Summary of deep sea coral patterns and habitat modeling results from Cordell Bank, CA

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Executive summary

Cordell Bank is a productive offshore ecosystem situated on the edge of the continental shelf in northern California. The Bank, which rises from 130m to within 35m of the surface, contains diverse habitats including high relief rock, flat bedrock pavement, boulders, mixed cobble and sand, sand ripples, and mud. Deep sea corals are a prominent feature on Cordell Bank, with at least seven species known to occur on the rocky continental shelf feature (i.e., *Stylaster californicus*, *Stylaster venustus*, *Swiftia spp.*, *Balanophyllia elegans*, *Ptilosarcus sp.*, *Labyrinthocyathus quaylei*) (Whitmire and Clark 2007, Pirtle 2005, collections at California Academy of Sciences and Smithsonian National Museum of Natural History). Of these species, the hydrocorals (*Stylaster californicus* and *Stylaster venustus*) and gorgonians (*Swiftia spp.*) are structure-forming species that are found in abundance on the Bank.

This project represents a data analysis and data mining effort focusing on hydrocorals and gorgonian corals on Cordell Bank that builds on previous research and specimen collections. Specific objectives include: 1) investigate the distribution of hydrocorals in the temperate northeast Pacific Ocean, with emphasis on central California and Cordell Bank, 2) describe the distribution and habitat associations of hydrocoral and gorgonian corals on Cordell Bank, 3) use fine-scale seafloor mapping data and *in situ* submersible data to predict hydrocoral and gorgonian presence on Cordell Bank.

Results from our data mining and verification of museum specimens confirmed that both *Stylaster venustus* and *Stylaster californicus* are present on Cordell Bank, making this location an important intersection for these two species that have northern and southern distributions, respectively. Our examination of museum specimens resulted in a summary of range extensions for these two species.

Examination of coral species occurrence by habitat variables and spatial distribution across the Bank indicate that hydrocorals and gorgonians occupied different niches – *Stylaster spp.* was restricted to a small proportion of the Bank, while *Swiftia spp.* was more broadly distributed. In particular, *Stylaster spp.* was associated with shallow, hard substrate, high sloping habitats, while *Swiftia spp.* showed affinity with deeper, low sloping environments and a diversity of substrate types.

Results of predictive habitat modeling indicate that there are small-scale habitat features on Cordell Bank that are driving the species distribution patterns of deep sea corals. Bathymetry, slope, and topographic position index were important habitat predictors for both *Stylaster spp.* and *Swiftia spp.*; however, slope had the opposite influence on these two groups. Rugosity had a strong influence on the presence of *Stylaster spp.*, while substrate type and aspect significantly contributed to the presence of *Swiftia spp.*

The results of this study indicate some of the challenges as well as advantages of working with these types of data (transect data on fine spatial resolution) and provide an analysis framework for applying GIS-based predictive modeling for examining other rocky seafloor features and their associated communities. Results of this study can be compared with broader-scale modeling efforts (e.g., entire west coast of U.S.) that incorporate simpler habitat variables on a coarser resolution to evaluate the importance of scale and complexity in modeling these seafloor communities. Predicted locations of coral presence from this study have been used to meet several management needs at Cordell Bank National Marine Sanctuary and can be used as the basis for designing future research and monitoring programs. In addition, the knowledge gained from this project in regards to deep sea corals and their habitat associations on Cordell Bank has been integrated into various education and outreach efforts.

Stylaster spp. distribution data mining

One of the objectives of this project was to investigate the distribution of hydrocorals in the temperate northeast Pacific Ocean, with emphasis on central California and Cordell Bank (Figure 1). Previous information suggested that the Farallon Islands off of San Francisco, CA marked the northern and southern distributional extent of *Stylaster californicus and S. venustus*, respectively (Whitmire and Clarke 2007). Given the location of Cordell Bank (center point 38.027 N, -123.441 W) 40 km north of the Farallon Islands, known occurrences of *Stylaster spp.* on Cordell Bank highlighted that a comprehensive evaluation of specimens for these species was necessary to understand their distribution and areas of overlap. We hypothesized that Cordell Bank represents an important intersection in these species' range distribution.

Investigations of hydrocoral (*Stylaster spp.*) distribution have been completed by conducting online searches for specimens within collections held at the California Academy of Sciences (http://research.calacademy.org/izg/collections) and the Smithsonian National Museum of Natural History (http://collections.nmnh.si.edu/search/iz/). Results include specimens of *Stylaster californicus* and *Stylaster venustus* in collections at both institutions. *Stylaster spp.* specimens from the Smithsonian National Museum of Natural History displayed a larger range distribution than what was previously documented in Whitmire and Clarke (2007). According to specimens in this museum collection, the southern extent of *Stylaster venustus* (the more northerly species) is at Point Sur, CA (3 Mile WSW of Point Sur, CA; Identified By S. Cairns (Smithsonian collection – catalogue number 86832)), over 190 km south of the previously documented southern range at the Farallon Islands. For *Stylaster californicus* (the more southerly species), the northern extent of specimens in these museum collections is documented at Race Rocks, British Columbia (Victoria, Race Rocks (British Columbia); Identified By S. Cairns (Smithsonian collection – catalogue number 76559)), over 1000 km north of the previously documented northern range at the Farallon Islands.

Focusing on Cordell Bank hydrocorals, collections held at the California Academy of Sciences include specimens of *S. californicus* and *S. venustus* from Cordell Bank (catalogue numbers 101846, 107820, 97001, 97998). To verify these findings and confirm that both *Stylaster* species overlap at Cordell Bank, four of the California Academy of Sciences *Stylaster* specimens from Cordell Bank were sent to Stylasteridae coral expert, Steve Cairns at the Smithsonian Institution, for species identification. Three of the specimens were confirmed as *S. californicus* and one as *S. venustus,* thus supporting our theory that Cordell Bank represents an important intersection of the range distribution of these species. Knowing that both the southerly and northerly *Stylaster* species occur on Cordell Bank provides the opportunity to design future studies to investigate the habitat requirements of these congeners and the potential impacts of climate change on some of the shallower deep sea corals.

Cordell Bank deep sea coral modeling

This work represents an exploratory analysis of *in situ* data collected with the *Delta* submersible on the prominent geological feature of Cordell Bank by relating hydrocoral (*Stylaster spp.*) and gorgonian coral (*Swiftia spp*.) presence to various seafloor features, as measured by multibeam acoustic sampling. It has been recognized that *in situ* observational data can provide critical information in understanding deep, cold-water coral distribution patterns and habitat associations. These data coupled with fine-scale seafloor mapping provide robust assessments of habitat relationships and allow predictions of species occurrence.

Data collection methods

Cordell Bank in northern California is a productive offshore ecosystem recognized as nationally significant when it was designated as our nation's sixth National Marine Sanctuary in 1989. Cordell Bank is situated on the edge of the continental shelf of California and rises from 130m to within 35m of the surface (Figure 1). The Bank contains diverse habitats including high relief rock, flat bedrock pavement, boulders, mixed cobble and sand, sand ripples, and mud (Anderson et al. 2009, Young et al. 2010). Its perimeter includes large expanses of white sand waves on the eastern side and relatively flat mud on the northern and western sides. The central portion has extensive reef systems and the shallowest pinnacles, while the northern half is deeper, with mixed bolder and reef habitats. Throughout the Bank, rocky reefs are cut by sand channels as well as mixed habitats of sand, boulders and cobbles.

Deep sea corals are a prominent feature on Cordell Bank, with at least seven species known to occur on the rocky continental shelf feature (i.e., *Stylaster californicus*, *Stylaster venustus*, *Swiftia spp.*, *Balanophyllia elegans*, *Ptilosarcus sp.*, *Labyrinthocyathus quaylei*) (Whitmire and Clark 2007, Pirtle 2005, collections at California Academy of Sciences and Smithsonian National Museum of Natural History). Of these species, the hydrocorals (*Stylaster californicus* and *Stylaster venustus*) and gorgonians (*Swiftia spp.*) are structure-forming species that are found in abundance on the Bank.

The human-occupied submersible *Delta* was used to conduct non-extractive video surveys of the benthic invertebrate and fish community and associated physical habitats on Cordell Bank from 2001-2005. Dives consisted of multiple quantitative starboard-looking transects (15 minutes each) conducted at a height of 1m off the bottom traveling at a speed of approximately 1 knot. In addition, several exploratory dives were conducted to provide video and photo documentation of Bank habitats and communities. Submersible observations were documented with a Hi-8 color video camera externally mounted above the starboard viewing porthole looking down at an angle 27° below the horizontal. A set of parallel lasers were mounted 20 cm apart on either side of the external starboard camera to enable size estimation.

The position of *Delta* was tracked using an ORE Trackpoint II Plus Acoustic Tracking and Navigation System (ORE Offshore, West Wareham, Massachusetts). Trackpoint II data were integrated with the ship's differential GPS position and gyro heading using Fuguro Pelagos Winfrog navigation software (Fuguro, Leidschendam, Netherlands). Tracking data received from the *Delta* survey team contained a number of spurious data points. To remove spurious data and more accurately determine the track of the *Delta* the following processing steps were executed. First, tracklines were plotted using Fuguro Pelagos Ribbit software and spurious data points were removed using the interactive data editor. Trackline data points were then interpolated to 1 second intervals using the 'sample1d' routine of (Geographic Information Systems) GIS Generic Mapping Tools GIS software (http://www.soest.hawaii.edu/gmt/). Finally, interpolated tracklines were smoothed using the GMT routine 'filter1d' which applied a Gaussian filter over a 30 sample window. Positions were assumed to be accurate within 10m (M. Amend, NOAA/NMFS, pers. comm.).

Video tapes of the *Delta* dives were viewed for all invertebrates for 2002 and 2003, while video of dives were viewed for just *Stylater spp.* and *Swiftia spp.* for 2001, 2004, and 2005. Transects viewed for deep sea corals exhibit good coverage across the Bank, including different depths and habitat types. Data from a total of 101 transects and 2 exploratory dives that covered over 50km were viewed for coral observations (Figure 2).

