Monitoring Santa Barbara Channel Sea Urchin Populations in Experimental Kelp Forests

An initial assessment of red and purple urchin test sizes at Arroyo Quemado and Mohawk Reefs, Santa Barbara, California (November 2009 and 2015)

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Introduction

Red sea urchins, *Strongylocentrotus franciscanus*, and purple sea urchins, *Strongylocentrotus purpuratus*, are two species of invertebrates integral to the kelp forest ecosystem found along the Central California coast. As herbivores, they are responsible for consuming algae and smaller invertebrates and recycling nutrients in the ecosystem; their predators include lobsters, crabs, and sea otters [1,2]. They also support productive urchin fisheries world-wide [3], and *S. franciscanus* is the most commonly caught species in California [4]. The dynamics between giant kelp, *Macrocystis pyrifera,* and sea urchin populations are complex and due to their vastly different life cycles – urchins may live to be over 100 years old [3], while kelp tends to live no longer than 5 years [5] – their interactions warrant additional study.

While urchins provide a crucial service as consumers of primary producers, they can also be responsible for the destruction of the kelp forest ecosystem. If urchins become abundant, they can begin to overgraze the kelp and leave less resources for other urchins. Then, the population becomes undernourished and begins to seek out additional sources of food, namely other algae and sessile invertebrates. The less resources available, the less well-nourished the urchins become, and the more intensely they will graze upon any food resource they are able to find [2]. This negative-feedback system establishes what is known as an urchin barren in an area that once was a productive kelp forest and returning to the original kelp forest state requires much more energy than it takes to create an urchin barren [1]. Purple sea urchins are most often the species that cause the establishment of an urchin barren [4], and the initial spike in urchin abundance may be due to a variety of factors, including release from predation pressures [1] or a storm that clears out large swaths of kelp habitat [6]. Regardless of what triggers the increase in urchin population, the effects quickly cascade throughout the ecosystem.

In order to maintain the health of both red sea urchin and lobster fisheries in the Santa Barbara Channel, kelp forests must remain large and abundant [1], and studies have called for the establishment of additional Marine Protected Areas (MPAs) and kelp restoration projects [4] in the Channel to further both commercial and environmental goals. The Santa Barbara Coastal Long Term Ecological Research Program (SBC LTER) has established an ongoing study to monitor the effects of kelp habitat loss on urchin size and abundance [7] to better advise future MPA and kelp restoration efforts. With the data collected by the SBC LTER, researchers and policy makers will be able to estimate the age of local sea urchin populations and assess the potential for recovery of urchin barren regions. Studies have shown that areas with dominantly adult urchin populations are at greater risk of becoming urchin barrens as compared to areas with a mixed – larval, juvenile, and adult – urchin population [6]. As such, it is imperative that local research and government organizations be cognizant of the size and abundance of red and purple sea urchins in Santa Barbara Channel kelp forests to better manage their populations, their habitats, and the fisheries they support.

The following report analyzes red and purple sea urchin sizes from two SBC LTER locations, Arroyo Quemado Reef and Mohawk Reef, where data is collected along kelp removal and control transects. The size of *S. franciscanus and S. purpuratus* individuals are compared across sites and transect treatments to observe the effect of location, kelp cover, and time on local sea urchin populations. This report also presents how robust red sea urchin fisheries might be at these locations and suggests future steps for monitoring fishery health.

DATA AND METHODS

Data was provided courtesy of the SBC LTER Program's kelp removal project overseen by Dan Reed and Shannon Harrer. In 2008, a 2000 m^2 control plot, where *M. pyrifera* is left intact, and a 2000 m^2 removal plot, where *M. pyrifera* is cleared, were established in several coastal kelp forest sites. Observations are collected each month at along 40 m x 2 m transects in control and removal locations within Mohawk Reef and Arroyo Quemado Reef (see Figure 1). Divers record the number of red and purple urchins spotted along the transect and estimate their test (skeleton) diameter to the nearest 0.5 cm [7].

