Palos Verdes Kelp Forest Restoration Project

Project Year 4: July 2016 – June 2017

Prepared by:

The Bay Foundation

(Parker House, Armand Barilotti, Heather Burdick, Tom Ford)

Vantuna Research Group

(Jonathan Williams, Chelsea Williams, Dan Pondella)

The Bay Foundation
P.O. Box 13336, Los Angeles, CA 90013
(888) 301-2527
www.santamonicabay.org

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Introduction

Kelp forest ecosystems are iconic and productive features along the coast of California with services that span a wide array of consumptive (e.g., commercial and recreational fishing) and non-consumptive (e.g., tourism, scuba diving and coastal protection) uses. *Macrocystis pyrifera* (giant kelp) forms a 3-dimensional habitat supporting over 700 species of fish, algae, and invertebrates (Graham, 2004). The importance of kelp as a habitat for fish species is enormous; this habitat functions as nursery habitat for newly settled juvenile fishes and has a demonstrated value as a refuge from predation (Dayton, 1985; Steneck et al., 2002). Drift kelp and associated dissolved organic matter provide an energetic resource to populations of species both within and around kelp forests (Harrold and Reed 1985; Duggins et al., 1989; Graham et al., 2007; Tegner and Dayton, 2000). These habitats support fisheries for a number of invertebrates [e.g., *Strongylocentrotus spp.* (sea urchins), *Panulirus interruptus* (California spiny lobster), *Parastichopus spp.* (sea cucumbers)] and finfish [e.g., *Paralabrax clathratus* (kelp bass), *Semicossyphus pulcher* (California sheephead)], in addition to giant kelp being harvested itself for a variety of human uses (Tegner and Dayton, 2000). Through both fishing activities and non-consumptive uses, California's ocean-related activities support the state economy by bringing in 40+ billion dollars a year in revenue (Kildow and Colgan, 2005) and giant kelp is a critical and iconic feature of this system.

California kelp forests have been severely depleted by human activity, mainly overfishing, which has caused several ecological shifts within the habitat, primarily attributed to the loss of key predator species (Dayton et al., 1998; Tegner and Dayton, 2000). In a balanced ecosystem, sea urchin consumption of kelp is limited primarily by predation on urchins (Dayton, 1985; Edwards, 2004). Three species historically controlled sea urchin populations in the Southern California Bight (SCB): *Enhydra lutris nereis* (southern sea otter), California spiny lobster and California sheephead. The Southern Sea Otter was locally extirpated in the 1850's (Jackson, 2001). Spiny lobster *and* sheephead are under significant fishing pressure, which simultaneously reduces the size and number of individuals able to successfully prey on sea urchins (Cowen, 1983; Lafferty, 2004). Additionally, thriving populations of abalone once served as competitors to urchins (Tegner and Dayton, 2000). Currently two species are now Federally Endangered (Black Abalone, *Haliotis cracherodii*; and White Abalone, *H. sorenseni*) and two more are Federal Species of Concern (Pink Abalone, *H. corrugata*; and Green Abalone, *H. fulgens*) (CDFW, 2005). Thus, both urchin predators and competitors have been chronically depleted throughout the SCB.

Predation is one of the most significant and persistent causes of kelp forest loss in southern California (Steneck et al., 2002). Sea urchins, typically *Strongylocentrotus purpuratus* (purple sea urchins) and *Strongylocentrotus franciscanus* (red sea urchins), will aggregate in fronts and clear expanses of kelp forest if left unchecked, leaving the reef devoid of standing macroalgae (Harrold and Reed 1985; Graham 2004). These urchin barrens are observed to support far fewer species and a corresponding decrease in biomass (Bradley and Bradley, 1993; Graham, 2004). This reduction in ecosystem structure and function leads to spatially and temporally unstable kelp forests and reduces production. Though Graham (2004) described urchin barrens in the Channel Islands National Park (CINP) as short-lived and localized, they have persisted for more than 30 years in the northeastern and northwestern Atlantic along the border of Norway and Russia (Norderhaug and Christie, 2009). Similar observations have been made in the northeastern Pacific from Alaska to California (Jackson, 2001; Smith et al., 2004; Steneck et al., 2002). A survey spanning the SCB in 2008 determined that approximately 30% of the reefs contain urchin barrens (Pondella et al., 2011), suggesting that they are a widespread phenomenon in our region.

Project Background

This project developed from an interest in the protection and preservation of giant kelp communities in the Southern California Bight. Roughly one hundred years of data exists on the extent of giant kelp canopy off of the Palos Verdes Peninsula. These data describe a loss over this timeframe of approximately 80% (Figure 1).

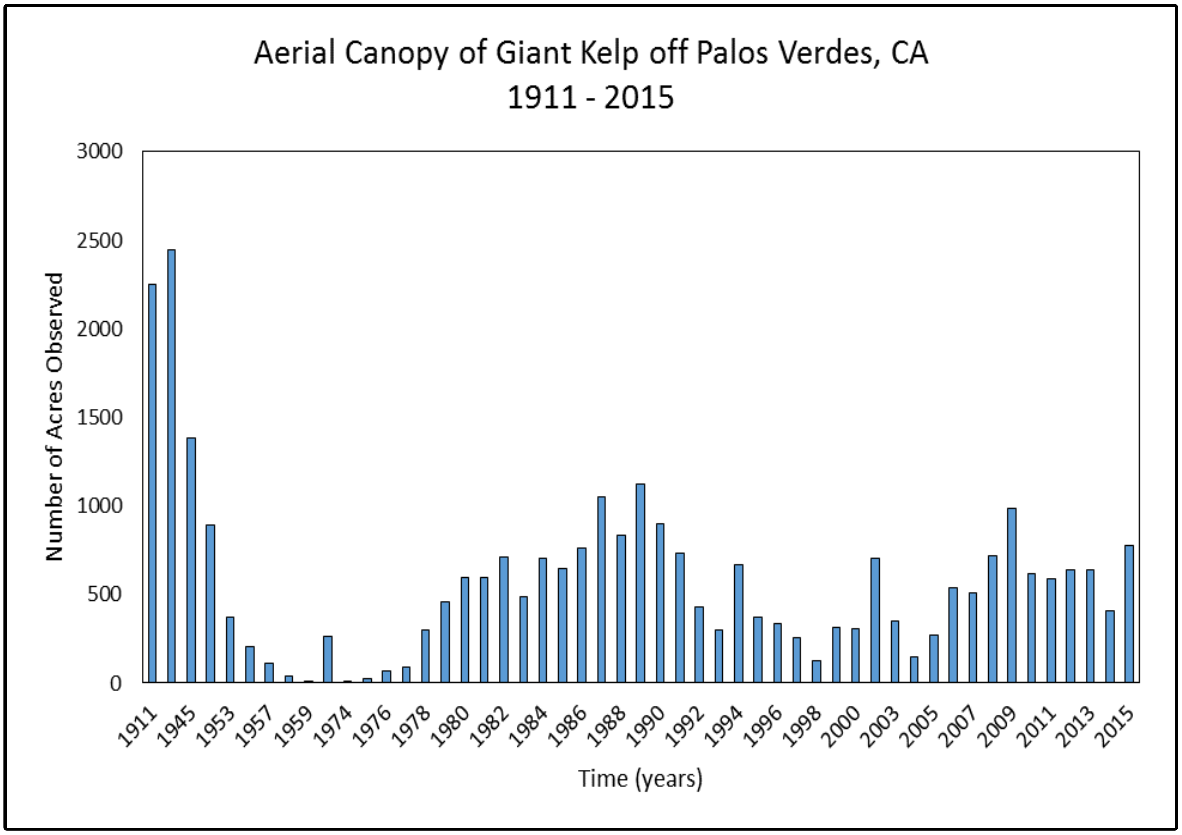

Figure 1. Status of the Kelp Beds 2015, Ventura Los Angeles, Orange, and San Diego Counties. Central Region Kelp Survey Consortium and Region Nine Kelp Survey Consortium, July 2016. Prepared by: MBC Applied Environmental Sciences. Costa Mesa, CA 92626

Subtidal observations based upon mapping efforts conducted by the Santa Monica Baykeeper in 2010 identified large expanses of nearshore rocky reef that were dominated by high densities of purple and red sea urchins*.* In total, 61.5 hectares were described to exist in an urchin barren state. Subsequent SCUBA based community monitoring has further qualified these barrens as areas featuring low diversity and productivity relative to areas of the Palos Verdes Peninsula supporting temporally and spatially stable giant kelp forests. Additional study has defined the status of the urchins themselves in these barrens of being in poor physical condition with low gonadosomatic indices relative to urchins in neighboring kelp forests (Claisse et al. 2013).

The persistence of these urchin barrens, especially in the context of favorable conditions for giant kelp recruitment and development in southern California, argues for the active restoration of these barren reefs.

Kelp forests in Santa Monica Bay, adjacent to the largest urban area on the west coast of the United States, are directly affected by anthropogenic impacts associated with urban development and population increase. These include an extensive and diverse set of stressors (e.g., commercial and recreational fishing, sedimentation, urban runoff, and pollution) (Stull et al. 1987; Dojiri et al. 2003; Schiff 2003; Love 2006; Pondella 2009; Foster and Schiel 2010; Sikich and James 2010; Erisman et al. 2011) that combine to further contribute to the decline of productive, stable kelp habitat along this important stretch of coastline. Given the complexity of factors impacting these urban rocky reefs, conservation and resource management efforts demand an equally diverse and proactive suite of strategies. One such endeavor is kelp restoration as conducted by The Bay Foundation, and the partners of the project which include, commercial sea urchin harvesters, academic researchers, federal and state biologists, resource managers, and public aquaria.

To enable the recovery of historical kelp forests in Santa Monica Bay, the “Kelp Project” has engaged in sea urchin suppression to reduce the density of urchins on shallow rocky reefs since 1997, these early efforts (1997-2009) were supported by the Santa Monica Baykeeper. The Kelp Project has demonstrated that reducing urchin density from as high as 100 sea urchins per square meter to < 2 sea urchins per square meter enabled the natural development of giant kelp and other macroalgae at restoration areas in Malibu and Palos Verdes (Figures 2, 3). Restoration areas off of Escondido Beach, Malibu have proven resilient to disturbances for over 10 years. After reaching restoration targets of < 2 sea urchins per square meter and > 1 giant kelp holdfast per 10 square meters the restoration measures were stopped in 2004 (Ford and Meux 2010). The kelp in this area has matured and recovered from many disturbances of note, namely large-scale red tide events in 2005 and 2006 and a 200-year storm event in the same period. This resilience to disturbance was a key test for the permanence of the restoration effort. Surveys performed in the restoration areas off Escondido Beach in 2008 have quantified large kelp plants in high densities (Pondella et al. 2011). Kelp restoration efforts are now focused on 61.5 hectares of existing urchin barrens which have been identified along the Palos Verdes Peninsula (Figure 4).

Kelp Restoration Goals

The purpose of the project is to reduce the density of purple sea urchins to two per square meter within the boundaries of sea urchin barrens off the Palos Verdes Peninsula. This will allow for the recruitment and development of giant kelp and other species of macroalgae. This project will reduce sea urchin grazing pressure to restore biogenic habitat to rocky reefs that historically supported kelp forests. This will increase the spatial and temporal stability, biomass and production associated with the kelp forest/rocky reefs on the Palos Verdes Peninsula.

In addition, an initial focus of the kelp project has been to generate a more inclusive community engaged in the management of this highly productive and highly valued ecosystem. The red sea urchin fishery is one of the most important commercial fisheries in the State of California. In 2015, red urchin landings ranked 4th by weight (8.1 million lbs.) and 7th in value (6.8 million US Dollars) (CDFW 2016). The gonads of both male and female red sea urchins, known as “uni” in Japanese, are the object of the fishery. The majority of effort for this fishery is concentrated in southern California with Santa Barbara, Oxnard-Ventura, and Los Angeles ports having the most landings in the region (CDFW 2016). Commercial sea urchin harvesters have been a central part of this project since its inception. Several commercial sea urchin harvesters have retained contracts with The Bay Foundation to cull the excess purple sea urchins from the restoration sites. This collaboration between scientists, project management, and the fishermen has been very productive and efficient. The direct results of the restoration work impact the rocky reef-kelp forest ecosystem and have the ability to increase the value of the reefs for the commercial red sea urchin fishery. The disparate and complimentary expertise of the project partners in this effort has been central to its success. Thus, the project directly increases the ecological structure and function of the rocky reefs off of Palos Verdes while creating a more comprehensive Santa Monica Bay community in restoring the kelp forests off our coast.

Figure 2. Long Point pre-restoration in 2005.

Figure 3. Long Point post-restoration in 2008.

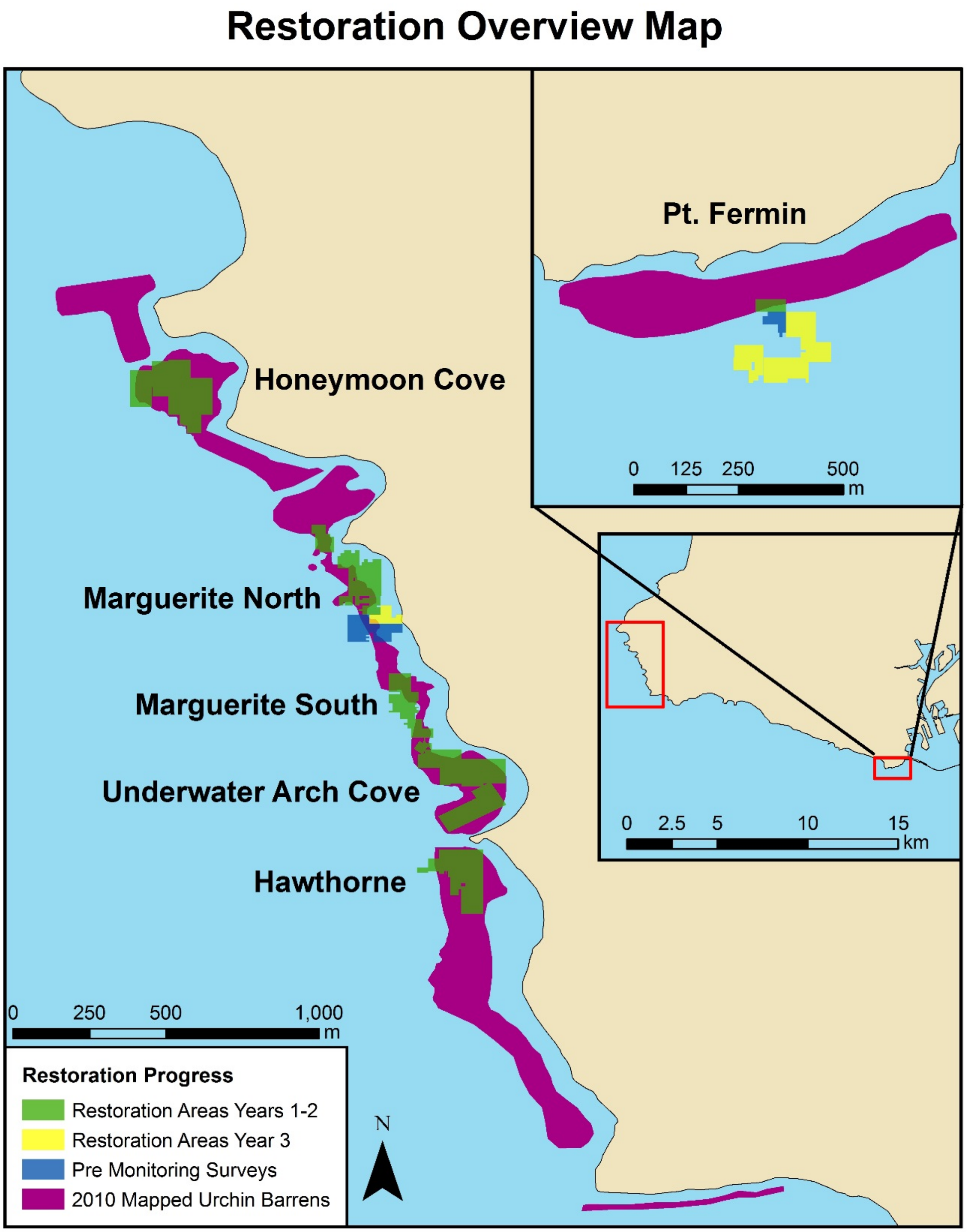

Figure 4. Urchin barrens as mapped in 2010 and areas restored, representing a possible expansion and/or shift of urchin barrens. The locations of restoration areas completed in years 1 and 2 are in green, areas restored in year 3 are yellow, and areas currently in progress are blue.

