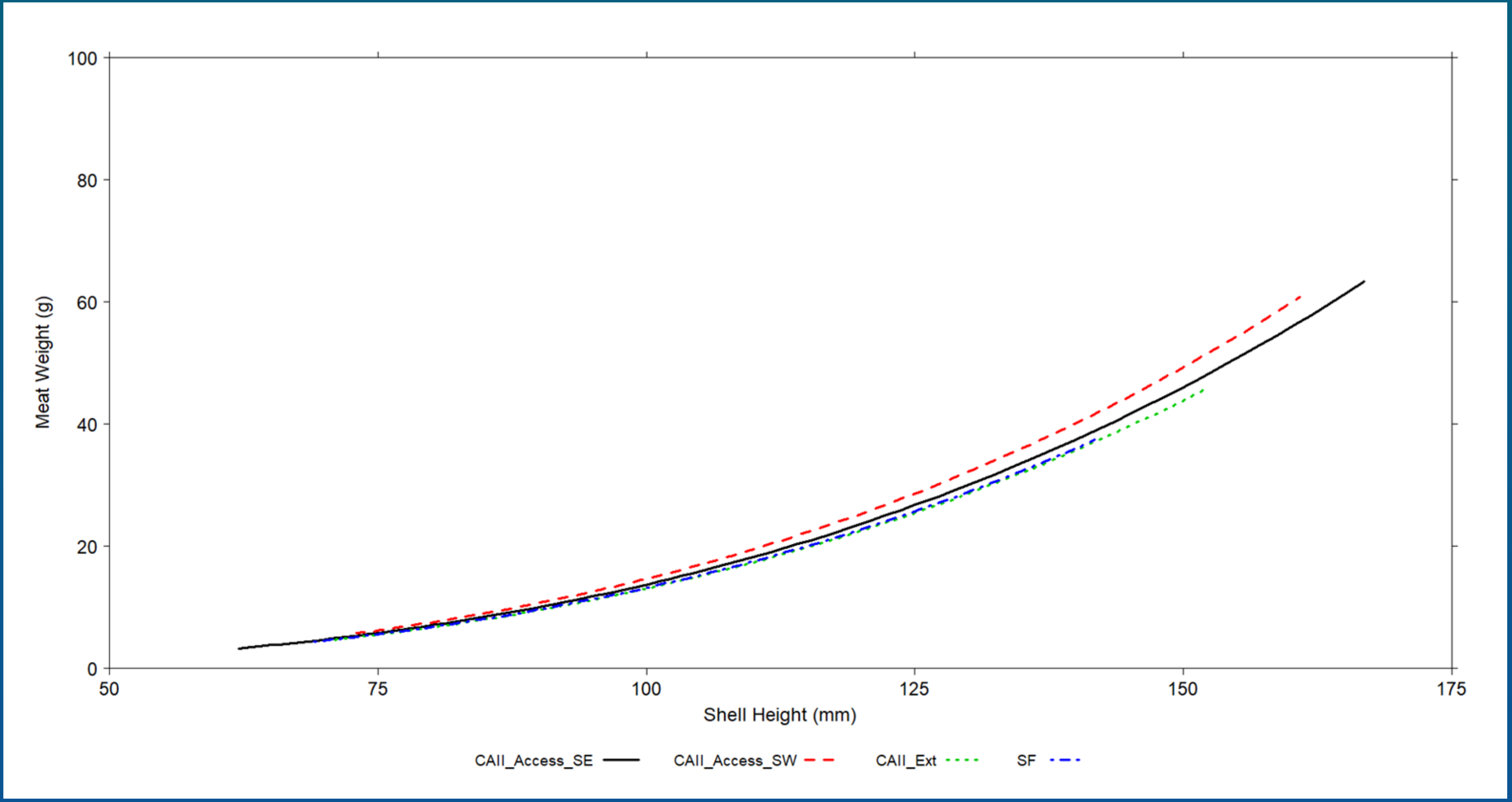
- SHMW samples (meat & gonad weight) were taken from all stations that had scallops (15/station):
  - MAB Survey: 4,761 (377 stations)
  - CA I II Survey: 1,352 (104 stations)
  - NL Survey: 2,302 (180 stations)
- The objective is to construct a model to predict meat weight based on a suite of potential covariates (i.e. shell height, depth, SAMS Area, sex, disease…)
- Maturity stage considered this year to account for trip delays
- A GLMM was used to fit model (Gamma distribution, log link, random effect at the station level) with R v 3.3.1 Package lme4

2020 MAB Survey
SHMW Results



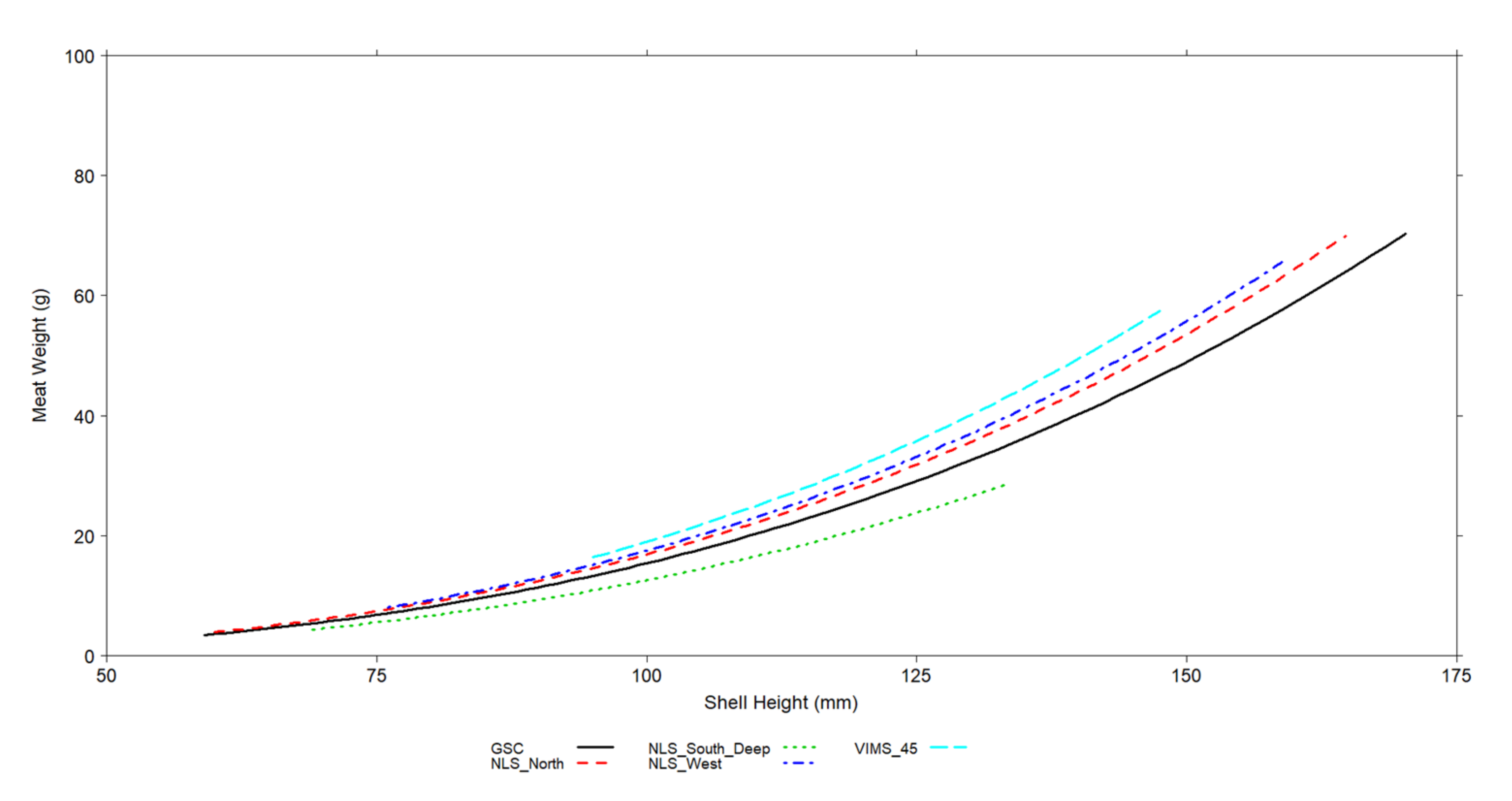
- **Majority of SAMS Areas have similar SHMW relationship**
- **HCS has the smallest meat weight at a given shell height**

