Analysis of ancillary survey data and surfclam fishery tow data for the Georges Shoals Habitat Management Area on Georges Bank and the Great South Channel Habitat Management Area

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The following analysis describes metrics that may be indicative of complex habitat for the region encompassing the Georges Shoals and Great South Channel Habitat Management Areas, maps of these metrics, and an examination of the likelihood that surfclam dredging activities will impact complex habitat in these regions. The analysis is based on ancillary data collected by the NMFS-NEFSC[1] clam survey and data on tow locations provided by vessels in the surfclam fishery.

Data Resources

Surfclam and ocean quahog survey data from 1982 to 2014 were obtained from the primary NMFS-NEFSC assessment database. These data included standardized catch of surfclams and ocean quahogs, haul and gear codes, and, for years after 1999, comments for each tow with a non-zero haul and gear code[2]. Ancillary information on bycatch[3] was obtained from survey data sheets for surfclam and ocean quahog surveys from 1978 to 1999. All of these data sheets were digitized into PDF documents and the data obtained therefrom entered into excel spreadsheets[4]. Additional data from 2002 to 2011 for the ancillary data were obtained from FSCS electronic archives. The 1978 to 1980 surveys were conducted with a much smaller and likely less efficient dredge: comparability to the post-1980 dataset is limited[5]. For this study, the 1978-1980 dataset contained only three tows in the studied domain, so that the limitations of this this database do not significantly influence the analyses presented later in this document.

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[1]National Marine Fisheries Service-Northeast Fisheries Science Center

[2]Simultaneous zero codes for haul and gear indicate that the tow was judged to be unimpaired and useable for assessment purposes.

[3]The term ‘bycatch’ is used on the datasheets to apply to a range of live species, dead shells, and substrate. In addition, certain live species such as scallops, horse mussels, some other clam species, various gastropods, and various crabs were counted; these species were identified by survey species code. In this document, all are considered ancillary to the surfclam and ocean quahog target species and the term bycatch is expanded to include the species counted and recorded by species code.

[4]Complete data files will be provided to NEFSC as soon as all survey tows have been entered for 1978-1999 comprehensively across the survey domain.

[5]Surfclam and ocean quahog working group analyses of the 1978-1980 databases concluded that survey limitations prevented use of this dataset in the survey time series used in benchmark assessments. Stock assessments are based on the 1982-present time series.

Analytical approach

Survey tow locations were specified by the recorded position at the initiation of the tow. Tows with similar initial positions were considered to be replicates. The definition of a replicate was based upon the distance traveled by a *F/V Pursuit* survey tow. The *F/V Pursuit* is the present survey vessel. In this region, the distance of a *F/V Pursuit* survey tow is approximately 0.29 minutes of latitude or 0.39 minutes of longitude. Survey tows initiated within this distance apart were considered to be replicates even if taken in different years. Defining replicates based on the shorter distance for the *R/V Delaware II* survey tows did not materially change the outcome of analyses (see later discussion). In general, the highest value amongst replicates was taken for further analysis. This emphasized the presence of indicators of complex habitat and also retained information on live animals that might not be stable constituents over the 30+ years of the survey time series.

Most non-living variables can be considered to be stable constituents over much, if not all, of the entirety of the survey time series. For shells, for example, taphonomic[6] loss rates are low for surfclam and ocean quahog shells and likely to be low for clam species of lesser volumetric contribution. Stability over time would not be the case for live animals, all but one of which has a life span less than the survey time series[7] and so would be expected to vary in their presence and extent of occupation of any particular location throughout the time series. The presence of temporally more ephemeral living components should be interpreted to indicate the potential for occupation of a site, not the expectation of continual occupancy. Regardless, no temporal variations have been tracked in this analysis.

Haul and Gear Codes

Haul and gear codes encompass a range of incidents, mechanical problems, and miscellaneous misfortunes that might have compromised the tow. Generally, these incidents fell into two broad categories: issues associated with the proper functioning of the dredge itself and issues associated with bottom type that might compromise a successful tow. Our focus was on the latter set of incidences. Unfortunately, the haul and gear codes used by NMFS-NEFSC were developed for the trawl survey; thus, an analysis was required to determine how these codes were applied to clam dredge hauls and the degree of consistency in that application across surveys.

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[6]Taphonomy is the process by which skeletal material deteriorates after death. Taphonomic processes include breakage, abrasion, dissolution, bioerosion, maceration, etc.
[7]The exception is *Arctica islandica*.

This analysis relied on annotations for each of these tows in the survey database for the period 2002-2014. Unfortunately, no annotations occur in the survey database prior to 2002.

In order to investigate the consistency and meaning of haul and gear codes, the data for 2002-2014 were sorted by haul and gear code combination and comments were examined. Haul and gear codes were restricted to the recording of a single prejudicial type of occurrence, hence many haul and gear code combinations exist. A total of nine combinations of haul and gear codes indicated problems with the tows stemming from bottom obstruction (e.g. damage to the dredge or location dropped from the survey after scouting bottom). These events were consolidated into one of three categories: 1.) locations where "bad bottom" was identified, such that the dredge was not deployed; 2.) locations where dredge damage occurred, including broken nipples, broken or bent knife blades, torn hoses, or damage to the dredge frame; and 3.) locations where rocks were caught by the dredge in sufficient number to be judged to have compromised the tow, but which did not cause significant/any damage to the dredge. Dredge damage of the sort identified under (2) typically would occur if the dredge encountered large immovable objects such as boulders or during capture of large rocks and boulders.

Tows for surveys from 2002-2014 could be assigned to the above three categories without qualification. Unfortunately, with a few exceptions, haul and gear codes were not used predictably over the survey time series and often tows influenced by non-bottom-contact events (e.g., clogged pump, power supply issues) were given haul and gear codes also used for bottom contact events. Thus, earlier tows (1982-1999) with haul and gear codes could rarely be assigned to one of the three categories without qualification. However, for essentially all of these tows, annotations were recorded on the original data sheets. Accordingly, the raw data sheets were examined for tows prior to 2002, for which haul and gear comments were missing. Comments recorded on the raw data sheets permitted extraction of tows falling into the three afore-mentioned categories, so that the entire survey time series was assembled. Plots of these data identify the locations where each of the three incident types occurred.

Bycatch data - substrate

The term 'bycatch' was used in a general way on the 1978-1999 data sheets to apply to a series of materials obtained in the dredge including substrate, shell, and a selection of live animals. Some species of live animals, including surfclams, ocean quahogs, horse mussels, and scallops, were excluded from the bycatch categories given on the data sheets: these species were counted and recorded under their species code.. Bycatch data from 1978 to 1999 was present on each digitized data sheet. Electronic data were available in the FSCS database. Terminology and category were relatively consistent between 1978 and 1982 and essentially identical from 1982 to 2011. Data ceased to be collected at the end of the 2011 survey when the survey transitioned from the *R/V Delaware II* to the *F/V Pursuit*, because the new survey vessel had insufficient berthing to support the scientific complement required for ancillary data collection.

The bycatch data comprise three categories: shell, substrate, and other invertebrates. Information regarding tows where substrate such as gravel, rocks, cobbles, and boulders was present in the haul was extracted into a common database. The category "cobbles" encompassed anything smaller than six inches and larger than gravel, the size of which, however, was not specified. The category "rocks" encompassed material between six and twelve inches and "boulders" were anything larger than twelve inches. Over the history of the survey, the annotations regarding substrate varied considerably. From 1978 to 1980, substrate data were recorded in either liters or bushels. The survey dredge used during this time period was considerably smaller than the dredge used from 1982 to 2011. Due to the extreme variability of recorded data from 1978 to 1980, presence and predominance values were assigned to these data. A value of 0 indicates an absence of a particular substrate (e.g., cobbles). A value of 1 was given to volumes ≤1 bushel or where presence was indicated without a volume given (e.g., "trace" was recorded in the place of a numerical value). A value of 2 was given to any volume >1 bushel.

From 1982 to 1999 substrate data were recorded on the data sheet in terms of check marks (1 check for present and 2 checks for predominant) and categories include gravel as well as finer-grained substrates such as sand, mud, and clay; however, these substrate types are not further defined and would have been retrieved with widely varying efficiency as the particle size was smaller than the dredge liner mesh size. These smaller substrate constituents were not further analyzed in this study as a consequence. The categories "cobble", "rock", and "boulder" were defined by the same sizes as used on the 1978-1980 data sheets. The survey dredge for this time period was larger than the dredge used from 1978 to 1980. Volume of bycatch was routinely recorded, as was the percent composition of the various components. In order to provide more quantitative and consistent values for substrate, the total volume of substrate in bushels was calculated for each tow for the period 1982 to 1999 from the percent of total volume. The total substrate volume was then divided proportionally by the sum of presence and predominance values (i.e. number of check marks) in order to estimate a number of bushels of gravel, cobble, rocks, and boulders. This permitted an estimate to be made of the volume of each constituent present in the dredge. For example, a substrate type listed as 'present' in a tow with a high total substrate volume would have contributed a higher portion of the total catch relative to a substrate type listed as 'predominant', but with a low total substrate volume. For instances where the percent composition for substrate or total bycatch volume was not recorded, the data were entered as presence and predominance values (i.e. number of checks seen on datasheet) because a total substrate volume could not be calculated. These instances were relatively rare, however. In most cases, a volumetric estimate could be made. Using these volumetric estimates, the data were then coded as 0 for absence or <1 bushel, 1 where the volume of a particular category was <30 bushels, and 2 where the volume was ≥30 bushels.

For 2002-2011, substrate absence, presence, and predominance data were entered into FSCS as 0, 1, or 2, respectively. Substrate volumes were given in bushels (2002) or liters (post-2002) and percent composition was recorded in each case. An assumption was made initially that the criteria for presence and predominance were consistent across the transition from data sheets to FSCS files. However, subsequent statistical analysis showed that the substrate volumes recorded in the FSCS database were consistently lower per tow than those values on the pre-2002 data sheets, by a factor of 10. Further investigation, including interviews with people who participated in the survey across the 1999-2002 transition, did not elucidate an explanation for the differential, but evaluation across a series of surveys showed that the differential coincided with the transition from data sheet to FSCS files and that the differential was relatively consistent forwards and backwards in time from that point. To standardize the data, the FSCS substrate volumes were increased by a factor of 10.

The divisions at zero and one bushel and 29 and 30 bushels used to distinguish absent, present, and predominant in the figures and data analyses that follow were obtained by examining the corrected (factor of 10) FSCS data from 2002-2011 where the tows for the entire survey could be analyzed as they were already in electronic format. The median and 75th percentile for all tows was 0 (no substrate larger than gravel collected) for these tows, except for cobbles where the 75th percentile fell near the tail of the distribution. That is, cobbles, rocks, and boulders were rarely encountered by the survey. The value of 30 fell between the 90th and 99th percentiles of all tows for these substrate types except cobbles where it fell close to the 90th

percentile (Table 1). The value 1 fell at or above the 90th percentile of all tows for these substrate types except cobbles where it fell near the 75th percentile (Table 1). Thus, we include as present all tows where at least one bushel of material was obtained and list as predominant the rare tows where 30 or more bushels were obtained.

