Hoonah Indian Association Traditional Coastal Resource Vulnerability Assessment

Black seaweed: Rhodophyta; Laak’ásk (Tlingit)
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Executive Summary

Black seaweed (Laak’ásk) is a traditional coastal resource of the indigenous peoples of Southeast Alaska. Seaweeds are among the oldest organisms on the planet and have persisted through an incredible amount of exposure to harmful environmental trends. However, Laak’ásk is potentially directly and indirectly vulnerable to the unprecedented combined stressors of climatic, oceanic, and anthropogenic change. The resilience of Laak’ásk as a traditional coastal resource is explored and assessed using a synthesis of scientific and traditional ecological knowledge, with a focus on the potential impacts of ocean acidification, ocean warming, and relative sea-level change and associated processes on resource sustainability. Much remains to be discovered about the vulnerability and resilience of Laak’ásk to climate change. Indigenous organizations can contribute to marine resource management by documenting traditional ecological knowledge and participating in scientific investigations. Indigenous organizations can bolster Laak’ásk as a traditional coastal resource and source of cultural heritage, a commercial product, and a component of coastal ecosystems and ecosystem service through sustainable triple bottom-line strategies. This report proposes management actions, research topics, and sustainable business opportunities that may be a good fit for indigenous organizations.
Introduction

Laak’ásk is a species of red algae in the phylum *Rhodophyta*. Although it is a member of the red algae family, Laak’ásk has a green thallus “leaf” and turns black when dried. It is commonly referred to as black seaweed and is a traditional coastal resource of the Huna Tlingit on the coast of Chichagof Island, Alaska. It is approximately 8-15 inches long, elastic and stretchy when it is ready to be harvested. Laak’ásk is harvested annually and begins to grow in early spring. It has 3 growth seasons that correspond to different seasons: winter, spring, and summer. Laak’ásk is primarily available in April and May, but harvest times vary each year in relation to changes in temperature, sun, and rain (Garza, 2012). The nutritional benefits of Laak’ásk are seasonally and geographically variable depending on oceanic, atmospheric conditions such as the availability of nitrogen, salinity levels, light exposure, temperature, nitrate exposure, and physical exposure (Dumay & Morancais, 2016).

Laak’ásk is an excellent source of protein, iron, B vitamins, vitamin A, vitamin C, riboflavin, niacin, and is a good source of fiber, essential amino acids, and omega-3 fatty acids (Alaska Native Tribal Health Consortium, 2015) (Hamid, Ma, & Boulom, 2015). Laak’ásk is a traditional cultural food used for bartering & sharing, in part due to its taste and its medicinal health benefits such as treating iron deficiency, drawing out infections, and serving as a natural laxative (Turner & Clifton, 2006). The salt and iodine in Laak’ásk are traditionally used to soothe a sore throat and may be beneficial for the thyroid if taken in moderation (Alaska Native Tribal Health Consortium, 2015).
Gathering Laak’ásk is a cultural tradition of many coastal indigenous peoples (Figure 1). The book *Eating and Healing: Traditional Foods as Medicine* details the importance of many seaweed species to indigenous peoples in the North American Pacific. The Tlingit word Laak’ásk may apply variably to genera *Porphyra* and *Pyropia* species prevalent in Southeast Alaska, the Gulf of Alaska, and the Aleutian Islands (Sutherland, et al., 2011) (Garza, 2012). *Porphyra abbottae* is the species name for the ribbon-like variety of Laak’ásk that is gathered in the spring (Figure 2). *Porphyra torta* is the species name for “early season” Laak’ásk that is available during winter. *Porphyra perforata* grows in a circular shape and can resemble a dinner plate, approximately 12 inches in diameter (Figure 2).
As a commercially important species in Asia to make sushi (nori), a culinary delight in Northern Europe (laver), and as a cultural staple of coastal indigenous peoples, red algae are a highly appreciated nearshore resource in temperate water regions. There at least 70 species of Porphyra worldwide, many of which were recently reclassified into the genus Pyropia in 2011 (Sutherland, et al., 2011). However, most of the scientific information regarding the species appears in literature review searches under Porphyra. Information relevant to Laak’ásk is also referred to colloquially as nori, laver, dulse, and spring seaweed.