2020 CAII Survey
SHMW Results



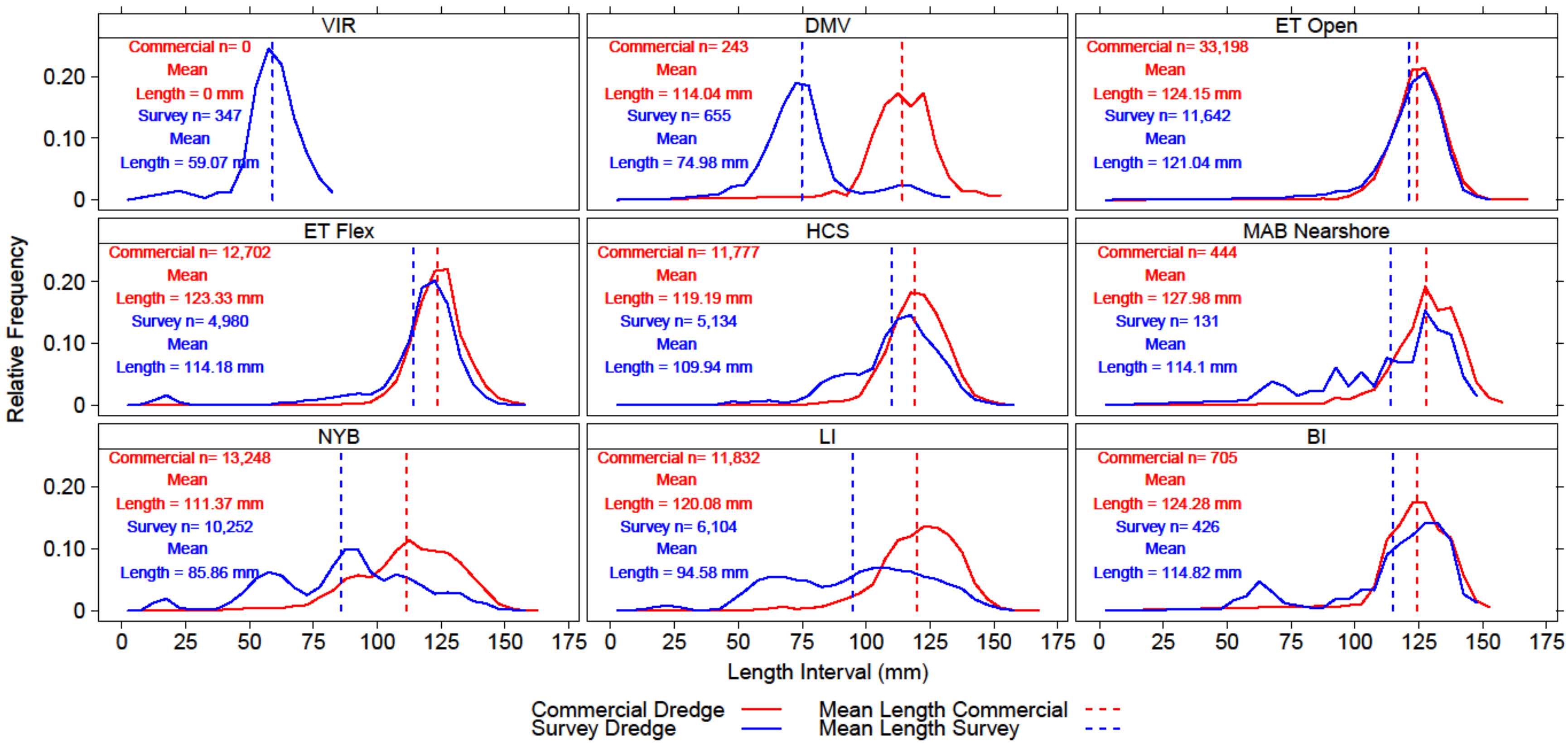
- **Extension and SF SHMW curves are lower than the Access Area SAMS Areas**

