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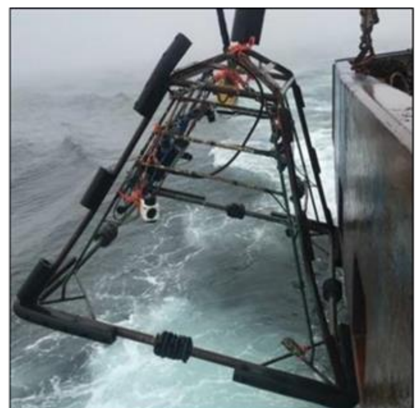
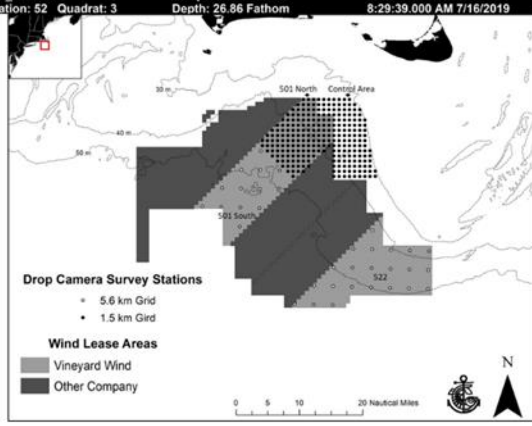
Final Report

2019 Drop Camera Survey of Benthic Communities and Substrate in Vineyard Wind Lease Area OCS-A 0522 Study Area





Submitted to:
Vineyard Wind LLC
700 Pleasant Street
New Bedford, MA 02740

January 2020 **SMAST-CE-REP-2020-075**

Final Report

2019 Drop Camera Survey of Benthic Communities and Substrate in Vineyard Wind Lease Area OCS-A 0522 Study Area

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SMAST-CE-REP-2020-075

Project Summary: The University of Massachusetts Dartmouth School for Marine Science and Technology (SMAST) conducted drop camera surveys to examine the benthic community and substrate in Vineyard Wind’s Outer Continental Shelf (OCS) Lease Area OCS-A 0522 (522 Study Area). The primary goal of this project was to collect preliminary data to help determine the sampling intensity needed to collect enough baseline data for environmental assessment of windfarm development impact. Our objectives were to provide:

1) distribution and density estimates of dominant benthic megafauna and,
2) classify substrate across the survey domain.

We utilized a centric systematic sampling design to sample 22 stations in the 522 Study Area. Stations in were placed 5.6 km apart following a grid design. At each station a sampling pyramid was deployed, and a high-resolution camera was used take four quadrats (2.3 m^2 images) samples. The area was surveyed in July and October 2019 using a commercial scallop vessel to deploy the sampling pyramid. Eighteen different benthic animal groups were observed in the 522 Study Area. The most common groups were similar to the dominant groups in other OCS Study Areas, but sea stars, moon snails, and moon snail eggs cases were observed at higher frequencies. Decreases in animal occurrence in October, except skates, was observed but wide confidence intervals are associated with most estimates. Sand was the substrate type at the majority of stations, but gravel was present at 5 stations during July. In October, only sand was observed.

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Introduction

In 2019, Vineyard Wind LLC leased a 516 km^2 area for renewable energy development on the Atlantic OCS (OCS-A) named Lease Area OCS-A 0522, located south of Nantucket, Massachusetts off the south coast of Massachusetts. Vineyard Wind is conducting fisheries surveys within Lease Area OCS-A 0522 (the "522 Study Area)," which is the focus of this report. Vineyard Wind is also conducting fisheries studies within the northern portion of Lease Area OCS-A 0501 (the "501 North Impact Area"), considered the development area, and within the southern portion of Lease Area OCS-A 0501 (the "501 South Study Area"); these studies are reported separately.

The University of Massachusetts Dartmouth School for Marine Science and Technology (SMAST has developed a minimally invasive, image-based drop camera survey that allows for practical data collection of the epibenthic community without causing a disturbance to the seafloor. The SMAST drop camera survey can be used to better understand benthic macrofaunal community characteristics, substrate habitats, and the spatial and temporal scales of potential impacts on these communities and habitats. The survey techniques were developed collaboratively with scallop (*Placopecten magellanicus*) fishermen and apply quadrat sampling methods based on diving studies (Stokesbury and Himmelman 1993,1995). Initial surveys in the early 2000s focused on estimating the density of scallops within closed portions of the U.S Georges Bank fishery and the survey approach has since expanded to cover most of the scallop resource in U.S. and Canadian waters (≈100,000 km^2, Figure 1). Information from the survey has been incorporated into the scallop stock assessment through the Stock Assessment Workshop process and reliably provided to the New England Fisheries Management Council to aid in annual scallop harvest allocation (NEFSC 2010, 2018).

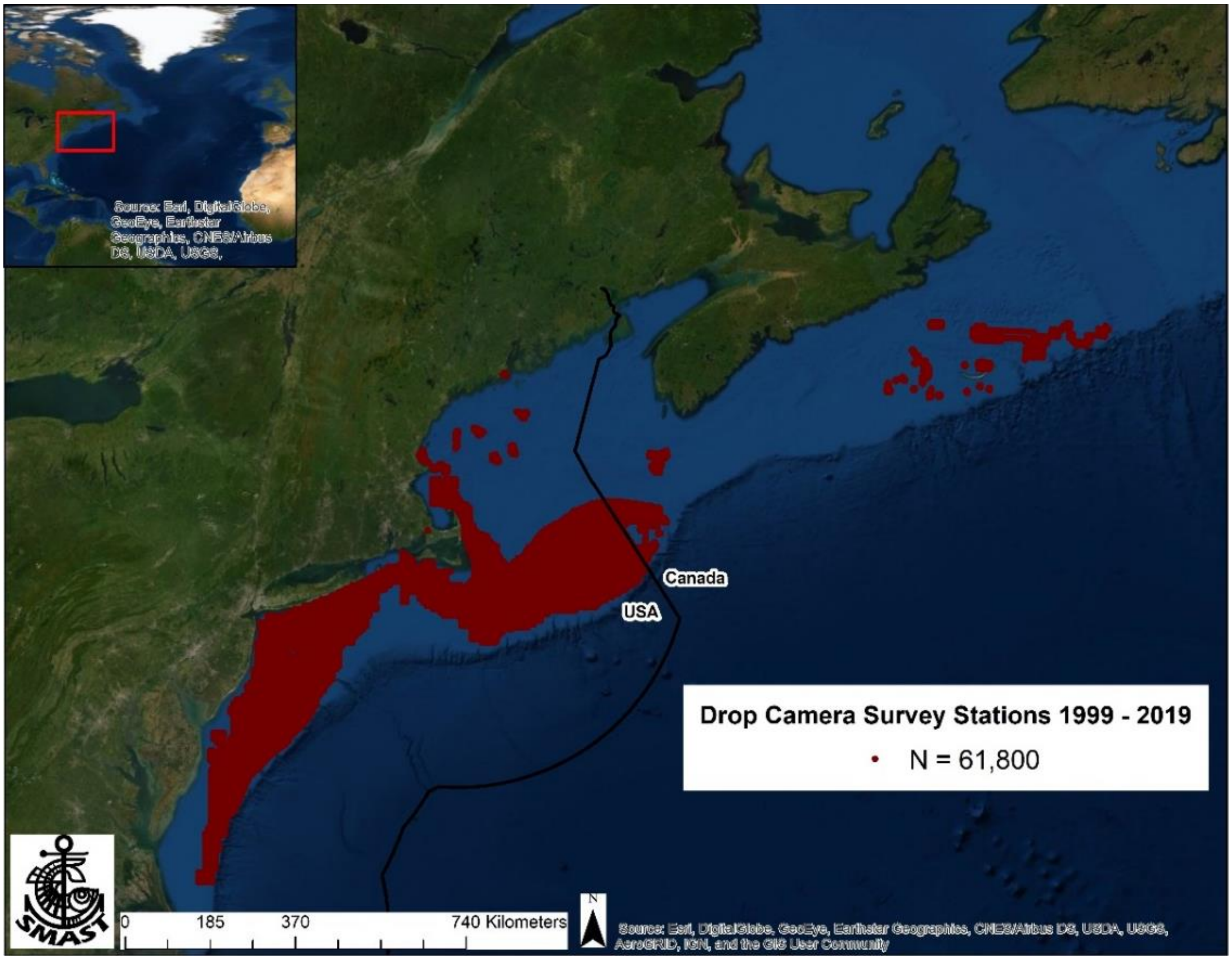

Figure 1. Spatial extent of SMAST drop camera surveys in the northern hemisphere. All stations surveyed since 1999 are displayed.

Data from the drop camera survey has contributed in numerous ways to understanding the ecology of non-scallop species (Marino et al. 2009, MacDonald et al. 2010, Bethoney et al 2017, Asci et al. 2018, Rosellon-Druker and Stokesbury 2019) and the characterization of benthic habitat (Stokesbury and Harris 2006, Harris and Stokesbury 2010, NEFMC 2011, Harris et al. 2012). This work contributed to several ecosystem-based management activities such as the New England Fisheries Management Council Swept Area Seabed Impact model (NEFMC 2011). Drop camera surveys have also been used to define habitat characteristics and spatial distribution of benthic marine invertebrates in potential wind energy areas off the coasts of Maryland and southern New England (Guida et al 2017). Ecologically and economically important species that would be difficult to sample with a net or dredge, such as longfin squid (*Doryteuthis pealeii*) egg clusters or habitat forming filamentous fauna (bryozoans or hydrozoans), can be counted using the drop camera survey (Figure 2).

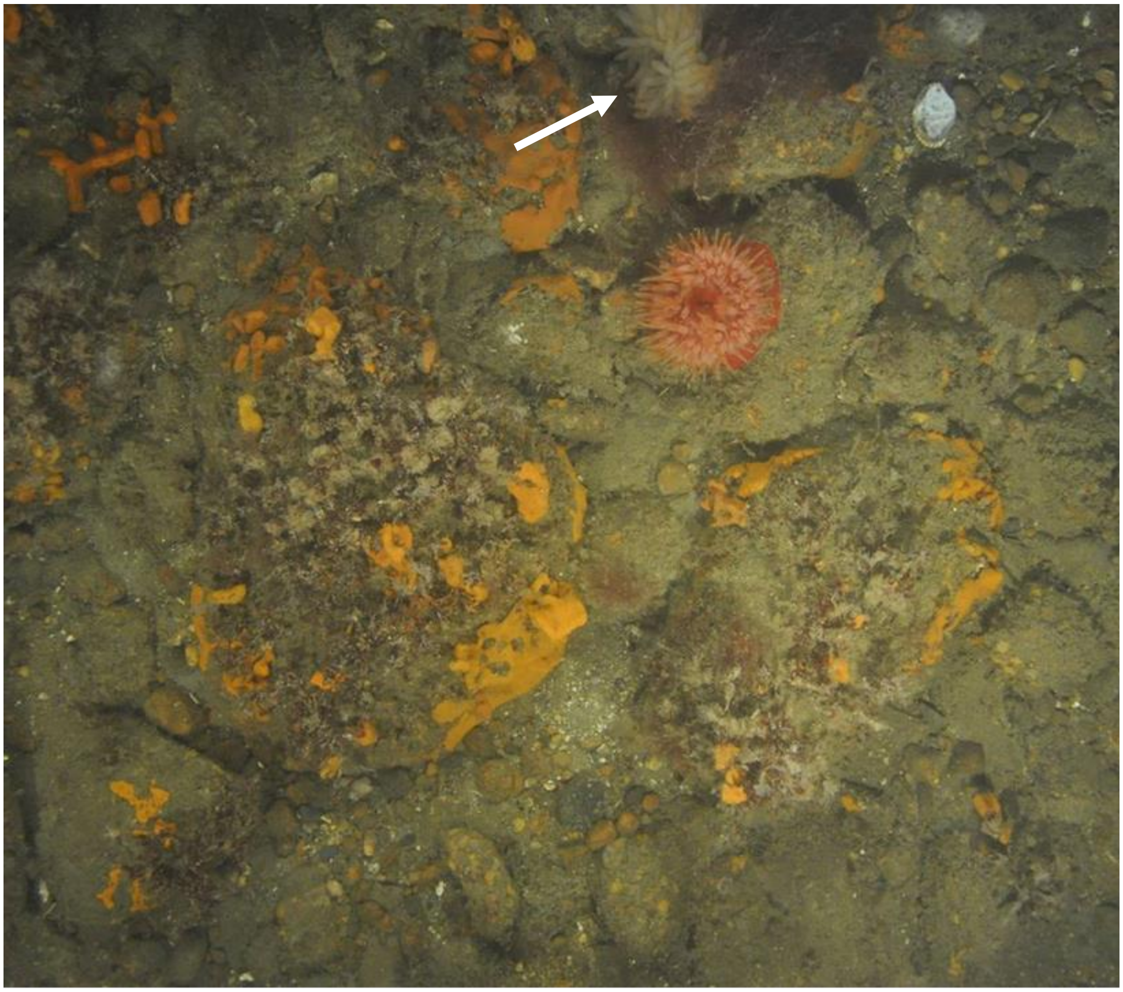

Figure 2. Example of digital still image taken by the SMAST drop camera survey in complex habitat of the Rhode Island Wind Energy Lease Area on Cox's Ledge during a survey in 2013. A longfin squid *(Doryteuthis pealeii*) egg cluster is present (top, middle).

The data collected by the drop camera survey can be used in an impact assessment to determine whether a change to the environment occurred due to a specific stressor, such as wind development, and to what extent the components are affected (Smith 2006). The Before-After Control-Impact (BACI) study is an experiment designed for assessing anthropogenic impacts on natural habitats and is particularly useful in large-scale anthropogenic disturbances or environmental management (Green 1979; Underwood 1991; Kerr et al. 2019). To account for naturally fluctuating characteristics, a designated area outside of the impact area, but containing similar environments and communities, is chosen to be the control site (Eberhardt 1976). The approached is strengthened with an asymmetrical design that uses multiple control sites at different distances from the impact site, incorporating the concepts of Beyond BACI (Underwood 1993) and Before After Gradient (Elllis and Scheider 1997). The standardized, systematic approach of the drop camera survey allows each survey the potential to become a dataset integrated into this design with the ultimate goal of comparing epibenthic faunal variance between impact and control sites over time. Based on the drop camera survey's history and this analytical approach, drop camera surveys within and near areas slated for offshore wind energy development will aid in building a regional, standardized baseline dataset needed to address development impacts on epibenthic communities and habitats. From this study the data collected can be used as a preliminary estimate enabling the calculation of a power analysis detailing the number of samples required to detect a significant change with a specific level of precision. This will enable an accurately designed BACI experiment prior to development of the area.

Goal and Objectives

The primary goal of this project was to collect preliminary data on the benthic community and substrate in the southern portion of Vineyard Wind's OCS Lease Area OCS-A 0522 (522 Study Area). This data could be used to help determine the sampling intensity needed to collect enough baseline data for environmental assessment of windfarm development impact in the 522 Study Area. To do this we used information from drop camera surveys of the 522 Study Area during two different time periods to (Figure 3):

1) Map the distribution and estimate the density of dominant benthic megafauna

2) Classify substrate

These two objectives documented the primary epibenthic animals and habitats within the 522 Study Area and help identify the sampling intensity needed for future analysis of variance. They also document seasonal changes in distribution and density.