Methods

Description of Restoration, Control, and Reference Sites
All of the project restoration, reference, and control sites are located off the Palos Verdes Peninsula, Los Angeles County, California. Table 1 below shows all potential restoration sites along with the area in hectares, initially described in 2010 surveys, and representative central GPS coordinate for each.

Table 1. Area and GPS coordinates for restoration, reference and control sites.

Restoration Site Name	Area (Hectares)	Perimeter (Meters)	Centroid (Decimal Degrees)
Honeymoon Cove	4.07	1,509	33.764, -118.423
Christmas Tree Cove	4.09	2,264	33.761, -118.419
Marguerite	5.19	2,522	33.757, -118.418
Underwater Arch	5.36	2,183	33.752, -118.415
Hawthorne	8.96	1,789	33.747, -118.414
Portuguese Point	1.73	1,604	33.737, -118.376
Inspiration Point	2.57	1,965	33.736, -118.368
Whites Point	3.38	2,395	33.713, -118.315
Point Fermin	4.37	3,367	33.704, -118.291

The following sites were identified as urchin barrens in 2010 and are located within the Marine Protected Areas surrounding Point Vicente. Thus far these sites have only been monitored and will continue to be monitored as part of the experimental design of the overall project. Three of these sites received restoration work in the past, pre-MPA, (2005-2011) i.e., Kaplan Cove, Long Point and Old Marineland. Restoration work was conducted on a limited basis inside the MPA in the early part of 2012. Furtherance of restoration efforts within the MPAs might yield benefits to the goals of the MPAs generally and specifically to the MPA cluster on the Palos Verdes Peninsula.

Site Name	Area (Hectares)	Perimeter (Meters)	Centroid (Decimal Degrees)
Point Vicente East	4.8	2,812	33.740, -118.406
Kaplan Cove	2.3	1,115	33.737, -118.401
Long Point	0.82	1,240	33.736, -118.398
Old Marineland	1.2	744	33.737, -118.395
120 Reef	1.74	1,226	33.738, -118.392
Abalone Cove Kelp	9.1	3,397	33.740, -118.385
Reference Site Name	**Area (Hectares)**	**Perimeter (Meters)**	**Centroid (Decimal Degrees)**
Point Vicente West	-	-	33.740, -118.412
Rocky Point North	-	-	33.779. -118.426
Control Site Name			
Abalone Cove West	9.10	3,397	33.740, -118.385
Marguerite Central	5.19	2,522	33.757, -118.418

Pre-Restoration Monitoring

Restoration sites have been established in 5 sites off Palos Verdes: Honeymoon Cove, Marguerite, Underwater Arch Cove, Hawthorne and Point Fermin. Pre-restoration monitoring is conducted on all sites according to CDFW standards stipulated in the terms of the scientific collecting permit (SCP). Sites are divided into 30 m by 30 m blocks each comprised of 5 transects (2 m by 30 m swath) monitored by divers. Each transect is divided into 10 m long segments to estimate the density of purple urchins, red urchins, giant kelp and a characterization of the substrate. In certain instances these blocks, or the individual transects comprising them are truncated to fit the natural topography. This fine scale and spatially comprehensive methodology allows for greater resolution of inter-block variability and has been beneficial to the adaptive management of restoration teams.

Post-Restoration Monitoring

Post-restoration monitoring is conducted within 1-2 weeks after urchin suppression by the restoration teams. This work is performed by The Bay Foundation staff to ensure that restoration work is achieving performance standards. The standards are 1) the initial reduction of purple sea urchins to a density of 2 per square meter and 2) that this is being applied in a comprehensive manner sweeping through an area and not leaving pockets of high urchin densities. All restoration areas are surveyed pre and post restoration actions to describe the status of the restoration areas and entered into a georeferenced database. Post-monitoring can be completed more quickly than pre-monitoring as only the density of urchins are counted. All 15 (30 m x 2 m) transects, covering 100% area of the 30 m x 30 m block are surveyed during post-monitoring to ensure that no pockets of high density urchins are left in the site. All restoration sites are re-surveyed, by roaming over the area, on a monthly to quarterly basis to ensure that purple urchin densities remain at two sea urchins per square meter and to observe the response of the biota to the restoration actions.

Response Monitoring (August 2016 through April 2017)

This monitoring focuses on responses of the natural community to restoration activities. The focus of this effort is subtidal utilizing an adapted Cooperative Research and Assessment of Nearshore Ecosystems (CRANE) methodology led by the Vantuna Research Group. These data provide values relating to production, species richness, and biomass. In addition, an adaptation of the Core and Biodiversity protocols used throughout the west coast of North America as part of the MARINe network will be applied to the intertidal and shallow subtidal areas addressed in the scope of work (led by the Vantuna Research Group). This method identifies trends in sessile and motile organisms and coverage in the intertidal zone. Lastly, the application of a gonadosomatic index generated in 2011 for red and purple sea urchins specific to the Palos Verdes Peninsula is applied to gather data on secondary production values for these species that play a pivotal role in the ecology of the kelp forests and support one of California’s largest nearshore fisheries (Claisse et al. 2013). Urchins were collected and dissected for this report in fall 2015.

Community Analyses

As part of the quantitative characterization of the community structure of the reefs, we examined patterns in the overall kelp forest community using UPC (percent cover) data as well as the fish and swath (benthic macroinvertebrates and kelps) data combined. Density metrics were square root transformed (fish and swath data), while percent-cover metrics (UPC benthic cover data) were arcsine square root transformed. Two-dimensional, non-metric multidimensional scaling (nMDS) was used to examine patterns among kelp forest communities.

Table 2. Response monitoring (CRANE) metadata. See Appendix B for all CRANE data tables.

CRANE Survey Date								
						Spring	Summer	
Site	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2016**	**2017**
Abalone Cove Kelp West	5/27/2011	6/22/2012	6/21/2013	7/25/2014	9/2/2015	2/10/2016	6/29/2016	7/21/2017
Marguerite Central	5/3/2011	6/8/2012	7/3/2013	6/20/2014	9/23/2015	2/10/2016	7/26/2016	7/18/2017
Golden Cove	2/7/2011	6/12/2012	6/12/2013	7/11/2014	9/23/2015	2/10/2016	6/22/2016	7/18/2017
Honeymoon Cove	1/28/2011	3/13/2012	5/31/2013	7/2/2014	8/19/2015	2/10/2016	6/22/2016	7/18/2017
Point Vicente West	10/12/2011	8/10/2012	4/24/2013	4/18/2014	9/23/2015	2/10/2016	6/22/2016	7/21/2017
Rocky Point North	6/24/2011	6/29/2012	7/2/2013	7/11/2014	9/25/2015	2/10/2016	6/10/2016	6/29/2017
Bottom Temperature (ºC)						Spring	Summer	Summer
Site	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2016**	**2017**
Abalone Cove Kelp West	16	13	18	17	20	14	14	20
Marguerite Central	15	17	17	20	22	14	14	20
Golden Cove	15	19	15	15	22	14	14	17
Honeymoon Cove	15	12	18	16	21	14	14	20
Point Vicente West	11	19	15	14	21	14	14	21
Rocky Point North	18	15	18	21	21	15	15	18
Coordinates								
Site	**Latitude**	**Longitude**						
Abalone Cove Kelp West	33.73942	-118.38828						
Marguerite Central	33.75694	-118.41772						
Golden Cove	33.75300	-118.41507						
Honeymoon Cove	33.76490	-118.42339						
Point Vicente West	33.74093	-118.41257						
Rocky Point North	33.77942	-118.42731						

Timeline and Effort of Restoration

Restoration and monitoring activities have been conducted in restoration, control and reference sites since July 2013. Urchin suppression efforts have expanded each year to encompass two coves (Underwater Arch and Honeymoon), and two open shore areas (Marguerite and Hawthorne). These areas are located somewhat centrally on the Palos Verdes Peninsula. The sites are nearly contiguous and share similarities in ocean exposure. An additional site, Point Fermin, was started to the south and east of these other locales. In fact, Point Fermin is roughly the south east terminus of the Palos Verdes Peninsula. Further south and east of Point Fermin is Cabrillo outer beach and the break wall for the Ports of Los Angeles and Long Beach. The progression of restoration activities by expanse restored by area and by year is contained in Table 3. Table 4 provides values for the hours of effort spent SCUBA diving by the project to achieve these results.

All of the field work involved in this project is subject to sea state, oceanic climate and weather. Remaining work in all of the sites listed in Table 4 is projected for this coming operational year, July 1, 2017 through June 30, 2018. Much of the area yet to be monitored and restored can be very challenging i.e., comprised of high relief and/or shallow subtidal habitat. The windows for safe and effective operations in these areas are few in a typical year in southern California. The atypical El Nino conditions that persisted throughout 2015-2016 provided few opportunities for restoration or monitoring activities to be conducted safely and with appropriate accuracy. During the winter of 2016-2017 El Niño conditions relaxed, a resurgence of juvenile purple urchins emerged in new areas off the peninsula, and the pace of our work increased.

Table 3. Total effort diving towards project goals July 1, 2013 through June 30, 2017.

Effort (dive hours)	Monitoring	Restoration
The Bay Foundation	1200.13	71.93
Commercial Sea Urchin Harvesters	-	4862.66
LA Waterkeeper	133.37	1030.86
Total Dive Hours	1333.50	5965.45

Table 4. Restoration areas targeted for July 1, 2017 through June 30, 2018. During this reporting period, Honeymoon Cove, Underwater Arch Cove, and Marguerite are considered complete e.g. the barrens that dominated these coves have been systematically and comprehensively treated by urchin suppression and concordant monitoring. Ongoing periodic monitoring of these sites will continue to ensure that purple urchin densities remain at no more than two per square meter. During the summer of 2017 an area of Underwater Arch had to be revisited for further urchin suppression. We believe this to be due to the largest tidepool on the peninsula being located on the edge of this site. It is possible this tidepool served as a refuge for purple urchins during the wasting event of 2017. Areas at the margins or in neighboring areas further offshore and in shallow subtidal - intertidal will be surveyed to determine if urchin barrens are emerging. Periodic SCUBA and shore-based surveys will continue to determine that urchin densities remain at target values for the coming years.

Site Name	Total Area hectares	Start Date	Area Cleared (ha)	Status	Centroid
Hawthorne	8.96	January 2015	1.74	In Progress	33.747, -118.414
Point Fermin	4.37	July 2015	2.14	In Progress	33.704, -118.291
Whites Point	3.38	Fall 2017	0.00	Pending	33.713, -118.315
Resort Point/Honeymoon	3.80	Summer 2017	0.00	Pending	33.764, -118.315

Results

Urchin Densities Pre and Post Restoration

During 2017, monitoring and restoration activities occurred in 2 sites; Marguerite and Point Fermin (Figures 5 and 6 respectively). The following maps display the estimated purple urchin densities before restoration activities [within each 10 m segment]. Density data from previous years are transparent and gray areas represent blocks currently in progress and will be cleared in project year 5. Figures 7 and 8 display the estimated purple urchin densities after urchin suppression and restoration within each 10m segment for Marguerite, Hawthorne and Point Fermin. Urchin density maps for all sites are included in Appendix A.

Table 5. Restoration progress by site years 1 through 4.

Site Name	Area Cleared (ha) Year 1 July 2013 - June 2014	Area Cleared (ha) Year 2 July 2014 - June 2015	Area Cleared (ha) Year 3 July 2015 - June 2016	Area Cleared (ha) Year 4 July 2016 - June 2017	Total Area (ha)
Honeymoon Cove	2.74	0.63	0	0	**3.37**
Underwater Arch Cove	2.39	1.00	0	0	**3.39**
Marguerite	0.00	2.73	0.83	2.06	**5.62**
Hawthorne	0.00	1.74	0	0	**1.74**
Point Fermin	0.00	0.00	1.59	0.55	**2.14**
Total Area	**5.13**	**6.10**	**2.42**	**2.61**	**16.26**

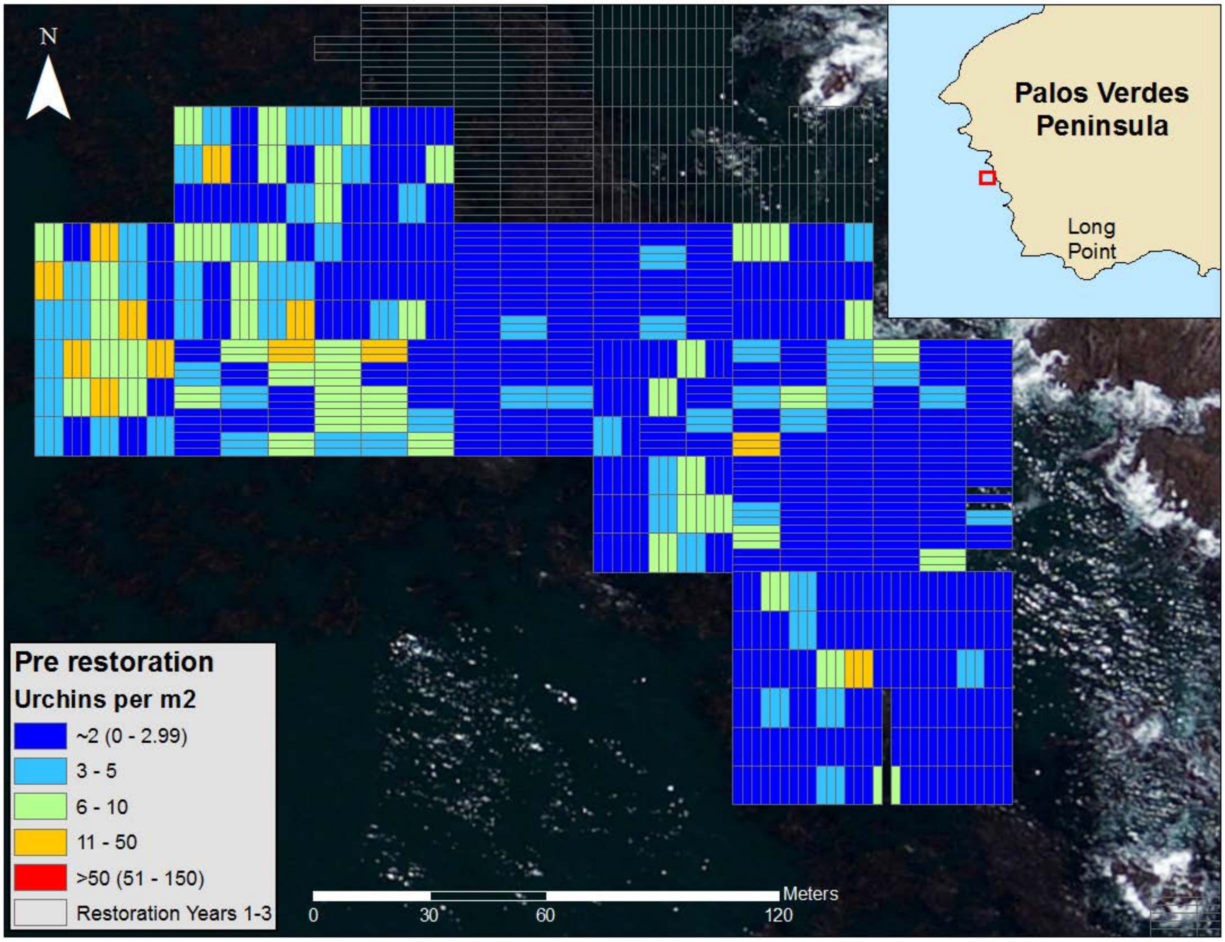

Figure 5. Density of *S. purpuratus* (individuals per square meter) pre-restoration in Marguerite, Palos Verdes, California for Year 4 of the kelp project. The transparent blocks represent density data for previous years and gray blocks are currently in progress. See Appendix A for larger map images.