**Vulnerability and Resiliency of Laak’ásk**

Vulnerability is the propensity or predisposition to be adversely affected, encompassing a variety of concepts and elements, including susceptibility to harm and lack of capacity to cope and adapt (Wong, et al., 2014). It is highly uncertain how future physical, biological, and chemical changes to the environment may adversely affect seaweed (Harley, et al., 2012). Ecologically, little is known about how ‘small changes can make a big difference’, from ‘farm-to-table’, in consideration of the impacts of climate change on seaweed as a traditional coastal food. Local environmental conditions are highly variable and complicate the ability to ‘downscale’ the impacts of climate change on specific functions of Laak’ásk. The value of a seaweed vulnerability assessment seems to be lessened because there is abundant uncertainty.

*Figure 2: Porphyra perforata (left) and Porphyra abbottae (right). Both are species of red algae that are traditionally dried and consumed. The Tlingit word Laak’ásk may apply to both (Artists: M. Lindeberg, 1996; J. Agardh; Alaska Sea Grant Seaweeds of Alaska).*
when assessing macroalgae, the rank of research priority is not as great as other species, and seaweed appears to be well adapted to climate and oceanic change. However, an exploration of the vulnerability of seaweed is valuable because 1) all knowledge has value and understanding it will contribute to conserving its intrinsic worth; uncertainty should not dissuade interest, 2) macroalgae provide services and have ecological linkages that are means to the end of a larger discussion of direct and indirect impacts of climate and oceanic change, 3) several tribes and tribal organizations have demonstrated interest in the topic but have underdeveloped actions, 4) the rank of research priority by academics is not equal to the rank of research priority of local community members; positivistic approaches and 5) exploring a single resource at risk is a gateway into more advanced, and comprehensive studies.

Laak’ásk has numerous and complex life stages that make it vulnerable to different climate related stressors at different times (Schiel & Foster, 2006). During Laak’ásk’s “leafy” growing and harvest phase, traditional use is vulnerable to thermal physiological stress, relative sea level change, and changing food web dynamics (Harley, et al., 2012) (Schiel & Foster, 2006). During reproduction, seaweeds such as Laak’ásk require climatically sensitive environmental variables such as temperature, salinity, desiccation, wave heights, nutrient supply, and carbon dioxide concentrations (Harley, et al., 2012). In all phases of its lifecycle, Laak’ásk depends on biotic and abiotic (living and non-living) linkages. Very little information is available about the impacts of climate stressors such as ocean acidification and warming ocean waters on seaweed reproductive cycles.

**Ocean Acidification**

Ocean acidification is a reduction in the pH of the ocean, accompanied by other chemical changes over an extended period of time which is caused primarily by uptake of carbon dioxide but can also be caused by other chemical additions or subtractions from the ocean (Bindoff, et al., 2019) (NOAA PMEL Carbon Group, 2020). pH is the measure of hydrogen ions in an aqueous solution – more carbonate and bicarbonate ions result in reduced pH (Figure 3). Understanding the adverse effects of ocean acidification on nearshore ecosystems is a crucial first step for assessing the vulnerability and risk of coastal resources such as Laak’ásk. Unfortunately, the impacts of ocean acidification on Laak’ásk is not clear, and its vulnerability to ocean acidification is not fully understood. The best available knowledge suggests marine algae is not predicted to be as vulnerable to ocean acidification as other important traditional coastal resources because ocean acidification impacts certain species and types of organisms disproportionately (Kroeker, Gambi, & Micheli, 2013).
One major question when concerning the vulnerability of seaweeds to ocean acidification is what will change, by how much, and where (Harley, et al., 2012). Ocean acidity has increased by approximately 30% since pre-industrial times, and high latitude, cold water areas like coastal Alaska are more vulnerable to future changes on shorter time scales due to the chemical properties of cold & nutrient-rich seawater, human reliance on coastal resources, and sensitivity of some commercial and subsistence coastal resources to change (Figure 4) (Mathis, et al., 2015). Global ocean acidification projections by the United Nations predict decreases between .036-.042 or .287-.29 pH units by 2081-2100, perhaps reaching levels that are unprecedented in the last 2 million years (Hartin, Bond-Lamberty, Patel, & Mundra, 2016) (Bindoff, et al., 2019). However, ocean acidification will likely impact different areas disproportionately, in part due to complex biogeochemical and physical factors such as the amount of carbon and oxygen in seawater.