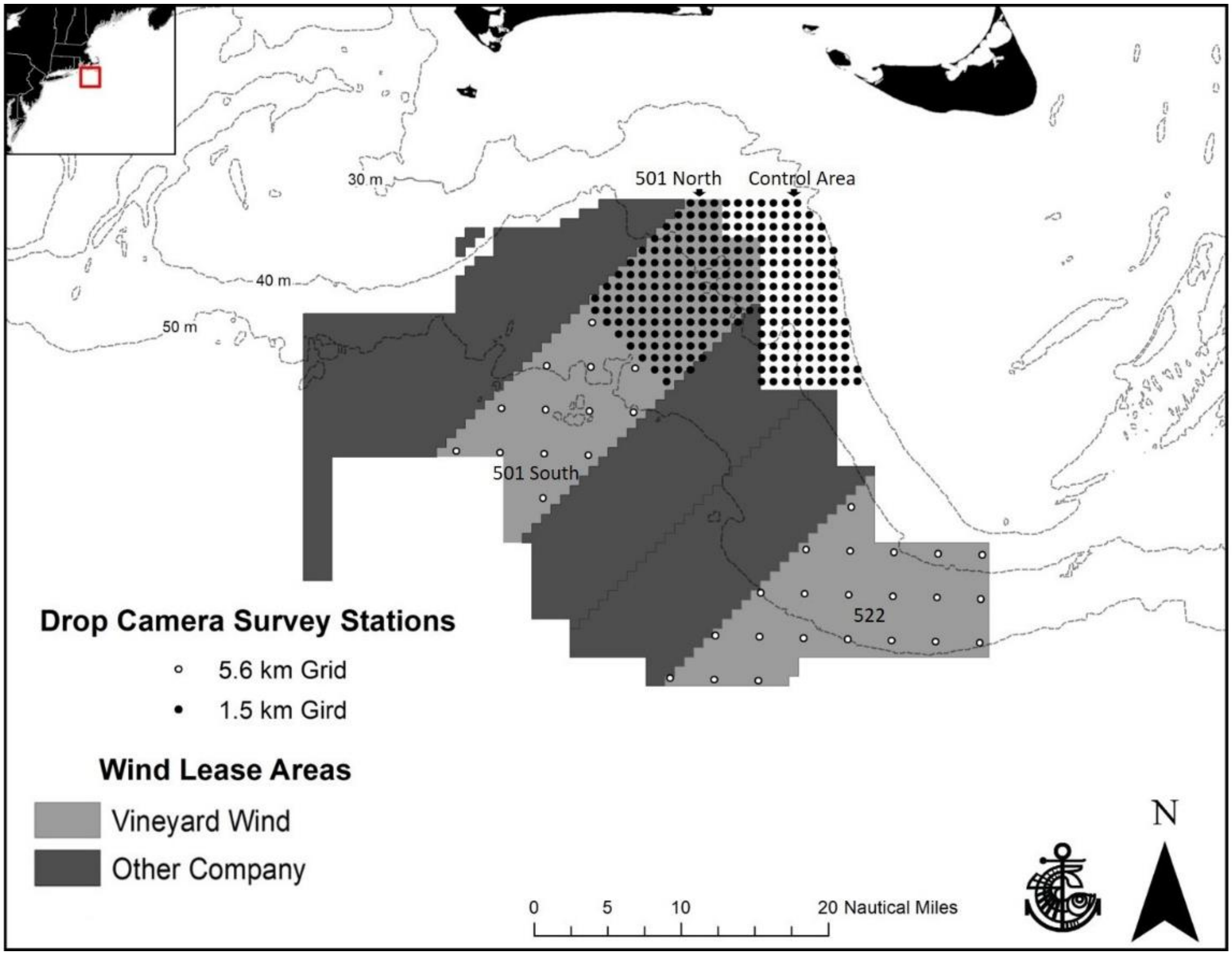

Figure 3. 2019 Drop camera survey station grids and Wind Energy Lease Areas.

Methods

We utilized a centric, systematic sampling design to sample survey stations in the 522 Study Area. Stations were placed 5.6 km apart following a grid design (Figure 3). At each station a sampling pyramid was deployed, and a high-resolution camera was used take four quadrat (2.3 m^2 images) samples (Figure 4). This provided the same sampling resolution as the 2012 and 2013 drop camera surveys of Massachusetts Wind Energy Areas. The information from these surveys was used to determine the 1.5 km station distance applied to the 501 North Impact and Control areas (Figure 3).

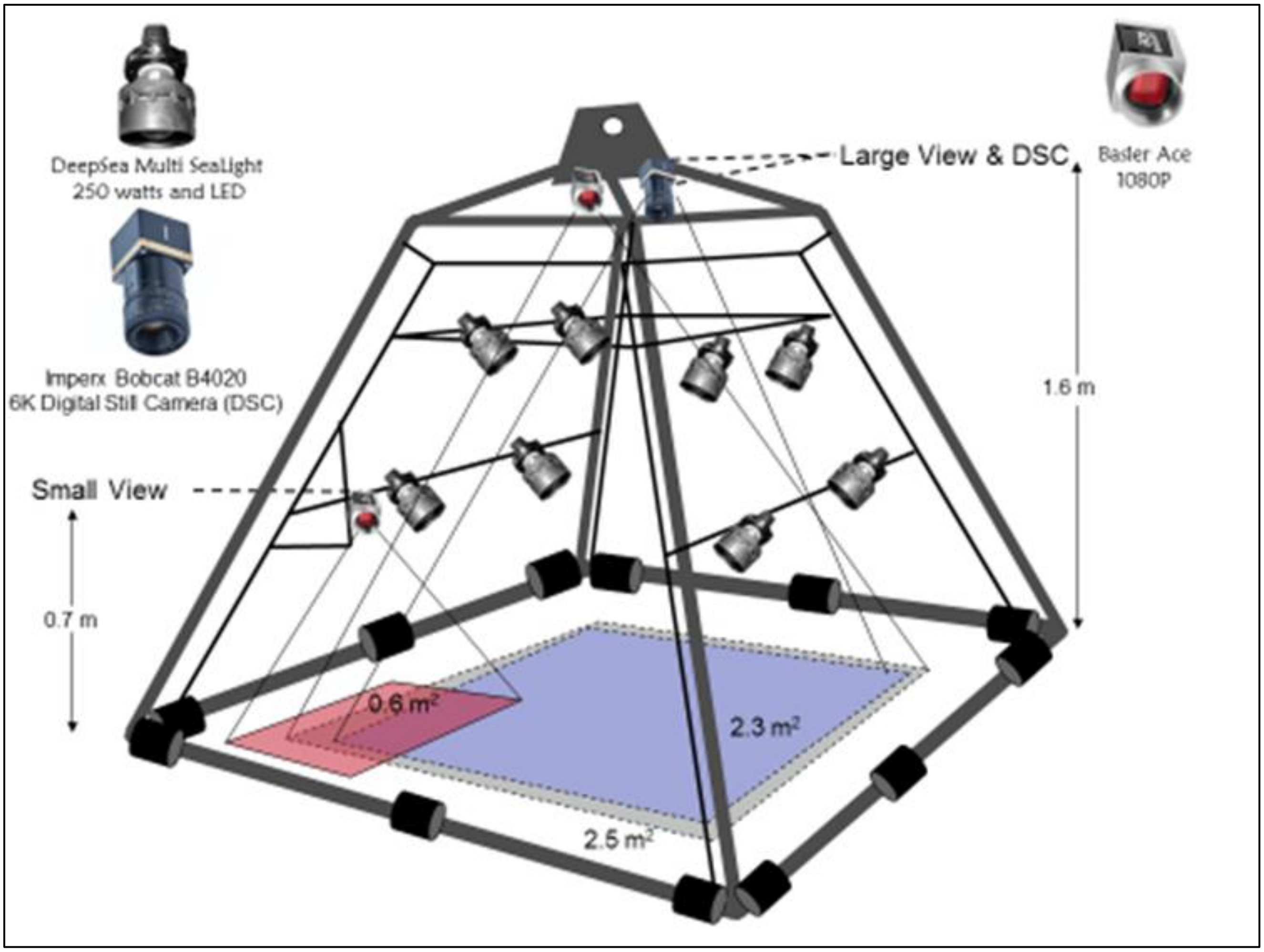

Figure 4. SMAST drop camera survey pyramid with cameras and lights used for data collection. The camera used for the small view was turned to the side to provide a view parallel to the seafloor for some stations.

At each station, we deployed the drop camera pyramid (Figure 4) affixed with cameras and lights to the seafloor from a commercial fishing vessel (Stokesbury 2002, Stokesbury et al. 2004, Bethoney and Stokesbury 2018). A mobile studio including monitors, computers for image capturing and data entry, and survey navigation (software integrated with the differential global positioning system) was assembled in the vessel's wheelhouse. The two downward facing cameras mounted on the sampling pyramid provided 2.3 m^2 and 2.5 m^2 quadrat images of the sea floor for all stations. Additionally, a third camera providing a 0.6 m^2 view or view parallel to the seafloor was also deployed. Images from all cameras and video footage from the 2.5 m^2 quadrat view of the first quadrat was saved and then the pyramid was raised, so the seafloor could no longer be seen. The vessel was allowed to drift approximately 50 m and the pyramid was lowered to the seafloor again to obtain a second quadrat; this was repeated four times, so that each station had four images from each camera. Onboard the survey vessel, scallop counts, station location, and depth were recorded and saved through a specialized field application for entry into a SQL Server Relational Database Management System.

After the survey, the high resolution digital still images were used as the primary data source (Figure 2). Other images and video collected were used as aids. Within each quadrat, macrobenthos were counted or noted as present, and the substrate was identified (Stokesbury 2002, Stokesbury et al. 2004, Bethoney and Stokesbury 2018). Fifty taxa of macrobenthos are identified if present in the sample, counted or noted as present or absent (Appendix I). For animals noted as present, the percent of a quadrat they were present within was calculated by portioning the quadrat into equal sized cells and recording presence or absence for each cell. In addition, longfin squid egg clusters *(Doryteuthis pealeii*), which are not typically enumerated, were counted. Sediments were visually identified following the Wentworth particle grade scale from images, where the sediment particle size categories (in grain diameters) are based on a doubling or halving of the fixed reference point of 1 mm; sand = 0.0625 to 2.0 mm, gravel = 2.0 to 256.0 mm and boulders > 256.0 mm (Lincoln et al. 1992). Gravel was divided into two categories, granule/pebble = 2.0 to 64.0 mm and cobble = 64.0 to 256.0 mm (Lincoln et al. 1992). The presence of each sediment category was noted for each image. Maps and analysis focused on classifying stations by the largest sediment particle size observed in a digital still image from that station (Harris and Stokesbury 2010). Shell debris was also identified. After the images were digitized, a quality assurance check was performed on each image to ensure accuracy of counted and identified species and sediments.

Mean densities and standard errors of animals counted were calculated using equations for a two-stage sampling design where the mean of the total sample is (Cochran 1977):

$$\bar{\bar{x}} = \sum_{i=1}^{n} \left(\frac{\bar{x}_i}{n} \right)$$

where *n* is the number of stations and $\bar{x}_i$ is the mean of the 4 quadrats at station *i*. The SE of this 2-stage mean was calculated as:

$$S.E.(\bar{x}) = \sqrt{\frac{1}{n}(s^2)}$$

where:

$$s^2 = \sum^{n} (\bar{x}_i - \bar{\bar{x}})^2 /(n-1)$$

According to Cochran (1977) and Krebs (1989) this simplified version of the 2-stage variance is appropriate when the ratio of sample area to survey area (*n*/*N*) is small. In this case, thousands of square meters (*n*) are sampled compared with millions of square meters (*N*) in the study area. A similar multi-stage approach was used to calculate mean presence values. Mean density or quadrats present per station within the 522 Study Area were mapped (Figures 7-27). The analysis was limited to the 12 most common benthic animal groups in the 522 Study Area, to focus results on the groups detected at high enough rates for future analysis of variance (Bethoney et al. 2017). Densities for animal group were compared by graphing mean estimates with their associated 95% confidence intervals (Sokal and Rohlf 2012).

Results and Discussion

The two drop camera surveys of the 522 Study Area were conducted on July 18th and October 19th, 2019. All images and video collected were shared with Vineyard Wind. All 22 stations in the area were surveyed in July and October. Whelks. Eighteen different benthic animal groups were observed in the 522 Study Area. The most common groups were similar to the dominant groups in the 501N Impact and Control Areas, but sea stars, moon snails, and moon snail eggs cases replaced waved whelks, sponges, and skate egg cases (Table 1). In addition to these animals several others were observed at lower frequencies. These animals included scallops (1 in October) and flat fishes (2 in July and 1 in October). Decreases in animal occurrence in October, except skates, was observed but wide confidence intervals are associated with most estimates (Figures 5 & 6). Confidence intervals were extremely large for sea stars as they were found at one station in July and October at very high densities (Figures 7 & 8). Crabs also had a large confidence interval compared to the other animals, but high-density stations were spread through the survey area (Figures 9 & 10)). All other animals appear to be common at depths shallower than 50 meters, except burrowing animals (Figures 11-25). Sand was the largest substrate type at the majority of stations, but gravel was present at 5 stations during July (Figure 26). In October, only sand was observed (Figure 27).

Table 1. The 12 most common benthic animal groups, in order of most to least quadrats present, during the 2019 SMAST drop camera survey of the 522 Study Area. Groups left blank in the "Counts" column are tracked as present or absent.

Animal Group	Quadrats Present	Counts
Holes (burrowing animals)	55	
Crabs (cancer spp.)	34	75
Hermit Crabs	18	22
Sand Dollars	17	
Red hake	13	21
Silver hake	13	13
Sea Stars	10	141
Anemones	6	
Skates	6	6
Moonsnails	5	6
Moonsnail Egg Cases	5	5
Bryozoans/Hydrozoans	4	

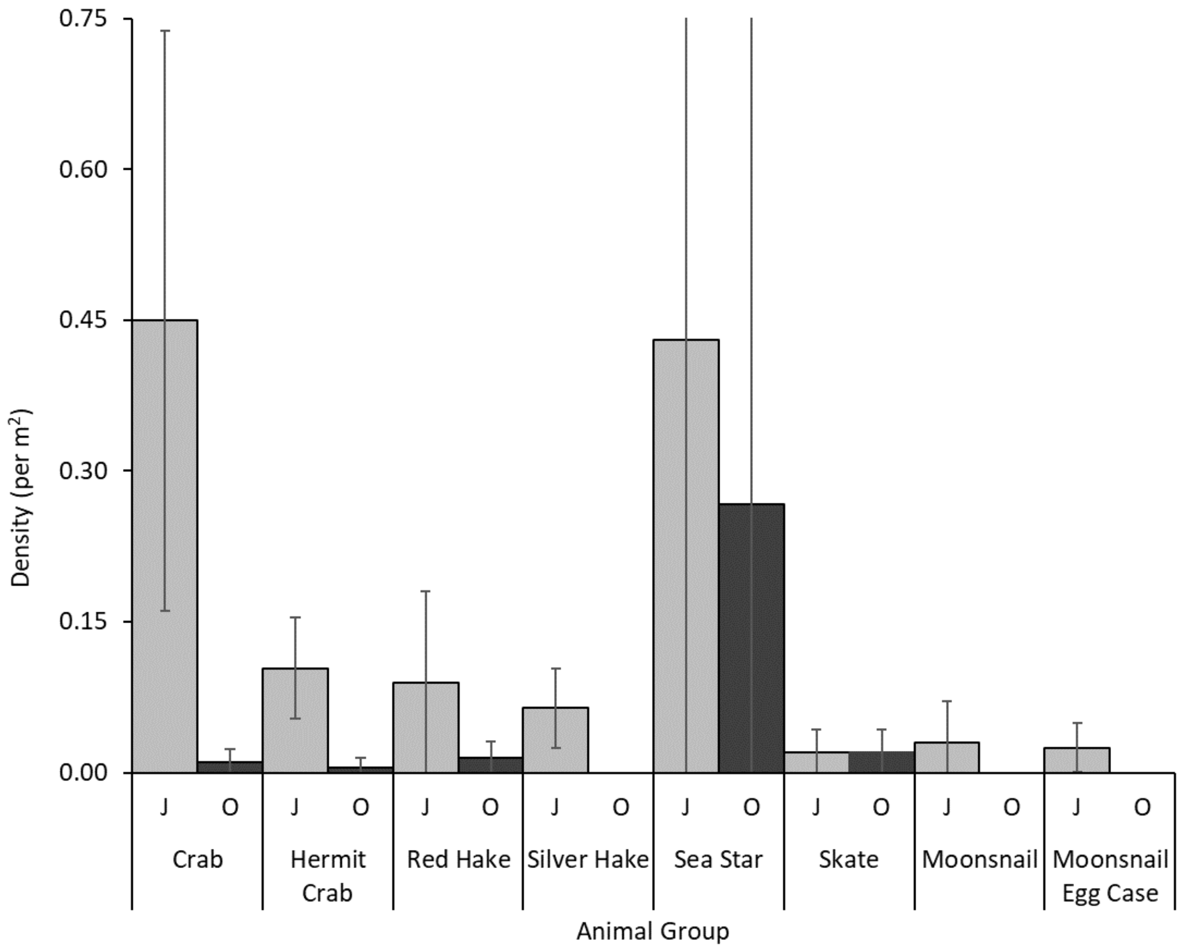

Figure 5. Density of common benthic animals found in the July (J) and October (O) 2019 drop camera surveys of the OCS 522 Study Area. Error bars are 95% confidence intervals.

