



An Optical Assessment of Sea Scallop and Predator Abundance and Distribution in the Nantucket Lightship Closed Area and Surrounds in Coordination with the VIMS Dredge Survey

An Optical Assessment of Sea Scallop Abundance and Distribution in Select Areas of the Northern Gulf of Maine Scallop Management Area

2017 Sea Scallop Research Set-Aside (RSA) Program

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List of acronyms and terms

AA	Access Area - all or part of an otherwise Closed Area periodically reopened for a specified number of pounds for the various vessel categories in the scallop fleet.
CFF	Coonamesett Farm Foundation, Inc.
CAII	Closed Area II Access Area, scallop rotational fishing area within the Closed Area II groundfish closure area located on central Georges Bank.
EEZ	Exclusive Economic Zone
ftm	fathom or fathoms
FOV	field of view
m	meters
mm	millimeter
mt	metric ton
NEFMC	New England Fishery Management Council
NEFSC	Northeast Fisheries Science Center
NGoM	Northern Gulf of Maine Scallop Management Area
NLS	Nantucket Lightship Scallop Access Area
NLS-AC-N	Nantucket Lightship Scallop Access Area North
NLS-AC-S	Nantucket Lightship Scallop Access Area South
NLS-Ext	Nantucket Lightship Scallop Extension Area
NLS-NA	Nantucket Lightship Scallop No Access Area
NOAA	National Oceanic and Atmospheric Administration
nm	nautical mile
NMFS	National Marine Fisheries Service or NOAA Fisheries
PDT	NEFMC Plan Development Team(s)
RSA	NEMFC/NEFSC Research Set Aside Program
SAMS	Scallop Area Management Simulator (model) areas
SH	shell height
VIMS	Virginia Institute of Marine Science, College of William and Mary
VMS	Vessel Monitoring System
WHOI	Woods Hole Oceanographic Institution

Executive summary: Coonamesett Farm Foundation (CFF) completed two 2017 RSA projects entitled “*An Optical Assessment of Sea Scallop and Predator Abundance and Distribution in the Nantucket Lightship Closed Area and Surrounds in Coordination with the VIMS Dredge Survey*” and “*An Optical Assessment of Sea Scallop Abundance and Distribution in Select Areas of the Northern Gulf of Maine Scallop Management Area.*” They were designed to provide critical survey-based information to help inform scallop fishery management efforts. The primary objectives of these projects were to:

1. Provide biomass estimates and size distribution of scallops in Nantucket Lightship (NLS) and Northern Gulf of Maine (NGoM) scallop management areas.
2. Provide cursory geographical information on potential scallop predator distributions in NLS and NGoM management areas.
3. Generate comparisons of biomass, scallop density and scallop length-frequency estimates generated by the Virginia Institute of Marine Science (VIMS) survey dredge and CFF’s HabCam v3 in overlapping survey areas.

CFF’s 2017 RSA HabCam surveys got underway on July 7, 2017 with an optical survey of select portions of the NGoM Management Area. This was followed up by a 9-day optical survey of the NLS Management Area on July 14-22, 2017. Both trips were undertaken on the F/V Kathy Marie.

Northern Gulf of Maine Scallop Management Area

Biomass: Total estimated biomass in the surveyed areas in the NGoM is 688 metric tons (mt; **Table 1**). Scallops 25-50mm were seen within the Jeffreys Ledge survey area (NGoM-N), particularly in the southwestern edge. There are likely two age classes of scallops in the Jeffreys Ledge survey area, as evidenced by the bimodal length-frequency distribution. Scallops were somewhat widely distributed throughout the Stellwagen Bank survey area (NGoM-S) and scallops less than 75mm were not evident in substantial abundance along the Stellwagen Bank cruise track.

Table 1. Scallop biomass estimates (> 40 mm) for northern and southern survey areas in the Northern Gulf of Maine derived from the 2017 RSA HabCam survey. Biomass in metric tons.

Area	Estimate (mt)	SE	Images annotated
NGoM-N	177	42	680
NGoM-S	511	75	2120
Total	688		

Potential scallop predator distribution: A relatively high density (i.e., greater than 5 individuals per image) of sea stars (*Asterias* spp.) was noted in the southwestern portion of Jeffreys Ledge as compared to other areas surveyed in the NGoM. This overlapped with the noted occurrence of pre-recruit scallops. Short-term monitoring of any impact *Asterias* may have on scallop recruitment in this area was recommended to the Atlantic Sea Scallop Plan Development Team (PDT).

Nantucket Lightship Scallop Access Area

Biomass: Total estimated biomass in the NLS (scallop > 40mm) is 149,658 metric tons (**Table 2**). The highest densities and biomass were found within the Nantucket Lightship Scallop Access Area South (NLS-AC-S) Scallop Area Management Simulator (SAMS) area, while the lowest estimated biomass was from the Nantucket Lightship Scallop Extension Area (NLS-Ext) SAMS area. Median scallop size increased markedly with decreasing depth (and a corresponding generally northward geographical shift) towards the Nantucket Lightship Scallop Access Area North (NLS-AC-N). Scallops 50-75mm were encountered in relatively high densities (i.e., greater than 25 individuals per image, with an image field of view being approximately 0.5-0.75 m²) in approximately 75-80 m of water in NLS-AC-S, and in moderate densities (i.e., greater than 10 individuals per image) in the Nantucket Lightship Scallop No Access Area (NLS-NA), both of which are open to scallop access trips in 2018.

Table 2. Scallop biomass estimates (> 40 mm) for survey areas in the Nantucket Lightship Scallop Management Area derived from the 2017 RSA HabCam survey. Biomass in metric tons.

Area	Estimate (mt)	SE	Images annotated
NLS-AC-S	77827	3174	2375
NLS-NA	56066	1831	2278
NLS-AC-N	10083	300	1566
NLS-Ext	5682	1831	2135
Total	149658		

Potential scallop predator distribution: Relatively high densities of *Astropecten spp.*, a known predator of juvenile sea scallops, were seen in an area immediately to the south of the NLS-AC-S SAMS area. *Astropecten spp.* was also noted in somewhat lesser densities in the NLS-Ext area. No seed or juvenile scallops were seen in these two areas of the NLS during this survey and it is not known at this time if the high density of *Astropecten spp.* is an artifact of a predation event. Seed and small juvenile scallops were noted in the NLS-Ext area as recently as 2013. Review of previous survey data to determine if data exists that may aid in determining if a predation event may have taken place is recommended.

Dredge efficiency comparisons: Scallop biomass estimated from the VIMS dredge survey were substantially lower than RSA HabCam estimates in all SAMS areas except NLS-AC-N. Comparative length-frequency plots exhibited minor shifts in length distribution between the optical survey and the dredge survey, with the exception of the NLS-AC-S. A comparison of estimated scallop meat weight per square meter as calculated from the dredge survey and the RSA HabCam survey was also performed. Although the calculated survey dredge efficiency (using estimated HabCam density as a proxy) was less than the assumed efficiencies for both soft and hard bottom, the results of this analysis did not show a substantial decrease in survey dredge efficiency with increased scallop density. This may be due to a lack of sample overlap and/or small sample sizes.

Background

The Atlantic sea scallop fishery is one of the most valuable fisheries in the United States (US), with revenues averaging \$400-\$600 million since 2006 ([Smolowitz 2016](#)). The scallop resource rebounded from a depleted state in the early 1990's due, in part, to a number of management changes implemented to protect the resource in certain areas until scallops achieve marketable size. The primary management methods responsible for this turnaround included a reduction in Days-At-Sea (DAS), limits on crew size, gear modifications, and, perhaps most importantly, the institution of rotationally fished Scallop Access Areas. This last approach also included management provisions to temporarily close newly identified areas with high numbers of small scallops. These measures, coupled with the additional measures set forth in the open access areas aimed at ensuring continued growth and spawning of those populations, have aided in facilitation of the current high and relatively stable output of the Atlantic sea scallop fishery ([Hart 2004](#); [NEFSC 2014](#)).

Successful rotational management and the opening or closing of spatial management areas for harvest, as well as limiting effort in other management areas, is highly dependent on a sound estimation of the resource. Because the resource is spread over a large geographic scale, reliance on industry-based surveys has become increasingly important in the face of limited federal resources. Traditional surveys (e.g., dredge-based), while providing critical biological information, have been shown to be potentially limited due to decreased catch efficiency in areas of dense scallop aggregation ([NEFSC 2004](#); [Gedamke et al. 2005](#)).

Optical surveys are becoming increasingly important components to an overall survey strategy for sea scallops and hold several key advantages over traditional dredge surveys. Optical surveys overcome the issue of decreased dredge efficiency, leading to underestimation of biomass, in dense aggregations. Additionally, optical surveys are able to characterize the spatial scale of areas containing seed and very small scallops which may be missed or only qualitatively noted by dredge surveys due to size selectivity ([Rudders 2015](#)). Optical surveys can also cover large swept areas in a relatively short time frame, allowing for detection of fine-scale distribution changes. The images and metadata collected during optical surveys also holds ancillary information such as species interactions, distribution of additional flora and fauna, temperature, salinity, and substrate type.

Summary of Existing Knowledge

Large scallop settlement event along the Southern New England shelf

In the summer of 2013, the Northeast Fisheries Science Center (NEFSC) and Virginia Institute of Marine Science (VIMS) Research Set Aside (RSA)-sponsored scallop survey efforts located areas of high density age-1 scallop settlement south of the Great South Channel, extending both east and west along the 30-40 fathom edge of the Southern New England shelf ([NEFSC 2013](#)). In August 2013, the HabCam Group conducted a 3-day, 300nm survey in the areas identified by the NEFSC and VIMS surveys, with expanded coverage in the western, southern, and eastern portions of the Nantucket Lightship (NLS) Scallop Management Area. A large concentration of 15-25mm scallops were noted in the NLS Scallop Access Area South (NLS-AC-S), with this high-density area extending just to the south of the NLS scallop management southern border.

Scallop densities were also noted to be high in the NLS No-Access (NLS-NA) and within the current NLS extension (NLS-Ext) SAMS areas (see **Figure 1** for a graphical depiction of the NLS SAMS areas).

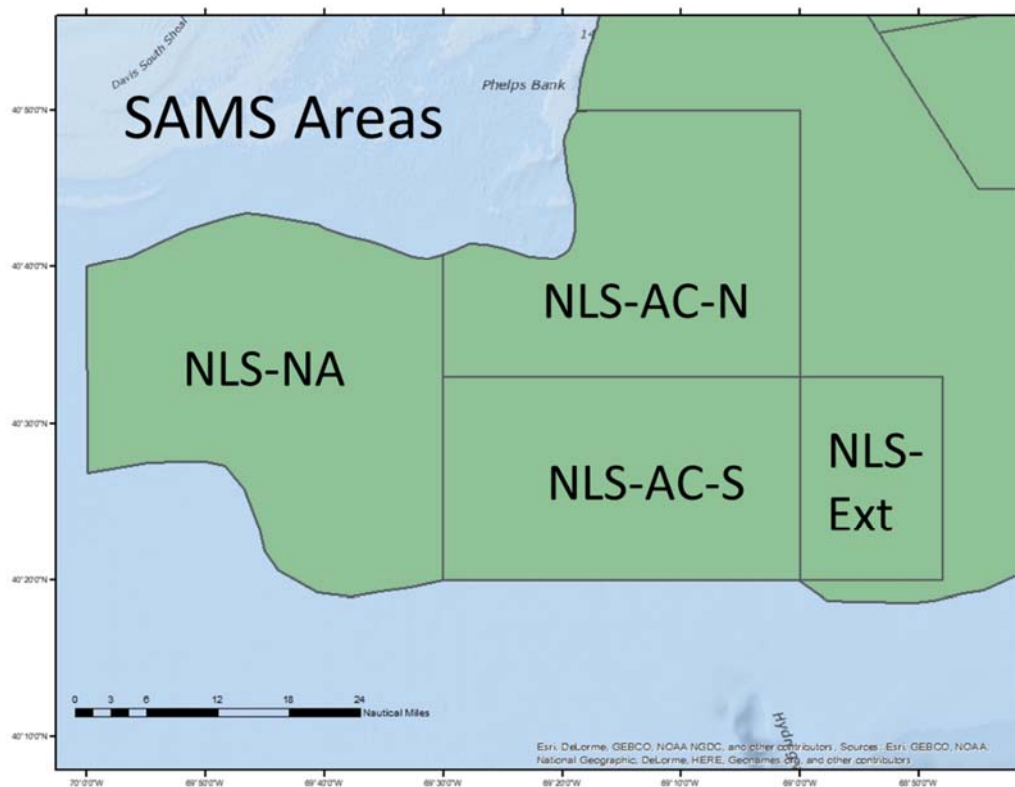


Figure 1. Scallop Area Management Simulator (SAMS) areas in the Nantucket Lightship Scallop Management Area (NLS-NA: non-access habitat closure; NLS-AC-N: Access area north; NLS-AC-S: Access area south; NLS-EXT: eastern extension).

2014-RSA sponsored HabCam v2 settlement survey - NA14NMF4540083

Over the course of four separate trips in June and July of 2014, HabCam Group surveyed the 2012 set of scallops on the southern New England shelf. Dense settlements of small scallops were seen in the NLS-AC-S (**Figure 2**). HabCam imagery was also used to map the density of predators, particularly sea stars.

