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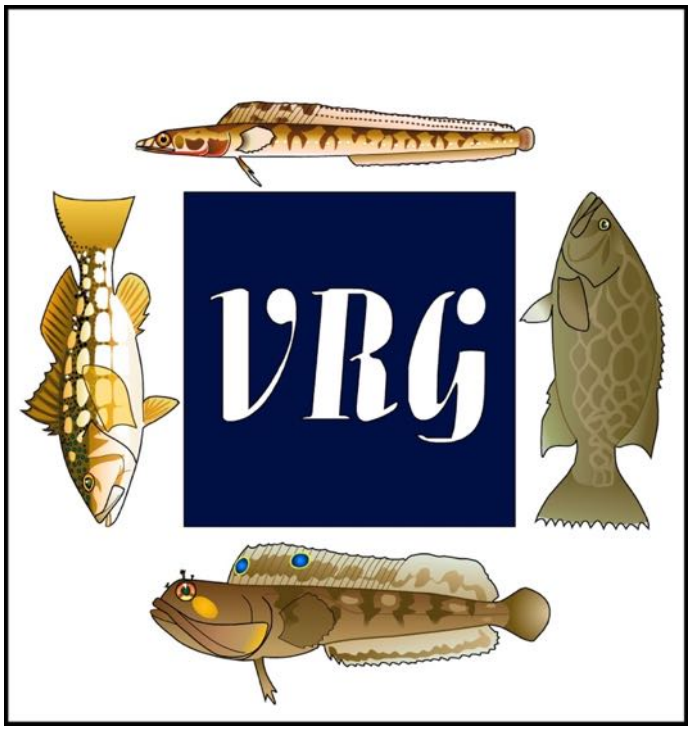
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APPENDIX B

BUNKER POINT REEF RESTORATION PROJECT: CRITERIA, DESIGN, AND MONITORING

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October 2016

EXECUTIVE SUMMARY

In this report we detail the biological, physical, engineering, and theoretical constraints for developing a subtidal rocky-reef restoration project on the Palos Verdes Peninsula. We begin with detailing the restoration need. There are well documented declines in available reef and giant kelp habitat, commercial and recreational fishing opportunities and rocky reef ecosystem health. We present the theoretical constraints and justification for restoring rocky reefs in an area of approximately 70 acres of loss habitat.

The purpose of the Palos Verdes Reef Restoration Project is to restore rocky-reef habitats and associated marine species on the Palos Verdes Shelf that were impacted by contamination in the sediments from the discharge of DDT and PCB from the Joint Water Pollution Control Plant's Whites Point Outfall (JWPCP), as well as to restore reefs that have been impacted by sedimentation and scour. This restoration project will fulfill the objective of the Montrose Settlements Restoration Program (MSRP) to restore fish and the habitats upon which they depend within the Southern California Bight (SCB). This reef will provide essential fish habitat and substrate for kelp, other marine algae, and marine invertebrates to become attached to, creating a productive rocky-reef ecosystem in an area with limited hard substrate (Claisse et al., 2012).

The amount of giant kelp and rocky reef habitat on the Palos Verdes Peninsula has declined appreciably over the last 100+ years. Originally kelp canopy loss was attributed to pollution from the Whites Point outfall; however, this deleterious problem has been ameliorated. Currently, we describe a variety of other drivers for the continued loss of this habitat (i.e., urchin barrens, sedimentation and turbidity). From Abalone Cove to Point Fermin sedimentation and associated processes are responsible for the loss of reef and kelp habitat. Landslides were the primary drivers of this process, and this latent sedimentation continues to bury reefs, reduce visibility and scour exposed habitat. This report details the documentation of these processes along this valuable stretch of coastline and, more importantly, delineates the steps necessary to restore productive habitat under these stressors.

Developing a subtidal rocky-reef restoration project of this type is a unique endeavor. Currently reefing projects in southern California have been used to construct fishing reefs (Lewis and McKee 1989), mitigate for lost kelp bed habitat (Reed et al. 2006a; Reed et al. 2006b), provide underwater scuba opportunities (e.g., Yukon), create fishery habitat in estuaries (Pondella et al. 2006) and shoreline protection from breakwaters and jetties (Stephens et al. 1994; Froeschke et al. 2005). Restoring lost habitat, *in situ*, which is currently being employed in oyster habitat and coral reefs (Rinkevich 2005; Beck et al. 2011), has not been attempted in a temperate kelp community.

In order to accomplish this objective, we generated a conceptual model of highly productive reef system based upon natural reef performance along this stretch of coastline. The next challenge is to utilize limited resources and engineering criteria to develop a restoration reef plan that maximizes the biological benefits. These benefits include insights drawn from reefs at Palos Verdes and throughout the Southern California Bight and include species richness, diversity and biomass. Our research indicates that multiple factors including reef size, spacing, relief, rock size, heterogeneity, depth, sediment depth, location relative to kelp bed perimeter and flux all influence reef performance. We developed a secondary production model that specifically analyzes the production of fish biomass to evaluate reef performance. In this project, these factors were juxtaposed with the economic, physical and engineering constraints to develop the restoration plan.

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INTRODUCTION TO RESTORATION PROJECT STUDY AREA

For a variety of reasons, the nearshore environment of the Palos Verdes Peninsula (Figure 1) has been intensively studied for decades. In particular, the nearshore reefs of this headland have garnered attention due to a variety of anthropogenic activities (e.g., commercial and recreational fishing, establishment of marine protected areas, giant kelp beds lost to pollution, landslides)(Stull 1987; Pondella 2009; Foster and Schiel 2010). Historically the greatest deleterious impact to the reefs at Palos Verdes was the loss of its kelp beds due to pollution from the Joint Water Pollution Control Plant's (JWPCP) Whites Point outfall. By 1960 due to untreated sewage, the only kelp left on the peninsula was at Abalone Cove and in Portuguese Bend (North 1964). To exacerbate the situation, road construction on Palos Verdes Drive triggered the Portuguese Bend Landslide in 1956. From 1956 to 1999, approximately 5.7 to 9.4 million metric tons of sediment slid onto the inner shelf (Kayen 2002). By 1999, the landslide was dewatered, slowed appreciably and now only releases sediment due to wave action. Nonetheless the biological damage has been extreme, highlighted by the loss of the Portuguese Bend Kelp Bed leaving only the Abalone Cove Kelp Bed by 1974. Due to the infrastructure improvements of the Whites Point Outfall, between 1937 and 1967 the three deep outfalls were built and currently the two deepest outfalls, which reside ~1.5 miles offshore in 200' of water are used. In 1984, partial secondary treatment of the flow (60:40 mix of secondary:primary) started and continued until late 2002 when the discharge of 100% secondary effluent began. In the early 1970s, Wheeler North kelp restoration efforts at the Palos Verdes Peninsula for giant kelp were successful and giant kelp remains present to this time.

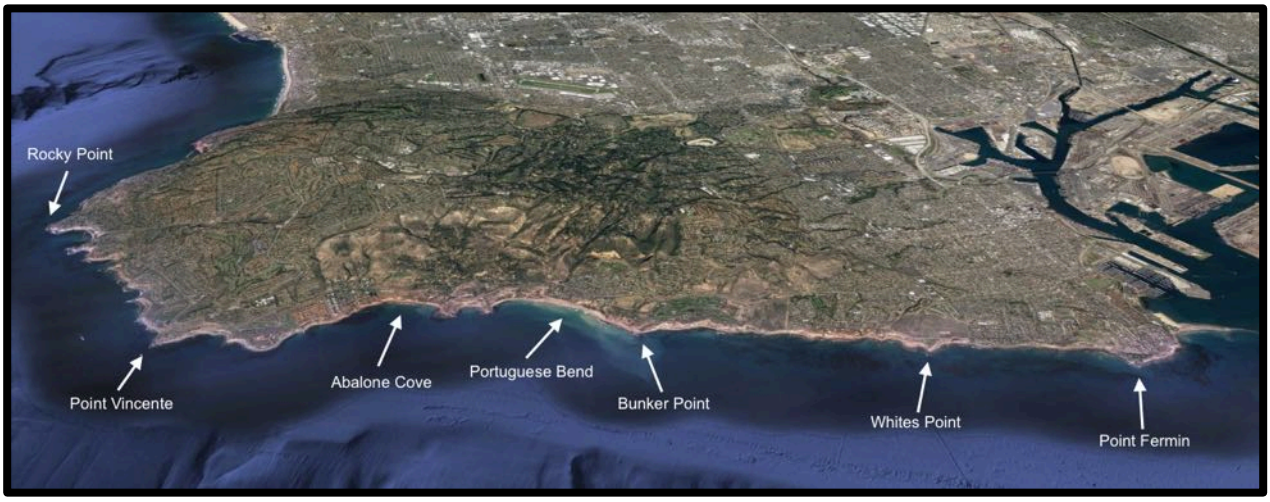


Figure 1. Satellite image of the Palos Verdes Peninsula (image adapted from NASA/JPL taken on 2/2/2016).

While these restoration and enhancement efforts ameliorated the historical consequences of the Whites Point Outfall throughout the peninsula, sedimentation and associated turbidity continue to have chronic impacts. First there is continued turbidity, sediment transport and scour associated with the sediment deposited in Portuguese Bend from the landslide (Figure 2). Turbidity currently is caused by wave action and is much reduced compared to Figure 2, which is an example of the turbidity plume prior to stabilization of the landslide. Further exacerbating this influx of sediment was the 16-acre landslide on June 2, 1999 from the 18th hole of the Trump National Golf Club, which sits above Bunker Point. Reef burial near Bunker Point was not observed during the extensive surveys of this region in the 1990s (Stephens 1996), but has been observed in more recent surveys (Pondella et al. 2012a; Pondella et al. 2015b). Proximity to the Trump National Golf Course landslide suggests that the reef has likely been buried since 1999. A third point source of turbidity and sedimentation comes from the large storm drains that empty into this nearshore environment. With these various chronic stressors there is continued deleterious impacts to the nearshore rocky environment, especially from Portuguese Bend (buried reef) to Point Fermin (Stephens 1996; Pondella et al. 2012b).



Figure 2. Turbidity plume from the Portuguese Bend landslide (left: circa 1980s; right: April 2016).

MAPPING THE RESTORATION STUDY AREA

We examined three potential restoration area alternatives in Portuguese Bend, the West Area (Bunker Point) and the East Area (Whites Point to Point Fermin) (Figure 3). Portuguese Bend was eliminated early in the evaluation process because the sediment depth was too deep and quarry rock would sink and be buried. The restoration study area was defined as the area from just east of Bunker Point to just west of the JWPCP Outfall at Whites Point (Figure 7). The western border was defined by the high relief reef at Bunker Point and the eastern border was delineated so as not to include the Whites Point Outfall.

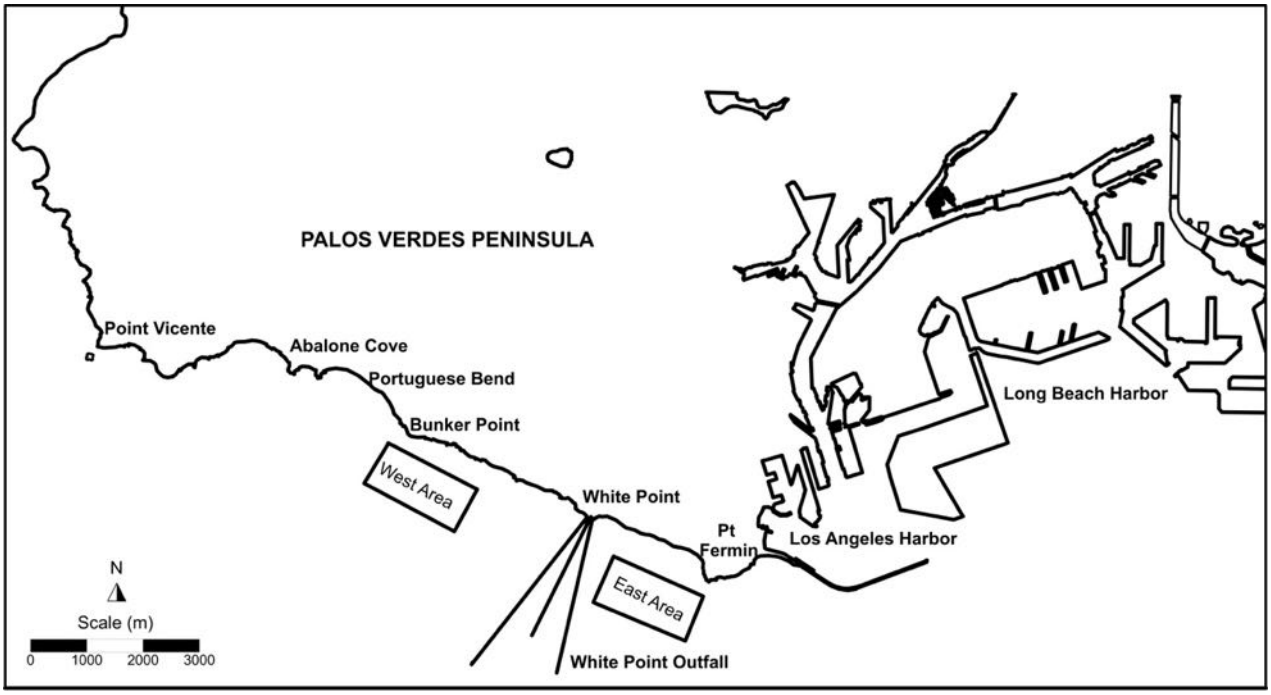


Figure 3. Location of the two proposed sites (West area and East area) for the Palos Verdes Reef Restoration Project, showing major landmarks in the area

The southern border is approximately the 30 m isobath and the northern border is the shoreline. This area consisted of approximately 2.9 km^2 (2,899,280 m^2) of nearshore environment. The geographic extent and character of marine hard bottom/reef was mapped by combining several different spatial datasets into a preliminary habitat data layer (Claisse et al. 2012). This layer was then verified and corrected using underwater field observations and analyses of aerial and satellite photography. All mapping and spatial analysis was done using ArcGIS software. Spatial data layers were created and maintained in the shapefile format, using the UTM Zone 11 North, WGS84 projection to minimize distortion in both area and length measurements. Kelp canopy was a highly precise polygon spatial layer created by using a 2-meter rectangular grid to classify georeferenced aerial photography (Kelner 2005). Kelp canopy varies significantly over seasons and years and has decreased well below historical levels (Figure 4,6). In this layer several years

(2008 and 2011-2014) of data was used additively. This project area is outside the kelp canopy but inside the area where historic kelp was found (Figures 5,7). Reefs are buried and /or suffer from scour at this depth prohibiting historical kelp growth (Pondella et al. 2012b). Triple beam and side scan sonar data were obtained from the Sea Floor Mapping Lab at California State University, Monterey Bay.

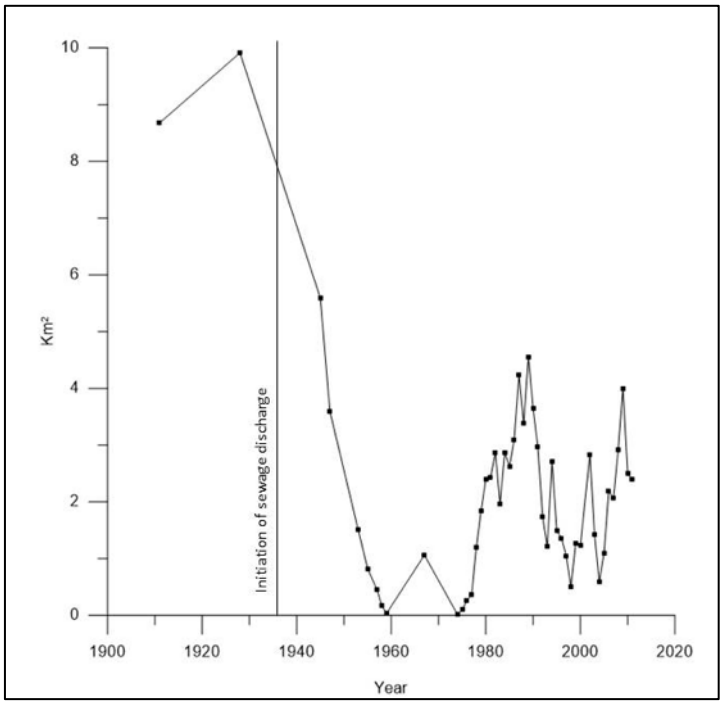


Figure 4. Kelp canopy coverage (km2) from 1911 – 2011 on the Palos Verdes Peninsula (data from MBC, 2012).