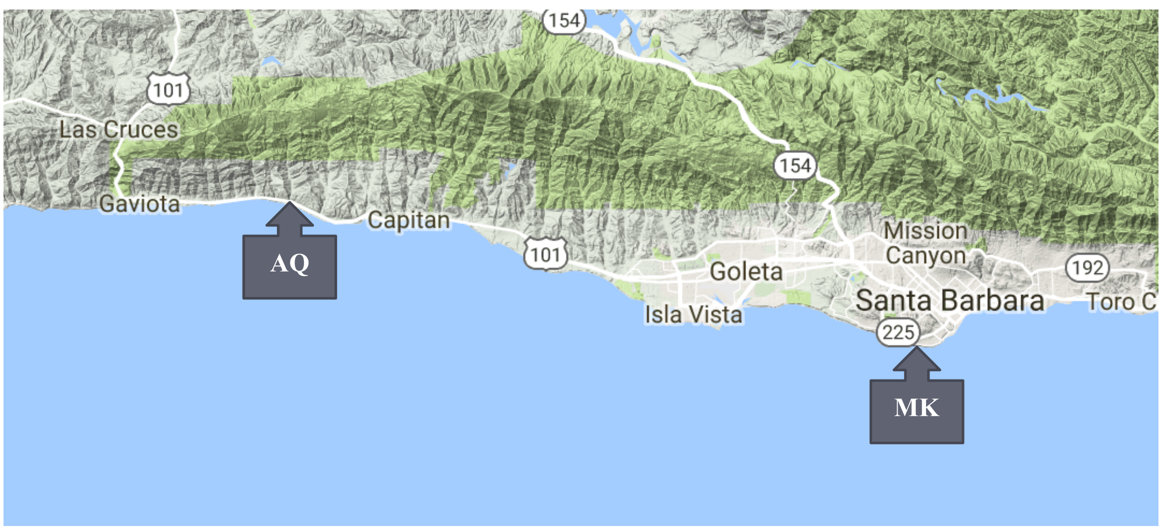

Figure 1. Map of kelp forest sampling locations (AQ – Arroyo Quemado Reef, MK – Mohawk Reef) along the Santa Barbara coast from which data was collected for this report [7].

Data regarding date, location, habitat treatment, size, count, and species of urchins observed was compiled for November of 2009 and 2015 to determine mean population statistics and analyze for significant differences in size based on temporal, location, or habitat factors. Sizes of urchin tests were compared using two-sample Student's t-tests ($\alpha = 0.05$ unless otherwise indicated). Mean SBC LTER urchin size data was also compared to mean literature values using one-sample Student's t-tests. Literature values were used to determine robustness of locations sampled as compared to sites of red urchin fisheries [4]. Data analysis and graphics were performed in Microsoft Excel 2015 (v. 15.24) and *R* Statistical Software (v. 0.99.903).

RESULTS AND DISCUSSION

Sea Urchin Size between November 2009 and 2015

Neither population of purple sea urchins experienced a significant change in mean test size between 2009 and 2015 (Table 1). The mean purple sea urchin test diameters at Arroyo Quemado Reef in 2009 (4.78 ± 0.77 cm) and 2015 (4.71 ± 0.67 cm) did not differ significantly based on a two-sample Student's t-test ($t(226) = 0.78$, $p = 0.44$, $\alpha = 0.05$). In addition, the mean purple sea urchin test diameters at Mohawk Reef in 2009 (5.27 ± 0.84 cm) and in 2015 (5.48 ± 0.92 cm) did not differ significantly based on a two-sample Student's t-test ($t(242) = -1.91$, $p = 0.06$, $\alpha = 0.05$). Since they are often the culprits of urchin barrens, purple sea urchins and their population's mean test size will be revisited in a later section examining kelp habitat removal.

Both populations of red sea urchins experienced a significant increase in mean test size between 2009 and 2015. At Arroyo Quemado Reef, the mean red sea urchin test diameter increased significantly from 2009 (6.31 ± 1.24 cm) to 2015 (7.64 ± 1.00 cm) based on a two-sample Student's t-test ($t(225) = 8.98$, $p < 0.001$, $\alpha = 0.05$). At Mohawk Reef, the mean red sea urchin test diameter also increased significantly from 2009 (7.49 ± 1.63 cm) to 2015 (8.19 ± 1.31 cm) based on a two-sample Student's t-test ($t(65) = 2.54$, p-value = 0.007, $\alpha = 0.05$). The goal of managing the ecosystem to support robust red sea urchin populations appears to have succeeded in these locations, but further analysis is required to determine the direct cause of red sea urchins' enlargement during this timeframe.