To standardize the width of the transect sampled, corals were counted in the bottom half of screen, below the lasers. When lasers were not available (e.g., 2001 dives), the middle of the screen was estimated and individuals were counted below this point. Lasers were used to estimate the size of individuals and corals greater than 5cm were counted. Maximum size was estimated at the greatest dimension to the nearest 5cm for species greater than 10cm. *Swiftia* spp. was not sized. Some observations are not associated with sizes when lasers were not available (e.g., 2001). To increase the sample sizes and increase the spatial and habitat coverage across the Bank, we used observations of presence and absence not only from quantitative transects, but also observations from between-transect segments (off transect) and exploratory photo dives. An observation time (to the nearest second) was assigned to each coral observation. All other times (with a frequency of every second) were coded as absence of the focal species. The times in the observation files were joined with times in the Delta tracking file to give each presence and absence observation point a position (latitude/longitude).

In 2005, multibeam acoustic data of Cordell Bank were collected and bathymetric products were created by California State University-Monterey Bay (CSUMB), while substrate analyses were conducted by CSUMB in collaboration with U.S. Geological Survey (Young et al. 2010). Derived bathymetric and habitat parameters at 3m resolution include: depth, slope, rugosity, aspect, topographic position index (TPI) and substrate (hard, mixed, soft) (Data available at: http://seafloor.csumb.edu/SFMLwebDATA_c.htm#CORDELL). The three-class substrate variable was derived using a combination of bathymetry and backscatter data. TPI indicates the position of a given point relative to the overall surrounding landscape and can therefore be used to delineate landforms. TPI was calculated at different scales (30m, 60m, 120m, 240m) to differentiate between small scale and large scale features (e.g., tops of pinnacles to an entire Bank). Aspect represents the compass direction that a slope faces.

Preliminary modeling methods

Due to the uncertainty in the *Delta* position data and the resulting observation locations, bathymetric raster data were coarsened from 3m to 18m resolution to be conservative and provide a better match in resolution between the position data and the observation data. Coral presence and absence data were joined to bathymetric rasters by position, and the values for the nine habitat parameters were extracted and associated with each presence and absence data point.

We used generalized linear model (GLM) logistic regression to describe habitat associations of two species of deep sea corals (presence/absence of *Stylaster spp.*, *Swiftia spp.*) by habitat (depth (continuous), slope (continuous), aspect (categorical, 8 classes), topographic position index at 4 different scales (continuous), rugosity (continuous), substrate (categorical, 3 classes). Using ArcRStats, logistic regression models were run separately for *Stylaster spp.* and *Swiftia spp.* and the best fit models were selected by stepwise regression using AIC (Akaike Information Criterion). ArcRStats integrates ArcGIS with the R statistical package to produce multivariate habitat prediction rasters (Best et al. 2005). Using the best fit model of habitat parameters explaining the presence of corals, ArcRStats was used to make predictions of probability of presence of corals across the habitat space of Cordell Bank, given the habitat raster data.

Stylaster and Swiftia distribution patterns and habitat associations

A total of 726 observation of *Stylaster spp.* and 389 observations of *Swiftia spp.* were acquired with *Delta* video across Cordell Bank from 2001-2005. There were nearly 100,000 absence points from the video data. Plots of species occurrence by habitat variables and spatial distribution across the Bank indicate that hydrocorals and gorgonians occupied different niches – *Stylaster spp.* was restricted to a small proportion of the Bank, while *Swiftia spp.* was more broadly distributed (Figure 3). In particular, *Stylaster spp.* was associated with shallow, hard substrate, high sloping areas, while *Swiftia spp.* showed affinity with deeper, low sloping environments and a variety of substrate types.

Cordell Bank habitat raster data were summarized to understand the amount of different habitat types available on the Bank (e.g., Figure 4, 'Cordell Bank' values). Further, an analysis of the frequency of absence data points for corals by habitat type provides an indication of the habitat types that were sampled with the *Delta* surveys relative to their availability on Cordell Bank (e.g., Figure 4, 'Absence' values). Lastly, the frequency of coral presence data points by habitat type compared to the amount of available habitat on Cordell Bank provides an indication of habitat selection or affinity by species (e.g., Figure 4, 'Presence' values). In general, the *Delta* surveys sampled Cordell Bank habitats in proportion to their availability, as indicated by the similarity in the Cordell Bank and Absence proportions by habitat class. It appears that the Delta surveys were slightly biased in the following cases: over-sampling of 70m depth class (Figure 4), under-sampling low (0°) slope class (Figure 5), over-sampling hard substrates (Figure 7), and under-sampling mid-range (neutral, close to zero) TPI classes (Figure 9).

Stylaster spp. corals were strongly associated with shallower depths, with the greatest number of observations and the strongest habitat selection within the 50 and 60m depth classes (Figures 3&4). Observations of *Stylaster spp.* decrease dramatically at depths greater than 80m. *Stlyaster spp.* observations ranged between 43 and 92m. The majority of *Swiftia spp.* were found at slightly deeper depths than *Stylaster spp.*, with over 50% of the observations found in the 60m depth class and then a small number of observations at the 70-90m depth classes (Figures 3&4). Interestingly, another peak in observations was found at 130-140m depth classes. Further exploration into this bimodal depth distribution for *Swiftia spp.* suggests that smaller individuals were found in the deeper depths. *Swiftia spp.* observations ranged between 53 and 139m. Although there is complexity in bathymetric features across the Bank, in general, shallower depths are found in the central portion of Cordell Bank as well as in the northern portion of the Bank where there is a small shallower feature (Figure 3).

Stylaster spp. and *Swiftia spp.* showed contrasting patterns of association with slope characteristics on Cordell Bank (Figure 5&6). High sloping habitats are found throughout Cordell Bank; however, areas of high slope are concentrated in the central portion of the Bank as well as in the northern portion of the Bank in association with shallower depths (Figure 6). Nearly all of the *Swiftia spp.* observations were found on low sloping habitats, with the strongest habitat selection for a narrow range of slopes between 2.5-7.5°. In contrast, *Stylaster spp.* were found on a broader range of sloping environments, showing habitat selection of higher slopes between 7.5 and 27.5°.

Swiftia spp. gorgonians did not show strong habitat selection for substrate type, and were found in soft, mixed, and hard substrates in a similar proportion to the amount of available habitat (Figures 7&8)). Nevertheless, more *Swiftia spp.* were observed in mixed and hard substrates compared with soft substrates. In contrast, *Stylaster spp.* hydrocorals were found almost exclusively within hard substrate environments, with only a few observations noted in mixed substrates and no observations within soft substrates (Figures 7&8). Hard substrates are concentrated in the central portion of the Bank in areas that are generally shallower with high slope, while mixed substrates are interspersed throughout the Bank (Figure 8). The majority of soft habitats are found along the margins of the Bank in deeper waters (Figure 8)

Gorgonians and hydrocorals exhibited very different patterns of association with levels of the topographic position index at the larger scale of 240m (Figures 9&10). The proportion of *Swiftia spp.* observations were similar to the amount of available habitat, with slight habitat selection at lower positive levels of TPI, which are indicative of flat and low sloping environments. *Stylaster spp.* illustrated strong habitat selection for higher TPI levels (indicative of the upper reaches of a mounded feature and the top of a rise) and aversion towards lower positive and neutral TPI values. On Cordell Bank, areas of both the highest and lowest TPI values are juxtaposed in regions of high slope, illustrating the peaks and low valleys associated with high sloping features (Figure 10).

Stylaster spp. and *Swiftia spp.* showed contrasting patterns of association with aspect characteristics on Cordell Bank (Figure 11). *Stylaster spp.* corals were strongly associated with West, Northwest, and North facing substrates with a majority of the observations in these aspect classes. In contrast, *Swiftia spp.* corals were found on a more diverse array of aspect conditions (including South, Southeast, Southwest, West, and North) and exhibited habitat selection for South and Southeast facing substrates (Figure 11).

Preliminary modeling result

Preliminary predictive modeling using GIS provides a comprehensive understanding of gorgonian and hydrocoral distribution across Cordell Bank and illustrates the different habitat niches of these corals. The predictive model for *Stylaster spp.* illustrates a patchy distribution with hydrocoral presence in very discrete habitat space within the Cordell Bank region (Figure 12). In contrast, *Swiftia spp.* distribution is less restrictive in its habitat associations and more homogeneous across Cordell Bank (Figure 13). This difference in habitat selectivity between hydrocorals and gorgonians is mirrored in the predictive capability of the models for these two groups. For *Stylaster spp.*, the predictive probability of presence was as high as 0.533, whereas the predictive model for *Swiftia spp.* had a maximum probability of presence of 0.08 (Figures 12&13).

Bathymetry, slope, and topographic position index were important habitat predictors for both *Stylaster spp.* and *Swiftia spp.* (Tables 1&2); however, slope had the opposite influence on these two groups. Rugosity had a strong influence on the presence of *Stylaster spp.*, while substrate type and aspect significantly contributed to the presence of *Swiftia spp.* (Tables 1&2).

Statistical considerations and techniques

Examination of preliminary model results indicates that there are several aspects of the predictive modeling that could be improved to increase the rigor and utility of the model results. First, it is evident that the observations of coral presence are clustered, and therefore, the results are likely biased by the presence of spatial autocorrelation. Spatial autocorrelation violates the assumption of independence of observation and can lead to an increase in type I errors and reduced explanatory power and predictive capability of the model. If spatial autocorrelation is detected, methods should be employed to incorporate the influence of spatial autocorrelation within the modeling framework. The models could also potentially be improved by adding squared terms to describe non-linear relationships.

