# Kwakwa̲ka̲’wakw use of the edible seaweed ***ɬəqq’əstən*** (*Porphyra abbottiae* Krishnamurthy: Bangiaceae) and metal bioaccumulation at traditional harvesting sites in Queen Charlotte Strait and Broughton Strait

By

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B. Sc., Saint Francis Xavier University, 2007

A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of

MASTER OF SCIENCE

in the School of Environmental Studies
University of Victoria

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## Abstract

*Porphyra abbottiae* Krishnamurthy (Rhodophyta) is an intertidal red alga harvested by a number of coastal First Nations in British Columbia. The Kwakwa̱ka̱'wakw have a long history of harvesting *P. abbottiae* as food and medicine, reflected in the language, songs and stories of the Kwakwa̱ka̱'wakw oral tradition. Harvesting and drying practices for this alga have undergone changes with the introduction of new technologies and a decrease in time available for seaweed harvesting. The adoption of timesaving equipment into the seaweed harvest has given harvesters the flexibility to work around constraints including work and school obligations, tides, long distances to harvesting sites, and unpredictable weather conditions. Harvesting and drying practices reflect a thorough understanding of the lifecycle, biology, and ecology of *P. abbottiae*. Timing of the harvest during the seasonal round optimizes the taste and texture of *P. abbottiae* fronds while avoiding the seaweed in its reproductive stage. Songs and taboos associated with the harvest promote safety and efficiency while harvesting the seaweed.

Concerns about potential contamination of edible seaweed led to the second part of this research: testing for metal contamination. Inductively coupled plasma mass spectrometry analysis for selected metals and trace elements revealed the presence of arsenic, cadmium, lead, and mercury in *Porphyra abbottiae* sampled from the southern Queen Charlotte and Broughton Straits. Mercury concentrations fell below the detection limit of 0.01 ng/mL in 28 of 112 samples. Calcium was the most abundant element measured, averaging 1445 mg/kg dry seaweed. The remaining metals, in decreasing order of concentration, are: Fe>As>Zn>Mn>Cu>Cd>Pb>Cr>Co>Se>Hg. Copper-zinc ($r=0.835$) and copper-lead ($r=0.948$) concentrations are significantly correlated ($p<0.05$), suggesting selective uptake of these elements. PCA analysis suggests that the location of harvesting sites within specific water channels is influencing metal concentrations. Hazard quotients calculated using guidelines set by Health Canada and the World Health Organization revealed that, among the suite of elements surveyed, arsenic followed by cadmium ranked the highest in relative risk for consumers of *P. abbottiae*. An average 60 kg adult consumer can safely consume approximately 9.4 g dried seaweed per day and not exceed tolerable upper intake limit guidelines. In conclusion, *Porphyra abbottiae* can be eaten in moderation with minimal risk of chronic metal contamination. Kwakwa̱ka̱’wakw consumers can also benefit from cultural reconnection with this important traditional food.

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Preface

It became clear to me that true science consists not in describing single plants, but in a knowledge of their structure and life and in the comparison of all classes of plants with one another.

-Franz Boas (undated; in Cole 1999: 25)

This is an ethnoecological study of the edible red alga *Porphyra abbottiae* Krishnamurthy (Rhodophyta) and its place in the traditions and practises of the Kwakwa̲ka̲’wakw First Peoples of coastal British Columbia. While there are many academic papers that deal with the effects of human activities on the biological functions of *Porphyra* species, few examine the role of *Porphyra* in human society and culture outside of Asia. Our knowledge of *Porphyra abbottiae*, or ***ɬəqq̓əstən*** as it is named in K$^{w}$ak’wala, the language of the Kwakwa̲ka̲’wakw, cannot be complete if we only study its biology in isolation from other species, including humans. Franz Boas, as seen in the quote above, realized that to study each species individually gives too narrow a focus. He would later begin an ethnographic study of the Kwakwa̲ka̲’wakw that, despite shortcomings, laid the foundation for future ethnological and ethnoecological work that reflected a broader integration of knowledge and ideas around the cultural knowledge of plants and environments.

My academic history prior to arriving in Victoria was filled with a great deal of ecology, phycology, and chemistry, but included relatively little anthropology or other humanities. It was only late in my undergraduate degree that I had the opportunity to explore archaeology and anthropology, but I enjoyed every single lecture! In fact, my background in biology complemented the archaeology, and anthropology gave food for thought while I was working on coastal ecology. I began the transition from traditional ecology to ethnoecology and eventually came to learn that human cultures and traditions introduce significant, non-random effects into ecosystems. Likewise, our cultures and traditions are shaped by our immediate surroundings in non-random manners. It is a happy coincidence, then, that the classical ecological term *community ecology* (a study of the ecological interactions between two or more species living in the same area) can apply to this project: this is a study of the traditional cultural and ecological interactions between the Kwakwa̲ka̲'wakw community and ***łəqq̓əstən***, *Porphyra abbottiae*.

Ethnoecological studies cannot be conducted using either purely ecological or purely ethnographic methods; ethnoecology is a unique blend of the theory behind both disciplines. As a student with a background in traditional ecology, this was an unfamiliar but logical approach to studying an ecosystem. Much of conventional ecology has relied on modelling ecosystems while excluding human interactions and effects on their immediate environments in order to simplify and identify the primary drivers of ecological change. When human activities *were* included in ecosystems models, they were often presented as detrimental or counter-intuitive to a 'pristine' ecosystem state. My position was that humans, particularly Indigenous Peoples worldwide, are a naturalized species in their ecosystems with area-specific cultural adaptations. With many, if not most, of the world's landscapes now known to show at least some anthropogenic manipulation,[1] it would be odd not to include humans as legitimate participants in ecosystems! To dismiss humans in the study of ecology does a disservice to the societies that have manipulated, co-existed, and benefited from ecosystems and their processes.