Table 1. Percentiles of bushel catch per tow for all survey tows taken in 2002-2011.

Substrate constituent	25th percentile	50th percentile	75th percentile	90th percentile	95th percentile	99th percentile
Cobble	0.0	0.0	3.3	42.7	71.3	120.
Rock	0.0	0.0	0.0	8.8	41.6	100.
Boulder	0.0	0.0	0.0	0.0	0.0	47.5

Bycatch data - shell and miscellaneous invertebrates

For shell and other invertebrates, abundance data were entered as presence and predominance values (0, 1, 2) in the FSCS portion of the database. This information was also recorded by check marks on the pre-2002 data sheets (Table 2).

For shell, abundance of shell was recorded in either liters or bushels from 1978 to 1980. Presence and predominance values were then assigned where 0 indicated absence, 1 indicated presence of ≤50% of the total shell volume, and 2 indicated presence of >50% of the total shell volume. From 1982 to 1999, each of the shell types of concern were listed separately and given presence and predominance values seen as check marks on the datasheets. For 2002-2011, the data were retained as entered into FSCS as 0, 1, or 2. An assumption was made that the criteria for presence and predominance were consistent across the transition from data sheets to FSCS files. Interviews of survey personnel were confirmatory.

Analysis of substrate constituents as described earlier was specifically designed to permit between-tow comparisons of quantity. Generally, shell volume as a percentage of total bycatch was recorded for each tow, as it was for substrate constituents. Thus, the afore-described analysis for substrate could be recapitulated for shell. However, our approach was to focus on the relative importance of shell types at each location rather than comparing the absolute quantity across all tows because this provided a relative ranking of the habitat as a function of species preference. Determining whether total quantity was interpretable with respect to the time-averaged intensity of occupation of the site would require further analyses, although the present database may support such an analysis. Thus, we relied on the number of check marks to assign values of 0, 1, and 2 for absent, present, and predominant within-tow for the 1978-1999 portion of the time series. Shells of a series of miscellaneous clams were tracked (e.g., *Astarte, Pitar*). For presentation, we took the maximum value amongst these species (0, 1, 2) and assigned that to the 'Clam shell' category. Many of these species (e.g., *Astarte*) are small enough that the survey dredge selectivity was low. Thus, the presence of these shells is of limited value beyond a presence-absence determination.

Table 2. Bycatch composition. From 1978 to 1980, all shell other than *Arctica*, *Spisula*, and *Placopecten* were placed in a category "Other" and described in a comment. Gravel is not used as a substrate size class prior to 1982. From 1982 on, values are also given for sand, mud, and clay. Interviews with survey personnel determined that the degree of washing of the dredge material varied over the survey time series and tended to increase in later years to speed up on-deck processing. Thus, substrate values for sand, mud, and clay are likely not comparable across surveys and gravel values are in doubt, as the definition of gravel is not given. Cobbles, rocks, and boulders are likely to be consistent across surveys due to the mesh size of the dredge liner used, as would be the larger bivalve species.

Shell	Substrate	Other Invertebrates
Arctica	Gravel	Sponges
Spisula	Cobble (<6")	Sea Squirts
Placopecten	Rock (6-12")	Anemones
Ensis	Boulder (>12")	Barnacles
Astarte		
Veneridae		
Crassostrea		
Gastropoda		
Other		

The four taxa selected from the "Other Invertebrates" bycatch category are epibionts that indicate presence of substrate that is of a size that might be colonized (i.e. anything gravel sized or larger). These four were sponges, tunicates, anemones, and barnacles. Specific species are not identified on the data sheets. As with the shells, a volumetric conversion is provided for most tows; however, our focus once again was on presence/absence and a within-tow evaluation of predominance. Thus, values are assigned based on check marks as 1 for present and 2 for predominant within-tow, as these determinations were provided during the survey on the datasheets or in the FSCS electronic database in the same manner as used for shells. A value for total bionts was calculated as the sum of the four values.

Table 3. Live species composition recorded by species code.

Mercenaria campechiensis
Placopecten magelanicus
Spisula polynyma
Pitar morrhuanus
Venus borealis
Astarte castanea
Modiolus modiolus
Ensis directus
Asteroids *(Asterias spp., Astropecten sp.)*
Limulus polyphemus
Crabs (Cancer borealis, Cancer irroratus, Ovalipes guadalupensis, Ovalipes ocellatus Libinia emarginata, Pagurus)
Gastropods (*Busycon spp., Buccinum undatum, Neptunea decemcostata, Colus stimpsoni, Lunatia heros, Polinices duplicatus, Nassarius*)

Species data - live animals

The numbers per tow for a suite of clams, asteroids, crabs, and gastropods were also recorded by survey species code (Table 3). For 1978 to 1999, data were obtained from data sheets and entered into a common database as the number of individuals. For 2002 to 2011, data regarding the number of individuals were obtained from the NMFS-NEFSC FSCS database. The number of individuals for each species were allocated to three categories and tallied; the categories being: asteroid species, spider crabs and hermit crabs, and gastropods. *Placopecten* and *Modiolus* were retained as separate species. Only *Modiolus* data are included in this study, as this bivalve may be indicative of a potentially important habitat type. Total numbers of *Modiolus* were converted into a qualitative scale of 0, 1, 2, and 3 using 0 for absent, 1-2 individuals per tow for 1 (present), 3-10 individuals per tow for 2 (some), and >10 individuals per tow for 3 (many)[8].

Commercial Tow Data

Track files were obtained from vessels fishing in the Southern New England to Georges Bank region. These vessels use a software product called *P-Sea WindPlot*. All track files were downloaded from these vessels. In some cases, tracks were as old as the late 1990s. Many of these tracks were for trips to locations outside of the two HMAs. That is, the downloaded track

[8]This grouping is based on the observation of hundreds of tows by the lead author. Mussels are rarely observed and the presence of more that 2 in a tow is highly unusual. The lead author has never observed a tow where >10 mussels were obtained. Dredge selectivity for these species is unknown, although large horse mussels, being the size of smaller but still fully-selected surfclams, are likely retrieved with high efficiency.

files were comprehensive of the vessel activities as saved by the Captain/Mate as *P-Sea WindPlot* track files.

The track files consisted of a track name in the header line, followed by a date and then a string of latitudes and longitudes saved as degrees and decimal minutes. No track file included a time stamp with each position, although *P-Sea WindPlot* permits this information to be included if requested. Extraction of the portions of these files that represented periods of fishing using a hydraulic dredge was challenged, therefore, by the absence of a time stamp, as vessel speed is a primary indicator of vessel activity and clam tows are routinely conducted at a vessel speed of 2.8 to 3.5 knots. Besides clam dredge tows, the files also contained tracks recorded while the vessel was steaming and, in some cases, tracks of scallop tows as certain of the captains also operated vessels with scallop permits.

As a consequence of the absence of time stamps, the following procedures were used to excise from the dataset tracks or portions of tracks where the vessel was clearly not involved in clam dredging activities. To be conservative, any ambiguous track was retained, so that the dataset represents vessel activities that include all clam dredge tows, but the dataset also contains some tracks or portions of tracks where the vessel likely was occupied in other activities that could not be clearly distinguished from clam dredge tows.

Initially, the distance traveled between each consecutive pair of positions was calculated and binned in 0.01-km intervals. This resolved three groups of positions. One group represented small changes in position clearly attributable to periods when the vessel was laying to. A second group represented changes in position well in excess of 0.2 km, indicative of steaming. These two groups were excised from the dataset. The third group contained changes in location from one position to the next of 0.13 to 0.18 km.

P-Sea WindPlot permits positions to be recorded at specified time intervals. Typically, captains choosing this option record positions at intervals of 30 sec or 1 min. A 1-min recording interval at about 3.5 knots is consistent with a change in position of about 0.09 nm or 0.16 km. Some vessels recorded a mode of positions about half of these values, consistent with a 30-sec recording interval. Thus, both of these groups of positions were retained for further analysis.

Unfortunately, *P-Sea WindPlot* also permits positions to be recorded at 0.1 nm intervals, an interval also consistent with the above group of positions. Set thusly, the vessel may have been moving at any speed and the recording would generate a mode at 0.10 nm. Initial visualization of tracks retained in this group revealed some tracks that were clearly not clam dredge tows, as they were excessively long and straight, as if the vessel were steaming with a *P-Sea WindPlot* setting to retain positions every 0.1 nm. The ambiguity of an ~0.1 nm change in location between consecutive positions required a further evaluation of the group of tracks with location changes of 0.13-0.18 km.

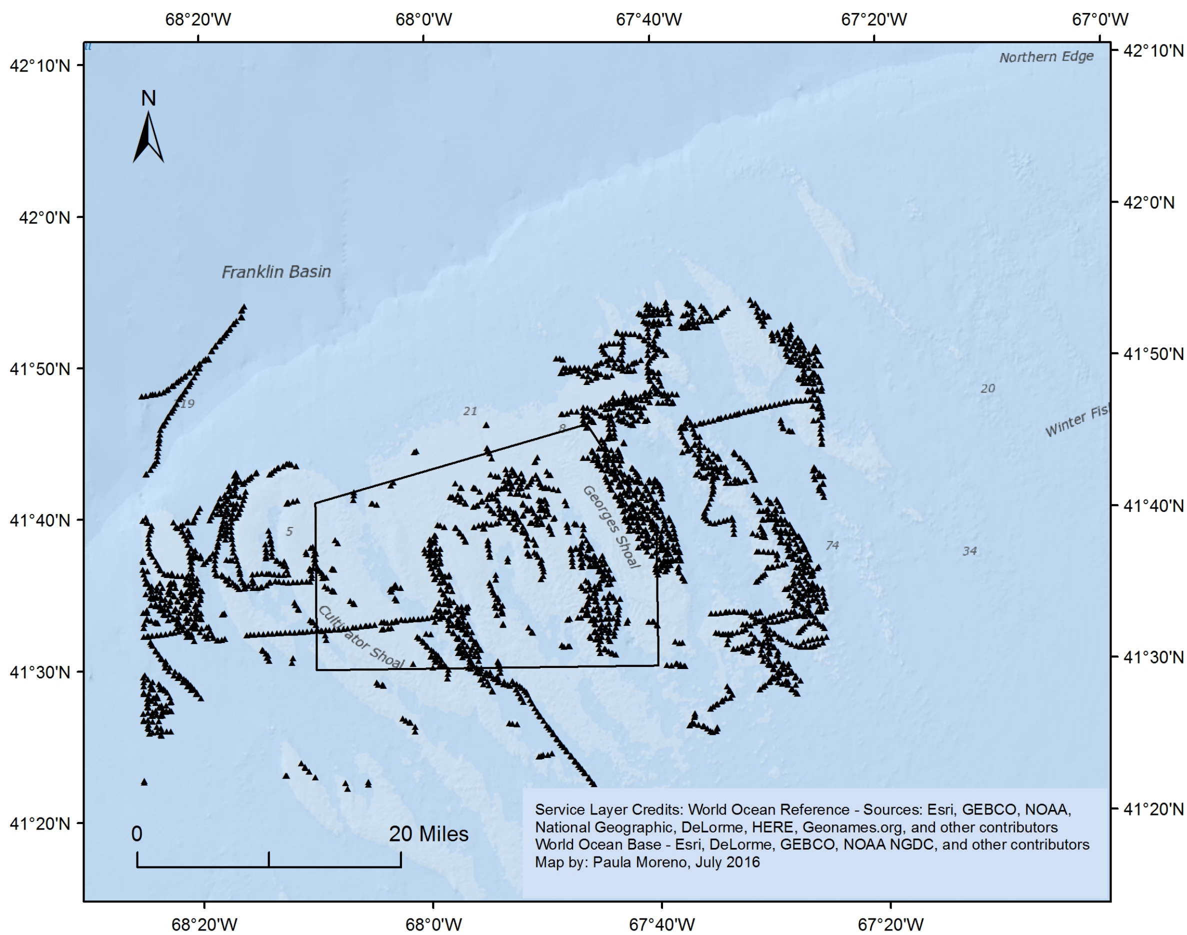
Clam dredge tows rarely exceed 20 min and other activities, such as steaming, typically exceed this time considerably. A 30-min tow at about 3.5 knots covers 1.75 nm. To err on the side of caution, all tow tracks from the final group with a total distance ≤2 nm were retained as likely clam dredge tows. A distance of 2 nm represents a tow time of about 34 minutes which exceeds essentially all clam tow durations.

