Santa Cruz Port District
Kelp Monitoring, Habitat Assessment and Aerial Photography Analysis

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 inner harbor sediments. These sediments have been restricted from surfzone disposal in the past according to Environmental Protection Agency (EPA) Region IX standards for grain-size disposal (Sea Engineering, 2005, Foss, 1999). The concern is that silt and clay sediment may disturb the local wildlife and be retained on local beaches and in nearshore benthic habitats. In addition to sediment studies and the existing 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 conducted a three-year, base line study of the kelp forests in the historic dredge disposal area. Kelp forest habitat is designated as a Habitat Area of Particular Concern (HAPC) and is a subset of EFH. HAPCs are 1) rare, 2) particularly susceptible to human-induced degradation, 3) especially ecologically important, or 4) located in an environmentally stressed area. The purpose of this study was to determine the current condition of the nearby kelp forests and evaluate the trends of abundance and density from 2008-2010. This supplemental report presents the monitoring program results and conclusions from historical kelp canopy data analysis.

The study area is located offshore of the Santa Cruz harbor. Four kelp forests were identified within this area and chosen as monitoring sites. They include areas at Steamers (Pt. Santa Cruz) East and West, Blacks Point (near Twin Lakes beach), and Pleasure (Soquel) Point. The Blacks Point and Pleasure Point kelp forest sites are down current of the historic dredging release point and were chosen as monitoring sites. The Steamers kelp forest sites were surveyed as control sites. Seven

years of historical aerial photos were also analyzed to determine kelp canopy surface areas for each site.

Due to *M. pyrifera's* alternating life cycle (Abbott and Hollenberg, 1976, Dawson and Foster, 1982, see also Figure 2), Sandoval & Associates (**S&A)** recommended sampling of adult sporophyte plants to monitor the health of a kelp forest. The purpose of the swath sampling was to estimate the density of conspicuous, specific macroalgae. At each monitoring site, visual surveys by SCUBA divers were used to quantify the relative abundance and density of *M. pyrifera*.

A spatial, GIS model was developed to establish a maximum extent for kelp canopies for six years and then used as a spatial mask to calculate the surface area for each year, for each of the study sites. At the time of initial evaluation, 2007 data from CDF&G were unavailable. Canopy area estimates were then calculated from 1999-2008. Since kelp forest sites were chosen with different maximum extents and persistent kelp canopy area, comparisons of "surface area" would not provide useful information. Rather than testing for differences in "surface area" we looked for differences in trends over time. This was accomplished with regressive least squares modeling and parallelism of regression slopes was analyzed to determine the trend (increasing or decreasing) at each of the sites (Zar, 1998). A more advanced, 4th order polynomial regression model was also used to enhance the predictive (R squared) value and evaluate the long term trends.

The data from SCUBA surveys suggests that the control sites and impact sites are similar in relative kelp abundance, without a significant trend in year to year comparisons. The *Macrocystis* abundance numbers (Table 1) are similar to other sample sites in the Monterey Bay area (Sandoval, 2005). The baseline data for *Macrocystis* stipe density suggests that Site #2 which is the furthest from the disposal area has significantly higher stipe density numbers. This increasing trend, from 2008-2010 could also be indicative of a kelp community in recovery from a natural or anthropogenic event. Neither abundance nor stipe densities show a statistically significant decrease among control and impact sites or over the 2008-2010 time periods. Anecdotally, all sites exhibited an increasing trend in stipe density over the 2008-2010 time periods and the control and Site #2 remained similar for plant abundance. Site #1 showed a decrease in plant abundance over the 2008-2010 time periods, but without statistical significance.

The GIS, spatial analysis of the historic aerial photos revealed some interesting trends regarding the control and impact sites. Unlike the density and relative abundance estimates from the SCUBA surveys, the kelp canopy surface areas suggest differences among sites. If these canopy extents are an indication of suitable kelp habitat, then an assumption can be made that persistent kelp habitat is less at the impact sites when compared to the control sites. This is evident when comparing the Blacks persistence map (and surface area estimate) with the control sites. The Pleasure Point differences are less evident. The kelp canopy suitability analysis or canopy persistence model reveled that canopy area within a study site showed persistence for 1, 3 and 5+ years. Maximum extents from the persistence model were used to calculate annual area estimates and data from the historical aerial photo analysis indicate a highly variable kelp canopy for the four (4) sites. Surface area measurements fluctuated over the 7-year span with 1999, generally being the lowest year. For the control sites of Steamers West and East, 2006 had the highest surface area. For the impact sites of Pleasure Point and Blacks, 2002 had the highest surface area. The annual trends (Figures 9) are very similar with noticeable lower kelp canopy surface area for the Blacks study site.

Linear regression models suggest an increase in kelp canopy surface area over time for the control and both impact sites. Based on the trend lines, the control sites are increasing at a higher rate (slope) than the impact sites. R^2 and probability values for the trend lines are listed in Table 5. The comparison of slopes, F-test indicates the slopes significantly differ ($F_{0.05(1),2,22}$= 5.4004, P=0.012358, Table 6). The 4th order polynomial regression model indicates a cyclical pattern of canopy area over time. The R^2 values for the control and impact sites were much higher than the linear regression model (Table 7). The predictive model for control sites indicates significance (P= 0.0494), while the models for the impact sites do not.

The polynomial least squares regressive model has much better predictive value for kelp canopy area over time. The Control and Pleasure Point (site #2) models are similar in amplitude and intercept and both models show a high degree of predictive value, R^2= 0.64 and 0.83, respectively. Even though Black's (site #1) has a lower predictive value (R^2= 0.49) it still shows similar trends as the other sites. The trends suggest that the Santa Cruz kelp beds are in a decreasing (surface canopy) phase and we should expect lower surface area values over the next few years. These trends are probably correlated with cyclical, oceanographic phase and the relative life expectancy of individual kelp plants.

The baseline data suggests the Santa Cruz kelp forests at all sites are robust but the available and suitable habitat may be small (or decreasing) for one of the impact sites (Blacks). It also appears the kelp forests may be in a "down" phase and decreasing in surface canopy area. 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, and Dayton et.al., 1992). In light of this data, Sandoval and Associates recommends future monitoring focus on the Black's and control sites. The data suggests that the surface canopy at the Pleasure Point site may not be affected by dredging operations. If the model is correct in evaluating surface canopy trends, monitoring should continue for three more years before trends begin increasing again. Also, an important factor to monitor is the relative amplitude of recovery for canopy surface area. Additional information on sediment loads and *Macrocystis* spore settlement would help determine plant recruitment trends (Devinny and Volse 1978, CDFG 1995). Research suggests a long term monitoring approach before evaluating the condition of these ecosystems.

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 inner harbor sediments. These sediments have been restricted from surf zone disposal in the past according to Environmental Protection Agency (EPA) Region IX standards for grain-size disposal (Sea Engineering, 2005, Foss, 1999). This guideline states that dredged (non-toxic) sediment released into the surf-zone must contain at least 80% sand. 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.

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. 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 existing 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 conducted a three-year, base line study of the kelp forests in the historic dredge disposal area. Kelp forest habitat is designated as a Habitat Area of Particular Concern (HAPC) and is a subset of EFH. HAPCs are 1) rare, 2) particularly susceptible to human-induced degradation, 3) especially ecologically important, or 4) located in an environmentally stressed area. Sandoval & Associates (S&A) designed and conducted the kelp monitoring program for the summers of 2008 thru 2010.

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). The giant kelp *Macrocystis pyrifera* is the dominant canopy-forming kelp in the area, and can form dense beds except in the areas where sandy substrate is unsuitable for kelp attachment (NOAA, 1992). The shallow areas inshore of these kelp forests are characterized by surface canopies of *Egregia menziesii,* subsurface canopies of *Pterygophora californica* and *Laminaria setchellii*, and the alga *Cystoseira osmundacea* (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). In addition, 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). The fronds and blades of adult *Macrocystis pyrifera* (hereafter, *Macrocystis* or kelp) float on the ocean surface, and surface canopies can be surveyed efficiently and cost-effectively using aerial photographic techniques. Since the 1960s, low altitude aerial photography with infrared-sensitive film (e.g., Jamison 1971, Deysher 1993) combined with in-situ (e.g., SCUBA) sampling techniques, provide information that has been used for resource assessment and management (reviewed in Larson and McPeak 1995) and ecological research (e.g., Kimura and Foster 1984, Reed and Foster 1984, North et al. 1993, Bushing 1996, Tegner et al. 1996, Graham et al. 1997).

Aerial surveys are a powerful tool for studying kelp canopies, but do have limitations. The limitations of infrared aerial surveys are as follows: 1) poor water penetration (Jamison 1971); 2) the inability to identify species or individuals (North et al. 1993; Donnellan 2004); and 3) a lack of strong relationship between the amount of canopy on the surface and the density or size (i.e. number of stipes per plant) of the individual plants that produce the canopy (Foster 1982a, Kimura and Foster 1984, Tegner et al. 1996, Graham et al. 1997). Even though the methodology has some limitations, recent work by Cavanaugh, et al. (2009), provides evidence that aerial imagery can be an indicator of kelp biomass.

Regardless of the limitations, aerial imagery is an effective indicator of the location, geographic distribution, and spatial extent of kelp forests. Further, comparisons of historical geographic and spatial distributions of kelp canopies may reveal declines (McFarland 1912, Crandall 1915, Hodder and Mel 1978), and substantial differences in geographic distribution and relative abundance of *Macrocystis* (Miller and Geibel 1973, Yellin et al. 1977, Van Blaricom 1984). Such differences can, however, occur inter-annually in kelp forests as a result of natural disturbances such as El Niño (e.g., Foster and Schiel 1985),

Macrocystis canopies are important economically and ecologically (North 1994, Foster and Schiel 1985). 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 1984), 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 are important and potentially limiting habitat (at least during certain times of the year) 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, reviewed in Foster and Schiel 1985 and Graham et al. 2003) 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 fish densities (Anderson 1994, Carr 1989, Holbrook et al. 1990). Most canopy-related studies to date have assessed canopy variability by calculating the surface area within a given area of interest, plotting values as a function of time, then relating the time series to independent or dependent variables (but see Bushing 1996 and 1997; North et al. 1993, Graham 1997, Strampe 2001). Additionally, canopy abundance may vary substantially from month to month in central California (Graham et al. 1997), making comparisons of inter-annual changes in canopy abundance sensitive to the precise time of annual sampling.