2020 NL & GSC Survey
SHMW Results

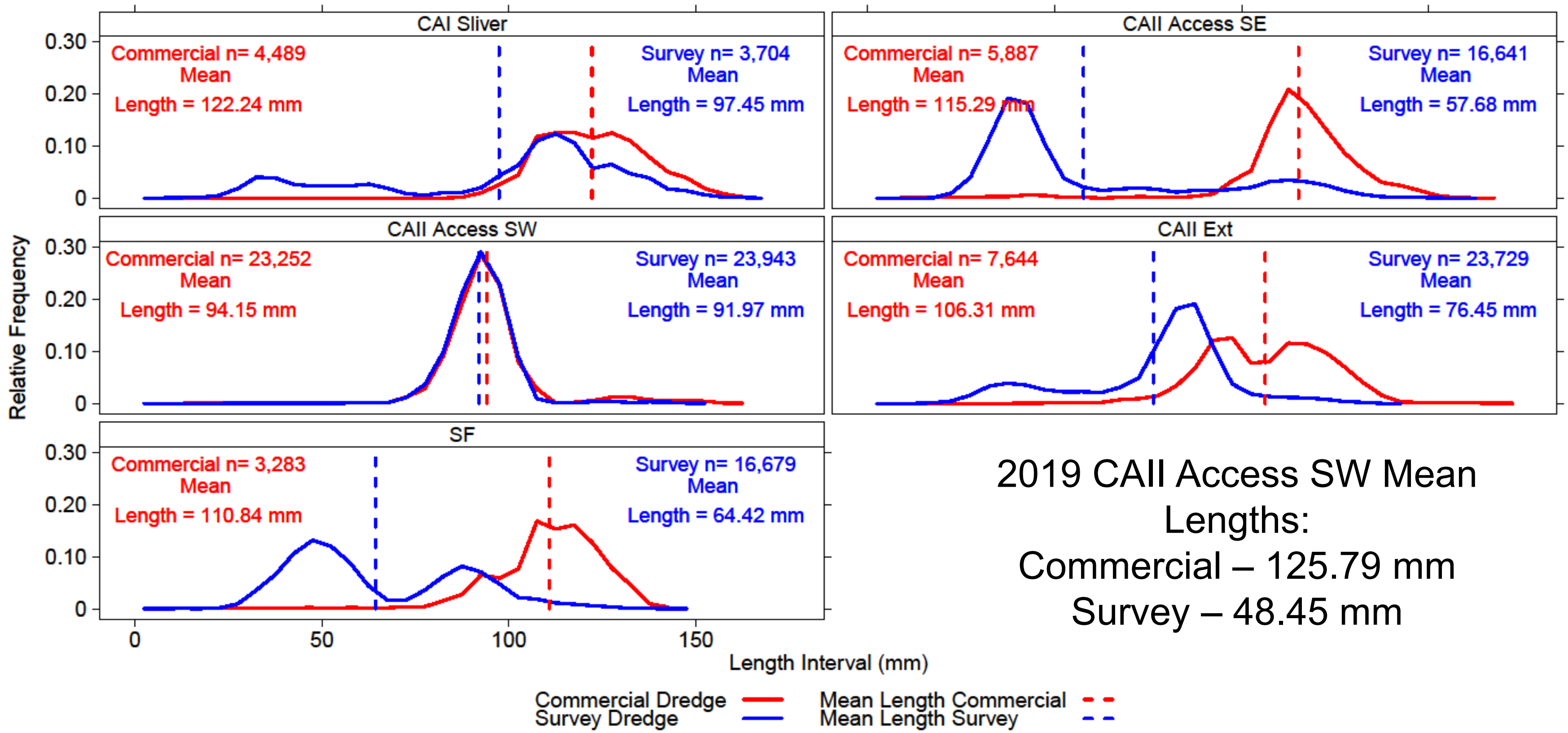


- **Similar trend to previous years - South Deep SAMS Area has the lowest meat weight at shell height**
- **South Deep SAMS Area only area significantly different than reference area: NLS-North**

2020 MAB Survey
Length Frequency- SAMS Areas



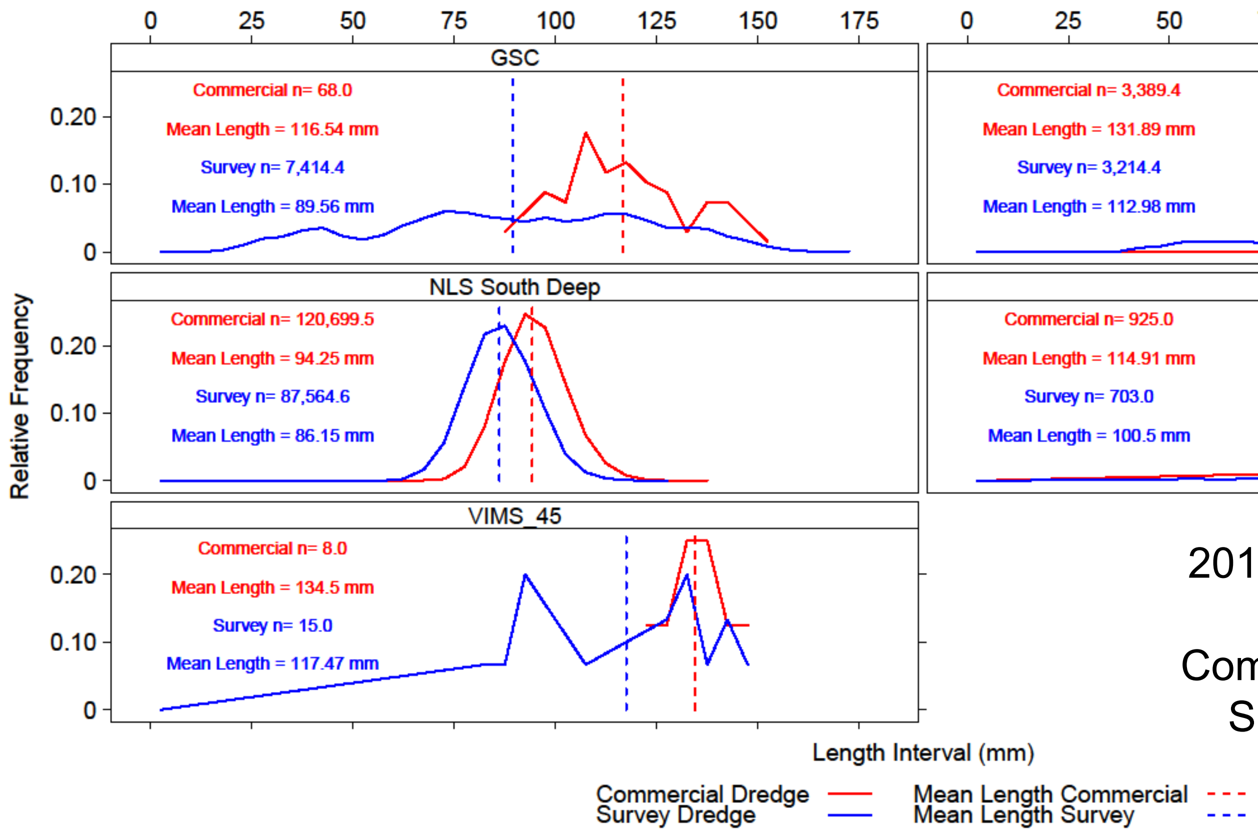
2020 CA I & CAII Survey
Length Frequency- SAMS Areas



2019 CAII Access SW Mean Lengths:
Commercial – 125.79 mm
Survey – 48.45 mm

2020 NL & GSC Survey

Length Frequency- SAMS Areas



2019 South Deep Mean Lengths:
Commercial – 91.41 mm
Survey – 86.36 mm

2020 VIMS-Industry Cooperative Surveys

Total Biomass Survey Gear – SAMS Areas

- NLS South Deep* estimates are with reduced q=.13
- SARC SHMW

SAMS Area	Total Biomass (mt)	SE Biomass (mt)	CV Biomass (mt)	Density (scal/m²)	Avg MW (g)	Total Number
BI	809.49	117.83	36.39	0.03	31.29	25,306,074
LI	6,151.03	337.95	13.74	0.02	20.32	294,927,146
HCS	4,095.27	232.76	14.21	0.06	23.33	174,733,150
NYB	4,006.92	229.92	14.35	0.07	16.04	256,377,426
MAB Nearshore	308.64	45.5	36.85	0.003	30.47	10,113,304
ET Flex	3,207.99	282.54	22.02	0.08	28.34	113,945,394
ET Open	7,811.18	369.51	11.83	0.12	29.63	265,744,949
DMV	351.48	60.5	43.03	0.01	9.52	36,976,499
VIR	70.87	11.1	39.16	0.01	4.71	16,057,046
GSC	6,055.78	850.7	14.05	0.09	24.55	241,832,123
NLS North	1,713.41	213.32	12.45	0.03	38.26	44,479,831
NLS South Deep*	36,046.60	7,704.96	21.37	1.79	10.02	3,613,124,841
NLS West	277.64	45.6	16.42	0.01	24.55	11,403,282
VIMS 45	12.59	5.76	45.75	0.001	46.37	270,343
CAI Sliver	1,489.72	270.51	45.4	0.07	24.67	60,239,016
CAII Access SE	5,185.14	528.15	25.46	0.2	13.66	370,563,308
CAII Access SW	21,356.75	4,722.28	55.28	1.03	19.72	1,079,041,330
CAII Ext	12,924.04	1,524.47	29.49	0.49	14.34	913,839,789
SF	6,747.69	819.44	30.36	0.42	8.81	765,698,558

