

Virginia Institute of Marine Science Dredge Survey Methods Report

Scallops Survey Methods Review

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Executive Summary

Dredge surveys for the sea scallop, *Placopecten magellanicus*, resource along the US East Coast have a long history dating back to the early 1960's. These early surveys, conducted by the National Marine Fisheries Service at the Northeast Fisheries Science Center in Woods Hole, MA endeavored to generate abundance indices to characterize annual changes in the abundance and distribution of sea scallops across the entire resource area. These data were used to populate assessment models, culminating in the determination of stock status and fishery specifications. For many years, the data generated from these efforts represented the primary source of fishery independent information used in the assessment process. Fishery-independent data needs began to change by the late 1990's in response to an evolution of sea scallop management strategies.

The creation of the groundfish closed areas in 1994 and their subsequent impact on the trajectory of sea scallop management strategies had a profound influence on the spatial and temporal resolution of sea scallop abundance data required to manage the fishery (Link et al, 2005). Formal spatial management of the resource as implemented in Amendment #10 and the surveys needed to support annual or biannual fishery specifications at that scale have been continuing on an annual basis since the first cooperative industry dredge survey of Closed Area II conducted in 1998. The cooperative industry dredge survey of Georges Bank Closed Area II in conjunction with the National Marine Fisheries Service, the School for Marine Science and Technology, the Virginia Institute of Marine Science and others has served as a precursor for many of the concepts still in use to guide scallop cooperative research, rotational spatial management and scallop population assessment.

While there are many similarities to the aforementioned survey in 1998, there has also been evolution both from objective and methodological standpoints. As a direct result of investment by the industry via a research set aside program, the fishery typically has the luxury of multiple surveys of both the entire resource as well as discrete management areas. The multiple surveys consist of a diversity of experimental approaches and methods that have provided an incredible body of data to understand not only the sea scallop but the varied ecosystem components of the habitat that the scallop inhabits. With such a wide diversity of survey tools and experimental designs, an evaluation of the merits of each approach is a healthy means to support the responsible utilization of survey resources to continue to support the fishery that has become one of the most valuable single-species fisheries in the United States (van Voorhees, 2014).

The remainder of this report will provide, based on the Terms of Reference, a detailed explanation of the methods used by the Virginia Institute of Marine Science to conduct dredge surveys aboard commercial platforms. We endeavor to present the conceptual basis for the methodologies used by this survey effort in addition to the rationale behind the decisions to collect certain data or employ a specific experimental or analytical approach.

ToR1. Review the statistical design and data collection procedures for each survey system.

The change to rotational spatial management in the sea scallop fishery prompted an increase in the data needs required to manage the fishery. The management of discrete areas of scallop resource benefits from accurate and timely abundance and distribution information. Resource wide surveys typically focus on characterizing the status of the scallop population across the entire stock area and as a result of this spatial scale can tend to lack the spatial resolution to precisely estimate abundance in smaller, discrete areas. Historically, VIMS' survey efforts have focused on these areas, instead of synoptically surveying the entire resource. Table 1 shows the areas surveyed by VIMS since the late 1990s.

Year	Area	Vessel	Tows
1999	HCCA, VA Beach	Courageous	225
2000	HCCA, VA Beach	Alice Amanda	208
2005	NLCA, CAII, ETCA	Westport, Celtic, Carolina Boy	248
2006	ETCA, NLCA, CAI	Carolina Boy, Celtic	209
2007	CAII, CAI, NLCA, ETCA	Celtic, Pursuit	306
2008	CAII, DMV	Celtic, Pursuit	203
2009	NLCA	Celtic	92
2010	CAI, HCCA	Celtic, Pursuit	190
2011	CAII, SNE/LI, NYB,DMV	Celtic, Kathy Ann, Pursuit	422
2012	DMV, HCCA, NLCA, NEG, NYB	Stephanie B II, Kathy Ann, Celtic, Regulus,	553
2013	MAB, NEG,NLCA,DMV	Carolina Boy, Kathy Ann, Celtic, Concordia, Stephanie B II	650
2014	MAB, SNE/LI	Carolina Boy, Kathy Ann, Celtic	564

Table 1. Historical record of the VIMS sea scallop dredge survey. Each row of data represents a year of survey efforts with area(s) surveyed, vessel(s) used and the number of tows completed. HCCA=Hudson Canyon Closed Area, VA Beach=Virginia Beach Closed Area, NLCA=Nantucket Lightship Closed Area, CAII= Closed Area II, CAI=Closed Area I, ETCA=Elephant Trunk Closed Area, DMV=DeIMarVa Closed Area, SNE/LI=Southern New England/Long Island, MAB=Mid-Atlantic Bight, NEG=Northeast Georges Bank.

The experimental design of these surveys has been based on a 2 dimensional systematic design with a random starting point. For spatial management areas, the boundaries of the sampled domain were set by the spatial extent of that area (Figure 1.1). For “open” areas the spatial extent was delineated by NMFS survey strata or a modified version of those strata based upon prior year’s survey efforts. This sampling design is constructed by decomposing the domain into smaller sub-units. A random point inside an arbitrarily selected subunit (i.e. the most northwestern sub-unit) is selected. The remaining stations are selected by calculating the same relative point within each subsequent subunit. Each survey was designed with a unique random start point. For example, if an access area is sampled in 3 consecutive years, then a unique set of stations was generated for each survey effort (Figure 1.2).

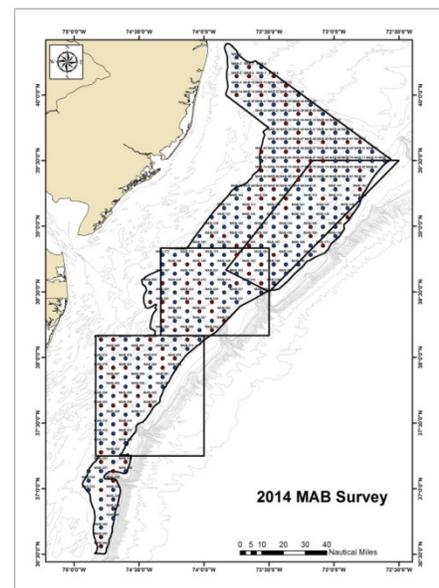


Figure 1.1 Example of systematic design for the VIMS dredge survey 2

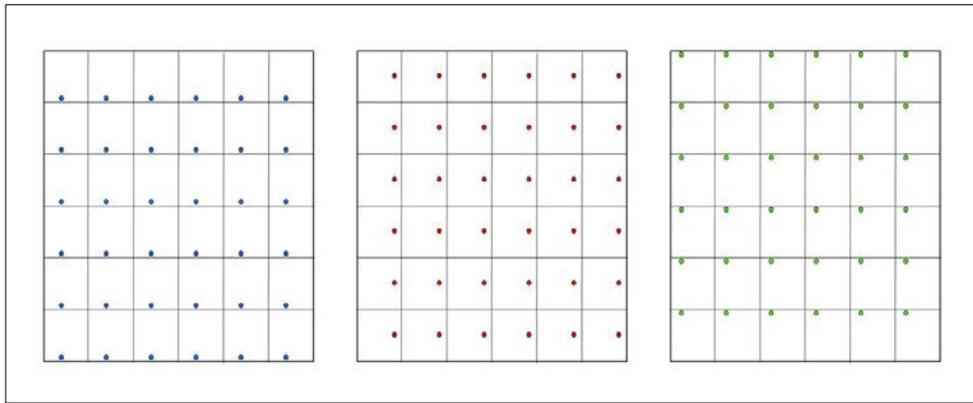


Figure 1.2 Example of survey stations generated for the same area for three consecutive surveys. Each two-dimensional systematic grid has a unique random

