Emma Flattery, Scripps Institution of Oceanography, University of California San Diego

Mentors: Fanny Girard, James P. Barry

Summer 2022

Keywords: benthic,

ABSTRACT

Insert

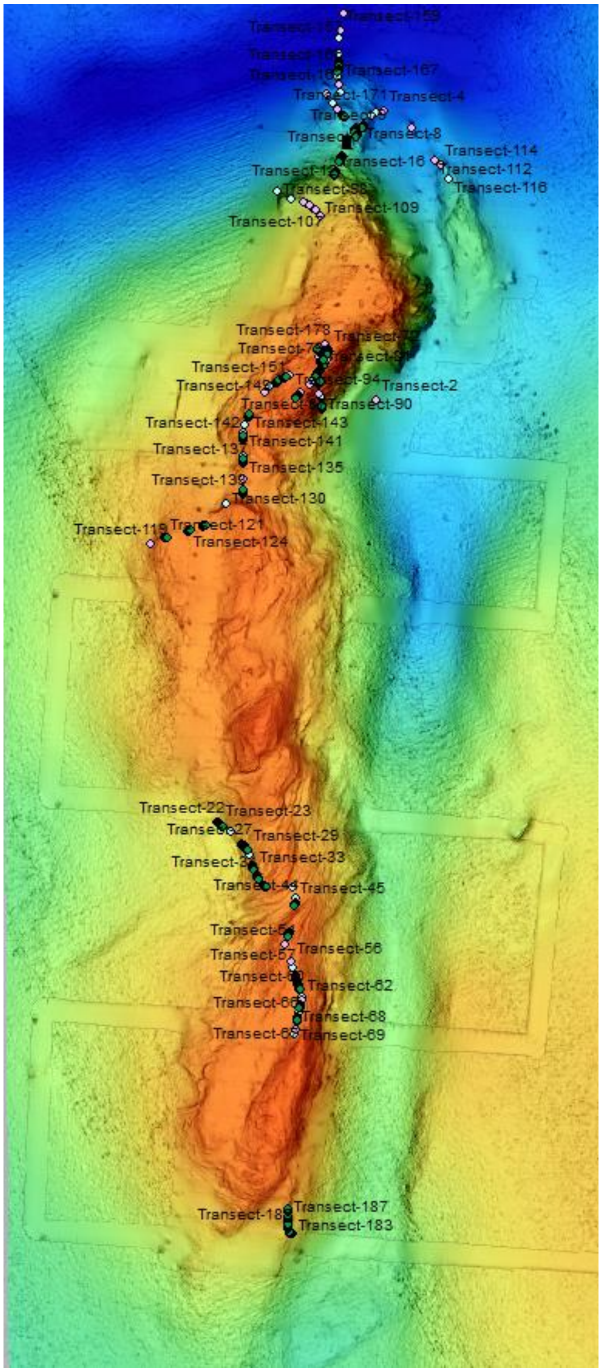
INTRODUCTION

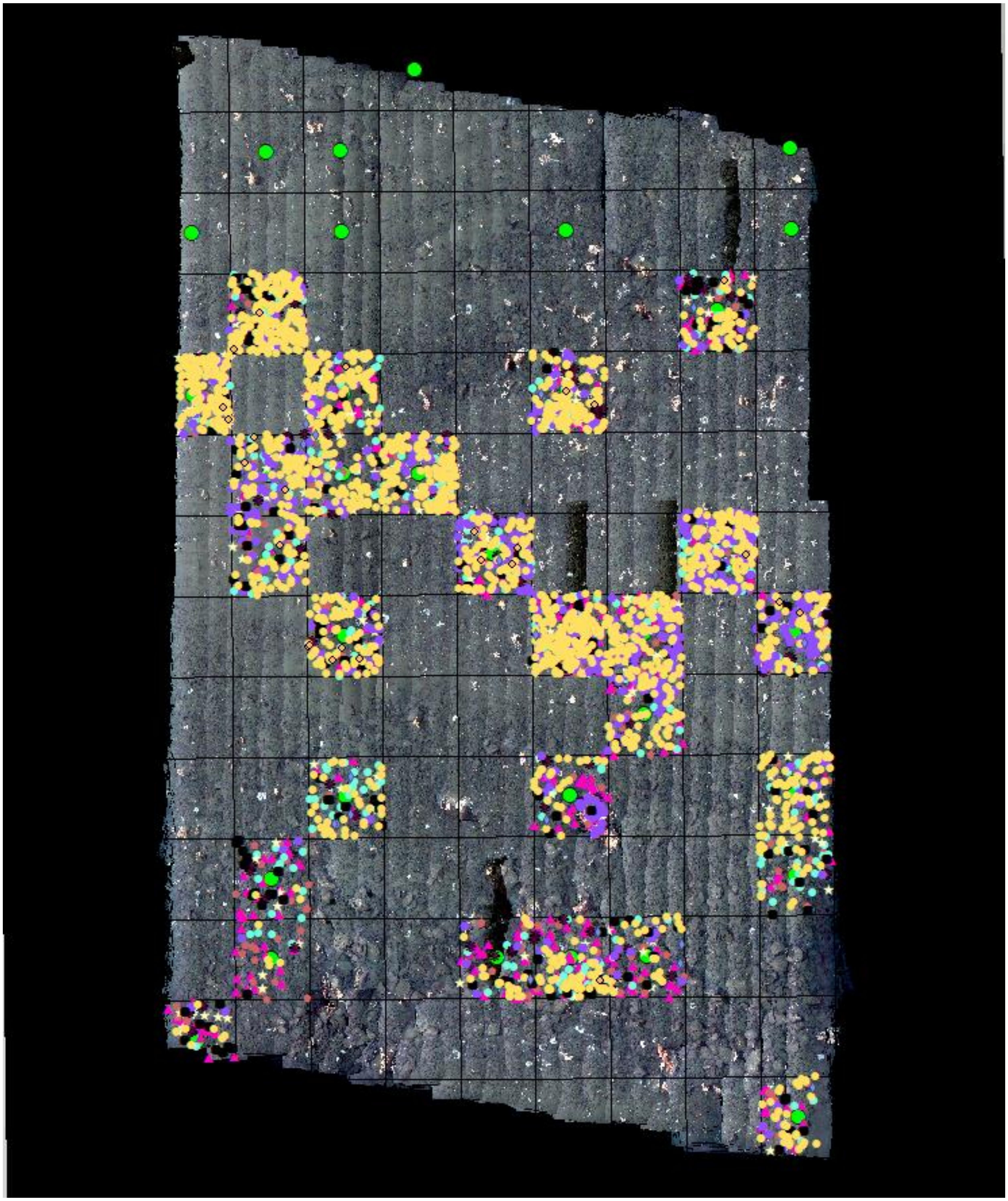
The deep ocean and its benthic communities remain relatively un-impacted by anthropogenic influences when compared to shallower marine habitats. As marine technology has developed and spread in recent decades, the obstacles of depth, pressure, and oxygen limitation have become surmountable, and this has exposed the deep sea to the exploitation and extraction that was previously confined to the terrestrial environment. Now, the deep seems a burgeoning frontier for rare mineral mining, deep-sea waste disposal, and carbon-sequestration dumping (Ahnert et al., 2000). These, in addition to the mounting effects of climate change, ocean acidification, long-term heating, and pollution, pose a looming threat to the well-being of the deep sea benthos (Morato et al., 2020).