Figure 3: The pH scale by numbers, and percent change in acidity. A change of one pH unit results in 10x change in hydrogen ion concentration, drastically increasing acidity. (PMEL 2020)
Ocean acidification is primarily caused by elevated concentrations of carbon dioxide in seawater (Figure 3). In addition to atmospheric processes, the concentration and flow of carbon-rich seawater adds to ocean acidification. The availability of carbon depends on local habitat types, bathymetry, and taxa, and the temperature of the water, and other factors such as seawater temperature and shape of the coast in areas with strong gradation such as slopes, canyons, and

Figure 4: Surface pH (top), saturation state of aragonite (middle), and aragonite saturation horizon (bottom) ocean acidity data for Alaska. (Mathis, et al., 2015)
seamounts (Bindoff, et al., 2019). Southeast Alaska is a fjordic archipelago, and interior channels are narrow, steep-sided and typically include both vertical and lateral constrictions with strong upwelling of cold, carbon rich water (Weingartner, Eisner, Eckert, & Danielson, 2009). Upwelling, freshwater inputs, human waste, and glaciers provide carbon in nearshore environments that power algal photosynthesis, but also increase the vulnerability of local ecosystems to ocean acidification (Harley, et al., 2012) (Alaska Ocean Acidification Network, 2019). However, due to seaweeds reliance on carbon dioxide for photosynthesis, it is also possible that increased carbon availability will increase the amount of seaweed, leading to a natural balance. Increased levels of carbon dioxide in seawater could may directly impact Laak’ásk’s performance of photosynthesis by enabling increased productivity, and potentially increasing the abundance of macroalgae, and potentially buffering acidity in local ecosystems (Jones, 2016).

The variable impacts and magnitudes of ocean acidification on seaweed, and how these changes will work together or against other ongoing processes are currently very difficult to predict. For example, macroalgae communities may reduce acidification in nearshore ecosystems, possibly offering refuge to associated organisms (Baweja, Kumar, Sahoo, & Levine, 2016) (Alaska Ocean Acidification Network, 2019). However, these generalizations ignore the mechanistic complexity of ocean acidification in nearshore ecosystems and may be inaccurate (Harley, et al., 2012). Red algae such as Laak’ásk may be directly vulnerable to ocean acidification during its complex reproductive cycle, in which spores attach to a calcified substrate and grow to form swollen, microscopic filamentous branches that release germinated spores (Figure 5).
It is possible that ocean acidification could directly reduce the calcified macroalgal growth and increase dissolution during red algae reproduction cycles (Figure 5). Ocean acidification is predicted with high confidence to reduce growth and survival of calcifiers such as calcereous red algae (IPCC, 2014). However, estimates show there are over 6200 species of red algae, and uncertainty is so high that it is easier to summarize what is known rather than what is not known (Mouritsen, 2013). Most seaweed species remain undiscovered and significant knowledge gaps and more research is required on the impacts of ocean acidification on algal life cycles (Mouritsen, 2013) (Harley, et al., 2012).

Laak’ás is indirectly vulnerable to ocean acidification due to complex linkages between many organisms in nearshore marine ecosystems in its role as a primary producer, competitor, and ecosystem engineer. Ocean acidification can indirectly impact Laak’ás by changing community structure, reducing calcification, and increasing the dissolution of calcium carbonate by reducing its saturation state. For example, Laak’ás attaches to surfaces using a holdfast, which be conceptualized as the “roots” (holdfast) of the “plant” (thallus) attaching to the “soil” (substrate). Laak’ás tendency to attach to yaak (blue mussel) using a holdfast makes it vulnerable to ocean acidification because yaak are susceptible to ocean acidification. Recent
research shows that Yaak species (*Mytilus edulis*, *Mytilus trossulus*) decrease in calcification, shell density, shell weight, shell length, immune response, and hatching when exposed to acidic conditions that are within global ocean acidification projections (Parker et al. 2013).