The approximate number of samples required to achieve a desired level of precision can be estimated based on prior year's survey data (Gunderson, 1993). The upper and lower limits to the variance of the prior year's catches are used to determine the approximate magnitude of 95% confidence intervals given a desired level of precision given by:

$$n = \left(\frac{2s_i}{W} \right)^2$$

where:

- s_i = approximate standard deviation obtained from the catch data from the prior year's survey.
- W = desired half width of confidence interval.
- n = sample size required.

Prior to conducting the survey, the sample size was evaluated for each area using the most recent information available (i.e. NMFS or VIMS survey data). The estimates of sample size are tempered by two mitigating factors. The data that forms the basis for the calculation is typically one year old. In most cases, there has been some level of fishing effort since the prior year's survey occurred. Areas of high density typically have been reduced resulting in a potential overestimation of standard deviation in the current year with a concomitant overestimation of n to achieve the desired precision. Additionally, the constraint of available vessel time is also considered in the determination of survey scope of work.

Cochran (1977) provides a comprehensive review of the theoretical underpinnings of the design, pointing out the relative strengths and weaknesses of the method compared to other common designs (simple random and stratified random). We calculate mean abundance and variance with estimators in Gunderson (1993) acknowledging the statistical considerations inherent especially in the calculation of variance associated with the systematic design. A discussion of design specific issues related to mean and variance estimation are presented in ToR4.

Proposed 2015 VIMS Survey

As capacity of the VIMS scallop program has grown, so has the ability to expand our survey past the boundaries of the closed areas and conduct work in the "open" areas. These forays had been manifested as extensions of survey grids into "open" areas adjacent to closed areas (Table 1). In 2015, based, in part, to changes in the priorities of the RSA grant program and a desire to both expand the footprint of the work and concomitantly allowing the survey to

organically evolve and address technical issues, we proposed to change the design of the survey. Given the VIMS survey efforts did not have the continuity of a time series to honor, we endeavored to make improvements to reflect recommendations in the 2014 Sea Scallop Stock Assessment as well as general enhancements to increase precision and address possible sources of uncertainty. While many of the operational characteristics of the surveys have remained constant, proposed changes include: 1) a stratified random design utilizing NMFS shellfish strata, 2) three survey legs on unique vessels utilizing an adaptive station allocation approach and 3) additional stations and analyses to estimate vessel effects. The proposal narrative detailing the salient design changes are shown in the following section.

We propose to conduct a fine scale dredge survey of the MA resource area from The VA/NC border to Block Island, RI during the spring of 2015 (Figure 1.3). The survey domain will be comprised of a combination of NMFS core scallop survey strata within the MA area as well as additional strata that have been determined as important scallop habitat but are not well covered. Confirmation of the extent of this area will be verified by a combination of prior survey results (VIMS, NMFS), and available vessel monitoring system (VMS) data. The NMFS core scallop and expanded strata provide a reasonable starting point to capture the spatial extent of the resource in the MA and facilitate the incorporation of survey data into existing assessment models that use this spatial definition. This survey domain includes coverage of both the MA access areas as well as open areas.

The proposed survey will consist of 3 consecutive cruises that will each sample the entire domain. The spatio-temporal aspect of this approach allows for multiple objectives to be addressed. One objective will be to provide comparative catch data to estimate vessel inter-calibrations. An additional and higher priority will allow for an adaptive allocation approach to increase the precision of abundance estimates.

For a stratified random design, relative gains in precision are realized from a number of different sources. Compared to simple random sampling, effective stratification that accurately reflects scallop abundance and divides the population into homogenous subgroups (strata) is a critical initial step. Additional gains are realized by allocating sampling stations to those strata to result in the minimization of within-strata variance (Cochran, 1977). In the absence of *a priori* information, a reasonable approach is to allocate to each strata proportionately to their spatial contribution to the total domain. Methods that rely on information from a pilot survey to inform allocation tend to perform with higher precision relative to a naïve allocation. In the case of this proposal, prior year distributional data does exist; however, fishing effort has the potential to alter the spatial distribution of scallop abundance over the course of the year. This can result in a drastically different spatial distribution of abundance than assumed, negating hoped for gains in precision.

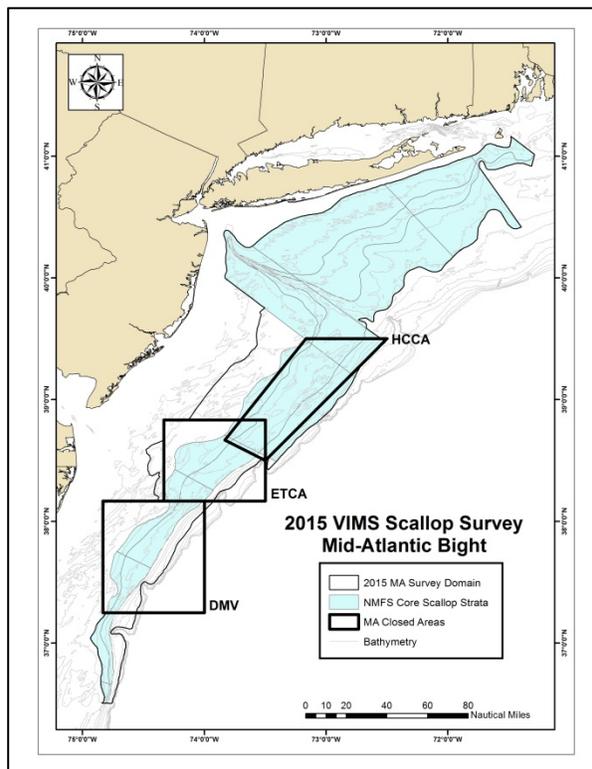


Figure 1.3 Proposed sampling domain and strata definitions for the 2015 VIMS MA survey.

An alternative technique would be to use an adaptive allocation approach. One such approach uses the first leg(s) of a multi-phase survey to inform changes to the allocation in subsequent stages (Smith and Lundy, 2006). Stations are added to strata when an attribute characteristic has a value at or above a pre-determined decision rule (i.e. mean number of scallops), as in many cases mean and variance are correlated. For this survey, our initial allocation of samples will be based on the areal proportion of each strata to the entire domain. Additional survey legs will draw on the previous leg(s) to allocate extra tows to strata based upon a scallop abundance threshold. This threshold will be calculated based upon prior year catch data. As a result of higher abundance of animals in the MA rotational areas, additional stations will likely be allocated to these areas to provide higher precision estimates for those subareas. Estimators of mean abundance and variance for this design will be based on Rao-Blackwell estimators as developed in Smith and Lundy, 2006.