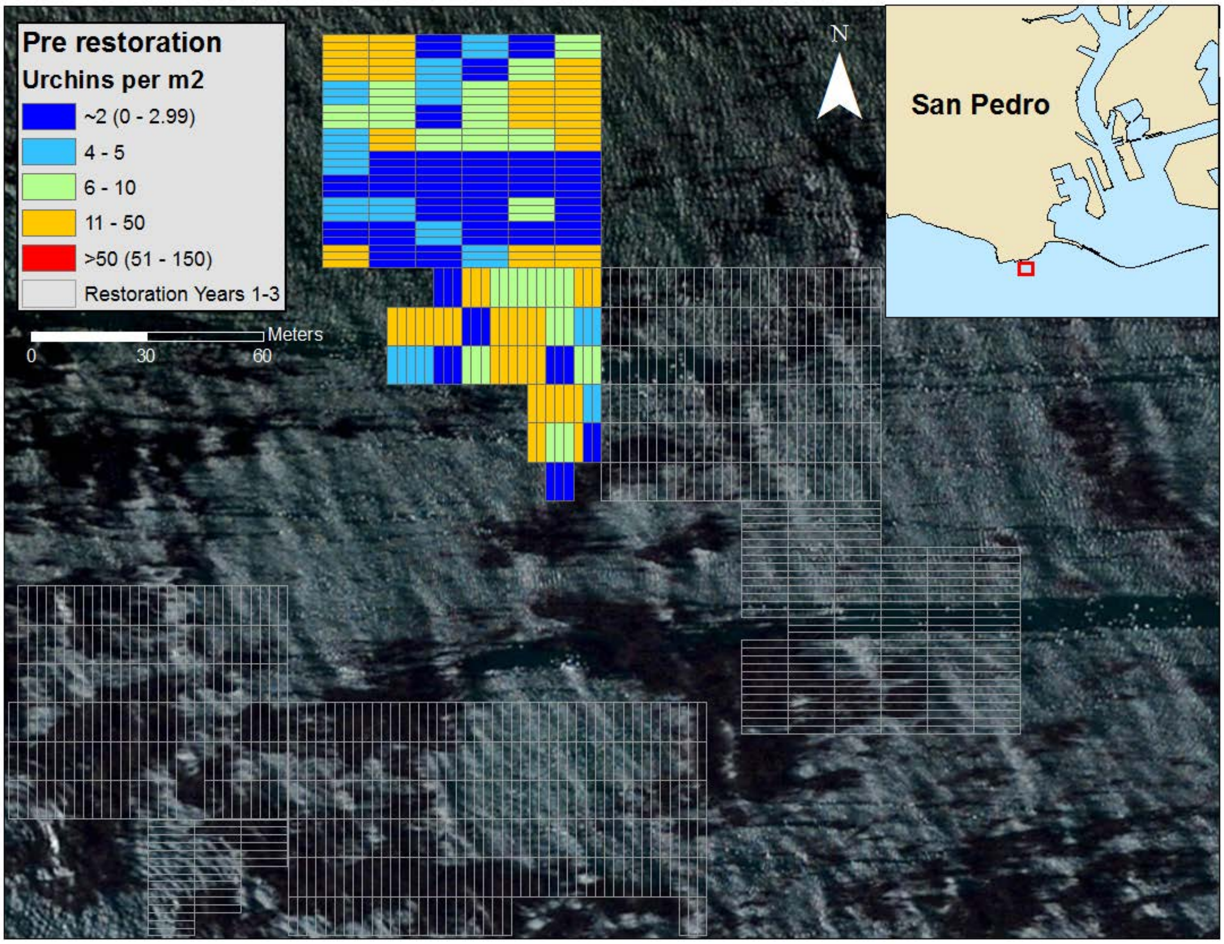

Figure 6. Density of *S. purpuratus* (individuals per square meter) pre-restoration in Point Fermin, Palos Verdes, California for Year 4 of the kelp project. See Appendix A for larger map images.

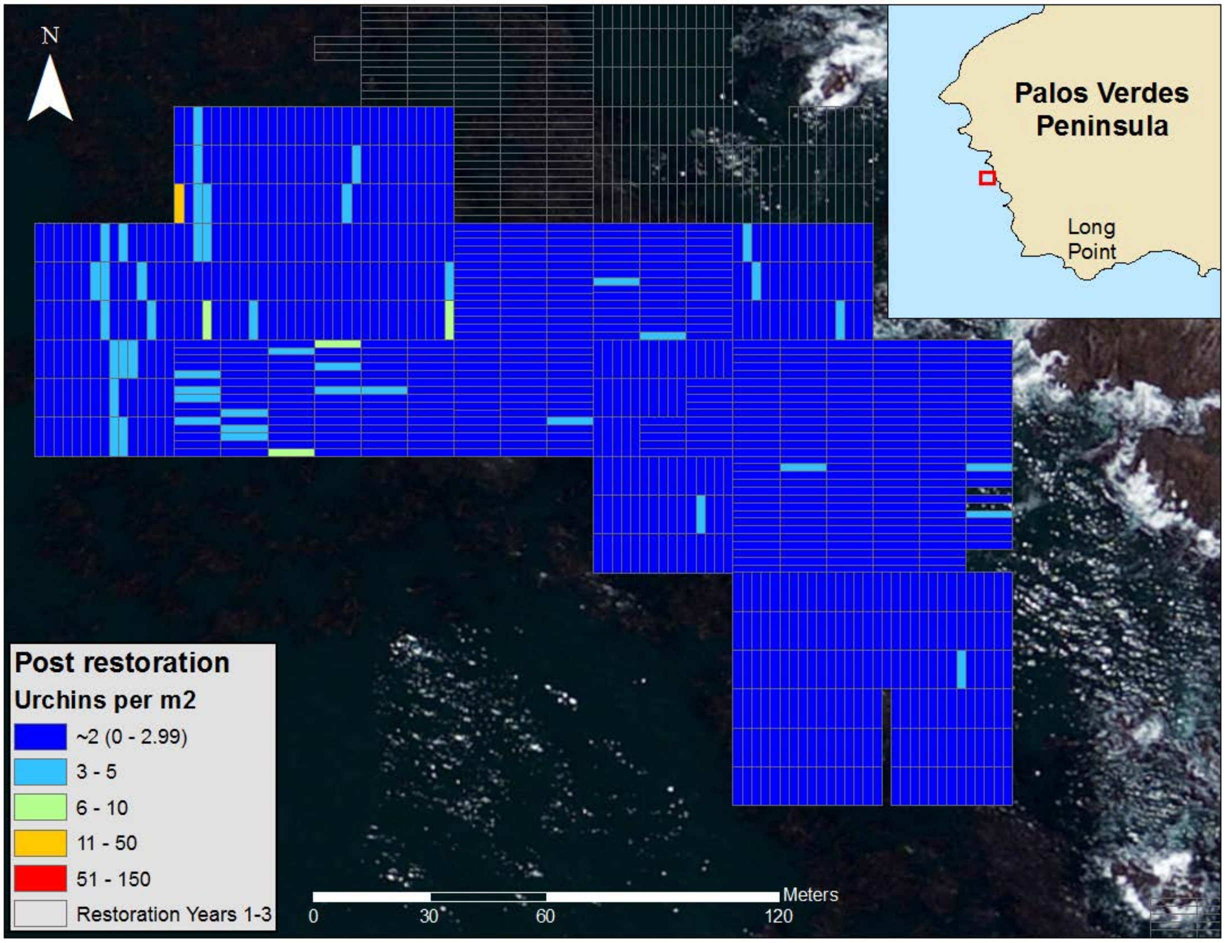

Figure 7. Density of *S. purpuratus* (individuals per square meter) post-restoration in Marguerite (north), Palos Verdes, California for Year 4 of the kelp project. The transparent blocks represent density data for previous years and gray blocks are currently in progress. See Appendix A for larger map images.

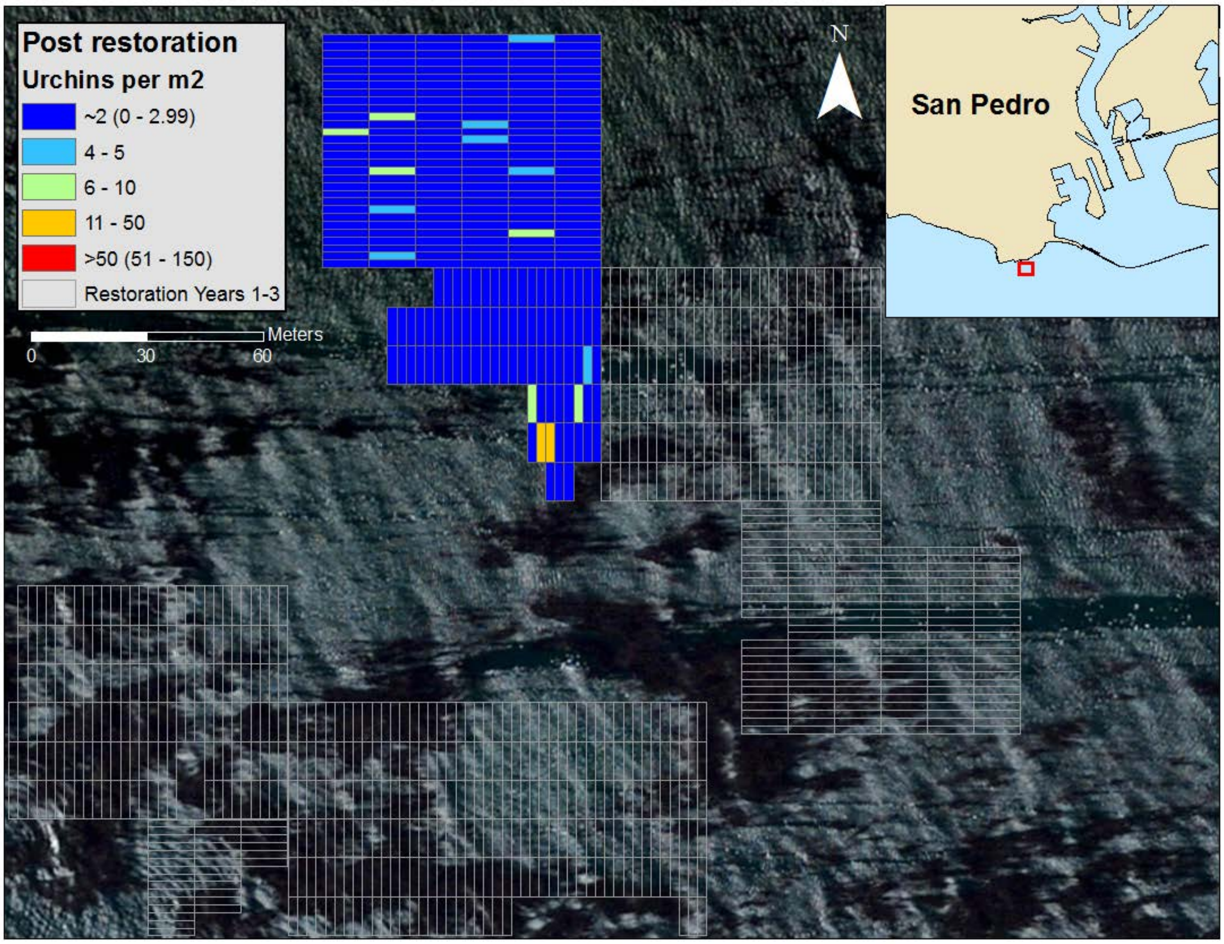

Figure 8. Density of *S. purpuratus* (individuals per square meter) post-restoration in Point Fermin, Palos Verdes, California for Year 4 of the kelp project. See Appendix A for larger map images.

An estimated 3,359,669 purple urchins have been suppressed reducing the overall average density for the restoration sites off Palos Verdes from 18.45/m^2 to 1.37/m^2. The first observations of wasting sea urchins were reported in January of 2015 in isolated locations along the peninsula. The wider spread occurrence of wasting urchins has been observed in nearly all sites off of Palos Verdes. However, near the end of Year 4 a large number of juvenile purple urchins were observed in cryptic crevices and under boulders at numerous sites around the peninsula. We speculate that this may indicate a resurgence of urchins off the peninsula in the near future, and we will continue to monitor and restore these reefs. Table 6 below shows the estimated number of urchins removed and density values by year.

Table 6. Estimated quantity of purple urchins *(S. purpuratus)* removed and urchin density (individuals per square meter) pre and post restoration (July 1, 2013 – June 30, 2017).

Time Period July 1- June 30	Pre Purple Urchin Density/m^2	Post Purple Urchin Density/m^2	Urchins Removed
Year 1	40.60	1.81	1,990,173
Year 2	17.98	1.31	1,016,269
Year 3	10.81	1.10	234,639
Year 4	4.45	1.24	118,589
Average Density	18.46	1.37	3,359,669

Underwater Arch Cove (Revisited)

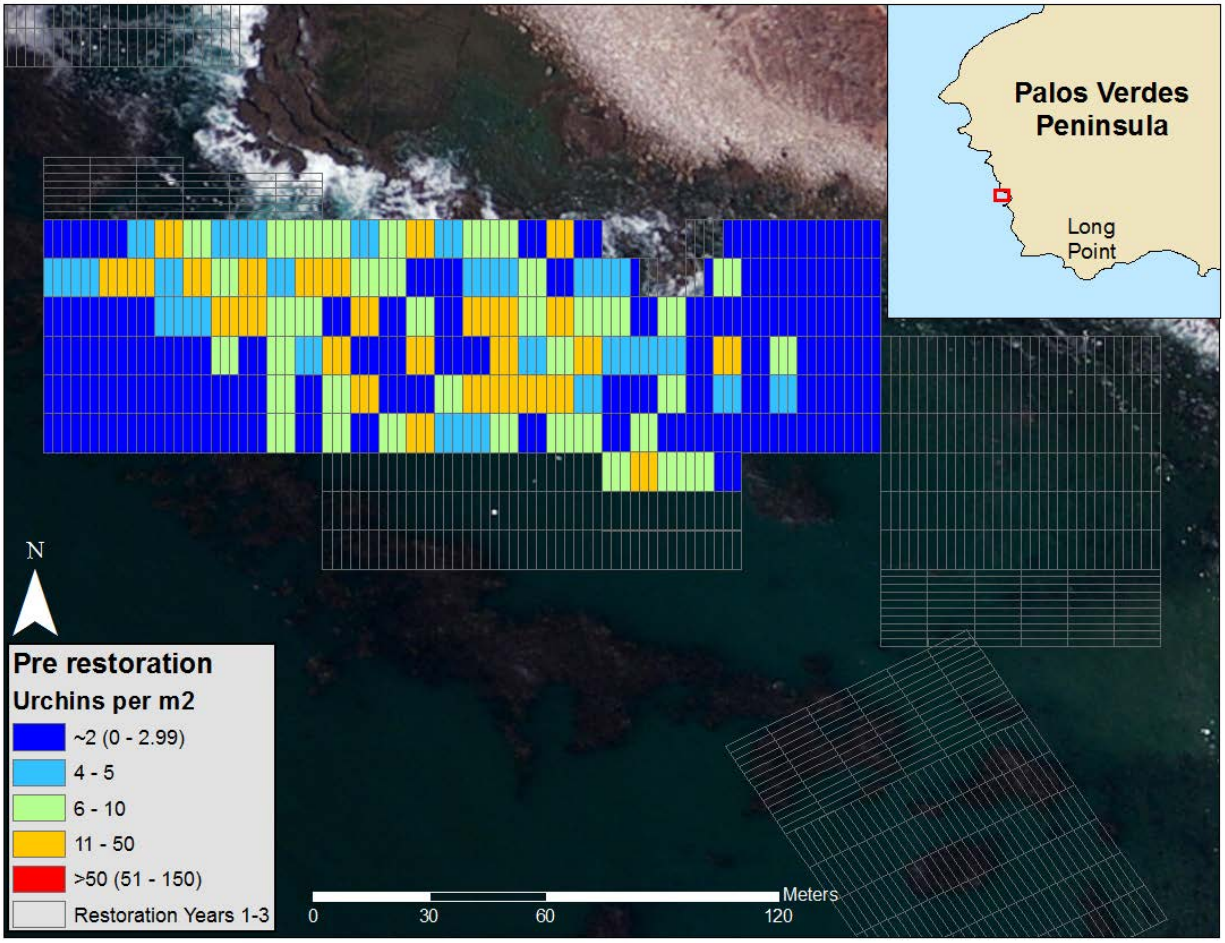

Figure 9. Density of *S. purpuratus* (individuals per square meter) prior to revised restoration in Underwater Arch, Palos Verdes, California.

