An Analysis of the Potential of Giant Kelp and Eelgrass to Lower the Acidity of the Santa Monica Bay

Project Report

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Abstract

The purpose of this study was to better understand the interplay between sea plants and ocean acidification in the Santa Monica Bay. Giant kelp (*Macrocystis pyrifera*) and eelgrass (*Zostera marina*) were the target plants for this study as they are both abundant in the area and hot spots for biodiversity. Ocean acidification, caused by increased levels of carbon dioxide, threatens calcium carbonate producing species which could destabilize entire ecosystems. Previous work between UCLA's practicum program and The Bay Foundation identified the potential of kelp to draw down dissolved carbon dioxide, reducing the acidity of the surface waters. With this understanding, this study aims to explore kelp and eelgrass to determine if either or both plants can alter the pH throughout the water column. Dissolved surface carbon dioxide measurements as well as pH depth profiles taken with a hand-held water quality sensor were the basis of this study's data. Additionally, satellite images and drone images helped to visualize the study site. After comparing pH depth profiles to control data, it was apparent that kelp and eelgrass both displayed some capacity for reducing ocean acidity. More research needs to be done to understand the mechanisms at play but it is hoped that these results will help drive and influence restoration projects on order to provide refuges from ocean acidification and maintain biodiversity.

1. Introduction

Understanding of modern-day pollution has improved drastically over the last couple of decades with a strong consensus that human caused pollution is directly responsible for a rise in global temperature (Oreskes, 2004). As humans continue to pollute, a portion of that carbon dioxide (CO_2) is absorbed into the ocean creating another problem, ocean acidification. A natural exchange of carbon dioxide gas exists between the ocean and air, however, atmospheric CO_2 concentrations have been on the rise and this has elevated the concentration of carbon dioxide in the ocean as well. The problem of ocean acidification begins after carbon dioxide is absorbed into water. When CO_2 is absorbed by water, it dissociates first into carbonic acid and then into bicarbonate and carbonate ions, all the while increasing the concentration of hydrogen ions (H^+) (Ash, 2017). Acidity is the measure of H^+ concentration and as more hydrogen ions are produced, oceans become more acidic.

$$CO_2 \text{ (atmos)} \leftrightarrow CO_2(aq) + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$$
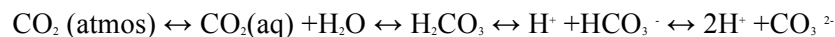
There has been a global decline of ocean pH marked by the beginning of the industrial revolution when concentrations of anthropogenic carbon dioxide saw a sharp increase (O.Hoegh-Guldberg, 2007). Over the last 150 years, the pH of the ocean has declined 0.1 on the pH scale. Although seemingly small, this accounts for, about, a 30% increase in acidity, enough to destabilize ocean communities. On top of this, "[ocean pH] will become another 0.3–0.4 units lower" by the end of this century (Orr et. al, 2005).

This paper specifically aims to understand ocean acidification in the Santa Monica Bay. Unique geography and wind forces cause upwelling along the California coast creating a hot spot for marine life and biodiversity (Steneck et. al, 2002). As a result, the impact of ocean acidification is more pronounced in the bay as it affects a diverse number of marine species. Ocean acidification will acutely harm organisms who use calcium carbonate (CaCO3) for the construction of protective shells, exoskeletons, and/or structure. The dangers are twofold. Carbon dioxide being drawn down into the ocean will decrease the concentration of available carbonate making it harder for organisms to form protective structures (Orr et. al, 2005). Second, decreasing pH will cause already formed calcium carbonate structures to become unstable, potentially dissolving them, and make it more difficult for structures to form in the first place. As populations of shelled organisms begin to wither and destabilize, so too will the marine food web.

Two sea plants present in the Southern California Bight play important roles in maintaining biodiversity along the coast and are therefore important when studying the impact of ocean acidification. Eelgrass meadows, *Zostera marina*, often serves as a nursery for young marine animals while giant kelp forests, *Macrocystis pyrifera*, "are probably the most species-rich, structurally complex and productive communities in temperate waters" (Foster & Schiel, 1985). In recent history, eelgrass and kelp, both

credited with playing a large role in carbon cycling, have faced widespread deforestation around the world. Kelp deforestation in California is a direct result of a local, human-caused sea otter extinction which led to unchecked sea urchin growth. Sea urchin populations took over regions where kelp normally grows creating barren areas along the coast. Seagrasses, such as eelgrass, which are much more vulnerable to eutrophication and coastal construction that results from humans living along the coast and agricultural runoff have also faced decline along the California coast (Duarte, 2002).

For this study, research was conducted on eelgrass and kelp in Solstice Cove, Malibu, CA (**Figure 1**) to determine these plants' ability to mitigate the effects of ocean acidification, creating a protective haven for marine life. This paper will discuss the viability of eelgrass and kelp as a short-term solution for the preservation of biodiversity in an ever-acidifying ocean.

2. Location

The Santa Monica Bay is located within the Southern California bight, a shallow curve in the California coastline. While not officially defined, the Santa Monica Bay is often considered as the area between Point Dume in the north and the Palos Verdes Peninsula in the south. Although there are two deep-water canyons in the bay (Santa Monica Canyon and Redondo Canyon), the bay is generally no deeper than ten fathoms (NOAA). The bay is sprinkled with inlets, canyons, and coves lending itself to a diverse spread of habitat. Solstice Canyon, a canyon found on land, lets out into Solstice Cove, five miles east of point Dume, and is our area of study for this project.

According to bathymetry from the National Oceanic and Atmospheric Administration, our area of interest is around three to five fathoms in depth which lends itself to calm, less turbulent waters (NOAA). The overall shape of the Southern California Bight coupled with the curved geometry of the bay creates a protected inlet which contribute to Solstice Cove's calm waters. Storms originating from the north and south are usually dispersed or deflected by the land masses of Point Dume and Palos Verdes Peninsula before they reach the cove. Because of this, kelp and eelgrass can establish themselves here where they will face a lower frequency of disruptive events.

Upwelling is a phenomenon where dense, cold, nutrient rich waters are brought towards the ocean's surface. Off the coast of California, southward winds and the Coriolis effect push water west, away from the coast. This results in colder water rising to the surface to fill the deficit of water close to the coast. Nutrient rich upwelling areas can create some of the most productive habitats in the world. The abundance of nutrients in the Santa Monica Bay make it a perfect place for kelp and eelgrass to thrive. Waters brought from the deeper water masses by upwelling also tend to have a lower pH. These factors lend themselves in making Solstice Canyon and ideal location to study impacts these plants can have in an acidic environment.

3. Plant Species

3.1 Giant Kelp (*Macrocystis pyrifera*)

Giant kelp, hence the name, is known for its size; this plant can grow over 15 meters in 1-3 years (Steneck et. al, 2002) and typically has a life expectancy of 25 years (Steneck & Dethier 1994). These forests are found along rocky shorelines where light can easily penetrate surface waters and promote their growth (Steneck et. al, 2002). At full growth, their canopies will reach the surface and appear incredibly dense, however, their growth and canopy density vary seasonally.

Giant kelp forests support vibrant ecosystems and are home to an array of different organisms. In Southern California specifically, giant kelp are known to support over 200 species of algae, fishes, mammals and invertebrates (Graham, 2004) as well as more than 10 different phyla (Steneck et. al, 2002). Because of the energy produced and carbon that is fixed within/ exported from these forests, they are fundamental to marine food webs (Graham, 2004).

Historically, giant kelp deforestation has been attributed to natural storm/ weather events such as El Nino events which produce warm surface waters and halt upwelling along the coast (Dayton et al. 1998). While kelp can quickly rebound from events like these, recovery from deforestation events will

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have long term repercussions. Giant kelp forests are part of intricate trophic cascades and recent losses of key species in the Southern California Bight have led to widespread deforestation (Steneck et. al, 2002). These deforestation events can be attributed to sea urchins that have grown unchecked by predators and competitors. Sea otters, a top predator of sea urchins, were eliminated by the maritime fur trade in the early 1800s (Tegner & Dayton 2000); however, deforestation events were delayed due to other competitors keeping the urchin populations under control (Steneck et. al, 2002). Without the pressure of sea otters, populations of abalone and spiny lobster grew and made up for the absence of otter predation on sea urchins. With time, fisheries began targeting the growing populations until all predators and competitors of sea urchins were wiped out and urchins took over creating barren areas without giant kelp (Steneck et. al, 2002). As kelp is a major contributor of nearshore phytodetritus (Zobell, 1971), the effects of kelp trickled down resulting in lower biodiversity in the Southern California bight as well as a whole host of other nutrient- related problems (Graham, 2004).

3.2 Eelgrass (*Zostera marina*)

Marine eelgrass (*Zostera marina*), an angiosperm, is commonly found in shallow waters along the coast (Adams, 1971) and offer diverse ecosystem services. Eelgrass meadows are known for stabilizing sediment (Orth et. al, 2006) and can serve as nurseries for young fish (Adams, 1971). In fact, in many places, they are home to the greatest populations of fishes (Adams, 1971).

Recent studies have shown that worldwide, eelgrass communities have declined and become fragmented (Waycott et. al, 2009). Fragmentation of these meadows, has been shown to alter the community compositions along the coast of these sites (Frost, 1999) while total loss of these meadows can be catastrophic for coastal systems that rely on these meadows for nutrients. Eelgrass in general, are vulnerable to diseases, eutrophication, construction near the coast, and increased severity of storms due to climate change (Waycott et. al, 2009 & Duarte, 2002). Similar to giant kelp forest deforestation, the loss of seagrasses threatens to disturb food webs and biodiversity along the coast as well as the loss of sediment oxygenation (Duarte, 2002).

4. Methods

This study is designed to have 3 different field sites: kelp, eelgrass and control sites. Sites given the designation of 'Kelp' are areas where measurements are taken within a kelp forests, 'Eelgrass' sites are areas containing eelgrass meadows and no kelp, and 'Control' sites contain neither kelp nor eelgrass. All eelgrass sites are located within the same eelgrass patch and all kelp sites are located within the same kelp patch. All sites were similar depth and distance from shore. The final sites chosen were all in the same cove so conditions would be similar and external factors would be limited as much as possible. After locating the sites, data were collected. Surface CO_2 concentration, temperature, salinity, and fluorescence were measured from the sensors on the UCLA Research Zodiac (Zodiac). The Zodiac is a 27-foot long research ship operated by UCLA and designed for coastal research. Parameters at depth such as pH, pressure, conductivity, salinity, temperature were measured using an In-Situ smarTROLL Multiparameter Handheld device. The data were then processed with a combination of MATLAB, ArcGIS, R, and Microsoft Excel.

4.1 Preliminary Survey

To locate the study sites, we began by examining past data. Satellite images for the year 2017 from the Landsat program showing the locations of kelp were overlaid with sonar data from 2015 showing the location of eelgrass patches. After a map was created demonstrating promising sites with both sea plants in the same area, the next step was to verify that kelp and eelgrass was growing in each potential site this year.

The first authentication of the data was done in person by visiting the beaches directly adjacent to the potential sites, where kelp forests in shallow areas were found and evidence of both kelp eelgrass were observed in the form of washed up plant matter.

Checking the offshore locations of kelp was easily done, as there were many sizeable kelp patches with plants extending to and above the surface of the water. Ground-truthing of eelgrass was more difficult and ultimately was done by using a boat with sonar capability to find unusual patches on the seafloor and then sending a diver down to check. On subsequent field days, in the absence of a diver, a GoPro Hero 6 camera was lowered and raised to video the depth profile and seafloor of an area. The video was then viewed to confirm the presence, or absence, of eelgrass.

Another action that was performed before actual data collection was visiting the marina to familiarize the team with the Zodiac's capabilities and equipment operation.