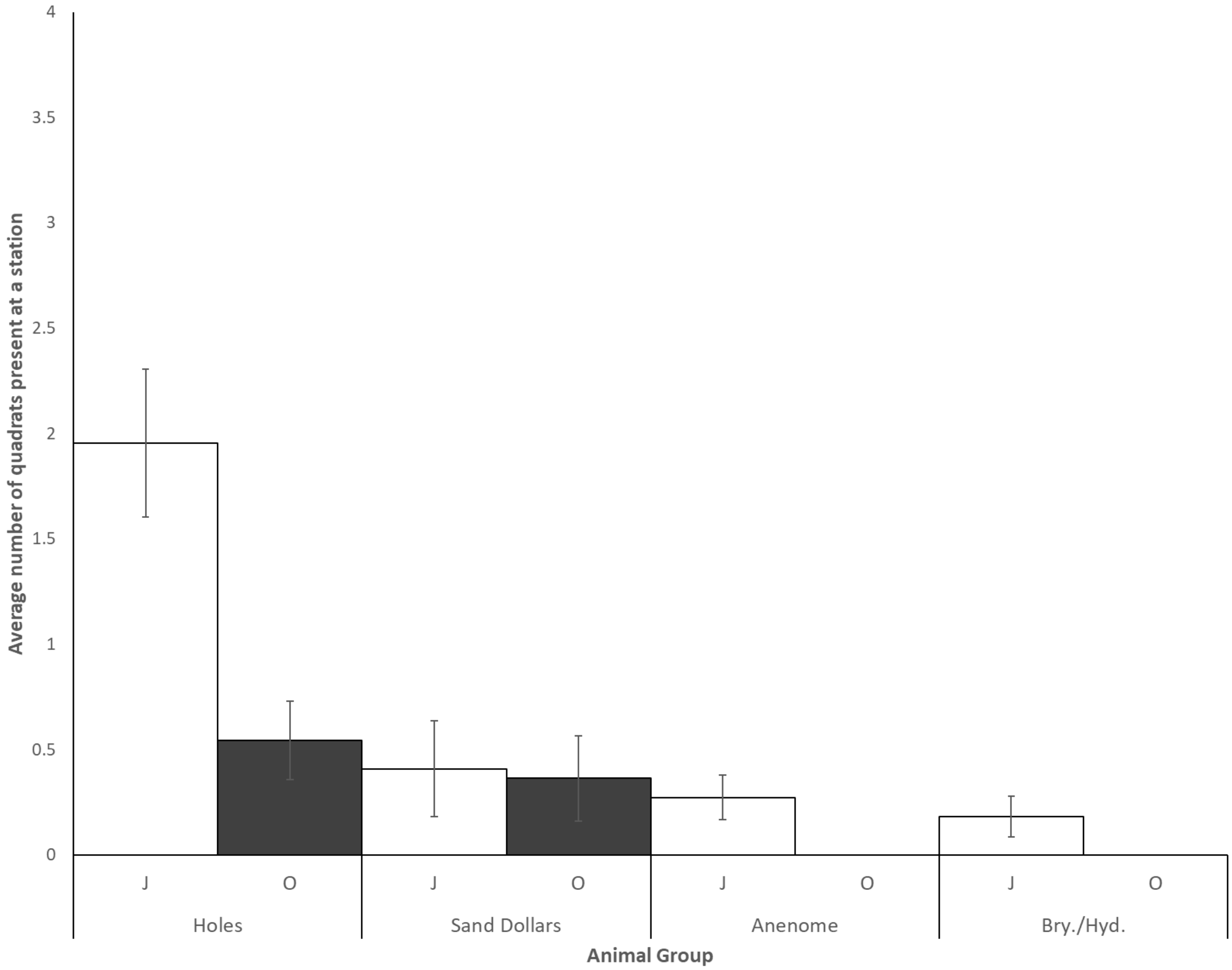

Figure 6. The average number of quadrats benthic animals were present in at each station during the July (J) and October (O) 2019 drop camera surveys of the OCS 522 Study Area. Holes represent burrowing animals and Bry./Hyd. indicates bryozoans and hydrozoans. Four quadrats (2.3m^2 images) were observed at each station.

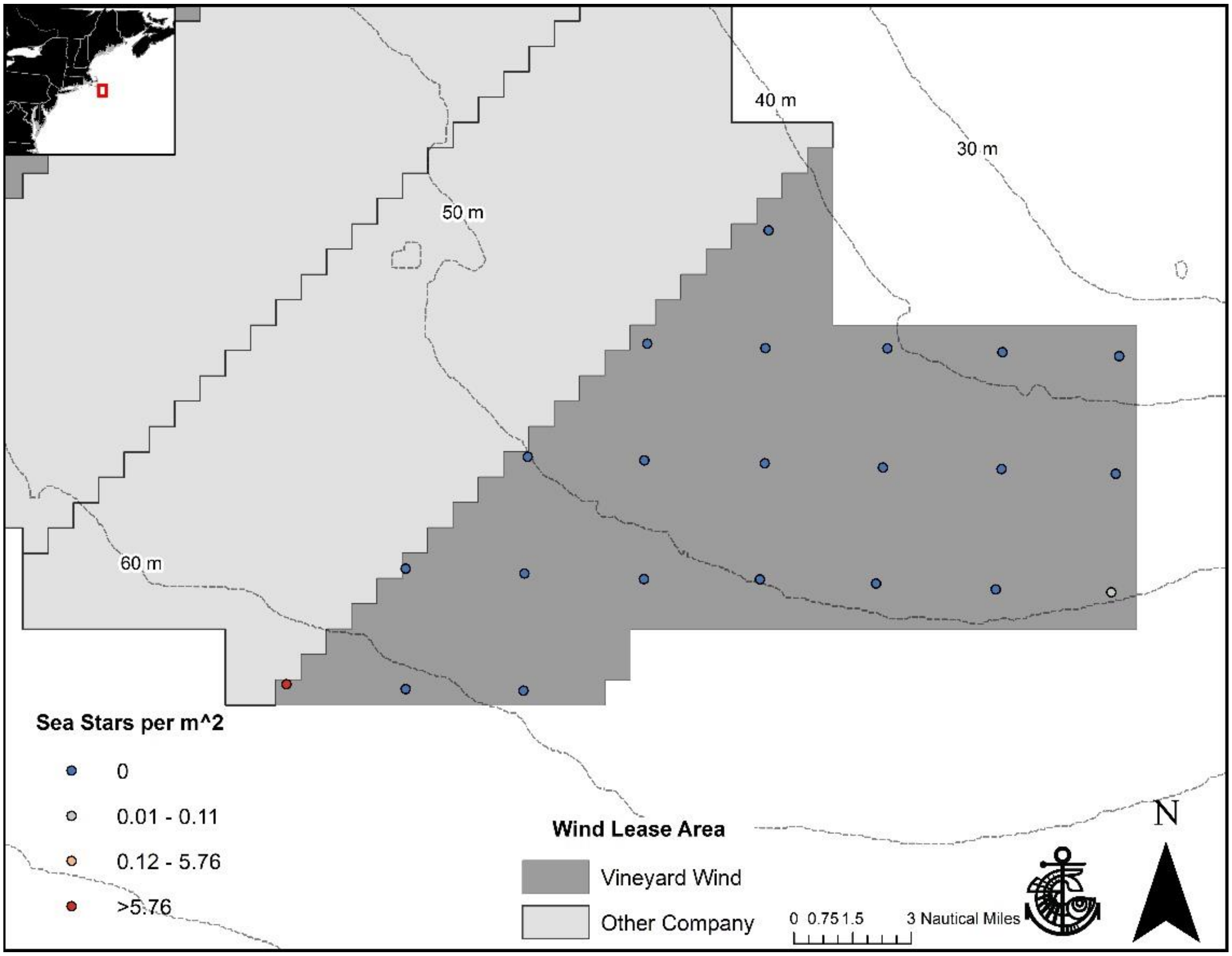

Figure 7. The distribution of sea stars in the 2019 July drop camera survey of OCS 522 Study Area. Density categories equally divide the data above zero based on observations in July and October.

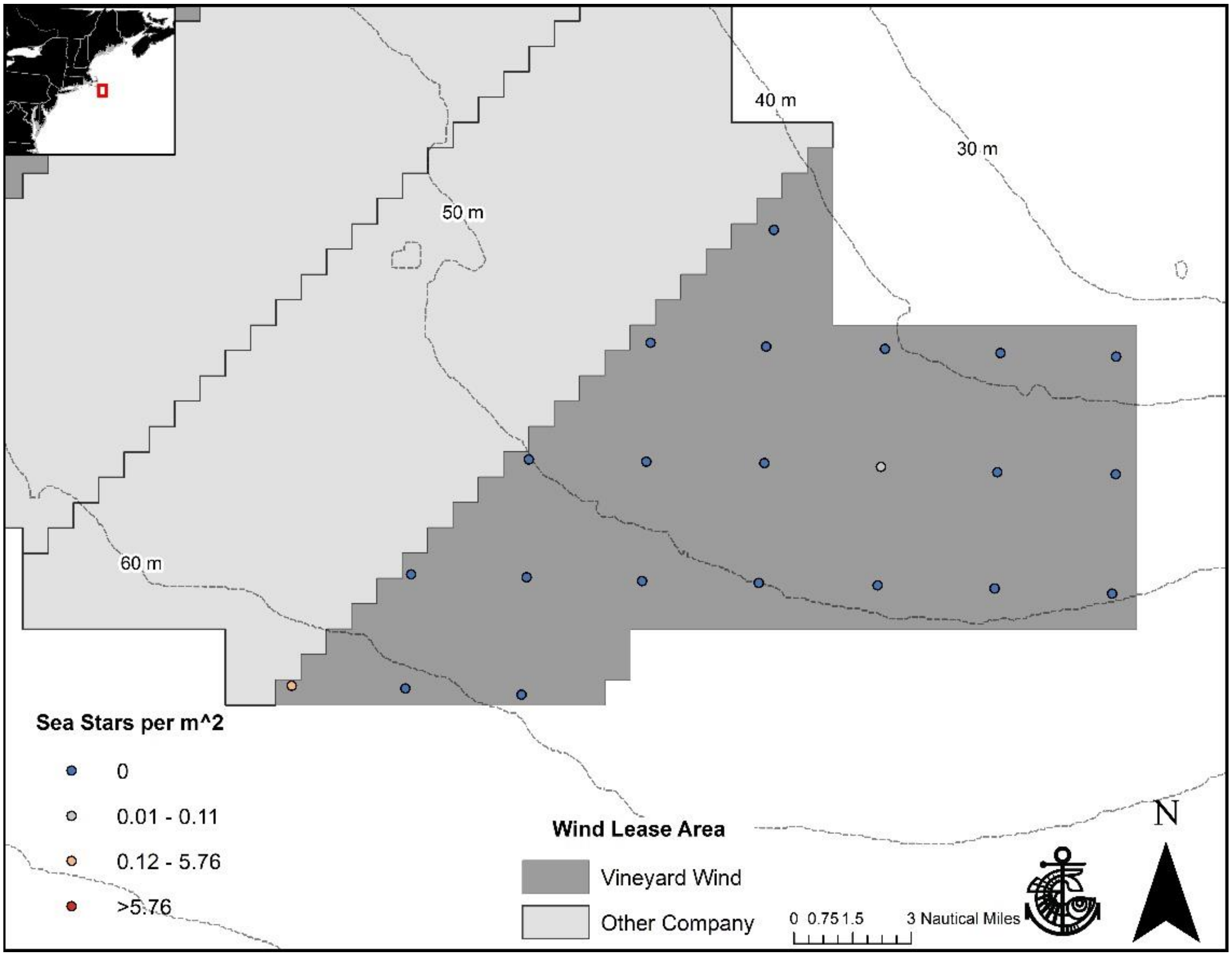

Figure 8. The distribution of sea stars in the 2019 October drop camera survey of OCS 522 Study Area. Density categories equally divide the data above zero based on observations in July and October.

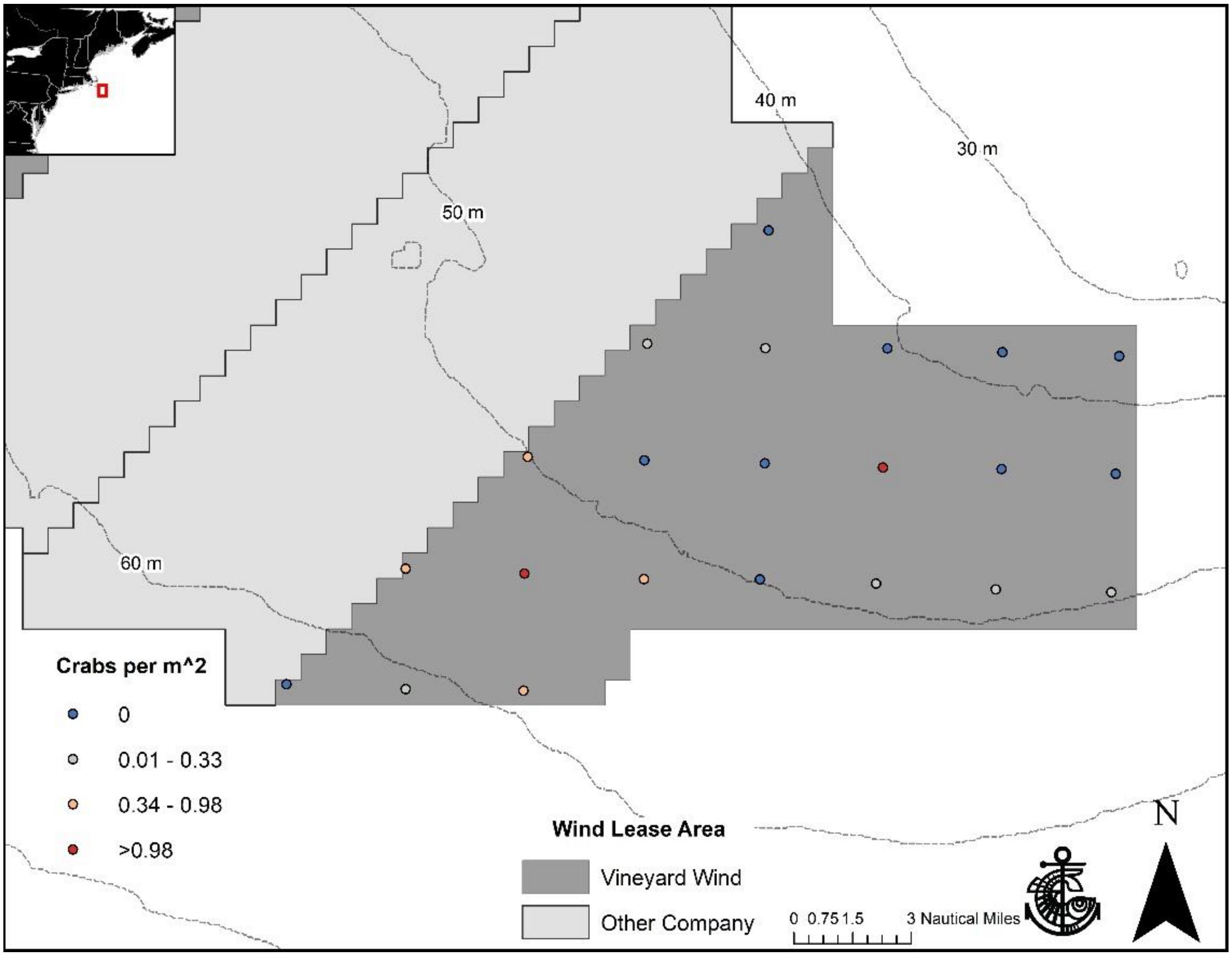

Figure 9. The distribution of crabs in the 2019 July drop camera survey of OCS 522 Study Area. Density categories equally divide the data above zero based on observations in July and October.

