The Biogeography and Distribution of Megafauna
at Three California Seamounts

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Abstract

Video recordings from Remotely Operated Vehicle (ROV) dives are used to describe the biogeography and distribution of megafauna communities found at three seamounts off central and southern California, USA. In total, 27 ROV dives were annotated in detail using the Monterey Bay Aquarium Research Institute's (MBARI) Video Annotation Reference System (VARS). Video analysis yielded 136,716 biological observations. In all, 236 megafauna taxa are described from observations at these seamounts. Seamount bathymetry was analyzed to relate the observed faunal distribution to seamount slope, aspect, and bathymetric position index. Video transects, collected at Davidson Seamount in 2006 and at Pioneer Seamount in 2007, were analyzed to quantify species' densities. Thirteen new species including sponges, corals, and echinoderms were observed and collected as part of this research; most of these are being or have been described by taxonomists. This study shows there is little or no endemism among invertebrate megafauna and demersal fishes identified at these seamounts. Results also indicate that many seamount organisms have specific depth distributions, and because of this, the depth of the seamount influences community composition. Additionally, proximity to the continental slope and seamount shape are important in determining community structure and organism distribution.

Introduction

Seamounts are defined as undersea features that rise from the seafloor without breaking the sea surface and have vertical elevations of 1,000 meters or more (Rogers, 1994). They are typically of volcanic origin, conical in shape with circular, elliptical, or elongate bases. Flat topped seamounts are called guyots. Estimates for the global number of seamounts vary widely from 9,000 - 100,000; most of these remain uncharted (Sandwell et al., 2006; Wessel 1997, 2001).

Seamounts often extend over large depth intervals and contain heterogeneous habitats encompassing hard rock to soft sediments (Boehlert and Genin, 1987). Seamount communities are often dominated by long-lived corals and sponges and many also support commercially important species such as precious corals and seamount-aggregating fishes (Grigg, 2002; Koslow et al., 2001; McClatchie and Coombs, 2005; Mortensen and Buhl-Mortensen, 2005; Risk et al., 2002; Richer de Forges et al., 2000; Rowden, et al., 2004). The distribution, diversity, and abundance of these organisms appear to be related to several factors, including local hydrographic conditions, proximity to sources of larvae, geographic location, and seamount topography (Boehlert and Genin, 1987; Grigg et al., 1987; Wilson and Kaufmann, 1987). High biomass and increased diversity and abundance has also been attributed to enhanced productivity due to the formation of Taylor columns (Richer de Forges, et al., 2000; Rogers, 1994), entrapment of migrating zooplankton (Genin et al., 1988), and elevated current velocities (Rogers, 1994; White and Mohn, 2004).

Seamount-current interaction can create flow complexity which depends upon current speed, stratification, latitude, and seamount morphology and may produce effects such as internal wave generation, eddy formation, local upwelling, Taylor Columns, and increased current velocities, with varying degrees of intensity (Boehlert and Genin, 1987). These effects can enhance surface productivity through upwelling and may act to retain both locally produced or advected water masses which are rich in nutrients. The vertical extent and residence time of seamount-induced upwelling determines the magnitude of its effect on local biology; a residence time on the order of days would affect primary production, several weeks would increase the growth and abundance of zooplankton. A residence time of months would be needed to affect micronekton. Elevated current velocities tend to increase animal density due to "feeding pathways" and "settlement pathways," whereby more food and more larvae flow past a given area with increased current speed (Genin et al., 1986). Additionally, the alteration of hydrographic conditions by seamounts may favor organisms that have either direct developing or short duration planktonic larvae, which can become entrained in circulation cells caused by Taylor columns (Parker and Tunnicliffe, 1994; Mullineaux and Mills, 1997).

Many seamount faunas have also been shown to have high rates of endemism with biogeographic patterns analogous to land-based island faunas (Rogers, 1994; Richer de Forges, et al., 2000; Wilson and Kaufmann, 1987). Wilson and Kaufman's (1987) global estimate on seamount endemic species was 15.4% for invertebrates and 11.6% for fishes, although they stated that most

estimates of endemism reported in the literature appear to be too high because of poorly understood species distribution and because many species first reported at seamounts have been described elsewhere since initial descriptions. A recent study by O' Hara (2007) and editorial by McClain (2007) support this claim.

Research on seamount biology in general is sparse, haphazard, and often under-represents many taxonomic groups because of the limited knowledge of the specialists conducting the research (Wilson and Kaufmann, 1987). Some groups, like the Ophiuroidea and Crinoidea, are often overlooked or noted only as present or absent (Wilson and Kaufmann, 1987).

Among seamount invertebrate phyla globally, the Cnidaria, Mollusca, and Arthropoda are most widely distributed, although arthropods appear to be most abundant. Of seamount fishes globally, macrourids, scorpaenids, morids, squalids, alepocephalids, and serranids are most diverse, while scorpaenids, morids, serranids, macrourids, and squalids are most abundant (Wilson and Kaufmann, 1987).

Wilson and Kaufmann (1987) found that the fauna on shallow seamounts are represented by equal percentages of provincial and cosmopolitan species, while deep seamount faunas are dominated by cosmopolitan species. In general, provincial species decrease with depth relative to cosmopolitan species. Latitude and distance from shore also influence the balance between provincial and cosmopolitan species; seamounts at higher latitudes and seamounts closer to a continental shelf will have more provincial species (Wilson and Kaufmann, 1987).

Wilson and Kaufman (1987) proposed two models of dispersal for seamount faunas: 1) fauna of subsiding islands or seamounts are successively transfered in whole or in part to nearby younger islands or seamounts crossing ocean basins on island stepping-stones over millions of years and 2) islands and seamounts serve as way stations for expanding populations allowing organisms to expand across ocean basins in small steps at time scales of tens to hundreds of generations.

At Cross Seamount in the Western Hawaiian Seamount Chain, Grigg et al. (1987) reported 3,124 organisms representing 61 species with an average density of 0.14 individuals m^{-2}, although communities were patchy and dense aggregations of 5 individuals m^{-2} were found on the summit. A pattern of vertical zonation was described at Cross Seamount with 81% of the organisms occurring shallower than 500 m, 15% between 500 and 1,500 m, and only 4% below 1,500 m. Thirteen species of coral were found at Cross Seamount and coral densities were greatest on shallow southwest, west, and north rims and on dikes and other prominences at deeper depths. Similarly, Genin et al. (1986) found higher densities of organisms on the crest of peaks and, when peaks were flat-topped, higher densities were found near the rim.

Little work has been done that describes or compares deep seamount communities within the same region (Richer de Forges et al., 2000; Rowden, et al., 2002) and few studies describe biological communities found at the seamounts examined here (DeVogelaere et al., 2005; Kogan et al., 2006).

The seamounts described by this study, Davidson, Pioneer, and Rodriguez (Fig. 1), are 9 - 16 million years old, have similar volcanic origins, and are located atop older oceanic crust formed 19-20 million years before present (MYBP) (Davis et al., 2002). Davidson Seamount is bounded by a magnetic anomaly to the north-west and south-east and it's north-east-to-south-west orientation is parallel to these anomalies and it, therefore, has been interpreted to sit astride an abandoned spreading center (Clague, pers. com.). Because Pioneer and Rodriguez Seamounts have the same orientation, it is inferred that they formed under similar conditions although magnetic anomaly mapping does not show symmetric anomalies as at Davidson Seamount. Though formed under similar conditions, the topography, size, and depth of these seamounts differs from each other (Table 1). Davidson and Pioneer Seamounts have peaked summits with cones arranged along parallel ridges with sediment filled troughs between them and they are located ~90 and ~80 km, respectively, from the shore at the base of the continental slope. Rodriguez Seamount is located 250 km to the south of Davidson Seamount midway upon the continental slope, approximately ~60 km from shore and it was subaerially exposed approximately 10 MYBP. Rodriguez Seamount is flat-topped (a guyot) with rugged flanks and extensive flat regions encrusted with pavements and a thin sediment veneer. Each seamount encompasses a variety of habitats including volcanic lavas, talus slopes, and sediment ponds.

In many regions of the world seamount-aggregating fisheries have collapsed and, in locations where deep-water trawls have been used, benthic

invertebrate communities have been decimated (Fosså et al, 2002; Fry et al., 2006; Koslow et al., 2001). Koslow et al. (2001) described depleted biomass and species richness when comparing heavily fished to unfished seamounts off southern Tasmania, with 106% greater biomass and 46% more species per sample at unfished seamounts. The seamounts examined in this study appear to be relatively pristine, particularly Davidson Seamount, where the benthos appears to be undisturbed (DeVogelaere et al., 2005).

Methods

Seamount communities were observed using MBARI's ROV *Tiburon* and were recorded using high-resolution video equipment. To determine seamount community composition, a total of 191 hours of Digital Betacam video representing 27 dives on Davidson, Pioneer, and Rodriguez seamounts off the coast of California, USA, was annotated in detail using MBARI's Video Annotation and Reference System (VARS) (Schlining and Jacobsen-Stout, 2006).

Video data were collected from various depths at each seamount. Davidson Seamount was sampled from its summit at 1,246 m to a depth of 3,289 m (90% of depth range sampled) (Table. 1). Pioneer Seamount was sampled from its summit at 811 m to a depth of 1,815 m (66% of depth range sampled). Rodriguez Seamount was sampled from its summit at 619 m to a depth of 2,120 m (91% of depth range sampled).

All benthic and demersal megafauna were identified to the lowest possible taxon. Organisms were identified using *in situ* video frame grabs and digital still

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images of voucher specimens that were identified by taxonomists. When possible, voucher specimens were collected using the ROV manipulator, ROV suction sampler, or in some cases, were removed from rock samples collected for other research objectives. Voucher specimens were not collected for organisms that could be easily identified in video and were known from the California shelf and Monterey Canyon. When voucher specimens were not collected and the animal was not known by the video analyst, video frame grabs, digital still images, and/or video segments were reviewed by taxonomists with expertise in the taxonomic group of the organism in question. The resulting identification was then used as a reference during the detailed video analysis.

Species accumulation curves were plotted for dominant taxa in an effort to determine if they were adequately sampled by the qualitative video analysis. These smoothed species accumulation curves were plotted for each seamount based on 1 km bins of the total distance traversed by the ROV and species presence/absence data within those bins. They were calculated analytically using EstimateS Version 8.0 (Colwell, 2005).

Quantitative video transects, collected at Davidson Seamount in 2006 and Pioneer Seamount in 2007, were used to estimate organism density. In all, 40 transects were analyzed (Davidson 33, Pioneer 7) (Table 2). Two 640 nm red lasers placed 29 cm apart were used to estimate transect width. Transect length was calculated in ArcView® 3.2 using the Animal Movement Analysis Extension, Version 2, which was used to calculate successive distance between transect start and end points (Hooge and Eichenlaub, 1997). Linear regression was used

to determine if there was a relationship between mean transect depth and organism density.

Categories of feeding method and motility were assigned to all animal observations and analyzed to determine the functional roles of dominant members of the seamount communities. While feeding method for many of the organisms identified in this study are not known for certain, morphological similarity to shallow water organisms were used to infer feeding methods to the taxa identified in the video analysis. These categories included passive suspension feeding (corals, crinoids, brisingids), filter feeding (sponges and tunicates), deposit feeding (echinoids and holothurians) and carnivory (primarily asteroids and fishes) (Brusca and Brusca, 1990; Gage and Tyler, 1991). The categories used for organism motility included sessile (corals, sponges, stalked crinoids, tunicates), functionally sessile (brisingids and crinoids), and mobile (asteroids, echinoids, fishes, and holothurians) (Brusca and Brusca, 1990; Gage and Tyler, 1991). The group of cnidarians referred to as "corals" in this study includes alcyonaceans, gorgonians, pennatulaceans, scleractinians, and antipatharians as defined in Deep-Sea Coral Collection Protocols (Etnoyer et al., 2006).

Geographic Information System (GIS) was used in conjunction with video analysis to determine how seamount bathymetry influenced seamount organism distribution. Each video observation was merged with ancillary data (geographic position, depth, temperature, and oxygen concentration) within VARS. These data were then imported into ArcGIS® 9.1 and mapped with high-resolution

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bathymetric data. Thirty-meter bathymetric grids were analyzed using ArcGIS's

Spatial Analyst extension to calculate seamount slope and aspect. NOAA's

ArcGIS extension, the Benthic Terrain Modeler (BTM), was used to calculate

Bathymetric Position Index (BPI) for each observation (Rinehart et al., 2004). BPI

is a measure of the elevation of a referenced cell relative to a neighborhood of

cells surrounding it. For this analysis, a scale factor of 90 meters was used.

Positive values indicate areas of elevated relief. Negative values indicate areas

of low relief. Using these methods, we identified areas considered to be a peak,

valley, or uniform relative to the neighboring terrain (DeVogelaere et al., 2005).

Raster layers were created and used to extract bathymetric properties for each

organism observation.

Electivity indices were used to asses habitat utilization by dominant

invertebrate groups (corals, sponges, echinoderms) and fishes. Electivity are

used determine whether organisms are utilizing habitat at a higher or low rate

than than expected based on ratio of habititat utilization to habitat availability.

Vanderploeg and Scavia's electivity indices (E*) were calculated for 8 aspect

categories, 3 BPI categories, and 3 slope categories using the following

equation:

$E* = [W_i - (1/n)]/[W_i + (1/n)]$, where n= the number of resource types

(substratum categories), $W_i = (r_i/p_i)/\sum(r_i/p_i)$, r = the proportion of resource utilized

(frequency of taxa observed in each category), and p= the proportion of

resources available (frequency of all observations in each category) (Eagle et al.,

2001; Lechowicz, 1982). The resulting electivity indices for corals, echinoderms,

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sponges, and fishes from each seamount were averaged and standard error was calculated and plotted for each habitat parameter. Single-factor analysis of variance (ANOVA) was used to compare the electivity values for each taxonomic group in each habitat category (aspect, slope, and BPI) in order to determine the significance of electivity.

Bray-Curtis coefficients were calculated to assess the faunal similarity between seamount communities using standardized and fourth-root transformed taxa abundance data from each seamount using Primer, V6 (Clark and Gorley, 2001).

Results

The video analysis resulted in 136,716 observations of 236 taxa at the three seamounts examined. At Davidson Seamount, 60,374 benthic invertebrates and demersal fishes were identified representing 168 taxa. At Pioneer Seamount 37,153 organisms representing 125 taxa were identified. At Rodriguez Seamount 39,187 observations representing 156 species of benthic invertebrates and demersal fishes were identified. In all, 225 specimens were collected and sent to taxonomists for identification; 13 of these are new to science and are currently being described by taxonomists (Cairns, in press; Reiswig and Lee, in press).

The percentage of biological observations occurring in ~500 m depth intervals varied at each of the seamounts examined. At Davidson Seamount, nearly 60% of the biological observations occurred from the seamount summit (1,246 m) to a depth of 1,789 m; 11.3% occurred between 1,789 and 2,289 m; 19.3% occurred between 2,289 and 2,789 m; 9.9% occurred from 2,789 to 3,289

m. Pioneer Seamount had a more restricted depth zonation where 93.8% of the biological observations occurred between the seamount summit at 810 m to a depth of 1,310 m; 6.1% of the observations occurred between 1,310 and 1,810 m. At Rodriguez Seamount, 64.7% of the biological observations occurred from the seamount summit at 618 m to a depth of 1,118 m; 17.9% occurred between 1,118 m and 1,618 m; 17.4% occurred from 1,618 m to 2,118 m.

Smoothed accumulated species curves (Fig. 2) show that corals, sponges, echinoderms, and fishes have been characterized adequately by the video analysis. Because the curves rise steeply, they indicate that the communities sampled had patchy distributions.

Quantitative video transects, which were collected at Davidson and Pioneer Seamounts only, differed in mean organism density. Thirty-three video transects were collected at Davidson Seamount. The depths at which transects were collected ranged from 1,298 m to 3,276 m (Table 2). These video transects varied in length (45 - 445 m) and width (0.97 - 6.78 m). Organism density averaged 0.87 individuals m^{-2} (std error 0.103, range of 0.1 - 2.2 individuals m^{-2}) (Figs. 3 & 4). Seven video transects were collected at Pioneer Seamount. Transects were collected from depths that ranged from 844 to 1,240 m. Transect length (66.8 - 261.6 m) and width (1.57 - 2.62 m) varied. Organism density averaged 2.2 individuals m^{-2} (std error 0.28, range 1.1 - 3.2 individuals m^{-2}). Linear regression of mean transect depth vs. organism density showed that there was no relationship between depth and density.

Qualitative video observations revealed that at all three seamounts the dominant invertebrate phyla encountered were the same, although the frequency at which these phyla were observed varied. Cnidarians were the most frequently observed phylum at Davidson (33.9%) and Pioneer Seamounts (39%) but they were less frequently observed at Rodriguez Seamount (34.6%) than the Echinodermata (Fig. 5). Echinoderms were also observed frequently and accounted for 32.1%, 33.8%, and 44.2% of the observations at Davidson, Pioneer, and Rodriguez Seamounts. Sponges were observed more frequently at Davidson Seamount (29.3%) than at Pioneer (19.8%) or Rodriguez (14.3%) Seamounts. Fishes constituted a small percentage of the total observations at Davidson Seamount (0.73%) and were observed more frequently at Pioneer (1.9%) and Rodriguez (2.8%) Seamounts.

Analysis of categorized feeding methods showed that at all three seamounts suspension feeders were most frequently observed. At Davidson Seamount 58% of the organisms were suspension feeders, 29.6% were filter feeders, 8.46% were detritivores and 3.82% were carnivores (Fig 6). At Pioneer Seamount, most of the observed taxa were categorized as suspension (66.5%) and filter (19.2%) feeders. Detritivores (8.5%) and carnivores (5.8%) were observed less frequently. At Rodriguez Seamount, most organisms were suspension feeders (58.6%), followed by detritivores (18.9%), filter feeders (14.4%), and carnivores (8.1%).

Sessile and functionally sessile animals were most frequently observed at the three seamounts examined in this study. When combined, functionally sessile

and sessile organisms accounted for 88.1%, 85.7%, and 73.1% of the observations, respectively, at Davidson, Pioneer, and Rodriguez Seamounts (Fig. 6). Mobile organisms accounted for fewer of the observations at Davidson (11.9%) and Pioneer Seamounts (14.2%) when compared to Rodriguez Seamount (26.9%).

The Gorgonacea were the most abundant cnidarians at all three seamounts, accounting for 72.9%, 61.1%, 74.7% of observations at Davidson, Pioneer, and Rodriguez Seamounts. Antipatharians (22.8%), and alcyonaceans (3.8%) were also abundant at Davidson Seamount, where 25 coral species were identified. Abundant coral species identified there included *Trissopathes pseudotristicha* (18.32%), *Corralium* sp. (16.5%), *Keratoisis* sp. (15.85%), Primnoidae (12.8%), *Paragorgia arborea* (7.8%) *Parastenella* sp. (5.6%), *Anthomastus ritteri* (4.7%), and *Acanthogorgia* sp. (4.6%) (Fig. 7). At Pioneer Seamount gorgonian (61.1%) and alcyonacean (38.6%) corals dominated, accounting for ~99% of observations. In all, 23 species of coral were identified. The alcyonacean, *Anthomastus ritteri* (38.2%), was the most abundant coral and second most abundant organism observed. The gorgonian corals *Lepidisis* sp. (22.4%), *Isidella* sp. (9.6%), *Keratoisis* sp. (8.5%), *Acanthogorgia* sp. (7.4%), *Swiftia kofoidi* (4.8%), *Paragorgia* sp. (4.4%), *Swiftia simplex* (1.5%), and *Paragorgia arborea* (1%) were also observed. In addition to the Gorgonacea (74.7%), Alcyonaceans (19.6%) and pennatulaceans (5.5%) were also frequently observed at Rodriguez Seamount, where 26 species of coral were identified. Abundant species included *Anthomastus ritteri* (19.5%), *Isidella* sp. (16%),

Narella sp. (14.5%), *Parastenella* sp. (14.3%), *Acanthogorgia* sp. (12.8%),

Paragorgia sp. (6.75%), *Keratoisis* sp. (5.13%), *Anthoptilum grandiflorum* (3.3%)

and *Swiftia simplex* (2.1%).

Coral depth distributions varied at each seamount and clear patterns

were apparent when depth distributions and percent of observations were viewed

together at a higher level of taxonomy (e.g. Alcyonacea, Antipatharia,

Gorgonacea, Pennatulacea, and Scleractinia) (Fig.8). Alcyonaceans were

abundant at Pioneer (38.6%) and Rodriguez (19.6%) Seamounts and the mean

depth of observation was above 1,000 m at both locations. Alcyonaceans were

less frequently observed at Davidson Seamount (3.83%) and mean depth of

observation was ~2,000 m. Antipatharians were very abundant at Davidson

Seamount (22.8%) and had a mean depth of observation of ~2,125 m.

Antipathrians were infrequently observed at Pioneer (0.06%) and Rodriguez

(0.07%) Seamounts. The Gorgonacea were the most frequently observed corals

at all three seamounts and although the mean depth of observation varied.

