The Importance and Persistence of Abalone (*Haliotis spp.*) along the California Coast

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Abstract

Abalone was once a common sight along the California Coast. Native tribes co-existed with the species for thousands of years. They relied on it for sustenance and they used it for tools, utensils, jewelry, trading, and regalia. In return, they took care of the abalone as if it were one of their own. When colonization devastated Native Californian culture, much of their knowledge disappeared along with the species they cared for. Abalone was highly valuable for its taste and beauty. When commercialization of abalone fisheries began their populations began to decline.

Now, they face more obstacles to recovery than ever before. Current abalone stressors include, poaching, low population densities, pollution, and disease. Warming ocean temperatures also subject abalone to sea level rise and ocean acidification. I recommend a combined approach of traditional ecological management and western science be used to provide adaptive management strategies for policy makers and fisheries managers. In preserving these creatures we are inherently preserving cultural heritage and traditions of over 20 tribes in California.
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Introduction

The presence of Abalone (*Haliotis spp.* ) along the California coast has been felt for thousands of years. It may not be a keystone species such as the sea otter, it may not be represented on the state flag like the grizzly bear, and it may not be as beloved as the California poppy, but it is nonetheless, irreplaceable. Abalone is so important to California history that it is regarded as a cultural key stone species. This means that the cultural underpinnings of certain coastal tribes in California have been shaped by the presence and use of Abalone. If this species were to have never existed these societies would be profoundly changed (Garibaldi & Turner, 2004). The earliest known signs of people along the western coast of North America date back roughly 12,000 years ago, in accordance with archeological evidence of abalone use in these regions (Erlanderson *et al.*, 2008). Since then, the use of abalone has manifested through tools, jewelry, language, ceremonies, and oral traditions in California Indian tribes. Unfortunately, today the native’s relationship with abalone has been somewhat dampened by the effects of colonialism in the mid-1700s.

The purpose of this paper is to display abalones importance ecologically, economically, and culturally. It will touch on the union of ecology and society as a way of understanding the spiritual world of natives along the coast. Their connection to abalone still exists and California tribes are rejuvenating their culture as a way of reclaiming their traditions and way of life.

This paper synthesizes differences in abalone management techniques used between Western Scientific and Traditional Ecological Knowledge systems, which is the knowledge acquired by indigenous peoples concerning natural resource use over hundreds of years. By synthesizing the two separate approaches to conservation, a management plan that successfully increases abalone populations in the face of climate change may be possible. Education,
patience, and an understanding of what stressors are affecting abalone populations the most and to what extent is important when creating an adaptive management plan. Each stressor has its own set of remediation measures. Unfortunately, the abalone along the California coast are subject to a wide array of environmental pressures. Even with an adaptive management regime that seems effective and efficient, restoring abalone populations to sustainable levels will be a long and difficult task.

**Background**

Abalone (*Haliotis spp.*) are single shelled marine snails that dwell in the intertidal regions of coastlines. They cling to rocks near the shore and prefer dark areas with cooler water (UC Santa Cruz, 2018). Abalone belong to the Haliotidea family. There are approximately 130 different species of abalone in existence today, and they are found along the coastlines of every continent (NOAA Fisheries, 2018). Seven of them are endemic to California although all have a somewhat different habitat range (Figure 1) (NOAA Fisheries, 2018). These seven species include the red abalone (*Haliotis rufescens*), black abalone (*Haliotis cracherodii*), pink abalone (*Haliotis corrugate*), green abalone (*Haliotis fulgens*), pinto abalone (*Haliotis kamtschatkana*), white abalone (*Haliotis sorenseni*), and flat abalone (*Haliotis walallensis*) (Howorth, 1994). These abalone are unique because of their size. For example, the red abalone is not only the most common abalone found in northern California, but it is also the largest abalone species in the world with a maximum shell length of 12 inches (UC Santa Cruz, 2018). The green and white abalone have a maximum size of about 10 inches in length. Most other abalones range between 3 to 8 inches, sometimes smaller (Oregon State, 2018). The abalone of California once bejeweled the coast and because of their large size they were a treasure to those who had access to them.
Biology

Abalone are sessile creatures. In North America they are found along the western coastline from Oregon down to Baja California although, some are as far north as Alaska (Howorth, 1994). They love cold water and their preferred habitat includes intertidal zones where they can avoid predation and light. Most abalone in California live in waters that are between 20 to 120 feet deep (Howorth, 1994). The white abalone is found at the deepest depths at about 200 feet and the red and pink are typically found 100 feet down (Oregon State, 2018). Those abalones prefer water that is between 45 and 60°F (Oregon State, 2018). In contrast, the black abalone likes shallow waters and is usually only found around 20 feet deep and in slightly warmer waters (Oregon State, 2018).

The bulk of abalone consists of a huge muscular foot (Howorth, 1994). This foot also happens to be the meat of the abalone. A legal sized 8 inch abalone in California has at least a quarter pound of meat. Some red abalones yield up to three pounds of meat (Ibid). The meat that abalone produce is typically 25% protein with very little fat (Ibid). Abalone cling to rocks because of the surface adhesion produced by the foot (Ibid). All abalones are herbivores that feed on algae, particularly kelp from kelp forests. When abalone sense food nearby they glide towards it slowly until they reach the source (Ibid). It will then raise its foot and trap the plant (Ibid). Once it has the plant secure it will start eating it using its radula, or spiky tongue (Ibid). When fully extended the radula is about one third of the animal’s length (Braje et al. 2009).

