Annual Report

Santa Cruz Port District Three Year Baseline Monitoring of Giant Kelp Final Report

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Executive Summary

The Santa Cruz Harbor (SCH), located in the Santa Cruz Bight in northern Monterey Bay, CA, is subject to sediment accumulation which requires dredging of sand, silt and clay from its federal entrance channel and inner harbor. A three-year kelp forest monitoring program has been initiated to comply with Army Corp of Engineers permit 2011-00051S Special Condition 2. The concern is that silt and clay sediment may disturb the local wildlife and be retained in nearshore benthic habitats, potentially changing the existing sedimentary conditions and sediment transport properties in the Santa Cruz Bight and nearby kelp forest habitats. The purpose of this baseline study is to determine the current condition of the nearby kelp forests and evaluate the trends of kelp plant abundance and stipe density from 2013-2015. This baseline study does not intend to investigate causality. Its objective is to determine if there are statistically significant ($\alpha=0.05$) trends or differences among a potential impact site and control sites.

The study site is located offshore of the Santa Cruz Harbor and is an area approximately 1.5 km by 4.5 km. Three kelp forests are located within this area and have been chosen as monitoring sites. They include areas at Blacks Point (near Twin Lakes beach), Pleasure Point and Steamers Lane (Mitchell Cove). The Blacks Point kelp forest site is down current of the dredging release point and has been chosen as a monitoring site. The Pleasure Point and Steamers Lane kelp forests were surveyed as control sites. In September, 2015, Sandoval & Associates (S&A) sampled adult *Macrocystis pyrifera* (here after referred to as kelp) sporophyte plants in September around the time of maximum occurrence of *M. pyrifera* at these sites. At each monitoring site, visual surveys by

SCUBA divers were used to quantify the density of *M. pyrifera* by counting individual kelp plants and the number of their stipes along standardize 30m transects. The results of this survey were compared to estimates from the 2010, 2013, 2014, and 2015 surveys conducted by S&A.

Both, kelp plant densities and kelp stipe densities increased in recent years at all three study sites. Plant densities seemed to not have changed between 2010 and 2013 but in subsequent years they have more than tripled and this patterns seems to be holding across all three sites as we did not detect any significant site by year interactions other than a somewhat greater increase in density at one of the control sites compared to the other in 2015. While there was also an overall increase in stipe densities in recent year, 2015 density seems similar to densities detected in 2010. Stipe/plant ratios were decreasing over the time period of the study from around 60 stipes per plant in 2010 to under 20 stipes in 2015. Together these patterns suggest that more plants with less stipes each are present in the later years of the study. This would be consistent many smaller plants replacing the fewer larger plants counted in the earlier years. *Macrocystis* stipe density is a better estimator of kelp biomass as well as net primary productivity than plant density in a kelp forest (Reed et al. 2009). As stipe density levels were similar in 2010 and 2015 this change from large mature plants to smaller younger plants might not have had much of an effect on the standing biomass or productivity of these kelp forests.

A three-way Permutation Analyses of Variance (PANOVA) for differences in kelp plant density (number of plants/m^2) indicated that there were no significant differences in kelp plant densities between the three sites or between the east or west side of the kelp beds. However, there was a significant effect of year on the plant density and kelp plant densities have increased in recent years. These trends seem to be constant across sites as indicated by the non-significant results of all planned comparisons for site by year interactions with one exception of the comparison between the two control sites when 2015 is compared to the previous years.

Kelp stipe densities were lower at the impact site than at the control sites. But this general pattern was reversed in 2014 when stipe densities were higher at the impact site. The significant effect of year on the stipe density suggest temporal variability and while there were no clear temporal trends it seems like stipe density have increased in recent years. Kelp stipe density is higher on the east side of the kelp beds when compared to the west sites. This pattern held for all sites but was more prominent at the control sites than the impact site. Lower stipe densities on the west side of Blacks could be interpreted as a result of the dredge deposits because due to the prevailing currents at the impact site deposits are delivered to the west side of the kelp bed. However, the fact that the same pattern is seen at the control sites suggests that it might be the result of other factors.

The stipes/plant ratio was higher at the control sites than the impact site but as with the stipe density this pattern was reversed in 2014. This interaction is indicating the variability in these response variables and caution against interpretation of the overall patterns (i.e. main effects in the statistical model). Overall, stipe/plant ratio was lower in 2014 and 2015 than in previous years but again interactions among the years and study sites make the interpretation of this trend difficult.

Since this study did not investigate changes in kelp densities before the dredging began (i.e. full BACI design), we cannot evaluate if the kelp densities at the impact site are correlated to the dredge deposits. We can only evaluate if changes have occurred over the time period of the study. No significant trends were detected over time in this variable system. It is important to note that kelp forests are extremely variable both in space and time (Dayton and Tegner, 1984, Dayton et.al., 1984, and Dayton et.al., 1992). This is demonstrated by the many interactions among the factors in the statistical analysis. Therefore, if the current dredging volume, conditions and deposit location are kept constant, any effects on the nearby kelp forest (impact site) may not be detectable above the ambient variability of the system.

1.0 Introduction

The Santa Cruz Harbor (SCH), located in the Santa Cruz Bight in northern Monterey Bay, CA, is subject to sediment accumulation which requires dredging of sand, silt and clay from its federal entrance channel and inner harbor. A three-year kelp forest monitoring program has been initiated to comply with Army Corp of Engineers permit 2011-00051S Special Condition 2. The concern is that silt and clay sediment may disturb the local wildlife and kelp forest communities and be retained in nearshore benthic habitats, potentially changing the existing sedimentary conditions and sediment transport properties in the Santa Cruz Bight.

The SCH has continued their ongoing effort to maintain and clear the harbor of non-contaminated, mixed sand, silt, and clay sediment by hydraulically dredging the sediment and piping it offshore of Twin Lakes Beach. Dredging occurred during the winters of 2009-10, 2011-12, 2012-13, and 2013-14, but did not occur during 2014-15 (Santa Cruz Port District, 2016). Sediment monitoring programs of 2001 and 2005 indicated that beach and offshore sedimentary conditions near SCH were not significantly altered or impacted by the addition of fine-grained sediment from the harbor (Watt 2003, Watt & Greene 2003, Sea Engineering, Inc 2005). In addition to the sediment studies and the current monitoring program, at the request of the National Marine Fishery Service (NMFS) and as part of an Essential Fish Habitat (EFH) review, the Port District has commissioned a three-year, baseline study of the kelp forests in the historic dredge disposal area. Sandoval & Associates (S&A) designed and conducted this kelp monitoring program for the summers of 2008 thru 2010 (Sandoval & Associates, 2011).

S&A's study suggested that the Santa Cruz kelp forests at all sites are robust but the available and suitable habitat may be small (or decreasing) for the site impacted by the dredge disposal at Blacks Point. It should be noted that limited kelp harvesting has occurred in the area (Ebert 2008), but Donnellen and Foster (1999) note that these activities have minimal (non-significant) effect on kelp distribution and abundance. It is also important to note that kelp forests are extremely variable both spatially and temporally (Dayton and Tegner 1984, Dayton et.al. 1984, Dayton et al. 1992). The data from the baseline study suggests that the surface canopy at nearby Pleasure Point is not affected by dredging operations (Sandoval & Associates, 2011). In light of this data, Sandoval and Associates recommended a long-term monitoring approach focused at Blacks Point and associated control sites before evaluating the condition of these kelp forests in more detail. The current study is the direct result of these earlier efforts and employs the same sampling protocols as the previous study. This report presents the findings from the third and final year of the ongoing monitoring study.

1.1 Natural history Background

Similar to other regions of central California, the rocky subtidal of the Santa Cruz Bight is characterized by dense forests of kelp growing at depths of 2 m to 30 m (Foster and Schiel 1985). Giant kelp, *Macrocystis pyrifera,* is the dominant canopy-forming kelp in the area, and can form dense beds of forest where suitable rocky reef habitat is present (NOAA 1992). The shallow areas inshore of these giant kelp stands are characterized by surface canopies of *Egregia menziesii*, subsurface canopies of *Pterygophora californica* and *Laminaria setchellii*, and the alga *Cystoseira osmundacea* are common on nearshore rocky reefs (McLean 1962, Devinny and Kirkwood 1974

Foster and Schiel 1985, Harrold et al. 1988). Although they occur throughout the Santa Cruz Bight, these understory kelps are more characteristic of areas more exposed to wave action, such as the Point Santa Cruz area (Harrold et al. 1988). The Santa Cruz region has a small kelp harvesting industry that collects the upper 3 ft of the floating kelp canopy. This harvest is for abalone mariculture production and usually takes place from November to June, from Pleasure Point to Sand Hill Bluff. Harvesting has been ongoing since 1989 and averages 15,000 pounds per week (Ebert 2008), but Donnellen and Foster (1999) note that these activities have minimal (non-significant) effect on kelp distribution and abundance.

Giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis luetkeana*) supply the majority of the biomass, primary production, and three-dimensional structure in rocky, nearshore (<30 m depth) marine environments of central California. The "forests" formed by aggregations of individual plants provide food and habitat for hundreds of species (North 1971, Foster and Schiel 1985). *Macrocystis* canopies are economically and ecologically important (Foster and Schiel 1985, North et al. 1993). Approximately 35% - 60% of giant kelp biomass is present in the upper 1-2 m of surface canopy (McFarland and Prescott 1959, North 1971, Gerard 1976), and more than 98% of *Macrocystis*' primary production occurs within the upper 3 m of water column (Towle and Pearse 1973). Canopy fronds serve as food for grazers (e.g., snails, invertebrates) and serve as critical recruitment habitat for many fish species (Carr 1994). Therefore, the vertical structure provided by kelp forest can potentially be limiting habitat for various animal species, including sea otters and fish (reviewed in Foster and Schiel 1985). The seasonal loss of kelp canopies results in drift kelp that is consumed within the kelp forests and exported to adjacent habitats (e.g., beaches, deep sea)

(Harrold et al. 1988, Figurski 2010). Surface kelp canopies strongly mediate inter- and intra-specific competition for light and space among benthic algal communities (e.g., Dayton 1975, Pearse and Hines 1979, Reed and Foster 1984, Kimura and Foster 1984, Edwards 1998, Dayton et al. 1999) and influence local fish densities (Anderson 1994, Carr 1989, Holbrook et al. 1990) as well as fish movement patterns and habitat use (Freiwald 2009).

Kelp forests in central California have been studied extensively and the methods for quantifying kelp abundance and density by SCUBA surveys have been extensively tested (Carr et al. 2013) and their value in estimating ecosystem properties such as net primary productivity or diversity have been established (Reed et al. 2009). Temporal variability of kelp abundance in central California appears to be correlated with wave exposure (Harrold et al. 1988, Graham et al. 1997, Sandoval 2005), and to a lesser extent, substrate type/geology (Foster 1982a). Further, structure provided by giant kelp can greatly influence the benthic communities beneath them (Dayton 1975, Pearse and Hines 1979, Reed and Foster 1984, Kimura and Foster 1984; Dayton et al. 1999, Graham et al. 2008); and spatially discrete forests with consistent patterns of temporal variability may be correlated with characteristic species assemblages or functional groups.

Near shore reefs along the central California coast are subject to strong seasonal fluctuations of sediment dynamics due to the local wave climates. The northern hemisphere swells typically occurring over the winter month, southern hemisphere swells during the summer and wind driven waves throughout the year (Wingfield and Storlazzi 2007). Along central California up to 30% of the bedrock reefs are buried under sediment and/or exhumed in a single year (Storlazzi et al. 2011).

These burial and exhumation events can have strong effects on the local rocky reef communities. Species diversity and community composition of sessile and mobile invertebrates and algae species have been shown to be over 50% lower on reefs that underwent burial compared to rocky reef habitat not periodically buried (Storlazzi et al. 2013). Disturbed communities exhibit a subset of species found in stable habitats. These species exhibited a variety of physiological and life history adaptations that contributed to their success in sand-disturbed reef habitats such as resilient physiology of sessile species, rapid colonization, and mobility (Figurski et al. in press).

1.2 Challenges for Impact Studies

Traditional field experimental designs presume the data are sampled from a population that follows a normalized distribution curve, samples are independent and that treatments (impacts) can be replicated (Zar, 2010). These presumptions are not suited for accidental impact events (or after the fact investigations), making it necessary to control for natural variability and confounding factors that will allow justifiable findings. Unlike field experiments, environmental monitoring or impact studies carry methodological limitations and ecological assumptions. Unless an impact or man-made (anthropogenic) event is known before hand, (i.e. power plant construction) there are limitations in the design of field monitoring. The environmental monitoring of events such as forest fires, oil spills or similar unplanned events is categorized as accidental environmental impact studies. Similar to accidents, monitoring of environmental impacts after they have occurred or are ongoing cannot (or should not) be replicated therefore sampling cannot be randomized. Consequently, these types of studies have some degree of confounding factors and pseudoreplication (Underwood, 1994). Pseudoreplication is when an experiment does not have the proper replicate samples within a test factor. The sampling designs also carry methodological limitations and ecological assumptions.

Methodological issues for accidental impact studies are sampling of various exposure levels and/or the delay of observations (Wiens and Parker, 1995). As with all studies, standardizing the sampling methods and minimizing observer differences is important. Defining the appropriate scale of measurement (spatially and temporally) as well as the exposure levels can assure the data are properly measuring the effects of random and fixed factors within a sampling design.

Since Hulbert (1984) described pseudoreplication and how it can increase Type I hypothesis testing errors, ecologists have focused on eliminating pseudoreplication from their experimental designs. In impact studies, replicates taken at different times from the same area will be temporally correlated, especially with long lived species such as *Macrocystis pyrifera.* Replicates taken at the same time from impact and control sites will be spatially correlated. The degree of correlation for space and time will depend on the degree of habitat differences among and within sites. Because accidental impact studies result in impact and control sites, an ecologist can replicate control sites but it would be unacceptable (socially & professionally) to replicate impact sites. In fact, Underwood (1994) recommends that control sites be replicated even if the non-replication of impact sites creates an unbalanced statistical design.

Ideally environmental impacts are studied using a before-after-control-impact design (BACI) to evaluate the effects of anthropogenic disturbance. This approach relies on sampling before the

event and after the event, comparing impact sites and control sites. Because the Santa Cruz Harbor dredging and disposal has already occurred collecting “before” samples is impossible.
The overlying assumption for impact monitoring is that the impact and control sites are alike in all aspects except that one is impacted by some factor and the others are not (Wiens and Parker, 1995). For this reason, sites must be stratified based on existing knowledge (Peterson, 2001). Once stratification is complete, monitoring data can be used to determine natural patterns of variability and identify data gaps for the areas of interest. Based on the assumptions and limitations of accidental environmental impact studies, the most robust study designs are the level-by-time and trend-by-time designs. By using a repeated measures analysis or sampling the same sites over time, an ecologist can reduce the severity of pseudoreplication, correlation, and lack of replication.

1.3 Research Questions

This study will use a modified BACI sampling design (Underwood 1991, Smith et. al. 1993) to investigate if there are (1) differences between the impacted site and the control sites with respect to: number of kelp plants per m^2, number of stipes per m^2, and ratio of stipes to total number of plants (2) if there are differences among the three sites over time (i.e. 2010 to 2015) and (3) if there are differences between the East and West sides of the kelp patches at the control and impact sites.

2.0 Monitoring Methods

2.1 Field methods

The study area is located offshore of the Santa Cruz harbor and is an area approximately 1.5 km by 4.5 km (Figure 1). Three kelp forests were identified within this area and chosen as monitoring sites. The respective kelp forest areas are Blacks Point (near Twin Lakes beach), Pleasure Point and Steamers (Mitchell Cove). The Blacks Point kelp forest site is down current of the dredging release point and has been chosen as a monitoring (i.e. impact) site. The Pleasure Point and Steamers kelp forests were surveyed as control sites.

Because of the unique assumptions pertaining to accidental (i.e. oil spills; refer to section 1.2) environmental impact studies, it's best to account for confounding variables or covariates. This can be accomplished by identifying the obvious environmental factors. Sandoval & Associates indentified four important environmental factors that have the potential to confound the results of the study: depth, long shore current, site habitat differences and sediment plume effects. To account for depth and current, a stratified design was implemented (Zar, 2010). Habitat differences are accounted for by utilizing multiple control sites. One of the control sites (Pleasure Point) in the current study was identified as impact site in S&A's 2008-10 study (Sandoval & Associates, 2011). But since no impact was detected at this site it is used as control in the current study.

Figure 1. Study Area. Green areas indicate the approximate location of kelp forests; yellow points are SCUBA monitoring dive locations.

Due to *M. pyrifera's* alternating life cycle (Abbott and Hollenberg, 1976, Dawson and Foster, 1982, see Figure 2), S&A is sampling of adult sporophyte plants to monitor the kelp forest. We are employing a swath sampling methods to estimate the density of conspicuous (i.e. taller than 1 m) *M. pyrifera*. Individual plants are counted along a 30 m long x 2 m wide transect. Typically, a diver slowly swims one direction counting targeted plants and then swims back counting stipes of each plant (Figure 3). The number of stipes at 1 m above the substrate of each *M. pyrifera* plant is entered on the datasheet. This survey methodology is consistent with other kelp forest research and information from this study may therefore be compared to historical information.

