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The Physical Characteristics of Nearshore Rocky Reefs in The Southern California Bight

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Abstract.—We present a GIS method for mapping and characterizing nearshore reef habitats. Utilizing this technique, we were able to successfully map all nearshore (<30 m depth) rocky reefs in the Southern California Bight and then quickly assess and characterize these data layers with expert opinion. The southern California coastline is 1198 km in length, with the eight Channel Islands and mainland comprising 503 km and 695 km of coastline, respectively. This is approximately the same amount of coastline as the rest of California. Within this region, we identified and characterized 122 natural reefs comprising 49,055 hectares, which is 26.6% of the 184,439 ha of nearshore habitat in the bight, the remainder comprised of soft bottom. Reefs varied appreciably in size ranging from 6 – 2498 ha. We sampled a subset of these reefs using a generalized random tessellation stratified design and quantified their physical characteristics as measured by scuba surveys. The reefs also varied with respect to habitat type and five distinct sub-habitat types varying from sheer oceanic pinnacle reefs to low-lying cobble were observed. The distribution of reef types varied between the mainland and islands. Island reefs were, in general, higher relief and had a greater percentage of rocky substrate. Mainland reefs generally had lower relief and a higher percentage of sand and cobble substrates.

The Southern California Bight (SCB) is a unique and increasingly critical stretch of the California coastline. The physical constitution of the coastline along the mainland SCB is primarily picturesque sandy beaches, broken up by rocky-headlands. In contrast, the remainder of the state is dominated by iconic palisades associated with the coastal uplift from the shearing of the right-lateral strike slip-transform San Andreas fault system (Zoback et al. 1987). Similar and associated strike-slip faults and resulting uplift are the origins of the major coastal headlands in the SCB that are broken up by sandy beaches (Emery 1960). The San Andreas fault system that runs along the coast in central and northern California moves inland proximate to Point Conception the upper limit of the bight. The SCB is floored by a ~300 km wide region of extensively faulted and extended continental crust comprising Mesozoic metamorphic and intrusive igneous rock as well as Neogene sedimentary and volcanic units (Crouch and Suppe 1993). This region of submerged continental crust is referred to in the geological literature as the California Continental Borderlands (CCB). It differs markedly from the continental shelf north of Point Conception, which is typically less than 100 km wide. The northern end of the CCB is formed by the east-west oriented Transverse Ranges, a large fault-bounded crustal block that

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underwent 90° of clockwise rotation between 15 MYA and 5 MYA, the age of the SCB (Luyendyk 1991). The unique east-west transverse ranges of southern California extend through the CCB as the Northern Channel Islands (San Miguel, Santa Rosa, Santa Cruz and Anacapa) and, as such, these islands are comprised of metamorphic and igneous rock (Atwater 1998). Differential subsidence along the many faults that cut the CCB has produced the distinctive topography of islands separated by ~1 km deep basins. Rotation of the transverse range block and the submergence of extended continental crust in its wake created the SCB from a preexisting coastline that had relatively straight, NW-SE trend and continuous with central and northern California (Atwater 1998).

The Northern Channel Islands currently appear as extensions of the Santa Monica Mountains and were all connected at the last glacial maximum (Graham et al. 2003). The orientation of these islands is an indication of the torsion caused by the shear of the North American and Pacific Plates forming the SCB during the Miocene (Atwater 1989). The subsequent uplift of metamorphic rock from the Catalina Schist formed Catalina Island. Meanwhile, San Nicolas Island is primarily an eroding anticline comprised of sandstone and shale marked by characteristic marine terraces with some igneous rock (Kemnitzer 1933). In contrast, Santa Barbara Island juts imposingly out of the sea with vertical cliffs up to 150 m in height and is comprised of brittle igneous rock, which exhibits less pronounced marine terracing. Kemnitzer (1933) also noted that a rock sample he received from Begg Rock, an exposed pinnacle reef 8 km off the west end of San Nicolas Island was also volcanic. San Clemente Island lies on the San Clemente fault, is formed of volcanic rock and has an anticlinal structure and prominent marine terracing (Olmsted 1958). The origins of the various rocky reef habitats in the SCB are diverse and complex, with considerable spatial variability.

It was previously estimated that the amount of nearshore reef habitat (< 30 m depth) was proportional to the rocky intertidal habitat, approximately 15% of the mainland (Stephens et al. 2006). The southern California islands, however, support a greater proportion of coastal reefs versus soft substrate in the nearshore environment (Ebeling 1980, Pondella and Allen 2000). Due to accessibility and increasing stress by a growing population, these reefs are under a variety of anthropogenic stressors (e.g., turbidity, river plumes, sedimentation, overfishing and pollution) and subject to harmful algal blooms (Stull et al. 1987, Horner et al. 1997, Dojiri et al. 2003, Schiff 2003, Love 2006, Pondella 2009, Foster and Schiel 2010, Sikich and James 2010, Erisman et al. 2011), which in many instances are not well understood and in all cases necessitate a bight-wide perspective and coordination to contextualize and manage. These reefs have been impacted by sewage, habitat loss, runoff and climate change and, as such, can serve as a model for dealing with these complex anthropogenic interactions (North 1964, Steneck 2002, Ford and Meux 2010). It has been demonstrated that large-scale management actions can have significant positive effects on this complex ecosystem (Pondella and Allen 2008). In 2012, a network of Marine Protected Areas (MPAs) was created throughout the Bight (CDFG 2012). These MPAs were generally placed on rocky headlands, as this habitat is limited in the region. This limited reef habitat was the most contentious issue during the implementation process even though the amount of this reef habitat and the relative spatial distribution and characterization remained unknown making current and future evaluations difficult (Pondella 2009). Marine Protected Areas in California limit catch of extractable resources within their boundaries (CDFG 2012). The establishment of these MPAs, while not specifically designated as fishery management tools during implementation, was in part due to the decline of commercial and recreational fisheries. Fisheries associated with rocky reefs in the region have been particularly impacted. Examples include rockfishes (Love et al. 1998), abalone (CDFG 2005) and most recently the kelp and sand basses (Erisman et al. 2011), and these serial depletions have caused significant socioeconomic damage. A critical task for advancing various research, restoration, assessment and resource management programs is the quantification and characterization of this nearshore habitat.