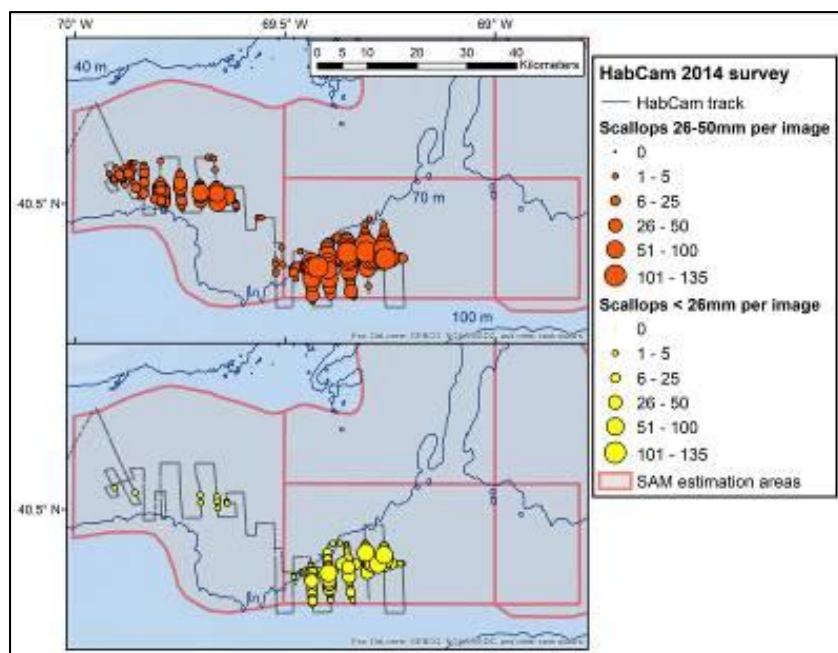


Figure 2. Distributions of 0-25mm and 26-50mm scallops from 2014 RSA HabCam survey in the NLS.

2015 RSA-sponsored survey of the NLS area - NA15NMF4540064

In June 2015, optical survey data was collected in southern New England waters and on Georges Bank. Dense scallop concentrations were again located in the eastern two thirds of the NLS, with much smaller numbers in the deeper waters southeast of Closed Area II. Overall, about 80% of the scallops in this region were located in the NLS. Most of the scallops were under 75 mm (**Figure 3**), presumably belonging to the 2012 year class.

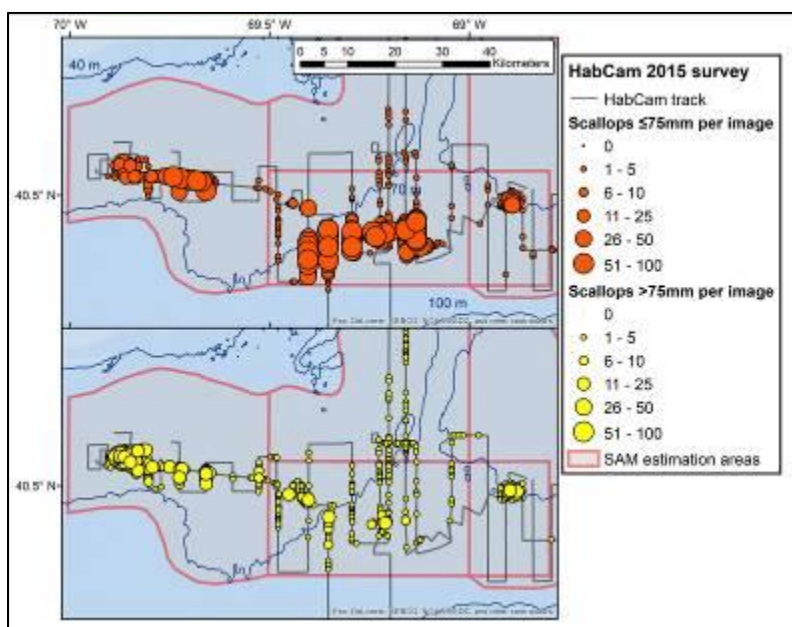


Figure 3. Distributions of 0-75mm and over 75mm scallops from 2015 RSA HabCam survey in the NLS.

Need for additional surveys in the Gulf of Maine

Large removals from Jeffreys Ledge and Stellwagen Bank in 2016 and 2017 prompted the NEFSC to request additional survey information in select areas of the NGoM to help guide future management efforts. It is estimated that during the period the NGoM was open to fishing in 2017 (March 1st to 23rd, 2017) approximately one million pounds (450 mt) of scallops were landed from this area. This level of removals prompted the NEFMC to issue a special request for surveys in the NGoM management area in the summer of 2017. The scallop fleet effort was concentrated on southern Jeffreys Ledge and Stellwagen Bank in 2016 and 2017 ([Galuardi, 2017](#)). Therefore, understanding the impacts of fishery removal on the scallop resource in these areas was deemed critical. Additionally, documentation of spatial distribution as well as any evidence of recruitment in this area was also requested.

Project Goals and Objectives

The overarching goal of this survey was to provide data for biomass estimates to the Atlantic Sea Scallop Plan Development Team (PDT) to inform management decisions. The primary objectives of the project were to:

1. Provide biomass estimates and size distribution of scallops in Nantucket Lightship (NLS) and Northern Gulf of Maine (NGoM) management areas.
2. Provide cursory geographical information on potential scallop predator distributions in NLS and NGoM management areas.
3. Generate comparisons of biomass, scallop density and scallop length-frequency estimates generated by survey dredge and HabCam v3 in overlapping survey areas in the NLS.

Methods

CFF's 2017 RSA HabCam surveys got underway on July 7, 2017 with a 2-day optical survey of select areas of the NGoM Management area (**Figure 4**). This was followed up by a 9-day optical survey of the NLS Management Area on July 14-22, 2017 (**Figure 4**). Both trips were undertaken on the F/V Kathy Marie.

Actual cruise tracks were somewhat modified from proposed cruise tracks in the NGoM and NLS. After consultation with fishermen, the NGoM cruise track was refined to concentrate effort on areas with known scallop abundance and to avoid unmarked and marked shipwrecks and other underwater hazards. The cruise track was further altered, particularly on Jeffreys Ledge, due to the high density of fishing gear present in the survey area. The survey track in the NLS was modified due to extreme bathymetric features (e.g., 10 to 15 m sand waves) and the resulting strong localized currents, particularly around the Asia Rip area. Thus, the northern portion of the north-south transects in the NLS Access area North (NLS-AC-N) area were truncated and “prospecting” tracks were added south of the NLS –AC-S.

It is worth noting that after analysis and discussions with other survey teams, it was suggested that including survey areas beyond where scallops are present would be beneficial information to

collect so that the models and plots will more accurately portray the extent of scallop distributions. This consideration will be factored into subsequent survey track planning.

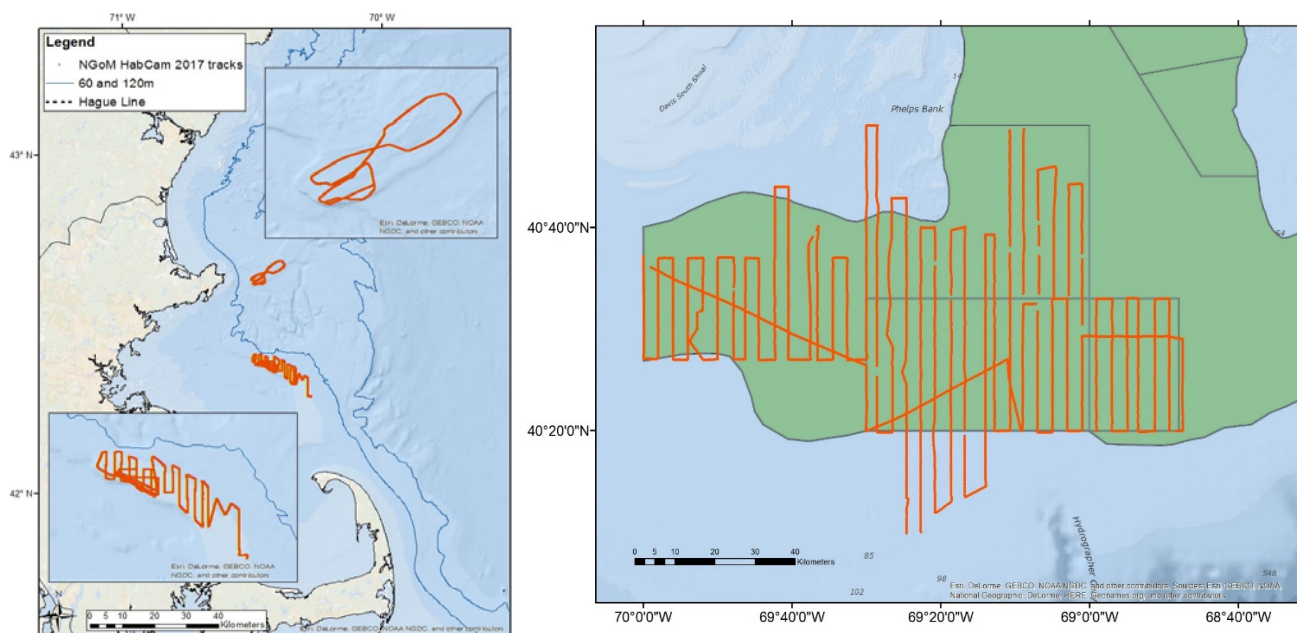


Figure 4. Survey tracks in the Northern Gulf of Maine (left panel) and Nantucket Lightship (right panel) scallop management areas.

The HabCam v3 optical imaging system was “flown” 1.5 to 2.5 meters off the seafloor while being towed at 4-5 knots. Raw images were captured and saved as 12-bit high dynamic range TIF files to a Synology Network Attached Storage system. The TIF files also contained the metadata associated with a particular image (e.g., date, time, latitude, longitude, temperature, conductivity, speed, vessel sounder depth, and heading). After collection, copies of the raw TIF files were processed into 8-bit JPG image files, which were used for annotation.

Images were annotated using the MATLAB® Manual Identification Program (MIP). Scallops were counted and measured, while fish, sea stars, and other organisms of interested were counted. Scallop shell heights were measured when the hinge was visible – if this was not possible, scallop shell width was used in lieu of height. Annotation data was recorded into data files that also include HabCam v3 sensor measurements. These data files were supplied to NEFSC staff for biomass modeling.

All annotated images were reviewed for quality control prior to final data being sent to the NEFSC for biomass estimate modeling. The resulting image-based annotation data was also plotted for scallop size distributions, scallop length frequency, and potential predator distribution in both the NGoM and NLS.

Biomass estimates: Scallop lengths are initially recorded in pixels and were subsequently converted into shell heights based on the image field of view (FOV). Each shell height (SH) measured from the HabCam images is converted to a meat weight (MW) in grams using published location-specific SH-MW equations that include depth as a covariate (e.g., [Hennen](#)

and Hart 2012). Biomass per m² is calculated by summing all MWs in an image and dividing by the FOV of that image.

To estimate biomass, the NEFSC used a combination of a hurdle generalized additive model (GAM) and ordinary kriging (Chang et al. 2017). The hurdle GAM (quasi-binomial distribution for the presence/absence model and quasi-Poisson distribution for the positive model) was used to estimate the large-scale trends in biomass with respect to latitude, longitude, and depth. Kriging on the model residuals was used to improve estimates over smaller scales.

Optical survey tracks: The total optical survey track in the NGoM was 90 nautical miles (nm); 67 nm in the Stellwagen Bank area and 23 nm on Jeffreys Ledge. Approximately 400,000 images were collected in the NGoM, of which 2,000 were annotated, resulting in an annotation rate of 1:200 collected images.

The total optical survey track in the NLS was 875 nm; 680 nm consisted of north-south transects with 1.5 nm spacing in between. A 130-nm east-west transect was conducted after completion of the north-south transects and targeted areas with high scallop density. Approximately 3.7 million images were collected over the course of the NLS survey and 10,745 were annotated, resulting in an annotation rate of 1:400.

Results and Discussion

Northern Gulf of Maine Survey

Total estimated biomass in the surveyed areas in the NGoM scallop management area is 688 mt (Table 1; Figure 5). Scallops 25-50mm were seen within the Jeffreys Ledge survey area (NGoM-N), particularly in the southwestern edge. There are likely two age classes of scallops in the Jeffreys Ledge survey area, as evidenced by the bimodal length-frequency distribution. Scallops were somewhat widely distributed throughout the Stellwagen Bank survey area (NGoM-S) and scallops <75mm were not evident in substantial abundance along the Stellwagen Bank cruise track.

Table 1. Scallop biomass estimates (> 40 mm) for northern and southern survey areas in the Northern Gulf of Maine derived from the 2017 RSA HabCam survey. Biomass in metric tons.