Captains may carry out multiple tows on one "track", however, so that longer track distances may occur due to multiple tows in a single track file. However, captains never tow sequentially in the same direction for extended periods; thus, long tracks for clam dredge activities will include many changes in direction. Perusal of the remaining tracks in the group with total distances >2 nm fell into two subgroups. In one subgroup, the total track length relative to the straight-line distance from the initial to the final position had a ratio <3. That is, these tracks were nearly linear. In a second subgroup, this ratio was very high, typically >5. The former set of tracks are not tracks produced by clamming activities, whereas the latter group very likely are. The former were excised from the dataset; the latter were retained.

Prior to 2008, no track east of 69° W longitude could have contained clam dredge tracks, as this longitude represented the western boundary of the PSP closure. All of these tracks were excised from the dataset. In 2008, test tows were taken in the closed area pursuant to the eventual opening of Georges Bank. Although such tows were few, all tows taken in 2008 or later that remained in the dataset after the previous excisions were retained.

Figures 1-2 show the locations of dredge tracks accepted under the above constraints as likely or possible clam dredge tows. This dataset is conservative in that it very likely includes all of the clam dredge tracks, but also includes some number of tracks occurring for other vessel activities. In addition, most clam boats will continue to steam at a towing speed between tows while the catch is handled and these time periods may represent a small or large portion of the track. Thus, the dataset is highly conservative in that it very likely includes all periods of bottom contact, but also contains periods when the dredge was not deployed.

Figure 1. Locations of tow tracks in the region of the Georges Shoal HMA that likely or possibly represent clam dredge tows. Each dot represents a 0.29 minutes of latitude by 0.39 minutes of longitude rectangle through which the potential tow traveled and in which bottom contact may have occurred. Some squares were towed through multiple times. The relative frequency of excursions is not provided. Long linear tracks are unlikely surfclam tows, but could not be excluded based on criteria provided in the text.



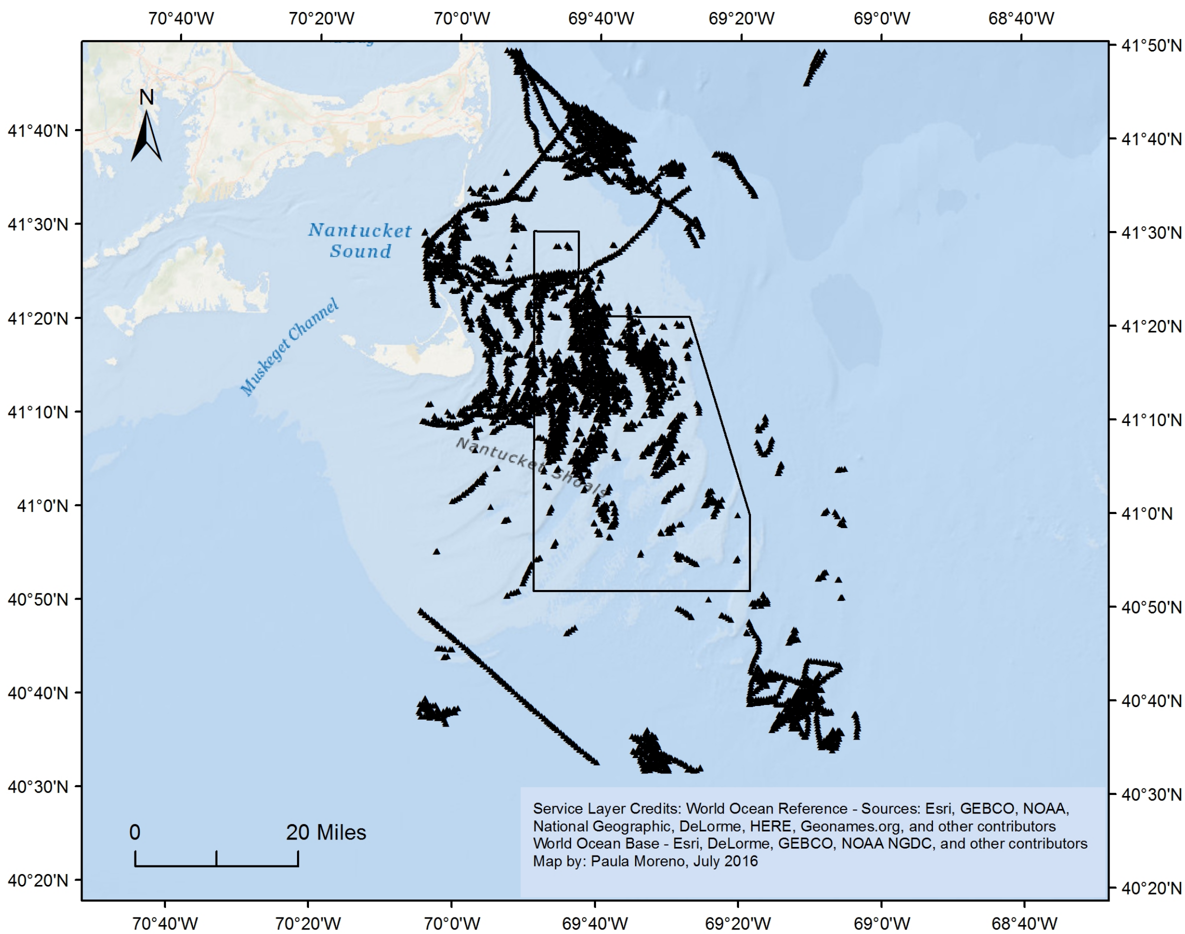
Data analysis

Data analysis focused on identifying the frequency at which survey tows encountered complex habitat and the frequency at which commercial tows intersected locations where survey tows had encountered complex habitat. Throughout, statistical evaluations are based on exact binomial tests for $N < 30$ and a normal approximation to the binomial for $N \geq 30$[9]. Only the southern portion of the Great South Channel HMA was routinely surveyed because survey strata

[9]A useful reference is: Conover, W. J. 1980. Practical nonparametric statistics. New York: John Wiley & Sons. 493 pp.

did not extend into the northern portion (see later discussion). Thus, analysis of this HMA is focused perforce on the southern portion.

Figure 2. Locations of tow tracks in the region of the Great South Channel HMA that likely or possibly represent clam dredge tows. Each dot represents a 0.29 minutes of latitude by 0.39 minutes of longitude rectangle through which the potential tow traveled and in which bottom contact may have occurred. Some squares were towed through multiple times. The relative frequency of excursions is not provided. Long linear tracks are unlikely surfclam tows, but could not be excluded based on criteria provided in the text.



Survey data

Surfclam shells were the predominant shell type over much of both study regions (Figs. A1-A2) indicating that the majority of the region is habitable now or has been habitable by surfclams over recent history. Figures 3-10 show the survey data for the metrics examined in later statistical analyses. Certain additional metrics are provided in the Appendix as Figures A1-A8 for completeness, as they do not substantively influence the subsequent statistical analysis.

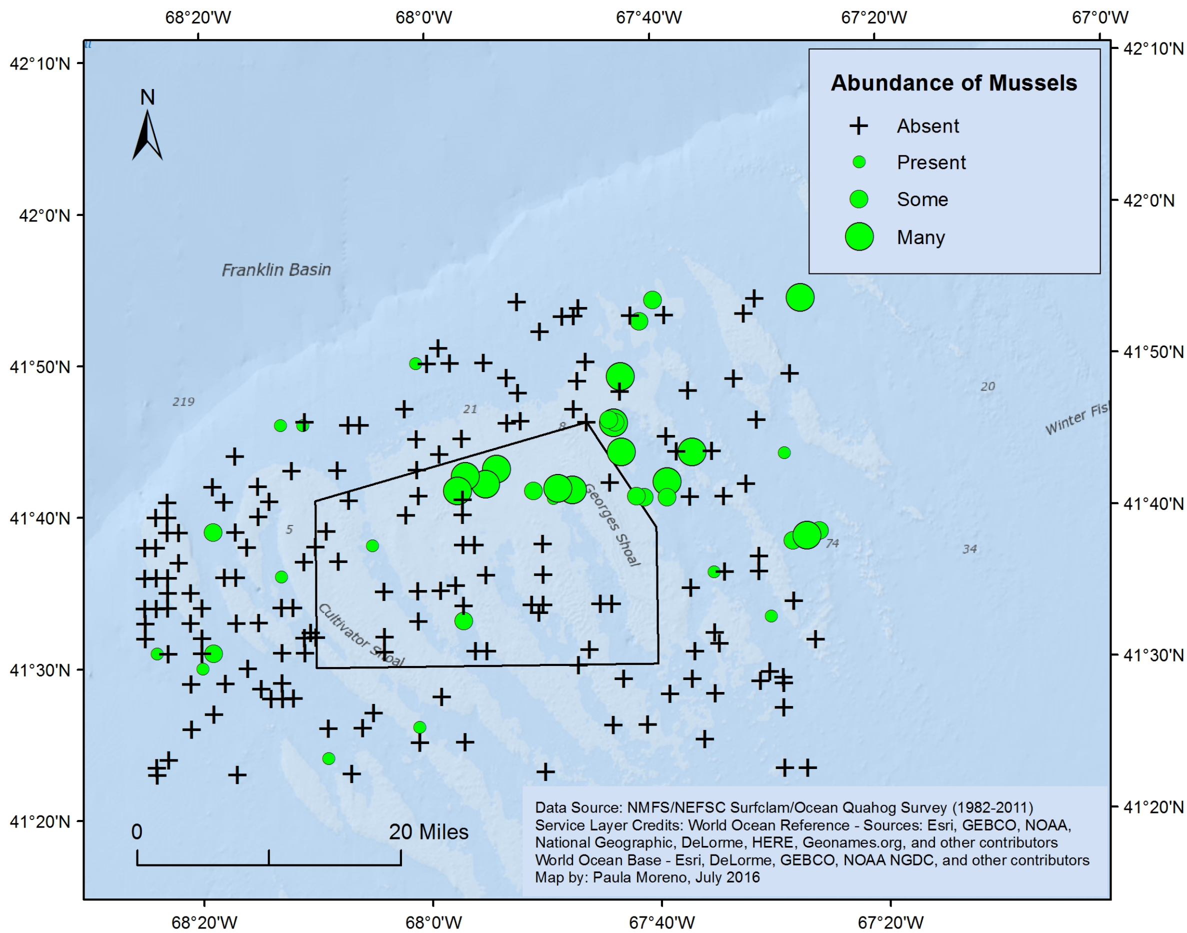
These figures and the figures in the appendix include plots of locations where shell of various types, such as surfclam, ocean quahog, or other species of clams were found, locations of gear damage, locations where cobbles, rocks, or boulders were encountered, locations where attached bionts were collected, and locations where other living bivalves were collected, particularly horse mussels.