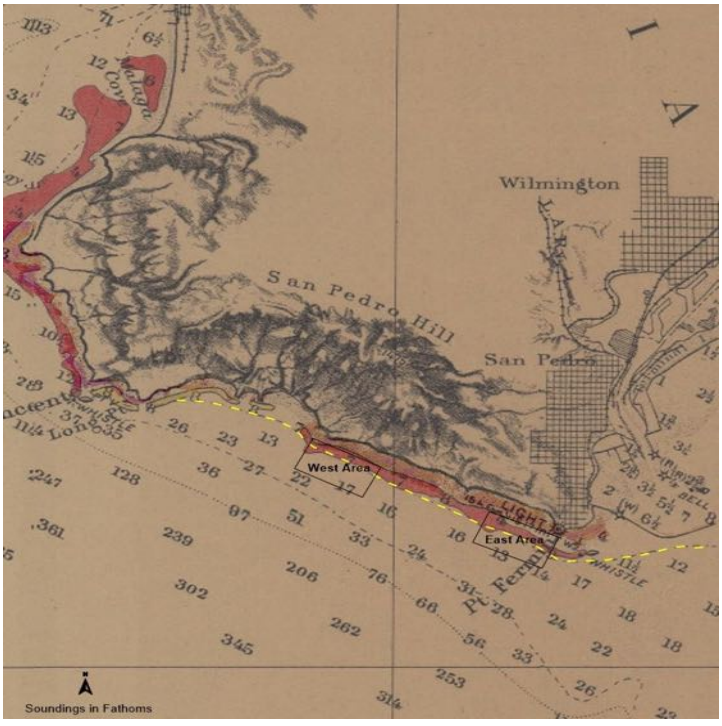


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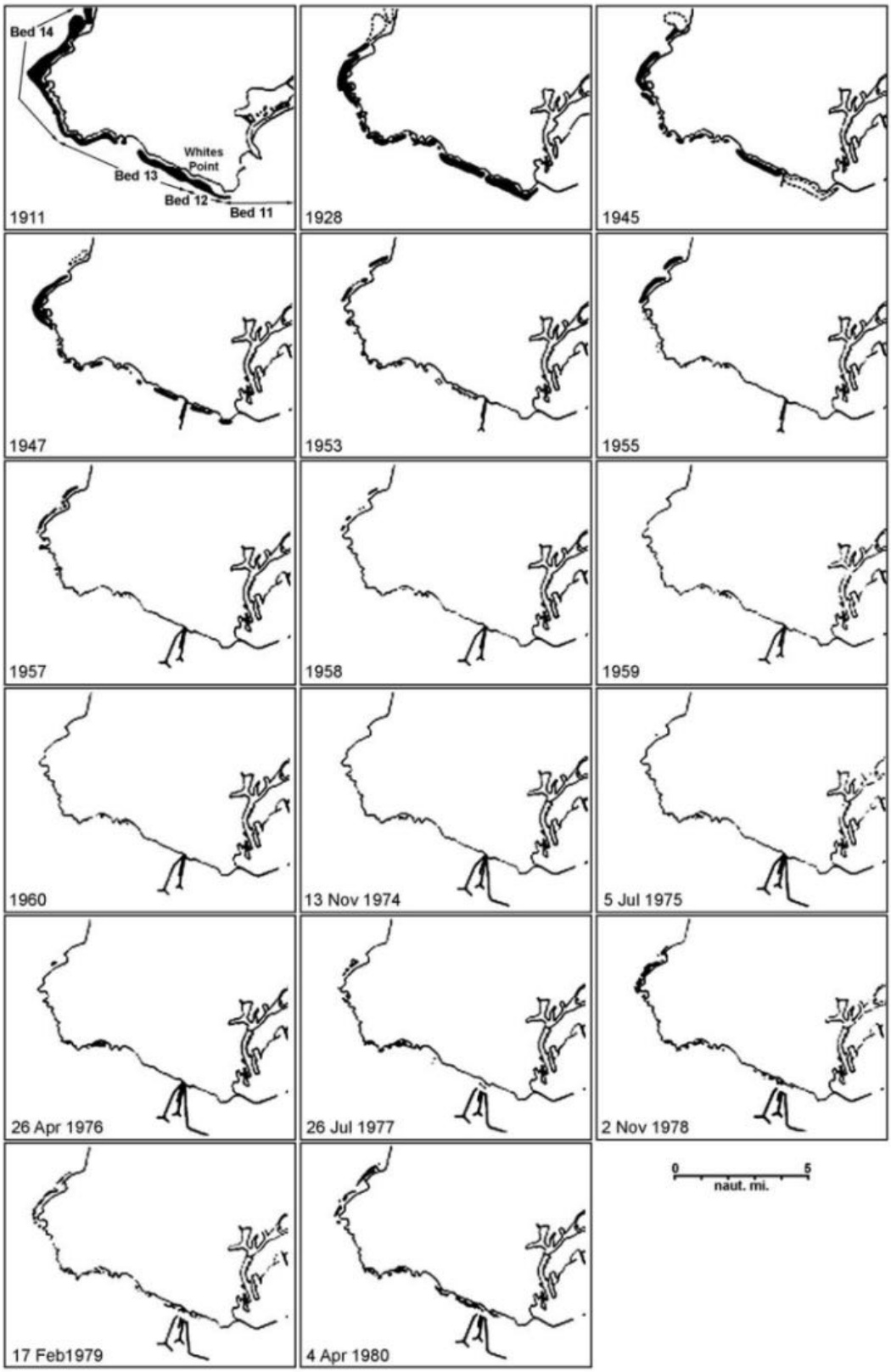


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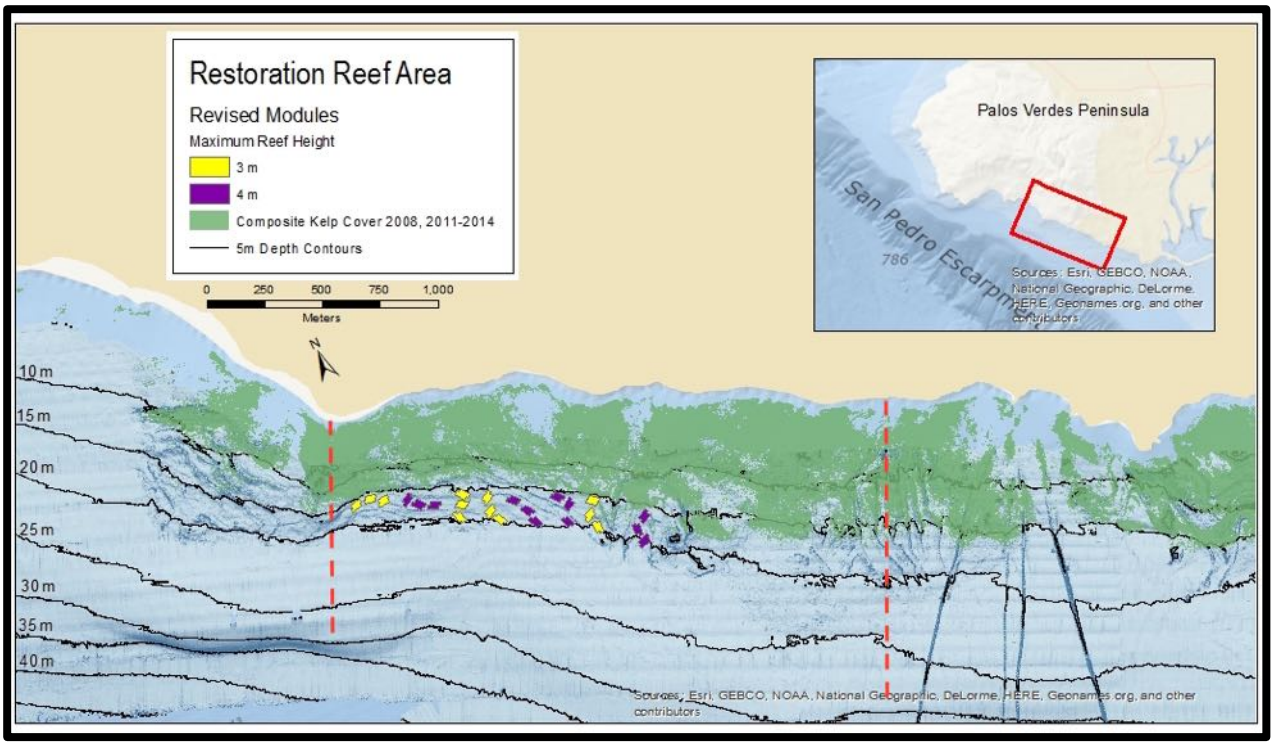


Figure 7. Bunker Point restoration site study area with kelp canopy, side scan imagery, and isobaths in 5-m increments. Western and eastern boundaries for the study area are shown as dashed red lines. This map also includes the proposed locations for the restoration reef blocks. Blocks have a maximum reef height of either 3 m (yellow) or 4 m (purple). The characteristics and placement of each block are described in more detail later in the report.

COMPREHENSIVE MONITORING OF REEFS AROUND PALOS VERDES PENINSULA

We examined the potential efficacy of fishery production enhancement reefs in this region by conducting an intensive biological and physical sampling program throughout the subtidal areas of Palos Verdes Peninsula. As part of multiple kelp forest monitoring programs we have conducted 578 surveys at 38 sites from 2004-2015 in this region (Figure 8, Table 1) using the CRANE protocol. This is a standardized comprehensive community monitoring survey method that quantifies fishes, invertebrates, algae and habitat characteristics within multiple depth zones at each site (for more details on the protocol see Claisse et al. 2012; Pondella et al. 2015a; Pondella et al. 2015b; Zahn et al. 2016). This protocol is focused primarily on sampling rocky reef habitats, and therefore areas that are primarily soft bottom, including the proposed locations for the restoration reef blocks, were sampled with additional supplementary methods (see Sediment Depth Surveys below). In order to determine the effects of the sedimentation and turbidity on rocky reef habitats around the Palos Verdes Peninsula, we conducted a habitat

characterization utilizing metrics generated from uniform point contact (UPC) data from the comprehensive kelp forest monitoring dataset. The physical substrate and relief of reefs varied throughout the peninsula. Most of the variation in substrate was associated with the fraction of sand versus bedrock, and most of the variation in physical relief was associated with the proportion of flat (0 – 0.1 m) reef versus moderate (1-2 m) and high relief (> 2m) reef. The restoration study area was characterized by flat to low relief reef with larger portions of sand, cobble, and boulders versus other areas of the peninsula where bedrock reefs are the dominant feature.

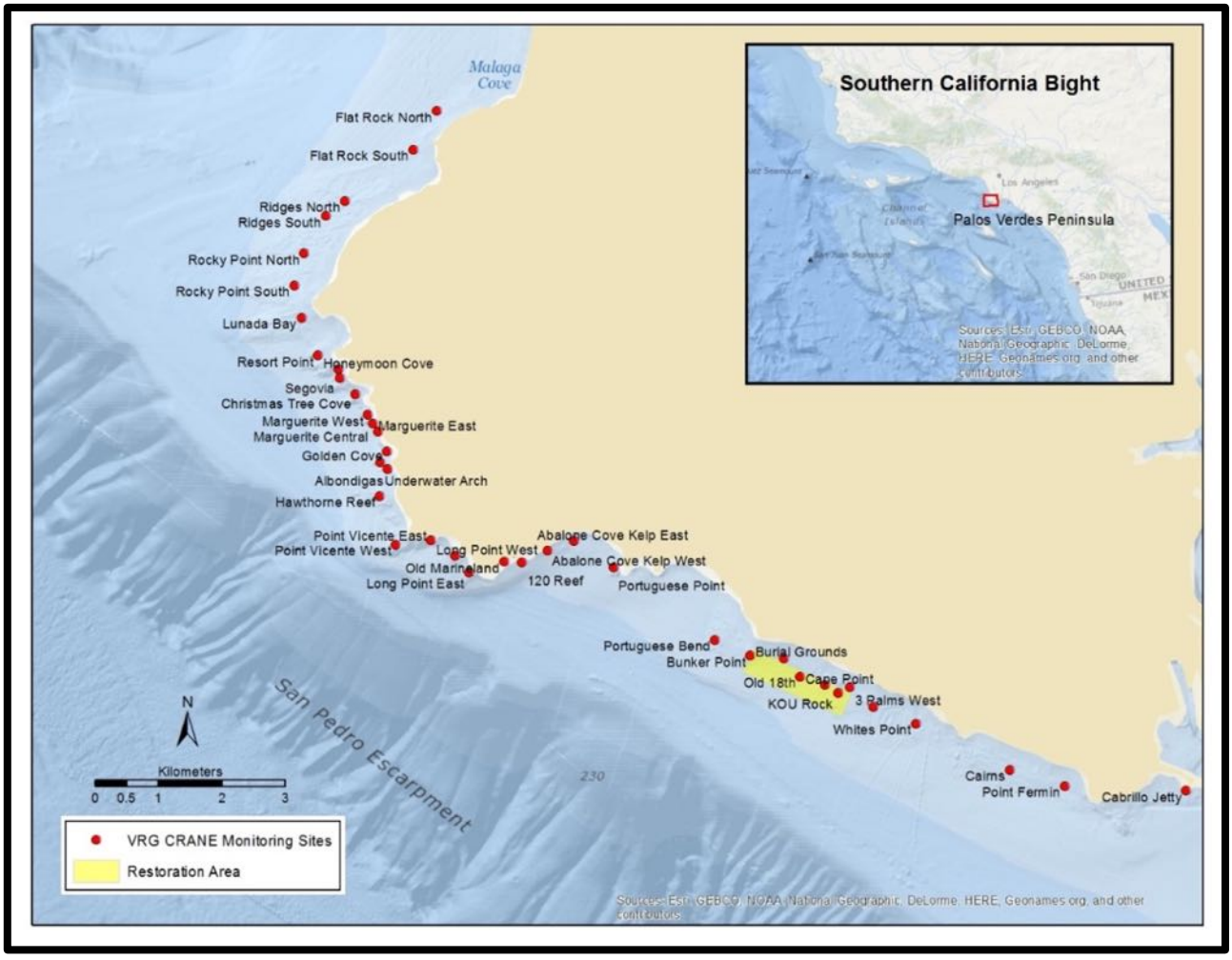


Figure 8. CRANE monitoring sites around the Palos Verdes peninsula with the restoration area (yellow).

Table 1. Sites surveyed using CRANE protocols by year, listed from northwest to southeast (Figure 8). The sites surveyed within the restoration area are indicated in gray. CRANE protocols require >50% coverage of rocky reef, the restoration area has not supported kelp or significant percentages of rocky substrate precluding it from previous CRANE surveys.

Site	2004	2007	2008	2009	2010	2011	2012	2013	2014	2015
Flat Rock North		X	X							X
Flat Rock South		X								X
Ridges North	X	X		X	X	X	X	X	X	X
Ridges South	X	X	X				X	X	X	X
Rocky Point North	X	X	X	X		X	X	X	X	X
Rocky Point South		X			X	X	X	X	X	X
Lunada Bay						X	X	X		X
Resort Point			X				X	X	X	X
Honeymoon Cove						X	X	X	X	X
Segovia							X	X		X
Christmas Tree Cove					X	X	X	X	X	X
Marguerite West						X	X	X	X	X
Marguerite Central						X	X	X	X	X
Marguerite East						X	X	X	X	X
Golden Cove						X	X	X	X	X
Underwater Arch					X		X	X		X
Albondigas						X	X	X	X	X
Hawthorne Reef		X		X	X	X	X	X	X	X
Point Vicente West	X	X	X	X	X	X	X	X	X	X
Point Vicente East		X								
Long Point West		X					X	X		X
Long Point East		X		X	X	X	X	X	X	X
Old Marineland						X	X	X		X
120 Reef					X	X	X	X		X
Abalone Cove Kelp West					X	X	X	X	X	X
Abalone Cove Kelp East					X		X			
Portuguese Point					X		X	X		X
Portuguese Bend								X		X
Bunker Point		X				X	X	X	X	X
Burial Grounds										X
Old 18th								X		X
Cape Point										X
KOU Rock				X		X	X	X	X	X
3 Palms West		X						X	X	X
3 Palms East		X	X	X					X	X
Whites Point		X	X		X	X	X	X	X	X
Cairns						X	X	X	X	X
Point Fermin		X	X		X	X	X	X	X	X

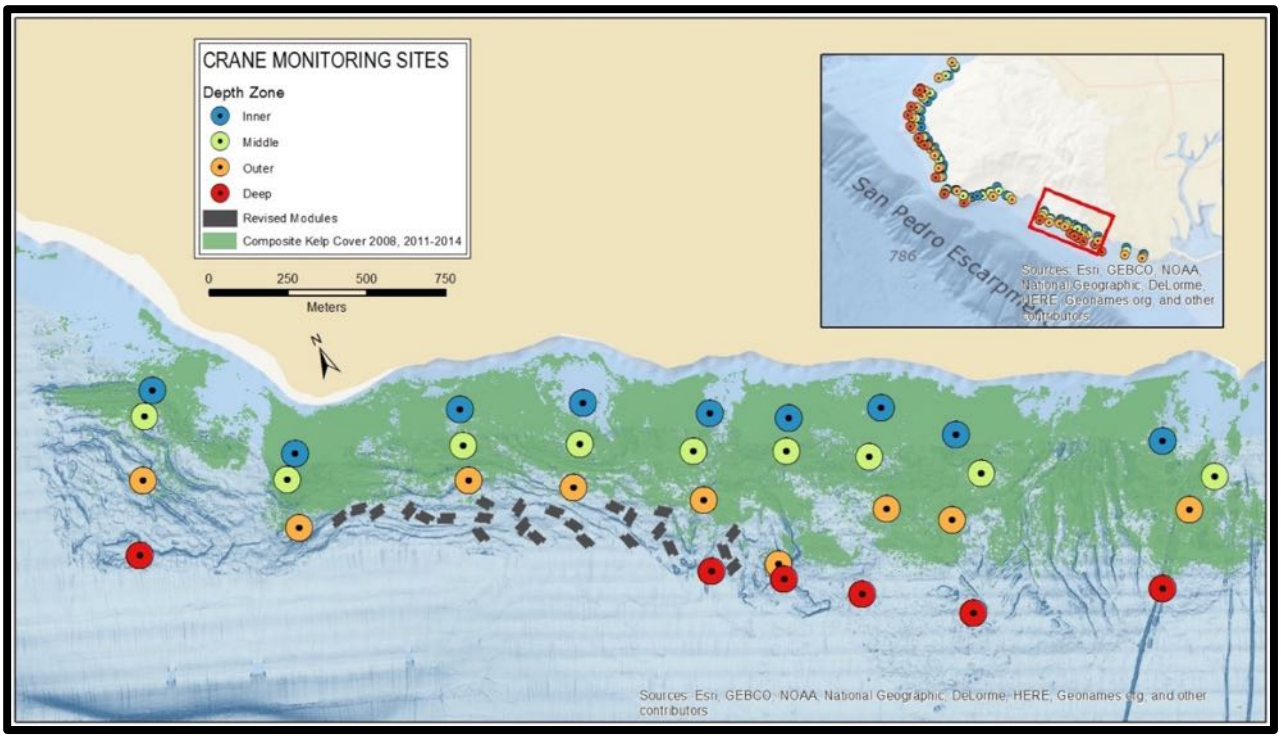


Figure 9. Mapped reef habitat, composite kelp cover, and subtidal survey locations by depth zone with currently proposed restoration reef blocks (gray). Multiple depth zones (Inner, Middle, Outer, Deep) are surveyed at each CRANE monitoring site.

