10 Traditional coastal resources of the indigenous people: resilience and vulnerability Assessment

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1. Introduction

Pyropia abbottiae is an edible species of seaweed found on lower to mid-intertidal areas of exposed rocky shorelines of the Northeast Pacific Ocean, including the temperate seas of Southeast Alaska, USA (Garza, 2012). It is an important annual early-spring traditional coastal food of the Tlingit, Coast Tsimshian, Haida, Heiltsuk, Kwakwaka'wakw and other coastal indigenous peoples of the Northeast Pacific Ocean, and it plays a unique role in shaping and characterizing their identity (Garibaldi & Turner, 2004). *Pyropia*, herein referred to using the Tlingit word Laak̲'ásk, is a valuable cultural keystone species that is accompanied by significant tradition, knowledge, and experience. Laak̲'ásk's vulnerability to the combined stressors of climate, marine, and anthropogenic change impacts the social resilience and identity of the coastal indigenous peoples in Alaska.

Cultural keystone species are organisms that significantly contribute to the cultural identity of a people, as reflected in the fundamental roles these species have in diet, materials, medicine, or spiritual practices (Garibaldi & Turner, 2004). Cultural keystone species such as Laak̲'ásk feature prominently in the language, ceremonies, and narratives of native peoples and can be considered cultural icons (Figure 1) (Garibaldi & Turner, 2004). Seaweed can define the identity and heritage of a people, and its continued use represents the resiliency of a people because every aspect of its harvesting, processing, and use is infused with culture and ways of life (Turner & Clifton, 2006). For example, in the Tsimshian language Sm'álgyax, the month of May is called the month of seaweed (Turner & Turner, 2008). An enrolled tribal citizen of the Hoonah Indian Association noted, "I remember my aunties and relatives gathering Laak̲'ásk when I was a kid. It makes me feel connected to them when I have it…being out on the coast picking it is special".

Cultural traditions and heritage strengthen social resilience (Holtorf, 2018). Social resilience is often defined as the ability of groups or communities to cope with external stresses and disturbances because of social, political, and environmental change (Adger, 2000). Ernestine Hanlon of Hoonah, Alaska, notes that "the health of the sea life is the health of our life" (E. Hanlon, October 27, 2020). Wanda Culp of Hoonah expresses that "As indigenous people, we use the water and the land. We depend on it" (W. Culp, October 27, 2020). The sea and its bounty are of unfathomable importance to local people. The role of Laak̲'ásk in organizing social relations is present in many ways, including sharing. Julie Jackson of the Hoonah Indian Association communicates, "The essence of living is sharing [resources such as seaweed] … I see the dying of our traditional foods and I want to share it". Darlene See of the Hoonah Indian Association observes, "Laak̲'ásk feeds the soul – there is a feeling of renewal when practicing, something that helps you connect… It's Haa K̲usteeyí [Our Culture]".

Figure 1 Near HERE

Many Tlingit words such as Laak̲'ásk encompass meaning that is without a direct English language equivalent, creating something of a paraphrase rather than a transcription (Dauenhauer & Dauenhauer, 1996; Murray & Rice, 1996). Julie Jackson and Darlene See suggested that there is no good way to get people to understand what it means to share and experience something like Laak̲'ásk. Ownership or property is a critical principal that organizes Tlingit social relations, such as the historical ownership of salmon streams (Langdon, 2006). However, ownership in this context does not necessarily correspond to American social and economic constructs – although these certainly seem to be observable in Hoonah, Alaska. It seems to describe not only the physical possession resource itself, but also a person's social role and social responsibility associated with the resource, especially through sharing. These social relations are perhaps best observable to an outsider at K̲u.éex [feast, potlatch; party]. It conveys a deep social, cultural connection between people and place, that involves a close connection with the seascape.

Seascapes are a multidisciplinary concept that are comparable to landscapes, where geophysical and socio-cultural elements integrate to create a synthesis of people and place. Seascapes generally refer to the value of the ocean and coast to humans and can be experienced through every major sense: touch, smell, taste, sound, and sight. In the fine arts, seascapes are art that conveys the sea and coastal environments, and perhaps people's relationship with it. The aesthetic, cultural and spiritual value of the sea to humans is an ancient concept that is visible through art in many distinct cultures, including the indigenous peoples of the North American Pacific coast. For example, many of the Tlingit clan names refer to marine and coastal species, such as Wooshkeetaan (salmon shark) and L'uknax.ádi (Coho salmon), which are depicted in formline art and totem carvings and show historical, cultural, and spiritual connections with the sea (Figure 2). The distinct character of Xunaa Shuká Hit, the Huna Ancestor House in Glacier Bay National Park, Alaska, conveys a deep historical relationship between people and place and its continuing presence in indigenous lives.