Analysis was conducted in two stages. In one case, we looked at just the confines of the HMA. However, this restricts analysis unduly in some cases because an important question is the likelihood of clam dredging impacting complex habitat and clam dredging activities cross the HMA boundaries. We, therefore, enlarged the domain for some analyses to include twice the maximum north-south and east-west area determined by the range of latitudes and longitudes for the HMA corner markers.

The quantity of survey data encompassed by this region varied modestly between metrics as certain metrics were missing from a few stations. However, for most metrics, the total number of survey stations in the Georges Shoal HMA expanded domain was 206, excluding a few replicate tows, as earlier defined, from the tally. These stations were *R/V Delaware II* survey tows of approximately 231.3 m length or a swept area of 352.8 m^2. Thus the information came from 206 towed locations with a swept area of approximately 72,677 m^2, again excluding replicate tows. The Great South Channel HMA encompassed 186 tows, excluding replicate tows, with an approximate total swept area of 65,621 m^2.

Plots of the primary metrics used in the analysis are provided in Figures 3-10. Analysis focused on metrics that indicated the potential for complex habitat that might be damaged by dredging activities. For the Georges Shoals plots provided, the domain which encompasses the area as shown contains 206 survey locations (defined by the length of an *F/V Pursuit* tow) of which 71 recovered some combination of predominant catches of horse mussels, cobbles, rocks, or boulders, attached bionts, or for which gear damage occurred. These were identified by having one or more of the following: mussel numbers at level 3 ($\geq$ 10/tow: Figs. 3-4), cobbles, rocks, or boulders predominant (level 2 – Figs. 5-6), attached bionts at levels 2-3 (Figs. 7-8), and any degree of dredge damage (levels 1-3: Figs. 9-10). Accordingly, 34.5% of the tows occurred in potentially complex habitat. Reducing the definition of a replicate tow to tows taken within a distance equivalent to the length of an *R/V Delaware II* tow modestly increases both counts (210 and 74, respectively) as a few tow pairs occur in the database that would be defined as replicates based on the larger distance scale, but as separate tows based on the alternative smaller distance scale. The larger distance scale is retained because subsequent evaluation of the frequency of commercial tow intersections with survey locations is maximized at this scale

Figure 3. Locations in the Georges Shoal HMA region where horse mussels were present in NMFS-NEFSC clam survey tows. Present: 1-2. Some: 3-10; Many: >10.



Only the southern portion of the Great South Channel HMA was routinely surveyed. For the domain as a whole, including the under-sampled northern portion, 186 survey tows were taken (defined by the length of an *F/V Pursuit* tow) of which 30 recovered some combination of predominant catches of horse mussels, cobbles, rocks, or boulders, attached bionts, or for which gear damage occurred. Reducing the cell size to the length of an *R/V Delaware II* tow modestly increases the first count, but not the second (193 and 30, respectively) as a few "replicates" occur in the database when survey locations are defined at the larger scale. Accordingly, 16.1% of the tows occurred in potentially complex habitat. Restricting the domain to the region routinely surveyed by NMFS reduces the number of survey tows to 162 tows, of which 20, 12.3%, engaged complex habitat. Thus, 87.1% of the survey tows are in the lower approximately one-half of the HMA.

Figure 4. Locations in the Great South Channel HMA region where horse mussels were present in NMFS-NEFSC clam survey tows. Present: 1-2. Some: 3-10; Many: >10.

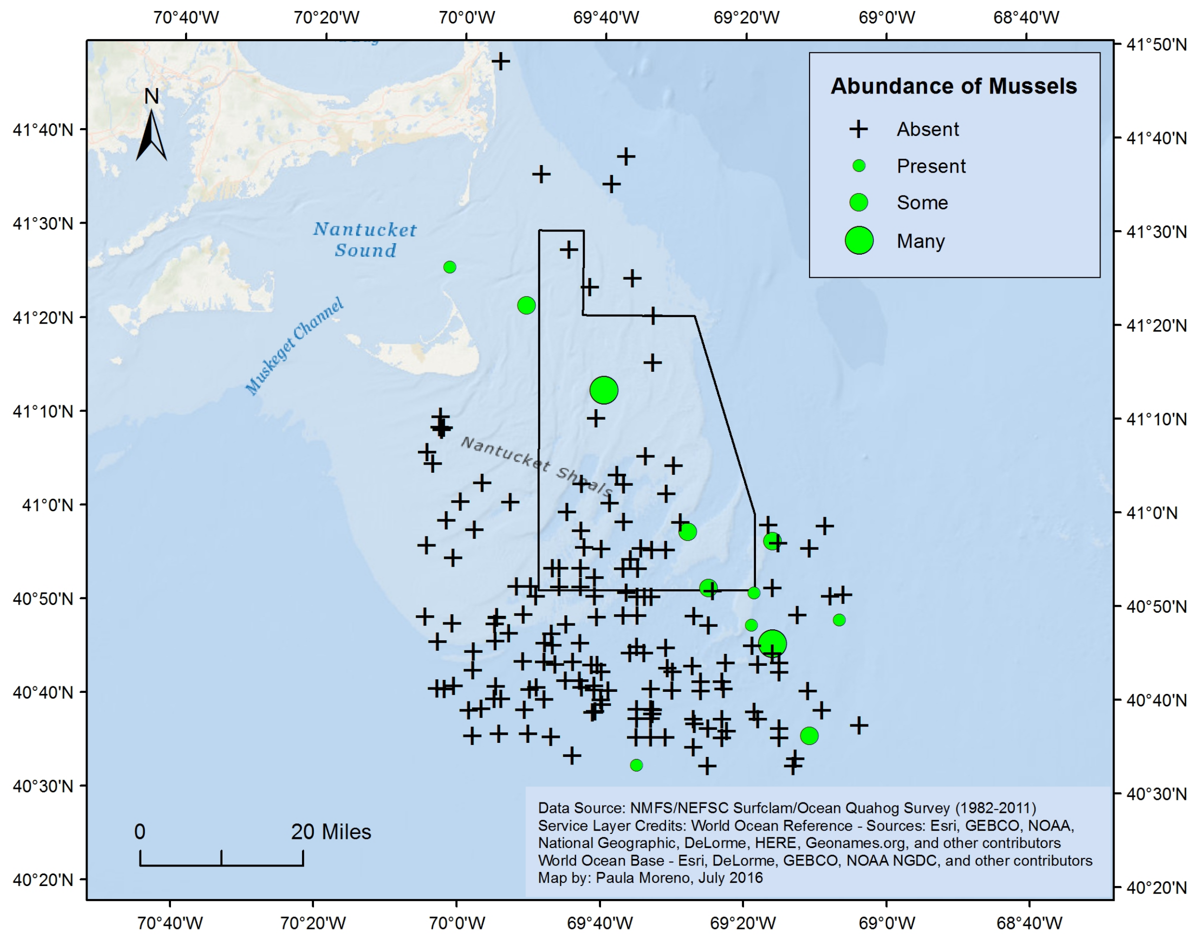


Figure 5. Locations in the Georges Shoal HMA region where cobbles, rocks, and boulders were present in NMFS-NEFSC clam survey tows. Present: 1-29 bushels. Predominant: ≥30 bushels. Locations where none of these particle types were retrieved are not shown for clarity. Locations of all survey tows are shown in Figures 3-4, 7-8 and most subsequent figures.