Next, predictive models should include a validation process, which indicates the accuracy of the model predictions and how confident one can be in the model results. Validation results would give a manager a measurement of variability and aid in making management decisions based on different levels of acceptable risk. Validation could involve holding back some data that could be used to validate the model or potentially conducting additional sampling to create new presence and absence observations that could be used for model validation. Given the logistic and financial effort required to collect new data points, preference would be given to model validation using the existing data set. However, consideration needs to be given to the smaller sample size and the ability to create a robust model with a proportion of the total data set.

The current modeling effort has highlighted the nature of transect data and the possibility of sparse presence points of uncommon taxa relative to a large abundance of absence points. Further, fine scale surveys such as transect data and high resolution habitat data lead to extremely large number of data points, which can lead to potential difficulties in the amount of computational energy needed to produce results.

Next steps for modeling analyses

Given the potential limitations in the preliminary predictive modeling for Cordell Bank deep sea corals, we have recognized the need to explore multiple methods for inclusion of spatial autocorrelation and model validation. The following section describes work that is currently in progress by Barry Nickel, Director of the Center for Integrated Spatial Research at University of California-Santa Cruz.

It is well documented that dealing with spatial data in traditional statistical frameworks can be problematic. This is generally a function of the processes generating the observed data inducing some form of spatial dependence, that is, observations from one location tend to exhibit values similar to those from nearby locations. Such spatial interdependence, or autocorrelation, violates the assumptions of the conventional statistics and thus any relationship modeled under such a framework will not fit particularly well. This is especially germane given the method of data collection used in this study, that is, the high spatial (and temporal) resolution of data measurement from the submersible.

Efforts are underway to adopt a spatial filtering methodology to account for spatial autocorrelation in a way that enables conventional statistical estimation techniques to be exploited, including the entire family of generalized linear models. The spatial filtering technique intuitively converts variables that are spatially autocorrelated into spatially independent variables using an eigenvector decomposition of a connectivity matrix characterizing the spatial relationship between observations. The eigenvector approach presents the advantage of decomposing the variation into spatial and non-spatial components, and the orthogonality of eigenvectors facilitates the analysis and the understanding of any spatial structure in the data.

As fitting spatial eignevector models are computationally demanding, we are currently exploring different methods of spatial subsampling to reduce model estimation overhead. Considering the underlying predictors are at a nominal resolution of 18 meters we can reliably perform subsampling while still maintaining data integrity. A further advantage is that the subsampled data also provides for a reasonable dataset to use for subsequent validation of the fitted statistical models.

Management applications

Preliminary results of predicted locations of coral presence have been used to meet several management needs at Cordell Bank National Marine Sanctuary. First, results have been used to choose a target location for the placement of an oceanographic instrument mooring that would minimize impact to sensitive benthic communities, by finding locations with a low probability of deep sea coral presence. Next, model results were assessed in exploratory efforts to establish monitoring locations of benthic communities of Cordell Bank. Since *Stylaster spp.* and *Swiftia spp.* occupy such different habitat niches, they are indicators of different benthic community types. Further, locations of high *Stylaster spp.* abundance are being considered for focused studies of the impacts of ocean acidification on deep sea corals at Cordell Bank. Modeling results have also be useful in the consideration of locations that would be appropriate for testing proposed experimental fishing techniques to minimize the potential for damage to any sensitive benthic communities. Lastly, preliminary modeling results will be used in illustrating the importance of the existing essential fish habitat conservation zone that prohibits the use of bottom contact fishing gear on Cordell Bank in protecting sensitive biogenic habitats for groundfish. Overall, these habitat models aid our ability to make informed management decisions regarding these sensitive and diverse communities within a national marine sanctuary.

Education and outreach applications

The knowledge gained from this project in regards to deep sea corals on Cordell Bank has been integrated into various education and outreach efforts. Specifically, our understanding of the spatial distribution and habitat associations of corals on Cordell Bank is being incorporated into a three-dimensional physical model of a Cordell Bank pinnacle that will be a highlighted feature of renovated exhibits at the Oakland Museum in Oakland, CA. The sanctuary will continue to use established education and outreach tools such as evening lectures, websites, and interpretive exhibits to disseminate project results and promote sanctuaries, ocean exploration, and the importance of marine conservation.

Summary

The results of this study provide important information for understanding fine-scale habitat associations of cold-water corals. Rarely are modeling efforts of deeper marine habitats and communities conducted on such a fine spatial resolution (both observation and habitat data) nor do the habitat models include both presence and absence data. The results of this study indicate some of the challenges as well as advantages of working with these types of data (transect data on fine spatial resolution) and provide an analysis framework for applying GIS-based predictive modeling for examining other rocky seafloor features and their associated communities.

Results of the preliminary modeling indicate that there are small-scale habitat features on Cordell Bank that are driving the species distribution patterns of deep sea corals. As a result, the Bank cannot be considered a homogenous feature in terms of habitat suitability. Results of this study can be compared with broader-scale modeling efforts (e.g., entire west coast of U.S.) that incorporate simpler habitat variables on a coarser resolution to evaluate the importance of scale and complexity in modeling these seafloor communities.

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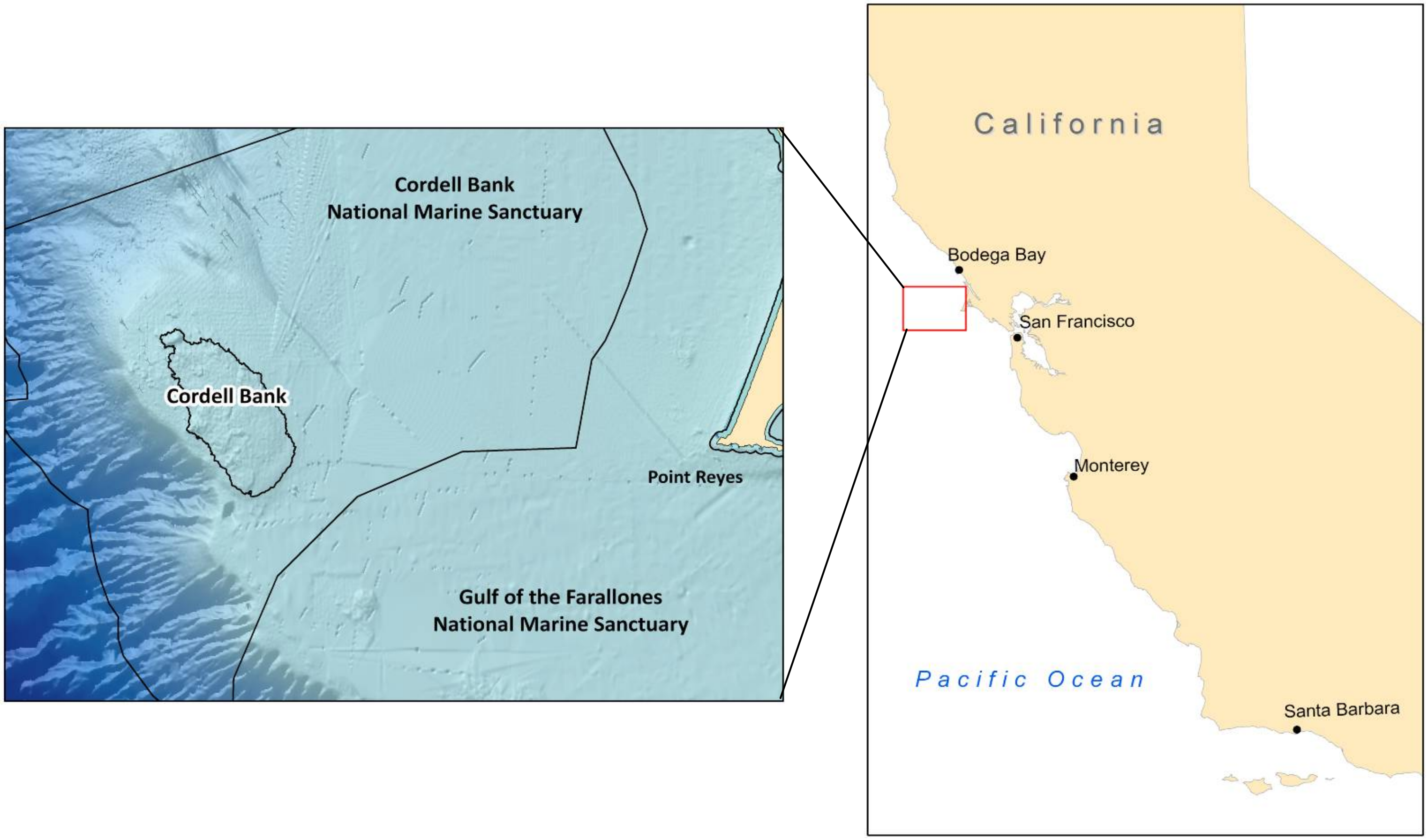


Figure 1. Location of Cordell Bank, a four-and-a-half mile by nine-and-a-half mile rocky undersea feature located 22 miles west of the Point Reyes headlands, California. The bank sits at the edge of the continental shelf and rises from 130m to within 35m of the surface.