Pennatulaceans were seen in low abundance at Davidson and Pioneer

Seamounts but accounted for 5.5% of coral observations at Rodriguez

Seamount, where the mean depth of observation was ~750 m. Scleractinians

were infrequently observed at all three seamounts, however those that did occur

were observed at deeper depth at Davidson Seamount (mean ~2,400 m) than at

Pioneer (mean 1,100 m) or Rodriguez (mean 1,300 m) Seamounts.

The sponge communities at each seamount were often composed of

different percentages of the same species, such as *Chonelasma* sp., *Farrea* sp.,

Heterochone sp., and *Staurocalyptus* sp (Fig. 9). Abundant sponge species identified at Davidson Seamount included *Farrea* sp. (22.5%), *Sclerothamnopsis* sp. (14.8%), and *Staurocalyptus* sp. (13.2%); other taxa that were seen less frequently included *Chonelasma* sp. (6.4%), Porifera sp. 10 (4%), Porifera sp. 3 (3.9%), *Aspestopluma* sp. 2 (3.1%), Porifera sp. 13 (2.3%), Poecilosclerida (2.1%), and *Heterochone* sp. (1.8%). At Pioneer Seamount the goiter sponge, *Heterochone* sp. (17.7%) was the most frequently observed species. *Thenea muricata* (16.1%), *Staurocalyptus* sp. (13.1%) *Farrea* sp. (11.4%), and *Chonelasma* sp. (9.7%) were also abundant. At Rodriguez Seamount, *Farrea* sp. (47.1%), *Chonelasma* sp. (6.5%), *Staurocalyptus* sp. (4.1%), *Thenea muricata* (3.2%), and *Heterochone* sp. (3.2%) were the most commonly observed species. Sponges which could not be identified in video, Porifera (21.2%) and Hexactinellida (10.3%), were also abundant.

The depth distribution of many sponges appeared to be related to the depth of the seamount summit with the depths of observations for taxa consistently deeper and of a larger interval at Davidson Seamount when compared to the shallower Pioneer and Rodriguez Seamounts (Fig. 10). At Davidson Seamount *Chonelasma* sp. (1,500 m – 1,750 m) was observed at deeper depths than at Pioneer (830 - 950 m) and Rodriguez (750 - 810 m) Seamounts. *Farrea* sp. was abundant near the peaks of Davidson and Pioneer Seamounts but was observed far deeper at Rodriguez Seamount. *Heterochone* sp. had a mean depth of observation of ~1,400 m at Davidson Seamount but had a similar, although shallower mean depth of occurrence of ~800 - 850.

Sclerothamnopsis was observed in deeper water at Davidson Seamount than at either Pioneer or Roriguez Seamounts, where it was observed less frequently. *Staurocalyptus* sp. constituted a similar percent of sponge observations at Davidson and Pioneer Seamounts but had a deeper mean depth of occurrence at Davdson Seamount than at Pioneer Seamount. At Rodriguez Seamount, this species had a mean depth of observation that was very similar to that found at Pioneer Seamounts, although it was not as frequently observed at Rodriguez Seamount. *Thenea muricata* was abundant between 1,090 - 1,230 m at Pioneer Seamount but was observed at much shallower depths at Rodriguez Seamount (675 - 825 m) and was absent at Davidson Seamount.

Echinoderm observations at Davidson and Pioneer Seamounts were dominated by the class crinoidea, but at Rodriguez Seamount holothurians were the dominant echinoderm class observed (Fig. 11). At Davidson Seamount, Crinoidea (44.6%), Ophiuroidea (28.7%), and Holothuroidea (16.1%) were the most abundant; Asteroidea (10.3%) and Echinoidea were observed less frequently (0.4%). The Crinoidea (61.5%) were the most abundant echinoderm class at Pioneer Seamount, followed by Holothuroidea (23.5%), Asteroidea (9.0%), Ophiuroidea (5.9%), and Echinoidea (0.02%). The most abundant species was *Florometra serratisima* (61.2%), followed by *Psolus squamatus* (13.5%), unidentified ophiuroids (4.3%), unidentified asteroids (3.9%), and an unidentified Ophiocanthidae (1.6%). At Rodriguez Seamount, holothurians accounted for 37.9% of the observations. Crinoids comprised 22.2% of the echinoderm fauna; echinoids (14.2%), asteroids (13.7%), and ophiuroids (12%)

were less abundant. Dominant species included *P. squamatus* (25.3%), *F. serratissima* (18.9%), an unidentified urchin in the family Echinothuriidae (13.9%), *Pannychia moseleyi* (11.7%), and two species of brisingids which were identified from samples collected, but indistinguishable in video (5.7%).

Echinoderm classes had a similar depth distribution at Pioneer and Rodriguez Seamounts, but most of these same classes were found to have deeper mean depths at Davidson Seamount. At Pioneer and Rodriguez Seamounts the mean depth of all echinoderm class observations was above 1,300 m, except the Crinoidea at Rodriguez Seamount, which had a mean depth of ~1,650 m (Fig. 12). At Davidson Seamount, the mean depth of observations for all asteroids (mean 2,200 m), crinoids (mean 2,625), and holothurians (mean 2,475 m) was below 2,000 m. Ophiuroids had a mean depth of observation of 1,650 m.

The ichthyofauna found at these seamounts transitions from a shelf fauna dominated by scorpaenids at Pioneer and Rodriguez Seamounts to an abyssal fauna dominated by macrourids, ophidiids, and other rare deep-sea fishes at Davidson Seamount. Demersal fishes were low in abundance when compared with invertebrates at Davidson Seamount, where only 381 fishes (0.73%) were identified. Dominant fish families included the Macrouridae (53%), Ophidiidae (13.3%), Liparidae (10.9%), Moridae (10.2%), Zoarcidae (5.2%), Bythitidae (3.8%), and Alepocephalidae (1.2%) (Fig. 13). Other rare but significant observations include members of the families Chaunacidae (2002), Chimaeridae, Halosauridae, Psychrolutidae, and Synaphobranchidae. Of the 694 (1.9%) fishes

that were observed in the video at Pioneer Seamount, 23 species were identified. Dominant families included Scorpaenidae (42.1%), Macrouridae (37.8%), Moridae (8.8%), Liparidae (4.6%), Zoarcidae (3%), Pleuronectidae (1.6%), and Arhynchobatidae (1.3%). *Sebastolobus* was the most commonly observed fish genus, accounting for 41.4% of all observations, followed by *Coryphaenoides* (18.9%), and *Antimora microlepis* 8.8%. Unidentified macrourids (17.4%) were also abundant. Demersal fishes were found in higher abundance at Rodriguez Seamount when compared with the other seamounts reported in this study (1,092 out of 39,187 or 2.8%). Dominant families identified at Rodriguez Seamount included the Scorpaenidae (64.4%), Macrouridae (19%), Moridae (3.9%), Zoarcidae (3.2%), Pleuronectidae (2.7%), Liparidae (2.6%), Arhynchobatidae (1.7%), and Anoplopomatidae (1.2%). Dominant genera include *Sebastolobus* (63.3%) and *Coryphaenoides* (13.5%). A Pacific sleeper shark, *Somniosus pacificus*, was observed at 1,076 m during video analysis as well.

The depth distribution of fish families that were found in common between the seamounts was similar, except at Davidson Seamount, where the mean depth of observations for these families were deeper and encompassed a larger depth interval (Fig. 14). This pattern was consistent for alepocephalids, arhynchobatids, bythitids, liparids, macrourids, morids, scorpaenids, and zoarcids. Scorpaenids were observed at Pioneer and Rodriguez Seamounts from the summit of each to ~1,300 m, but the mean depth of observation was shallower at Rodriguez Seamount than at Pioneer Seamount. Macrourids had a broad depth distribution and were observed from all seamount summits to 3,250

m at Davidson Seamount. The morid, *Antimora microlepis*, was observed from all seamount summits to 2,600 m. Liparids and Zoarcids showed similar patterns, while Pleuronectidae had a narrowly defined depth range of 830 - 1,020 m. At Davidson Seamount several families which were represented by a single species were seen, albeit rarely, at deeper depths including Chimaeridae (2,100 m), Halosauridae (1,900 m), and Synaphobranchidae (2,500 m).

Vanderploeg and Scavia's electivity indices indicated that dominant taxa were observed more frequently in certain types of habitat but this was only significant for fishes and sponges using electivity indices calculated from BPI values. Corals were utilizing northwest, southwest, and west facing slopes (Fig. 15) with moderate and steep inclination (Fig. 16) and habitat with peak BPI values when compared to available habitat (Fig. 17). Sponges utilized northeast and southwest facing slopes (Fig. 18) with moderate and low inclination (Fig. 19) and uniform and peak BPI values (Fig. 20). Echinoderms were utilizing northeast, south, southeast, and southwest facing slopes (Fig. 21) with low and steep inclination (Fig. 22) and habitat indicated as valleys through BPI analysis (Fig. 23). Fishes appeared to be utilizing north, northwest, and southeast facing slopes (Fig. 24) in areas with low inclination (Fig. 25) and habitat with uniform and valley BPI values (Fig. 26). A single-factor ANOVA was performed to asses the significance of the electivity indices for each of the dominant taxa (corals, sponges, echinoderms, and fishes) within each category of habitat (slope, aspect, and BPI). Results showed that fishes (p=0.016) had a significant preference for uniform and valley habitat and sponges (p=0.047) had a significant

preference for uniform and peak habitat. No other results of ANOVA were significant.

These seamounts share many species in common, and similarity analysis suggests that they are all very similar, although Pioneer and Rodriguez are more closely related. Of the 236 taxa identified in this study, 133 (56%) were seen at more than one of the seamounts described. Thirty-four percent were seen at all three seamounts; 22% were seen at Rodriguez Seamount only, 17% were seen at Davidson Seamount only, and 5% were seen at Pioneer Seamount only. Bray-Curtis coefficients (B-C) show that Pioneer and Rodriguez Seamounts are more similar to each other (B-C = 62.98) than either are to Davidson Seamount (B-C Davidson-Pioneer = 54.68, B-C Davidson-Rodriguez = 54.51) (Fig. 27).

Discussion

The differences in seamount shape, depth, distance from shore, and proximity to the continental slope alter seamount community composition to varying degrees, although general patterns of dominant phyla remained consistent. At all three seamounts the invertebrate communities were dominated by cnidarians, echinoderms, and sponges.

The dominant invertebrate phyla reported here are consistent with those reported from other seamounts (Koslow et al., 2001; Wilson and Kaufman, 1987), however, gorgonian corals, crinoidean and holothurian echinoderms, and sponges were all dominant constituents of the communities observed in this study. In most published seamount studies, scleractinians have been reported as the dominant group of corals living on seamounts (Clark et al., 2006) and

echinoderms and sponges are often listed as present or absent only (Wilson and Kaufman, 1987). A comparable number of total species was found in this study when compared with other studies of seamount communities (Grigg et al., 1997; Koslow et al., 2001), however, individual observations were much higher in this study than reported elsewhere, which is an indication of the uniqueness of these data.

A higher number of total taxa was observed at Davidson and Rodriguez Seamounts when compared to Pioneer Seamount and these results are probably related to several factors. The higher number of taxa observed at both Davidson and Rodriguez Seamounts is most likely due to the greater area and depth ranges surveyed (Table 1). Observations of species that were infrequently observed also added to the higher number of species reported at these seamounts. For example, at Davidson Seamount several fish species that are known from the California abyssal plain were observed infrequently such as *Pachycara bulbiceps* (n=9) and *Psychrolutes phrictus* (n=2). Another fish that was only observed at Davidson Seamount was *Spectrunculus grandis* (n=56), an abyssal species known from this area. In other cases rare fish species were observed, like *Hydrolagus trolli* (n=3), which represented a range extension, or appeared to be new altogether (Synaphibranchidae sp. 1, n=1). Similarly infrequent observations of corals and sponges occurred at each seamount as well, increasing the number of taxa seen at only one seamount.

Mean organism density differed between Davidson and Pioneer Seamounts, but was higher at both seamounts than the mean organism density

reported by Grigg et al. (1987) at Cross Seamount. Pioneer Seamount had a much higher mean density than Davidson Seamount (Figs. 3 & 4), perhaps because the video transects that were conducted at Pioneer Seamount were all from relatively shallow depths and they also tended to be shorter and narrower with less variability between transects than those conducted at Davidson Seamount, which varied greatly in depth, length, and width sampled (Table 2). Davidson Seamount transect data revealed that organism density was not related to depth (Fig. 3), as many of the deepest transects collected there also had the highest density. The differences in mean density found between Davidson and Pioneer Seamounts may be related to larval recruitment, nutrient availability, and/or proximity to sources of either.

Categories of feeding method and motility were similar at Davidson and Pioneer Seamounts but differed at Rodriguez Seamount. The invertebrate communities at Davidson and Pioneer Seamounts were dominated by sessile suspension feeding corals, crinoids, and filter feeding sponges. At Rodriguez Seamount the invertebrate community was dominated by holothurian echinoderms, with increased frequencies of echinoids. This change in community structure is most likely attributable to the extensive sediment covered regions found at Rodriguez Seamount, which favor deposit feeders. The greater extent of sedimented regions found at Rodriguez Seamount is, no doubt, due to it being a flat-topped seamount, however, this scenario is convoluted because the most abundant holothurian at Rodriguez Seamount, *Psolus squamatus,* is a suspension feeding organism. Still, the conclusion put forth above does

represent a valid explanation for the change in echinoderm community structure, based on the high number of deposit feeding holothurians and echinoids.

Octocorals dominated the coral communities found at these three seamounts. Contrary to other studies of, which have shown that scleractinians dominate (Clark et al., 2006; Wilson and Kaufman, 1987), this study shows that gorgonians and other octocorals are the primary constituents of the coral fauna, with abundant observatios of antipatharians occurring as well. The dominance and high diversity of octocorals reported here may be related to several factors, including the fact that the North-East Pacific is known to have a shallow aragonite saturation horizon, which limits the ability of scleractinians to build their hard skeletons (Clark et al., 2006). This fact is further illustrated by the low percentage of scleractinian observations found in this study, which accounted for only 1.6% of the total coral observations when data from all seamounts was combined.

Fishes accounted for a relatively low percentage of the observations at all three seamounts examined here and the ichthyofauna community structure shifted from a continental shelf fauna to an abyssal plain fauna when comparing Rodriguez and Pioneer Seamounts to Davidson Seamount (Fig. 13). Observations of fishes at Davidson Seamount showed that the ichthyofauna there is dominated by deep-sea abyssal species in the Macrouridae, Ophidiidae, Liparidae, and Moridae. Fishes were observed more frequently at Rodriguez Seamount and these observations were dominated by the Scorpaenidae genus *Sebastolobus*, a common continental shelf species. Pioneer Seamount had a

pattern that appeared to be a combination of the findings at Davidson and Rodriguez Seamounts. These results are probably due mostly to depth, but may also be influenced by seamount shape, distance from shore, and proximity to the continental shelf. Rodriguez Seamount is closer to shore and it is located upon the continental shelf with a relatively flat and shallow summit. Pioneer Seamount has a shallower summit than Davidson Seamount, but, like Davidson, it is a peaked seamount and its base is at the foot of the continental shelf. Davidson Seamount is a deep seamount located on the abyssal plain and, as expected, it has a deep-water fish fauna. However, at all of these seamounts the majority of fish species that were identified are known from the continental shelf or abyssal plain off California and in general the dominant fish families reported here are consistent with other studies of deep-sea fish fauna off central California (Cailliet et al., 1999).

Rare and new invertebrate species have been discovered through this work (Cairns, in press; Lee, W. and Reiswig, H. in press, Mah, C., pers. com., Williams, G., pers. com.), but none of these species appear to be endemic at the scale of an individual seamount. For example, two new corals in the genus *Chrysogorgia* (*C. monitcola* and *C. pinnata*) had distinct patterns of distribution (Cairns, in press), but they were seen at multiple seamount locations including the seamounts examined here and several that were visited on other MBARI seamount expeditions including San Juan Seamount and the Vance Seamounts (personal observation). Other examples include an unidentified urchin in the family Echinothuriidae that was found in high abundance at Rodriguez Seamount

"kelp falls" but was absent at Davidson Seamount and only rarely seen at Pioneer Seamount (n=2). A new branched form of *Asbestopluma* (*Asbestopluma* sp. 2) that was an abundant member of the peak community at Davidson Seamount was discovered in February of 2006, however, it was later observed by the author at several locations at ROV dive sites in Monterey Bay, for example on *Tiburon* dive 1163. *Cladorhiza pteron* (Lee and Reiswig, in press), a new species of predatory sponge was described from a specimen collected at Rodriguez Seamount in 2004, but this species was also seen at San Juan Seamount on that same expedition, although the data from San Juan Seamount are not presented here (personal observation).

Many studies have concluded that rates of endemism at seamounts can be very high (Koslow et al., 2001; Richer de Forges, 2000), however, the data presented here for Davidson, Pioneer, and Rodriguez Seamounts shows that seamount endemism is low, if present at all. These results here are in agreement with the notion put forth by McClain (2007), O'Hara (2007), and Wilson and Kaufman (1987) that the high rate of endemism reported at many seamounts are more likely due to a lack of knowledge than to true species endemism. Certainly, seamount isolation will most likely increase rates of endemism and perhaps the results found here are have low endemism due to their proximity to the continental margin and to each other. However, it is very plausible that with increased sampling and knowledge within a given region the high rates of endemism reported in the literature are likely to decline.

Electivity indices showed that dominant taxa may utilize habitats that have specific bathymetric properties with regards to aspect, slope, and BPI values. However, these results were only significant for electivity indices calculated from BPI values of fishes and sponges. This may be due to the fact that corals and echinoderms have too many niches that they occupy to be studied at such a high taxonomic level. Future studies might benefit by performing this analysis at lower taxonomic levels or by comparing organisms with differing feeding styles or motility. Higher resolution bathymetric grids would also be more useful in detecting subtle changes in topography which might provide a more accurate picture of habitat utilization.

Because much of the video data that was reviewed in this study was collected primarily for geologic purposes, it was not collected systematically and, therefore, the qualitative nature of the data collected precluded the use of many statistical methods in comparing the seamounts examined. Future studies would benefit by a more thorough, quantitative sampling design stratified by depth or habitat type on each seamount. However, the general patterns of dominant phyla and community structure changes due to seamount shape, depth, and proximity to the continental shelf will undoubtedly be similar to the results reported here. Few published papers describe the biological communities at seamounts offshore California. Globally little is known about the relationship between shelf and seamount faunas, the similarity of seamount faunas within a region, nor what factors might cause changes in community structure. This effort has increased

our understanding of these systems and can be used to aid in hypothesis generation and the design of surveys to be conducted in the future.

The seamounts examined here represent unique and diverse habitats that are not well understood. Much of the work to date has been exploratory and merely describes a snapshot of the communities observed. Many new species have been found through this work, and no doubt, many more are awaiting discovery. In the future, a more systematic sampling design and interdisciplinary approach might better explain the patterns described here. Because of the long-lived and fragile nature of the dominant organisms found at these seamounts more effort should be placed on understanding how these systems function, identifying the community constituents, and finding out how best to preserve them for future generations.

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Jim Barry, Greg Cailliet, and Jon Geller. Dave encouraged me to pursue the study of seamount biology and he has treated me as a colleague since my first seamount cruise in 2003, although I was very green at the time. Greg Cailliet has brought and continues to bring a contagious enthusiasm to every class, cruise, and discussion which has inspired countless numbers of students, myself included. With every meeting and reading of my thesis drafts, Greg's enthusiasm and dedication were unwavering. Jim Barry provided generous support and enthusiasm for this work, including discussing appropriate analyses to perform on the data, editing draft versions, and coauthoring posters with me that were presented at various scientific meetings. Jon Geller provided support, encouragement, and direction over the past few years and has always been willing to help when needed. My wife, Eve Elkins, has provided a tremendous amount of support and encouragement in every facet of my life.

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Literature Cited

Andrews, AH, Cordes, EE, Mahoney, MM, Munk, K, Coale, KH, Cailliet, GM, Heifetz, J. "Age, growth and radiometric age validation of a deep-sea, habitat-forming gorgonian (Primnoa resedaeformis) from the Gulf of Alaska." Hydrobiologia 471: 101, 2002.

Boehlert, G. W., and A. Genin.1987. A review of the effects of seamounts on biological processes. In: B. H. Keating, P. Fryer, R. Batiza, and G. W. Boehlert (editors), Seamounts, islands, and atolls, p. 319-334. Geophys. Monogr. 43.

Brusca, Richard C. and Gary J. Brusca. 1990. Invertebrates. Sinauer Associations, Sunderland, Massachusetts.

Cailliet, G.M., Andrews, A.H., Wakefield, W.W., Moreno, G., Rhodes, K.L. 1999. Fish faunal and habitat analyses using trawls, camera sleds and submersibles in benthic deep-sea habitats off central California. Oceano. Acta. 22:579-592.

Clark MR, Tittensor D, Rogers AD, Brewin P, Schlacher T, Rowden A, Stocks K, Consalvey M. 2006. Seamounts, deep-sea corals and fisheries: vulnerability of deep-sea corals to fishing on seamounts beyond areas of national jurisdiction.UNEP-WCMC, Cambridge, UK.