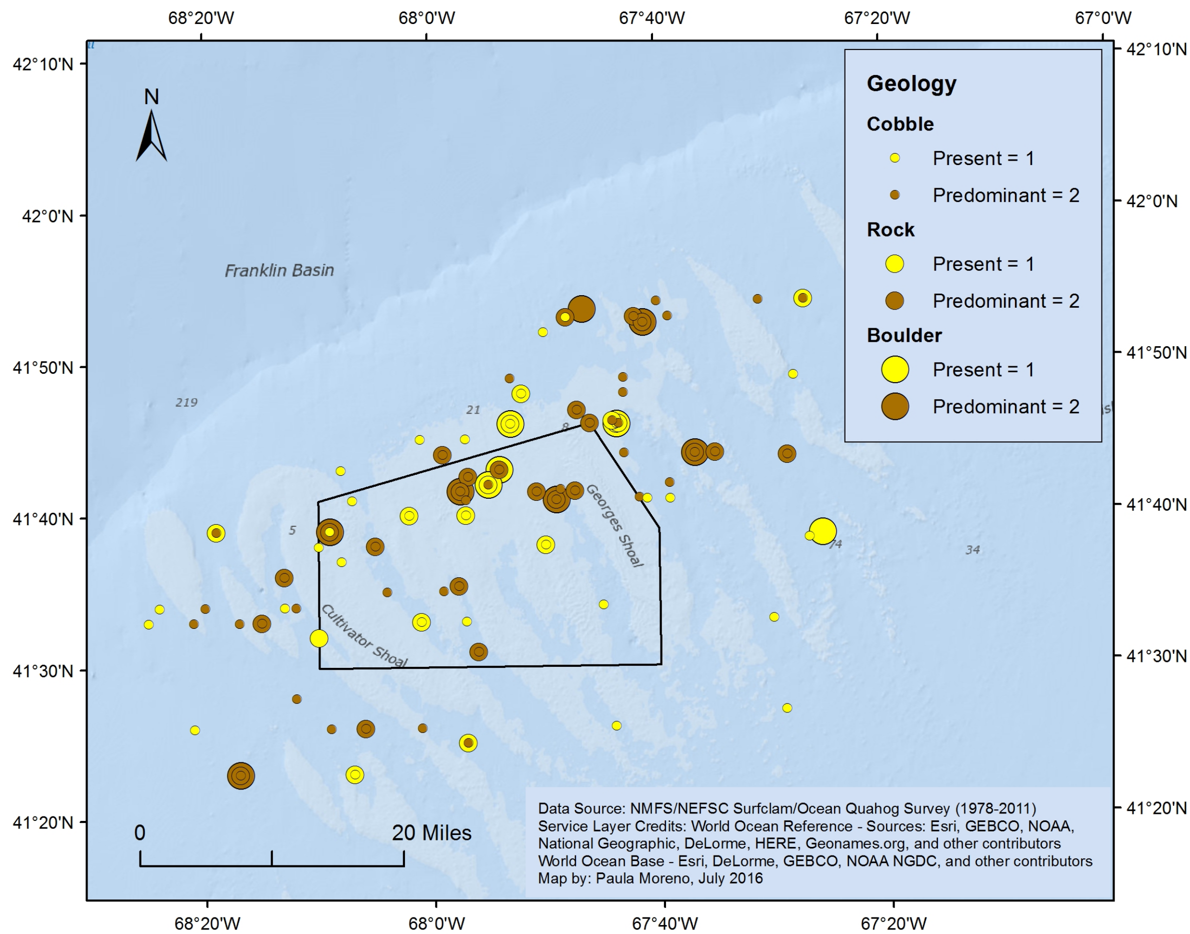


Figure 6. Locations in the Great South Channel HMA region where cobbles, rocks, and boulders were present in NMFS-NEFSC clam survey tows. Present: 1-29 bushels. Predominant: ≥30 bushels. Locations where none of these particle types were retrieved are not shown for clarity. Locations of all survey tows are shown in Figures 3-4, 7-8 and most subsequent figures.

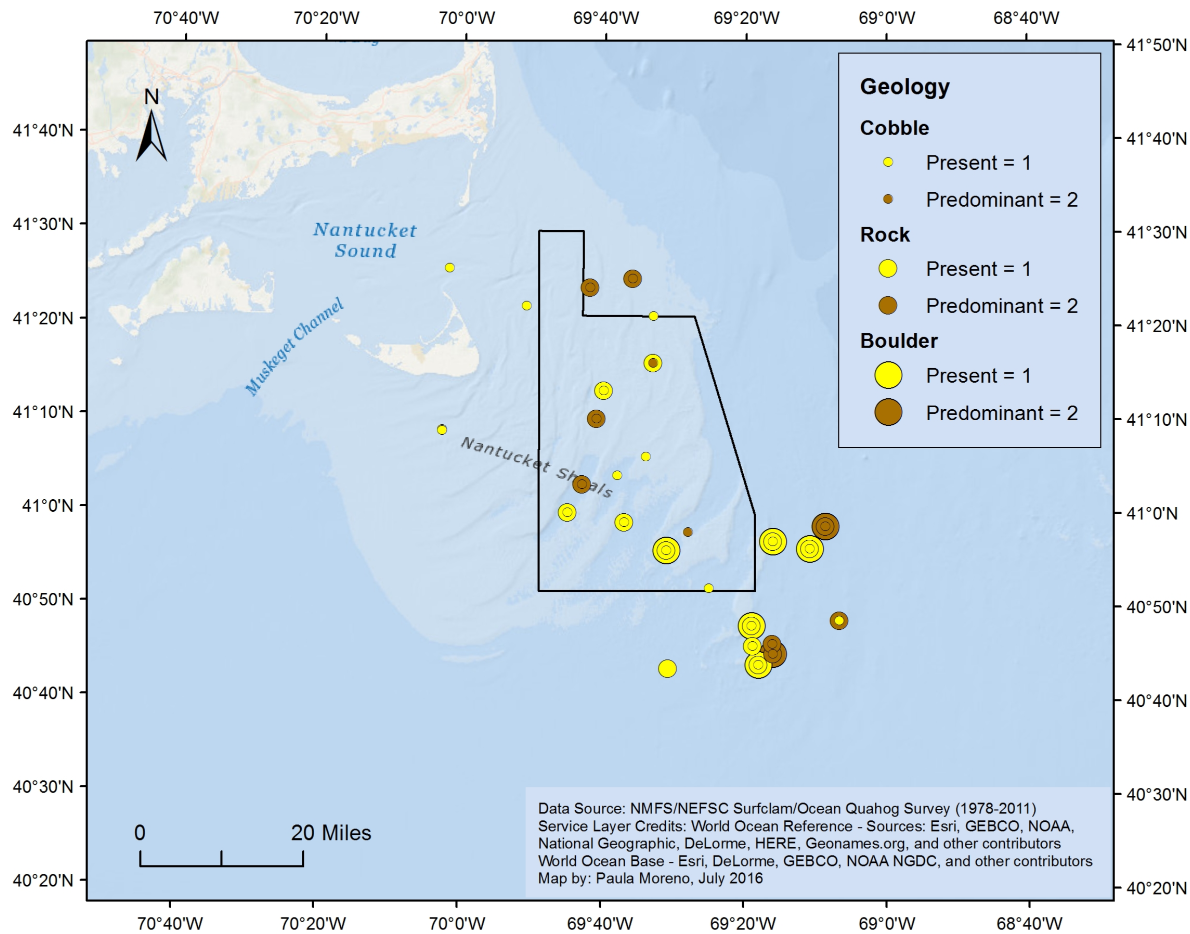


Figure 7. Locations in the Georges Shoal HMA region where attached bionts were present in NMFS-NEFSC clam survey tows. Numbers represent the sum of the survey indices for anemones, barnacles, sponges, and tunicates with a value given for each of 1 for "present" and 2 for "predominant".

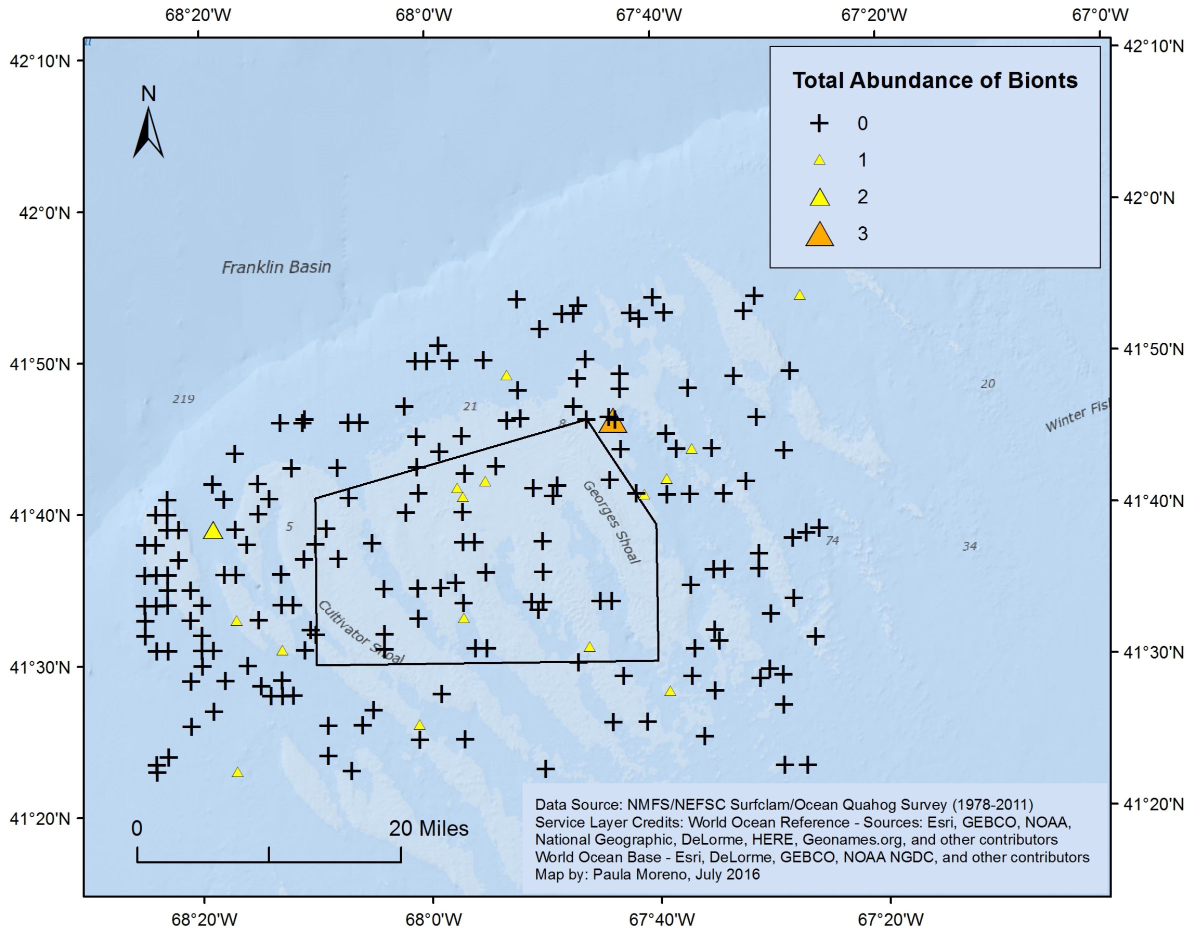


Figure 8. Locations in the Great South Channel HMA region where attached bionts were present in NMFS-NEFSC clam survey tows. Numbers represent the sum of the survey indices for anemones, barnacles, sponges, and tunicates with a value given for each of 1 for "present" and 2 for "predominant".