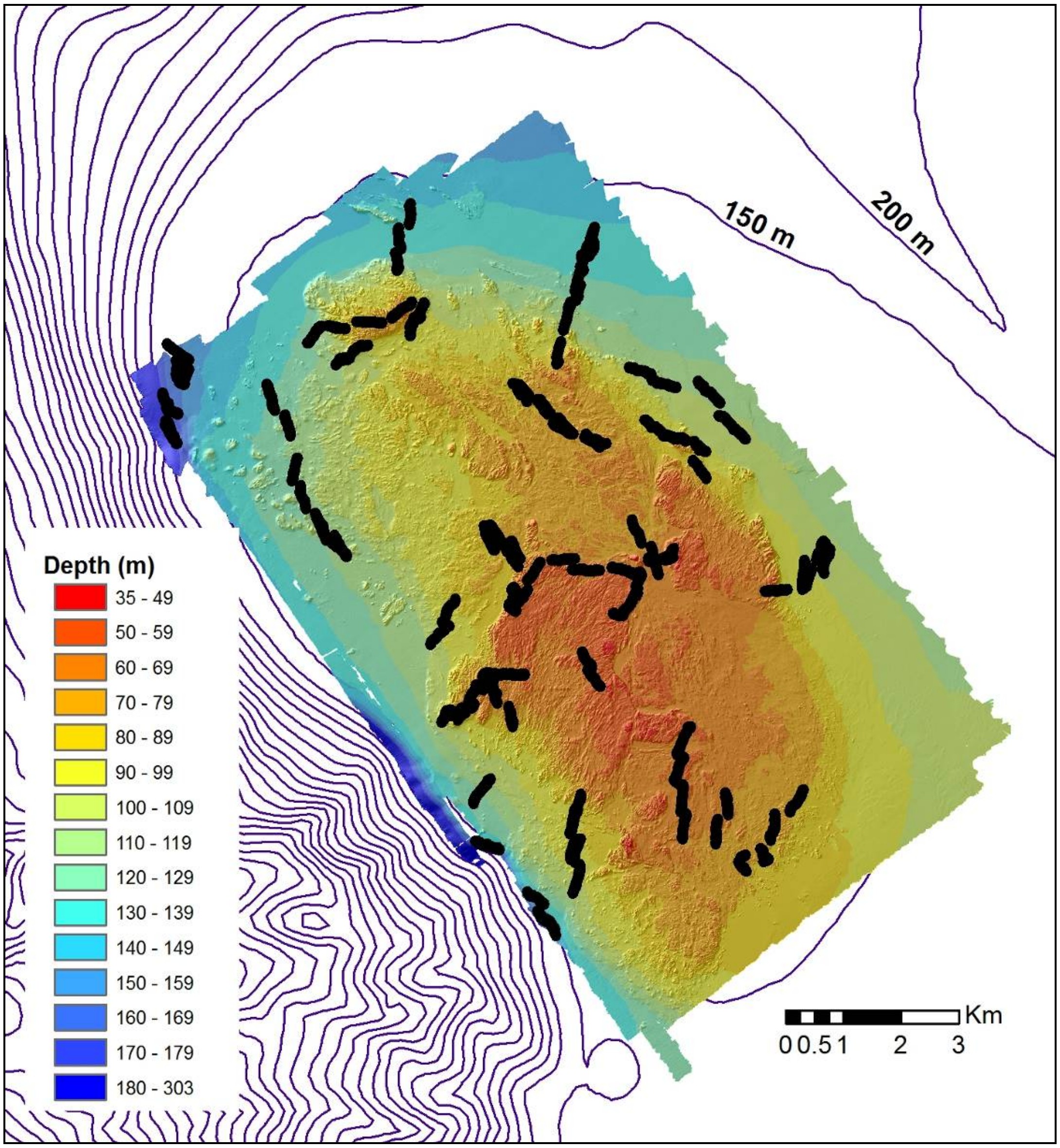


Figure 2. Transects (2001-2005) viewed for coral observations across Cordell Bank using the *Delta* submersible.

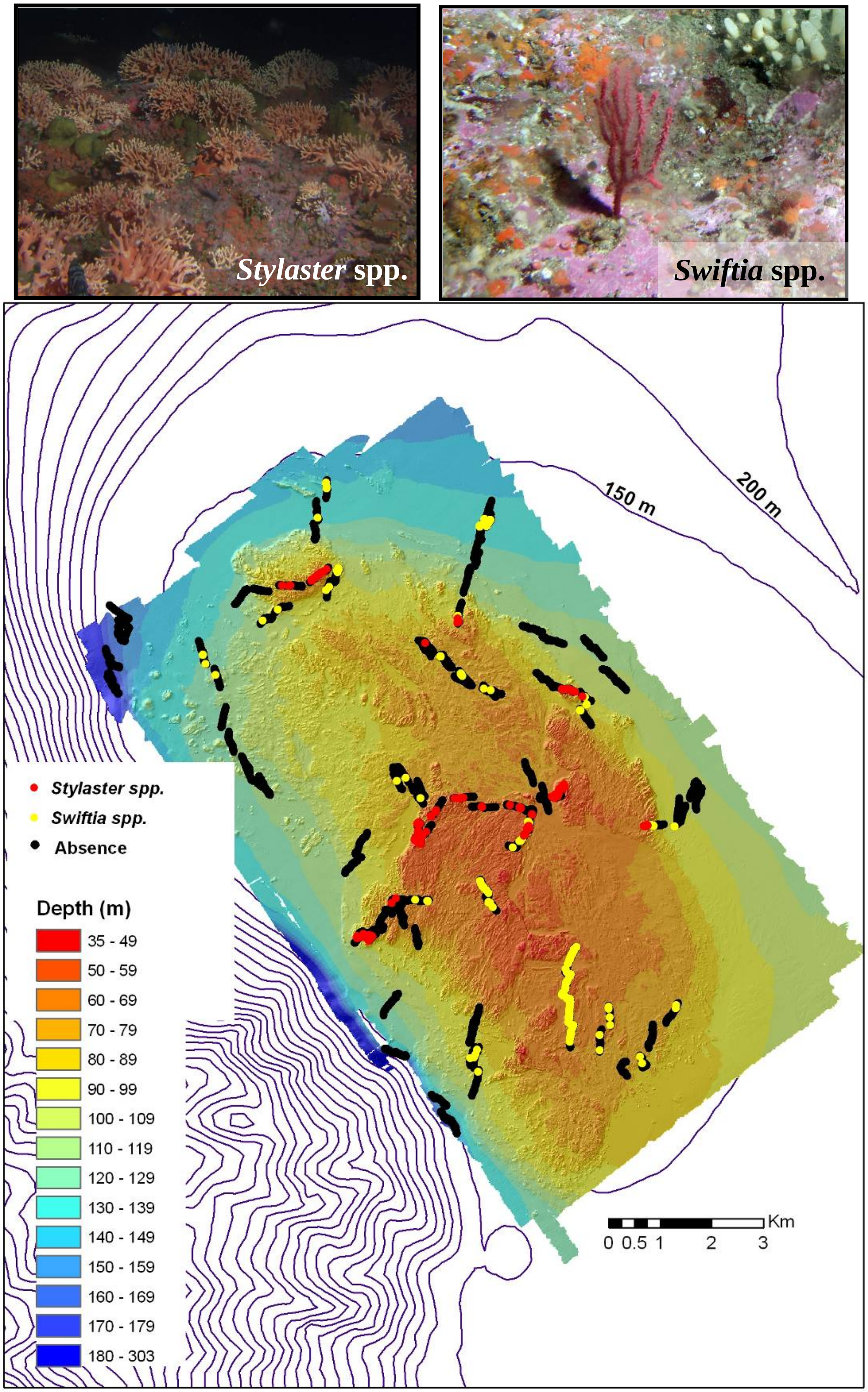


Figure 3. Distribution of *Stylaster spp*. and *Swiftia spp*. across Cordell Bank relative to depth.

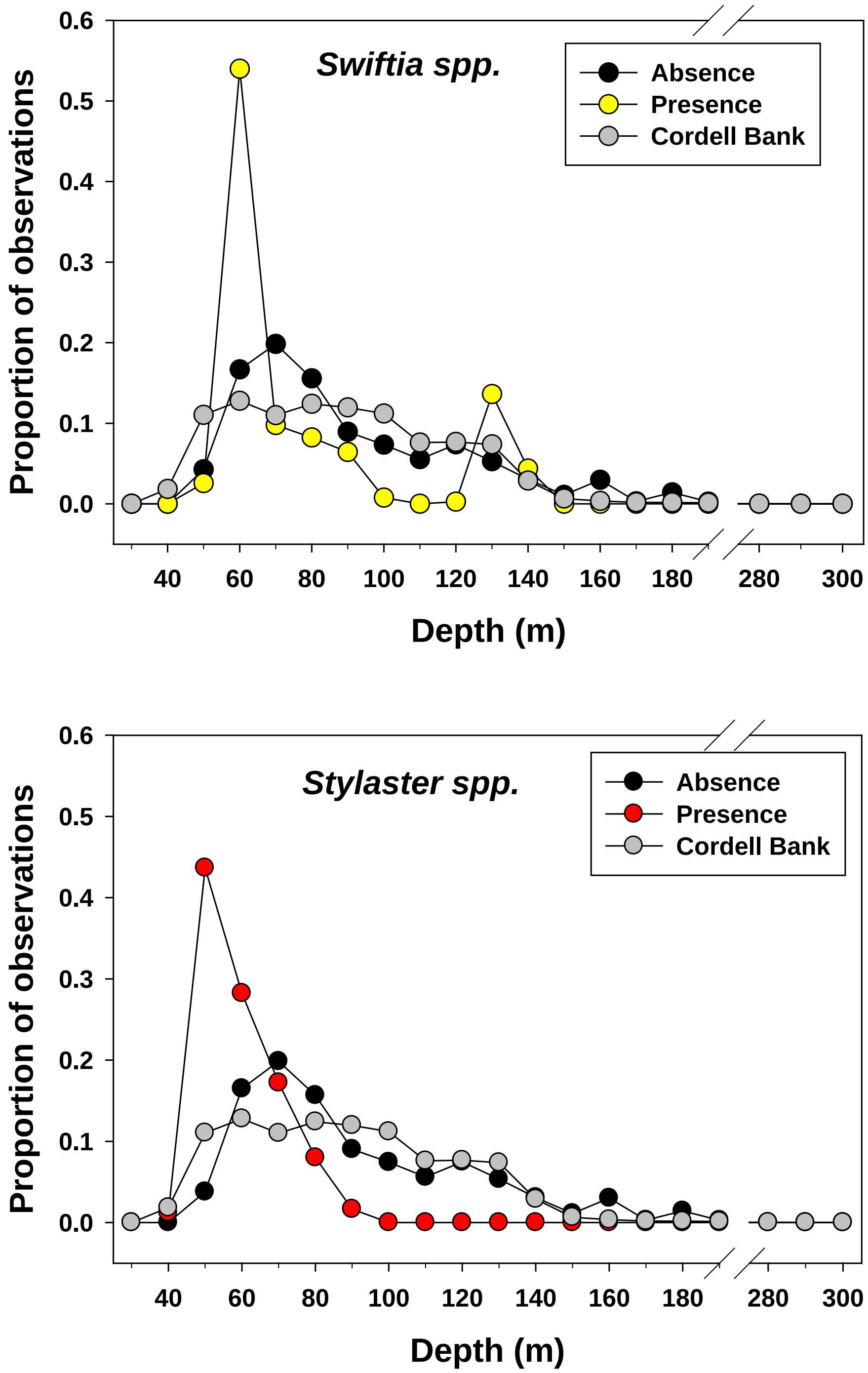


Figure 4. *Swiftia spp*. and *Stylaster spp*. observations relative to depth classes. Grey circles indicate the amount of available habitat on Cordell Bank, using all of the multibeam backscatter data. Comparison of the Cordell Bank data with the coral absence and presence data illustrate the sampling of representative habitats on Cordell Bank (absence) and the habitat selection by corals (presence). Proportions are within each data category (i.e., absence, presence, Cordell Bank). Depth labels represent the mid-points of depth classes (e.g., 60m class includes 55-65m depths).