4.2 Data Collection and Analysis

The data for this project was collected primarily from two main sources: the Zodiac's surface sensors and the handheld In-Situ SmarTROLL Multiparameter Handheld device (SmarTROLL), which collected data at different depths. With the study sites determined, the Zodiac was driven around to collect transects of surface data and the SmarTROLL tool was lowered to obtain depth profiles of various parameters. The Zodiac was taken out to collect data twice (5/3 and 5/16), and the SmarTROLL thrice (4/14, 5/3, and 5/16). On 5/3 only kelp and control depth data were collected, while on 4/14 and 5/16 kelp, eelgrass, and control data were collected.

4.2.1 Zodiac Surface Sensor Data Collection

The Zodiac measured parameters such as temperature, salinity, conductivity, and fluorescence through its flow-through sensors, as well as information on latitude, longitude, time, speed of travel, and heading through its sensors attached to the boat. It merely needed to have its engine running in order to collect data. The Zodiac also had a separate sensor for measuring surface dissolved CO_2 concentration in parts per million (ppm). The CO_2 sensor had an intake pump that brought in water from the surface. This process is important to mention because it can (and was) interrupted by the drawing in of kelp resulting in the jamming of the intake pump.

The parameter of greatest importance to this study was the surface dissolved CO_2 concentration for this measurement can provide evidence for/ against the hypothesis that kelp and eelgrass are taking up CO_2 from the surrounding waters. The other parameters like temperature and salinity were used to check inconsistencies across various sites. Additionally, the latitude and longitude data were used to assign time and location information to other data points so as to enable a more thorough analysis. Since the CO_2 data was collected by a separate sensor that took measurements at different intervals, the CO_2 data file has its own latitude and longitude data.

4.2.2 Zodiac Surface Sensor Analysis: ArcGIS, Matlab

The surface dissolved CO_2 data was interpolated over the whole study area and the average over the surface of each type of study site (kelp, eelgrass, and control) was calculated. This was done in ArcGIS using ArcMap's Geostatistical Analysis toolbar and the Zonal Statistics as Table tool.

The Geostatistical Wizard generated a CO_2 value (measured in ppm) for the whole, continuous study area, instead of having just a few tracks of discrete data points from the Zodiac, through interpolation. This assumes that points that are close together tend to have similar characteristics (values). The tool calculates a prediction of what the value for each area should be from the points originally recorded by the sensor using Empirical Bayesian Kriging as the method of interpolation. Kriging is a geostatistical method of interpolation that factors in spatial distribution and relationships among the known points of data - distance is not the only factor in predicting unknown values, but the spatial distribution is as well. It assumes that the spatial correlation of the data can be used to explain and predict the variable values, and that the data has spatial correlation. This method was chosen because it was assumed that surface concentrations of dissolved CO_2 would have spatial correlation (the values of the CO_2 concentration would depend in part on their location).

The "Zonal Statistics as Table" tool was used in ArcGIS after creating a buffer (with a 0.75 m radius as the eelgrass patches were quite small) around the control and eelgrass measurement points (from

the GPS location of the SmarTROLL) to represent the sites. The tool calculated the mean for each polygon area using the interpolated layer's values.

The zonal statistics for the kelp was calculated by drawing a polygon around a georeferenced image of the kelp patch first, then performing the same steps done for the other sites. The georeferenced image was obtained by flying a drone (with GPS) over the study site on May 8, 2018 (it is assumed that between the field days the patch did not undergo significant changes in shape and size). There is only one patch singled out for polygon creation and analysis because the depth data were from that patch. MATLAB was mainly used to generate time vs. CO_2 plots and longitude/latitude vs. CO_2 charts, and to help interpret and process the data into a more easily accessible form. Fluorescence was converted to chlorophyll to better understand the locations of kelp and eelgrass on the plots. Temperature and salinity were also plotted over time and GPS data respectively to check the effectiveness of CO_2 data and so that outliers and anomalies of CO_2 data could be recognized quickly.

4.2.3 Multiparameter Handheld SmarTROLL Data Collection

The SmarTROLL sensor is a cylinder attached to a long cable (100m) and battery pack. The cylinder end, containing most sensors, is lowered into the water and measures 14 factors, chemical and physical. The chemical factors include dissolved oxygen, actual conductivity, specific conductivity, oxidation reduction potential, salinity, total dissolved solids, resistivity, density, and perhaps most importantly, pH. The physical factors include air and water temperature, barometric pressure, water level, and water pressure. The instrument must be connected to a smartphone to operate, this connection also allows for the time, date, and GPS data to be recorded. The specific sensors on the instrument work in different ways but the actual operation of the equipment is simple; to record data, the sensor merely needs to be turned on and connected to a smartphone via Bluetooth and it will record a reading every 10 seconds, though it needs to be in the water for most measurements to be appropriate. To facilitate easier and speedier readings, the cord was marked every 25 cm so that there would be approximately the same depth between readings.

4.2.4 Multiparameter Handheld SmarTROLL Data Collection Analysis: Excel, Matlab, R

The SmarTROLL depth data was processed with Microsoft Excel, MATLAB, and R. Excel and MATLAB was used to generate depth profiles. Line plots and scatter plots of pH vs. depth were generated to compare the general trends and ranges of pH for each study site type. Water columns are divided into three parts: surface, middle and bottom. The mean pH for these three columns were calculated for each field site on each day to better analyze the potential of the sea plants to mitigate ocean acidification. For instance, the first two meters were sectioned off because the surface waters tended to be much more basic than the rest of the column, while the bottom one meter was sectioned off because that is the approximate height to which eelgrass grows. A regression line of pH vs. depth was performed in the middle water column as well to show trends of pH decreasing for different sites. Depth profiles of temperature and salinity were generated to check whether the outliers of pH data were accidental or not.

Statistical tests of significance (t-test) were performed in R on the differences of surface mean pH, intermediate mean pH, and bottom mean pH between study sites with kelp/eelgrass and the control site for that day.

5. Results

The data in this paper was recorded over three field days on April 14th (field day 1), May 3rd (field day 2), and May 16th (field day 3). These field days will be referenced as field days 1, 2, and 3 for the remainder of the paper.

5.1 Study Area Surface CO_2 Concentration

Figures 2.1 and **2.2** are maps of interpolated values of dissolved carbon dioxide concentration at the ocean's surface. The locations of the kelp, eelgrass, and open ocean (control) field sites are overlaid for field day 2 and 3. Areas with lower CO_2 concentrations are in shades of blue to yellow, while areas

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with higher CO_2 concentrations are in shades of orange and red. The overall ranges for the two days differ - the maps are meant to compare the conditions over different areas on the same day, not between days. When comparing the two field days, it is evident that similar areas vary in dissolved surface CO_2 concentration.

The maps (**Fig. 2.1 & Fig. 2.2**) and table (**Table 1.0**) display opposing trends depending on the field day - on field day 2 the kelp patch and surrounding area had a lower surface dissolved CO_2 concentration, while on field day 3, the same area had a higher concentration.

Table 1.0 – Surface Dissolved CO_2 Concentration (Mean | Range)		
	Field Day 2 (5/3/18)	Field Day 3 (5/16/18)
Control	257.003155 | 250.258469 - 261.753052	255.535685 | 251.139359 - 260.37204
Eelgrass	--	254.82933 | 250.186234 - 255.916977
Kelp	243.25669 | 223.842468 - 254.632324	273.068742 | 258.87851 - 294.451935

Table 1.0- One Field Day 2, trends in surface dissolved CO_2 concentration were as expected; in the kelp patch there was a lower concentration, and, in the control, there was a higher concentration. On Field Day 2 however, there was an opposing trend in which the control site had a lower concentration of surface dissolved CO_2. These different trends could be due to many factors including ocean conditions on each day. Because of the opposing trends, we did not incorporate this data into our final analysis.

5.2 pH Depth Profiles of All Study Sites

The following scatter plots (**Fig. 3, Fig. 4, Fig. 5**) visualize all pH depth profile data from the SmarTROLL instrument for field days 1, 2, and 3. Each dot represents one datum point of pH value and its corresponding depth. Red dots represent data taken from control sites. Blue dots represent data taken from eelgrass sites. Green dots represent data taken from kelp sites. Although day-to-day variations exist, there is an overall trend that pH decreases with depth.
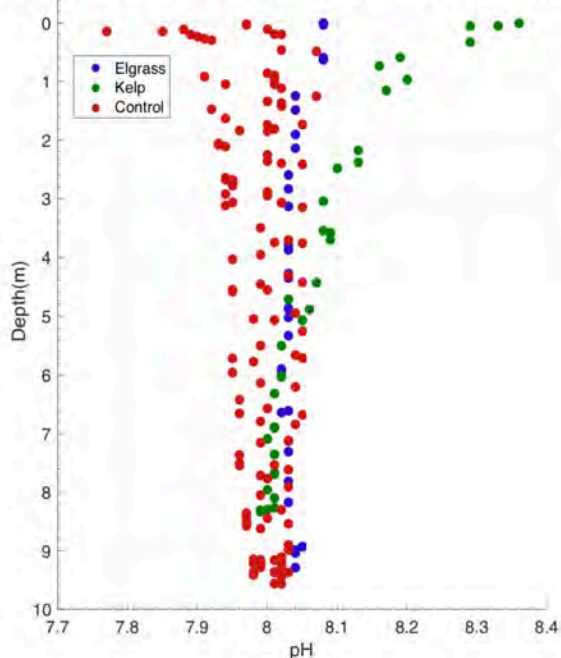
Figure 3- This figure shows all of the pH data from kelp sites, eelgrass sites, and control sites on Field Day 1 (April 14, 2018). Each dot represents a pH value on a certain depth.
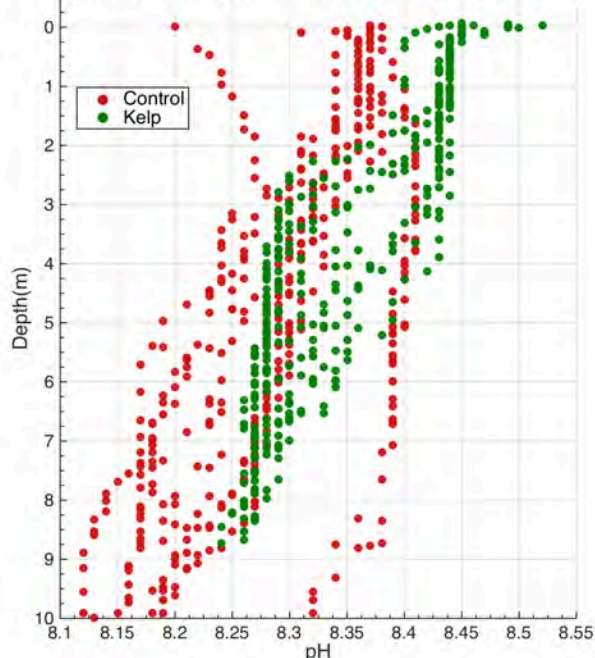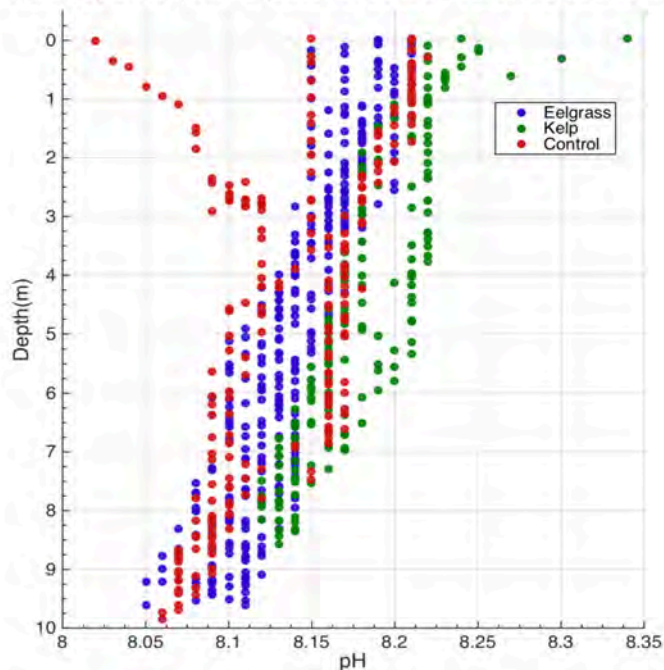

Figure 4- This figure shows all of the pH data from kelp sites and control sites on Field Day 2 (May 3, 2018). Each dot represents a pH value on a certain depth.