Since abalone are sessile creatures, they partake in broadcast spawning. This is when both males and females release millions of sperm or eggs into the water during a synchronized
spawning event (Howorth, 1994). The eggs then become fertilized externally (Braje et al., 2009). Usually California species spawn in late spring or early fall. For these spawning events to be successful there must be high population densities of abalone (Howorth, 1994). Warm water has been shown to have negative effects on the sperm production and larval development rate of red abalone (Li et al., 2013). If an egg is fertilized it develops quickly. It only takes a few weeks for an egg to become a juvenile, four to five years to become reproductive, and five to ten years to reach legal size. Some abalone live upwards of 50 years (Howorth, 1994). These abalone have the largest shells.

The shell is the most famous part of the abalone. It is known for its multicolored pear-like inner shell and exterior color bands that are merely the result of dietary fluctuations (Gurney, Mundy, & Porteus, 2005). Abalone age can be determined by the bands that follow the growing edge of the shell (Gurney, Mundy, & Porteus, 2005). Their shells are made of calcium carbonate tiles that are stacked on each other and are extremely strong (UC Santa Cruz, 2018). Between these stacked layers is a sticky protein material (UC Santa Cruz, 2018). If an abalone is hit by something, instead of breaking, the calcium carbonate tiles absorb much of the blow by sliding and stretching past each other to accommodate the impact (UC Santa Cruz, 2018). Their strength is what made them so useful for tools such as fish hooks.

Ecology

Being a sessile creature, abalone become molded to their surrounding ecosystem (Kovet, 2018). Small species such as gastropods and barnacles use abalone as shelter (Jenkins, 2004). One species, the food-stealing limpet (Hipponix conicus), favors abalone shells because it provides greater access to food particles (Jenkins, 2004). Aside from being the preferred habitat of many small species, abalone themselves usually reside in kelp forests.
Kelp forests are found in cool water coastlines and are some of the most productive ecological communities on earth (Erlanderson et al., 2005). Unfortunately, they are also highly susceptible to environmental stressors such as pollution, over fishing, and removal of sea otters. Sea otters play a key role in kelp forests by influencing its food webs (Erlanderson et al., 2005). Shellfish are the primary food of otters. When Europeans colonized California both the Native American culture and sea otter population were devastated. Due to a lack of predation by sea otters, the abalone population boomed in kelp forests along the west coast of California (Erlanderson et al., 2008). During this period of reduced predation large abalone fisheries were instigated, with ensuing overexploitation of abalone. Other predators of the abalone include octopus, crabs, lobster, and bottom feeding fish (NOAA Fisheries, 2018). To defend themselves from predation, abalone will suction themselves to a rock to prevent them from being moved by the predator (Braje, 2007). If the risk of predation is low, usually in deeper waters, abalone will move around freely (Braje, 2007). The presence of competitors also effects how abalone move and survive.

Sea urchins are abalones main competitor because they both feed on drift algae (Tarr, Williams, & Mackenzie, 1996). In high abundance sea urchins dominate the ecological structure feeding off of kelp forests until they turn into sea urchin barrens that are covered in crustose coralline algae (Tarr, Williams, & Mackenzie, 1996). When food is not a limiting resource abalone tend to out compete sea urchins for space (Tegner & Dayton, 2000). Abalone will reside in larger crevices and sea otters will extract sea urchins more readily than abalone because they are easier to move (Ibid.).
Native Californian History and Cultural Significance

It is impossible to talk about the current status, threats, and management of abalone without first delving into its history with Native Americans along the coast of California. Spanning from far reaches in the north, in what modern-day Humboldt and Del Norte Counties is to as far south as San Diego, numerous tribes used and managed abalone (Field, 2008). There were over 20 California Indian tribes who relied on oceanic resources such as abalone, some of which include the coastal Pomo, Miwok, Karuk, Hupa, Ohlone, Wiyot, and Chumash (Field, 2008) (Figure 2). Being a cultural keystone species, Abalone has helped shape the cultural identity of these tribes. To truly understand the importance of this reality, one must learn about the history of the Native Californian’s connection to abalone and how abalone integrated itself deep into their daily lives, religion and spirituality. The Native Californians understand that their relationship with the land and their food not only has an economic and cultural impact, but an ecological one as well (Braje, 2009).

Native Californians were the first people to manage abalone and they used it for much more than sustenance. Abalone was used for trading among Native Americans within California (Field, 2008). They traded materials from inland tribes who had different resources and goods to offer. Some of these materials included animal skins, baskets, food, and obsidian. Abalone has even been found as far east as the Mississippi River and as far north as Canada suggesting abalone was traded to tribes across the continent (Ibid). Access to abalone was extremely valuable because of its trading potential. It was also valuable because of its beauty and usefulness.

Abalone was entwined in the daily lives of many California tribes. The shells and jewelry made with them, reflected their status and wealth within a tribe (Field, 2008). Abalone was used
for regalia, bowls, and fishhooks. Abalone regalia is one of the most sacred materials used in
traditional dances and customs. These customs evolve through the different struggles, beliefs,
and cultures of the time (Field, 2008). They reflect Native Californian reliance on and love of
abalone. Pomo people of Mendocino County tell the story of abalone as being the First Creature
of the Sea, the parent of all abalone (Ibid). Through it all other abalone were created. When the
parent of all abalone dies it will let out a cry that everyone will hear. This will mean that all other
abalones have died, and it is the end of the world. This story reflects the respect that the Pomo
have for abalone, the First Creature of the Sea, and their regalia reflects their love for the Earth
and all the creatures in it (Ibid). Pomo consider themselves the Dreamers. The Dreamers in the
tribe would dream of the regalia and then create the different shapes using abalone shells once
they awoke (Ibid). They often used red, pink, and green abalone to create the shapes (Ibid). To
wear a piece of regalia is to honor the species spirit by becoming one with it, uniting the abalone
to the person. Therefore, the regalia can only be worn by one person and when that Dreamer dies
the regalia that that person used dies with them (Ibid).