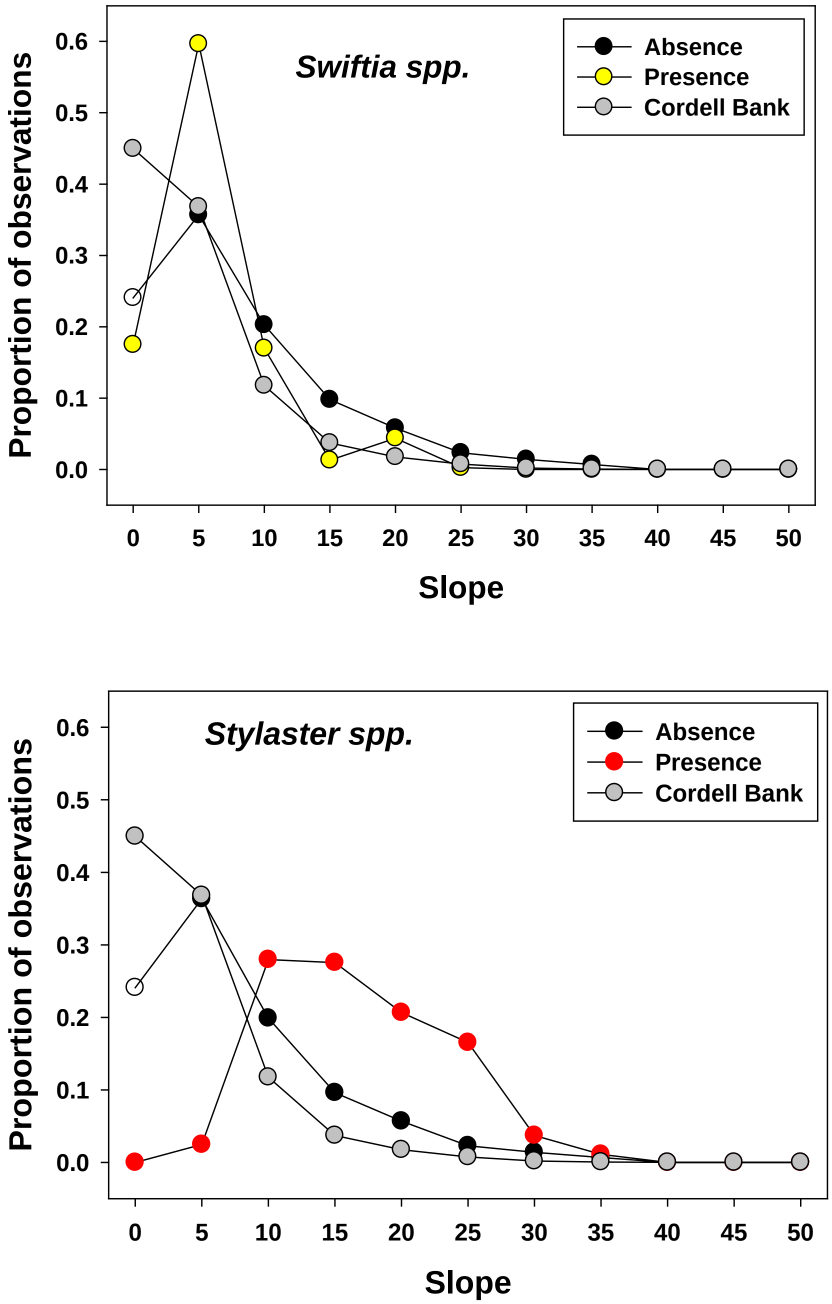


Figure 5. *Swiftia spp*. and *Stylaster spp*. observations relative to slope classes. Grey circles indicate the amount of available habitat on Cordell Bank, using all of the multibeam backscatter data. Comparison of the Cordell Bank data with the coral absence and presence data illustrate the sampling of representative habitats on Cordell Bank (absence) and the habitat selection by corals (presence). Proportions are within each data category (i.e., absence, presence, Cordell Bank). Slope labels represent the mid-points of slope classes (e.g., 10° class includes 7.5-12.5° slopes).

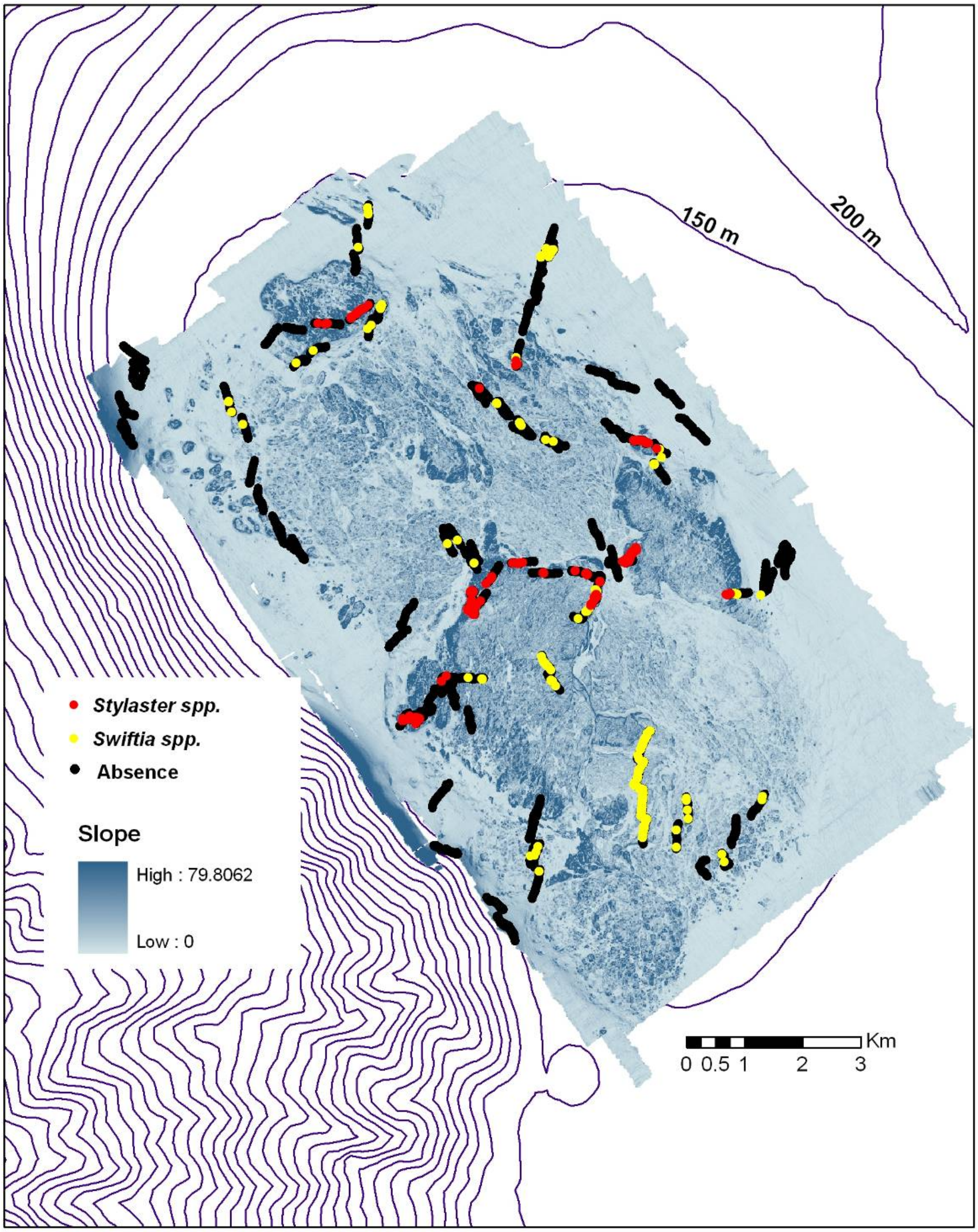
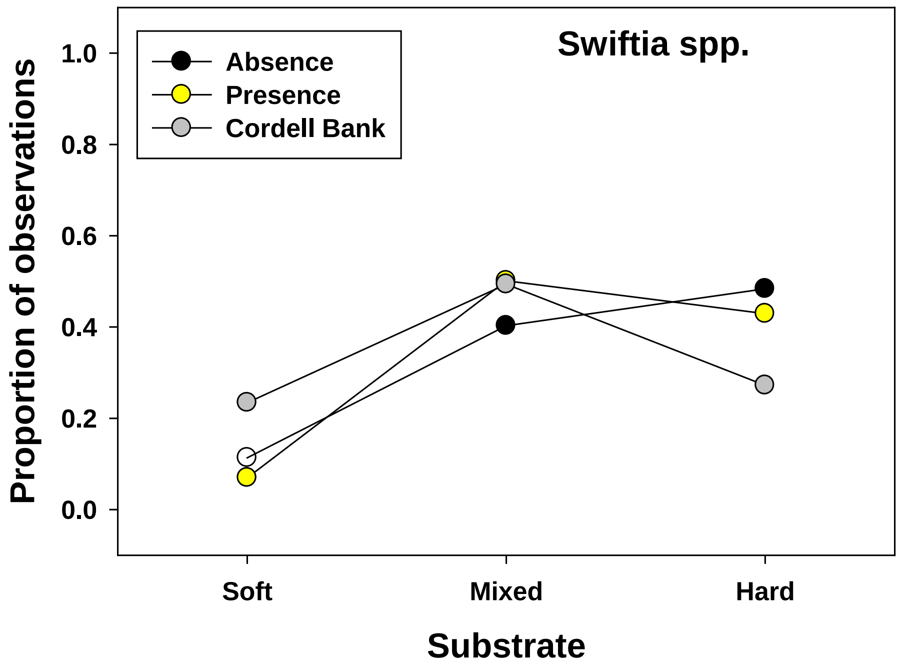


Figure 6. Distribution of *Stylaster spp*. and *Swiftia spp*. across Cordell Bank relative to slope.