Although it was not usually explicitly mentioned, I was aware that academia traditionally took the stance that one must remain independent and unaffected by the research topic in order to make unbiased, objective conclusions. Hunn (2007) mentions that researchers of the past would often arrive at an indigenous community, try to impartially observe and record their findings, and then depart. There would be, in this case, no need for emotional investment by the researcher into the community, and no incentive to help the community meet its own goals. The community might or might not see benefits from this research, and in some cases would see their intellectual or material property used without consent or compensation. Fortunately, attitudes have changed; there is a greater movement

[1] Ellis and Ramankutty 2008.

towards truly collaborative research and towards strengthening and protecting the rights of the community through this collaboration.[2]

While considering graduate programs I knew that I wanted to remain in a science program, but I also wanted my work to help people; all too often had I seen other research that would only be read and discussed by a small group of academics. This graduate degree became an opportunity to expand into the humanities while still retaining a strong grounding in science, and to hopefully produce work that would be useful both to communities and to researchers.

This thesis is a step in my life-long education, but it also represents discussions with knowledgeable elders and cultural experts, personal stories, chance meetings with seaweed enthusiasts, and the shared experience of seaweed harvesting. This is their knowledge that describes an aspect of Kwakwa̲ka̲'wakw food culture. It is my hope that this study will help members of Kwakwa̲ka̲'wakw communities who choose to continue a modern day seaweed harvest.

[2] Lertzman 2003.

Acknowledgements

| | |
|---|---|
| *'Duair bha an f hairge mhor* | What time the great sea |
| *'Na coille choinnich ghlais,* | Was a grey mossy wood, |
| *Bha mis am mhuirneig oig,* | I was a joyous little maiden, |
| *Bu bhiadh miamh maidne dhomh* | My wholesome morning meal |
| *Duileasg Lioc a Eigir,* | The dulse of the Rock of Agir |
| *Agus creamh an Sgōth,* | And the wild garlic of 'Sgōth,' |
| *Uisge Loch-a-Cheann-dubhain,* | The water of 'Loch-a-Cheann-dubhain,' |
| *Is iasg an Ionnaire-mhoir,* | And the fish of 'Ionnaire-mor,' |
| *B' iad siud mo ragha beatha-sa* | Those would be my choice sustenance |
| *Am fad 's a bhithinn beo.* | As long as I would live. |
| (Carmichael 1928) | |

Ethnoecology can be described as "the study of the interrelationships between human cultures and their ecosystems," but I've found that it is a much more complex subject than that statement suggests. This definition does not capture the importance of friendships or understanding different world outlooks and traditions that the researcher encounters with the people and communities involved in the study. Without these qualities, a research project could easily become a 'listing' of plants and their uses with anecdotes on a people's culture. These relationships continue to remind me that far beyond simply using plants with known medicinal, edible, or technological properties, the flora can become part of a people's collective cultural identity.

One of my earliest memories is of my family, my aunts, uncles, and cousins going to the beach to harvest fresh *goémon* (*Palmaria palmata* L.; dulse) from the waters of the St. Mary's Bay, part of the Bay of Fundy in Nova Scotia. The adults would often roll up the seaweed and dip it into vinegar before eating it. Today many of my relatives regularly go to the beach to harvest seaweed. Many of our routines besides gathering seaweed take place at the shore. We watch the tides and have been known to wake up at 5 am in chilly weather to pick *des moucles* (Fr. *des moules*; mussels) or go *grater pour des cocques* (clam digging). From friends we will buy or trade for *molue* (Fr. *la morue*; cod), *des homards* (lobsters), *des harengs* (herring), *du haddeck* (Fr. *l'aiglefin*; haddock), *du plais* (flatfish), *les maquereaux* (mackerel), *du poisson boucané* (smoked fish), and *les scalopes* (scallops). *Le poisson sec* (dried fish) was like candy while I was growing up,

and is still one of my favourite snacks. We watch the low-lying island, Gull Rock, on the horizon to determine tomorrow’s weather, and see spectacular sunsets over the mouth of the bay. We are still practising centuries-old traditions of salting and drying fish, despite the easy access to convenience foods and improvements in food preservation technology. Much of our area’s livelihood depends directly or indirectly on the sea.

It wasn’t until partway through my undergraduate degree that I gave thought to whether people in other regions in a contemporary, modern Canada lived as we did: with the sea being the foundation for much of our economy, our food, and our history. It seems silly in retrospect, but while growing up it did not seem that fishing culture defined the West Coast as it did the East Coast. I soon found out that this was incorrect; while fishing may not contribute proportionally as much to the economy in British Columbia as it does in Nova Scotia, fish such as salmon are highly significant cultural and culinary icons to both First Nations and non-indigenous peoples in BC.[3]

I came to this project as a stranger to the Northeast Pacific coast culture, ecology, and geography. First Nations history in western Canada was barely discussed in school while I was growing up, and ethnoecology was certainly never mentioned. *Porphyra abbottiae* was unknown to me, in part due to the absence of *Porphyra* harvesting or consumption along the Acadian shore of Nova Scotia where I grew up. My personal and academic experience with seaweed had primarily lain with Atlantic coast macroalgae and the dulse harvest in the Bay of Fundy. I had no idea that there were other local-level seaweed harvests along the western shores of the country!