Laak’ásk is indirectly vulnerable to ocean acidification due to its close relationship with invertebrate organisms. Ocean acidification is likely to be generally detrimental to calcified
invertebrate herbivores and calcified coralline algae (Harley, et al., 2012). Marine molluscs such as the snails that predate on seaweeds are expected to suffer a range of negative impacts including changes in metabolism, immune response, and reduced survival and reproduction (Parker, et al., 2013). Reductions to invertebrate urchins and molluscs that feed on seaweeds such as Laak’ásk could potentially disturb delicate food web dynamics and cause trophic cascades that can unbalance coastal ecosystems (Wong, et al., 2014) (Parker, et al., 2013). Ocean acidification impacts biotic “living” factors, in turn impacting Laak’ásk (Figure 5) (Mouritsen, 2013) (Harley, et al., 2012).

**Increasing Atmospheric Temperatures and Changing Light Environment**

Resilience is the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or re-organizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation (Wong, et al., 2014). Laak’ásk is naturally resilient to changing environmental conditions in many ways. For example, it is adapted to daily changes in tides that bring periodic desiccation or “drying out” and sunlight exposure, while maintaining its essential life processes (Contreras-Porcia, Lopez-Cristoffanini, Meynard, & Kumar, 2017). Seaweeds are among the oldest organisms on the planet and have persisted through an incredible amount of exposure to harmful environmental trends.

However, Laak’ásk may become more vulnerable as rapidly changing climatic conditions bring changes to which the species is not adapted, as the rate of increase in atmospheric concentrations of carbon dioxide, methane, and nitrous oxide greenhouse gases are unprecedented in the last 800,000 years (Wong, et al., 2014). Mean annual temperature predictions are predicted to increase from 3.2 °C to 4.9-6.9 °C or 6.4-8.7 °C in Southeast Alaska (Figure 6) (Shanley, et al., 2015). Many marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change (Wong, et al., 2014). However, it is unclear if increased temperatures and decreased precipitation will impact seaweed communities. It is possible that these temperature changes will impact intertidal seaweed communities when they are exposed to the atmosphere (EcoAdapt, 2014). However, seaweeds such as Laak’ásk are tolerant and resilient to desiccation stress from increased temperatures and drought through changes in form, structure and subcellular mechanisms. Seaweeds tolerate desiccation by limiting damage to a repairable level, maintaining physiological integrity under desiccation, increasing antioxidant scavenging power, and activating repair mechanisms after the post-desiccation rehydration processes (Contreras-Porcia, Lopez-Cristoffanini, Meynard, & Kumar, 2017).
Figure 6: A map series of potential climate change showing the current mean annual temp (MAT), mean annual precipitation (MAP), and precipitation as snow as water equivalent (PAS) compared to corresponding projections for the 2080s (2071–2100; 30-year normal period) using a five global climate model ensemble average (CCSM4, GFDL-CM3, GISS-E2-H, IPSL-CM5B-LR, and MRI-CGCM3) from the IPCC CMIP5 scenarios RCP 4.5 and RCP 8.5. (Shanley, et al., 2015)
Laak’ásk grows through several life phases that depend on light and temperature (Figure 7) (Baweja, Kumar, Sahoo, & Levine, 2016). The conchospore life phase exists when Laak’ásk spores have been germinated, towards the beginning of their life cycle. Conchospore formation and release depends on a specific light conditions such as photoperiod and photon flux density (Pereira & Yarish, 2008). Photoperiod is the period each day during which and organism receives illumination. Photon flux density refers to the rate of flow of sunlight photons per unit volume – or more simply, the intensity of sunlight on a specific area. Since Laak’ásk’s life cycle is triggered by specific, seasonal photoperiods and photon flux densities, quick changes to the long-term these normal in the atmosphere and marine environments may impact harvesting times and increase the vulnerability of Laak’ásk to climate change.