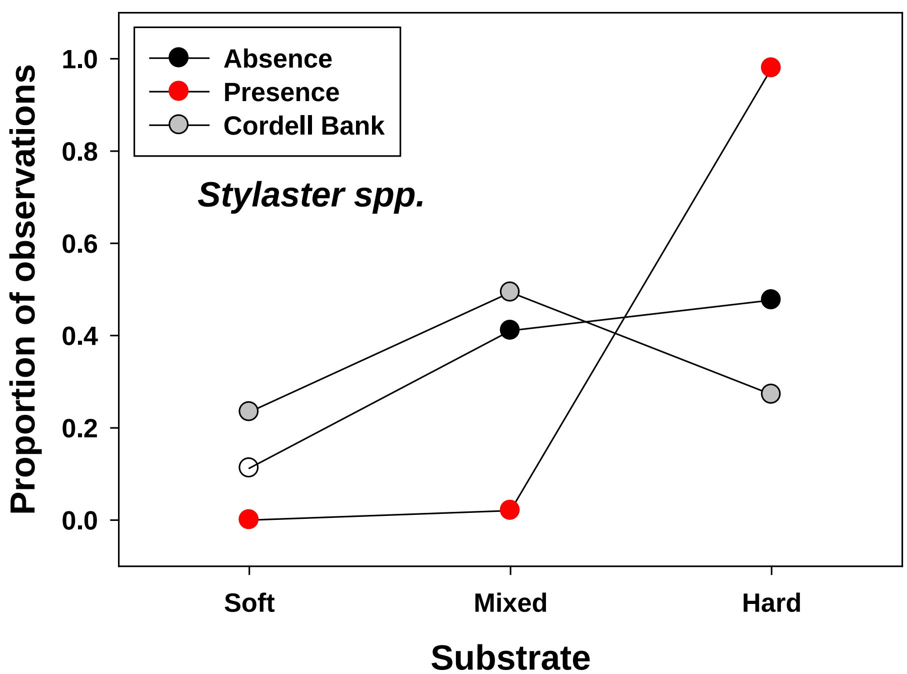


Figure 7. *Swiftia spp*. and *Stylaster spp*. observations relative to substrate types. Grey circles indicate the amount of available habitat on Cordell Bank, using all of the multibeam backscatter data. Comparison of the Cordell Bank data with the coral absence and presence data illustrate the sampling of representative habitats on Cordell Bank (absence) and the habitat selection by corals (presence). Proportions are within each data category (i.e., absence, presence, Cordell Bank).

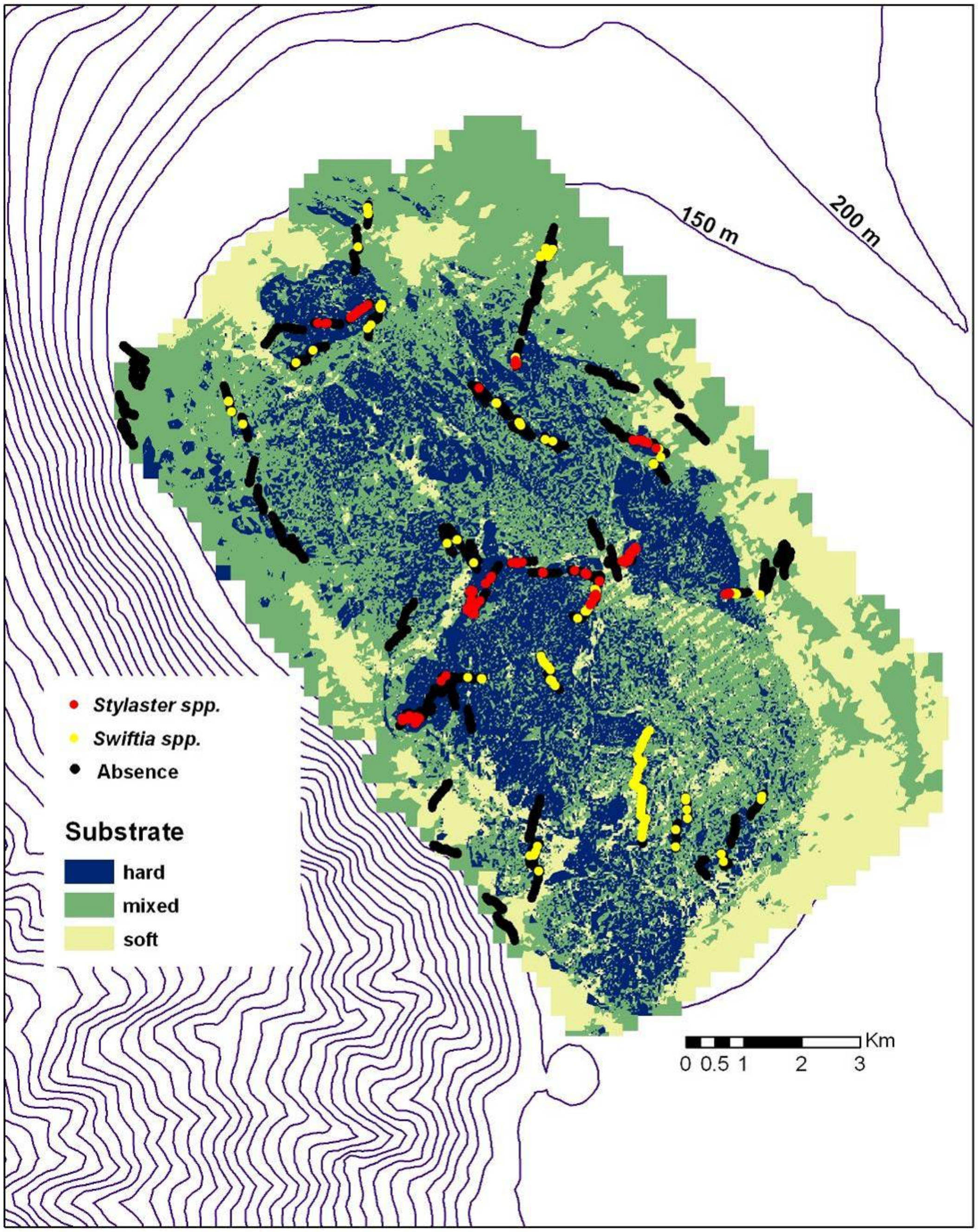
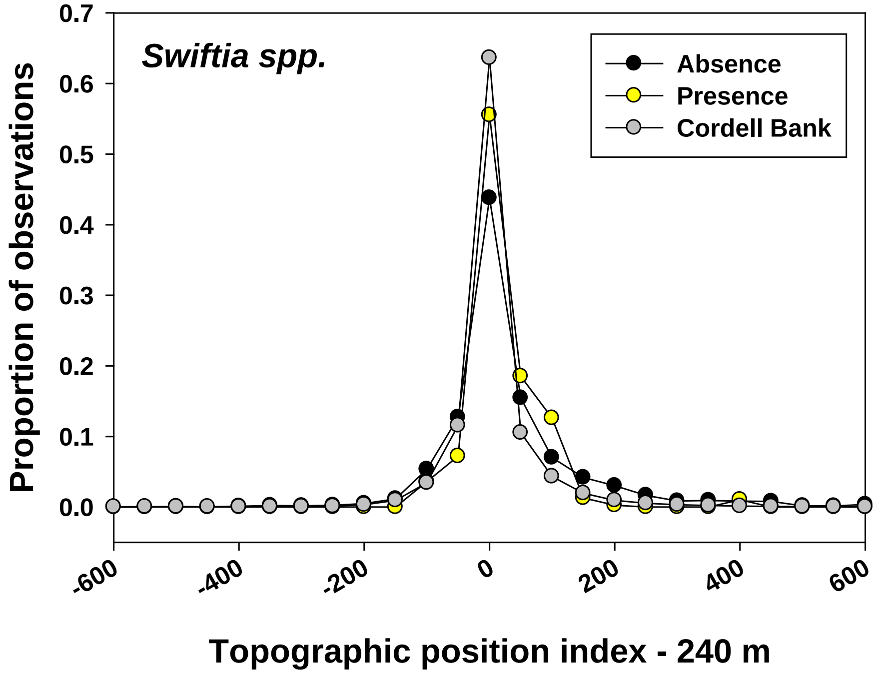


Figure 8. Distribution of *Stylaster spp*. and *Swiftia spp*. across Cordell Bank relative to substrate.