Soon upon my arrival in British Columbia, I had the pleasure of meeting several knowledgeable Kwakwa̱ka̱’wakw elders. *$K^{w}$axsistalla* (hereditary Clan Chief Adam

[3] In 2006 commercial fishermen in BC landed $360 million or 19% of the total fishing value in Canada, after Nova Scotia (35%, or $661 million) and Newfoundland (24%, or $474 million) (DFO 2006). Both commercial fisheries and aquaculture accounted for 0.6% of British Columbia’s total GDP in 2005 (BC Stats 2007), whereas in Nova Scotia fisheries represented 22% of the province’s ocean sector GDP (Gardner et al. 2009). The ocean sector represents 15.5% of Nova Scotia’s total GDP, meaning that fisheries makes up about 3.4% of the province’s total GDP.

Dick), *Mayanił* (Dr. Daisy Sewid-Smith), and *Og*$^{w}$*iloğ*$^{w}$*a* (Kim Recalma-Clutesi) must be thanked for their patience, good humour, and their desire to share their world with us, their students. They are the gatekeepers and key bearers to a large body of traditional Kwakwa̱ka̱'wakw knowledge. I gratefully thank them for allowing me to venture through that gate into their world to document and better understand traditional Pacific coast seaweed culture. To Adam, *t'as du sang dessous les ongles*. Your fighting spirit is an inspiration.

I would like to say a big 'thank you' to my thesis co-supervisors Drs. Nancy Turner and John Volpe. Your patience has been nothing short of amazing, and I've learned quite a lot about plants, bread making, proper pizza parties, and salmon farming. I'd like to say another big 'thank you' to my committee member Dr. Peter Ross. You helped make statistical analysis of metal loads in seaweed fun. Two other very kind people that helped me better understand the natures of the seaweed and food contamination are Dr. Sandra Lindstrom and Dr. Hing Man (Laurie) Chan. It had been a while since I'd last been botanizing seaweed, and I enjoyed every minute of it in the Broughton with Dr. Lindstrom. My session at UNBC in Dr. Chan's laboratory was another great experience, and I am very grateful for the invitation to use the facilities and expertise with tissue chemical analysis. I would also like to thank Allen Esler, the laboratory technician at UNBC who ran the samples through the spectrometer once my stay in Prince George was over.

Many people were crucial to the planning and carrying out of the seaweed harvests in May 2008 and 2009. Many thanks go to our boat captains Dr. Marty Krkosek (Delucio) and Ashley Park (Captain Blood), without which we couldn't have accessed any of those seaweed sites. A big thank you to Abe Lloyd; I don't know what we would have done without those bentwood boxes, your super-fast harvesting skills, or those forced-air dryers and makeshift tents over the seaweed racks when the rain came! Melissa Grimes, Leigh Joseph, Lee Glazier, Victoria Wylie de Echeverria, Tom Child: you all helped shape this study. I would also like to thank Mary Vickers; it was wonderful chatting about Bella Bella and candied seaweed, and the smoked salmon was delicious. You are a very strong person, and I hope that you and your family will keep opening the eyes of others towards traditional foods.

And to my family: to my parents and my brother Ian, I want to thank you for encouraging me unconditionally onwards despite your own struggles. There were scary moments in the past few years, but we got through them. Thank you, too, for giving me a sense of pride in our sea and our food. To Andrew, thank you for your support and love when I was feeling lonely on a coast so far from our own. Thank you for visiting over the summers, for helping with the chemical analysis work in Prince George, and for those evenings during seaweed camp when you would stay up late to make sure the last of that day's seaweed was dry in Kim's dehydrator. I'm sorry that we always had to wake you up so early the next morning to catch the tide.

Thank you all!

# Chapter 1 Introduction

[We] noticed [that], some of the ones we bought, it's bitter. It's tasteless. And we assumed that the younger generation doesn't know the rules concerning the four-finger rule, or the rain rule, and they pick it. And therefore you end up with tasteless seaweed.
- *Mayanił* (Dr. Daisy Sewid-Smith), May 2009

## 1.1 Background to the Study

*Porphyra abbottiae* Krishnamurthy, commonly known as laver, is an edible, intertidal red alga found and consumed by people of the First Nations on the Northeast Pacific Coast of Canada.[4] It was first described in scientific literature as a new species by Krishnamurthy (1972) and was named after Dr. Isabella A. Abbott (1919-2010), an expert on Hawaiian seaweeds and ethnobotanist (e.g. Abbott 1996a, 1996b).[5] Its use by humans, however, precedes its formal description by hundreds if not thousands of years. *Porphyra abbottiae* is only one of many edible *Porphyra* species in the world (Turner 2003). Indigenous to the Pacific Ocean, *P. abbottiae* is found from the Kodiak Archipelago in Alaska to southern Vancouver Island and northern California (Lindstrom 2008).

Cosmopolitan, nutritious, and easily digestible, many species of *Porphyra* are harvested and consumed by people of diverse cultures on all populated continents (Lindstrom and Cole 1992), but for this region, the North American Pacific coast, *P. abbottiae* is the most widely used (Turner 2003). Its close proximity to the coastline, the relative ease of access to it, and the presence of other nearby foods, materials and medicines (shellfish, fish, algae, shorebirds, etc.) may have led to the incorporation of *Porphyra* spp. into food-gathering events and yearly cycles. Consequently, members of the red alga genus *Porphyra* have been consumed and utilized by peoples around the world for many centuries. Some species of *Porphyra* have become particularly significant parts of human diets and cultures for many centuries up to the present day. *Porphyra* is commonly called

[4] Often referred to as the Northwest Coast (of North America).
[5] More recently Sutherland et al. (2011) have reassigned *P. abbottiae* into the resurrected genus *Pyropia*, and *Porphyra abbottiae* has become *Pyropia abbottiae* (V. Krishnamurthy) S. C. Lindstrom comb. nov. For the purpose of this study, I will continue to use the name *Porphyra abbottiae* to reduce confusion and provide continuity with earlier ethnographic accounts.