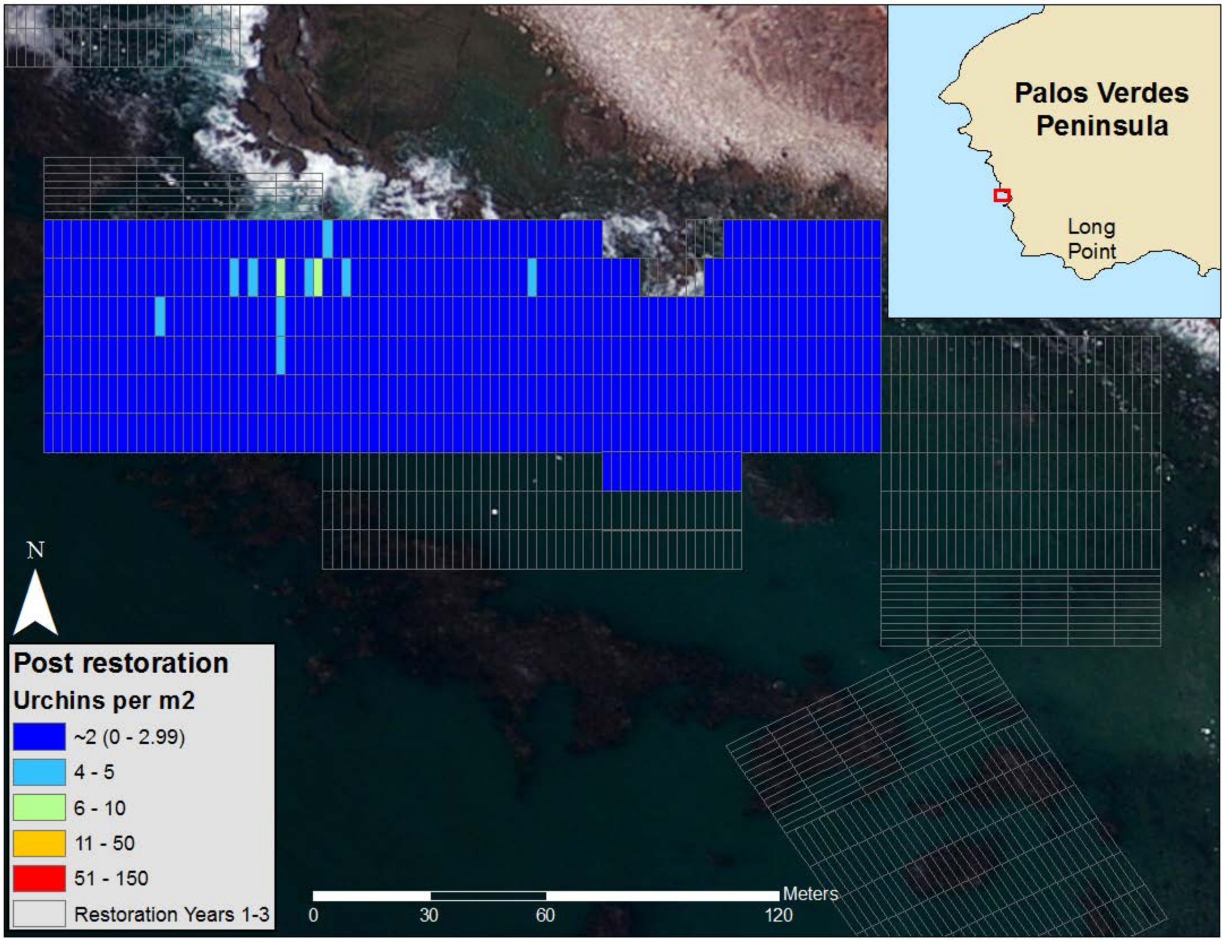

Figure 10. Density of *S. purpuratus* (individuals per square meter) after revised restoration and urchin suppression in Underwater Arch, Palos Verdes, California.

Underwater Arch Cove was similarly considered restored prior to this report period, being that no expanses of the reef were observed to support densities of purple urchins in excess of two per square meter in fall of 2015. However, one locale within Underwater Arch Cove showed higher than two purple urchins per square meter during the summer of 2016. The Bay Foundation re-monitored Underwater Arch to determine the reappearance - expansion of urchins in the area and if restoration, i.e. urchin suppression, should be undertaken. The expansion of urchins was found to be relatively contained near the large tidepool at the north edge of the site. The renewed restoration of this section of Underwater Arch took place from 1/4/17 – 7/6/17 during the same time as other sites, on the peninsula, were being restored. Purple urchin densities were reduced from 5.3 m^2 to 1.2 m^2 in a total area of 1.06 hectares.

We have a few hypotheses of what could have led to the resurgence of urchins at Underwater Arch. First being that it was early in this project's inception when Underwater Arch was restored, and steady work in urchin suppression by commercial sea urchin harvesters was limited. Additionally this site was largely restored by volunteer divers who were on SCUBA not hooka and lacked the same amount of continuity of effort and experience as the sea urchin harvesters contracted elsewhere. It is possible that urchins were missed under boulders and in cryptic crevices during this period using volunteers. Furthermore, the region of Underwater Arch inhabiting the resurgence of urchins surrounded the largest tidepool on the peninsula. It is possible this tidepool acted as a refuge for urchins during restorative urchin suppression and the recent wasting event.

As with Honeymoon Cove increased efforts were made to collect georeferenced photos and video to visually represent the changes overtime in the same if not similar locations.

Gonadosomatic Indices of Purple Urchins

A total of 68 red and 394 purple urchins were collected for the gonadosomatic study over two sampling dates in 2016 (October 26 and December 1) (Table 7). All urchins test diameter were measured to the nearest mm (Figure 11) and weighed to the nearest .01g. In addition, gonads were carefully removed from all individuals and weight to the nearest .01g. Urchins were collected from one existing kelp/reference site and two restoration sites in October, and three restoration sites and one existing kelp/reference site in December to compare gonad indices between site types. Only two red sea urchins were collected at our kelp/reference sites, therefore statistical comparisons between kelp/reference sites and restoration could not be performed.

Table 7. Urchin collections for 2016 dissections.

Collection Date	10/26/2016		12/1/2016	
Site Type	Reds	Purples	Reds	Purples
Kelp/Reference	2	76	0	54
Restoration 1	0	54	2	56
Restoration 2	0	39	35	53
Restoration 3	-	-	29	62

Gonad weight was significantly different among all sites kelp reference and restoration sites ($F_{6,380}$=25.24, p <0.001) (Figures 12 & 13). A posthoc Tukey's test revealed the kelp reference site and the restoration sites were not significantly different among each other in October. The most variation in gonad weight to test diameter was among all sites within December, where restoration sites had both the greatest and smallest ratios. The smaller gonad values in the Underwater Arch sites are most likely due to the lack of kelp within those sites brought on by the warm waters from the El Nino.

The measurement of gonad development in sea urchins is an important measure of secondary production in the giant kelp forest ecosystem, and will be used to inform adaptive management of the restoration project and inform research related to giant kelp forests and associated fisheries.

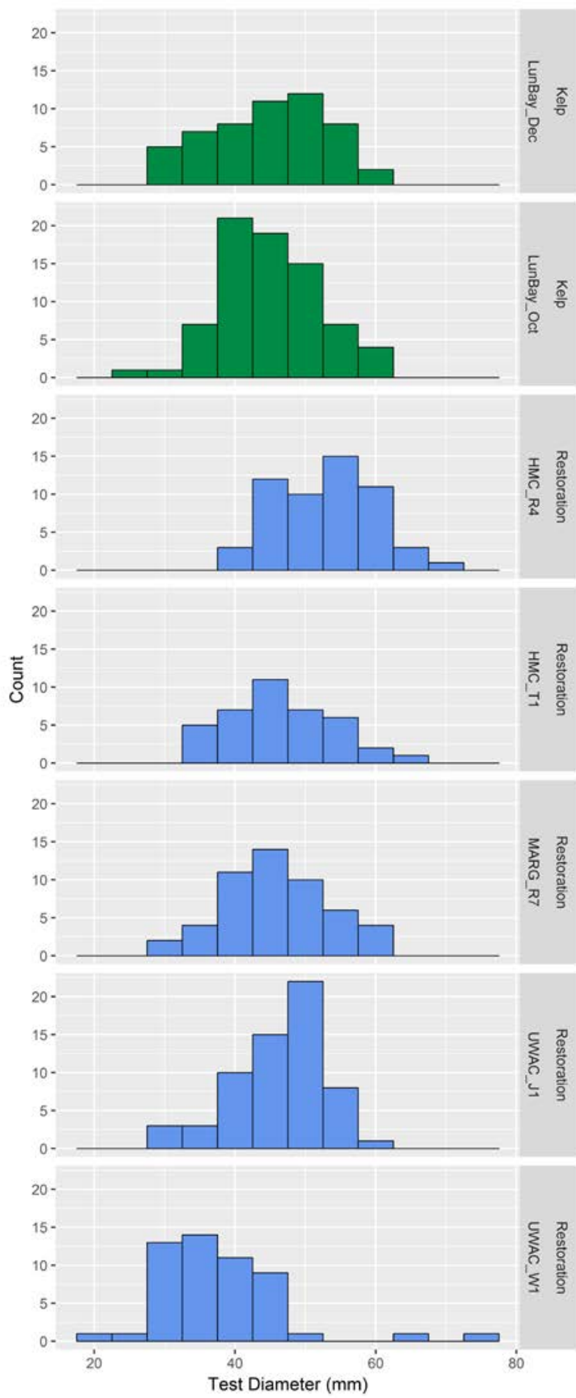

Figure 11. Histogram of Purple Urchin (*Strongylocentrotus purpuratus*) test diameter for urchins collected in Kelp Forest Reference and Restoration Sites with data from collections during the Fall of 2016. Site codes are as such: MARG = Marguerite, HMC = Honeymoon Cove, Lun = Lunada Bay, UWAC = Underwater Arch Cove.

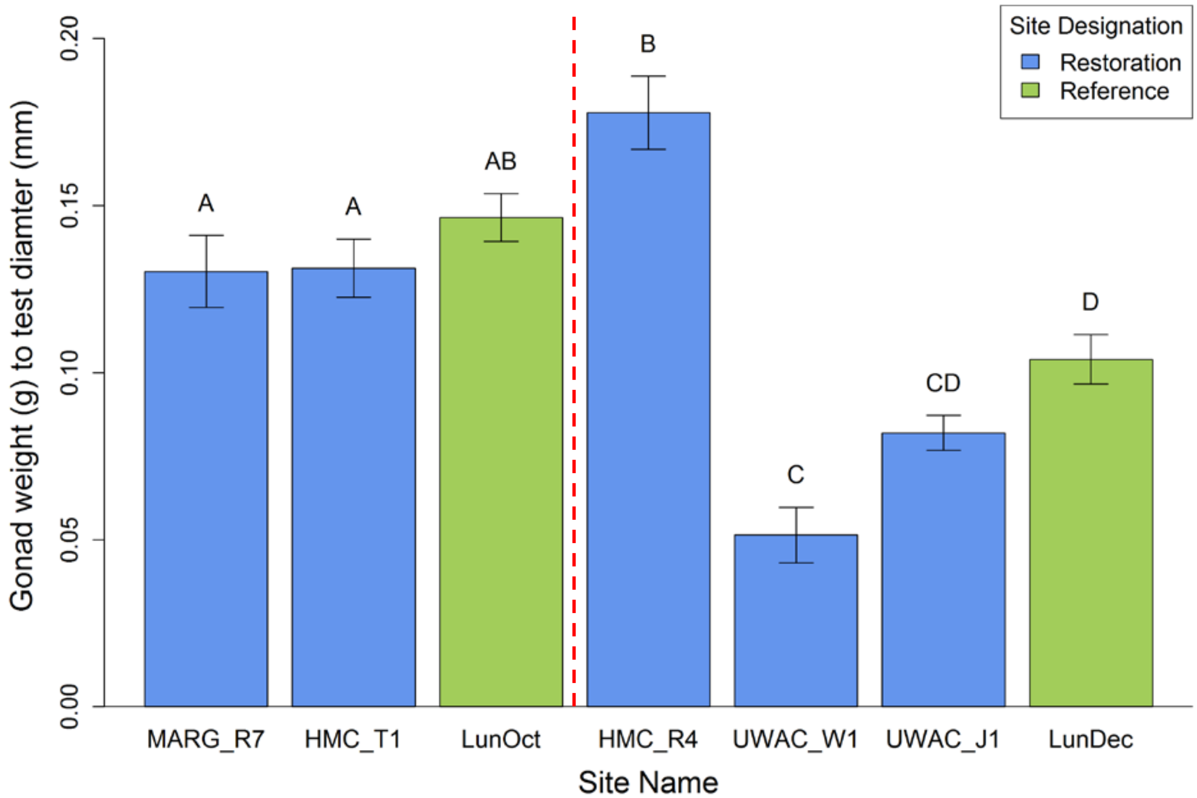

Figure 12. Ratio of gonad weight (g) to test diameter (mm) for Purple Urchins (*Strongylocentrotus purpuratus*). Gonad weight was significantly different among the Kelp reference and restoration sites ($F_{6,380}$=25.24, p <0.001). The red dashed line separates urchins collected in October (left) from December (right). Letters above error bars show which sites are significantly different from each other from a Tukey's posthoc test. Site codes are as such: MARG = Marguerite, HMC = Honeymoon Cove, Lun = Lunada Bay, UWAC = Underwater Arch Cove.

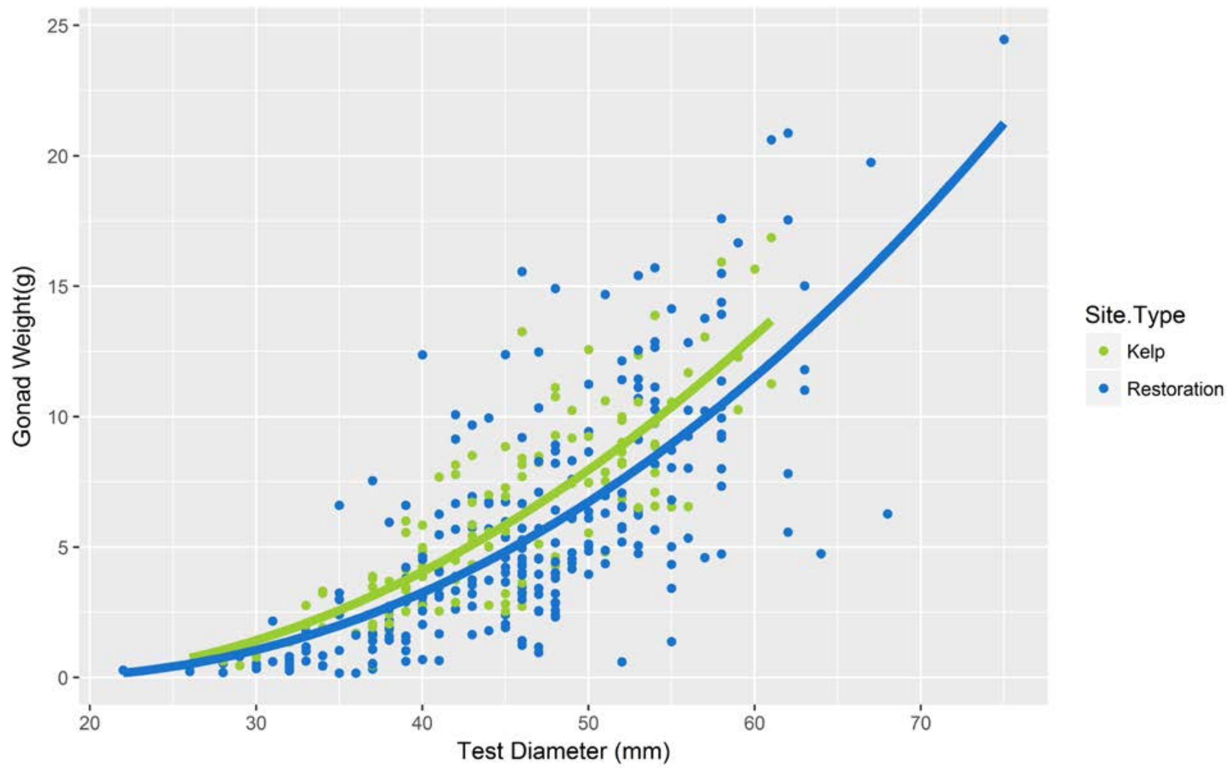

Figure 13. Relationship between Purple Urchin (*Strongylocentrotus purpuratus*) gonad weight (g) and urchin test diameter (mm) in site designations Kelp Forest Reference (green) and Restoration (blue) from 2016 collections.