To standardize comparisons of kelp canopies among years, surveyors have attempted to record the maximum surface area occupied by kelp canopy within a year (hereafter, "maximum canopy"). Surveying during maximum canopy maximizes the chances that the kelp plants producing the canopy are detected because near-infrared aerial photography cannot detect plant tissue deeper than a few centimeters (Jamison 1971). Canopies in the Santa Cruz region have been reported as generally increasing due to growth in spring and summer, leading to maximum canopy in late summer or early fall (Miller and Geibel 1973, Gerard 1976, Cowen et al. 1982, Foster 1982b, Kimura and Foster 1984, Reed and Foster 1984, Harrold et al. 1988). Timing of maximum canopy development for *Macrocystis* has been determined quantitatively or semi-quantitatively for only four local areas in central California, all of which fringed the Monterey peninsula (Kimura and Foster 1984, Graham et al. 1997). Despite the proximity of these study sites, the timing of maximum canopy and the patterns of inter-annual abundance were variable between and within studies. Furthermore, large inter-annual differences in canopy abundance have also been reported in addition to differences in timing (Cowen et al. 1982, Foster 1982b, Reed and Foster 1984, Graham et al. 1997, Strampe 2001).

Kelp forests in central California are categorized into five characteristic types based on general patterns of: 1) wave exposure, 2) depth, 3) substrate type and relief, 4) benthic species composition and abundance, and 5) variability of kelp surface canopies (Foster & Schiel 1988, Foster and Van Blaricom 2001) Of these factors, determination of surface canopy variability does not require expensive *in situ* surveys or vessel-based remote sensing (e.g., multibeam bathymetry). However, temporal variability of surface canopies 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), and therefore may serve as a proxy for these variables to some extent.

Further, canopies 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); and spatially discrete canopies with consistent patterns of temporal variability may be correlated with characteristic species assemblages or functional groups. Therefore, patterns of canopy variability may be an effective indicator of kelp forest "types" in central California

1.1 Challenges for Impact Studies

Traditional field experimental design 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, 1998). These presumptions are not suited for accidental impact events, 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 can be categorized as accidental environmental impact studies. Similar to an oil spill, monitoring of environmental accidents must be initiated after the fact and because these accidents generally cannot (or should not) be replicated, sampling cannot be entirely 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 multiple sampling protocols, varying levels of measurement, 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 always important. Varying protocols and observer (sampler) bias have profound effects on the data integrity and can lead to spurious or incorrect conclusions. 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. The last methodological issue that can be controlled is the delay or lack thereof, of observations and sampling. The longer the delay between impact event and observations, the more likely the detection of impact effects will be overlooked.

In addition to methodological issues, ecological assumptions and issues must also be considered. Three main assumptions for impact studies are temporal variance, spatial variance and pseudoreplication (Wiens and Parker, 1995). One assumption is that temporal variance is low or constant and can be regarded as “noise” or added to the overall variation of the system. Other than main effects of the system, factors affecting the system will not change over time. This is the steady-state equilibrium assumption. The steady-state equilibrium assumption is not indicative of ecological reality. Marine communities vary in time and every location bears the imprint of its past biotic and abiotic history (Sandoval, 2005). This spatial legacy correlation violates the steady-state assumption. This can cause confounding conclusions from natural catastrophic events such as El Nino Southern Oscillation (ENSO) events. Since kelp forests are highly susceptible to ENSO events (Edwards, 2004) anthropogenic impacts may be masked or superimposed on the natural variation of these events (Ebeling et. al., 1985).

An alternative assumption is that natural factors change over time and consequently, field measurements will change over time, but the magnitude of these changes will be consistent among impact and control sites. This is the dynamic equilibrium assumption.

Generally the marine ecologist must assume that factors other than the anthropogenic exposure do not differ in their effects on the biotic variable among sites. Because accidental impact studies result in impact and control sampling sites, these sites are not randomly distributed. To account for this lack of randomness, a stratified design can be implemented that accounts for confounding environmental and habitat factors, such as depth or site orientation (Graham, 1997). It is important to account for confounding factors in an ordinal or continuous sampling design to determine if the observed differences are actually a response to dredging and not some other covaring factor or feature.

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 on unbalanced statistical design.

The before-after-control-impact design (BACI) is a standard design used to evaluate the effects of anthropogenic disturbance. It 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. In the absence of historical samples, an impact-reference design could be considered. This type of design relies on paired-fixed samples, which is implausible for the Santa Cruz study area due to safety and logistical concerns (lack or limited visibility for SCUBA divers).

The overlying assumption for impact monitoring is that the impact and control sites are alike in all aspects except for which is being tested for effects. (Wiens & 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.

It’s critical to understand the purpose of the study and focus on analyzing the important factors of variation. Due to the timing of the study in relation to the start of dredging, we chose a sampling design that was best suited for the situation and was able to provide information as baseline data for the kelp forest community near Santa Cruz Harbor, CA. As stated earlier, kelp canopy assessment provides information about the spatial extent of particular kelp beds that cannot be easily monitored with in-situ techniques. Utilizing existing aerial photo datasets from the California Department of Fish and Game (CDF&G) provide useful information about the Santa Cruz kelp beds and their surface canopies over the past few years. Focusing the analysis on the study sites and control sites provide useful information about the potential impacts of dredging operations. The purpose of this study was to 1) determine kelp canopy inter-annual trends, and 2) implement an in-situ SCUBA survey of kelp plant abundance and stipe density. Data from both methods are used to compare trends among control and potential impact sites and develop a predictive model. In addition, the data from this study provides information about kelp abundance and density over space and time and estimates the spatial scale of dredging disposal impacts.

2.0 Monitoring Methods

Because of the unique assumptions pertaining to accidental environmental impact studies, it's best to account for confounding variables or covariates. This can be accomplished by identifying the obvious environmental factors. For the Santa Cruz Harbor Kelp Study, 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 dredging disposal plume effects. To account for depth and current, a stratified design was implemented (Zar, 1998). Habitat differences are accounted for by utilizing multiple control sites and to evaluate the scale of impacts, the sampling design evaluates multiple impact sites along an assumed gradient (i.e. multiple sites), down-current of a disposal site.

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). Four kelp forests were identified within this area and chosen as monitoring sites.

They include areas at Steamers (Pt. Santa Cruz) East and West, Blacks Point (near Twin Lakes beach), and Pleasure (Soquel) Point. The Blacks Point and Pleasure Point kelp forest sites are down current of the proposed dredging release point and were chosen as monitoring sites. The Steamers kelp forest sites were surveyed as control sites.

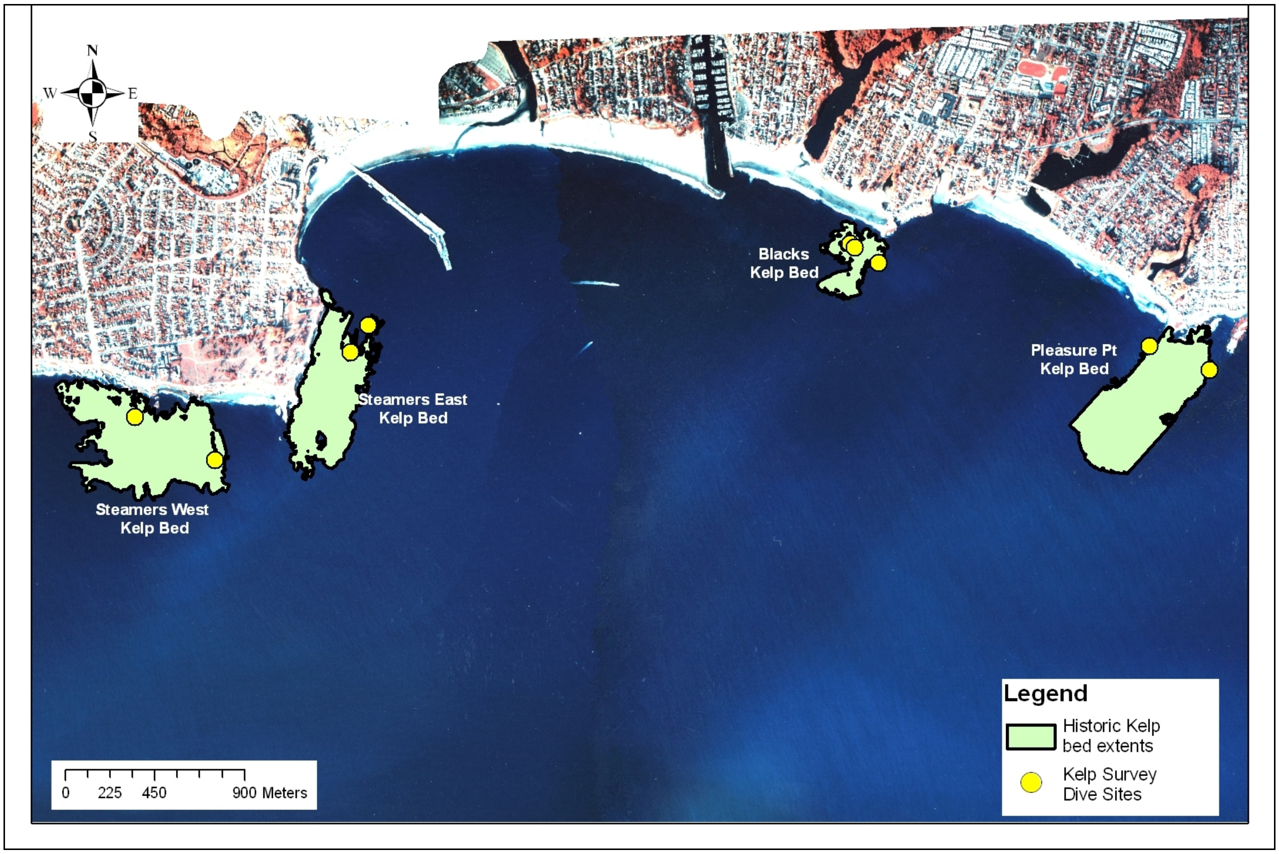

Figure 1. Study Area. Green areas indicate the approximate location of kelp forests; yellow points are SCUBA monitoring dive locations.

Due to *M. pyrifera's* alternating life cycle (Abbott and Hollenberg, 1976, Dawson and Foster, 1982, see also Figure 2), **S&A** recommended sampling of adult sporophyte plants to monitor the health of a kelp forest. The purpose of the swath sampling was to estimate the density of conspicuous, specific macroalgae. At each monitoring site, visual surveys by scuba divers were used to quantify the relative abundance and density of *M. pyrifera*. To ensure that the entire kelp forest was sampled representatively, benthic transects were stratified across the face of the reef (alongshore). Each site was divided into two areas (east and west) to stratify confounding factors of current and kelp bed orientation. To determine the scale of sedimentation effects (if any) the impacts sites were chosen along a current gradient (Schroeter et. al., 1993).