*laver*, and is sometimes referred to as *nori* (Garza 2005). The former name is related to the common name of another member of the genus *Porphyra*, *P. umbilicalis*, or purple laver that is used in Britain and particularly Wales to make laverbread. The latter, *nori*, is a Japanese name referring to the *Porphyra* (*P. yezoensis* or *P. tenera*) species used in making sushi.

*Porphyra abbottiae* is a significant cultural and nutritional staple for many First Nations (Turner 2003). It is harvested by a number of coastal First Nations in British Columbia and Alaska each year, and traded to those peoples with limited or no access to this seaweed within their traditional territories (Turner 1975, 2003). It can be classified as a significant, "cultural keystone species" to some of the First Nations such as the Coast Tsimshian, Haida, Kwakwaka'wakw and Heiltsuk on the Northeast Pacific Coast (Garibaldi and Turner 2004; Turner and Turner 2008). As a traditional food, knowledge associated with *P. abbottiae* is vulnerable to changes in: 1) form of knowledge transmission (e.g. loss of mother language; oral tradition or written texts); 2) extent of transmission from elders to younger generation; 3) the number of elders who retain this knowledge; and 4) the willingness and opportunities of the youth to acquire and incorporate the information into their lives (Thompson 2004). The consumption of *P. abbottiae* is also subject to its availability in the wild, to changing food trends in the community and society, to socioeconomic factors[6] that allow or prevent the harvest or purchase of the seaweed (Kuhnlein 1989, 1992; Turner and Clifton 2006), to contamination of the alga from industrial development or other sources, and to changing climate (Turner and Clifton 2009).

For most communities today, the steady, year-round availability of marketed foods means that the seaweed is no longer necessary for sustenance. Store-bought foods offer

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[6] Socioeconomic factors identified by Kuhnlein (1992) include: employment during the harvesting season that prevents the time investment needed to locate, harvest, and prepare traditional foods for consumption and to have the opportunity to teach this knowledge to younger generations; legislation that restricts access to traditional foods; demographic shifts from rural to urban centres; and social perceptions of traditional and introduced foods influenced by the media and society.

convenience and a stable food source for families. Turner and Turner (2008) note, however, that the most affordable and accessible foods in North America are generally also deficient in nutrients. There is concern that the modern diet of store-bought foods in First Nation communities is lacking in folate, vitamins A and D, iron, and calcium, which were formerly provided by a traditional food diet (Kuhnlein 1992). Additionally, First Nations across Canada show disproportionately higher rates of health problems than non-First Nations peoples. In 2004, 19.7% of First Nations adults living on reserves reported having diabetes compared to 5.2% in the rest of the adult population of Canada (Health Canada / Santé Canada 2009). Furthermore, Kuhnlein and Chan (2000) point out that partaking in traditional harvesting activities can contribute to better First Nations health by re-introducing nutrient-dense foods into their diets and increasing physical activity. This recommendation would certainly stand for continuing the harvesting and use of *Porphyra abbottiae*.

Continuing the traditional seaweed harvest provides the youth of Northeast Pacific coast communities with a tangible (and edible) link to their history, culture, and health. Recording these traditions with the help of elders is one step towards preserving their knowledge for future generations. This study focuses on the narratives and practices of elders from the Kwakwa̱ka̱’wakw Nation in relation to *P. abbottiae*. It is at the invitation of Kwakwa̱ka̱’wakw elder and Hereditary Clan Chief Adam Dick (*K$^{w}$axsistalla*) and Kwakwa̱ka̱’wakw cultural specialist Kim Recalma-Clutesi (*Og$^{w}$iloğ$^{w}$a*) that the use and Traditional Ecological Knowledge of *P. abbottiae* on the coast be documented and that it be studied for potential contaminants that I began this study. They and others have expressed concern that industrial and domestic sewage effluents contaminate some sites where the seaweed was traditionally harvested, and therefore they have not wanted to use it. They wanted to better understand the risks of harvesting and consuming this time-honoured and favourite food from these sites (pers. comm. 2007).

## 1.2 Thesis Objectives

There are two primary objectives for this thesis. The first is to document traditional harvesting and preparation practises as relayed by Kwakwa̱ka̱'wakw elders with first-hand experience in the harvest. The second is to provide baseline data on the metal content and variation in *Porphyra abbottiae* populations in the Broughton Strait, an area within the traditional territories of several Kwakwa̱ka̱'wakw bands, and which has been identified as having concerns for contamination.

Chapter 2 focuses on the documentation of Kwakwa̱ka̱'wakw traditional ecological knowledge (TEK), both historical and modern, concerning ***ɬəqq̓əstən*** (*Porphyra abbottiae*; also written ***lhəq'əstə΄n***). I present the history, terminology, technology, and practises involved in the harvesting, preparation, and consumption of ***ɬəqq̓əstən*** as recollected by key Kwakwa̱ka̱'wakw elders and knowledge holders, especially Chief Adam Dick (*Kʷaxsistalla*) and Dr. Daisy Sewid-Smith (*Mayaniɬ*) and additional informants. Using this information, I: 1) evaluate how new technologies and practices have been integrated into the TEK of ***ɬəqq̓əstən***; and 2) compare ***ɬəqq̓əstən*** as a "cultural keystone species" (as defined in the literature) for the Kwakwa̱ka̱'wakw in early historical and contemporary times, examining the technologies and practises involved in the harvest and preparation of this alga from the past and present, and discussing what factors may have led to the development and adaptation of new technologies.

