Climate Change Vulnerability Assessment

Final Report

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1. Abstract

We created a climate change tool inventory and assessed the vulnerability of Goal 9 in the *Santa Monica Bay Restoration Commission Bay Restoration Plan 2013* — "Protection and Restoration of Kelp Forest and the Population of Abalone in Santa Monica Bay Area." As two crucial participants of the marine ecosystem, kelp forests and abalones are currently at risk due to climate change. According to various studies, seawater temperature rise, increasing wave height, and invasive species are the three main threatening factors, other than human activities, that have led to the decline of the population of these two species. By using the tools in our inventory, such as California's Ocean in an El Nino year (CeNCOOS), California Swell Model Archive, and Marine Invasive Observation Map, we analyzed the impacts of climate change on the population of kelp forest and abalone. In the end, we concluded that climate change affects these two species negatively.

2. The Problem

The Bay Foundation (TBF), an organization dedicated to preserving the environment of Santa Monica Bay area, is trying to assess the vulnerability of its Bay Restoration Plan (BRP) under the impacts of climate change. In order to understand how climate change will directly affect the goals, priorities, and objectives of the foundation, we need an inventory of climate change resources to provide specific analysis on the subjects of interest. We started by constructing the inventory, and then used the tools to conduct a vulnerability assessment.

Creating a tool inventory requires narrowing down the scope of the search (many of the tools we initially found were not relevant to our project). After obtaining a small pool of climate change tools, we documented them comprehensively and appropriately, so that a user can get the most important knowledge on each tool quickly and easily by simply reading through the documentation. Also, this documentation helped us categorize and compare the tools for specific purposes. In the end, we created a scoring mechanism that outputs the ranking of all the tools in the inventory based on the task of interest.

After creating the climate change tool inventory, we focused on assessing the vulnerability of Goal 9 in the *Santa Monica Bay Restoration Commission Bay Restoration Plan 2013* — "Protection and Restoration of Kelp Forest and the Population of Abalone in Santa Monica Bay Area." The effects of global warming can be seen in the world around us today. Historical records have shown that, near southern California, seawater temperature has been rising at an increasing rate since the 1960s according to "California's Ocean in an El Nino Year" (CeNCOOS, 2016). This area serves as an important freshwater habitat for wildlife, and the rising seawater temperature can significantly threaten the survival of native species, especially for those with low resistance to temperature variation.

As one of the most productive ecosystems, kelp forests are subtidal areas with a high density of kelp. They support the diverse assemblage of life that inhabits them. The blades and holdfasts of kelp provide refuge for many fish, invertebrates, and marine mammals. Moreover, kelp forests provide humans with benefits known as ecosystem services: ocean currents are slowed by dragging of large kelps, and consequently, wave actions onshore are decreased. By altering the waves, kelp forests can curb the erosion of coastal areas and lower the protection and replacement costs of properties (NOAA, 1999). However, despite their environmental values, kelp forests in the Santa Monica Bay are now at risk due to a number of factors listed by BRP. The primary contributing factors include overharvesting of the predators of sea urchins, pollution, coastal development, nutrient overload, sedimentation, and changes in ocean temperature and current.

As a member in the kelp forests habitat, abalones are marine snails that live primarily in intertidal and subtidal zones. They are extremely important for local ecosystems and human beings: studies have shown that herbivorous grazing by adult abalones in rocky subtidal zones helps regulate ecosystem dynamics of the benthic community. For instance, filter-feeding animals eat the eggs and larvae of abalone, and juvenile abalones are the main prey for crabs, lobsters, octopuses, starfish, etc. (Bouma, 2007). For humans, the flesh of abalone is widely considered to be a desirable food source and is consumed raw or cooked in many cultures. Due to overharvesting, the abalone population in Southern California has decreased drastically in recent years, and the situation is exacerbated by the decreasing quality of kelp forests, a natural habitat for abalones.

3. Methodology

3.1 Climate Change Tool Inventory

In order to create our climate change tool inventory, we searched for all available climate change tools related to the Santa Monica Bay area and the goals of the BRP. More specifically, we documented all climate change tools whose data are relevant to the area encircled by the red line in Figure 3.1, and also those that concern at least one goal in the BRP. Since TBF is particularly concerned with marine preservation and natural habitats restoration in the Santa Monica Bay area, we selected tools with information about climate change stressors directly related to our project goals, such as temperature rise, precipitation change, sea-level rise, and ocean acidification, and we filtered out the irrelevant ones. For example, a climate change tool that only includes data collected from the east coast of the United States or one that simply records the economic benefit of the fishing industry near the west coast would not be included in our inventory. After the filtration, approximately 70 tools related to the conditions of climate change near Santa Monica Bay area were recorded.