Area	Estimate (mt)	SE	Images annotated
NGoM-N	177	42	680
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Total	688		

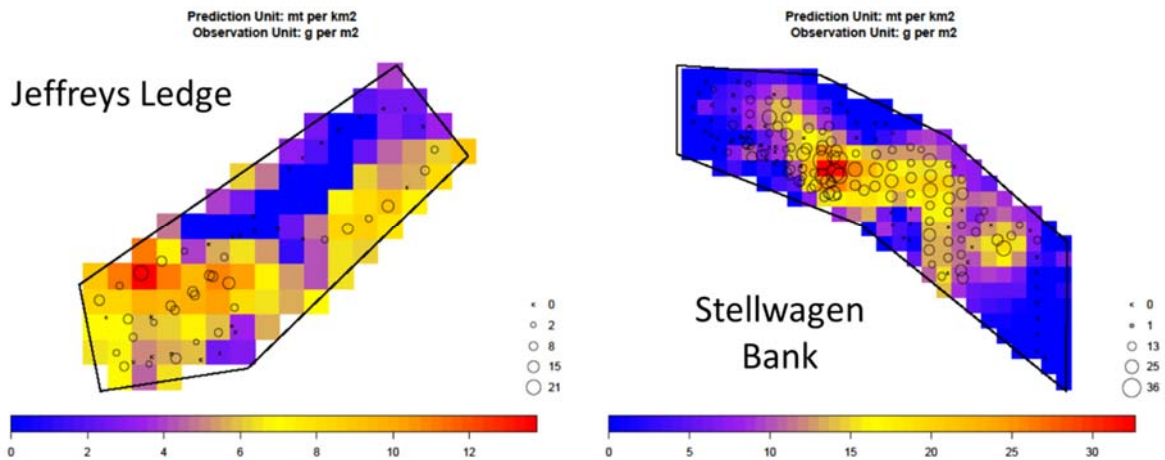


Figure 5. Spatial representation of scallop biomass estimates (> 40 mm) and density (as grams per square meter) for northern (left panel) and southern (right panel) survey areas in the Northern Gulf of Maine derived from the 2017 RSA HabCam survey. Biomass in metric tons.

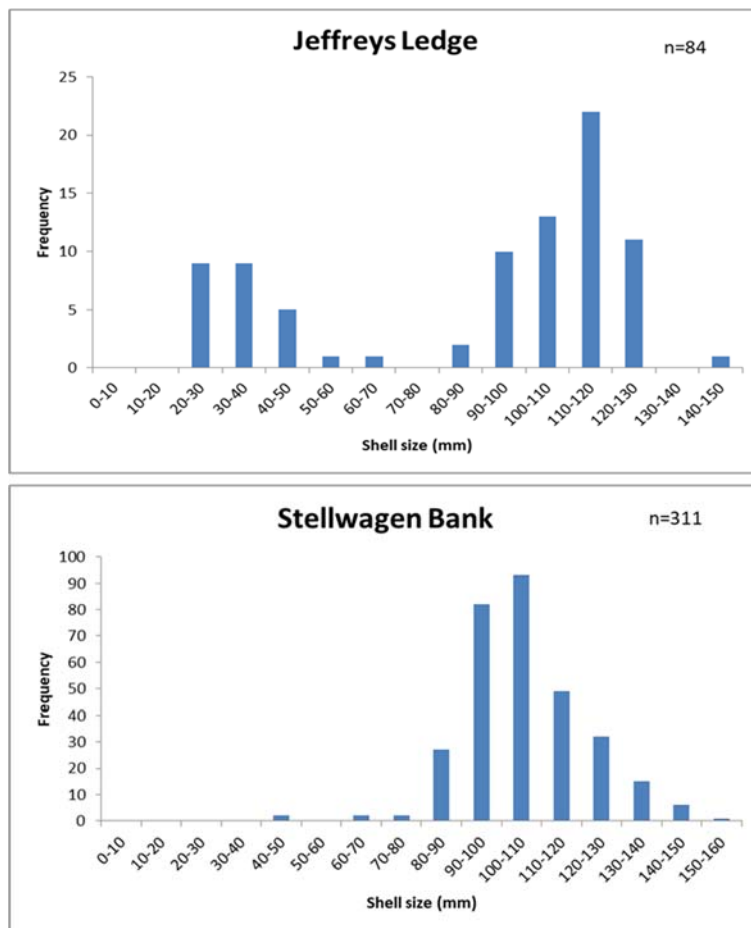


Figure 6. Length-frequency plots of scallops (by 10mm size bin) in surveys areas within the Northern Gulf of Maine Scallop Management Area.

There are likely two age classes of scallops in the Jeffreys Ledge survey area, as evidenced by the bimodal length-frequency distribution (**Figure 6**). Scallops were somewhat widely distributed

throughout the Stellwagen Bank survey area (NGoM-S) and scallops <75mm were not evident in substantial abundance along the Stellwagen Bank cruise track (**Figure 7**).

The sea star *Asterias spp.* is known to prey on a wide variety of benthic invertebrates, including juvenile scallops (Sloan 1980). Among other factors (e.g., depth), abundance of *Asterias spp.* can strongly influence scallop recruitment (Hart 2006). A relatively high density of sea stars (*Asterias spp.*) was noted in the southwest portion of Jeffreys Ledge as compared to other areas surveyed in the NGoM. This overlapped with the noted occurrence of pre-recruit (<50 mm) scallops (**Figure 8**). It is not known if the density of *Asterias spp.* (approximately 3-5 individuals per m² in some areas) is of the magnitude that would influence scallop recruitment. Short-term monitoring of *Asterias spp.* density, distribution and any impacts on scallop abundance on Jeffreys Ledge is recommended.

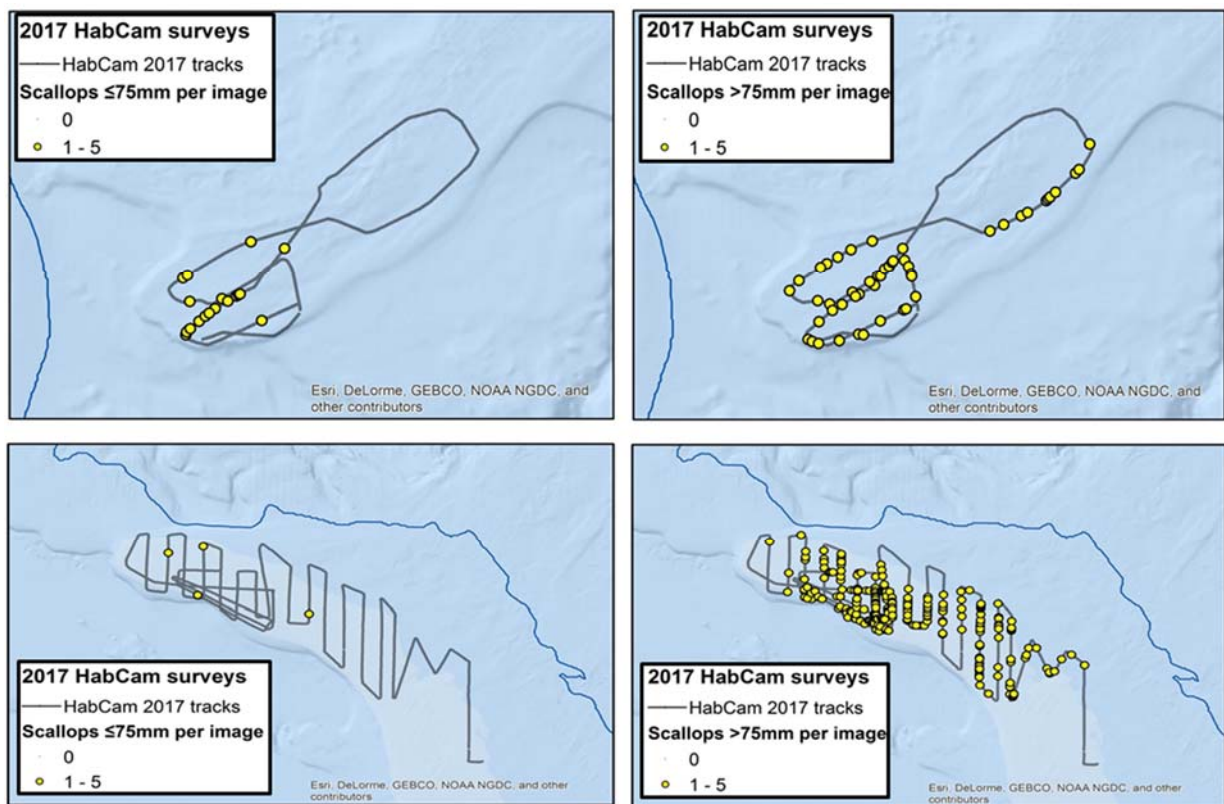


Figure 7. Scallop frequency distribution on Jeffreys Ledge (top) and Stellwagen Bank (bottom) in the Northern Gulf of Maine Management Area.

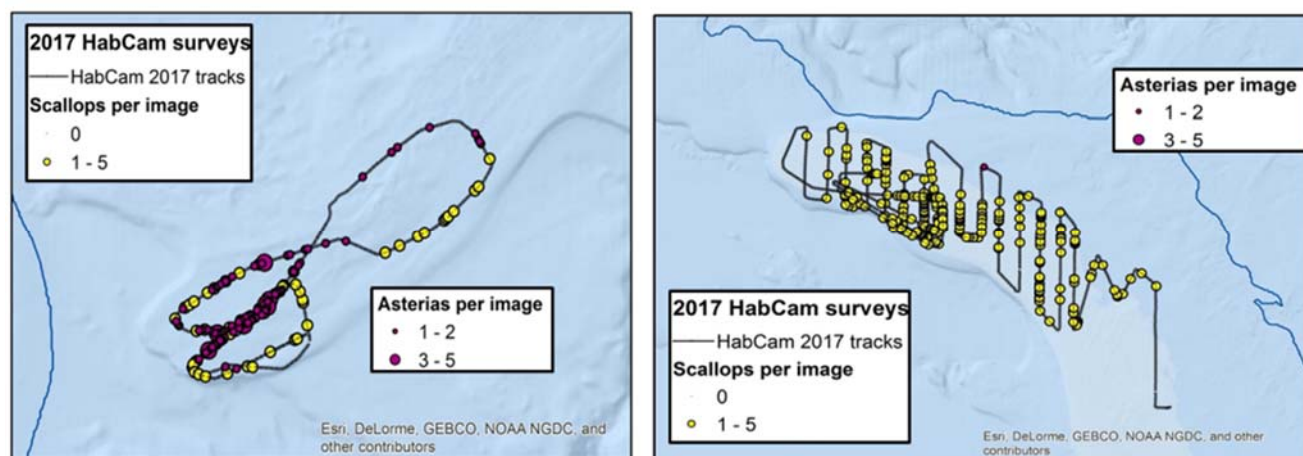


Figure 8. *Asterias* sea star and scallop distribution on Jeffreys Ledge (left) and Stellwagen Bank (right) in survey areas within the Northern Gulf of Maine Management Area.

At the request of the NEFSC, six non-random dredge tows were completed within the Stellwagen Bank survey area in the NGoM (**Appendix Table A1**). The primary objective of these tows was to collect biological data (shell samples, gonad weights, SH-MW, etc.). Tow duration was 10 or 15 minutes. The catch was separated on deck and weighed by category (scallops, fish, skates, other bycatch, and “trash”). One bushel of scallops was measured (shell height) from each tow; meat and gonad weights were measured from a subsample of 10 scallops from each tow (see **Figures A1** and **A2** in Appendix). Shell samples and data were supplied to NEFSC staff.

Nantucket Lightship Survey

Biomass, distribution and scallop length-frequency in the Nantucket Lightship is presented by SAMS area (see **Figure 1** for a graphical description of SAMS areas). Total estimated biomass in the NLS (scallops > 40mm) is 149,658 metric tons (mt; **Table 2**). The highest densities and biomass were found in NLS-AC-S, while the lowest estimated biomass was from the NLS-Ext (**Figures 9** and **10**). The NLS-NA area also yielded strong distribution and biomass.

Table 2. Scallop biomass estimates (> 40 mm) for Nantucket Lightship SAMS derived from the 2017 RSA HabCam survey using the shell-height-meat weight relationships from SARC 50 (NLS-AC-N and NLS-Ext) and VIMS 2016 / 2017 surveys (NLS-AC-S and NLS-NA).

