Beyond The Kelp:
Examining Fish Diversity and Economic Value of a Southern California Artificial Reef Mitigation Project

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ABSTRACT

Wheeler North Reef (WNR) is an artificial reef off the coast of San Clemente, California constructed as an ecological mitigation project for Southern California Edison. As a part of its requirements, the reef must meet certain performance standards instituted by the California Coastal Commission (CCC) in order to evaluate its success. This paper analyzes new metrics quantifying the biological diversity of the reef and its economic impact on commercial fishing in order to determine whether WNR functions as a natural reef and has a quantifiable impact on the local community. We assessed species diversity, richness, and evenness across WNR and two natural reference reefs by calculating the Gini-Simpson index, Shannon-Wiener index, species accumulation curves, and rank abundance curves. We observed comparable values and trends between WNR and the natural reefs within the Simpson, Shannon, and rank abundance indices, as well as similar variations in frond density and net primary production. The rank abundance curve for WNR exhibited the lowest species evenness compared to both natural reefs, however WNR did show an increase in species evenness over the developmental lifetime of the reef. We also analyzed commercial fish landing data of five different species from 1995-2011 to assess the economic value of WNR. We charted total landings per year and average landings per phase to examine the different trends of each species across three phase stages. California Spiny lobster showed the most definitive positive increase in landings since the construction of WNR in 2000, while the other species showed random variation in their landing trends. The results of our study indicate that WNR performs biologically similar to natural reefs and provides additional local economic benefits that influence commercial fishing. We conclude that WNR can act as a model for future artificial reef implementation.

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Introduction

Kelp forests are some of the most productive ecosystems on Earth; consisting of giant kelp (*Macrocystis pyrifera*) that grow along the coast of the eastern Pacific Ocean. Giant kelp forms dense forests that provide a habitat for a vast array of marine organisms. Because kelp thrives in areas where there is high nutrient availability, light, and cool water temperatures, there are a great deal of reefs located from central to Baja California (Dayton 1992). Their high productivity and influence on trophic interactions within their ecosystems have made them highly important players in ongoing research regarding ecosystem resilience and ecosystem services. In a study that examined species abundance at Californian kelp reefs, researchers found that the removal of a protective kelp forest resulted in significant declines in the majority of studied species with no noted increase in abundance (Bodkin 1988). Because of the high potential for photosynthesis in these waters, kelp are also a major source of net primary production (NPP) at these reefs by serving as a means to convert solar energy into usable energy for local wildlife (Rassweiler et. al. 2008).

However, as with most natural environments in the world, there is the potential for anthropogenic activities having adverse effects on kelp reefs. Disturbances in the nutrient availability, light, water temperatures, and other environmental conditions can have negative impacts on kelp reef success (Dayton 1992). Worldwide, there are ongoing problems with nutrient runoff and trawling, which can disturb habitats and lead to the degradation of kelp reefs (Rengarajan 1996). The result can sometimes be a complete loss of species associated with those habitats.

In southern California, researchers found that the San Onofre Nuclear Generating Station (SONGS) run by electrical company Southern California Edison (SCE) was disturbing the local kelp beds off the coast of San Onofre. Specialists connected hot water dispensers from the plant to increased turbidity in the area, which then disturbed the nearby 200-acre San Onofre Kelp Bed (Reed 2010). In July 1991, the California Coastal Commission (CCC) ordered SCE to establish a 150-acre artificial kelp reef habitat to mitigate these losses. The resulting artificial reef, named Wheeler North Reef (WNR), has become one of the world's largest artificial reefs (Elwany 2011). To evaluate the success of the reef, 14 performance standards were defined and implemented for semi-annual monitoring reports. The performance standards include requirements for resident fish, juvenile fish, benthic community density, species richness, kelp density, and hard rock substrate (Reed 2010).

Species diversity is an important indicator of the ecological success of any kelp reef. High biodiversity strengthens an ecosystem in the face of environmental change and increases its likelihood to survive. In the CCC monitoring report (Reed et. al. 2010), species richness is assessed for WNR as well as BK and SMK in years 2010 and 2011. Species richness is defined as the total number of species in a given community (Gotelli et al. 2011). Because of its use as an indicator of ability to sustain large communities, conservation biologists often use it as an intuitive and natural index of community structure. However, it is important to note that species richness can be limited in its ability to holistically evaluate biodiversity in a particular ecosystem (Gotelli et al. 2011). This metric is simply a measure of the total number of species, which provides no indication of the abundance of the species in the ecosystem and does not fully represent the diversity of an ecosystem. For example, an area with endemic species but lower species richness may be more valuable than an area with common species and relatively high species richness (Gotelli et al. 2011). Therefore, species evenness, which is how even the distribution of species are, should also be a factor in determining the overall diversity of a community.

Recent monitoring reports indicate that despite not meeting 3 of the 14 performance standards in 2010, trends are heading towards meeting the goals in the near future (Reed 2010). The 2009 monitoring report stated that 9 of the 14 standards that were met relating to kelp, invertebrates, and fish colonization (Reed 2010). The data collected was also able to indicate to scientists that there were the high fish abundance and diversity at WNR, meaning improved reproduction and growth rates that were similar to or greater natural reference reefs (Reed 2010). Furthermore, the 2010 monitoring reports showed a huge jump in kelp acreage from 19 to 174 due to juvenile giant kelp coming into adulthood.

Species Diversity

Several common measures of species diversity take into account relative proportions of species in an area may be more effective in evaluating the biodiversity of a given ecosystem (Maurer et al. 2011). The Gini-Simpson Index measures the probability that two individuals randomly selected from a community will belong to different species. It takes into account both species richness as well as the relative proportion of each species. Higher Gini-Simpson index values indicate greater biodiversity. Another widely used diversity index is the Shannon-Wiener index, which also accounts for species richness and the proportional distribution among the species (Gray 2000). It quantifies the uncertainty in predicting a species that is taken at random from the community as a measure of species biodiversity. The idea is that the higher the number of species and the more equal their proportional abundances are, the greater the uncertainty value.

Species accumulation curves are utilized as a measure of species richness within a population, which looks at the total number of species present within a sample (Gotelli and Colwell 2001). Species richness is considered one of the main metrics of biodiversity, and the accumulation of numerous species with increased samples helps to illustrate the growth in species diversity over time. The general shape of any one-accumulation curve can show whether a reef will likely encounter more species as more individuals are assessed, or remain relatively constant in the number of species within the community.

Rank abundance is important to assessing the diversity of a community because it shows how rare or common species are relative to other species in a provided population. It can be used to assess both species richness and species evenness, as it allows for comparison between the number of species relative to the abundance of each species in the population. Analyzing the slope gradients of rank abundance curves provides insight about the evenness of species in a given area. A shallower slope indicates that the distribution of species in a given population is more even. A steeper, sharper slope demonstrates that the distribution of species is less even and dominated by a select number of species. Our study not only explains the shapes of the curve at WNR, but also compares curves for all three sample populations.

Species diversity is an important indicator of the ecological success of artificial kelp reefs including WNR. High biodiversity strengthens an ecosystem in the face of environmental change and increases its likelihood to survive. The ability to sustain a wide array of different species is a critical characteristic and goal of artificial reefs as a mitigation tool (Kang et al. 2011).

Economic Value

Traditionally, artificial reefs are most prominently utilized worldwide to enhance fishing opportunities rather than for mitigation purposes (Sutton & Bushnell 2007). Artificial reefs have been shown to affect commercial fishing operations in their surrounding communities (Santos and Monteiro 1997, 1998; Whitmarsh 2008). Whitmarsh 2008 concluded that by increasing the amount of available fish inhabiting an artificial reef, there is an increased economic opportunity for the local area and most notably the fishing community. Therefore, analyzing WNR's economic effects on commercial fishing is a logical step in investigating WNR's performance beyond its primary purpose of mitigation. When artificial reefs are utilized by commercial fishing, substantial positive economic returns can be gained by the fishing industry (Sutton & Bushnell 2007). Our research on WNR's economic effects on local commercial fisheries began by acquiring fishing data dating from 1995-2011 and specifically observing California spiny lobster (*Panulirus interruptus*), red sea urchin (*Strongylocentrotus franciscanus*), California sheephead (*Semicossyphus pulcher*), Pacific sardine (*Sardinops sagax*) and Pacific mackerel (*Scomber Japonicus*). We chose to analyze California spiny lobster, red sea urchin, and California sheephead because all of these bottom-feeding species find shelter and forage in the crevices and holes of kelp reefs (DFG 2011; Jessee 1985; Harrold 1995). As a reference frame, we analyzed Pacific sardine and Pacific mackerel because they are pelagic species that exhibit relatively low interaction with kelp reefs and contrast bottom-feeding species.

El Niño

El Niño Southern Oscillation (ENSO) is a periodic shift in ocean temperatures in the Pacific Ocean. It is well known that the ENSO cycle can locally increase or decrease nutrient availability, reduce fish and phytoplankton populations, and cause heavy precipitation and storm events (Hallegraeff 2010, Lo-Yat 2011). It is necessary to introduce this topic as reefs are highly susceptible to such changes. Furthermore, as we learn more about global warming and its effect on the ENSO cycle, we will discover new ways in which reefs are affected (Seager 2012).

Specifically for kelp reefs in southern California, studies of these particular niches need to account for the possible effects of ENSO years. In a study of both natural and artificial kelp beds across California, scientists found that ENSO can have catastrophic effects on the kelp at a reef (Grove et. al. 2002). The team noted that as kelp were ravaged by the weather conditions brought on by ENSO, there were also largely negative effects on all biological activities associated with the reef (Grove et. al. 2002). One possible explanation is the close connection to net primary production and fronds at any reef being studied, which can have ripple effects throughout the environment.

Hypotheses:

1) We hypothesize net primary production has followed similar trends to neighboring reference reefs.
2) We hypothesize that fish diversity measures including species evenness and richness have increased throughout the construction phases and follows similar trends to neighboring reference reefs.
3) We hypothesize that the landings of California spiny lobster, red sea urchin, and California sheephead have increased in the local region since the introduction of WNR.

4) We hypothesize that the landings of Pacific sardine and California mackerel have decreased in the local region since the introduction of WNR.
5) We hypothesize that ENSO events have negative effects on net primary production and other associated measures of reef success at WNR.

The purpose of our study is to evaluate the progress of the WNR project by using metrics that extend beyond the 14 required performance standards set by CCC. To accomplish this, we followed a two-pronged approach to evaluate WNR, looking first at diversity and then at economic value, giving the reef quantifiable value. A calculation of diversity establishes trends in the makeup of fish at WNR and can be compared to fluctuations in economic value to show the relationship between these two metrics. This differs from the official monitoring report, which examined more specific metrics of reef health including: giant kelp density, understory algae abundance, and invertebrate abundance and diversity. Furthermore, we analyzed the economic benefits reaped by the local region due to the presence of Wheeler North Reef through analysis of the landings of local aquatic species. These measures allowed us to determine the performance of WNR as compared to a natural reef.

Methods

Diversity Analysis

For our analyses we used data collected by researchers at the University of California, Santa Barbara (UCSB). We compared WNR to two nearby reference reefs, BK and SMK. These reference reefs are natural reefs that existed before WNR was established and are driven by similar environmental conditions. In this paper, we divide the collection time periods into phases.

For diversity, the data was divided up by reef and by transect (Table 1) (Reed 2010). Thus for fish diversity, WNR, BK, and SMK all had their own data sets from 2000-2011, excluding the years 2007 and 2008 during which time data was not collected. Data on benthic richness spans 2009-2011. Fish diversity measurements were collected by reef, while benthic richness was collected by transect (Figure 1). The phases and years for diversity are in the table below.

Phase 1 (including preconstruction)	Phase 2	Phase 3/ Post-Construction
2000-2005	2006-2008	2009-2011

Table 1. Diversity analysis study phases by year.

Species Diversity

Gini-Simpson Index

Based on fish abundance data from transect surveys, we calculated Gini-Simpson index values in Microsoft Excel for WNR, BK, and SMK for years 2000 to 2011 excluding 2007 and 2008 using the following formula:

$$D = S\frac{n(n-1)}{N(N-1)}$$

where n = the total number of individuals of a particular species and N = the total number of individuals in the entire dataset. Then we subtracted **D** from 1 to get the Gini-Simpson index values (**1 – D**).

Shannon-Wiener Index

We calculated Shannon-Wiener index values using Microsoft Excel for WNR, BK, and SMK from years 2000-2011 excluding 2007 and 2008. Using existing data on fish counts for each reef per year, we inputted into the formula below:

$$H' = -\sum pi \ln pi$$

where *pi* = n/N, n = the total number of individuals of a particular species, N = the total number of individuals in the entire dataset, and **H'** is the Shannon-Wiener index value.