2020 VIMS-Industry Cooperative Surveys
Exploitable Biomass Commercial Gear - SAMS Areas

SAMS Area	Exp Biomass (mt)	SE Biomass (mt)	CV Biomass (mt)	Density (scal/m²)	Avg MW (g)	Exp Number
BI	498.17	90.89	28.07	0.02	36.68	13,631,037
LI	6,081.67	426.12	10.78	0.01	34.4	176,077,048
NYB	2,566.31	175.51	10.52	0.02	29.76	85,181,778
MAB Nearshore	430.34	118.24	42.27	0	39.43	10,912,934
HCS	3,601.18	383.61	16.39	0.04	28.68	124,068,373
ET Flex	3,080.81	371.52	18.55	0.06	32.37	92,208,708
ET Open	7,443.41	621.97	12.86	0.11	31.74	233,926,657
DMV	88.53	46.08	80.07	0	26.34	3,360,604
VIR	0	0	0	0	0	0
GSC*	4,474.16	519.91	11.62	0.09	36.39	123,007,928
NLS North*	1,452.92	186.06	12.81	0.029	45.44	31,788,408
NLS South Deep	4,070.21	943.57	23.18	0.41	14.33	279,501,324
NLS West	167.37	25.82	15.43	0	37.9	4,379,582
VIMS 45	12.82	5.17	40.29	0	65.23	196,543
CAI Sliver	579.93	65.99	17.51	0.02	35.85	16,137,354
CAII Access SE	1,342.36	267.34	30.64	0.02	33.72	38,746,562
CAII Access SW	2,941.00	1,052.32	55.05	0.12	24.01	121,665,083
CAII Ext	1,468.64	261.52	27.4	0.02	30.86	47,537,237
SF	801.84	111.05	21.31	0.01	29.57	27,113,845

- GSC* & NLS North* estimates are from the survey dredge
- NLS South Deep has selectivity profile applied
- SARC SHMW

SARC 65 Total Biomass Estimates Compared to VIMS 2016-2020 Estimates NL & reduced q for South Deep

SAMS Area	Total Biomass (mt) SARC 65 q=.40	Total Biomass (mt) VIMS 2016-2020 q=.40	Total Biomass (mt) SARC 65 q=.13	Total Biomass (mt) VIMS 2016-2020 q=.13
NLS North	1,713.41	1,725.24		
NLS South Deep	11,715.14	12,547.05	36,046.60	38,606.31
NLS West	277.64	254.55		
VIMS 45	12.59	12.56		

Acknowledgements

- The owners, captains and crews:
  - *F/V Carolina Capes II*
  - *F/V Italian Princess*
  - *F/V Pyxis*
  - *F/V Celtic*
- Scientific Staff:
  - Lee Rollins, Heather Smith, Victoria Thomas, and Erika Mincarellia
- Reidar's Manufacturing Inc.
- Support from NMFS NEFSC: Dvora Hart and Pete Chase.
- Funding through Sea Scallop RSA program.

Appendix C

2019 update on the nematode, *Sulcascaris sulcata*: Spatial distribution and effect on the sea scallop fishery

David B. Rudders, Sally Roman, Erin Mohr and Kaitlyn Clark
Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA

Sea Scallop Plan Development Team
Falmouth, MA
August 27-28, 2019

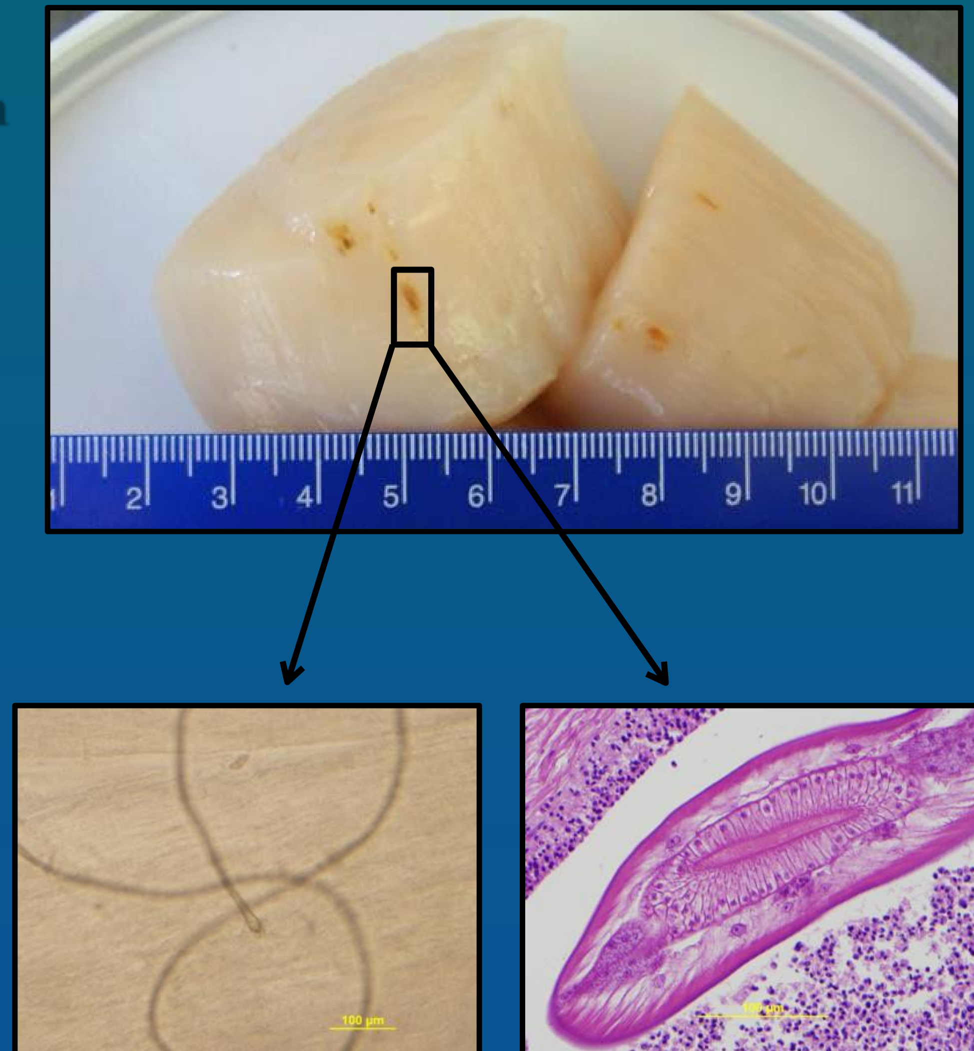
VIMS | WILLIAM & MARY
VIRGINIA INSTITUTE OF MARINE SCIENCE

A persistent epizootic

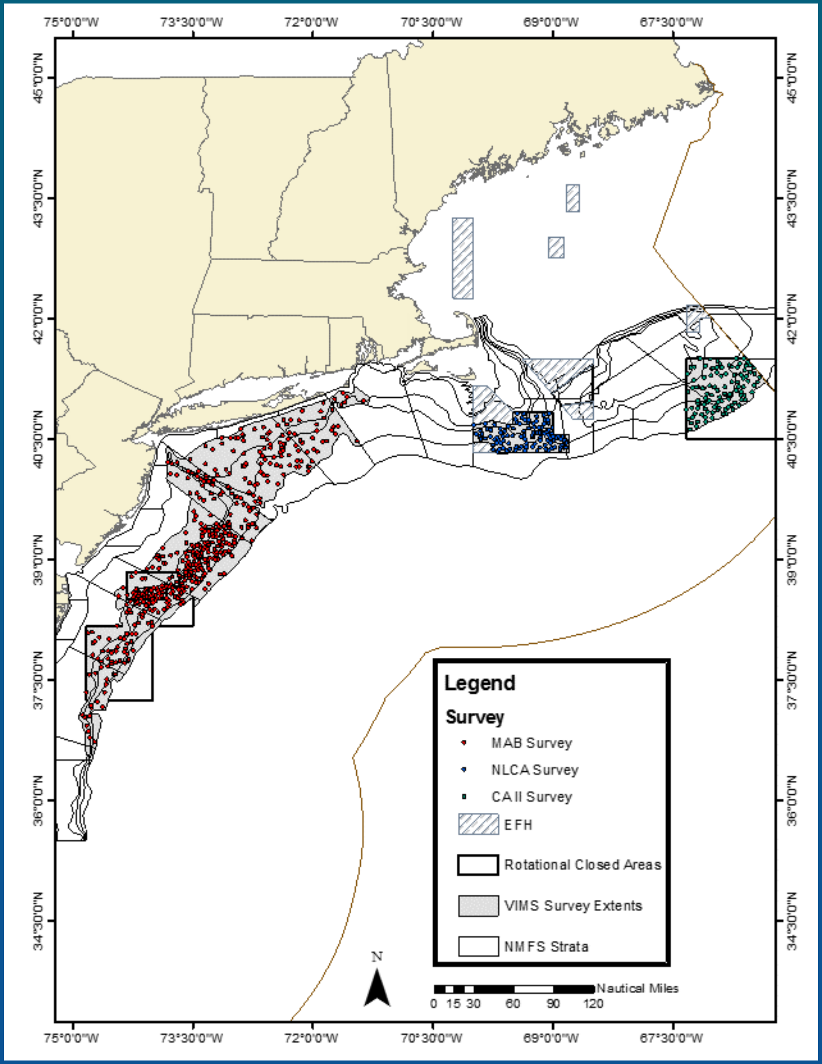
- Nematodes were first observed in 2015 in the newly re-opened MAAA.