Area	Estimate (mt)	SE	Images annotated
NLS-AC-S	77827	3174	2375
NLS-NA	56066	1831	2278
NLS-AC-N	10083	300	1566
NLS-Ext	5682	1831	2135
Total	149658		

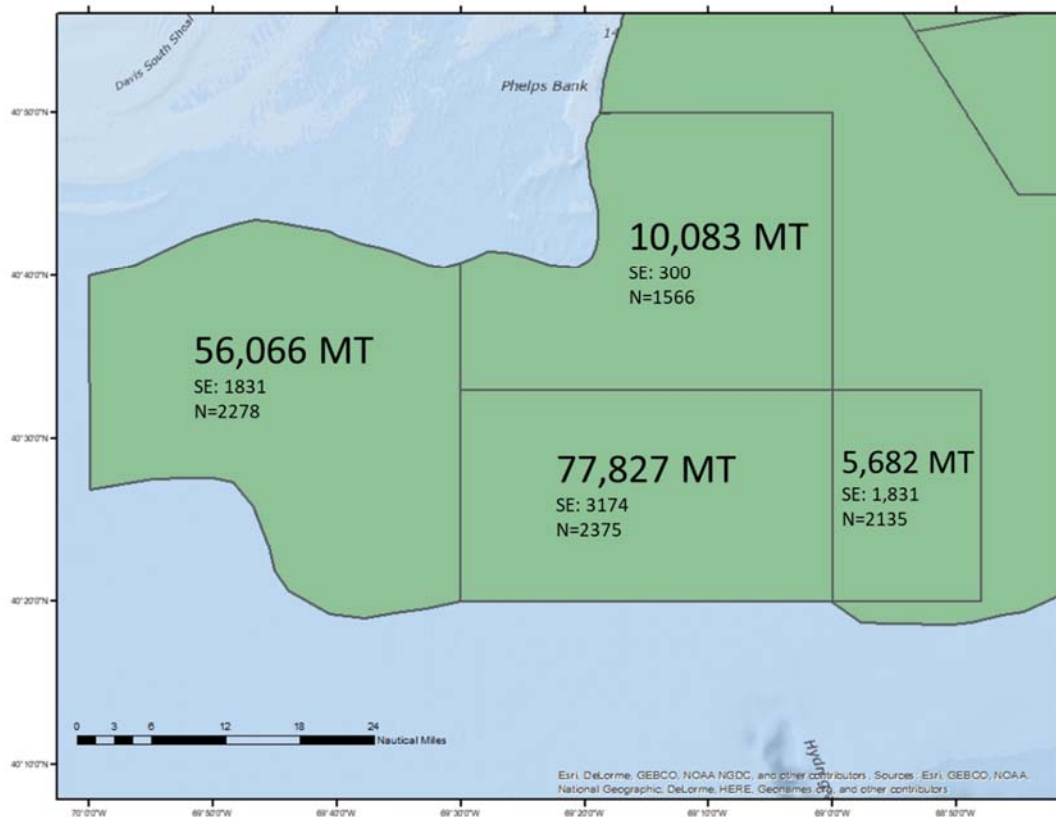


Figure 9. Scallop biomass estimates (> 40 mm) for Nantucket Lightship SAMS areas derived from the 2017 RSA HabCam survey using the shell-height-meat weight relationships from SARC 50 (NLS-AC-N and NLS-Ext) and VIMS 2016 / 2017 surveys (NLS-AC-S and NLS-NA).

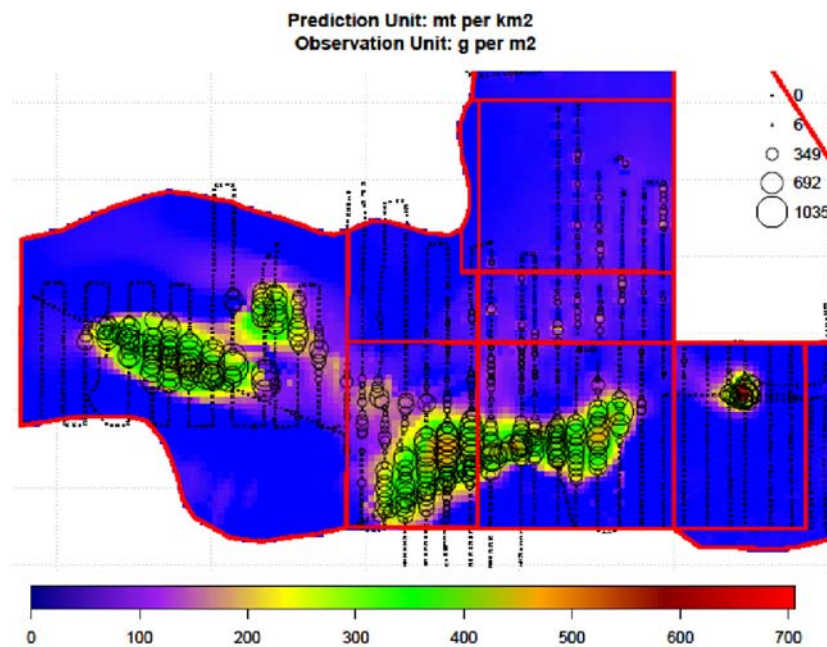


Figure 10. Scallop biomass estimates (> 40 mm) for Nantucket Lightship management areas derived from the 2017 RSA HabCam survey.

The largest scallop shell heights were measured in the NLS-AC-N, with the majority of scallops measuring 110-140mm (average: 124mm; **Figure 11**). The majority of scallops in the NLS-AC-S area were 60-90mm (average: 76mm; **Figure 11**).

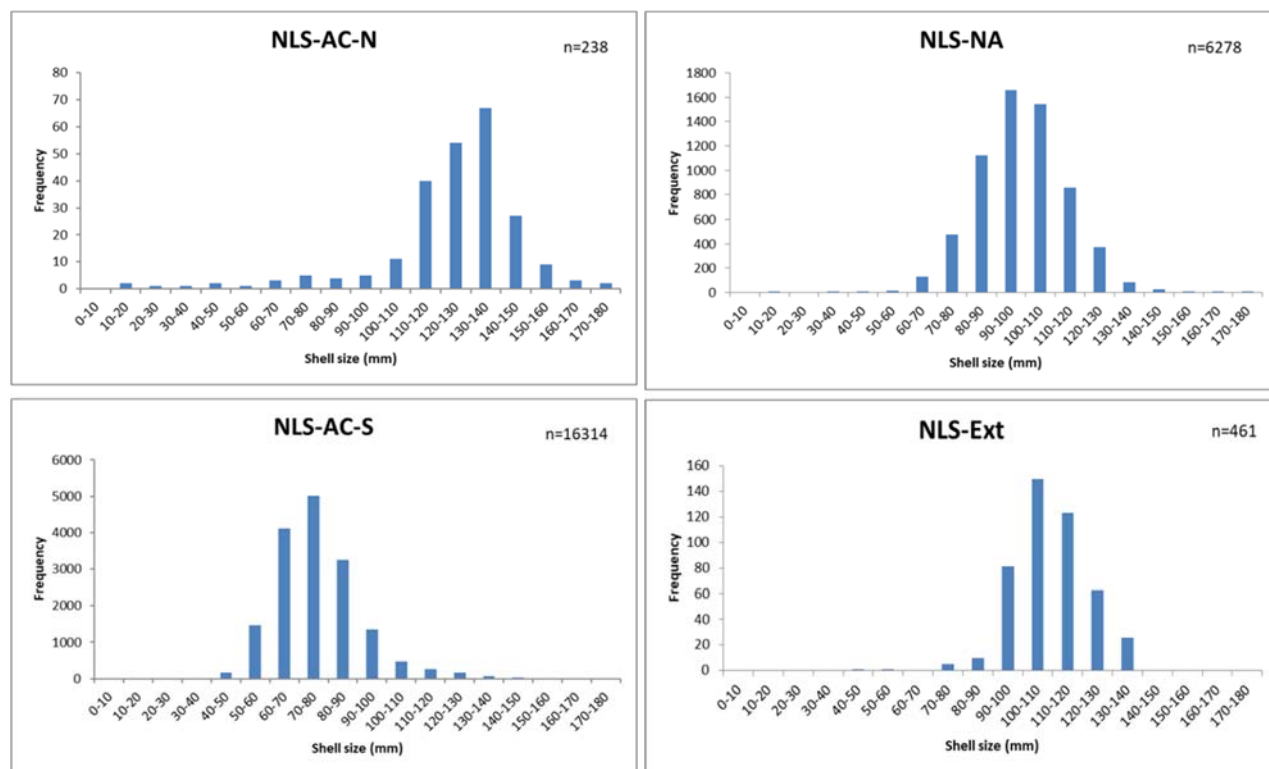


Figure 11. Length-frequency plots of scallops (by 10mm size bin) in the Nantucket Lightship Management Area.

Scallop density in the NLS was concentrated in the NLS-AC-S and NLS-NA (**Figure 12**). Scallops were more widely distributed in the NLS-AC-N SAMS area. There was also a concentrated patch of dense scallops 90-125mm noted in the NLS-Ext (**Figures 11 and 12**). Median scallop size increased markedly with decreasing depth (and a corresponding generally northward geographical shift; **Figure 12**). Because it is hypothesized that the majority of scallops in the NLS are from a single or two consecutive-year recruitment event(s), this size gradient may be explained partially by the demonstrated difference in scallop growth rates between shallow and deep waters ([Schick et al. 1988](#)). However, density-dependent effects may also be evident, as scallops 50-75mm were encountered in high densities (i.e., greater than 25 individuals per image, with an image field of view being approximately 0.5-0.75m²) in approximately 75-80m of water in NLS-AC-S area. Scallops 50-75mm were also encountered in moderate densities (i.e., greater than 10 individuals per image) in the NLS-NA in water depths of 60-70m (**Figure 12**).

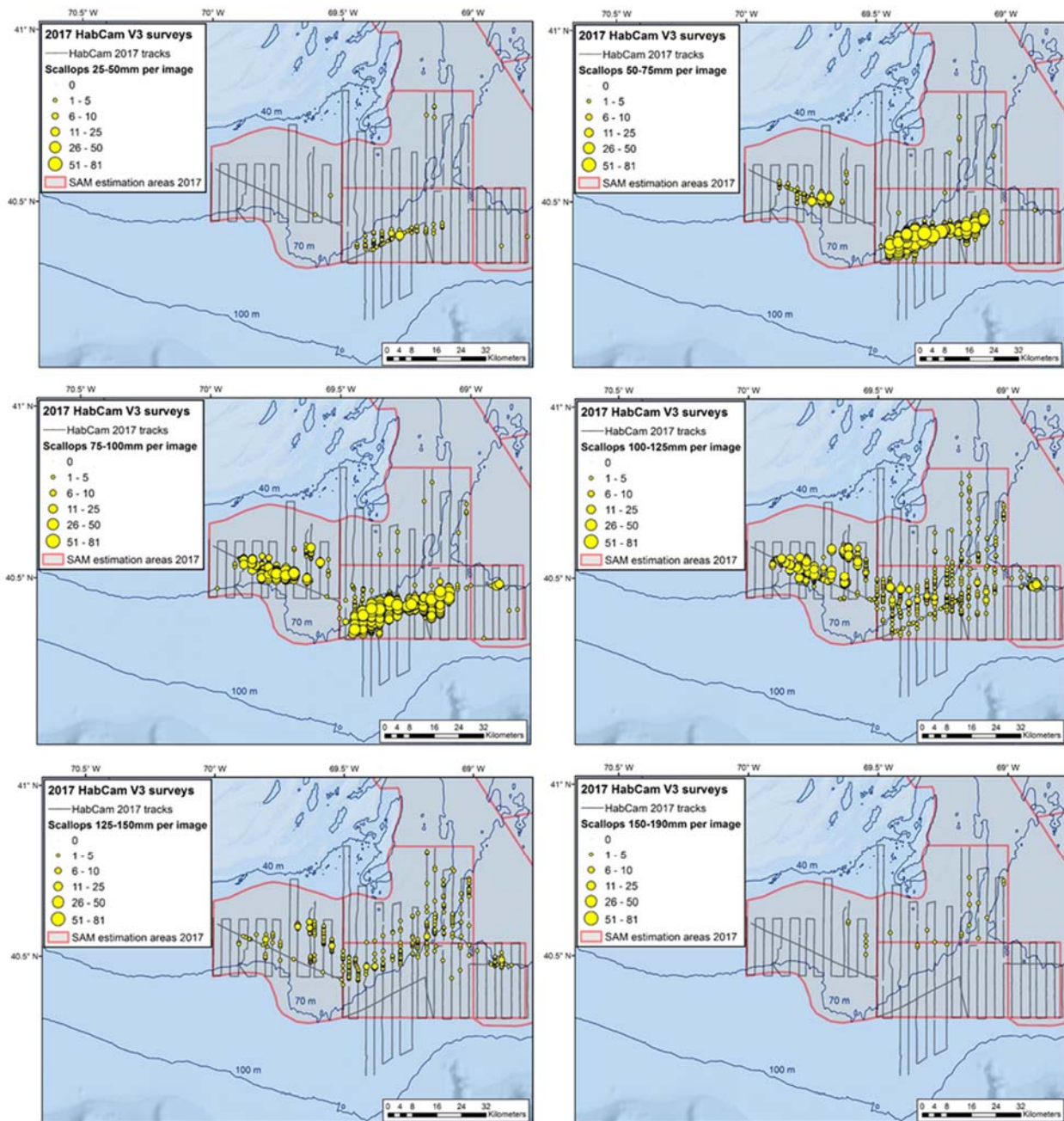


Figure 12. Length-frequency plots of scallops (by 25mm size bin) in the Nantucket Lightship Management Area.

Relatively high densities (i.e., greater than 5 individuals per image) of *Astropecten spp.*, a known predator of juvenile sea scallops, were seen in an area immediately to the south of the NLS-AC-S SAMS area (**Figure 13**). *Astropecten spp.* was also noted in somewhat lesser densities in the NLS-Ext area. No seed or juvenile scallops were seen in either area during this survey and it is not known at this time if the high density of *Astropecten spp.* is an artifact of a predation event in either area. Seed and small juvenile scallops were noted in the NLS-Ext area as recently as 2013. Review of previous survey data to determine if data exists that may aid in determining if a predation event may have taken place is recommended.