The inaccessibility of the deep seafloor does not make this habitat any less vital to global functions. The CO_2 naturally sequestered by the ocean can be locked away for millennia within the deep benthos, but this process relies on the uninterrupted functions of the organisms that make up its biological pump (Devries, 2022). As beacons of high relative biodiversity, deep seamounts offer habitat to many of these organisms. Some of the main discourses on seamounts propose that seamounts have high endemicity and are therefore ecologically distinct from the surrounding seafloor (the seamount endemicity hypothesis, SMEH) and others suggest the near opposite, that seamounts are nursing grounds and larval dispersal sources that seed the ocean benthos. Irrespective of an individual seamount's nuances in function, seamounts are dense, diverse, havens for commercially important and slow-growing species (McClain et al., 2009).

Foundation species like *Paragorgia arborea* (found at Sur Ridge) which provide habitat for seamount organisms will soon experience the destruction and habitat loss of its shallower cousins and may experience extinction before the end of the century (Morato et al., 2020). Unlike the hard-structured coral reefs of the coastal tropics, wherein long-deteriorated baselines have made it difficult to understand the ecological structure of these habitats before major anthropogenic influence (Bradley et al., 2017) these seamount coral environments are at the precipice of major change. This paper characterizes the faunal structure of Sur Ridge, a seamount in the Northern Pacific, in order to gain insight into its ecological makeup, understand how its topography influences faunal distribution, and comprehend what factors influence its biodiversity. This contributes to creating an ecological baseline for the deep benthos habitat as a future of disturbance makes it uncertain, and it is an endeavor to influence the rising need for seamount conservation.

MATERIALS AND METHODS


Transect-159
Transect-167
Transect-171
Transect-4
Transect-8
Transect-16
Transect-114
Transect-112
Transect-116
Transect-109
Transect-107
Transect-178
Transect-151
Transect-94
Transect-2
Transect-90
Transect-143
Transect-141
Transect-135
Transect-130
Transect-121
Transect-124
Transect-22
Transect-23
Transect-29
Transect-33
Transect-45
Transect-56
Transect-62
Transect-68
Transect-69
Transect-187
Transect-183



I. DATA COLLECTION

MOSAIC

In October 2020, the MBARI ultra-resolution low altitude survey system (LASS) was mounted to the MBARI's Doc Ricketts ROV and utilized to create a [size] composite image mosaic of a section of the North Flat of Sur Ridge. The LASS captured stereo-photographic color images of the benthic terrain and any incident organisms with 2.5 mm resolution. It also used a multi-beam sonar imaging system with 5 cm resolution to survey corresponding bathymetry. [a separate, mounted ROV camera captured video corresponding to the route of the ROV]. The images were compiled into a single, compound-image mosaic that corresponds to the bathymetric sonar-generated map. This mosaic allowed for the analysis of faunal distribution in relation to benthic topography.

VIDEO TRANSECTS

Between June 2014 and December 2021, the MBARI ROV Doc Ricketts aboard the Western Flyer was used to film transects of Sur Ridge. Alternating zoomed-in (1m wide) and wide transects videos were taken. The videos along with the corresponding measurements of depth, oxygen concentration, temperature, and light transmission were stored, annotated, and reviewed on MBARI's Video Annotation and Reference System (VARS), an annotation database which holds all organismal and topographical observations made using MBARI ROV footage. Light transmission data was omitted from analysis due to variability in the ROV increasing turbidity.

II. ANNOTATION

MOSAIC

The program ArcMap from ArcGIS was utilized to divide the image mosaic into 125 grids. Thirty-five grids were randomly selected for annotation, 26 of which were used for analysis. The accompanying ROV video footage was referenced in the placement of points over each identifiable organism, denoting them spatially. Each organism was assigned to its most identifiable taxonomic designation using the Sur Ridge Field Guide [source] as reference. Organisms which could not be identified to a corresponding taxa within the guide were catalogued and given a general taxonomic designation and assigned a number or morphology. (i.e. Porifera sp. 5 or Actiniaria bright yellow). Fish and other highly mobile organisms that were present in the ROV footage but not recorded in the mosaic were not denoted in ArcMap. Sessile organisms that were present in the ROV footage but not recorded in the mosaic due to [threading] error were denoted in ArcMap.

The Benthic Terrain Modeler (BTM) of ArcMap was used to create increase the cell size of the [mosaic] from 5cm into an aggregate 10cm. This aggregate was then utilized to calculate the slope, aspect, ruggedness, and curvature (slope of slope) of the North Flat terrain, then assigned to their corresponding species points. The data was then extracted by table and assembled/condensed in Excel before moving to RStudio for analysis.

VIDEO TRANSECTS

Of the total transects recorded, 25 wide transects and 20 zoomed-in transects were selected for full annotation. Trained annotators analyzed transect footage in VARS and identified each organism by its most identifiable taxonomic designation using the Sur Ridge Field Guide [source] as reference. Organisms which could not be identified to a corresponding taxa within the guide were catalogued and given a general taxonomic designation and assigned a number or morphology. The same designations were used in the mosaic and video transect annotations. Once transects were fully annotated, they were queried from the VARS databank and the first 50m were used of each transect for uniformity in area. Each of the wide transect videos was separately measured three times to give a rough estimate of the transect's average width and area.

The data was queried from VARS and arranged into matrixes in Excel before moving to RStudio for analysis. The transect latitudes and longitudes at each observation were imported into ArcMap and laid over a terrain model of Sur Ridge. BTM was used to make a 20m aggregate of the Sur Ridge map to account for placement error with coordinates. This aggregate was used to calculate the slope, aspect, ruggedness, and curvature (slope of slope) of Sur Ridge, then assigned to their corresponding species points. The data was then extracted by table and assembled/condensed in Excel before moving to RStudio for analysis.

III. ANALYSIS

MOSAIC

Tables of the extracted North Flat data were condensed in R such that only organisms with at least 2 observations were included. Averages of each taxa's corresponding curvature, aspect, ruggedness, and slope were calculated and plotted as dot charts in RStudio. An ANOVA and Tukey post hoc test were completed for each variable to find species significantly different from the others. The data was also arranged by transect and their averages were calculated and plotted along with their ANOVA tests.

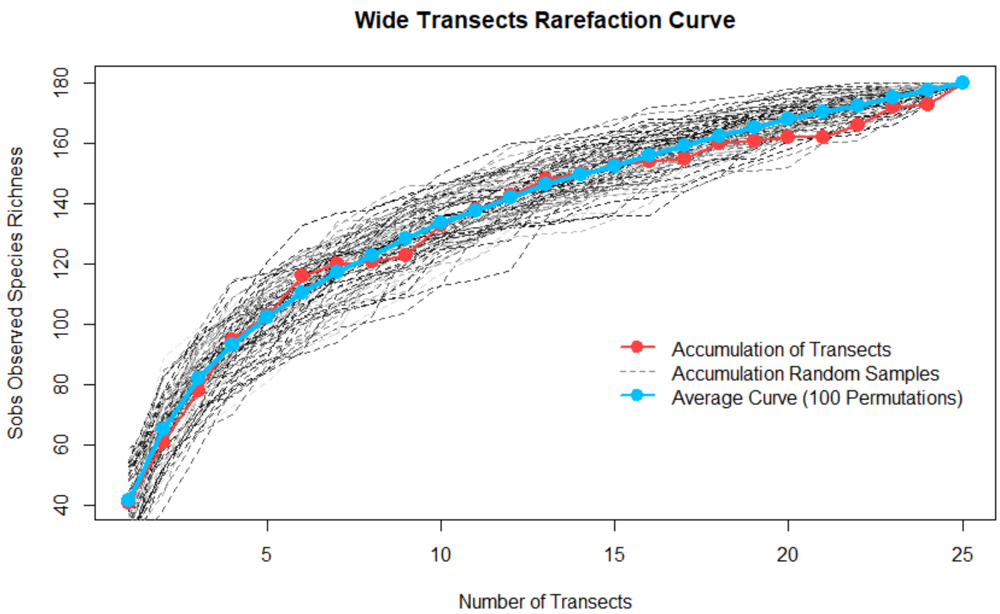
VIDEO TRANSECTS

Video transect data were arranged into species matrixes of density using their estimated areas. Both wide and zoomed transects were utilized to generate rarefaction curves to analyze the effectiveness of sampling at Sur Ridge. The transects were organized into dendrograms by transect type and both were split into 4 groups, then an analysis of similarity (Anosim test in R) was performed on them, denoting them as significantly different. This analysis produced the taxa which had the most influence over the difference between the groups, the first two most influential taxa for each comparison, these taxa were recorded. The taxa were paired with their associated group. These groups were color coded and then used to produce two PCAs analyses. PCA and MDS plots were generated from the data to analyze [what factors or species most influenced structure]. Simpson indexes were calculated for both transect types and dendrograms were created using Hellinguer distance. The BTM data was used to calculate the average curvature, aspect, ruggedness, slope, oxygen concentration, depth, and temperature for each taxa and transect separately. These data were divided into categories of "sponge", "coral", and "crustacean" and used to make both dot charts and boxplots. ANOVA and post hoc tests were performed on each category to find those species significantly different from others. Both tests were also performed on the transect data.