For this survey effort, we propose to occupy roughly 600 stations (~200/leg). Included for each leg of the survey will be comparative stations occupied by all vessels (~20). These comparative stations in addition to the overall catch data will provide the basis for vessel inter-calibration analyses.

Data Collection Procedures

In an effort to facilitate the comparability of surveys as well as the combining of results, the VIMS dredge survey protocols closely mirror those used in the NMFS dredge survey. While some differences do exist, dredge gear and towing protocols are essentially the same. The following section will detail these protocols. Standard operating procedures for the VIMS dredge surveys can be found in Appendix 1.

The dredge gear used throughout the history of the VIMS survey duplicates those used by NMFS. A standard dredge design had been used since 1979, however at the urging of the industry and in conjunction with the changing of the NMFS research vessel platform used to conduct their survey, an updated version of the survey dredge has been in use since 2008. A rigging diagram of the current survey dredge design can be found in Appendix 1. This dredge is 8 feet (2.46 m) in width, with a dredge ring bag knit with 2 inch (51mm) rings, and 3.5" (88.9mm) twine top and a 1.5" (38.1mm) liner. Rock chains are used in some NMFS survey strata to increase safety as well as increase the ability to conduct operations in hard bottom areas. The effect of this design change has been calibrated and estimates of survey dredge efficiency have been conducted across substrate. A comprehensive history of the evolution and design rationale of the NMFS survey dredge is contained in the NMFS Dredge Peer Review document (ToR1).

Utilizing a commercial sea scallop vessel as a platform enables the ability to tow two dredges simultaneously. We have taken advantage of this vessel attribute to also tow a commercial sea scallop dredge consistent with current gear regulations. These dredges are typically 15' (4.57m) in width, with a ring bag knit with 4" (101mm) rings and equipped with at 10" (254mm) twine top. Not only does the use of this type of dredge provide an estimate of exploitable biomass, it also provides comparative data to estimate size selectivity and relative efficiency. We have also used catch data from this gear to report on the spatiotemporal distribution of finfish bycatch potentially encountered by the commercial fishery.

For each paired tow, the dredges will be fished for 15 minutes at a towing speed of approximately 3.8-4.0 kts with 3:1 wire scope. A Star-Oddi tilt sensor (records angle of inclination, temperature, depth) is used to determine dredge bottom contact time and the NMEA data stream obtained from a differential GPS unit is logged every 2 seconds. These data will be

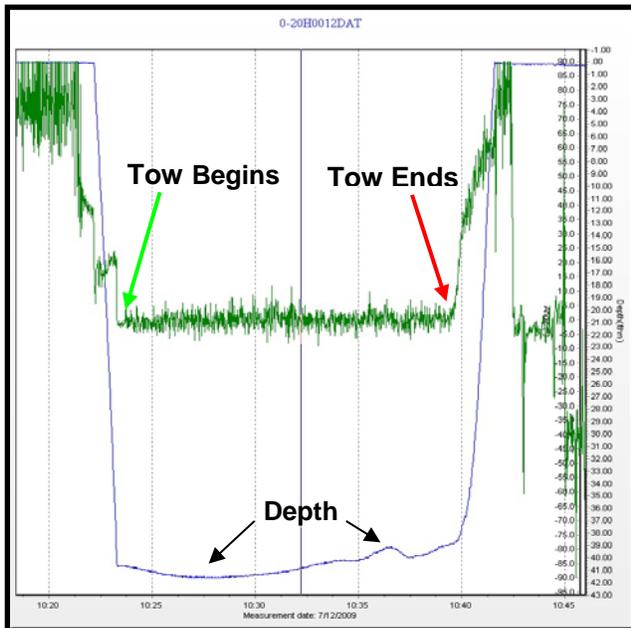


Figure 1.4 Example of a Star-Oddi tilt sensor trace for a representative survey tow. The start and end of the tow are shown with the green and red arrows as well as bottom depth over the duration of the deployment.

used to determine vessel position and speed over ground. Time stamps for both the tilt sensor and the navigational log will determine both the location and duration fished by the dredges. Bottom contact time and vessel location are integrated to estimate area of gear coverage. Figure 1.4 shows a representative inclinometer trace from a survey tow deployment. Since the surveys are conducted on different vessels, and the gear deployment/retrieval procedures can vary, we have started, in 2014, to deploy a GoPro camera attached to the survey dredge to ensure correct interpretation of the inclinometer traces.

A member of the scientific party is present on the bridge at all times. The role of this individual is to coordinate with the vessel operator to ensure correct station alignment, proper speed as well as monitoring the tow time and signaling the correct time to haul back the gear. In addition, this individual records the station level information including: location and time for each tow, sea state, atmospheric conditions and any problems that might occur with the tow. For each survey tow, the operator is instructed to use the station coordinates as a tow midpoint, setting the gear roughly 0.5 nm prior to the station coordinates towing through them for the duration of the tow. If the tow track is determined to be untowable due to any reason (i.e. fixed gear, boulders on bottom), the station location can be adjusted slightly to avoid the obstacles. The individual on the bridge, in conjunction with the vessel operator has the discretion to suspend operations if the operational parameters threaten personnel safety or if the limits of reasonable gear performance are exceeded. While the surveys generally operate during periods of calm weather, rough weather conditions do exist and a sea state in excess of 8 ft. (2.46m) is sufficient to suspend operations.

At the completion of each survey tow the gear is hauled back to the vessel and the catch dumped on the deck. If a problem is detected with the tow (i.e. flipped dredge, fouled gear, hang-up, large object in dredge) the tow is repeated until it is successfully completed. If a tow is considered to be valid, the catch is then subject to the biological sampling protocols. A detailed treatment of the biological sampling protocols for the VIMS surveys is



Fig.1.5 NOAA NMFS sea scallop measuring board.

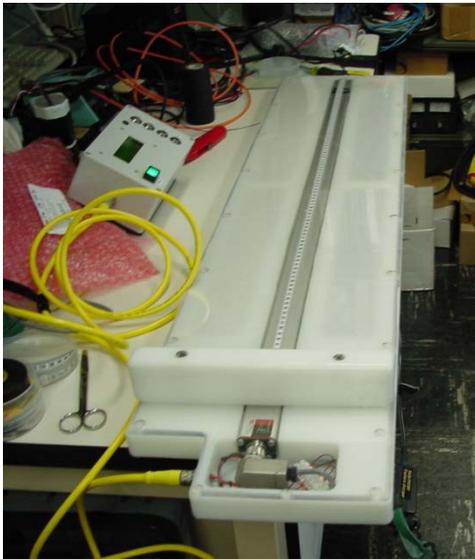


Figure 1.6 Ichthystick measuring board and display box

presented in ToR3 including the catch processing, subsampling procedures as well as the suite of additional biological samples collected. Data acquisition for the VIMS surveys has evolved over the years, progressing from manual counting boards (5 mm bins) and paper logs (Figure 1.5) to the current electronic measuring board (1mm resolution, under development and scheduled to be implemented in 2015) (Figure 1.6) with a custom front-end database (Figure 1.7). Any weight measurements taken are obtained by a Marel M1100 PL2260 motion compensating scale with 0.5 gram resolution which are also captured by the database.