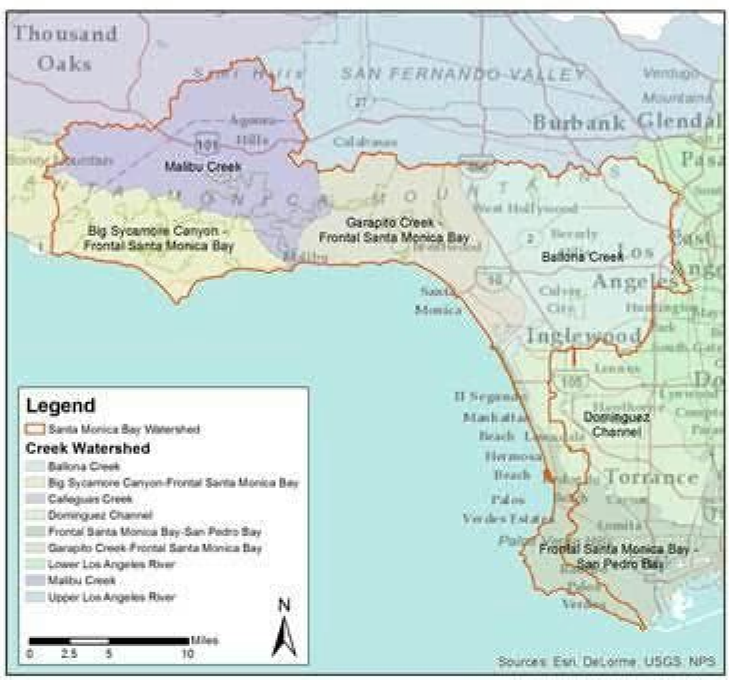

Figure 3.1 Map of Santa Monica Bay Area

Next, we categorized each tool in terms of its (A) name, (B) type (e.g., online, journal, software, etc.), (C) geographical scale (e.g., global, national, etc.), (D) major agencies responsible for creating the tool, (E) aspects of climate change addressed, and (H) website where the tool can be found. Notice that if a tool is labeled as "Global" in column (C), it means that the tool includes data on a global scale, but can still provide useful information related to our area of interest if we narrow down the scale of data. In addition to these six fundamental layers, we also categorized each tool according to its (F) topics of interest. "Climate Change I" includes tools that record data or trends of direct climate change stressors, such as temperature and precipitation. "Climate Change II" includes tools that record the subsequent effects of changes caused by direct climate change stressors, such as sea level rise and ocean acidification. Additionally, for tools that include information related to both types, we labeled them as Climate Change I & II. Meanwhile, some of the tools could directly contribute to one or more of our goals, so we gave suggestions to the type of project goals, to which this tool might be related, in column (G). As for the other tools that cannot be directly used in our goals, we left that cell blank. As a result, users can conveniently find the tools related to their projects simply by going through the column (G). Column (I) records the time scale of the data used in the tool, with "pa" referring to the recorded data in the past and "f" referring to the predictions made for the future.

Last, we evaluated the effectiveness of our tools based on four categories: 1) convenience, 2) relevance of the tool to the Bay Foundation's goals, 3) reliability of the source of data, and 4) whether the records are up-to-date. The detailed criteria for each aspect are listed in Tables 3.1-3.4. Generally speaking, we evaluated each category separately with a scale of 1 - 5 to maintain the consistency and validity of the score. After the separate evaluations, we calculated an integrated score, which is an average of the four independent scores. A high integrated score means a better overall performance of the tool based on our criteria.

Score	Convenience[1]

[1] Please note that the evaluation process based on the "convenience" of each tool is a subjective judgement from the grader rather than an objective measurement, especially for comparison with the other dimensions. Nonetheless, we think this is an efficient way to show some information about user-friendliness of each tool.

5	The graphs and the explanations of climatic trends are easy to read and follow; the users could quickly find their information of interest; the user interface is well-designed.
4	The graphs and the explanations of climate trends are relatively easy to read and follow; the users could relatively quickly find their information of interest; the user interface is relatively well-designed.
3	One of the aspects mentioned above does not reach an acceptable convenience level.
2	Two of the aspects mentioned above does not reach an acceptable convenience level.
1	The illustration of the graphs and the explanation of the trends are cumbersome or hard to follow; the users could hardly find the information they are interested in; the user interface is messy.

Table 3.1. Criteria Used to Score Each Tool According to Its Convenience

Score	Relevance
5	Data directly related to the Santa Monica Bay area.
4	Data related to the coastal area of southern California and not specific to the Santa Monica Bay area.
3	Data related to the coastal area of California and not specific for southern California.
2	Data related to western coastal areas and not specific to the coastal area of California.
1	Data contained the target area on a large scale but cannot be zoomed in to get useful information.

Table 3.2. Criteria Used to Score Each Tool According to Its Relevance

Score	Reliability
5	More than two major authorities (i.e. governmental agencies[2], university research centers, major non-profit organizations) are responsible for creating the tool.
4	One or two major authorities (i.e. governmental agencies, university research centers, major non-profit organizations) are responsible for creating the tool.
3	More than two organizations are responsible for creating the tool (without the involvement of any governmental agency, academic institution or major non-profit organization).
2	One or two organizations are responsible for creating the tool (without the involvement of any governmental agency, academic institution or major non-profit organization).
1	Has no record regarding which agencies are responsible for creating the tool.

Table 3.3 Criteria Used to Score Each Tool According to Its Reliability

Score	Records up-to-date
5	The most recent data is recorded up-to-date
4	The most recent data is recorded after 2010 but is not constantly being updated.
3	The most recent data is recorded between 2000 and 2010

[2] If a governmental agency is composed of separate departments (such as NOAA), then we consider each distinct department as one authority.

2	The most recent data is recorded in the 20th century
1	The most recent data is recorded before the 20th century

Table 3.4 Criteria Used to Score Each Tool According to Whether the Data is Up-To-Date

In conclusion, the inventory is a comprehensive and convenient collection of climate change tools relevant to the main research goals of TBF. Additionally, the four-dimensional evaluation system can be a framework of inventory construction for similar scientific studies in the future.

3.2 Vulnerability Assessment

The second part of our project focuses on the vulnerability assessment of a specific aspect of climate change by employing several tools from our inventory. Our choice is Goal #9 from the Bay Restoration Plan - "Restoring Rocky Intertidal and Subtidal Habitats" with a concentration on two of its sub-objectives - "Restoring and Monitoring Sixty Acres of Kelp Forest" and "Protecting and Managing Rocky Intertidal Habitats." We first did a literature review on the impacts of climate change on kelp forests and abalone. Based on the arguments and conclusions in the academic papers, we then selected several relevant tools from our inventory and studied the historical data and trends of climate change presented in the tools. In the end, we applied the selected tools to our chosen objectives and conducted the vulnerability assessment on how our objectives will react to climate change.