While general biogeographic patterns have been discerned for this ecosystem (Murray and Littler 1981, Pondella et al. 2005), the gap in our knowledge of the quantity, structure and habitat quality of shallow nearshore reefs in the SCB is surprising. These gaps in knowledge are similar in other ecosystems where management actions need to be implemented and managers are challenged by a paucity of quantitative data (Mumby and Harborne 1999, Pittman et al. 2011). Further complicating our understanding of this nearshore ecosystem is the necessity of modeling processes on both small and large spatial scales (10^1–10^5 m) (Garcia-Charton 2004) as physical forcing and associated oceanographic conditions will be critical for contextualizing reef performance into the future. Similarly, easily expressible metrics of ecosystem health are needed for managers and non-scientific audiences. While the declines in fishery species are well documented, the effects of pollution on rocky reefs in this area are not well understood. Whether analyzing pollution, fishing practices, or ecological performance (including MPA effectiveness), these processes are all couched within the extent, characteristics and variation in the underlying habitat. Here we report on a novel method to determine the spatial scale of reefs in the SCB. Then, we contextualize this system by describing the underlying substructure and amount of nearshore rocky reefs in the region establishing a template for future research.

Materials and Methods

The methods in this study were composed of three sections. First, we assembled and mapped all the available GIS layers for the region. The remote sensing techniques used in this study did not characterize reef types. Thus, these hard bottom layers were then reviewed by experts in the region to determine accuracy and characterize habitat types. Following this mapping exercise, we conducted a stratified random draw to determine sites for a field-sampling program based upon biogeographic region (which were based upon fish assemblages) insuring statistically equal representation of reefs throughout the SCB. The field-sampling program then characterized a subset of reefs allowing inferences to the reef types of the SCB as a whole.

Mapping.—The best available compilations of mapped rocky reef habitat in the SCB were assembled using GIS. These included maps of hard bottom habitats and kelp canopy (Kelner 2005). GIS spatial analysis techniques were used to integrate existing spatial data that characterizes bottom type, kelp cover, and bathymetry to create a preliminary habitat map. Using these data in GIS, we met with experts who have conducted multiple subtidal scuba research projects on various geographic areas of the SCB. These working groups delineated reefs ($<$ 30 m depth) (Figure 1) and categorized each as either a major reef complex, patchy reef complex, cobble reef, offshore or pinnacle reef, or manmade. Reef dimensions were made based upon the available GIS layers, while reef types were based upon expert opinion. The size of each reef was calculated in GIS and categorized as large, medium or small based upon the distribution of reef sizes. All other nearshore ($<$ 30 m depth) substrate was classified as soft bottom. In better-studied regions (e.g., Palos Verdes, Santa Catalina Island) investigators identified reefs on a finer scale (continuous reef tracts were identified as multiple smaller reefs). Therefore, so as not to bias the sampling draw by these regions for the survey portion of this study (see below), reefs in these regions were grouped into larger reef areas. Similarly, to not deemphasize large reef tracks, reef designations were adjusted to be as consistent as possible in size and distribution throughout the bight while mindful of natural habitat gaps. At Horseshoe Kelp in Los Angeles County and Point Loma, the large reef areas were broken into two and three reefs, respectively, for the sampling draw so as to not underestimate their impact.

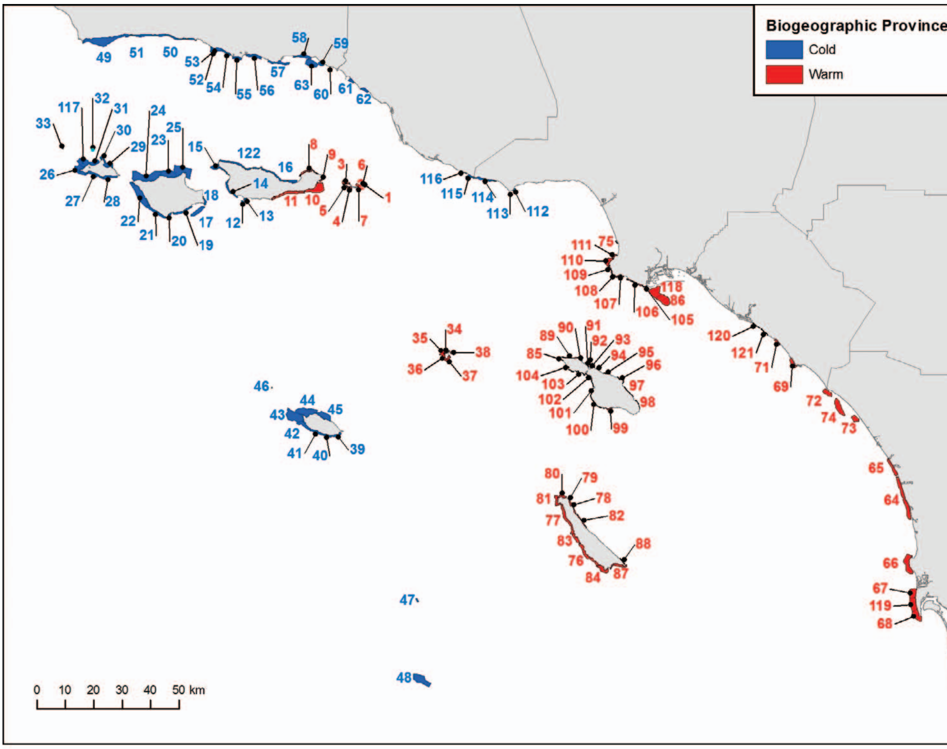

Fig. 1. Nearshore rocky reefs of the SCB. Reefs are color coded by biogeographic province (cold vs. warm) and numbers correspond to the table used for the sampling draw (Appendix 1).