RESULTS

I. VIDEO TRANSECTS

Approximately 290 taxa were identified across Sur Ridge. The rarefaction curves generated for both wide and zoomed transects (Fig. 3), suggest that there may be more species to sample at Sur Ridge as both plots lacking a distinct asymptote. The diversity indices displayed in Table 1 produce a Simpson average of 0.8430 and 0.8657 for the wide and zoomed-in transects respectively. The Shannon index averages were 2.62 for the wide transects and 2.73 for the zoomed-in transects. Both indices are relatively similar between both transect types and indicate relatively high diversity across all transects.



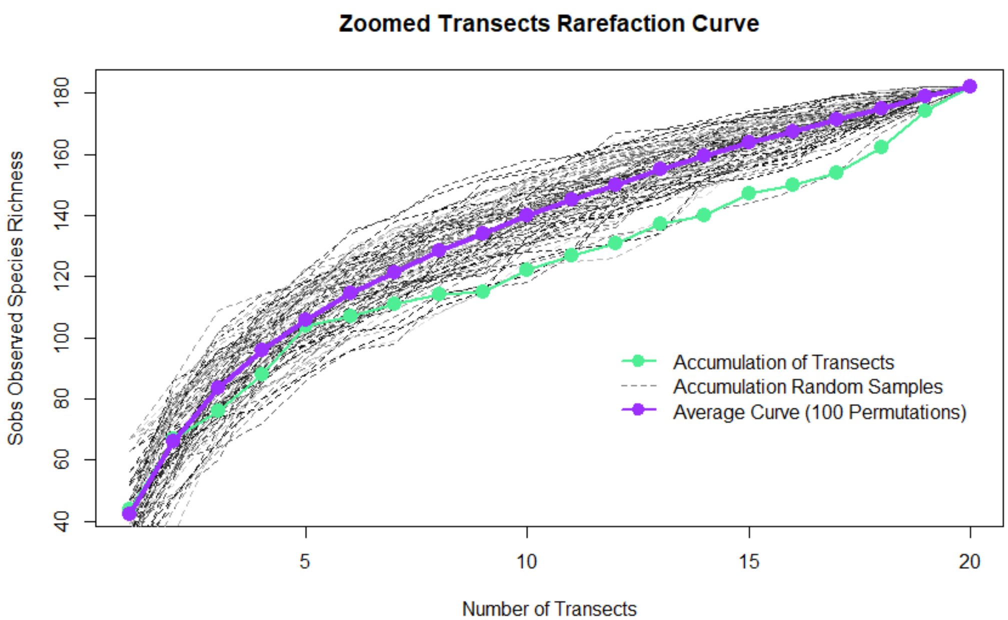


Figure 3: Rarefaction and accumulation curve assessments for Sur Ridge transects. Each generated average rarefaction curve is calculated based on the 100 permutations visualized in grey dashes. The accumulation curves were based on the species matrixes produced from the queried VARS data.

Wide Transect Indexes

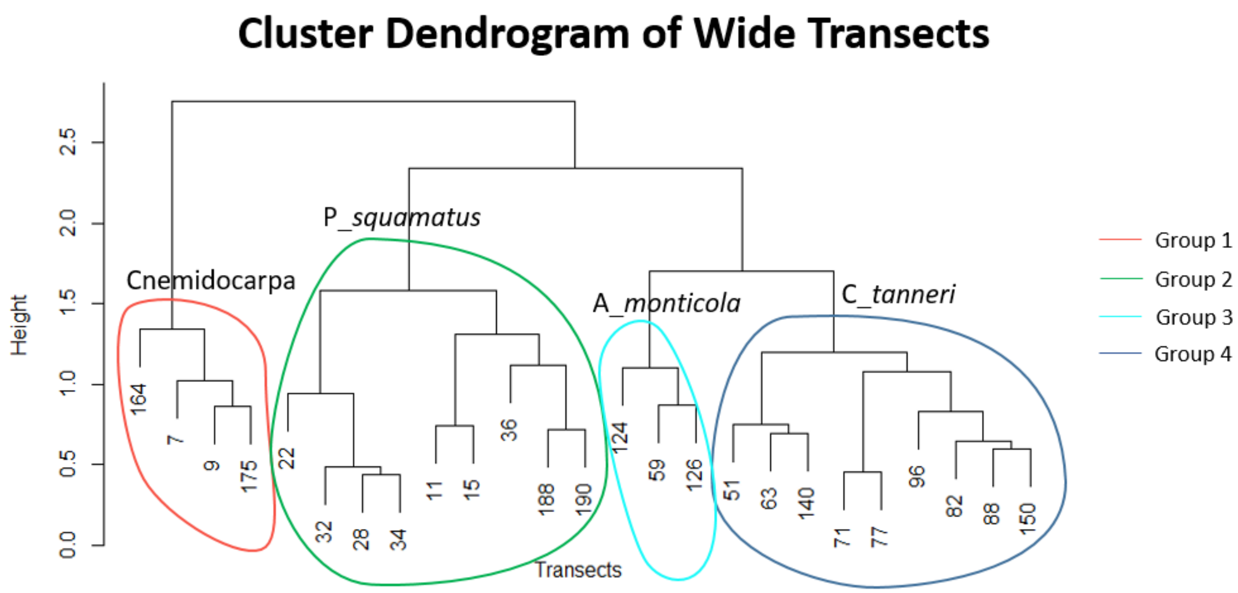
Wide Transect ID	Simpson Index	Shannon Index
7	0.8585	2.75
9	0.9010	2.70
11	0.9244	3.13
15	0.9572	3.49
22	0.8231	2.31
28	0.9107	3.05
32	0.9409	3.21
34	0.9103	2.98
36	0.9236	2.89
51	0.9130	3.03
59	0.7453	2.09
63	0.9407	3.22
71	0.9154	3.01
77	0.9030	2.78
82	0.9510	3.38
88	0.9144	3.00
96	0.8831	2.52
124	0.7744	1.99
126	0.7763	2.21
140	0.9207	3.15
150	0.8999	2.82
164	0.7087	1.75
175	0.7859	2.12
188	0.6641	2.03
190	0.7973	2.64
Average	0.8430	2.62

Zoomed Transect Indexes

Zoomed Transect ID	Simpson Index	Shannon index
12	0.8288	2.44
23	0.8115	2.54
27	0.8040	2.34
45	0.9036	2.95
58	0.9334	3.21
66	0.8636	2.63
72	0.8964	2.83
79	0.9190	3.17
81	0.9150	3.08
90	0.8650	2.46
121	0.8889	2.99
133	0.7843	2.34
137	0.9110	3.21
143	0.8633	2.66
149	0.8591	2.61
156	0.7315	1.89
163	0.5622	1.42
171	0.7792	2.14
183	0.8777	2.75
185	0.8618	2.74
Average	0.8657	2.73

Table 1: Simpson and Shannon indices of both transect types with included averages.