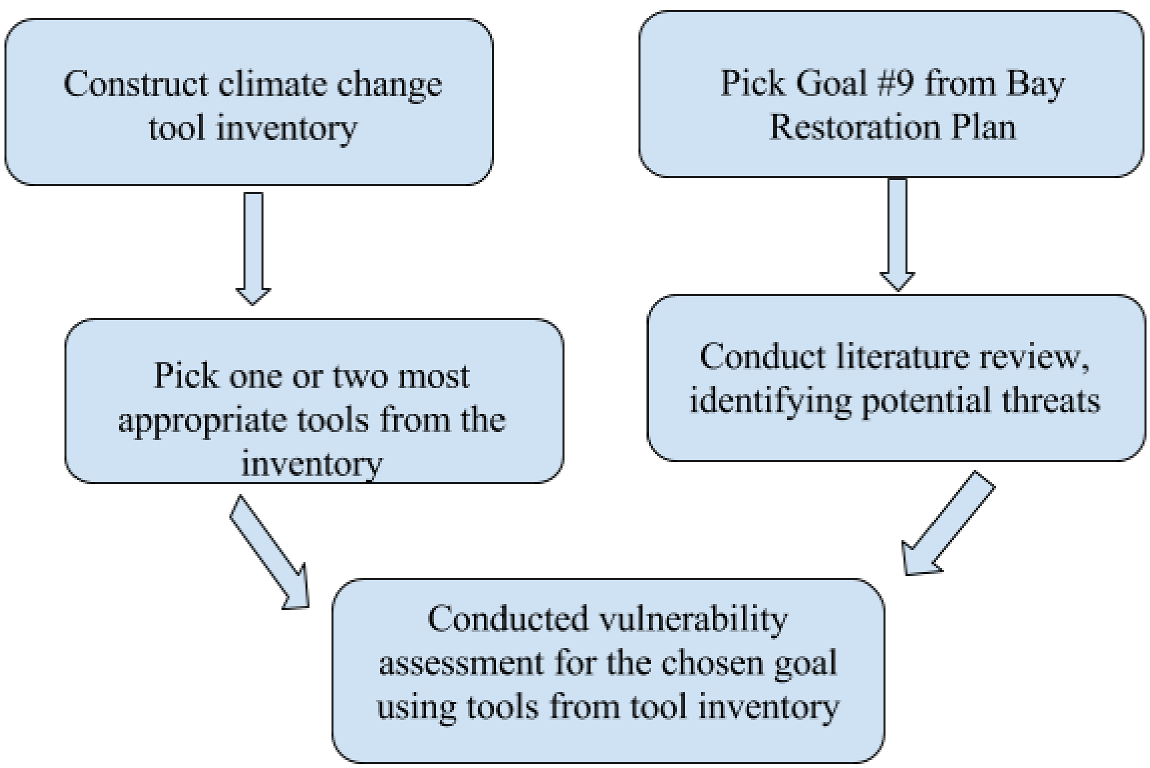

Figure 3.2 Methodology Flow Chart

4. Literature Review

In this section, we present some previous research related to the impacts of climate change on the populations, physiological responsiveness, and ecological performances of kelp forest and abalone. We especially focus on two climate change stressors - seawater temperature rise and the increase in wave disturbances. There are two main reasons that we picked seawater temperature and wave disturbance as stressors: first, stressors such as ocean acidification have not occurred in the Santa Monica Bay area yet and no tool or article predicts that these stressors will occur in future. Second, research and articles we found indicate that seawater temperature and wave disturbances have significant impacts on kelp forest and abalone. However, when talking about the impacts of climate change on abalone, most of the research results focus on seawater temperature.

According to various studies, climate change has negatively affected the populations of kelp forest in the following ways. First, kelps are cold water species. A healthy environment for kelps should be nutrient-rich with moderate water temperature ranging from 43 °F to 57 °F (Thomas, 2006). In addition, based on the well-known inverse relationship between nutrient concentration and water temperature, it is natural to suspect that sea temperature rise will have a direct and devastating effect on kelp forest habitats (Jackson, 1997, McPhee-Shaw et al., 2007, Foster et al., 2015). Indeed, such an argument is well supported by a long-term controlled study on giant kelps, in which the researchers manipulated water temperature in a small cove in Central California to be 3.5 °C higher than normal for ten years (Schiel et al., 2004, Foster et al., 2015). Most of the 172 subtidal species they studied demonstrated dramatic population decline and, in particular, the abundance of *Pterygophora californica* and *Laminaria setchelli*, two subtidal understory kelps, reduced by as much as 82%. *Nereocystis luetkeana*, a cold-water kelp, was almost completely replaced by *Macrocystis*, a genus of giant kelp, showing that in addition to kelp abundance, seawater temperature rise can also affect the distribution and diversity of kelp forests (Steinbeck et al., 2005, Foster et al., 2015).

Warmer waters can also reduce the physiological responsiveness of kelp forests to perturbations and their ecological performances (Wernberg et al., 2010). Wernberg et al. (2010) surveyed kelp canopy cover, kelp biomass, and density of juvenile kelp within four regions of subtidal rocky reefs in Western Australia. Poloczanka et al. (2007) predicted a temperature rise of 2.0 °C - 4.0 °C in these regions in the upcoming 25 years. Their research findings included a negative relationship between seawater temperature and metabolic function, very likely resulting from reduced pigment, nutrients, and enzymes (Wernberg et al. 2009). In other words, the higher temperature could make kelp forests more sensitive to additional environmental impacts such as extreme weather and reduced water quality, which could potentially lead to permanent loss of habitat and ecological functions. In addition, Wernberg et al. (2010) showed that warmer ocean climate could weaken the photosynthesis ability and recovery capacity of kelp recruits if changes in the intensity of wave disturbances and light conditions occur.

Frequent large storm waves can also negatively affect kelp forest ecology. Climate models predict increasing frequency of the occurrence of extreme weather events such as large storms, extreme warm events, and significant wave disturbances. Such a trend will decrease the diversity and complexity of food webs of giant kelp forests (Byrnes et al. 2011). Byrnes et al. demonstrated this by modeling the effect of large wave disturbances on food webs using kelp forest community data in the Santa Barbara Channel. By examining the impact of storm wave disturbances on kelp abundance, kelp food web structure, and food chain length after the storms, they showed that one year of large waves may, in fact, lead to an increase in complexity and diversity of kelp food webs; whereas the effect of having frequent large storm-driven waves will be destructive to kelp forest food webs, which is more relevant to the problems we are facing now in the Santa Monica Bay area.