The most striking aspect of the benthos was the evidence of sedimentation effects in the study area as well as surrounding reefs. Sedimentation effects are evident upcoast and downcoast based upon the direction of the longshore current and suspension by swells. We observe these effects from Abalone Cove (ending at Long Point) through Whites Point (Figure 9). Bare rock cover on rocky reefs can be an indicator of scouring by either abiotic sources (e.g., sand, shell hash, wave action) and is typical of areas that are under stresses of high flow and/or high sedimentation (Figure 10). The proportion of abiotic cover (including bare rock, bare sand, shell hash, sediment, and detritus) on rocky reefs was far higher in sedimentation affected areas, such as those near storm drains, landscaping runoff zones, and landslide areas and is what we found in the study area (Figure 11). Biological indicators of sedimentation effects include the benthic cover proportion of sediment resistant tubeworms, including *Phragmatopoma californica*, *Salmacina tribranchiata*, and *Diopatra ornata* (Figure 12). These three metrics provide insight into the extent of ecosystem damages caused by various forms of sedimentation along Palos Verdes Peninsula.

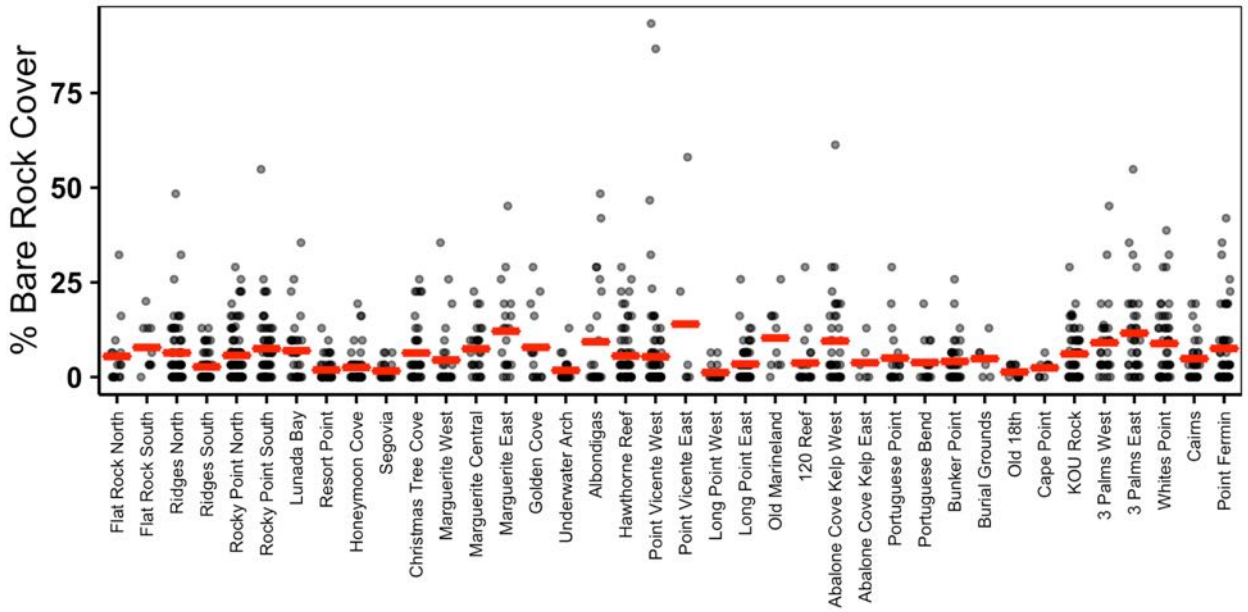


Figure 10. Percentage of bare rock cover on rocky reefs at each site along Palos Verdes Peninsula. Dots represent values for every transect, red crossbars represent mean values.

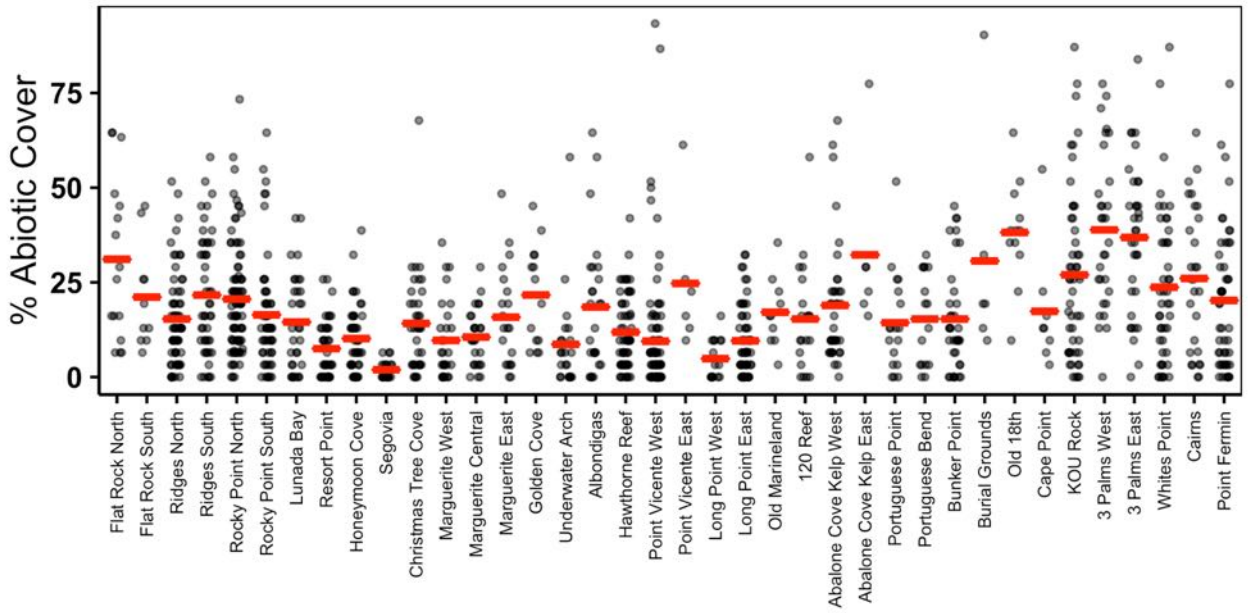


Figure 11. Percentage of abiotic cover (including bare rock, bare sand, shell hash, sediment, and detritus) on rocky reefs at each site along Palos Verdes Peninsula. Dots represent values for every transect, red crossbars represent mean values.

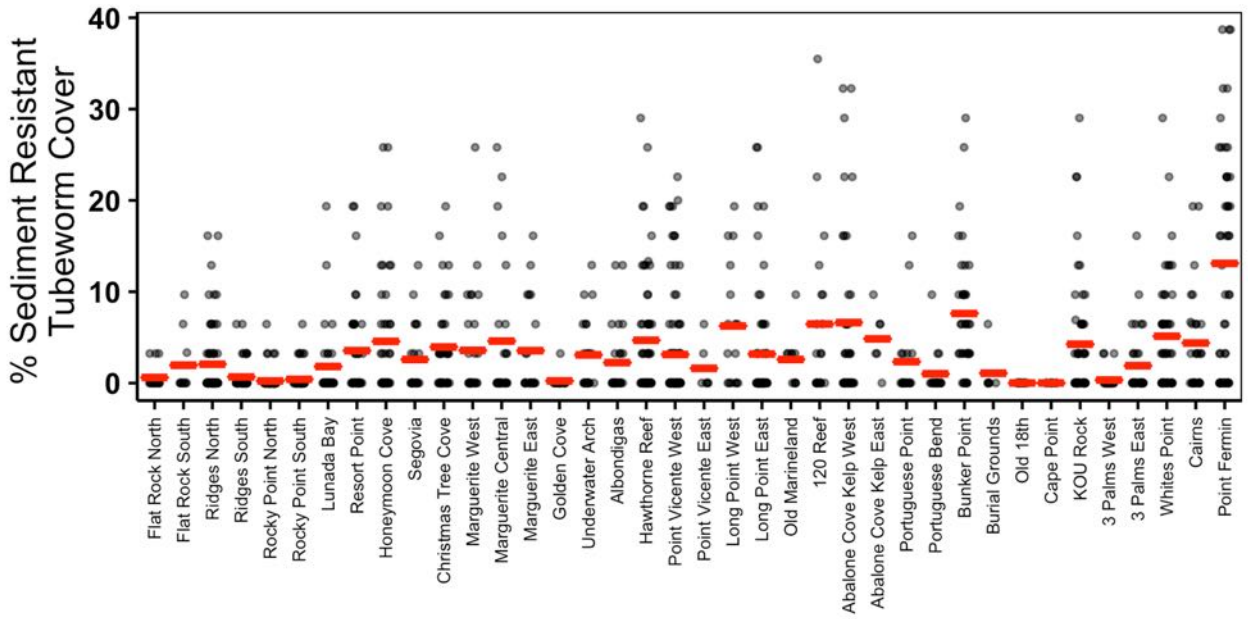


Figure 12. Percent sediment-resistant tubeworm cover on rocky reefs at each site along Palos Verdes Peninsula. Dots represent values for every transect, red crossbars represent mean values.

A second part of the CRANE subtidal survey protocols (swath) was used to determine macroalgal and macroinvertebrate densities in conjunction with the UPC surveys at each reef. Macroalgal densities provided insight into the community structure of each reef and the presence or absence of appropriate habitat for fishes and invertebrates that depend on macroalgae for food and/or shelter. While macroalgae along the Palos Verdes Peninsula consisted of several species, including giant kelp *Macrocystis pyrifera*, *Pterygophora californica*, *Laminaria farlowii*, and other understory kelps, giant kelp was the lone canopy creating species. Reefs with dense giant kelp forests require relatively clear, nutrient rich water, and are considered to be among the most productive areas in southern California. Giant kelp forests were found inside the restoration study area, but were far thinner and more ephemeral than in areas with less turbidity and sedimentation issues (Figures 13 & 14). *Pterygophora californica* creates understory canopies on flatter, low-relief reefs, and can withstand more turbidity than giant kelp. This macroalgae was found in high densities in the sediment-affected reefs in the study site, creating an understory in addition to the sparse giant kelp canopy (Figure 15). However, many of these individual kelps were completely denuded of blades and their stalks were parasitized by epiphytic macroalgae including giant kelp and *Laminaria farlowii*. It was hypothesized that these atypical epiphytes used the hearty stalks as substrate for their holdfasts largely as a product of availability versus natural substrate due to sedimentation effects.

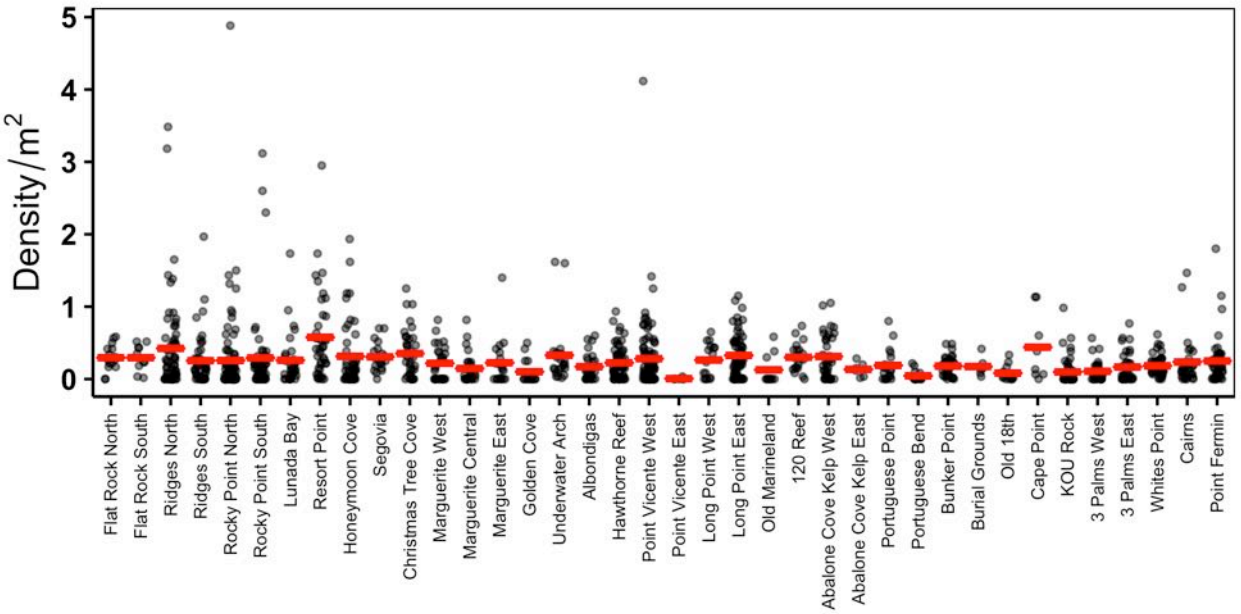


Figure 13. Giant kelp (*Macrocystis pyrifera*) density on rocky reefs at each site along Palos Verdes Peninsula. Dots represent values for every transect, red crossbars represent mean values.

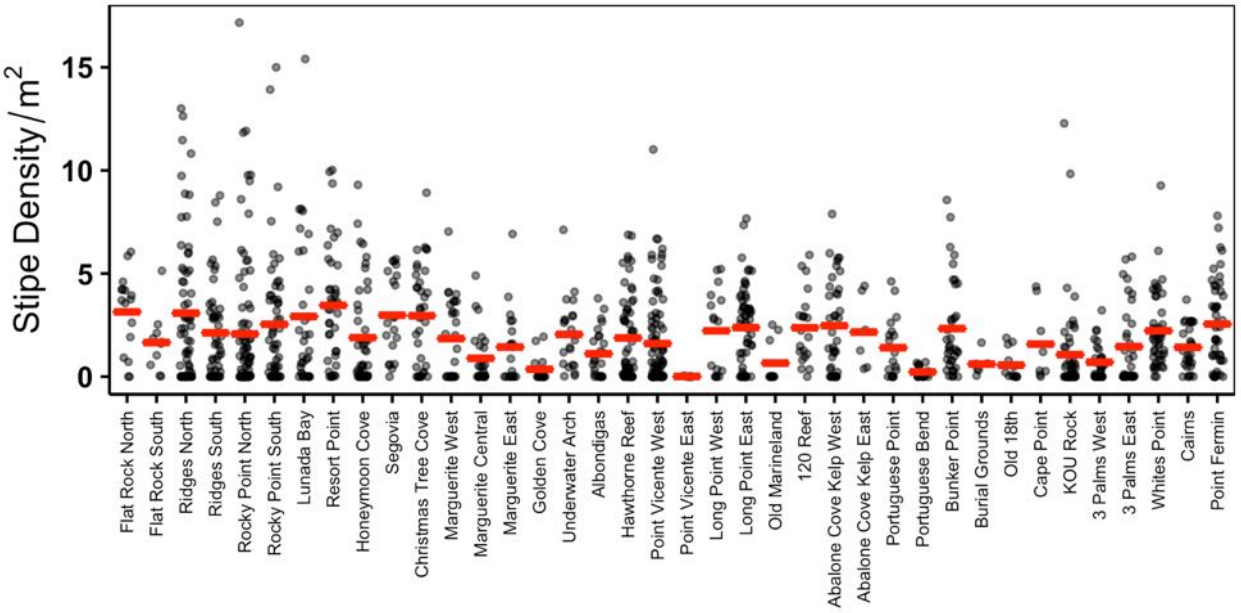


Figure 14. Giant kelp (*Macrocystis pyrifera*) stipe density (stipes per m^2) on rocky reefs at each site along Palos Verdes Peninsula. Dots represent values for every transect, red crossbars represent mean values.

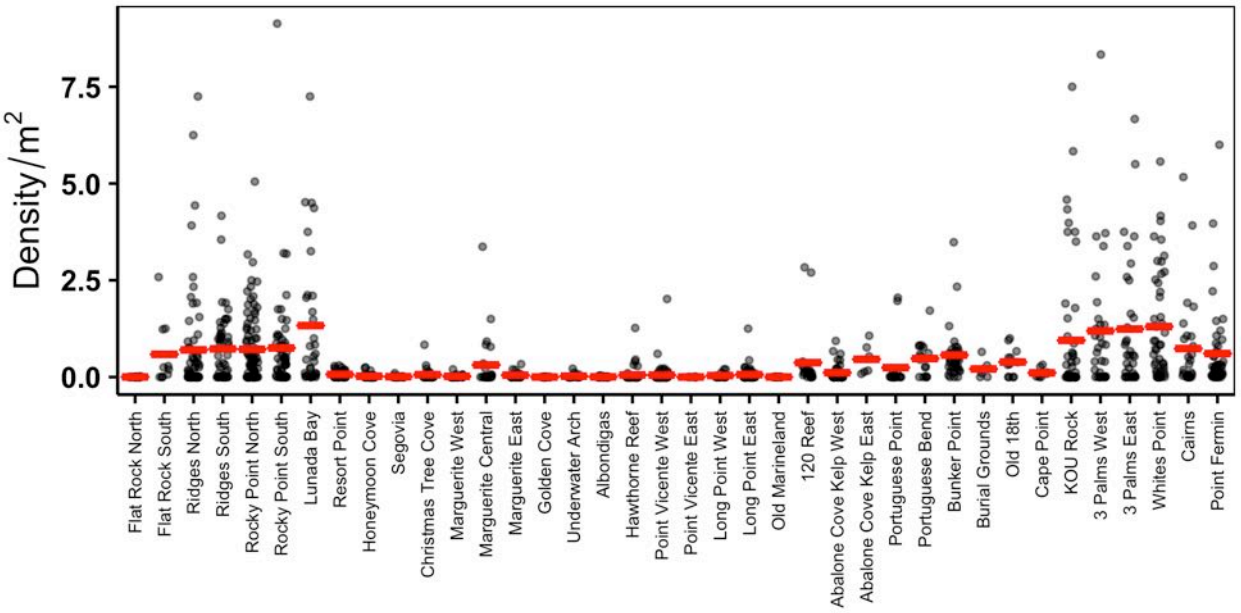


Figure 15. *Pterygophora californica* density on rocky reefs at each site along Palos Verdes Peninsula. Dots represent values for every transect, red crossbars represent mean values.