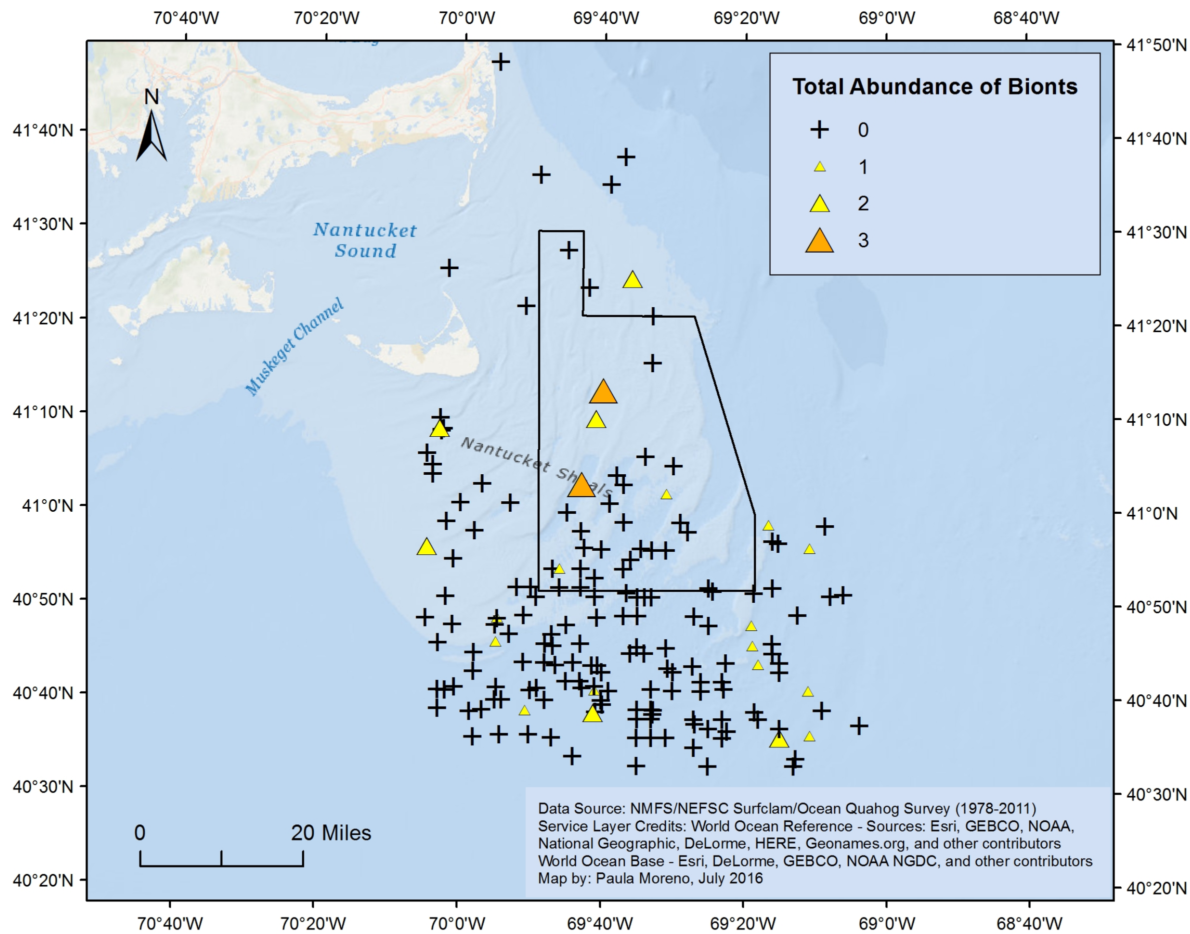


Figure 9. Locations in the Georges Shoal HMA region where dredge damage occurred in NMFS-NEFSC clam survey tows, where the tow was abandoned due to untowable bottom, or where the dredge was retrieved nearly full of rocks/boulders. Tows without any of these three conditions are not plotted, for clarity. Locations of all survey tows are shown in Figures 3-4, 7-8 and most subsequent figures.

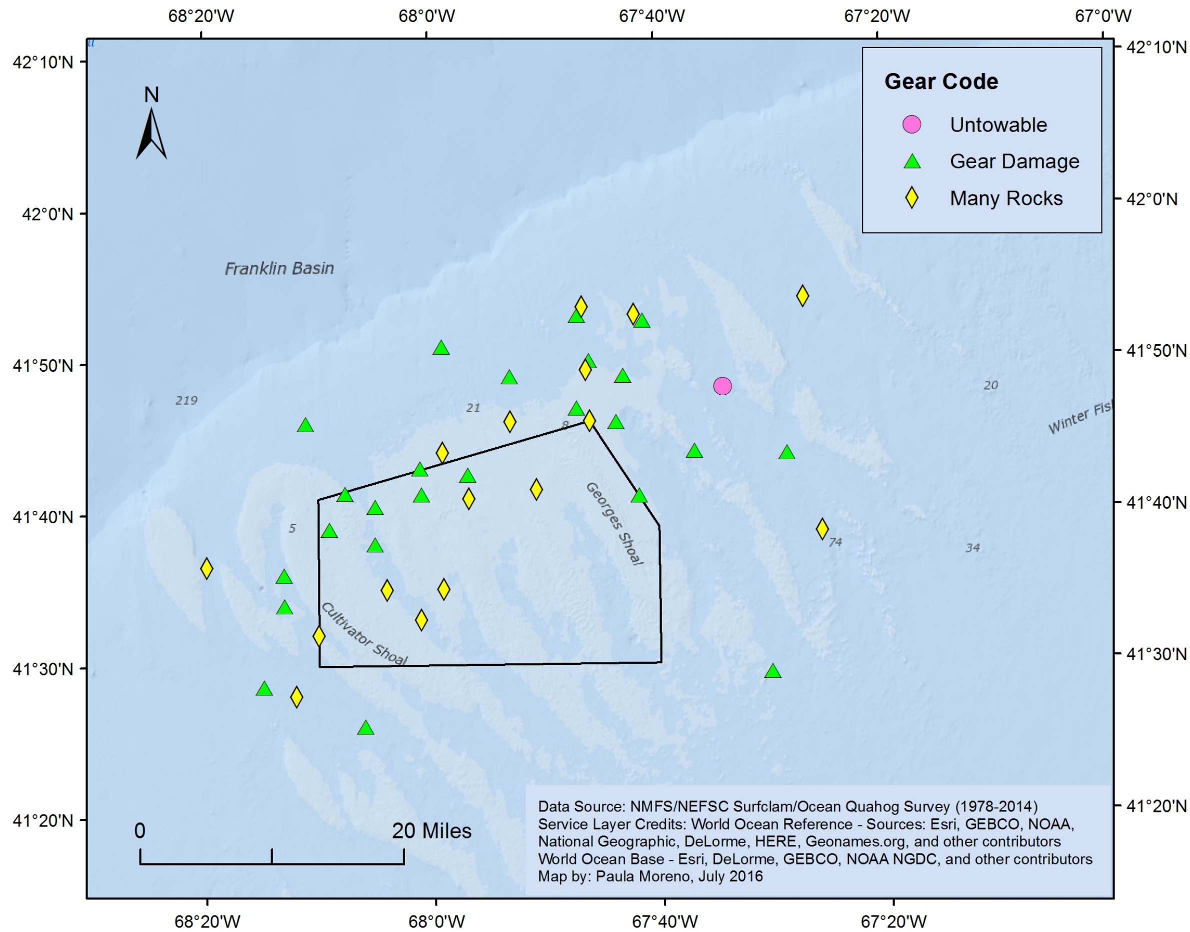
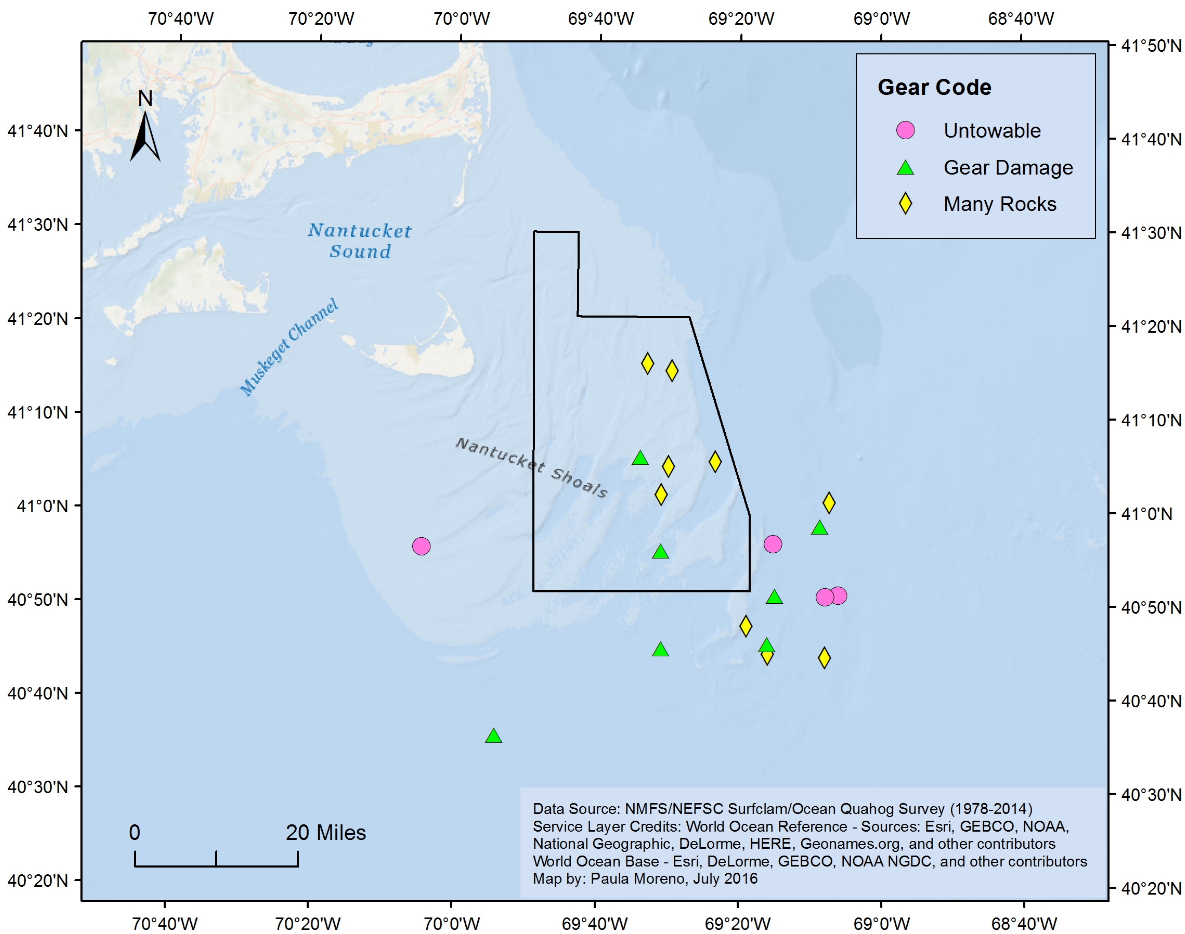


Figure 10. Locations in the Great South Channel HMA region where dredge damage occurred in NMFS-NEFSC clam survey tows, where the tow was abandoned due to untowable bottom, or where the dredge was retrieved nearly full of rocks/boulders. Tows without any of these three conditions are not plotted, for clarity. Locations of all survey tows are shown in Figures 3-4, 7-8 and most subsequent figures.