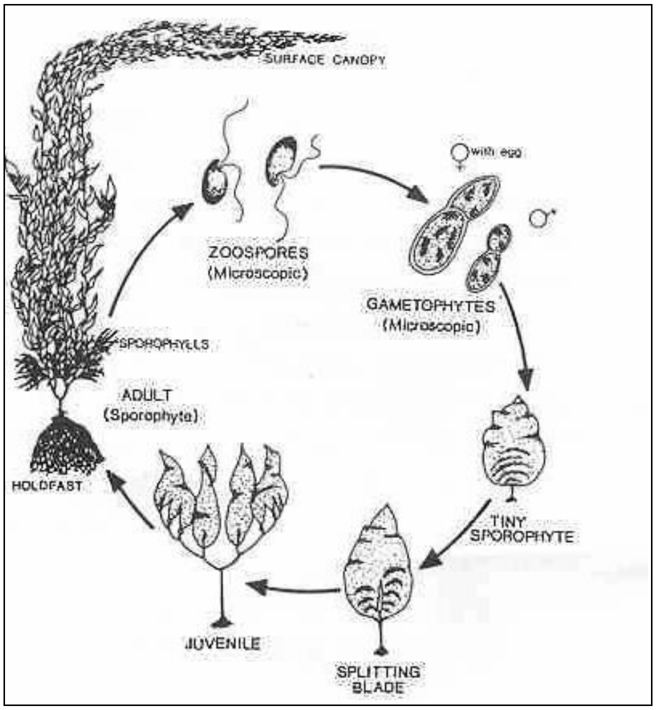


Figure 2. Life cycle of the giant kelp Macrocystis pyrifera (from Foster & Schiel 1985)

To ensure that the entire kelp forest is sampled representatively, benthic transects are stratified across the face of the reef (alongshore and cross-shore). Two areas of a kelp forest (east and west) constitute a site and transects are placed within 5-8 m depth at each area. In order to maintain an orthogonal design for the modified BACI sampling design the number of transect varied among impact and control sites so that a total of 12 transacts were completed in the impact site (6 transects in each area, east and west respectively) and a total of 12 transects were conducted in the controls sites (i.e. 6 transects at each control site, 3 east and west, respectively). Transects were placed randomly along isobaths (constant depth) parallel to shore in each area (Figure 4). To avoid direction bias (in the direction of kelp holdfasts), pre-assigned compass headings were used to minimize bias. If a diver deploying a transect on a predetermined bearing encounters > 10 m of sand, he/she will alter the bearing to get back onto rocky reef substrate. If he/she does not pass any kelp and/or rocky substrate (bedrock or boulders) coming up through the sand in < 10 m, the transect will be voided and redeployed once they have found the reef again (Freiwald, et al. 2013). On the other hand, if divers encounter algae emerging from the sand frequently, this suggests they are surveying rocky reef habitat that has been recently covered with sand and will continue the transect according to the heading.

Figure 3. SCUBA divers setting up an underwater transect for kelp forest sampling.

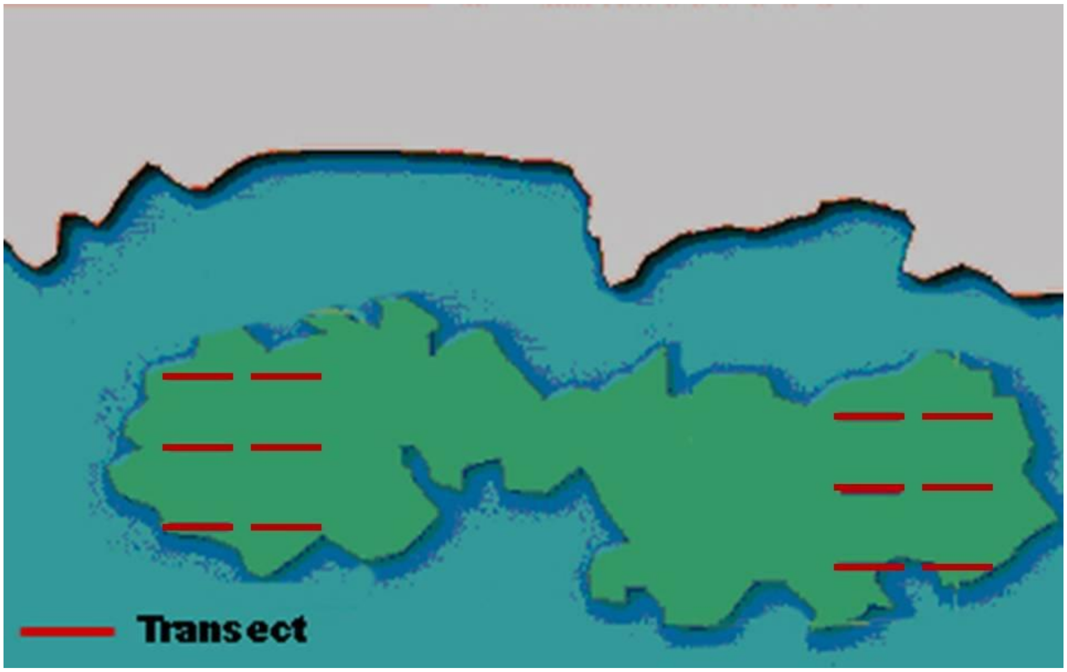


Figure 4. Study Site Sampling Design. Red line indicates a swath transect located on the east and west sides of a site. Green areas indicate the approximate location of a kelp forest site.

2.1 Data Analysis

Field (SCUBA) data were using a three-way Permutation Analyses of Variance (PANOVA) conducted using the *lmp()* function in the *lmPerm* R package (R Core Team 2013). Site (Steamers, Pleasure Point and Blacks), Year (2010, 2013 2014, 2015) and Patch Side (East, West) were used as the independent variables. Separate analyses were conducted for each of three dependent variables: Plant density (number of plants per m^2), Stipe Density (number of stipes per m^2) and Stipe per Plant (ratio of stipes/plants). Because of restrictions on randomization, conclusions drawn from results are restricted to the three sites. In previous analyses, Levenes's tests of homogeneity of variance indicated that variances were not homoscedastic and transforms failed to correct the problem (Sandoval & Associates, 2014). Therefore, the use of a standard 3-way ANOVA was contraindicated. When sample sizes are equal, departures from the assumption of equality of variance are less problematic with a permutation test (Box and Anderson, 1955; Hayes 2000). To investigate differences among impact and control sites two planned comparisons for each dependent variable was conducted. The first comparison examined the difference between Pleasure Point and Steamers combined versus Blacks. In the second planned comparison, Steamers was compared to Pleasure Point. Planned comparisons among factors (i.e. impact vs. controls) were computed with *testFactors()* in the Phia R package . Planned comparisons for interactions were computed with *testInteractons()* in the Phia R package. To investigate changes in the differences among the sites over time we examined the Site by Year and Site by Year by Side interactions in the three way PANOVA. A significant Site by Year interaction would indicate that the magnitude of differences among sites changed over the years. A significant Site by Year by Side interaction would mean that the magnitude of the interaction between Site and Side changed with respect to years. To investigate differences between the East and West sides of the kelp patches; planned comparisons were computed for each interaction containing the Side independent variable.

Power of each test was computed using G*Power 3.1.6. Effect sizes for each test were computed as follows:

Simple Effect Size = $\sqrt{\frac{MS_{Effect}}{MS_{Error}}}$.

Effect Size as computed in G-Power ™ 3.1.6 $\sqrt{\left(df_{Effect} * F_{Effect} \big/ Total\ n\right)}$

3.0 Results

Twelve transects (six at each side of the kelp bed) were completed at the impact site (Blacks) and six transects (three at each side of the kelp bed, respectively) were completed at each of the control sites (Steamers and Pleasure Point) between September 14th – 16th, 2015. The summary statistics for the surveys from all years for the three dependent variables (Kelp Plant Density, Stipe Density, and Stipes per Plant) are summarized in Table 1. Overall, Pleasure Point has the highest mean values and Blacks the lowest values for all three variables and means at both control sites are higher than at the impact site for all variables. Summaries of the means and Standard deviations of all three variables for all years for the east and west side of the three study sites are provided in (Table 1)

Table 1. Sample size (N), mean and standard deviation of the three measurements (Plant Density, Stipe Density and Stipe/Plant ratio) for each site across all years of the study (2010, 2013, 2014, 2015).