Station Draw.—Reefs were coded as island or mainland within each biogeographic province, San Diegan (warm temperate) or Oregonian (cold temperate). Biogeographic province (Appendix 1) was determined for the eight Channel Islands by biogeographic assessment of benthic fish assemblages studied during the 2003–04 CRANE survey (Tenera 2006). In this biogeographic analysis young-of-year (YOY) fishes whose density is seasonal, and highly abundant pelagic species (*Engraulis mordax* and *Sardinops sagax*) present at only two sites, were excluded from the data set. All statistics were run using PRIMER (version 6). The number of fishes observed by station was Log (x+1) transformed. A Bray-Curtis similarity matrix was then calculated and a hierarchical cluster analysis was performed. Using the similarity matrix, non-metric multi-dimensional scaling was performed and using 45% similarity ellipses calculated from the Bray-Curtis cluster the biogeographic regions were determined (Figure 1, Appendix 1). Mainland reefs were divided along previous described biogeographic assemblages utilizing Santa Monica Bay as the faunal break between Oregonian and San Diegan faunas (Horn and Allen 1978, Horn et al. 2006). Manmade reefs (i.e., breakwaters and jetties) were not included in this mapping effort because they are well mapped and not part of the random station draw. For the spatial scale aspect of this program, 60 natural rocky reefs (Figure 1; Appendix 1) from this map were selected using a nested random draw (Stevens and Olsen 2004), a probability-based design developed for monitoring aquatic resources, through EPA's Environmental Monitoring and Assessment Program (EMAP) (Stevens 1999). The advantage of the generalized random tessellation stratified design (GRTS) is that it allows for random sampling in a way that provides good spatial coverage (without the clumping of sites often seen with simple random sampling). In addition, various strata or subpopulations can be defined and weighted proportionally to a host of subpopulation characteristics (e.g., the size of the resource, the size of the reef, variability of subpopulation estimates) so as to maximize efficiency when estimating population totals or comparing among subpopulations. Two additional reefs (Escondido and Big Rock) were not included in the random draw but were sampled as a part of this study to fill in a gap in Santa Monica Bay.

Field Sampling.—teams of SCUBA divers that accessed sample sites from a research vessel collected data visually. A single site consisted of at least 250 m of reef habitat. Within each site four depth strata (if present) were sampled and geo-referenced. These strata were the inner (~5 m), middle (~10 m), outer (~15 m) and deep (~25 m) portions of a natural reef. Within each depth stratum Uniform Point Contact (UPC) sampling protocol was completed. Therefore, the maximum sampling effort for a site includes 8 UPC transects – 2 transects per each of the 4 depth strata. All transects were 30 m in length. Substrate type and relief were recorded at each meter mark along the 30 m transect tape to estimate percent cover. Substrate type was defined as: bedrock (>1 m), boulder (1 m–10 cm), cobble (<10 cm), or sand. Substrate relief was defined as the maximum relief (0–0.1 m, 0.1–1 m, 1–2 m or >2 m) within a rectangle centered on the point that is 0.5 m along the tape and 1 m wide. The percentage of each type of substrate category (bedrock, boulder, cobble or sand) was determined by pooling the number of contact points for all replicates at each site by category, and dividing the sum of each category by the total number of contact points at that site. Percentage of reef relief category (0–0.1 m, 0.1–1 m, 1–2m or >2m) was calculated in the same manner. Reef structure categories (% relief and substrate) were square root transformed and normalized prior to being clustered using Euclidean distances.

Results

In our calculations the southern California coastline is 1198 km in length. The islands comprise 503 km of coastline while the mainland coast has a length of 695 km. On the mainland, rocky reefs are offshore (within 500 m) of 176 km (25.4%) of the coastline. At the islands, reefs are offshore of 377 km (75.1%) of the coastline. For the islands the faunal break was in the middle of Santa Cruz Island, on the mainland it fell in the middle of Santa Monica Bay (Figure 1). In the cold temperate region reefs span offshore of 290 km of the coast and in the warm temperate region they span 263 km of coastline. We identified 122 natural reefs (< 30 m depth) comprising 49,055 hectares in the SCB (Figure 1, Table 1). A greater fraction (60.8%) of reefs were found in the cold temperate. This was in part due to the Santa Rosa and San Nicolas Islands where the greatest expanse of reefs were identified (9088 and 5250, respectively). A priori, eighty-nine reefs were classified as major reef complexes, seventeen as patchy reef areas, two cobble reefs, and twelve pinnacle/offshore deep reefs (Appendix I). 10,164 ha of the reefs identified in this study were previously described as soft bottom habitat. Demarcated by the 30-m isobath, there are 184,439 ha of nearshore habitat in the bight, of which reefs comprised approximately a quarter (26.6%) while the remainder was sand.

Natural reefs (< 30 m depth) ranged in size from 6.2 (Begg Rock) to 2498 ha (Cojo) followed by Talcott at Santa Rosa Island (2493 ha) (Appendix 1). The total for three Point Loma reef designations, which are continuous, is 2296 ha. Santa Rosa and San Nicolas Islands contained the largest contiguous reef tracks and kelp beds in the SCB. The lee of Santa Rosa Island (Rodes, Talcott and Carrington Point) comprised 5284 ha and the four reefs at west end of San Nicolas Island comprised 4663 ha. On the mainland, Cojo Anchorage was the largest reef (2498 ha) followed by three Point Loma reefs. The mean size of a natural reef was 409 hectares (sd ± 497). The distribution of reef areas was plotted and reefs were classified into three size classes. Sixty-

Table 1. The following metrics for the Southern California Bight are summarized below for the islands, mainland, the cold temperate (Oregonian) and warm temperate (San Diegan) provinces: the length of the Southern California coastline (Mexico to Point Conception); reef coastline length in km (reefs which are within 500 m of the coast); and the area of natural reef habitat. The total amount of nearshore habitat in SCB is 184,439 and the non-reef habitat is primarily sand.

SCB coastline length (km)			
Mainland	694.5		
Island	502.7		
Total	1197.2		
Reef coastline length (km)			
Mainland	176.2	Cold	290.7
Island	377.4	Warm	262.9
Total:	553.6	Total:	553.6
Reef habitat (ha)	**Cold**	**Warm**	**Total**
Mainland	8213.8	10823.6	19037.4
Island	21587.4	8430.1	30017.4
Anacapa		545.1	545.1
Cortez Bank	1359.6		1359.6
San Clemente		3593.2	3593.2
San Miguel	3461.8		3461.8
San Nicolas	5249.9		5249.9
Santa Barbara Island		888.5	888.5
Santa Catalina		931.1	931.1
Santa Cruz	2365.4	2472.3	4837.7
Santa Rosa	9087.5		9087.5
Tanner Bank	63.2		63.2
Grand totals:	29801.2	19253.7	49054.9

seven reefs were classified in the small category (6–293 ha), with 40 as medium (325–932 ha) and 13 as large (1086–2498 ha). Reef size categories had a mean of 95 ha (sd $\pm$ 69) for small reefs, 558 ha (sd $\pm$ 183) for medium reefs and 1567 (sd $\pm$ 484) ha for large reefs.