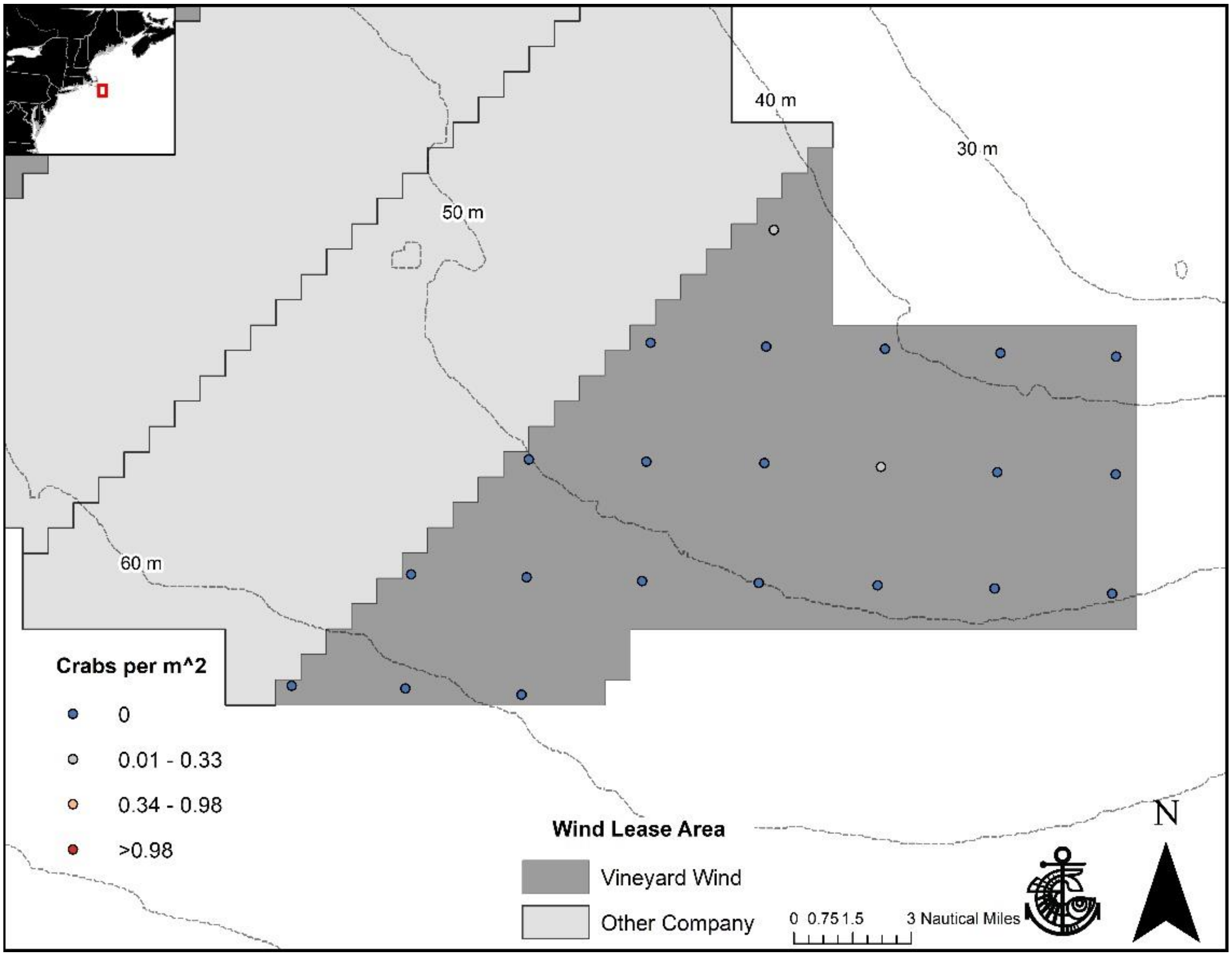

Figure 10. The distribution of crabs in the 2019 October drop camera survey of OCS 522 Study Area. Density categories equally divide the data above zero based on observations in July and October.

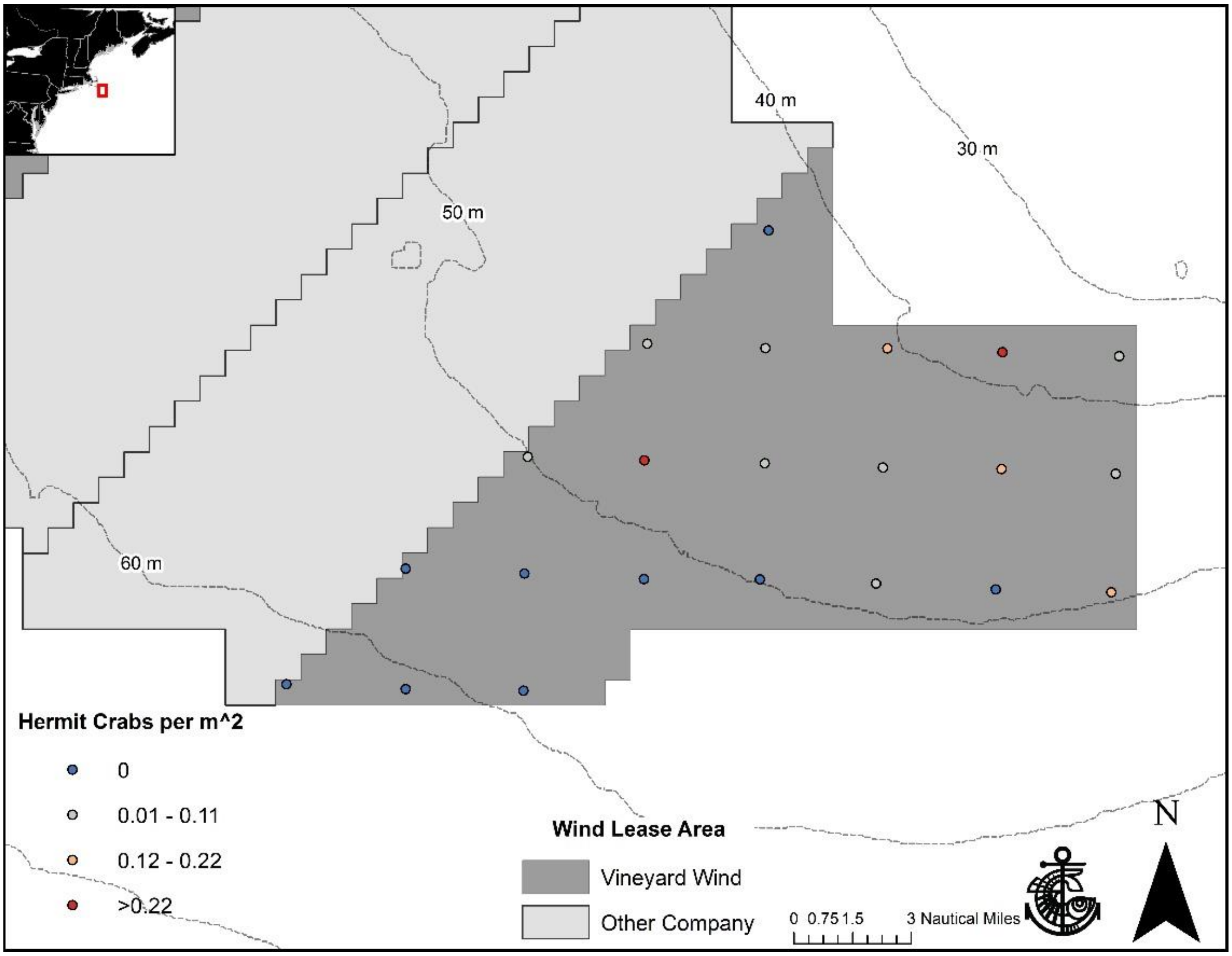

Figure 11. The distribution of hermit crabs in the 2019 July drop camera survey of OCS 522 Study Area. Density categories equally divide the data above zero based on observations in July and October.

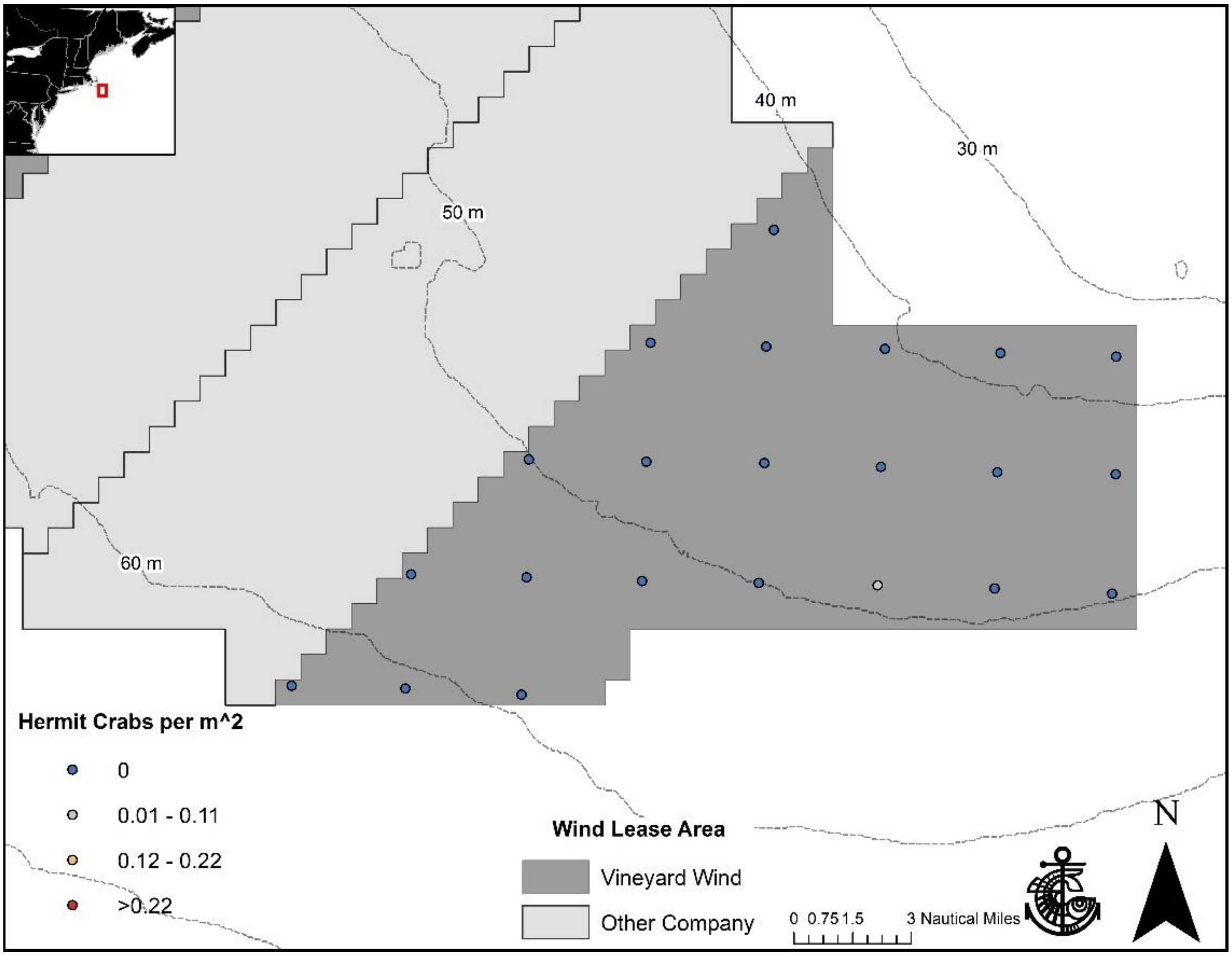

Figure 12. The distribution of hermit crabs in the 2019 October drop camera survey of OCS 522 Study Area. Density categories equally divide the data above zero based on observations in July and October.

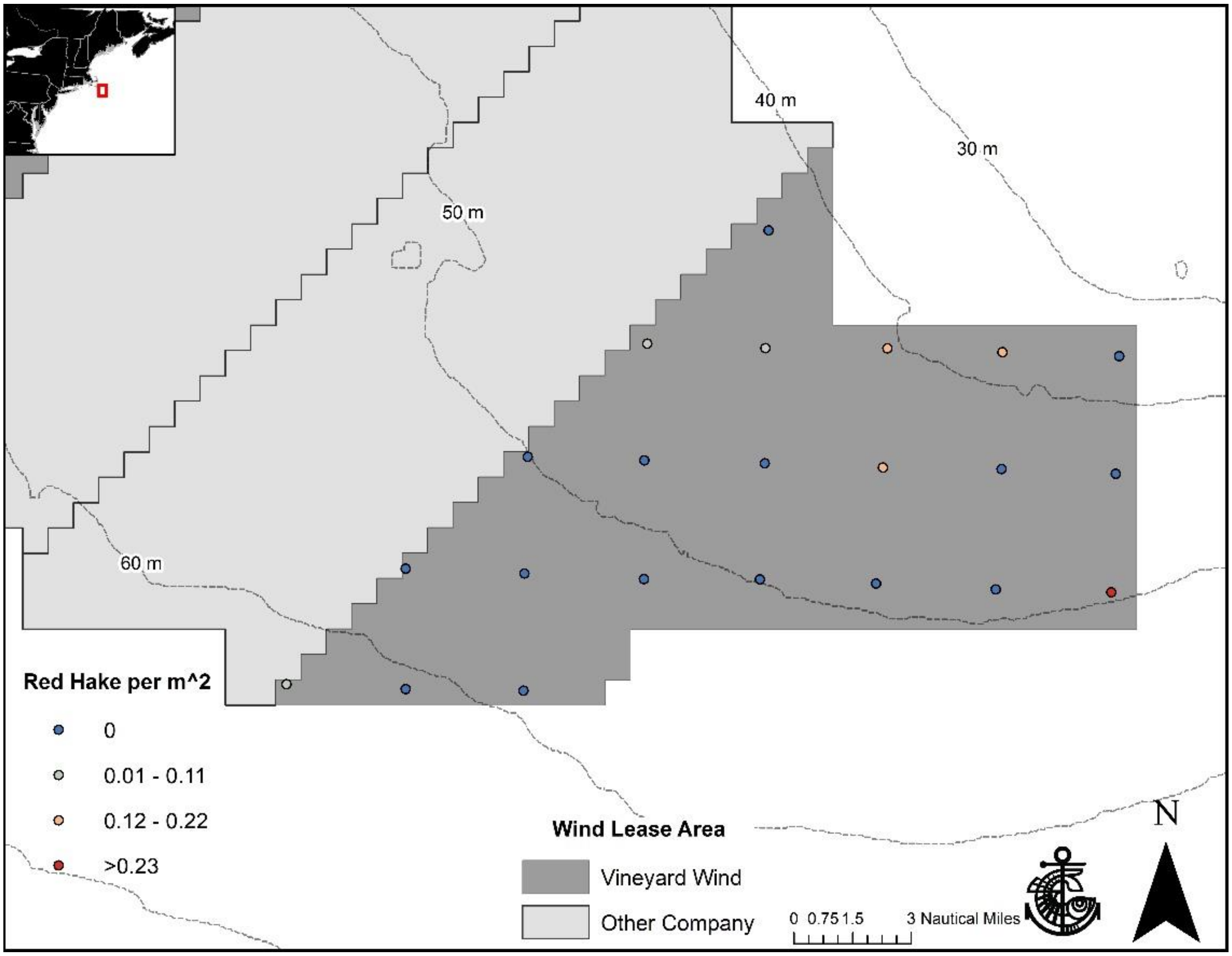

Figure 13. The distribution of red hake in the 2019 July drop camera survey of OCS 522 Study Area. Density categories equally divide the data above zero based on observations in July and October.