Data storage for both bridge and biological information is housed in a Microsoft Access database designed for the specifics of the VIMS sea scallop survey. The biological data is passed through the front end database (FEED) and combined with the bridge data in the MS Access DB. Inclinometer and

navigation data are stored separately. All survey data is stored locally as well as archived on VIMS institutional servers.

Previously, when the manual NOAA NMFS Scallop Measuring Boards were used, all data was entered by hand from the paper data sheets. Bridge log data will continue to be entered by hand with QA/QC performed using ArcGIS to map station latitude and longitude. QA/QC of organismal data is performed in a series of procedures. At the point of collection, the FEED database has error checking programming to ensure critical information is collected as well as constraints to the acceptable ranges of entered data for various fields. These initial checks represent efforts to reduce entry error. Post-processing of collected data is performed as a series of algorithms to examine the data for outliers. QA/QC as well as subsequent data analysis is performed using SAS version 9.3. A detailed treatment of analytical approaches is included in ToR4 and sample SAS code is provided in Appendix 1.

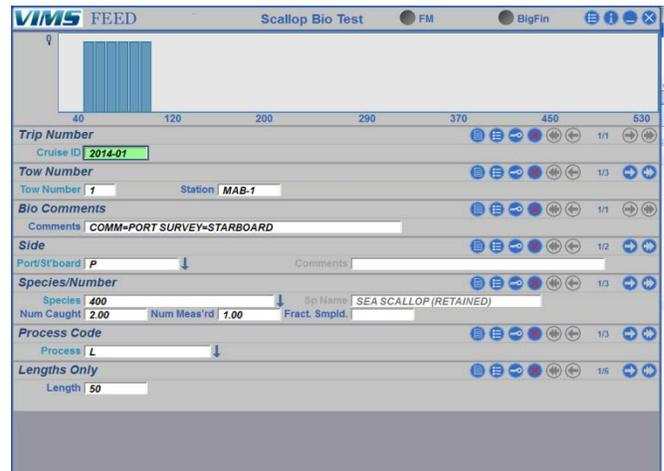


Figure 1.7 FEED data acquisition software developed by Chris Bonzek at the Virginia Institute of Marine Science. This version of the software was designed specifically for the sea scallop dredge survey program.

ToR2. For each survey, evaluate measurement error of observations including shell height measurement, detection of scallops, determination of live vs. dead scallops, selectivity of gear, and influence of confounding factors (e.g., light, turbidity, sea state, tide etc.).

Measurement error with respect scallop shell height can manifest itself as a result of disparity between the recorded measurement and the true dimension of the shell. As the dredge survey method to measure scallops has evolved, so has the resolution of the measurement and presumably a corresponding reduction in measurement error. Prior to the current implementation of electronic measuring boards, the manual NMFS boards were used which binned scallops into 5mm intervals. The process of measuring an animal with this approach entailed sighting down the ventral margin of the scallop to the interval on the board where this shell edge fell. Parallax between the line of sight, the shell margin and the interval on the board is the likely process responsible for measurement error. The newer electronic boards, not only have a finer resolution of measurement (1mm), but also use physical contact between a magnetic wand, the shell margin and a magnetic sensor to initiate a length reading. Characterization of the level of measurement error in scale and directionality is an important attribute of a survey system.

The characterization of measurement error for the manual NMFS measuring boards was reported in Jacobson *et. al.*, 2010. The results, reported in the NMFS Dredge Survey Peer Review document (TOR2) from this exercise indicated that bias relative to the shells measured with calipers was relatively small. Measurement error for the newer electronic boards has also been examined and those results are also presented in the NMFS Dredge Survey Peer Review document (TOR2). As expected, these results indicated more accuracy and precision from the new boards. While evidence suggests that being able to handle the animal results in small levels of measurement error, because, for VIMS the electronic boards are a new advancement in our survey protocol, a directed experiment to assess shell height measurement error is planned as part of the implementation of the new system.

One objective of the VIMS dredge surveys is to detect incoming recruiting year classes. This is especially important in the context of the spatial management strategy that is currently used in the fishery to protect spatially explicit aggregations of juvenile scallops from fishing mortality and allow them realize to substantial gains in yield. A sampling gear that can capture these animals is required to meet this objective. Early gear designs utilized unlined dredges and the catchability of 2 year old scallops was low. In 1979, the survey dredge design included a 1.5" (38mm) liner to increase the catchability of two year old scallops. Experiments to estimate the selectivity of the unlined dredge using the lined dredge as a control are included in the NMFS Dredge Survey Peer Review document (ToR1). This work in addition to subsequent selectivity experiments using the lined survey dredge as a control do suggest that the addition of the liner decreases the relative efficiency of the gear (Yochum and DuPaul, 2008). The NMFS Dredge Survey Peer Review document (ToR2) also report on comparative work that was completed using optical methods as a comparative tool to examine relative differences in size selectivity of the dredge and optical techniques. Overall, the lined survey dredge is able to reliably detect two year old scallops and smaller animals can also be retained by the gear

(Figure 2.1). The animals should be considered present in an area, however, the spatial scale and magnitude of abundance is highly uncertain.

One advantage of using a vessel that can simultaneously tow two dredges is the ability to collect comparative catch data. The VIMS survey has utilized this attribute to estimate the size selective characteristics of various designs of the commercial dredge relative to the assumed, non-selective NMFS lined survey dredge. Yochum and DuPaul (2008) reported on the selectivity of the New



Figure 2.1 Sub-one year old scallop captured by the lined NMFS survey dredge.

Bedford style sea scallop dredge equipped with 4" (101mm) rings. The generated probabilities of retention form the basis for scaling length frequency distributions collected by optical techniques as well as the lined survey dredge into a measure of exploitable biomass in the fishery specification process. In subsequent years, as mandated changes to the dredge frame have been implemented, the VIMS survey has been able to estimate size selectivity associated with these changes. The analytical method used (Millar, 1992) includes a measure of relative efficiency (split parameter) in the estimation. This parameter is especially informative to calculate efficiency for the commercial gear relative to the known efficiency of the lined survey dredge (see ToR4 for discussion of estimated efficiency). Results, while variable, indicate that the lined survey dredge is less efficient at capturing large scallops than the unlined commercial dredge than would be expected solely as a function of gear width.

Determination of live vs. dead scallops is included in the sampling protocols and is a straightforward determination. For the animals that are measured for length frequency, no effort is made to separate live and dead animals. The dead scallops with both valves still articulated by the resilium are called "clappers" and are coded with a distinct species identifier to differentiate them from live animals. The dead animals are sampled in proportion to their abundance and a length based account of dead scallops is recorded. The ratio of live to dead scallop has been used to estimate natural mortality (Merril and Posgay, 1964). Depending on time since death, as well as the rigors of the capture process, clappers may disarticulate. A qualitative record of the relative occurrence of the disarticulated shell is also noted in the database.