Figure 2 Near HERE

Seascapes are defined by the International Union for Conservation of Nature (IUCN) as a location where the interaction of people and nature over time has produced distinct character with significant aesthetic, ecological, or cultural values (International Union for Conservation of Nature, 2020). European land use planners in Wales and Ireland define seascapes as views of the sea and land along the coast and the effect on the landscape of the conjunction of sea and land (Hill, et al., 2001). In these views, seascapes seem closely tied to the concept of ecosystem services, in which humans derive, directly and indirectly, tangible and intangible benefits from ecosystem processes and functions.

Ecosystem services are generally categorized as supporting, provisioning, regulating, and cultural services (Millenium Ecosystem Assessment, 2005). The concept of ecosystem services is important for linking the functions of ecosystems to human welfare, such as the diverse value of the Laak̲’ásk seascape to indigenous peoples and how it contributes to their social resiliency. Understanding the benefit of Laak̲’ásk is important for vulnerability assessments that understand the impacts of change on indigenous coastal resources and people. However, although there are a variety of methods used to quantify the benefits of ecosystem services, very few if any of these methods are capable of fully valuing the local cultural benefits between people and place. Classifying and defining the value of ecosystem services in a decision-making framework is difficult due to the subjective context (Fisher, Turner, & Morling, 2009).

Seascapes can be defined strictly in terms of their biophysical and geographic characteristic, in which spatially heterogenous and dynamic spaces are delineated at a wide range of scales in space and time (Pittman, 2017). For example, the Alaska ShoreZone project classified the shorelines of Southeast Alaska into habitat classes by examining shoreline character such as substrate mobility, biological exposure, coastal type, and dominant structuring processes such as wave energy, fluvial and estuarine processes, current energy, glacial processes, and man-made modifications. The seascape can be described in terms of fundamental components from a reductionist point of view in a variety of disciplines, with varying degrees of emphasis on human involvement.

However, because the coast is the most densely populated place in the globe and because it is increasingly difficult to delineate where humans have not had an impact on earth, holistic marine spatial planning and vulnerability assessments often include elements of the social sciences. There is a Tlingit phrase: Sagú yáx kaa yayík du.axji nooch héendei yaa ana.ádi [Men's voices would always sound happy when they went to the sea] (Edwards, 2009). The seascape plays a critical role in the social resilience of the indigenous peoples of Southeast Alaska. Laak'ásk's vulnerability to climate, marine, and anthropogenic change impacts the social resilience and identity of the coastal indigenous peoples in Alaska.

2. Vulnerability and resiliency of black seaweed

Laak'ásk is a cryptic species in terms of its taxonomy and nomenclature. The Sealaska Heritage Dictionary of Tlingit defines Laak'ásk as dulse, a type of seaweed (Edwards, 2009). However, dulse is more commonly associated with *Palmaria mollis (*red ribbon seaweed). The Tlingit word for red ribbon seaweed is k'áach (Edwards, 2009). Personal correspondence with tribal citizens of the Hoonah Indian Association indicates that Laak'ásk may encompass several species of *Pyropia,* and that some species are more desirable than others.

There are several similar species in the *Pyropia* genus that are prevalent on the coast of the Northeast Pacific Ocean, with at least 70 species worldwide (Sutherland, et al., 2011;

Lindstrom S. C., 2008). This paper focuses on *Pyropia abbottiae* while acknowledging that the local term black seaweed and the Tlingit word Laak̲’ásk may refer broadly to several species of edible seaweeds, such as *Pyropia torta* , an “early season” Laak̲’ásk that is available during winter, *Pyropia perforata*, or even *Pyropia nereocystis* (Figure 3) (Alaska Native Tribal Health Consortium, 2015). *Pyropia fallax* appears similar to *Pyropia abbottiae.* The recent discovery of new species in the *Pyropia* genus and significant diversity therein leaves open the possibility that it is an unidentified species or other genus such as *Neopyropia fucicola* (Lindstrom S. C., 2008). Most seaweed species remain undiscovered and significant knowledge gaps exist (Mouritsen, 2013; Harley, et al., 2012).