The Hupa have similar beliefs about their abalone regalia. They believe that their regalia
should be used and shared, not traded. Like the Hupa it too has a life and a spirit. For it to fulfill
its destiny the regalia must be handled with care and they must be worn during festivities and
dances (Field, 2008). The Hupa even love to listen to the abalone and believe it has a voice of its
own. The sound of abalone clicking together is unique and nothing sounds quite like it (Ibid).
The use of this regalia is seen during the Jump Dance where men wear five to six abalone
necklaces that all clack together as they dance. So when someone hears the clacking of regalia,
they know dancing will soon begin (Ibid) (Figure 3). The difference between native jewelry and
regalia is important. Bradly Marshall, a highly appreciate Hupa regalia maker, believes jewelry
in not as sacred, it has no bond to its owner and can be bartered or traded (Ibid). He says that the construction of regalia is much more intimate and the use of abalone as regalia reflects the species importance (Ibid).

The oral traditions highlight Abalone’s importance by providing insight into Native Californian identities and struggle. Each narrative discusses different societal themes and struggles of the time and much can be learned from them (Field, 2008). Historical narratives about abalone have been recorded by ethnographers since the early 20th century. These narratives about abalone are still told today in different variations from tribes as far north as the Oregon boarder down to Santa Barbara (Field, 2008).

The Wiyot people of Humboldt County tell the tale of the Abalone Woman. This story reflects the important relationship between the Wiyot people and their abalone. Unlike other tribes the Wiyot people endured incredible hardships. In 1806 they were victim to what came to be known as the Indian Island Massacre (History, n.d.). During this event almost 200 men, women, and children were killed by the hands of 6 landowners (History, n.d.). They lost their land and were forced to relocate losing much of their past along with it (Ibid). Their version of Abalone Woman is a sad violent story that may be the result of their experiences with colonizers, although the true origin is unknown (Ibid). In the 1950s, Della Prince, a decedent of an Indian Island Massacre survivor, tells the story of Abalone Woman and her abusive husband. Her version of the story was recorded and translated by linguist, Karl Teeter (Field, 2008). The story is as follows: Abalone women married a man named Dentalium and he was welcomed by her family, but after some time he became homesick and the two ventured to his home so that he could be with his family. After some time, him and his family began treating her with disrespect and cruelty, so she ran away to be with her family again. They helped her heal and recover until
one day her husband came looking for her. He apologized and received approval from her family
to take her back to his home with him again. But again, his family treated her poorly, so she ran
away again. This time he chased her to a place called Patrick’s Point. As she cried along the
shores her tear drops became mussels and she prayed that her death would be for the good of the
people. Soon after that her husband slashed her back and cut her up to throw her in the ocean.
The abalone shells one sees today is red depicting the red slashes on her back (Field, 2008)
(Figure 4).

The Wiyot stopped participating in dances and ceremonies when they lost their land back
in 1860 (Field, 2008). Since then 40 acres have been returned to the Wiyot people by the city of
Eureka and with that hope still holds fast in the hearts of their tribal members (Field, 2008).
Cheryl Seidner, Wiyot Tribal Chair, says that they are in the process of regaining knowledge of
their past and plan to reestablish sacred relationships with their regalia (Field, 2008). One day
they will participate in their traditional dances again and in doing so revitalize their tribal
identity.

The story of the Wiyot people is like those of other tribes within California. They
suffered great tragedies during the time of colonization and the effects of their traumas are long
lasting. The history and devastation that the Natives endured is paralleled to the devastation that
the abalone populations endured during this time as well. As land was ceased from the Natives,
respect for abalone and traditional management techniques of kelp forests were lost. The ecology
of the oceans soon began to change with the onset of anthropogenic environmental stressors.
20th Century Population Declines

In the 1700s and 1800s sea otter fur was highly valuable so the Russian fur traders and Spanish settlers hunted them to near extinction along the coast (Erlanderson et al., 2008). That caused a dramatic increase in the abalone population because they were no longer being preyed on. Abalone became so vast and abundant that their shells began to grow thick and coarse, showing signs of too much competition between one another and overcrowding (Howorth, 1994). When the Chinese came to California following the gold rush in the late 1850s, they were amazed when they saw the large abalone species of California. They consider abalone a delicacy and opened a fishery in Southern California that targeted green and black abalone (CDFW, 2018). By 1879 they had annual catches of an upwards of 4 million pounds per year (Howorth, 1994). However, local county regulations were then placed on Chinese fishermen and in 1900 the fishery was closed to commercial harvest (CDFW, 2018). Not long after the Japanese found a way around these regulations by free diving for abalone. They would use old rice wine casts to float on after a dive. Up until 1929 they dominated the commercial abalone fishing field (Howorth, 1994).

Abalone was always eaten by the California Indians, Chinese, and Japanese immigrants but it wasn’t until the 1950s and 60s that abalone became a recreational sport in California (Reid et al., 2016). Scuba diving equipment made it easy for anybody to dive for abalone at increasing depths. During the 1960s and 70s it is believed that the annual catch from recreational diving was equal to the commercial catch of about 4.4 million pounds of abalone totaling in over 8 million pounds (Reid et al., 2016). Even today with strict diving rules, 31,000 people go abalone diving per year and the industry receives between $24-44 million in recreational value (Reid et al., 2016). Sadly, over harvesting is not the only stressor that abalone must face.
In the late 1990s two major threats to abalone diminished populations in the south, El Nino events and disease. In 1982-1983 and 1997-1998 California experienced harsh El Nino years. This created warmer water conditions which negatively affected the kelp beds that abalone live in (Crosson et al., 2014). There was not enough nutrients in the water column for kelp forests to survive so they began to decline. With little food and undesirable environmental conditions, abalone populations in Southern California began to starve. Due to the warm water conditions, Withering Syndrom (WS), a disease that kills abalone, struck the southern populations and added to the devastation (Ibid). Abalone Withering Syndrome (WS) hit black abalone especially hard in these regions and has not recovered since (Ibid). In 1997, because of population declines, commercial abalone fishing was closed statewide and recreational abalone fisheries were closed south of San Francisco (CDFW, 2018). Northern abalone fisheries were never affected as much by El Nino years and over harvesting was never as severe. Consequently, abalone populations are much higher in the north (CDFW, 2018).