- Research efforts have focused on species identification, biology, life history and spatial distribution.

- 5 years of survey information related to spatial extent of affected scallops.

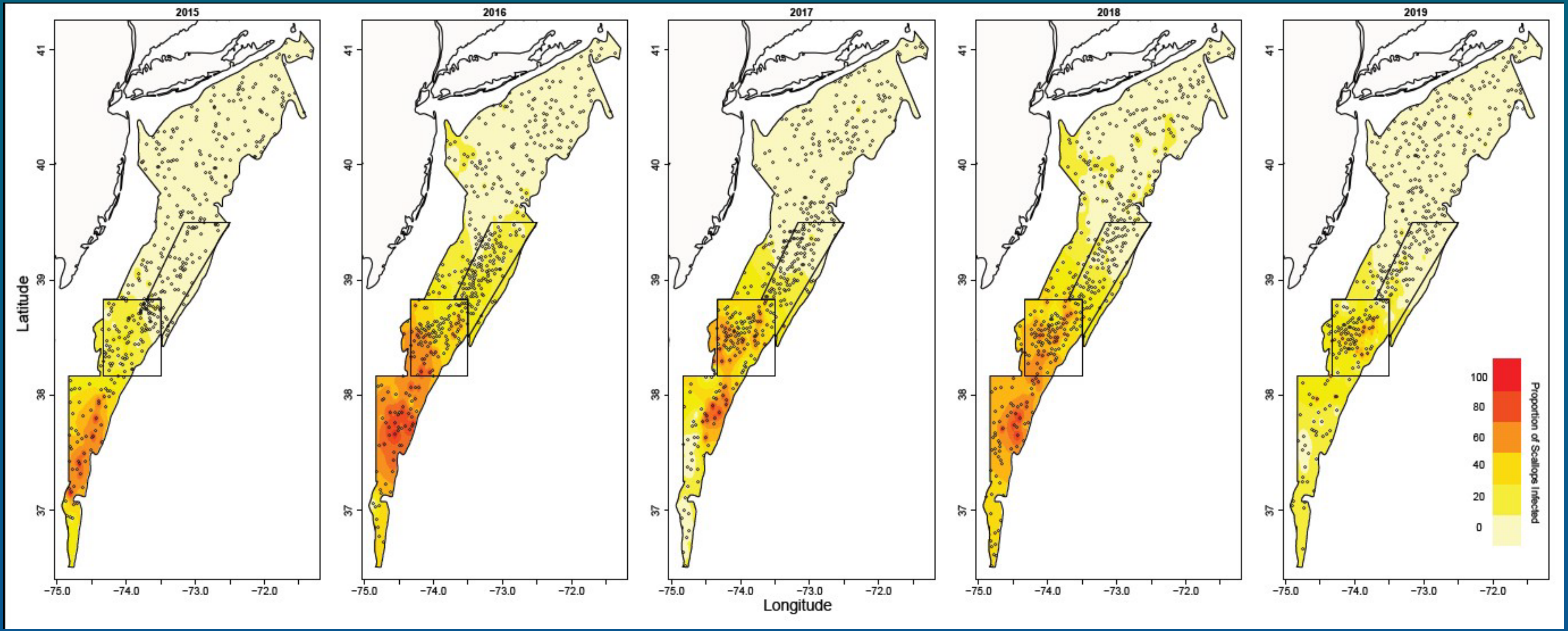


Parasite surveillance



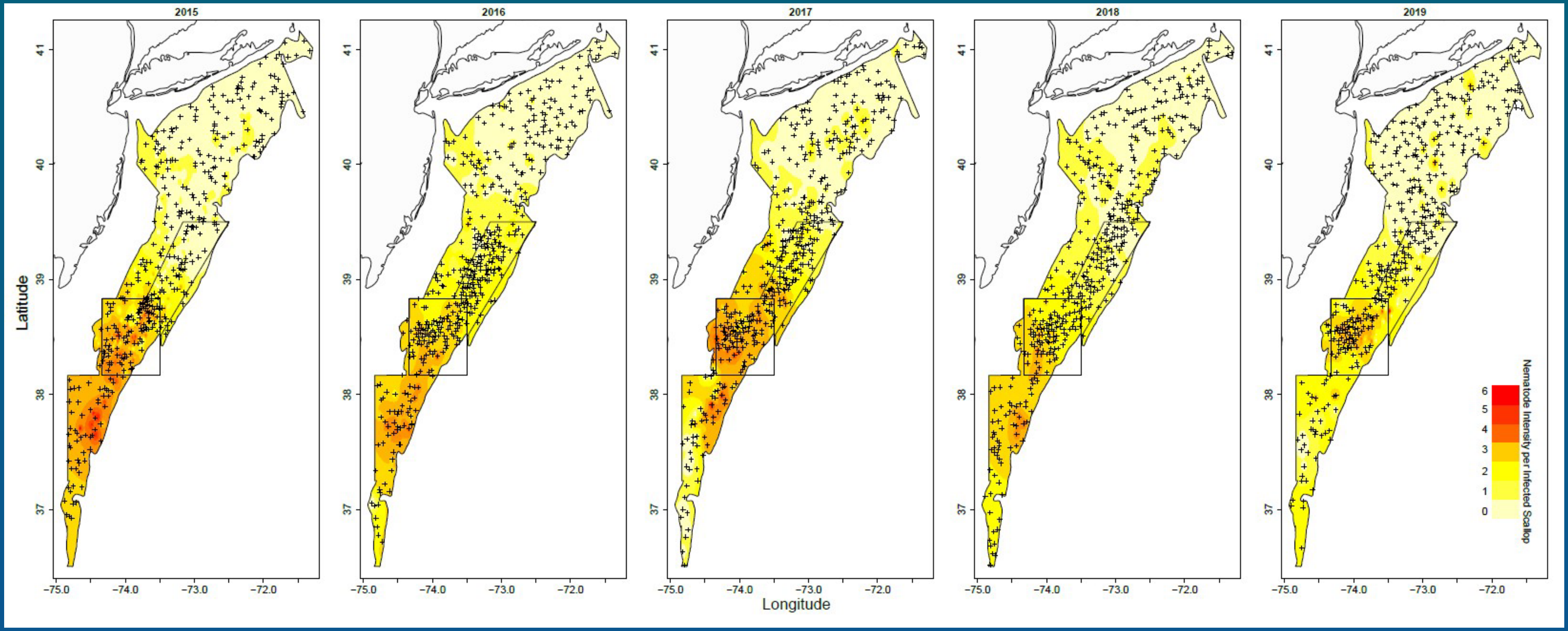
- For the 2015-19 surveys, VIMS expanded the biological sampling protocol to capture the spatial extent of the parasite as well as the prevalence and intensity of infected scallops.
- Sampled 15 animals at every station that had scallops .
    - Histological and genetic samples.
    - Gross observation of the number of infected scallops/sample (prevalence).
    - Gross observation of the number of nematodes/scallop (intensity).