Species Accumulation curves

We also used the statistical biodiversity program EstimateS (Version 7.5, Colwell) to compute species accumulation curves at the artificial reef and both natural reefs. The program utilized abundance-based data of fish species within each reef, and computed relative richness outputs based on mean number of individuals sampled and number of species sampled. Individuals, as quantified by EstimateS, were calculated using:

$$\frac{Q_d}{Q_{d(\max)}}N$$

where N is the total number of individuals in *Qd(max)* samples (Colwell 2004). The output values are quantified as the number of species in the pooled *Qd* samples. We transferred output data from EstimateS into Microsoft Excel and used it to construct graphical representations of the species accumulation.

Rank Abundance

We used Microsoft Excel to calculate the rank abundance of all reefs in our study. We first compared and analyzed the rank abundance curves for all three reefs. In another method, we looked at the rank abundance curves at WNR specifically and across all three developmental phases. We obtained averages of individual species counts over each phase of the reef and then converted on a log scale to obtain the relative abundance. We then assigned each of these calculated values an abundance rank with the highest value given a one, the second highest a two, and so on. In graphical format, the X-axis is labeled as the "abundance rank" which is contingent upon the number of species in our sample. The X-axis indicates the species richness of the reef as it charts how many species are in the population. The Y-axis is labeled as the relative abundance and is traditionally displayed in the log form.

NPP

Reed (2009) noted that frond density can function as a sufficient proxy to estimate NPP. We graphed the frond density (fronds m^{-2}) over the years 2000-2011 for WNR, BK, and SMK and included standard error bars to show empirical increases or decreases in NPP throughout the pre-, during- and post-construction phases of WNR.

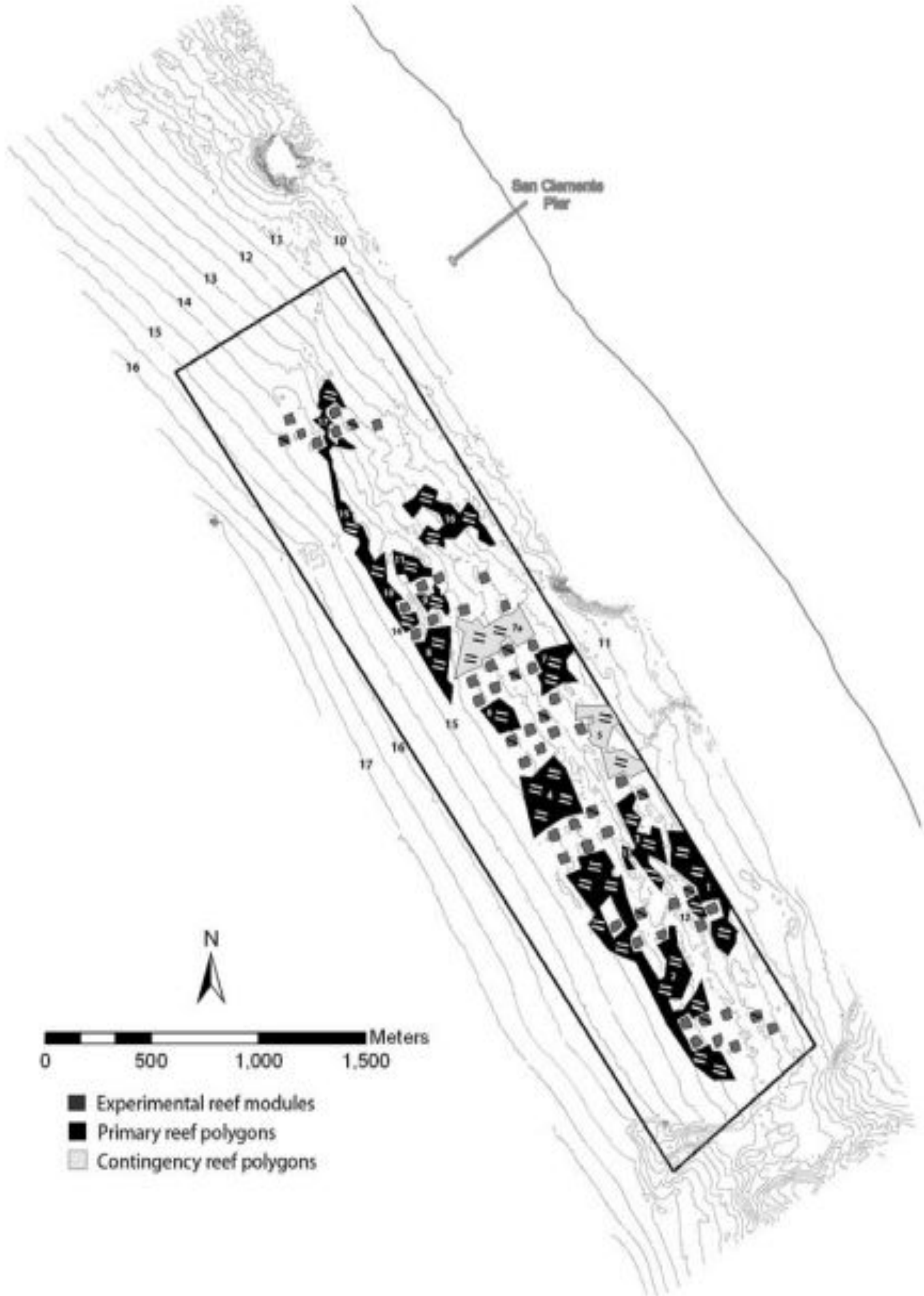

Figure 1. Schematic map of WNR showing the location of the 92 transects that are monitored to assess the performance standards.

Economic Value

The study area for the Economic portion of the project was confined by the Department of Fish and Game (DFG) commercial fisheries chart (See Appendix). This fishery chart divides California coastal waters into blocks of approximately 10-minute quadrants to track historical landing data. For our study, we focused on the 3 fishery blocks in closest proximity to the WNR. The northernmost block, Block 757 acted as the northern control site and encompassed Dana Point Port. Similarly, Block 801 served as the southern control site as it encompassed Oceanside Port as well as the natural reef, BK. In between these two blocks is Block 756, the most integral block to our study since it included WNR and the smaller natural reef, SMK. In our hypotheses, the "local area" refers to Block 756, or the Wheeler North Block.

The study period used for the economic portion of this project encompassed the years 1995-2011 and were broken up into 3 distinct phases; preconstruction phase (1995-2000), phase I (2001-2008) & phase II (2009-2011). phase I was characterized by SCE's completion of the 22.4-acre experimental reef while phase II was marked by the completion of an additional 127.6 acres added to the existing phase I experimental reef.

In order to conduct our study we used previously recorded data on commercial fishing landings, gathered by DFG. For each of the 3 aforementioned blocks, commercial fish poundage and value data was acquired for all species caught commercially over the time period of 1995-2011. In this study we focused on the 5 species of California Spiny lobster, Red Sea Urchin, California sheephead, Pacific mackerel and Pacific sardine. All of these species had been caught consistently over the study period in all 3 blocks.

Each species was analyzed for trends between commercial landings (poundage) over time. For visual simplicity, the monthly data for landings were aggregated into individual years and XY straight lined scatter plots was created in Excel. This documented the change in mean poundage over time for all 3 blocks with standard error bars to account for deviation in the data. These results are also presented using clustered bar plots that averaged the pounds caught per year over each phase in each of the 3 blocks.

Results

Species Diversity

Diversity: Gini-Simpson Index

The Gini-Simpson index values for WNR, BK, and SMK from years 2000-2011 excluding 2007 and 2008 are shown in Table 2. Highest 1 – D values for all three reefs are in 2010 and 2011 during the post-construction phase, while lowest values are seen in 2005 and 2006.

Year	**WNR** (1 – D)	**BK** (1 – D)	**SMK** (1 – D)
2000	0.7414	0.4067	0.4022
2001	0.8165	0.3263	0.4297
2002	0.7451	0.2344	0.5379
2003	0.7626	0.2836	0.2670
2004	0.8318	0.5367	0.5049
2005	0.4829	0.3049	0.2423
2006	0.4791	0.2942	0.2591
2009	0.6294	0.6875	0.6231
2010	0.8896	0.8986	0.8785
2011	0.8769	0.8353	0.8707

Table 2. Gini-Simpson index values for WNR, BK, and SMK from years 2000-2011 excluding 2007 and 2008.

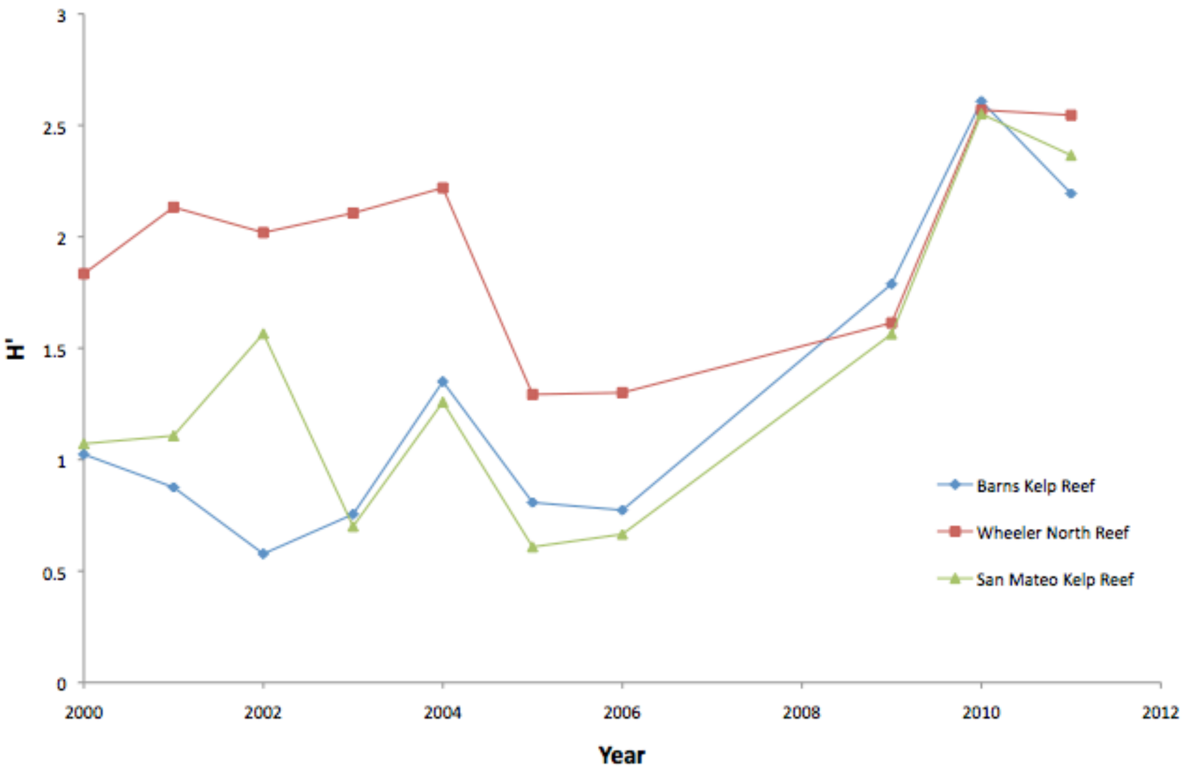

Figure 2. Gini-Simpson chart for WNR, BK, and SMK from years 2000-2011 excluding 2007 and 2008.

Diversity: Shannon-Wiener Index

The Shannon-Wiener index values for the three reefs from 2000-2011 excluding 2007 and 2008 are shown in Table 3. Like Gini-Simpson index values, highest H’ values for the three reefs are in 2010 and 2011, while lowest values are in 2005 and 2006. In 2011, WNR has a greater index value than BK and SMK.

Year	WNR (H')	BK (H')	SMK (H')
2000	1.8338	1.0237	1.0712
2001	2.1324	0.8758	1.1072
2002	2.0188	0.5774	1.5655
2003	2.1063	0.7548	0.7003
2004	2.2191	1.3502	1.2582
2005	1.2926	0.8077	0.6084
2006	1.3005	0.7733	0.6653
2009	1.6136	1.7881	1.5636
2010	2.5686	2.6079	2.5511
2011	2.5455	2.1940	2.3656

Table 3. Shannon-Wiener index values for WNR, BK, and SMK from years 2000-2011 excluding 2007 and 2008.