Rising seawater temperature can also indirectly damage kelp forest populations by influencing the behaviors of major herbivores. In 2015, NASA discovered that global warming has opened the door for invasive species such as algae, sea urchin, and tropical fishes, which has severely endangered a number of native kelp species (Rocchio, L., 2014). The Invasive Species Council of Australia published a blog in 2012 explaining how the invasive sea urchins threatened the survival of local giant kelp forest. Since the 1940s in Tasmania, the water temperature has experienced an average increase of 1.5 °C – 2.0 °C due to a southward shift of the warm east Australian current (Stevens 2006). The current brings warm, nutrient-poor water from the Coral Sea and larvae of sea urchins *Centrostephanus rodgersii* to the Tasmania coast, followed by the establishment of large populations of sea urchins along the coast (Johnson et al. 2011, Foster et al. 2015). Studies have shown that such an expansion of sea urchin populations coincided with a massive decline of giant kelps, indicating that warming is detrimental for giant sea kelps and helps sea urchins establish larger populations (Ling et al. 2009, Foster et al. 2015). Another invasive species mentioned in the blog is the Japanese seaweed *Undaria pinnatifida*, which will thrive and form dense stands as water temperature rises and will very likely to threaten giant kelp forests as well.

In 2014, a team of scientists from the Smithsonian Environmental Research Center conducted a search for a group of invasive species in eight popular kelp forest dive spots between Monterey and Carmel, California. They found a bright red coral-like creature, fanning out like a head of baby lettuce, called *Watersipora subtorquata*, which spread to the local kelp forests. Because scientists currently have very little knowledge about this species, it's impossible to predict what it will do to native kelp forests. The recent invasion of *Sargassum horneri*, a brown alga native to northeast Asia, has been tracked, as this non-native species rapidly becomes established into southern California. Observations of this species suggest that it will have a much greater impact on California kelp forests than the previous algal introduction as extensive kelp habitat is now dominated by dense patches of this alien species, and it continues to spread. First observed at Long Beach Harbor in 2003, *S. horneri* has since spread throughout kelp forests at five of the eight Channel Islands (Kushner et al., 2011).

The migration of tropical fish, as a result of ocean warming, also poses a serious threat to the temperate areas they invade, because they over-graze kelp forest seagrass meadows, according to research conducted at the University of New South Wales. Although the negative impact of invasive tropical fish species is more evident in southern Japanese waters and the eastern Mediterranean, there is emerging evidence in Australia and the US that the invasion of tropical fish towards the poles is causing damage in the areas they enter (Verges, 2014).

Kelp forests foster important habitats for many species, one of which is abalone; thus, the deterioration of kelp forests has inevitably affected the population of abalone. Nutrient concentration in water is negatively correlated to water temperature. This is mainly because the increase of water temperature decreases the dissolved oxygen, phosphorus, and nitrogen

(Jackson 1997). The increase in water temperature would weaken the health of the kelp forest and eventually lower the population of abalone. Experiments conducted by Friedman et al.(2000) showed that the shell length and body mass of abalone experienced a significant decrease under the condition of warm temperature and low food quantity. In addition to size and mass of abalone, the reproduction of abalone is also affected by the warm temperature. Experimental results of Vilchis et al. (2005) reveal that when exposed to warm water (18 °C) (with no other stressor), 71% of male red abalone failed to produce sperm, and only 5% of male red abalone had abundant sperm, while 78%-83% wild abalone produced sperm and 25%-32% wild male abalone had abundance sperm (Vilchis et al. 2005). Meanwhile, those male exposed in warm water had only 46,000 cells/mm^3, while wild abalone males have 300,000 cells/mm^3. Since it is already discussed that the increase of water temperature will decrease the food resource of abalone, food shortage is also a problem that abalone will face in future. Vilchis et al. (2005) show that starvation also strongly affect reproduction of abalone: under the condition of starvation, 71% of abalone failed to produce sperm, and none had abundant sperm. Warm water temperature also affects female abalone. 97% percent of wild females have mature eggs, while in the experiment (18 °C water temperature) this rate reduces to 83%. Wild females produce 2.8 million eggs per female on average, but females in the experiment have only 400,000 eggs per female (Vilchis, 2005).

Moreover, the warmer temperature has been shown to cause infectious disease of abalone such as Withering Syndrome (WS), a fatal bacterial disease characterized by a severely shrunken body (Friedman et al, 2014). According to research by Harvell et al. (2009), pathogen outbreaks due to climate change have caused serious declines and extinction in several species. One of the species that has been affected is California red abalone, which has experienced serious population decline due to infectious diseases associated with warming water. Specifically, the increase in seawater temperatures has contributed to "[drive] both transmission of the rickettsial agent and development of associated clinical disease (WS) in red abalone" (Harvell et al. 2009, 3). In fact, abalone can carry bacterium without showing clinical sign of WS, and the developing of the disease is associated with seawater temperature (Friendman et al., 2014). An investigation by Steinbeck et al (2012) shows that animals with clinical sign of WS are exclusively found in the thermal discharge zone where the water temperature is up to 11 °C higher than ambient. Meanwhile, WS among abalone is always associated with thermal events such as severe ENSO. For example, when severe ENSO occurred in 1997-1998, up to 70% of black abalone at surveyed field sites showed clinical signs of WS (Friedman et al, 2014).

5. Methods

Based on the background research, we found that some of the main climate change stressors, which can directly influence the population and behaviors of kelp forest and abalone, include warmer seawater temperature, ocean acidification, and increase in storminess. We did not include the other main climate change stressors such as rising sea level and change in precipitation level because they do not directly relate to our project objectives. We used four climate change tools in total: “California's Ocean in an El Nino Year” (CeNCOOS 2016), the California Swell Model Archive supported by Coastal Data Information Program (CSIP), the Ocean Acidification Hotspot plot by NRDC (NRDC 2016), and the Marine Invasive Observation Map (OSU, 2015).