Purple and Red Urchin Densities by Site

Both red and purple sea urchin abundance declined in 2015 and has remained low for the past couple of years (Figures 14 & 15). The initial decline of purple sea urchins within restoration sites is due to our restoration efforts; however, the decline of purple sea urchins in our control and reference sites is most likely due to the localized wasting event of purple sea urchins. TBF suspended sea urchin suppression from the fall of 2015 through the spring of 2016 to monitor the wasting event. TBF continued sea urchin suppression in the late spring of 2016 once lesions on sea urchins were no longer found and densities of greater than $2/m^2$ were found within our restoration sites. Red sea urchin densities also dropped during this time period even though TBF does not suppress this species. The decline in abundance is most likely caused by two factors, 1) sea urchin wasting event, and 2) commercial sea urchin harvesters extracting the red sea urchins for the fishery.

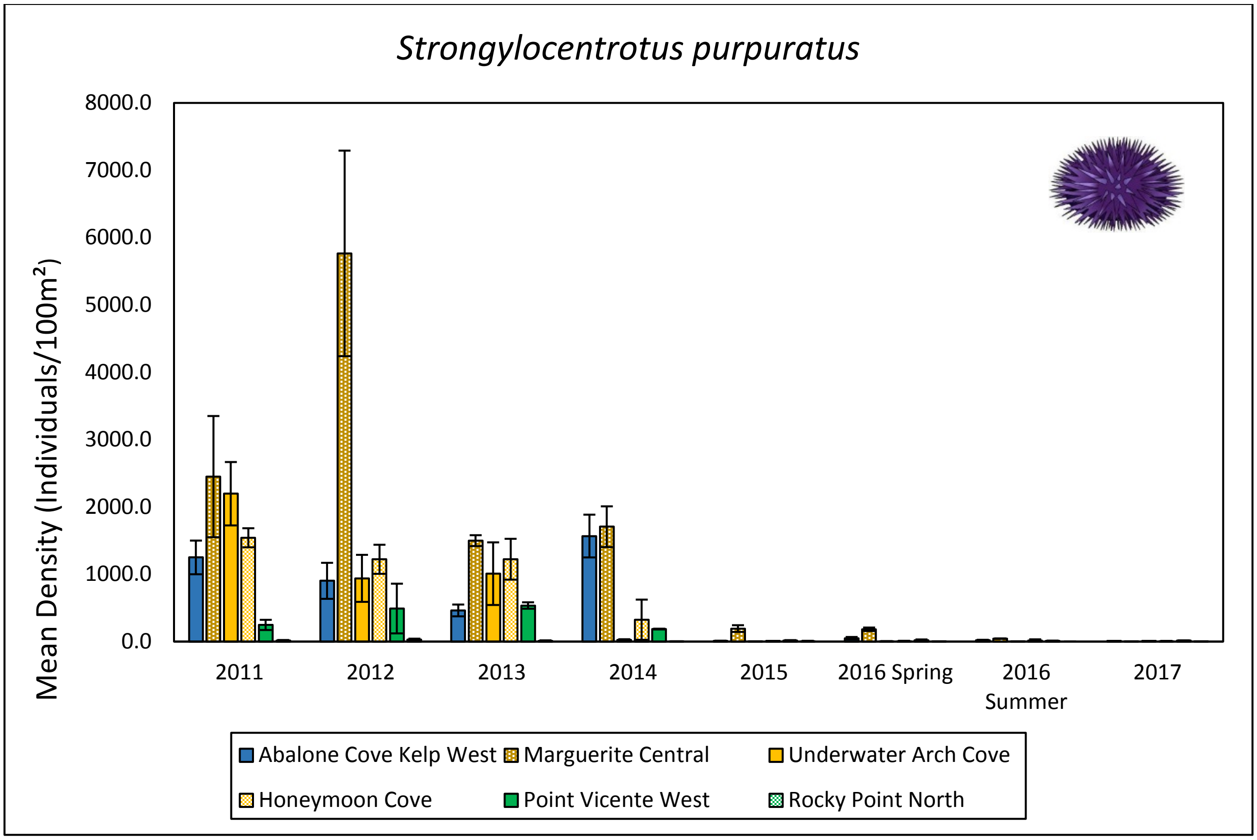

Figure 14. Purple sea urchin density (individuals/100 m^2). Sites Underwater Arch and Honeymoon Cove were restored as of 2014. Restoration began in 2015 at the site Marguerite Central (previously a control site) restoration was completed in the fall of 2016. Density was not significantly different by site designation in 2017 ($F_{2, 15}$= 0.52, p = 0.61).

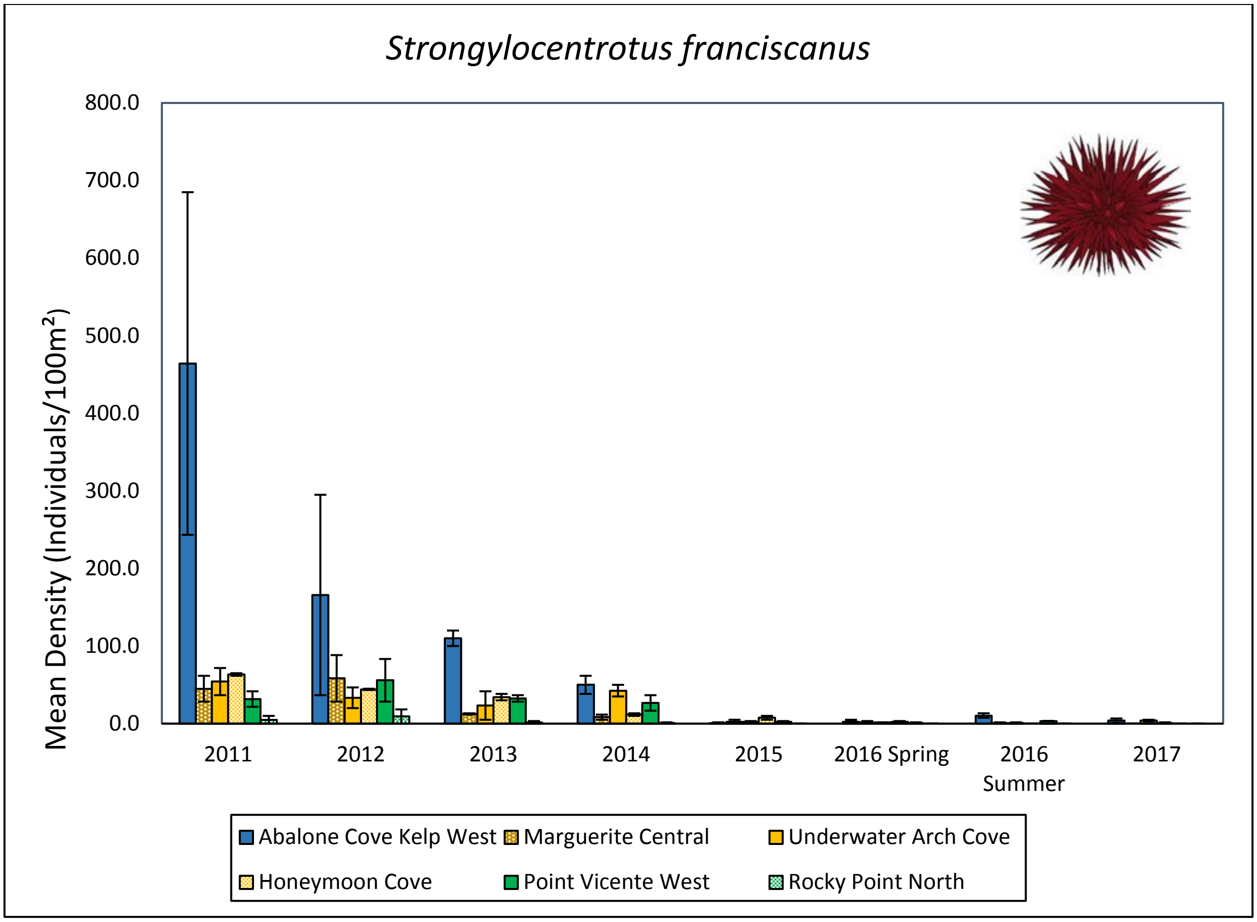

Figure 15. Red sea urchin density (individuals/100 m^2). Sites Underwater Arch and Honeymoon Cove were restored as of 2014. Restoration began in 2015 at the site Marguerite Central (previously a control site) and was completed in the fall of 2016. Density was not significantly different by site designation in 2017 ($F_{1,6}$= 1.42, p = 0.28).

Kelp Canopy Area and Percent Cover by Site

Since 2003, MBC Applied Environmental has been hired by the Central Region and Region Nine Kelp Survey Consortium to to take quarterly aerial surveys of the mainland Southern Californian kelp forests. These kelp surveys inform the consortiums about the status of the kelp forests and serve to determine possible impacts that dischargers and environmental variables are having on kelp. These surveys consist of digital color and infrared color photos taken of the kelp beds that are then processed into base maps. These surveys cover approxiamtely 355 km of the southern California coastline.

The consortiums provided TBF with the base maps of annual kelp bed maxiums of the Palos Verdes kelp beds, which can be used to show the progress of restortion off Palos Verdes. Surveys from 2007 through 2016 show an overall increase in kelp canopy acreage off the peninsula; however, kelp canopy encroachment into restoration areas is found only to start in 2014 and further increases in 2015 (Figure 16). Focusing on kelp restoration areas where urchin suppression had occured, canopy percent cover (Figure 17) and area of the site (Figure 18) increased in the completed restoration sites of Honeymoon Cove and Underwater Arch Cove. Canopy cover percentage as of 2015 has reached 52% for Underwater Arch and 83% for Honeymoon Cove, which is an approximate 250% increase for both sites from the previous kelp bed maxium in 2010 (Figure 18). In 2016, kelp suffered at all sites with the exception of Point Fermin due to warm El Niño conditions. This increase in kelp was additionally quantified in the CRANE surveys (Figure 19). In 2016, kelp canopy decreased throughout the peninsula (Figure 16). Warm waters/El Niño conditions are likely to have caused these results. In both Hawthorne and Underwater Arch kelp canopy decreased to 0%, while Marguerite (which already had low amounts of kelp canopy) also decreased. Kelp canopy at Honeymoon Cove decreased slightly, but still possessed a large kelp canopy area. Point Fermin was the only site to increase its kelp canopy in 2016 (Figure 17).

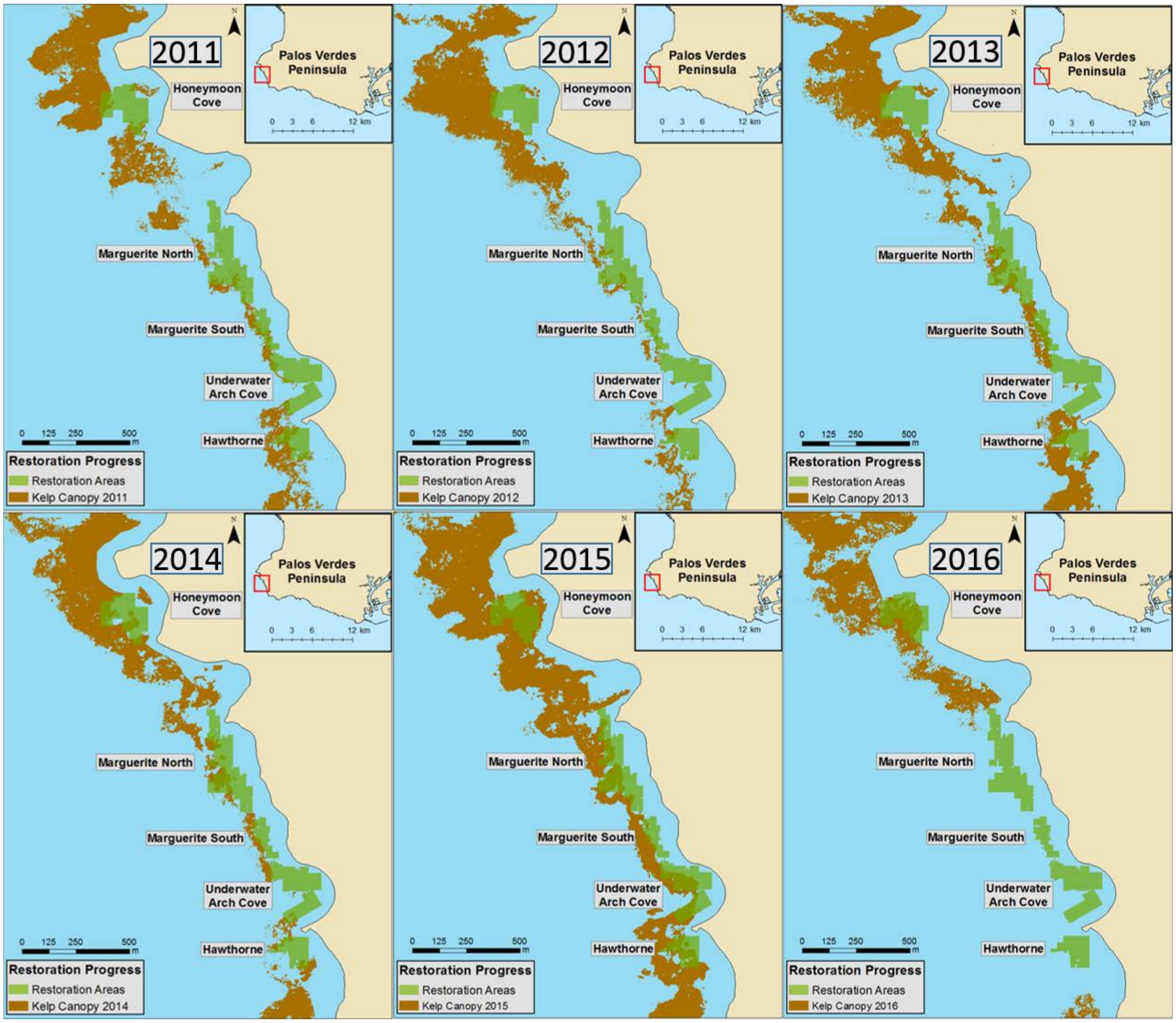

Figure 16. Aerial kelp canopy coverage (*Macrocystis pyrifera*) from 2007 – 2016. Data provided by MBC Applied Environmental. Canopy coverage is represented in brown while restoration areas are in green. The map shows the western side of the Palos Verdes Peninsula.