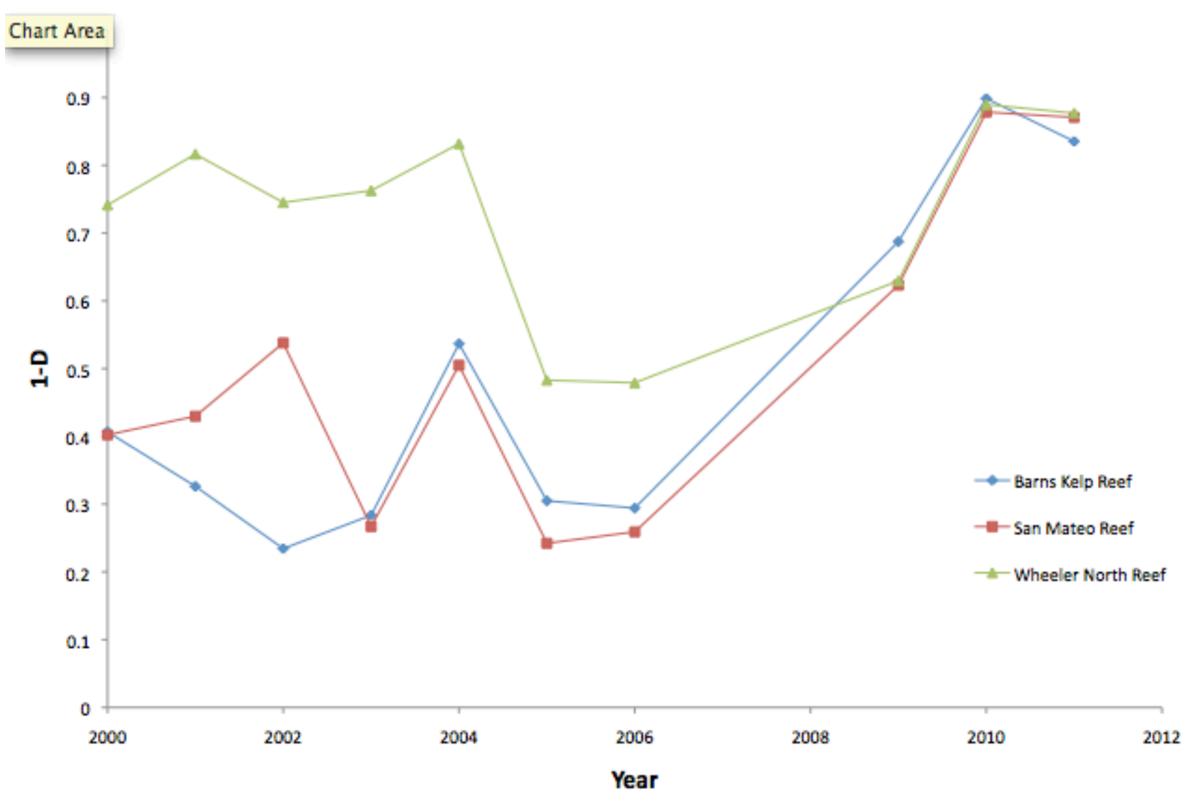

Figure 3. Shannon-Wiener chart for WNR, BK, and SMK from years 2000-2011 excluding 2007 and 2008.

Species Accumulation

Our analyses of species accumulation included WNR as well as BK and SMK in order to compare the rates of accumulation of an artificial reef to that of the natural reefs.

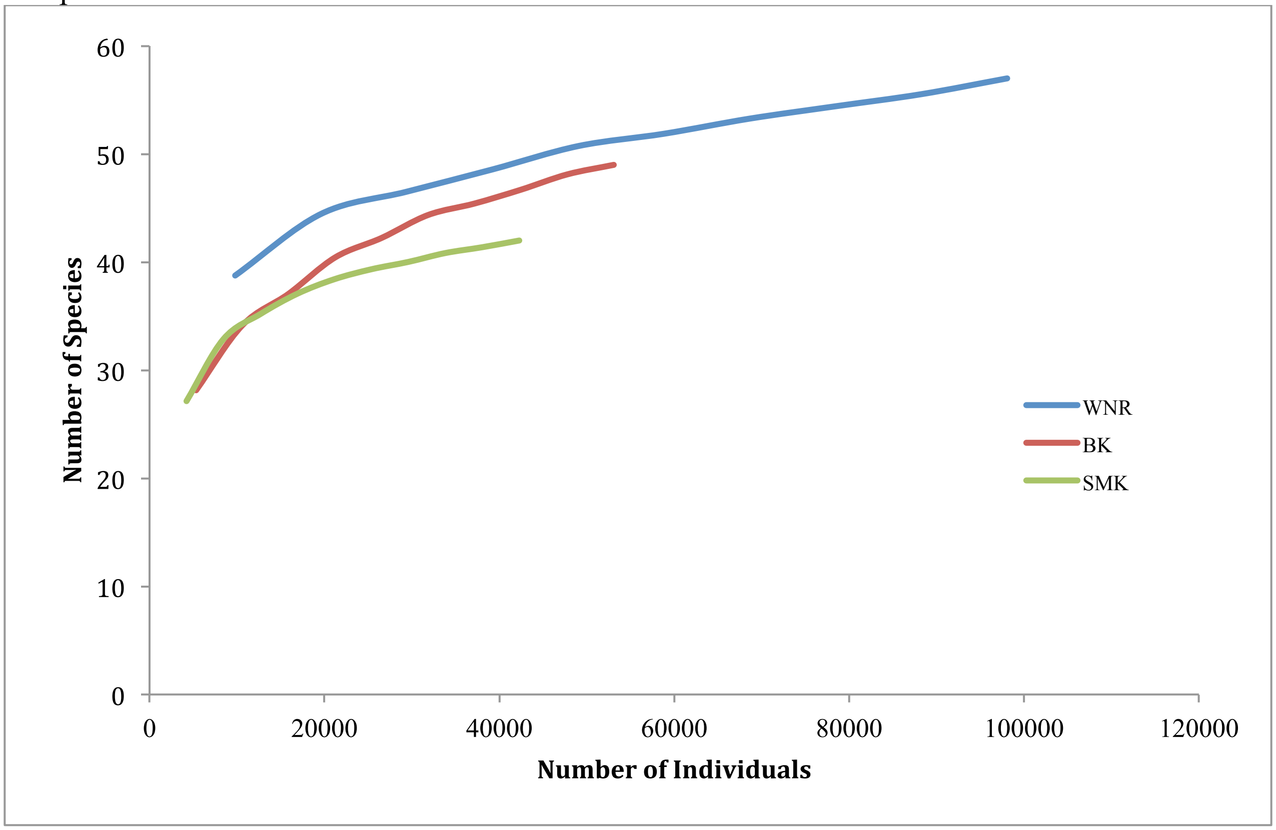

Figure 4. Species accumulation curve for Wheeler North Reef, Barn Kelp Reef, and San Mateo Kelp Reef.

The species accumulation curve at WNR offers the most gradual slope compared to BK and SMK. Using computational data from EstimateS, the number of individuals sampled (x-axis) ranges from 9,807 to 98,075 fish. Within this range, the number of species sampled (y-axis) changes from 38 species to 57 species, yielding an increase of 19 species. Our results indicate that the WNR curve has not yet reached its asymptote (maximum species count), and still exhibits an increasing trend in the y-axis as the number of individuals sampled increases.

The species accumulation curve for BK has a fundamentally different slope than WNR, showing a sharp increase during initial sampling and eventually at a similar rate of the artificial reef. The number of individuals sampled (x-axis) ranges from 5,308 to 53,087 fish. Within this range, the number of species discovered (y-axis) changes from 28 to 49 species, yielding an increase of 21.

The species accumulation curve for SMK shows the greatest leveling-off toward a particular species count with increased samples as compared to WNR and BK. The number of individuals sampled (x-axis) ranges from 4,228 to 42,279 fish. Within this range, the number of species discovered (y-axis) changes from 27 to 42 species, yielding an increase of 15 species within the smallest sample size.

Diversity: Rank Abundance curve

Our results obtained in Figure 5 indicate that WNR has the lowest species richness while BK has the highest. Based on the data provided, BK has the highest number of recorded species at 44, while WNR has 38. SMK is documented as having 40 species.

In analyzing the slope gradients of each curve in Figure 5, WNR seems to have the shallowest slope, and therefore the lowest species evenness. The steepness of WNR curve can be attributed to the high relative abundance of the first ranked species—the species with the largest number of individuals. The slope of WNR starts on the Y-axis at 3.409 and obtains higher relative abundance (y-axis) values for proceeding rank species until it converges at its tail with the SMK and BK curves. The curves for BK and SMK are shallower slopes indicating greater species evenness (distribution) at the reefs.

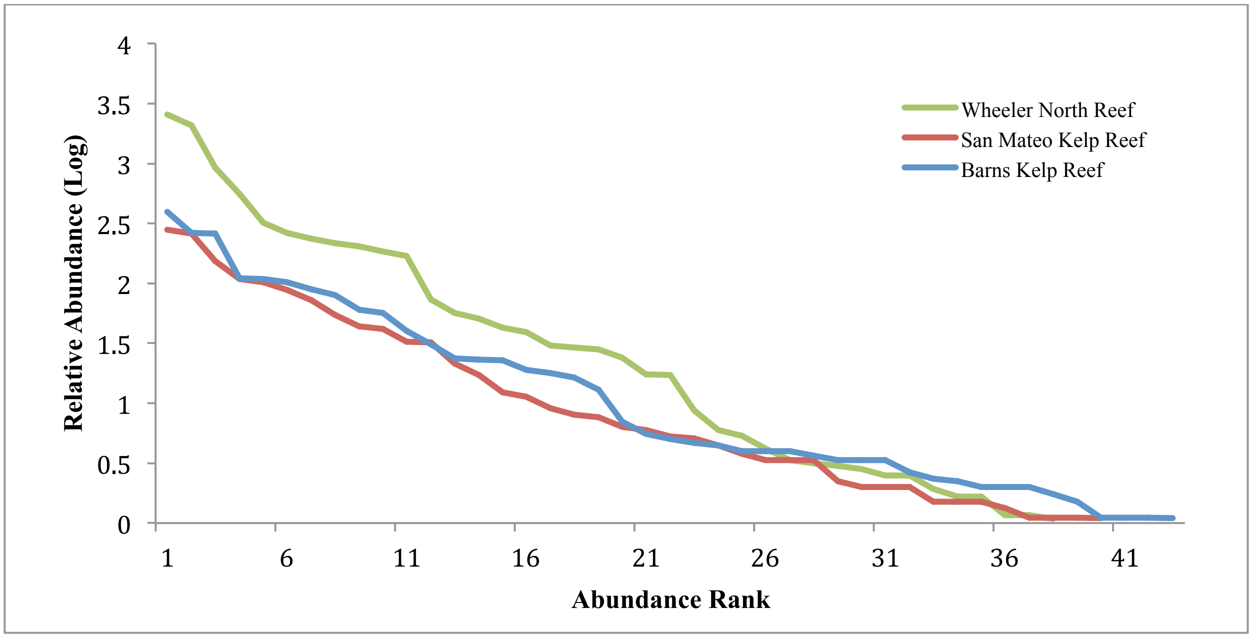

Figure 5. Figure shows the rank abundance at WNR, SMK, and BK. Results show that WNR has the lowest species evenness and richness compared to the reference reefs.

Figure 6 shows inconsistent growth in species richness at WNR. During the phase I, 38 species were documented as being in the sample population. This number decreases to 29 during phase II, but then increases to 44 species during phase III. The increased yield in species from phase II to phase III is 15.

Phase II is seen has having the sharpest, steepest slope relative to phase I and phase III. This indicates that the species evenness during phase II was the lowest. However, the slope during phase III development is the shallowest and therefore the highest species evenness. (Figure 6). Another trend noted from Figure 6 is that the relative abundance of the first ranked species (x-axis) decreases throughout the development of the reef. The values for the relative abundance of the first ranked species are 3.582, 3.281 and 3.124 for phase 1, phase II and phase III, respectively.