		N	Mean	Std. Deviation
Site	**Measure**	Statistic	Statistic	Statistic
Blacks	Plant per m^2	48	0.192	0.161
	Stipe per m^2	48	4.123	3.846
	Stipe/plant	47	25.211	16.211
Pleasure Point	Plant per m^2	24	0.233	0.151
	Stipe per m^2	24	6.767	4.322
	Stipe/plant	24	48.815	72.622
Steamers	Plant per m^2	24	0.228	0.190
	Stipe per m^2	24	5.883	4.121
	Stipe/plant	23	48.735	64.418

3.1 Kelp Plant Density

The three-way Permutation Analyses of Variance (PANOVA) for differences in plant density (number of plants/m^2) indicated that there were no significant differences in kelp plant densities between the three sites or between the east or west side of the kelp beds (Table 2). However, there was a significant effect of year on the plant density ($p< 0.000$). This means that one or more years were statistically different from other years. Interaction between the plant density in 2015 vs. all previous years ($p < 0.000$) and between 2014 and all previous years ($p < 0.000$) were both significant as indicated by the planned comparisons but differences between 2013 and 2010 were

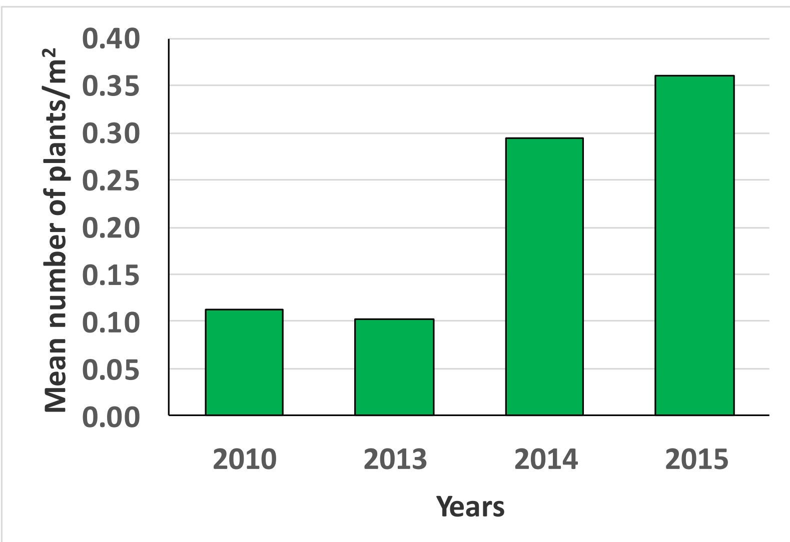


Figure 5. Composite of significant planned comparisons for factor Years in mean number of plants per m2 from a 3-way PANOVA. Horizontal bar indicates groups were not significantly different.

not significant (Figure 5). Due to the gap in sampling between 2010 and 2013 it is difficult to infer plant density trends in the early years of the study but in recent years there seems to be an increase in kelp plant density across all three study sites. These trends seem to be constant across sites as indicated by the non-significant results of all planned comparisons for site by year interactions with the exception of the comparison between the two control sites when 2015 is compared to the previous years (Table 2). This difference between the control sites was driven by an increase in plant density at Pleasure Point in 2015 (Appendix 1).

Despite there being no overall effect of patch side (east, west), there is an interaction between the side of the kelp beds when the impact site is compared to the two controls ($p < 0.000$) (Table 2). The mean plants density at the impact site was not different from the control sites on the west side but, on the east side, it was lower than the two control sites (Figure 6).

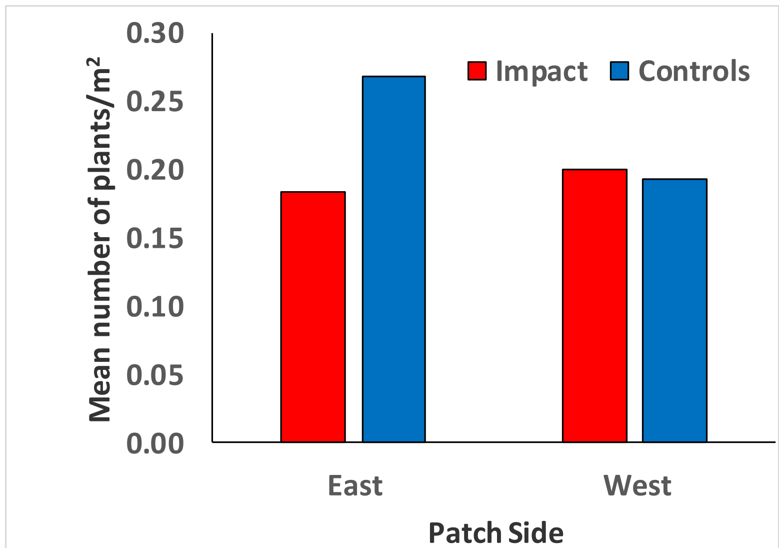


Figure 6. Significant Treatment (Blacks = Impact, Steamers & Pleasure Point=Controls) vs Patch Side (East, West) interaction in mean number of plants per m2 from a 3-way PANOVA.

Table 2: Three - Way PANOVA for examining differences in mean number of plants per m^2 among three factors, Site (Blacks, Steamers, Pleasure point), Patch Side (East, West) and Year (2010, 2013, 2014, 2015). Planned comparisons are included for Site (Blacks vs Steamers&Pleasure Point; Steamers vs Pleasure point) and Year (2010&2013&2014 vs 2015; 2010&2013 vs 2014; 2010 vs 2013). Potential power problems are indicated as "Suspect" when 0.05<Pr(>F)≤0.8 and Power<0.6.

Source	Df	Sum Sq	Mean Sq	Iterations	Pr(>F)	Sig.	Effect Size	Effect Size G-Power	Power
Site (Blacks, Steamers & Pleasure Point)	2	0.0359	0.0180	1,402	0.139		1.201	0.173	0.309
B vs S&P	1	0.0356	0.0356		0.095		1.692	0.173	0.389
S vs P	1	0.0003	0.0003		0.881		0.150	0.015	0.052
Side (E and W)	1	0.0435	0.0435	1,446	0.065		1.870	0.191	0.457
Year (2010, 2013, 2014, 2015)	3	1.0922	0.3641	5,000	0.000	***	5.408	0.956	1.000
Prev vs 2015	1	0.2137	0.2137		0.000	***	4.143	0.423	0.984
Prev vs 2014	1	0.2497	0.2497		0.000	***	4.478	0.457	0.993
2010 vs 2013	1	0.0458	0.0458		0.059		1.918	0.196	0.476
Site*Side	2	0.0537	0.0269	2,114	0.085		1.469	0.212	0.431
B vs S&P	1	0.3781	0.3781		0.000	***	5.511	0.562	1.000
S vs P	1	0.0123	0.0123		0.324		0.994	0.101	0.165
Site*Year	6	0.2181	0.0364	5,000	0.014	*	1.709	0.427	0.875
B vs S&P,Prev vs 2015	1	0.0256	0.0256		0.156		1.435	0.146	0.293
B vs S&P,Prev vs 2014	1	0.0163	0.0163		0.256		1.145	0.117	0.206
B vs S&P,2010 vs 2013	1	0.0006	0.0006		0.830		0.216	0.022	0.055
S vs P, Prev vs 2015	1	0.1376	0.1376		0.001	**	3.325	0.339	0.908
S vs P, Prev vs 2014	1	0.0113	0.0113		0.345		0.951	0.097	0.156
S vs P, 2010 vs 2013	1	0.0267	0.0267		0.148		1.464	0.149	0.304
Side*Year	3	0.0591	0.0197	3,530	0.189		1.258	0.222	0.402
Site*Side*Year	6	0.1111	0.0185	3,458	0.186		1.220	0.305	0.543
B vs S&P, Prev vs 2015, Side	1	0.0003	0.0003		0.881		0.150	0.015	0.052
B vs S&P, Prev vs 2014, Side	1	0.0389	0.0389		0.081		1.768	0.180	0.415
B vs S&P, 2010 vs 2013 Side	1	0.0033	0.0033		0.607		0.517	0.053	0.081
S vs P, Prev vs 2015, Side	1	0.0032	0.0032		0.614		0.507	0.052	0.080
S vs P, Prev vs 2014, Side	1	0.0341	0.0341		0.102		1.655	0.169	0.374
S vs P, 2010 vs 2013, Side	1	0.0313	0.0313		0.117		1.586	0.162	0.348
Residuals	72	0.8966	0.0125						

3.2 Stipe density

Kelp stipe density is an estimation of the numbers if *Macrocystis* stipes per unit of space regardless of the number of individual plants. The three-way Permutation Analyses of Variance (PANOVA) test for differences in stipe density (number of stipes/m^2) showed significant main effects of site, year and side but none of their interactions showed significant results (**Table 3**). The significant effect of site on the stipe density of giant kelp was driven by the higher densities at the control sites vs. the impact site as identified in the significant ($p = 0.004$) planned comparison between the impact vs. control sites (Figure 7). However, this conclusion should be mediated by significant planned comparison of the interaction between site and year (Table 3). As with plant density, the stipes density is higher at the control sites in the east than in the west and higher overall compared to the impact site (Figure 8). Similarly, there is an interaction between the patch sides within the two control sites (**Table 3**).