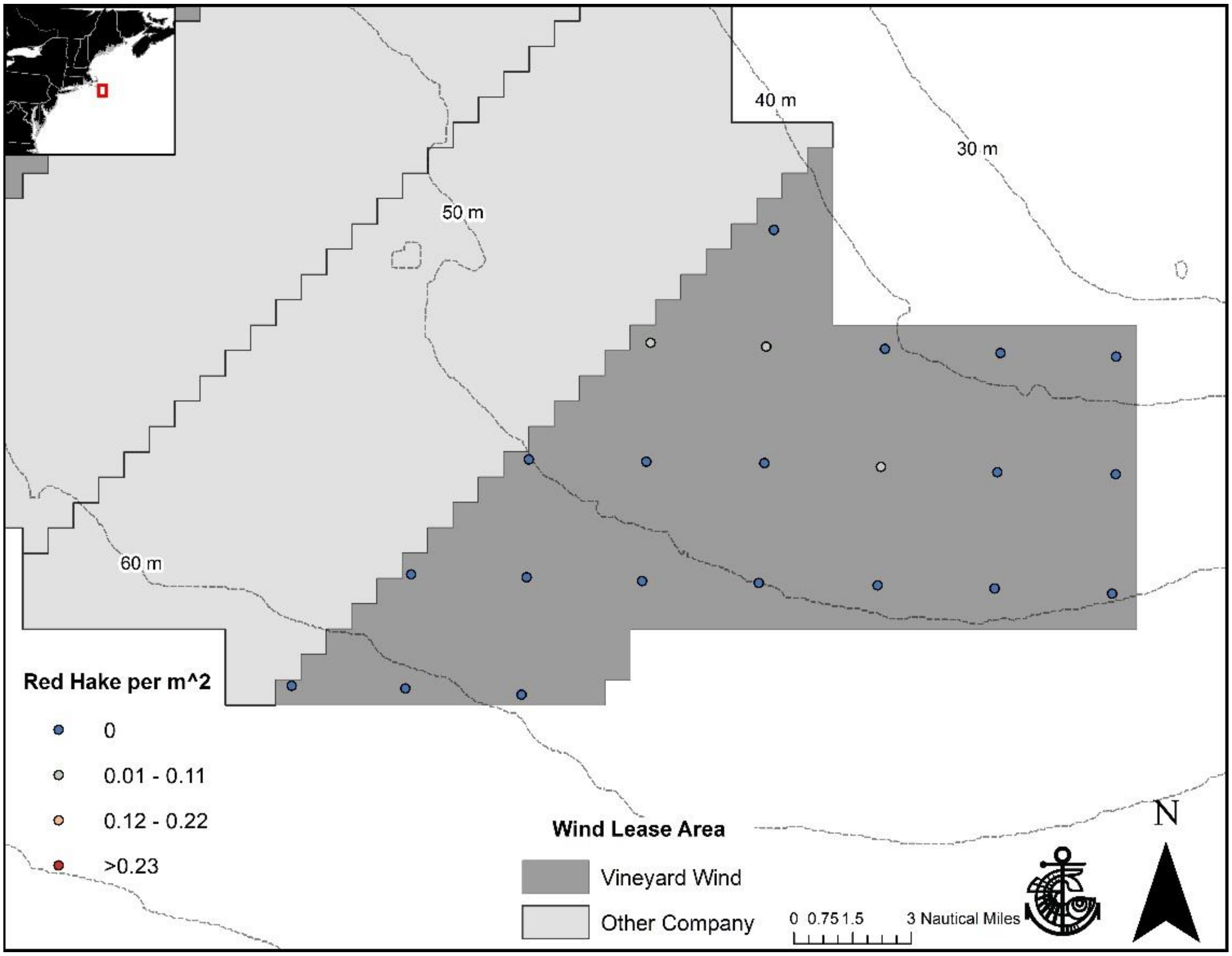

Figure 14. The distribution of red hake in the 2019 October drop camera survey of OCS 522 Study Area. Density categories equally divide the data above zero based on observations in July and October.

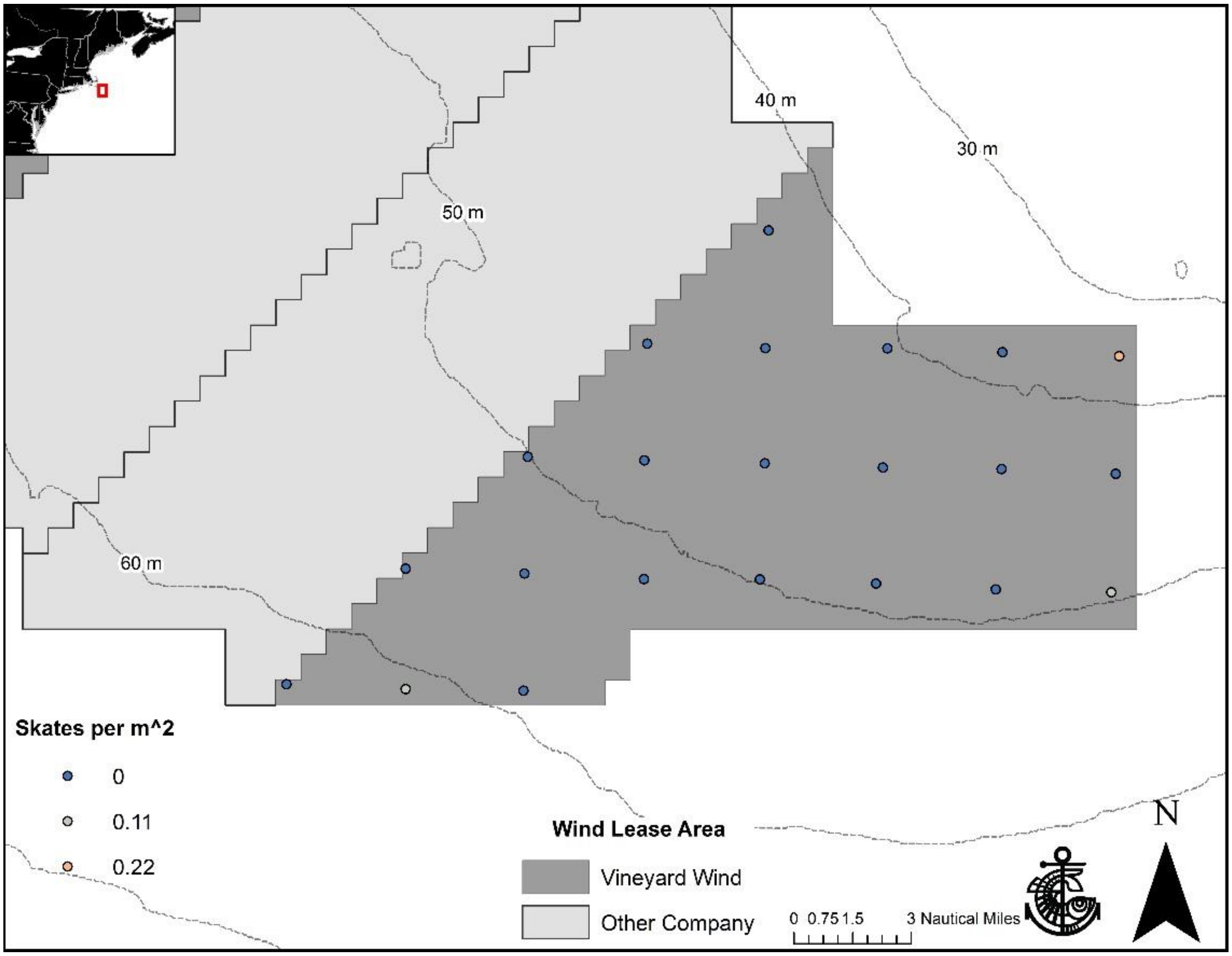

Figure 15. The distribution of skates in the 2019 July drop camera survey of OCS 522 Study Area. Density categories represent zero, one, or two skates observed at a station.

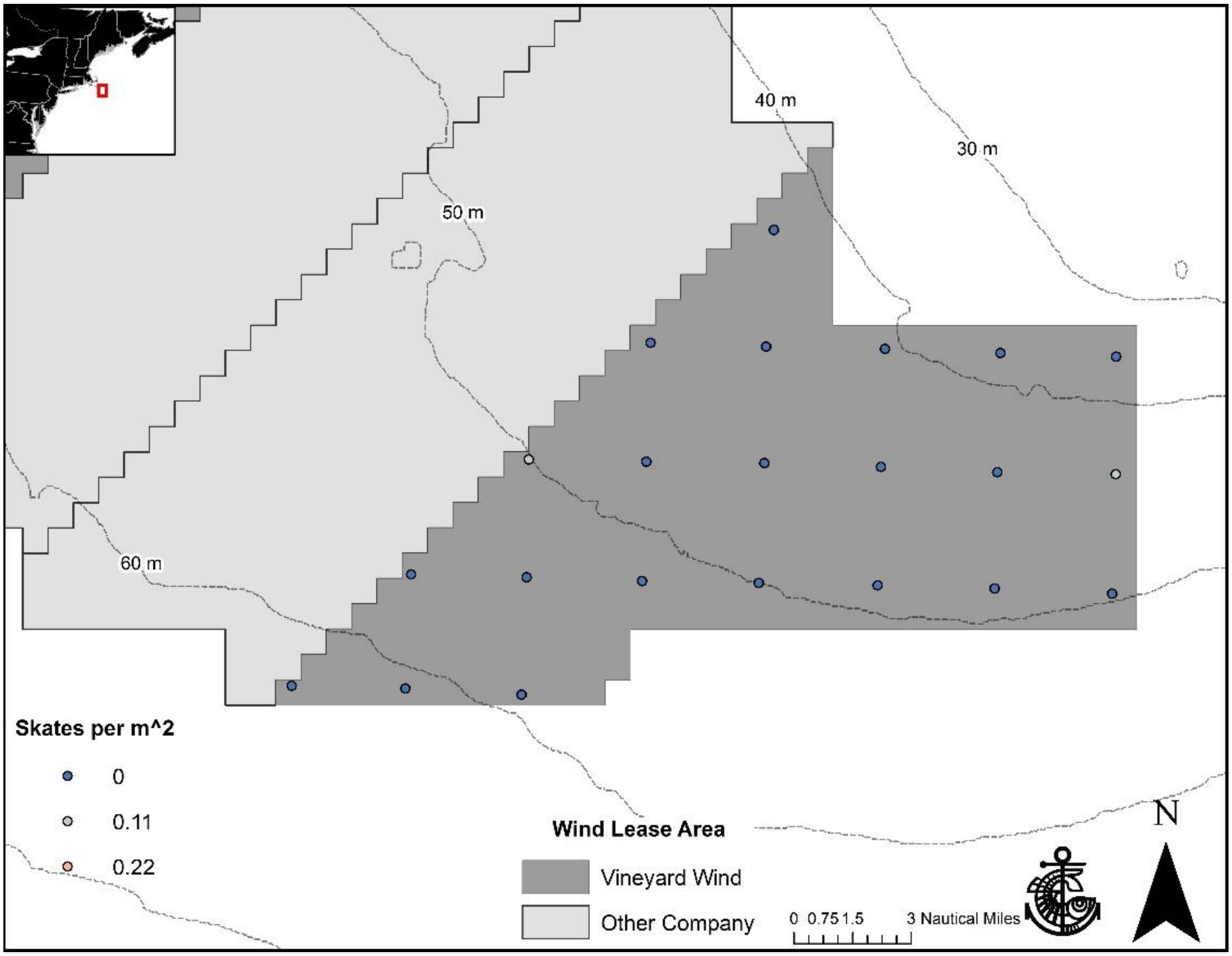

Figure 16. The distribution of skates in the 2019 July drop camera survey of OCS 522 Study Area. Density categories represent zero, one, or two skates observed at a station.

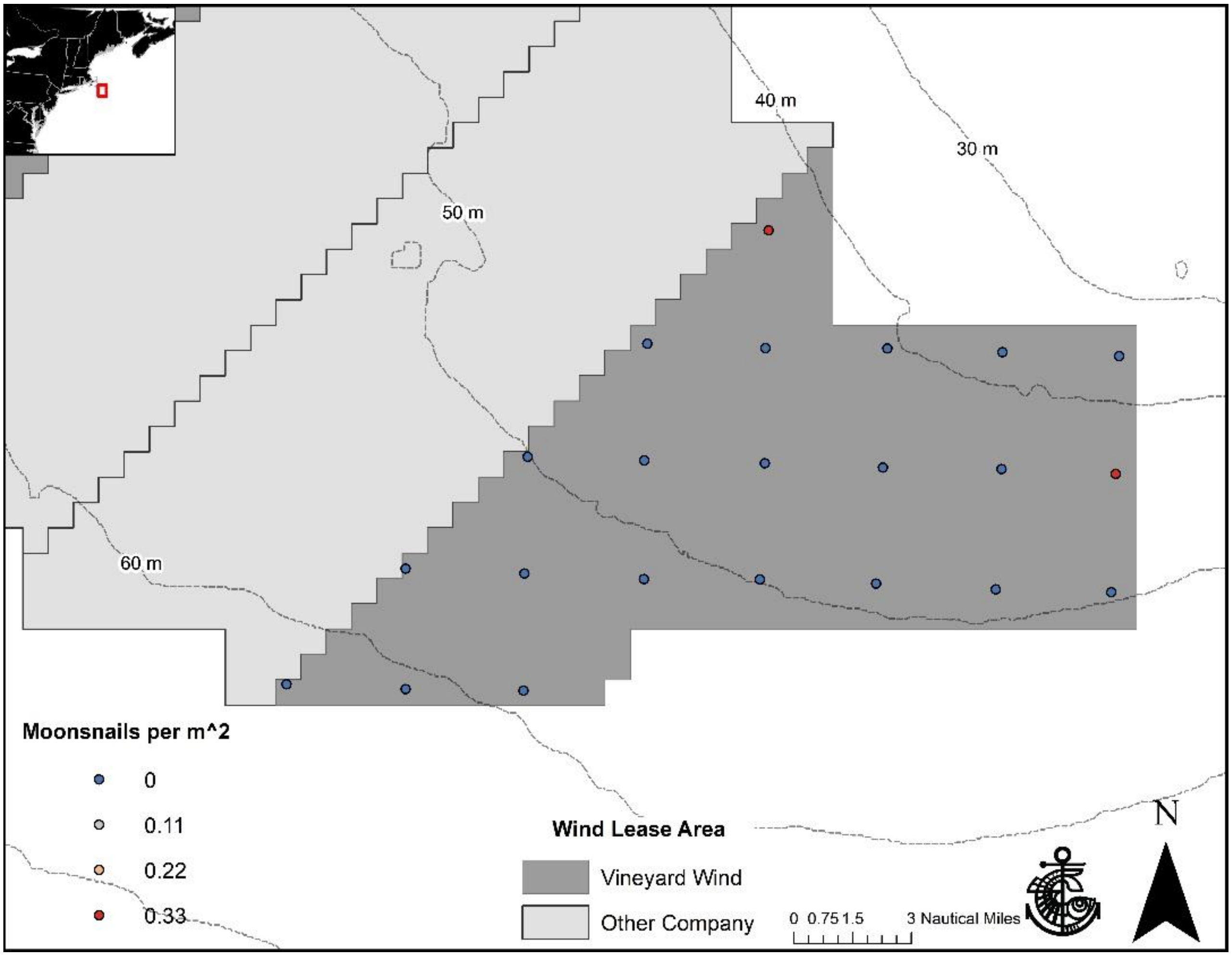

Figure 17. The distribution of moonsnails in the 2019 July drop camera survey of OCS 522 Study Area. No moonsnails were observed in an October survey of the same area. Density categories represent zero, one, two or three moonsnails observed at a station.