“California's Ocean in an El Nino Year” (CeNCOOS 2016) is a climate change tool that monitors the ocean temperature change in California’s coast over the past 35 years. Users can pick several specific locations in the west coast and access the seawater temperature data in these locations. The California Swell Model Archive supported by Coastal Data Information Program (CSIP) records all wave heights measured by a buoy placed in the Santa Monica Bay area over the year 2004-2015. The Ocean Acidification Hotspot generated by NRDC plots the coastal region in California that is most subject to ocean acidification over the past few years. The Marine Invasive Observation Map, provided by the Oregon State University, monitors the trends and synthesis of Pacific rocky intertidal zones.

6. Analysis and Results

Based on the information provided by "California's Ocean in an El Nino Year" (CeNCOOS 2016), it is shown that the average seawater temperature in 2016 in east Santa Barbara is warmer than the average of past 22 years during 96% of the past year (Figure 6.1). Moreover, using the data provided by California Swell Model Archive supported by Coastal Data Information Program (CSIP), we plotted the trend of significant swell height in Santa Monica Bay area over the past 10 years (Figure 6.2). The light blue curve plots the highest wave height measured vs year in the Santa Monica Bay area and the dark blue line is a regression fitting line that plots the trend of the growth of significant wave height. Therefore, both trends provide evidence for rising seawater temperature and wave disturbances in Santa Monica Bay area. However, ocean acidification has not been a huge issue in the Santa Monica Bay area over the past few decades, as illustrated by the Ocean Acidification Hotspot plot by NRDC (Figure 6.3).