Figure 5- This figure shows all of the pH data from kelp sites, eelgrass sites, and control sites on Field Day 3 (May 16, 2018). Each dot represents a pH value on a certain depth.

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Table 2.0- pH Range for each field site organized by day

	Field Day 1 (4/14/18)	Field Day 2 (5/3/18)	Field Day 3 (5/16/18)
Control	7.77 – 8.07	8.11 – 8.41	8.03 – 8.22
Eelgrass	8.02 – 8.08	N/A	8.07 – 8.21
Kelp	7.99 – 8.36	8.24 – 8.52	8.12 – 8.34

Table 2.0- This table demonstrates the range of pH values exhibited by each field site organized by day. The ranges varied significantly depending on the day.

5.3 pH Depth Profiles in Eelgrass Site vs. Control Site

The following figures (**Fig. 6 & Fig. 7**) show the vertical pH profiles of eelgrass and control field sites. These profiles are separated into 3 categories defined by depth: surface (0 to 2-meter depth), intermediate (2 meters to 1 meter from the seafloor), and bottom (1 meter from the seafloor to the seafloor). For each category the mean pH was calculated. On field day 1, the eelgrass had a mean pH greater than the control mean pH in all three columns. On field day 3, eelgrass only had a greater mean pH in the bottom column when compared to the control mean pH.

T-tests were performed on the differences between eelgrass mean pH and control mean pH. The result is that all p-values are 0, meaning even these seemingly tiny differences in pH values are statistically significant. For better analysis and understanding, tails of control data on all scatter plots are considered as outliers and excluded.
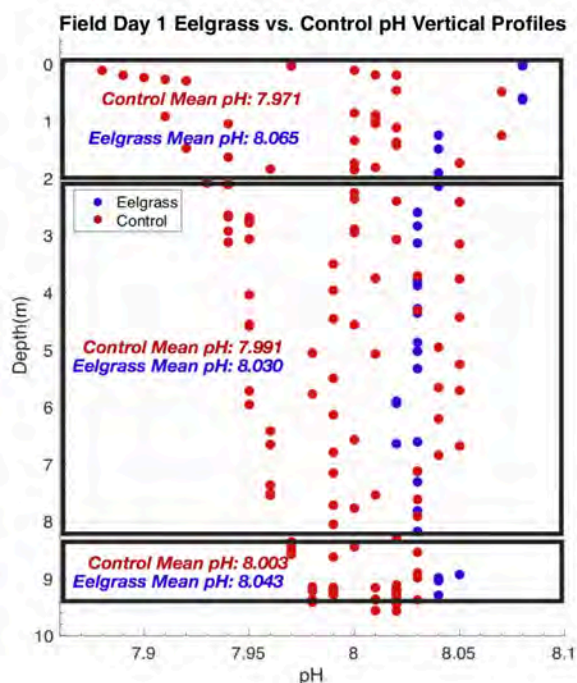

Figure 6- This figure shows pH data from eelgrass sites and control sites on Field Day 1 (April 14, 2018), excluding all the outliers and errors. Each dot represents a pH value on a certain depth.
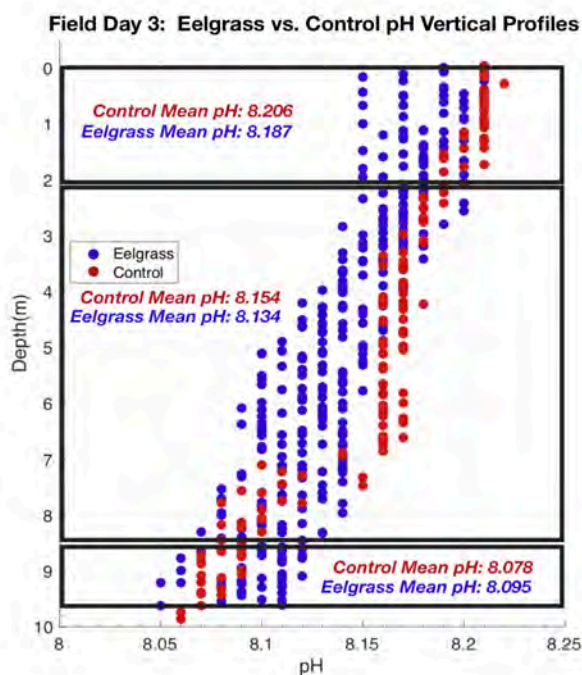

Figure 7- This figure shows pH data from eelgrass sites and control sites on Field Day 3 (May 16, 2018), excluding all the outliers and errors. Each dot represents a pH value on a certain depth.

Table 3.0- Difference in mean of pH between Eelgrass and Control Sites

		Field Day 1 (4/14/18)	Field Day 3 (5/16/18)
Surface	Diff mean pH (Eelgrass – Control)	0.094	-0.019
	p- value	0	N/A
Intermediate	Diff mean pH (Eelgrass – Control)	0.039	-0.020
	p- value		N/A
Bottom	Diff mean pH (Eelgrass – Control)	0.040	0.017
	p-value	0	0

Table 3.0- This table demonstrates the difference in the average pH of the eelgrass locations and the field day locations. In the surface and intermediate sections of the water column, on Field Day 3, the Control maintained a lower average pH than the eelgrass, this is unexpected and therefore these numbers are in red.

5.4 Time difference between control and eelgrass/Temperature and Salinity Profiles

Uncertainties exist in surface and intermediate water columns; this could be due to turbulent surface waters present in the early morning of field day 3.
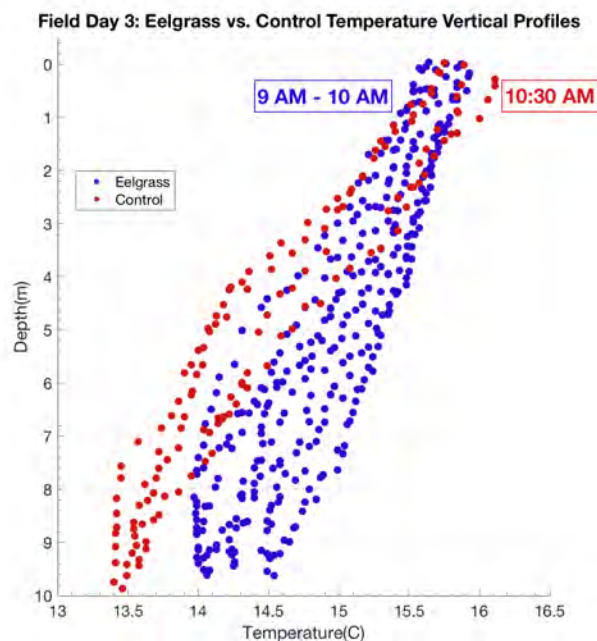

Figure 8- This figure shows temperature data from eelgrass sites and control sites on Field Day 3 (May 16, 2018), excluding all the outliers and errors. Each dot represents a temperature value on a certain depth.
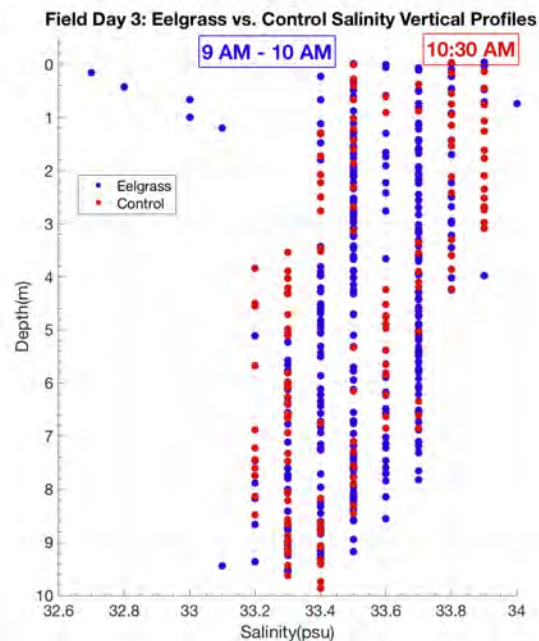

Figure 9- This figure shows salinity data from eelgrass sites and control sites on Field Day 3 (May 16, 2018), excluding all the outliers and errors. Each dot represents a salinity value on a certain depth.

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While salinity data between control and eelgrass are mostly overlapping and constant, there are obvious trend in temperature profiles. At around 9 am to 10 am when eelgrass data were collected, temperature was more uniform because strong turbulence increased mixing between surface and bottom. At around 10:30 am when control data were collected, temperature decreased more drastically with depth because water became more stable. Nevertheless, there was not much difference between eelgrass sites and control sites on the surface column at both time periods.

5.5 pH Depth Profiles in Kelp Site vs. Control Site
      The following figures (**Fig. 10, Fig. 11, Fig. 12**) show the kelp and control mean pH for the surface water column, bottom-water column, and the intermediate water column. In all water columns (surface, intermediate, and bottom) the kelp has a mean pH greater than the control mean pH except in the case where the kelp mean pH is the same as control mean pH at the bottom column during Field Day 1.

      During Field Day 1, the mean pH in control sites and kelp sites were the same and the control pH exhibited much greater variance than kelp pH. Therefore, temperature and salinity profiles were generated to identify if there was any extraneous factors affecting water conditions.
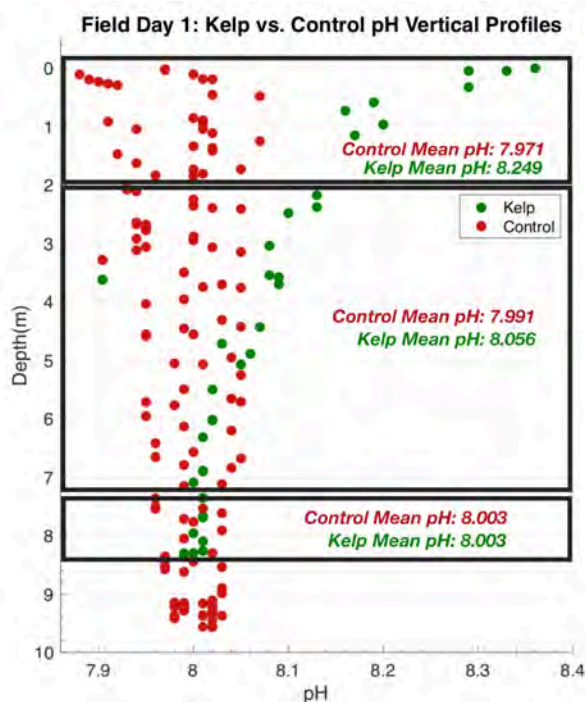