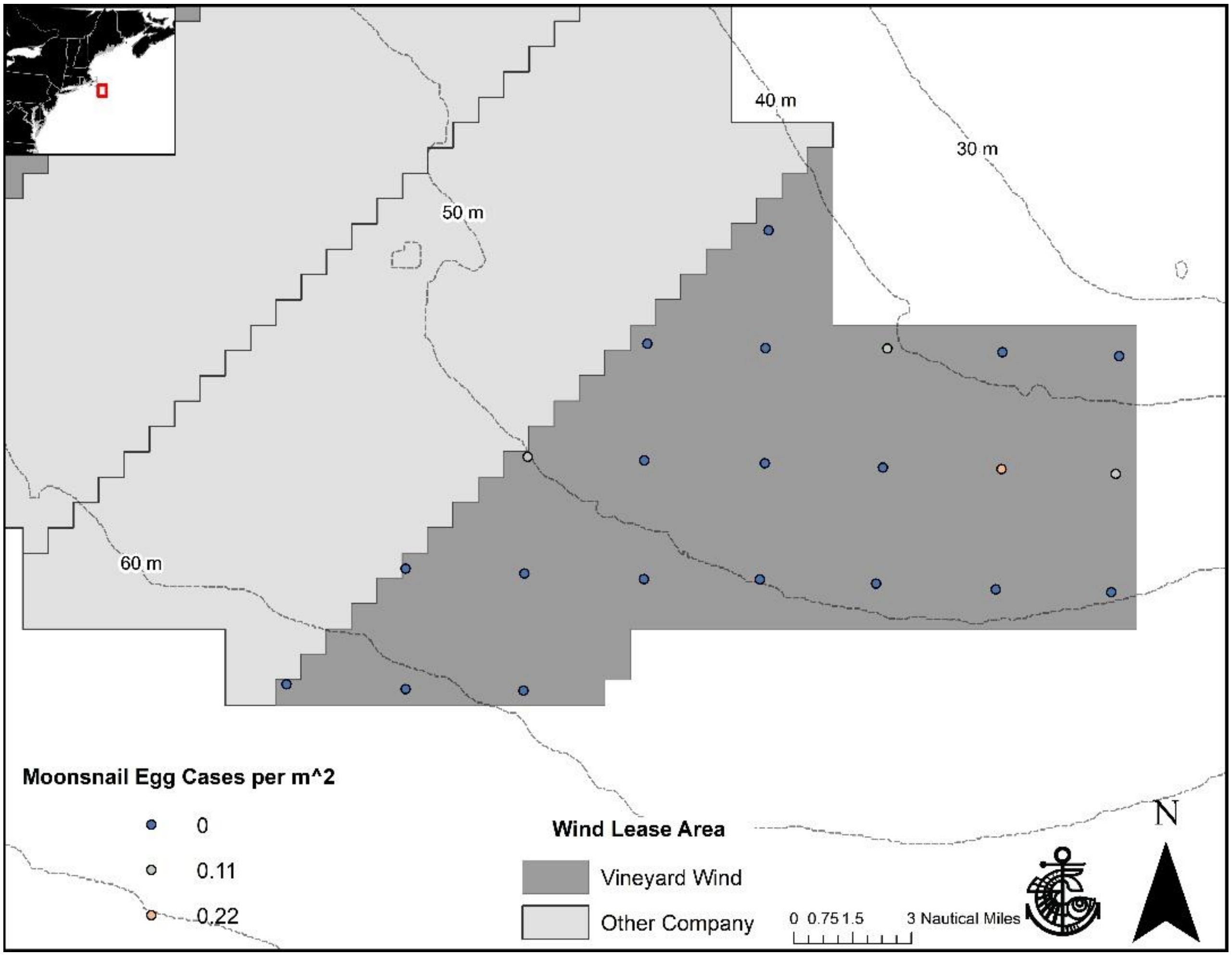

Figure 18. The distribution of moonsnail egg cases in the 2019 July drop camera survey of OCS 522 Study Area. No moonsnail egg cases were observed in an October survey of the same area. Density categories represent zero, one or two moonsnail egg cases observed at a station.

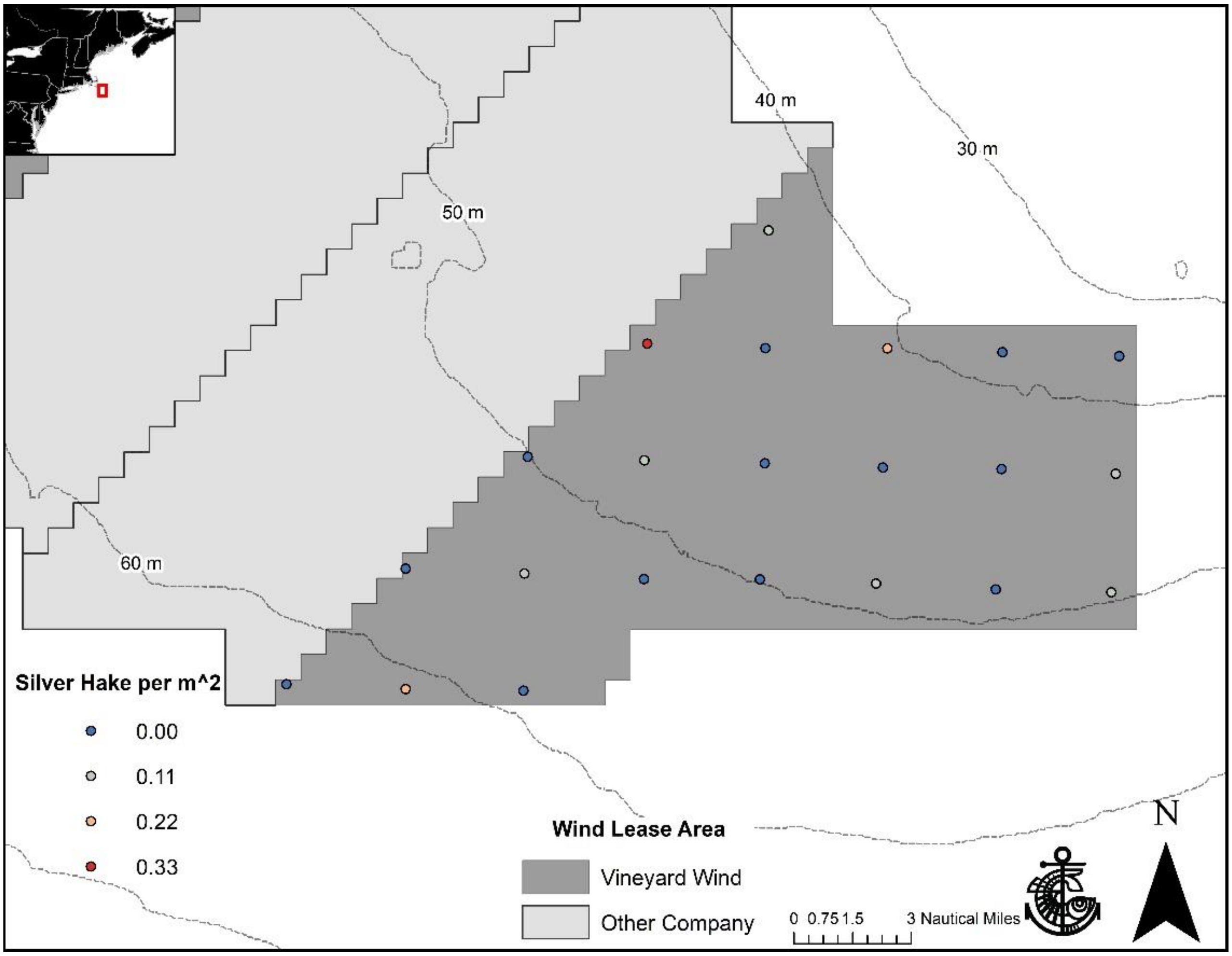

Figure 19. The distribution of silver hake in the 2019 July drop camera survey of OCS 522 Study Area. No silver hake were observed in an October survey of the same area. Density categories represent zero, one, two or three silver hake observed at a station.

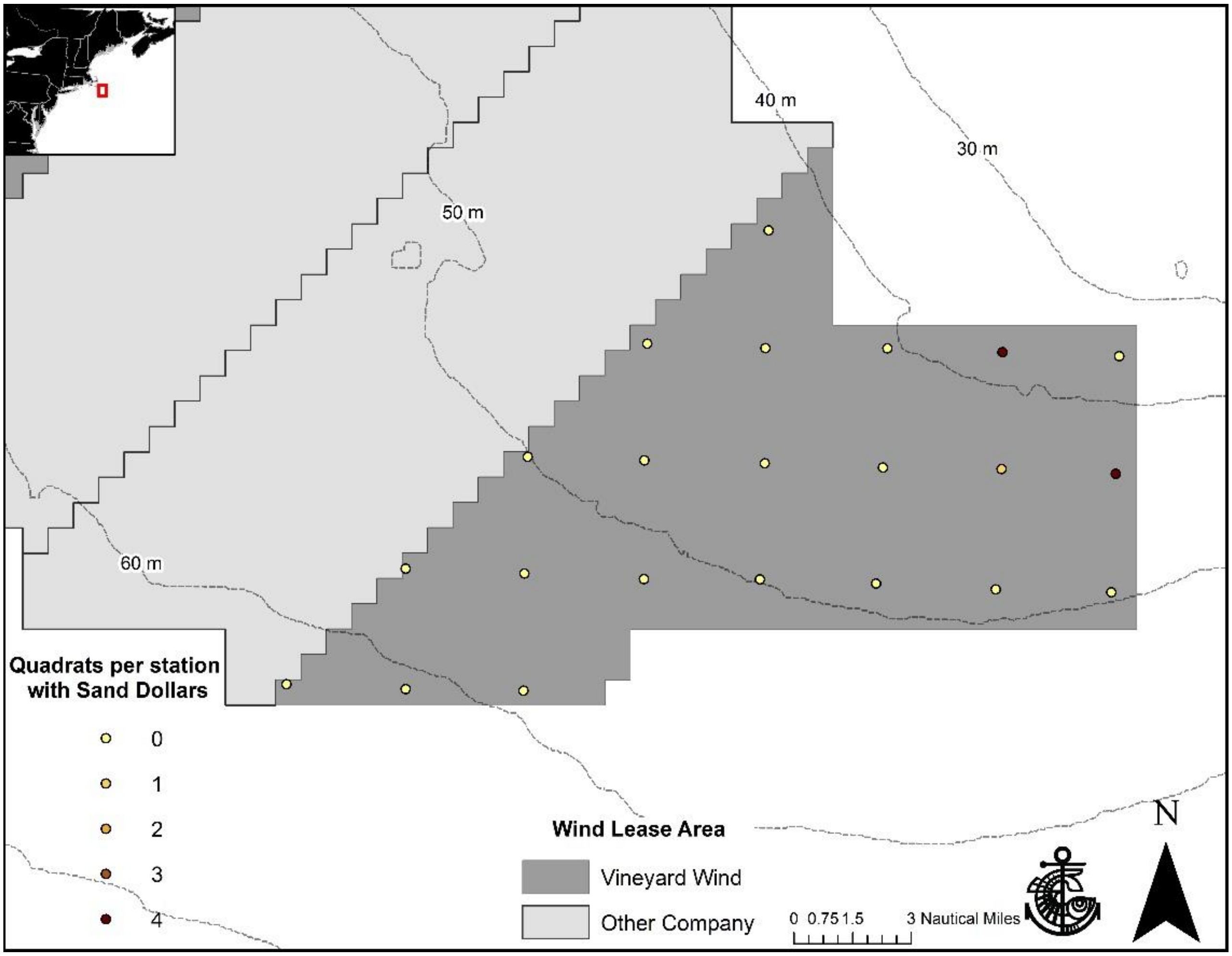

Figure 20. The distribution of sand dollars in the 2019 July drop camera survey of OCS 522 Study Area. Four quadrats (2.3m^2 images) were observed at each station.

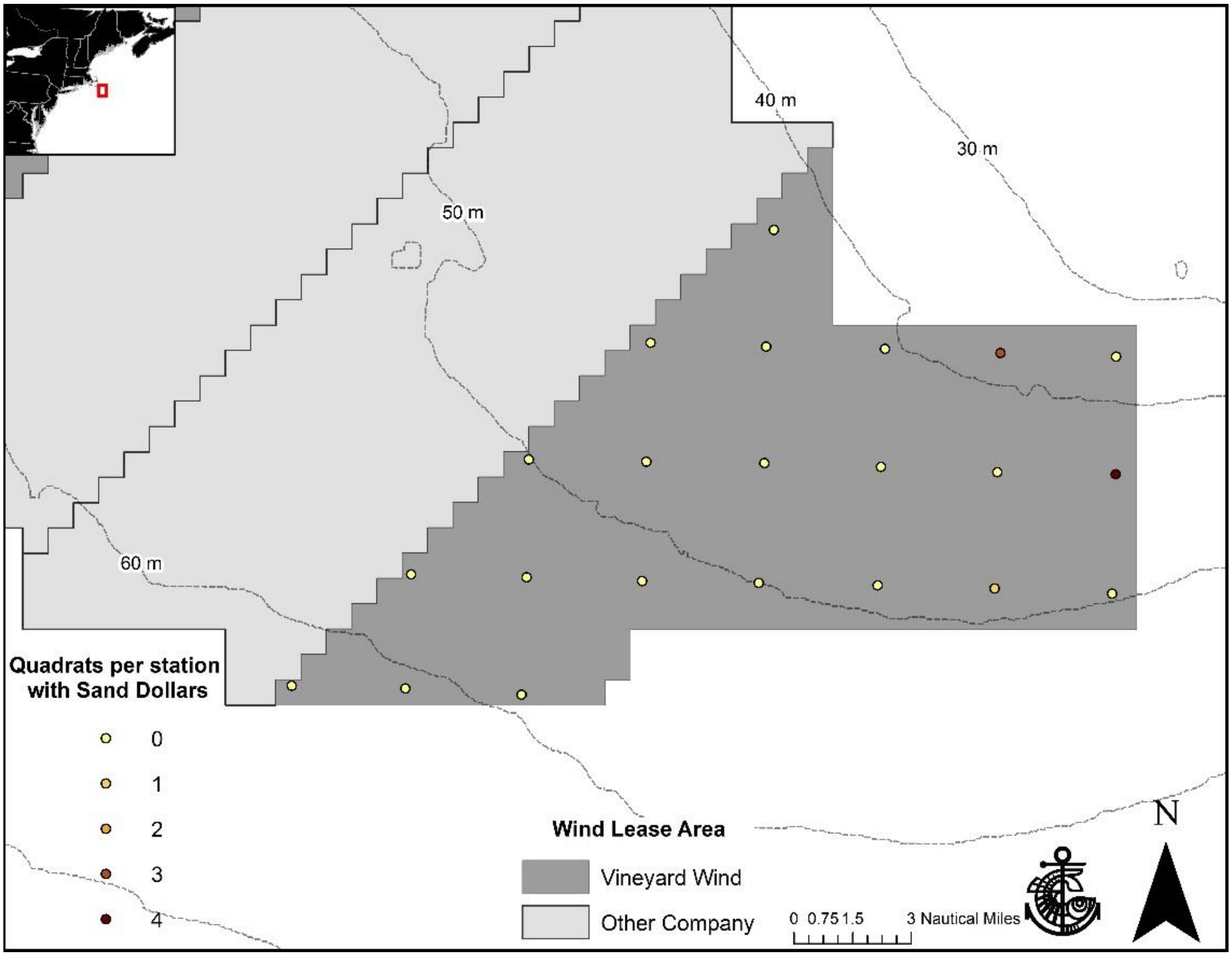

Figure 21. The distribution of sand dollars in the 2019 October drop camera survey of OCS 522 Study Area. Four quadrats (2.3m^2 images) were observed at each station.