SEDIMENT DEPTH SURVEYS

We conducted supplementary scuba surveys at 9 locations to determine the sediment depth over rocky reef throughout this area (Figure 16) in an effort to better characterize soft bottom habitat areas in the study area and determine proposed locations for the restoration reef blocks. These surveys were conducted perpendicular to the coastline starting at the 20 m isobath, and divers would measure the sediment depth at 10 m intervals until completely uncovered and unbroken reef habitat was found. Sites that were found to be primarily exposed rocky reef were excluded from successive surveys. The initial sediment characterization was conducted in Spring 2009 and a second survey was conducted in Spring 2010. A third survey was conducted in Spring 2011 to fill in spatial gaps and further concentrate surveys on possible restoration sites. Between each of the first three study periods we had long winters of cold El Niño storms associated with heavy rains. This set up a natural experiment of the effects of heavy swell and rain on the study site, and helped determine fidelity of buried reefs (Pondella et al. 2012). A final survey was conducted in 2013 at sites that were considered prime options for restoration as a product of the previous surveys, all of which were across large, well-defined areas of buried rocky reef. While sediment depth and the amount of rocky reef covered by sand remained buried over time, no previously identified buried reefs were cleared of sand during this period (Table 2). Consistent

with the visual observations of the *Pterygophora* beds, these findings indicated that reef habitat continued to be buried at proposed locations for the restoration reef blocks.

Table 2. Sediment depth survey results summarized as mean sediment depth and percentage of exposed and buried reef by line (Figure 16) and survey year.

	2009	2010	2011	2013		2009		2010		2011		2013	
Line #	Mean Sediment Depth (cm)					% Exposed	% Buried	% Exposed	% Buried	% Exposed	% Buried	% Exposed	% Buried
1	19.2	–	–	–		71	29	–	–	–	–	–	–
2	8.7	4.5	21.4	3.3		60	40	15	85	11	89	30	70
13	–	–	10.7	8.7		–	–	–	–	15	85	20	80
3	3.2	10.7	4.0	10.8		0	100	0	100	10	90	18	82
4	2.6	6.0	–	–		22	78	42	58	–	–	–	–
5	–	21.3	–	–		–	–	0	100	–	–	–	–
6	3.0	–	–	–		38	62	–	–	–	–	–	–
7	3.0	5.5	10.3	7.4		0	100	8	92	27	73	20	80
8	1.9	4.6	5.4	4.6		40	60	0	100	26	74	41	59

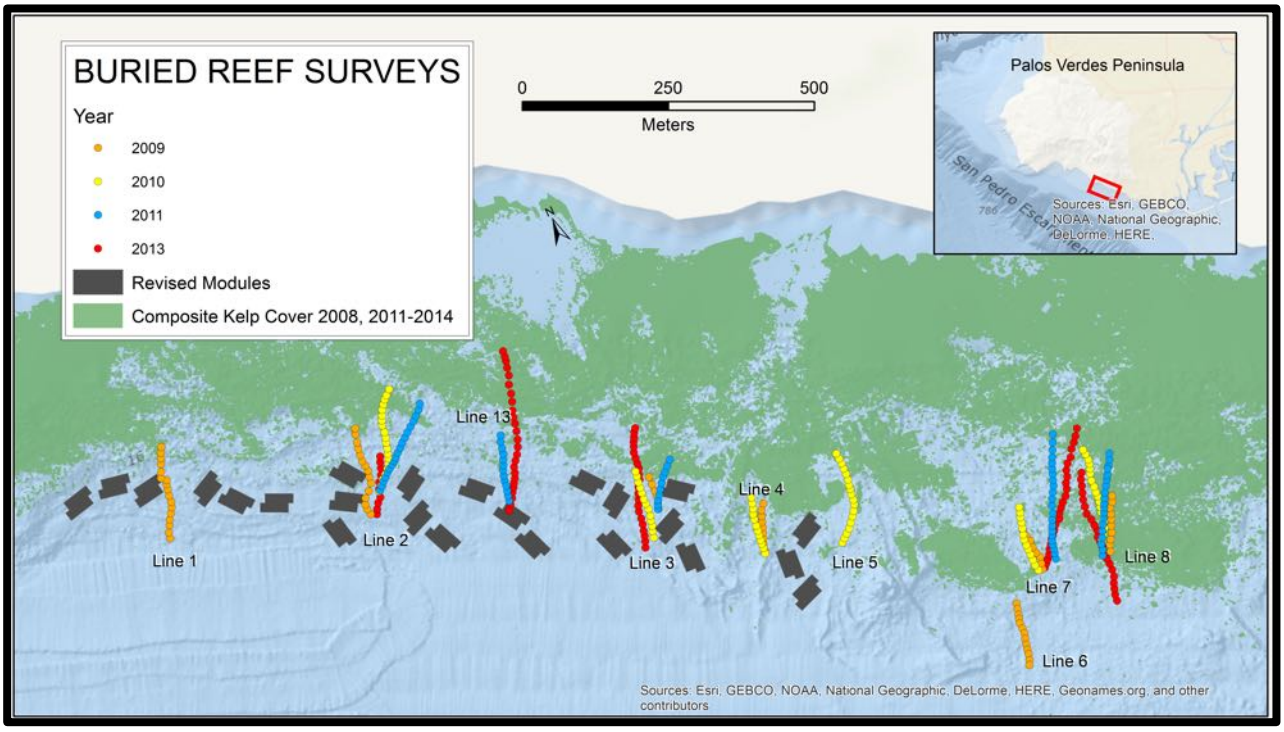


Figure 16. Mapped reef habitat, composite kelp cover, and yearly sediment survey locations with currently proposed restoration reef blocks.

PROXY REEF SURVEYS

In order to further our understanding of how reef shape, size, structure, and relief affect the fish, invertebrate, and macroalgal communities, 25 isolated reefs along and adjacent to Palos Verdes Peninsula at depths of 16-24 m were surveyed using CRANE protocols (Figure 17). These reefs included six natural reefs, 10 manmade reefs built with quarry rock, three shipwrecks, three sites with scattered debris, two sites with quarry rock resting on discharge pipes, and one site with engineered shelters. In addition to typical survey techniques, total reef height was also measured by recording depth at the bottom and top of the reef. During these surveys and all other subtidal surveys using CRANE protocols, fish densities were calculated by identifying, counting, and estimating the sizes of all conspicuous fishes throughout the water column. Fish length estimates were converted to biomass using standard species-specific length-weight conversions from the literature (e.g., Claisse et al. 2012; Williams et al. 2013) or FishBase (FishBase 2012).

Total fish biomass was generally found to be higher on the manmade quarry rock reefs than on the natural reefs, and there was positive relationship between fish biomass and total reef height for each habitat type (Figure 18). Quarry rock reefs performed better at lower heights when compared to natural reefs, most likely due to the increased rugosity and interstitial space afforded by the piled quarry rock, as opposed to the generally solid bedrock formations of a natural reef. These results are consistent with another study comparing manmade (primarily quarry rock) reefs with natural reefs in southern California (Granneman 2011; Granneman and Steele 2014). They found that manmade reefs had higher rugosity than natural reefs and that fish tissue production was positively correlated with the abundance of large boulders. On average, mean biomass for quarry rock artificial reefs we studied was 63 g/m^2 when reef height was less than 1.5 m, while mean biomass for isolated natural and manmade quarry rock reefs greater than 1.5 m in height was 189 g/m^2 (Figure 19).

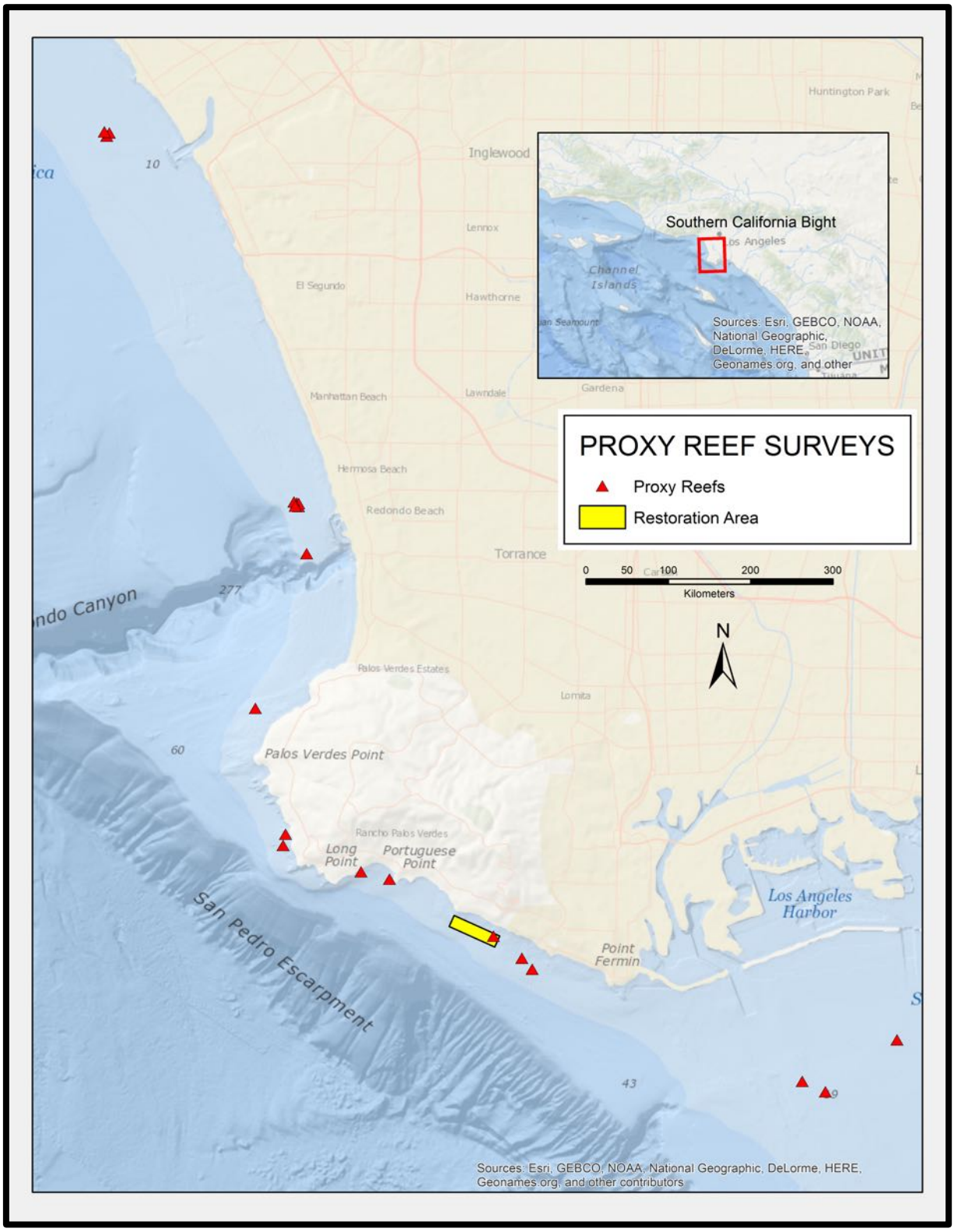


Figure 17. Location of artificial and high-relief natural reefs at Palos Verdes Peninsula and in Santa Monica and San Pedro Bays that were studied using CRANE surveys.

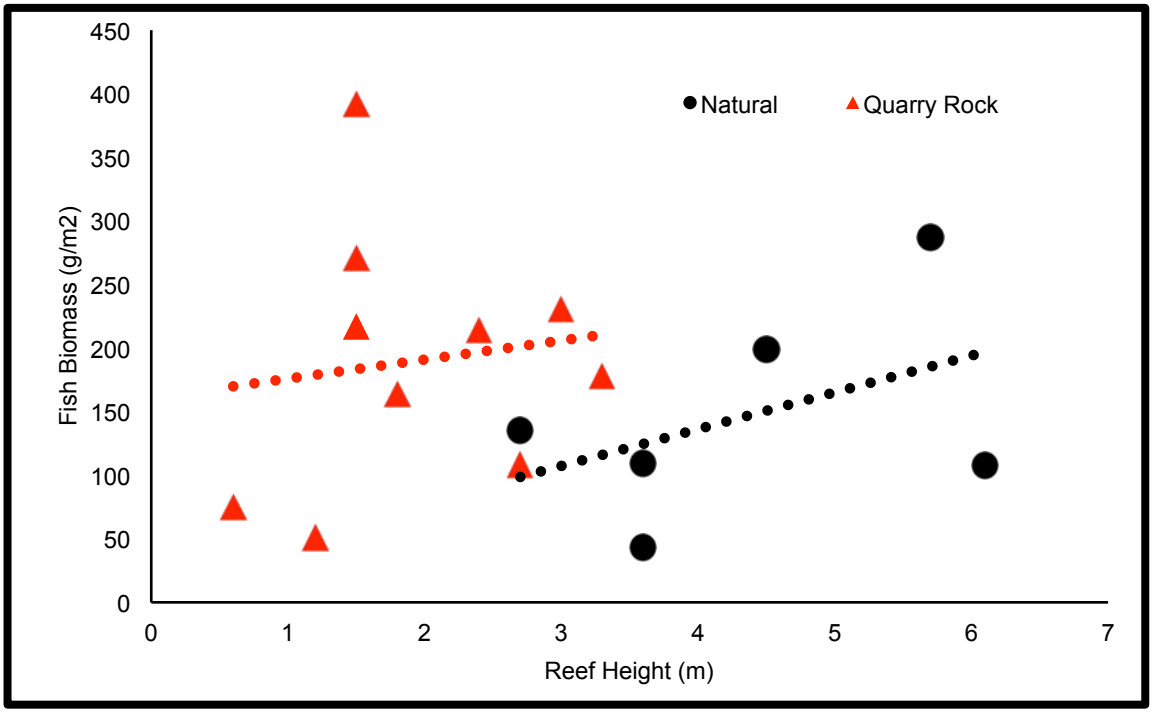


Figure 18. Reef height by total fish biomass (excluding young-of-the-year and pelagic species) at both natural isolated reefs and artificial reefs at Palos Verdes Peninsula and Santa Monica and San Pedro Bays.

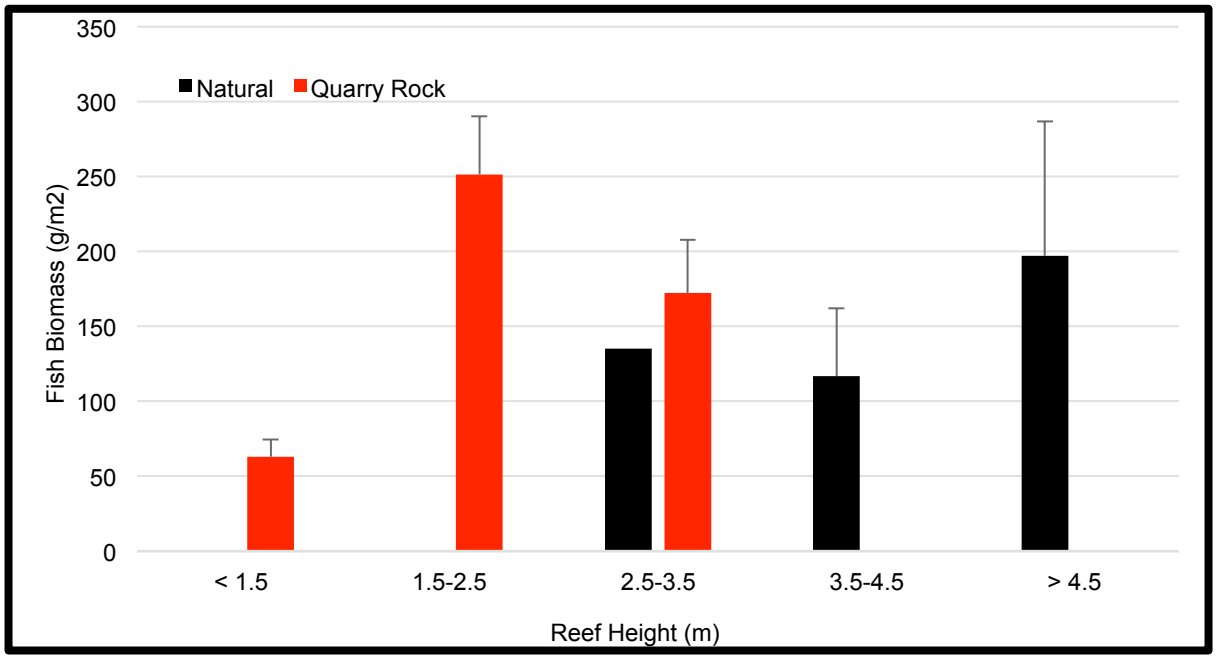


Figure 19. Mean reef height by total fish biomass (excluding young-of-the-year and pelagic species) at both natural isolated reefs and artificial reefs at Palos Verdes Peninsula and Santa Monica and San Pedro Bays.

HIGHLY PRODUCTIVE PALOS VERDES REEFS

Illustrating the complexity of this system, in spite of the sedimentation and turbidity problems from Bunker Point to Whites Point, the biomass and production potential for commercial and recreational fish species of the reefs was remarkably high where rocky reefs are present above the sediment. The biomass of kelp bass *Paralabrax clathratus* was higher at nearly every reef from Portuguese Bend to Cairns compared to the rest of the peninsula (Figure 20). California Sheephead, *Semicossyphus pulcher*, showed similar patterns, specifically from Portuguese Bend to KOU Rock, and at sites within MPAs (Long Point East and Point Vicente West; Figure 21). The reason for this increased biomass of fishery species in the area may reflect differential fishing pressure around the peninsula and/or elevated production along this stretch of coastline. Most salient to the design of the restoration reef is the total fish biomass at each site and depth zone (Figure 22). A typical reef along Palos Verdes Peninsula has the highest amount of fish biomass in the middle (~10 m) and outer (~15 m) depth zones. Notable among all depth zones and sites is the outer depth zone at the site named KOU Rock, which consistently has the highest fish biomass among anywhere on the peninsula averaging over 300 g/m^2. This semi-isolated pinnacle reef is inside the restoration project study area and subject to the same turbidity and sedimentation pressures as other reefs in the area, but its high (~5 m) total relief prevents accumulation of and burial under sediment. This reef was and continues to be the model for proposed restoration reefs at the study site. Details of the reef design are provided in subsequent sections.