Clarke K.R., Gorley R.N. 2001. PRIMER v6: User Manual/Tutorial. PRIMER-E Ltd., Plymouth

Colwell, R. K. 2005. EstimateS: Statistical estimation of species richness and shared species from samples. Version 7.5. User's Guide and application published at: http://purl.oclc.org/estimates.

Davis, A.S., D.A. Clague, W.A. Bohrson, G.B. Dalrymple, H.G. Greene. 2002. Seamounts at the Continental Margin of California: A Different Kind of Oceanic Intra-Plate Volcanism. Geological Society of America Bulletin: Vol. 114, No. 3, pp. 316–333..

DeVogelaere, A.P., E. J. Burton, T. Trejo, C. E. King, D. A. Clague, M. N. Tamburri, G. M. Cailliet, R. E. Kochevar, W. J. Douros, 2005. Deep-sea corals and resource protection at the Davidson Seamount, California, USA. In: Freiwald A, Roberts JM (eds), 2005, Cold-water Corals and Ecosystems. Springer-Verlag Berlin Heidelberg, pp 1189-1198.

Eagle, J.V., Jones, G.P., McCormick, M.I. 2001. A multi-scale study of the relationships between habitat use and the distribution and abundance patterns of three coral reef angelfishes (Pomacanthidae). Vol. 214: 253–265.

Etnoyer. P., Cairns, S.D., Sanchez, J.A., Reed, J.K., Lopez, J.V., Schroeder, W.W., Brooke, S.D., Watling, L., Baco-Taylor, A., Williams, G.C., Lindner, A., France, S.C., and Bruckner, A.A. 2006. Deep-sea coral collection protocols. NOAA Technical Memorandum NMFS-OPR-28, Silver Spring, MD. 55p.

Fosså, JH, PB Mortensen & DM Furevik. 2002. The deep water coral Lophelia pertusa in Norwegian waters: distribution and fishery impacts. Hydrobiologia 471: 1-12.

Fry, GC, Brewer, DT, Venables,WN. 2006. Vulnerability of deepwater demersal fishes to commercial fishing: Evidence from a study around a tropical volcanic seamount in Papua New Guinea. Fisheries Research Vol. 81, no. 2-3, pp. 126-141.

Gage, J.D., P.A. Tyler. 1991. Deep-Sea Biology: A Natural History of Organisms at the Deep-Sea Floor. Cambridge University Press, Cambridge, CB2 1RP, UK, 504 pp.

Genin, A., P.K. Dayton, P.F. Lonsdale, and F.N. Spiess. 1986. Corals on Seamount Peaks Provide Evidence of Current Acceleration over Deep-Sea Topography. Nature. 322: 5961.

Genin, A., L. R. Haury, and P. Greenblatt. 1988. Interactions of migrating zooplankton with shallow topography: predation by rockfish and intensification of patchiness. Deep-Sea Research, 35:151-175.

Grigg, R. W., A. Malahoff, E. H. Chave, and J. Landahi. 1987. Seamount benthic ecology and potential environmental impact from manganese crust mining in Hawaii. . In: B. H. Keating, P. Fryer, R. Batiza, and G. W. Boehlert (editors), Seamounts, islands, and atolls. Geophys. Monogr. 43: 379-390

Grigg, R.W. 2002. Precious Corals in Hawaii: Discovery of a New Bed and Revised Management Measures for Existing Beds. Marine Fisheries Review, 64 (1):13-20.

Hooge, P.N. and B. Eichenlaub. 1997. Animal movement extension to arcview. ver. 1.1. Alaska Science Center - Biological Science Office, U.S. Geological Survey, Anchorage, AK, USA.

Kogan, I., Paull, C., Kuhnz, L., Burton, E., von Thun, S., Greene, H.G., Barry, J. 2006. ATOC/Pioneer Seamount cable after 8 years on the seafloor: Observations, environmental impact. Continental Shelf Research, 26, 771-787.

Koslow, J.A., K Gowlett-Holmes, J.K. Lowry, T. O'Hara, G.C.B Poore. 2001. Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. Marine Ecology Progress Series 213, 111-125.

Lechowicz M.J. 1982. The Sampling Characteristics of Electivity Indices. Oecologia, 52:22-30.

McClain, C.R. 2007. Is Seamount Biogeography Island Biogeography. Journal of Biogeography 34 (12), 2001–2008.

McClatchie,S. and R.F. Coombs (2005). Spatial variability of orange roughy around the Northwest Hills on the Chatham Rise, New Zealand. Deep-Sea Research I 52, 589-603.

Mortensen, P. B., Buhl-Mortensen, L. 2005. Morphology and growth of the deep-water gorgonians Primnoa resedaeformis and Paragorgia arborea. Marine Biology Vol. 147, no. 3, pp. 775-788.

Mullineaux, L.S. and S.W. Mills. 1997. A test of the larval retention hypothesis in seamount-generated flows. Deep-Sea Research 44: 745-770.

O'Hara, T.D. 2007. Seamounts: centres of endemism or species richness for ophiuroids? Global Ecology and Biogeography 16 (6), 720–732.

Parker, T. and V. Tunnicliffe. 1994. Dispersal strategies of the biota on an oceanic seamount: implications for ecology and biogeography. Biological Bulletin, 187: 336-346.

Richer de Forges, B., J. Anthony Koslow, G.C.B. Poore, 2000. Diversity and endemism of the benthic seamount fauna in the southwest Pacific. Nature 405, 944-947.

Rinehart, R., Wright, D., Lundblad, E., Larkin, E., Murphy, J., and Cary-Kothera, L. 2004. ArcGIS 8.x Benthic Terrain Modeler: Analysis in American Samoa. Proceedings of the 24th Annual ESRI User Conference, San Diego, CA. Paper 1433.

Risk, MJ, Heikoop, JM, Snow, MG, Beukens, R. 2002. Lifespans and growth patterns of two deep-sea corals: Primnoa resedaeformis and Desmophyllum cristagalli. Hydrobiologia. Vol. 471, no. 1-3, pp. 125-131.

Rogers, A.D., 1994. The Biology of Seamounts. Advances in Marine Biology 30, 305-350.

Rowden, A.A., O'Shea, S., Clark, M.R. 2002. Benthic biodiversity of seamounts on the northwest Chatham Rise. Marine Biodiversity Biosecurity Report No. 2, 21p

Sandwell, D. T., W. H. F. Smith, S. Gille, E. Kappel, S. Jayne, K. Soofi, B. Coakley, L. Geli. 2006. Bathymetry from space: Rationale and requirements for a new, high-resolution altimetric mission. Comptes Rendus Geoscience Vol. 338, pp. 1049-1062.

Schlining, B. and N. Jacobsen Stout. 2006. MBARI's Video Annotation and Reference System. In: Proceedings of the Marine Technology Society / Institute of Electrical and Electronics Engineers Oceans Conference, Boston, Massachusetts: 1 – 5.

Stocks, K. 2004. Seamount Invertebrates: Composition and vulnerability to fishing. T. Morato and D.Pauly (eds). Seamounts: Biodiversity and fisheries. Fisheries Centre Research Reports 12(5): 78pp.

Wessel, P. 1997. Sizes and ages of seamounts using remote sensing: Implications for intraplate volcanism, Science, 277, 802-805.

Wessel, P. 2001. Global distribution of seamounts inferred from gridded Geosat/ ERS-1 altimetry, J. Geophys. Res., 106(B9), 19,431-19,441.

White, M. and C. Mohn. 2004. Seamounts: a review of physical processes and their influence on seamount ecosystems. OASIS report, University Hamburg, 40 pp

Wilson, R.R. and R.S. Kaufmann. 1987. Seamount Biota and Biogeography. In: B. H. Keating, P. Fryer, R. Batiza, and G. W. Boehlert (editors), Seamounts, islands, and atolls, p. 355-377. Geophys. Monogr. 43. [Am. Geophys. Union.]

Figures

Fig. 1, Location of Davidson, Pioneer, and Rodriguez Seamounts off Central California, USA.
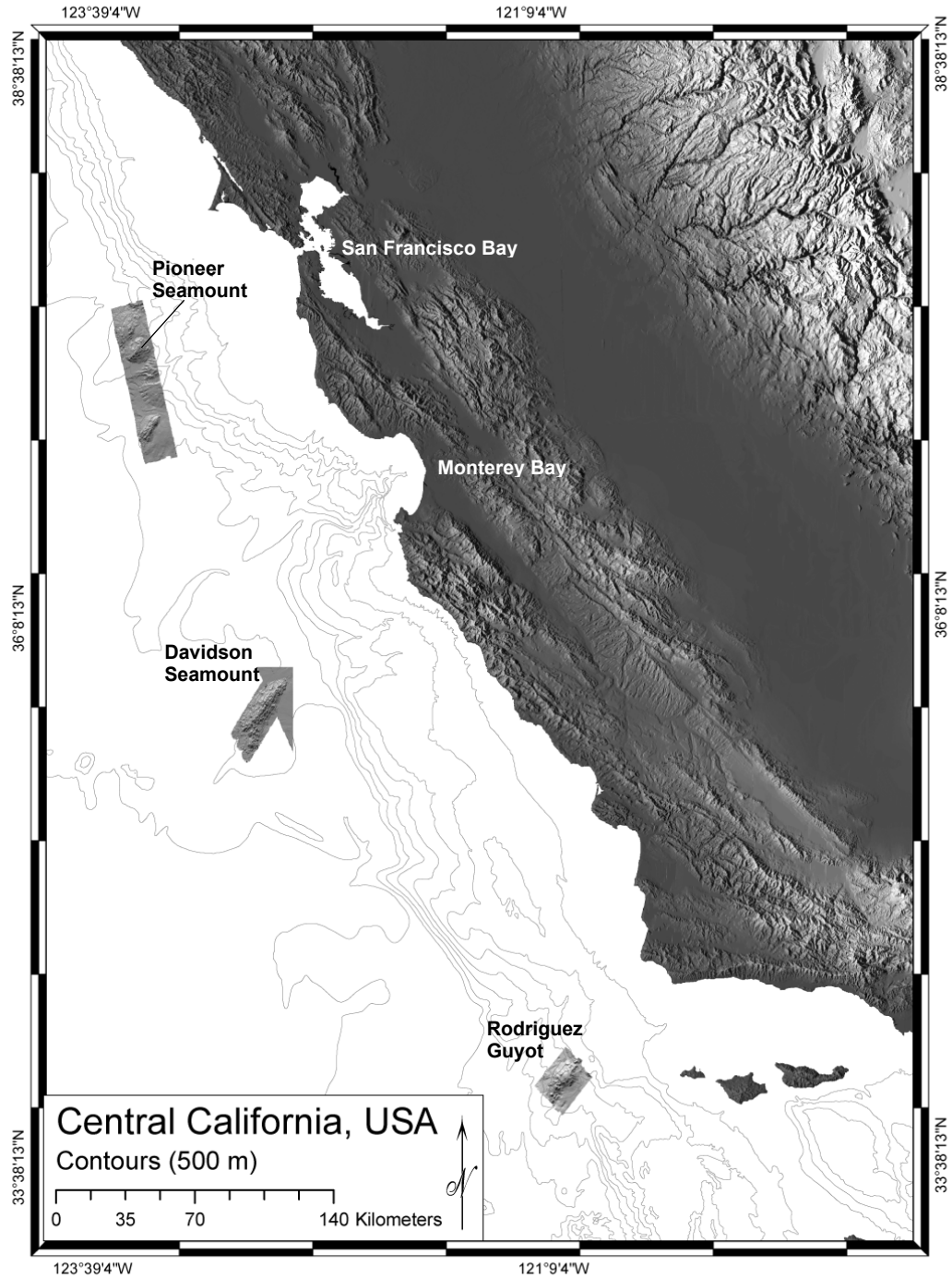
Fig. 2, Smoothed species accumulation curves for dominant groups are shown including coral (2a), Porifera (2b), Echinodermata (2c), and fishes (2d). In all figures, the y-axis represents accumulated species and the x-axis is distance traversed by the ROV in km.
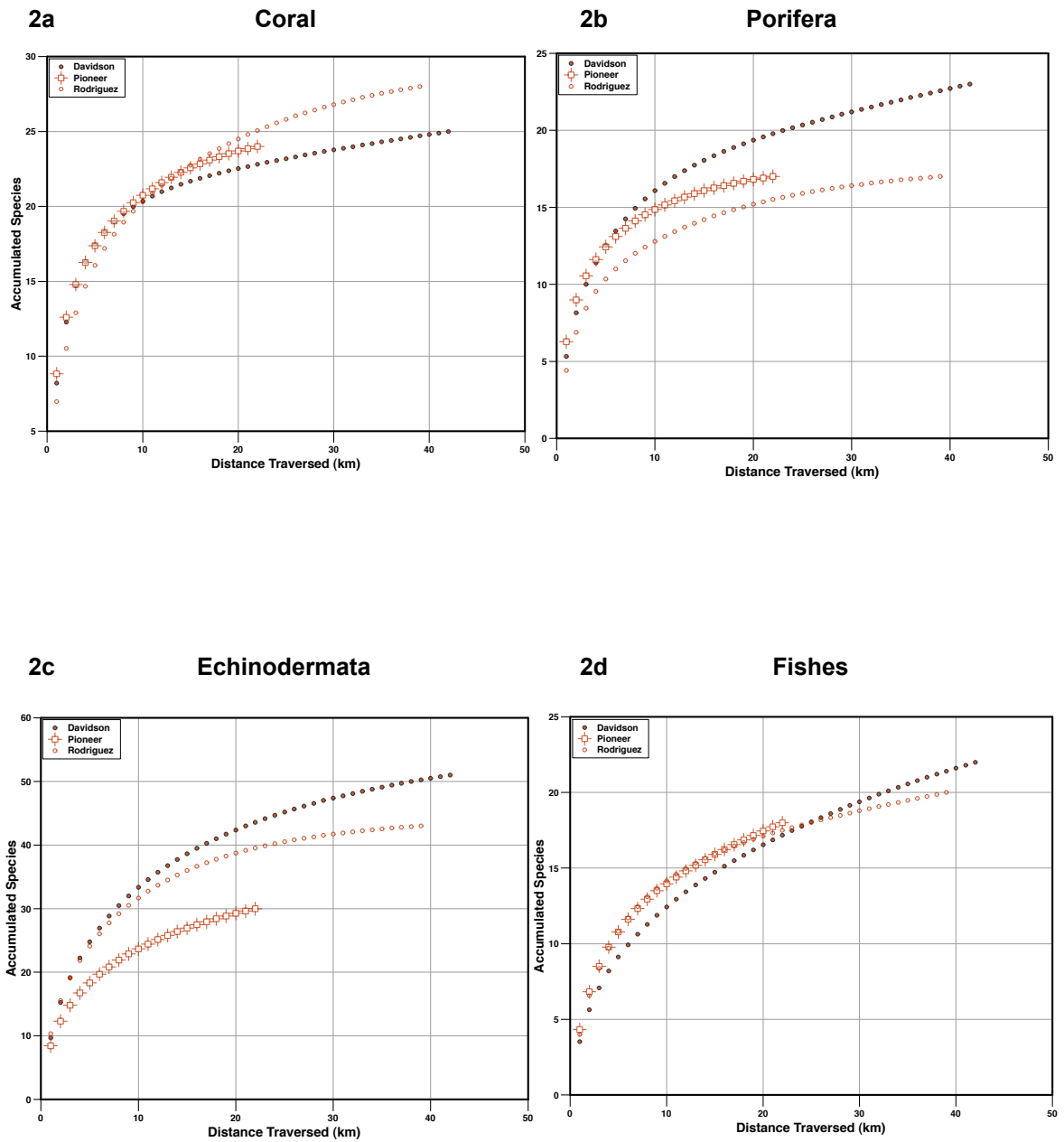
Fig. 3, Organism density vs. mean transect depth for quantitative video transects collected at Davidson Seamount in 2006 and Pioneer Seamount in 2007.
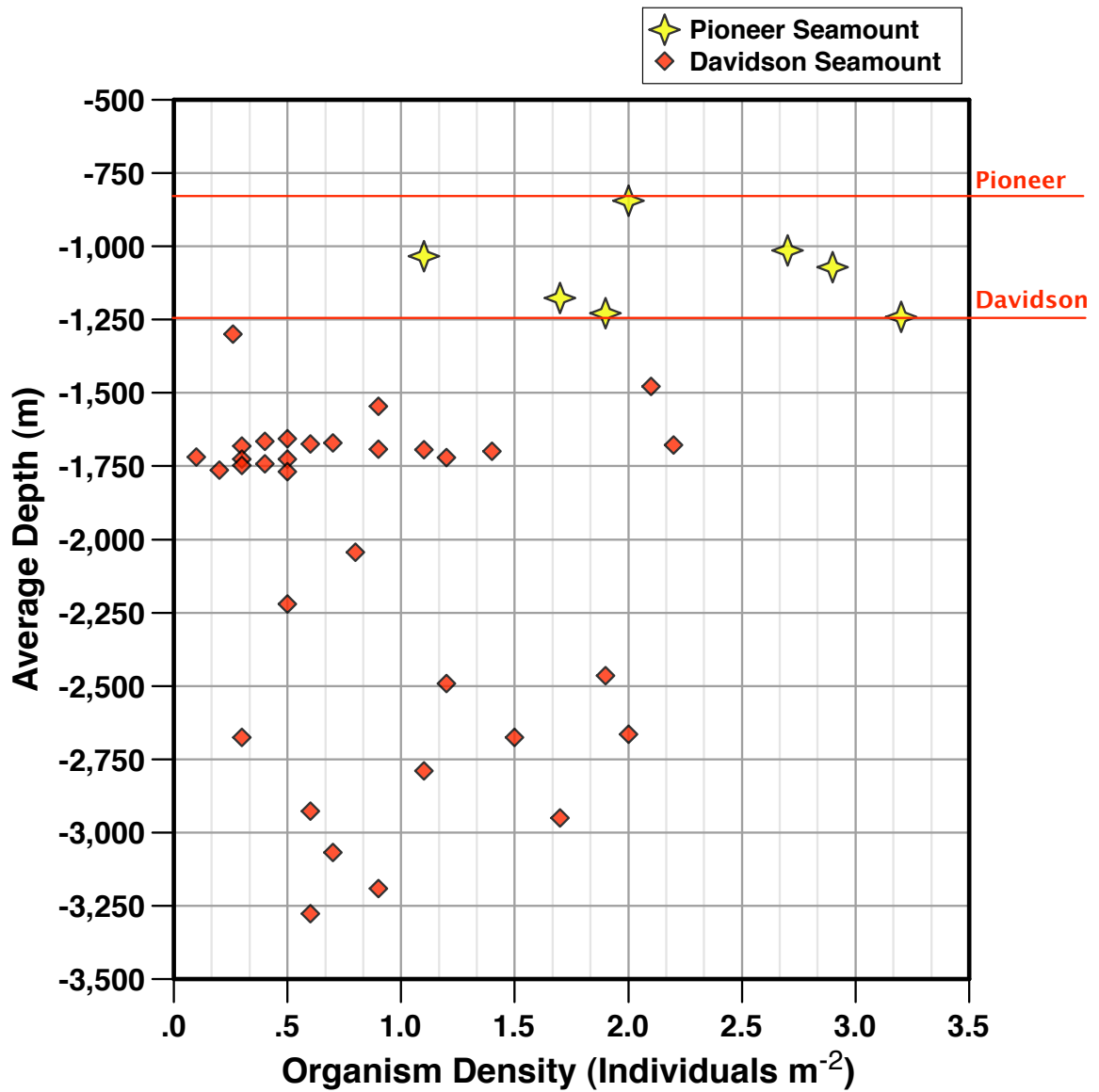
Fig. 4, Mean organism density (+/- Std. Err.) for quantitative video transects collected at Davidson Seamount in 2006 and Pioneer Seamount in 2007.