There are many potential factors that could contribute to bias or uncertainty in indices or absolute measures of abundance. ToR4 provides an in-depth discussion of a number of those factors, however, for ToR2, the effect of sea state and tide are explicitly mentioned. NMFS Dredge Survey Peer Review document (ToR2) provides the details of an analysis that estimates the effect of sea state on scallop catches. That analysis finds no strong support for sea state being a significant factor predicting catch and out operational protocols set an upper bound on sea state for both safety and potential gear performance issues. Presumably this ToR was

concerned with the impact of confounding factors on the measurement error of scallops. This is less of an issue with the dredge relative to perhaps optical techniques that might encounter difficulties in rough conditions should the operational parameters of the image acquisition procedures become variable in the adverse conditions.

ToR3. Review the biological sampling aspects of the surveys, including sub-sampling procedures and the ability to sample all size classes. For each survey, evaluate the utility of data to detect incoming recruitment, assess the potential ability to assess fine scale ecology (e.g., Allee effect, predator-prey interactions, disturbance from fishing gear, etc.).

Biological sampling of the material captured on the dredge tows consists of multiple levels of sampling. Given the primary objective of assessing sea scallop abundance and distribution, the first order sample relate to the determination of sea scallop length frequency distribution. In most cases, all animals are measured, however large catches require subsampling. Regardless of whether a subsample is taken, the material from the dredge is sorted by hand and all scallops are placed in baskets. If a subsample is taken, then the basket(s) are selected at random for measurement. The choice of subsample rate is dependent upon total catch as well as the size composition of the catch. In cases where there are large amounts of seed scallop (<50mm), the material may be divided fractionally and a random section of the material is sorted for scallops. In rare cases, a different subsampling fraction may be employed for different size classes. For example, during our 2014 MA surveys, approximately 300,000 scallops were estimated to have been caught. Once the scallops are sorted from the material, finfish, skates as well as commercially important invertebrate species (i.e. lobster, whelk) are retained for measurement.

Once a sample has been obtained, measurements are taken with the Icthystick measuring boards with data being stored in the front-end FEED database. The shell height (umbo to the ventral margin) measurement is taken for each sampled scallop. At roughly 25% of the survey stations, 15 scallops that encompass the size distribution observed will be sampled for length:weight characteristics. The shell height of each scallop is measured to the nearest millimeter and the adductor muscle carefully removed and weighed on a Marel motion compensating balance to the nearest 0.5 gram. In addition to shell height and meat weight, each sample is associated with specific tow level data as well as biological characteristics (reproductive state, sex, presence of disease, meat quality). In addition to length:weight data collected for each cruise, we also collect data related to scallop meat quality and shell blister disease. Scallop meat quality is an emerging issue that has some important ramifications to realized yield to the fishery (Figure 3.1). For example, during a 2012 survey on the Northern Edge of Georges Bank in an area that contained a large amount of older animals, it was estimated that only 55% of those animals would have been marketable. This has significant ramifications to the “effective biomass” that may be in an area and how much that amount may differ relative to an estimate based on length frequencies alone. In addition to marketability, we also sample for



Figure 3.1 Gradient of marketability characteristics for sampled scallops.

the prevalence and distribution of a blister disease (Figure 3.2). This condition appears to be caused by an invasive polychaete (*Polydora spp.*) that penetrates the mantle cavity and elicits a defense response from the scallop. While it is uncertain whether this is fatal, we have been able to document its spatial extent, create a predictive model and assess its impact on meat yield (Figure 3.3). See Appendix 2 for details. Pending the outcome of the 2015 competition, we



Figure 3.2 Scallop with severe shell blister

have also agreed to collect samples for researchers at SMAST investigating the spatial extent and prevalence of “grey meats”. We also have collected shell samples for a student project with the objective of developing novel ageing techniques. Upon request, we have also collected genetic samples to aid in a project examining source-sink dynamics of scallops from persistent aggregations.

The VIMS dredge surveys also allow access to biological samples of non-scallop organisms captured as bycatch. Information that is commonly taken is finfish maturity staging (yellowtail, windowpane, blackback and summer flounders). We have also served as the means to collect material for the examination of the effect of density dependence on the

life history characteristics of a recovering batoid skate (Coutre et.al, 2013). Upon request, we have also collected samples of a whelk species (*Buccinum undatum*) that is the target of a developing fishery off the US East Coast.

Given the dimensions of the liner in the dredge, two year old scallops (35-80mm shell height) are fully recruited to the gear. Scallops smaller than the stretched mesh dimension of the liner (38mm) are not fully retained by the gear, however that does not mean that they are not captured (Figure 2.1). Their presence serves as an indicator of a recruiting year class in that area. Animals less than one year old are sometimes observed still attached to pieces of substrate by byssal threads. While not able to assess magnitude and scale of recruitment events of one year old scallops, observing these animals serves as a reasonable predictor of areas to monitor. For example in 2012, we observed huge numbers of 1 year old scallops (<20mm) in the southern part of the Nantucket Lightship Closed Area. This area had not seen significant recruitment in many decades. These results were shared with other surveys conducted later in

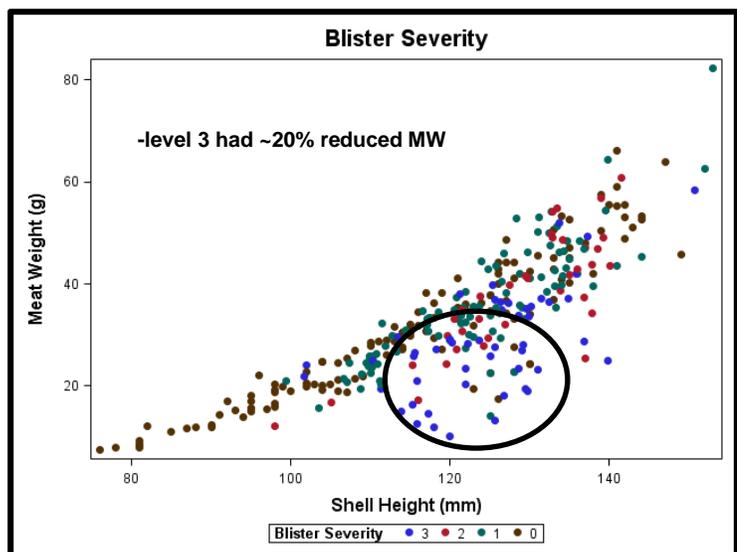


Figure 3.3 Impact of varying levels of shell blister on meat yield

the season to enable additional information to be gathered for this potentially historic event. This area has subsequently been monitored and persisted to a high degree. It is now included in the spatial management strategy for the fishery as a rotational access area.

The capacity to understand scallop ecology is determined by the ability to relate animal attributes to factors present in its environment at varying levels of spatial scale. Being able to collect physical samples allows for unique data to be collected and models developed to describe those observations. Scallop growth, meat yield, disease prevalence, reproductive attributes and presence of predator assemblages are all characteristics that can be used to describe the biology and ecology of the scallop. The NMFS dredge survey has provided the platform to collect data that described the predator-prey processes that contribute to the spatial distribution of scallops in the mid-Atlantic (Hart, 2006).