Tow Probability – Georges Bank

The NMFS stations can be considered to represent a random sampling of the two HMAs, bearing in mind the poverty of stations north of 41° N in the Great South Channel HMA. The industry tow locations were mapped over this random set of data and intersections tallied. Industry tows intersected survey sites 182 times in the Georges Shoal HMA domain. Here, intersection is defined as a commercial tow position[10] and the initiating position of a survey tow falling within 0.29 minutes of latitude and 0.39 minutes of longitude or each other, the earlier

[10]A survey tow position as used herein is a single event recorded in a *P-Sea WindPlot* track file.

defined distance of a *F/V Pursuit* survey tow. Of these 182 intersections, 48 intersected survey tows that were located on complex habitat (Figure 11). A binomial test showed that the probability of 48 intersections in complex habitat occurring by chance out of 182 intersections was 0.011. That is, industry tows intersected complex habitat significantly less often than expected by a random encounter based on the prevalence of complex habitat as deduced from the survey time series. A perusal of the source of the 48 intersections meriting attention shows that 28 of the 48 intersections occurred in locations where the only indication of complex habitat was cobbles. Cobbles are commonly encountered in coarse sands, so that the mere presence of cobbles is a poor indicator of habitat complexity. Excluding these locations, a binomial test showed that the probability of a tow encountering complex habitat is 1.3×10^{-11}. That is, excluding tows where only cobbles were encountered, industry tows very rarely intersect complex habitat even in a location where 34.5% of the randomly located survey tows did so. Note that one survey location contributed 18 of the lone cobble intersections and 37.5% of all intersections. Excluding just this site yields an encounter probability of 1.6×10^{-7}. Thus with the exception of one survey location, industry tows rarely encounter complex habitat even if the definition includes locations where the only indication of such is the presence of cobbles.

If the domain is restricted to the Georges Shoals HMA boundary (Table 4), the survey data contained 23 occasions where complex habitat was encountered, as previously defined, out of a total number of stations numbering 47, a probability of encounter of 48.9%. The putative surfclam dredge tows intersected with these locations 54 times, with 13 being encounters of complex habitat as previously defined. This is significantly fewer than what would be expected by chance ($P = 0.00013$). Of the 13 intersections, one site accounts for 5 of the 13 intersections, this site yielding rocks and cobbles. Removing this site drops the probability of intersection by chance to 4.3×10^{-7}.

Figure 11. Locations in the region of the Georges Shoal HMA where putative commercial surfclam tows intersected NMFS-NEFSC survey tow locations that themselves occupied habitat with characteristics that indicated the potential presence of complex habitat based on the presence of attached bionts, live mussels, cobbles, rocks, and/or boulders, dredge damage, and/or a determination of untowable bottom. The number of times that a commercial dredge tow intersected a specific location is specified by the number of hits: the number of hits defines the symbol size. These hits may have occurred on a single tow or multiple tows; certain of them may have occurred when the dredge was not on the bottom (see earlier discussion)

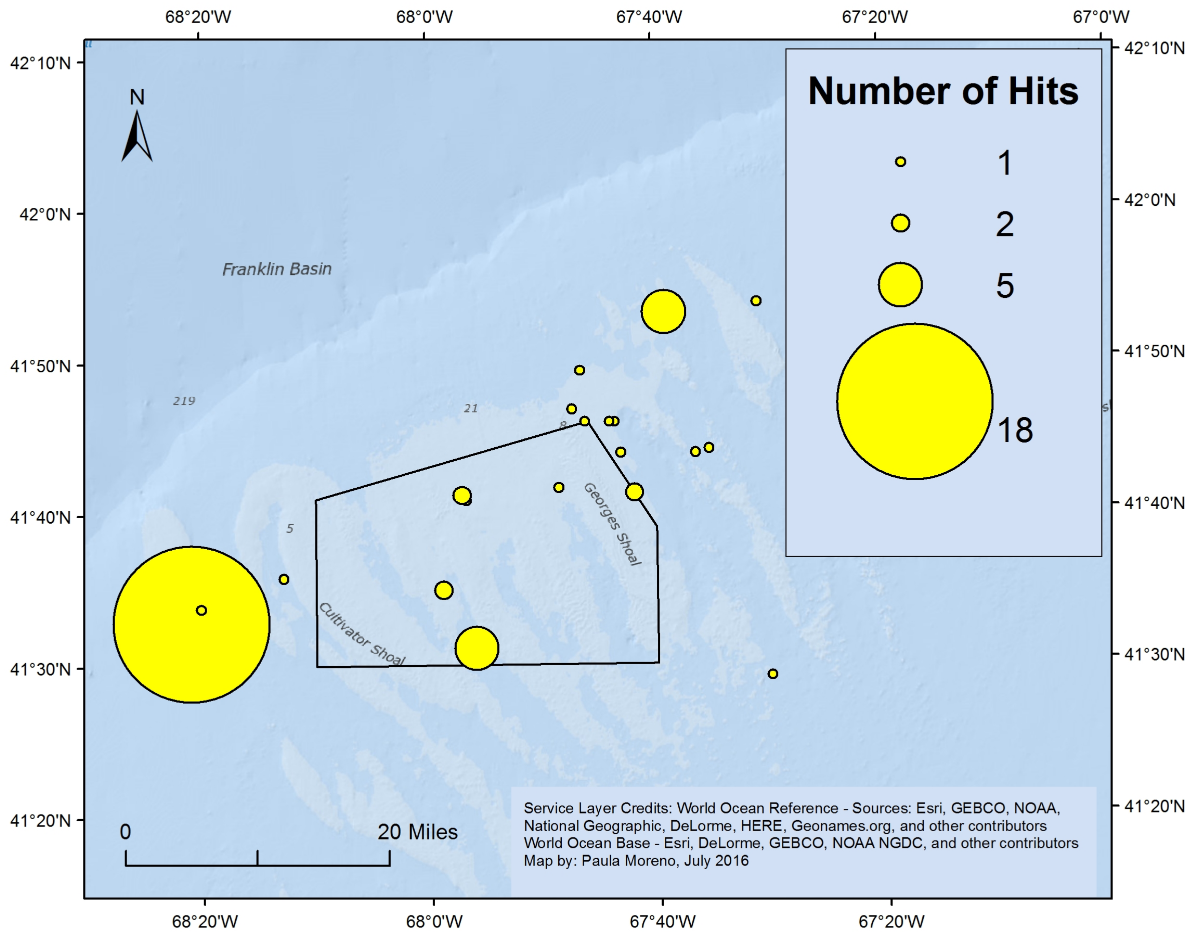


Figure 12. Locations in the region of the Georges Shoal HMA where putative commercial surfclam tows intersected NMFS-NEFSC survey tow locations that themselves occupied habitat with characteristics that indicated the potential presence of complex habitat based on the presence of attached bionts, live mussels, cobbles, rocks, and/or boulders, dredge damage, and/or a determination of untowable bottom. The number of times that a commercial dredge tow intersected a specific location is specified by the number of hits: the number of hits defines the symbol size. These hits may have occurred on a single tow or multiple tows; certain of them may have occurred when the dredge was not on the bottom (see earlier discussion)

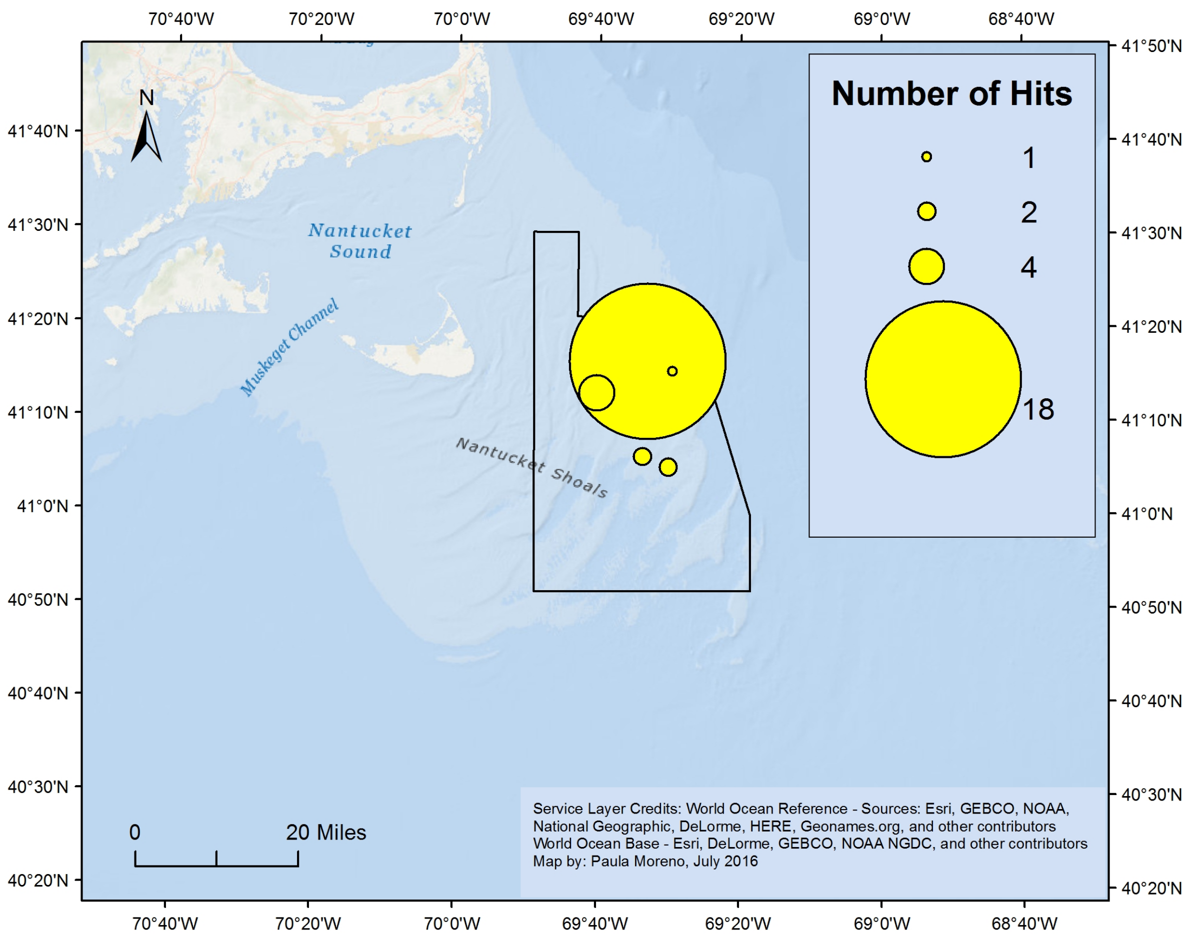


Table 4. Summary of tows in the Georges Shoals region, but outside of the Georges Shoals HMA in which clam dredge tows encountered complex habitat. Category columns show the characteristics of intersected survey tows. Numbers are the values depicted on Figures 3-10.