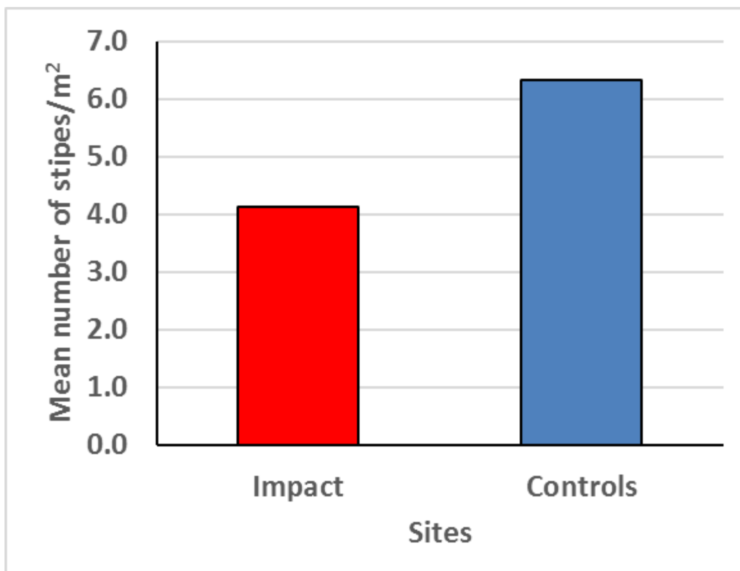


Figure 7: Significant Control vs Impact planned comparison in mean number of stipes per m2 from a 3-way PANOVA.

The PANOVA indicated a significant difference (p=0.021) in stipe density among years but none of the planned comparisons indicated a significant trend with time. Nevertheless, there seems to be an increase in number of stipes/m2 in recent years from a low level in 2013 to densities previously seen in 2010 (Figure 9).

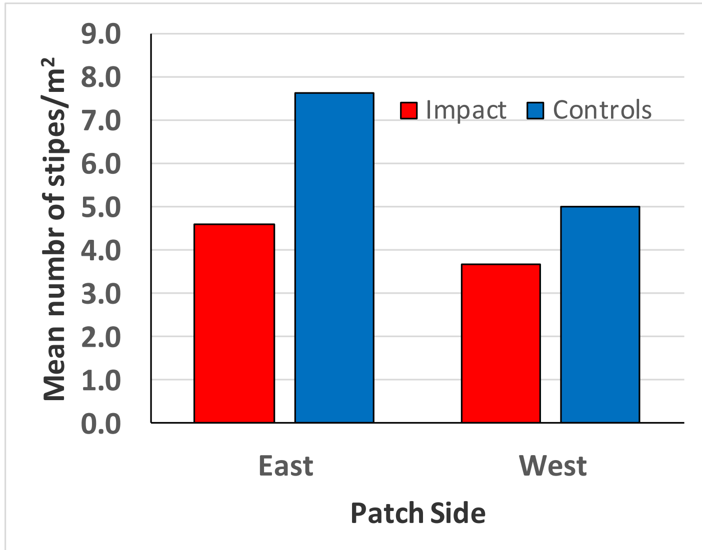


Figure 8. Significant interaction planned comparison between Treatments (Blacks=Impact, Steamers & Pleasure Point=Controls) and Patch Side (East, West) in mean number of stipes per m2 from a 3-way PANOVA.

In both 2010 and 2013, mean stipe density was greater at the control sites than at the impact site but this trend reversed in 2014 (Figure 10) as identified by the significant interaction (p=0.007) in the planned comparison.

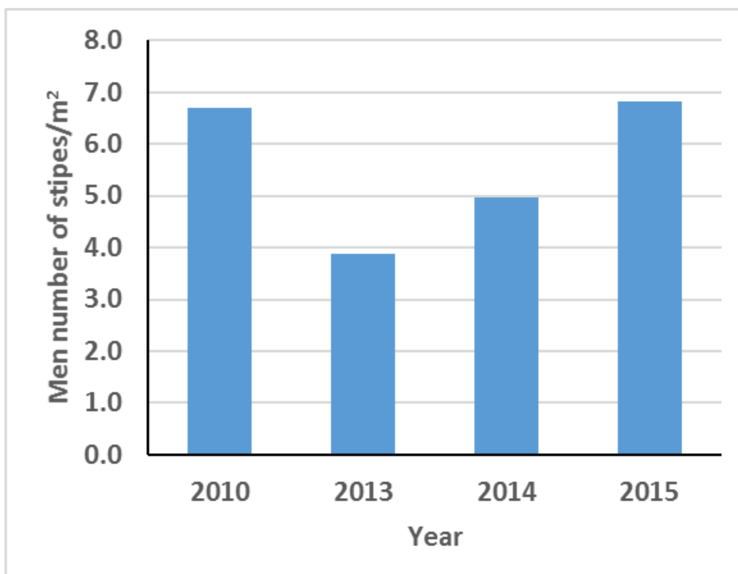


Figure 9. Mean number of stipes/m2 across years at all three study sites

In 2015, there was no significant interaction between treatment and time when compared to the previous years (Table 3). Therefore, we cannot identify a clear temporal trend but rather variability in the stipe densities across years and sites.

Overall, the stipe densities are higher on the east side of the study sites compared to the west (Figure 11) and there were no interactions between the patch sides and time (Table 3) suggesting this is not a cumulative effect and that this pattern doesn't change over time.

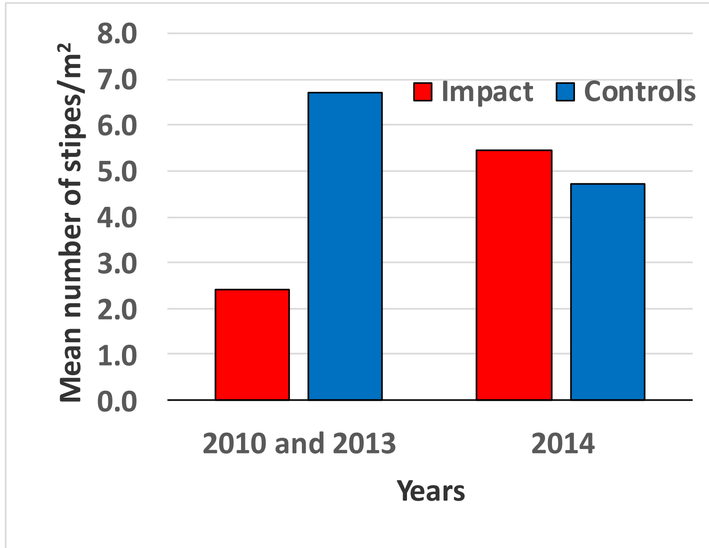


Figure 10. Significant interaction planned comparison between Treatments (Blacks=Impact, Steamers&Pleasure Point=Controls) and Years (2010&2013, 2014) in mean number of stipes per m2 from a 3-way PANOVA.

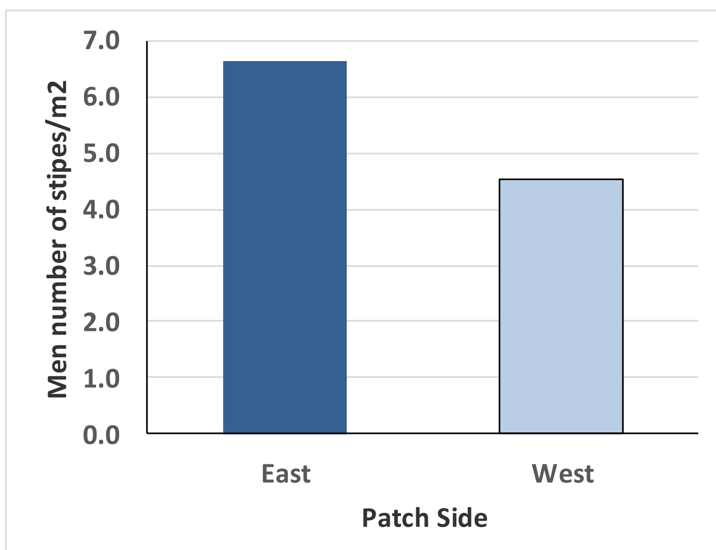


Figure 11. Significant Patch Side (East, West) effect in mean number of stipes per m2 from a 3-way PANOVA.

Table 3. Three - Way PANOVA for examining differences in mean number of stipes per m2 among three factors, Site (Blacks, Steamers, Pleasure point), Patch Side (East, West) and Year (2010, 2013, 2014, 2015). Planned comparisons are included for Site (Blacks vs Steamers&Pleasure Point; Steamers vs Pleasure point) and Year(2010&2013&2014 vs 2015; 2010&2013 vs 2014; 2010 vs 2013). Potential power problems are indicated as "Suspect" when $0.05<Pr(>F)\leq 0.8$ and $Power<0.6$.