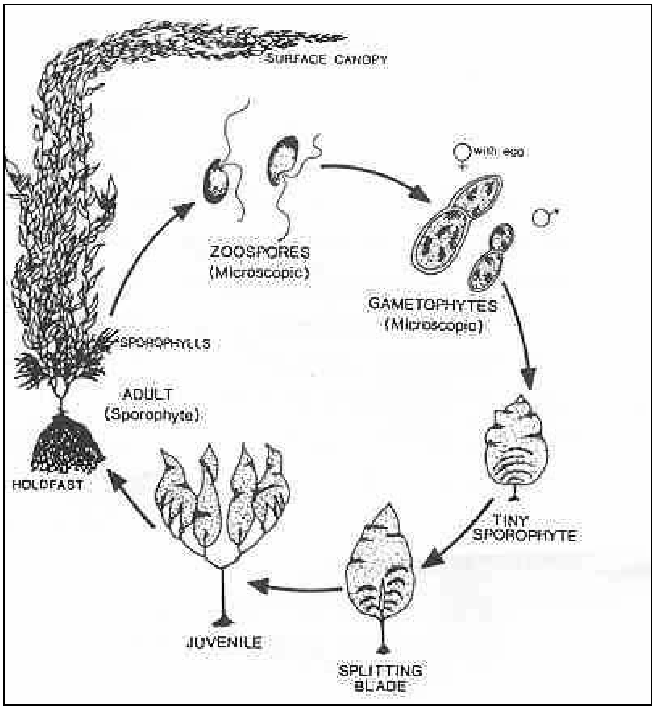

Figure 2. Life cycle of the giant kelp Macrocystis pyrifera (from Foster & Schiel 1985)

Two areas of a kelp forest (east and west) constitute a site, three transects were sampled in the 5 m depth zone at each area for a total of six transects per site (Figure 3). Based on Underwood's (1994) recommendation for impact studies, two control sites were used and compared against the near impact site (site #1, Blacks) and far impact site (site #2, Pleasure Point). This is an un-balanced design with 12 annual replicates for the control site and 6 annual replicates for both impact sites. As an adaptive sampling strategy, the number of transects for the impact sites were increased when it was determined "among site" variances were as high as "within site" variances. The increase in sampling was done in the 2010. Randomly located transects were sampled along isobaths (constant depth) parallel to shore. Swaths transects 30m X 2m wide were used to estimate the relative abundance of *M. pyrifera* plants and the density (number of stipes).

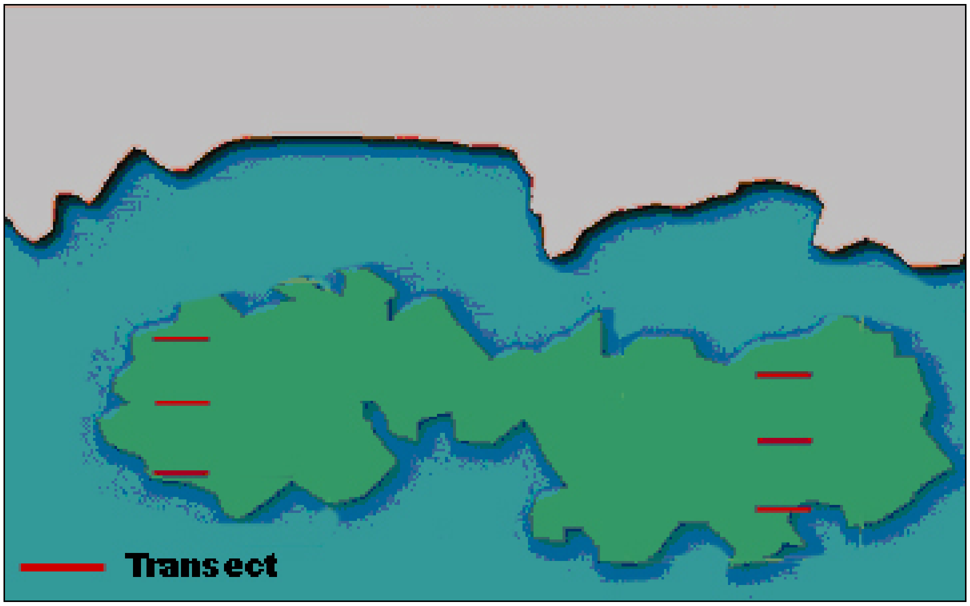

Figure 3. Study Site Sampling Design. Red line indicates a swath transect located on the east and west portion of a site. Green areas indicate the approximate location of a kelp forest site.

Individual *M. pyrifera* plants were counted along a transect. Divers slowly swam one direction, counting targeted plants and then swam back counting stipes of each plant (Figure 4). The number of *Cystoseira osmundacea*, *Laminaria* sp, and *Desmarestia* sp. plants was also recorded. Each transect was sampled by two divers with each diver surveying one side of the transect (i.e. transect 1a and 1b). Only *M. pyrifera* plants taller than 1 m and *Cystoseira osmundacea* greater than 6 cm in radius were recorded. The number of stipes at 1 m above the substrate on each *Macrocystis* plant was entered on the datasheet. This survey methodology is consistent with other kelp forest research.

Figure 4. SCUBA divers setting up an underwater transect for kelp forest sampling.

In addition to field surveys a GIS analysis was conducted to review historical datasets. Seven years of color, near-infrared aerial photos were collected (Data courtesy of California Department of Fish and Game (CDFG), Marine Resources Division) and analyzed by S&A to determine the kelp canopy distribution and extents. To evaluate changes in kelp canopy surface area, the region where kelp canopies are persistent was established in GIS and a model for maximum extents was developed. This spatial model was created using six datasets from 1989-2006. It should be noted that the 2007 and 2008 datasets were unavailable from CDFG at the time this model was developed. These data were compiled by S&A, converted to geodatabases, clipped to the study site region and converted to a standard extent and coordinate system (Universal Transverse Mercator, WGS 84, zone 10N, meters). Areal estimates of kelp canopies were adjusted for differences in tide height during surveying. Although no metadata from survey flights were available, it was apparent from retrospective inspection of tide tables that aerial surveys were done during tidal stages ranging from approximately -1.5 feet to +3.5 feet relative to the Mean Lower Low Water datum. The standardized data was cleaned to eliminate data gaps and slivers then converted to a grid format with 2 X 2 meter cell size. The grid cells were reclassified to indicate either kelp canopy or no kelp canopy. Using a weighted sum calculation, data from all years were analyzed to produce a kelp canopy suitability grid or canopy "persistence" model.

This model establishes a maximum extent for kelp canopies for the six years. This maximum extent was then used as a spatial mask to calculate the surface area for each year, for each of study sites and summarize canopy area statistics for each site. Canopy area estimates were then calculated from 1999-2008. Due to a 10 year data gap, 1989 was classified as outlier information and discarded from the trend analysis. Data from the control sites (Steamers West and East) were pooled and compared against Blacks and Pleasure Point impact sites with standard linear regression. Since kelp forest sites were chosen with different maximum extents and persistent kelp canopy area, comparisons of "surface area" would not provide useful information. Rather than testing for differences in "surface area" we looked for differences in trends over time.

2.1 Data Analysis

Field (SCUBA) data were analyzed using a repeated measures, 2-factorial, nested design ANOVA (Figure 5). Since there are sometimes zero values, a log transformation requires adding a constant. We chose 0.167 for abundance, the smallest possible non-zero value for mean abundance per transect (i.e. 1 plant/60 m^2). Data for abundance were transformed using ln(x+.0167) and density values were transformed using ln(x+1). Statistical analysis for the field data was done using SAS Institute, Inc, *Statview 5.0.*

Testing for surface canopy surface area over time was accomplished with regressive least squares modeling and provides an R^2 statistic and P-value. R^2 is a statistic that will give some information about the goodness of fit of a model. In regression, the R^2 coefficient of determination is a statistical measure of how well the regression line approximates the real data points. An R^2 of 1.0 indicates that the regression line perfectly fits the data. The R-squared of the regression is the fraction of the variation in your dependent variable that is accounted for (or predicted by) your independent variables, in this case time. The R-squared value is of importance, when using the regression equation to make accurate predictions. For this study an R squared value greater than 0.80 is considered significant. The P value tells you how confident you can be that each individual variable has some correlation with the dependent variable. To evaluate the trend in surface canopy areas, parallelism of regression slopes were analyzed to determine the trend (increasing or decreasing) of each of the sites (see comparison of slopes, Zar 1998). A more advanced, 4th order polynomial regression model was also used to enhance the predictive (R squared) value and evaluate the long term trends.

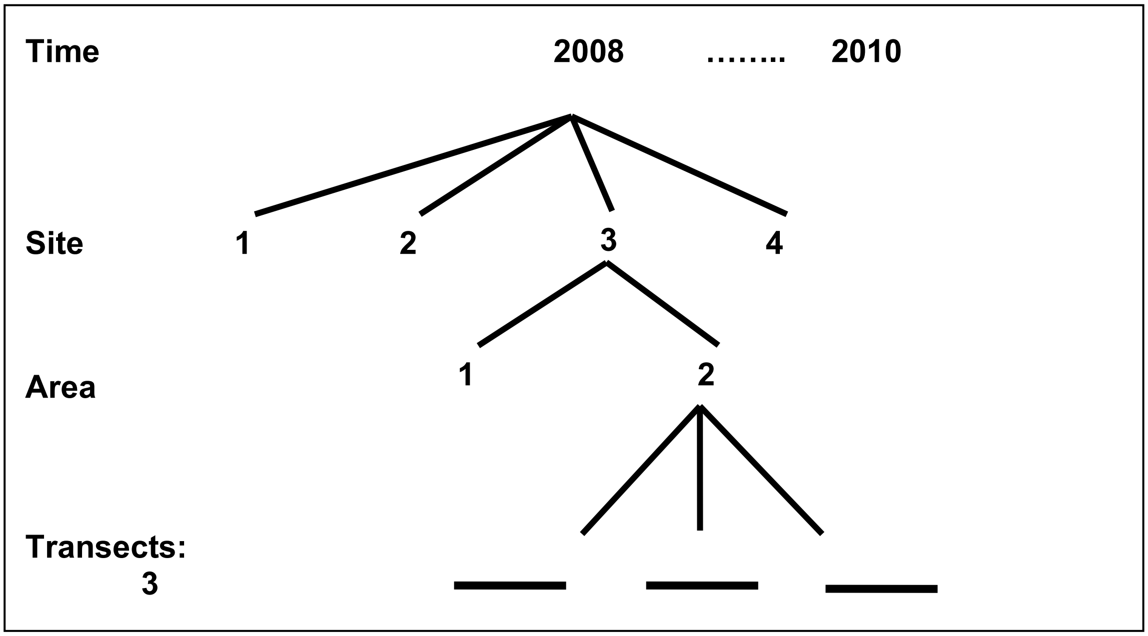

Figure 5. Sampling Design. Hierarchical nested design with Time, Site, and Area as factors. Transects are the sampling units.