Figure 10- This figure shows pH data from kelp sites and control sites on Field Day 1 (April 14, 2018), excluding all the outliers and errors. Each dot represents a pH value on a certain depth.
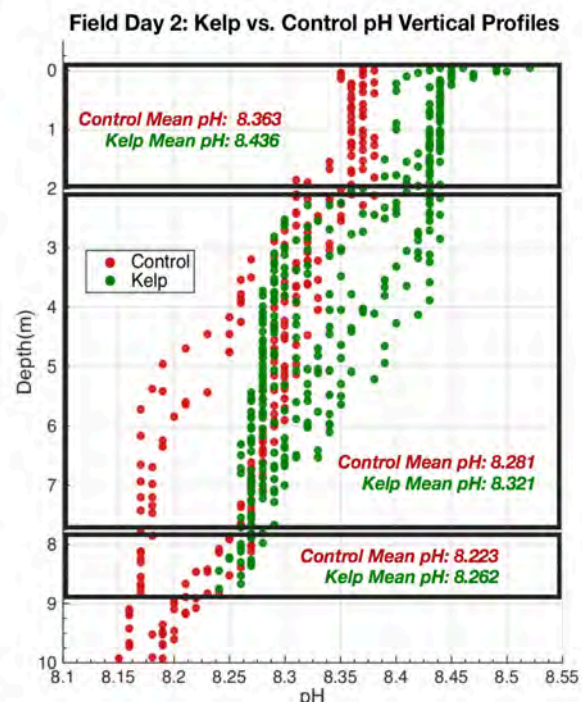
Figure 11- This figure shows pH data from kelp sites and control sites on Field Day 2 (May 3, 2018), excluding all the outliers and errors. Each dot represents a pH value on a certain depth.
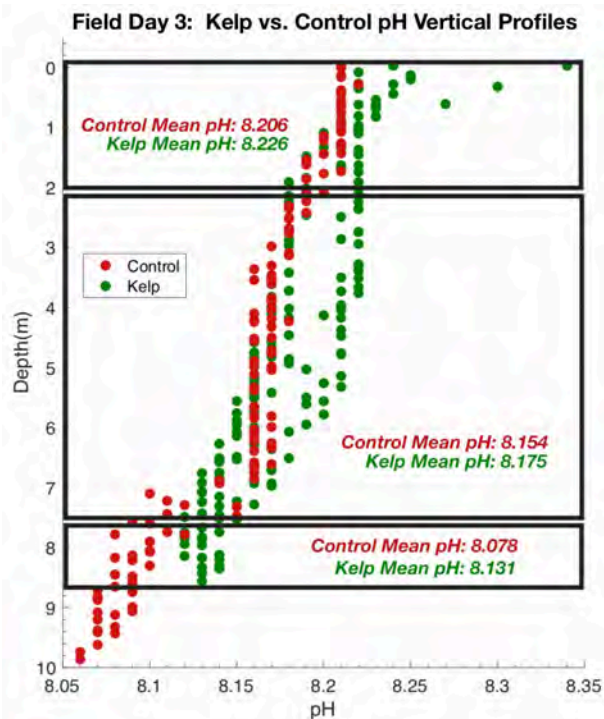
Figure 12- This figure shows pH data from kelp sites and control sites on Field Day 3 (May 16, 2018), excluding all the outliers and errors. Each dot represents a pH value on a certain depth.

Table 4.0- Difference in mean pH between Kelp and Control Sites		Field Day 1 (4/14/18)	Field Day 2 (5/3/18)	Field Day 3 (5/16/18)
Surface	Diff mean pH (Kelp – Control)	0.278	0.073	0.020
	p- value	0	0	0
Intermediate	Diff mean pH (Kelp – Control)	0.065	0.040	0.021
	p- value		0	0
Bottom	Diff mean pH (Kelp – Control)	0	0.039	0.053
	p-value	0	0	0

Table 4.0- This table demonstrates the difference in the mean pH between the Kelp and the Control Field Sites. Most often, the Kelp had a higher average pH than the Control except during Field Day 1 in the bottom section of the water column when the mean pH of both sites was equal. This is unexpected and therefore is printed in red font.

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5.6 Time difference between control and kelp/Temperature and Salinity Profiles

        The following figures show temperature and salinity profiles with time indications for field day 1. It is obvious that there were greater temperature and salinity variance in control sites than kelp sites. There is also more variance on the surface than at the bottom. This evidence implies that greater ranges of parameters in control sites were caused by long time gap between measurements, and surface water was more vulnerable to time gap due to greater mobility of water on the surface.

        Nevertheless, temperature and salinity data points in control sites and kelp sites show similar patterns to control pH and kelp pH at the bottom-1-meter water column. This fact reveals that the variations between control pH and kelp pH at the bottom could be merely caused by the natural variation of water quality during different time periods. Therefore, the same value of kelp mean pH and control mean pH cannot prove that kelp does not affect pH.
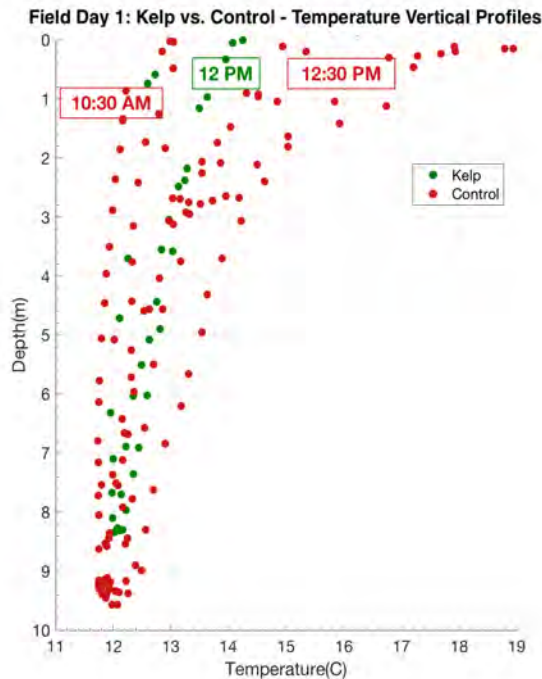

Figure 13- This figure shows temperature data from kelp sites and control sites on Field Day 1 (April 14, 2018), excluding all the outliers and errors. Each dot represents a temperature value on a certain depth.
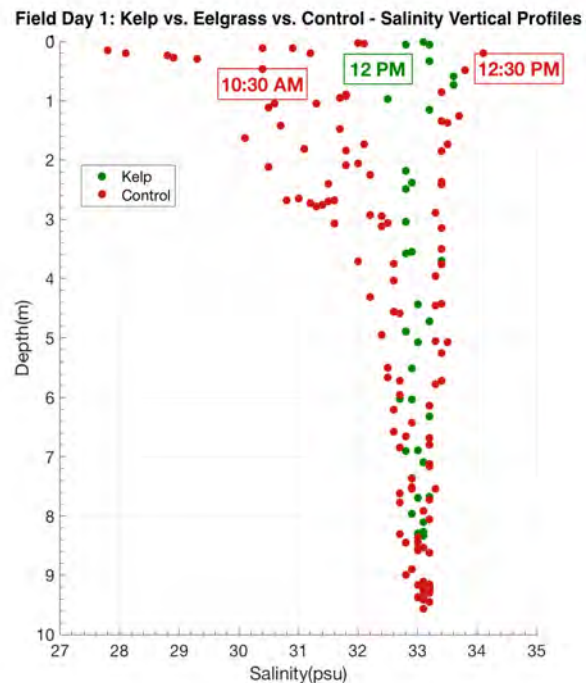
Figure 14- This figure shows salinity data from kelp sites and control sites on Field Day 1 (April 14, 2018), excluding all the outliers and errors. Each dot represents a salinity value on a certain depth.

        As a result, the comparison between pH vs. depth data in kelp sites and control sites demonstrates that kelp pH is significantly higher than open ocean pH, meaning that kelps have the capability of mitigating ocean acidification, especially on the surface and in the middle water column.

6. Discussion

6.1 Outcome

To support our study on the potential of kelp and eelgrass as significant sources of carbon sequestration, pH depth profiles between study sites were analyzed. Temperature and salinity changes were also measured to determine water column conditions and confirm correlations that support pH trends. When comparing pH depth profiles between our eelgrass and control sites both days showed greater mean pH of eelgrass in the bottom 1 meter of the water column. As for comparisons between kelp and control, the mean pH of kelp was consistently greater than that of the control at all levels aside from the bottom 1 meter on field day 1 (in which the means were the same). The trends here are consistent with the hypotheses that kelp has the greatest ability to offset some of the effects of ocean acidification. There is also evidence to suggest eelgrass has an ability to reduce the acidity of surrounding waters, but not to the same effect as kelp. These differences are especially pronounced in kelp surface water column compared to control. (reference graphs)

The samples taken on field days 1, 2, and 3 all occurred in a similar geographic area and within the same 2-3 hour window on their respective days; however, temperature and salinity profiles were generated to corroborate our data and support the notion that pH differences were due to sea plans and not changing ocean conditions (**fig 16,17,18**). This evidence reveals that when other parameters were unchanged, surface mean control pH is higher than surface mean eelgrass pH, implying that eelgrass patch has less of a mitigation effect on acidification. In the intermediate water column, control temperature was lower than eelgrass temperature, suggesting that temperature may have acted as a confounding factor. The higher value of control pH could be affected by temperature differences between eelgrass sites and control sites. Therefore, it is uncertain whether the eelgrass patch affected pH in the middle water column.

On top of gathering data parameter changes across depths, measurements of surface dissolved CO_2 were also collected on our field days. However, limitations are present within this data due to complications with instrument use in the kelp patch along with temporal length between individual data point measurements. Additionally, the prevailing water conditions on each day were different - on field day 2 the ocean's swell was smaller allowing for calmer surface conditions, whereas on field day 3 the ocean surface was more turbulent (**Table 5.1 & Table 5.2**), suggesting more mixing. Of course, there are many other factors that determine surface CO_2 concentration, like biological activity, upwelling, and other processes.

The error in the interpolation is very large in some areas, though overall it is not too high. The mean standardized error for May 3rd is -0.0071 and 0.0006 for May 16th, though at the worst for both days there are areas with very high standardized error at over 30. It is likely that there are many smaller areas with many similar values where it is easy to make an accurate prediction, so the overall error is not too high, but there are also areas with wildly inconsistent and conflicting points that make it very hard to make a prediction there. This unpredictability is likely because the surface of the ocean is quite chaotic (the ocean mixing layer reaches far below the deepest of our study sites), and due to the limitations of the CO_2 sensor; the sensor has a time delay of a 150 seconds. This lag could contribute to some of the sensor's error.

In general, the difference in surface layer turbulence between field days emphasizes the role of prevailing oceanographic conditions in affecting data. Thus, our depth pH results are likely more suitable to draw conclusions for preliminary implications.

6.2 Outliers in Control Site

Control pH data points from field day 2 and 3 have a tail-like pattern and occurred when the very first measurement was taken early on that field day. This evidence raises a question of whether this pattern is caused by operational mistakes or an anomaly during the morning. Therefore, outliers of control

values on May 3rd and May 16th were filtered out and plotted, these graphs can be found in the appendix (**Fig. 15, Fig. 16, Fig. 17, Fig. 18**).

Temperature and salinity profiles on both days show similar non-overlapping trends to pH profiles, revealing that different values on the same depth within one measurement are simply caused by operational mistakes when the instrument was put down and pulled up. Therefore, it is plausible to exclude this two measurements in the previous analysis section.

6.3 Time difference between control and kelp/Temperature and Salinity Profiles

The following figures show temperature and salinity profiles with time indications for field day 1. It is obvious that there were greater temperature and salinity variance in control sites than kelp sites. There is also more variance on the surface than at the bottom. This evidence implies that greater ranges of parameters in control sites were caused by long time gap between measurements, and surface water was more vulnerable to time gap due to greater mobility of water on the surface.

Nevertheless, temperature and salinity data points in control sites and kelp sites show similar patterns to control pH and kelp pH at the bottom-1-meter water column. This fact reveals that the variations between control pH and kelp pH at the bottom could be merely caused by the natural variation of water quality during different time periods. Therefore, the same value of kelp mean pH and control mean pH cannot prove that kelp does not affect pH.

As a result, the comparison between pH vs. depth data in kelp sites and control sites demonstrates that kelp pH is significantly higher than open ocean pH which is consistent with the idea that kelp is better able to mitigate ocean acidification.

6.4 Implications

When comparing pH data across all three sites, results show that that range of kelp pH and eelgrass pH are higher than the range of pH in the control area, with the range of kelp pH being the highest of the three. This implies that kelp forests could, perhaps, play a more significant role in minimizing the effects of ocean acidification through carbon sequestration. Eelgrass and other seagrasses, however, are still important when considering future studies dealing with ocean acidification. Eelgrass, although according to this study has less of an affect on ocean pH, has a much wider environmental tolerance than kelp does. Eelgrass can exist close to the shoreline but also in much deeper ocean than kelp. This is worth noting because perhaps eelgrass and other seagrass can be used to lower the acidity in areas where kelp just cannot survive.