Source	Df	Sum Sq	Mean Sq	Iterations	Pr(>F)	Significance	Effect Size	Effect Size G-Power	Power
Site (Blacks, Steamers & Pleasure Point)	2	125.79	62.90	5000	0.003	**	4.762	0.315	0.781
B vs S&P	1	116.42	116.42		0.004	**	8.815	0.303	0.836
S vs P	1	9.38	9.38		0.402		0.710	0.086	0.132
Side (E and W)[7]	1	93.92	93.92	5000	0.016	*	7.111	0.272	0.751
Year (2010, 2013, 2014, 2015)	3	132.07	44.02	5000	0.021	*	3.333	0.323	0.742
Prev vs 2015	1	17.24	17.24		0.257		1.305	0.117	0.206
Prev vs 2014	1	32.92	32.92		0.119		2.493	0.161	0.345
2010 vs 2013	1	17.04	17.04		0.260		1.290	0.116	0.203
Site*Side	2	18.84	9.42	88	0.796		0.713	0.122	0.167
B vs S&P	1	85.56	85.56		0.013	*	6.478	0.260	0.713
S vs P	1	69.15	69.15		0.025	*	5.236	0.234	0.621
Site*Year	6	167.65	27.94	5000	0.052		2.116	0.364	0.730
B vs S&P,Prev vs 2015	1	12.36	12.36		0.337		0.936	0.099	0.160
B vs S&P,Prev vs 2014	1	101.76	101.76		0.007	**	7.705	0.283	0.783
B vs S&P,2010 vs 2013	1	9.83	9.83		0.391		0.744	0.088	0.137
S vs P, Prev vs 2015	1	15.74	15.74		0.279		1.192	0.111	0.190
S vs P, Prev vs 2014	1	5.16	5.16		0.534		0.391	0.064	0.095
S vs P, 2010 vs 2013	1	22.82	22.82		0.193		1.728	0.134	0.245
Side*Year	3	4.34	1.45	83	1.000		0.110	0.059	0.069
Site*Side*Year	6	146.38	24.40	1094	0.107		1.847	0.340	0.653
B vs S&P, Prev vs 2015, Side	1	18.07	18.07		0.246		1.368	0.119	0.212
B vs S&P, Prev vs 2014, Side	1	15.90	15.90		0.276		1.204	0.112	0.192
B vs S&P, 2010 vs 2013 Side	1	9.23	9.23		0.406		0.699	0.085	0.131
S vs P, Prev vs 2015, Side	1	51.19	51.19		0.053		3.876	0.201	0.495
S vs P, Prev vs 2014, Side	1	17.50	17.50		0.254		1.325	0.117	0.205
S vs P, 2010 vs 2013, Side	1	34.48	34.48		0.111		2.611	0.165	0.359
Residuals	72	950.92	13.21						

3.3 Stipes per plant

The three-way Permutation Analyses of Variance (PANOVA) test for differences in the ratio of stipes per plant indicated significant differences between the sites (p=0.025), and study years (p <0.000) (**Table 4**). The control sites had great stipe/plant ratios than the impact site (Figure 12) However, this needs to be interpreted in light of the interaction of the planned comparisons of Site, Year and Side.

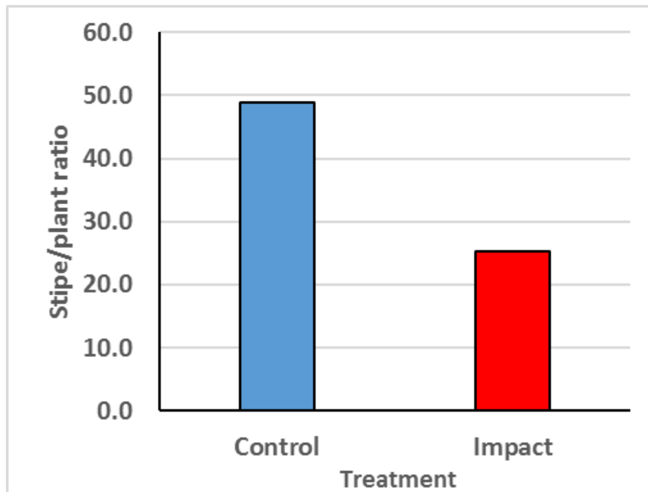


Figure 12. Significant Control vs Impact planned comparison in mean Stipe/plant ratio from a 3-way PANOVA.

In 2010 and 2103, the mean stipe/plant ratio was lower in the impact site than in the control sites but the trend stopped or reversed in 2014 (Figure 13). This was indicated by the significant (p=0.008) interaction planned comparison between the treatments (Impact, Controls) and Year (prev vs. 2014).

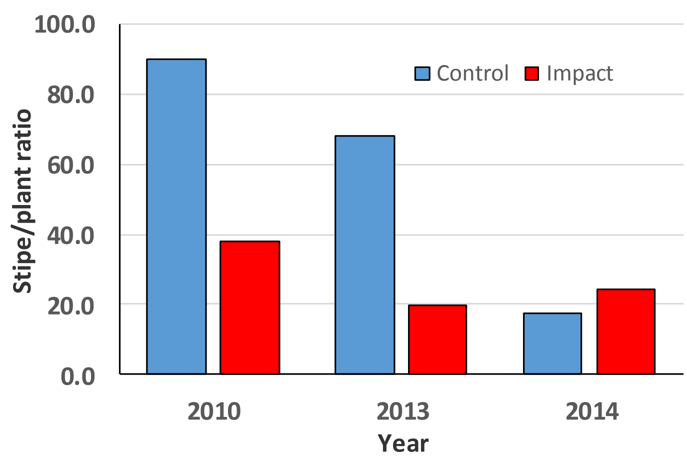
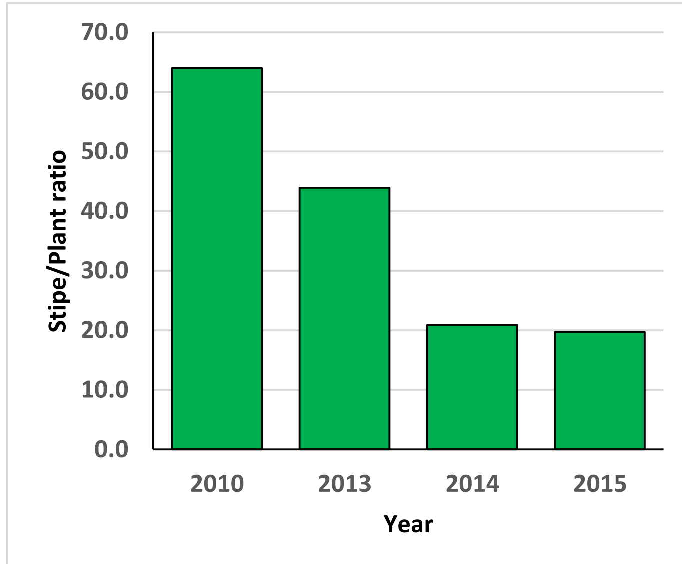


Figure 13. Significant interaction planned comparison between Treatments (Blacks=Impact, Steamers&Pleasure Point=Controls) and Year (2010&2013, 2014) in mean stipe/plant ratio from a 3-way PANOVA.

The mean Stipe/plant ratio in 2015 and 2014 was less than in previous years, respectively as indicated by the significant (p<0.001) 2015 versus previous years planned comparison as well as the significant (p=0.002) 2014 vs previous years comparison but the non-significant (p=0.107) 2010 versus 2013 comparison (Figure 14).

Figure 14. Composite of significant planned comparisons for factor Years in mean Stipe/plant ratio from a 3-way PANOVA.



The stipe/plant ratio varied over the years between the east and west sides of the study sites and between years as indicated by the significant planned comparisons between site and year as well as between site, year and side (**Table 4**). These make the interpretation of the main effects difficult, especially because the dynamics between the two control sites showed significant differences between east and west sides (Figure 15) and over the years (Figure 16). Further, the stipe/plant ratio decreased in the years 2010 and 2013 on the east sides of the control sites so that control and impact sites were more similar in 2013 on the east but on the west sides of sites the opposite trend was observed with the ratio increasing at the control sites but not at the impact site indicated by the significant (p=0.002) interaction planned comparison between treatments (Impact, Controls), Years (2010, 2013) and Patch Side (E, W) (Figure 17).

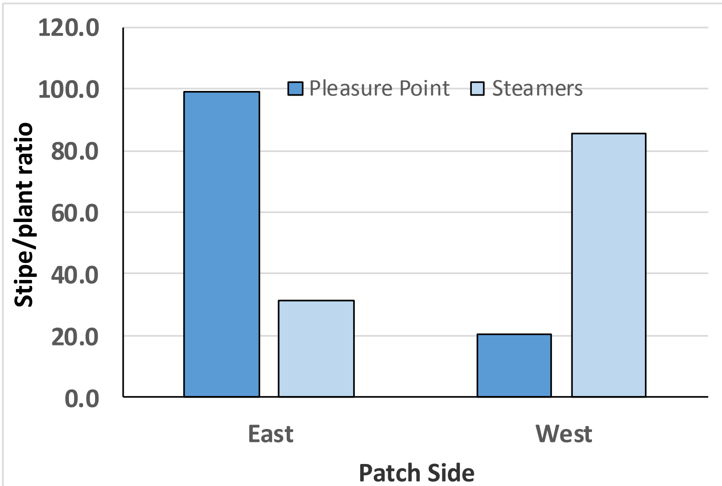


Figure 15. Significant Site (Pleasure Point, Steamers) * Patch side (East, West) interaction planned comparisons for mean Stipe/plant ratio from a 3-way PANOVA.