The habitat groups produced by the Anosim based on the transect dendrograms (Fig. 4) are visualized in two-dimensions within the PCAs (Fig. 5). These groups can reasonably be used to describe distinct faunal communities on the ridge. The taxas of influence described in the Anosim are present in the PCAs, influencing the same groups as they were in the dendrograms, However, there are exceptions with wide transect group red which was mostly influenced by the tunicate cnemidocarpa in the dendrograms but shown near Actiniaria sp. 6 in the PCAs. Wide transect group blue was shown to be influenced by Chionoecetes tanneri (tanner crab) in both plots, but the sponge Heterochone *calyx* was also present grouped near blue in the PCA. The species *Asbestopluma monticola* was influential both within the wide transect cyan and the zoomed transect yellow.



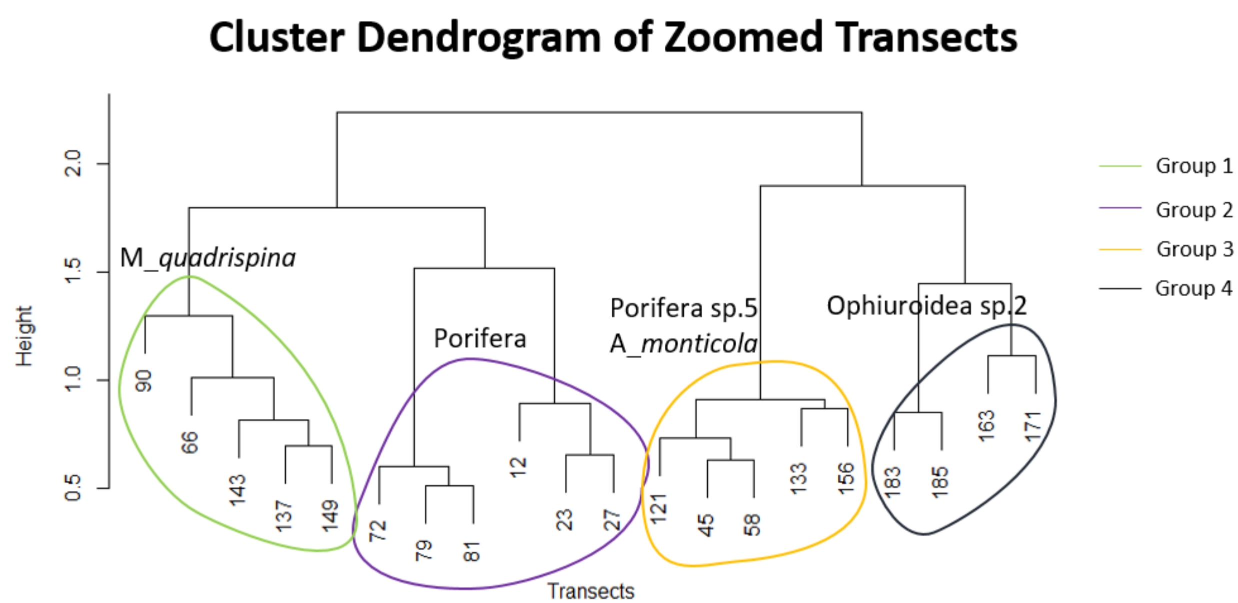


Figure 4: Dendrograms of faunal similarity for both transect types. The taxa of influence associated with each group are placed above their color-coded circles.

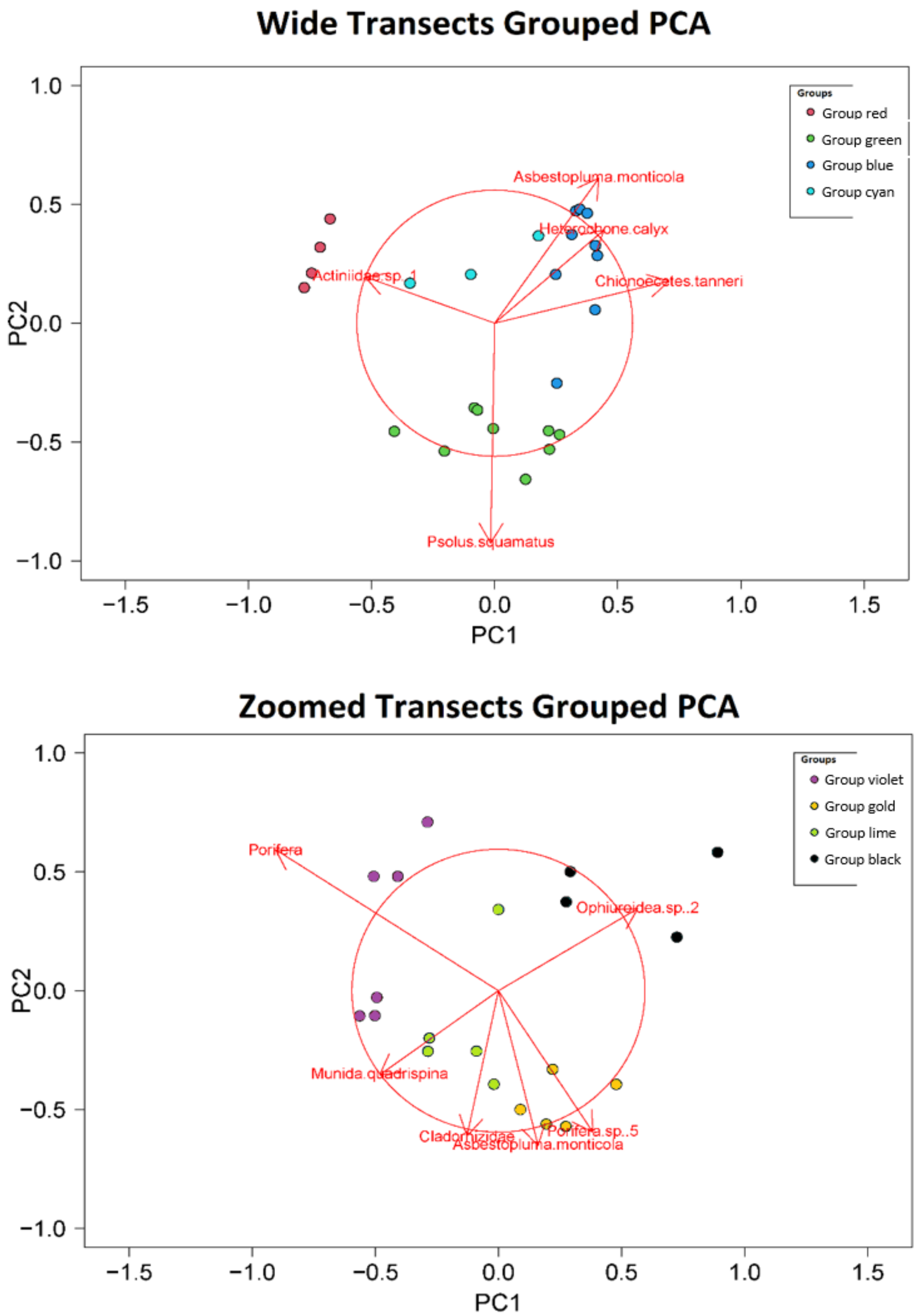


Figure 5: Plot of principle component analysis for the groups of both transect types. The color codes used here are the same as those used in the dendrograms. Proximity of dots to arrows indicates the taxa (arrows) that contribute the most to the difference between transect groups (each dot represents a transect). The length of each arrow is correlated to the strength the species contribution to the variance in the data.