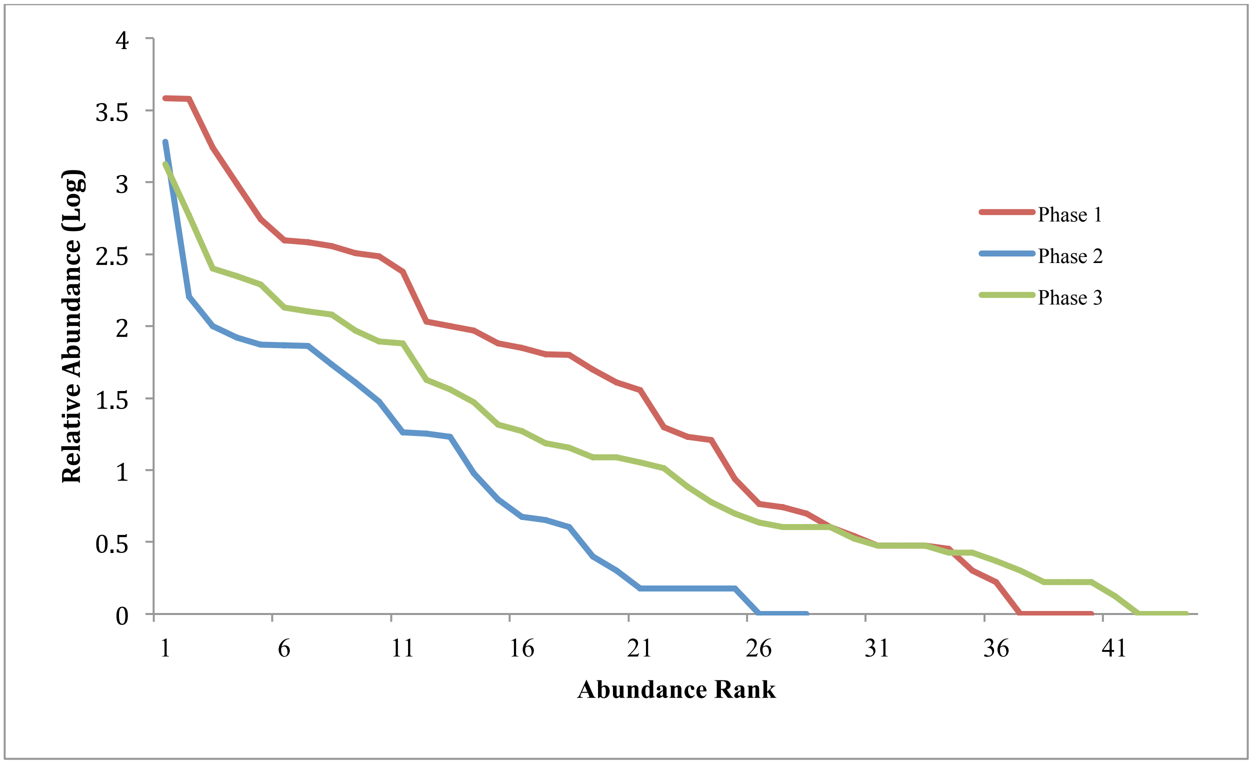

Figure 6. Rank abundance at WNR for all three developmental phases. phase III has the highest species richness and evenness.

NPP

Based on frond density data provided by Dr. Dan Reed from the University of California, Santa Barbara, we were able to draw certain conclusions about the NPP at all 3 reefs that we studied. A summary of this provided data can be seen in the table below. When presented in graphical form as seen in the figure below, some trends in the frond density become apparent. With a range of frond density from 10.05 fronds m^{-2} as seen in 2002 by WNR to 0 fronds m^{-2} in 2008 at all 3 reefs, it is clear that these kelp forests are variable from year to year in their frond density. Despite the wide array of measurements at all 3 reefs, there is an apparent pattern visible across all three reefs. What we see across all 3 reefs is a rise in frond density from 2000 to 2002, followed by sharp decrease from 2002 to 2008, ending with resurgence in the remaining years of measurement from 2008 to 2011.

Year	WNR	BK	SMK
2000	0.0247	4.6928	0.8986
2001	4.6899	6.6232	1.4786
2002	10.04702	5.925	2.6314
2003	8.9786	4.0589	3.1043
2004	6.9693	1.2911	1.3457
2005	3.0161	2.3161	0.5943
2006	0	1.1535	0
2007	0.6610	2.3375	0.2714
2009	5.3738	4.51	3.4281
2010	6.8018	3.7661	2.6378
2011	5.1074	1.3585	1.3928

Table 4. Frond density at WNR, BK, and SMK from 2000 to 2011 in fronds m^{-2}

Economic Value

California spiny lobster

There is an increase in total pounds of lobster caught in the WNR Block when the total commercial landing poundage is aggregated per year from 1995-2011 as seen in Figure 5. While the data shows that the WNR Block increases in total landing poundage, it further shows a decrease in total landings of lobster caught in Dana Point Block and Oceanside Block.

During the pre-construction phase, total landings between 1995-1999 increase from 4,000 lbs. to 12,000 lbs. The average pound landed in the pre-construction phase is 11,000±500 lbs. (Mean±SE). During phase I, total landings between 2000-2008 increases from 18,000 lbs. to 25,000 lbs. The average pound landed in phase I is 25,000±2000 lbs. Finally, the total landings of phase II between 2008-2011 increase from 25,000 lbs to 36,000 lbs. The average pound landed during this final phase is 26,000 lbs±2,500 lbs. While the total and average landings across the three phases increases, the standard error increases as well. However, the data shows that between the preconstruction phase and phase I, there is a range of 3,500lbs of similarity and overlap between the average pounds of lobster. The increase in standard error affects our interpretation of our results because it not only slightly reduces our confidence that the average value is 26,000 pounds, but it also reduces our confidence of how large the increase between the phases may be. Overall, the trend in Figure 6 across the three phases shows a decrease in average poundage of lobster for Dana Point control block and Oceanside control block.

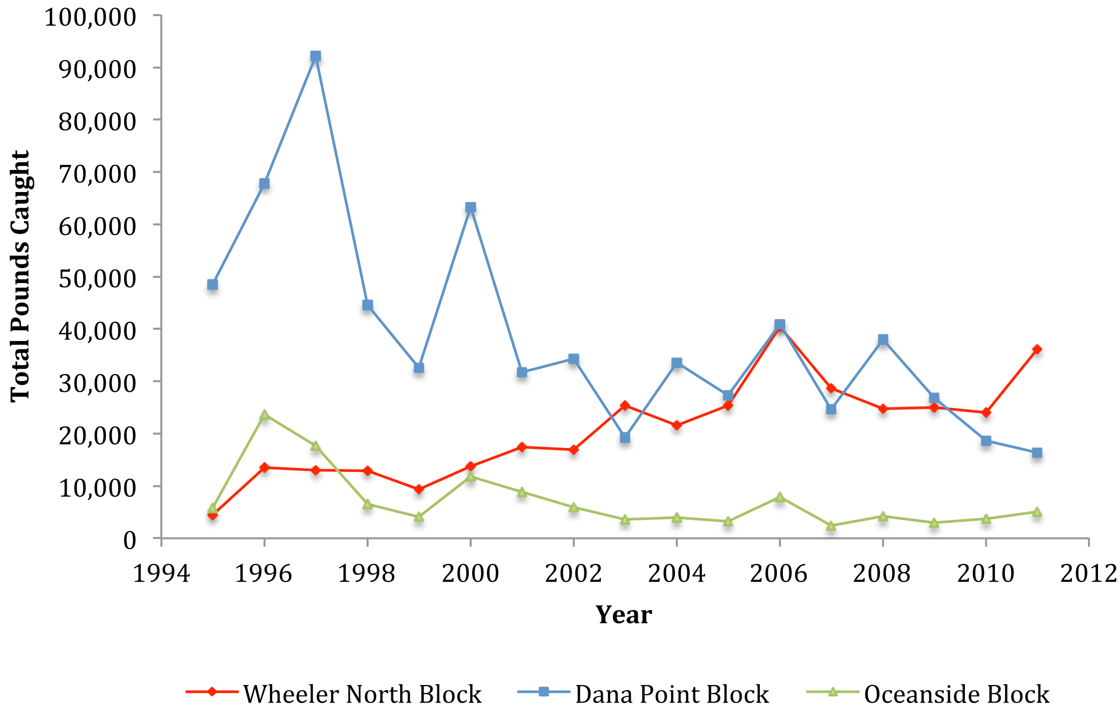

Figure 7. Total poundage of California spiny lobster landings over study period

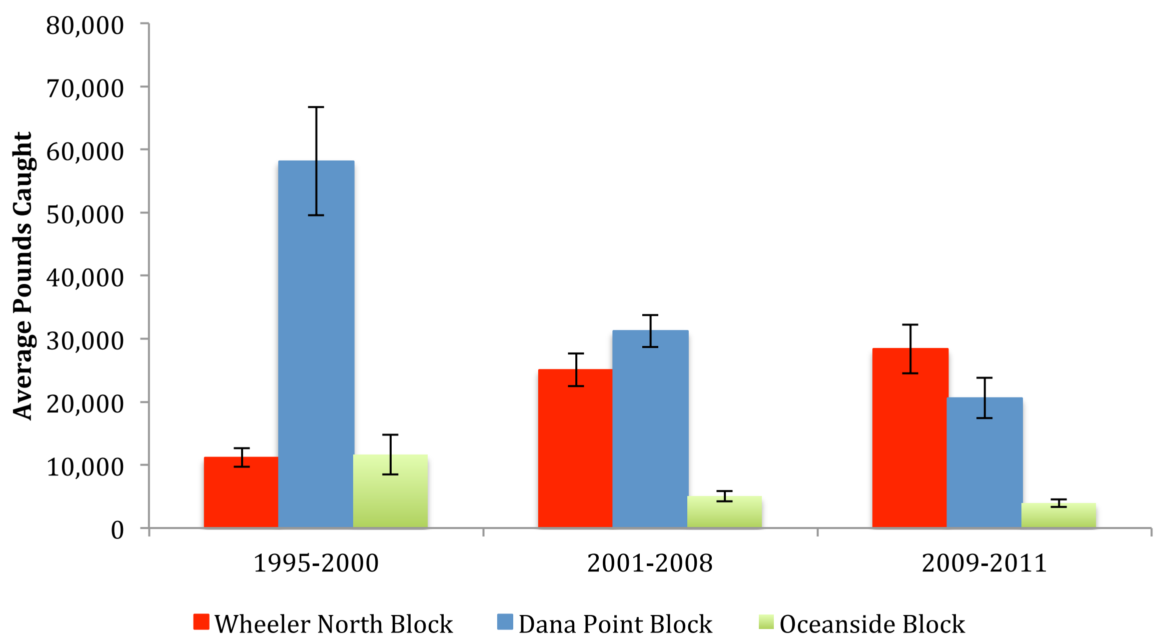

Figure 8. Average poundage of California Spiny lobster landings by phase.

Red Sea Urchin

Figure 9 remained stable across the 16-year span that would show a positive, or even negative, relationship between Wheeler North Block, Oceanside Block, or Dana Point Block. The Dana Point increases from 70,000 to 90,000 pounds in the first year, and then drops to 0 pounds recorded for 1998,1999, and 2001. There is an increase in recorded poundage in 2000 at 100,000 pounds, which is a 10,000lbs increase from the previous increase. Thereafter from 2002 to 2004 we see a positive increase up to 130,000 and 140,000 pounds, followed by a decrease to 15,000 pounds in 2006. Finally the poundage of urchin caught in 2008 decreases post construction of the WNR. Throughout the 16 mitigation project's lifetime, the Oceanside block has low poundage relative to the poundage at WNR,. Sea urchin catch in the Wheeler North Reef shows a stable trend over the 16 years despite a few dips of low poundage caught in 2001 and 2006 that are closer to 0lbs. While we predicted an increase in red sea urchin, there is no trend showing increase or decrease.

Beginning in preconstruction phase of the reefs construction, Dana Point produces average poundage per phase of approximately 42,000 in preconstruction phase, 83,000 in phase I, and 100,000 in phase II, showing an increasing trend. Oceanside block shows that there has been no increase since the reef has been constructed in 2008. The WNR block shows a dramatic increase in average landings from 43,000±20,000lbs to 98,000±2,000. However, the large standard error in the preconstruction phase and phase I reduce our confidence in how much the landings of red sea urchin have increased over time.