**Current Status**

Currently two abalone species in California are on the IUCN Red List, the black abalone and the pinto abalone. The black abalone is listed as critically endangered and the pinto is endangered with stable populations at this time (Table 1) (ICUN Red List, 2018). Under the US Endangered Species Act the black and the white abalone in California are listed as endangered (Table 1), meaning they are at risk of becoming extinct in most of its livable range. The pink, pinto, and green abalone are all a part of the Species of Special Concern Program which is dedicated to proactive conservation to avoid being placed on the endangered species list (Table 1) (NOAA Fisheries, 2018). These species are particularly vulnerable to becoming threatened or endangered due to the current rate of habitat loss (CDFW, 2018).
The red and flat abalone are the only two species that are not listed at all. They are still closely monitored and studied to prevent population loss and decline. The Department of Fish and Wildlife (2018) has recently found that there are very few young red abalone within the 2-5 inch size class. This suggests that no large reproductive events are taking place. Because red abalone grow so slow, new legal sized individuals will not be seen for at least a decade (CDFW, 2018). In 2018 the California Fish and Game Commission decided to close the state abalone fishery until April of 2021 (CDFW, 2018). Any abalone diving until then is illegal.

**Current Stressors**

Environmental pressures that abalone have faced in the past have left many scars on the current population. Most Californian species have not fully recovered from the intense overfishing that occurred decades ago. Most of the state’s abalone fisheries have shut down and recreational diving in northern California has even been halted for the coming years, yet abalone continue to decline. Unfortunately, they face many other pressures as well. In addition to the devastation left by overfishing, abalone face illegal poaching, low population densities which lead to the Allee effect, pollution, and disease.

**Illegal Poaching**

No matter how many restrictions are placed on abalone fishing by state and local governments, illegal harvesting has been and will be an issue. During an open abalone season in California there are many laws and regulations pertaining to legal catch. If any of these regulations are broken during a dive, the abalone will be taken, and the license revoked (CDFW, 2014). Many of the rules are species specific. For red abalone, there is a minimum size limit of 7 inches (CDFW, 2014). For all abalone species there is an annual bag limit of 18 abalone and
divers must have fixed arm measuring gauges to determine the length of the shell (CDFW, 2014). No abalone can be taken by use of scuba equipment or may be aboard any boat, kayak, or floating device with scuba diving gear present (CDFW, 2014). These are just a few rules set in place by the California government to regulate abalone diving.

California Department of Fish and Wildlife Wardens estimate that illegal take of abalone is about 12% of the legal take (CDFW, 2014). So, although legal take is considerably larger than the illegal take, it is still an issue for struggling abalone populations. With abalone being an upwards of 125 dollars per pound, it is an enticing resource to exploit for economic gains (Reid, 2016). With that said, some of the consequences for abalone poaching in the state of California include fines of an upwards of $40,000 dollars, 1-2 years of jail, up to 3 years of probation, and they are prohibited from obtaining a sport or commercial fishing license for life (CDFW, 2014).

The effects of illegal poaching can harm species and habitats, reduce biodiversity, and jeopardize the success of protected areas (Lewis, 2015). Aside from ecological effects, it can have social and community level impacts as well (Lewis, 2015). These impacts can lead to tension among resource users, a mistrust of regulators, non-compliance, and it can undermine conservation efforts (Lewis, 2015). Unfortunately, it is difficult to quantify and to mitigate the effects of poaching because there are no reliable estimates as to how often and to what extent people are harvesting abalone illegally (Lewis, 2015). Traditionally fisheries managers indirectly estimate the practice of abalone poaching by using a combination of biological and economic indicators. Other common regulations such as law enforcement records, direct monitoring, and self-reporting are unreliable and not effective in estimating illegal poaching (Lewis, 2015). A cost effective and reliable method for estimating illegal take is needed.
One method that seems to be more effective is called Randomized Response Technique (RRT). It is usually used in sociological studies but works in the study of illegal resource use as well (Lewis, 2015). It basically assures participants that the questionnaire is confidential and there will be no legal repercussions for answering honestly (Lewis, 2015). The participants are then more willing to answer and give reliable data. A survey conducted on Mendocino county recreational fishers found that visitors had higher non-compliance rates (72%) than locals (18%), there was 29% non-compliance with daily take limits, and 23% non-compliance with minimum size limits (Lewis, 2015). Randomized Response Technique is importance because it can potentially help fisheries managers prioritize their actions and what law enforcement needs to look for the most (Blank & Gavin, 2009). Abalone poaching will always be an issue, but with techniques such as Randomized Response Technique, it can be more effectively managed.

**The Allee Effect**

Currently three species of abalone in California are threatened species and two are on the endangered species list. Their populations have declined so much that reproducing in the wild is almost impossible (Vilchis, 2005). Since abalone are broadcast spawners they need high population densities to reproduce externally (Ibid). A male and a female must be within a few meters of each other to spawn successfully. If population densities are too low, reproduction decreases and overall fitness declines (Vilchis, 2005). This is the Allee effect. It occurs when some component of fitness declines as population densities decline, leading to a positive density dependent relationship (Ibid).