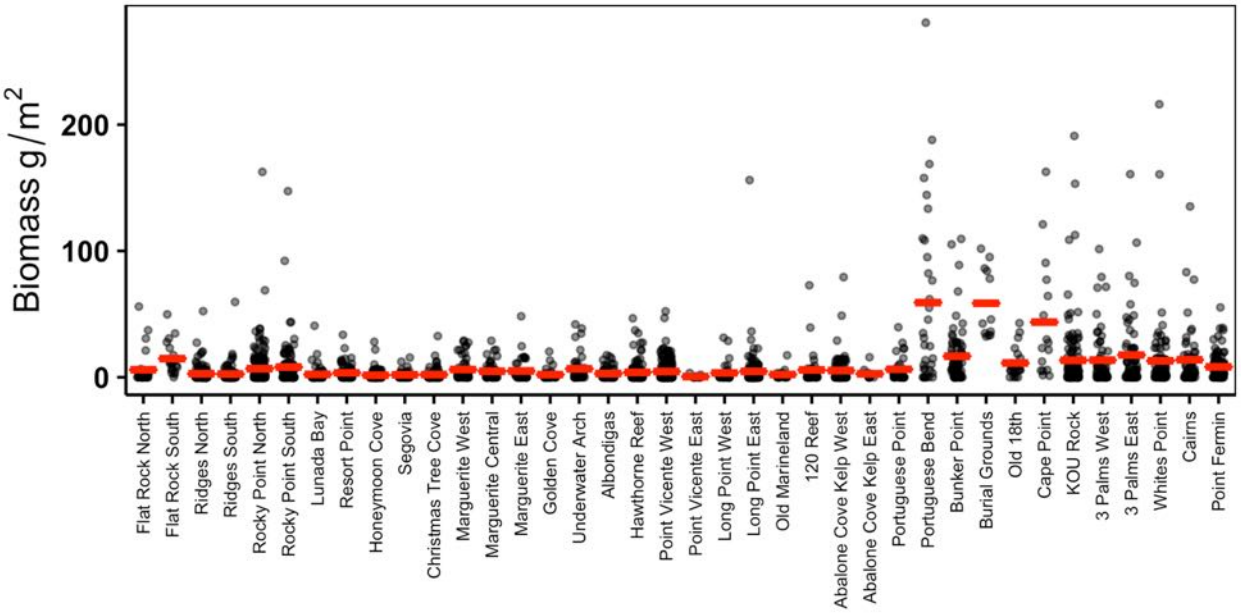


Figure 20. Biomass density of Kelp Bass (*Paralabrax clathratus*) at each site along Palos Verdes Peninsula. Dots represent values for every transect, red crossbars represent mean values.

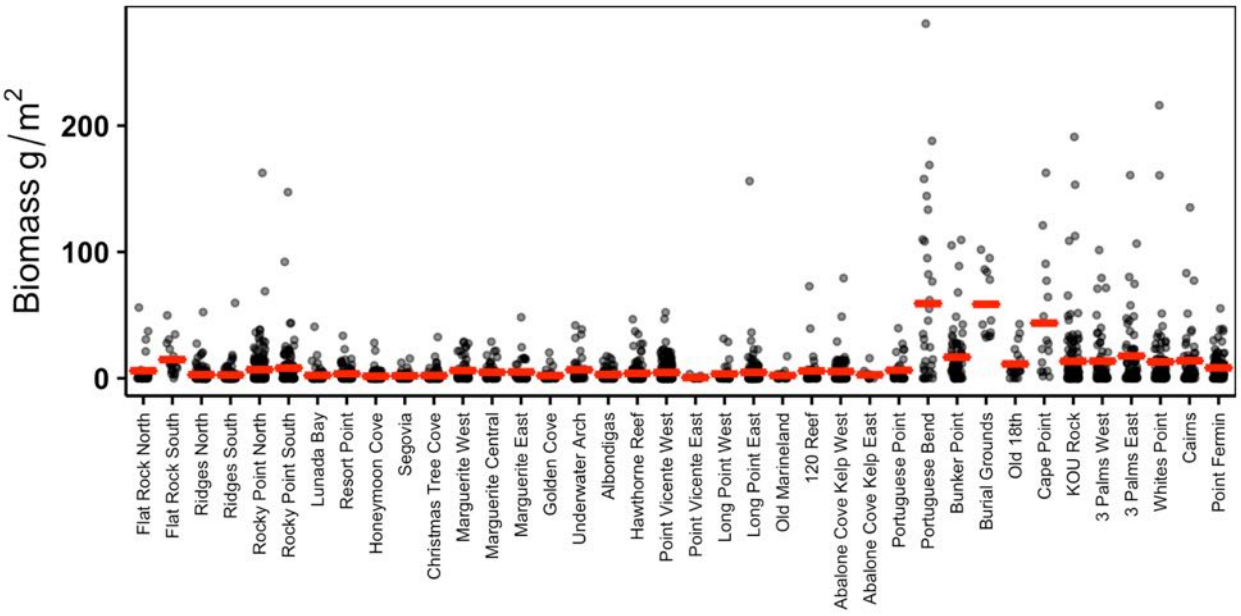


Figure 21. Biomass density of California Sheephead (*Semicossyphus pulcher*) at each site along Palos Verdes Peninsula. Dots represent values for every transect, red crossbars represent mean values.

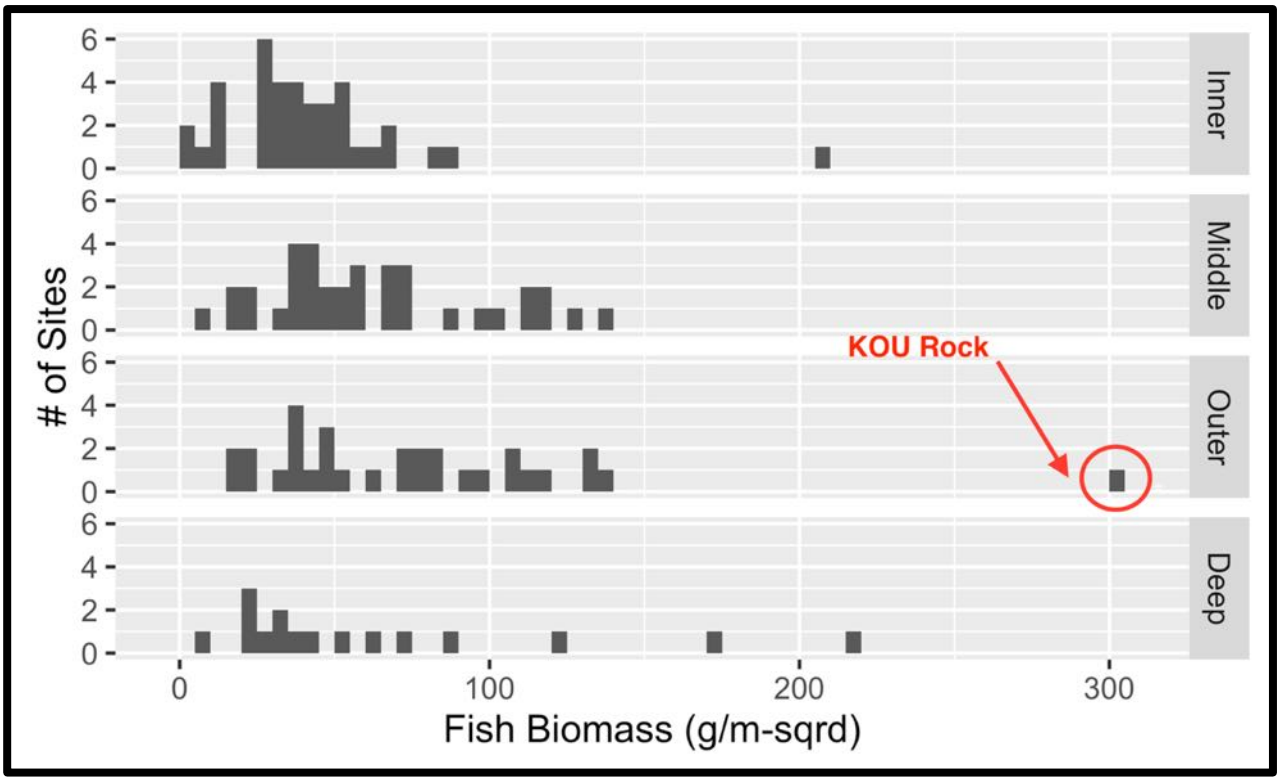


Figure 22. Distribution of total fish biomass at sites within specific depth zones. Note young-of-the-year and pelagic species are excluded from biomass estimates; The outer depth zone at the site named KOU Rock is where the large semi-isolated pinnacle reef is located in the restoration project study area. This high relief reef in the outer depth zone (surveyed six times from 2009-2015) is highlighted here as it served as the general model for the restoration reef design.

RESTORATION REEF DESIGN

The restoration reef is designed as set of eight "blocks" (Figures 23-25). Each block contains three modules (A, B, C). Each module consists of a 3 x 2 set of six "piles". The three piles on each side of the module are offset by 1/2 of the pile width (8 m). Each pile is a 16 m x 16 m square pyramid of quarry rock with an overall height of 1 m, 2 m, 3 m, or 4 m (Figure 23). The blocks will be in two designs, either with a 3 m overall pile height or a 4 m overall pile height. There is a 10 to 20 m wide sand channel between modules and at least 50 m of space between blocks. These distances were chosen due to the previously described 'halo' effect around reef of ~30 m (Johnson et al. 1994). Reef modules that are separated by < 30 m are more likely to operate as a single reef for many species, while blocks separated by > 30 m operate more independently (Pondella et al. 2006). In our design criteria reef blocks are spaced at least 50 m apart. By separating the blocks and modules by the appropriate distances we can restore a greater amount of reef perimeter sand-rock ecotone habitat and we can increase the independence of replicate reef blocks. The overall approach is to try to balance scientific study design considerations with maximizing the potential for an effective restoration effort across the range of important species, and kelp forest biodiversity. Major motivations included incorporating heterogeneity throughout the restoration reef design both within (e.g., varying pile heights within blocks) and amongst (e.g., varying block orientation across blocks) the reef blocks. Specific design elements and block placement considerations are discussed in more detail below.

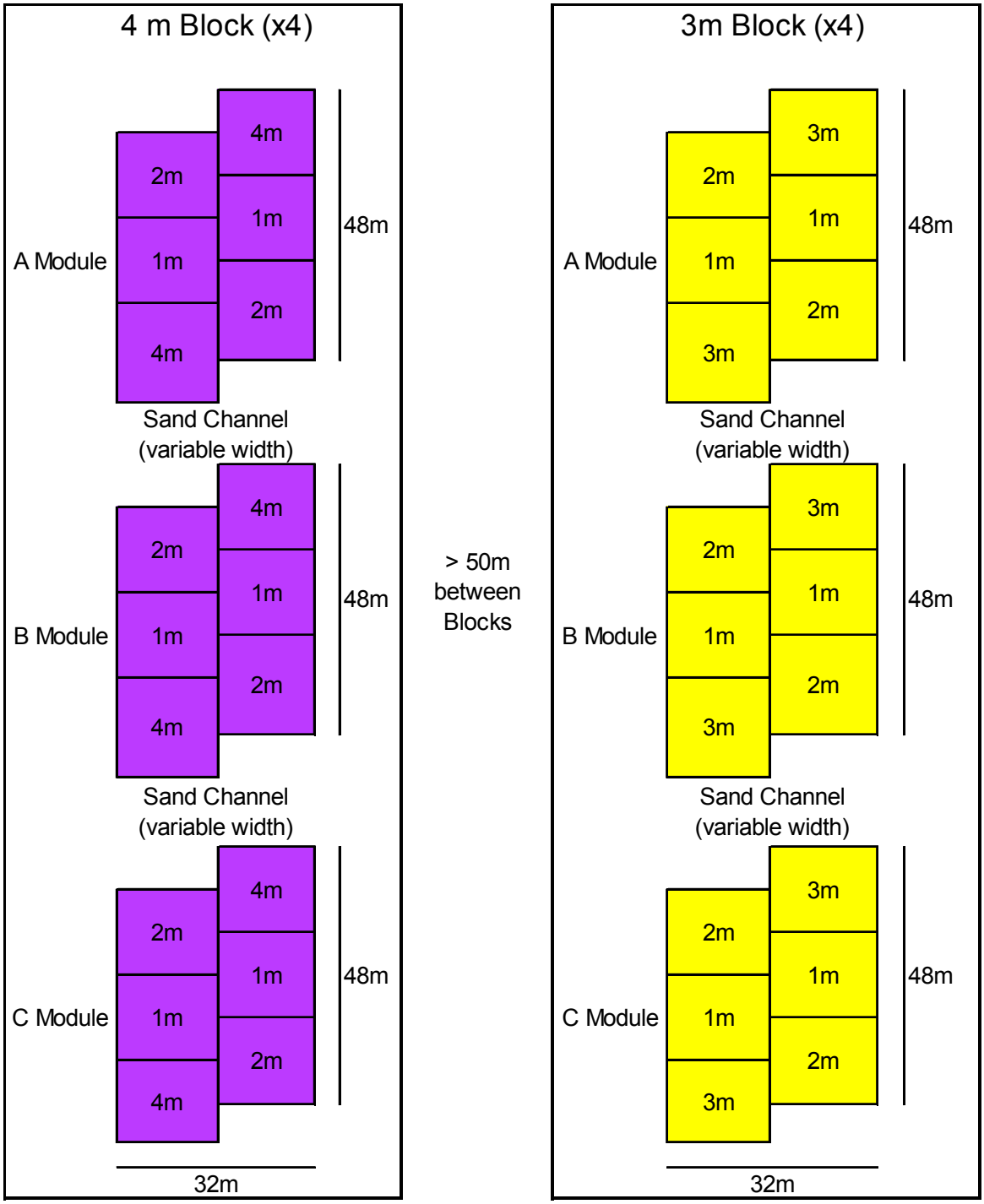


Figure 23. Design of 3m blocks and 4m blocks. Each block contains three modules (A, B, C). Each module consists of a 3 x 2 set of piles, offset by ½ pile length. Each pile is a 16 m x 16 m square pyramid of quarry rock with the overall height listed. There is a 10 to 20 m wide sand channel between modules and at least 50 m of space between blocks (construction design, control and precision details are contained in Appendix I).

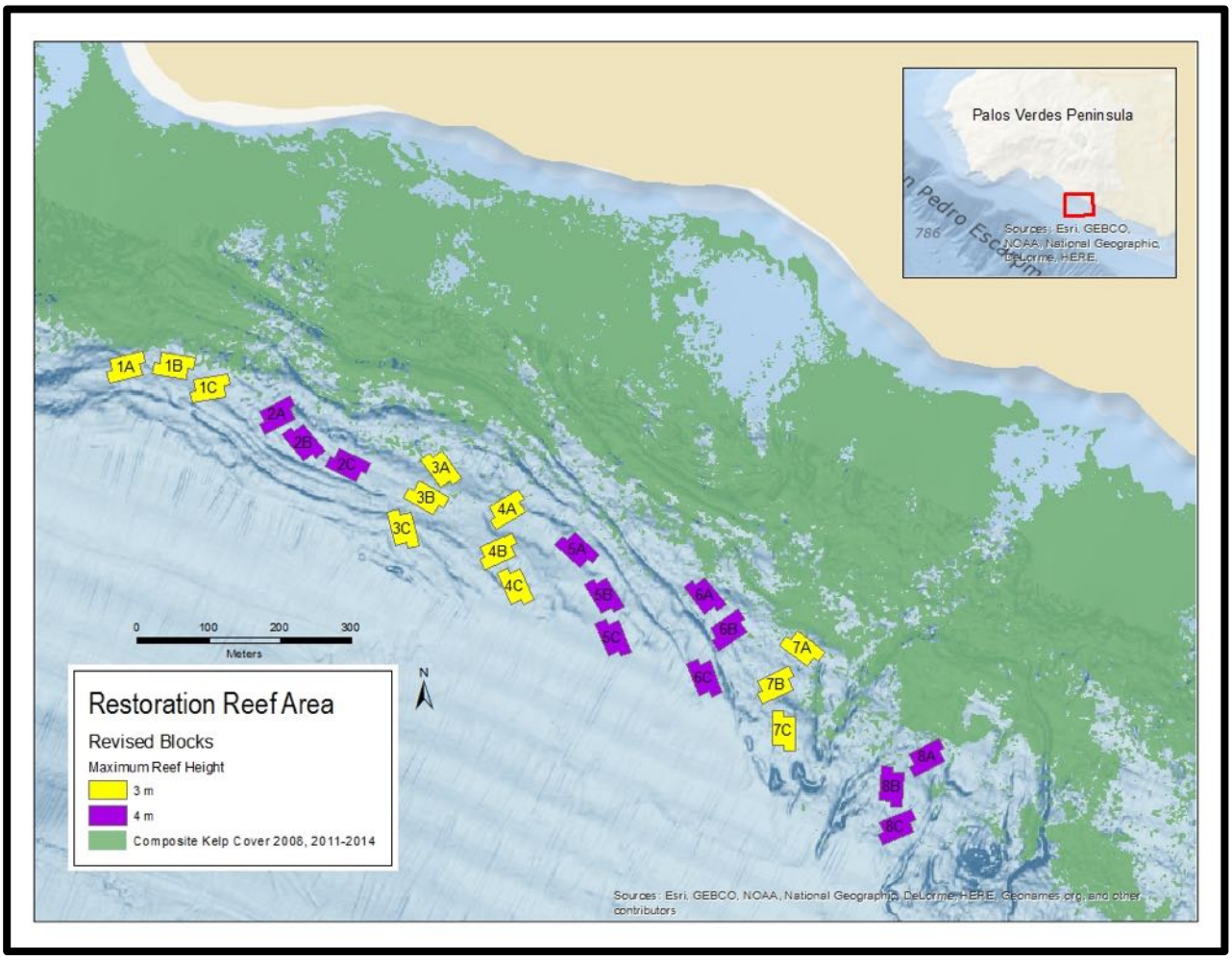


Figure 24. Proposed locations for the restoration reef blocks (1-8) at the Bunker Point restoration site study area with kelp canopy, side scan imagery. Each block consists of 3 modules (A-C). Blocks have a maximum reef height of either 3 m (yellow) or 4 m (purple).