2.2 individuals m⁻²

0.87 individuals m⁻²
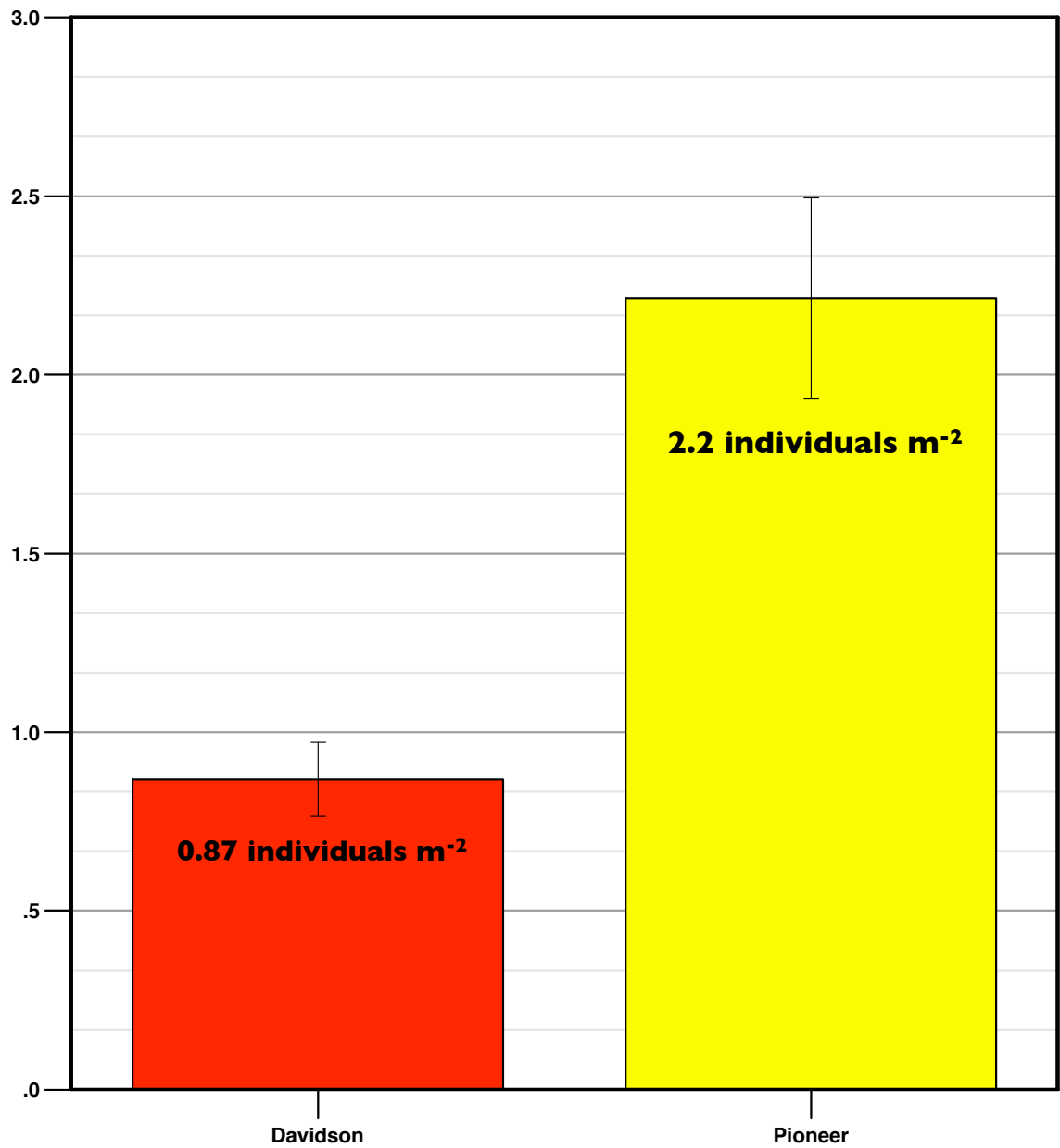
Fig. 5, Percent observation of phyla at Davidson, Pioneer, and Rodriguez Seamounts.
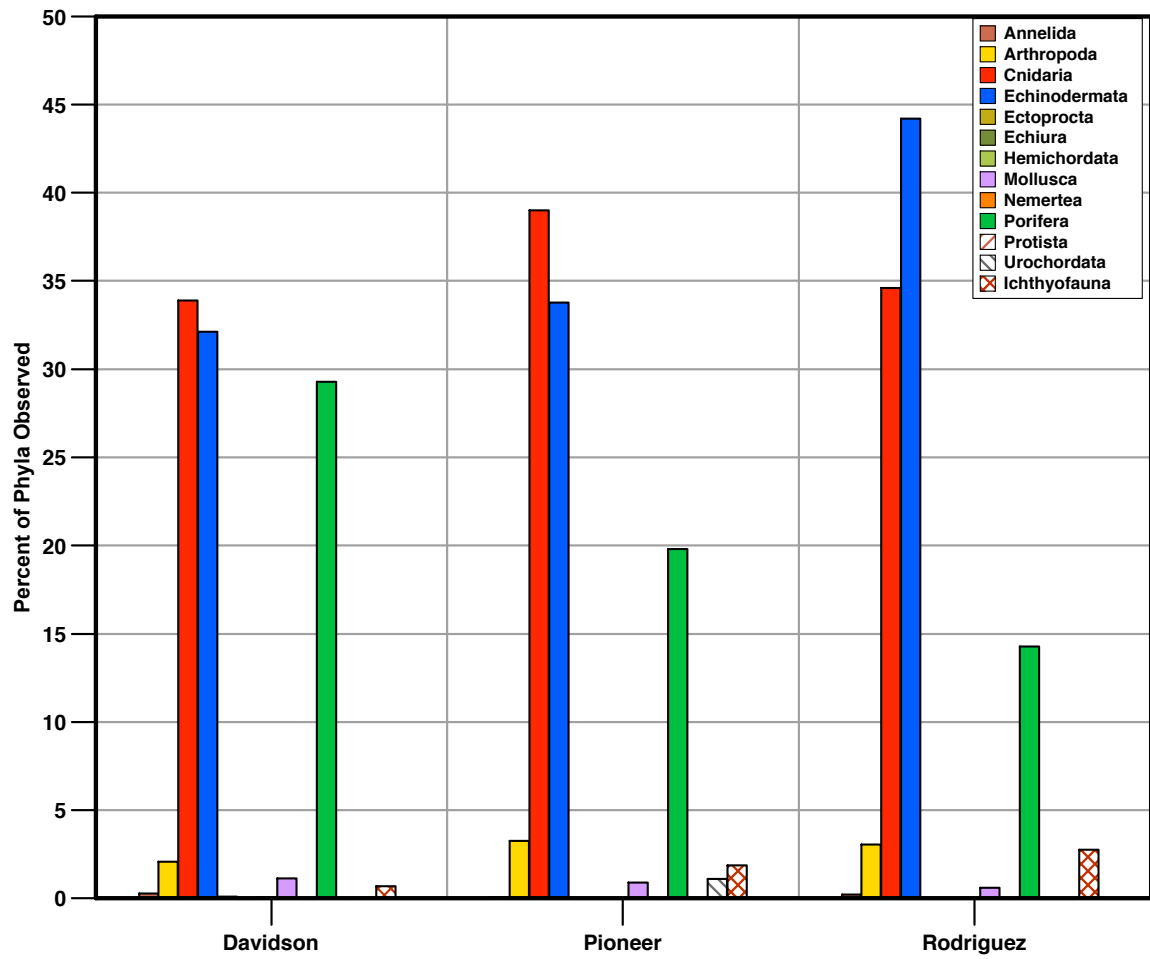
Fig. 6, Percent observation of motility and feeding style of seamount organisms at Davidson, Pioneer, and Rodriguez Seamounts.
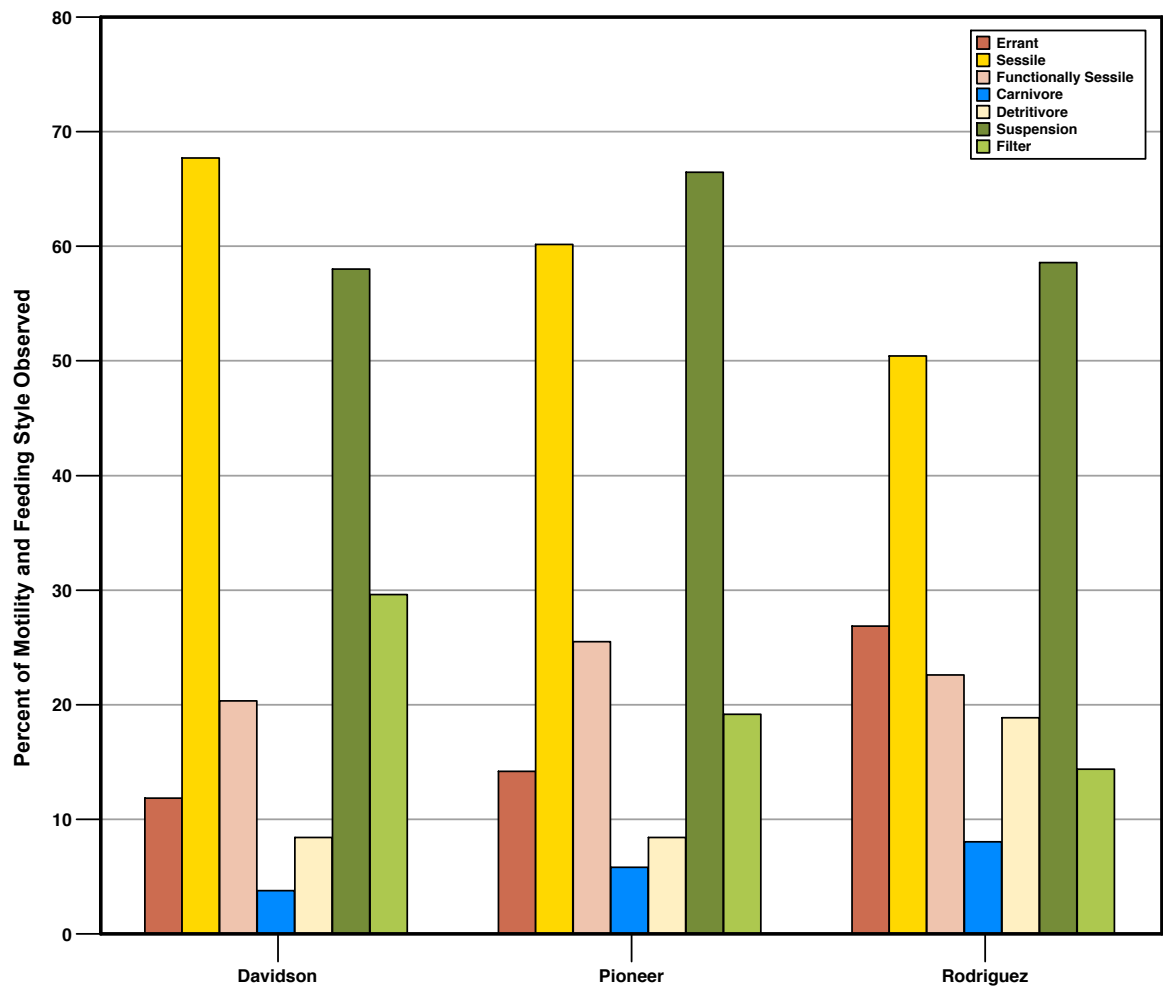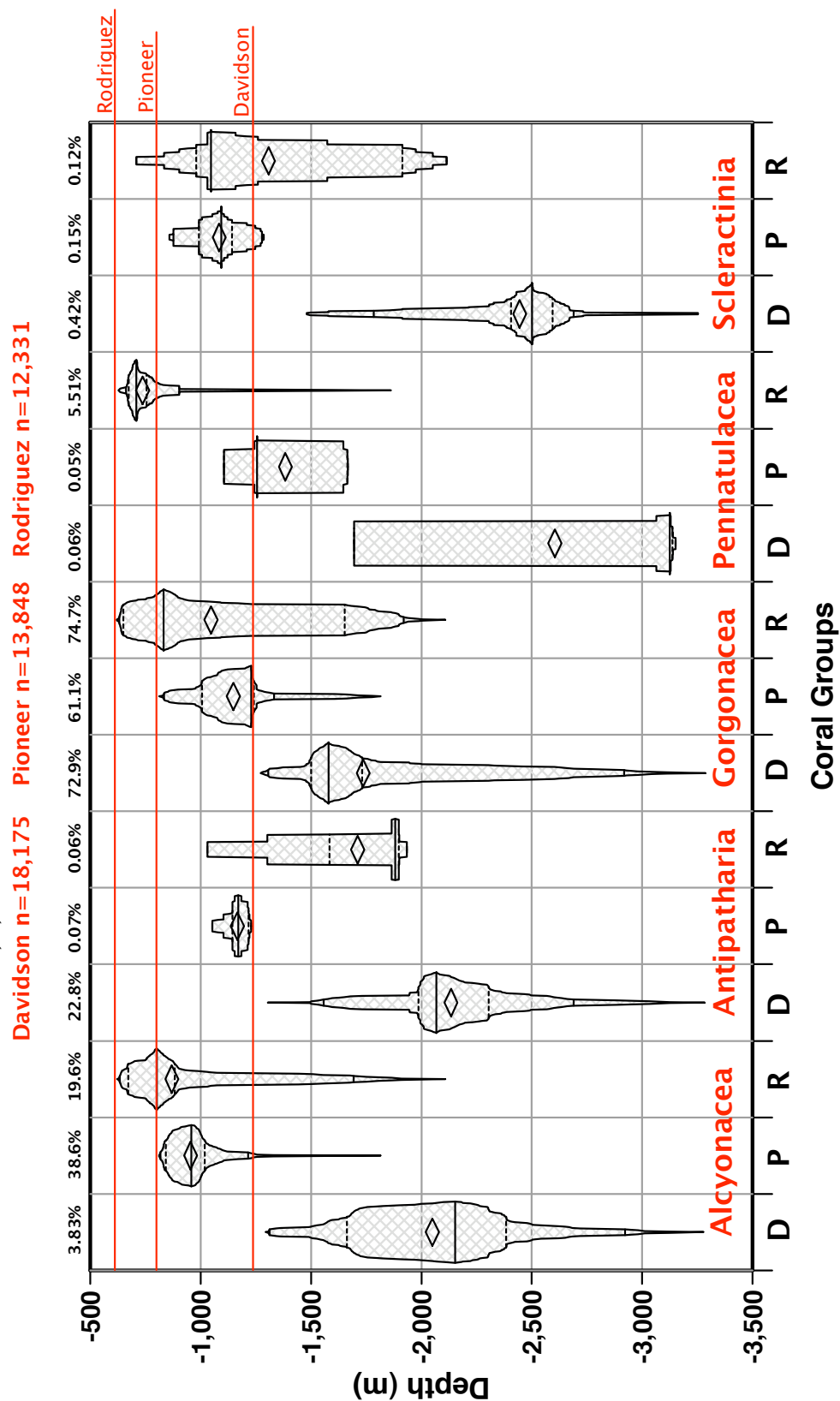
Fig. 7, Percent observation of corals taxa at Davidson, Pioneer, and Rodriguez Seamounts.
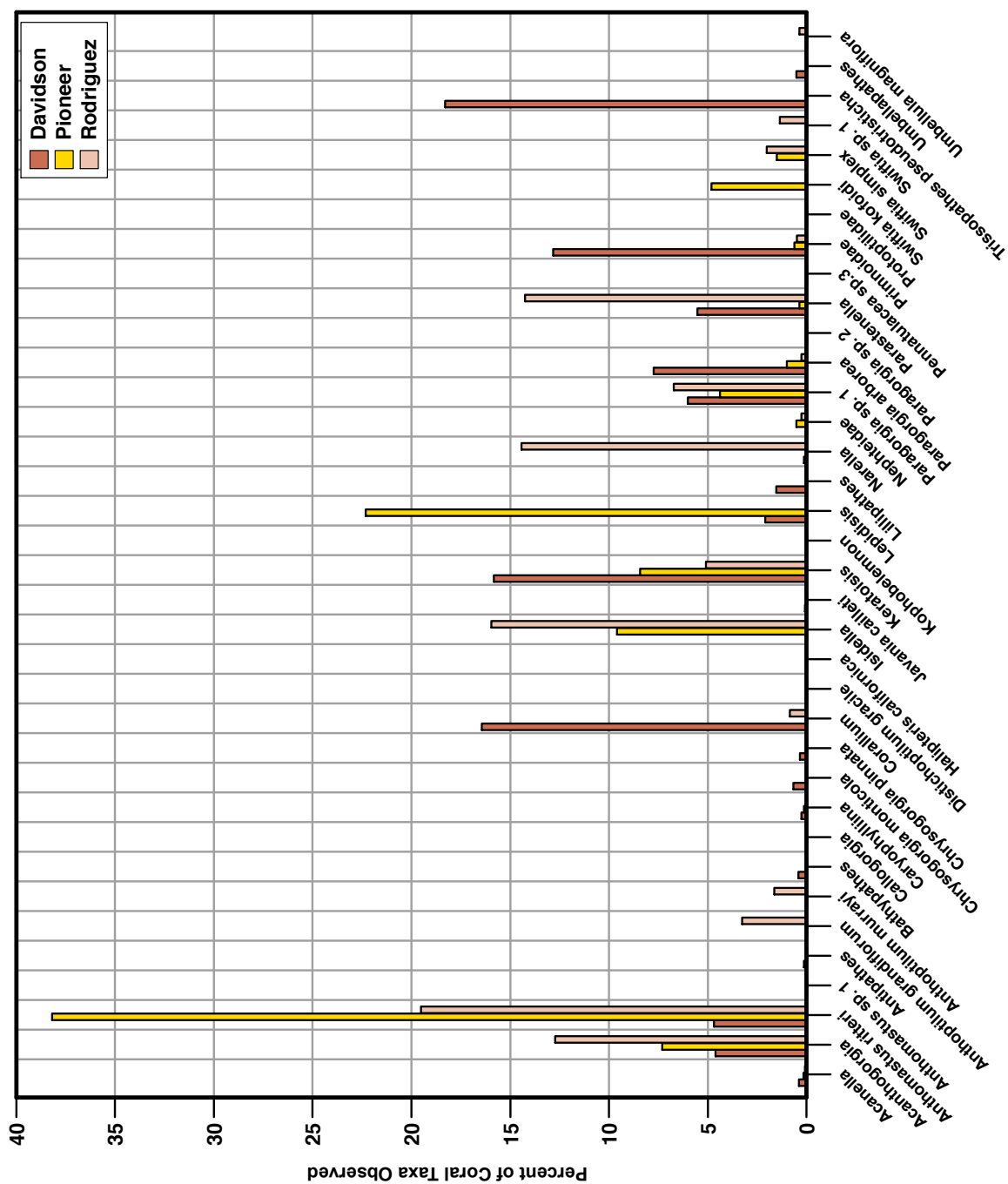
Fig. 8, Depth distribution of abundant coral groups at Davidson, Pioneer, and Rodriguez Seamounts. Mean depth is indicated by diamond. The width of the box at any given height is proportional to the percent of observations at that height. Fifty percent of the observations occur between the dotted lines. The red horizontal lines indicate the summit of each seamount. The percent values at the top of each column represent the percentage of total observations hat group represents for that seamount (indicated at the bottom of the column with a D, P,or R.

Davidson n=18,175   Pioneer n=13,848   Rodriguez n=12,331

Fig. 9, Percent observation of sponge taxa at Davidson, Pioneer, and Rodriguez Seamounts.
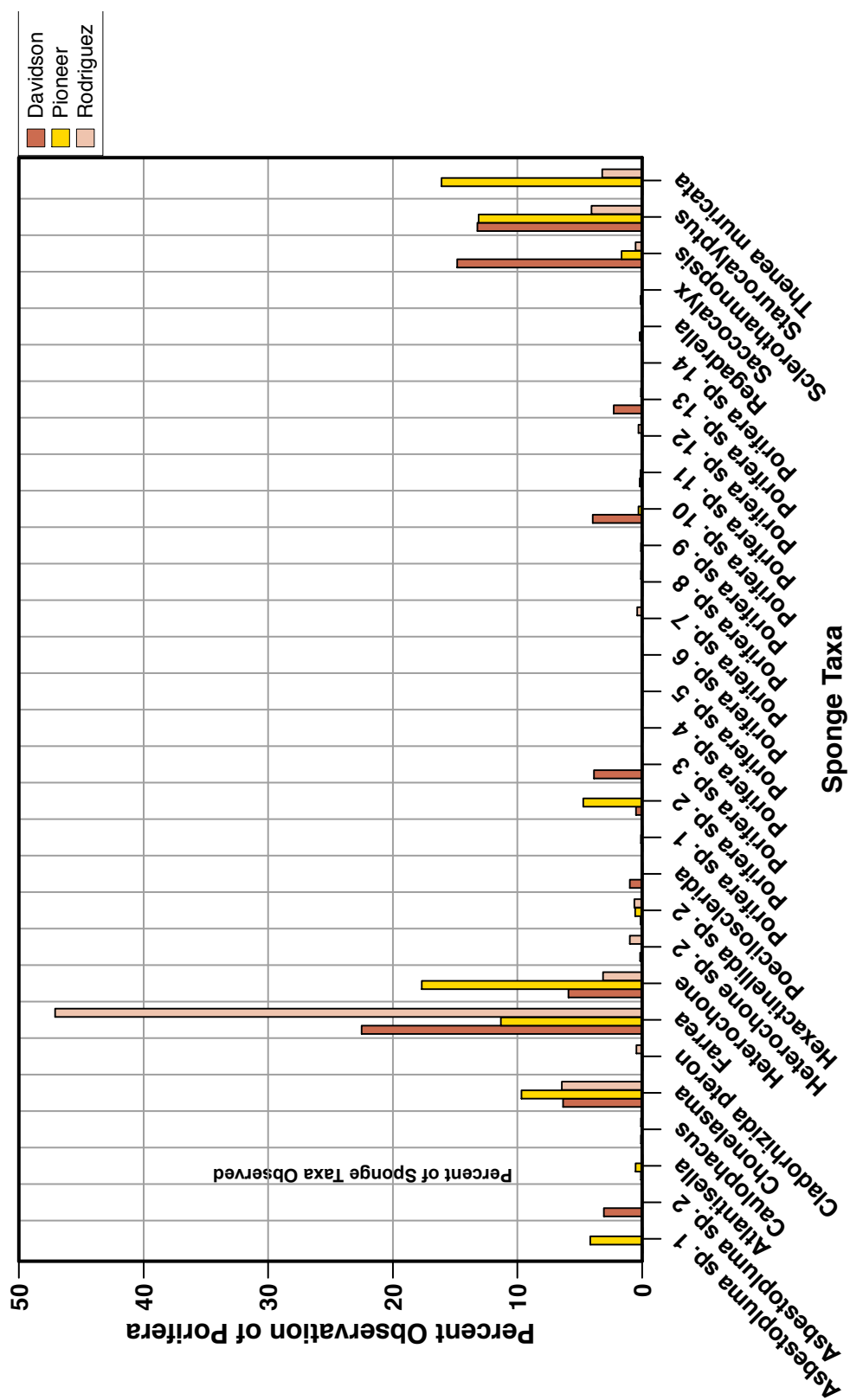
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Fig. 10, Depth distribution of abundant sponge taxa at Davidson, Pioneer, and Rodriguez Seamounts. Mean depth is indicated by diamond. The width of the box at any given height is proportional to the percent of observations at that height. Fifty percent of the observations occur between the dotted lines. The red horizontal lines indicate the summit of each seamount. The percent values at the top of each column represent the percentage of total observations hat group represents for that seamount (indicated at the bottom of the column with a D, P,or R.