The topographical average preferences of each sponge and coral taxa (Figs 6 and 7) suggest some significantly different species. The ANOVA tests performed on the sponge and coral taxa returned p-values that were less than the alpha of 0.05 for every variable, meaning that each there was at least one sponge and one coral that were significantly different from the others in figures 6 and 7.

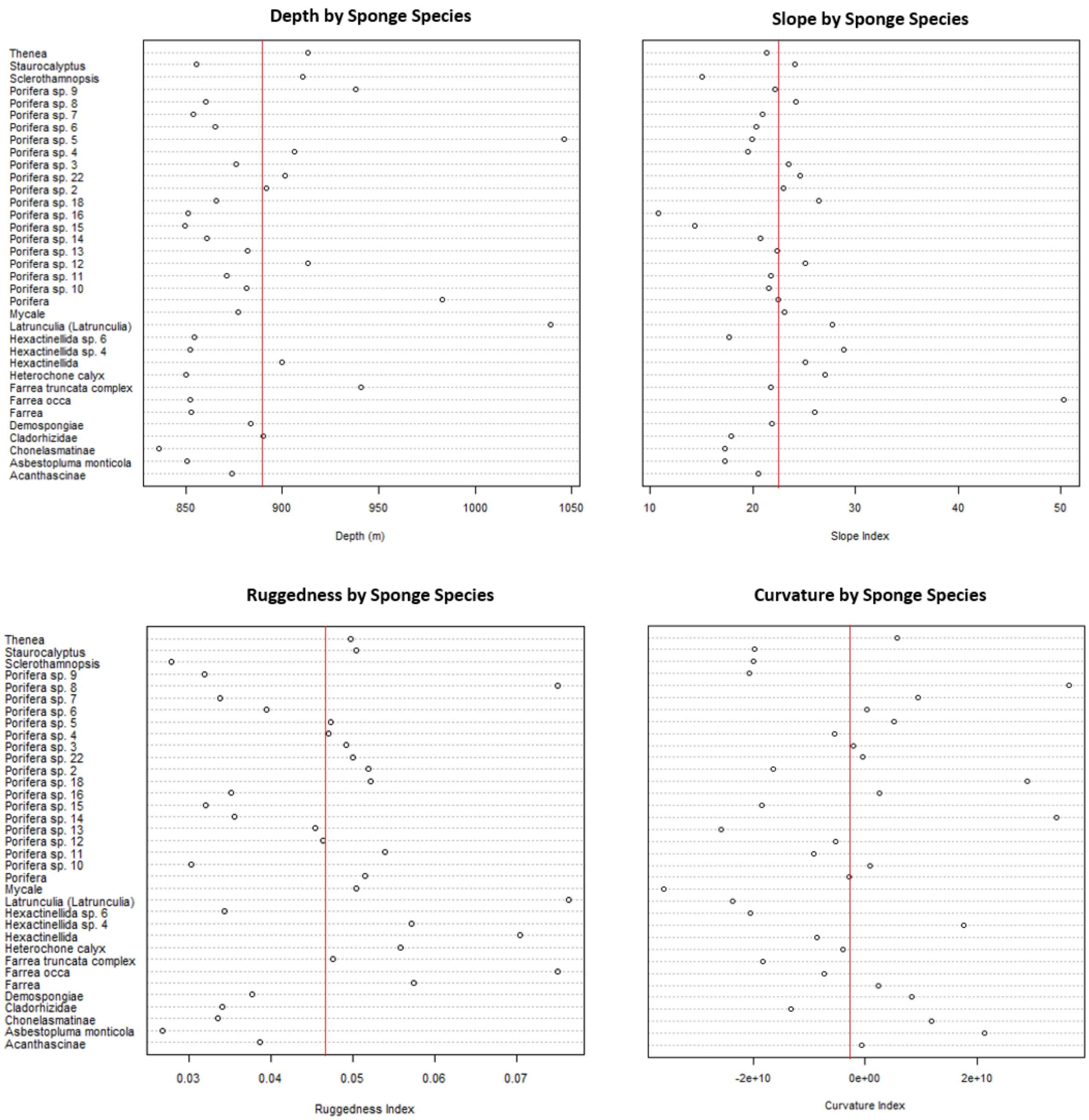


Figure 6: Dot Charts of benthic terrain variable averages for the identified sponge taxa of Sur Ridge. Each sponge average is represented by a dot. The red lines represent the average value of the variable for all sponge taxa.

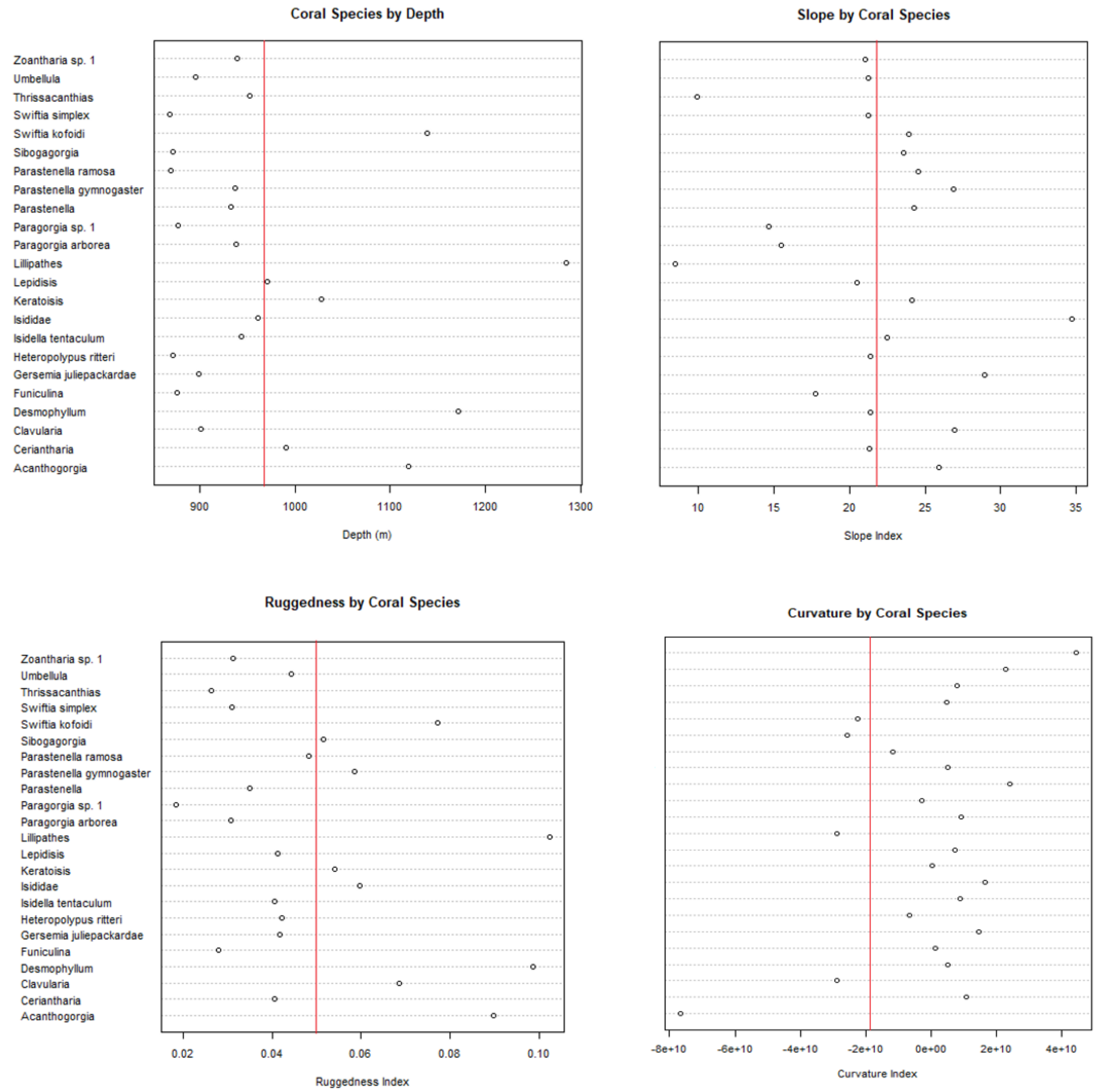


Figure 7: Dot Charts of benthic terrain variable averages for the identified coral taxa of Sur Ridge. Each coral average is represented by a dot. The red lines represent the average value of the variable for all coral taxa.