To begin to assess the range in physical habitat characteristics of the nearshore rocky reefs in the SCB, we began with a physical characterization of the reef habitat including substrate type and relief (Appendix II). Island reefs were primarily composed of bedrock or boulders (85.9%) while mainland reefs had a more even mix of substrate types (Figure 2). Nearly half (47.8%) of mainland reefs had a 0–0.1 m relief – more than double the fraction at the islands (23.3%). The amount of 1–2 m and >2 m relief reef habitat at the islands were 2 and 6 times the fraction found on the mainland, respectively. For relief, breakwaters were generally more similar to island reefs. Reef structure, classified by relief and substrate through cluster analysis and overlaid on a nMDS plot (Figure 3; Appendix II), varied from an oceanic pinnacle (Begg Rock) that was a sheer vertical structure composed of bedrock and an intertidal component to mainland reefs such as Carp Reef with large fractions of sand with little relief. Five reefs were not classified into a reef type (Figure 3) since they did not form distinct clusters in the cluster analysis (i. e., had relatively high distance from the other reefs). Five reef types were found. Type 1 included a pinnacle reef (Begg Rock) and breakwaters comprised almost completely of bedrock or large boulders. The second grouping (Type 2) was low relief and cobble reefs (Carp Reef and La Jolla) that had significant fractions of sand. Type 3 reefs were predominantly island reefs with some exceptions (Big Rock, Cabrillo Breakwater, Point Loma North, Point Vicente and Little Corona). These reefs were almost completely composed of high relief (1–2 m) bedrock.

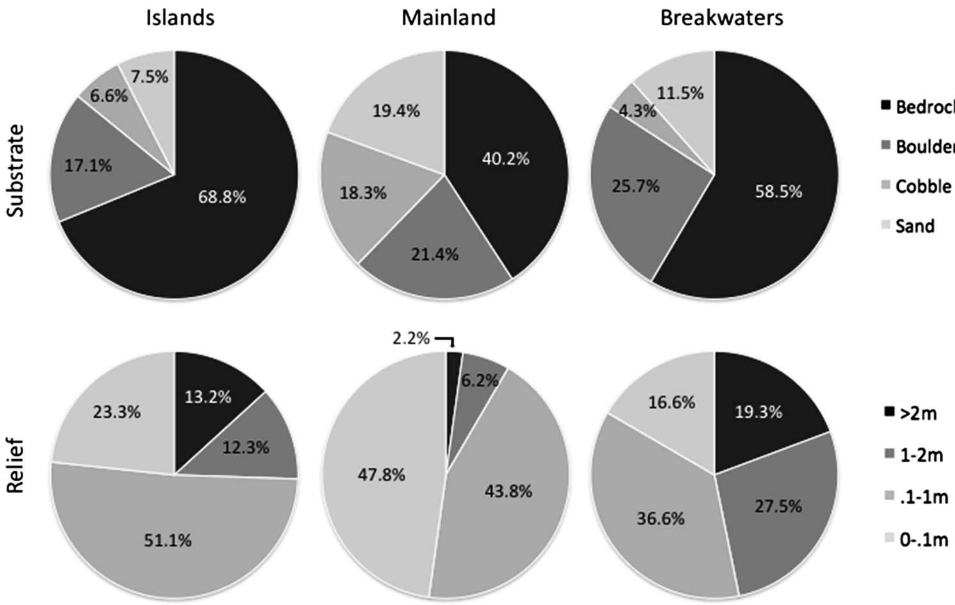

Fig. 2. Substrate type and relief categories for island reefs, mainland reefs and breakwaters.

Alternatively, Type 4 reefs were predominantly mainland reefs with three island reefs (East Quarry, SCAI, Lil Flower, SCLI, and Lion's Head, SCAI). These reefs were comprised of bedrock and boulders with large fractions of lower relief (0–1 m) components. Type 5 reefs were bedrock reefs that were primarily flat (0–0.1 m relief). Thus, reefs can be grouped into five major reef categories: low relief and cobble (Type 2), flat reefs (Type 5), moderate relief (Type 4), high relief (Type 3), and pinnacles (Type 1). Three of these reefs (Banana Rock, Southeast Rock and Point Dume), found on the perimeter of the nMDS plot, were pinnacle reefs (similar to Type 1) that jut abruptly up from a sandy substrate. These types of habitats can be particularly difficult to sample with a 30 m tape, as portions of the transect may wind up on the sand, obfuscating the results.

Discussion and Conclusions

While the 122 natural reefs that were identified in the SCB spanned three orders of magnitude in size (6 to 2498 hectares), most were relatively large major reef complexes and they were distributed throughout the San Diegan (warm temperate) and Oregonian (cold temperate) biogeographic regions. Island reefs tended to be higher relief, primarily bedrock. In general Mainland reefs were lower relief and had more variable substrate composition. Mainland reefs typically were associated with littoral cells and longshore sediment transport and have larger fractions of sand (Figure 2)(Inman and Frautschy 1966). We report that approximately a quarter of the nearshore (<30 m) habitat of the bight is comprised of rocky reef habitat. This is a greater percentage than would be expected from just analyzing the GIS layers available in 2008 (Kelner 2005) or from an extrapolation based upon rocky intertidal habitat (Stephens et al. 2006). This technique was successful at elucidating some generally unexpected patterns. The largest reefs in the SCB and the western coast of North America were at Santa Rosa and San Nicolas Islands. The kelp forest on west end of San Nicolas Island, while not the longest in terms of linear coastline, illustrated the utility of this study. The potential contribution of large reef islands