ToR4. Review methods for using survey data to estimate abundance indices. Evaluate accuracy (measures of bias) of indices as estimates of absolute abundance.

Data from the VIMS sea scallop surveys is used to estimate both abundance indices as well as biomass in areas surveyed. Typically, the objective of the majority of VIMS surveys conducted is to provide guidance related to biomass levels in rotational access areas in support of openings. These data are also used in conjunction with NMFS dredge survey to utilize all available dredge data. A description of the approach used to integrate the VIMS dredge data is available in NMFS Dredge Survey Peer Review document.

To estimate the biomass (total or exploitable), the following formula is used (Gunderson, 1993):

$$\hat{B} = \sum_{i=1}^h \left(\frac{\left(\frac{\bar{C}_i}{\bar{a}_i} \right)}{\bar{E}_i} \right) A_i \quad (2.1)$$

where \hat{B} = biomass within area surveyed
 A_i = area of the domain of interest in subarea i
 \bar{a}_i = mean area swept per tow in subarea i
 \bar{C}_i = mean biomass caught per tow in subarea i , based on n_i samples = $\frac{1}{n_i} \sum_{j=1}^{n_i} C_{ij}$
 C_{ij} = biomass caught per tow in the j th sample taken in subarea i
 h = number of subareas
 E = Gear efficiency in subarea i

The variance of the biomass estimate is the sum of the within stratum variances:

$$Var(\hat{B}) = \sum_{i=0}^n \left(\frac{A_i}{a_i} \right)^2 Var(\bar{C}_i) \quad (2.2)$$

where

$$Var(\bar{C}_i) = \frac{1}{n_i(n_i - 1)} \sum_{j=1}^{n_i} (C_{ij} - \bar{C}_j)^2 \quad (2.3)$$

As can be seen from formula 2.1, the estimate of biomass is essentially a mean biomass per survey tow scaled by both gear efficiency and the areal extent of the domain of interest. Each component of the formula is comprised of a number of components that are in themselves a function of calculations. Catch weight per tow is a calculated value that is comprised of the length frequency distributions of scallop captured at tow i . The scallop shell heights are converted into biomass by applying an appropriate length:weight relationship. As detailed in ToR3, SH:MW relationships are estimated for each subarea surveyed. We use a generalized linear mixed model (GLMM, gamma distribution, log link,) to fit the following models:

$$W = \exp(\alpha + \beta \ln(\text{length})) \quad (2.4)$$

$$W = \exp(\alpha + \beta \ln(\text{length}) + \gamma \ln(\text{depth})) \quad (2.5)$$

Where W =weight in grams, length represents scallop shell height in millimeters and depth represent the depth the sample was taken in meters. α , β and γ are parameters to be estimated. Depth has been shown to be a significant factor influencing meat weight. This predictor is evaluated and retained in the model if found to be significant. Due to the spatial nature of the relationship, samples from the same station tend to be similar, so the station from which the sample was taken was assigned as the random effect in the GLMM. While not included in the parameters used to estimate are level biomass, additional covariates are explored to better understand the factors that influence the SH:MW relationship. While the estimated relationships do represent a snapshot in time and space, they are informative with respect to demonstrating the spatiotemporal variability in the estimates. In addition to the estimates collected on the cruise, a relationship (regional or area specific) from 2014 SARC document (NEFSC, 2014) is also presented. Given that the objective of many of the VIMS surveys is to provide estimates of scallop biomass in support of fishery specifications, it is informative to present biomass estimates with respect to what is available to the current regulated dredge gear used in the fishery. This estimate of exploitable biomass is calculated by scaling the length frequency distributions at tow i by the estimated probabilities of capture generated by the size selectivity estimates found in Yochum and DuPaul (2008).

Areal calculations for the mean area swept (a_i) are the product of the estimated linear distance covered per tow and the dredge width. Linear distance is calculated by using the integration of the navigation data and the tow start/stops calculated from the interpretation of inclinometer traces. The tow start/stop times are used to parse the navigation logs that record the synchronized timestamp and latitude and longitude every 2 seconds. The inter-point distance (~12m) is calculated by the Pythagorean theorem and summed over all points to estimate a linear distance covered for a given tow. The linear distance is then multiplied by the dredge width to calculate area swept. The spatial extent of the sampling domain (A_i) is a constant and typically consists of a closed area or more recently a SAMS area (Scallop Area Management Simulator).

In order to scale an index of abundance to an absolute measure, an estimate of gear efficiency (E_i) is essential. Depletion experiments have been used to estimate catchability coefficients for fishing gear (Leslie and Davis, 1393, Delury, 1947). Rago *et. al.*, (2006) and Hennen *et. al.*, (2012) extend these approaches to develop a generalized spatially explicit depletion model to estimate capture efficiency. On a larger spatial scale Gedamke *et. al.*, 2004, and Gedamke *et. al.*, 2005 used an open-ocean DeLury analysis and index removal approaches to estimate commercial dredge efficiency. While depletion type experiments offer a method to estimate gear efficiency, optical techniques offer a different experimental approach to examine this process. Comparative evaluations of dredge tows and images acquired by HabCam have been used to model the probability of capture of scallop in the path of the survey dredge (NEFSC, 2014). A subset of stations (110) occupied during the 2008-09 surveys were also occupied with the HabCam system and the comparative data was used as the basis to construct models to predict gear efficiency across two substrate types (sand and gravel). Model output estimates the efficiency of the survey dredge for the sand substrate strata at 40% and for the gravel substrate at 25%. These estimates of gear efficiency are used in the VIMS analyses of biomass.

Survey operations need to remain constantly vigilant to aspects of their protocols that have the potential to introduce bias or increase the uncertainty of estimates. These sources of bias should be addressed and corrected through protocol changes or the scale/direction of the bias as well as the impact on the precision of estimates is characterized. There are two additional sources of potential uncertainty that have been identified and investigated. The first is the issue

of variance estimation for a systematic design. This issue has long been a concern and we examine the issue via simulation and pursuit of alternative estimators to provide an unbiased estimate of variance. The second issue relates to the effect of vessel and its potential impact on survey catchability.

Systematic sampling, where samples are selected from a population according to a random starting point, with subsequent observations obtained at a fixed interval, is a popular design. This design is attractive because it is straightforward to complete, provides complete coverage of the domain and requires little *a priori* information regarding the spatial distribution of the sampled population to construct appropriate strata. This design has been shown to be more efficient with respect to the accuracy of measurements of central tendency (Cochran, 1977; Rivoirard *et. al.*, 2000, Rudders, (2010 (Appendix 3)), Fewster, 2011). A limitation of this design is with the estimate of the sample variance for a one sample systematic survey (Cochran, 1977; D'Orazio, 2003, Fewster, 2011).