The findings presented in this paper are able to spur the direction of additional studies to help determine scientific focal points necessary to support a spatial monitoring plan along with the possibility of direct restoration projects. Through the installation of additional kelp forests throughout The Santa Monica Bay along with implementation of management practices, the ability for such marine vegetation to store carbon can be enhanced on a greater level.

6.5 Future Research

Due to time constraints and limited data points, we recommend further research to be performed to strengthen evidential support and fill in the gaps within our findings. Potential directions including the following:
1. Methodological work on identification of areas where eelgrass is present. Due to the turbidity of the ocean and the depth at which eelgrass patches are located, our team encountered complexities in finding exact points of potential sites for data collection.
2. Further assessment to compare whether or not distance of kelp and eelgrass patches from the shore play a role in changing mean pH across the water column.
3. As shown in **Figure 2.1** our CO2 vs. time data on field day 2 was consistent with the possible drawdown of CO2 by kelp. However, this interpretation was not supported by the data collected on field day 3 (**Fig. 2.2**). Therefore, it will be beneficial to perform a more in-depth exploration of

daily variations of carbon dioxide uptake of kelp forests. An important factor to take into account in this study is surface layer mixing and how this may induce uncertainties of collected data. In addition, a large-scale exploration of seasonal variations can also help to explain resulting trends.

7. Conclusion

Ocean acidification poses a global threat and anthropogenic pollution is the main driving force behind it. As the world's understanding of how to better control carbon dioxide emissions evolves, protecting marine biodiversity will remain paramount. This study looked at giant kelp and eelgrass off the coast of Malibu, CA and found strong evidence, consistent with the theory that sea plants can buffer ocean acidification locally. Although preliminary, this study strongly supports additional testing to further understand how kelp and eelgrass buffer the waters around them and the viability of projects focused on restoring these sea plants. It is also important to continue studying other sea plants and determining their buffer capabilities in the face of climate change. The results of this study highlight a potential avenue to preserve precious biodiversity into the future and a way to locally combat ocean acidification.

8. Appendices

8.1 Appendix 1 – Maps / Figures

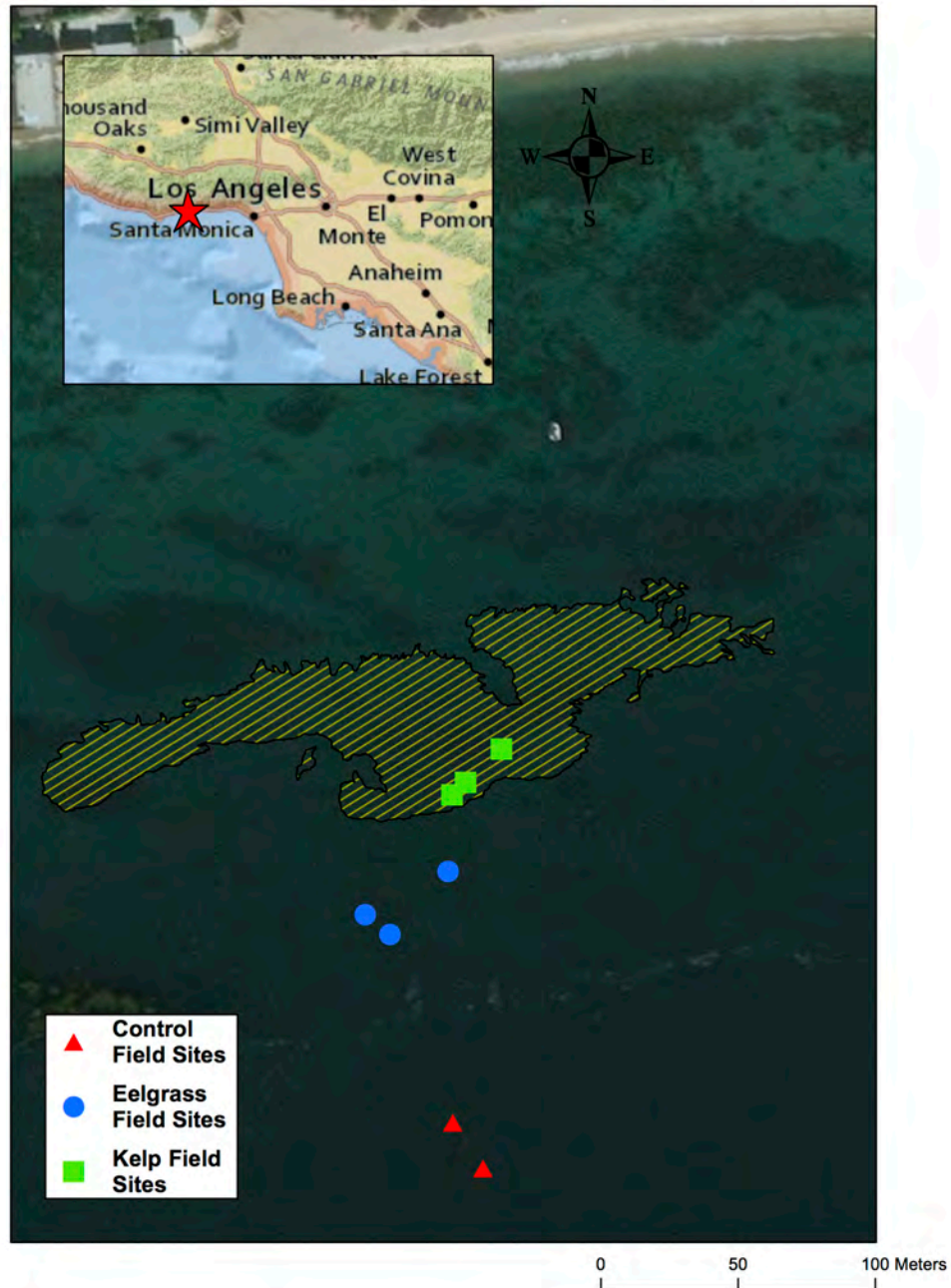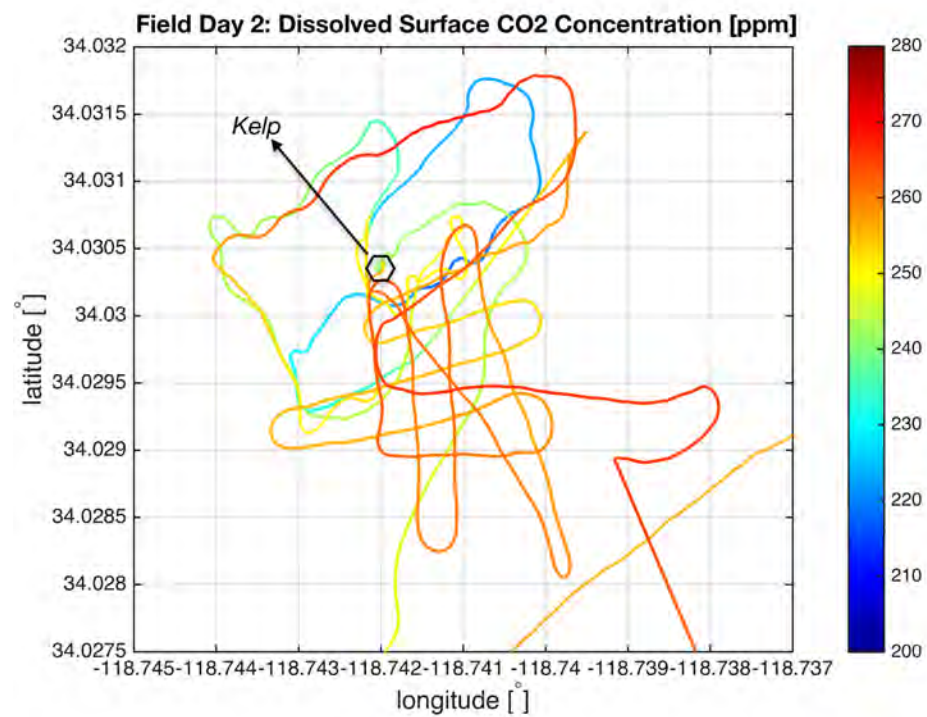**Figure 1.0**

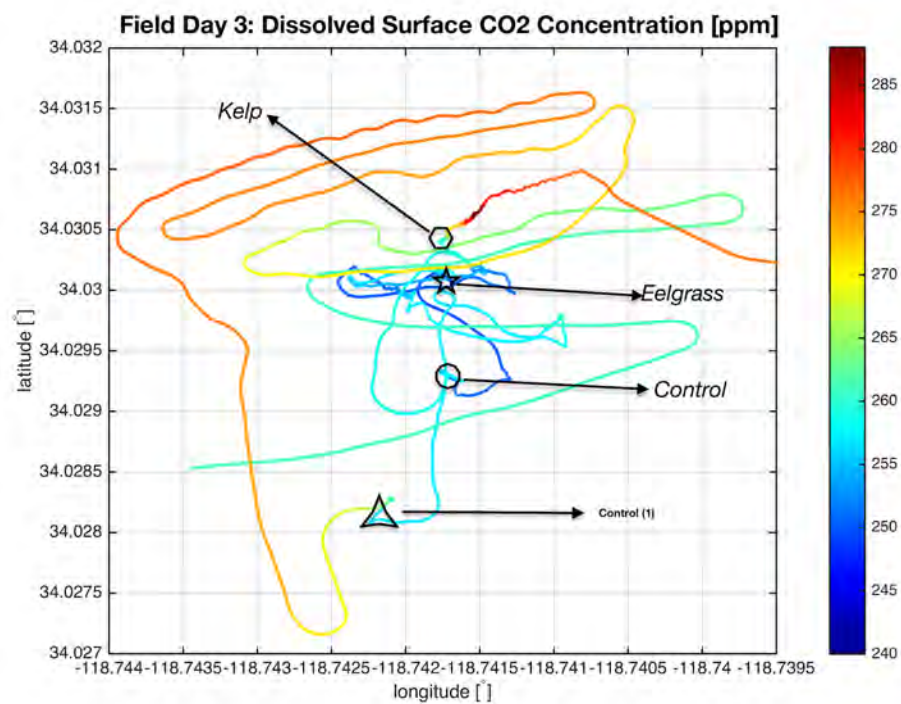Field Location: Solstice Cove, Malibu, CA

Figure 2.1

Field Day 2: Dissolved Surface CO2 Concentration [ppm]

Figure 2.2

Field Day 3: Dissolved Surface CO2 Concentration [ppm]

19

Figure 3.0-

Field Day 1: Kelp vs. Eelgrass vs. Control - All pH Vertical Profiles
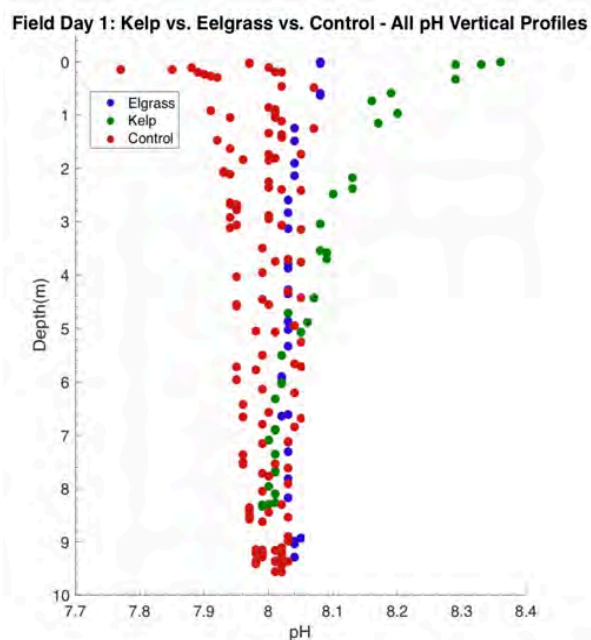
Figure 3.0- This figure shows all of the pH data form kelp sites, eelgrass sites, and control sites on Field Day 1. Each dot represents a pH value at a corresponding depth