Laak̲’ásk is approximately 8-15 inches (20-50 cm) in length, elastic and stretchy when it is ready to be harvested. It has 3 growth seasons that correspond to different seasons: winter, spring, and summer. Laak̲’ásk is harvested annually and begins to grow in early spring and is primarily available in April and May, but harvest times vary each year due to changes in temperature, sun, and rain (Garza, 2012). The nutritional benefits of Laak̲’ásk are seasonally and geographically variable depending on oceanic and atmospheric conditions such as the availability of nitrogen, salinity levels, light exposure, temperature, nitrate exposure, and physical exposure (Dumay & Morancais, 2016). According to Julie Jackson and Darlene See of the Hoonah Indian Association, the season and variability impacts taste, color and texture.

Figure 3 Near Here

Laak̲’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). The salt and iodine in Laak̲’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). 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).

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). The vulnerability of Laak’ásk is a multidisciplinary topic that spans natural sciences, formal sciences, and social sciences, including at least aspects of biology, anthropology, statistics, chemistry, physics, oceanography, geography, and environmental science. This paper discusses prevailing oceanographic, ecological, and climatic trends in the Anthropocene and evaluates how potential impacts to a single resource-at-risk may impinge indigenous social resilience in Southeast Alaska. There is a high degree of uncertainty on how future physical, biological, and chemical changes to the environment may adversely affect seaweed (Harley, et al., 2012).

Ecologically, little is known about how climate change will impact seaweed as a traditional indigenous coastal food in Southeast Alaska. Although nearshore temperate marine ecosystems in Southeast Alaska are less biologically diverse than tropical marine ecosystems, they are still inherently complex and complicated, and unweaving different levels of components in an understudied system is a challenging task. Local environmental conditions and natural variability in biotic ecosystems complicate the ability to project the impacts of climate change (Eckert, 2009). However, nearshore intertidal ecosystems are well characterized and developing monitoring protocols to detect ecological changes due to climate change is achievable (IPCC, 2014) (Murray, Ambrose, & Dethier, Monitoring Rocky Shores, 2006).

Some traditional harvesters observe synchrony between several species as signals or bio-indicators that are seasonally observable. The annual emergence of skunk cabbage (*Lysichiton americanus*) signals that Laak’ásk will soon be available (Anonymous, August 25, 2020). Increased activity by humpback whales (*Megaptera novaeangliae*) and Pacific herring (*Clupea pallasii*) and marine birds signal the approach of Laak’ásk season. As an early spring food, its availability is synchronous with increasing water temperatures, sunlight, and seasonal species. When Laak’ásk is approximately 3-4 inches long, the harvest will begin approximately one week after the next sunny day, during a negative tide [a low tide that is beneath the mean lower low water (MLLW) datum] (Anonymous, August 25, 2020). However, different harvesters maintain different traditions in regard to timing, and more information on synchrony and harvesting knowledge is needed to understand if synchronous species could assist with Laak’ásk population biology, climate modeling, and vulnerability assessments.

Climate is defined as the long-term average of conditions, and variability in the climate is caused by natural external forcings such as Milankovitch Cycles, natural internal forcings such as the Pacific Decadal Oscillation, and human-caused forcings such as increased albedo on glaciers due to greenhouse gas emissions (Kelly, et al., 2007). Downscaling global climate models is a challenging task that is limited by uncertainty in climate variability, model uncertainty, and forcing uncertainty. Alaska’s large geographical extent, complex terrain, and proximity to oceans and sea ice and glaciers, and historically heterogeneous climate divisions complicate the ability to downscale global climate models and climate information into climate projections (Bieniek, et al., 2012). Although progress has been made on defining climate divisions within the Southeast Alaskan panhandle and decreasing uncertainty, many indigenous communities are remote and are bio-culturally adapted to microclimates (Wyllie de Echeverria &

Thorton, 2019). Therefore, downscaled climate models may not accurately represent indigenous communities. For example, Chichagof Island is located at the climate division between the Northeast Gulf of Alaska and the Central Panhandle (Bieniek, et al., 2012).

Documenting traditional ecological knowledge may assist with characterizing ecosystems in order to assess the impacts of climate change on traditional harvesting sites in an understudied region. According to a tribal citizen of the Hoonah Indian Association, Laak’ásk is typically found on rocky shorelines with freshwater input that are exposed to the Northeast sky and open water (Anonymous, August 25, 2020). However, personal correspondence with other gatherers emphasizes that there is uncertainty in the orientation of seaweed harvesting sites to a cardinal direction, and that many gathering sites are southward facing. It is also uncertain if Laak’ásk harvesting sites feature freshwater input. However, it seems that most harvesting sites feature boulder or cobble rock surfaces, moderate wave action due to exposure, low substrate mobility, and current energy. The biological, physical and oceanographic characteristics of traditional harvesting sites are a topic that deserves further research and classification.