Typically, solutions to this problem fall into three categories. The first is to perform replicate surveys with unique random starting points (Cochran, 1977, Gunderson, 1993). The variance can then be estimated from the deviations in the population estimates around each survey iteration. This approach implies a number of distinct survey efforts that is usually untenable given constraints of resources. The second approach has been to assume that the random start point for the systematic survey approximates and justifies the use of estimators developed for such designs. These estimators have been shown to be biased high with the magnitude of the bias a function of the level of autocorrelation present in the underlying population (D'Orazio, 2003, Rudders (2010 (Appendix 3)), Fewster, 2011). Evidence suggests that while estimates of the mean are actually unaffected and more precise than a random or stratified random design, the variance around that mean is biased and results in computed confidence limits that are wider than they are in reality. The third approach to reconcile this issue is through the construction of alternative variance estimators. Some work had been recently done in this area and falls into approaches to post-stratify the data and extend estimators developed by Wolter (1984) to the two-dimensional case. Rudders (2010(Appendix 3)) examined these estimators via conditional simulation using actual scallop abundance data from dredge surveys to evaluate the relative bias and precision (for mean abundance and variance of the mean) for candidate survey designs. Results indicate that the systematic design performed comparable to simple or stratified random sampling with respect to mean abundance. For the systematic design, all estimators for variance of the mean resulted in some level of bias, although some D'Orazio (2003) estimators did reduce the magnitude of the bias. More recent promising work by Fewster (2011) has developed alternative variance estimators that incorporate the continuous nature of space appear to perform well under a broad range of circumstances. The case most appropriate to the VIMS dredge survey (two dimensional, systematic, quadrat type designs with incomplete detection) is still under development (Rachel Fewster, 2015 personal communication).

As can be seen from formula 2.3, we have traditionally used the variance estimator that results in an overstated variance estimate. Attempts to reconcile that through post-stratification, have improved the results, however bias still exists. This topic is one that is still being worked on and in part has contributed to a proposed change to a stratified random design with unbiased estimators for mean and variance.

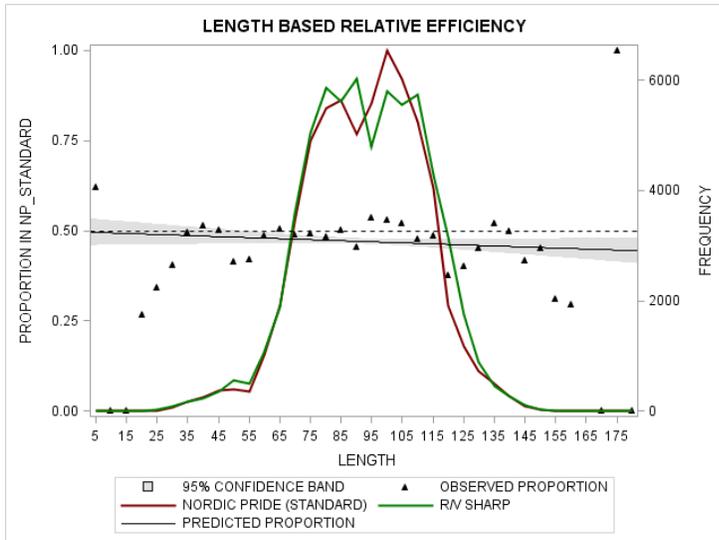


Figure 4.1 Length based relative efficiency between the R/V *Hugh Sharp* and F/V *Nordic Pride*.

The assumption of stationary catchability is one that can be violated when a survey changes protocol. Changing gear, vessels or the use multiple vessels in a survey can potentially introduce a bias to a time series if not accounted for. It is incumbent upon survey operators to examine such changes in a relative sense and apply adjustment if they are warranted. The NMFS Survey Peer Review (ToR1) provides a discussion of early calibration results in the NMFS time series. In 2007 the R/V *Albatross IV* was being retired and at the time no replacement platform for the scallop survey was named. One option was to transition the NMFS dredge survey to commercial platforms. VIMS

proposed and was awarded funding to conduct calibration experiments to provide vessel inter-calibration factors should the survey need to be performed on commercial vessels in the future. The NMFS dredge survey platform was placed on the R/V *Hugh R. Sharp* in 2008, however, there was no ability to perform a calibration between the R/V *Albatross IV* and the R/V *Hugh R. Sharp* due to logistical constraints. The VIMS/Industry calibration experiments represented the only link to the historic time series and an additional experiment was conducted in 2009 with one of the F/Vs that participated in the initial experiment to form a bridge for the NMFS sea scallop time series. It was during this time that the re-designed dredge was instituted.

The results of the two experiments are presented in Rudders, 2010 (Appendix 4), Rudders and DuPaul, 2010 (Appendix 5); and Appendix 6. Consistent with prior calibration efforts, the sea scallop dredge appears to be robust to change in vessel as well as small changes in dredge design. Examining the results from the F/V *Nordic Pride*, the vessel that was consistent across both experiments, relative to the F/V *Albatross IV*, there was some evidence to support differences in dredge design, however the standard dredge design fished almost identically to the R/V *Albatross IV* (+4%). Subsequent experiments between the F/V *Nordic Pride* and the R/V *Hugh R. Sharp* indicate no difference between the two vessels

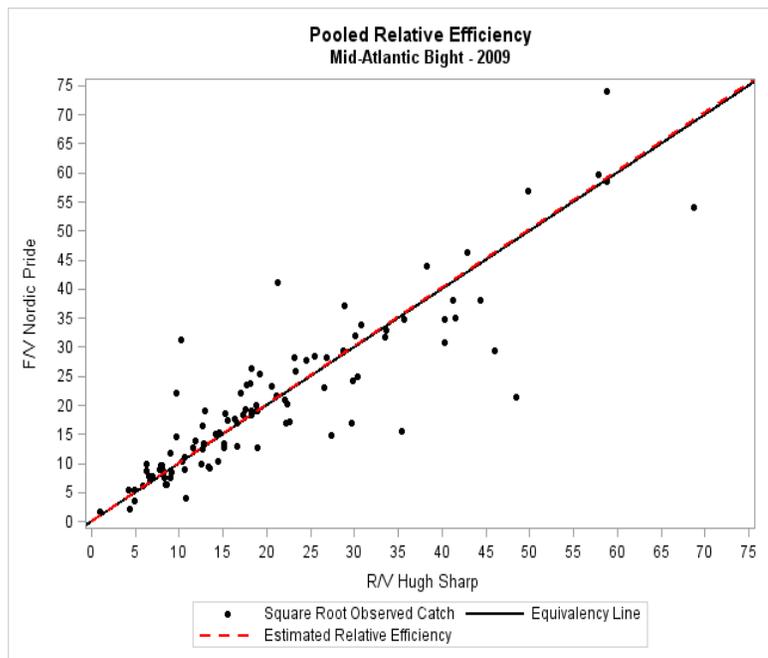


Figure 4.2 Pooled relative efficiency of the F/V *Nordic Pride* and R/V *Hugh Sharp*

fishing the prototype dredge especially after the tow path of the R/V *Hugh R. Sharp* was adjusted to account for the longer tow path as a result of a reinterpretation of the dredge behavior as a function of the winches used on that vessel. There was a slight suggestion of some length based effects (Figure 4.1), but overall numbers of scallops (Figure 4.2) caught were within 1% (Appendix 6). While the evidence across all comparative studies examining fishing power between vessels in sea scallop survey operations suggests that differences are minor, we propose to further examine these effects in 2015 in efforts to establish a new survey framework.