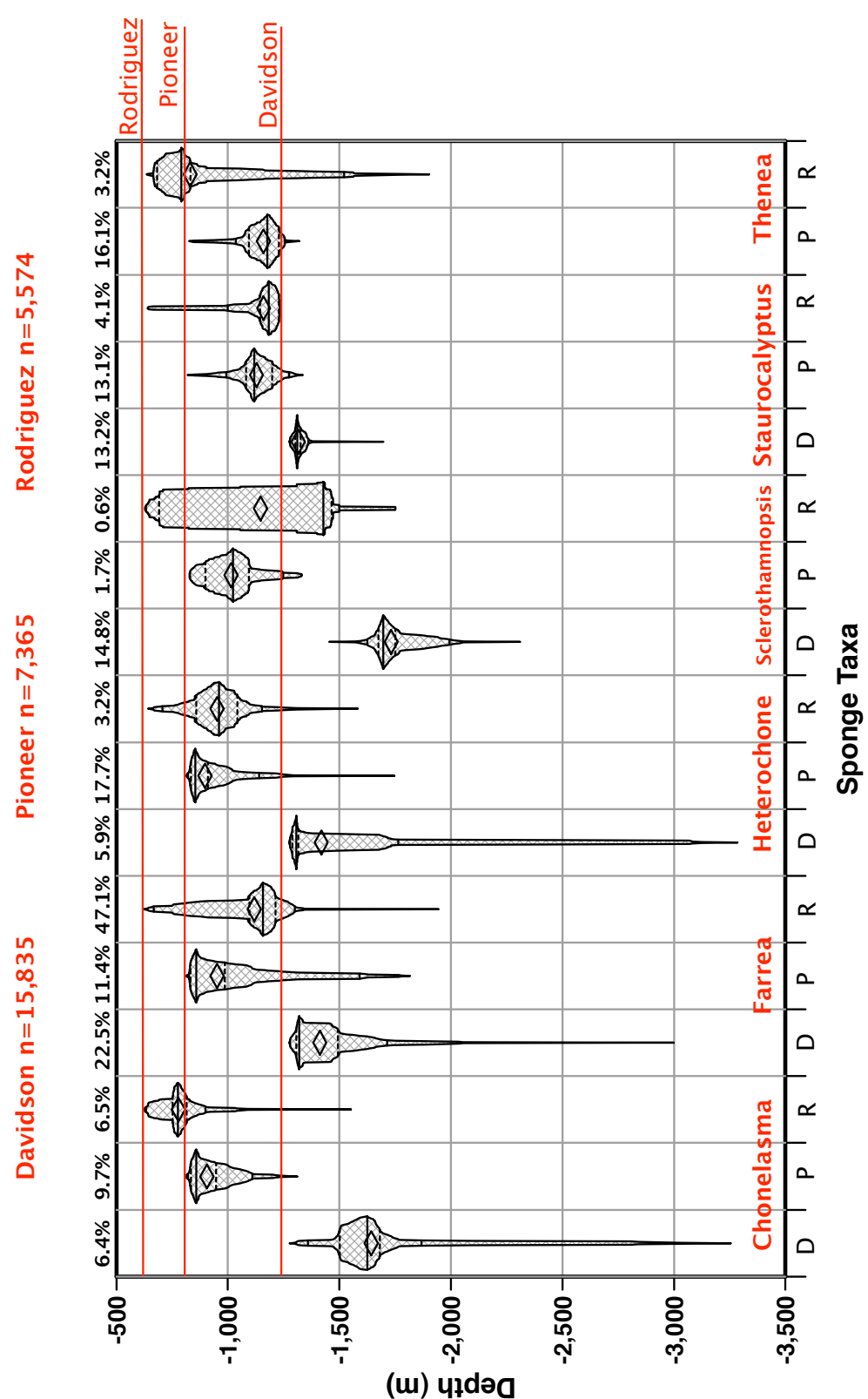*Fig. 11, Percent observation of echinoderm classes at Davidson, Pioneer, and Rodriguez Seamounts.*
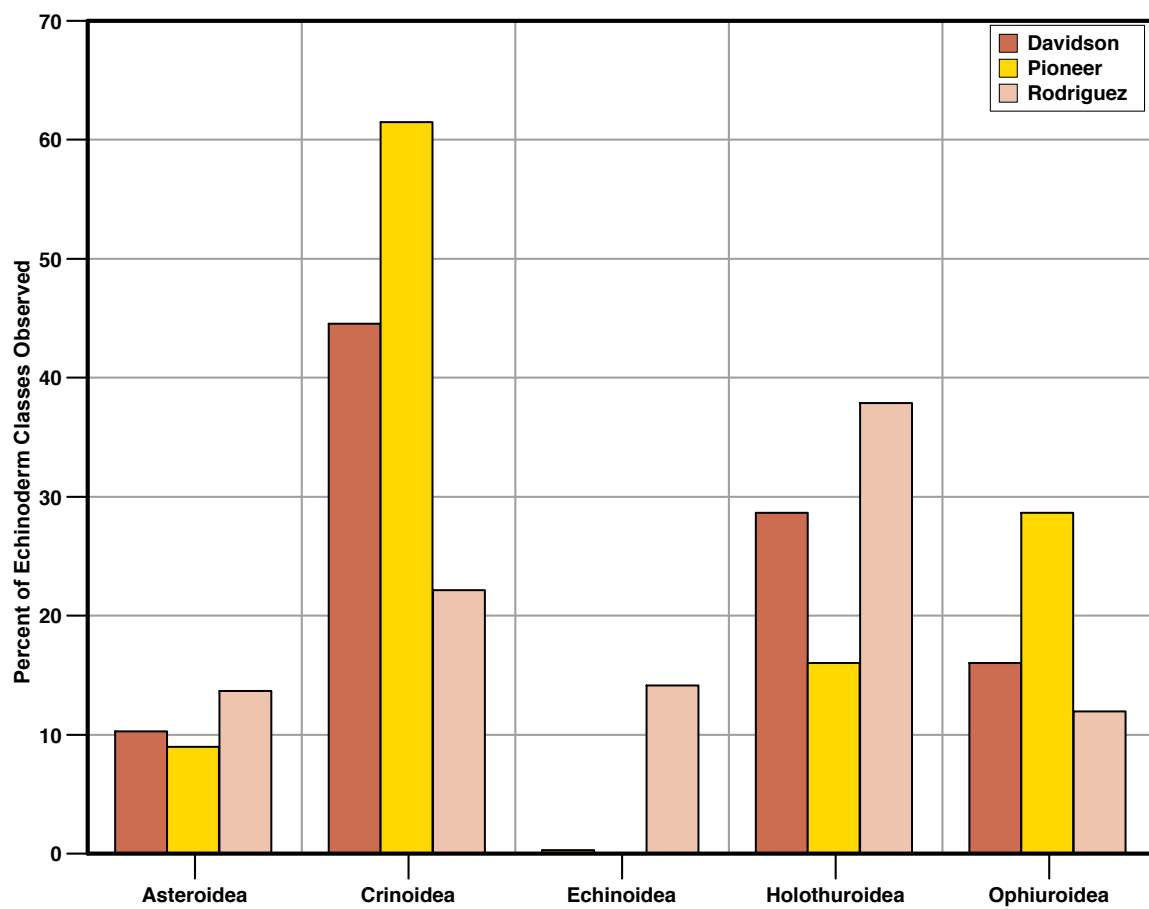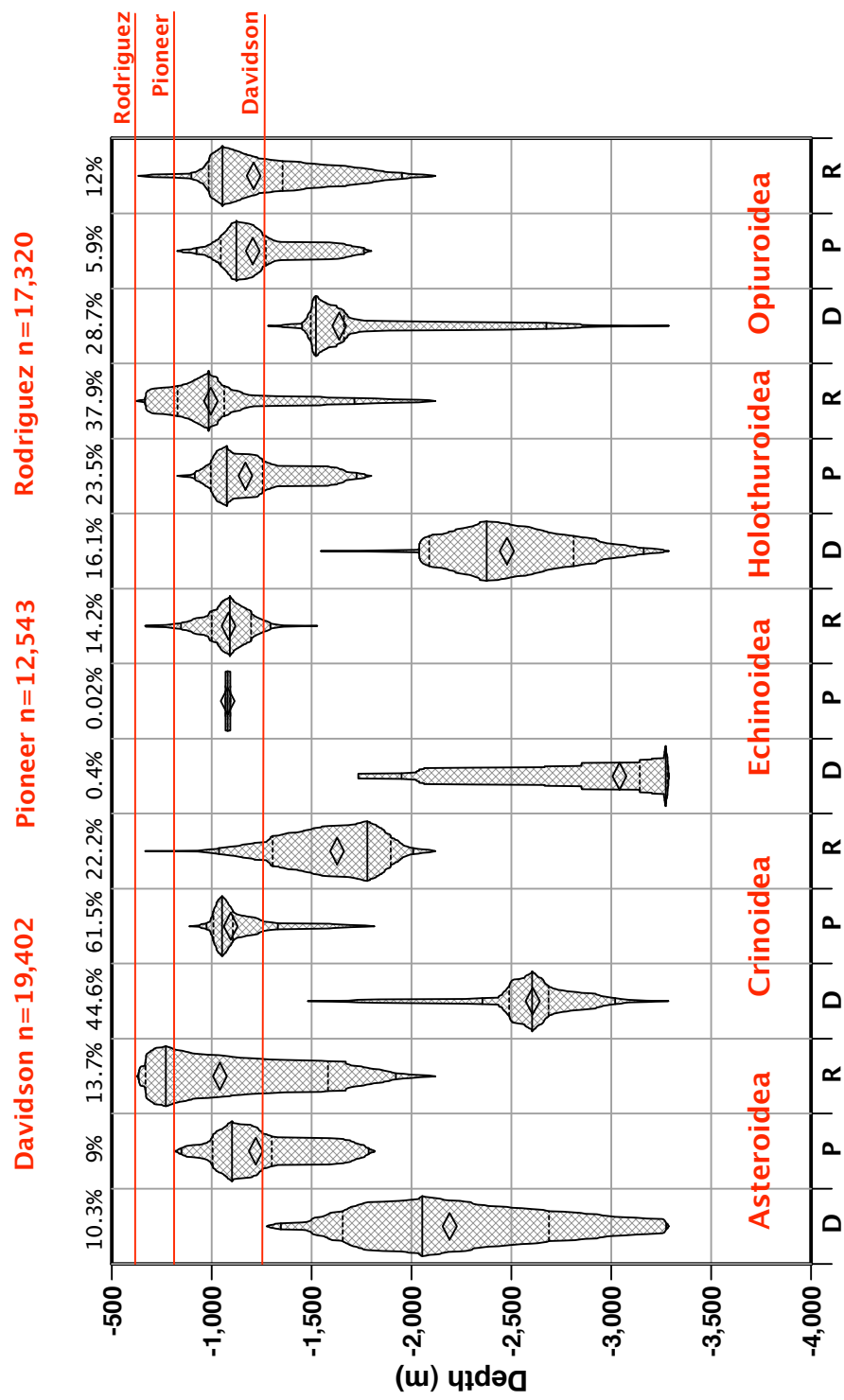
Fig. 12, Depth distribution of echinoderm classes at Davidson, Pioneer, and Rodriguez Seamounts. Mean depth is indicated by diamond. The width of the box at any given height is proportional to the percent of observations at that height. Fifty percent of the observations occur between the dotted lines. The red horizontal lines indicate the summit of each seamount. The percent values at the top of each column represent the percentage of total observations hat group represents for that seamount (indicated at the bottom of the column with a D, P, or R.

Fig. 13, Percent observation of fish families at Davidson, Pioneer, and Rodriguez Seamounts.
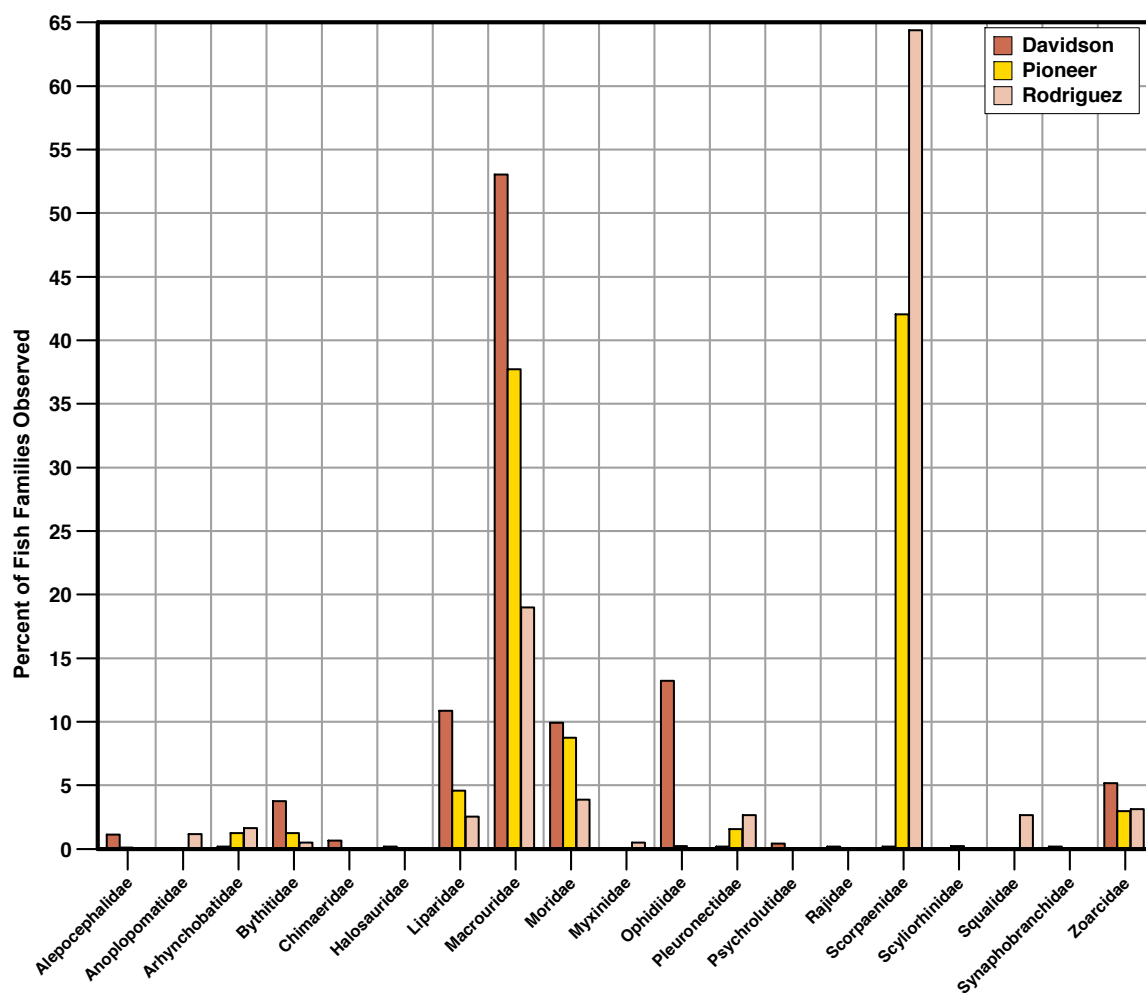
Fig. 14, Depth distribution of abundant fish families at Davidson, Pioneer, and Rodriguez Seamounts. Mean depth is indicated by diamond. The width of the box at any given height is proportional to the percent of observations at that height. Fifty percent of the observations occur between the dotted lines. The red horizontal lines indicate the summit of each seamount. The percent values at the top of each column represent the percentage of total observations hat group represents for that seamount (indicated at the bottom of the column with a D, P, or R.