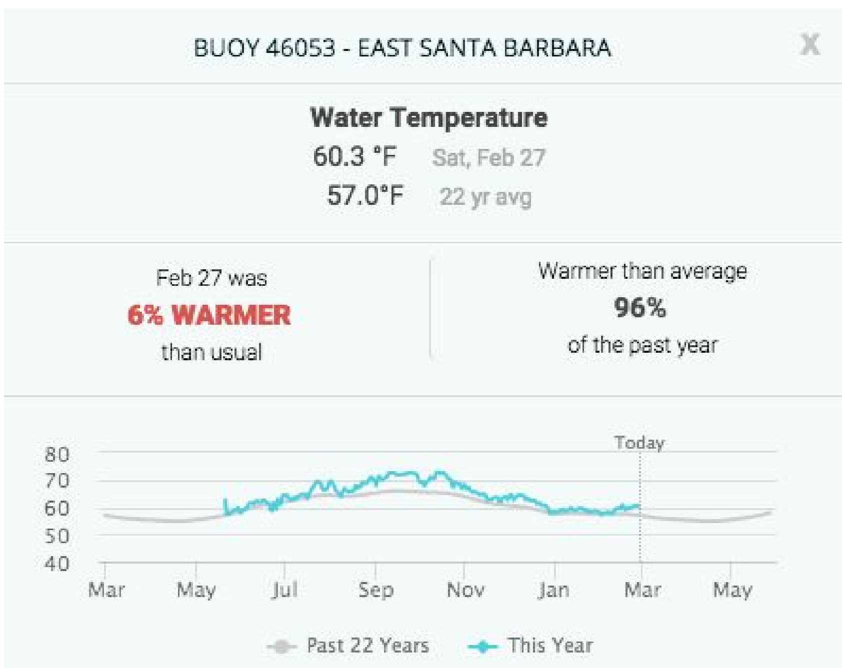

Figure 6.1 Seawater Temperature Rise in East Santa Barbara Area

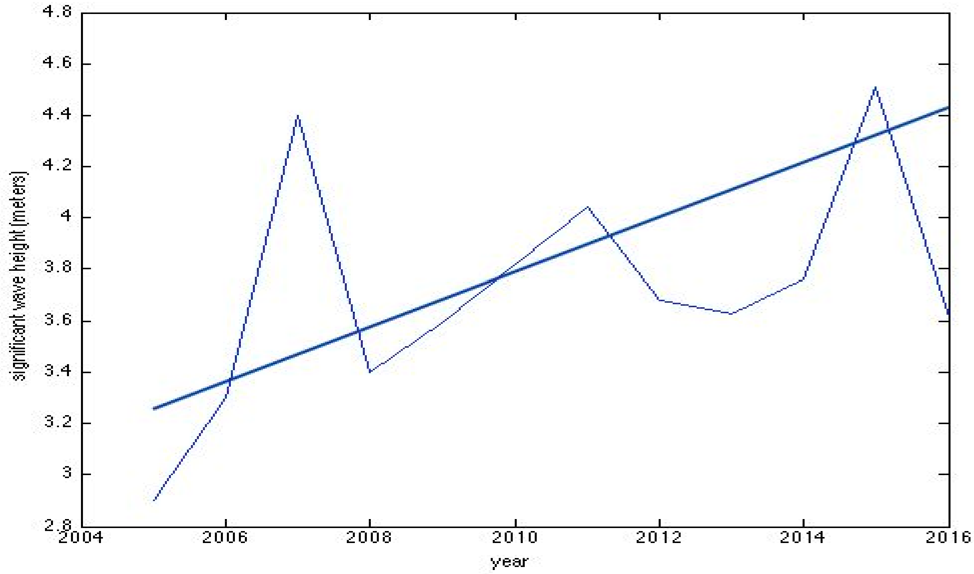

Figure 6.2 Significant Wave Height in Santa Monica Bay over 2004-2015

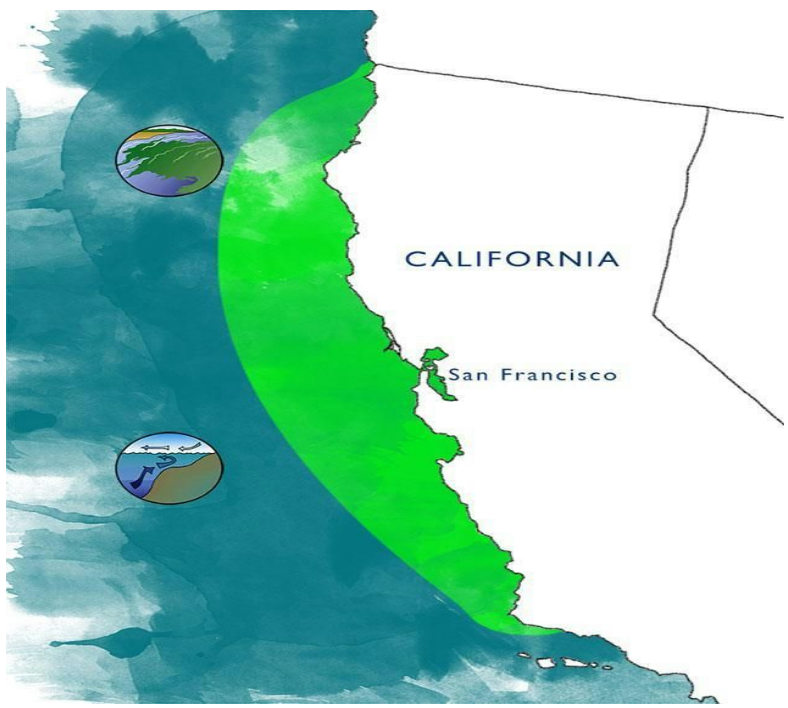

Figure 6.3 Ocean Acidification Hotspots (Light Green) Area in California

6.1 Kelp Forests

Based on the literature review section and climate change data provided above, it is definitive that the kelp forests in the Santa Monica Bay area are vulnerable to climate change impacts in the following aspects: because of the increase in seawater temperature and storminess, the acreage of kelp forests will very likely decline; the physiological responsiveness to environmental changes and ecological functions will likely diminish; and the diversity of kelp forest food webs will likely decline.

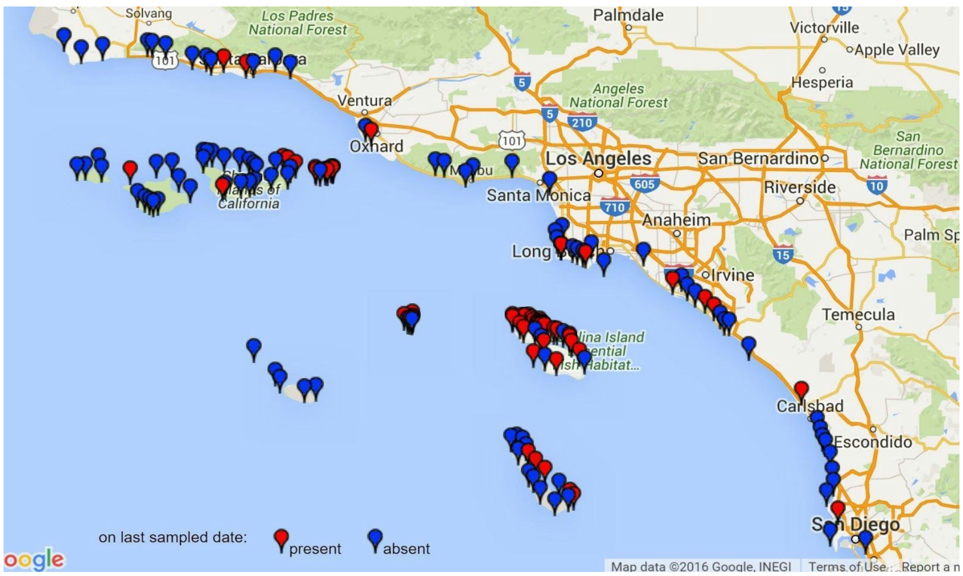

Figure 6.4 Spread of *Sargassum Horneri*

Figure 6.4 shows the distribution of an invasive seaweed species called *Sargassum horneri*, originally from Asia on June 25, 2015. The red points indicate where this invasive species is present, and the blue points indicate its absence. This species grows extremely fast and out-competes the native species, giant kelp in particular, for substrate, light, and nutrients, forming a virtual monoculture on Catalina's leeward side. Biodiversity at these sites plummets (J. H., 2013, May 22). In 2014, Komatsu et al. published a paper on the possible change in the distribution of *S. horneri* under the scenario of global warming. They pointed out that the distribution of this species is greatly dependent on water temperature, and the conclusion was “the water temperature rise caused the replacement from the temperate to the subtropical Sargassum species,” such as *S. horneri* (Komatsu et al., 2014).