Figure 4.0-

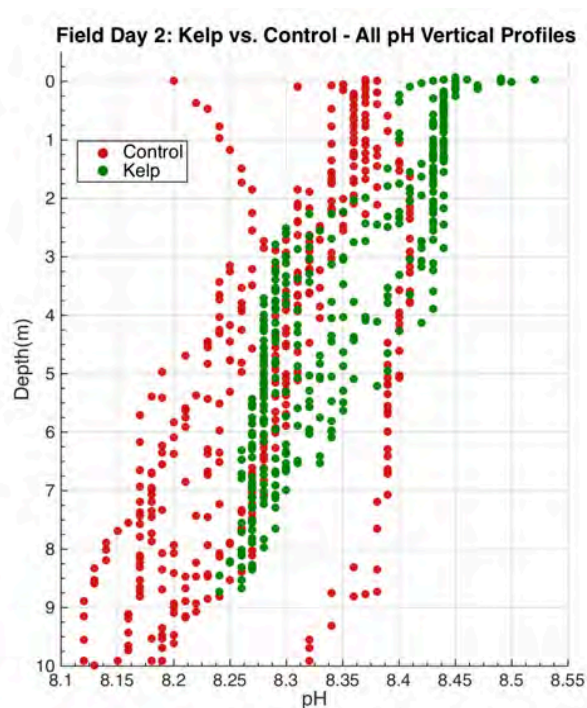Field Day 2: Kelp vs. Control - All pH Vertical Profiles

Figure 4.0- This figure shows all of the pH data from kelp sites and control sites on Field Day 2. Each dot represents a pH value at a corresponding depth. Measurements at eelgrass sites were not take on field day 2

20

Figure 5.0 -

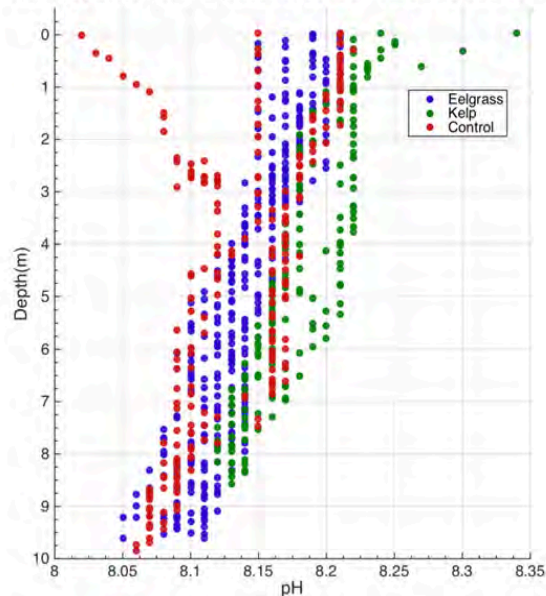Field Day 3: Kelp vs. Eelgrass vs. Control - All pH Vertical Profiles

Figure 5.0- This graph shows all of the pH data from kelp sites, eelgrass sites, and control sites on Field Day 3. Each dot represents a pH value at a corresponding depth

Figure 6.0 -

Field Day 1 Eelgrass vs. Control pH Vertical Profiles

Control Mean pH: 7.971
Eelgrass Mean pH: 8.065

Control Mean pH: 7.991
Eelgrass Mean pH: 8.030

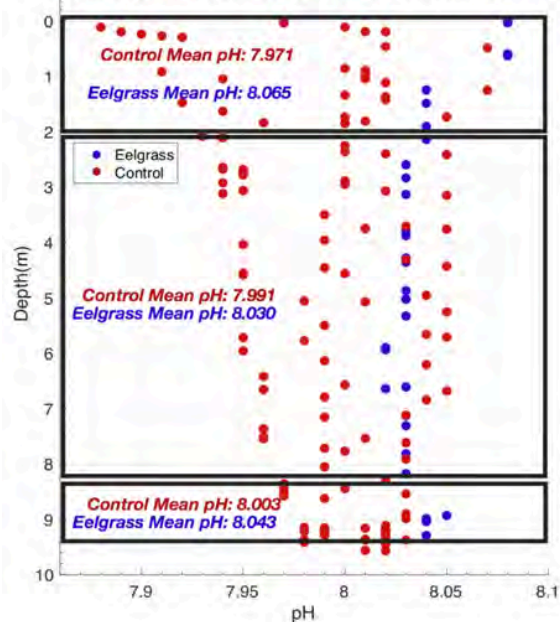Control Mean pH: 8.003
Eelgrass Mean pH: 8.043

Figure 6.0- This graph shows pH data from eelgrass sites and control sites on Field Day 1, excluding all the outliers and errors. Each dot represents a pH value at a corresponding depth
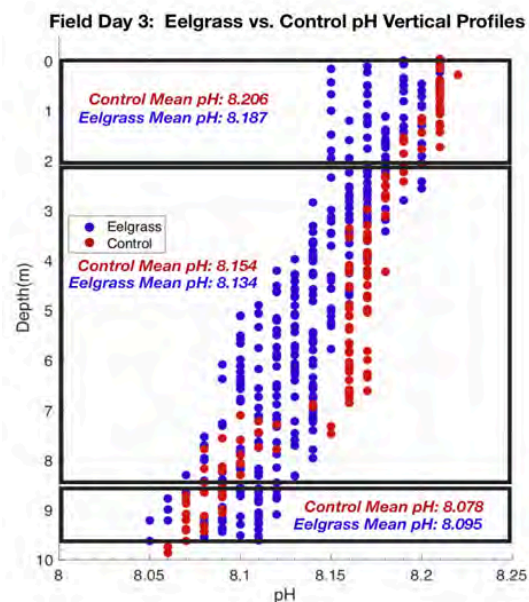
21

Figure 7.0-

Figure 7.0- This graph shows pH data from eelgrass sites and control sites on Field Day 2, excluding all the outliers and errors. Each dot represents a pH value at a corresponding depth
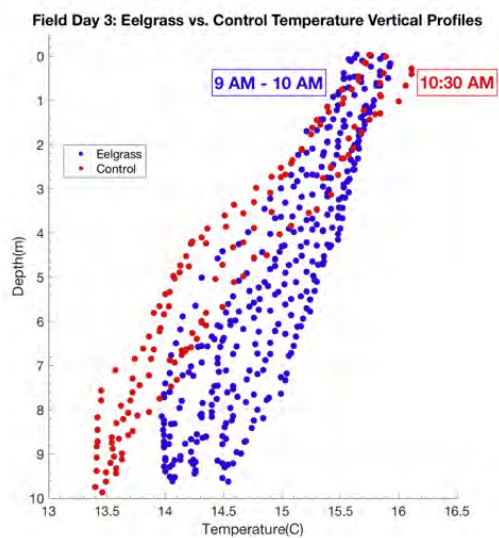
Figure 8.0 -

Figure 8.0- This graph shows temperature data from eelgrass sites and control sites on Field Day 3, excluding all the outliers and errors. Each dot represents a temperature value at a corresponding depth
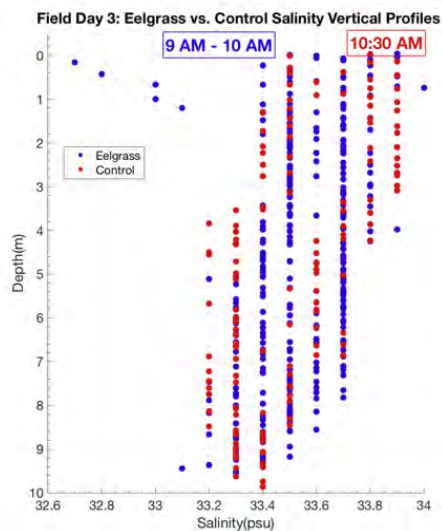
Figure 9.0 –

Figure 9.0 – This graph shows salinity data from eelgrass sites and control sites on Field Day 3, excluding all the outliers and errors. Each dot represents a salinity value at a corresponding depth.
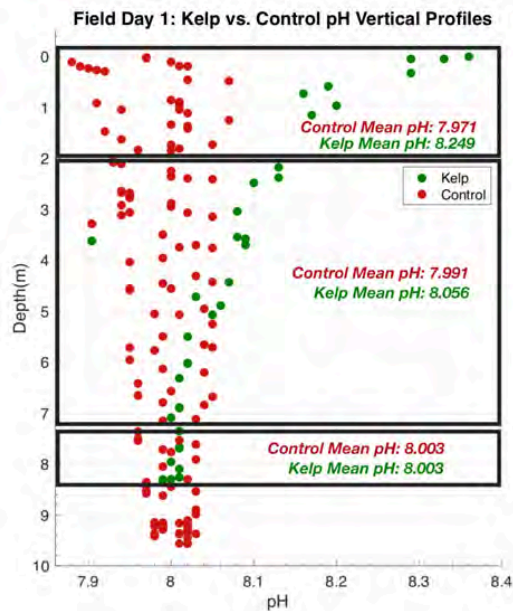
Figure 10.0 –

Figure 10.0- This graph shows pH data from kelp sites on Field Day 1, excluding all outliers and errors. Each dot represents a pH value at a corresponding depth.

Figure 11.0

Figure 11.0- This graph shows pH data from kelp sites and control sites on Field Day 2, excluding all outliers and errors. Each dot represents a pH value at a corresponding depth.

Figure 12.0
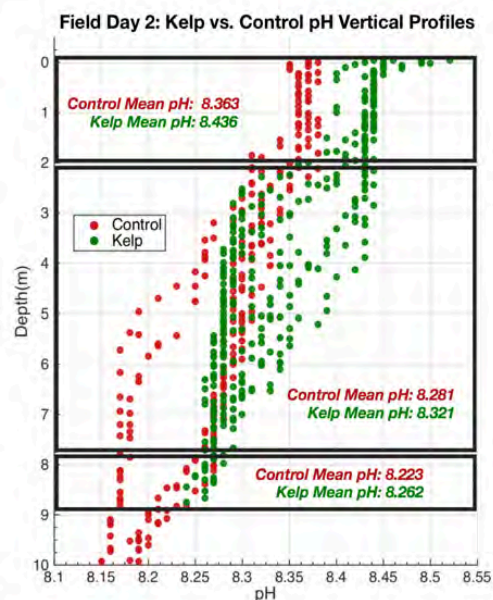

Figure 12.0- This graph shows pH data from kelp sites and control sites on field day 3, excluding all outliers and errors. Each dot represents a pH value at a corresponding depth.