![Life history of Porphyra showing different stage development.](Baweja, Kumar, Sahoo, & Levine, 2016)

More research is needed to understand the vulnerability of Laak’ásk life cycle phases to changing air temperature and light environments. According to one study, Laak’ásk grows optimally with 80 µmol photons m⁻² s⁻¹ and 30ppt salinity (Stekoll, Lin, & Lindstrom, 1999). Specific research directions include understanding the relationship between fluctuations in photon flux density as a result of increased spring algal blooms and atmospheric changes in Southeast Alaska, which ostensibly impact the amount of light reaching Laak’ásk spores through reduced cloud cover, reduced precipitation, algal blooms, and other factors.
Increasing Sea Surface Temperatures

Over the course of the next century, global average sea surface temperatures are projected to increase between 1 to 2 degrees Celsius between 2046-2065, and between 1 to 3.7 degrees Celsius over 2081-2100 (IPCC, 2014). Sea surface temperature anomalies are also predicted to increase, in which there will be an increase in the percentage of months in each decade of the 21st century that exceed the warmest month on historical record (Alexander, et al., 2018). In other words, sea surface temperatures will increase on average over time, and will also feature more frequent “ocean heat waves” where the sea surface temperatures are consistently higher than ever recorded.
Figure 8: (a) Time series of global annual change in mean surface temperature for the 1900–2300 period (relative to 1986–2005) from Coupled Model Intercomparison Project Phase 5 (CMIP5) concentration-driven experiments. (b) Same as (a) but for the 2006–2100 period (relative to 1986–2005). (c) Change in Northern Hemisphere September sea-ice extent (5 year running mean). The dashed line represents nearly ice-free conditions (i.e., when September sea-ice extent is less than 106 km2 for at least five consecutive years). (d) Change in global mean sea level. (e) Change in ocean surface pH. For all panels, time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). The number of CMIP5 models used to calculate the multi-model mean is indicated. {WGI Figure SPM.7, Figure SPM.9, Figure 12.5, 6.4.4, 12.4.1, 13.4.4, 13.5.1} (IPCC, 2014)
Water temperature is a fundamental abiotic “non-living” factor in the resilience and distribution of seaweed species, and many other organisms. Sea surface temperatures directly influence the ability of seaweeds to photosynthesize energy, maintain metabolic functions, and enzymatic processes (Pineiro-Corbeira, Barreiro, Cremades, & Arenas, 2018). Laak’ásk survival and growth is directly vulnerable to changes in temperature, desiccation, salinity, wave heights, nutrient supply via upwelling and runoff, and carbon dioxide itself (Harley, et al., 2012). Seaweeds are adapted to temperature changes, but changes in temperature still cause cellular and subcellular stress, impacting growth and development, and potentially leading to mortality.

Figure 9: SST trends in Large Marine Ecosystems in the Arctic and around North America and Europe. Colors denote the CMIP5 ensemble mean area-averaged SST trends (°C decade⁻¹) during 1976–2099. All trends are significant at the 95% level using a Mann-Kendall test. (Alexander, et al., 2018)

Increasing sea surface temperatures may directly impact seaweed’s ability to reproduce and grow, however, much remains to be discovered about how key physiological processes that control growth, reproduction, and survival in seaweeds depend on a range of temperatures (Harley, et al., 2012). The direct impacts of increasing sea surface temperatures on Laak’ásk reproductive cycle are not completely known since its optimal temperature and temperature-tolerance limits can vary among life stages and among different species. However, recent research has determined the optimal growth for 2 indigenous Alaskan species of Laak’ásk during the conchocelis life phase. The optimal growth of *Porphyra abbottae* occurs at 11 degrees Celsius, 80 µmol photons m⁻²s⁻¹ and 30ppt salinity (Stekoll, Lin, & Lindstrom, 1999). Porphyra torta grows best at 15 degrees Celsius, 80 µmol photons m⁻²s⁻¹ and 30ppt salinity (Stekoll, Lin, & Lindstrom, 1999).
Sea surface temperature change may be a significant driver of impacts to traditional foods in the oceans. Traditional foods and other organisms that inhabit rocky coasts are projected with high confidence to change in abundance and distribution due to increasing sea surface temperature (IPCC, 2014). Recent research shows that community shifts in seaweed abundance were correlated with seaweeds with higher temperature dependence, in other words, seaweeds that can maintain photosynthesis at higher energies may have greater abundances as a result of increased temperatures (Pineiro-Corbeira, Barreiro, Cremades, & Arenas, 2018). Increasing sea surface temperatures will have many indirect impacts on seaweed communities, as there is high
confidence that abundance and distribution of rocky shore species will continue to change (Wong, et al., 2014).