ToR5. Evaluate any proposed methods for integrating and using surveys outside of a stock assessment model for management purposes.

The VIMS dredge surveys have typically endeavored to provide managers with current abundance and distribution information to help set fishery specifications for the following season (a sample presentation of annual VIMS survey data given to the PDT is included as Appendix 7 in the supplemental materials). This data is also used in stock assessment, but the primary objective is to assist in the decision making process for management actions. The Scallop Plan Development Team (PDT) is tasked with synthesizing the available information to be able to make informed decisions. Typically, the PDT is faced with multiple surveys of the same spatial area and the task of how to use all of the information to provide the most accurate biomass estimates. The approaches have included a simple averaging of estimates and an inverse variance weighted approach. Recently, geostatistical approaches have been explored in an effort to develop a method to synthesize information that comes from different survey methods with dissimilar experimental designs (Shank et al, 2015). These efforts are outside the scope of work of an individual survey group and have been the responsibility of the PDT.

In addition to the scallop management weighted use of the data, prior VIMS dredge surveys have also been used to inform other management plans. In 2012 and 2013 VIMS completed dredge surveys of the Northeast Georges Bank region. This area encompasses a spatial management area that had been in place since 1994. Some portions of that area were very productive scallop habitat and the Omnibus Habitat Amendment #2 sought to re-evaluate how habitat was managed in the region. The VIMS survey provided some fine scale data related to the scallop population in that area. We also provided finfish bycatch information as there were several stocks of species of concern whose range was contained in that area (Appendix 8).

ToR6. Comment on potential contribution of each survey to assessments for non-scallop species and use of data apart from assessment purposes such as characterizing species habitat, understanding sea scallop ecology, and ecosystem studies.

Data from the VIMS sea scallop surveys have been used as a data source for the assessment of Georges Bank yellowtail flounder. One analysis that was completed for Transboundary Resource Assessment Committee (TRAC) in 2011 was to examine the relative catches of yellowtail flounder between the commercial and survey gears used (Legault *et. al.*, 2011 (Appendix 9)). There was a desire to use the NMFS sea scallop survey as a time series for this species. There was concern that for yellowtail, the survey dredge may exhibit dome shaped selectivity. The comparative analyses of our paired tow data demonstrated that this was not the case and that yellowtail flounder of >35cm TL were captured with equivalent catchabilities therefore supporting the use of the NMFS dredge time series as an index of yellowtail abundance. An additional analysis of VIMS dredge survey data was undertaken for the 2014 TRAC process (Rudders and Legault, 2014 (Appendix 10)). This analysis examined yellowtail catch data from our surveys of the Georges Bank Closed Area II to assess trends in the population there. This analysis used data across a number of survey years to examine an index of abundance by gear (survey & commercial).

In addition to providing data and analyses for the TRAC process, some of our finfish bycatch information has served to make available baseline abundance and distribution information related to finfish species of concern to the industry who were operating under bycatch caps. These data were presented to industry as data reports in addition to scallop information as well as in conjunction with the SMAST bycatch avoidance program to serve as a starting point for industry vessels for the inception of a rotational area opening (Appendix 11).

See ToR2 for a discussion of the additional sampling completed by the VIMS dredge survey and the potential contribution that it has and potentially can contribute to understanding non-scallop species information and questions related to sea scallop ecology.

ToR7. Comment on the current and/or any proposals for optimal frequency and combination of survey methods.

The sea scallop management plan is currently operating on an annual specification schedule. Given that schedule, annual surveys that provide the most current information to managers represent a significant value. There may be a time when specification packages are for two years, but with the uncertainty in the resource and how the fishery exploits it, coupled with the small spatial subunits that the management strategy operates on, there is significant value to have annual comprehensive coverage with focal area (i.e. rotational areas that may be opening in the following year) that receive increased levels of examination. Given the cost/benefit of these surveys, there is a strong argument for maintaining their regular frequency.

ToR8. Identify future research and areas of collaboration among investigators and institutions.

The suite of methods that are currently used to survey sea scallops represent a diverse toolbox that has the potential answer a diverse array of research questions. These questions are not limited to sea scallops but can be generalized across a range of species and habitats. Given this diversity, these methods serve as a series of confirmatory checks for each other. Dredge surveys play an important role by providing a low-cost, resource assessment tool that can groundtruth optical methods and *visa versa*. This avenue of comparison between the methods is one area where the potential for collaborations exist. The comparison with HabCam and the dredge survey to estimate dredge efficiency is one such example. An additional avenue of research that has great potential is in assessing gear impacts. Some of this work has been completed (re-occupation of VIMS survey tows by HabCam) and additional investigations are currently proposed. A current study involving VIMS and researchers at the University of Delaware involves the estimation of sea scallop incidental mortality as a result of interaction with dredges. This interaction is estimated with a before-after-control-impact experimental design utilizing the precision navigational capabilities of an AUV coupled with a sensor payload that can photograph the extent of the dredge path to enumerate scallops in the tow path but not captured by the dredge.

Sea Scallop Survey Peer Review Report Appendixes

Appendix 1 - VIMS dredge survey operations manual

Appendix 2 – A hisopathological and spatial analysis of conchiolin blisters in sea scallops, *Placopecten magellanicus*, following observations of reduced meat quality and elevated mortality.

Appendix 3 – A Simulation Study to Evaluate Sampling Designs for Highly Autocorrelated Populations: with an Application to Sea Scallop Closed Areas. From: Rudders, 2010. Incorporating Industry Based Dredge Surveys into the Assessment of Sea Scallops, *Placopecten magellanicus*. *College of William and Mary*, 257 pp.

Appendix 4 – Calibrating Industry Vessels to the NMFS Sea Scallop Time Series: Commercial Vessels and the R/V Albatross IV. from: Rudders, 2010. Incorporating Industry Based Dredge Surveys into the Assessment of Sea Scallops, *Placopecten magellanicus*. *College of William and Mary*, 257 pp.

Appendix 5 - Rudders, D.B. and W.D. DuPaul. 2010. Continuing the time series: Calibrating the NMFS sea scallop time series to the R/V *Hugh R. Sharp*. VIMS Marine Resource Report 2010-4. 36pp.

Appendix 6. Continuing the time series: calibrating the NMFS sea scallop survey to the R/V *Hugh R. Sharp*. – a re-estimation due to changes in area swept.

Appendix 7 – An assessment of sea scallop abundance and distribution in the mid-Atlantic Bight. Scallop Plan Develop Team Presentation

Appendix 8 – An inventorty of the sea scallop resource in the Georges bank Closed Area II and surrounds. Habitat Plan Development Team Presentation

Appendix 9 - Yellowtail flounder catch at length by scallop dredges: A comparison between survey and commercial gear. Transboundary Resource Assessment Committee Working Paper 2010/.

Appendix 10 - Yellowtail Flounder Estimates from the VIMS Scallop Dredge Surveys in Closed Area II. Transboundary Resource Assessment Committee Working Paper 2014/.

Appendix 11 SMAST Bycatch Fleet mailing

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