Chapter 3 reviews the distribution, biology, ecology and ethnoecology of ***ɬəqq̓əstən*** (*P. abbottiae*); I examine the biological factors that have shaped TEK and associated management practices and taboos, and evaluate the potential for TEK and its practices to influence *P. abbottiae* distribution, density, and quality.

Chapter 4 presents the results of a metal analysis performed on *P. abbottiae* samples collected at traditional harvesting sites in the Broughton Strait north of Vancouver Island in May 2008 and 2009. I discuss how these results fall into federal and international guidelines for human health, and compare risks and benefits of continued harvesting and consumption of *P. abbottiae* from a health perspective.

Chapter 5 summarizes my overall thesis conclusions relating to metals in *Porphyra abbottiae*, the traditional ecological knowledge documented from the interviews and field expeditions with the elders, and the overall importance of ***ɬəqq̓əstən*** as a culturally valued food and component in the intertidal ecosystem of the northeastern Pacific coast.

## 1.3 Introduction to *Porphyra abbottiae* biology

*Porphyra abbottiae* Krishnamurthy is an epilithic red alga (phylum Rhodophyta) found along the Northeast Pacific Coast[7] from Alaska to northern California. Figure 1.1 shows the size and form of *P. abbottiae* at the time of usual harvest as a food. This alga is found at low- to upper mid-intertidal zones. This species is only accessible to harvesters during low tides. It is one of up to 25 known species in the genus *Porphyra* in the northeast Pacific, including five cryptic species[8] (Lindstrom 2008). Genetic studies have revealed a morphologically similar species of *Porphyra* whose distribution overlaps that of *P. abbottiae*. It can be distinguished from *P. abbottiae* because the cryptic can be epiphytic, whereas *P. abbottiae* is not known to grow epiphytically (Lindstrom 2008).

The ecology and biology of *P. abbottiae*, including its lifecycle and preferred habitats, are reviewed in greater detail in Chapter 3.

[7] This region is also often called the Northwest Coast—this is from the perspective of the North American continent instead of from the ocean.
[8] Cryptics are two or more species whose identification is difficult or impossible based on morphological features alone. They are often misidentified as one species until a combination of ecological, molecular, or genetic studies show speciation has occurred. The cryptic species are usually closely related (Bickford et al. 2007).

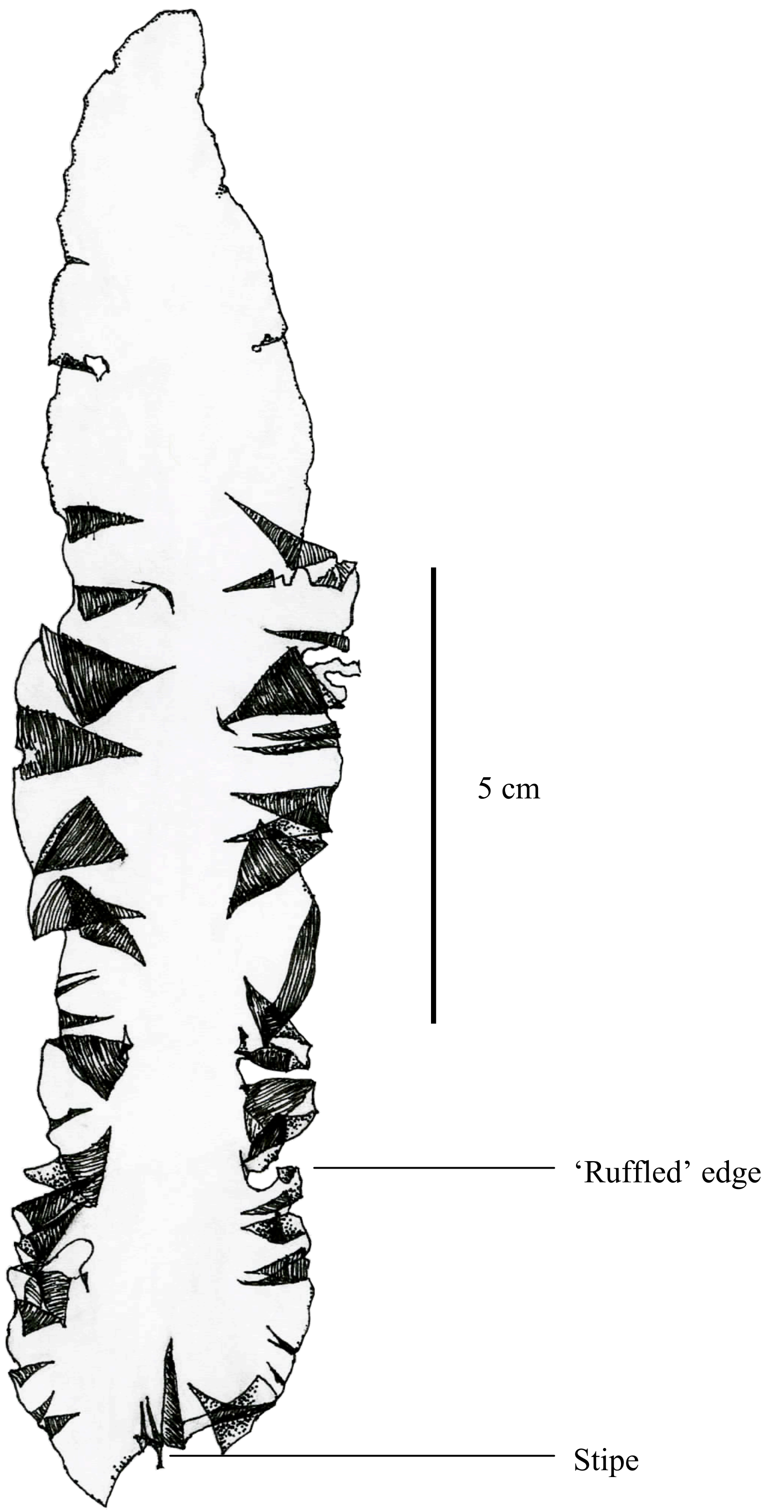


Figure 1.1. Typical form of *P. abbottiae* at time of harvest as a food in mid to late May.