Table 1. Red and purple sea urchin test diameter measurements (centimeters) at Arroyo Quemado and Mohawk Reef sites in November 2009 and 2015 [7]. Values represent mean ± standard deviation, and sample sizes are listed immediately next to each population sampled.

		Red and Purple Sea Urchin Test Sizes ***(Mean ± Standard Deviation)*** **Diameter (cm)**	
		November 2009	**November 2015**
Red Sea Urchin (*S. franciscanus*)	Arroyo Quemado Reef	6.31 ± 1.24 (n=127)	7.64 ± 1.00 (n=100)
	Mohawk Reef	7.49 ± 1.63 (n=43)	8.19 ± 1.31 (n=108)
Purple Sea Urchin (*S. purpuratus*)	Arroyo Quemado Reef	4.78 ± 0.77 (n=133)	4.71 ± 0.67 (n=100)
	Mohawk Reef	5.27 ± 0.84 (n=150)	5.48 ± 0.92 (n=119)

Sea Urchin Size between Arroyo Quemado and Mohawk Reef Locations in 2015

When comparing between locations sampled in 2015, both red and purple urchins were larger at Mohawk Reef than they were at Arroyo Quemado Reef (Figure 1). The mean test size of red urchins was significantly greater at Mohawk Reef (8.19 ± 1.31 cm) than it was at Arroyo Quemado Reef (7.64 ± 1.00 cm) according to a two-sample Student's t-test ($t(199) = 3.45$, p-value < 0.001, $\alpha = 0.05$). In the same year, mean test sizes of purple urchins at Mohawk Reef (5.48 ± 0.92 cm) were significantly greater than at Arroyo Quemado Reef (4.71 ± 0.67 cm) according to a two-sample Student's t-test ($t(213) = 7.24$, p-value < 0.001, $\alpha = 0.05$). Mohawk Reef is situated off the coast of a heavily-developed area, while Arroyo Quemado is offshore of a primarily agricultural and natural watershed. Urban development in the Mohawk Reef area may lead to the input of more nutrients to the kelp forest ecosystem that may spur *M. pyrifera* growth and, in turn, urchin growth. This comparison between sites merits continued data collection.