The transect terrain variable averages display a relatively even sample of all variable ranges (Fig 8).

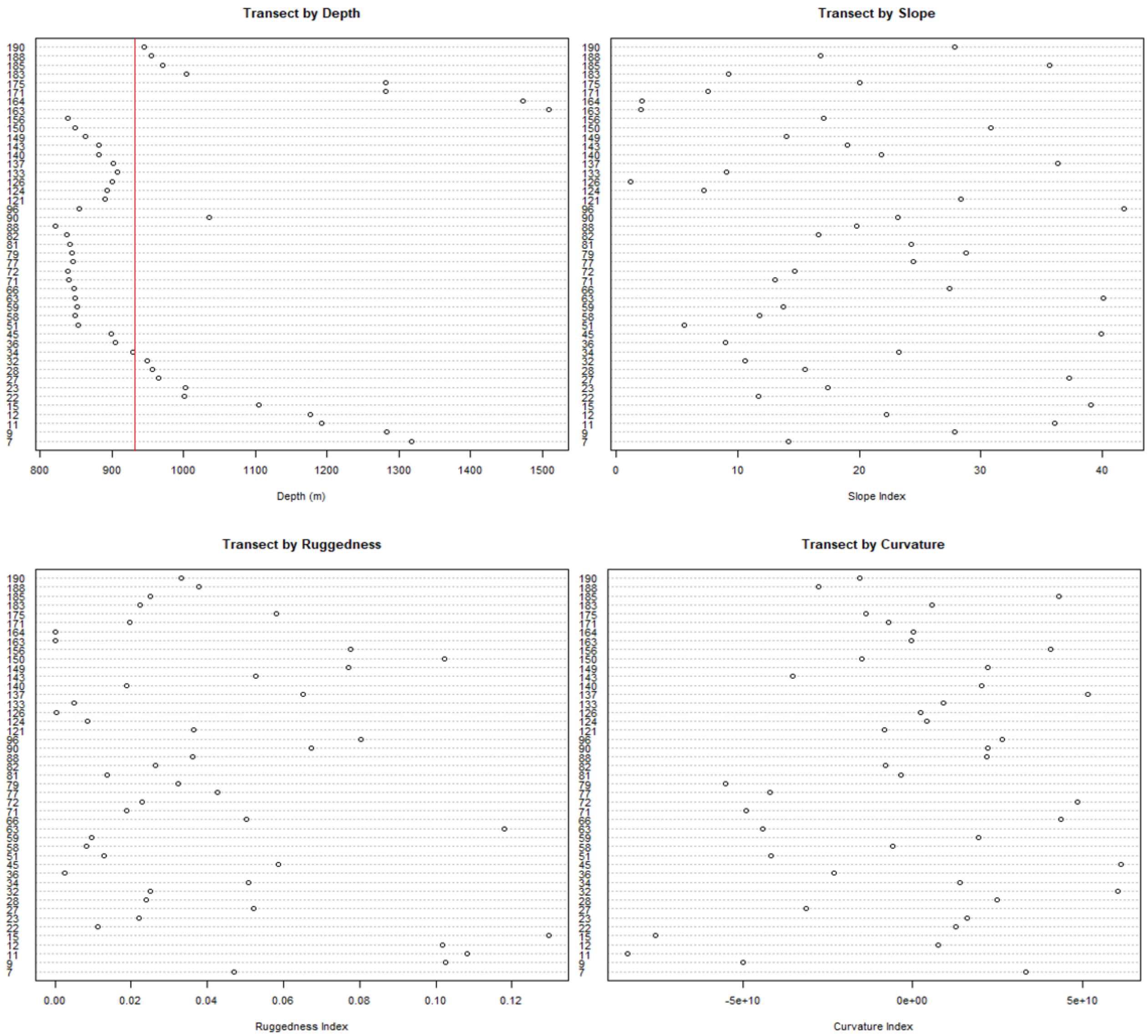


Figure 8: Dot Charts of benthic terrain variable averages for each transect on Sur Ridge. Here the wide and zoomed-in transect data was combined. Each transect average is represented by a dot. The red line represents the transect depth average.

II. MOSAIC DATA

The topographical preferences of each North Flat taxa (Fig. 9) suggest some significantly different species. The ANOVA tests performed on these data indicated that at least one species in each variable was significantly different from the others.