Relative Sea Level Change

Relative sea level change is defined as a change in the mean high tide line as a result of climate and ocean change. Some coastline types are more susceptible to sea level change than others. Rocky coasts are characterized by very strong environmental gradients, which are observable as biobands of band-forming coastal biota that grow across-shore elevation at characteristic wave energies and substrate conditions. Sea level rise is expected to result in shifts in the zonation of intertidal and subtidal seaweeds (Harley, et al., 2012). Southeast Alaska is predicted to undergo coastal geomorphic change in which sea level will be relatively lower than before (Johnson, Noel, Gregovich, Kruger, & Buma, 2019).

Relative sea level decrease is not expected to directly impact rocky shorelines as strongly as low-gradient coastal areas such as estuaries and muddy bays (Johnson, Noel, Gregovich, Kruger, & Buma, 2019). However, there are many potential indirect impacts of relative sea level change on rocky shorelines in Southeast Alaska as coastal ecosystems are experiencing large cumulative impacts related to human activities (Wong, et al., 2014). Several efforts are underway to
understand how sea level change will impact traditional coastal resources. Laak’ásk is typically found on rocky shorelines with large boulders with high wave energy and exposure (Garza, 2012). Laak’ásk, can be mapped using multispectral satellite images with emission bands of 720-730 mµ (Vernon & Seely, 1966). However, this spectral band may also include a variety of other species with similar spectral emissivity to green leaves. Rock platforms have reduced resilience to any change that increases the efficiency of processes acting on them (Wong, et al., 2014). For example, blue mussel zonation on rock platforms is thought to be controlled by physical limitations towards the mean high tide line, and predation response to starfish towards the mean low tide line. Any relative sea level change has the potential to negatively impact species distribution through a variety of direct and indirect impacts, such as trophic cascades in nearshore foodwebs or physically induced mortality such as reduced submergence as a result of relative sea level decrease.

Conclusions and Future Research Recommendations

Seaweed is a naturally resilient species that has persisted and adapted through millions of years of harmful environmental trends; however, there is high uncertainty in how multiple anthropogenic, climate, and ocean changes will combine and directly and indirectly impact specific resources in highly variable local ecosystems. Assessing the vulnerability and risk of culturally important macroalgae communities to climate, oceanic, and anthropogenic change is a fundamentally difficult task that is further complicated when considering the role of uncertainty in adaptation planning. The main sources of uncertainty include lack of measurements and or measurement errors, aggregation errors, natural variability, model limitations of prevailing harmful environmental trends, and uncertainty in future climatic & non climatic factors (European Climate Adaptation Platform, n.d.). Future efforts to expand upon this report for adaptation and resilience planning for Laak’ásk will benefit from additional synthesis of traditional ecological knowledge and available scientific information. Performing a comprehensive multi-lingual literature review, semi-directed interviews, and using focus groups will compliment nomothetic science with ideographic, place-based knowledge (Rinkevich, Greenwood, & Leonetti, 2011). This is especially important for assessing the impacts of climate change on red algae as impacts are expected to be highly localized.

Macroalgae communities, including Laak’ásk, are vulnerable to warming sea surface temperatures, ocean acidification, relative sea-level change, and other changes in nearshore areas. This vulnerability will likely impact ecosystem communities and the people that rely on them. As broad environmental changes impact the accuracy experience-based traditional ecological knowledge in management regimes, the importance of generating new local observations and technical scientific knowledge increases. A variety of practical and scientific observations can be made to increase the resilience of traditional coastal foods to climate change.

<table>
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<th>Black Seaweed management actions</th>
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<td>Monitor coralline algae increasing ocean acidity and seawater temperatures</td>
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More research into the impacts of thermal stress on Laak’ásk life cycles is needed.