6.2 Abalone

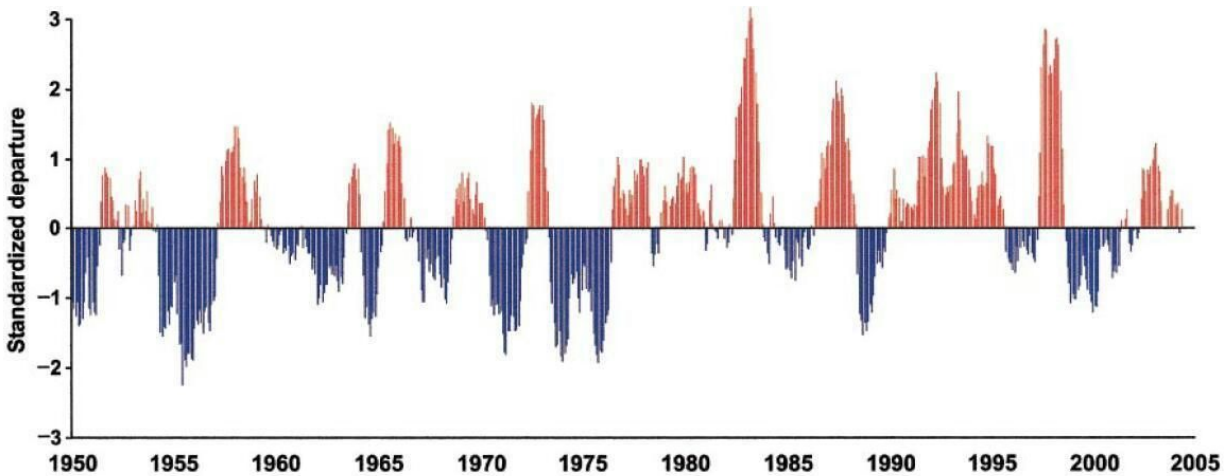

FIG. 1. Time series of a multivariate El Niño Southern Oscillation (ENSO) index that combines sea level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky over the tropical Pacific. Positive values are shown in red, and negative in blue; indices greater than 1 and less than −1 are considered strong El Niño and La Niña events, respectively. Monthly indices were acquired from the NOAA-CIRES Climate Diagnostic Center at the University of Colorado at Boulder (*available online:* ⟨http://www.cdc.noaa.gov⟩).

Figure 6.5 Time Series of El Nino and La Nina

The climate change tool “California's Ocean in an El Nino year” clearly shows that the average seawater temperature is increasing in Santa Monica Bay area. Also, the red bars in the plot above (Figure 6.5) indicate the increasing frequency of El Nino phenomenon in the tropical Pacific area (Vilchis et al. 2005). Combining the results from these two sources, we conclude that the seawater temperature in Santa Monica Bay area is increasing. Warm seawater has both direct and indirect effects on abalone. On one hand, the warm temperature would strongly influence the health of abalone by a fatal abalone disease called withering syndrome, which interrupts the growth and reproduction of abalone (Friedman et al. 2014). On the other hand, Vilchis et al. (2005) state that abalone species and kelp forests ecosystems are closely related to each other: the increase in seawater temperature would weaken the quality of kelp forests and eventually cause the decrease in abalone population. Conclusively, in order to achieve the objective of restoration of abalone population, we suggest focusing on amelioration of seawater temperature rise, protection of kelp forests, and reduction in fishing.

7. Solutions

Regarding the impact of invasive species on kelp forest, although most experts agree that it is almost impossible to eradicate *Sargassum horneri* completely (Kushner et al., 2011), small-scale removal experiments may be an effective way to improve our understanding of this alga's effects on kelp forest communities. Channel Islands National Park's long-term kelp forest monitoring program (KFMP) is one example of such an effort. It is designed to observe differences between areas inside and adjacent to marine reserves. "Removal plots situated inside and outside marine reserves may demonstrate whether reserves provide increased resilience to invasive species" (Kushner, D. J., 2011).

For restoring abalone stocks, the first step is to establish marine protected areas (MPAs). For example, the Bay Foundation could consider establishing protected areas, functioning as breeding centers for abalone, at 5-10 mile intervals along the coast of the Santa Monica bay. This could help abalone maintain a minimum viable population. (Karpov, K., 2000)

Besides the survival of abalone, reproduction success is also important for restoring abalone habitats. The continuous increase of seawater temperature, for example, might cause the shift of abalone distribution because the historical abalone regions might become harsh for abalone in the future due to sea water temperature rising. It is not adequate if we only restore abalone at current abalone regions. Therefore, we recommend that the Bay Foundation consider establishing restoration areas deeper or further north than current abalone regions. (Rogers-Bennett et al. 2010)

Moreover, we recommend that the Bay Foundation monitor the seawater temperature during spawning season of abalone because the reproduction of abalone is closely associated with water temperature. The optimal water temperature for abalone reproduction is 12°C (Rogers-Bennett et al. 2010). If the water temperature during the spawning season is higher than 12°C, the reproduction rate of abalone will be quite low, and abalone will even stop breeding. Therefore, if abalone experience a high water temperature (> 12°C) during spawning season, it is probably a good idea to request a reduction of fishery activities in that year to protect the population of abalone.

In addition, when making conservation plans for abalone, people should be aware that the timing of the reproduction season might be different from historical seasons. It is largely believed that the spawning season for abalone is late winter to early spring (Heath 1925, Bonnot 1930). However, based on data provided by California Swell Model Archive, the water temperature in late winter is becoming not suitable for abalone reproduction. Therefore, it is reasonable to suspect that abalone is experiencing a shift in reproduction pattern because of the abnormal change of water temperature. If the water temperature in December is too high for abalone to reproduce, the spawning season of abalone might shift from late winter and early spring to early spring and late spring. We don’t know how this shift can potentially be an obstacle to the conservation of abalone. Thus, more research needs to be done to investigate how this shift will affect abalone and abalone conservation.

8. Future Work

First, almost all of the climate change tools we found and included in our inventory are online user interfaces. However, there are still a large number of climate change tools taking the form of scientific journals, scholarly articles, and databases that we did not assess in this study. Thus, as an area for future work, we recommend investigating as many types of climate change tools as possible, as they will likely help TBF bridge the data gaps mentioned below and conduct a more thorough vulnerability assessment.

Second, throughout this project, we did not consider the effect of sea-level rise and ocean acidification on kelp forests and abalones because of limited time and data gaps. Compared to rising seawater temperature and storminess, there was a relatively limited amount of evidence we could find that links sea level rise with kelp forest and abalone population. Therefore, even though we did not consider the effect of sea level rise on kelp forest and abalone due to the time limit, it doesn't necessarily mean that sea level rise won't be a contributor to the decline of these two species. In addition, despite the current low level of ocean acidification near the Santa Monica Bay area, we have not found any tool that predicts the ocean acidification level in the near future and therefore cannot guarantee that the level won't significantly increase. Given that our literature review provided evidence for a positive correlation between rising ocean acidification level and the decline in kelp forests population (not included in the report), if the ocean acidification level does increase in the near future, it will have a devastating effect on both species. Thus, for future work, we recommend investigating the effect of sea level rise on abalones and kelp forests, and we recommend researching climate change tools that make predictions about ocean acidification level near the Santa Monica Bay.