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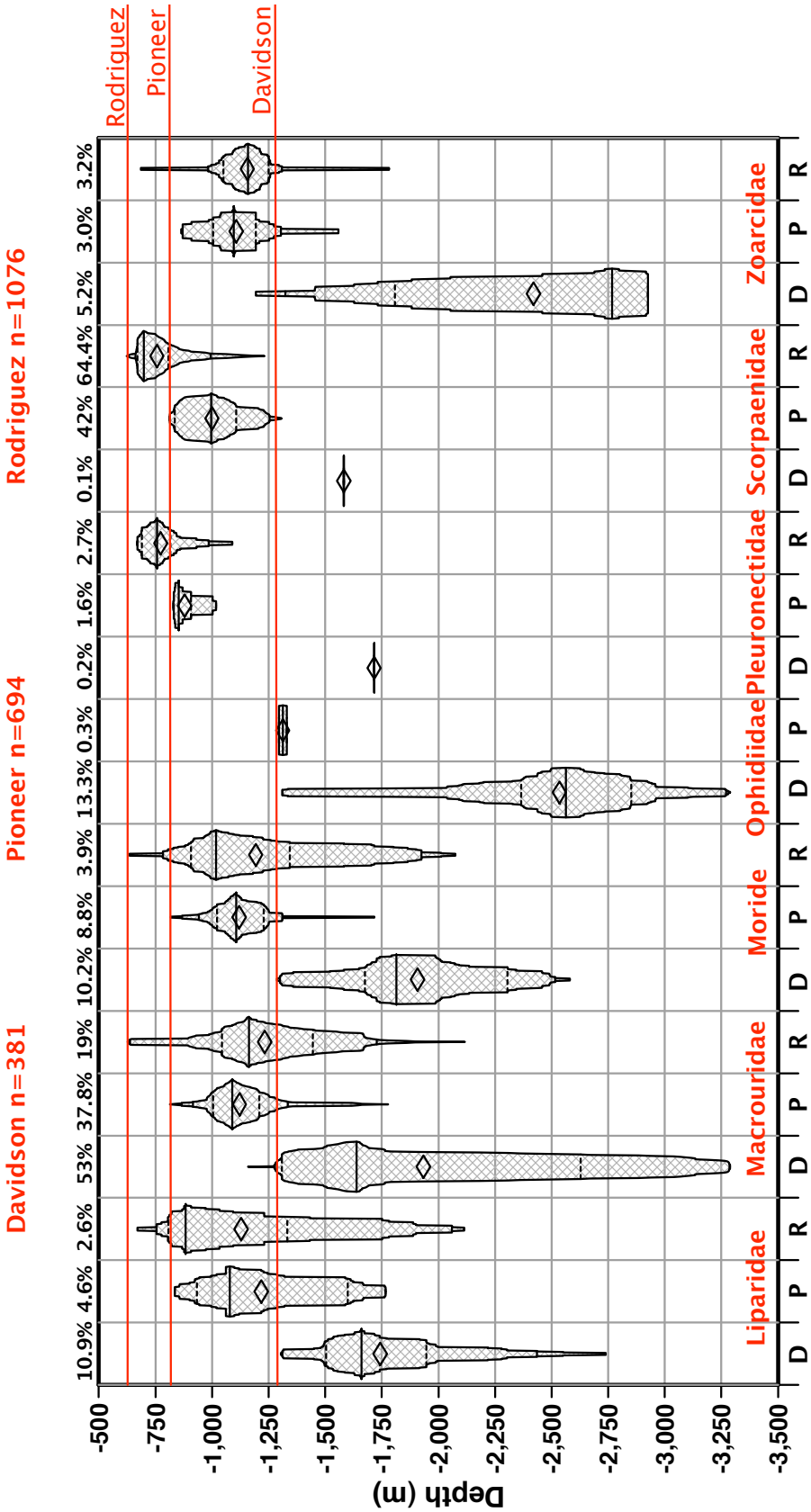
Fig. 15, Mean of E* calculated from E* each location (+/- Standard Error) for Seamount Corals in 8 Aspect Categories. Positive values indicate increased utilization of habitat type; negative values indicate less habitat selectivity. Corals appear to utilize habitats with northwest, southwest, and west facing slopes.
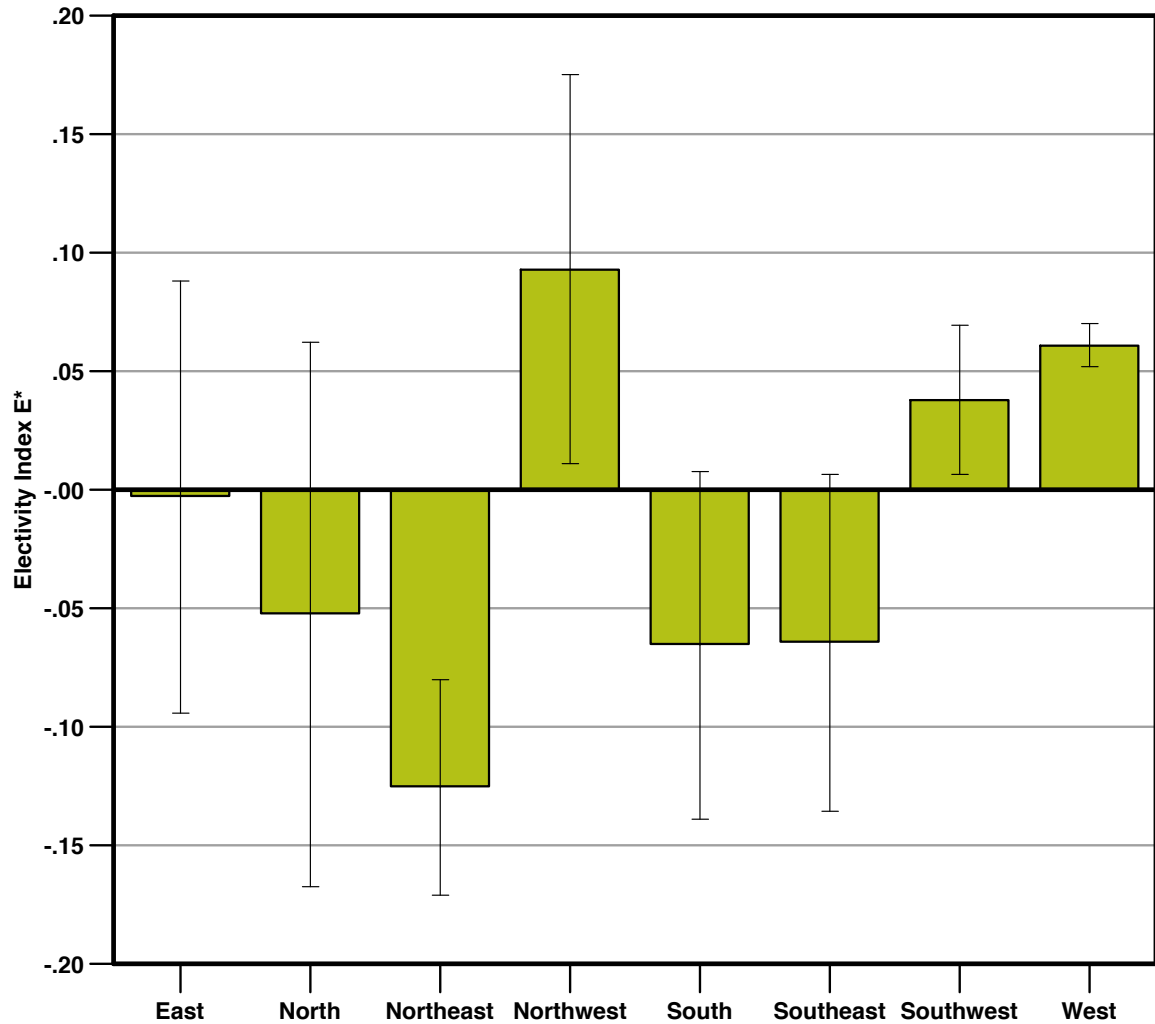
Fig. 16, Mean of E* calculated from E* each location (+/- Standard Error) for Seamount Corals in three calculated slope types. Positive values indicate increased utilization of habitat type; negative values indicate less habitat selectivity. Corals appear to utilize habitats with moderate (11° - 30°) and steep (>30°) slopes when compared with available habitat.
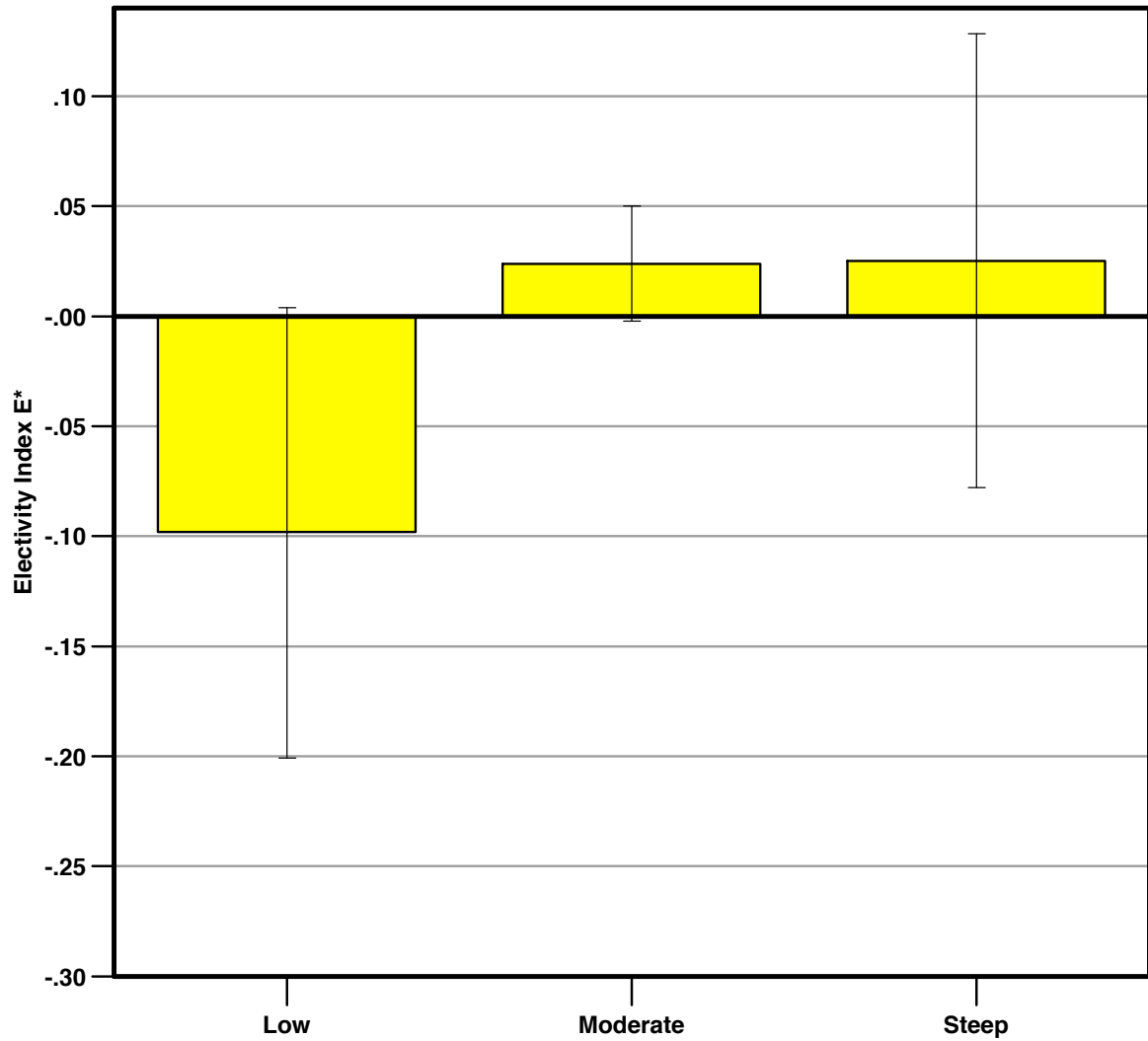
Fig. 17, Mean of E* calculated from E* each location (+/- Standard Error) for Seamount Corals in three categorized BPI types. Positive values indicate increased utilization of habitat type; negative values indicate less habitat selectivity. Corals appear to utilize habitats with peak BPI values when compared with habitat availability.
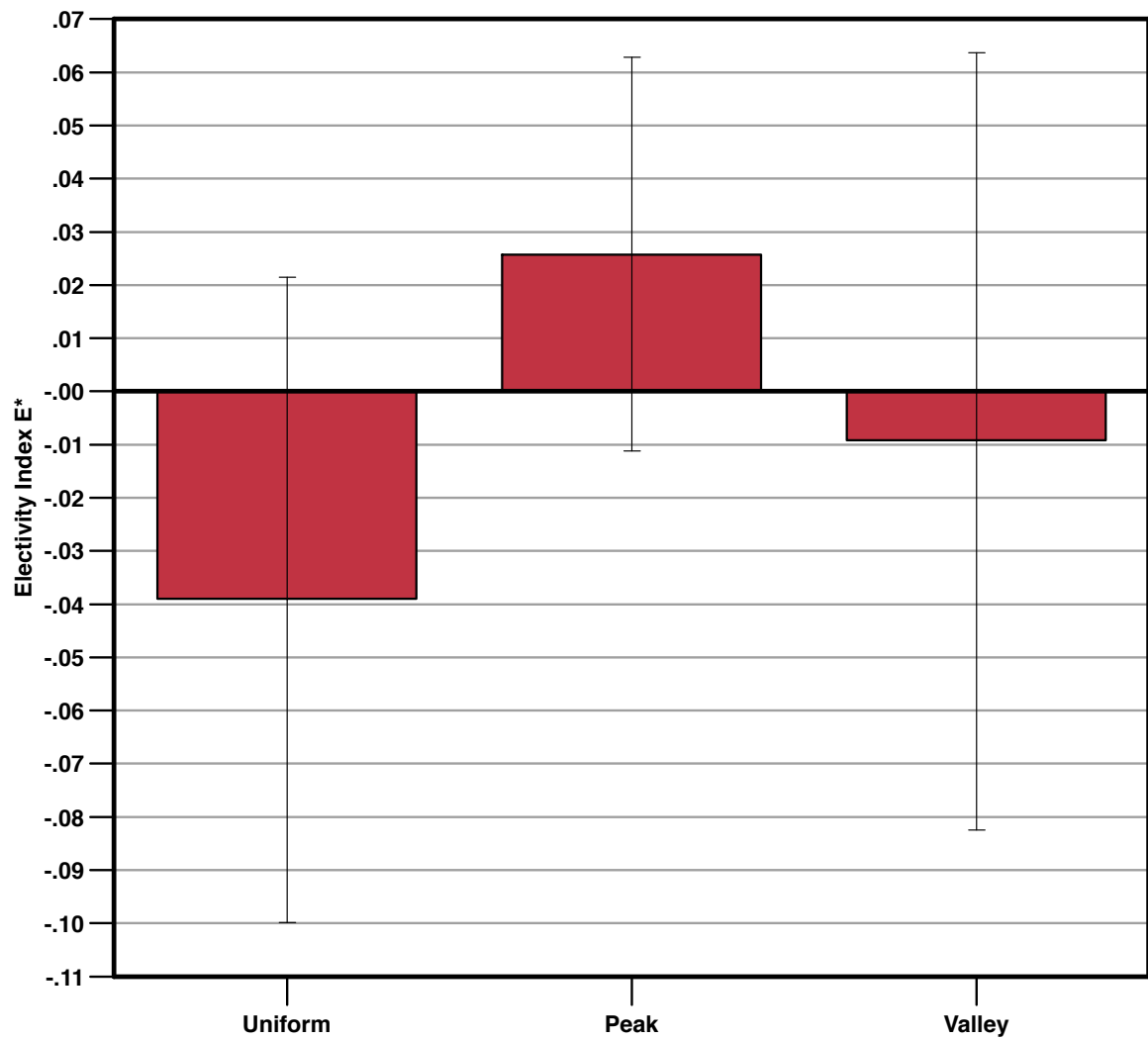
Fig. 18, Mean of E* calculated from E* each location (+/- Standard Error) for Seamount Porifera in 8 Aspect Categories. Positive values indicate increased utilization of habitat type; negative values indicate less habitat selectivity. Porifera appear to utilize habitats with northeast and southwest facing slopes.

Fig. 19, Mean of E* calculated from E* each location (+/- Standard Error) for Seamount Porifera in three calculated slope types. Positive values indicate increased utilization of habitat type; negative values indicate less habitat selectivity. Porifera appear to utilize habitats with low (<11°) and moderate (11° - 30°) slopes when compared with available habitat.

Fig. 20, Mean of E* calculated from E* each location (+/- Standard Error) for Seamount Porifera in three categorized BPI types. Positive values indicate increased utilization of habitat type; negative values indicate less habitat selectivity. Porifera appear to utilize habitats with uniform and peak BPI values when compared with habitat availability.