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<tr>
<th>Activity</th>
<th>Description</th>
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<tbody>
<tr>
<td>Monitor populations of calcifying invertebrates and herbivorous grazers in nearshore environments</td>
<td>Few projections of the effect of climate change on rocky shores have considered the effects of direct and indirect species interactions (Wong). The most prominent effects are range shifts of species in response to ocean warming and changes in species distribution and abundance mostly in relation to ocean warming and acidification.</td>
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<tr>
<td>Monitor timing of spring bloom of black seaweed at traditional gathering sites and estimate biomass</td>
<td>Opportunity to document traditional ecological knowledge and practice cultural heritage</td>
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<tr>
<td>Install temperature and light sensors in nearshore environments to assess ambient environmental conditions during spring bloom</td>
<td>Very little long-term information of sub-surface temperatures at different depth profiles are available in nearshore environments</td>
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<tr>
<td>Create an adaptation plan for sustainable black seaweed harvesting</td>
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<tr>
<td>Comprehensive TEK and scientific literature review using poly-lingual approach</td>
<td>Identify and document traditional ecological knowledge</td>
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<td></td>
<td>Identify traditional gathering sites</td>
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<td></td>
<td>Identify traditional and local gathering and management practices</td>
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Due to its importance as a traditional tribal and cultural resource and to the large amount of uncertainty pertaining to the capacity of black seaweed to cope with harm and its susceptibility to climate drivers, it is imperative that tribes take a leadership role in investigating the impacts of climate change on seaweeds. Focusing on a primary producer such as algae, it is also possible to gather a variety of data that pertains to other tribal coastal resources. Macroalgae are the main primary producers in coastal benthic ecosystems, provide habitats, refuge, and recruitment sites for fish, algae, invertebrates, and other organisms against predators or other physical threats in food web directly and indirectly reliant on algae.

During the vulnerability assessment, the impacts of ocean acidification, sea surface temperature increase, and relative sea-level change on other organisms were also considered. Further research onto the impacts of climate and oceanic change on tribal coastal resources is needed. In order to advance the tribe to the next step of resilience planning, it would be most beneficial to take the lessons learned during the course of this research and expand the scope of...
the vulnerability assessment, create an adaptation plan, and implement ocean and coastal management & planning actions.

<table>
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<tr>
<th>Recommended next steps</th>
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<tr>
<td>Phase 2 Vulnerability Assessment</td>
<td>Use adaptive management to identify other community-identified priorities on the impacts of sea surface temperature increase, ocean acidification, and relative sea-level change on other tribal coastal resources</td>
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<tr>
<td>Develop adaptation plan</td>
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<tr>
<td>Establish community engagement and outreach strategy</td>
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<td>Implement management actions</td>
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The identified management actions and proposed next steps are critical to restore and provide resilience to tribal coastal resources and further understand the vulnerability and adaptive capacity of coastal resources.

**Glossary**

**Ocean acidification** refers to a reduction in the pH of the ocean over an extended period, typically decades or longer, which is caused primarily by the uptake of carbon dioxide from the atmosphere but can also be caused by other chemical additions or subtractions from the ocean. Anthropogenic ocean acidification refers to the component of pH reduction that is caused by human activity (IPCC 2014). Increased concentrations of atmospheric CO2 are projected by the IPCC to reduce the pH of surface water from 8.1 to 7.7 units and reduce the carbonate ion (CO$_3^{2-}$) over the next 100 years (IPCC, 2014; Parker et al. 2013). Ocean acidification impacts the physiology, behavior and population dynamics of organisms (IPCC 2014). Reducing pH increases the cost of calcification and increased the likelihood of dissolution, making most calcifying organisms sensitive to elevated CO2 in seawater (Harley et al. 2012). Ocean acidification acts together with other global changes and with local changes, leading to interactive, complex and amplified impacts for species and ecosystems (IPCC 2014).

**Vulnerability** is the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including susceptibility to harm and lack of capacity to cope and adapt. (IPCC 2014).

**Resilience** is the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or re-organizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation (IPCC 2014).
Bibliography