In addition to the two objectives considered in this report -- restoring and monitoring kelp forest and abalone population, Goal 9 in the Bay Restoration Plan also includes two more objectives -- the restoration of intertidal habitats and the protection of seagrass habitats. To make a thorough vulnerability assessment of Goal 9, we recommend that TBF also consider and evaluate the impacts of climate change on these two objectives.

9. Bibliography

Bonnot, Paul. 1930. Abalones in California. Calif. Fish & Game., 16 (1):15--23.

Bouma, J. V. 2007. Early life history dynamics of pinto abalone (Haliotis kamtschatkana) and implications for recovery in the San Juan archipelago , Washington state. University of Washington.

Byrnes, J. E., Reed, D. C., Cardinale, B. J., Cavanaugh, K. C., Holbrook, S. J. and Schmitt, R. J. (2011), Climate-driven increases in storm frequency simplify kelp forest food webs. Global Change Biology, 17: 2513–2524. doi:10.1111/j.1365-2486.2011.02409.x

California's Ocean in an El Nino Year (CeNCOOS). Retrieved February 27, 2016, from http://www.cencoos.org

Friedman, Cs, N. Wight, Gr Vanblaricom, I. Kiryu, Jd Moore, and Lm Crosson. "Abalone Withering Syndrome: Distribution, Impacts, Current Diagnostic Methods and New Findings." *Diseases of Aquatic Organisms Dis. Aquat. Org.* 108.3 (2014): 261-70. Web.

Friedman, C. S., Andree, K. B., Beauchamp, K. A., Moore, J. D., Robbins, T. T., Shields, J. D., & Hedrick, R. P. (2000). 'Candidatus Xenohaliotis californiensis', a newly described pathogen of abalone, Haliotis spp., along the west coast of North America. International Journal of Systematic and Evolutionary Microbiology, 50(6 part 2), 847-855.

Harvell, D., Altizer, S., Cattadori, I. M., Harrington, L. and Weil, E. (2009), "Climate change and wildlife diseases: When does the host matter the most?." Ecology, 90: 912–920. doi:10.1890/08-0616.1

Heath, H. 1925. The abalone question. Calif. Fish & Game., 11(3): 138-139.

J. H. (2013, May 22). USC Dornsife Scientific Diving: An Analysis of Sargassum Horneri Ecosystem Impact. Retrieved February 27, 2016, from http://blogs.scientificamerican.com/expeditions/usc-dornsife-scientific-diving-an-analysis-of-sargassum-horneri-ecosystem-impact/

Karpov K., Haaker P., Taniguchi I., Rogers-Bennett Laura 2000. Serial depletion and the collapse of the California abalone (Haliotis spp.) fishery. Canadian Special Publication of

Fisheries and Aquatic Sciences (pp. 11-24). National Research Council of Canada. Retrieved from https://www.researchgate.net/publication/228491870_Serial_depletion_and_collapse_of_the_California_Haliotis_spp_fishery

Kushner, D. J. (2011). Alien species and a changing world: Will kelp forests ever be the same? Retrieved February 27, 2016, from http://www.georgewright.org/gws2011_poster_kushner.pdf

Michael S. Foster, David R. Schiel 2015. The Biology and Ecology of Giant Kelp Forests (1st ed., pp. 319–382). University of California Press. Retrieved from http://www.jstor.org/stable/10.1525/j.ctt14btfvw.21

National Data Buoy Center. Retrieved February 27, 2016, from http://www.ndbc.noaa.gov/historical_data.shtml

NOAA, *Economic Importance: Kelp Forest 1999*. http://www.w3.org/1999/xhtml

Ocean Acidification - California, NRDC, Retrieved March 22, 2016, from http://www.nrdc.org/oceans/acidification/california.asp

Poloczanska, E.S., Babcock, R.C., Butler, A., Hobday, A.J., Hoegh-Guldberg, O., Kunz, T.J. et al. (2007). Climate change and Australian marine life. Oceanogr. Mar. Biol. Ann. Rev., 45, 407–478.

Pacific Rocky Intertidal Monitoring: Trends and Synthesis. (2015, June 25). Retrieved February 27, 2016, from http://gordon.science.oregonstate.edu/marineinvasive/map.html

Rocchio, L. (2014, December 19). Finding Floating Forests: It Takes an Online Village to Map Massive Kelp. Retrieved February 27, 2016, from http://earthobservatory.nasa.gov/Features/FloatingForests/page3.php

Rogers-Bennett, Laura, Richard F. Dondanville, James D. Moore, and L. Ignacio Vilchis. "Response of Red Abalone Reproduction to Warm Water, Starvation, and Disease Stressors: Implications of Ocean Warming." Journal of Shellfish Research 29.3 (2010): 599-611.

Steinbeck JR, Groff JM, Friedman CS, McDowell T, Hedrick RP (1992) Investigations into a mortality among populations of the California black abalone, Haliotis cra che -rodii, on the central coast of California. In: Shepard SA, Tegner MJ, Guzmán del Próo SA (eds) Abalone of the world: biology, fisheries and culture. Fishing News Books, Cambridge, MA, p 203–213

Stevens, D. (2006). Climate Impacts and Kelp Forest. Retrieved February 27, 2016, from http://www.sahfos.ac.uk/climate encyclopaedia/kelpforest.html

Thomas, D. 2002. Seaweeds. The Natural History Museum, London, p. 15.

Vilchis, L. I., Tegner, M. J., Moore, J. D., Friedman, C. S., Riser, K. L., Robbins, T. T., & Dayton, P. K. (2005). Ocean warming effects on growth, reproduction, and survivorship of Southern California abalone. Ecological Applications, 15(2), 469-480. doi:10.1890/03-5326

Wernberg, T., Thomsen, M. S., Tuya, F., Kendrick, G. A., Staehr, P. A. and Toohey, B. D. (2010), Decreasing resilience of kelp beds along a latitudinal temperature gradient: potential implications for a warmer future. Ecology Letters, 13: 685–694. doi:10.1111/j.1461-0248.2010.01466.x