Laak’ásk has numerous and complex life stages that make it vulnerable to different climate related stressors at different times (Waaland, Dickson, & Duffield, 1990). In 2016, there was a failure of the black seaweed crop from at least the central coast of British Columbia to Southeast Alaska, which was potentially caused by a trophic cascade stemming from the 2014-2015 Gulf of Alaska warm water anomaly, nicknamed “the Blob” (Clark, Lindstrom, Liggan, Hessing-Lewis, & Martone, 2018). Progress in understanding algal populations depends on better knowledge of microscopic stages and on feedback through reproductive life phases (Schiel & Foster, 2006). During reproduction phases, seaweeds are climatically sensitive to environmental variables such as temperature, salinity, desiccation, wave heights, nutrient supply, and carbon dioxide concentrations (Harley, et al., 2012).

3. 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 (NOAA PMEL Carbon Group, 2020; Bindoff, et al., 2019). In the past 250 years, carbon dioxide concentrations have increased by 100 parts per million in the atmosphere, and approximately one-third of anthropogenic carbon emissions in the past have been absorbed by the ocean, decreasing the pH of the ocean (Clark, Ott, Rabe, Vincent-Lang, & Woodby, 2010). pH is the measure of hydrogen ions in an aqueous solution – more carbonate and bicarbonate ions result in reduced pH, which corresponds to more acidic conditions. Since the industrial revolution, the pH of the ocean surface waters has decreased by .1 units (Clark, Ott, Rabe, Vincent-Lang, & Woodby, 2010). Global ocean acidification projections by the United Nations predict decreases between .036-.042 or .287-.29 pH units by years 2081-2100, projecting acidic levels that are unprecedented in the last 2 million years (Hartin, Bond-Lamberty, Patel, & Mundra, 2016) (Bindoff, et al., 2019). Understanding the potential adverse effects of ocean acidification on nearshore ecosystems is a crucial step for assessing the vulnerability and risk of coastal resources such as Laak’ásk. The waters around Alaska are more vulnerable to the impacts of ocean acidification on shorter timescales (Mathis, et al., 2015).

Unfortunately, the impacts of ocean acidification on Laak’ásk are not clear, and its vulnerability to ocean acidification is not fully understood. Although the impacts of ocean acidification have been investigated on rocky shorelines, seaweed ecosystems have received less attention from researchers than other marine ecosystems (Harley, et al., 2012; Wong, et al., 2014). Documenting biodiversity and species richness in traditional harvesting sites may be important. Recent research suggests that acidification decreases the variability of communities, resulting in homogenization and ecosystem simplification (Kroeker, Gambi, & Micheli, 2013). Local ecological knowledge that observes synchrony between Laak'ásk and other species may be useful to investigate environmental cues impacting algal lifecycles, or to ascertain if ecosystem simplification is ongoing.

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 (Mathis, et al., 2015). More information on the local biophysical setting of Laak'ásk traditional harvesting sites is needed to understand the potential impacts of ocean acidification on nearshore algal ecosystems in Southeast Alaska. Fundamental investigations in population and community ecology may be important for assessing change in the future.

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). The pH of seawater is impacted by biophysical factors such as biological communities, bathymetry, carbon, and the temperature of the water, generating sharp ecological zonation (Bindoff, et al., 2019). Seasonal upwelling processes may influence local ocean acidification (Feely, Sabine, Hernandez-Ayon, Ianson, & Hales, 2008). Characterizing the impact of upwelling on nearshore waters in the context of ocean acidification may be important to determine the vulnerability of algal ecosystems to change. Creating or utilizing pre-existing networks in Southeast Alaska to monitor ocean acidification and gathering samples will be beneficial to future vulnerability assessments.

Laak’ásk may be indirectly vulnerable to ocean acidification due to complex linkages between organisms in nearshore marine ecosystems. Ocean acidification may indirectly impact Laak’ásk by impacting calcification during reproductive life phases and increasing the dissolution of calcium carbonate. *Pyropia* is known to inhabit barnacle shells and other calcium carbonate substrates during the conchocelis life phase. Laak’ásk may be indirectly vulnerable to ocean acidification due to its close linkage to invertebrate organisms such as clam and cockle shells and other calcium carbonate substances. However, seaweed species do not respond uniformly to ocean acidification due to differences in dissolved inorganic carbon uptake among seaweed species that do not have CO2-concentrating mechanisms among other processes (Cornwall & Hurd, 2019).