The Allee effect is seen most frequently in broadcast spawners and in highly exploited regions (Vilchis, 2005). Before overfishing and other environmental pressures, the Allee effect in abalone was never an issue. Now that population densities are so low it makes it difficult for
them to recover naturally in the wild. Management strategies must take into consideration the Allee effect on vulnerable populations by taking a precautionary approach. One option to mitigate this issue is to raise abalone in captivity to potentially increase wild population with them (Vilchis, 2005). Introducing captive-bred animals into the wild possess its own set of issues but for some abalone species, such as the white and black species, it may be necessary (Vilchis, 2005).

Other concerns associated with the Allee effect include inbreeding, reduced evolutionary potential, and predator dilution (Vilchis, 2005). Low densities lead to an increased number of mating events between small populations and close relatives resulting in inbreeding (Vilchis, 2005). On that same note, a reduced number of beneficial alleles and an increase in harmful mutations lead to decreased evolutionary potential (Ibid). The Allee effect may alter their genetic makeup in a way that further reduces their ecological fitness. It may also increase the rate of predation. As abalone populations get smaller their individual vulnerability increases. Essentially the probability of getting caught or eaten increases (Ibid). Although the Allee effect is a secondary effect of overexploitation, human predation, and disease, it is one of high concern for recovering populations. Being able to persist into the future is essential for species survival.

**Pollution and Eutrophication**

Pollution is another environmental stressor to California abalone. 80% of pollution found in the ocean comes from nearby land (Ocean Protection Council, 2019). This pollution is generally made up of agricultural run-off and municipal discharge (Ibid). As fertilizers and other nutrients are leached into coastal waters, algal growth increases. Then a dense growth of plant life occurs and shortly after death occurs due to a lack of oxygen in the water and a blockage of sunlight (Ibid). Eutrophication effects kelp forests by resulting in kelp die offs and reduced food
availability for abalone. Some of these algal blooms are cause Red Tides (Ibid). Occurrence of these blooms have been on the rise in California and it is believed to be due to warmer waters. Some Red Tides are toxic and have detrimental impacts of marine sea creatures and humans. The California Ocean Protection Council focuses on three major aspects of environmental pollution in their policy and programs including downstream impacts, marine debris, and sediment management (Ibid). Some of their more specific programs include the California Harmful Algal Bloom Monitoring and Alert Program (HBMAP) which is a response program for efficient harmful algal bloom mitigation, prevention, and prediction, low impact development which limits contaminated water runoff into the ocean, and the 2018 California Ocean Litter Prevention Strategy (Ibid).

Disease

Like most organisms, abalone is subject to disease. One disease called Withering Syndrome has devastated the black abalone population along southern California. It is a fatal disease caused by _Candidatus Xenohaliotis californiensis_ and occurs from central California down to Baja California (Crosson et al., 2014). The disease attacks the lining of the digestive tract which stops the production of digestive enzymes (Crosson et al., 2014). To stay alive the abalone will begin to consume its own body causing its muscular foot to wither away (Ibid). The abalone’s foot is the meat of the abalone and it helps them adhere to rocks and surfaces. If the foot is damaged it can no longer inhabit rock surfaces thus becoming more vulnerable to predation. If an individual is not eaten it will most likely starve to death (Ibid). Susceptibility varies among different species. Some abalone, such as _H. diversicolor supertexta_ from Thailand show no losses due to WS (Neuman, Tissot, & Vanblaricom, 2010). Others, such as black
abalone experience up to 99% mortality. Some abalone can even be infected with the bacterium and avoid developing the disease (Ibid).

WS was first seen in California along the Channel Islands in the mid-1980s (Neuman, Tissot, & Vanblaricom, 2010). It then spread to the mainland in the following years. WS almost eliminated already struggling black abalone populations during that time (Ibid). It has also been seen in the pink, green, and red abalone although to a lesser degree (Ibid). The northern populations are not as severely affected because the cooler water temperatures prevent the disease from spreading.

During 1997 and 1998 California experienced a heavy El Nino season. From Mexico to the central Coast water temperatures were much warmer with temperatures above 23°C (Neuman, Tissot, & Vanblaricom, 2010). At the same time abalone experienced both high mortality rates and signs of WS. With warmer temperatures many of the abalone that were infected with the disease but showed no sign of WS suddenly produced symptoms (Crosson et al., 2014). Southern and central red abalone farms usually experience the disease in summer and in fall when once again, temperatures are warmer (Ibid). It is now believed that the most important environmental factor effecting the spread of WS is temperature (Ibid). In the face of climate change this may become more of a concern for conservation efforts.

For now, monitoring and containing infected abalone is the best approach (Neuman, Tissot, & Vanblaricom, 2010). To prevent it from spreading the establishment of a health history report and multiple health exams must be completed on the species before it is moved to a new location (Ibid). For the populations in the south to recover a resistance to the disease must take place. We may have to depend on development of resistant stocks from natural or hatchery-based environments (Ibid). Since the population of black abalone was almost destroyed selection
pressures may have favored resistant individuals. These individuals have the potential of becoming a founder population that can survive in warmer temperatures and resist infection, assuming enough genetic diversity exists to avoid inbreeding (Ibid). Although there may be hope for the black abalone, management of this species will remain a difficult task well into the future.

**Future Stressors**

While current abalone stressors are difficult enough to manage, future stressors will compound the effects of these stressors while adding new problems. Future stressors include all the negative effects associated with climate change in marine ecosystems such as, ocean warming, sea level rise, and ocean acidification. To effectively manage abalone, one must consider the effects of both current and future problems and plan accordingly.

**Ocean Warming**

Oceans compose most of the earth’s surface and absorb much more heat than the landmasses. The excess heat that it absorbed due to climate change will have far reaching effects on marine communities that are sensitive to variability. Some of the biggest concerns of ocean warming on California’s abalone include ecosystem loss due to trophic cascades, the spread of disease, reduced reproduction, and sea level rise (SLR).