Nematode Prevalence 2015-19



- % of scallops in a sample that contain at least one lesion.
- Northward expansion 2015-16.
- Apparent stabilization of the spatial extent 2016-17.
- Possible slight northward expansion from 2017-18.
- Reduction in prevalence in 2019

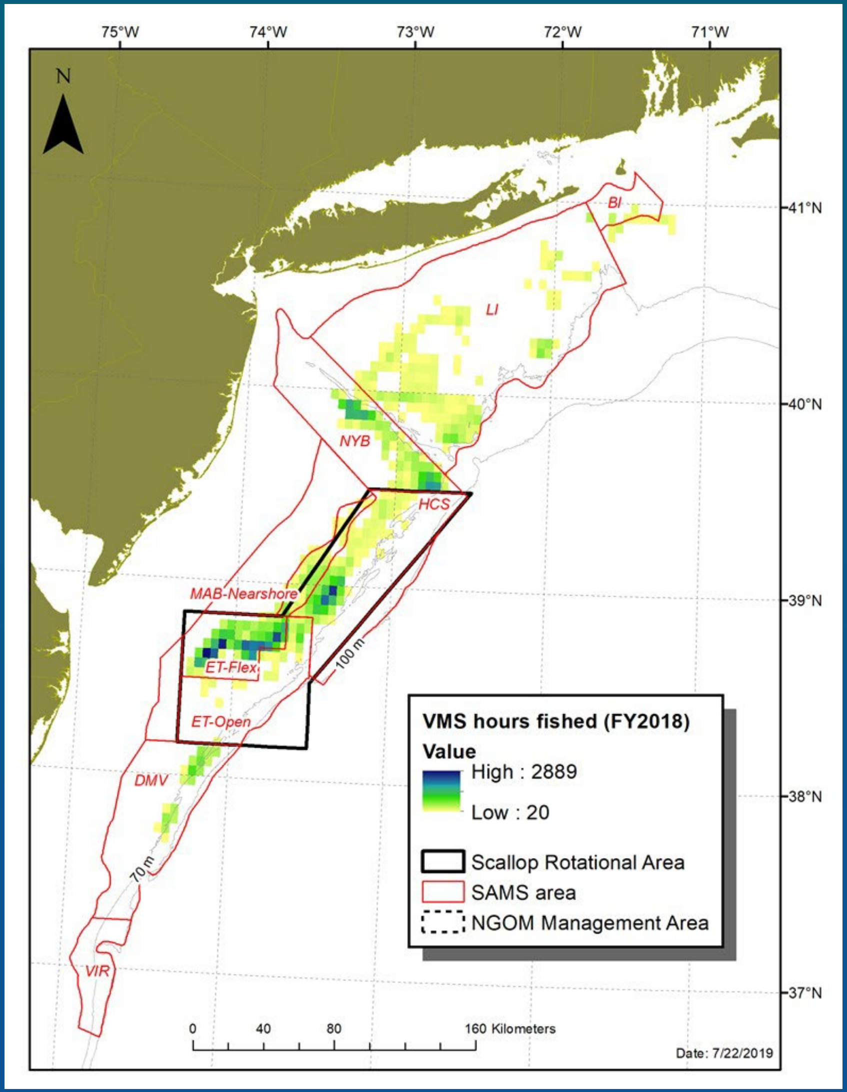
Nematode Intensity 2015-19



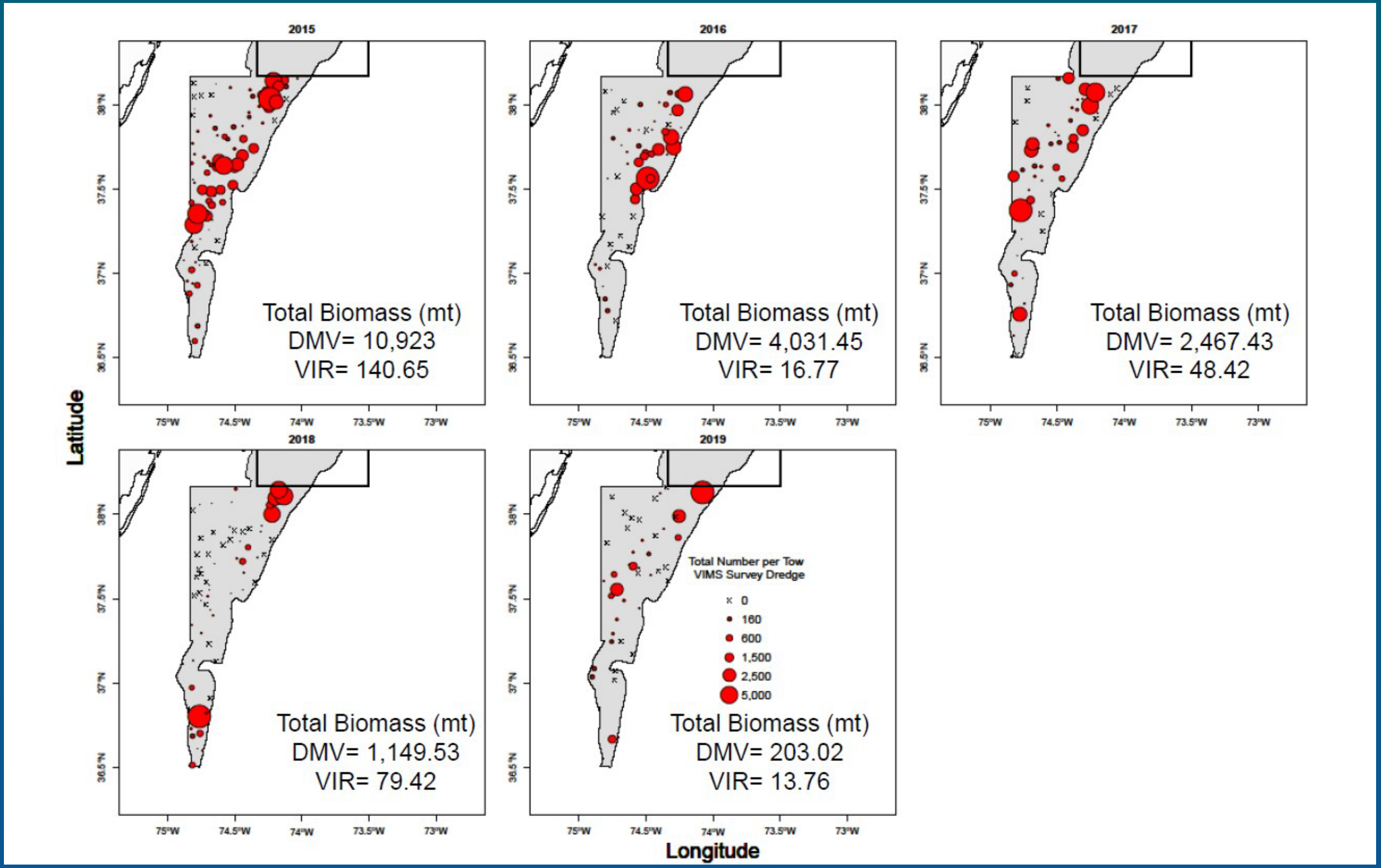
- Number of lesions in scallops that had at least one lesion.
- Northward expansion 2015-16.
- Apparent stabilization of the spatial extent 2016-17.
- Possible slight northward expansion from 2017-18.
- Reduction in 2019

2018 Fishing Effort

- Aggregate annual fishing effort.
- MAAA effort centered upon “flex and HC portions.
- Very little effort in Southern ET and DelMarVa.
- Potentially influenced by product quality issues?