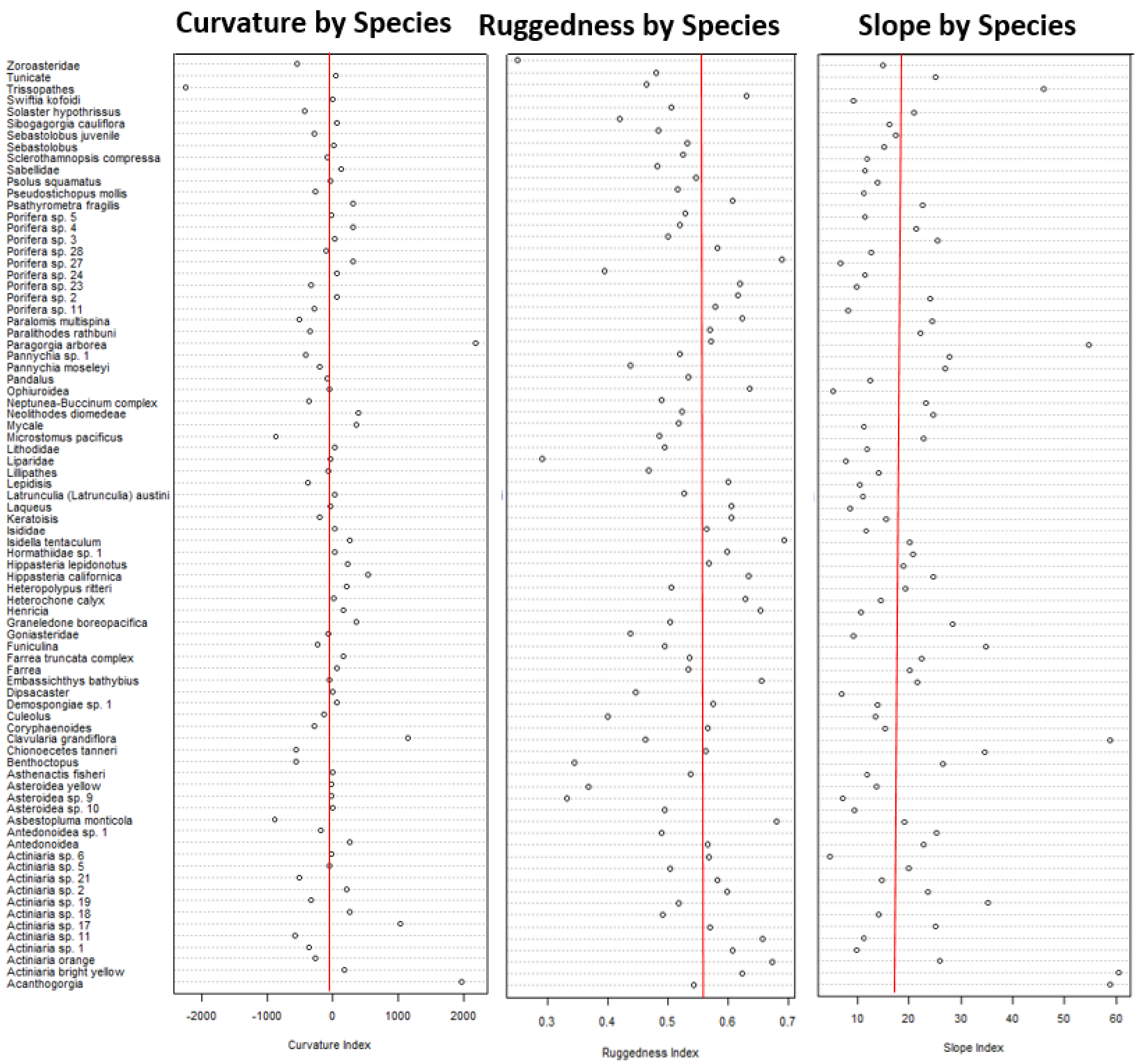


Figure 9: Dots charts of the variable averages for the identified taxa of the North Flat.

The grid terrain variable averages display a general and accurate description of the North Flat.

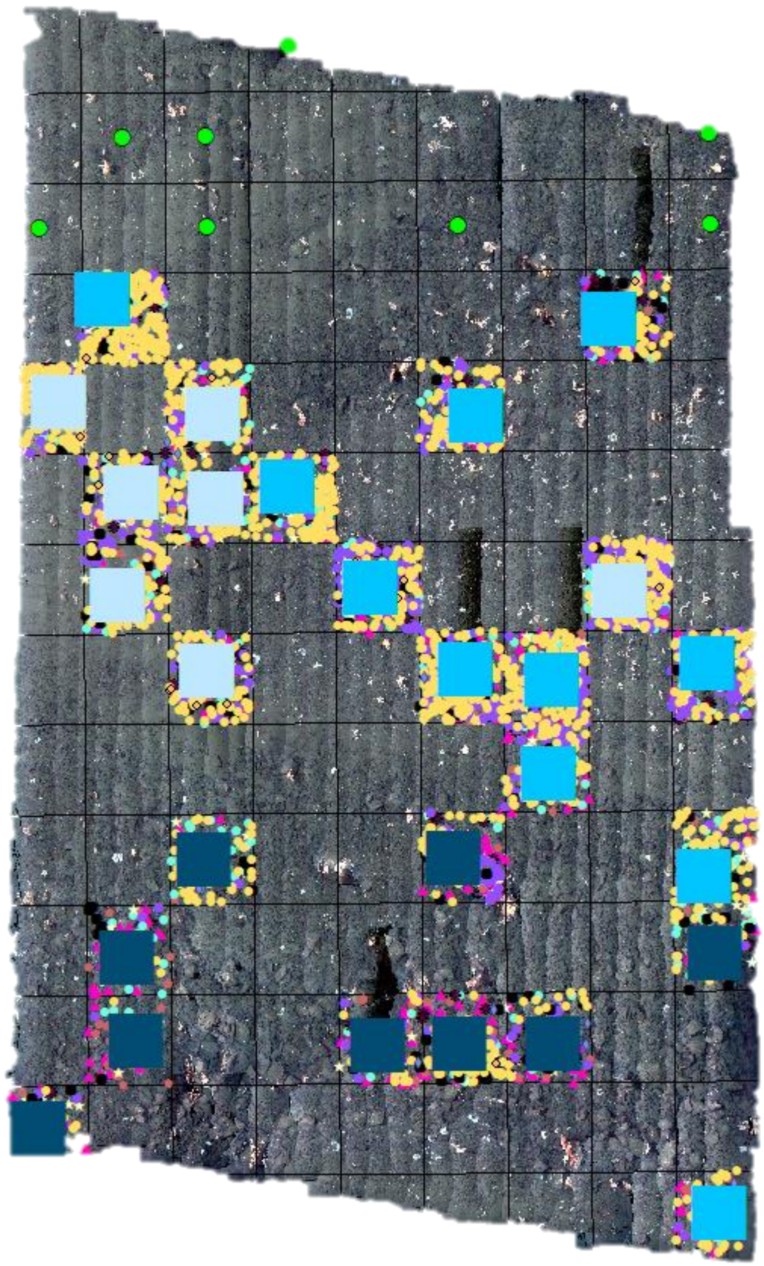


Figure 10: Image Mosaic of the North Flat with color-coded broad topographical habitats. The dark blue ("tall rocks" habitat) indicates the presence of large boulders and complex topography, the medium blue ("rubble" habitat) indicates a rugged benthos of smaller rocks, and the light blue ("mud flat" habitat) indicates a mostly silt benthos.

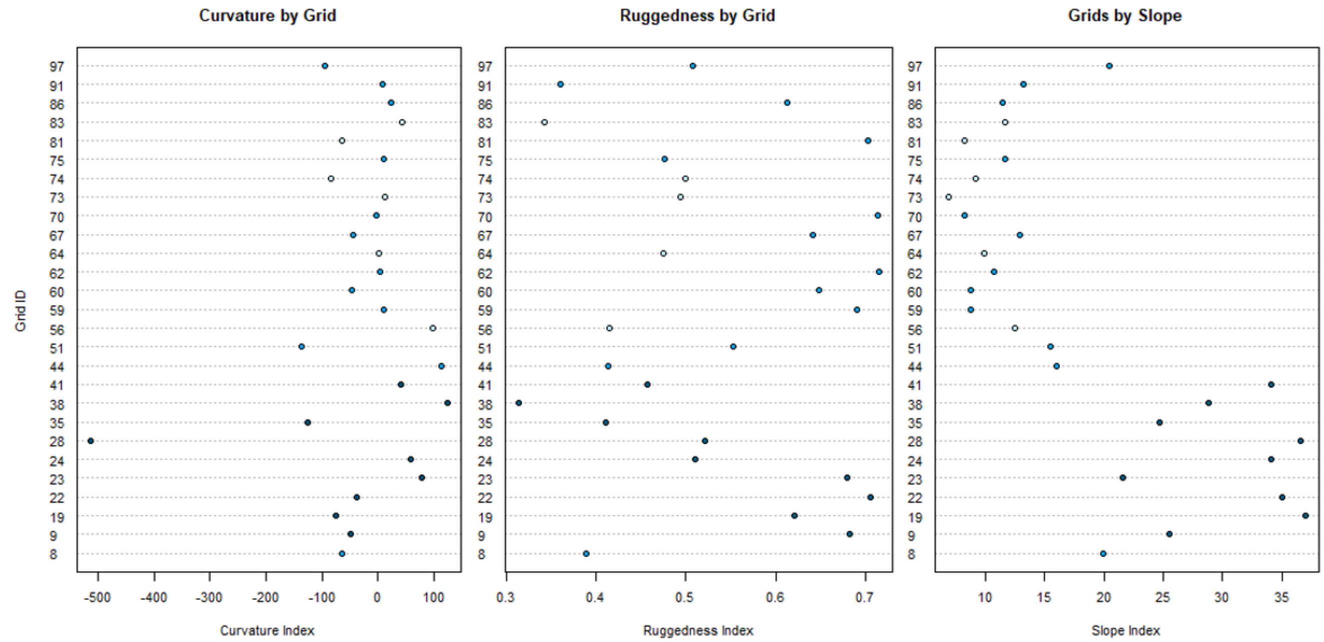


Figure 11: Figure 8: Dot Charts of benthic terrain variable averages for each grid of the North Flat.