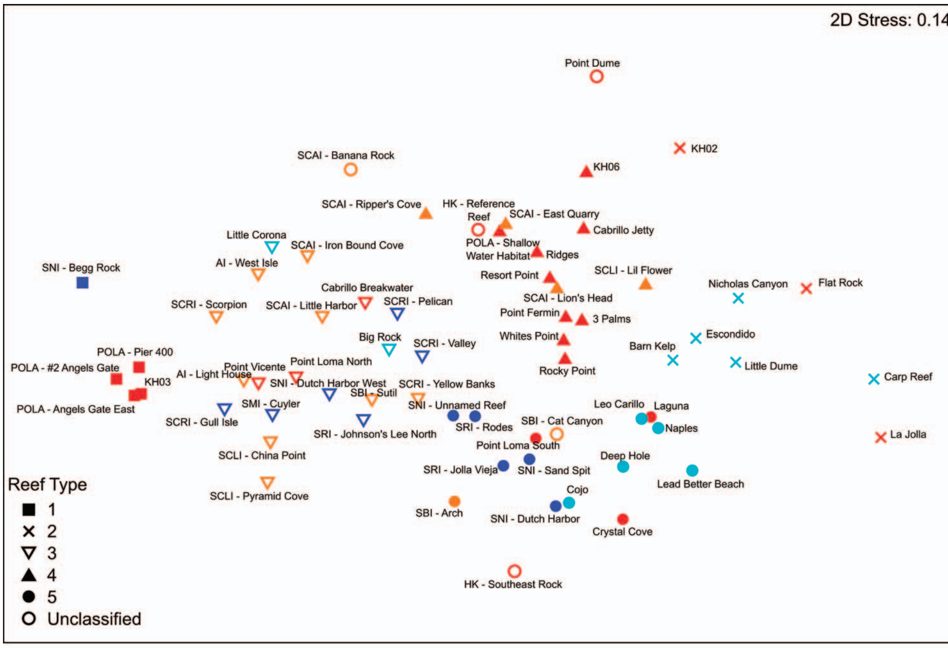

Fig. 3. Reef structure nMDS plot based on Euclidean distances using UPC substrate and relief measures. Reef Type determined by cluster analysis. Colors refer to biogeographic provinces: blue = cold temperate islands, orange = warm temperate islands, light blue = cold temperate mainland, red = warm temperate mainland.

habitats to the ecology of this region is important. This study also identified a substantial amount of the previously described soft bottom habitat as hard bottom by experts and over flight data of giant kelp canopy. Part of this difficulty is that side scan surveys are limited to the perimeter of kelp beds and the nearshore environment changes over time, but utilizing multiple data layers increases the detection of reefs. More fine-grained reef mapping approaches have been and continue to be developed since this program (e.g., Claisse et al. 2012, Parnell 2015). Incorporating more data layers in the future will increase the accuracy of this reef layer.

What is evident is that the nearshore rocky reefs in the SCB are highly variable in terms areal extent and physical habitat structure. Based upon relief and substrate characteristics alone, there are five major reef types in the SCB. Efforts need to be made to understand the influence of reef habitat characteristics (substrate type, rugosity and relief) on the associated biota (e.g., Parnell 2015). Nearshore reefs in the SCB are typically comprised of igneous, metamorphic or mudstone rock (Emery 1960). These rock types may be the cause of additional habitat variation in terms of the biota they support and the rates at which they erode. Further, the geological processes that created the reefs in the Miocene are manifested in the composition and amount of habitat. The geology of our islands and mainland, while quite variable, mirrors the composition of the proximate reefs. Where volcanic processes (Santa Barbara Island, Begg Rock) and the uplift of the Catalina Schist result in dramatic palisades, the resulting fringing nearshore reefs are also sheer and tight to the shoreline. The Northern Channel Islands are essentially a relocated mountain range and have proportionally large nearshore reefs. The eroding marine benches observed on San Nicolas and San Clemente Islands produced kelp beds. As an example, the entire offshore side of San Clemente Island is a continuous reef and the island is ~34 km in length. The geological processes observed on these islands (eroding anticlines, marine benches, sheer palisades, etc.) are mirrored in the nearshore subtidal habitat.

While macroscale processes vary considerably, individual reefs are significantly diverse as well. This habitat heterogeneity impacts the ecology of the region. In the SCB, rocky reef vertical relief was correlated with increased fish density and production with high relief reef significantly outperforming low relief reefs (Ambrose and Swarbrick 1989, Anderson 1989, Pondella et al. 2002, Pondella et al. 2006). Depth has also been shown to be a useful characteristic in modeling reef habitats (Claudet et al. 2006, Claisse et al. 2012, Parnell 2015); we did not include depth in our analyses here, but note that depth components may be a significant factor in reef performance. For instance, Horseshoe Kelp (in Los Angeles County) was only distributed in the deepest strata while many others lacked a deep stratum and some did not have a shallow stratum. A finer-scaled approach evaluating the influence of depth strata on reef performance would be beneficial. The structure, amount and distribution of reefs in the SCB vary appreciably and are important to consider in the potential performance of this system.

Approximately 122 natural rocky reefs/reef complexes comprise approximately one-quarter (26%) of the subtidal habitat in the nearshore (<30 m depth) SCB. Prior to this study, estimates of nearshore subtidal (<30 m) rocky reef habitat were inferred from the linear distribution of intertidal rock and these estimates significantly underestimated the amount of shallow subtidal reef habitat in the SCB. The mapping exercise undertaken in this region was the most exhaustive to date and is the best estimate of reef area for the region. We were able to accomplish this effort relatively quickly and inexpensively using previously collected data sets and expert interviews. Data from multiple sources including side-scan sonar, aerial overflights, satellite imagery, subtidal visual surveys and professional judgments were combined to create our estimates of habitat extent. As more spatial data sets become available, they should be integrated into more fine-scaled reef maps.

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Appendix I. Station numbers corresponding to Figure 1, sampled reefs, biogeographic region, reef category.