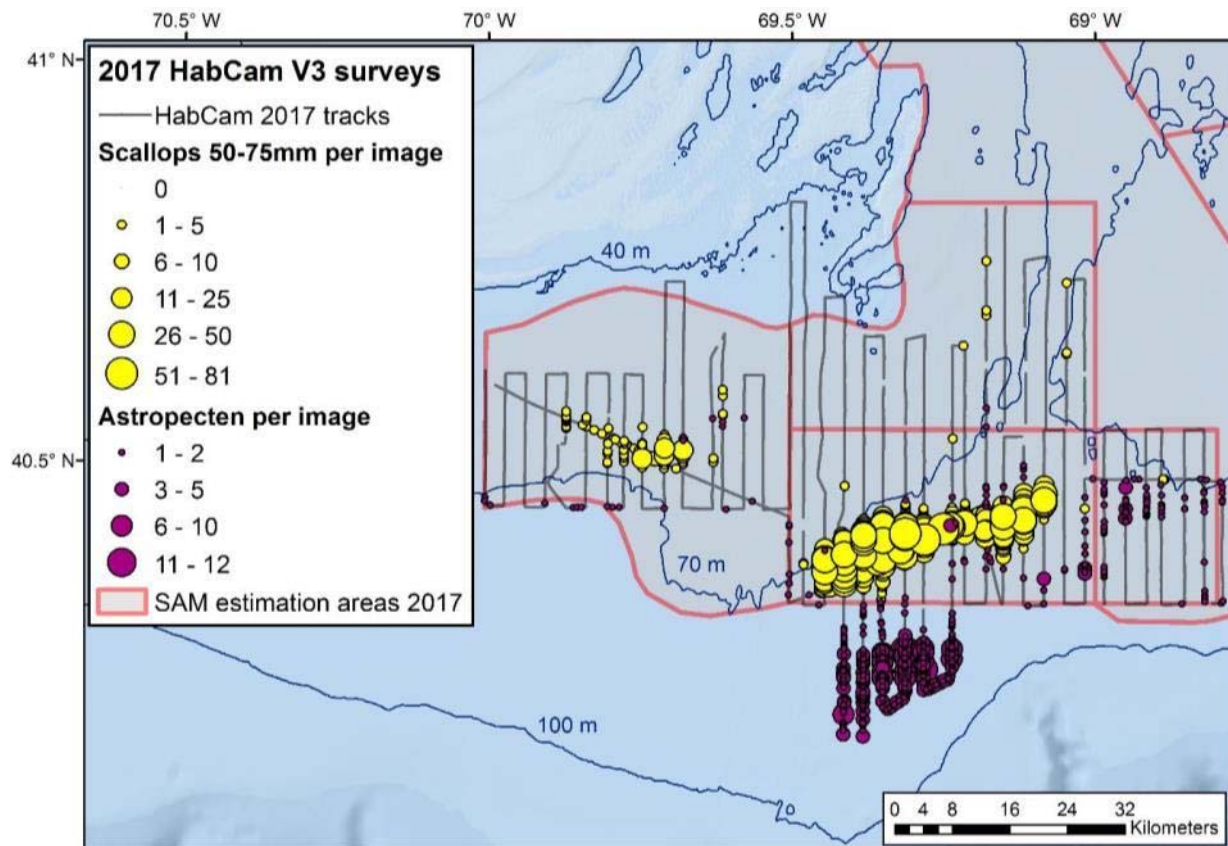


Figure 13. *Astropecten* sea star and scallop distribution within the Nantucket Lightship Scallop Management Area.

The 2012 scallop year class that has settled in the deeper waters south of the Great South Channel has the potential to yield a substantial exploitable biomass. It is generally accepted that the majority of the scallop biomass in the NLS are from a single or two consecutive year-classes (Hart, pers. comm.). However, it has been noted that scallops that settled in NLS-AC-S appear to be substantially smaller than those in other areas in the NLS and are thought to be growing at a slower rate. A comparison of scallop length-frequency from surveys in 2015 and 2017 appears to confirm this (**Table 3, Figure 14**).

Table 3. Average shell heights (in mm) for measured scallops in the NLS 2015 and 2017 from the RSA HabCam surveys.

	NLS-NA	NLS-AC-N	NLS-AC-S	NLS-Ext
2015	69.8	85.4	50.5	69.3
2017	98.8	124.0	76.0	109.2
Difference	29.0	38.6	25.5	39.9

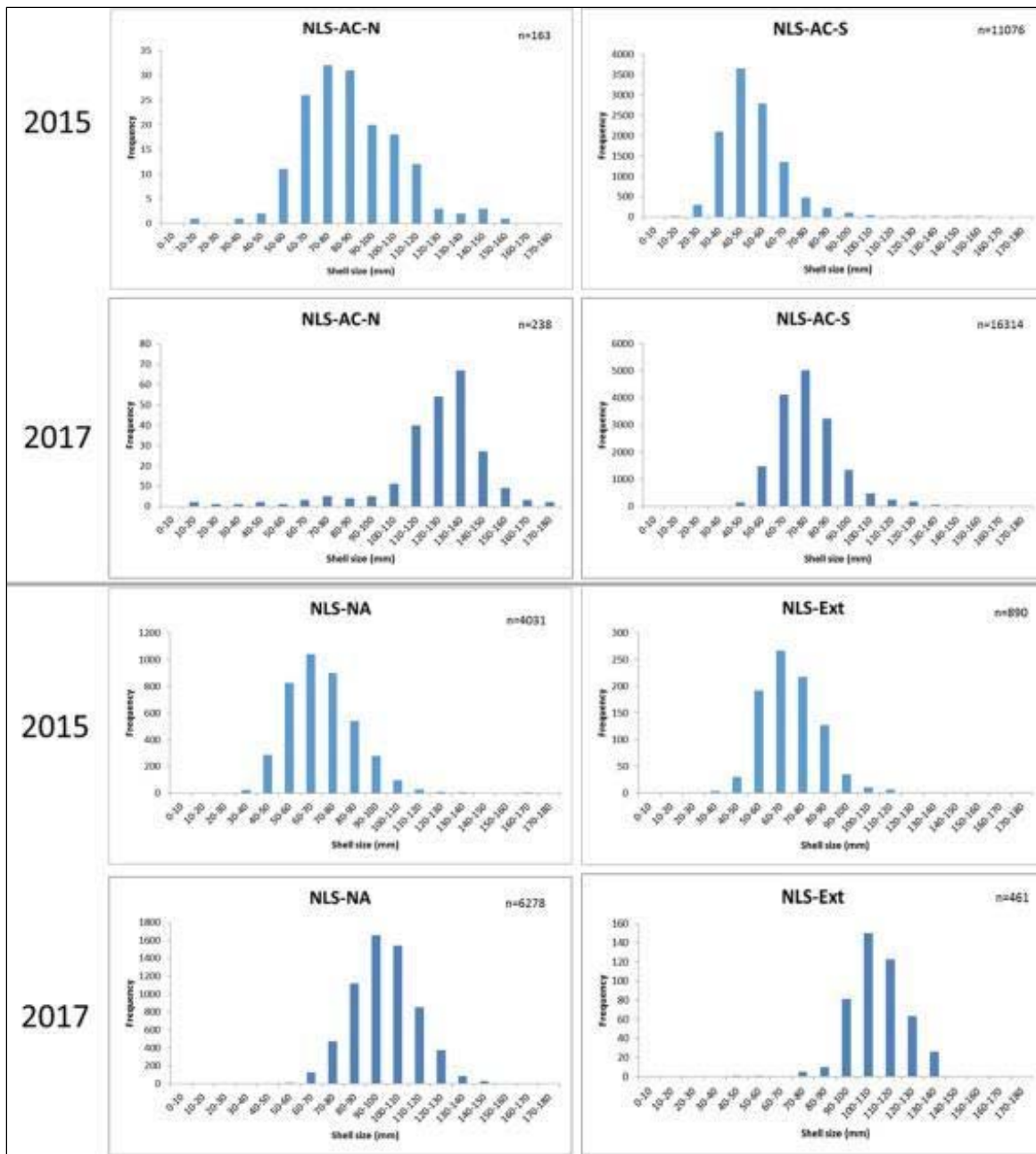


Figure 14. Length-frequency plots of measured scallops in HabCam images from the NLS SAMS areas – NLS-AC-N (top left boxes), NLS-AC-S (top right boxes), NLS-NA (bottom left boxes) and NLS-EXT (bottom right boxes) in 2015 and 2017.

Dredge efficiency comparisons: Nantucket Lightship

Due to delays in the 2017 NLS VIMS dredge survey, the HabCam survey took place before the VIMS dredge survey and thus we were not able to closely coordinate overlapping survey track as originally intended. Initially, we postulated that there was a potential advantage to this circumstance in that it afforded us the opportunity to perform the optical survey prior to the area being subjected to the dredge survey. However, it is likely the density estimate analysis suffered from lack of discreet overlapping survey tracks.

Biomass estimates by SAMS area generated by the two surveys are presented below in **Table 4**. The largest discrepancies between the survey methodologies appear to be evident in areas with the highest scallop densities.

Table 4. Scallop biomass estimates (in metric tons) from the 2017 RSA VIMS dredge survey (total biomass) and the 2017 RSA HabCam survey in the Nantucket Lightship Scallop Management Area.

	VIMS Dredge	RSA HabCam
NLS-AC-N	6098	10083
NLS-AC-S	34600	77827
NLS-NA	5782	56066
NLS-EXT	488	5682
Total	46968	149658

Comparative length-frequency plots showed minor shifts in length distribution between the optical survey and the dredge survey, with the exception of the NLS-S SAMS area (**Figure 15**). This may be due to a lack of sample overlap, dredge efficiency effects, or a combination of both.

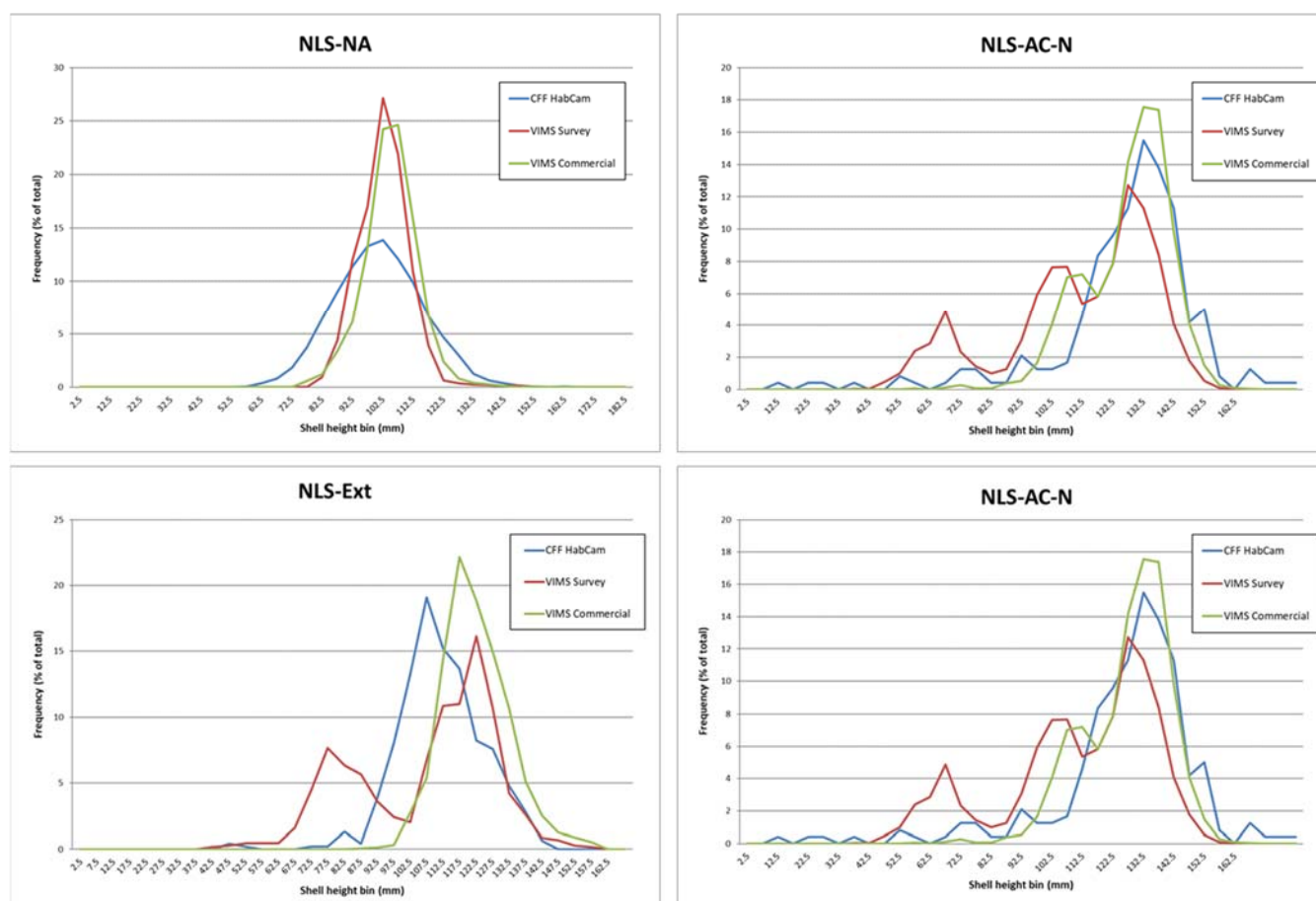


Figure 15. Comparative length-frequency plots between the RSA HabCam survey (blue lines) and the VIMS survey dredge (red lines) and commercial dredge (green lines) by NLS SAMS area.