Figure 13.0

Figure 13.0- This graph shows temperature data from kelp sites and control sites on Field Day 1, excluding all outliers and errors. Each dot represents a temperature value at a corresponding depth.
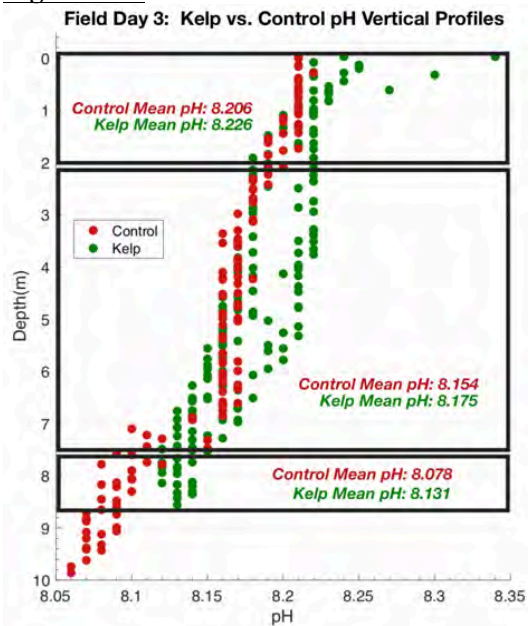
Figure 14.0

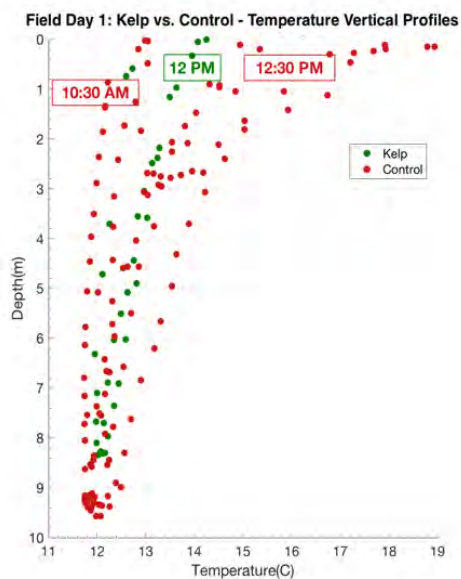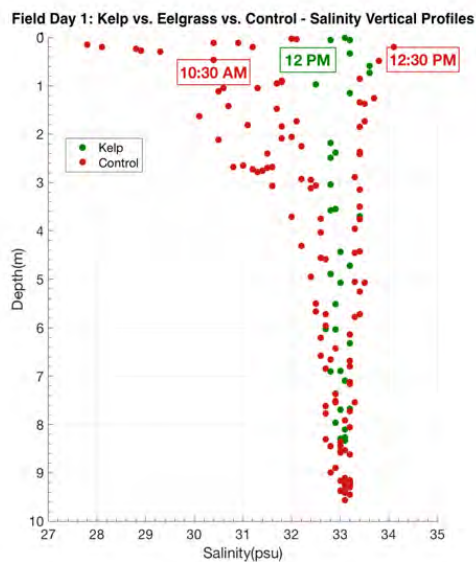**Figure 14.0**- This graph shows salinity data from kelp sites and control sites on Field Day 1, excluding all outliers and errors. Each dot represents a salinity value on at a corresponding depth.

8.2 Appendix 2- Tables

Table 1.0 – Surface Dissolved CO_2 Concentration (Mean | Range)		
	Field Day 2 (5/3/18)	Field Day 3 (5/16/18)
Control	257.003155 | 250.258469 - 261.753052	255.535685 | 251.139359 - 260.37204
Eelgrass	--	254.82933 | 250.186234 - 255.916977
Kelp	243.25669 | 223.842468 - 254.632324	273.068742 | 258.87851 - 294.451935

Table 2.0- pH Range for each field site organized by day			
	Field Day 1 (4/14/18)	Field Day 2 (5/3/18)	Field Day 3 (5/16/18)
Control	7.77 – 8.07	8.11 – 8.41	8.03 – 8.22
Eelgrass	8.02 – 8.08	N/A	8.07 – 8.21
Kelp	7.99 – 8.36	8.24 – 8.52	8.12 – 8.34

Table 3.0 - Difference in mean of pH between Eelgrass and Control Sites			
		Field Day 1 (4/14/18)	Field Day 3 (5/16/18)
Surface	Diff mean pH (Eelgrass – Control)	0.094	-0.019
	p- value	0	N/A
Intermediate	Diff mean pH (Eelgrass – Control)	0.039	-0.020
	p- value		N/A
Bottom	Diff mean pH (Eelgrass – Control)	0.040	0.017
	p-value	0	0

		Field Day 1 (4/14/18)	Field Day 2 (5/3/18)	Field Day 3 (5/16/18)
Table 4.0 - Difference in mean pH between Kelp and Control Sites				
Surface	Diff mean pH (Kelp – Control)	0.278	0.073	0.020
	p- value	0	0	0
Intermediate	Diff mean pH (Kelp – Control)	0.065	0.040	0.021
	p- value		0	0
Bottom	Diff mean pH (Kelp – Control)	0	0.039	0.053
	p-value	0	0	0

Table 5.1 - Float Plan May 3, 2018 Field day 2	
Departure	0530
Arrival	1400
Area of Operation	Solstice Cove, Malibu, CA
Forecast/ Notes: **.THU...Winds variable 10 kt or less, becoming W 10 to 20 kt in the afternoon. Wind waves 2 ft or less, building to 2 to 3 ft in the afternoon. W swell 2 to 3 ft at 7 seconds.** National Oceanic and Atmospheric Administration	

Table 5.2 - Float Plan May 16, 2018 Field day 3	
Departure	0600
Arrival	1400
Area of Operation	Solstice Cove, Malibu, CA
Forecast/ Notes: .WED...W winds 10 to 15 kt. Wind waves 1 to 3 ft. Mixed swell W 2 to 4 ft at 7 seconds and S 2 ft at 13 seconds. National Oceanic and Atmospheric Administration	

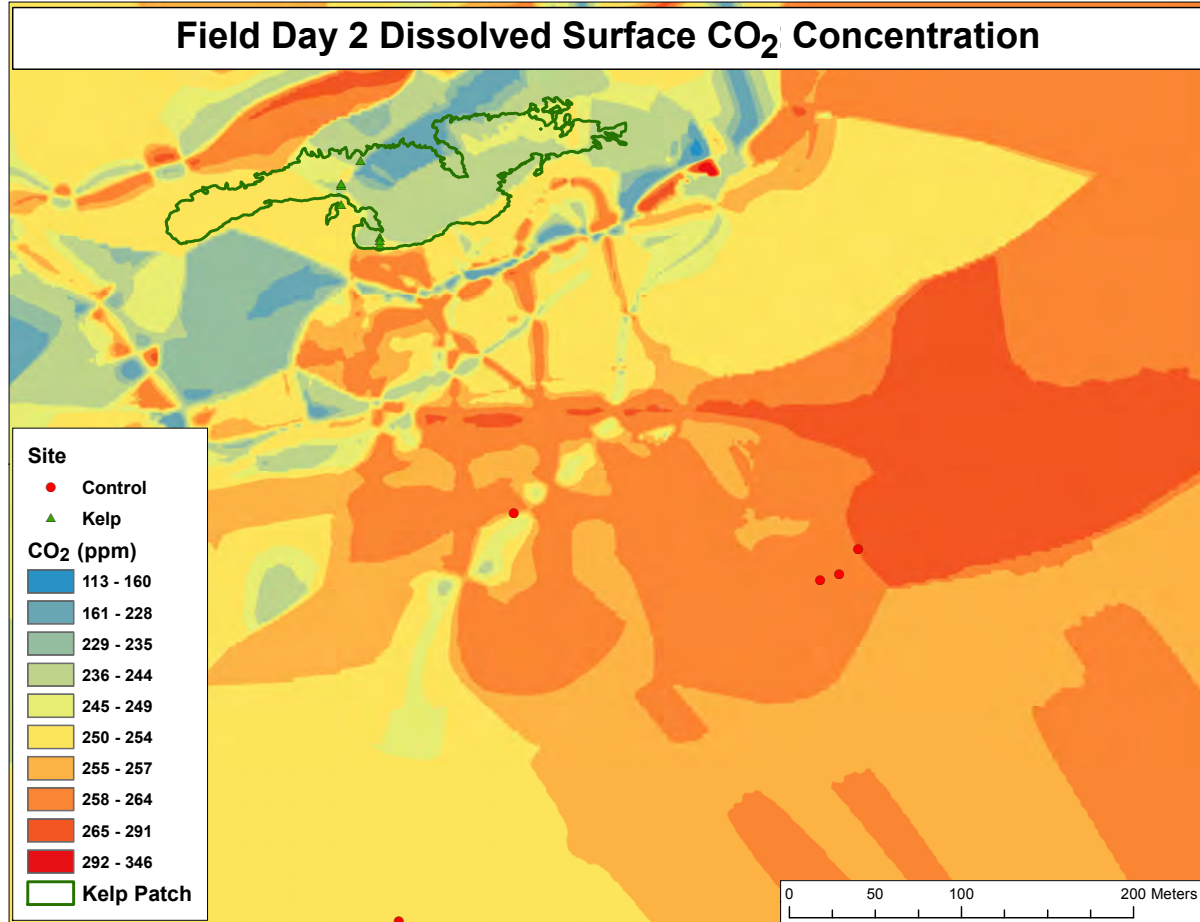 *Forecast for April 14, 2018 not available.

8.3 Appendix 3- Supplemental Information
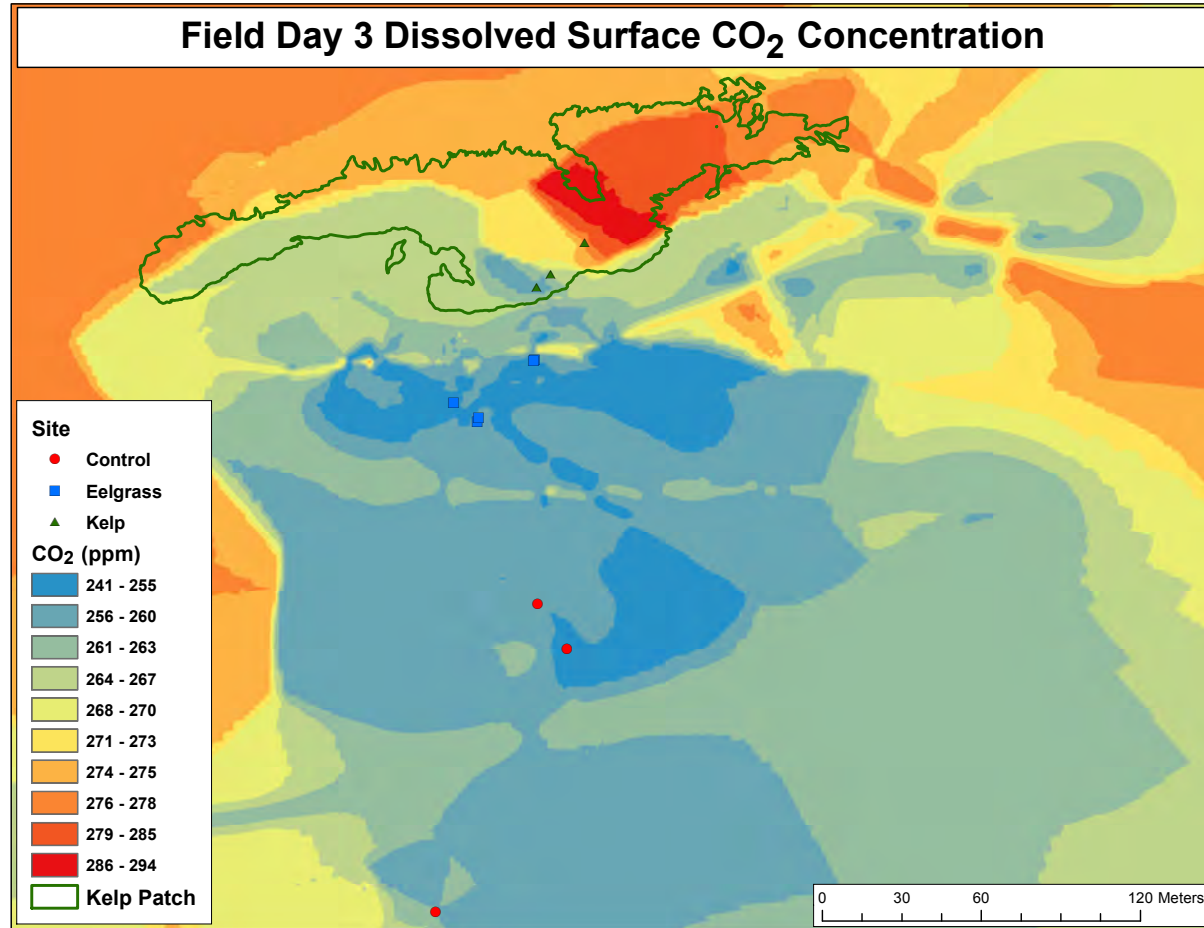
Supplemental 1.
All Zodiac Data vs. Time

Field Day 2 Dissolved Surface CO_2 Concentration

Site

- **Control** (red circle)
- **Kelp** (green triangle)

CO_2 (ppm)