Reef #	Region	Reef polygon	Bioregion	# Stations	Latitude	Longitude	Area (Ha)	Reef category
1	Anacapa	Landing Cove	Warm Island		34.017	−119.369	45.0	Major Complex
2	Anacapa	The Hump	Warm Island		34.012	−119.390	91.3	Major Complex
3	Anacapa	Port Rock	Warm Island	1	34.019	−119.437	173.4	Patch Reefs
4	Anacapa	Cat Rock	Warm Island		34.003	−119.418	94.3	Major Complex
5	Anacapa	Coral Reef	Warm Island		34.009	−119.435	59.9	Major Complex
6	Anacapa	Lighthouse	Warm Island	1	34.011	−119.370	55.5	Patch Reefs
7	Anacapa	East Fish Camp	Warm Island		34.005	−119.386	25.7	Patch Reefs
8	Santa Cruz I.	Scorpions	Warm Island	1	34.050	−119.581	324.5	Major Complex
9	Santa Cruz I.	San Pedro Point	Warm Island		34.028	−119.525	103.8	Major Complex
10	Santa Cruz I.	Yellow Banks	Warm Island	1	33.998	−119.544	1267.6	Major Complex
11	Santa Cruz I.	Blue Banks	Warm Island	1	33.980	−119.651	776.3	Patch Reefs
12	Santa Cruz I.	Gull Island	Cold Island	1	33.951	−119.824	56.7	Major Complex
13	Santa Cruz I.	Malva Real	Cold Island		33.958	−119.815	74.8	Major Complex
14	Santa Cruz I.	Morris to Kenton	Cold Island		33.987	−119.874	393.9	Major Complex
15	Santa Cruz I.	Forneys	Cold Island		34.054	−119.923	475.9	Major Complex
16	Santa Cruz I.	Painted Cave	Cold Island		34.067	−119.840	691.5	Patch Reefs
17	Santa Rosa I.	Rosa Pinnacles	Cold Island		33.916	−119.995	632.4	Pinnacle/Offshore
18	Santa Rosa I.	East Point	Cold Island		33.948	−119.969	144.9	Major Complex
19	Santa Rosa I.	Ford Point	Cold Island	1	33.915	−120.054	402.7	Patch Reefs
20	Santa Rosa I.	Johnson’s Lee	Cold Island	1	33.900	−120.105	134.6	Major Complex
21	Santa Rosa I.	Chickasaw	Cold Island		33.910	−120.157	618.0	Major Complex
22	Santa Rosa I.	Bee Rock	Cold Island		33.962	−120.218	1871.2	Major Complex
23	Santa Rosa I.	Rodes	Cold Island		34.031	−120.111	1131.4	Major Complex
24	Santa Rosa I.	Talcott	Cold Island		34.021	−120.197	2492.6	Major Complex
25	Santa Rosa I.	Carrington Point	Cold Island	1	34.041	−120.059	1659.8	Major Complex
26	San Miguel I.	Judith Rock	Cold Island		34.034	−120.449	781.2	Major Complex
27	San Miguel I.	Miracle Mile	Cold Island		34.023	−120.394	413.7	Major Complex
28	San Miguel I.	Crook Point	Cold Island		34.015	−120.339	427.7	Major Complex
29	San Miguel I.	Cuyler Harbor	Cold Island	1	34.054	−120.341	427.7	Major Complex
30	San Miguel I.	Harris Point	Cold Island		34.071	−120.363	160.3	Major Complex
31	San Miguel I.	Simonton Cove	Cold Island		34.059	−120.396	409.3	Major Complex
32	San Miguel I.	Wilson Rock	Cold Island		34.100	−120.403	10.3	Pinnacle/Offshore

Appendix I. Continued.

Reef #	Region	Reef polygon	Bioregion	# Stations	Latitude	Longitude	Area (Ha)	Reef category
33	San Miguel I.	Richardson's Rock	Cold Island		34.102	−120.518	16.7	Pinnacle/Offshore
34	Santa Barbara I.	Santa Barbara north	Warm Island	1	33.487	−119.036	82.6	Major Complex
35	Santa Barbara I.	Websters	Warm Island		33.487	−119.053	411.8	Major Complex
36	Santa Barbara I.	Sutil	Warm Island	2	33.470	−119.047	171.7	Major Complex
37	Santa Barbara I.	Southeast Sealion	Warm Island		33.466	−119.031	181.3	Major Complex
38	Santa Barbara I.	Santa Barbara offshore	Warm Island		33.487	−119.019	41.1	Pinnacle/Offshore
39	San Nicolas I.	Daytona Beach	Cold Island	1	33.217	−119.446	186.6	Major Complex
40	San Nicolas I.	Dutch Harbor	Cold Island	1	33.216	−119.486	199.6	Major Complex
41	San Nicolas I.	Station 2	Cold Island	1	33.226	−119.525	194.9	Major Complex
42	San Nicolas I.	Unnamed reef	Cold Island	1	33.246	−119.572	501.5	Major Complex
43	San Nicolas I.	Boilers	Cold Island		33.273	−119.608	1781.6	Major Complex
44	San Nicolas I.	Station 3	Cold Island		33.288	−119.565	1503.2	Major Complex
45	San Nicolas I.	Alpha Foul	Cold Island		33.277	−119.495	876.2	Patch Reefs
46	San Nicolas I.	Begg Rock	Cold Island	1	33.362	−119.696	6.2	Pinnacle/Offshore
47	Tanner Bank	Tanner Bank	Cold Island		32.697	−119.130	63.2	Pinnacle/Offshore
48	Cortez Bank	Cortez Bank	Cold Island		32.446	−119.110	1359.6	Pinnacle/Offshore
49	Mainland	Cojo Anchorage	Cold Mainland	1	34.447	−120.379	2497.5	Major Complex
50	Mainland	Refugio	Cold Mainland		34.463	−120.083	482.9	Major Complex
51	Mainland	Gaviota	Cold Mainland		34.467	−120.219	786.0	Patch Reefs
52	Mainland	Naples Reef	Cold Mainland	1	34.422	−119.952	168.4	Major Complex
53	Mainland	Inshore Naples	Cold Mainland		34.431	−119.939	416.6	Cobble Reefs
54	Mainland	Ellwood	Cold Mainland		34.419	−119.900	140.0	Major Complex
55	Mainland	Isly Reef	Cold Mainland		34.405	−119.862	227.3	Major Complex
56	Mainland	More Mesa	Cold Mainland		34.412	−119.796	480.6	Patch Reefs
57	Mainland	Mohawk	Cold Mainland	1	34.393	−119.699	511.3	Major Complex
58	Mainland	Carp Reef	Cold Mainland	1	34.415	−119.609	472.2	Major Complex
59	Mainland	Rincon	Cold Mainland		34.393	−119.539	197.2	Patch Reefs
60	Mainland	La Conchita Banana	Cold Mainland		34.383	−119.505	9.6	Major Complex
61	Mainland	Soledad	Cold Mainland		34.342	−119.423	160.7	Major Complex
62	Mainland	Pitas	Cold Mainland		34.314	−119.371	198.0	Patch Reefs
63	Mainland	Horseshoe Reef	Cold Mainland		34.394	−119.577	809.6	Pinnacle/Offshore
64	Mainland	Cardiff-Encinitas	Warm Mainland		33.037	−117.301	1448.2	Patch Reefs

Appendix I. Continued.