4. **Increasing atmospheric temperatures and changing light environment**

Many seaweeds are adapted to semidiurnal tidal exposure to the atmosphere, in which periodic desiccation and sunlight exposure occurs (Contreras-Porcia, Lopez-Cristoffanini, Meynard, & Kumar, 2017). 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). Mean annual surface temperatures are predicted to increase from 3.2 °C to 4.9-6.9 °C or 6.4-8.7 °C in Southeast Alaska (Shanley, et al., 2015). *Porphyra* abbotae (now *Pyropia abbottiae*) is adapted to high light and temperature stress and can lose 85-95% of cellular water during low tide exposure (Blouin, Brodie, Grossman, Xu, & Brawley, 2011). 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 (Harley, et al., 2012).

Seaweeds grow through several life phases that depend on light and other environmental cues (Baweja, Kumar, Sahoo, & Levine, 2016). Laak’ásk spores enter the conchospore life phase towards the beginning of their life cycle. Conchospore formation and release depends on specific light conditions such as photoperiod and photon flux density (Pereira & Yarish, 2008). The photoperiod is the period each day during which the 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, climatic anomalies in the atmosphere and ocean may impact both harvesting times and vulnerable life phases.

For example, *Pyropia haitanensis* growth was significantly inhibited under decreased light conditions, but not under normal ambient light conditions (Jiang, Zou, Lou, Deng, & Zeng, 2018). According to one study, Laak’ásk grows optimally with 80 μmol photons m^{-2} s^{-1} and 30ppt salinity (Stekoll, Lin, & Lindstrom, 1999). Using this reference point, it may be possible for tribal organizations to scientifically assess the impacts of physical climatological factors on Laak’ásk in traditional harvesting areas using simple tools. Specific research directions may include understanding the timing of resource availability in comparison to incident solar radiation, intertidal temperatures, and salinity in local traditional harvesting sites.

5. Increasing sea surface temperatures

Over the course of the next century, global average sea surface temperatures are projected to increase between 1 to 2 °C between 2046-2065, and between 1 to 3.7 °C 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). Sea surface temperatures are projected to 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. In 2016, there was a failure of the black seaweed crop from at least the central coast of British Columbia to Southeast Alaska, which was potentially caused by a trophic cascade stemming from the 2014-2015 Gulf of Alaska warm water anomaly, nicknamed “the Blob” (Clark, Lindstrom, Liggan, Hessing-Lewis, & Martone, 2018).

Water temperature is a fundamental abiotic factor in the distribution and abundance of Laak’ásk. Organisms that inhabit rocky coasts, such as Laak’ásk, are projected with high confidence to change in abundance and distribution due to temperature increases (IPCC, 2014). Sea surface temperatures directly influence the ability of seaweeds to photosynthesize energy, maintain metabolic functions, and enzymatic processes (Pineiro-Corbeira, Barreiro, Cremades, & Arenas, 2018). Recent research shows that community shifts in seaweed abundance were correlated with seaweeds that can maintain photosynthesis at higher energies, resulting in greater abundances due to increased temperatures (Pineiro-Corbeira, Barreiro, Cremades, & Arenas, 2018). However, it is unclear if Laak’ásk will respond in the same way.

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). Seaweeds are directly vulnerable to changes in temperature, desiccation, salinity, wave heights, nutrient supply via upwelling and runoff, and carbon dioxide itself (Harley, et al., 2012). The direct impacts of increasing sea surface temperatures on Laak'ásk's reproductive cycle are not completely known since its optimal temperature and temperature-tolerance limits can vary among life stages and among different species. The optimal growth of the conchocelis of Porphyra abbotae (now Pyropia abbottiae) occurs at 11 ºC, 80 µmol photons m-2 s-1 and 30ppt salinity (Stekoll, Lin, & Lindstrom, 1999). The conchocelis of Porphyra torta (now Pyropia torta) grows best at 15 degrees Celsius, 80 µmol photons m-2s-1 and 30ppt salinity (Stekoll, Lin, & Lindstrom, 1999). Increasing sea surface temperatures will have many direct and 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). However, more research is required that specifically investigates the impacts of warming sea surface temperatures on Laak'ásk. Tribal organizations may be able deploy data loggers to record temperatures in traditional harvesting sites and contribute to baseline data gathering and vulnerability assessments of Laak'ásk in the context of increasing sea surface temperatures.