Fig. 21, Mean of E* calculated from E* each location (+/- Standard Error) for Seamount Echinodermata in 8 Aspect Categories. Positive values indicate increased utilization of habitat type; negative values indicate less habitat selectivity. Echinoderms appear to utilize habitats with northeast, south, southeast, and southwest facing slopes.
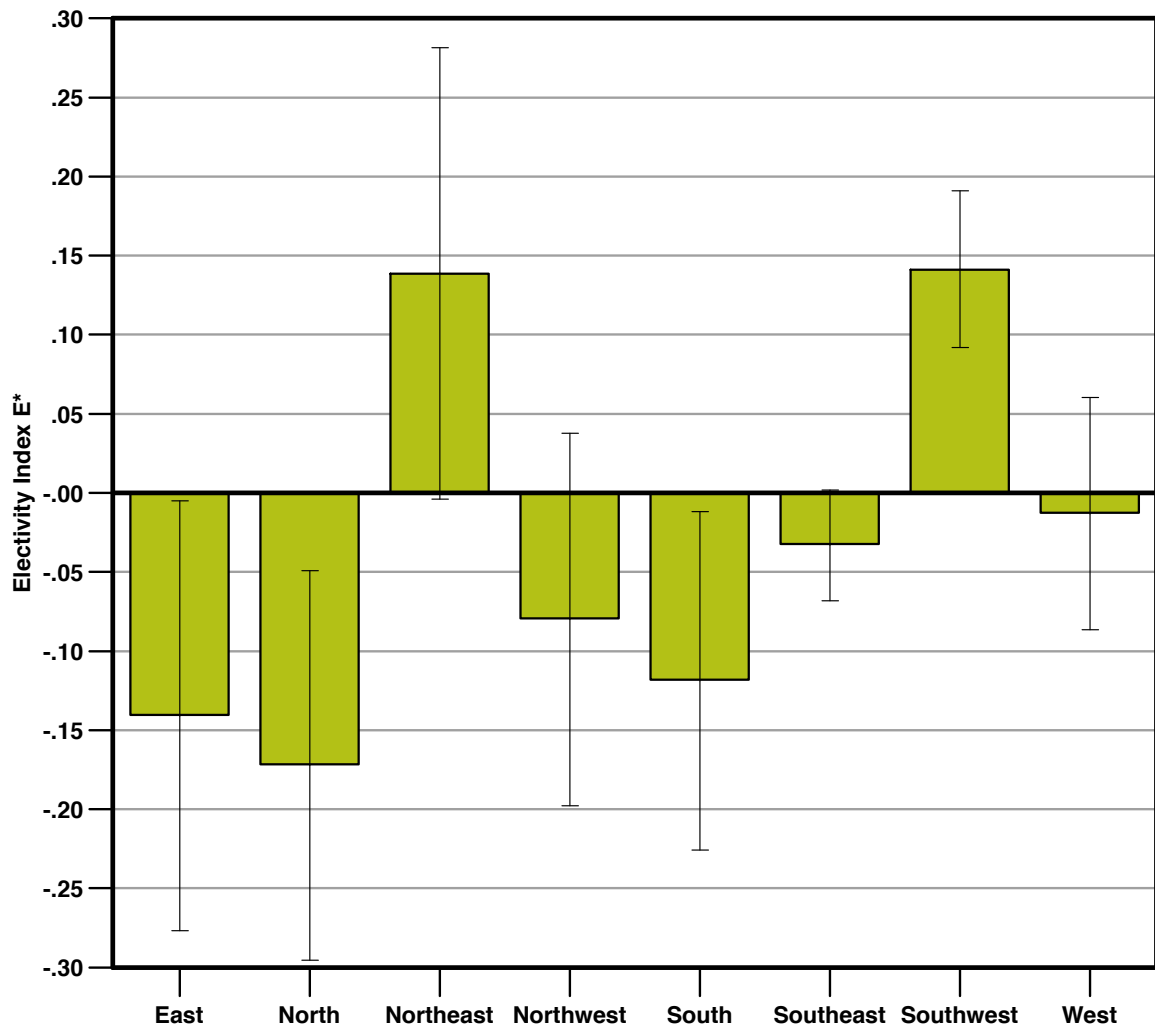
Fig. 22, Mean of E* calculated from E* each location (+/- Standard Error) for Seamount Echinodermata in three calculated slope types. Positive values indicate increased utilization of habitat type; negative values indicate less habitat selectivity. Echinoderms appear to utilize habitats with low (<11°) and steep (>30°) slopes when compared with available habitat.
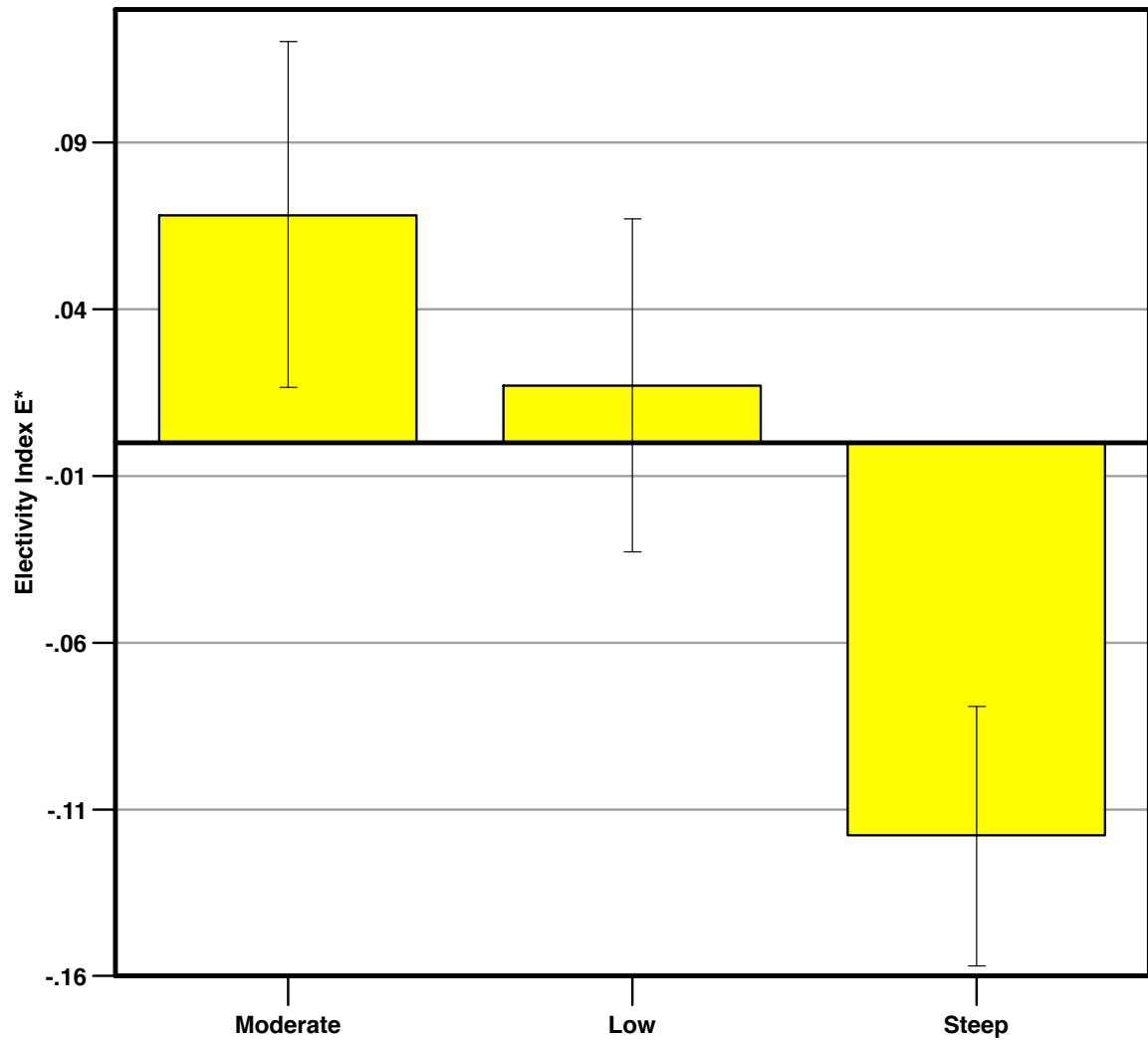
Fig. 23, Mean of E* calculated from E* each location (+/- Standard Error) for Seamount Echinodermata in three categorized BPI types. Positive values indicate increased utilization of habitat type; negative values indicate less habitat selectivity. Echinoderms appear to utilize habitats with valley BPI values when compared with habitat availability.
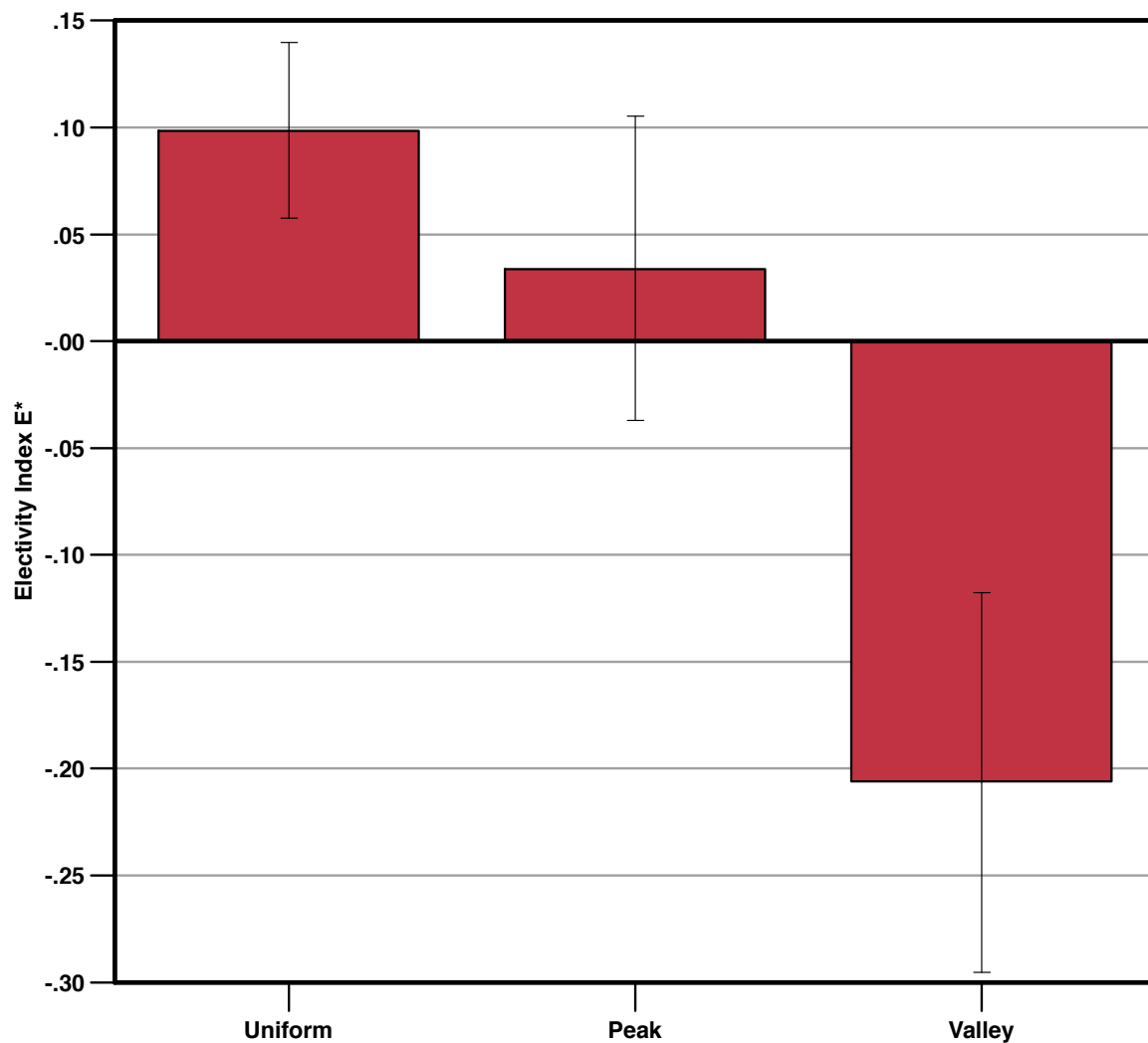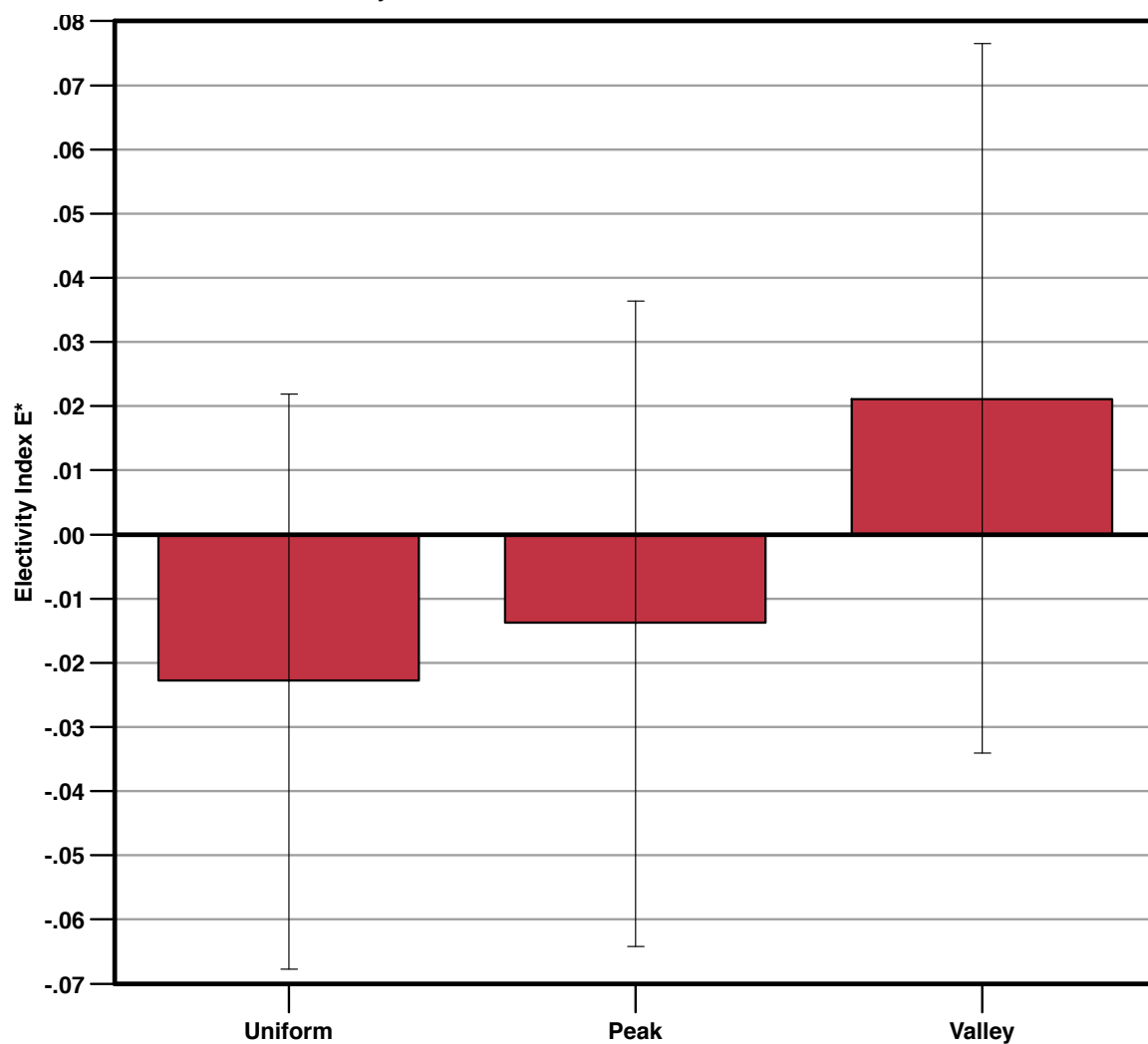
Fig. 24, Mean of E* calculated from E* each location (+/- Standard Error) for Seamount fishes in 8 Aspect Categories. Positive values indicate increased utilization of habitat type; negative values indicate less habitat selectivity. Fishes appear to utilize habitats with north, northwest, and southeast facing slopes.
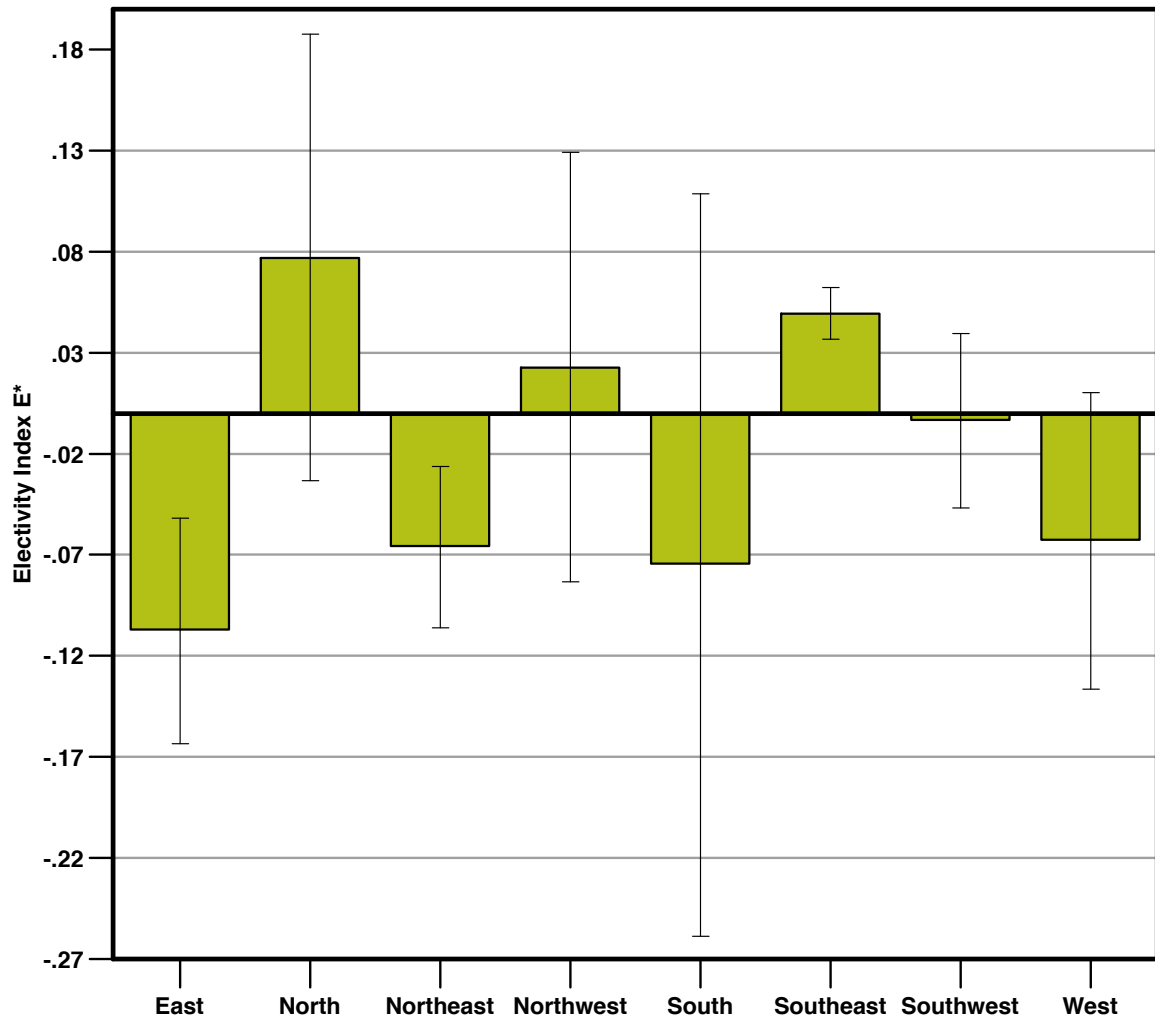
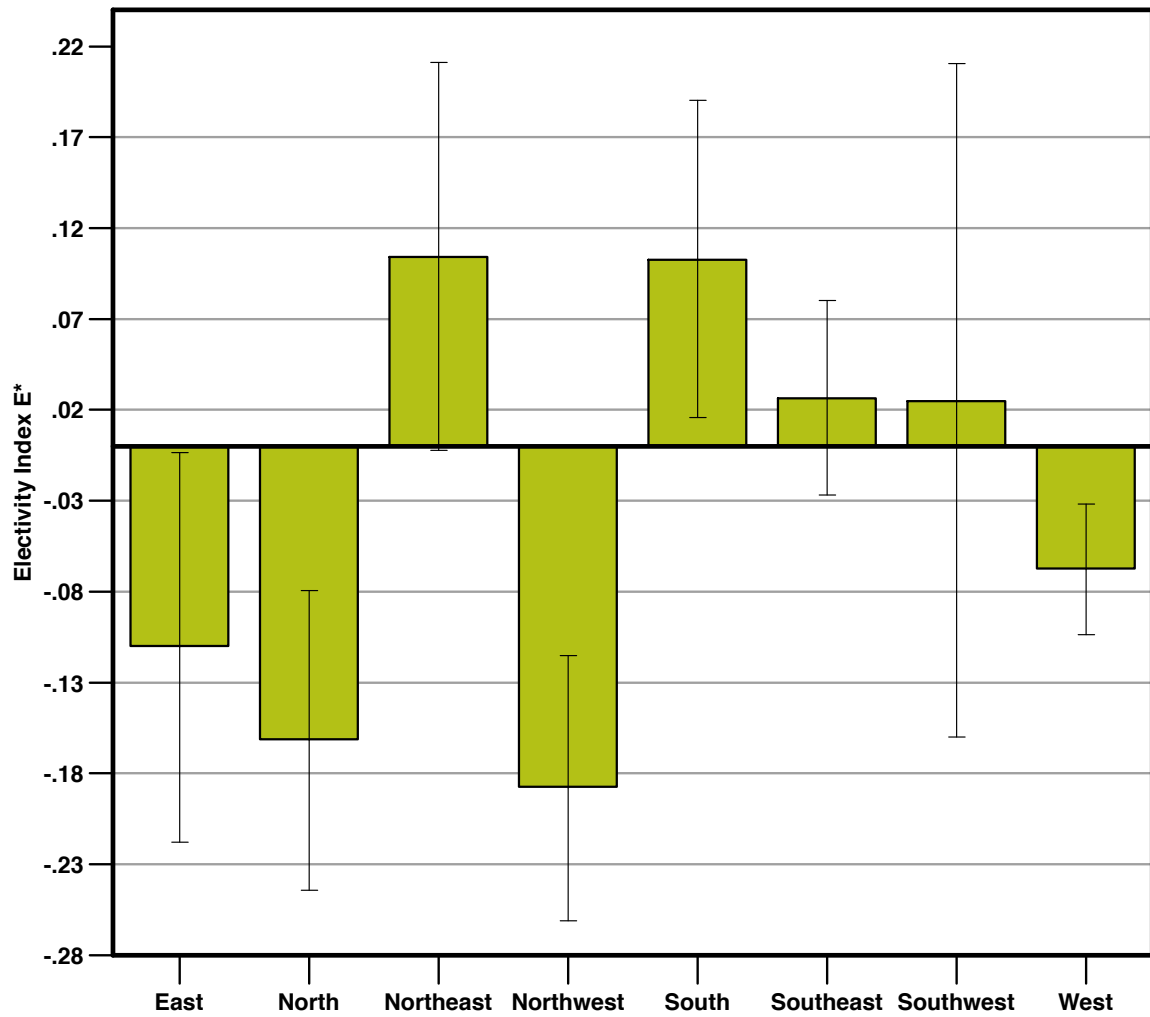Fig. 25, Mean of E* calculated from E* each location (+/- Standard Error) for Seamount fishes in three calculated slope types. Positive values indicate increased utilization of habitat type; negative values indicate less habitat selectivity. Fishes appear to utilize habitats with low (<11°) slopes when compared with available habitat.
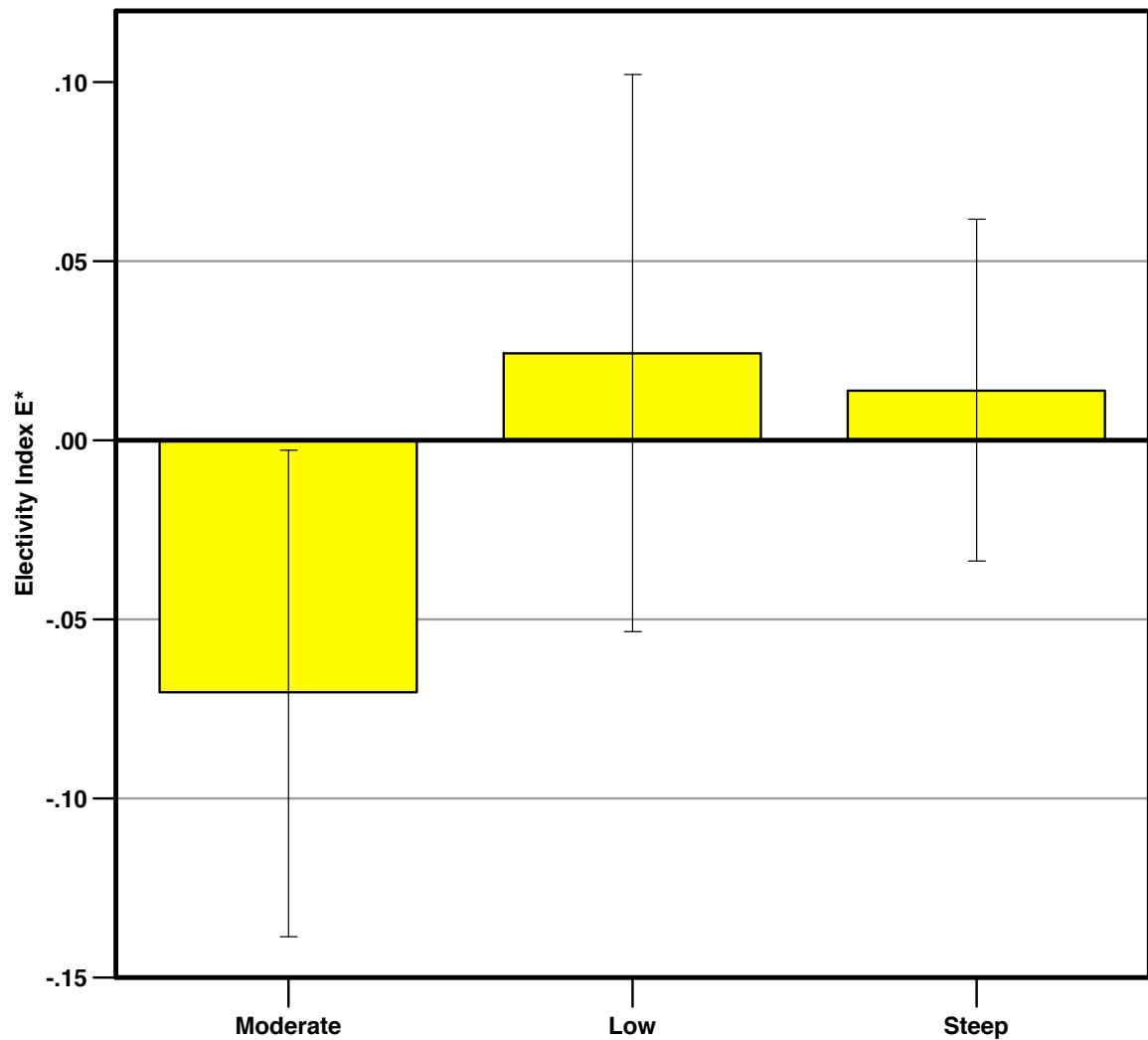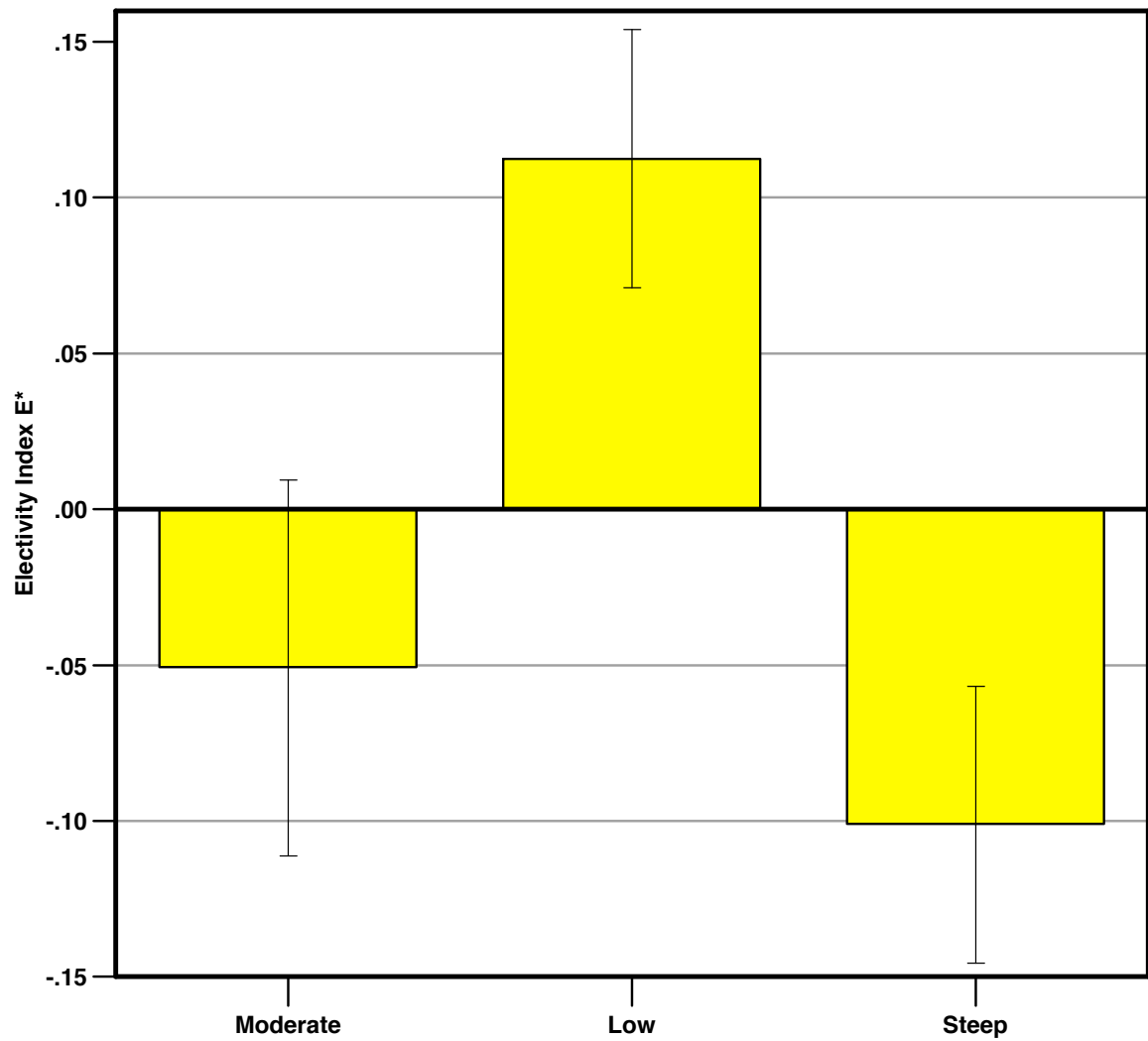
Fig. 26, Mean of E* calculated from E* each location (+/- Standard Error) for Seamount fishes in three categorized BPI types. Positive values indicate increased utilization of habitat type; negative values indicate less habitat selectivity. Fishes appear to utilize habitats with valley and uniform BPI values when compared with habitat availability.
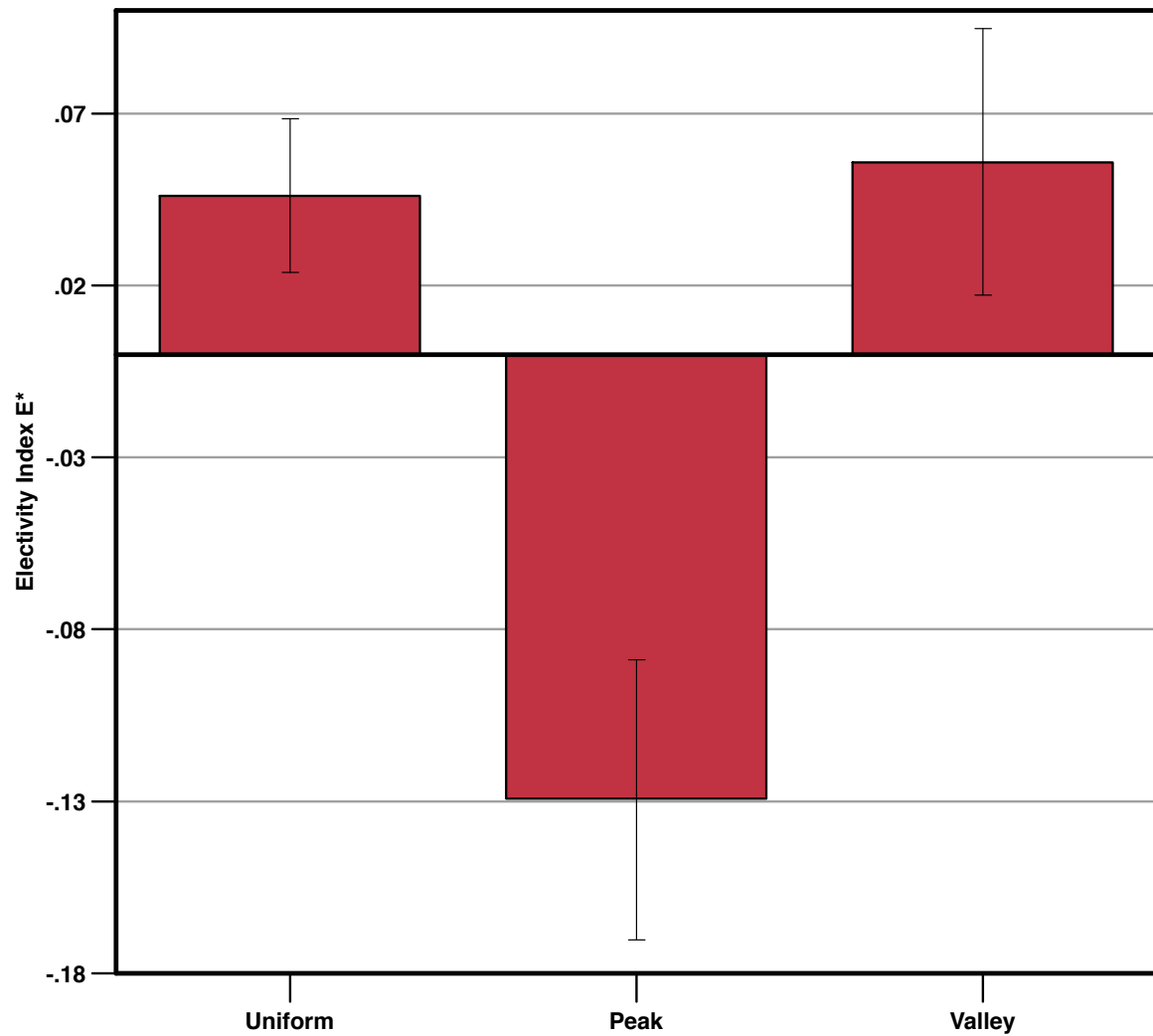
Fig. 27, Dendrogram of Bray-Curtis similarty coefficients calculated using Primer V6 using standardized and fourth root transformed taxa abundance data.
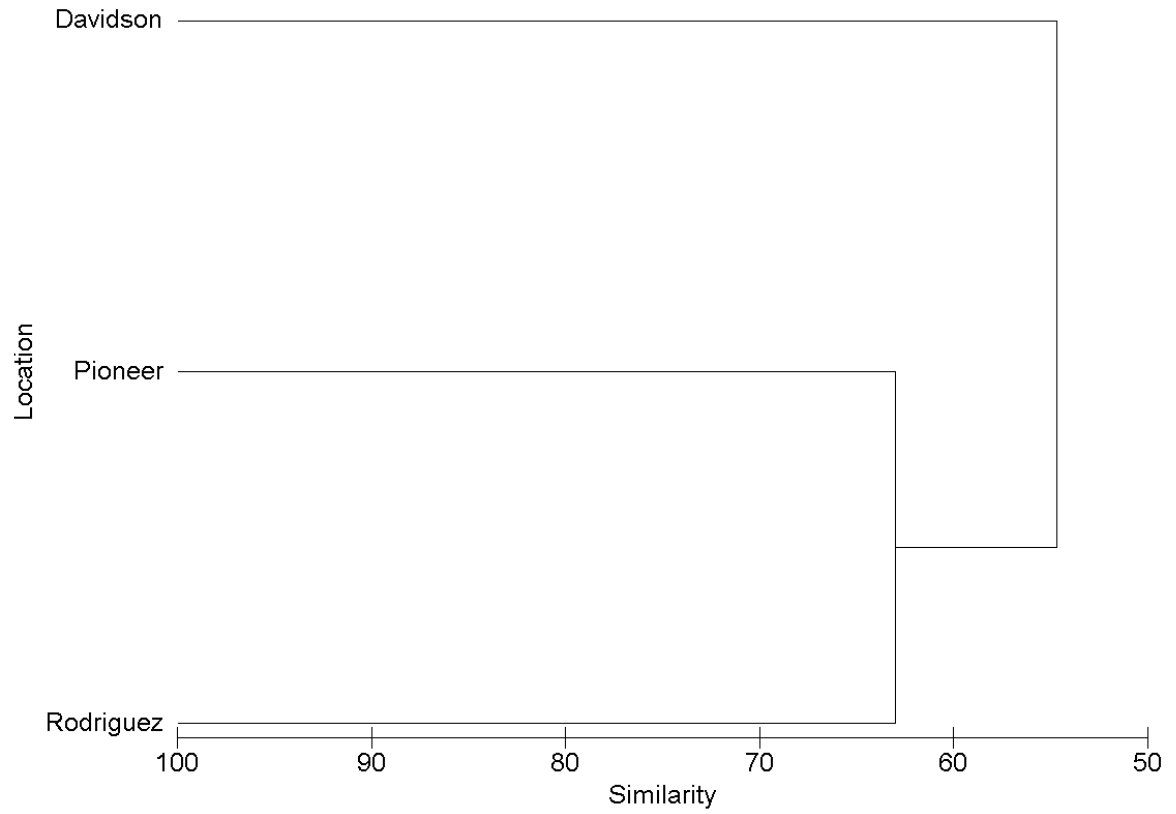
Table 1, Seamount dimensions, distance from shore, and depths sampled.