Reef #	Region	Reef polygon	Bioregion	# Stations	Latitude	Longitude	Area (Ha)	Reef category
65	Mainland	Carlsbad	Warm Mainland		33.136	−117.345	506.2	Major Complex
66	Mainland	La Jolla	Warm Mainland	1	32.831	−117.286	1136.5	Major Complex
67	Mainland	Point Loma north	Warm Mainland	1	32.737	−117.268	673.8	Major Complex
68	Mainland	Point Loma south	Warm Mainland	1	32.667	−117.253	745.4	Major Complex
69	Mainland	Dana Point	Warm Mainland		33.466	−117.724	355.9	Major Complex
71	Mainland	Laguna Beach	Warm Mainland	1	33.534	−117.784	105.1	Major Complex
72	Mainland	San Mateo Kelp	Warm Mainland		33.373	−117.593	460.0	Major Complex
73	Mainland	Barn Kelp	Warm Mainland	1	33.292	−117.487	379.2	Major Complex
74	Mainland	San Onofre	Warm Mainland		33.328	−117.548	931.6	Cobble Reefs
76	San Clemente I.	East Clemente	Warm Island		32.851	−118.493	712.5	Major Complex
77	San Clemente I.	West Clemente	Warm Island		32.963	−118.571	785.6	Major Complex
78	San Clemente I.	Wilson Cove	Warm Island		33.005	−118.553	202.4	Major Complex
79	San Clemente I.	Reflector Reef	Warm Island		33.027	−118.565	19.1	Major Complex
80	San Clemente I.	Northwest Harbor	Warm Island		33.037	−118.590	204.4	Major Complex
81	San Clemente I.	Target Rock	Warm Island		33.023	−118.610	347.8	Major Complex
82	San Clemente I.	Navy Reef	Warm Island		32.959	−118.516	158.8	Major Complex
83	San Clemente I.	Eel Point	Warm Island		32.902	−118.537	292.9	Major Complex
84	San Clemente I.	China Point	Warm Island	1	32.806	−118.434	478.8	Major Complex
85	Santa Catalina I.	West Kelp	Warm Island		33.470	−118.601	24.7	Major Complex
86	Mainland	Horseshoe Kelp 1	Warm Mainland	2	33.664	−118.217	1131.0	Pinnacle/Offshore
87	San Clemente I.	Pyramid Cove	Warm Island	1	32.817	−118.376	349.5	Major Complex
88	San Clemente I.	Lil Flower	Warm Island	1	32.830	−118.360	41.5	Major Complex
89	Santa Catalina I.	Parson’s Landing & Black Pt	Warm Island		33.476	−118.566	112.8	Major Complex
90	Santa Catalina I.	Indian Rock	Warm Island		33.470	−118.528	31.6	Major Complex
91	Santa Catalina I.	Lionhead	Warm Island	1	33.452	−118.501	26.8	Major Complex
92	Santa Catalina I.	Ship Rock and Eagle Reef	Warm Island		33.461	−118.506	13.1	Pinnacle/Offshore
93	Santa Catalina I.	Blue Cavern and Wrigley	Warm Island		33.447	−118.486	38.3	Major Complex
94	Santa Catalina I.	West Quarry	Warm Island		33.441	−118.464	11.3	Major Complex
95	Santa Catalina I.	Rippers Cove	Warm Island	1	33.428	−118.431	33.9	Major Complex
96	Santa Catalina I.	Hen Rock and Italian Gardens	Warm Island		33.408	−118.375	54.2	Major Complex
97	Santa Catalina I.	Torqua	Warm Island		33.372	−118.347	70.4	Major Complex
98	Santa Catalina I.	East Quarry and Lovers Cove	Warm Island	1	33.333	−118.309	28.4	Major Complex

Appendix I. Continued.

Reef #	Region	Reef polygon	Bioregion	# Stations	Latitude	Longitude	Area (Ha)	Reef category
99	Santa Catalina I.	Salte Verde	Warm Island		33.316	−118.420	132.8	Major Complex
100	Santa Catalina I.	Ben Weston	Warm Island		33.340	−118.476	115.7	Patch Reefs
101	Santa Catalina I.	Little Harbor	Warm Island	1	33.375	−118.483	29.9	Major Complex
102	Santa Catalina I.	Pin Rock to Banana Rock	Warm Island	1	33.410	−118.492	105.3	Major Complex
103	Santa Catalina I.	Cape Cortez and Lobster Bay	Warm Island		33.429	−118.530	45.4	Major Complex
104	Santa Catalina I.	Ironbound and Ribbon Rock	Warm Island	1	33.439	−118.568	56.6	Major Complex
105	Mainland	Point Fermin Reef	Warm Mainland	1	33.705	−118.288	36.9	Major Complex
106	Mainland	Bunker Point to Whites Point	Warm Mainland	2	33.717	−118.327	177.7	Major Complex
107	Mainland	Abalone Cove	Warm Mainland		33.739	−118.382	50.0	Patch Reefs
108	Mainland	Point Vicente to Long Point	Warm Mainland	1	33.739	−118.406	78.9	Major Complex
109	Mainland	Rancho Palos Verdes	Warm Mainland	1	33.760	−118.422	98.6	Major Complex
110	Mainland	Rocky Point and Ridges	Warm Mainland	2	33.783	−118.429	356.2	Major Complex
111	Mainland	Flat Rock	Warm Mainland	1	33.800	−118.407	84.6	Major Complex
112	Mainland	Little Dume	Cold Mainland	1	34.007	−118.791	60.6	Major Complex
113	Mainland	Point Dume	Cold Mainland	1	33.999	−118.806	7.3	Pinnacle/Offshore
114	Mainland	Leo Carrillo to Encinal	Cold Mainland	2	34.039	−118.908	362.8	Major Complex
115	Mainland	Deep Hole	Cold Mainland	1	34.047	−118.965	163.0	Major Complex
116	Mainland	Deer Creek	Cold Mainland		34.060	−118.986	62.1	Major Complex
117	San Miguel I.	Castle Rock	Cold Island		34.058	−120.437	815.0	Major Complex
118	Mainland	Horseshoe Kelp 2	Warm Mainland		33.689	−118.249	1086.4	Pinnacle/Offshore
119	Mainland	Point Loma middle	Warm Mainland		32.702	−117.266	877.2	Major Complex
120	Mainland	Little Corona	Warm Mainland	1	33.586	−117.867	49.7	Patch Reefs
121	Mainland	Crystal Cove	Warm Mainland	1	33.566	−117.834	54.6	Patch Reefs
122	Santa Cruz I.	Pelican	Cold Island	1	34.031	−119.683	672.5	Patch Reefs
-	Mainland	Escondido	Cold Mainland	1	34.020	−118.772	-	-
-	Mainland	Big Rock	Cold Mainland	1	34.035	−118.608	-	-
KH	Breakwaters	King Harbor	Warm Mainland	3	33.842	−118.397	-	Manmade
POLA	Breakwaters	Port of Los Angeles	Warm Mainland	6	33.710	−118.260	-	Manmade

Appendix II. Percent substrate type and relief.