Abalone are tightly linked to kelp forests. They provide them with a healthy habitat and an abundance of food (Jenkins, 2004). Unfortunately, kelp forests are extremely sensitive to the effects of ocean warming (Tegner & Dayton, 2000). To survive, kelp depend heavily on the nutrients in the water column. As water temperatures increase, the amount of nutrients in the water decrease (Tegner & Dayton, 2000). This causes kelp biomass to decrease as well. In the past, El Nino events along the coast have caused a deepening of the thermocline which also
causes warmer, nutrient poor water, and widespread reductions in giant kelp densities (Vilchis et al., 2005). Taking past El Nino events into consideration the effect of global climate change will be similar on kelp forests in the future. A reduction of kelp biomass means a less food for the abalones and possible starvation (Vilchis et al., 2005). When food sources are limited sea urchins tend to out compete abalone for available resources (Jenkins, 2004). Kelp forests could transform into sea urchin barrens in the future with little hope for abalone growth and development (Jenkins, 2004).

Aside from contributing to a loss of habitat and available food sources, higher temperatures also help spread WS (Vilchis et al., 2005). Southern California populations of black abalone have already been hit hard by this disease and warming will only spread the geographic range of it up into the northern regions of California. Only two conditions need to be met for WS to be triggered. First, the WS bacterium must be present and secondly, there must be warm water conditions (Crosson et al., 2014). In the face of ocean warming, these conditions will be easily met. Studies done on red and green abalone, the two species of abalone with the highest probabilities of survival, found that both species showed more frequent signs of WS in warmer conditions (Crosson et al., 2014). Green abalone experienced subtle symptoms of the disease while red abalone experienced high rates of mortality in warmer than normal conditions (Crosson et al., 2014). In the north, abalone who prefer cooler waters will be greatly affected by WS if the geographic range of the disease continues to expand.

Sperm reproduction in abalone is also affected by warmer waters, starvation, and disease. Vilchis (2014) found that 71% of red male abalone had no sperm after being held at 18°C for 6 months. He also found that 71% of males who were starved but held at a cooler temperature of 12°C also showed a lack of sperm (Vilchis et al., 2014). Lastly, almost all males that tested
positive for WS and who were exposed to higher temperatures had no sperm after six month (Ibid). In contrast, female egg production was not as effected by warmer conditions as male abalone (Ibid). Instead their egg production was limited most by food conditions. Rather than making smaller mature eggs in the face of starvation, they simply stopped producing mature eggs all together (Ibid). These results suggest that the window for successful development, fertilization, and larval development might be too narrow for abalone to naturally persist into the future.

**Sea Level Rise**

Sea level Rise (SLR) is the last major effect of warming oceans. As the water heats up it expands on the surface. At the same time ice held up at the poles is continuing to melt into the oceans (Caldwell & Segall, 2007). The Intergovernmental Panel on Climate Change predicts that the world’s sea levels are projected to rise between 26-82 mm in the next 80 years depending on how aggressively we cut carbon emissions (IPCC, 2013). For marine organisms who live at a specific depth, such as abalone, their habitat is under serious threat. Intertidal regions are at the interface between land and sea and abalone require rocky surfaces and a certain temperature to be able to survive (Caldwell & Segall, 2007). SLR may affect the livable ranges of abalone and make it difficult for them to find suitable habitat (Caldwell & Segall, 2007). SLR does nothing but adding to the array of environmental stressors they already face.

**Ocean Acidification**

Ocean acidification (OA) and warming waters go hand in hand. They are both consequences of a warming world due to increased greenhouse gas emissions. The world’s oceans are taking up more and more carbon dioxide. As this happens the availability of carbonate
ions decreases as well as seawater pH (Raven et al., 2005). Since the industrial revolution surface pH has dropped from 8.21 to 8.10 (Raven et al., 2005). By the end of this century it is expected to drop even further by roughly 0.3-0.4 units (Raven et al., 2005). For marine calcifiers this is cause for major concern. They are more vulnerable than other species to OA because to form their shell they have to produce calcium carbonate (Li et al., 2013). This process will be difficult in acidic waters due to the limited availability of carbonate ions.

The larval stage of development in abalone will be particularly effected by OA. This is the stage where they construct their skeletons by the use of carbonate ions (Li et al., 2013). Even if abalone manage to have a successful reproductive event, death during this stage may soon follow. In a study done testing the effect of low pH on abalone development, abalone larvae typically show signs of an increased malformation rate (Li et al., 2013). They also show a prolonged hatching time and decreased metamorphosis rates at a pH of 7.6 to 7.3 (Li et al., 2013). At these pH levels, embryotic development is also delayed (Li et al., 2013). OA will most likely impair shell development and increase the rates of larval mortality.

In addition to these effects, OA induced a stress response in abalone that enhanced their energy metabolism (Li et al., 2013). Consequently, their growth and reproduction rates were suppressed (Ibid). So not only does OA reduce the ability of larvae to survive after fertilization, it effects how fast it will grow once it settles, and how reproductive it will be once it is stressed. Different species of abalone will be affected to varying degrees by OA (Ibid). Changing ocean chemistry is an emerging threat to already endangered abalone. It is unlikely that OA will be reversed before it causes major damage to our oceans. Conservation efforts in California and across the globe must preserve genetic diversity and mitigate other factors previously discussed that impact population sizes (Ibid).
Adaptive Management and Conservation

Abalone must be managed using an integrated approach of two different perspectives, western ecological knowledge (WEK) and traditional ecological knowledge (TEK). By combining the two a more inclusive management design can be made to preserve abalone for future generations of Native Americans and Californians alike. Both WEK and TEK are defined by a few key characteristics that inherently differ (Table 2). When the WEK and TEK are able to converge, an adaptive management system arises where TEK compliments WEK rather than competing with it (Zedler & Stevens, 2018). Together they illustrate a way to developed resiliency and sustainability.