All of this work was completed using the ESRI, Inc *ArcMap*, *3-D Analyst*, *Spatial Analyst* GIS software. Data was cleaned using the Spatial Techniques *ET Geo Wizards* software, and conversions and data exploration was done with the Data East, LLC *XTools* software. Statistical analysis was done using SAS Institute, Inc, *Statview 5.0*.and *JMP 8.0.*

3.0 Baseline Results

Data collected from the 2008-2010 SCUBA surveys showed the average relative kelp plant abundance was nearly equal among all sites (Figure 6), while the average stipe density increased for the Site #2 (Pleasure Point) location (Figure 7). The average relative kelp plant abundance dropped for all sites during the 2009 SCUBA surveys and Site #1 continued the negative trend in 2010. The control sites and Site #2 exhibited an increase in 2010. Average stipe density for all sites showed an increase in 2010 from the previous years' surveys. In general, the standard deviation for kelp density was high for all sites, for all years sampled (Table 1).

The repeated measures, ANOVA reports no significant differences ($p>0.05$, $F=0.949$, $F=1.607$, $F=1.243$) for abundance among sites, kelp bed orientation areas (East and West) or years (Table 2). Interactions between sites and orientation, years and sites, years and orientation, and years, sites and orientation were all insignificant ($p>0.05$, Table 2). Power for all tests and interactions was low; less than 0.60.

The repeated measures, ANOVA also reported no significant differences ($p>0.05$, $F=1.624$, $F=0.591$, $F=1.551$) for stipe density among sites, kelp orientation or years (Table 3).

Interactions between sites and orientation, years and sites, years and orientation, and years, sites and orientation were all insignificant ($p>0.05$). Power for all tests and interaction was also low (<0.50).

Ancillary data showed a decrease in *Cystoceira osmundacea* abundance from 2008 to 2010 and an increase in *Pterygophora californica* abundance. Sporadic observations of *Laminaria* spp were recorded in 2009 and *Desmarestia* sp was observed in 2010. These data sets were not statistically analyzed.

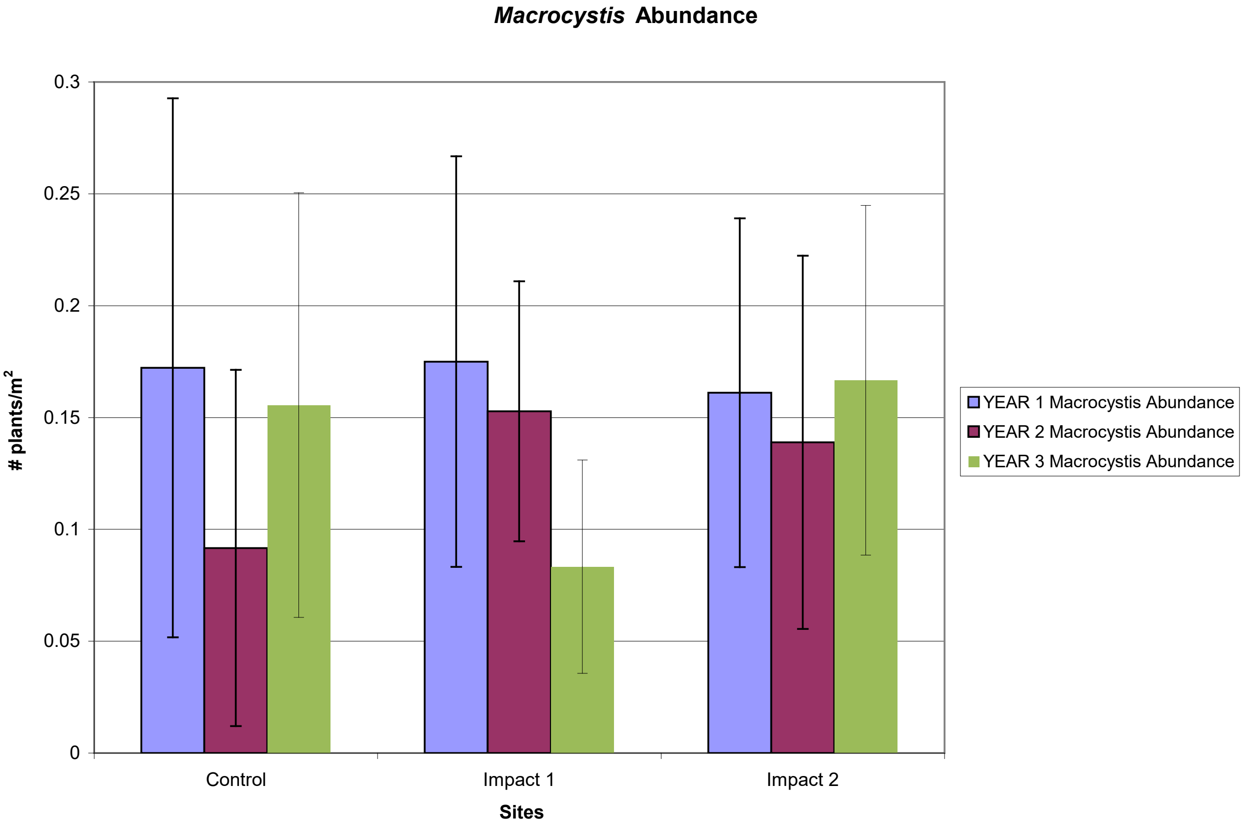

Figure 6. Graph of kelp abundance sampling results. Bars indicate standard deviation

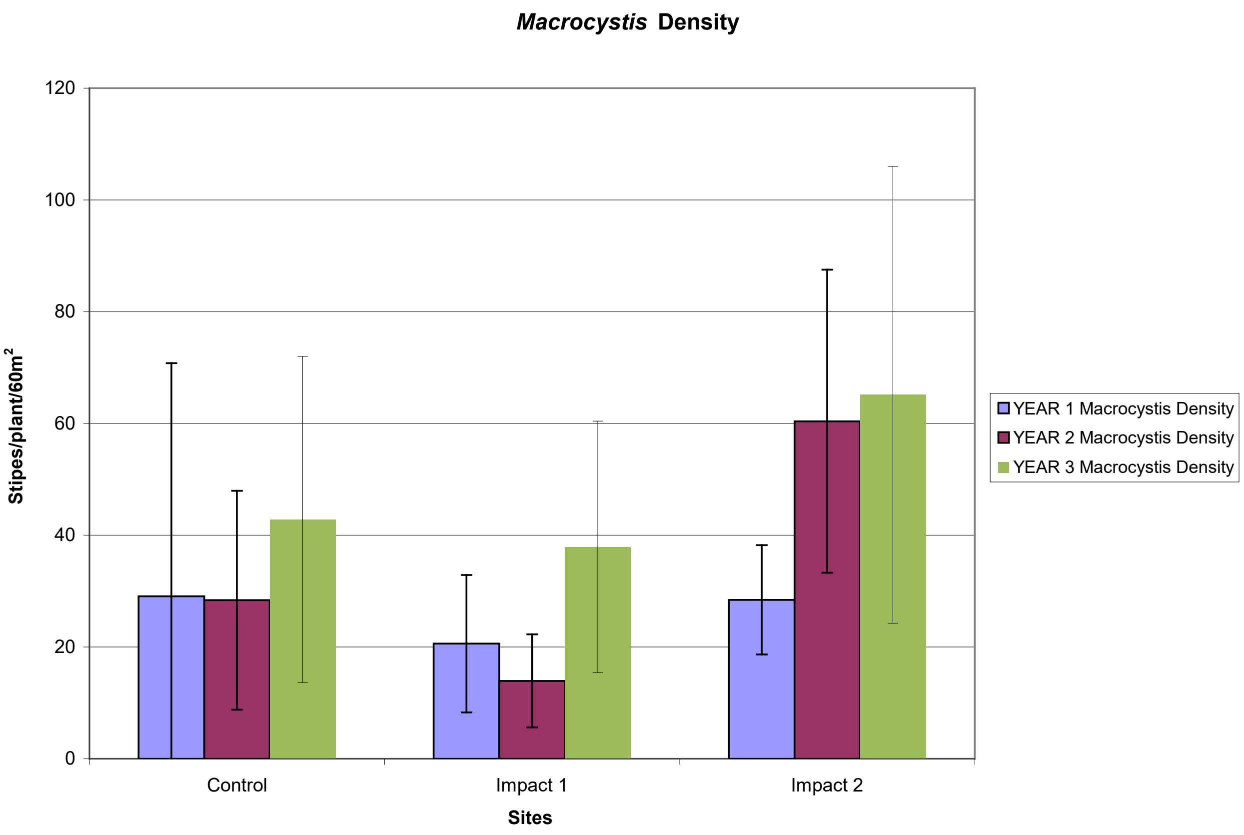

Figure 7. Graph of kelp density sampling results. Bars indicate standard deviation

Table 1. Summary statistics of raw kelp survey data for the sample sites near Santa Cruz Harbor, CA. The control site is the pooled data from the Steamers East and West sites, Site 1 is the Black’s site and Site 2 is the Pleasure Point site.

Sites	2008				2009				2010			
	Macrocystis		*Macrocystis*		*Macrocystis*		*Macrocystis*		*Macrocystis*		*Macrocystis*	
	Abundance	Std	Density	Std	Abundance	Std	Density	Std	Abundance	Std	Density	Std
Control	0.17222	0.12046	29.06820	41.70734	0.09167	0.07961	28.37898	19.57868	0.15556	0.09490	42.82384	29.18792
Impact 1	0.17500	0.09174	20.59808	12.29603	0.15278	0.05813	13.95060	8.34032	0.08333	0.04767	37.93988	22.49723
Impact 2	0.16111	0.07794	28.44754	9.76567	0.13889	0.08344	60.39834	27.12772	0.16667	0.07817	65.14346	40.88983

Table 2. Repeated Measures ANOVA Table for Kelp Abundance. Type = control, site 1 or site 2; Orient = East or West areas

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Type	2	.009	.005	.949	.4056	1.899	.183
Orient	1	.008	.008	1.607	.2211	1.607	.213
Type * Orient	2	.017	.008	1.701	.2106	3.402	.301
Subject(Group)	18	.088	.005				
Category for Year	2	.015	.007	1.243	.3005	2.487	.244
Category for Year * Type	4	.021	.005	.911	.4678	3.645	.255
Category for Year * Orient	2	.007	.003	.576	.5674	1.151	.135
Category for Year * Type * Orient	4	.050	.013	2.124	.0979	8.497	.565
Category for Year * Subject(Group)	36	.212	.006				

Table 3. Repeated Measures ANOVA Table for Kelp Density. Type = control, site 1 or site 2; Orient = East or West areas

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Type	2	3.520	1.760	1.624	.2247	3.248	.289
Orient	1	.641	.641	.591	.4520	.591	.109
Type * Orient	2	.838	.419	.387	.6849	.773	.101
Subject(Group)	18	19.509	1.084				
Category for Year	2	2.779	1.389	1.551	.2259	3.102	.297
Category for Year * Type	4	6.186	1.546	1.726	.1655	6.906	.468
Category for Year * Orient	2	1.178	.589	.657	.5243	1.315	.148
Category for Year * Type * Orient	4	2.021	.505	.564	.6903	2.256	.168
Category for Year * Subject(Group)	36	32.246	.896				

The kelp canopy suitability analysis or canopy persistence model reveled that area within a study site showed persistence for 1, 3 and 5 or more years. An example is shown in Figure 8. Maximum extents from the persistence model were used to calculate annual area estimates and data from the historical aerial photo analysis indicate a highly variable kelp canopy for the four (4) sites. The 7-year average kelp canopy surface areas for Steamers West and East, Pleasure Point and Blacks were 110,273 m^2, 72,723 m^2, 85,302 m^2, & 8,896 m^2, respectively (Table 4). Surface area measurements fluctuated over the 7-year span with 1999, being the lowest year for each site. For the control sites of Steamers West and East, 2006 had the highest surface area. For the impact sites of Pleasure Point and Blacks, 2002 had the highest surface area. The annual trends (Figures 9) are very similar with a noticeable smaller kelp canopy surface area for the Blacks study site.