## 1.4 Worldwide *Porphyra* use

*Porphyra and other algal use in South America*

Archaeological evidence strongly suggests the use of *Porphyra* spp. and other algae by Indigenous Peoples in South America beginning thousands of years ago up to the present. At Monte Verde in southern Chile, Dillehay et al. (2008) identified the remains of *Porphyra columbina* and other *Porphyra* spp. that were dated at approximately 14,000 years B.C.E. The authors also identified stone tools with traces of *Porphyra*, suggesting that the tools were used in cutting the seaweed. The abundance of seaweed remains in many hearths at the site and close association with the remains of medicinal plants led the authors to suggest that seaweed was used both as food and medicine. The authors found charred remains of seaweed, and suspected that the seaweed was dried for preservation and transport from the coast or cooked there on-site.

Another region of early settlement in South America with evidence of other seaweed consumption is in central coastal Peru (Aaronson 2000; Moseley 1975). Traces of kelp were found at several dating back to the early Cotton pre-ceramic period (approximately 2500 B.C.E.) (Moseley 1975). Aaronson (1986) also suggested that seaweeds were used in South America as both food and medicine. He noted that both marine and freshwater species of algae appear in traditional meals in among the Quechua peoples in Peru, and that Peruvian Inca had a bridge named *Chaquillcharo*, or 'seaweed bridge,' leading from the mountains toward the Pacific coast that could be used as a trade route. Aaronson thought that the iodine-rich seaweed might have been used to treat goitre in the Andes, and cited some known examples of goitre in mummies found there along with an example of a mummy with pieces of a seaweed stipe in cotton wrappings.

Seaweed consumption continues to the present day in South America. Aaronson (1986) notes that *Porphyra columbina*, one of several species grouped under the name of *luche*, was still being consumed in Chile at least as recently as the late 1960s. Nancy Turner observed seaweed harvesting taking place near Punta Arenas near Tierra del Fuego in 2002 (pers. comm. 2010). She noted that *Porphyra* was one of the genera of marine algae being cultivated experimentally at the Universidad de Magallanes (University of Magellan).

*Porphyra use in Southeast Asia and Pacific islands*

*Porphyra* has historically also been an important food in Asia and the Pacific. The earliest known form of Chinese algal mariculture began in the Fujian Province during the Song dynasty (960-1279 A.D.) as a springtime rock-cleaning technique (Tseng 1992). The rock cleaning allowed new generations of algal spores to settle and grow on coastal rocks. *Porphyra* cultivation employing the same rock-clearing technique has been recorded in the Fujian Province for several hundred years (Tseng 2001). It became a large-scale industry in the 1950s after Dr. Kathleen Drew Baker discovered that the conchocelis was not a separate species but the product of germinated spores from the *Porphyra* thallus (Drew 1949). This discovery allowed growers to cultivate conchospores from the conchocelis and seed the spores onto nets instead of relying on the currents to deposit wild stock onto rocks or ropes (Chapman and Chapman 1980).

In the Pacific, *Porphyra* was eaten alongside many other genera of algae. The Maori in New Zealand know *Porphyra* spp. as *karengo* (Schiel and Nelson 1990). Schiel and Nelson (1990) found that the Maori's technique of clipping the *karengo* would lead to more rapid regeneration than if the seaweed were plucked whole from the rocks, and now there are growing concerns that the commercialization of the industry is affecting the *Porphyra* populations. Before the time of the Europeans' arrival to New Zealand, the Maori were spreading *P. columbina* to increase its distribution to more suitable sites (Holland 2000). In Hawaii, Dr. Isabella Abbott (1996a) studied the ethnobotany of 14 local seaweeds including *limu pahe'e* ('slippery seaweed'; *Porphyra vietnamensis*). The *limu pahe'e* is harvested during the brief time in winter or early spring when the thallus has reached a harvestable size.

The popularity of the edible members of this genus has continued to rise thanks to the widespread popularity of Asian cuisine. The *Porphyra* cultivation industry has been valued at $1 billion worldwide in 1986 (Mumford and Miura 1988). By 1998 the value of the industry rose to $1.5 billion in Japan alone (Zemke-White and Ohno 1999). Zemke-White and Ohno (1999) reported that 130,614 t. dry wt. of *Porphyra* was produced in 1995, following only *Laminaria* (682,581 t. dry wt.) for the greatest quantity of cultured seaweed produced worldwide that year. By 2008, the Food and Agriculture Organization (FAO) estimated production of *Porphyra* spp. in China, Taiwan, Japan, and South Korea to have reached 1,376,820 tonnes wet weight and was valued at over $1,339,423,000 US (FAO 2010).