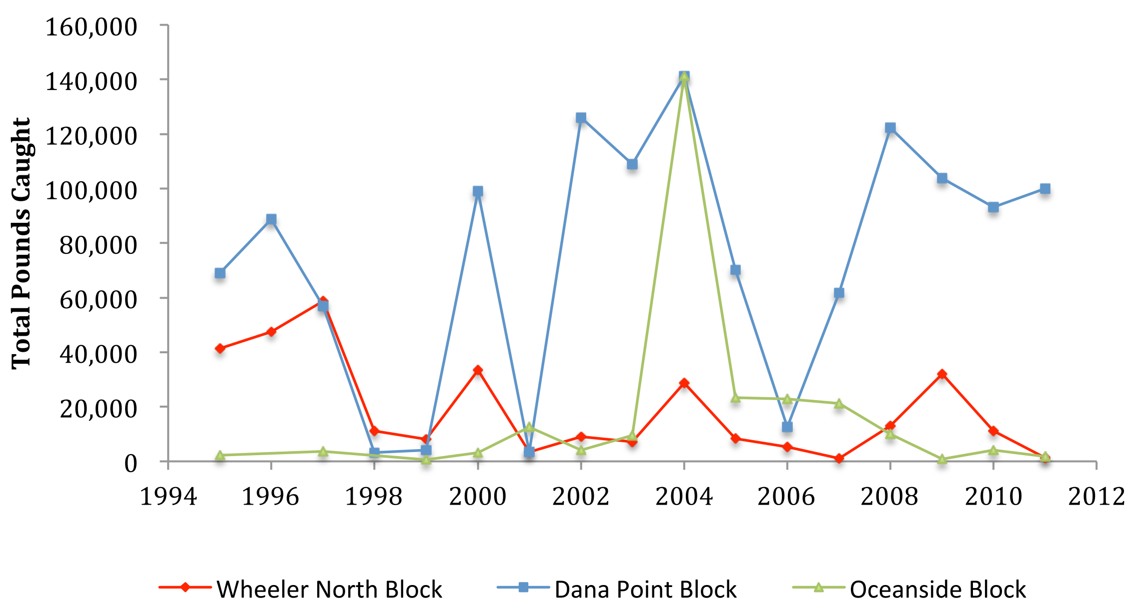

Figure 9. Total poundage of Red Sea Urchin landings over study period

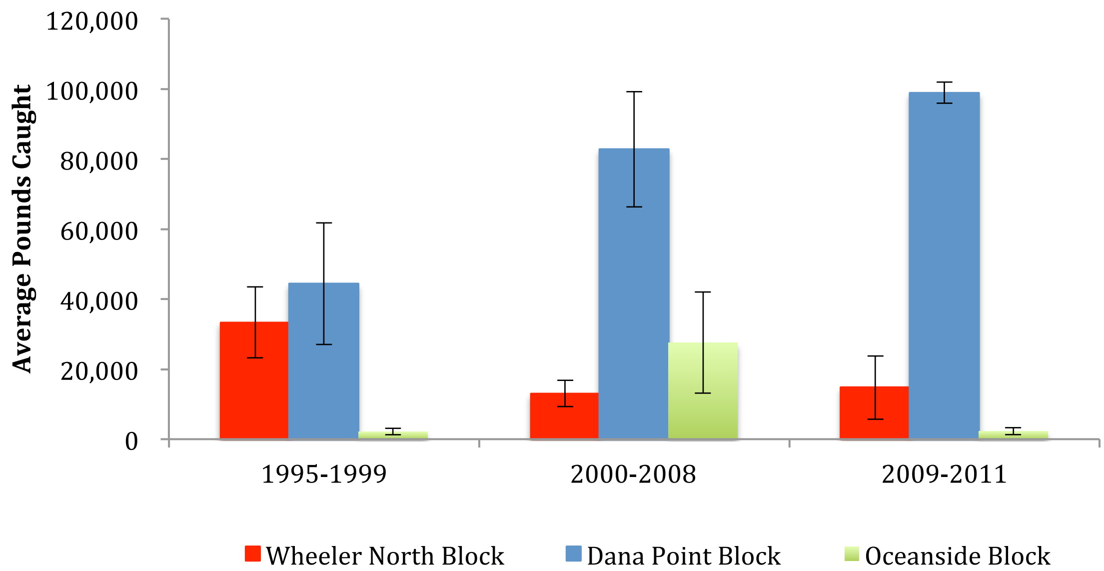

Figure 10. Average poundage of Red Sea Urchin landings by phase.

California sheephead

The WNR Block and Dana Point Block show that California sheephead landings have remained roughly stable from 1995 to 2011. In contrast, the Oceanside Block shows a decrease in total poundage from 10,000lbs to nearly zero lbs. These results do not support our first hypothesis. Instead of increasing, the total poundage in WNR block actually remains stable with no significant increasing or decreasing trend. The average poundage for California sheephead in WNR block increases from 400±50lbs in preconstruction phase to 1,900±200lbs. in phase I. Large standard error suggests that our confidence in an increase is reduced. We cannot state whether or not the catch has remained stable or significantly increased likely because our sample of data is small and not representative of a full year of data. Finally, Oceanside block has the most average poundage per phase with a decrease from 8,100±2,500lbs per phase 1 to 1,000±150lbs per phase 3. Our findings do not support our predictions that sheephead would increase.

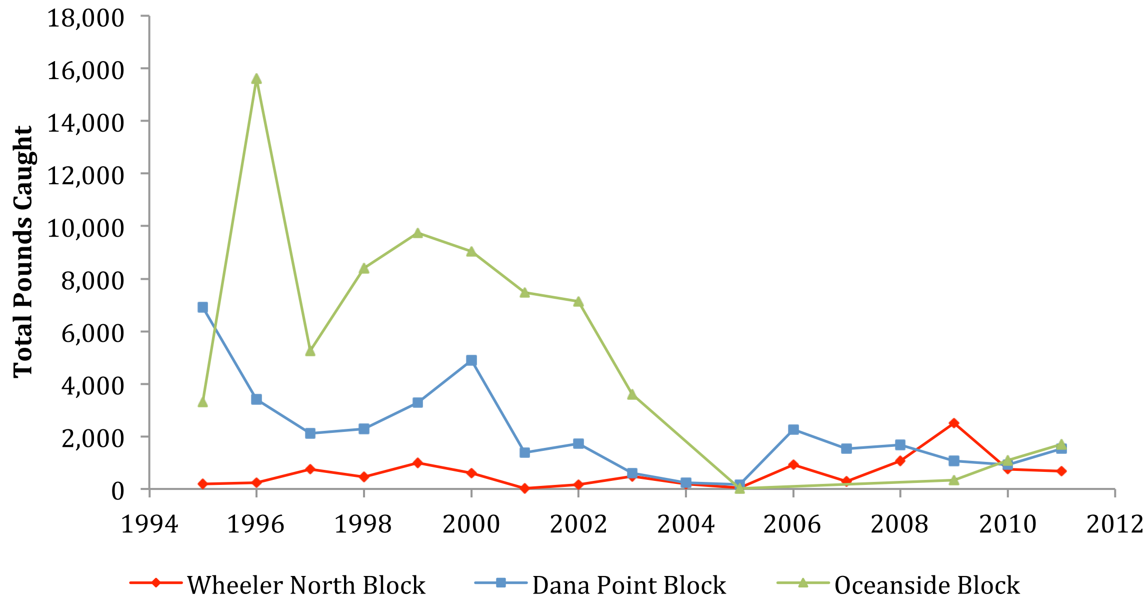

Figure 11. Total poundage of California sheephead landings over study period

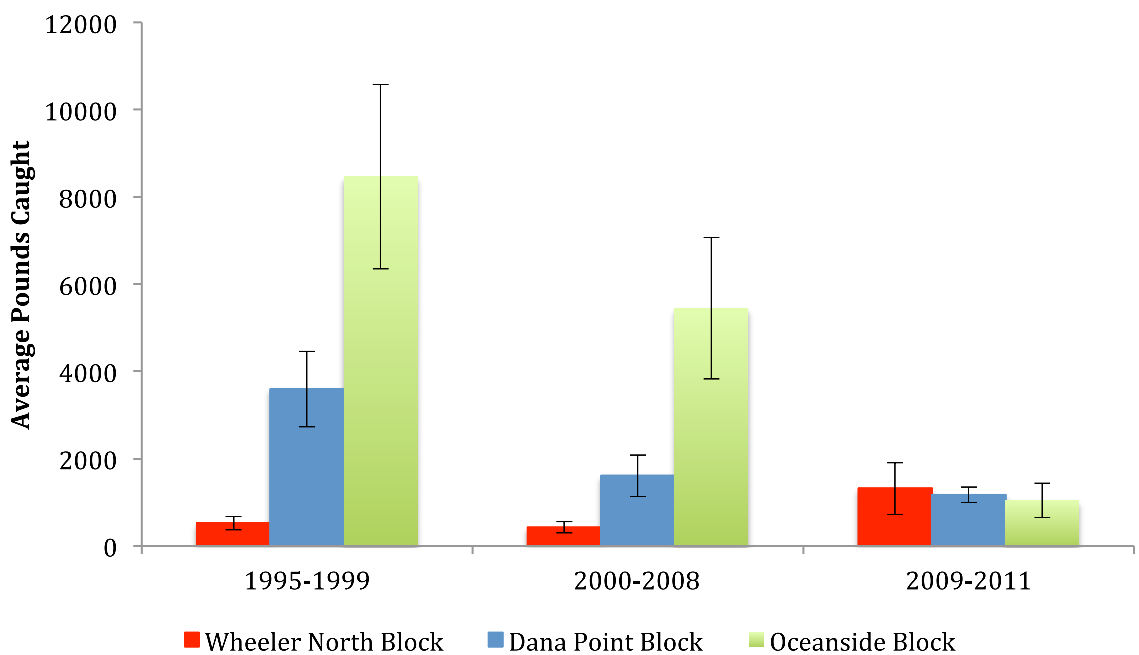

Figure 12. Average poundage of California sheephead landings by phase.

Pacific mackerel

Pacific mackerel in the Wheeler North Block shows a decrease in total poundage starting from 1999, correlating to the start of the construction of the phase I experimental reef in the same year. The Wheeler North Block shows a general increase in total poundage of Pacific mackerel until 1999 with a maximum of about 3,000,0000 pounds. In between this general increase, there was a sharp decrease in total pounds from 1997-1998. After 1999, the total poundage sharply decreases all the way down to zero pounds, where it remains until 2011. This trend shows that from the pre-construction phase to phase I and phase II, Pacific mackerel landings in the Wheeler North Block decreased in total poundage. This result supports our second hypothesis that Pacific mackerel landings will decrease due to the introduction of WNR. The Oceanside Block shows a similar trend to the Wheeler North Block, except the maximum poundage of 2,500,000 occurs in 1997. From 1997 on, Pacific mackerel landings in the Oceanside Block sharply drop to around zero pounds. This does not correlate with the year WNR was introduced, which strengthens our hypothesis that only in the Wheeler North Block will Pacific mackerel landings decrease due to the construction of WNR. The Dana Point Block shows maximum total poundage of around 3,000,000 in 1998, but also has another peak with a maximum of 2,500,000 in 2003 in phase I. This peak in phase I shows that Pacific mackerel in the Dana Point Block were unaffected by the introduction of WNR like the mackerel in the Wheeler North Block were.

The average poundage of Pacific mackerel in all three blocks show a general decline from phase to phase. Since no mackerel was caught in 2009-2011 in any of the blocks, phase II shows no bars for any of the blocks. From the pre-construction phase to phase I, the Wheeler North Block average poundage goes from about 1,250,000 pounds down to about 500,000 pounds. This result relates to our second hypothesis that Pacific mackerel landings will decrease after the construction of WNR. However, all of the standard error bars are very large, suggesting that any conclusions drawn from the average poundage graph cannot be made with high confidence.

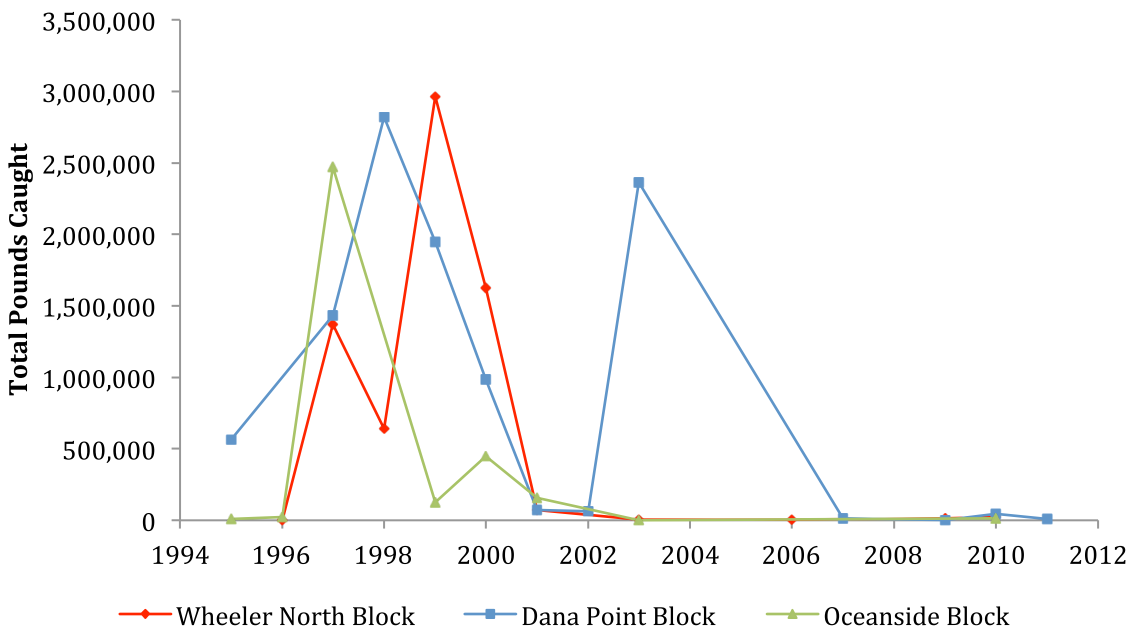

Figure 13. Total poundage of Pacific mackerel landings over study period.