Scallop density estimates derived from the HabCam optical survey and the VIMS dredge survey were compared by examining the densities from images and tow path midpoints that were less than 2000m apart (**Figure 16**; R-code in appendix). Comparisons included only pairs with at least 25 images in a 2000m radius of a tow midpoint, with the mean image density for the set used for further analysis. Scallop densities for HabCam images were estimated using the scallop counts from annotations and the estimated image field of view based on camera altitude, pitch, and roll. Scallop densities from the survey dredge tows were calculated using the scallop catch and the estimated tow swept area, with the tow length determined using the vessel GPS log and tow start and end times inferred from a tilt meter attached to the dredge.

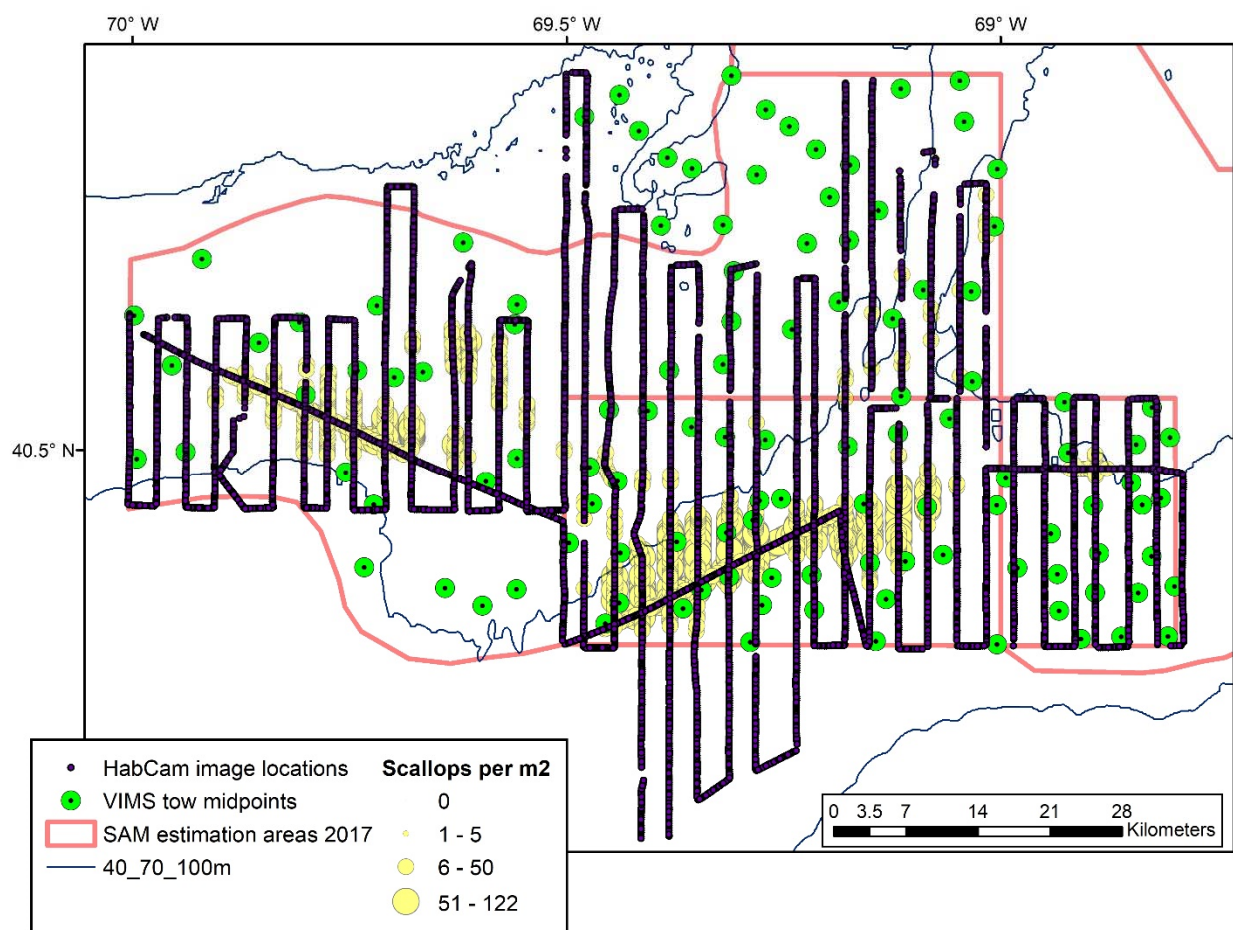


Figure 16. Overlay of VIMS survey dredge midpoints (green circles / black dots) on RSA HabCam survey track (black line) in the NLS.

Two plots were generated for this comparison. The ratio between the dredge and the image density estimates (catch ratio = tow scallops per square meter/image scallops per square meter) was plotted against the overall mean density from the two surveys for each image set-dredge tow pair. Additional plots, splitting the data by SAMS area, were also generated. A generalized additive model ("gam" in R package "mgcv") was used to model the relationship between the

density ratio and the mean density to investigate changes in dredge efficiency with scallop density (R Core Team 2017, Wood 2011).

Overall, 27 image-dredge pairs were used in the analysis, with the majority of pairs located in NLS-AC-S (14 pairs). The catch ratio did not change with scallop density (**Figure 17**), suggesting that dredge efficiency did not change with scallop density. Dredge efficiency appeared to be lower than published estimates for hard and soft bottoms (0.27 and 0.41 respectively; NEFSC 2014). In NLS-AC-S, where dredge saturation was expected in areas with dense scallops at depths below 70 meters, dredge efficiency stayed constant across observed image densities of 0.03-34 scallops per square meter (**Figure 18**). The number of pairs in other NLS SAMS areas were too low to draw any conclusions.

This data has been provided to the NEFSC to be combined with previously collected HabCam and dredge tow pair data in order to facilitate a more comprehensive analysis. The results of this comparative analysis were also discussed by the Sea Scallop Benchmark Assessment Working Group during their April 30-May 4, 2018 meeting. This result, combined with results from other studies focused on dredge efficiency, ultimately led to additional research on dredge efficiency under different conditions being recommended as a research priority.

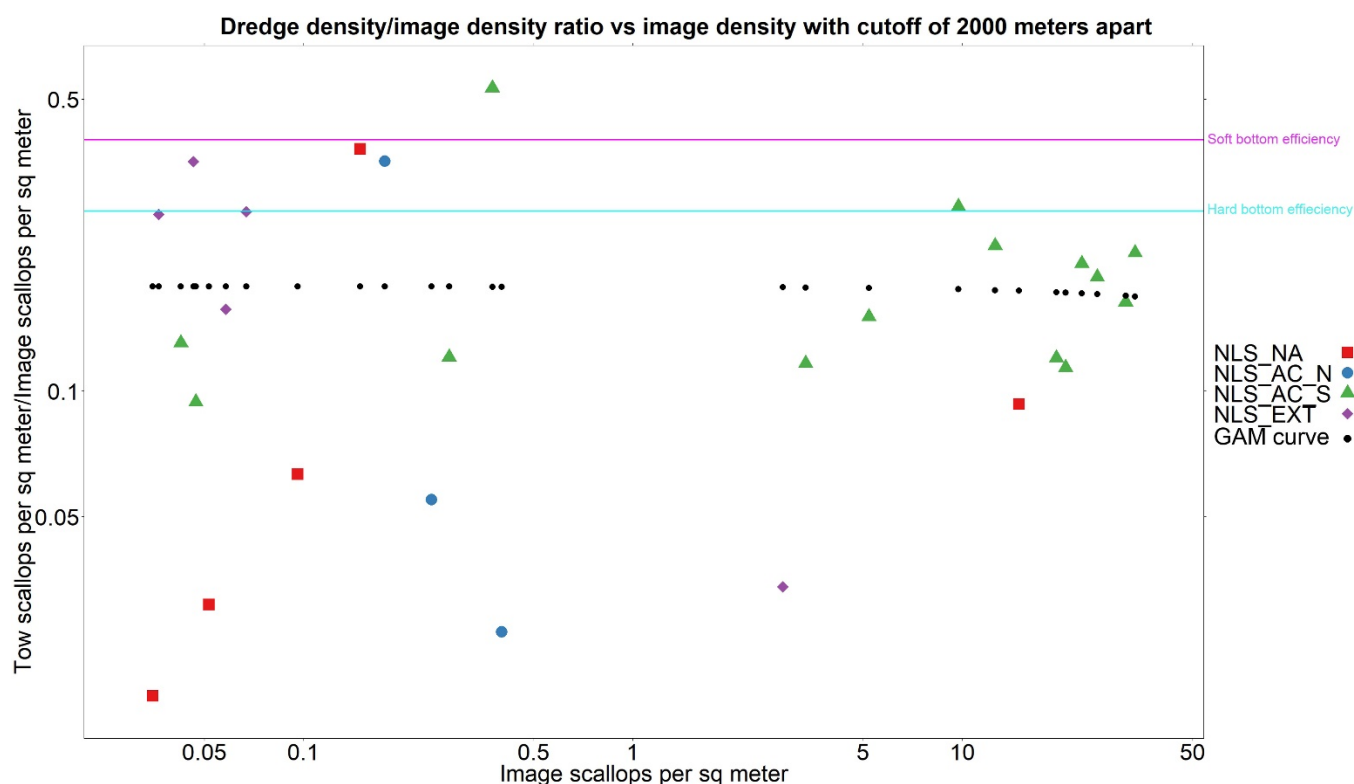


Figure 17. Plot of the ratio of dredge-derived to HabCam-derived scallop densities in the NLS. Scallop density (x-axis) is based on HabCam v3 survey (note: a y-axis value of 1 would indicate the calculated density was the same between the HabCam optical survey and the VIMS dredge survey).

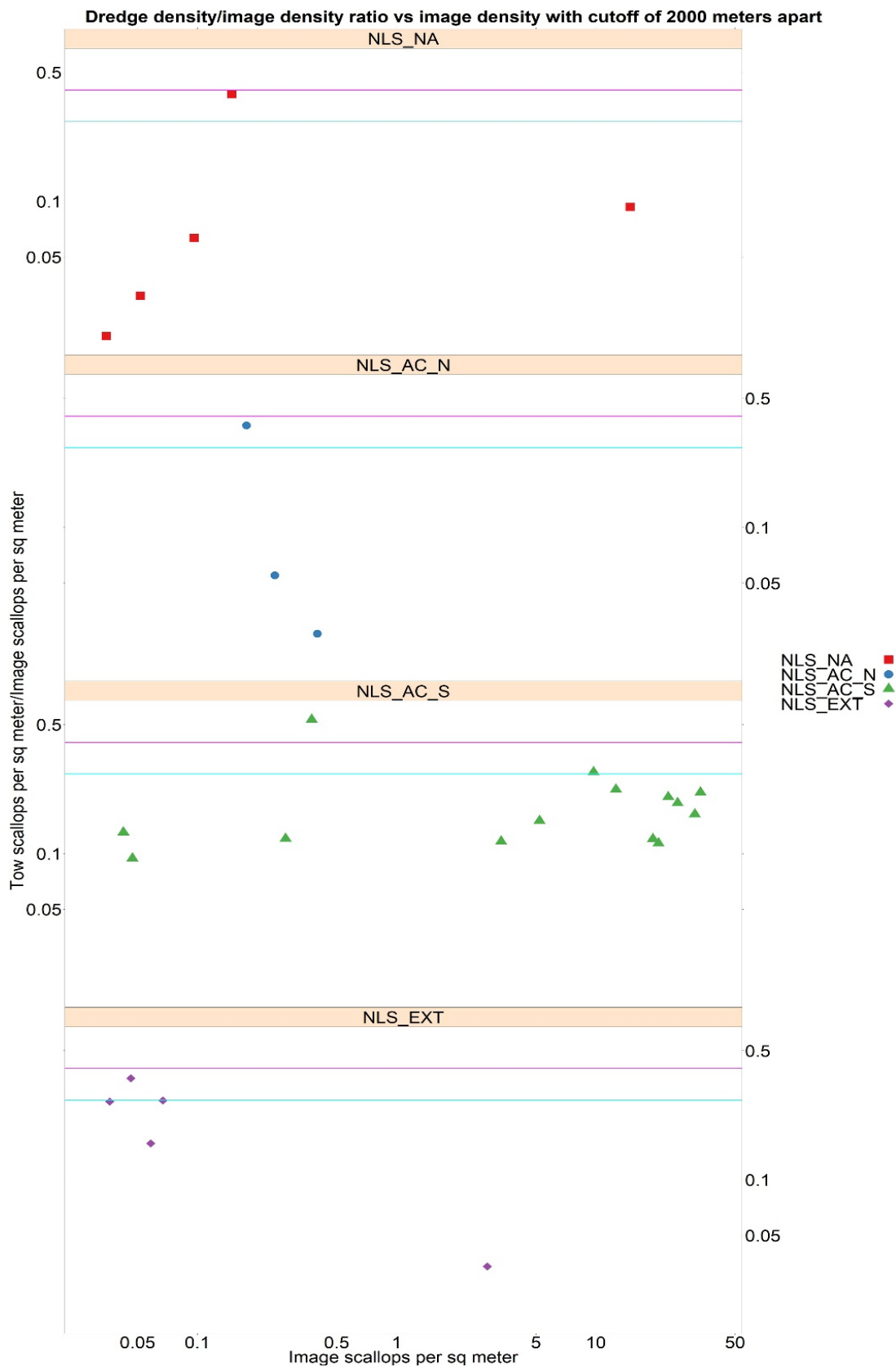


Figure 18. Plot of the ratio of dredge-derived to HabCam-derived scallop densities in each SAMS area. Scallop density (x-axis) is based on HabCam v3 survey (note: a y-axis value of 1 would indicate the calculated density was the same between the HabCam optical survey and the VIMS dredge survey).