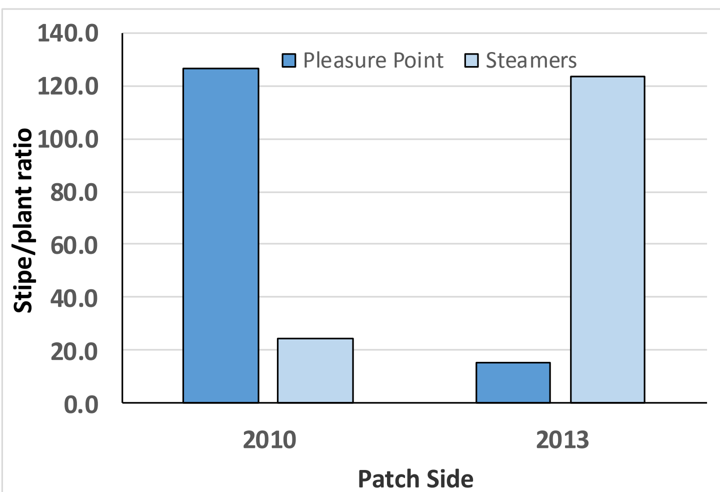


Figure 16. Significant Site (Pleasure Point, Steamers) * Year (2010, 2013) interaction planned comparisons for mean Stipe/plant ratio from a 3-way PANOVA.

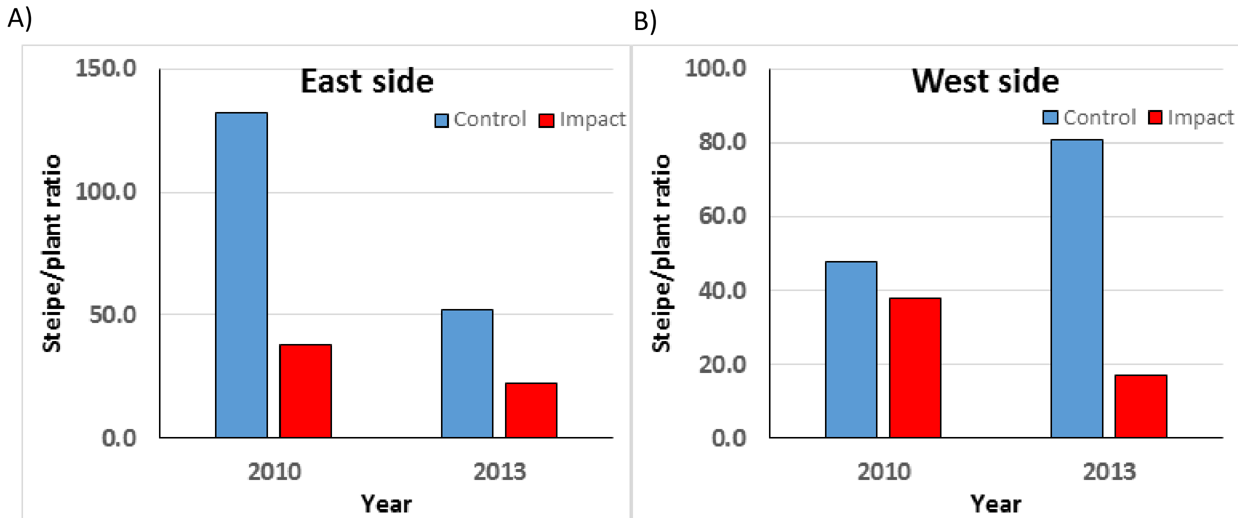


Figure 17. Significant interaction planned comparison between Treatments (Blacks=Impact, Steamers & Pleasure Point=Controls), Year (2010&2013, 2014) and Patch side (East, West) in mean Stipe/plant ratio from a 3-way PANOVA. Figure 11A illustrates values from the East patch side and Figure 11B illustrates values from the West patch size.

Table 4. Three - Way PANOVA for examining differences in mean stipe/plant ratio among three factors, Site (Blacks, Steamers, Pleasure point), Patch Side (East, West) and Year (2010, 2013, 2014, 2015). Planned comparisons are included for Site (Blacks vs Steamers & Pleasure Point; Steamers vs Pleasure point) and Year(2010&2013&2014 vs 2015; 2010&2013 vs 2014; 2010 vs 2013).

Source	Df	Sum Sq	Mean Sq	Iterations	Pr(>F)	Significance	Effect Size	Effect Size G-Power	Power
Site (Blacks, Steamers & Pleasure Point)	2	13495.00	6747.50	5000	0.025	*	4.019	0.292	0.702
B vs S&P	1	13494.56	13494.56		0.006	**	8.038	0.292	0.800
S vs P	1	3.30	3.30		0.965		0.002	0.005	0.050
Side (E and W)	1	2366.00	2366.00	463	0.179		1.409	0.122	0.189
Year (2010, 2013, 2014, 2015)	3	43024.00	14341.33	5000	0.000	***	8.542	0.522	0.992
Prev vs 2015	1	28604.73	28604.73		0.000	***	17.038	0.426	0.983
Prev vs 2014	1	16755.13	16755.13		0.002	**	9.980	0.326	0.879
2010 vs 2013	1	4468.89	4468.89		0.107		2.662	0.168	0.364
Site*Side	2	7595.00	3797.50	3377	0.112		2.262	0.219	0.448
B vs S&P	1	2949.00	2949.00		0.189		1.756	0.137	0.260
S vs P	1	7996.00	7996.00		0.032	*	4.763	0.225	0.579
Site*Year	6	32821.00	5470.17	5000	0.005	**	3.258	0.456	0.913
B vs S&P,Prev vs 2015	1	3727.00	3727.00		0.141		2.220	0.154	0.315
B vs S&P,Prev vs 2014	1	12586.00	12586.00		0.008	**	7.497	0.282	0.772
B vs S&P,2010 vs 2013	1	46.00	46.00		0.869		0.027	0.017	0.053
S vs P, Prev vs 2015	1	319.00	319.00		0.664		0.190	0.045	0.072
S vs P, Prev vs 2014	1	109.00	109.00		0.800		0.065	0.026	0.052
S vs P, 2010 vs 2013[14]	1	16891.00	16891.00		0.002	**	10.061	0.327	0.057
Side*Year	3	15560.00	5186.67	5000	0.018	*	3.089	0.314	0.703
Site*Side*Year	6	20863.00	3477.17	5000	0.065		2.071	0.364	0.712
B vs S&P, Prev vs 2015, Side	1	408.00	408.00		0.624		0.243	0.051	0.078
B vs S&P, Prev vs 2014, Side	1	1385.00	1385.00		0.367		0.825	0.094	0.147
B vs S&P, 2010 vs 2013 Side	1	9630.00	9630.00		0.019	*	5.736	0.247	0.658
S vs P, Prev vs 2015, Side	1	4689.00	4689.00		0.099		2.793	0.172	0.378
S vs P, Prev vs 2014, Side	1	3554.00	3554.00		0.150		2.117	0.150	0.301
S vs P, 2010 vs 2013, Side	1	917.00	917.00		0.462		0.546	0.076	0.113
Residuals	72	117524.00	1678.91						

4.0 Discussion and Recommendations

This study used three estimators to investigate potential effects of harbor dredge deposit offshore of Twin Lakes Beach. The response variables are *Macrocystis* plant density, stipe density and the ratio of stipes per plant. These variables were measured using scuba divers at three kelp forest sites Blacks, Pleasure Point and Steamers over four years (2010, 2013, 2014 and 2015). Pleasure Pt. and Streamers are used as the control sites and are assumed not to be affected by the dredging material. This assumption is based on their distance from the impact sites and the results from a previous monitoring study conducted by Sandoval & Associates at these sites that showed no effects of the harbor dredge deposit on the Pleasure Point site (Sandoval & Associates, 2011). The *Macrocystis* abundance at the sites is within the range of other sample sites in the Monterey Bay (Sandoval, 2005). Two of the variables are descriptors of the *Macrocystis* population at the sites (i.e. density of individuals (plants) or density of kelp stipes) and one variable, stipes/plant, is an estimate of individual plant size and not a population level response variable.