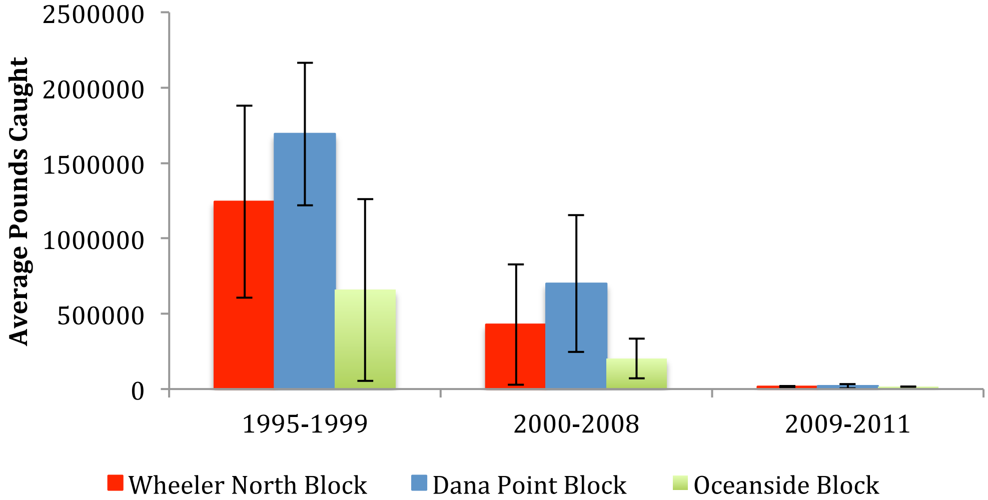

Figure 14. Average poundage of Pacific mackerel landings by phase.

Pacific sardine

Pacific sardine in the WNR Block shows a decrease in total poundage starting from 2000, correlating to when the phase I experimental reef was completed. The WNR Block shows a general increase until 2000, when it experiences maximum total poundage of about 5,000,000 pounds. In between this general increase, there is a decrease in total pounds caught from 1997-1998. After 2000, Pacific sardine landings decrease to zero pounds by 2002, where it remains until 2011. This result supports our second hypothesis that Pacific sardine landings will decrease after the construction of WNR. The Dana Point Block fluctuates up and down from 1995-1998, and then experiences a maximum of 3,000,000 total pounds in 2000. The Oceanside Block shows virtually no Pacific sardine landings throughout the given timespan, except for a small maximum of about 1,000,000 pounds in 2000. Congruent with the WNR Block, the other 2 blocks also experience decreases in total poundage after 2000, which slightly detracts from the conclusion that WNR was the cause of the decrease in Pacific sardine landings in the WNR Block. These results suggest that there may be other outside mechanisms causing the decrease in sardine landings in all three blocks. However, the WNR Block does show the most dramatic decrease in total pounds caught.

The average pound bar graphs of both the Wheeler North Block and the Dana Point Block have a similar trend, as average poundage goes up slightly from the preconstruction phase to phase I, then drops dramatically in phase II. This increase is slightly more pronounced at the Dana Point Block. This increase in average poundage from the preconstruction phase to phase I does not support our second hypothesis, which predicted a decrease. However, the observed increase in average poundage may be due to Pacific sardines not being immediately affected by the introduction of WNR, and thus experiencing a maximum in total poundage in 2000 rather than in 1999. Additionally, all of the standard error bars are very large, suggesting that any conclusions drawn from the average poundage graph cannot be made with high confidence.

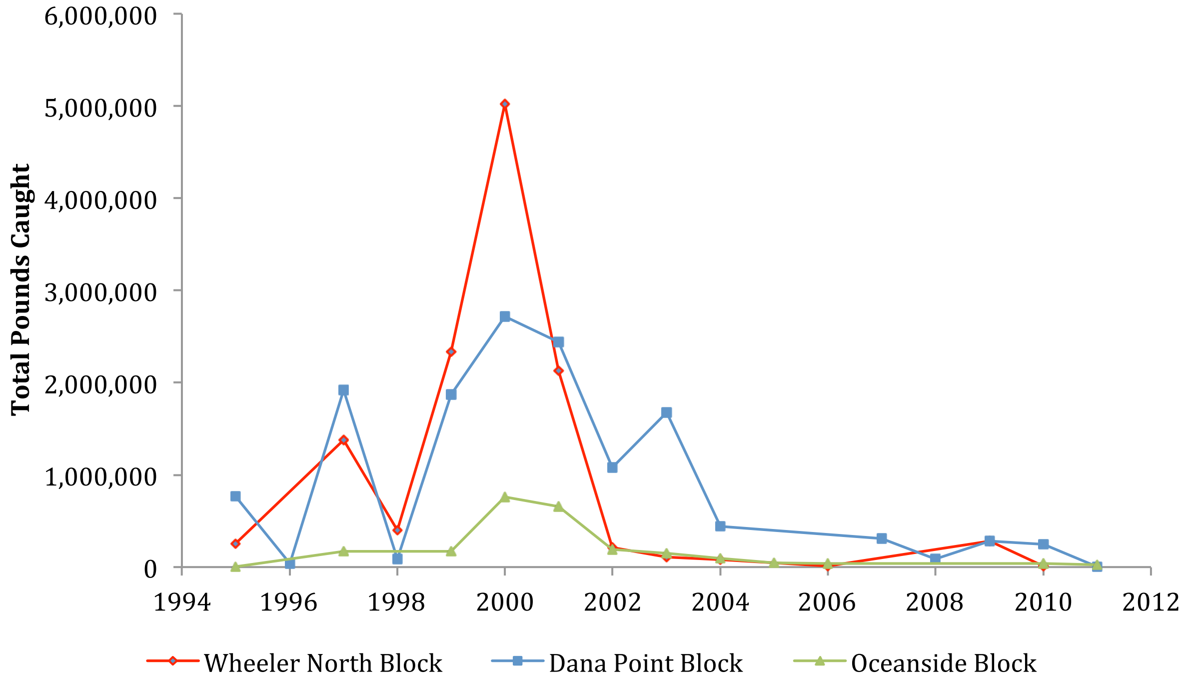

Figure 15. Total poundage of Pacific sardine landings over study period.

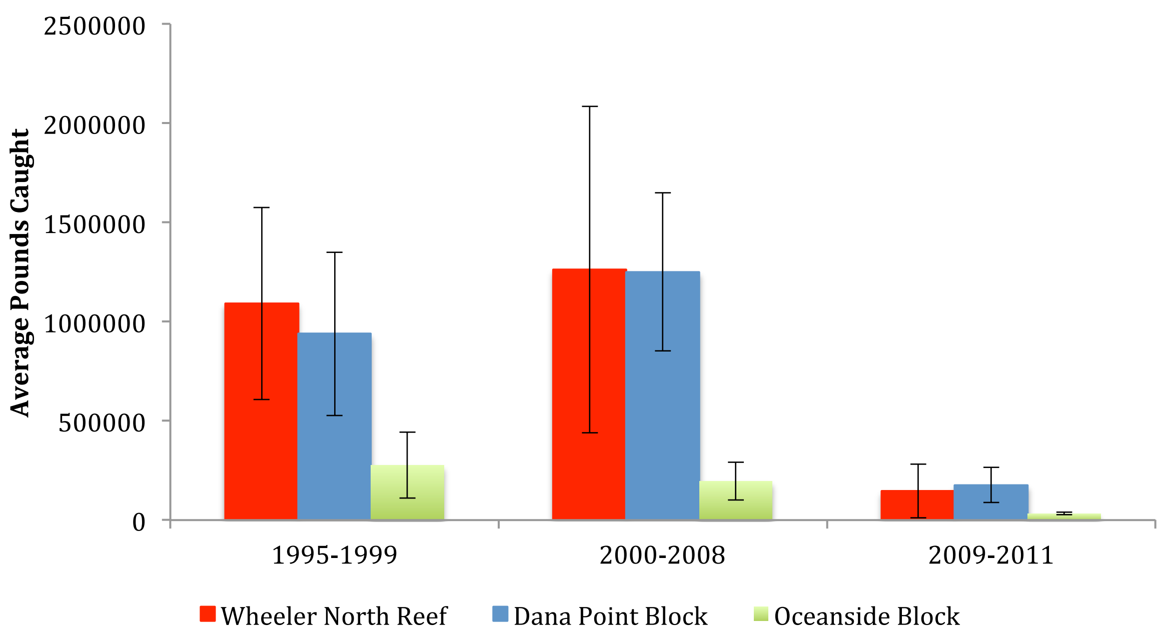

Figure 16. Average poundage of Pacific sardine landings by Pha

Discussion

NPP

When comparing the frond density at WNR to the two reference reefs (San Mateo Reef and Barn Kelp Reef), there is a clearly a similar trend across all three graphs. The sharp increase, followed by decrease, and then a weaker increase is seen across all three reefs indicating that WNR is acting in a similar fashion to the two natural reefs that we are using as controls. This indicates to us that WNR, an artificial reef created to mitigate for adverse effects on San Onofre Kelp Reef, has a similar NPP to what a natural reef would be experiencing in the region we are studying. Because WNR, SMK, and BK are located with a few miles of each other, it is safe to assume that variability in the conditions is negligible and thus WNR's similar performance in the past 11 years indicates a healthy artificial reef.

This argument is supported by the fact that the all three reefs experience a similar drop in frond density from 2006 to 2008. This can be attributed to the occurrence of an El Niño year, which likely affected kelp growth during this two-year span. In Paul Dayton and Mia Tegner (1984) discussed the negative effect of El Niño systems on kelp forests in their paper *Catastrophic Storms, El Niño, and Patch Stability in a Southern California Kelp Community*. They were able to trace a failure in recruitment of kelp juveniles and adults to the effect of El Niño years in 1982 to 1984. The paper also noted that disturbances such as these could have structural consequences on the community due to the fact that understory patches will resist proliferation of kelp. Based on these findings, which were studied in the same geographical region as WNR, we conclude that since WNR was affected in the same negative manner as its two neighbors, it is acting as a healthy natural reef would in its situation.

This is followed by a return of the kelp and frond density after 2008 across all three reefs. Tegner (1987) calculated NPP in southern California kelp communities during an El Niño event. Our analyses of WNR during the 2006 El Niño show similar response patterns. From this we can see that WNR is generating NPP in a similar manner as to what a natural reef would be producing during the same conditions. Three years after releasing preliminary findings on the results of El Niño on Southern California Kelp Dayton and Tegner (1984) were able to further shed light on the events in kelp forest communities subsequent to the event. They found that after kelp fronds had been ravaged by El Niño storms, there was a rapid renewal in all of the kelp communities they were studying. This is very similar to the case that occurred at WNR, SMK, and BK with its decline in 2008 and quick resurgence the next year. We can then draw the conclusion that because of the similarity in frond density spike following the El Niño occurrence in 2008 WNR is likely acting as a healthy natural reef should be based on its comparisons to SMK and BK.

While it is clear that WNR is following the same trend as the two reference reefs in terms of frond density change, we can also make an argument that SCE's artificial kelp reef has higher productivity than the two reference reefs. Reed, Rasweiler, and Arkema (2009) built on their earlier findings that frond density serves as a good estimator of net primary production at kelp reefs. In the paper, they note that accurate frond density measurements at the right time of year can make NPP calculations even more tractable. And with higher NPP findings, there can be a relation to greater ecological health at a reef. Across the 11 years of data that was collected, WNR has the highest level of frond density for 7 years. We can make the argument that WNR's NPP is high and robust, exceeding those of the surrounding reefs. Our results also show that fluctuations in species diversity, NPP, and other biodiversity indices are not independent, isolated occurrences at WNR, but are driven by natural forces affecting the entire region.

Species Diversity

The collection of indices utilized to assess the biodiversity of WNR aims to provide further detail to current findings regarding species diversity within the California Coastal Commission report. We rely on results from the Gini-Simpson's index, Shannon-Wiener index, species accumulation, and rank abundance in order to draw conclusions regarding the species diversity of the artificial reef. Throughout our review of previous literature assessing reefs, there was limited research on biodiversity metrics used to measure the diversity of reefs. Therefore, the analysis of species diversity at WNR is one of the first of its kind.

Diversity: Gini-Simpson's Index

The Gini-Simpson indices show that diversity fluctuates in a similar pattern for all three reefs through years 2000-2004, with WNR's diversity consistently exceeding those of the reference reefs by a large degree. All reefs experience a large drop in diversity in 2005 and 2006, which may correlate with the El Niño years and the subsequent drop in frond density in those years. From 2009 to 2011, all three reefs' diversities rise steadily and by 2011, WNR has a very close Gini-Simpson index to BK's and SMK's, exceeding them slightly.