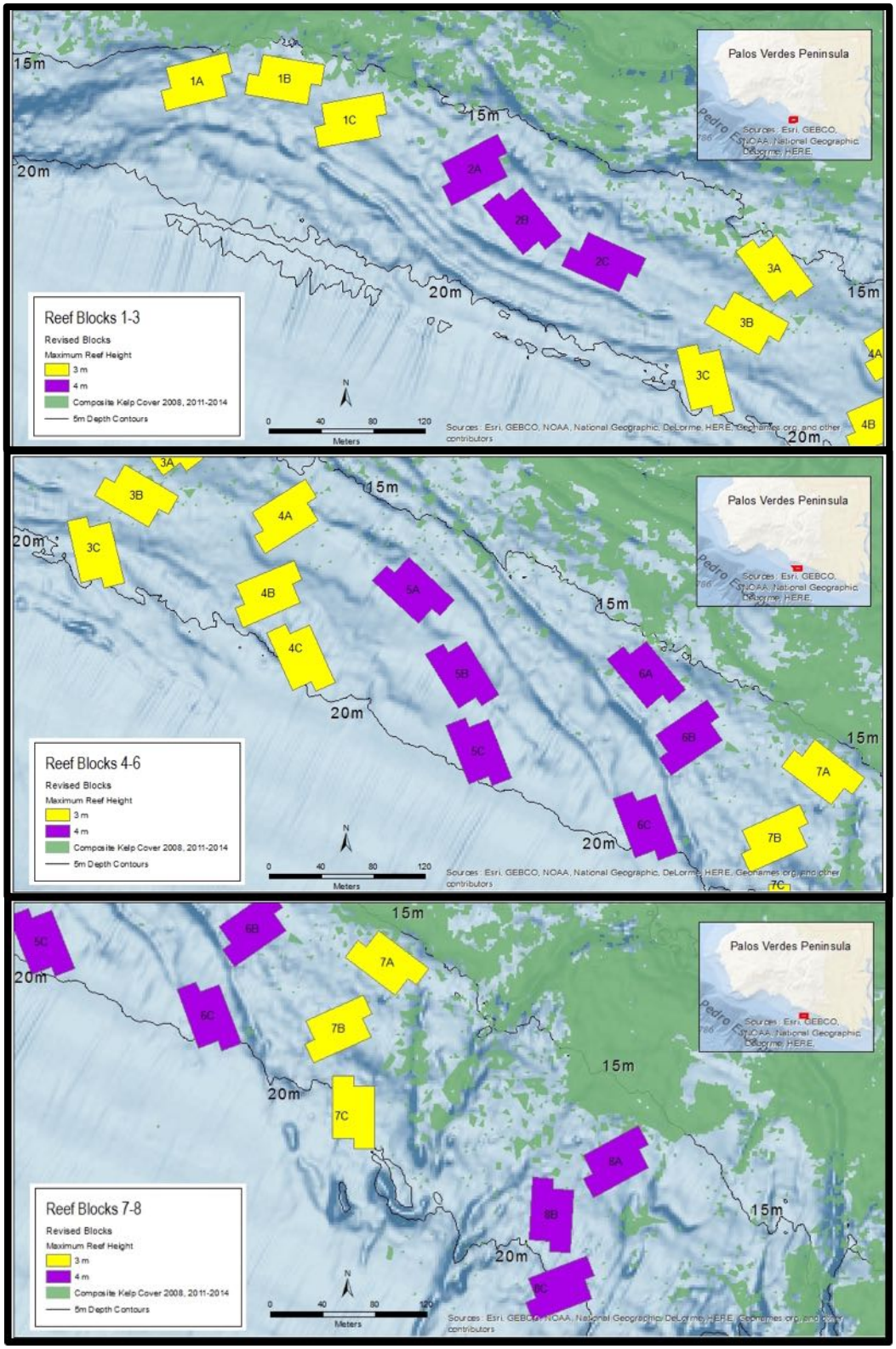


Figure 25. Close-up maps of the proposed locations for the restoration reef blocks (1-8) at the Bunker Point restoration site study area with kelp canopy, side scan imagery. Each block consists of 3 modules (A-C). Blocks have a maximum reef height of either 3 m (yellow) or 4m (purple).

PRIMARY BLOCK DESIGN CRITERIA

Based upon the contractor's estimate, there is 70,000 tons of rock available for this project. Thus, the overall objective is to utilize this limited resource to create the most productive habitat restoring the natural reef environment. The first criteria to consider is quarry rock size and the corresponding weight and void space. The quarry can filter rock sizes within a tight range (more expensive) to variation around a mean size (less expensive) diameters. Considering that this project's goal is to mimic natural reefs, using heterogeneously sized rocks was optimal as natural reefs are not composed of single sized rocks. Designating an average size (weight) within the constraints of the quarry results in the following percent size by weight profiles for rock (Figure 26). A previous study compared elements of fish production on natural and artificial rocky reefs in southern California (Granneman 2011; Granneman and Steele 2014). They found that tissue production was positively correlated with the abundance of large boulders, and they defined large boulders as those being at least 75 cm across. Production was lower on reefs with smaller boulders, most of these being natural reefs and the Wheeler North artificial reef. They explain that the Wheeler North artificial reef was designed with relatively low relief and low rugosity not to maximize fish production, but to mimic natural reefs in the southern Orange County region and to grow kelp. A higher proportion of larger boulders should also increase the likelihood of larger interstitial spaces between rocks in piles creating a variety (i.e., increase heterogeneity) of "hole" sizes for fishes and invertebrates that shelter within (Friedlander and Parrish 1998). Small rocks generally settle tightly, have small void spaces and are not considered as productive as larger rocks proportionally larger void spaces. The estimated average void space increases from 1 ft. to 1.5 ft. as rock size transitions from 0.25 ton to 0.50 tons, and then from 1.5 ft. to 2.0 ft. as rock size increase from 0.5-0.75 ton to 1 ton. Interstitial void space was also considered in the sizing criteria (Table 3). Additionally, having larger stones will minimize the chances of rocks at the edges of blocks from being covered in sediment while creating more complex eco-tone habitats at the sand/rock interface. The other trade-off to consider is that if you model rocks as sphere, as you increase the diameter, you get significantly heavier rocks without correspondingly significantly larger sizes (Figure 27). Note a 2-ton and 3-ton rock are not substantially larger than a 1-ton rock, but 2-3 times the cost, respectively, keeping in mind that weight is the cost estimate used for the quarry. Based upon these criteria, we chose 1.0-ton rock, which has the larger void spaces, is not overly heavy (costly) for our budget, and maximizes the known biological production.

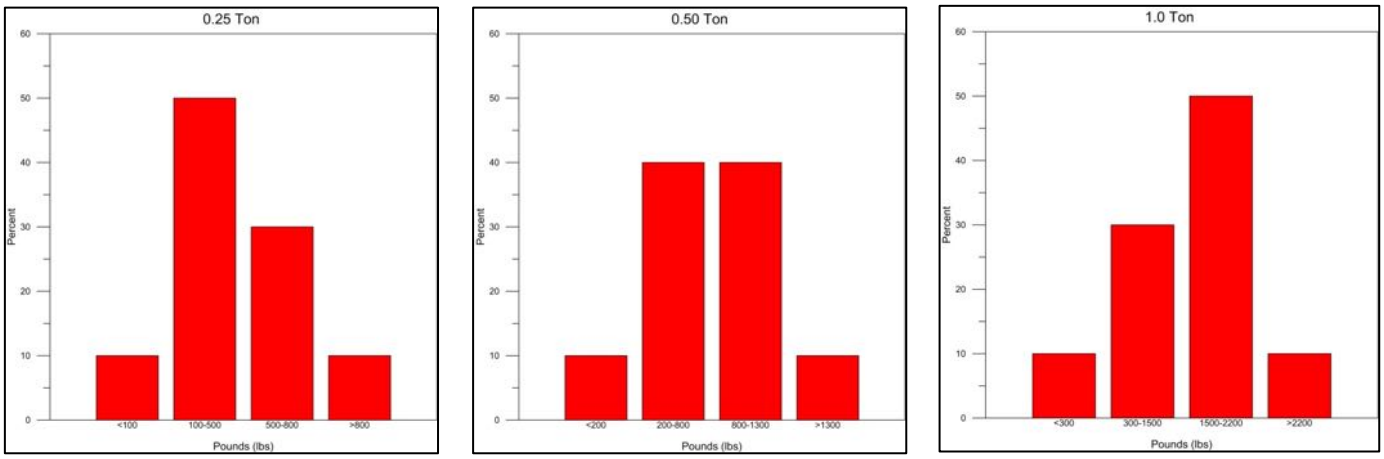


Figure 26. Percent size of quarry rock by weight based upon 0.25, 0.50 and 1.0 ton criteria.

Table 3. Quarry rock weight, dimensions and estimated average void size.

Rock Weight (lbs)	Rock Dimension (ft)	Estimated Average Void Size (ft)
200	1.5 x 1.0 x 1.0	1
300	1.5 x 1.3 x 1.0	
400	1.6 x 1.6 x 1.0	
500	2.0 x 1.5 x 1.0	
1000	3.0 x 2.5 x 2.0	1.5
1500	3.5 x 3.0 x 2.0	
2000	4.0 x 3.0 x 2.5	2
2500	4.0 x 3.5 x 2.5	
3000	4.5 x 3.5 x 2.5	
3500	5.0 x 4.0 x 2.5	



Figure 27. 3-ton, 2-ton and 1-ton quarry rocks arranged left to right.

In addition to optimizing rock sizes, the design of the blocks and modules maximize biological production based upon a variety of physical and biological criteria. First, maximizing the amount of exposed surface area and reef perimeter increase the production versus cost constraints. Engineering constraints dictate that reefs are constructed in a linear fashion as the 6-point barge anchoring systems are used to construct the habitat. Our goal is to design reef that maximize high relief components, surface area, perimeter, flux, and are consistent with the size of reefs along the Palos Verdes Peninsula. High relief reefs have a cost tradeoff, as they are more expensive (more weight per unit area) than low relief reefs. And, a critical consideration is how much rock is buried (and generally unavailable biologically) to create the high relief components. Modules within blocks are designed in 16 m^2 piles where variation in relief is staggered increasing the amount of surface area of the reef. These piles are also staggered maximizing the perimeter of the reef and surrounding ecotone.

The following additional design criteria were incorporated into our module and block designs:

- Stagger high relief piles within blocks. Vary pile heights across adjacent piles within blocks (Figure 23).
    - This should increase diversification of water flow by limiting overlap of high relief piles, reducing the occurrence of one high relief pile being in the "shadow" of another high relief pile. Heterogeneity in pile height may facilitate the creation of a mosaic of small-scale flow features, effectively facilitating microhabitat creation/diversification across the module/block/reef.
    - Maximize external surface area by limiting rock overlap of adjacent high relief piles.
    - Maximize heterogeneity in reef characteristics (e.g., relief, interstitial space, overall angle of outer reef surface) to increase biodiversity by increasing the heterogeneity of available micro-habitats within each block.
- Place high relief piles at the ends of each block to buffer any potential sedimentation of the 1 m relief piles in the middle of each block.
- Size blocks similar to current reefs along Palos Verdes. The pinnacle reef at KOU Rock is ~45m wide, the finger reef at Long Point East is ~120m wide, the finger reef at Point Vicente West is ~225m wide (Figure 8).
- Increase the amount of outer reef edge (the relationship between perimeter and area) by not making blocks too large. The highest biomass areas of the reefs we studied tended to be on the outer edges (zones) (Figure 22).

BLOCK PLACEMENT

The following design criteria were used to guide the positioning of restoration reef blocks (and the modules within them) across the Bunker Point restoration site study area:

- Blocks do not overlap with persistent kelp canopy. Persistent kelp canopy is an indication of stable rocky reef below that has not been covered by sediment (Figure 25).
- Blocks are placed at 15-20 m seafloor depth (Figure 25). The highest biomass areas of the reefs we studied tended to be in this depth zone (Figure 22). Placing blocks in these somewhat deeper depths would also limit wave action, scouring and seasonal excavation/deposition of sediments.
- Vary the orientation of each block and each module (Figure 24). This would again increase heterogeneity in reef characteristics, with respect to their relative orientation to the shoreline and to prevailing currents and wave action. This should increase the likelihood of high relief blocks causing creating a mosaic of small-scale flow features,

effectively facilitating microhabitat creation/diversification across the module/block/reef.

- Mimic natural features (reef width and orientation to natural features).
- Blocks placed in a maximum of 1m sediment to limit long-term burial/sinking.
- 10-20 m sand channels between modules within a block (Figures 23-25). Permits space for sediments moving with longshore current and wave action to move around/through modules. Modules are still close enough to provide connectivity (fishes can move over sand between them).
- Maintain connectivity with existing natural reefs. The was done by positioning the ends of at least one module within a block less than 30 m from existing nearshore natural exposed reef (kelp line) or existing (non-buried) rocky reefs so the blocks are not "isolated islands" in the sand (Figure 24-25).
- Maximize distance between blocks (>50 m) to increase independence of each block (Figure 24). Mimics natural reef ridges, these are typically oriented perpendicular to shore with large sandy areas between them.

Secondary Block Design Criteria

A secondary focus of our reef design was to create a reef design that would permit replicated elements that could be studied to inform future restoration programs (Figures 23-25). This was balanced however, with the primary goal of maximizing the potential for an effective restoration effort. A main question we are interested in examining is the effects of reef relief. Blocks will be in two forms, either with a 3 m overall pile height or a 4 m (Figure 23) overall pile height, with 3 replicate modules per block, and 4 replicate blocks of each height. This will permit a comparison of the two reef heights impact on fish biomass and production. Additionally, with the high level of heterogeneity, but many repeated elements (for example 1m, 2m, 3m and 4m piles, or blocks oriented at various angles relative to shore, or blocks in various seafloor depths), various other studies will also be possible. These could include fine scale habitat utilization patterns, effects of Block orientation relative to current), providing an opportunity to inform future restoration programs in the State.



Figure 28. Example of a 4 m high reef pile, an approximate representation of a module within a block.

RESTORATION REEF DESIGN EVALUATION

We produced simple estimates of the biomass of fishes expected on low (1 m) and higher (2 - 4 m) relief piles within the restoration reef Blocks, then summed these to produce an overall estimate of fish biomass for the restoration reef (Table 4). Fish biomass estimates are based on previously observed biomass densities from Proxy Reef study (Figures 18 & 19).

Table 4. Area and fish biomass estimates for current restoration reef design.

Block Type (Max Relief)	Blocks	Modules Per Block	Pile Relief (m)	Piles per Module	Pile Area 16m x 16m (m2)	Total Area (m2)	Total Area (Acres)	**Fish Biomass Density (g/m2)	Total Biomass (g)	Total Biomass (kg)
		3	4m	2	256	6144	1.5	189	1161216	1161
		3	2m	2	256	6144	1.5	189	1161216	1161
4m	4	3	1m	2	256	6144	1.5	63	387072	387
		3	3m	2	256	6144	1.5	189	1161216	1161
		3	2m	2	256	6144	1.5	189	1161216	1161
3m	4	3	1m	2	256	6144	1.5	63	387072	387
Totals						**36864**	**9.1**		**5419008**	**5419**

**63 g/m^2 is mean biomass for proxy reefs (all quarry rock) < 1.5 m relief and 189 g/m^2 is mean biomass for natural and quarry rock reefs > 1.5 m relief (Figures 18 & 19).

EVALUATION OF ALTERNATIVES

Four design alternatives were considered during initial stages of reef development (Figures 29-32). These used the same 70,000 tons of rock available for this project, but the rocks were placed in other configurations. Alternatives 1 and 2 (Figures 29 & 30) contained large areas of low relief "reef" (<1 or <0.5 m height), essentially individual rocks scattered over the landscape. This type of low relief design was used extensively throughout the Wheeler North artificial reef. However, it was not designed to maximize fish production, but to mimic the low relief natural reefs in the southern Orange County region. In the case of Palos Verdes where sedimentation and reef burial is a major concern, these low relief designs were deemed unlikely to meet the desired restoration objectives as they would likely be heavily impacted by sedimentation scour and burial. Alternatives 3 and 4 (Figures 31 & 32) contained only high relief elements. Early in the design process these alternatives served to motivate discussion of additional design elements (e.g., heterogeneity, spacing, orientation and depth of reef Blocks) that were ultimately included in the final proposed design.