Both, kelp plant densities and kelp stipe densities increased in recent years at all three study sites. Plant densities seemed to not have changed between 2010 and 2013 but in subsequent years they have more than tripled and this patterns seems to be holding across all three sites as we did not detect any significant site by year interactions other than a somewhat greater increase in density at one of the control sites compared to the other in 2015. While there was also an overall increase in stipe densities in recent year, 2015 density seems similar to densities detected in 2010. Stipe/plant ratios were decreasing over the time period of the study from around 60 stipes per plant in 2010 to under 20 stipes in 2015. Together these patterns suggest that more plants with less stipes each are present in the later years of the study. This would be consistent many smaller plants replacing the fewer larger plants counted in the earlier years. *Macrocystis* stipe density is a better estimator of kelp biomass as well as net primary productivity than plant density in a kelp forest (Reed et al. 2009). As stipe density levels were similar in 2010 and 2015 this change from large mature plants to smaller younger plants might not have had much of an effect on the standing biomass or productivity of these kelp forests.

As in previous report (2013), stipe densities were lower at the impact site than the control sites, however this pattern seems to change over the years and was reversed in 2014 when stipe densities were higher at the impact site than the controls. Similarly, overall stipe/plant ratio was higher at the control sites (i.e. large plants) than the impact sites but this pattern, again, was reversed in 2014 when the ratio was lower at the control sites. Therefore, for both of these response variables we cannot identify a clear trend in their dynamics when comparing impact and control sites. For kelp plant density we did not detect any site effects suggesting that this response variable shows similar densities across impact and control sites.

For kelp stipe density there were several interactions between kelp bed side (i.e. east, west) and impact vs. control sites as well as between the two control sites but the trends were similar at all sites with the east having lower densities than the west side. Plant density showed a difference between impact and control sites with respect to the east or west side of the kelp beds. On the east plant density was higher at the control sites but densities were similar on the west side of the control and impact sites. Stipe/plant ratio did not show an overall difference between the east and west sides of the beds but there were several interactions demonstrating changing dynamics on the east vs. west among years and sites. As currents transporting sediment are typically coming out of the west in this region and if resulting sediment deposits had an impact on the response variables (i.e. densities or ratio) they would be expected to be stronger on the west sides of the kelp beds. The results for stipe and plant density seem to support this notion. For stipe density this independent of impact or control 'treatment', whereas for plant density this seems more pronounced at the control sites than the impact site.

It is interesting to note that prior in the 2015 sampling no dredging operations took place over the preceding stormy season. Therefore, differences seen between the 2014 and 2015 sampling are unlikely to be the direct result of dredge deposits near the impact site. Since this study did not investigate changes in kelp densities before the dredging began (i.e. full BACI design), we cannot evaluate if the kelp densities at the impact site are correlated to the dredge deposits. We can only evaluate if changes have occurred over the time period of the study. While we see lower kelp stipe densities in 2015 at the impact site the interactions of the planned comparisons between the kelp bed sides at the three sites as well as the significant planned comparisons between treatment and years make it difficult to interpret this result and suggest densities at control and impact sites change annually. It is important to note that kelp forests are extremely variable both spatially and temporally and effects can be delayed with spatio/temporal autocorrelation. (Dayton and Tegner, 1984, Dayton et.al., 1984, and Dayton et.al., 1992). If the current dredging volume, conditions and deposit location are kept constant, any effects on the nearby kelp forest (impact site) may not be detectable above the ambient variability of the system.

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Appendix 1

Summary statistics for the three response variables: plant density, stipe density and stipe/plant ratio. Replication (N), means and standard deviation are reported for each study year and summarized by patch side for the impact and each control site.

Appendix Table 1. : Means and standard deviations for the impact site (Blacks) for each patch side (East or West) of the three measurements (Plant Density- number of plants/m2, Stipe Density - number of stipes/m2 sites and Stipe/Plant ratio – Number of Stipes per plant

Blacks- East Side					Blacks- West Side				
Year	Measure	N	Mean	Std. Deviation	Year	Measure	N	Mean	Std. Deviation
2010	Plants per m2	6	0.078	0.046	**2010**	Plants per m2	6	0.089	0.053
	Stipes per m2	6	2.547	1.860		Stipes per m2	6	3.928	2.932
	Stipe/Plant Ratio	6	37.813	26.176		Stipe/Plant Ratio	6	38.067	20.694
	Valid N (listwise)	6				Valid N (listwise)	6		
2013	Plants per m2	6	0.081	0.044	**2013**	Plants per m2	6	0.086	0.070
	Stipes per m2	6	1.925	1.768		Stipes per m2	6	1.286	0.828
	Stipe/Plant Ratio	6	22.208	9.871		Stipe/Plant Ratio	5	16.883	4.438
	Valid N (listwise)	6				Valid N (listwise)	6		
2014	Plants per m2	6	0.217	0.063	**2014**	Plants per m2	6	0.239	0.044
	Stipes per m2	6	6.122	3.389		Stipes per m2	6	4.811	1.396
	Stipe/Plant Ratio	6	27.495	10.536		Stipe/Plant Ratio	6	20.755	7.443
	Valid N (listwise)	6				Valid N (listwise)	6		
2015	Plants per m2	6	0.358	0.229	**2015**	Plants per m2	6	0.386	0.188
	Stipes per m2	6	7.811	7.963		Stipes per m2	6	4.553	2.431
	Stipe/Plant Ratio	6	21.934	15.501		Stipe/Plant Ratio	6	15.147	12.280
	Valid N (listwise)	6				Valid N (listwise)	6		

Appendix Table 2. Means and standard deviations for the Pleasure Point control site for each patch side (East or West) of the three measurements (Plant Density- number of plants/m2, Stipe Density - number of stipes/m2 sites and Stipe/Plant ratio – Number of Stipes per plant.

Pleasure Point - East Side					Pleasure Point - West Side				
Year	Measure	N	Mean	Std. Deviation	Year	Measure	N	Mean	Std. Deviation
2010	Plants per m2	3	0.061	0.035	**2010**	Plants per	3	0.167	0.000
	Stipes per m2	3	9.794	5.267		Stipes per	3	7.217	6.241
	Stipe/Plant	3	190.556	149.812		Stipe/Plant	3	43.300	37.447
	Valid N	3				Valid N	3		
2013	Plants per m2	3	0.222	0.025	**2013**	Plants per	3	0.111	0.077
	Stipes per m2	3	9.956	4.378		Stipes per	3	4.072	3.422
	Stipe/Plant	3	45.256	21.615		Stipe/Plant	3	34.361	5.793
	Valid N	3				Valid N	3		
2014	Plants per m2	3	0.544	0.082	**2014**	Plants per	3	0.228	0.059
	Stipes per m2	3	7.400	5.663		Stipes per	3	2.517	0.606
	Stipe/Plant	3	14.963	13.824		Stipe/Plant	3	11.847	5.552
	Valid N	3				Valid N	3		
2015	Plants per m2	3	0.283	0.145	**2015**	Plants per	3	0.244	0.020
	Stipes per m2	3	5.961	3.339		Stipes per	3	7.222	2.109
	Stipe/Plant	3	20.912	3.334		Stipe/Plant	3	29.324	7.070
	Valid N	3				Valid N	3		

Appendix Table 3. : Means and standard deviations for the Steamers control site for each patch side (East or West) of the three measurements (Plant Density- number of plants/m2, Stipe Density - number of stipes/m2 sites and Stipe/Plant ratio – Number of Stipes per

Steamers - East Side

Year	Measure	N	Mean	Std. Deviation
2010	Plants per m2	3	0.178	0.108
	Stipes per m2	3	11.483	4.879
	Stipe/Plant Ratio	3	73.885	25.438
	Valid N (listwise)	3		
2013	Plants per m2	3	0.061	0.092
	Stipes per m2	3	2.950	3.985
	Stipe/Plant Ratio	2	63.450	26.234
	Valid N (listwise)	3		
2014	Plants per m2	3	0.317	0.200
	Stipes per m2	3	3.389	0.352
	Stipe/Plant Ratio	3	15.775	13.245
	Valid N (listwise)	3		
2015	Plants per m2	3	0.478	0.092
	Stipes per m2	3	10.267	3.233
	Stipe/Plant Ratio	3	22.282	9.127
	Valid N (listwise)	3		

Steamers - West Side

Year	Measure	N	Mean	Std. Deviation
2010	Plants per m2	3	0.100	0.000
	Stipes per m2	3	5.267	2.237
	Stipe/Plant Ratio	3	52.667	22.369
	Valid N (listwise)	3		
2013	Plants per m2	3	0.056	0.067
	Stipes per m2	3	3.017	2.334
	Stipe/Plant Ratio	3	127.625	166.822
	Valid N (listwise)	3		
2014	Plants per m2	3	0.222	0.117
	Stipes per m2	3	5.578	1.767
	Stipe/Plant Ratio	3	28.025	8.830
	Valid N (listwise)	3		
2015	Plants per m2	3	0.411	0.242
	Stipes per m2	3	5.116	4.411
	Stipe/Plant Ratio	3	11.073	3.765
	Valid N (listwise)	3		