The demise of the DMV



- We assume that the nematode does not contribute to scallop mortality.....but
- Scallop biomass in the DMV had been reduced by two orders of magnitude over 4 years in the absence of significant fishing.
- Continues to be small pulses of recruitment but does not survive.

Summary

- Data suggests that nematode distribution appeared quickly, had stabilized, but in 2019 wasobserved to be reduced for both prevalence and intensity.
- Distribution in affected areas ispatchy.
- Southern areas of the resource (i.e. DMV, ETCA) are most affected.
- Contributing to elevated mortality??? DMV??
- Nematodes may be affecting the distribution of fishing effort.

Concluding thoughts

- Disease/parasites can represent a significant driver.
- For scallops grey meats and nematodes have the potential to shape how we view the resource.
- Indirect effects can be important
  - Elevated levels of F (from discards)
  - Redistribution of fishing effort.
- Effective biomass may bean appropriate framework.
  - Is it beneficial to attempt to anticipate this effect in projections/specifications?

Appendix D

2020 MAB Nematode Update from the VIMS Dredge Survey

Sally Roman
David B. Rudders
Russell Nicholson
Kaitlyn Clark

Virginia Institute of Marine Science

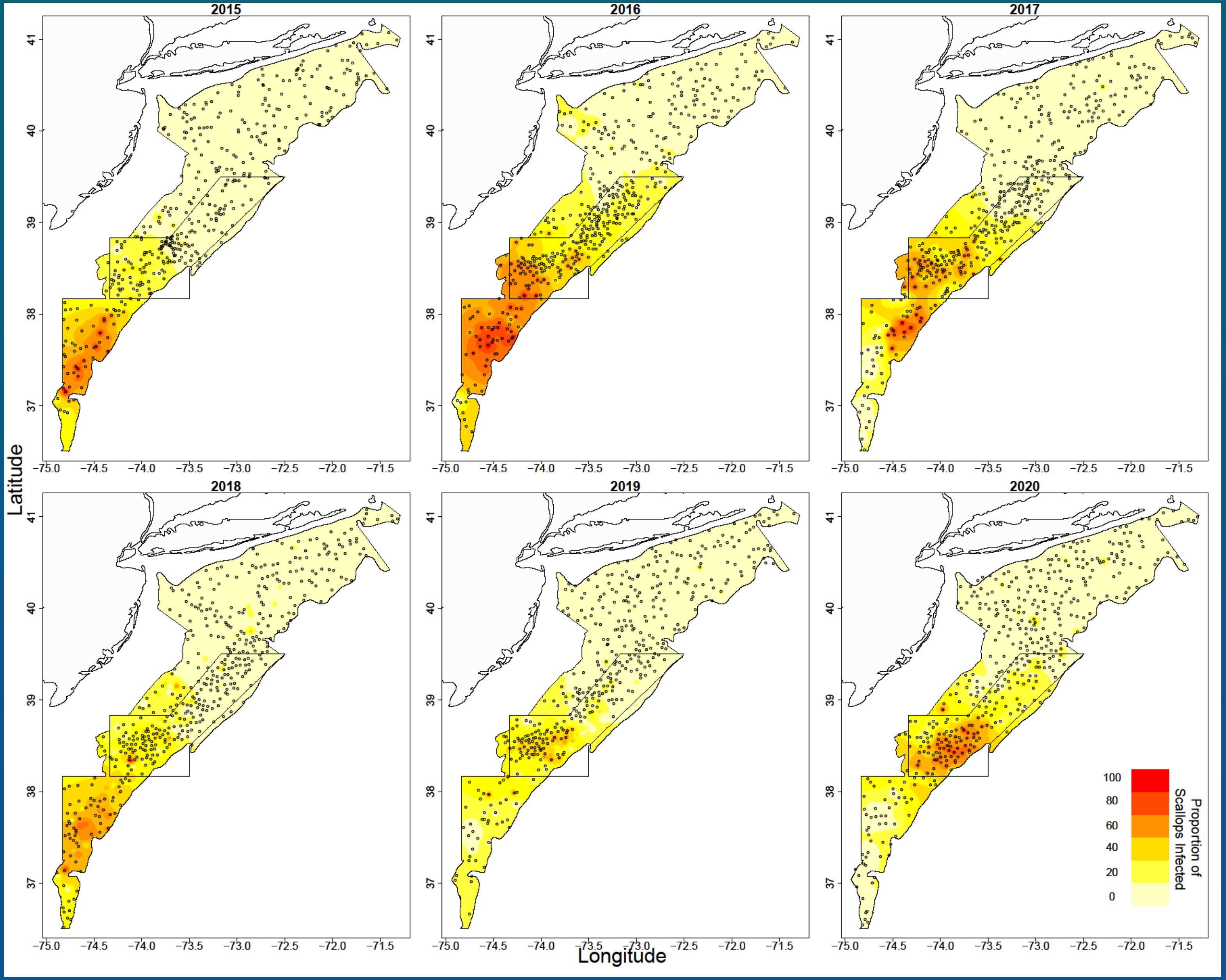
Sea Scallop Plan Development Team
Zoom Meeting
October 15, 2020

Preliminary – PDT use only.