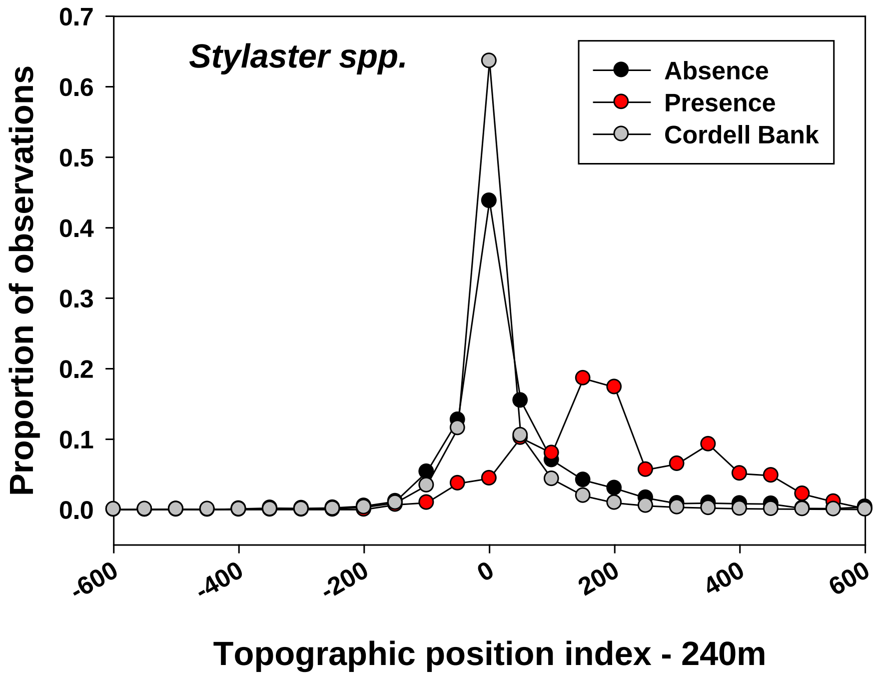


Figure 9. *Swiftia spp.* and *Stylaster spp*. observations relative to topographic position index (TPI) at 240m scale. Grey circles indicate the amount of available habitat on Cordell Bank, using all of the multibeam backscatter data. Comparison of the Cordell Bank data with the coral absence and presence data illustrate the sampling of representative habitats on Cordell Bank (absence) and the habitat selection by corals (presence). Proportions are within each data category (i.e., absence, presence, Cordell Bank). TPI labels represent the mid-points of TPI classes (e.g., 200 class includes 175-225 TPI values).

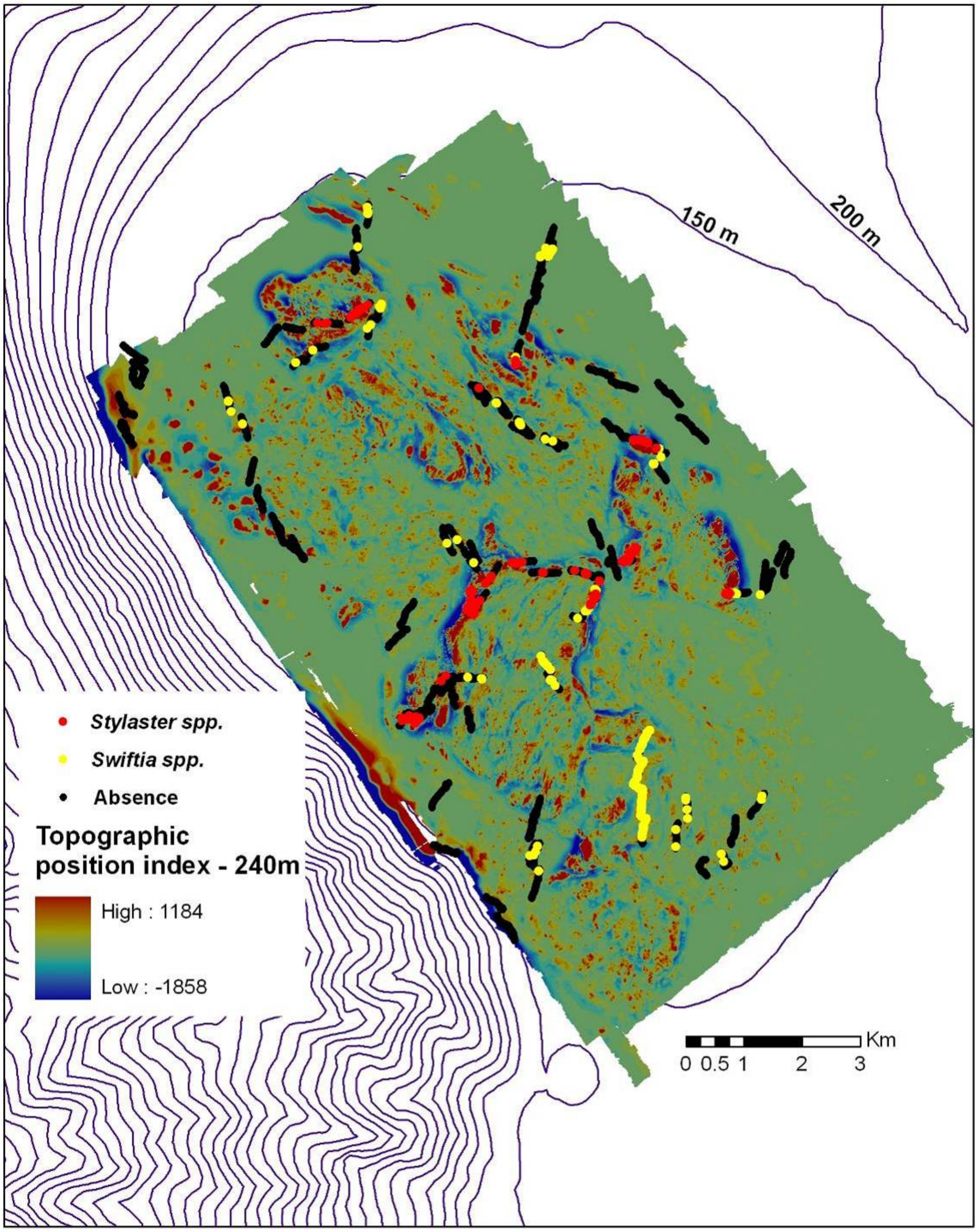


Figure 10. Distribution of *Stylaster spp*. and *Swiftia spp*. across Cordell Bank relative to topographic position index (TPI) at 240m scale.

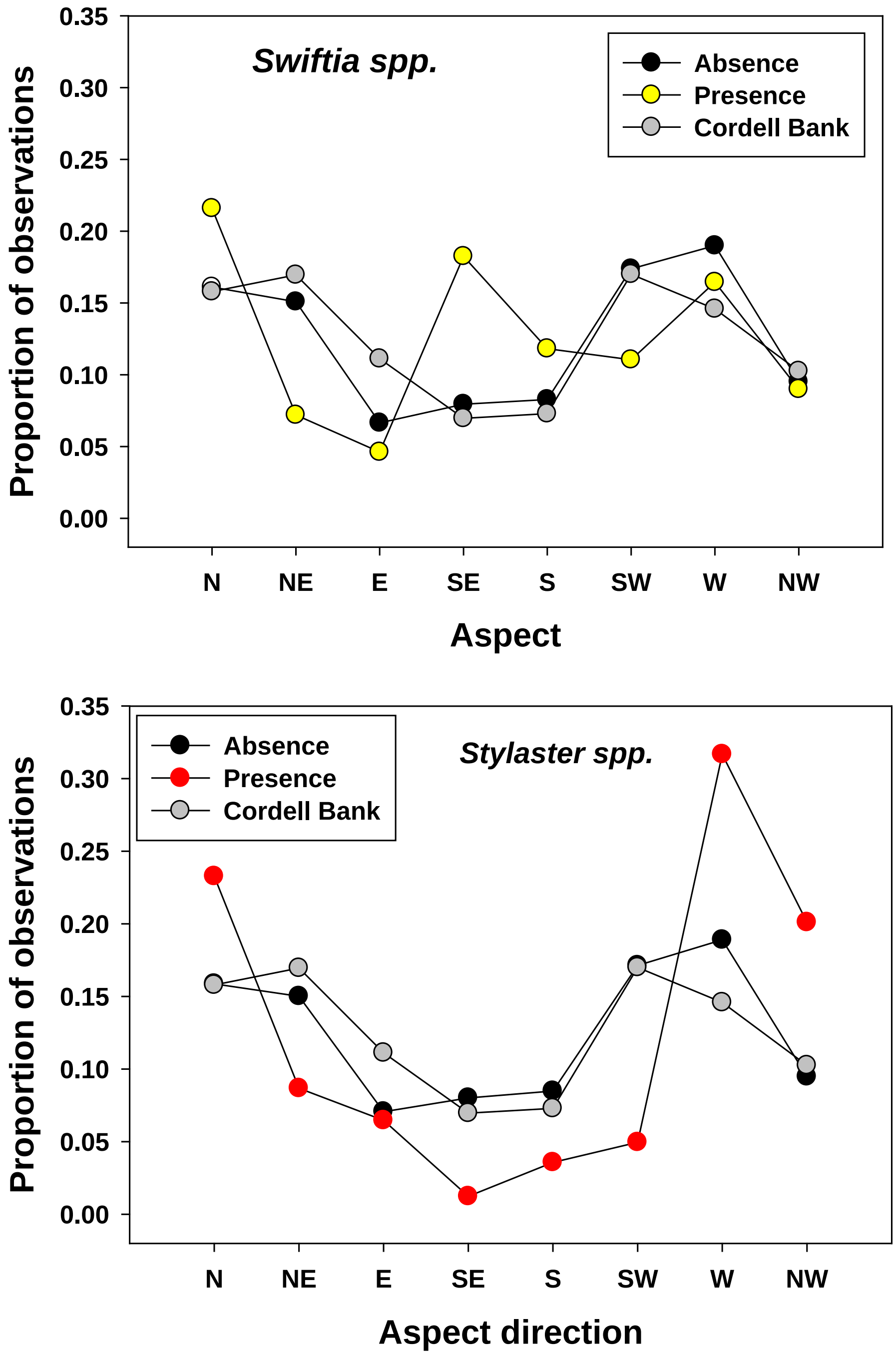


Figure 11. *Swiftia spp.* and *Stylaster spp*. observations relative to aspect. Grey circles indicate the amount of available habitat on Cordell Bank, using all of the multibeam backscatter data. Comparison of the Cordell Bank data with the coral absence and presence data illustrate the sampling of representative habitats on Cordell Bank (absence) and the habitat selection by corals (presence). Proportions are within each data category (i.e., absence, presence, Cordell Bank). Aspect labels represent the mid-points of aspect classes (e.g., S class includes compass directions 157.5 to 202.5°).