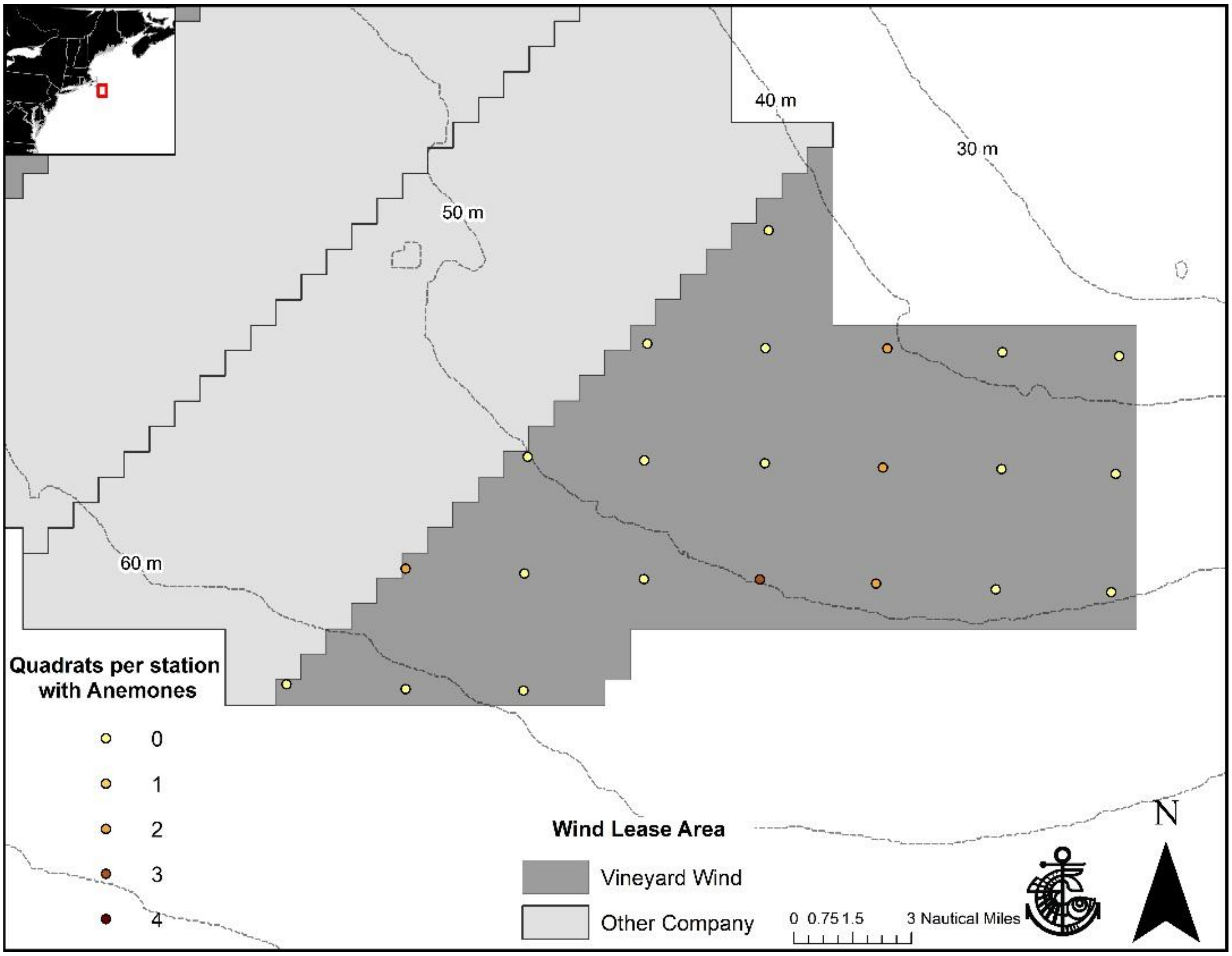

Figure 22. The distribution of anemones in the 2019 October drop camera survey of OCS 522 Study Area. No anemones were observed in an October survey of the same area. Four quadrats ($2.3m^2$ images) were observed at each station.

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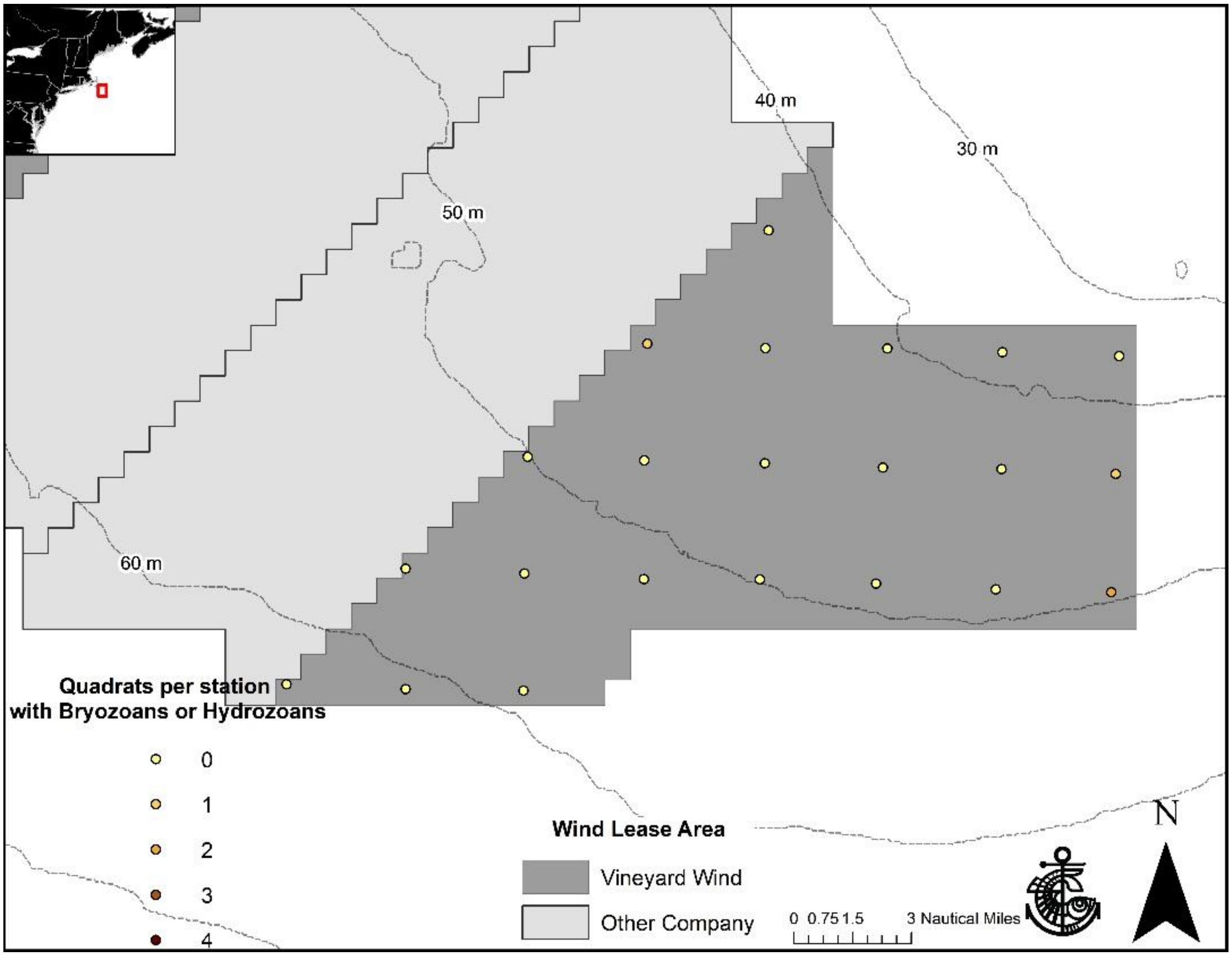

Figure 23. The distribution of bryozoans or hydrozoans in the 2019 October drop camera survey of OCS 522 Study Area. No bryozoans or hydrozoans were observed in an October survey of the same area. Four quadrats (2.3m^2 images) were observed at each station.

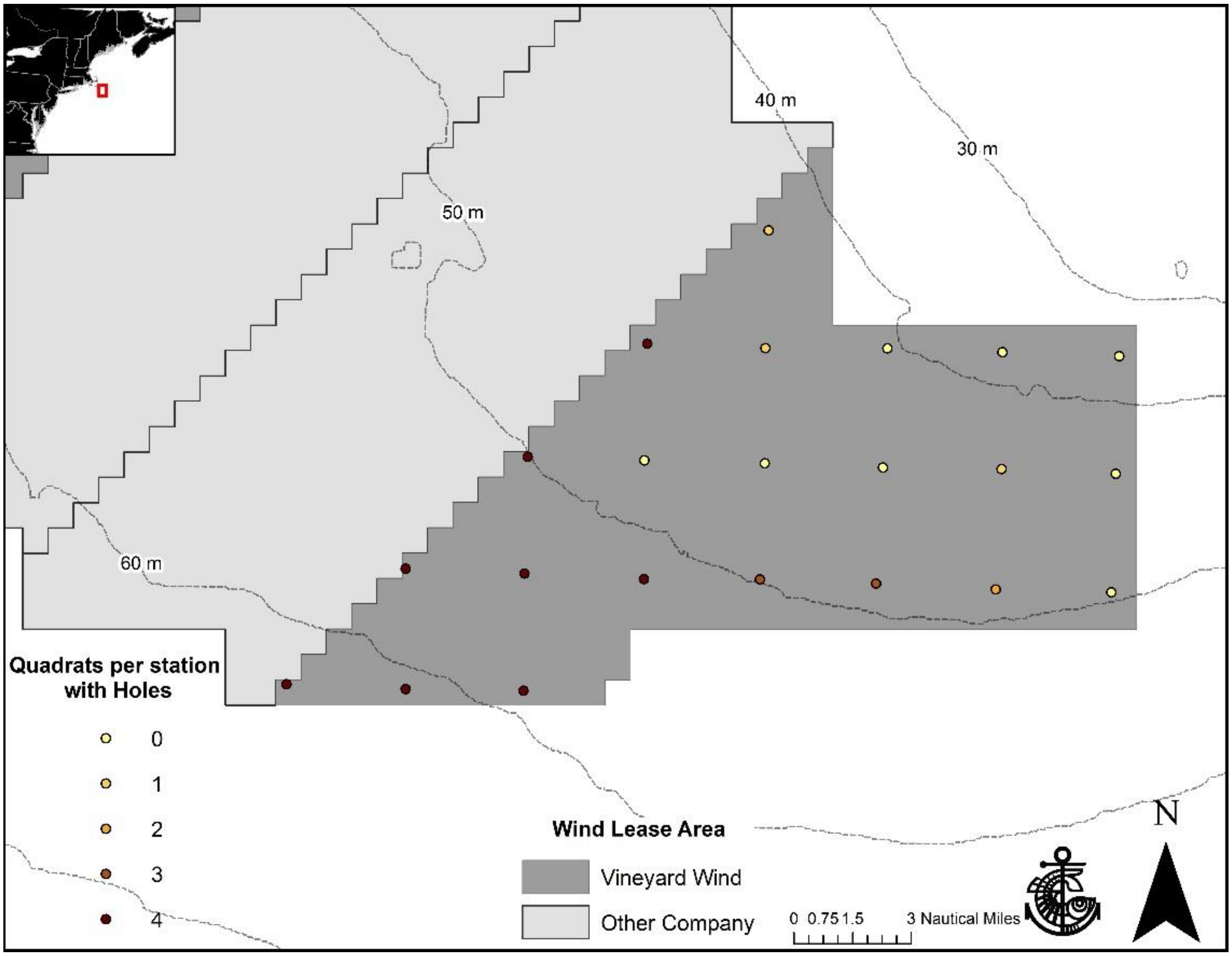

Figure 24. The distribution of holes (burrowing animals) in the 2019 July drop camera survey of OCS 522 Study Area. Four quadrats (2.3m^2 images) were observed at each station.

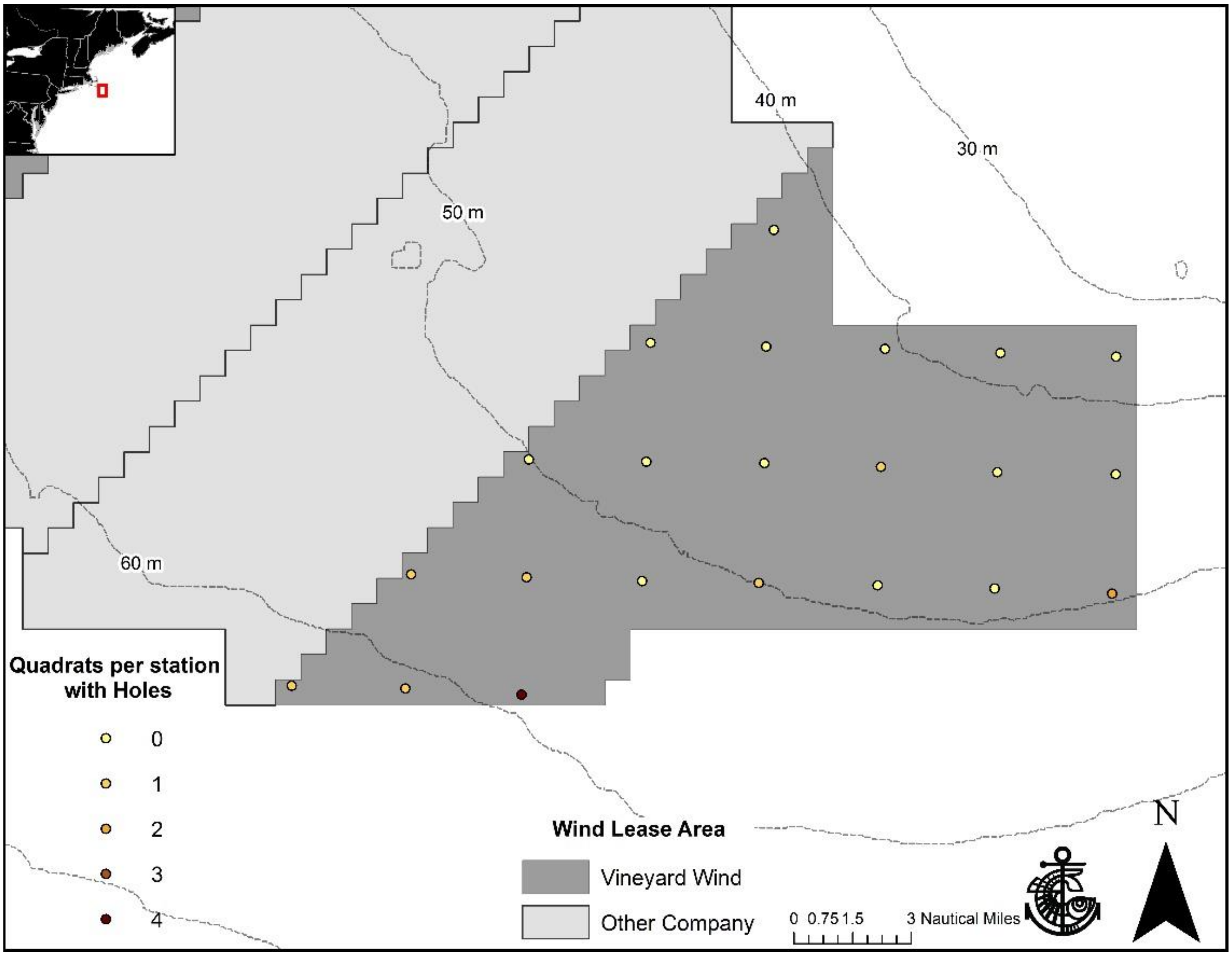

Figure 25. The distribution of holes (burrowing animals) in the 2019 July drop camera survey of OCS 522 Study Area. Four quadrats ($2.3m^2$ images) were observed at each station.