Accomplishments by objective

Objective 1: Provide biomass estimates and size distribution of scallops in Nantucket Lightship (NLS) and Northern Gulf of Maine (NGoM) scallop management areas.

We were able to provide timely estimates of biomass and scallop size distribution throughout the NLS and in select areas of the NGoM scallop management areas. Biomass estimates and size distributions (length-frequency and spatial distribution) for both the NLS and NGoM were presented to the Atlantic Sea Scallop PDT on August 29th and 30th, 2018. Of particular interest was the continued large biomass of presumably slower-growing scallops in the deeper waters of NLS-AC-S SAMS area.

Objective 2: Provide cursory geographical information on potential scallop predator distributions in NLS and NGoM management areas.

Sea stars (*Asterias spp.* in the NGoM and *Astropecten spp.* in the NLS), which are known predators on Atlantic sea scallops, were seen in substantial numbers in areas to the south of the NLS-AC-S SAMS area and on Jeffreys Ledge in the NGoM. *Asterias* sea star prevalence overlapped with a moderate density of scallops between 25-50mm in length. Although it is not clear if this overlap is indicative of a major predation event that could influence biomass, CFF recommends monitoring of this area to evaluate any impact, as well as to gather more information on sea star predation on pre-recruit scallops.

Generate comparisons of biomass, scallop density and scallop length-frequency estimates generated by survey dredge and HabCam v3 in overlapping survey areas.

RSA HabCam scallop density estimates and length-frequency distributions were compared with VIMS survey dredge tows. Comparative length-frequency plots exhibited minor shifts in length distribution between the optical survey and the dredge survey in all surveyed areas except the NLS-AC-S. A comparison of estimated scallop meat weight per square meter as calculated from the dredge survey and the RSA HabCam survey was also performed. Although the estimated dredge efficiency (using estimated HabCam density as a proxy) was less than assumed efficiency for both soft and hard bottom, the results of this analysis did not show a substantial decreasing dredge estimate trend with increased scallop density. This may be due to a lack of sample overlap and/or small sample sizes.

Future research recommendations

Nantucket Lightship: Continued optical monitoring of the 2012 cohort in the NLS, particularly in light of recently opened areas in the NLS-AC-S and NLS-NA is highly recommended. With pending removals in the NLS-AC-S area likely to take place in 2018, evaluation of any influence on subsequent growth of remaining scallops (i.e., removal of density-dependent growth inhibitors) could provide further insight on the factors that govern scallop growth and survival.

Hindcast to evaluate biomass model efficiency: A comparison of removals in the recently opened NLS-NA to estimated change in biomass as derived from the different survey methods currently in use (e.g., VIMS dredge, RSA HabCam optical survey) is recommended.

Northern Gulf of Maine: Short-term monitoring of any impact *Asterias* sea stars may have on scallop recruitment in areas of Jeffreys Ledge is recommended and may provide further insight on the influence of scallop predators on biomass and recruitment.

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Appendix

Table A1. Tow data from dredge tows completed within the Stellwagen Bank survey area in the Northern Gulf of Maine.

Tow	Date	Start time (EDT)	Start Latitude	Start Longitude	Start Depth (fathoms)	Speed (kts)	End time (EDT)	End Latitude	End Longitude	End Depth (fathoms)	Sea State	Winds
HC2017-001	7/8/17	23:00	42° 23.91 N	70° 25.75 W	15.8	4.5	23:10	42° 23.38 N	70° 24.85 W	16.3	1	1
HC2017-002	7/8/17	23:16	42° 23.20 N	70° 24.53 W	16.1	4.8	23:26	42° 22.80 N	70° 23.67 W	16.4	1	1
HC2017-003	7/8/17	23:34	42° 23.22 N	70° 23.22 W	15	4.6	23:50	42° 34.36 N	70° 23.42 W	18.1	1	1
HC2017-004	7/8/17	23:55	42° 24.37 N	70° 23.44 W	17.3	4	0:13	42° 23.23 N	70° 23.60 W	15.1	1	1
HC2017-005	7/9/17	0:40	42° 23.60 N	70° 23.70 W	15.1	4	0:50	42° 23.68 N	70° 23.70 W	15.4	1	1
HC2017-006	7/9/17	1:13	42° 23.86 N	70° 23.79 W	15.2	4.2	1:23	42° 23.00 N	70° 23.34 W	15.1	1	1

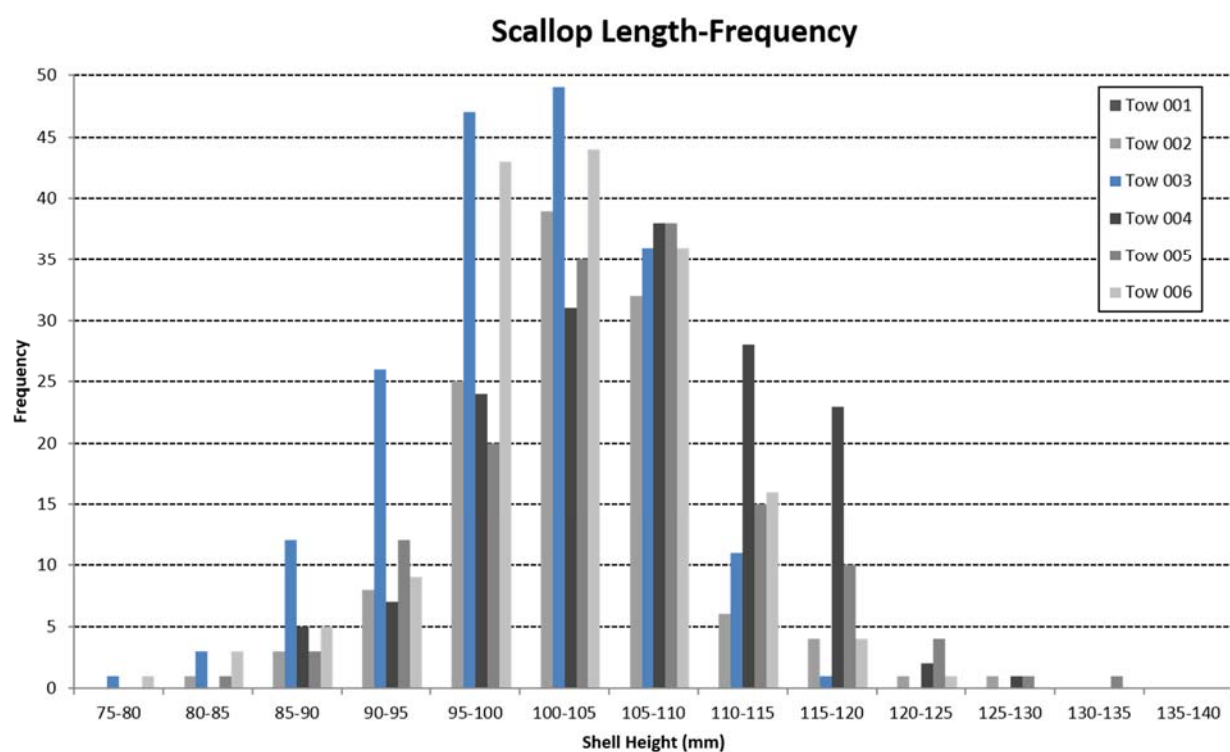


Figure A1. Length-frequency plot of scallops sampled from dredge tows from the Stellwagen Bank survey area in the Northern Gulf of Maine (5mm size bins).

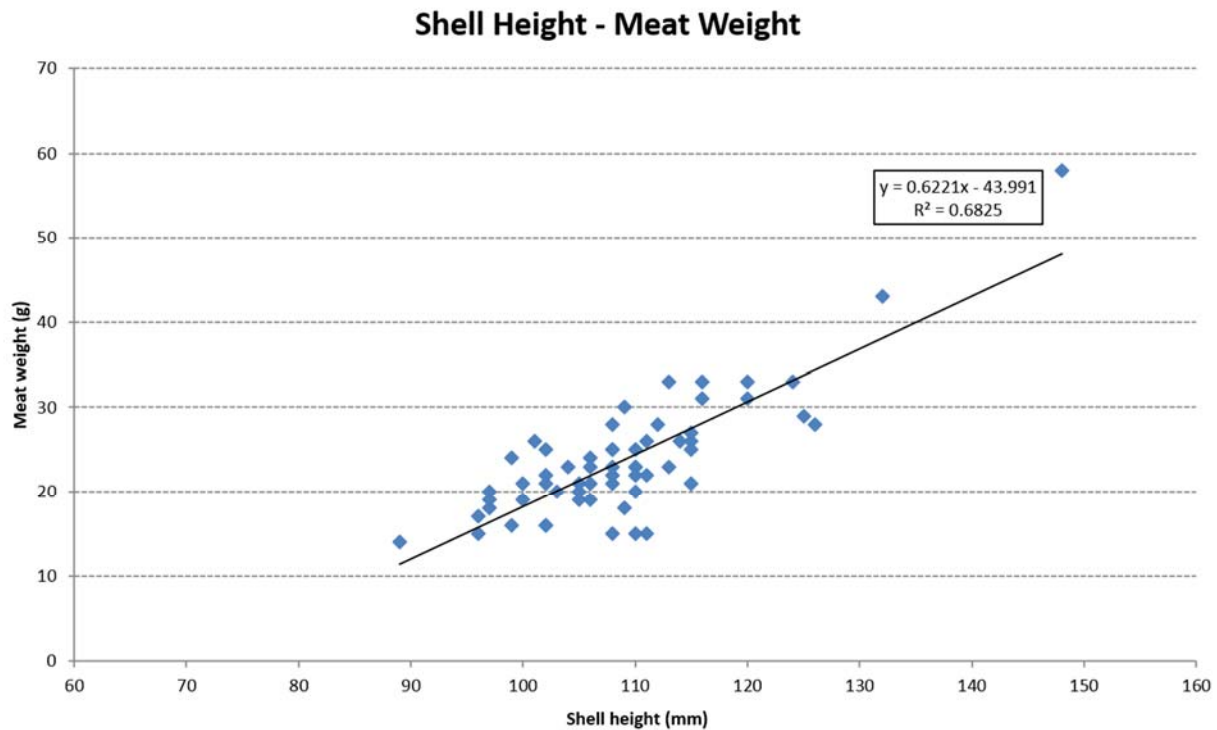


Figure A2. Shell height-meat weight linear regression plot of scallops sampled from dredge tows from the Stellwagen Bank survey area in the Northern Gulf of Maine.