Number of Intersections	Presence of Mussels	Presence of Cobbles	Presence of Rocks	Presence of Boulders	Attached Bionts	Gear Damage
1						2
5		2	2		0	
18		2				
1		2				
2		2				3
1		2	2			2
1						3
2		2				2
2		2				
1	3	2				
1		2	2			
1	3	2	2	2		2
1	3	2				
1	3				3	2
1		2				
1		2	2			3
1		2	2			2
1						3
5		2				
1		2				

The frequency at which the survey encountered complex habitat within the HMA is significantly higher, 48.9%, versus 30.2% outside of the HMA ($P = 1.2 \times 10^{-6}$) (compare Tables 4 and 5). As the survey occupied locations randomly, the inference is that complex habitat occurs more frequently inside the HMA than in that portion of the region outside included in this analysis (see Figures 3-9 for example). In comparison, the frequency at which commercial tows intersected survey locations having complex habitat within the HMA, 13 of 54, is not significantly different from the intersection rate outside of the HMA, 35 of 128 ($P = 0.20$). That is, although the likelihood that the survey encountered complex habitat inside the HMA is significantly higher than in the figured domain as a whole (e.g. Figures 1-2), the probability of intersection of a commercial clam dredge tow with complex habitat has not changed: the chance of encounter of complex habitat by commercial clamming activities inside the HMA relative to its potential is significantly lower than outside of the HMA. In other words, a commercial clam tow is more likely to intersect complex habitat outside of the HMA in comparison to inside the HMA.

Table 5. Summary of tows inside the Georges Shoals HMA in which clam dredge tows encountered complex habitat. Category columns show the characteristics of intersected survey tows. Numbers are the values depicted on Figures 3-10.

Number of Intersections	Presence of Mussels	Presence of Cobbles	Presence of Rocks	Presence of Boulders	Attached Bionts	Gear Damage
5	0	2	2	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
2	0	2	0	0	0	3
0	0	0	0	0	0	0
1	0	0	0	0	0	3
2	0	2	0	0	0	2
2	0	2	0	0	0	0
1	3	2	0	0	0	0
0	0	0	0	0	0	0

Tow Probability – Great South Channel

The same analysis for the Great South Channel HMA is compromised by the limited number of survey tows in the upper approximately one-half of the region. The following analysis is restricted to the lower approximately one-half which falls within the NMFS survey strata. In this region, the number of survey stations is 162, of which 20 engaged complex habitat, an encounter probability of 0.123 (12.3%). The clam dredge tow dataset contains very few tows in this region; however, of the 24 cases where a tow track intersected a survey station, none occurred in complex habitat. The probability of this occurring by chance is P = 0.043.

Within the HMA boundary in the same subregion, the survey dataset contains 26 tows, of which 4 encountered complex habitat, an encounter probability of 0.154 (15.4%). Only one occurrence exists where a clam dredge tow intersected a survey tow and this one did not occur in complex habitat. Outside of the HMA boundary, dredge tracks intersected survey tows 23 times. The rate of encounter of complex habitat by the NMFS survey is 0.118 (11.8%). None of the 23 clam dredge tow intersections occurred with the 11.8% of the survey tows that encountered complex habitat. The probability of zero intersections occurring by chance is 0.057. Thus, the limited data available suggest that clam dredge tracks rarely encounter complex habitat in this region, but then complex habitat also is rarely encountered in this region. This result is consistent with the analyses of the Georges Shoals HMA, in that, in both cases, commercial clam dredge tracks very rarely intersect complex habitat; however, the much higher frequency of complex habitat in the Georges Shoals HMA provides a statistically more robust evaluation of the degree to which commercial clamming activities intersect complex habitat. This frequency of intersection is very low

Appendix: Additional Data Plots

Figure A1. Locations in the Georges Shoal HMA region where surfclam shells were obtained in NMFS-NEFSC clam survey tows. Present and predominant represent onboard qualitative appraisals relative to the entire catch of material and relative to other survey tows

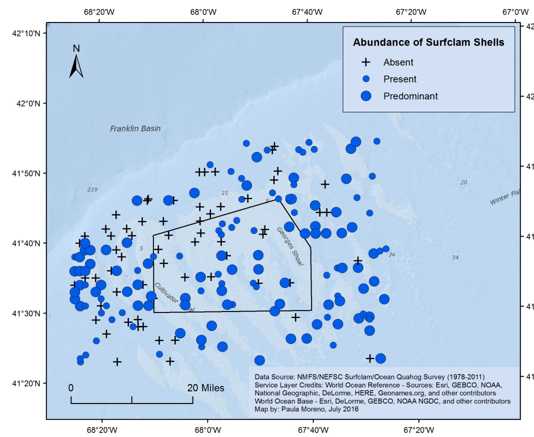


Figure A2. Locations in the Great South Channel HMA region where surfclam shells were obtained in NMFS-NEFSC clam survey tows. Present and predominant represent onboard qualitative appraisals relative to the entire catch of material and relative to other survey tows.

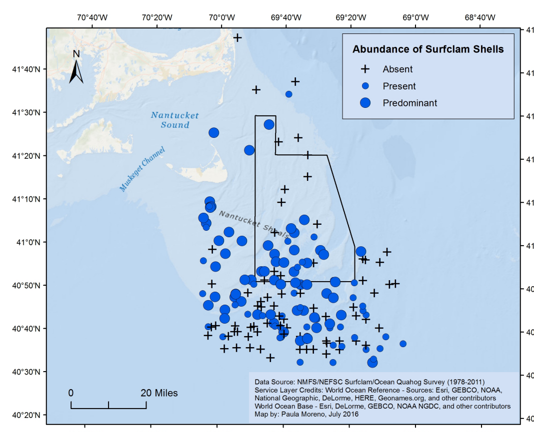


Figure A3. Locations in the Georges Shoal HMA region where ocean quahog shells were obtained in NMFS-NEFSC clam survey tows. Present and predominant represent onboard qualitative appraisals relative to the entire catch of material and relative to other survey tows

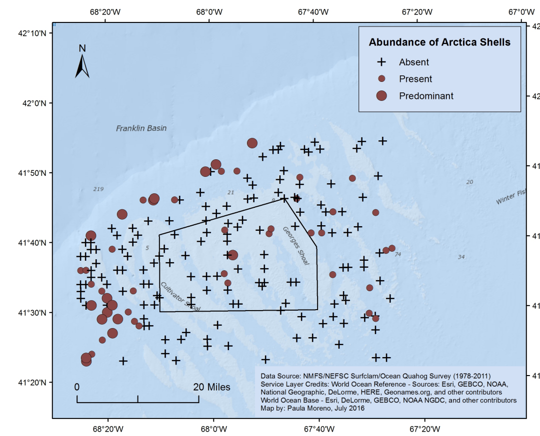


Figure A4. Locations in the Great South Channel HMA region where ocean quahog shells were obtained in NMFS-NEFSC clam survey tow,. Present and predominant represent onboard qualitative appraisals relative to the entire catch of material and relative to other survey tows

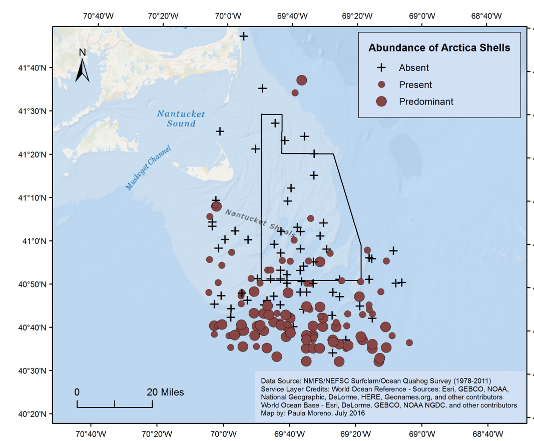


Figure A5. Locations in the Georges Shoal HMA region where scallop shells were obtained in NMFS-NEFSC clam survey tows. Present and predominant represent onboard qualitative appraisals relative to the entire catch of material and relative to other survey tows

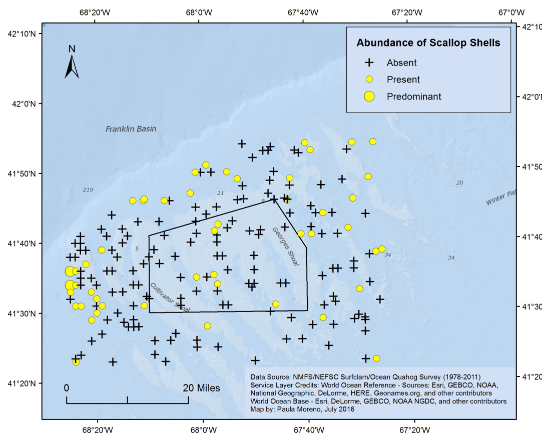


Figure A6. Locations in the Great South Channel HMA region where scallop shells were obtained in NMFS-NEFSC clam survey tows. Present and predominant represent onboard qualitative appraisals relative to the entire catch of material and relative to other survey tows

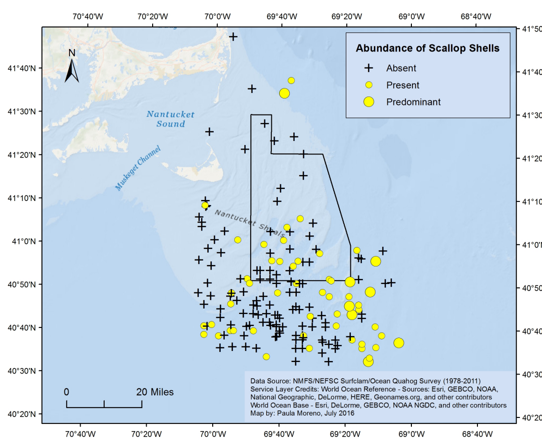


Figure A7. Locations in the Georges Shoal HMA region where other bivalve shells (various other clam species and oysters) were obtained in NMFS-NEFSC clam survey tows. Present and predominant represent onboard qualitative appraisals relative to the entire catch of material and relative to other survey tows. Values of 1 and 2 represent the sum of evaluations of present (1) and predominant (2).

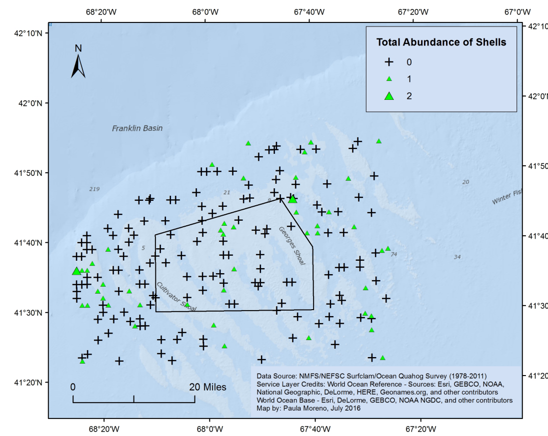


Figure A8. Locations in the Great South Channel HMA region where other bivalve shells (various other clam species and oysters) were obtained in NMFS-NEFSC clam survey tows. Present and predominant represent onboard qualitative appraisals relative to the entire catch of material and relative to other survey tows. Values of 1 and 2 represent the sum of evaluations of present (1) and predominant (2).