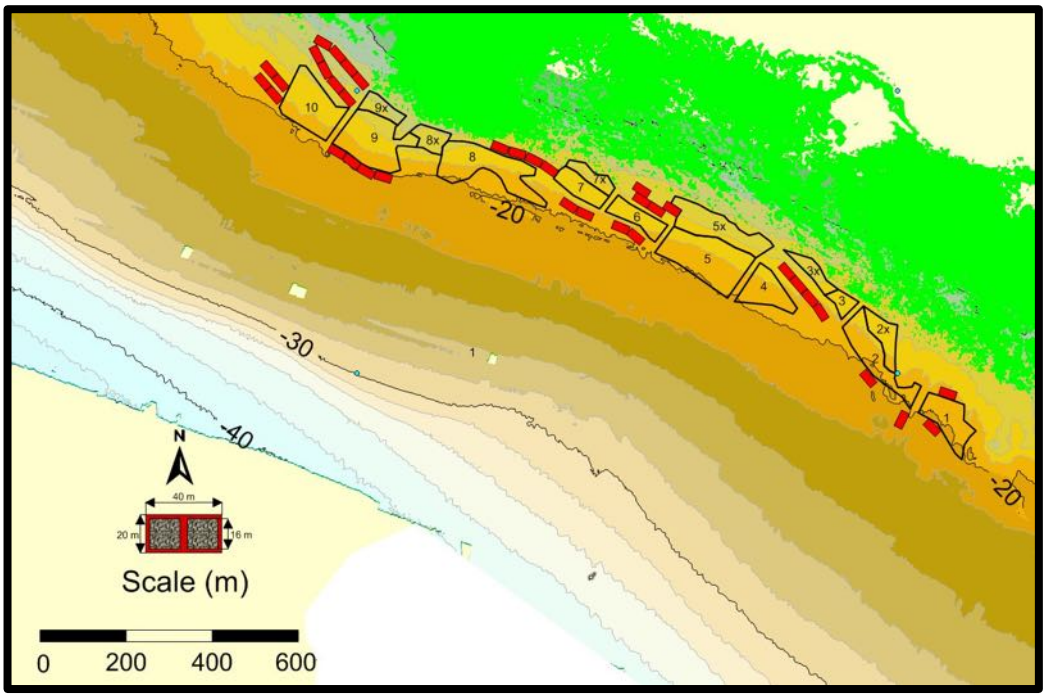


Figure 29. Alternative 1: A reef with high relief components (red polygons) and low relief components (black outlined polygons).

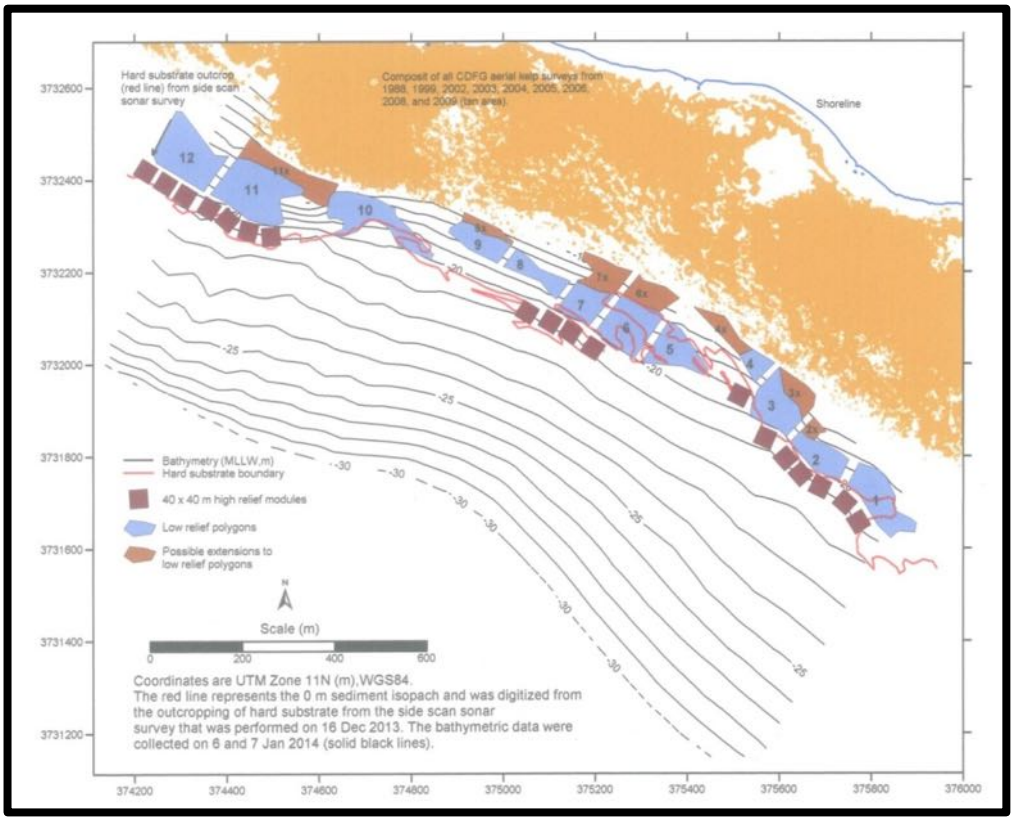


Figure 30. Alternative 2: In this alternative, a reef with high relief components (dark brown square polygons) and low relief components (blue and light brown polygons).

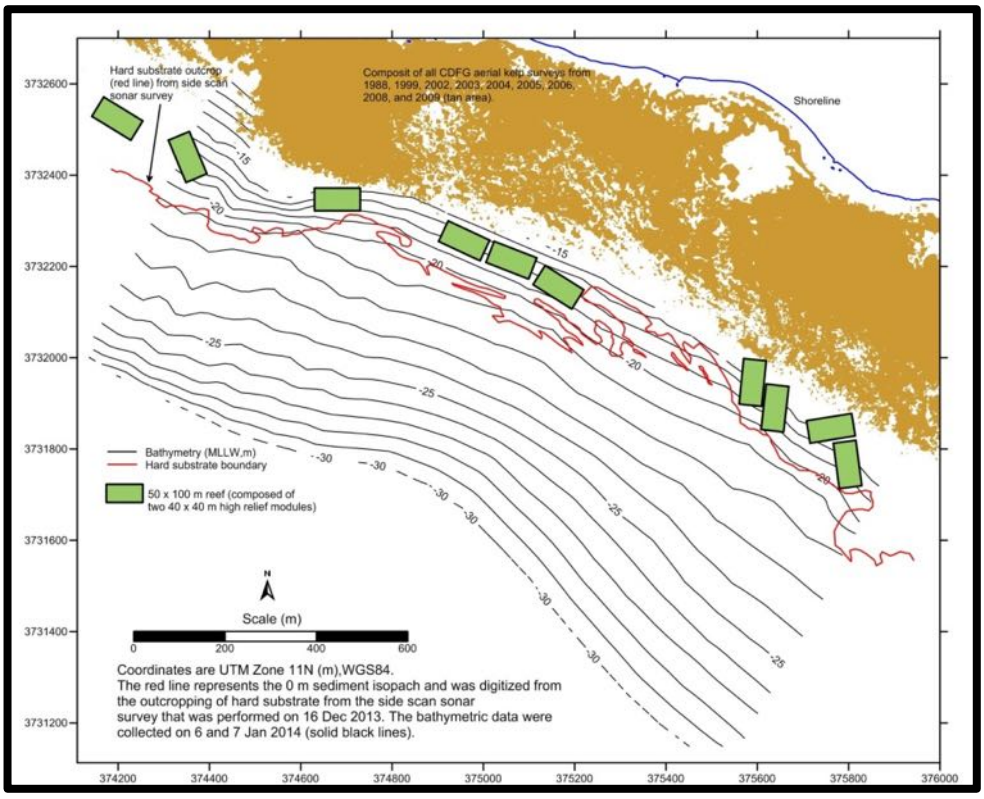


Figure 31. Alternative 3: In this alternative, a reef with high relief components (green polygons) located in shallower water.

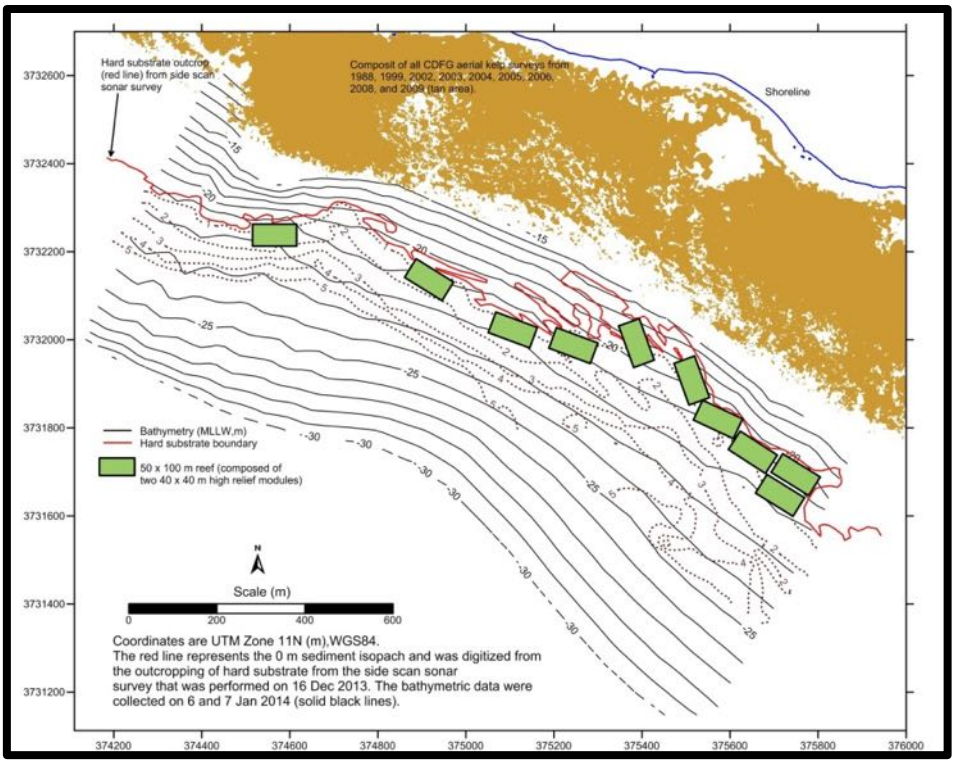


Figure 32. Alternative 4: In this alternative, a reef with high relief components (green polygons) located in deeper water.

GROUND TRUTHING SURVEYS

After the 2013 surveys were completed, it was determined that concentrating semi-contiguous restoration reefs on the west side of KOU Rock, a highly productive and anomalous pinnacle reef in the eastern half of the study area, would be more effective and less confounding to monitoring efforts. The depth of sediment cover on the buried reef between 15 and 20 m was significantly lower than what we found to the east. In addition, there was less slope to the reef increasing the amount of potential restoration habitat between 15-20 m. We determined that this was the optimal placement for the restoration reefs based upon feedback from the resource agencies. Subsequently, all further efforts at surveying the habitat were concentrated on the western side of the survey area. In 2014, eight surveys of the buried reef areas were performed to confirm the interpretation of the geophysical survey results (Figure 33). Divers descended at specific coordinates and swam perpendicular to shore for approximately 200 m. Every 10 m, sediment samples were taken and data was recorded on sediment type, sediment depth (up to 1.8 m), macroalgae, and macroinvertebrates. These data along with video documentation taken during this survey confirmed that the region contained primarily sand and sand-covered reef with scattered small areas of low-relief hard substrate dominated by gorgonians.

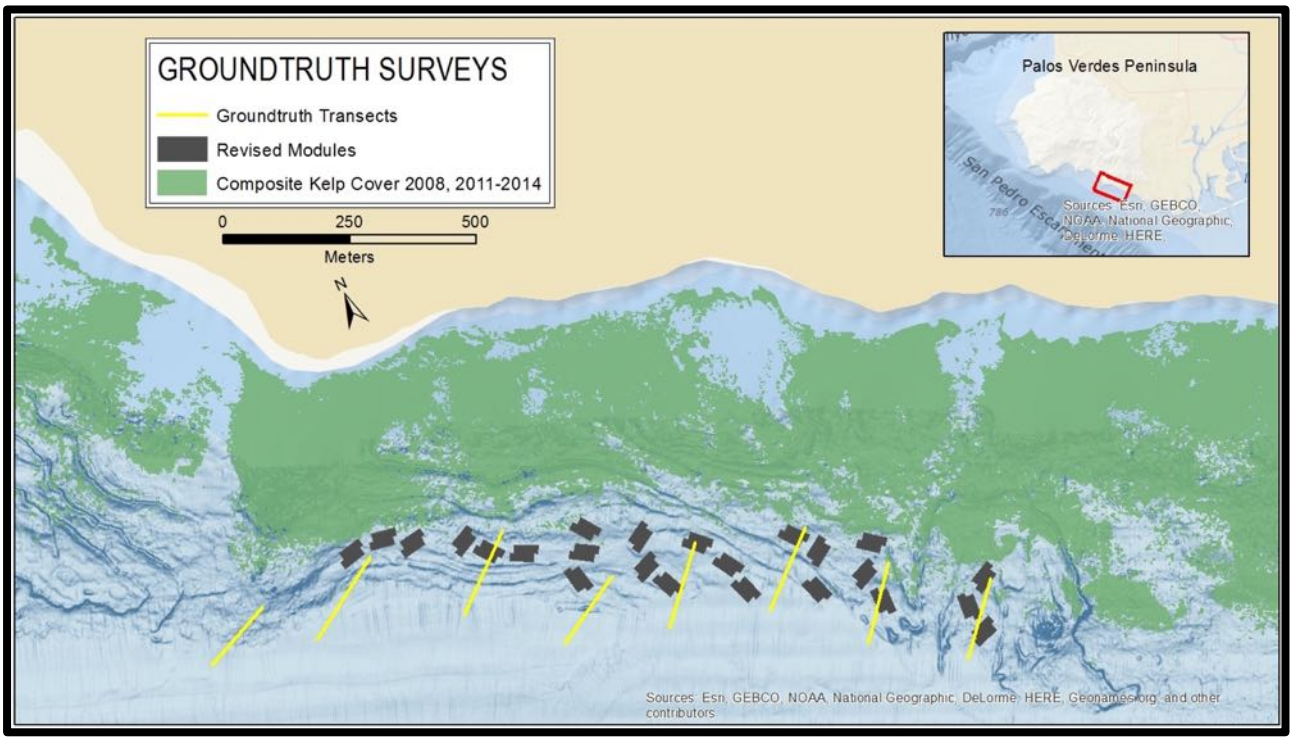


Figure 33. Mapped reef habitat, composite kelp cover, and ground truth transect locations with currently proposed restoration reef Blocks.

SITE INSPECTION SURVEYS

A final site inspection survey of the study area was conducted in 2015 using a simplified version of CRANE protocol (Figure 34). The 26 paired (end-to-end) transects provided information on the substrate composition as well as biological observations. The transect locations were chosen based on: (1) sites that represented areas that are commonly present throughout the proposed area of reef placement, (2) sites that cross ecotones (observed in backscatter data), and (3) sites in likely areas of reef restoration. In summary, 75% of the area was covered by sand (29% had hard substrate within 10 cm of the seafloor), while only a quarter of the substrate was rocky reef. These surveys provided further evidence of burial at specific locations and helped guide Block placement so that existing exposed rocky reef habitat will not be covered during restoration reef construction.

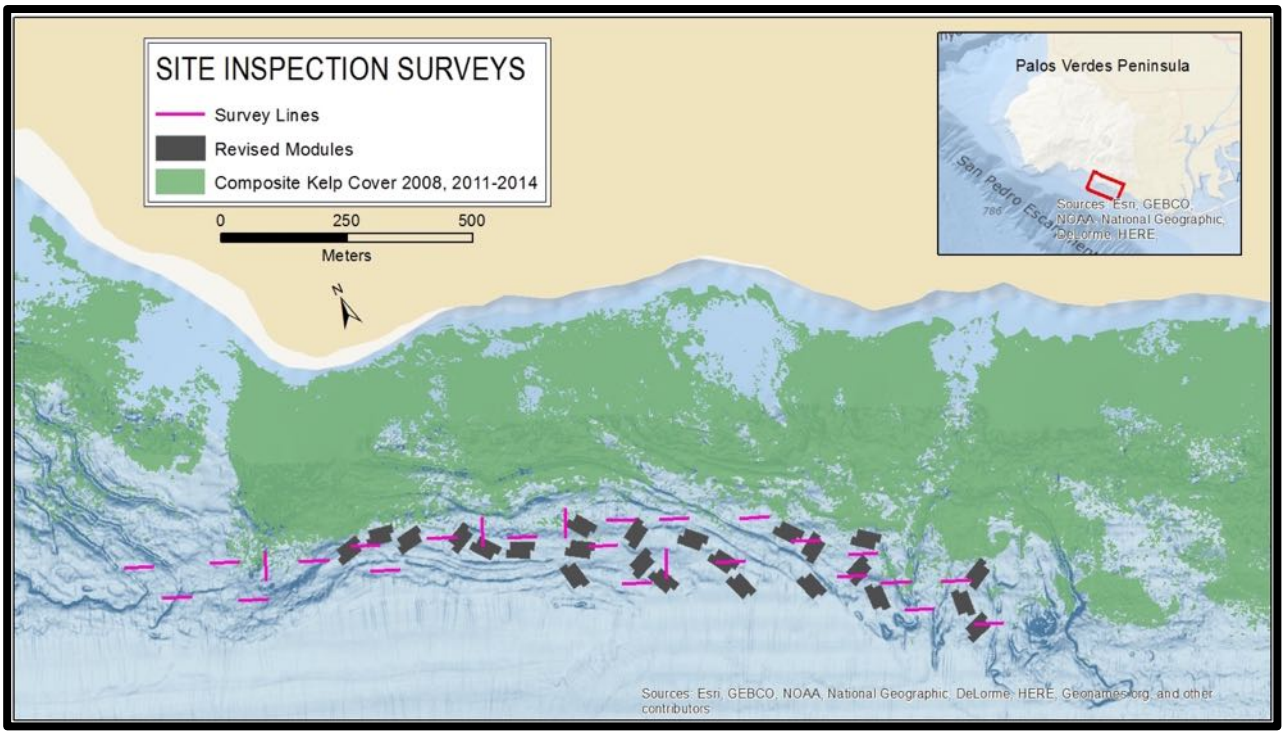


Figure 34. Mapped reef habitat, composite kelp cover, and site inspection survey locations with currently proposed restoration reef Blocks.