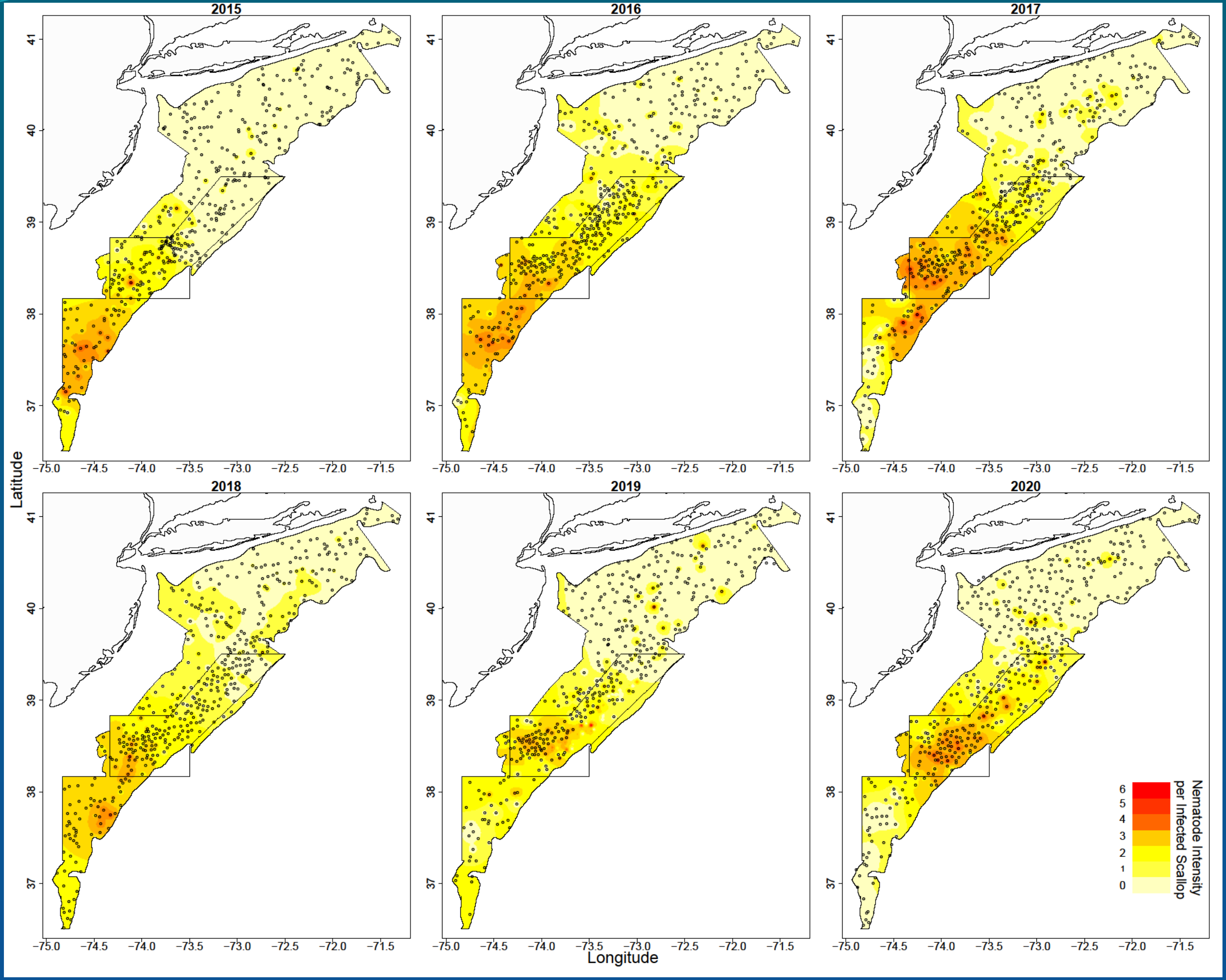
Nematode Observations

- All scallops evaluated for SHMW workups are also assessed for disease
  - Gross observation of nematode lesions
    - Number of lesions per scallops (intensity)
    - Number of infected scallops/sample (prevalence)
- Occurs during all surveys
- Information is used to document spatial distribution of infected scallops
- Six years of information related to the spatial extent of affected scallops for the MAB

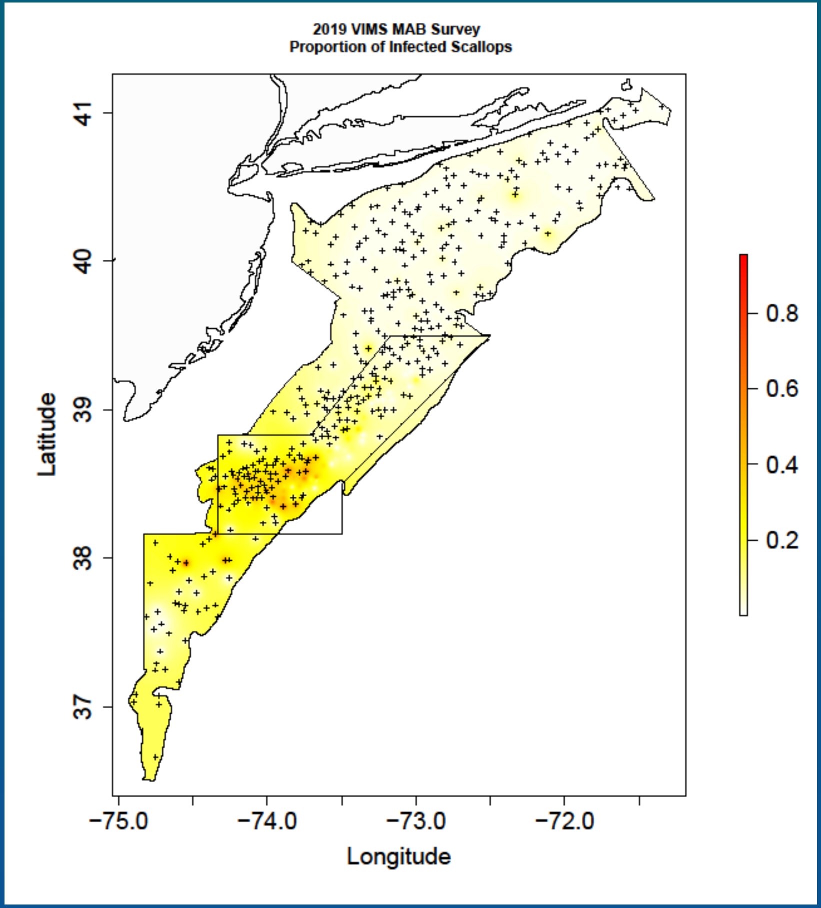
Nematode Prevalence 2015-2020

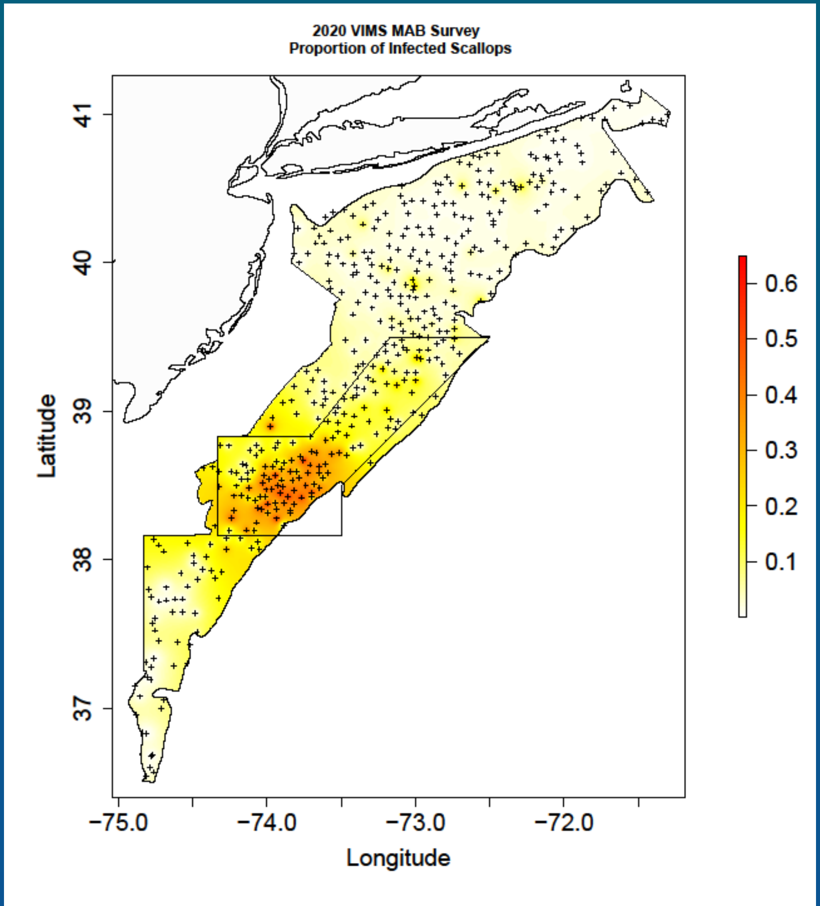


Nematode Intensity 2015-2020



Nematode Prevalence 2019 vs 2020





- Increased number of infected scallops observed in 2020 in ET & HCS
- Fewer infected scallops in VIR & DMV, maybe related to decline in biomass