Linear regression models suggest an increase in kelp canopy surface area over time for control and both impact sites. Based on the trend lines, the control sites are increasing at a higher rate (slope) than the impact sites (Figure 10). R^2 and probability values for the trend lines are listed in Table 5. The comparison of slopes, F-test indicates the slopes significantly differ ($F_{0.05(1), 2, 22}$= 5.4004, P=0.012358, Table 6). The 4th order polynomial regression model indicates a cyclical pattern of canopy area over time (Figure 11). The R^2 values for the control and impact sites were much higher than the linear regression model (Table 7). The predictive model for control sites indicates significance (P= 0.0405), while the models for the impact sites do not.

Table 4. Summary statistics of GIS kelp canopy data for the four sample sites near Santa Cruz Harbor, CA

		Canopy Surface Area (m^2)		
Year	Steamers West	Steamers East	Pleasure Pt	Blacks
1999	12,784	5,776	14,808	1,420
2002	181,976	144,608	247,300	25,464
2003	95,308	10,440	77,620	2,232
2005	45,888	59,572	21,736	13,244
2006	256,704	176,244	100,616	8,360
2007	84,762	61,832	51,506	5,092
2008	94,491	50,592	83,527	6,461
Average	**110,273**	**72,723**	**85,302**	**8,896**
Standard Deviation	83,023	64,584	78,201	8,311

Table 5. Summary statistics of Kelp Canopy Surface Area, Regression Models

Site	**R^2**	**P-Value**
Control	0.2845	0.0494
Blacks	0.1220	0.4423
Pleasure Pt	0.0711	0.5633

Table 6. Summary statistics of Kelp Canopy Surface Area, Comparison of Slopes

	∑ X^2	∑ XY	∑ Y^2	Residual SS	Residual DF
Control	56240376	308204.618	1705.586153	16.58453	12
Blacks	56240376	122158.874	536.5362565	271.1968	5
Pleasure Pt	56240376	154272.733	851.7792909	428.5944	5
Pooled				716.3758	22
Common	168721128	584636.225	3093.901701	1068.076	24

Table 7. Summary statistics of Kelp Canopy Surface Area, 4th Order Polynomial Regression Model

Site	R^2	P-Value
Control	0.6369	0.0405
Blacks	0.4878	0.7620
Pleasure Pt	0.8300	0.3111

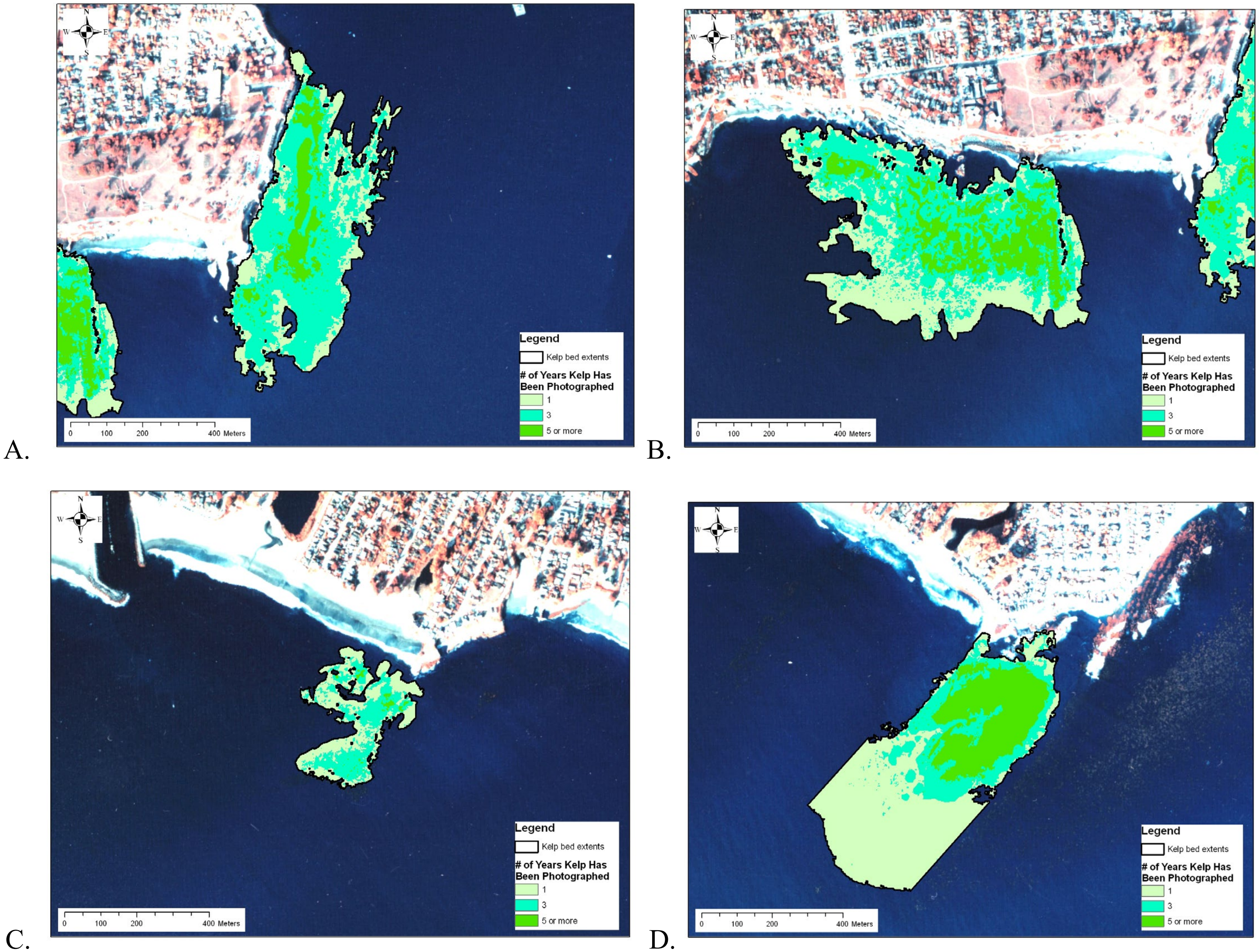

Figure 8. Kelp canopy, persistent coverage model for a) Control Site #1: East Steamers, b) Control Site #2: West Steamers, c) Impact Site #1: Blacks, d) Impact Site #2: Pleasure Point.

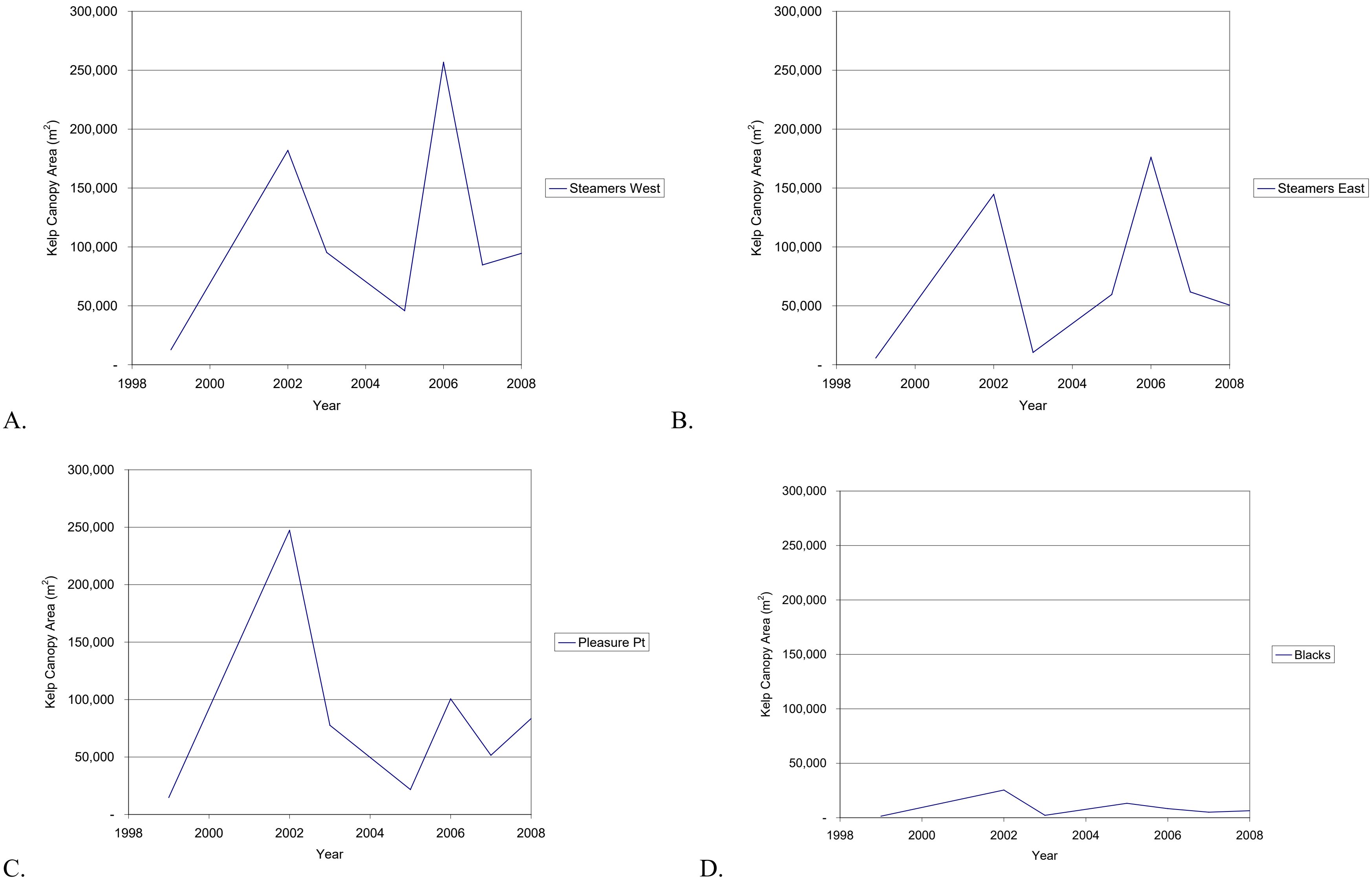

Figure 9. Annual Kelp Canopy Area. Calculations for kelp canopy coverage for a) Steamers West, b) Steamers East, c) Pleasure Point and d) Blacks study sites.