Porphyra *Use in Europe*

There is a long history of both coastal and inland use of marine algae including *Porphyra* in Europe. *Porphyra umbilicalis*, also known as purple laver or sloke/slake, was harvested along the coasts in the Scottish Highlands. Here it was eaten in broth or with butter, and was regarded so highly by western islanders that they said a person could survive on the seaweed alone (Kenicer et al. 2000; Martin 1716). It was also used in the western isles of Scotland to treat costiveness (constipation) in cows, in Cornwall to treat cancer, and in the Aran Islands, Ireland, to treat indigestion (Martin 1716; Allen and Hatfield 2004). *Porphyra* was not the only seaweed used by Europeans. The French, Irish, Scots, and Norwegians would harvest various seaweeds washed up on the shore and use it to enrich the soil in their gardens (Kain and Dawes 1987; Landsborough 1851). Landsborough (1851) records the use of the marine alga *tangle* (*Laminaria* spp., Kenicer et al. 2000) as a medicine for goitre by people in the Alps. In Iceland the oldest law book, the *Grágás*, affirms the right of a man to travel across another man's property in order to harvest *søl* (*Palmaria palmata*) and consume it while still fresh (Madlener 1977; Hallsson 1961).

*Porphyra umbilicalis* is sometimes eaten raw as a salad, but it is usually made into laverbread (Idyll 1970). Laverbread is made from boiled and gelled *Porphyra*, and *P. umbilicalis*, or laver, is the titular ingredient. After thoroughly cleaning the laver, it is boiled in salt water inside copper boilers for twelve hours. The liquid is poured over stone slabs to cool and solidify (Idyll 1970; Indergaard and Minsaas 1991). The laverbread can be sliced and cooked in fat, or coated with oatmeal and fried to make bannocks. It is often served as an accompaniment to bacon and eggs or with oatcakes (Martin 1716; Idyll 1970). Laverbread is primarily eaten in South Wales, but it is also exported around the world (Indergaard and Minsaas 1991). Kenicer et al. (2000) note that in Scotland, seaweed consumption has decreased from historical levels but is slowly beginning to increase again.

Porphyra *Use In North America*

For many North Americans today, seaweeds do not form the basis of important cultural, dietary, or social traditions. Yet, there is a growing awareness of the health benefits of seaweed consumption and an awareness of algal derivatives such as carrageenan appearing in commonly used products such as toothpaste and ice cream. Attempts at commercial seaweed operations on the northeast Pacific coast were made in the 1990s (Mumford 1990; Scagel 1990). Historically there has been documentation of Irish moss (*Chondrus crispus*) and dulse (*Palmaria palmata*) harvesting by European settlers on the East Coast, but historical records of Indigenous harvests along Canadian coasts are less common in the literature.

*Porphyra* consumption has historically been widespread along the northeast Pacific coast and inland, wherever palatable species of *Porphyra* have occurred. Several different species were and are consumed from southeast Alaska to California (Garza 2005; Moerman 1999; Turner 2003; Turner and Clifton 2006). (See Table 1.1 for a summary of the *Porphyra* species consumed from Alaska to Washington State.) The Pomo, Kashaya, and Yurok of California harvested and dried *Porphyra lanceolata* and "*P. perforata*" as food (Moerman 1998). In British Columbia, First Nations most commonly harvested and ate *Porphyra abbottiae* Krishnamurthy[9] (Turner 2003). Use of *P. abbottiae* and related species by First Nations on the Northwest Coast of North America was not universal, however, despite being located within the geographical range of the alga. Turner (2003) notes that the Ditidaht and Nuu-Chah-Nulth on the west coast of Vancouver Island did not traditionally consume *P. abbottiae*, despite its availability. Gunther (1973) also does not mention *P. abbottiae* among the seaweed types used by the Makah and Quileute of

[9] Often identified in earlier works as *P. perforata*.

Washington State, but noted that these people collected *Ulva* sp. (sea lettuce) and *Fucus* spp. (sea wrack, or rockweed). More recently there has been the recognition by academics that *P. abbottiae* is a cultural keystone species at least on some parts of the coast (Garibaldi and Turner 2004; Turner and Turner 2008).

Table 1.1. Edible *Porphyra* species and the First Nations that harvest and/or consume them along the Northwest Coast of North America from Alaska to Washington State.

| *Porphyra* species | Nation | Notes |
| --- | --- | --- |
| *P. abbottiae* Krishnamurthy | Kwakwaka'wakw,[a] Gitga'at,[a] Dakelh (Carrier),[a, b] Coast Salish,[b] Coast Tsimshian,[a] Haida,[b] Tlingit,[a, c] Tsilhqot'in[b] | First named in the literature in 1972,[d] *P. abbottiae* is the most commonly harvested and used species of *Porphyra* on the Northwest Pacific coast of North America.[a] A mid-intertidal zone species found in exposed shorelines with high wave energy.[c] Nations from the interior such as the Dakelh, Gitxsan, and Tsilhqot'in traded to obtain *P. abbottiae*. Can be found from Alaska to northern California.[e] |
| *P. fallax* Lindstrom and Cole | Possibly Massett Haida [a] | Might be confused with *P. perforata* or *P. abbottiae*.[a, e] May be sometimes mixed in with *P. abbottiae*.[a] Found from Alaska to Oregon.[e] |

| | | |
|---|---|---|
| *P. fucicola* V. Krishnamurthy | Tlingit, Haida [a] | A species collected as 'winter seaweed' in Haida Gwaii, but identification is tentative due to fragmented state of sample.[a] It is epiphytic on *Fucus* species,[d] and less thick than *P. abbottiae*.[a] Grows alongside *P. abbottiae* in the lower mid-intertidal zone at exposed sites.[c] Found from Alaska to Oregon.[e] |
| *P. miniata* C. Agardh | Kwakwa̲ka̲'wakw [f] (formerly known as Kwakiutl in the literature)[10] | Colloquially known as purple laver.[f] Originally described in the literature in 1824 as occurring *ad litus Grœnlandæ* (on the shores of Greenland),[g] *P. miniata* is a currently accepted taxonomic name for specimens growing in the North Atlantic.[h] Curtis (1915) identified the seaweed eaten by the Kwakwa̲ka̲'wakw as *P. miniata*, but the alga formerly identified as *P. miniata* C. Agardh on the coast of British Columbia has been renamed *Porphyra cuneiformis* (Setchell & Hus) Krishnamurthy.[i] *P. cuneiformis* is not mentioned in the literature as a widely consumed alga, and so historical references to *P. miniata* are likely to actually be *P. abbottiae* Krishnamurthy. It is collected in the springtime from the low-tide line.[f] |