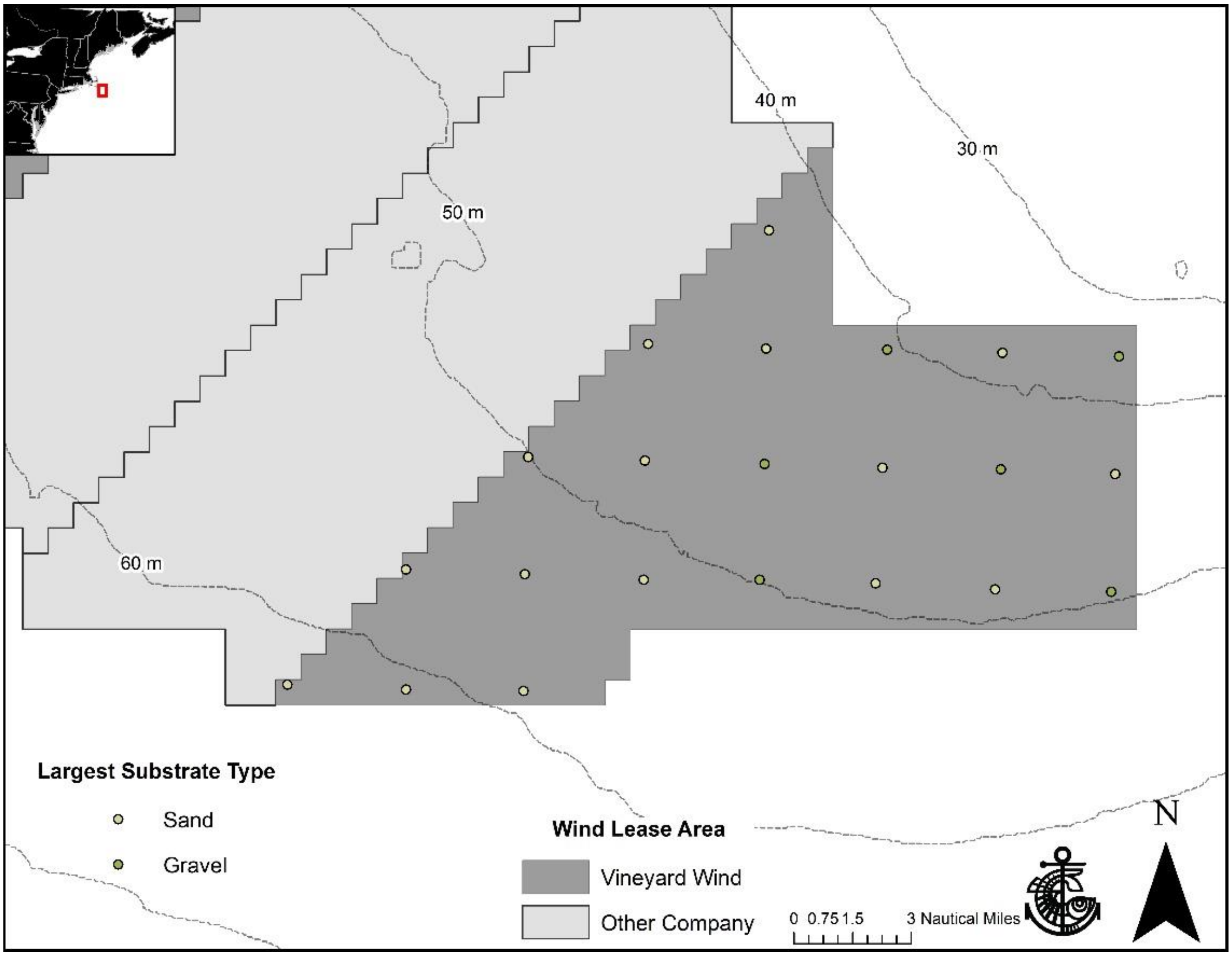

Figure 26. The distribution of substrate types in the October 2019 drop camera survey of OCS 522 Study Area. Four quadrats (2.3m^2 images) were observed at each station.

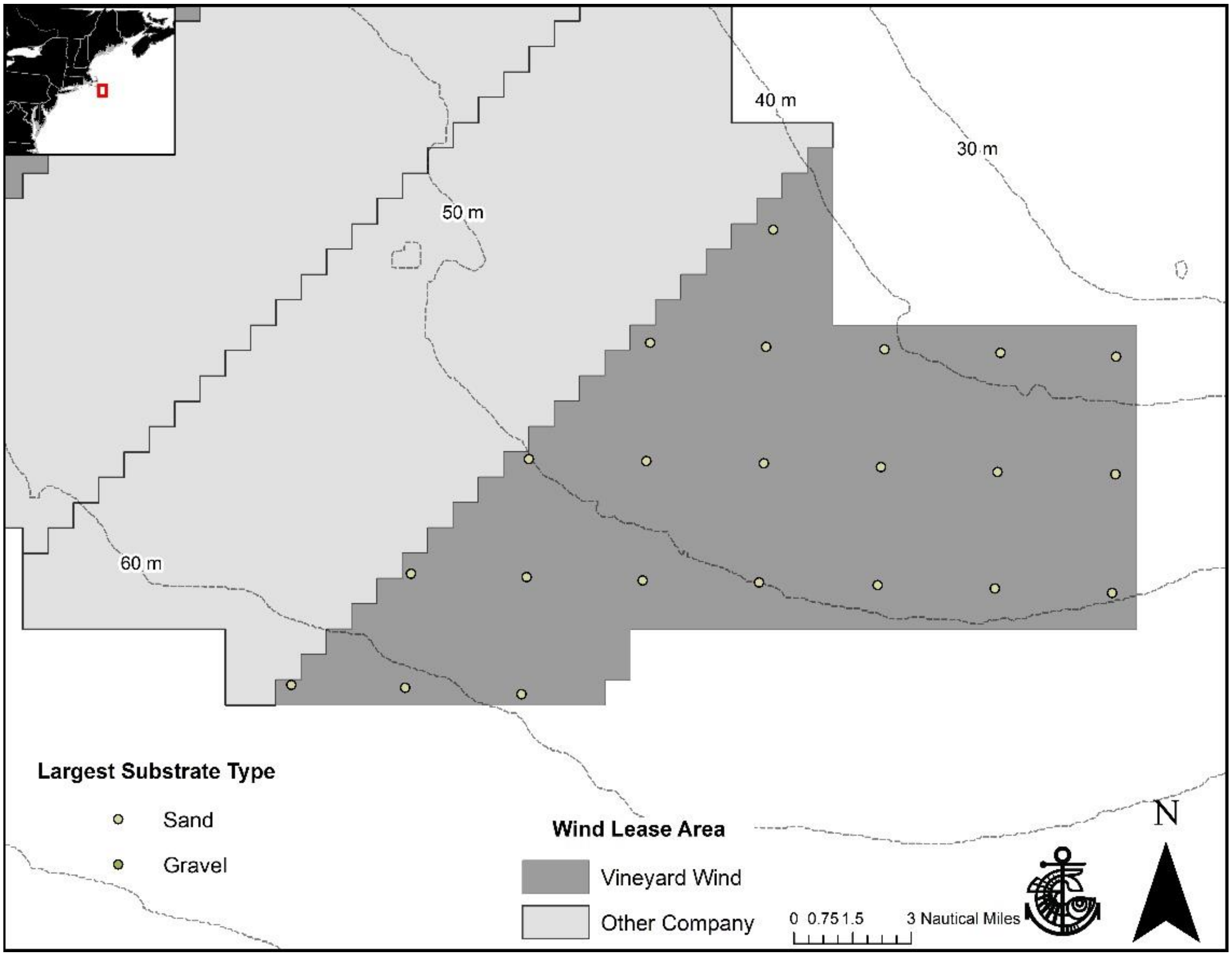

Figure 27. The distribution of substrate types in the October 2019 drop camera survey of OCS 522 Study Area. Four quadrats (2.3m^2 images) were observed at each station.

References

Asci SC, Langton RW, Stokesbury KDE (2018) Estimating similarity in benthic communities over decades and in areas open and closed to fishing in the central Gulf of Maine. *Mar. Ecol. Prog. Ser.* 595: 15-26.

Bethoney ND, Zhao L, Chen C, Stokesbury KDE (2017) Identification of persistent benthic assemblages in areas with different temperature variability patterns through broad-scale mapping. *PLoS ONE* 12 (5), e0177333. https://doi.org/10.1371/journal.pone.0177333

Bethoney ND, Stokesbury K (2018) Methods for Image-based Surveys of Benthic Macroinvertebrates and Their Habitat Exemplified by the Drop Camera Survey for the Atlantic Sea Scallop. *J. Vis. Exp.* (137), 57493. doi:10.3791/57493

Cochran WG (1977) Sampling Techniques 3rd Edition. John Wiley & Sons, New York

Eberhardt LL (1976) Quantitative ecology and impact assessment. *J. Environ. Manage*. 4, 27–70.

Ellis JI, Schneider DC (1997) Evaluation of a gradient sampling design for environmental impact assessment. *Environ. Monit. Assess.* 48, 157 – 172.

Green RH (1979) Sampling Design and Statistical Methods for Environmental Biologists. Wiley, Chichester, UK.

Guida V, Drohan A, Welch H, McHenry J, Johnson D, Kentner V, Brink J, Timmons D, Estela-Gomez E (2017) Habitat Mapping and Assessment of Northeast Wind Energy Areas. Sterling, VA: US Department of the Interior, BOEM. OCS Study BOEM 2017-088. 312 p.

Harris BP, Stokesbury KDE (2010) The spatial structure of local surficial sediment characteristics on Georges Bank, USA. *Cont. Shelf. Res.* 30, 1840-1853

Harris BP, Cowles GW, Stokesbury KDE (2012) Surficial sediment stability on Georges Bank in the Great South Channel and on eastern Nantucket Shoals. *Cont. Shelf. Res.* 49, 65-72

Kerr LA, Kritzer JP, Cadrin SX (2019) Strengths and limitations of before–after–control–impact analysis for testing the effects of marine protected areas on managed populations, *ICES J. Mar. Sci.*, fsz014, https://doi.org/10.1093/icesjms/fsz014.

Krebs CJ (1989) Ecological methodology. Harper & Row, New York

Lincoln RJ, Boxshall GA, Clark PF (1992) A dictionary of ecology, evolution, and systematics. Cambridge University Press, Cambridge.

MacDonald AM, Adams CF, Stokesbury KDE (2010) Abundance estimates of skates (*Rajidae*) on the continental shelf of the northeastern USA using a video survey. *Trans. Am. Fish. Soc.* 139, 1415-1420

Marino II MC, Juanes F, Stokesbury KDE (2009) Spatio-temporal variations of sea star *Asterias* spp. distributions between sea scallop *Placopecten magellanicus* beds on Georges Bank. *Mar. Ecol. Prog. Ser.* 382, 59–68

NEFSC (Northeast Fisheries Science Center) (2010) Stock assessment for Atlantic sea scallops in 2014. In: 59th Northeast Regional Stock Assessment Workshop (59th SAW) Assessment Report. U.S. Dept. of Commerce, NEFSC Ref. Doc. 14-09

NEFSC (2018) Sea scallop assessment summary for 2018. In: 65th Northeast Regional Stock Assessment Workshop (65th SAW) Assessment Summary Report. U.S. Dept of Commer, Northeast Fish Sci Cent Ref Doc 18-08, p 13-19

Rosellon-Druker J, Stokesbury KDE (2019) Characterization and quantification of echinoderms (Echinodermata) on Georges Bank and the potential role of marine protected areas on these populations. *Invert. Biol.* 132(2): https://doi.org/10.1111/ivb.12243

Sokal RR, Rohlf FJ (2012) Hypothesis testing and interval estimation. Pages 119–176 *in* M. Rolfes, editor. Biometry, 4th edition. Freeman, New York, New York.

Smith E (2006) BACI Design. Encyc. of Environmetrics. Vol. 1, pp141-148. https://doi.org/10.1002/9781118445112.stat07659

Stokesbury KDE, Himmelman JH (1993) Spatial distribution of the giant scallop *Placopecten magellanicus* in unharvested beds in the Baie des Chaleurs, Québec. *Mar. Ecol. Prog. Ser.* 96, 159-168

Stokesbury KDE, Himmelman JH (1995) Examination of orientation of the giant scallop, *Placopecten magellanicus*, in natural habitats. *Can. J. Zool.* 73, 1945-1950.

Stokesbury KDE (2002) Estimation of Sea Scallop Abundance in Closed Areas of Georges Bank, USA. *Trans. Am. Fish. Soc.* 131:1081–1092.

Stokesbury KDE, Harris BP (2006) Impact of limited short-term sea scallop fishery on epibenthic community of Georges Bank closed areas. *Mar. Ecol. Prog. Ser.* Vol 307: 85-100.

Stokesbury KDE, Harris BP, Marino MC, Nogueira JI (2004) Estimation of sea scallop abundance using a video survey in off-shore US waters. *J. Shellfish Res.* Vol 23, No. 1, 33-40.

Underwood AJ (1991) Beyond BACI: experimental designs for detecting human and environmental on temporal variations in natural populations. *Aust. J. Mar. Freshwater Res.* 42: 569–587.

Underwood AJ (1993) The mechanics of spatially replicated sampling programmes to detect environmental impacts in a variable world. *Australian J. Ecol.* 18: 99–116.

Appendix I: Georges Bank species are grouped into taxonomic categories (Stokesbury and Harris, 2006).

Category	Scientific name	Common name
Scallop	*Placopecten magellanicus*	Sea scallop
Starfishes	*Solaster endeca*	Purple sunstar
	Crossaster papposus	Spiny sunstar
	Leptasterias Polaris	Polar sea star
	Asterias spp.	Sea stars
	Henricia spp	Blood star
Sand dollars	*Echinarachnius parma*	Sand dollar
Bryozoans/hydrozoans	*Flustra foliacea*	Bryozoans
	Callopora aurita	Bryozoans
	Electra monostachys	Bryozoans
	Cribrilina punctate	Bryozoans
	Eucratea loricate	Bryozoans
	Tricellaria ternate	Bryozoans
	Eudendrium capillare	Hydrozoans
	Sertularia cupressina	Sea cypress hydroid
	Sertularia argentea	Squirrel's tail hydroid
	Diphasia fallax	Hydrozoans
	Filograna implexa	Lacy tube worm
Sponges	*Suberites ficus*	Fig sponge
	Haliclona oculata	Finger sponge
	Halichondria panacea	Crumb of bread sponge
	Cliona celata Grant	Boring sponge
	Polymastia robusta	Encrusting sponge
	Isodictya palmate	Palmate sponge
	Microciona prolifera	Red beard sponge
Lobster	*Homarus americanus*	American lobster
Crabs	*Cancer irroratus Say*	Atlantic rock crab
	Cancer borealis Stimpson	Jonah crab
Hermit crabs	*Diogenidae*	Left-handed hermit crabs
	Paguridae	Right-handed hermit crabs
	Parapaguridae	Deep water hermit crabs
Eel pout	*Zoarces americanus*	Ocean pout
Flounder	*Paralichthys dentatus*	Summer flounder
	Paralichthys oblongus	Fourspot flounder
	Scophthalmus aquosus	Windowpane flounder
	Pseudopleuronectes americanus	Winter flounder
	Limanda ferruginea	Yellowtail flounder
	Glyptocephalus cynoglossus	Witch flounder
	Trinectes maculatus	Hogchoaker
Haddock	*Melanogrammus aeglefinus*	Haddock
Hake	*Merluccius bilinearis*	Silver hake
	Urophycis spp.	Red and white hake
Sculpins	*Myoxocephalus octodecemspinosus*	Longhorn sculpin
	Prionotus carolinus	Northern sea robin
Skates	*Leucoraja erinacea*	Little skate
	Leucoraja ocellata	Winter skate
	Dipturus laevis	Barndoor skate
Other fish	*Myxine glutinosa*	Atlantic hagfish
	Scyliorhinus rotifer	Chain dogfish
	Squalus acanthias	Spiny dogfish
	Anguilla rostrate	American eel
	Conger oceanicus	Conger eel
	Clupea harengus	Atlantic herring
	Brosme brosme	Cusk
	Gadus morhua	Atlantic cod
	Lophius americanus	Goosefish
	Ammodytes dubius	Northern sand lance
	Scomber scombrus	Atlantic mackerel
	Sebastes fasciatus	Acadian refish
	Anarhichas lupus	Atlantic wolfish
Shell debris	*Buccinum undatum*	Waved whelk
	Euspira heros	Northern moonsnail
	Mercenaria mercenaria	Northern quahog
	Modiolus modiolus	Northern horse mussel
	Ensis directus	Atlantic jackknife
	Placopecten magellanicus	Sea scallops