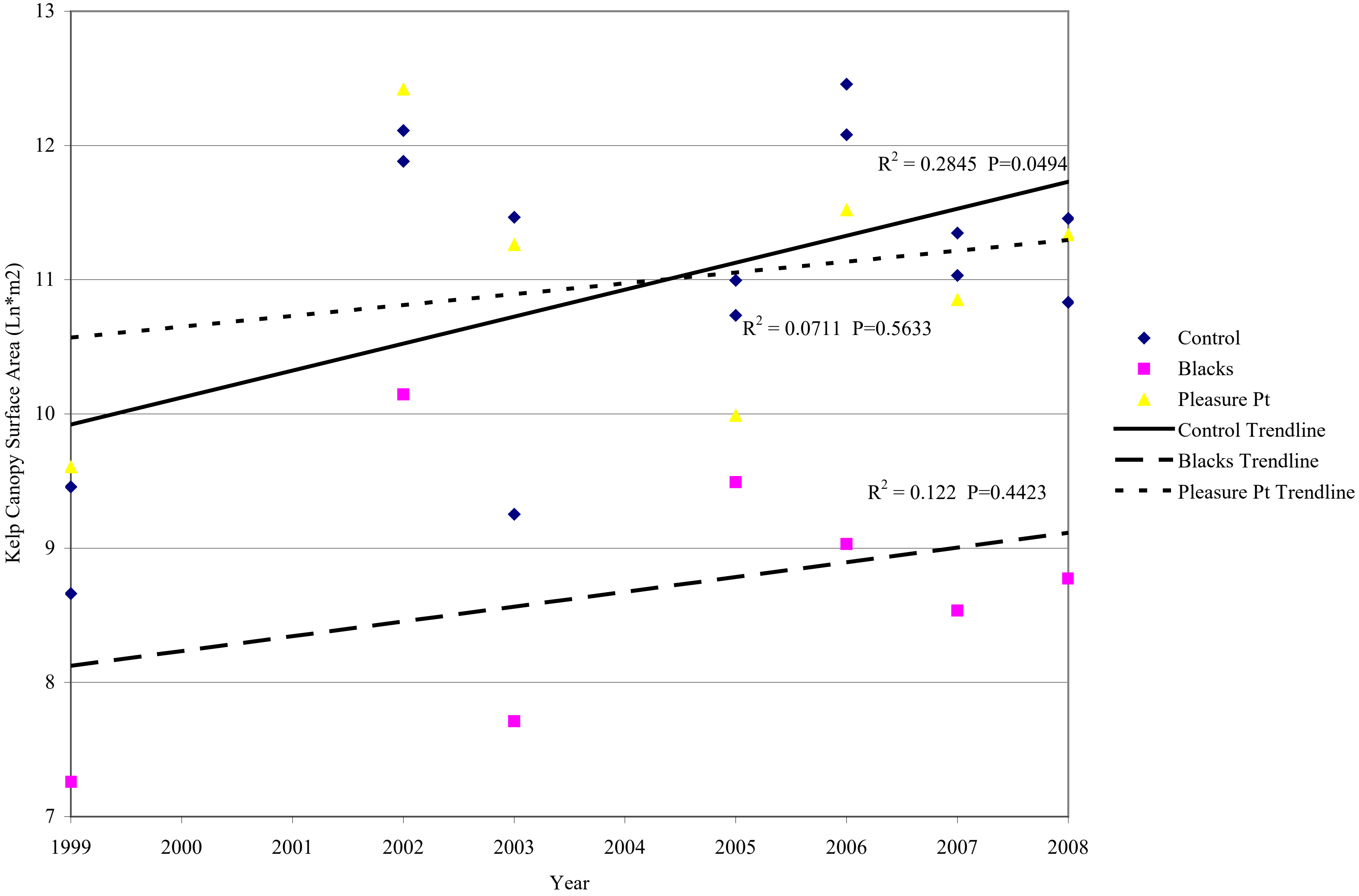

Figure 10. Persistent Kelp Habitat. Kelp Canopy Surface Area Regression models for Control and Impact Sites.

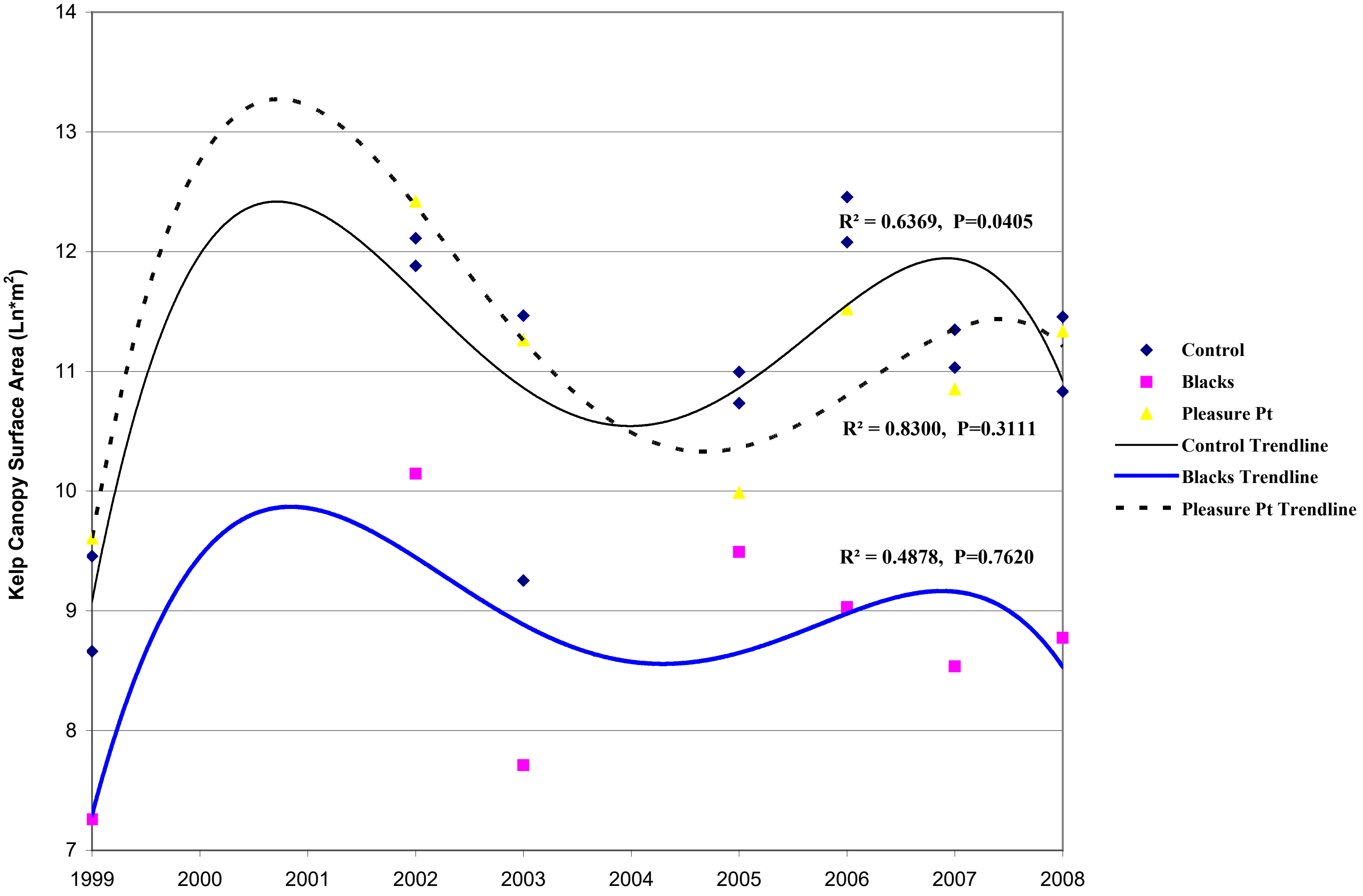

Figure 11. Persistent Kelp Habitat. Kelp Canopy Surface Area 4th Order Polynomial Regression models for Control and Impact Sites.

5.0 Discussion and Recommendations

The data from SCUBA surveys suggests that the control sites and impact sites are similar in relative kelp abundance, without a significant trend in year to year comparisons. The *Macrocystis* abundance numbers (Table 8) are similar to other sample sites in the Monterey Bay area (Sandoval, 2005). The baseline data for *Macrocystis* stipe density suggests that Site #2 which is the furthest from the disposal area has significantly higher stipe density numbers. This increasing trend, from 2008-2010 could also be indicative of a kelp community in recovery from a natural or anthropogenic event. Neither abundance nor stipe densities show a statistically significant <u>decrease</u> among control and impact sites or over the 2008-2010 time periods. Anecdotally, all sites exhibited an increasing trend in stipe density over the 2008-2010 time periods and the control and Site #2 remained similar for plant abundance. Site #1 showed a decrease in plant abundance over the 2008-2010 time periods, but without statistical significance.

Pterygophora californica, a competitive alga, increased in abundance during the 2009 and 2010 surveys (Appendix A). This understory forming kelp can suppress the recruitment of *Macrocystis* recruits through germination and pheromone competition (Reed, 1990) and may have an impact on future *Macrocystis* abundance or stipe density (Rosenthal, et. al., 1974; Foster, 1982a; Foster, et. al. 1983). Although much is known about growth and survivorship of adult *Macrocystis* sporophytes (Reed, 1990), relatively little is known about the ecology of their microscopic stages. These stages are probably highly vulnerable to grazing (Leonard, 1994), sedimentation (Devinny and Volse, 1978; Deysher and Dean, 1986) and light levels.

Natural variability in *Macrocystis* abundance and inter-specific species competition may also be confounded by the effects (if any) of dredging activities. Dredging impacts are periodic and may not have long term physical impacts (sexton flux, irradiance, etc), but may have pulse or shock biological impacts. Alternatively, *Macrocystis* canopies can reduce the amount of light reaching the substrate to less than 1% of surface irradiance (McLean, 1962; Reed and Foster, 1984). This reduction in light can suppress the recruitment and growth of understory kelps (*Pterygophora, Cystoceira, Laminaria*, etc). During the winter months increased water motion from winter storms removes kelp canopies thereby increasing the amount of light reaching the substrate, which in turn can have dramatic effects on the algal assemblages beneath them (Foster, 1982b; Reed and Foster, 1984; Breda and Foster, 1985). Widespread recruitment frequently occurs following these winter storms (Dayton and Tegner 1984; Reed and Foster, 1984; Tegner and Dayton 1987). The changes in understory kelp abundance (Appendix A) can result in decreased recruitment of *Macrocystis pyrifera* gametophytes and sporophytes. These changes in recruitment are part of the natural variability of the kelp forest system. With this in mind, this study may only be monitoring recovery of the kelp community as opposed to initial impacts. In addition, power analysis suggests an increase the number of samples at each impact site to increase statistical confidence.