DISCUSSION

The ecological make-up of Sur Ridge is relatively uniformly diverse, though more samples may reveal more species and wider array of potential habitats. Both the wide and zoomed transect types produced similar diversity and sampling data, indicating that they are equally sufficient measures of diversity on Sur Ridge.

These data can be used in conjunction to describe the geomorphological preferences of Sur Ridge species and further assessment could help define the ecological role of these taxa within precisely-defined faunal communities. Exemplarily, post-hoc assessment of the video transect data shows that the *Lillipathes*, S. *kofoidi*, *Acanthagorgia*, and *Desmophyllum* taxa are significantly different from most of the other corals in both depth and ruggedness, indicating that these taxa prefer significantly deeper and more rugged geomorphology than other species. This may suggest the possibility that these corals are foundation species in the areas of Sur Ridge with these parameters. Assessing this with the transect averages, transect 9 sits at an average depth of 1300m and a ruggedness value of about 0.10, both of which are similar to the Lillipathes' averages. In fact, this transect is where most of the Lillipathes corals were identified. This location is to the north of Sur Ridge in the deeper slope near the North Flat. This is corroborated on the image mosaic of the North Flat, where the Lillipathes was relatively abundant.

Among the sponges, A. *monticola* was influential for two faunal community groups (cyan and yellow), though its averages in each of the benthic terrain variables were not significantly different from most other sponges. This may indicate that it acts as a metropolitan foundation species, as it prefers the typical geomorphology of Sur Ridge and has influence over both smaller and larger organismal faunal groups. Porifera sp. 5 (the designation given to a small encrusting sponge taxa) is influential over faunal group yellow, but its average depth is significantly deeper than most other sponges. It was not significantly different in its ruggedness, curvature, or slope. This may indicate that it is foundational or influential in faunal communities where A. *monticola* is not, perhaps representing its deeper counterpart.

These differences along depth and the variances between the bulk of faunal communities on Sur Ridge's peaks from its deeper flats may indicate that there is a strong influence of depth over faunal structure. These descriptions of ridge-wide communities were made with $20m^2$ estimations, so the distinctiveness of these faunal communities is less certain, for greater detail we turned to the analysis of the image mosaic data.

Among the species whose topographical averages were recorded on the North Flat, the Paragorgia *arborea* proved significantly greater in curvature and slope. This quantifies the species' preference for tall rocks and distinctive convex edges from which to gain the best flow-rate for its polyps. The Sebastolobus taxa (thornyhead rockfish) saw little difference between the distribution of its adult and juvenile forms. This taxa was also not significantly different from the bulk of the species data, suggesting its role as a metropolitan organism.

The mosaic image data gives a highly-detailed general description of Sur Ridge's North Flat and provides more certainty in its averages. The differences in distributions of the species provide evidence that there are distinct "microhabitats" even within an area of 100x100m. The "tall rocks" habitat had high associations with large-bodied corals and anemones and it differed from the "rubble" and "mud flat" habitats' associations with small encrusting sponges. The Paragorgia *arborea* was more abundant in the "tall rocks" habitat, suggesting that it might prefer this microhabitat or that this microhabitat is can be characterized by Paragorgia.

CONCLUSIONS AND RECOMMENDATIONS

Our observations of Sur Ridge suggest that there are distinct habitats and or faunal communities within the area of Sur Ridge that can be seen distinctly even within a 100 by 100 meter area, and that certain foundation species (like the Paragorgia *arborea*) have significantly different geomorphological preferences. This knowledge comprises a baseline for describing the faunal distribution of Sur Ridge. Further and wider-ranging sampling at Sur Ridge could elaborate on a more complete understanding of this baseline and could provide a distinct categorization of these potential faunal communities within space and depth. The influence of depth on faunal community could be further explored with multiple mosaics completed along one of Sur Ridge's slopes and assessed for change in community structure. This would provide a better evaluation of if the communities are more influenced by depth or latitude change.

Greater utilization and more wide-spread creation of high-resolution mosaics could also provide greater insight into the distinctiveness of these Sur Ridge faunal communities. At a selection of depths and areas across the ridge, potential mosaics could further detail the community structures of each transect group and lead to habitat categorization. The knowledge of the location and characteristics of distinct habitats across multiple seamounts in the region including Davidson Seamount could support conservation within the Monterey Bay National Marine Sanctuary and facilitate the placement of "no-take" or other MPAs over benthic habitats with favorable conditions for foundation species like the P. *arborea.*

It is worth mentioning that though the taxa "Porifera" was influential for transect group violet, the near 1200 organisms labeled "Porifera" were not given morphological or numerical designations allowing them to be distinguished from the approximately 30 other porifera designations identified across Sur Ridge. This is a potential cause of uncertainty within the data and future research should ensure that taxa are designated as specifically as possible. Finally, the discrepancies in species present in the Anosim assessment and PCA plots could be due to the convention used to denote the circle size on the PCA, but further assessment could be warranted.

Increased efforts in the sampling of seamounts for conservation purposes is highly recommended.

ACKNOWLEDGEMENTS

This research was enabled and facilitated by the dedicated work of my mentors, Dr. Fanny Girard and Dr. Jim Barry. Without the unwavering support of Dr. George Matsumoto, Megan Bassett, and Lyndsey Claassen, this internship opportunity would have been impossible. I give my thanks to the entirety of the Barry Lab for welcoming me into their space and resources, and for the opportunity to be a part of a world-renowned scientific team. It is vital to acknowledge the work done by the steadfast crew of the *Western Flyer* and the pilots of the Doc Ricketts for helping to create the thousands of hours of MBARI video logs and who have braved the volatile conditions of the COVID-19 pandemic. I want to highlight also the major contribution of MBARI's video lab and its annotators, namely Larissa Lemon and Linda Kunz, whose thousands of hand-made observations made this project feasible. Finally, the MBARI Summer Internship Program was generously supported through a gift from the Dean and Helen Witter Family Fund and the Rentschler Family Fund in memory of former MBARI board member Frank Roberts (1920-2019) and by the David and Lucile Packard Foundation as well as additional funding provided by the Maxwell/Hanrahan Foundation.

References

Ahnert, A., & C. Borowski. (2000). Environmental risk assessment of anthropogenic activity in the deep-sea. *Journal of Aquatic Ecosystem Stress and Recovery,* 7:299–315. doi:10.1023/A:1009963912171

Bradley, D., Conklin, E., Papastamatiou, Y., McCauley, D., Pollock, K., Pollock, A., Kendall, B., Gaines, S., & J. Caselle. (2017). Resetting predator baselines in coral reef ecosystems. *Scientific Reports* 7, 43131. doi:10.1038/srep43131

DeVries, T. (2022). The Ocean Carbon Cycle. *The Annual Review of Environment and Resources*, 47:15.1–15.25. doi:10.1146/annurev-environ-120920-111307

McClain, C., & J. Barry. (2010). Habitat heterogeneity, disturbance, and productivity work in concert to regulate biodiversity in deep submarine canyons. *Ecology*, 91(4):964-976.

McClain, C., Lundsten, L., Barry, J., & A. DeVogelaere. (2010). Assemblage structure, but not diversity or density, change with depth on a northeast Pacific seamount. *Marine Ecology*, 31:14-25. doi:10.1111/j.1439-0485.2010.00367.x

McClain, C., Lundsten, L., Ream, M., Barry, J., & A. DeVogelaere. (2009). Endemicity, Biogeography, Composition, and Community Structure on a Northeast Pacific Seamount. *PLoS ONE*, 4(1): e4141. doi:10.1371/journal.pone.0004141

Morato, T., et al. (2020). Climate-induced changes in the suitable habitat of cold-water corals and commercially important deep-sea fishes in the North Atlantic. *Global Change Biology*, 26(4):2181-2202. doi:10.1111/gcb.14996