MONITORING PLAN

An important step in evaluating the effects of restoration actions along the Palos Verdes Peninsula is to develop an appropriate temporal and spatial sampling design for future monitoring. Short and long-term monitoring of the restoration reef Blocks and sites across the Palos Verdes Peninsula will be critical for evaluating the success of this restoration project and for evaluating the effect of various restoration reef design elements on the associated biological community. Over the first months to years after construction of the restoration reef, we will have the opportunity to measure the level of "attraction" of adult fishes relocating from nearby reefs to the new reef habitat (Figure 35). Over the medium to long-term (3-10 years) monitoring will provide the opportunity to estimate the increase in biomass of important species associated with the restoration reef Blocks, and for whole larger reef complex made up of the restoration reef and the adjacent natural reefs. A Before-After-Control-Impact Paired Series (BACIPS) sampling design (Osenberg et al. 2002) is likely the most appropriate, particularly with respect to also assessing potential changes in biomass due to fish movements (relocation from nearby reefs). This model will help to account for year-to-year environmental variability when assessing changes in biomass. The restoration reef as a whole would likely best be considered an unreplicated "treatment" in this context. While there will be multiple sites sampled within each treatment (i.e., restoration reef, adjacent natural reefs, reference natural reefs), these mostly adjacent sites will not be independent (Table 5; Figures 35). A key to a BACIPS design is having multiple "before" sampling events across sites. Reef construction is currently planned for the fall of 2017. The proposed monitoring design would include three complete rounds of sampling before reef construction (2015, 2016, and 2017 (pre); Table 5). The first round of "After" sampling would begin shortly after the completion of reef construction at the end of 2017 and would be completed in early (likely February) 2018. Subsequently, "after" sampling would be conducted annually for at least 5 years (Table 5). It will likely take at least this length of time for overall changes in biomass due to additional production to be begin to be observed (multiple years of recruitment followed by a few years for those fishes and invertebrates to mature). The restoration reef Modules will be sampled in a similar effort as is used to sample each Depth Zone at a natural reef site (Figure 35). At each module (A, B, C) within each reef block (1-8) we will perform four fish transects (bottom/midwater/canopy portions per transect), two benthic UPC transects, and two benthic swath transects. The quantification of habitat characteristics performed in the CRANE protocol will also permit us to incorporate appropriate methods in the analyses to account for differences in habitat characteristics among sites and treatments (e.g., Miller and Russ 2014).

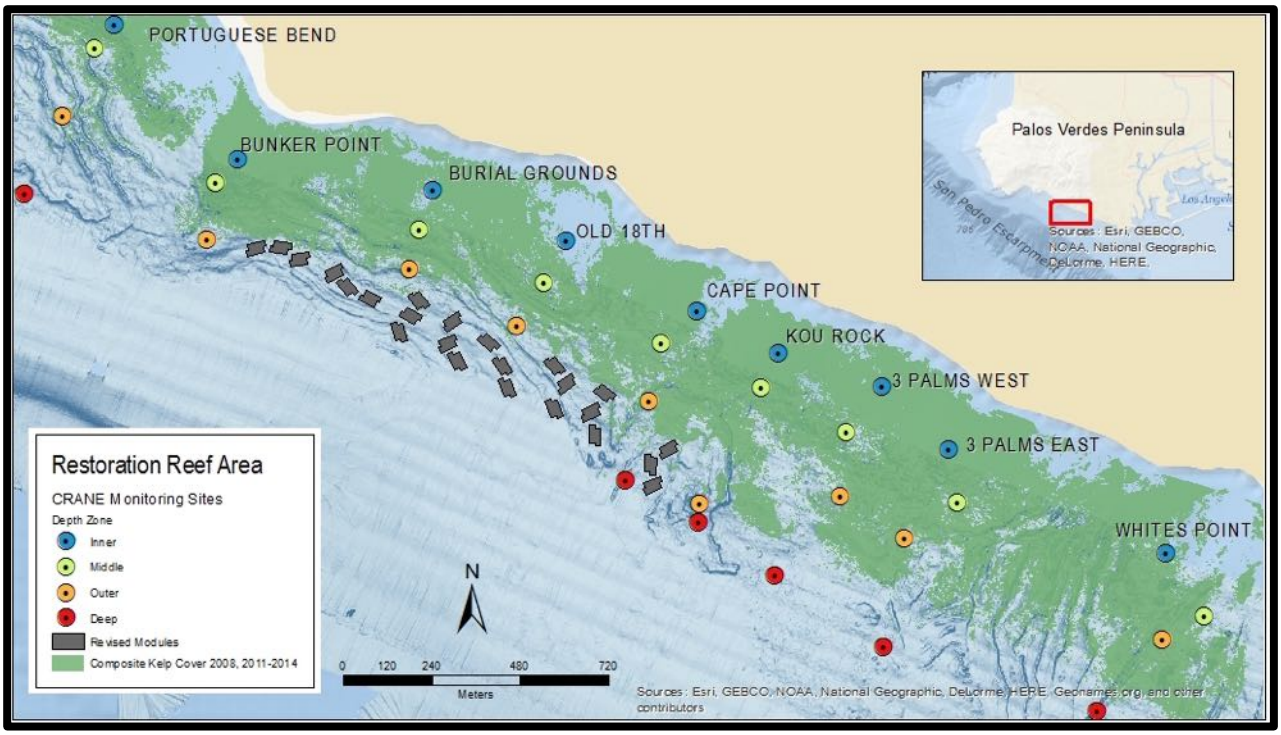


Figure 35. Restoration reef Blocks and CRANE monitoring Sites (individual depth zones indicated) at the Bunker Point restoration site study area with kelp canopy and side scan imagery.

Another part of this assessment is being able determine what proportion of biomass changes are due to fish movements to the restoration reef from the surrounding natural reefs compared with the increase in biomass from additional secondary production of fishes and invertebrates. The proposed sampling design will provide an opportunity to assess the degree to which increases in biomass on the new restoration reef are correlated with decreases in fish biomass on the adjacent natural reefs (Table 5, Figure 35) (Osenberg et al. 2002; Osenberg et al. 2006), suggesting some proportion of the fishes on the restoration reef relocated from nearby reefs. An increase in fish biomass on the restoration reefs and stable or increasing biomass on the adjacent reefs would suggest increased secondary production on entire reef complex. The monitoring data will also permit application of other novel analyses aimed at assessing the levels of 'local production' and 'biomass flux' within the restoration reef system (e.g., Smith et al. 2016). Performing additional studies would provide additional context from which to interpret the monitoring data and provide insight into the mechanisms behind changes in fish biomass in the system. These could include direct assessment of fish movements (e.g., traditional tagging, acoustic telemetry), which would be particularly informative if fishes on adjacent reefs could be tagged prior to reef construction. Other factors influencing fish production, such as increases in growth rates associated with higher relief habitat (e.g., Granneman 2011; Granneman and Steele 2014), could be assessed directly (e.g., through otolith studies for fishes).

Finally, the proposed reef and monitoring designs, with multiple replicated elements, will also provide an opportunity for subsequent studies to examine the effects of restoration reef design features. A primary assessment would be the effect of block relief, 3m versus 4m maximum pile heights, on the associated species biomass and habitat use patterns. Other features that can be assessed may include module orientation or position relative to the coast or dominant current pattern and Block depth. Understanding how these factors impact fish and invertebrate habitat utilization patterns will provide an opportunity to inform future restoration programs in the State.

Table 5. Historical monitoring (with S indicating years sampled) and proposed monitoring (with X indicating sites to be sampled). Sites include (Kelp Restoration) those involved in the kelp restoration project which may contain urchin barrens, be active kelp restoration sites, or sites where the kelp has been restored, (MPA) those within the MPAs that were implemented in 2012, (Within Reef) those located among the proposed restoration reef Blocks, (Adjacent Reef) those located just north or south of the proposed restoration reef, or (Reference) sites that do not currently involve any of the previously mentioned activities or designations. The monitoring plan includes sampling all sites in 2016 prior to reef construction, then once before and once after reef construction in 2017, then annually for at least 5 years after construction. CRANE protocols require >50% coverage of rocky reef, the restoration area has not supported kelp or significant percentages of rocky substrate precluding it from previous CRANE surveys.

		Historical Monitoring										Proposed Monitoring			
Site	Designation	2004	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017 (Pre)	2017 (Post)	2018 - 2022
Flat Rock North	Reference		S	S							S	X	X		X
Flat Rock South	Reference		S								S	X	X		X
Ridges North	Reference	S	S		S	S	S	S	S	S	S	X	X		X
Ridges South	Reference	S	S	S				S	S	S	S	X	X		X
Rocky Point North	Reference	S	S	S	S		S	S	S	S	S	X	X		X
Rocky Point South	Reference		S			S	S	S	S	S	S	X	X		X
Lunada Bay	Reference						S	S	S		S	X	X	X	X
Resort Point	Kelp Restoration			S				S	S	S	S	X	X		X
Honeymoon Cove	Kelp Restoration						S	S	S	S	S	X	X		X
Segovia	Kelp Restoration							S	S		S	X	X		X
Christmas Tree Cove	Kelp Restoration					S	S	S	S	S	S	X	X	X	X
Marguerite West	Kelp Restoration						S	S	S	S	S	X	X		X
Marguerite Central	Kelp Restoration						S	S	S	S	S	X	X		X
Marguerite East	Kelp Restoration						S	S	S	S	S	X	X		X
Golden Cove	Kelp Restoration						S	S	S	S	S	X	X		X
Underwater Arch	Kelp Restoration					S		S	S		S	X	X		X
Albondigas	Kelp Restoration						S	S	S	S	S	X	X	X	X
Hawthorne Reef	Kelp Restoration		S		S	S	S	S	S	S	S	X	X	X	X
Point Vicente West	MPA	S	S	S	S	S	S	S	S	S	S	X	X		X
Point Vicente East	MPA		S												
Long Point West	MPA		S					S	S		S	X	X		X
Long Point East	MPA		S		S	S	S	S	S	S	S	X	X	X	X
Old Marineland	MPA						S	S	S		S	X	X		X
120 Reef	MPA					S	S	S	S		S	X	X		X
Abalone Cove Kelp West	MPA					S	S	S	S	S	S	X	X		X
Abalone Cove Kelp East	MPA					S		S							
Portuguese Point	MPA					S		S	S		S	X	X		X
Portuguese Bend	Adjacent Reef								S		S	X	X	X	X
Bunker Point	Adjacent Reef		S				S	S	S	S	S	X	X	X	X
Burial Grounds	Within Reef										S	X	X	X	X
Old 18th	Within Reef								S		S	X	X	X	X
Cape Point	Within Reef										S	X	X	X	X
KOU Rock	Adjacent Reef				S		S	S	S	S	S	X	X	X	X
3 Palms West	Adjacent Reef		S						S	S	S	X	X	X	X
3 Palms East	Adjacent Reef		S	S	S					S	S	X	X	X	X
Whites Point	Reference		S	S		S	S	S	S	S	S	X	X	X	X
Cairns	Reference						S	S	S	S	S	X	X	X	X
Point Fermin	Reference		S	S		S	S	S	S	S	S	X	X	X	X

LITERATURE CITED

Beck MW, Brumbaugh RD, Airoldi L, Carranza A, Coen LD, Crawford C, Defeo O, Edgar GJ, Hancock B, Kay MC, Lenihan HS, Luckenbach MW, Toropova CL, Zhang G, Guo X (2011) Oyster Reefs at Risk and Recommendations for Conservation, Restoration, and Management. BioScience 61: 107-116 doi 10.1525/bio.2011.61.2.5

Claisse JT, Pondella DJ, II, Williams JP, Sadd J (2012) Using GIS mapping of the extent of nearshore rocky reefs to estimate the abundance and reproductive output of important fishery species. PLoS ONE 7: e30290 doi 10.1371/journal.pone.0030290

FishBase (2012) World Wide Web electronic publication. http://www.fishbase.org, version(04/2013). In: Froese R, Pauly D (eds)

Foster MS, Schiel DR (2010) Loss of predators and the collapse of southern California kelp forests (?): alternatives, explanations and generalizations. Journal of Experimental Marine Biology and Ecology 393: 59-70 doi http://dx.doi.org/10.1016/j.jembe.2010.07.002

Friedlander AM, Parrish JD (1998) Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. Journal of Experimental Marine Biology and Ecology 224: 1-30

Froeschke JT, Allen LG, Pondella I, D. J. (2005) The reef fish assemblage of the outer Los Angeles Federal Breakwater, 2002-2003. Bulletin of the Southern California Academy of Sciences 104: 63-74

Granneman JE (2011) A comparison of fish production on artificial and natural reefs in southern California. Masters Thesis, California State University, Northridge.

Granneman JE, Steele MA (2014) Fish growth, reproduction, and tissue production on artificial reefs relative to natural reefs. ICES Journal of Marine Science doi 10.1093/icesjms/fsu082

Johnson TD, Barnett AM, DeMartini EE, Craft LL, Ambrose RF, Purcell LJ (1994) Fish production and habitat utilization on a southern California artificial reef. Bulletin of Marine Science 55: 709-723

Kayen RE, H. J. Lee and J. R. Hein (2002) Influence of the Portuguese Bend landslide on the character of the effluent-affected sediment deposit, Palos Verdes margin, southern California. Continental Shelf Research 22: 911-922

Kelner JJ, R. Christensen, R. Clark, C. Caldow and M. Coyne (2005) Chapter 2, In: A Biogeographic Assessment of the Channel Islands National Marine Sanctuary (Randy Clark, John Christensen, Chris Caldow, Jim Allen, Michael Murray and Sara MacWilliams editors). NOAA Technical Memorandum NOS NCCOS 21: 89-134

Lewis RD, McKee KK (1989) A Guide to the Artificial Reefs of Southern California. Department of Fish and Game, Sacramento, California: 73

Miller KI, Russ GR (2014) Studies of no-take marine reserves: Methods for differentiating reserve and habitat effects. Ocean & Coastal Management 96: 51-60 doi 10.1016/j.ocecoaman.2014.05.003

North WJ (1964) Ecology of the rocky nearshore environment in Southern California and possible influences of discharged wastes. International Conference on Water Pollution Research, London, September, 1962 Pergamon Press, Oxford

Osenberg CW, Bolker BM, White J, Mary CMS, Shima JS (2006) Statistical issues and study design in ecological restorations: lessons learned from marine reserves. In: Falk, D., Palmer, M., Zedler, J. (Eds.), Foundations of Restoration Ecology. Island Press, Washington, DC: 280-302

Osenberg CW, St. Mary CM, Wilson JA, Lindberg WJ (2002) A quantitative framework to evaluate the attraction–production controversy. ICES Journal of Marine Science: Journal du Conseil 59: S214-S221 doi 10.1006/jmsc.2002.1222

Pondella D, Williams JP, Claisse JT (2012a) Biological and Physical Characteristics of the Nearshore Environment of the Bunker Point Restoration Area and the Palos Verdes Peninsula. Technical Report.

Pondella DI, Williams JP, Claisse J, Schaffner R, Ritter K, Schiff K (2015a) The Physical Characteristics of Nearshore Rocky Reefs in The Southern California Bight. Bulletin of the Southern California Academy of Sciences 114

Pondella DJ (2009) Science based regulation: California's marine protected areas. Urban Coast 1: 33-36

Pondella DJ, Allen LG, Craig MT, Gintert B (2006) Evaluation of eelgrass mitigation and fishery enhancement structures in San Diego Bay, California. Bulletin of Marine Science 78: 115-131

Pondella DJ, Caselle JE, Claisse JT, Williams JP, Davis K, Williams CM, Zahn LA (2015b) South Coast Baseline Program Final Report: Kelp and Shallow Rock Ecosystems https://caseagrant.ucsd.edu/sites/default/files/SCMPA-27-Final-Report_0.pdf

Pondella DJ, II, Williams J, Claisse J (2012b) Biological and physical characteristics of the nearshore environment of the Bunker Point Restoration Area and the Palos Verdes Peninsula II. NOAA Restoration Center/Montrose Settlement Restoration Program

Reed DC, Schroeder SC, Huang D (2006a) An experimental investigation of the use of artificial reefs to mitigate the loss of giant kelp forest habitat. A case study of the San Onofre Nuclear Generating Station's artificial reef project. . California SeaGrant, University of California San Diego

Reed DC, Schroeter SC, Huang D, Anderson TW, Ambrose RF (2006b) Quantitative assessment of different artificial reef designs in mitigating losses to kelp forest fishes. Bulletin of Marine Science 78: 133-150

Rinkevich B (2005) Conservation of Coral Reefs through Active Restoration Measures: Recent Approaches and Last Decade Progress. Environmental Science & Technology 39: 4333-4342 doi 10.1021/es0482583

Smith JA, Lowry MB, Champion C, Suthers IM (2016) A designed artificial reef is among the most productive marine fish habitats: new metrics to address 'production versus attraction'. Marine Biology 163: 1-8 doi 10.1007/s00227-016-2967-y

Stephens JS, Jr., D. J. Pondella, II, and P. Morris (1996) Habitat Value Determination of the Coastal Zone off the City of Rancho Palos Verdes Based on Habitat-specific Assemblage Data. US Corps of Engineers: 27 p.

Stephens JS, Morris PA, Pondella DJ, Koonce TA, Jordan GA (1994) Overview of the Dynamics of an Urban Artificial Reef Fish Assemblage at King-Harbor, California, USA, 1974-1991 - a Recruitment Driven System. Bulletin of Marine Science 55: 1224-1239

Stull JK, K. A. Dryden and P. A. Gregory (1987) A historical review of fisheries statistics and environmental and societal influences off the Palos Verdes peninsula, California. CalCOFI Reports 28: 135-154

Williams CM, Williams JP, Claisse JT, Pondella DJ, Domeier ML, Zahn LA (2013) Morphometric relationships of marine fishes common to central California and the Southern California Bight. Bulletin, Southern California Academy of Sciences 112: 217-227 doi 10.3160/0038-3872-112.3.217

Zahn LA, Claisse JT, Williams JP, Williams CM, Pondella DJ (2016) The biogeography and community structure of kelp forest macroinvertebrates. Marine Ecology: n/a-n/a doi 10.1111/maec.12346