The GIS, spatial analysis of the historic aerial photos revealed some interesting notes regarding the control and impact sites. Unlike the density and relative abundance estimates from the SCUBA surveys, the kelp canopy surface areas suggest differences among sites. If these canopy extents are an indication of suitable kelp habitat (Donnellan and Foster 1999), then the amount of persistent kelp habitat is lower at the impact sites when compared to the control sites. This is evident when

Table 8. Raw data for 2008 thru 2010 Macrocystis pyrifera surveys, Santa Cruz, CA

					YEAR 1			
					Macrocystis			
Date	Location	Type	Transect	Sample	Abundance	Abundance/m^2	Density	Stipe/plant
7/11/2008	East Steamers	Control	1	1	14	0.233333333	337	24.07142857
7/11/2008	East Steamers	Control	2	2	1	0.016666667	16	16
7/11/2008	East Steamers	Control	3	3	2	0.033333333	21	10.5
7/11/2008	East Steamers	Control	4	4	1	0.016666667	159	159
7/11/2008	East Steamers	Control	5	5	11	0.183333333	317	28.81818182
7/11/2008	East Steamers	Control	6	6	14	0.233333333	406	29
7/11/2008	West Steamers	Control	1	7	16	0.266666667	339	21.1875
7/11/2008	West Steamers	Control	2	8	20	0.333333333	322	16.1
7/11/2008	West Steamers	Control	3	9	20	0.333333333	416	20.8
7/11/2008	West Steamers	Control	4	10	9	0.15	113	12.55555556
7/11/2008	West Steamers	Control	5	11	2	0.033333333	17	8.5
7/11/2008	West Steamers	Control	6	12	14	0.233333333	32	2.285714286
7/9/2008	Pleasure Point	Impact 2	1	1	6	0.1	278	46.33333333
7/9/2008	Pleasure Point	Impact 2	2	2	7	0.116666667	121	17.28571429
7/9/2008	Pleasure Point	Impact 2	3	3	6	0.1	174	29
7/9/2008	Pleasure Point	Impact 2	4	4	14	0.233333333	322	23
7/9/2008	Pleasure Point	Impact 2	5	5	8	0.133333333	225	28.125
7/9/2008	Pleasure Point	Impact 2	6	6	17	0.283333333	458	26.94117647
7/8/2008	Blacks	Impact 1	1	1	4	0.066666667	16	4
7/8/2008	Blacks	Impact 1	2	2	8	0.133333333	144	18
7/9/2008	Blacks	Impact 1	3	3	13	0.216666667	371	28.53846154
7/8/2008	Blacks	Impact 1	4	4	8	0.133333333	138	17.25
7/8/2008	Blacks	Impact 1	5	5	10	0.166666667	158	15.8
7/8/2008	Blacks	Impact 1	6	6	20	0.333333333	800	40

Table 8 (cont). Raw data for 2008 thru 2010 *Macrocystis pyrifera* surveys, Santa Cruz, CA

					YEAR 2 *Macrocystis*			
Date	Location	Type	Transect	Sample	Abundance	Abundance/m2	Density	Stipe/plant
7/28/2009	East Steamers	Control	1	1	8	0.133333333	159	19.875
7/28/2009	East Steamers	Control	2	2	2	0.033333333	112	56
7/28/2009	East Steamers	Control	3	3	1	0.016666667	18	18
7/29/2009	East Steamers	Control	4	4	4	0.066666667	165	41.25
7/29/2009	East Steamers	Control	5	5	2	0.033333333	14	7
7/29/2009	East Steamers	Control	6	6	0	0	0	0
7/28/2009	West Steamers	Control	1	7	16	0.266666667	368	23
7/28/2009	West Steamers	Control	2	8	4	0.066666667	8	2
7/28/2009	West Steamers	Control	3	9	4	0.066666667	122	30.5
7/28/2009	West Steamers	Control	4	10	11	0.183333333	509	46.27272727
7/28/2009	West Steamers	Control	5	11	4	0.066666667	195	48.75
7/28/2009	West Steamers	Control	6	12	10	0.166666667	479	47.9
8/5/2009	Pleasure Point	Impact 2	1	1	2	0.033333333	92	46
8/5/2009	Pleasure Point	Impact 2	2	2	10	0.166666667	1002	100.2
8/5/2009	Pleasure Point	Impact 2	3	3	3	0.05	242	80.66666667
7/27/2009	Pleasure Point	Impact 2	4	4	13	0.216666667	677	52.07692308
7/27/2009	Pleasure Point	Impact 2	5	5	14	0.233333333	848	60.57142857
7/27/2009	Pleasure Point	Impact 2	6	6	8	0.133333333	183	22.875
7/27/2009	Blacks	Impact 1	1	1	5	0.083333333	88	17.6
7/27/2009	Blacks	Impact 1	2	2	12	0.2	237	19.75
7/27/2009	Blacks	Impact 1	3	3	8	0.133333333	17	2.125
7/27/2009	Blacks	Impact 1	4	4	14	0.233333333	216	15.42857143
7/27/2009	Blacks	Impact 1	5	5	10	0.166666667	233	23.3
7/27/2009	Blacks	Impact 1	6	6	6	0.1	33	5.5

Table 8 (cont). Raw data for 2008 thru 2010 *Macrocystis pyrifera* surveys, Santa Cruz, CA

					YEAR 3			
					Macrocystis			
Date	**Location**	**Type**	**Transect**	**Sample**	**Abundance**	**Abundance/m2**	**Density**	**Stipe/plant**
7/19/2010	East Steamers	Control	1	1	7	0.116666667	139.00	19.85714286
7/19/2010	East Steamers	Control	2	2	4	0.066666667	40.00	10
7/19/2010	East Steamers	Control	3	3	12	0.2	324.00	27
7/19/2010	East Steamers	Control	4	4	3	0.05	161.00	53.66666667
7/19/2010	East Steamers	Control	5	5	17	0.283333333	199.00	11.70588235
7/19/2010	East Steamers	Control	6	6	19	0.316666667	228.00	12
7/28/2010	West Steamers	Control	1	7	6	0.1	200.00	33.33333333
7/28/2010	West Steamers	Control	2	8	4	0.066666667	463.00	115.75
7/28/2010	West Steamers	Control	3	9	6	0.1	285.00	47.5
7/28/2010	West Steamers	Control	4	10	11	0.183333333	658.00	59.81818182
7/28/2010	West Steamers	Control	5	11	17	0.283333333	996.00	58.58823529
7/28/2010	West Steamers	Control	6	12	4	0.066666667	413.00	103.25
7/26/2010	Pleasure Point	Impact 2	1	1	18	0.3	485.00	26.94444444
7/26/2010	Pleasure Point	Impact 2	2	2	13	0.216666667	620.00	47.69230769
7/26/2010	Pleasure Point	Impact 2	3	3	10	0.166666667	316.00	31.6
7/26/2010	Pleasure Point	Impact 2	4	4	10	0.166666667	131.00	13.1
7/27/2010	Pleasure Point	Impact 2	5	5	12	0.2	703.00	58.58333333
7/27/2010	Pleasure Point	Impact 2	6	6	10	0.166666667	852.00	85.2
7/26/2010	Pleasure Point	Impact 2	7	7	5	0.083333333	262.00	52.4
7/26/2010	Pleasure Point	Impact 2	8	8	3	0.05	227.00	75.66666667
7/26/2010	Pleasure Point	Impact 2	9	9	8	0.133333333	805.00	100.625
7/26/2010	Pleasure Point	Impact 2	10	10	6	0.1	816.00	136
7/26/2010	Pleasure Point	Impact 2	11	11	17	0.283333333	635.00	37.35294118
7/26/2010	Pleasure Point	Impact 2	12	12	2	0.033333333	720.00	360
7/27/2010	Blacks	Impact 1	1	1	5	0.083333333	306.00	61.2
7/27/2010	Blacks	Impact 1	2	2	5	0.083333333	230.00	46
7/27/2010	Blacks	Impact 1	3	3	8	0.133333333	440.00	55
7/27/2010	Blacks	Impact 1	4	4	1	0.016666667	80.00	80
7/27/2010	Blacks	Impact 1	5	5	5	0.083333333	230.00	46

Table 8 (cont). Raw data for 2008 thru 2010 *Macrocystis pyrifera* surveys, Santa Cruz, CA

					YEAR 3			
					Macrocystis			
Date	**Location**	**Type**	**Transect**	**Sample**	**Abundance**	**Abundance/m2**	**Density**	**Stipe/plant**
7/27/2010	Blacks	Impact 1	2	2	5	0.083333333	230.00	46
7/27/2010	Blacks	Impact 1	3	3	8	0.133333333	440.00	55
7/27/2010	Blacks	Impact 1	4	4	1	0.016666667	80.00	80
7/27/2010	Blacks	Impact 1	5	5	5	0.083333333	230.00	46
7/27/2010	Blacks	Impact 1	6	6	7	0.116666667	325.00	46.42857143
7/19/2010	Blacks	Impact 1	7	7	8	0.133333333	98.00	12.25
7/19/2010	Blacks	Impact 1	8	8	2	0.033333333	18.00	9
7/19/2010	Blacks	Impact 1	9	9	5	0.083333333	166.00	33.2
7/19/2010	Blacks	Impact 1	10	10	10	0.166666667	382.00	38.2
7/27/2010	Blacks	Impact 1	11	11	2	0.033333333	42.00	21
7/27/2010	Blacks	Impact 1	12	12	2	0.033333333	14.00	7

comparing the Blacks persistence map (and surface area estimate) with the control sites (Figure 8 & 9, Table 4). The Pleasure Point data is less evident. Blacks' kelp forest may have historically smaller canopy surface areas due to it shallow depth and susceptibility to plant removal by winter storms (Harrold et. al., 1988, Graham, 1997). Differences in persistent kelp habitat (kelp canopy surface area) are less informative for the Harbor District's concerns. Available habitat is probably a function of geology, sediment transport and oceanographic conditions (Sandoval, 2005) and is not dictated by the Harbor's dredging operations.

The data from the Black's site suggests a reduced area of available kelp habitat based on kelp surface canopy (Table 4). Even though Blacks has a lower surface canopy area, the variability, over time is similar to the second impact site, Pleasure Point and the control sites. These annual trends are more noticeable in Figure 9 and suggest an increasing trend in surface canopy area at control and impact sites. The control site appears to be increasing (slope) in surface area more rapidly than the impact sites and the comparison of slopes (Table 6) indicates a significant difference. There are two possibilities for this difference: 1) there are external factors encouraging more rapid growth at the control sites or 2) there are external factors suppressing the growth at the impact sites. The linear regressive model should be interpreted with caution, as it is apparent from the R squared values, that the surface canopy system is not well described or predicted by a linear model. The P-values for the impact sites are both above a significance level of 0.05, which is understandable. The values suggest that kelp canopy surface area is not well correlated with the independent variable (time). Based on our current knowledge (see Introduction) of kelp forest limiting factors, the p-values should not be surprising. Kelp forests are, by far more influenced by oceanographic conditions than the year in which they grow.