6. 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. Sea level rise is expected to result in shifts in the zonation of intertidal and subtidal seaweeds (Harley, et al., 2012). However, Southeast Alaska is predicted to undergo coastal geomorphic change in which sea level will be relatively lower than before due to isostatic rebound from deglaciation (Johnson, Noel, Gregovich, Kruger, & Buma, 2019).

Laak̲’ásk is typically found on rocky shorelines with large boulders with moderate wave energy and exposure (Garza, 2012). Rocky coasts in Southeast Alaska are characterized by very strong environmental gradients, with distinct zonation of coastal biota that grow across-shore elevation at characteristic wave energies and substrate conditions (Lindstrom S. C., 2009). Some coastline types are more susceptible to sea level change than others. Relative sea level decrease in Southeast Alaska 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).

Laak̲’ásk can be imaged 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. Tribal organizations may be able to model and map the elevation and sediment characteristics of Laak̲’ásk traditional harvesting sites and contribute to vulnerability assessments of Laak̲’ásk in the context of geomorphic and relative sea level change.

7. Conclusions

Laak̲’ásk is a cultural keystone species that provides ecosystem services and supports the social resilience of the indigenous peoples of the Northeast Pacific Ocean. Laak̲’ásk is one of many such traditional coastal resources that entails a connection with the seascape. The seascape is a multidisciplinary concept that is observable in many facets of the Tlingit culture. Due to its importance as a traditional indigenous and cultural resource, significant traditional and local knowledge, and a large amount of uncertainty pertaining to the capacity of Laak’ásk to cope with climate, marine, and anthropogenic change, tribal organizations are well positioned to take a leadership role in investigating the impacts of change on seaweeds and social resilience (Figure 4).

Figure 4 near here

Tribal organizations can contribute to a vulnerability assessments and further action on Laak’ásk in many ways. More research, including documentation of traditional ecological knowledge is needed to identify habitat characteristics to model and map the abundance and distribution of Laak’ásk. Modeling and mapping that is performed with socio-cultural values will be more impactful than biophysical models (Crane, 2010). Improved understanding of the biogeochemical and physical setting through documentation of traditional ecological knowledge will increase understanding on the vulnerability of Laak’ásk to temperature changes. Deploying temperature and light data loggers that will record ambient conditions year-round will contribute to establishing baseline biophysical characteristics in-situ. Surveying and monitoring ecological communities in proximity to Laak’ásk harvesting sites will create a reference point for climate, marine, and anthropogenic change. Understanding the timing of the algal bloom with ambient light conditions will increase understanding around potential changes in incident solar radiation due to changes in the atmosphere. Traditional harvesting sites should be mapped to convey the cultural importance of the resource and record the supratidal, intertidal, and subtidal characteristics of traditional harvesting sites. Alaska native expertise is needed to clarify taxonomic definitions.

Bangiales, the group to which *Pyropia* belongs, has a fossil record going back over 1 billion years and is a naturally resilient group that has persisted through untold dynamic climatic trends. However, there is high uncertainty in how multiple climatic, marine, and anthropogenic changes will combine and directly and indirectly impact highly variable local ecosystems and their resources. More research on the vulnerability of Laak’ásk communities to climate change is needed, especially in consideration of its vulnerability to ocean acidification and combined stressors where limited information is available. The distribution and abundance of Laak’ásk in the interior waters of the Alexander Archipelago is uncertain.

It is imperative for actions that will impact Laak’ásk to engage and consult indigenous communities. Climate change mitigation and , sustainable business ventures, as well as ecological restoration should consider the value of Laak’ásk to local peoples. Documenting traditional ecological knowledge and forming a database to be used for tribal government-to-government consulting through the US National Environmental Policy Act and other State of Alaska request for public input opportunities will be beneficial to tribes in the environmental permitting process for sustainable mariculture business opportunities.

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. Although the resiliency of indigenous peoples does not hinge entirely on one-resource-at-risk, it is important to understand that the resilience of people is intrinsically linked to the character of their ecosystem, in this case, the Laak’ásk seascape. However, assessing the vulnerability and risk of culturally important macroalgae communities to climate, marine, and anthropogenic change is a fundamentally difficult task that is further complicated when considering the role of uncertainty.

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