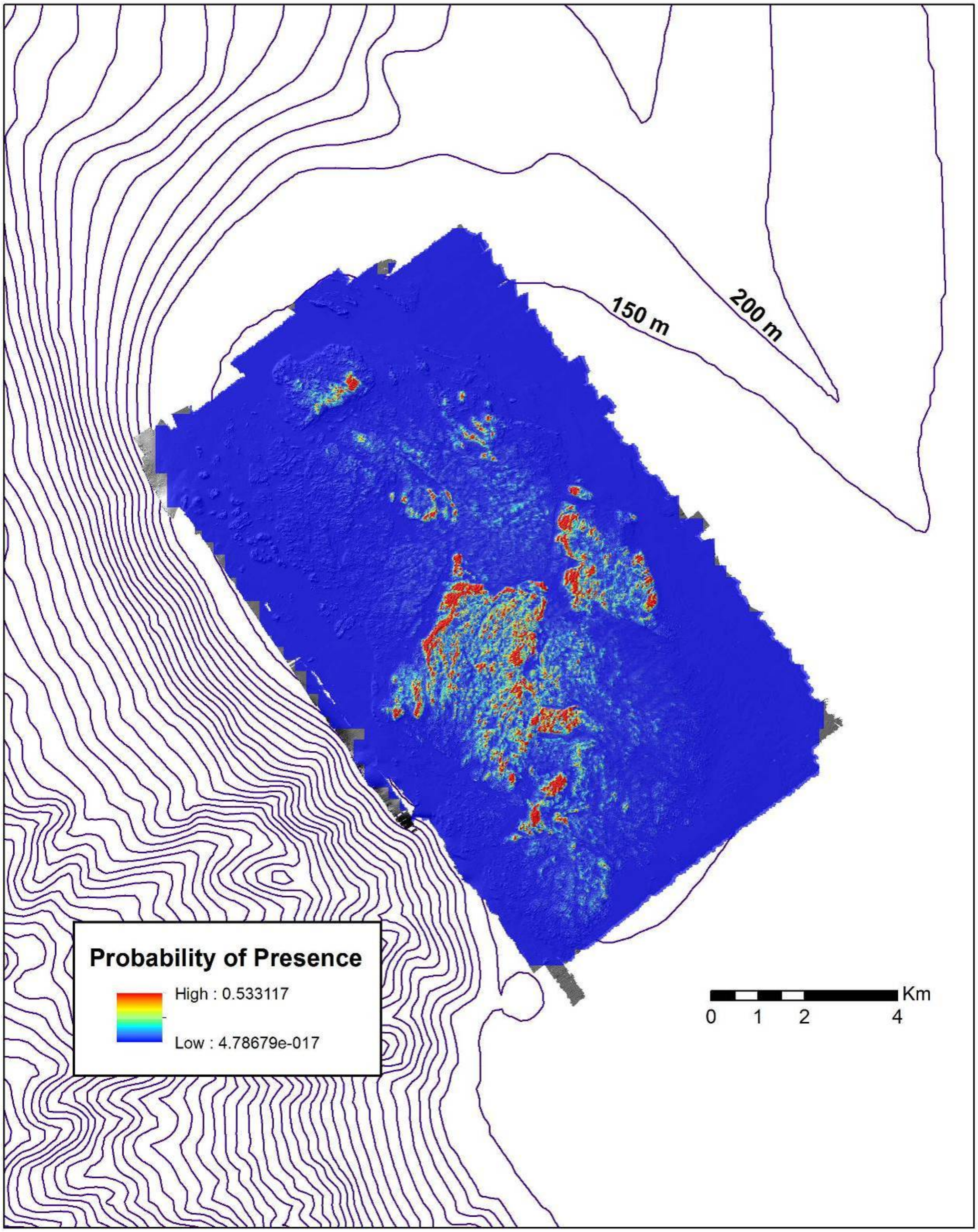


Figure 12. Predicted probability of presence of *Stylaster spp.* across Cordell Bank using best fit logistic regression model applied to habitat raster data using ArcRStats.

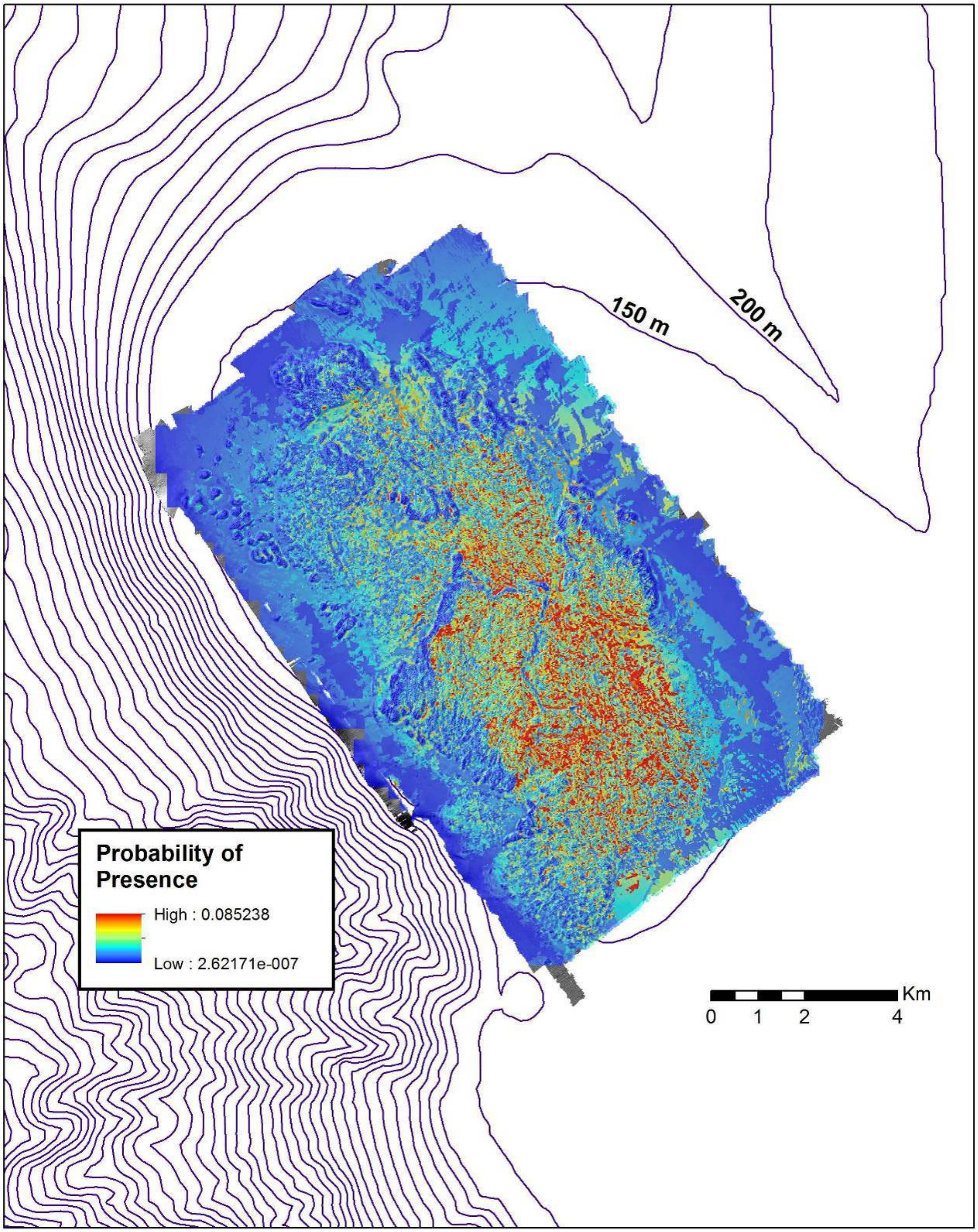


Figure 13. Predicted probability of presence of *Swiftia spp.* across Cordell Bank using best fit logistic regression model applied to habitat raster data using ArcRStats.

Table 1. Best fit generalized linear model (GLM) logistic regression results for Stylaster spp. using step-wise AIC selection of variables.

Variable	Parameter Estimate	Standard Error	p-value
Bathymetry	0.1039	0.005669	<0.001
Rugosity	-11.02	1.868	<0.001
Slope	0.2139	0.01989	<0.001
TPI_30m	-0.002171	0.0005932	<0.001
TPI_120m	-0.002524	0.0007186	<0.001
TPI_240m	0.005053	0.0006115	<0.001

Table 2. Best fit generalized linear model (GLM) logistic regression results for Swiftia spp. using step-wise AIC selection of variables.

Variable	Parameter Estimate	Standard Error	p-value
Bathymetry	0.030023	0.002666	<0.001
Slope	-0.132553	0.017668	<0.001
TPI_60m	0.005551	0.001853	0.002739
TPI_120m	-0.008136	0.002457	<0.001
TPI_240m	0.005403	0.001541	<0.001
Substrate_mixed	1.001628	0.208669	<0.001
Substrate_hard	0.426412	0.228595	0.062131
Aspect_45°	-1.183531	0.219822	<0.001
Aspect_90°	-1.117951	0.263371	<0.001
Aspect_135°	0.071601	0.166561	0.667283
Aspect_180°	-0.296422	0.187325	0.11356
Aspect_225°	-0.728403	0.18889	<0.001
Aspect_270°	-0.486718	0.168927	0.003961
Aspect_315°	-0.496416	0.205015	0.015462