Seamount	Length (km)	Width (km)	Base Depth (m)	Summit Depth (m)	Depths Sampled (m)	Percent of depths sampled	Distance from Shore (km)
Davidson	~42	13.5	3656	1246	1256 - 3289	90%	~90
Pioneer	~12.8	~12.8	2750	811	811 - 1815	66%	~80
Rodriguez	~12.8	~12.8	2325	619	619 - 2120	91%	~60

Table 2, Video transects collected at Pioneer and Davidson Seamounts varied in depth, length, and width. Pioneer Seamount had higher mean density, when compared with Davidson.

Pioneer			
Variable:	**Length**	**Width**	**Organism Density**
Min.:	66.8	1.57	1.1
Max.:	261.6	2.62	3.2
Mean:	166.4	2.2	2.2
Std. Err.:	22.5	0.2	0.3
N:	7	7	7
Davidson			
Variable:	**Length**	**Width**	**Organism Density**
Min.:	45.11	0.97	0.1
Max.:	444.97	8.17	2.2
Mean:	177.7	3.1	0.9
Std. Err.:	17.1	0.3	0.1
N:	33	33	33

Table 3, Identified seamount taxa and number of observations at each seamount.

Taxa	Davidson	Pioneer	Rodriguez
Abyssocucumis abyssorum	0	0	3
Acanella	75	27	15
Acanthogorgia	842	1014	1558
Acesta mori	622	55	67
Acesta sphoni	0	0	9
Actinernus	18	1	42
Actiniaria sp. 1 (Orange)	208	58	161
Actiniaria sp. 2 (Pink)	2	8	14
Actiniaria sp. 3 (Red)	11	1	233
Actiniaria sp. 4 (White)	8	10	87
Actiniaria sp. 5 (Yellow)	91	0	17
Actinostola	1	0	0
Albatrossia pectoralis	0	0	4
Aldrovandia	1	0	0
Alepocephalus tenebrosus	3	1	0
Allocentrotus fragilis	0	0	40
Amblyraja badia	1	0	0
Ampheraster marianus	0	0	3
Anoplopoma fimbria	0	0	13
Anteliaster	1	0	2
Anthomastus ritteri	858	5279	2386
Anthomastus sp. 1 (Orange)	1	1	0
Anthoptilum grandiflorum	0	0	403
Anthoptilum murrayi	0	0	201
Antimora microlepis	42	61	42
Antipathes	32	0	0
Arachnactis	0	0	2
Asbestopluma sp. 1	21	309	0
Asbestopluma sp. 2 (Branched)	404	0	0
Asteroidea sp. 1 (LRGWHT)	17	10	7
Asteronyx	0	0	3
Atlantisella	11	41	0
Bathycrinidae	743	0	0
Bathydoridae	1	0	0
Bathypathes	78	8	1
Bathyraja abyssicola	1	7	17
Bathyraja trachura	0	1	0
Bathysiphon	0	1	0
Benthoctopus	7	30	8
Benthodytes	2	0	5
Benthopecten claviger	0	109	0
Bothrocara brunneum	3	0	27
Brachiopoda	1	1	0
Brisingida	493	49	990

Taxa	Davidson	Pioneer	Rodriguez
Bryozoa sp. 1 (White)	20	0	0
Bryozoa sp. 2 (Yellow)	33	0	0
Calliostoma	2	10	8
Callogorgia	0	0	3
Caprellidae	9	0	0
Careproctus	2	0	1
Careproctus microstomus	0	0	1
Careproctus ovigerum	19	22	18
Caryophyllia	51	21	15
Cataetyx	16	1	6
Caulophacus	7	3	7
Caymanostella	0	0	1
Ceramaster clarki	0	0	94
Ceramaster patagonicus	3	1	6
Cerianthidae	210	56	256
Chionoecetes	0	39	1
Chonelasma	853	716	361
Chorilia longipes	1	24	0
Chrysogorgia monticola	128	0	4
Chrysogorgia pinnata	68	0	0
Cidaridae	10	0	7
Cirripedia	149	0	12
Cladorhizida pteron	0	0	27
Clavularidae	0	0	4
Cnemidocarpa sp.	4	24	5
Corallimorphus	14	1	15
Corallimorphus pilatus	0	0	2
Corallium	2992	2	108
Coryphaenoides acrolepis	16	1	122
Coryphaenoides armatus	4	0	0
Coryphaenoides cinereus	9	2	27
Coryphaenoides leptolepis	3	0	0
Crinoidea sp. 1 (SMWHT)	763	5	93
Crinoidea sp. 2 (WHTSTALKED)	44	0	0
Culeolus	29	5	4
Cystechinus loveni	43	0	0
Cystocrepis	2	0	0
Dromalia alexandri	1	0	11
Echinaster	0	1	1
Echinoidea sp. 1	0	2	2406
Echinoidea sp. 2	6	0	0
Echiura	0	1	2
Edwardsiidae	0	0	1
Enteropneusta	64	3	22

Taxa	Davidson	Pioneer	Rodriguez
Eolidoidea	0	2	0
Eptatretus stoutii	0	0	6
Evoplosoma	2	1	5
Farrea	3325	836	2640
Flabelligeridae	0	1	0
Florometra serratissima	5799	7644	3278
Forcipulatida	0	0	6
Galatheidae	344	714	371
Galatheoidea	0	26	0
Gastropoda	24	160	20
Glyptocephalus zachirus	0	0	1
Goniasteridae	0	0	18
Gorgonocephalus	4725	9	83
Graneledone boreopacifica	0	20	14
Halipteris californica	0	2	3
Henricia	262	81	222
Henricia sp. 2 (Yellow)	9	0	0
Heterochone sp. 1	251	1309	177
Heterochone sp. 2 (Yellow)	16	3	37
Hexactinellida sp. 1 (Yellow)	0	43	106
Hippasteria californica	2	0	153
Hippasteria spinosa	7	49	7
Holothuroidea sp. 1 (PINK)	14	1	41
Holothuroidea sp. 2 (Pink Smooth)	641	1	96
Holothuroidea sp. 3 (Purple Smooth)	2	0	0
Holothuroidea sp. 4 (Red)	2	0	0
Holothuroidea sp. 5 (Red Lumpy)	292	0	0
Holothuroidea sp. 6 (Red Smooth)	8	0	0
Hormathiidae	313	103	180
Hydractinidae	2	0	0
Hydrasterias	0	0	5
Hydrolagus trolli	3	0	0
Hydrozoa	90	18	2
Hydrozoa COLONY	11	2	0
Hymenaster koehleri	13	0	15
Hyocrinus	856	6	438
Ischnomesidae	0	0	1
Isidella	0	1330	1953
Javania Cailleti	21	0	0
Keratoisis	2880	1169	627
Kophobelemnon	0	2	0
Laetmogone	1171	0	0
Laetmonice	2	0	0
Lepidisis	385	3085	4

Taxa	Davidson	Pioneer	Rodriguez
Lillipathes	283	8	0
Liparidae sp. 1 (Black Head)	2	0	0
Liponema brevicornis	5	0	9
Lithodes	2	0	0
Lithodes cousei	0	41	0
Lophaster furcilliger	4	2	2
Luciobrotula	0	2	0
Luidia foliolata	0	0	1
Lycenchelys	2	10	0
Mediaster	9	3	110
Megalodicopia hians	8	20	1
Meseres	0	2	0
Microstomus bathybius	0	11	27
Myriothelidae	1	0	0
Myxoderma sacculatum	5	0	96
Narella	29	1	1766
Nemertea	4	0	0
Neolithoides diomedae	0	0	10
Neoloricata	24	16	32
Nephtheidae	0	75	35
Neptunea	0	40	76
Oneirophanta mutabilis	21	635	0
Ophiacanthidae	20	195	397
Ostreidae	1	0	0
Pachycara bulbiceps	9	0	0
Paelopadites confundens	90	0	0
Pandalopsis ampla	200	214	202
Pandalus platyceros	0	0	1
Pannychia moseleyi	758	576	2029
Paragorgia arborea	1410	143	34
Paragorgia **sp. 1**	1	609	825
Paragorgia **sp. 2 (Purp)**	0	7	2
Paralithodes	3	5	0
Paralomis multispina	13	5	1
Paralomis verrilli	13	20	47
Parastenella	1011	55	1745
Patellacea	7	0	0
Pectinidae	3	0	0
Peniagone leander	70	0	0
Pennatulacea sp. 3	0	0	1
Pentametrocrinus	4	35	14
Peribolaster biserialis	0	0	6
Pleuronichthys coenosus	0	0	1
Poecilosclerida	295	0	0

Taxa	Davidson	Pioneer	Rodriguez
Polynoidae	36	1	2
Porifera sp. 1 (Basket Sponge)	0	7	1
Porifera sp. 2 (Barrel or hexactinellida)	67	278	0
Porifera sp. 3 (Candelabra)	533	0	0
Porifera sp. 4 (Clamshell)	1	0	0
Porifera sp. 5 (Cup)	1	0	0
Porifera sp. 6 (Long Corregated)	1	0	0
Porifera sp. 7 (Fluffy)	0	0	16
Porifera sp. 8 (Fuzzy)	0	0	3
Porifera sp. 9 (Pipe)	0	4	0
Porifera sp. 10 (Siphonophore)	550	23	0
Porifera sp. 11 (Vase)	23	10	4
Porifera sp. 12 (White Lattice Sponge)	1	0	13
Porifera sp. 13 (Yellow Ruffled Sponge)	320	0	5
Porifera sp. 14 (Lolipop)	1	0	0
Primnoidae	2334	88	62
Pseudarchaster dissonus	0	22	3
Psolus squamatus	1	1691	4391
Psychrolutes phrictus	2	0	0
Pteraster	37	2	4
Pycnogonida	21	9	11
Raja	0	0	1
Regadrella	31	0	0
Sabellidae	51	4	74
Saccocalyx	38	2	0
Scalpellidae	94	0	0
Sclerothamnopsis	4275	123	31
Scotoplanes globosa	19	1	0
Scyliorhinidae	0	1	1
Sebastes	0	5	2
Sebastolobus	1	287	691
Serpulidae	89	10	4
Solaster	39	117	0
Solaster borealis	18	118	9
Somniosus pacificus	0	0	1
Spectrunculus grandis	56	0	0
Staurocalyptus	2817	967	228
Stephalia dilata	17	0	0
Stomphia	0	0	1
Swifta simplex	0	213	254
Swiftia kofoidi	5	668	7
***Swiftia* sp. 1 (White Polyps)**	0	0	168
Synaphobranchidae	1	0	0
Tarsaster	0	0	1

Taxa	Davidson	Pioneer	Rodriguez
Terebellidae	1	1	0
Thenaria	0	0	1
Thenea muricata	1	1190	180
Tjalfiella	1	0	0
Trissopathes pseudotristicha	3330	3	5
Tritonia	1	9	16
Tromikosoma hispidum	3	0	0
Tromikosoma panamense	4	0	4
Tubularidae	1	0	5
Umbellapathes	101	0	0
Umbellula magniflora	0	0	47
Xenophyophorea	15	0	0
Zoanthidea	16	0	9
Zoarcidae	8	8	7
Zoroaster	4	3	2
Zoroasteridae	50	0	0