			Substrate				*Relief*			
Reef #	Region	Station	Bedrock	Boulder	Cobble	Sand	0-.1m	.1-1m	1-2m	>2m
29	San Miguel I.	Cuyler	88	1	9	1	1	67	14	18
25	Santa Rosa I.	Rodes	9	1	8	1	34	67		
20	Santa Rosa I.	Johnson's Lee North	81	3	9	8	11	67	15	6
19	Santa Rosa I.	Jolla Vieja	77			23	48	52	<1	
122	Santa Cruz I.	Pelican	6	13	17	9	8	68	24	1
8	Santa Cruz I.	Scorpion	59	27	2	13	10	36	16	38
12	Santa Cruz I.	Gull Isle	88	1	6	5		56	19	24
11	Santa Cruz I.	Valley	66	6	13	15	4	93	2	1
10	Santa Cruz I.	Yellow Banks	72	4	18	6	11	82	4	3
3	Anacapa	West Isle	65	23	6	5	<1	59	31	9
6	Anacapa	Light House	8	9	2	1	4	49	18	29
46	San Nicolas I.	Begg Rock	67	33				2	7	91
42	San Nicolas I.	Unnamed Reef	94	2		3	4	56	4	
41	San Nicolas I.	Dutch Harbor West	94	2		5	7	69	18	6
40	San Nicolas I.	Dutch Harbor	65	4	3	28	69	23	6	2
39	San Nicolas I.	Sand Spit	81	4	1	14	69	29	2	
34	Santa Barbara I.	Arch	91	1	9		62	28	7	3
36	Santa Barbara I.	Sutil	9	1			28	52	15	5
36	Santa Barbara I.	Cat Canyon	52	16	31	1	54	34	1	2
104	Santa Catalina I.	Iron Bound Cove	59	37	1	3	5	56	3	9
102	Santa Catalina I.	Banana Rock	41	51	8	1	18	46	3	33
101	Santa Catalina I.	Little Harbor	69	25	1	6	9	65	9	19
91	Santa Catalina I.	Lion's Head	35	43	13	9	34	59	3	4
95	Santa Catalina I.	Ripper's Cove	4	45	2	13	15	57	26	2
98	Santa Catalina I.	East Quarry	34	63	2		33	58	9	
84	San Clemente I.	China Point	96	4			16	37	20	28
87	San Clemente I.	Pyramid Cove	68	14	9	9	24	23	23	30
88	San Clemente I.	Lil Flower	24	38	17	22	41	43	1	6
49	Mainland	Cojo	76		18	6	76	24		
52	Mainland	Naples	46	24	21	9	79	3		

Appendix II. Continued.

			Substrate				Relief			
Reef #	Region	Station	Bedrock	Boulder	Cobble	Sand	0-.1m	.1-1m	1-2m	>2m
57	Mainland	Lead Better Beach	38	1	44	9	81	18	1	
58	Mainland	Carp Reef		16	26	58	9	10		
115	Mainland	Deep Hole	65	18	4	14	9	10		
114	Mainland	Leo Carrillo	36	15	3	46	56	35	9	2
114	Mainland	Nicholas Canyon	7	28	16	48	40	6		
113	Mainland	Point Dume	13	6	27		44	18	39	
112	Mainland	Little Dume	15	19	38	28	56	44		
-	Mainland	Escondido	2	14	27	4	32	68		
-	Mainland	Big Rock	76	2		23		1		
111	Mainland	Flat Rock	1	32	4	28	52	48	1	
110	Mainland	Ridges	31	4	8	21	19	74	6	1
110	Mainland	Rocky Point	53	24	17	6	49	48	3	
109	Mainland	Resort Point	36	43	1	11	27	68	5	<1
108	Mainland	Point Vicente	95	5			4	52	23	22
106	Mainland	3 Palms	41	34	13	12	42	54	4	
106	Mainland	Whites Point	49	28	18	5	45	53	3	
105	Mainland	Point Fermin	39	32	19	1	35	60	4	2
86	Mainland	HK - Reference Reef	34	53	13		19	76	5	
86	Mainland	HK - Southeast Rock	4	19	37	3	44	27	16	13
120	Mainland	Little Corona	49	37	6	9	12	36	33	18
121	Mainland	Crystal Cove	55	2	2	42	82	15	3	
71	Mainland	Laguna	41	15	5	38	69	29	2	
73	Mainland	Barn Kelp	28	2	24	28	49	52		
66	Mainland	La Jolla		7	64	29	93	7		
67	Mainland	Point Loma North	88	2	9	1		76	2	4
68	Mainland	Point Loma South	73	2	4	2	51	49		
KH	Breakwaters	KH02	21	29		5	5	16	34	
KH	Breakwaters	KH03	95	5				13	5	38
KH	Breakwaters	KH06	15	6	3	23	26	59	16	
POLA	Breakwaters	Cabrillo Jetty	23	66	8	3	42	52	6	
POLA	Breakwaters	Cabrillo Breakwater	79	15		6		94	6	

Appendix II. Continued.

			Substrate				*Relief*			
Reef #	Region	Station	Bedrock	Boulder	Cobble	Sand	0-.1m	.1-1m	1-2m	>2m
POLA	Breakwaters	#2 Angel's Gate	81	9		11		16	4	53
POLA	Breakwaters	Angels Gate East	78	11	2	9	2	17	46	35
POLA	Breakwaters	Pier 400	89	1		2		19	32	48
POLA	Breakwaters	Shallow Water Habitat	47	27	26		29	45	26	
	Bightwide		*61*	*16*	*11*	*12*	*31*	*41*	*8*	*7*