R-Code for scallop density estimates:

to run script from command line type the following:

```
source("selectHabCamDredgeMidpointPairsDistance.R")
```

this uses the distance between HabCam image coordinates and the tow track midpoint

unless code is changed

column headings in dredge tow .csv file must include

```
("StationID","SAMS_Zone","LatBeg","LongBeg","LatEnd","LongEnd","SCALPERMETER")
```

column headings for HabCam .csv file must include

```
("ImageName","Latitude","Longitude","Depth","Altitude","Fov","NumPerM2")
```

other columns can also be included in each .csv file

load needed libraries

```
library(tcltk)
```

```
library(abind)
```

```
library(rgdal)
```

```
library(lattice)
```

```
library(latticeExtra)
```

```
library(RColorBrewer)
```

```
library(mgcv)
```

```

#identify dredge tow and HabCam data frames
dredge<-read.csv(tk_choose.files(caption = "Choose the file with dredge tow data"),stringsAsFactors =
FALSE)
habcam<-read.csv(tk_choose.files(caption = "Choose the file with HabCam data"),stringsAsFactors =
FALSE)

#convert coordinates in decimal degrees to UTM coordinates
xy=cbind(habcam$Longitude,habcam$Latitude)
xyUTM <- project(xy,"+proj=utm +zone=19 ellps=WGS84")
habcam$UTMlong<-xyUTM[,1]
habcam$UTMlat<-xyUTM[,2]

xy=cbind(dredge$LongBeg,dredge$LatBeg)
xyUTM <- project(xy,"+proj=utm +zone=19 ellps=WGS84")
dredge$UTMlongBeg<-xyUTM[,1]
dredge$UTMlatBeg<-xyUTM[,2]

xy=cbind(dredge$LongEnd,dredge$LatEnd)
xyUTM <- project(xy,"+proj=utm +zone=19 ellps=WGS84")
dredge$UTMlongEnd<-xyUTM[,1]
dredge$UTMlatEnd<-xyUTM[,2]

dredge$UTMlatMid=(dredge$UTMlatBeg+dredge$UTMlatEnd)/2
dredge$UTMlongMid=(dredge$UTMlongBeg+dredge$UTMlongEnd)/2

#set the distance threshold for pairing images and dredge tows
prD<- as.numeric(readline("What is the threshold distance for pairing HabCam images and dredge tows
by midpoint distance (enter a value in meters)?: "))
tmp <- as.numeric(readline("What is the threshold number of paired HabCam images with each dredge
tow for inclusion in analysis?: "))
prNum=tmp-1

# count the number of dredge tows
LenD = length(dredge[,1])

#count the number of HabCam images
LenH = length(habcam[,1])

Tow=numeric(length=LenH)
TowLatBeg=numeric(length=LenH)
TowLongBeg=numeric(length=LenH)
TowLatEnd=numeric(length=LenH)
TowLongEnd=numeric(length=LenH)
TowLatMid=numeric(length=LenH)
TowLongMid=numeric(length=LenH)
TowDist=numeric(length=LenH)
SAMS=character(length=LenH)
Image=character(length=LenH)
ImgLat=numeric(length=LenH)

```



```

ImgLong=numeric(length=LenH)
ImgDepth=numeric(length=LenH)
ImgAlt=numeric(length=LenH)
ImgFoV=numeric(length=LenH)
Distance=numeric(length=LenH)
TowScNum=numeric(length=LenH)
ImgScNum=numeric(length=LenH)
Ones=numeric(length=LenH)
allPairs=data.frame()
allOut=data.frame()

```

#create new data frames for each tow with distances to each image

```

for (i in 1:LenD){
  b=c(dredge$UTMLongBeg[i],dredge$UTMLatBeg[i])
  c=c(dredge$UTMLongEnd[i],dredge$UTMLatEnd[i])
  mid=c(dredge$UTMLongMid[i],dredge$UTMLatMid[i])
  for (j in 1:LenH){
    Tow[j]=dredge$StationID[i]
    TowLatBeg[j]=dredge$LatBeg[i]
    TowLongBeg[j]=dredge$LongBeg[i]
    TowLatEnd[j]=dredge$LatEnd[i]
    TowLongEnd[j]=dredge$LongEnd[i]
    TowLatMid[j]=(TowLatBeg[j]+TowLatEnd[j])/2
    TowLongMid[j]=(TowLongBeg[j]+TowLongEnd[j])/2
    TowDist[j]=dredge$TowDist[i]
    SAMS=as.factor(dredge$SAMS_Zone[i])
    Image[j]=habcam$Imagename[j]
    ImgLat[j]=habcam$Latitude[j]
    ImgLong[j]=habcam$Longitude[j]
    ImgDepth[j]=habcam$Depth[j]
    ImgAlt[j]=habcam$Altitude[j]
    ImgFoV[j]=habcam$Fov[j]
    a=c(habcam$UTMLong[j],habcam$UTMLat[j])
    Distance[j]=sqrt((a[2]-mid[2])^2+(a[1]-mid[1])^2)
    TowScNum[j]=dredge$SCALPERMETER[i]
    ImgScNum[j]=habcam$NumPerM2[j]
    Ones[j]=1
  }
}

```

```

Out=data.frame(Tow,TowLatBeg,TowLongBeg,TowLatEnd,TowLongEnd,TowLatMid,TowLongMid,TowDis
t,SAMS,Image,ImgLat,ImgLong,ImgDepth,ImgAlt,ImgFoV,Distance,TowScNum,ImgScNum,Ones,stringsAs
Factors = FALSE)

```

```

  Pairs=subset(Out, Distance<prD) #select only the images that are within the set distance from the tow
  allPairs=rbind(allPairs,Pairs) #keep a data frame with all of the selected tow/HabCam sets
  allOut=rbind(allOut,Out)
  rm(Pairs)
}

```

#create new table with aggregated data

```

allPairsAgg <- aggregate(TowScNum~Tow+SAMS,data=allPairs,mean)
tmp <- aggregate(ImgScNum~Tow+SAMS,data=allPairs,mean)
allPairsAgg$ImgScNum=tmp$ImgScNum
tmp <- aggregate(TowLatMid~Tow+SAMS, data=allPairs,mean)
allPairsAgg$TowLat=tmp$TowLatMid
tmp <- aggregate(TowLongMid~Tow+SAMS, data=allPairs,mean)
allPairsAgg$TowLong=tmp$TowLongMid
tmp <- aggregate(ImgLat~Tow+SAMS, data=allPairs,mean)
allPairsAgg$ImgLat=tmp$ImgLat
tmp <- aggregate(ImgLong~Tow+SAMS, data=allPairs,mean)
allPairsAgg$ImgLong=tmp$ImgLong
tmp <- aggregate(ImgDepth~Tow+SAMS, data=allPairs,mean)
allPairsAgg$Imgdepth=tmp$ImgDepth
tmp <- aggregate(Distance~Tow+SAMS, data=allPairs,mean)
allPairsAgg$Distance=tmp$Distance
tmp <- aggregate(Ones~Tow+SAMS,data=allPairs,sum)
allPairsAgg$SumOnes=tmp$Ones
tmp=allPairsAgg
allPairsAgg=subset(tmp, ImgScNum>0)
tmp=allPairsAgg
allPairsAgg=subset(tmp, TowScNum>0)
allPairsAgg$CatchRatio=allPairsAgg$TowScNum/allPairsAgg$ImgScNum
allPairsAgg$MeanDensity=(allPairsAgg$TowScNum+allPairsAgg$ImgScNum)/2
tmp=allPairsAgg
allPairsAgg=subset(tmp, SumOnes>prNum)
rm(tmp)
allPairsAgg$SAMS=factor(allPairsAgg$SAMS) #remove empty factor levels

# save csv files
filename=paste0("Image to tow distances.csv")
write.csv(allOut,filename,quote=T)
filename=paste0("Image to tow distance ",prD," meters apart.csv")
write.csv(allPairs,filename,quote=T)
filename=paste0("More than ",prNum," pairs ",prD," meters apart aggregated.csv")
write.csv(allPairsAgg,filename,quote=T)

#run gam
m_meanNum=gam(CatchRatio~s(MeanDensity, bs="tp", k=3), data=allPairsAgg)
allPairsAgg$NumFit=fitted(m_meanNum)
m_imgNum=gam(CatchRatio~s(ImgScNum, bs="tp", k=3), data=allPairsAgg)
allPairsAgg$NumFitlm=fitted(m_imgNum)

#create plots

#vs mean density
jpeg(filename = paste0("Catch ratio vs mean scallop density up to ", prD, " meters apart (over ", prNum,
" images).jpg"), width=3500, height=2000, units = "px", quality=100, pointsize=18)

```

```

ptmp=xyplot(CatchRatio~MeanDensity, data=allPairsAgg, groups=SAMS,
pch=15:(nlevels(allPairsAgg$SAMS)+15),
  col=brewer.pal(nlevels(allPairsAgg$SAMS),"Set1"), cex=5,
  main=list(label=paste0("Dredge density/image density ratio vs image density with cutoff of
",prD," meters apart"), cex=5),
  ylab=list(label="Tow scallops per sq meter/Image scallops per sq meter", cex=5),
  xlab=list(label="Mean scallops per sq meter", cex=5),
  #xlim=c(0.01,100), ylim=c(0.001,1),
  scales=list(log=T, cex=5,
at=c(0.00001,0.00005,0.0001,0.0005,0.001,0.005,0.01,0.05,0.1,0.5,1,5,10,50,100)),
  axis.line=list(col="black",lwd=2),
  key=list(text=c(list(levels(allPairsAgg$SAMS),"GAM"), cex=5), space="right",
  points=list(pch=c((15:(nlevels(allPairsAgg$SAMS)+14))),20), cex=5,
col=c(brewer.pal(nlevels(allPairsAgg$SAMS),"Set1"),"black"))),
  panel=function(...){panel.xyplot(...)}
  panel.abline(h=log10(0.27), col="cyan", lwd=3)
  panel.abline(h=log10(0.41), col="magenta", lwd=3)
})
pgam=xyplot(NumFit~MeanDensity, data=allPairsAgg, pch=20, col="black", cex=4, scales=list(log=T))
p=ptmp+as.layer(pgam)
print(p)
dev.off()
#split by SAMS
jpeg(filename = paste0("Catch ratio vs mean scallop density by SAMS area up to ", prD, " meters apart
(over ", prNum, " images).jpg"), width=3500, height=6000, units = "px", quality=100, pointsize=18)
p=xyplot(CatchRatio~MeanDensity|SAMS, data=allPairsAgg, groups=SAMS,
pch=15:(nlevels(allPairsAgg$SAMS)+15),
  col=brewer.pal(nlevels(allPairsAgg$SAMS),"Set1"), cex=6,
  main=list(label=paste0("Dredge density/image density ratio vs image density with cutoff of ",prD,"
meters apart"),cex=6),
  ylab=list(label="Tow scallops per sq meter/Image scallops per sq meter", cex=6),
  xlab=list(label="Mean scallops per sq meter", cex=6),
  #xlim=c(0.01,100), ylim=c(0.001,1),
  scales=list(log=T, cex=6,
at=c(0.00001,0.00005,0.0001,0.0005,0.001,0.005,0.01,0.05,0.1,0.5,1,5,10,50,100)),
  axis.line=list(col="black",lwd=2),
  par.strip.text=list(cex=6), layout=c(1,4),
  key=list(text=list(levels(allPairsAgg$SAMS), cex=6), space="right",
points=list(pch=15:(nlevels(allPairsAgg$SAMS)+14), cex=6),
  col=brewer.pal(nlevels(allPairsAgg$SAMS),"Set1")),
  as.table=T,
  panel=function(...){panel.xyplot(...)}
  panel.abline(h=log10(0.27), col="cyan", lwd=3)
  panel.abline(h=log10(0.41), col="magenta", lwd=3)
})
print(p)
dev.off()

```

#vs image density

```

jpeg(filename = paste0("Catch ratio vs HabCam scallop density up to ", prD, " meters apart (over ",
prNum, " images).jpg"), width=3500, height=2000, units = "px", quality=100, pointsize=18)
ptmp=xyplot(CatchRatio~ImgScNum, data=allPairsAgg, groups=SAMS,
pch=15:(nlevels(allPairsAgg$SAMS)+15),
col=brewer.pal(nlevels(allPairsAgg$SAMS),"Set1"), cex=5,
main=list(label=paste0("Dredge density/image density ratio vs image density with cutoff of
",prD," meters apart"), cex=5),
ylab=list(label="Tow scallops per sq meter/Image scallops per sq meter", cex=5),
xlab=list(label="Image scallops per sq meter", cex=5),
#xlim=c(0.01,100), ylim=c(0.001,1),
scales=list(log=T, cex=5,
at=c(0.00001,0.00005,0.0001,0.0005,0.001,0.005,0.01,0.05,0.1,0.5,1,5,10,50,100)),
axis.line=list(col="black",lwd=2),
key=list(text=c(list(levels(allPairsAgg$SAMS),"GAM"), cex=5), space="right",
points=list(pch=c((15:(nlevels(allPairsAgg$SAMS)+14)),20), cex=5,
col=c(brewer.pal(nlevels(allPairsAgg$SAMS),"Set1"),"black"))),
panel=function(...){panel.xyplot(...)
panel.abline(h=log10(0.27), col="cyan", lwd=3)
panel.abline(h=log10(0.41), col="magenta", lwd=3)
})
pgam=xyplot(NumFitIm~ImgScNum, data=allPairsAgg, pch=20, col="black", cex=4, scales=list(log=T))
p=ptmp+as.layer(pgam)
print(p)
dev.off()
#split by SAMS
jpeg(filename = paste0("Catch ratio vs HabCam scallop density by SAMS area up to ", prD, " meters apart
(over ", prNum, " images).jpg"), width=3500, height=6000, units = "px", quality=100, pointsize=18)
p=xyplot(CatchRatio~ImgScNum|SAMS, data=allPairsAgg, groups=SAMS,
pch=15:(nlevels(allPairsAgg$SAMS)+15),
col=brewer.pal(nlevels(allPairsAgg$SAMS),"Set1"), cex=6,
main=list(label=paste0("Dredge density/image density ratio vs image density with cutoff of ",prD,"
meters apart"),cex=6),
ylab=list(label="Tow scallops per sq meter/Image scallops per sq meter", cex=6),
xlab=list(label="Image scallops per sq meter", cex=6),
#xlim=c(0.01,100), ylim=c(0.001,1),
scales=list(log=T, cex=6,
at=c(0.00001,0.00005,0.0001,0.0005,0.001,0.005,0.01,0.05,0.1,0.5,1,5,10,50,100)),
axis.line=list(col="black",lwd=2),
par.strip.text=list(cex=6), layout=c(1,4),
key=list(text=list(levels(allPairsAgg$SAMS), cex=6), space="right",
points=list(pch=15:(nlevels(allPairsAgg$SAMS)+14), cex=6,
col=brewer.pal(nlevels(allPairsAgg$SAMS),"Set1")),
as.table=T,
panel=function(...){panel.xyplot(...)
panel.abline(h=log10(0.27), col="cyan", lwd=3)
panel.abline(h=log10(0.41), col="magenta", lwd=3)
})
print(p)
dev.off()

```