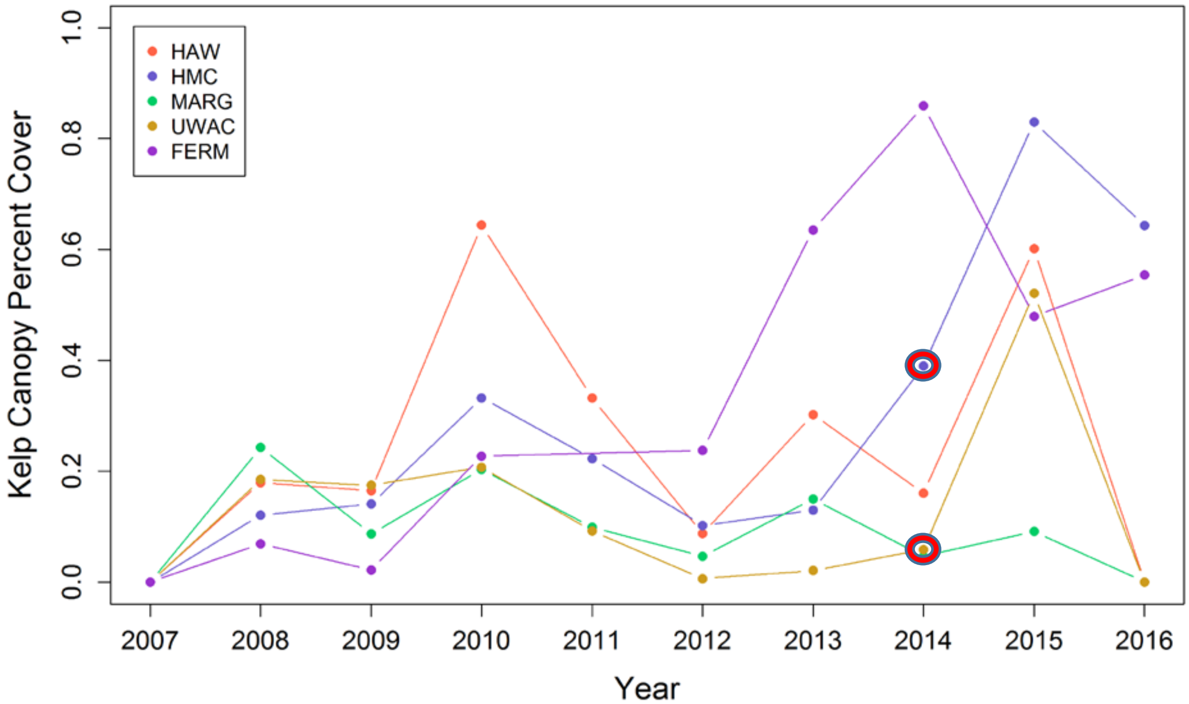

Figure 17. Annual kelp canopy percent cover from 2007 – 2016 per restoration site. Red circles indicate completed restoration sites Underwater Arch (brown) and Honeymoon Cove (blue) a year after restoration finished. Data provided by MBC Applied Environmental. At Hawthorne (HAW - orange) restoration actions have been initiated but not completed during the timeframe of these data. Monitoring and restoration efforts are expected to continue for Hawthorne.

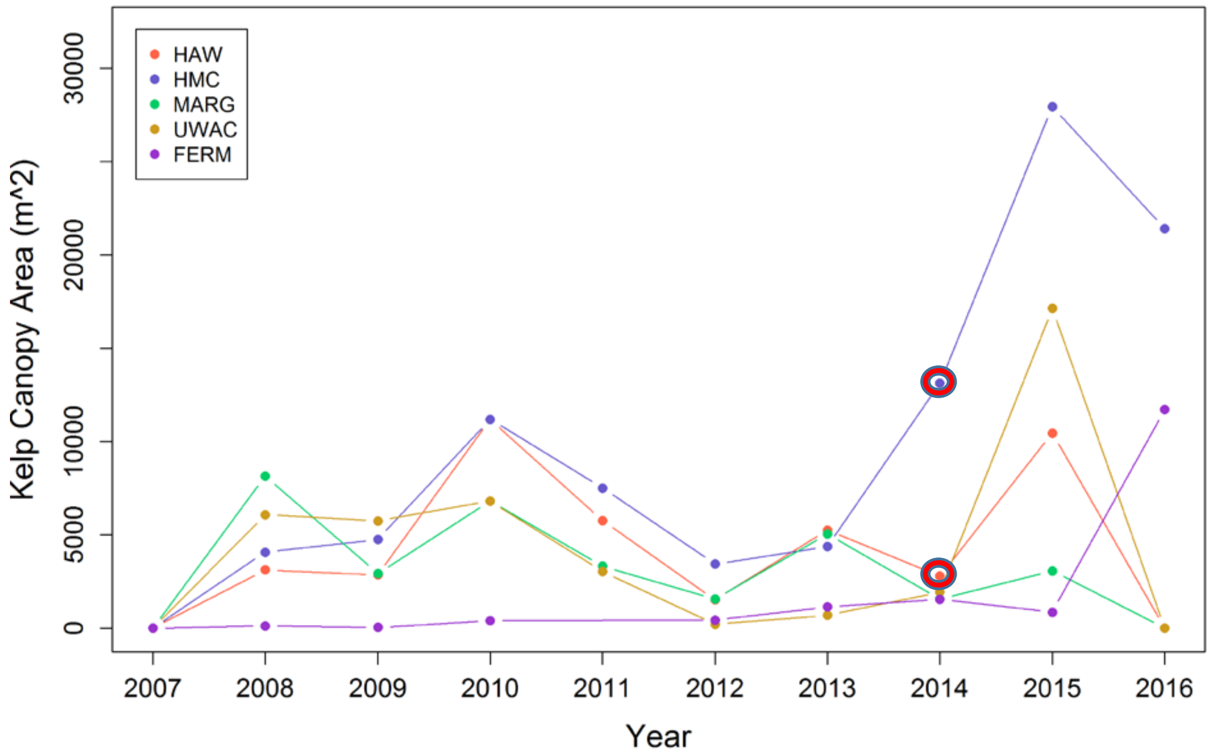

Figure 18. Annual total kelp canopy area from 2007 – 2016. Red circles indicate completed restoration sites Underwater Arch (brown) and Honeymoon Cove (blue) a year after restoration finished. Data provided by MBC Applied Environmental. At Hawthorne (HAW - orange) restoration actions have been initiated but not completed during the timeframe of these data. Monitoring and restoration efforts are expected to continue for Hawthorne.

Giant Kelp Density by Site

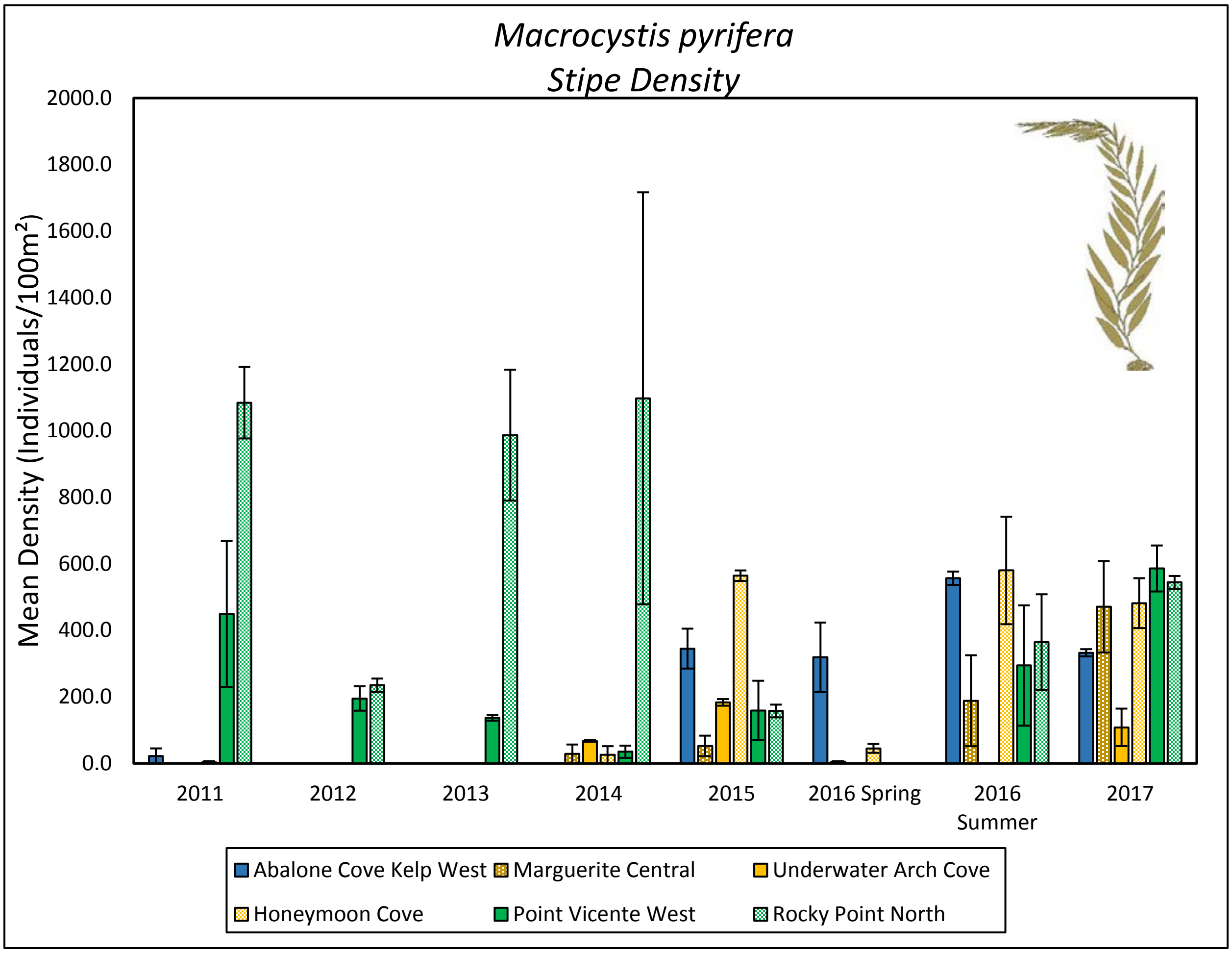

Figure 19. Giant kelp density (individuals/100 m^2). Sites Underwater Arch and Honeymoon Cove were restored as of 2014. Restoration began in 2015 at the site Marguerite Central (previously a control site) and was completed in the fall of 2016. Kelp was significantly different by site designation in 2017 ($F_{2,\,253}$= 3.71, p = 0.029).

Density of Kelp Bass and California Sheephead

Because sites were sampled over a time period of several months and seasons, young-of-the-year (YOY) were removed prior to fish density calculations because they could numerically dominate the assemblage at some sites sampled early during the sampling season but decline later in the year as a result of natural mortality. YOY were generally defined as fishes < 10 cm, except for some smaller species, where they were defined as individuals less than 1.5 or 5 cm (dependent on the species) based on published species-specific growth rates and expert opinion. Total length (TL) estimates were converted to biomass using standard species-specific length-weight conversions from the literature. YOY were not excluded from biomass calculations, as their small size will influence biomass estimation less than abundance estimation. Density/biomass density was then summed across all three portions (bottom, midwater and canopy) of each transect, except for when the water depth is less than 6 m, meaning that the volumes of the canopy and midwater portions would overlap, in which case no midwater portion was included. Density values were then scaled to the number per $100m^2$.

Kelp bass abundance and biomass has gradually increased in restoration sites post restoration efforts (Figures 20 & 22). In the survey's conducted in 2017, two of the restoration sites (Marguerite Central and Underwater Arch Cove) had the highest number of individual kelp bass counted compared to kelp reference and barren control sites. This increased number of kelp bass could be due to a multiyear increase and persistence of giant kelp in these restoration sites (Figures 16-19). Kelp bass recruit to kelp canopy, and use kelp as a refuge to hide from predators or to ambush prey. Biomass of kelp bass from 2017 shows that the largest biomass of kelp bass is within Point Vicente MPA site. This is expected as fishing is not allowed within this area, allowing for fish to grow larger without fishing pressure. All current restoration sites are not within MPAs so fishing is permitted, thus the larger individuals could be removed from the population. Another possibility for the lower biomass within restoration sites could be kelp bass recruited to these restoration sites, and with the persistence of kelp were able to remain at these sites. Lowe et. al (2003) found kelp bass show strong site fidelity, thus restoration efforts may have provided better habitat that allowed for a larger and growing population of kelp bass.

California sheephead abundance and biomass has been variable among monitoring years for all sites (Figures 21 & 23). This result could be due to the larger home ranges of CA sheephead and their ecological behavior being more generalist than kelp bass. It is possible our annual community response monitoring does not adequately show the amount of CA sheephead at our sites.

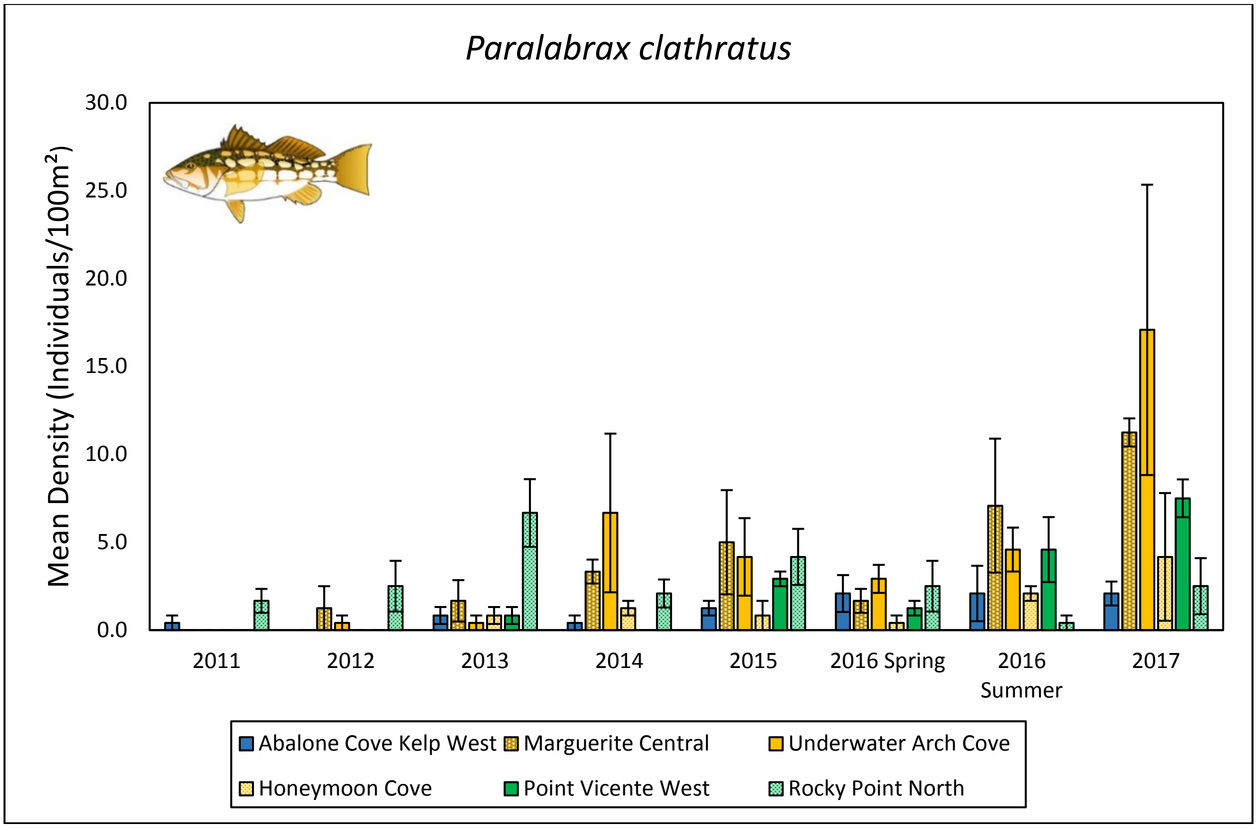

Figure 20. Density of kelp bass by site type; control, restoration, and reference. Sites Underwater Arch and Honeymoon Cove were restored as of 2014. Restoration began in 2015 at the site Marguerite Central (previously a control site) restoration was completed in the fall of 2016. Density was not significantly different by site designation in 2017 ($F_{2,\,61}$= 2.32, p = 0.107).