These observations may suggest that the diversity in terms of species richness and proportionality at WNR trumps those of the nearby reference reefs. Although its diversity exceeds the reference reefs, they all follow the same trend, which suggests that WNR is performing at the same level as natural reefs. The observed rise in WNR's diversity after the El Niño years may evidence its ability to bounce back after catastrophes and its resilience to environmental change.

Diversity: Shannon-Wiener Index

The Shannon-Wiener indices show that diversity at all three reefs constantly fluctuates. During phase I, WNR exhibited a constant Shannon-Wiener value, but eventually experiences a large drop. The two reference reefs had much more regular fluctuations in Shannon-Wiener values. All three reefs spiked in 2010 to the highest recorded Shannon-Wiener value in the data set.

We can see from the Shannon-Wiener index values, as we did from the Gini-Simpson values, that WNR is performing similarly to the two reference reefs and actually performed better for a period of time following the reef's initial launch. WNR appears to be the only site that is not immediately declining following the spike each reef experienced. This may indicate that WNR is as stable as the natural reefs under the same conditions.

Diversity: Species Accumulation curves

The graph of species accumulation curves are constructed such that the x-axis represents the number of individuals sampled, and the y-axis represents the number of species encountered. Fundamentally, as the number of individuals sampled within a population increases, the number of species within that population will increase until reaching a critical value (Gotelli & Colwell 2001). Once this critical value is reached, more individuals sampled will yield little to small increases in the number of species discovered, leading to a general limit of the number of species that a population consists of.

WNR contains by far the most number of individual fish sampled (88,268) as compared to BK (47,779) and SMK (38051), which is the reason why its species accumulation curve is much longer along the x-axis than the other two. Because of the large number of individuals sampled, the slope of the curve appears to be somewhat gradual and steady. However, the slope of the curve has not reached its asymptote, meaning that as more individuals are sampled in the future we expect to encounter even more species (albeit at a slower rate). It is also apparent that within the graph, WNR's curve is always above BK and SMK. This means that at any given number of individuals sampled, WNR contained a greater number of species encountered than BK or SMK. The fact that the curve's slope is gradually increasing in conjunction with consistently higher species-count values means that WNR exhibits a comparatively higher level of total species richness than BK or SMK.

The accumulation curve for BK shows the greatest increase in overall species (21) as compared to WNR (19) and SMK (15), and maintains a positive slope indicating additional species encounters with greater sampling. Two inferences can be made from looking at the BK reef as compared to WNR and SMK. The first is that BK's accumulation curve appears to run generally parallel to WNR with increasing number of samples, meaning that the two are expected to show similar rates of species encounter over time. Secondly, the stark difference in curve shape between BK and SMK increasing from two to 1,000 individuals shows that BK has greater species richness and that more species are expected to be encountered.

The species accumulation curve for SMK shows the greatest overall asymptote shape, meaning that it has come close to reaching the critical number of species that can be found in the reef as more individuals are sampled. While it increased similar to that of BK initially, the curve shows a more dramatic decrease in accumulation rate than the other reefs around 40 species, which is much lower than the number of species found at the BK and WNR.

Diversity: Rank-Abundance curve

Conclusions regarding rank abundance are made contingent upon the slope gradient of each curve. A high slope gradient indicates a low species evenness, which means that higher ranked species—those that have a high-count (quantity) number—dominate over species at lower quantities. A low slope gradient indicates opposite—that the reef is sustaining a greater number of species without one species dominating others. Higher slope gradients are most correlated with habitats that have trophic cascades.

When comparing the rank abundance of all three reefs, the slope gradient of WNR is the sharpest and steepest. This can be attributed as a result of phase I occurring beginning of WNR's construction and development. Due to this result, we decided to analyze rank abundance at WNR for all three phases as it provides more insight about fish diversity across a defined temporal scale. Thus, while WNR does have the steepest slope relative to the other reefs, our hypothesis is still supported by the growth seen across the developmental phases of the reef.

The "post construction", or phase III, slope at WNR is the most shallow relative to other two phases (Figure 6). The phase II curve is the most steep. This result can be attributed to an El Niño event, which occurred during phase II. The steep gradient during phase II (2001-2006) may have resulted in a trophic cascade at WNR. The phase III slope indicates an overall growth in fish diversity as this phase has the highest species evenness and richness of the three phases. Such an increase from phase II to phase III shows rapid growth and development at WNR.

Economic Value

California spiny lobster

Our results show an increase in spiny lobster landings since the implementation of WNR, therefore supporting our first hypothesis. This constant increase can be attributed to the use of rocky substrate from the experimentation phase that produced a heavy density of kelp. This is because the stock enhancement of lobster is directly related to the density growth of the artificial reef (Spanier 1993). Lobsters prefer anti-predatory void-substrates that suit their behavioral-ecological characteristics (Jensen 1993; Spanier 1993). Artificial reefs are effective at producing lobster if the design substrate, size, abundance, mortality, and other species metrics are assessed for the reef construction (Buchanan 1973; Stone et al. 1979). While the quarry stone has allowed for a greater increase in kelp canopy size than expected, it is also increasing the availability of legal sized lobster for catch by providing more habitat. Since the artificial reef is growing, the habitat size has allowed for a larger population of lobster, and therefore more lobster caught. Our hypothesis is further supported by a stable landings trend in the Oceanside block. This stable trend shows that the increase in catch due to WNR only affects the WNR block and not the Oceanside block.

Artificial reefs such as WNR have enhanced the population's size by up to at least six times its original population (Dean, 1983), and have also equaled or exceeded the population size of species of neighboring reefs (Ambrose and Swarbrick, 1989; Pickering and Whitmarsh, 1997). This further supports our hypothesis of why an increase in California spiny lobster landings in WNR is occurring. However, we are not certain how the increase in total landings aligns with the attraction vs. production debate. Lobsters are known, in regions of dense natural kelp reef, to simply move over to a neighboring artificial reef (Bohnsack, 1989; Davis, 1978; Davis, 1985; Pratt 1994). For these reasons, our hypothesis is not supported by the decrease in total landings in Dana Point Block. As these landings decrease, the WNR Block landings increase. This is attributed to many factors in the Dana Point Harbor, such as policy restrictions that prevent lobster catch in or near the harbor, and the establishment of Marine Protected Areas in Dana Point Block (most recently in 2011) that regulate catch. However, another likely reason, which would not support our hypothesis, is if WNR has been attracting lobster from the nearby Dana Point Block.

Also, a trend that deserves attention is a spike increase in total landings in WNR in 2006. The total pounds caught increases by greater than 10,000 lbs. in just one year, then proceeds to drop the year after. 2006 was an El Nino year. It is known that El Nino damages reefs because of storm disturbance and reduced nutrient-rich upwelling. However, CDFG 2010 Assessment reports that 80% of the annual catch of lobsters occurs in the first month of January. This spike could reflect an increase in legal sized lobster that developed out of the preceding years' high-nutrient La Nina waters for the first month of January. Since it takes lobster up to 3-5 years to grow to legal size, the larger intake of lobster in 2006 would be due to a larger available population of "legals" that had grown out of the La Nina years of 2004. Therefore, any damages to the reef and lobster population would be seen in 2007 and 2008. In support of this, there is a decrease in landings in 2007 and 2008. However, since we did not do research on these correlations, further research would need to be conducted on this relationship to determine if it is a valid explanation for WNR.

A limitation of ours, and a suggestion for further research, is determining whether the reef is producing or attracting lobster. This would determine if the total landings of California Spiny lobster are a productive increase, or if the reef is just recruiting lobster, and therefore catch opportunity, from neighboring reefs of San Mateo or Barnes. A further limitation of our data on lobster is that our landings data only includes commercial data. If we were to determine a wholesome effect that WNR has on lobster, we would need to incorporate the recreational data as well. This may influence our results by changing the trends.

Red Sea Urchin

Our hypothesis that red sea urchin landings in the WNR Block would increase due to the WNR's presence was shown to be incorrect based upon our results. Landings of red sea urchin actually showed a slight decrease over time when comparing the average poundage caught per phase from the preconstruction time period to both phases I & II. The reason for this decrease is unknown although it could be attributed to the presence of dense kelp forests at WNR that could potentially inhibit commercial red sea urchin divers. It is conceivable that the WNR and its kelp forest have in fact increased the production of red sea urchin in the area.

The Dana Point Block and Oceanside Block show sporadic trends with several periods of increases and decreases in the amount of red sea urchin caught commercially over the 16-year time span. The Dana Point block is characterized by having the highest average poundage while also containing the most drastic peaks and valleys. The 3 blocks are all similar in that they do display analogous increases and decreases on occasion throughout the study period. This suggests an external mechanism that could be responsible for driving the relative increase and decrease of red sea urchin landings in all 3 blocks.

El Niño is a well-documented phenomenon known to create warm eastern Pacific waters that causes a decrease in kelp forests, which is the main source of food for red sea urchins (Tegner & Dayton 1984). The years of 1997-1998 marked a strong El Niño event ,which may have caused the general decrease in landings as shown in all 3 blocks. This hypothesis is further supported by DFG's overview report on historical Red Sea Urchin landings (Kalvass & Rogers-Bennett 2002). In this report, the El Niño event of 1997-1998 was noted to have a large negative impact on all of Southern California's red sea urchin fisheries.

External market pressures like demand could also help to explain some of the fluctuations seen in commercial landings over time. California's fishing of red sea urchins mainly caters to the Japanese export market. This large share of the market is able to even drive up prices for red sea urchin catch around the Japanese New Year holidays. For this reason the California commercial landings are often contingent on the Japanese market demand, which is influenced by the status of Japan's economy (Kalvass & Rogers-Bennett 2002).

California sheephead

Compared to the other species in this study, California sheephead constitutes a relatively minor portion of the fisheries in Southern California (DFG 2004). Landings have consistently averaged between 40,000 and 70,000 fish annually, but the advent live fish trap fishery caused a rapid increase during 1990s (DFG 2004). Over the study period from 1995 to present, the Oceanside Block experiences the most variability landings in comparison to the WNR Block & Dana Point Block which only deviate slightly in landings over the study period. The Oceanside block experiences a large peak in the year 1996 with 15,606 pounds caught in comparison to the surrounding years, 1995 (3,316 pounds) and 1997 (5,250 pounds). This peak is not evident in either the WNR Block or the Oceanside Block, suggesting an external variable only affecting this southernmost region. According to a study done in 2001 by Leet et al., this discrepancy could be attributed to the fact that the California sheephead populations in kelp bed habitats tend to increase during El Niño conditions. When this research team did a comparative analysis between populations of California sheephead living in breakwater and kelp bed habitats, they observed that the density of California sheephead in the kelp bed was three times that of the breakwater (Leet et al., 2001).

The general trend shows a slight decrease in pounds of California sheephead throughout the preconstruction periods, indicated by phase I and phase II. Due to the small amount of California sheephead caught however there are large standard error bars present. These low catch rates result from a variety of regulations. According to the California Department of Fish and Game, California sheephead may not be commercially caught in Southern California in January and February. Furthermore, there is a minimum size limit of 12 inches total length for each fish caught and no more than five fish may be taken per day. This amount of deviation makes it difficult to make an empirical statement on whether the California sheephead landings have decreased in Blocks 757 & 801 or increased in Block 756.

California sheephead is primarily caught using fishing traps in the 3 Block study area. California sheephead is also caught as by-catch in lobster and crab traps. These fishing traps are deployed on the seafloor and could possibly be inhibited by the presence of kelp forest at WNR. This notion is not fully supported by the results though, since approximately stable landings of California sheephead are recorded in all years since the constriction of WNR.

Pacific mackerel

Our Pacific mackerel results support our second hypothesis in that Pacific mackerel landings have decreased to zero total pounds caught in the local area since the introduction of WNR. Our second hypothesis is critical because if the landings of mackerel actually increased in the local area, then it may suggest an overall increase in fishing effort and implies that WNR is not the cause of the observed increase in lobster landings. The decrease in Pacific mackerel landings observed in the Wheeler North Block in 1999 may be explained by the start of the construction of WNR in the same year. Commercial fishermen use purse seine gear to catch Pacific mackerel. These large nets may have been hindered by the growing kelp reef in the Wheeler North Block, which could have led to a reduction in fishing effort in the region.

From 1997-1998, a sharp decrease in total poundage can be observed in the Wheeler North Block. This could be correlated to a large El Nino event during the same years, which upwelled warmer waters to the area and may have accentuated the northerly migration of Pacific mackerel populations in the area (Crone 2011).

Our second hypothesis is further strengthened by our results in that the two control blocks experience maximums in different years than the Wheeler North Block. This is significant because if the Pacific mackerel landings decreased in the same year for all three blocks, then the decrease in landings observed in the Wheeler North Block would not necessarily be due to the implementation of WNR. Another result suggesting that landings in the two control blocks are independent of WNR is a second peak arises only in the Dana Point Block from 2002-2007. This second peak can possibly be explained by the fact that the market for canned mackerel fluctuates in different regions based on availability and economic conditions (Crone 2011).