- 113 - 160
- 161 - 228
- 229 - 235
- 236 - 244
- 245 - 249
- 250 - 254
- 255 - 257
- 258 - 264
- 265 - 291
- 292 - 346
- **Kelp Patch**
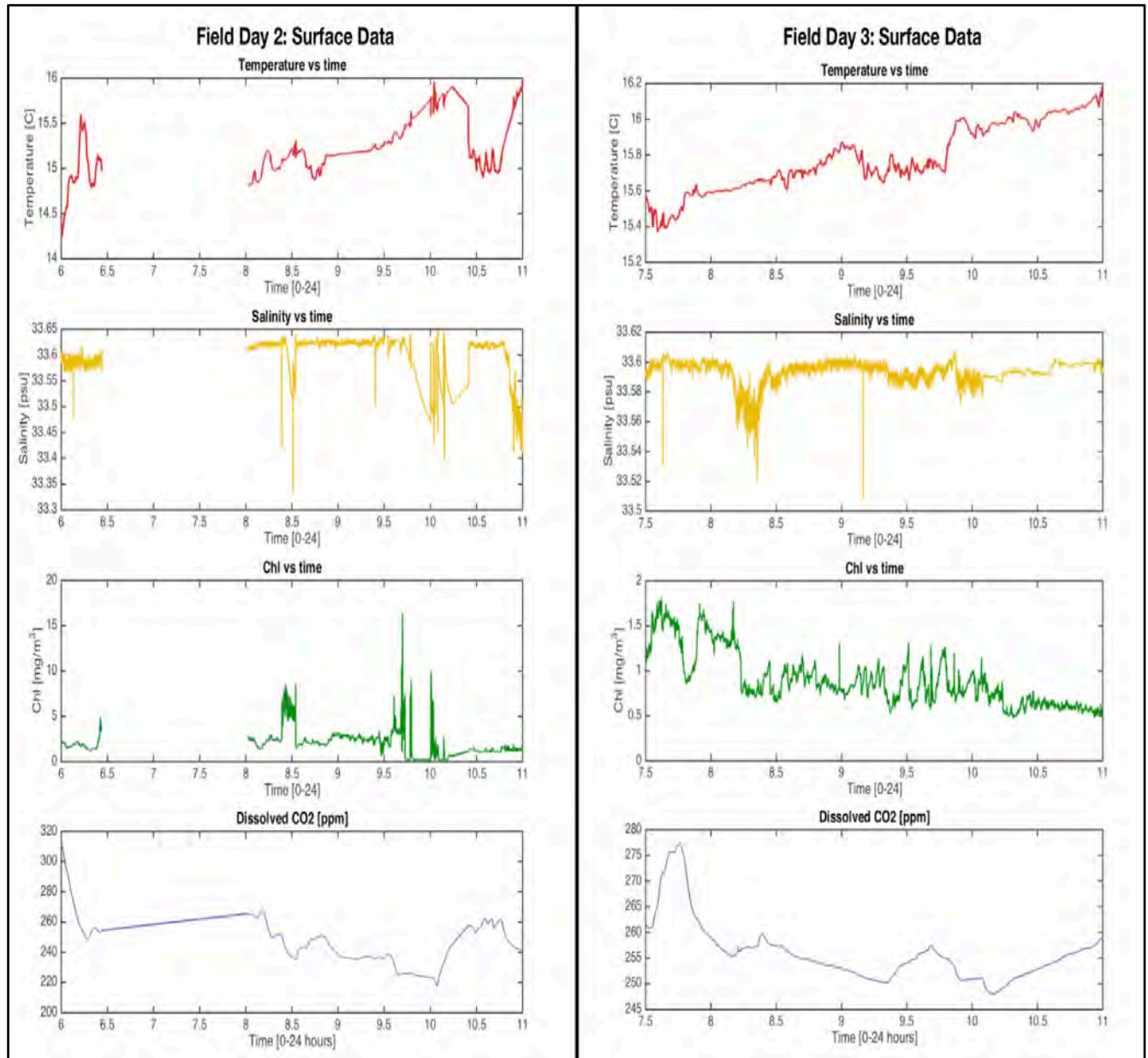
0   50   100   200 Meters

Supplemental 2.0 shows the predicted dissolved CO2 concentration in parts per million (ppm) at the surface of the ocean for field day 2 (May 3, 2018). Each color represents a range the dissolved CO2 concentration is calculated to belong to, with areas with lower concentrations bluer and areas with higher concentrations redder. The red circles represent where the control measurements were taken, and the green triangles where measurements for kelp was taken.

Field Day 3 Dissolved Surface CO_2 Concentration

Site
- ● Control
- ■ Eelgrass
- ▲ Kelp

CO_2 (ppm)
- 241 - 255
- 256 - 260
- 261 - 263
- 264 - 267
- 268 - 270
- 271 - 273
- 274 - 275
- 276 - 278
- 279 - 285
- 286 - 294
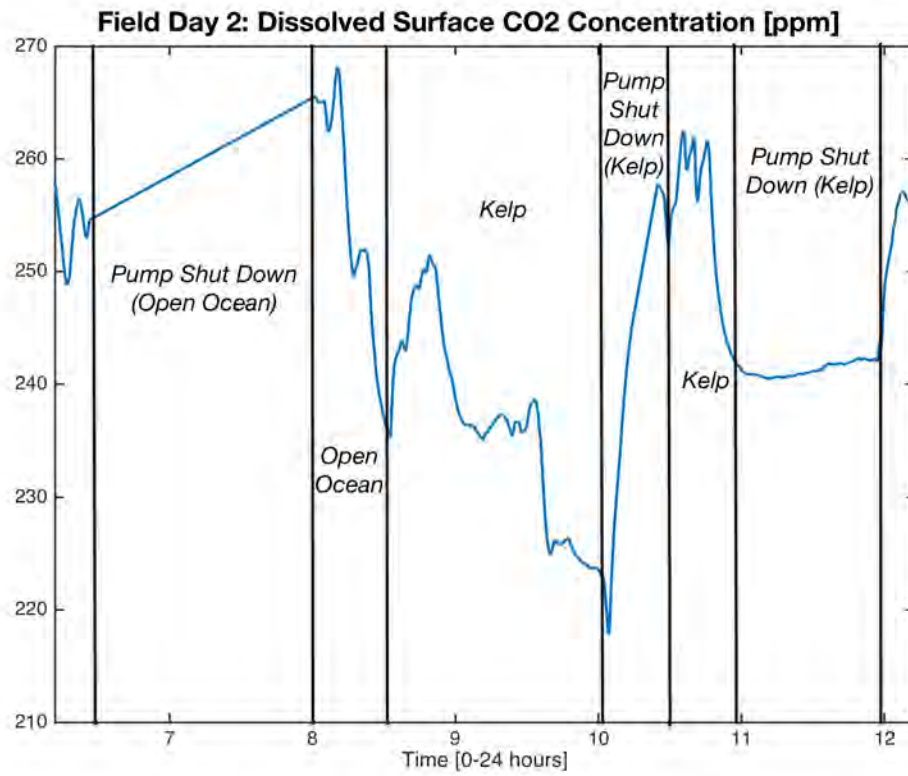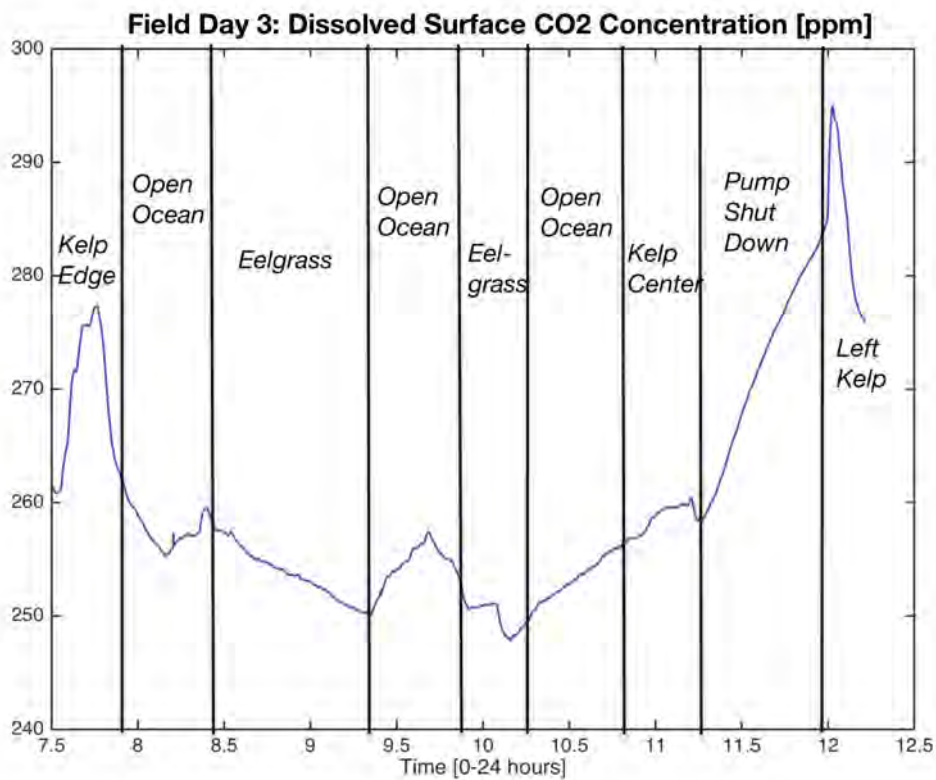
▢ **Kelp Patch**

0   30   60   120 Meters

Supplemental 3.0 shows the predicted dissolved CO2 concentration in parts per million (ppm) at the surface of the ocean for field day 3 (May 16, 2018). Each color represents a range the dissolved CO2 concentration is calculated to belong to, with areas with lower concentrations bluer and areas with higher concentrations redder. The red circles represent where the control measurements were taken, the blue rectangles where the measurements for eelgrass was taken, and the green triangles where measurements for kelp was taken

Supplemental 4.0

Field Day 2: Dissolved Surface CO2 Concentration [ppm]

Supplemental 5.0

Field Day 3: Dissolved Surface CO2 Concentration [ppm]

Supplemental 6.0 – Daily Itinerary (All times in Pacific Standard Time)	
April 14, 2018 (Field Day 1)	The team departed from the port of Los angles at 7:30am and we arrived at Solstice Cove at 10am. The Bay Foundation then scanned the sea floor using their sonar instrument looking for eelgrass signatures. Once found, the Bay Foundation deployed the ROV to visually confirm areas of eelgrass. Meanwhile the team assembled the handheld pH instrument and took control samples. The Bay Foundation also got in the water to collect sea weed samples as well as guide our instrument into the patches of eelgrass in order to confirm we were in the right area. The anchor was then let out to float closer to the kelp and measurements were taken there as well. Additional control measures were also taken before leaving the study site. The team arrived back at the port of Los Angeles at 1:30pm.
May 3, 2018 (Field Day 2)	The team departed from the marina at 5:30am. Upon arriving at Solstice Cove, measurements in the control sites were taken first. The Zodiac was then driven around the study site multiple times to collect surface dissolved carbon dioxide data. The boat was then anchored near the kelp patch to take data in and around the kelp. The team tried floating through the kelp to collect surface dissolved carbon dioxide data but the sensor clogged. Eelgrass data were not collected on this field day. Conditions can be found in **Table 5.1** but were very calm, mild and sunny. The team arrived back at the marina at 2:00pm.
May 16, 2018 (Field Day 3)	The team departed from the marina at 6:00am. Upon arriving at Solstice Cove, 2 measurements in the control sites were taken. The Zodiac was then driven around the study site multiple times to collect surface dissolved carbon dioxide data. The team then spent time locating eelgrass meadows by sending down a GoPro to video the seafloor. Data were then collected in the eelgrass meadows. The Zodiac was then anchored near the kelp and kelp data was taken. Before leaving the team collected more control site data. Conditions can be found in **Table 5.2** but were much rougher than Field Day 2. Swells were higher and the water was more turbulent. The team arrived back at the marina at 2:00pm.

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