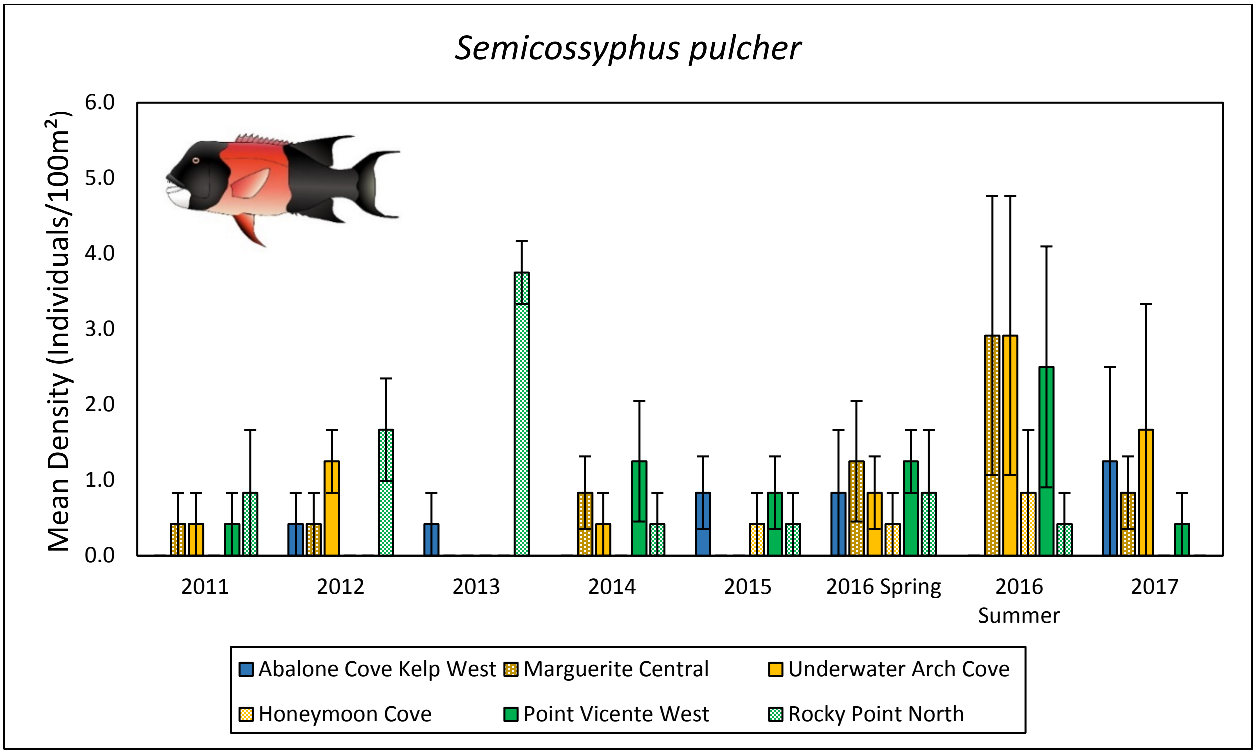

Figure 21. Density of CA sheephead by site type; control, restoration, and reference. Sites Underwater Arch and Honeymoon Cove were restored as of 2014. Restoration began in 2015 at the site Marguerite Central (previously a control site) restoration was completed in the fall of 2016. Density was not significantly different by site designation in 2017 ($F_{2,5}$= 0.42, p = 0.68).

Biomass of Kelp Bass and California Sheephead

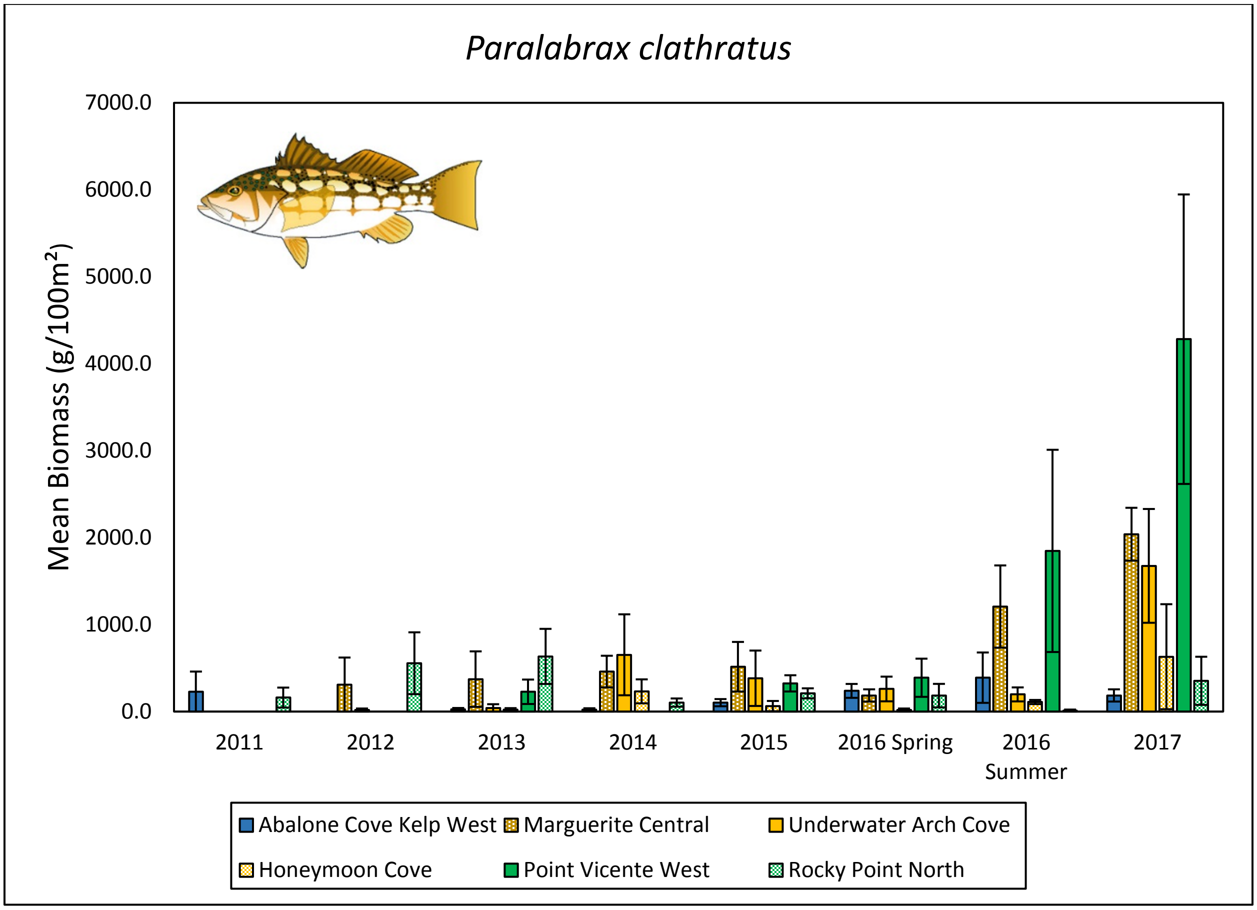

Figure 22. Biomass of kelp bass per 100 m^2, per site. Sites Underwater Arch and Honeymoon Cove were restored as of 2014. Restoration began in 2015 at the site Marguerite Central (previously a control site) restoration was completed in the fall of 2016.

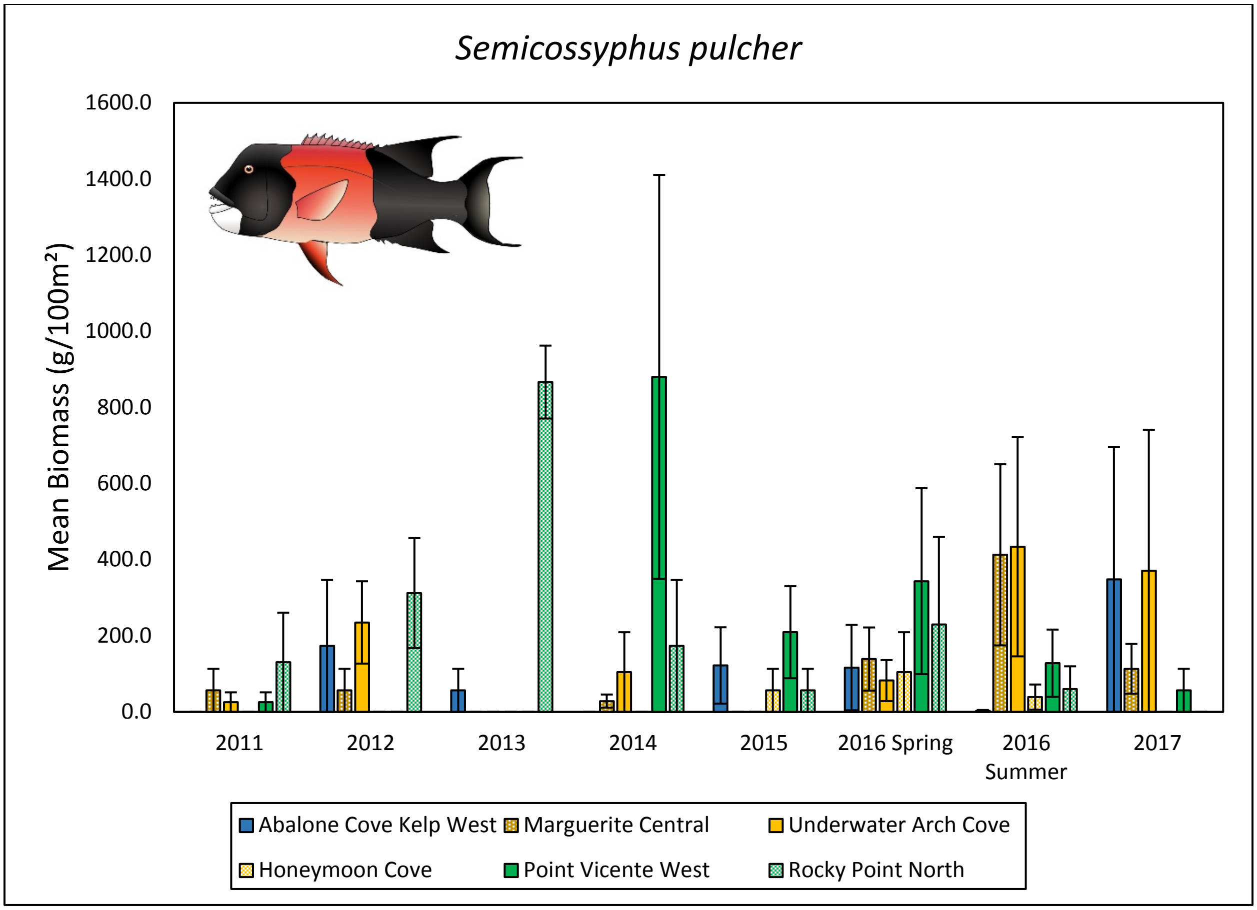

Figure 23. Biomass of CA sheephead per 100 m^2, per site. Sites Underwater Arch and Honeymoon Cove were restored as of 2014. Restoration began in 2015 at the site Marguerite Central (previously a control site) restoration was completed in the fall of 2016.

Species Richness

Table 8. Fish Species Richness (total number of species)

							Spring	*Summer*	
Designation	*Site*	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2016**	**2017**
Control	Abalone Cove Kelp West	7	7	10	9	8	13	13	9
	Marguerite Central	6	10	10	9	11	8	11	8
Restoration	Underwater Arch Cove	6	9	6	12	8	7	6	11
	Honeymoon Cove	0	2	4	8	5	5	12	7
Reference	Point Vicente West	8	6	10	11	12	11	12	9
	Rocky Point North	8	8	8	9	6	7	5	9

Note: 2014 is the first post-restoration year. Restoration began at the control site Marguerite Central in August 2014. However, urchin suppression was not done at the response monitoring location for this site. In the future, barren control sites will become restoration sites once these barrens are restored and analyses will compare differences between reference and restoration sites.

Community Analyses

The Shannon-Wiener diversity index came from information theory and measures the order (or disorder) observed within a particular system. The Simpson's index of diversity accounts for both richness and proportion of each species. It has been a useful tool to terrestrial and aquatic ecologists. Both diversity measures show a similar increasing trend of algal/invertebrate diversity since restoration was completed in Underwater Arch and Honeymoon Cove (Figures 24-25).

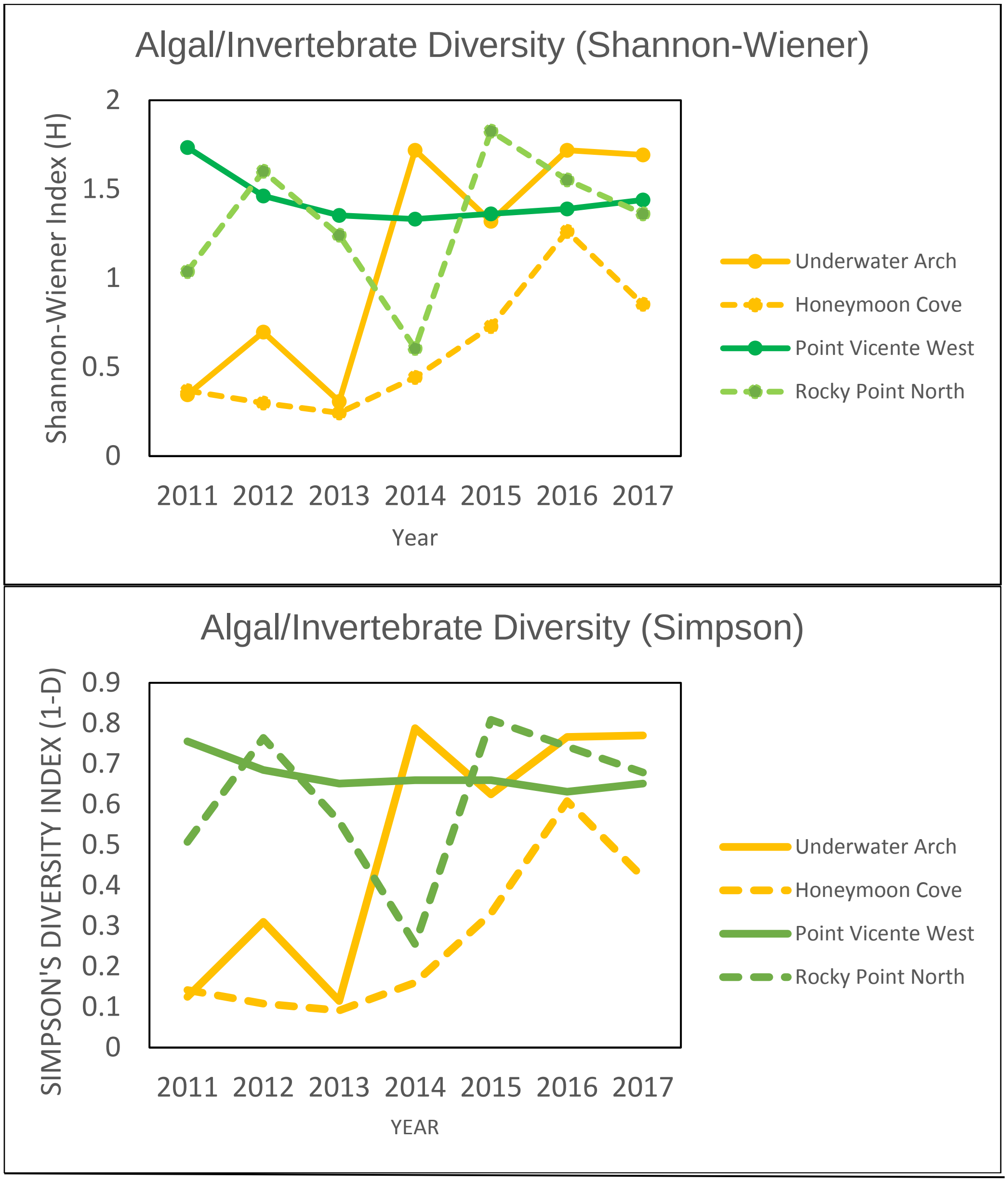

Figure 24. Algal and invertebrate diversity at Restoration (Underwater Arch & Honeymoon Cove) and Reference (Point Vicente & Rocky Point North) sites. Underwater Arch & Honeymoon Cove were restored as of 2014. Diversity measures used are Shannon-Wiener (above) and Simpson's Diversity (below).