The US Department of the Interior, Bureau of Indian Affairs recognizes over 100 different tribes in the state of California (CDFW, 2014). The state of California, through the Native American Heritage Commission, also recognizes numerous other tribes that are not federally recognized (CDFW, 2014). In 2011, the state of California adopted the Tribal Communication and Conservation Policy to ensure effective communication and intergovernmental consultation between California state departments and the Native Californians (CDFW, 2014). With this policy, the CDFW is required to consult with tribes about fish and wildlife issues, assess the potential impacts of proposed activities on tribal interests, and provide opportunities for Native Californians to co-manage and take part in the decision-making processes that will affect them (CDFW, 2014). This policy is a great step towards integrating traditional knowledge into western science at the state level. It shows respect to traditional knowledge by requiring consultation and co-management of cultural resources.
Unfortunately, sovereign California Tribes lack subsistence rights and are subject to California coastal management and wildlife laws. With the closing of abalone season until 2021, many tribes feel as though the connection they have with the ocean and the abalone in it will be dampened during this time (Krol, 2018). Although California Tribes are represented in decision making in the CDFW and the California Coastal Commission, their cultural knowledge and cultural resource responsibilities are misunderstood and underestimated in decision making by the CDFW (Krol, 2018). If the ban on abalone diving continues for years after 2021, many tribal members may never have access to abalone in their lifetime (Krol, 2018). The CDFW needs to consider allowing limited harvest of abalone for traditional and cultural use during closed abalone seasons. For traditional resource management practices to be fully implemented, ecological decisions effecting the states natural resources will need to be consulted with and co-managed by Native Californians. It is not enough just to be acknowledged, they must be heard and taken seriously.

Policy - Sustainable Abalone

As of now, the best way to mitigate the effects of climate change in the oceans is to mitigate the effects of local environmental stressors. These stressors include poaching, disease, the Allee Effect, and pollution. More enforcement is necessary to prevent illegal take (Lewis, 2015). Community education, awareness seminars, and activities can also be implemented to raise awareness about sustaining abalone populations so that they do not continue to decline (Lewis, 20915).

To manage the Allee Effect the western scientific approach uses methods of monitoring and surveying abalone populations to make adaptive management decisions. The Abalone Recovery and Management Plan (ARMP) was adopted by the California Fish and Game
Commission in 2005 (Kashiwada & Taniguchi, 2007). It monitors abalone in the Northern Red Abalone fishery. If densities in the fishery drop below critical levels, the total allowable catch is reduced and if there are less than 3,300 abalone/ hectare then they close the fishery altogether (Kashiwada & Taniguchi, 2007). Perhaps a stricter approach that raises the critical level could help abalone populations recover (Ibid). Captive bred abalone could also help low densities of abalone to have successful spawning events. Implementing these abalone in targeted areas are most important (Ibid).

Pollution is a more broad based and pervasive issue which is much more difficult to control. Most of the pollution seen off the coast comes from inland runoff, waste, and plastic. Runoff from non-point source pollutants and the elimination of wetlands and other natural filtration systems on land also lead to pollution and eutrophication in marine ecosystems. Changing the waste policies on land may lessen the effect of pollution in the ocean (Ocean Protection council, 2019). Restoring wetland areas, regulating agricultural practices that produce harmful runoff, and adopting more efficient and effective waste management and recycling policies may be key to limiting marine pollution. Policies such as these may be unpopular in the short term but crucial in the long term. In the past, pollution policies concerning land and sea have been separated. To be most effective policy must link the two as a connected entity rather than two separate realms (Ocean Protection Council, 2019).

Lastly, disease must be monitored and surveyed as well. If farmed abalone were to be used to raise wild population densities, they must be checked for disease before being placed in the wild (Neuman, Tissot, & Vanblaricomic, 2010). Because warm temperatures increase the rate of infection during El Nino years and Summer months abalone populations must be monitored more closely. Fortunately, local stressors to abalone result in adaptation favoring temperature
tolerance and resistance to pathogens (De Wit & Palumbi, 2013). Abalone that cannot survive under these conditions will die while those who can will pass their genes to their offspring so that they can survive. These adaptations may be the key for abalone survival in the future.

**Traditional Management**

I recommend that TEK be used to compliment WEK (Zedler & Stevens, 2018). A main attribute of TEK is that it fosters a sense of individual responsibility in being an environmental steward and it emphasizes that people are a part of the landscape and responsible for the future (Zedler & Stevens, 2018). Native Californians view themselves and nature as a part of an ecological community derived from a single ancestor (Salmon, 2000). They believe that their kin include all the elements of an ecosystem. This belief influences their interactions with the ecosystem and helps preserve and sustain it (Salmon, 2000). Their observations from a generational timescale helped them understand the biology and ecology of abalone better.

One practice Native Californians used to sustain abalone was to leave large abalone that have high fecundity to reproduce while taking only intermediate sized abalone (Vilchis et al., 2005). Today, the CDFW puts more restrictions on the minimum catch size rather than the maximum size. They want only mature individuals to be taken for recreation so that young abalone can reach maturity. By allowing mature abalone to be taken they drastically decrease the abalone population that is old enough to reproduce. The Allee effects then makes it more difficult to reproduce because population densities are so small and reproductive potential is lost. I recommend the CDFW put more restrictions on the maximum catch size allowing reproductive individuals to reproduce and raise population numbers. This knowledge may be extremely useful in the preservation of abalone and the furthering of adaptive management systems that incorporate TEK and WEK.
Native ecological knowledge is important to preserve to aid in the restoration of abalone. Conversely, abalone are just as important to preserve to aid in the cultural revitalization and conservation of Native identity. It is a reciprocal relationship between the culture, the community, the Great Spirit, and all abalone relatives.