Pacific sardine

Our Pacific sardine results support our second hypothesis in that Pacific sardine landings have decreased to zero total pounds caught in the local area since the introduction of WNR. After a maximum in total poundage in 2000, the Wheeler North Block experienced the fastest decline in Pacific sardine landings. This decrease may be explained by the completion of the artificial reef in 2000. Similar to Pacific mackerel, purse-seine gear is used to catch Pacific sardine and may have become too hindered by the blossoming kelp reef habitat of WNR.

The idea that WNR caused this decrease in sardine landings in the Wheeler North block is not conclusive since the two control blocks also exhibit maximums in total poundage in 2000. However, the Wheeler North Block does show the most dramatic decline in sardine landings, possibly signifying that WNR indeed had an effect on sardine landings in the local area. One possible explanation for the maximums experienced in all three blocks in 2000 is that the Pacific Fishery Management Council (PFMC) took over the management of the California sardine fishery in 2000, which was previously managed by the California Department of Fish and Game (DFG). In 2000, the PFMC specified a harvest guideline of 205,902 tons - a 65% increase over the 1999 limit set by the California DFG (Cascorbi 2004).

From 1997-1998, decreases in total poundage can be observed in the Wheeler North Block and Dana Point Block. This could be correlated to the same El Nino event discussed with Pacific mackerel, as Pacific sardine often travel in schools and migrate with other pelagic species such as Pacific mackerel (Hill 2011). From 2002-2011, the Wheeler North Block and Oceanside Block experienced virtually zero Pacific sardine landings, while the total poundage in the Dana Point Block declined towards the zero mark by 2004. This may be explained by a reduction in fishing effort in the 3-block area because most of the vessels that catch sardines use the same purse-seine gear to catch squid. This can mean that an active squid season takes California fishermen out of the sardine fishery, which was observed in 2002 (Cascorbi 2004).

Definitive conclusions cannot be made about the decrease in mackerel and sardine landings in the WNR block due to very large standard error bars. But ultimately, it was significant to find that the landings of these pelagic species were not shown to increase, which would suggest an overall increase in fishing effort in the local area and thus detract from our first hypothesis.

Conclusions

We used a two-pronged approach to study WNR, looking first at diversity and then at economic value. For diversity, we examined indices that give estimates of species diversity, richness, and evenness. We compared our results to existing natural reefs in the area and were able to conclude that WNR is functioning as a natural reef.

In terms of the economic value of WNR, our results showed an increase in California spiny lobster landings in the local area since the introduction of WNR in 2000. We supported this conclusion by revealing decreases in Pacific mackerel and Pacific sardine landings in the local area following the implementation of WNR. The observed decreases in landings of these pelagic species were critical to our lobster findings because they helped validate that the increase in lobster landings was not simply due to an increase in overall fishing effort in the local area. Rather, we were able to conclude that WNR is a logical reason for the increase in lobster landings and its implementation has therefore enhanced local economic opportunity.

High biodiversity strengthens an ecosystem in the face of environmental change and increases it’s likelihood to survive. If developers wish to create artificial systems, it is necessary to create standardized methods of evaluating the performance of artificial systems to ensure they are operating similarly to their natural counterparts. WNR is a unique site that provides scientists and researchers with opportunities to study the complex functions of a reef. From our analysis, we were able to conclude that WNR operates like a natural reef and, furthermore, it brings economic value to the surrounding area.

Future Studies

WNR is a unique site that provides scientists and researchers alike with opportunities to study the multifaceted interactions between a reef and its environment. We found that WNR functions similarly to a natural reef with regards to species diversity and net primary productivity, and furthermore, it brings economic value to the surrounding area. For future studies on diversity at WNR, benthic diversity should be assessed, as it is an integral factor to the overall biodiversity at kelp reefs. Benthic species function as major players in the transferal of energy to upper trophic levels (Dikou 2010). However, literature has noted the difficulty in assessing the condition of benthic communities as a result of various high spatial heterogeneity and temporal variations. These spatial and temporal factors are to the influence of seasonal environmental and reproduction changes, short life span of certain species, and alterations in physical structure of reefs (Munari 2011). Future studies should interpret EstimateS results and elaborate on our approach in analyzing benthic diversity at all WNR, BK, and SMK.

Benthos

Benthic diversity is an integral factor to the overall biodiversity at kelp reefs. Benthic species function as major players in the transferal of energy to upper trophic levels (Dikou 2010). However, literature has noted the difficulty in assessing the condition of benthic communities as a result of various high spatial heterogeneity and temporal variations. These spatial and temporal factors are to the influence of seasonal environmental and reproduction changes, short life span of certain species, and alterations in physical structure of reefs (Munari 2011).

In our research, we were able to obtain benthos data from UCSB scientists. After manipulating the data, we used EstimateS to analyze the benthic diversity at WNR specifically. Although information about incidence based coverages at WNR were obtained, we were unable to interpret and make any conclusions from the data. Future studies should interpret EstimateS results and elaborate on our approach in analyzing benthic diversity at all WNR, BK, and SMK.

Appendix

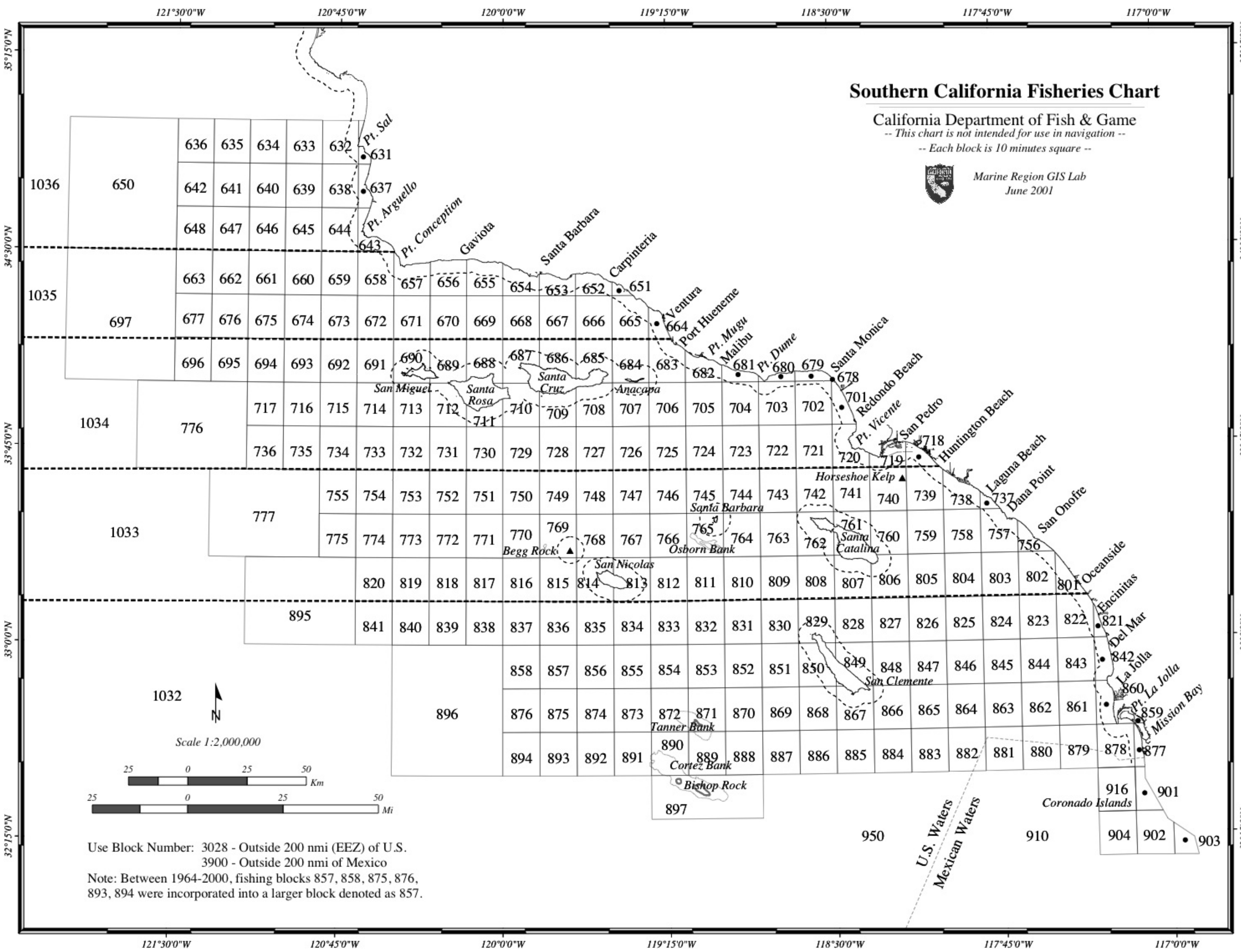

Figure 17. DFG Southern California Commercial Fisheries Chart

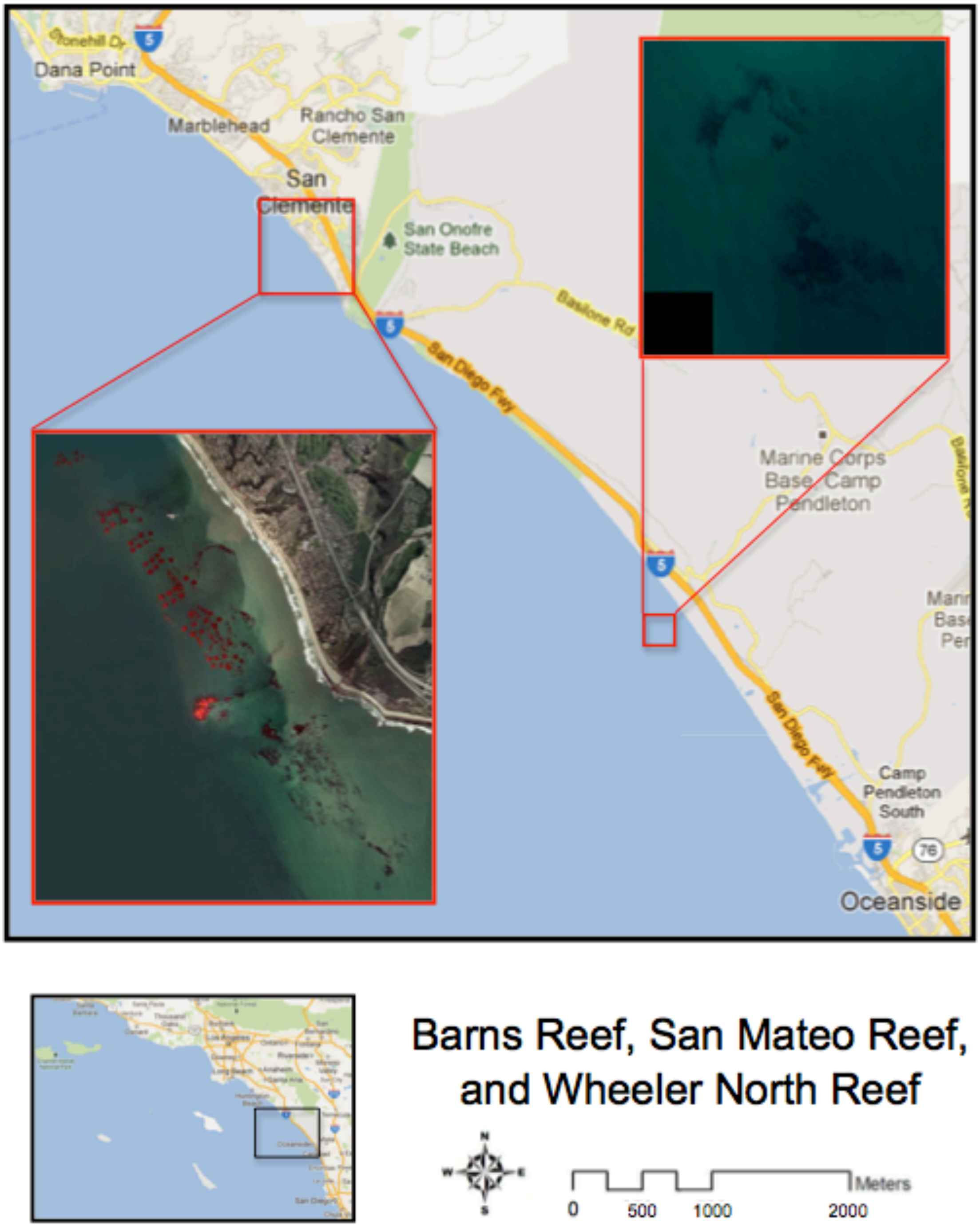

Figure 18. Map of BK, SMK, and WNR

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