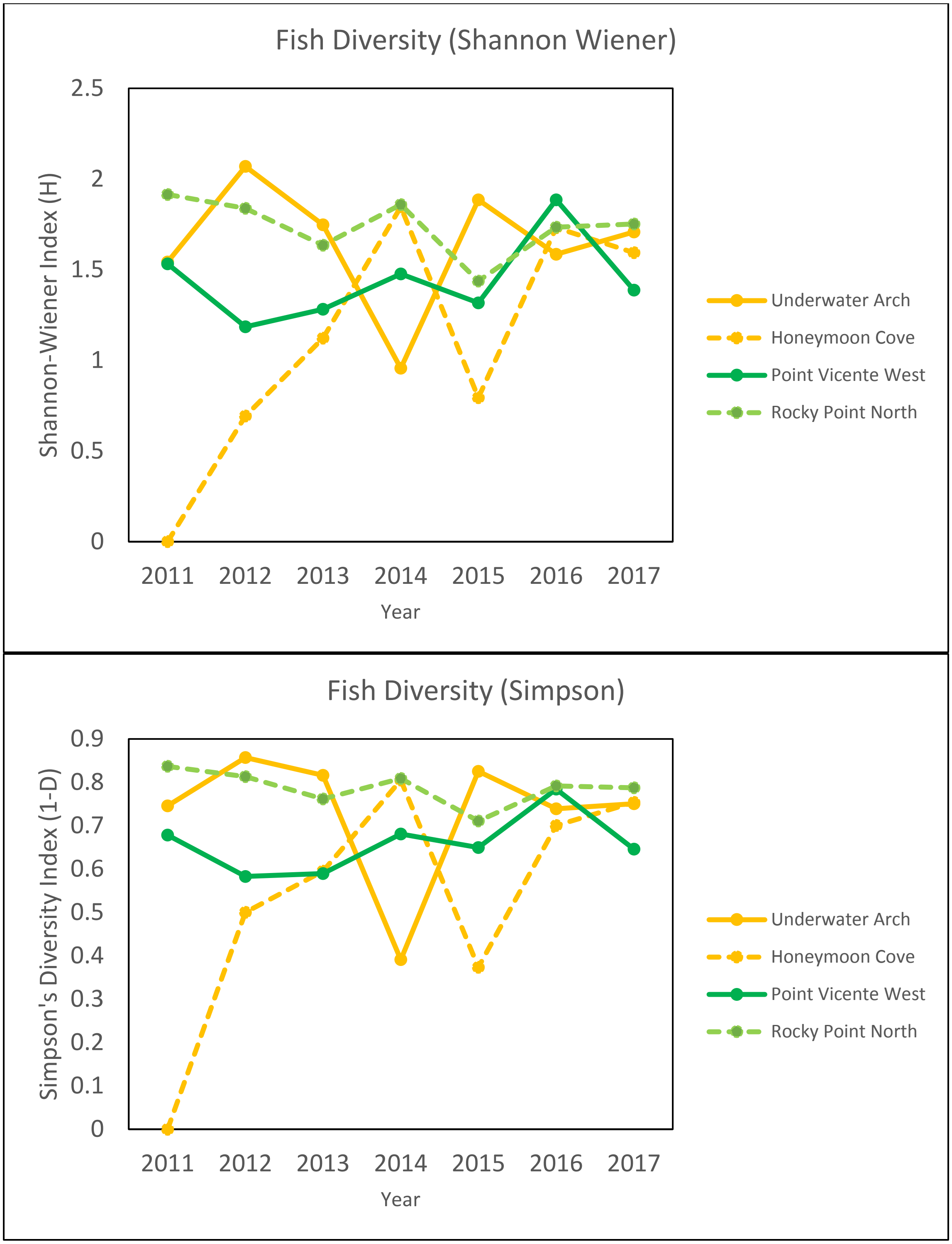

Figure 25. Fish diversity at Restoration (Underwater Arch & Honeymoon Cove) and Reference (Point Vicente & Rocky Point North) sites. Underwater Arch & Honeymoon Cove were restored as of 2014. Diversity measures used are Shannon-Wiener (above) and Simpson's Diversity (below).

Two-dimensional, non-metric multidimensional scaling (nMDS) was used to examine patterns among kelp forest communities (Figure 26) and benthic cover (Figure 27) at sites using the 'metaMDS' function in the 'vegan' package (Oksanen et al. 2016) in R (R Core Team 2016). A similarity matrix constructed with transformed taxon-specific values (site means for each site/sampling period combination) and the Bray-Curtis similarity. To provide context to the observed relationships amongst sites, patterns of taxa densities were visualized across the nMDS ordination plots using the 'ordisurf' function in the R package 'vegan' (Oksanen et al. 2016) which fits a smooth surface using generalized additive modeling (GAM) with thin plate splines (Wood 2003, Oksanen et al. 2016). These visualizations help inform drivers of community structure as seen in nMDS plots.

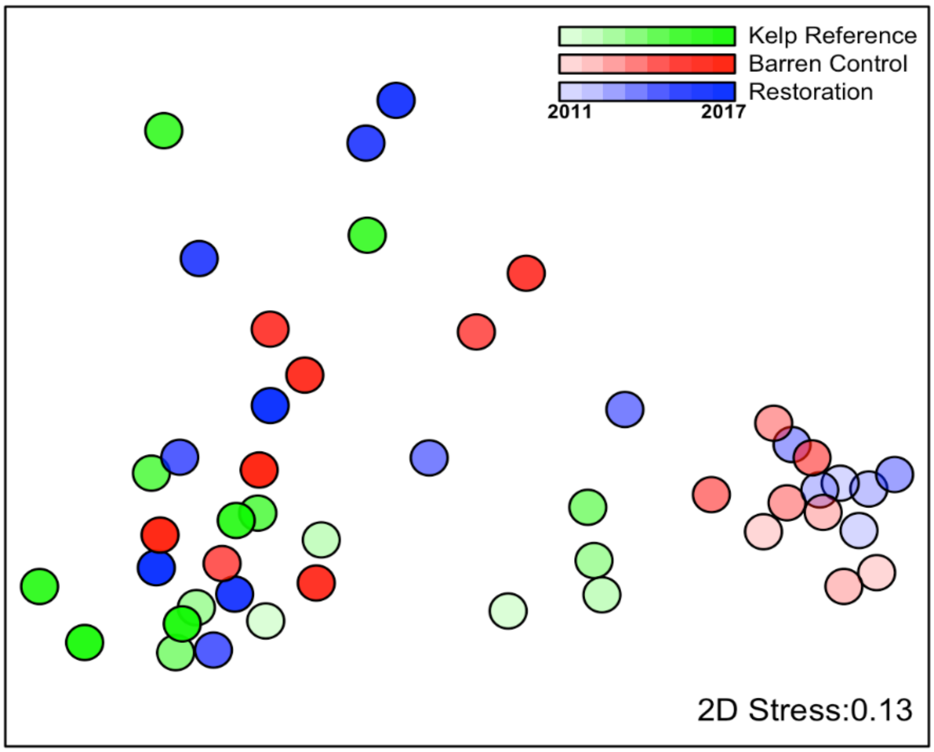

Figure 26. Non-metric multidimensional ordination plot of kelp forest communities (numerical density of fishes, invertebrates, and kelps) using Bray-Curtis similarity based on the square-root transformed mean taxa density for each site/sampling period combination. Site designation is indicated by color, survey year is indicated by the transparency of each point with earlier dates more transparent and later dates nearly opaque.

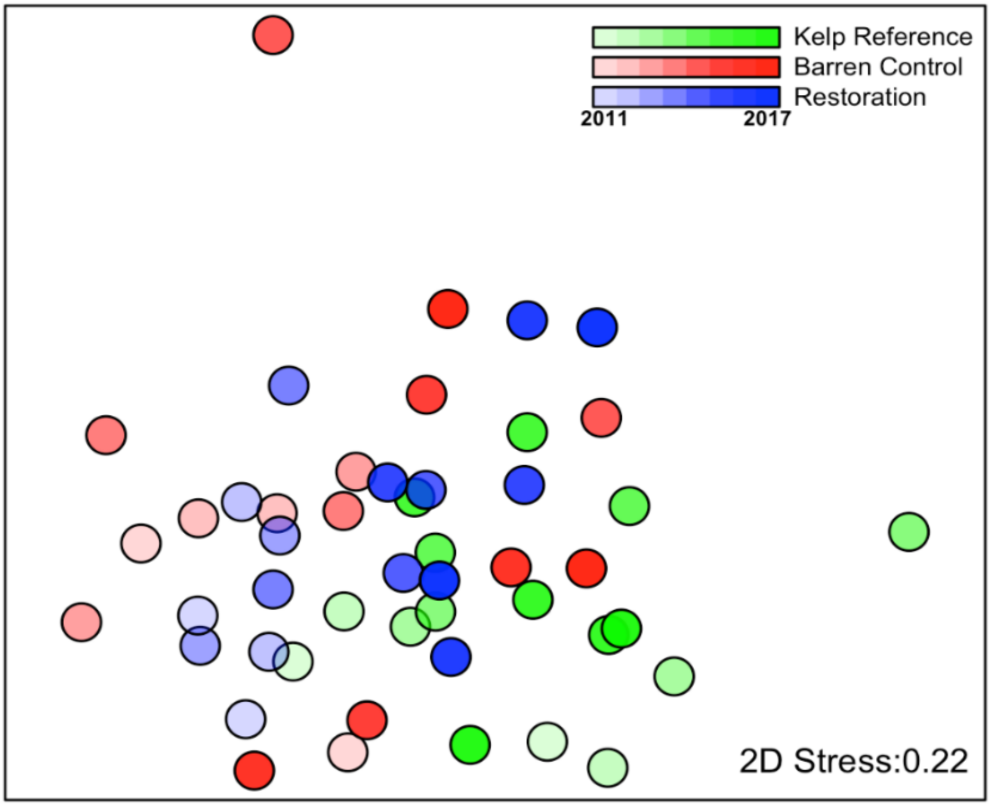

Figure 27. Non-metric multidimensional ordination plot of benthic cover using Bray-Curtis similarity based on the arcsine-square-root transformed mean taxa density for each site/sampling period combination. Site designation is indicated by color, survey year is indicated by the transparency of each point with earlier dates more transparent and later dates nearly opaque.

The two plots presented above display a convergence over time in which restoration sites begin to resemble, structurally, the reference sites. The earlier years depicted in these plots show that the converse was true in advance of restoration efforts that the structure of restoration sites, pre restoration, resembled control sites. What also is displayed in these plots is a similar progression of control sites to resemble the structure of restored and reference sites over time. This could be the result of a poor or inappropriate experimental design, e.g. control sites being influenced indirectly by the proximity-occurence of restoration actions, or other overwhelming factors.

In this case the interpretation of these results allows for a finer scale evaluation of the time of the shifts in community structure displayed more clearly in figure 26 than in figure 27. What we see in figure 26 suggests the movement of the restoration sites towards a more restoration-like structure in advance of the control sites, which display a lag in time.

Summary

The occurrence of a mass wasting event of red and purple sea urchins occurred with considerable severity on the Palos Verdes Peninsula impacting reference, restoration and control sites. This overall loss of top down pressure from urchins on the development of giant kelp and other macroalgae and the freeing from competition, of other grazers, may be the most likely cause of the progression of these three site types to converge in community structure in 2015-2017.

What may be said with greater confidence is that the loss of sea urchins (i.e. a reduction in their density) allows for the growth and development of other benthic organisms that are no longer limited by the direct and indirect impacts of sea urchin grazing. Further monitoring of these sites over time may detect trends that elucidate more subtle or developing relationships in community structure. Likely these characteristics will be displayed via divergence of these site types over time or in response to other forms of disturbance and other stressors. Fortunately this project will provide that opportunity to collect those data informing those potentials.

What may also be said is that sea urchin suppression creates similar near term changes in community structure to widespread reductions in urchins due to disease. These different causes of urchin density reduction (i.e. suppression and natural loss due to disease) have both driven formerly barren reef states to resemble reference sites (i.e. sites with persistent kelp and increased community structure). These results suggest that in the near term urchin suppression is a fair mimic for natural losses in urchin populations driving kelp forest community structure on a local scale.

It is also important to note which drivers within the community explain the bulk of the transitions/progression in each of the figures. In figure 26, sites with larger numbers of echinoderms are present at the right side of the plot while sites that have larger numbers of kelps are present on the left. In figure 27, sites with higher bare rock and crustose coralline algae appear on the left of the plot, sites with *Eisenia arborea* (southern sea palm) holdfasts and erect red algae present towards the bottom-right, sites with more red turf erect coralline algae are placed in the middle, and sites with more giant kelp holdfasts are placed towards the bottom.

Evaluation of Restoration Activities

A few statements can be made that generally describe conditions during this report period that directly impacted the amount, type, and accuracy of work conducted. 2015-2016 proved to be one of the most powerful El Niño signatures recorded on the west coast of the United States. This El Niño event followed and was perhaps strengthened by the persistence of "the blob", a large area of atypically warm ocean surface water that impacted the California Current. For Palos Verdes and elsewhere in southern California, these environmental factors resulted in abnormally high sea surface temperatures, which were only punctuated periodically by localized upwelling events. The thermal related stress associated with the confluence of these stressors slowed or prevented the development of giant kelp and other macroalgae, and may have contributed to the virulence and mass wasting of several genera of sea stars and in the fall of 2015 a seemingly similar yet less widespread wasting of sea urchins. In fall 2015, the project failed to collect sufficient numbers of red sea urchins and none of marketable size to successfully analyze their gonadosomatic scores. Sufficient purples were found but they too were also reduced in number. Restoration actions were suspended for all teams and all sites in fall 2015. The restoration teams were reengaged in June 2016 following a nine month hiatus, (starting with work in Marguerite). There are currently no signs of further wasting disease off of Palos Verdes and exploration into the boulder fields that comprise the nonconsolidated portions of the reef complexes show numerous purple sea urchins and some reds that are displaying cryptic behavior perhaps in response to the warm water and wasting event. During the summer of 2017 high densities of purple urchins started to reappear off the peninsula. The project partners will continue paying close attention to the extant condition of the reefs on the Palos Verdes Peninsula to identify any significant changes as they occur during the relaxation of the El Niño which is predicted for fall-winter 2016.

It is also important to note that the timing of the response monitoring for fishes and other community responses to the restoration efforts were conducted in the late spring and early summer in 2011-2014, with only two exceptions in 2011, (i.e., Honeymoon Cove and Point Vicente West were monitored on 1-28-2011 and 10-12-2011 respectively). In 2015, the surveys were conducted within the month of September with the exception of Honeymoon Cove which was surveyed on 8-19-2015. In 2016, two rounds of surveys were conducted in spring and summer (Table 2). This shift in seasonality may affect some species differentially skewing the data. Perhaps more significant is the strong ENSO signature this year sea surface temperatures have been elevated throughout 2015, with persistent sea surface temperatures off of Palos Verdes neighboring 20 degrees Celsius. These abnormally high temperatures are known to affect species composition within southern California rocky reef systems.

To date we have successfully reduced purple sea urchin densities in restoration sites. This reduction in urchins has shown a corresponding increase in giant kelp in restored areas and a shift in community structure towards kelp forest reference sites. As El Niño conditions and the urchin wasting event in southern California subside we anticipate further changes in the kelp forest community off the Palos Verdes peninsula.

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