Knowing that oceanographic conditions are cyclical over a decadal period, the polynomial, regressive least squares model is more informative.

The polynomial least squares regressive model has much better predictive value for kelp canopy area over time for all sites. The Control and Pleasure Point (site #2) models are similar in amplitude and intercept and both models show a high degree of predictive value, $R^2 = 0.64$ and 0.83, respectively. Black’s (site #1) has a lower predictive value ($R^2 = 0.49$) suggesting confounding or missing variables for this model. The overall trends suggest that the Santa Cruz kelp beds are in a decreasing (surface canopy) phase and we should expect lower surface area values over the next few years. The models for all sites suggest a local maximum for 2006. These trends are probably correlated with cyclical, oceanographic phase and the relative life expectancy of individual kelp plants. Under the right conditions adult kelp plants can live 2-3 years, which would correspond with the polynomial model.

Qualitatively, there is nothing to suggest an impact at the Black’s or Pleasure Point sites. Unlike the linear regressive models, the polynomial models suggest normal variability within the system and a pattern that is expected. For the impact sites, the models suggest little correlation among the dependent and independent variable, but the control site suggest there is some correlation. This can be partially explained by the nature of the data. Because the independent variables are correlated (time is not independent), the coefficients on individual variables may be insignificant when the regression as a whole is significant. This condition is known as multi-collinearity. Intuitively, this is because highly correlated independent variables are explaining the same part of the variation in the dependent variable, so their explanatory power and the significance of their coefficients is "divided up" between them. As with the linear model, there is little evidence to believe that kelp growth is dependent on the year but more on the underlying factors and conditions that may exhibit themselves in a time dependent pattern.

The baseline data suggests the Santa Cruz kelp forests at all sites are robust but that the available and suitable habitat may be small (or decreasing) for one of the impact sites (Blacks). It also appears the kelp forests may be in a “down” phase and decreasing in surface canopy area. It is important to note that kelp forests are extremely variable both spatially and temporally (Dayton and Tegner, 1984, Dayton et.al., 1984, and Dayton et.al., 1992). In light of this data, future monitoring should focus on the Black’s and control sites. The data suggests that the surface canopy at the Pleasure Point site may not be affected by dredging operations.

If the model is correct in evaluating surface canopy trends, monitoring should continue for three more years before trends begin increasing again. Also, an important factor to monitor is the relative amplitude of recovery for canopy surface area. Additional information on sediment loads and *Macrocystis* spore settlement would help determine the role of plant recruitment (Devinny and Volse 1978, CDFG 1995) and researchers suggest a long term monitoring approach before evaluating the condition of these ecosystems.

Current research suggests the importance of aerial photography when used to determine kelp forest biomass. Diver observations of biomass have been shown to be strongly correlated with normalized difference vegetation index (NDVI) signals (Cavanaugh, et al. 2009). The information from the Santa Cruz analysis may suggest alternate patterns in kelp biomass when compared with abundance and density. Conclusions about this hypothesis cannot be made at this time with the available data.

Research suggests a long term monitoring approach before evaluating the condition of these ecosystems. As a matter for functional and adaptive management S&A makes the following recommendations.

Recommendation #1: Increase sampling for impact sites #1and #2 to increase statistical confidence in results. An increase of 24 samples per site and sampling the 10 m depth contour is recommended based on statistical values.

Recommendation #2: S& A recommends that the Santa Cruz Harbor kelp management program process, fully document and analyze existing kelp habitat datasets stored at the California Department of Fish and Game (CDF&G) and the US Geological Survey, including research, monitoring and oil spill prevention programs. Throughout this initial process, the S&A has learned of numerous gaps in the knowledge base necessary to most effectively manage kelp resources in Santa Cruz waters due to the general lack of awareness and interagency disconnect. Many agencies and research institutes have collected data that would be valuable if compiled and analyzed by the Santa Cruz Harbor kelp management program. With regard to aerial photography, at a minimum, there should be increased effort to coordinate with CDF&G for data acquisition. Due to State budget cuts, this information may no longer be available and alternate sources should be sought out. S&A also encourages the Santa Cruz Port District to utilize hyperspectral imagery, if available. By assessing a broad spectrum of reflected light, these data may be able to assess subsurface kelp canopies.

Recommendation #3: S& A recommends that Blacks impact site be closely monitored for any signs of limited recruitment or kelp canopy growth. Information from the review of the

CDF&G aerial photography suggests the beds near Blacks Point may not be large enough to sustain a catastrophic event. Although 1999 was an exceptional year for high kelp growth due to state-wide coastal upwelling, there were very sparse kelp canopies in the control and impact sites. This observation is confirmed by the 1999 DFG data. This may be a function of oceanographic conditions and circulation in the Santa Cruz Bight. Not adopting this recommendation leaves a possibility that early detection of kelp forest degradation may be missed and limits of damaging anthropogenic activities (Kimura and Foster 1984, CDF&G, 1995, Schaefer and Foster, 1998) will not be enforced. Such an action is undesirable.

Recommendation #4: The S&A recommends that the State of California, other public agencies and organizations work with the Santa Cruz Harbor District to conduct regional research, or continue existing research on kelp resource management issues. Where appropriate, these recommended research items may be considered for funding and included in future research and monitoring plans:

1) Effects of nearshore development projects and other terrestrial activities on kelp forests;
2) Monitoring programs, including continuation of current aerial surveys, as well as underwater transect surveys, to assess natural temporal fluctuations of kelp beds along the Santa Cruz Bight;
3) Compile Geographical Information System (GIS) datasets on the nearshore geology in the Santa Cruz Bight;
4) Effects of non-extractive human activities (e.g., water pollution, diving, boating) on kelp forests;
5) Kelp forest enhancement projects, including the possibility of artificial reefs and no-take zones;

6) Socio-economic studies on the different human uses of kelp resources;
7) Resource stress criteria for determining kelp bed closures
8) Monitor kelp sporophyte recruitment

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7.0 Appendices

APPENDIX A. Linear Regression Statistics for Control and Impact Sites

Regression Summary
Control vs. YEAR

Count	14
Num. Missing	0
R	.533
R Squared	.285
Adjusted R Squared	.225
RMS Residual	1.002

ANOVA Table
Control vs. YEAR

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Regression	1	4.794	4.794	4.774	.0494
Residual	12	12.049	1.004		
Total	13	16.843			

Regression Coefficients
Control vs. YEAR

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Intercept	-9.165	9.225	-9.165	-.993	.3401
YEAR	6.364E-9	2.913E-9	.533	2.185	.0494

Regression Summary
Site1 vs. YEAR

Count	7
Num. Missing	7
R	.349
R Squared	.122
Adjusted R Squared	•
RMS Residual	1.019

ANOVA Table
Site1 vs. YEAR

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Regression	1	.722	.722	.696	.4423
Residual	5	5.191	1.038		
Total	6	5.913			

Regression Coefficients
Site1 vs. YEAR

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Intercept	-2.352	13.266	-2.352	-.177	.8662
YEAR	3.493E-9	4.188E-9	.349	.834	.4423

Regression Summary
Site2 vs. YEAR

Count	7
Num. Missing	7
R	.267
R Squared	.071
Adjusted R Squared	•
RMS Residual	1.007

ANOVA Table
Site2 vs. YEAR

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Regression	1	.388	.388	.383	.5633
Residual	5	5.072	1.014		
Total	6	5.460			

Regression Coefficients
Site2 vs. YEAR

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Intercept	2.888	13.113	2.888	.220	.8344
YEAR	2.561E-9	4.140E-9	.267	.619	.5633

APPENDIX B. 4^{th} Order Polynomial Regression Statistics for Control and Impact Sites

Parameter Estimates

Polynomial Fit Degree=4
Control = -383.0191 + 0.1963752*Year + 0.319889*(Year-2004.29)^2 - 0.0286981*(Year-2004.29)^3 - 0.0174636*(Year-2004.29)^4

Summary of Fit

RSquare	0.63695
RSquare Adj	0.475594
Root Mean Square Error	0.824263
Mean of Response	10.98292
Observations (or Sum Wgts)	14

Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	4	10.727847	2.68196	3.9475
Error	9	6.114681	0.67941	
C. Total	13	16.842528		0.0405

Parameter Estimates

Term		**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept		-383.0191	432.5338	-0.89	0.3989
Year		0.1963752	0.21574	0.91	0.3864
(Year-2004.29)^2		0.319889	0.180207	1.78	0.1096
(Year-2004.29)^3		-0.028698	0.021564	-1.33	0.2160
(Year-2004.29)^4		-0.017464	0.008554	-2.04	0.0716

Polynomial Fit Degree=4
Impact Site #1: Blacks = 13.599562 - 0.0025157*Year + 0.1985105*(Year-2004.29)^2 - 0.0125038*(Year-2004.29)^3 - 0.011105*(Year-2004.29)^4

Summary of Fit

RSquare	0.48781
RSquare Adj	-0.53657
Root Mean Square Error	1.230578
Mean of Response	8.706509
Observations (or Sum Wgts)	7

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	2.8844792	0.72112	0.4762
Error	2	3.0286429	1.51432	
C. Total	6	5.9131221		0.7620

Parameter Estimates

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept		13.599562	913.2263	0.01	0.9895
Year		-0.002516	0.455502	-0.01	0.9961
(Year-2004.29)^2		0.1985105	0.380478	0.52	0.6539
(Year-2004.29)^3		-0.012504	0.045528	-0.27	0.8094
(Year-2004.29)^4		-0.011105	0.01806	-0.61	0.6013

Polynomial Fit Degree=4
Impact Site #2 Pleasure Pt = 548.57006 - 0.268518*Year + 0.3436589*(Year-2004.29)^2 - 0.0004743*(Year-2004.29)^3 - 0.0152026*(Year-2004.29)^4

Summary of Fit

RSquare	0.829996
RSquare Adj	0.489987
Root Mean Square Error	0.681287
Mean of Response	10.99558
Observations (or Sum Wgts)	7

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	4.5321638	1.13304	2.4411
Error	2	0.9283031	0.46415	
C. Total	6	5.4604668		0.3111

Parameter Estimates

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept		548.57006	505.5909	1.09	0.3913
Year		-0.268518	0.25218	-1.06	0.3985
(Year-2004.29)^2		0.3436589	0.210645	1.63	0.2444
(Year-2004.29)^3		-0.000474	0.025206	-0.02	0.9867
(Year-2004.29)^4		-0.015203	0.009998	-1.52	0.2678