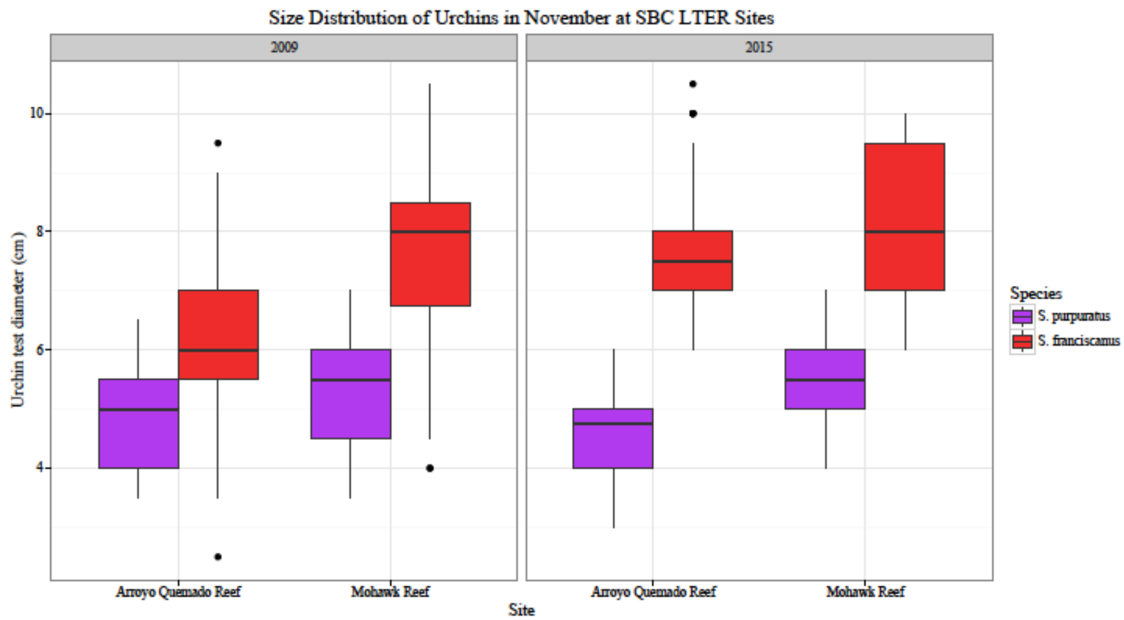

Figure 2. Collected observations of red (*S. franciscanus*) and purple (*S. purpuratus*) sea urchin test diameters (centimeters) presented for November 2009 and 2015 at Arroyo Quemado and Mohawk Reefs [7]. Please refer to Table 1 for sample size information for each population sampled. Boxes indicate the 25th and 75th percentiles, low and upper boundaries respectively, and the center solid line indicates the median. Whiskers indicate observations within one step (1.5x interquartile range) of 25th and 75th percentiles. Points indicate outlier observations that fall beyond whisker values.

Sea Urchin Size between Control and Removal Plots

To assess the effect of *M. pyrifera* density on urchin size, data for both species was compared between control (kelp abundant) and removal (kelp routinely removed) transects in both Mohawk and Arroyo Quemado Reefs. In order to incorporate the longest timeline of removal and any accrued effects, this analysis was performed for the year 2015 only. According to the statistics, there emerged no apparent relationship between urchin test size and *M. pyrifera* density. In 2015, the mean test size of red sea urchins along Mohawk's control transect (8.19 ± 1.58 cm) was not significantly different from the mean test size along the removal transect (8.20

± 0.96 cm) according to a two-sample Student's t-test (t (92) = -0.06, p-value = 0.95, $\alpha = 0.05$). Similarly, the mean test size of purple sea urchins in the same location along the control transect (5.62 ± 0.90 cm) was not significantly different from the mean test size along Mohawk's removal transect (5.33 ± 0.91 cm) according to a two-sample Student's t-test (t(116) = 1.78, p-value = 0.08, $\alpha = 0.05$). Data collected in 2015 at Arroyo Quemado Reef indicated that the mean test size of red urchins along the control (7.77 ± 1.01 cm) and removal (7.51 ± 0.98 cm) transects were not significantly different according to a two-sample Student's t-test (t(98) = 1.31, p-value = 0.19, $\alpha = 0.05$). The mean test sizes of purple sea urchins in the same location were not significantly different between control (4.76 ± 0.64 cm) and removal (4.65 ± 0.69 cm) transects according to a two-sample Student's t-test (t(97) = 0.82, p-value = 0.41, $\alpha = 0.05$). One factor preventing a significant shift in test sizes may be that the systems remain dominantly kelp forests, instead of actual urchin barrens, causing potentially muted effects on urchin test sizes. Behrens and Lafferty documented a range of kelp forest, transition, and urchin barren states that could be used as a key to more precisely categorize the habitat between SBC LTER control and removal transects and predict resulting urchin size [8]. Claisse et al. reported red sea urchin gonad biomass as up to four times greater in kelp forest regions than in urchin barren regions [4]. With these studies citing the significant impact habitat has on urchin populations and fisheries, further data must be collected to determine a pattern over the correct temporal and spatial scale.

Sustaining Red Sea Urchin Fisheries

In order to properly manage the local red urchin fisheries, commercial and government agencies must be aware of the mean sizes and abundance of the local red urchin population in order to preserve this resource and the ecosystem in which it thrives. Claisse et al. found the mean test size for red urchins in the Santa Monica Bay area to be 7.2 cm at middle-depths [4]. However, according to a one-sample Student's t-test, our data suggests the mean test size for red urchins in the Santa Barbara Channel is greater than 7.2 cm at both Mohawk Reef (t(99) = 4.4103, p-value < 0.001, $\alpha = 0.05$) and Arroyo Quemado Reef (t(107) = 7.8934, p-value < 0.001, $\alpha = 0.05$). Behrens and Lafferty suggest that urchin size depends greatly on whether the area is consistently fished or part of a reserve, with red sea urchin size distributions unimodal and bimodal, respectively, in these areas [8]. Therefore, it may not be as simple as comparing mean test diameter size for a species across sites without taking into account fishing activities in the area and age distribution of the local population.