**Conclusion**

Abalone was once a common sight along the California Coast, with beautiful shells scattered across rocky shores. Native tribes co-existed with the species for thousands of years. During this time, abalone became a part of their heritage and cultural identity. They relied on it for sustenance and in return they took care of the abalone, it is their kin (Salmon, 2000). Now, abalone face more obstacles to recovery than ever before. Poaching, low population densities, pollution, disease, warming ocean temperature, sea level rise, and acidification are all stressors on the population. Because of this, abalone will not recover within the next few years but with careful care and observation it is possible.

I recommend a combined approach using traditional ecological management (TEK) and western science to provide adaptive management strategies for policy makers, fisheries managers, tribal communities, and local communities who love abalone. TEK works on a generational timescale, meaning that patience and persistence is key to long-term development and success (Zedler & Stevens, 2018). Short term solutions of western science are no longer the only answer. Taking from Native Californian traditions of reciprocity, understanding, and patience a shift in western scientific thought processes on sustainable management could take place.
I believe that the most important place to foster this change is through the education system of our state. Outdoor and environmental education are beginning to gain popularity within California. Numerous organizations such as the California Environmental Education Foundation and the California Education and the Environment Initiative have already begun paving the way for environmental literacy from kindergarten through twelfth grade. Various tribes have also implemented environmental education taking place on and off reservation sites, such as the Wiyot (Environmental Education). These educational changes and reforms will promote environmental leadership and awareness contributing to a more sustainable future. Students learning about reciprocity through hands on outdoor activities cultivate a deeper connection to the environment and all that is in it. History and cultural classes that dedicate curriculum to Native Californians and traditional natural resource use may help students understand that in some cases, preserving a species, such as abalone, also means preserving part of a culture.

Education, cultural awareness, and adaptive management that utilizes TEK and WEK are all critical aspects of abalone management. Figuring out how to combine the two knowledge systems at a legal level will prove to be the most challenging aspect of adaptive management implementation, yet well worth it. Abalone are beautiful creatures that are loved by many Californian tribes and coastal inhabitants. They are a symbol of cultural identity and because of that they are irreplaceable.
### Tables & Figures

**Table 1.** ICUN, ESA, and CESA status of California abalone species and their corresponding stressors. (Data from NOAA Fisheries, 2018)

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>ICUN</th>
<th>ESA</th>
<th>CESA</th>
<th>Main Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Allee Effect, Poaching</td>
</tr>
<tr>
<td>Pinto</td>
<td>Threatened</td>
<td>Special Concern</td>
<td>-</td>
<td>Poaching, WS, Predation</td>
</tr>
<tr>
<td>Flat</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Historic over Harvesting, WS</td>
</tr>
<tr>
<td>Green</td>
<td>-</td>
<td>Special Concern</td>
<td>-</td>
<td>Allee Effect</td>
</tr>
<tr>
<td>Black</td>
<td>Endangered</td>
<td>Endangered</td>
<td>-</td>
<td>WS, Trophic Cascades, Historic Over Harvesting</td>
</tr>
<tr>
<td>White</td>
<td>-</td>
<td>Endangered</td>
<td>-</td>
<td>Allee Effect, WS</td>
</tr>
<tr>
<td>Pink</td>
<td>-</td>
<td>Special Concern</td>
<td>-</td>
<td>Historic over harvesting, WS, Allee Effect</td>
</tr>
</tbody>
</table>
Table 2. Attributes of WEK and TEK that differ or are shared. (Table from Zedler and Stevens, 2018).

<table>
<thead>
<tr>
<th>Attribute</th>
<th>WEK</th>
<th>TEK</th>
<th>Both WEK and TEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevailing Ethic</td>
<td>Develop and exploit natural resources;</td>
<td>Reciprocity; tend the earth so the earth</td>
<td>Express the need for sustainability and resiliency</td>
</tr>
<tr>
<td></td>
<td>focus on profit</td>
<td>can nurture humans and non-humans</td>
<td></td>
</tr>
<tr>
<td>Time Frame</td>
<td>Mostly short-term planning; long-term</td>
<td>Inter-generational</td>
<td>Forward-looking</td>
</tr>
<tr>
<td></td>
<td>view often lacking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictions</td>
<td>Mostly quantitative</td>
<td>Mostly qualitative</td>
<td>Feed information back to reconsider next steps, as in Adaptive Management</td>
</tr>
<tr>
<td>Methods</td>
<td>Tests, sampling, statistical analysis</td>
<td>Trials, observations</td>
<td>Observe, integrate, synthesize. Use accumulated knowledge to improve methods</td>
</tr>
<tr>
<td>Accumulating data</td>
<td>Tendency to collect synchronic data</td>
<td>Diachronic database over a long period of time</td>
<td>Respect evidence</td>
</tr>
<tr>
<td>Nature of Data</td>
<td>Mostly objective</td>
<td>Observers tend to be resource users,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>strongly invested in data</td>
<td></td>
</tr>
<tr>
<td>Reviewers</td>
<td>Peers from narrow specialty but broad</td>
<td>Elders from local tribe, known and</td>
<td>Stake-holder opinions are sought</td>
</tr>
<tr>
<td></td>
<td>geographic range</td>
<td>revered</td>
<td></td>
</tr>
<tr>
<td>Records</td>
<td>Dense literature</td>
<td>Oral Traditions</td>
<td>Experience is respected</td>
</tr>
</tbody>
</table>


Figure 1. Geographic range of California abalone species along the western United States. (Figure from NOAA Fisheries Service, 2018)
Figure 2. Pre-contact tribal territory map of Californian Indian Tribes. (Figure from Calindian.org)
Figure 4. Painting by Lyn Risling, Hupa tribal member. The piece is called Abalone Women. (Found from Lynrisling.com)
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