The greater the mean test diameter of the red urchin population, the more likely the area will be able to support a larger urchin fishery harvest. The "no-take" size range for red urchins is 3.8 to 8.25 cm, and the SBC LTER urchin data was analyzed for the proportion of red urchins that fell within these limits (Table 2). In 2009, the proportion of red urchins that were not allowed to be harvested from Arroyo Quemado Reef was 93.70% (CI_{95} = [0.88, 0.97]) and from Mohawk Reef, 62.79% (CI_{95} = [0.47, 0.77]). In 2015, the proportion of red urchins that were not allowed to be harvested from Arroyo Quemado Reef was 81.00% (CI_{95} = [0.72, 0.88]) and from Mohawk Reef, 54.63% (CI_{95} = [0.45, 0.64]). This analysis agrees with our prior results that report Mohawk Reef urchins as significantly larger than those at Arroyo Quemado Reef. Conditions in the Mohawk Reef habitat appear to support a red urchin population that is more suitable for harvest than the Arroyo Quemado habitat. However, fisheries managers must take care to avoid the situation described by Breitburg – without urchins in different life stages a kelp forest is more vulnerable to becoming an urchin barren – and maintain an urchin population with various ages that can withstand repeated disturbances [6].

Table 2. Red sea urchins that fall within the "no-take" rage (3.8 - 8.25 cm) at Arroyo Quemado and Mohawk Reef sites in November 2009 and 2015 [7]. Also reports 95% Confidence Interval for the proportion of red sea urchins that will fall within the "no-take" range.

		"No-Take" Red Sea Urchins			
		"No-Take" Red Urchins	**Total Red Urchins**	**Proportion "No-Take" Red Urchins**	**95% Confidence Interval**
Arroyo Quemado Reef	2009	119	127	93.70%	(0.88,0.97)
	2015	81	100	81.00%	(0.72, 0.88)
Mohawk Reef	2009	27	43	62.79%	(0.47, 0.77)
	2015	59	108	54.63%	(0.45, 0.64)

CONCLUSION

S. franciscanus and *S. purpuratus*, red and purple sea urchins, are marine herbivores that provide an important link from giant kelp to larger consumers, but they can also be responsible for decimating a kelp forest ecosystem and leave little opportunity for recovery. The energy required to establish these organisms as either helpful or harmful consumers remains difficult to define, and this report aims to characterize the local red and purple sea urchin populations to better understand what the drivers of urchin size and abundance are in the Santa Barbara Channel. The following statements summarize the main findings of this report:

(1) Red sea urchins at both Arroyo Quemado and Mohawk Reefs experienced an increase in mean test size between 2009 and 2015.
(2) In 2015, both red and purple sea urchins were significantly larger in size at Mohawk Reef than they were at Arroyo Quemado Reef.
(3) In 2015, there was no significant relationship between urchin test size and *M. pyrifera* density along control and removal transects at Arroyo Quemado or Mohawk Reefs.
(4) Arroyo Quemado Reef contained more red sea urchins that fell within the "no-take" size range than Mohawk Reef.

This report should be updated yearly with additional SBC LTER data since sites used may rapidly shift from kelp forests to urchin barrens year to year [6]. Based on the results described above, data should be collected to better determine what is driving larger urchin test sizes and a smaller proportion of "no-take" urchins at Mohawk Reef. In addition, data collections along removal and control transects should be monitored closely. Although this report found no significant difference in test size between control and removal sites, past studies have noted distinct differences in urchin sizes and biomass in kelp forest and urchin barren regions [4,8]. The conditions in the Santa Barbara Channel may begin to change in the near future as the demand for urchins increases and climate change warms ocean waters, causing a poleward migration in kelp species [9]. Programs like the SBC LTER will allow us to continue to collect the data necessary to monitor urchin species and their habitats so that commercial and environmental organizations alike can properly manage these areas and suggest the location of future MPAs.

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