[10] *$K^{w}$axsistalla* and *Mayanił* wished to clarify that the word 'Kwakiutl' is not a word in any of the nine dialects of $K^{w}$ak'wala (pers. comm. May 2011). While Franz Boas used 'Kwakiutl' to collectively refer to all of the Kwakwa̲ka̲'wakw tribes, it derives from *Kwagiulth* (Alfred 2004; Masco 1995). This is the name of the Kwakwa̲ka̲'wakw tribe whose territory is based in and around Fort Rupert and is where Boas' translator and primary contact George Hunt lived. 'Kwakiutl' is thus an inaccurate name from both a linguistic context and when discussing the collective $K^{w}$ak'wala-speaking peoples (such as in this study).

| | | |
|---|---|---|
| *P. perforata* J. Agardh | Alaska Haida, [a] Coast Salish, [j] Nuxalk [k] | *P. perforata* is a currently accepted taxonomic species[e] found growing in the lower to mid-intertidal zone [d, i], and as high as the upper-intertidal in Alaska[c]. The thallus of *P. perforata* is usually brown and appears in the winter[i]. *P. perforata* is found from Alaska to California.[e] *P. abbottiae* was at one time classified in the *P. perforata* J. Agardh complex.[a] Williams (1979) identified seaweed harvested by the Coast Salish as *P. perforata*, but it and other historical records naming *P. perforata* as the alga harvested and consumed by First Nations in British Columbia are now believed to have been *P. abbottiae* Krishnamurthy.[a] |
| *P. pseudolanceolata* V. Krishnamurthy | Haida [a] | Appeared mixed with a sample of *P. torta* identified by Dr. Sandra Lindstrom.[a] Found from Alaska to Oregon.[e] |
| *P. torta* V. Krishnamurthy | Massett Haida, [a] Skidegate Haida [a] | Another species known as 'winter seaweed' in Haida Gwaii and Alaska.[a, l] High-intertidal species and similar to *P. abbottiae* in thickness, but grey-brown to purple in colour.[a, c, d] Found from Alaska to Washington.[e] |

a. Turner 2003; b. Turner 1975; c. O'Clair and Lindstrom 2000; d. Krishnamurthy 1972; e. Lindstrom 2008; f. Curtis 1915; g. Agardh 1824; h. Brodie et al. 2008; i. Lindstrom and Cole 1992; j. Williams 1979; k. Kuhnlein 1989; l. Garza 2005.

*Haida*

The Haida of Haida Gwaii have long harvested *P. abbottiae* as a food. Turner (2003, 2004) found that the Haida harvest two main kinds: "winter seaweed" and "summer seaweed", the latter having been identified as *P. abbottiae*. The Kaigani Haida in southeastern Alaska would also harvest and dry seaweed, and consume it either as a snack or as a flavouring in other foods (Norton 1981). Some Haida would trade for paper birch wood (*Betula papyrifera*) from the Nass region to fashion seaweed chopping blocks (Turner 2007). These blocks were used traditionally when breaking up the dried seaweed prior to storage. The seaweed was a high-status food and a valuable gift to those unable to harvest it (Norton 1981).

*Gitga'at* (Coast Tsimshian)

Turner (2003; also Turner and Clifton 2009) has thoroughly documented the traditional and contemporary Gitga'at seaweed harvest. Gitga'at elder Helen Clifton and many of the other elders of Hartley Bay, BC have harvested seaweed throughout their lives, and have shared their extensive knowledge of all aspects of traditional seaweed harvesting and preparation (Turner and Clifton 2006; Turner and Thompson 2006).

*Straits Salish*

In the mid-1960s Williams (1979), an anthropology student working under Drs. Wayne Suttles and Barbara Lane, documented the ethnobotany and state of the harvest of "*Porphyra perforata*" [now known as *P. abbottiae*] by the Saanich (Straits Salish) of southern Vancouver Island. At that time, he viewed the seaweed harvest as a dying tradition that was sustained by only a few elders, several of whom did not consume the seaweed. Instead, starting in the early 1900s, they sold it to Chinese merchants from Victoria (Turner 2003). This was confirmed by Tsawout Saanich elder Elsie Claxton, who recalled picking and drying the seaweed as a child on Saturna and other Gulf Islands, and witnessing Chinese merchants coming by boat to purchase the seaweed from her parents (pers. comm. to Nancy Turner, 1995). Barnett (1938) remarks that among the Coast (Straits) Salish nations, only the Comox and other northeastern island groups prepared seaweed cakes:

> Food was prepared in one of three ways: by roasting on a spit, by baking in an earth oven, or by stone boiling in wooden vessels. Salt seems not to have been in demand, for only the Comox and some of the northeastern groups made use of seaweed cakes.

He implied that the seaweed cakes were used as ingredients in food preparation, perhaps as a salt substitute, rather than as a food unto itself. Barnett consequently assumed that salt was not in demand by most of the Straits Salish.

Elder Sophie Misheal of the Saanich Nation recounted to Williams how she would spend March to October in camps where many families amassed large quantities of food for the year. Williams (1979) said that the Saanich could harvest one type of laver as early as March. In some regions, particularly further north up the British Columbia coastline, some species of *Porphyra* are harvested from early spring up to July (Turner 2003), while the Saanich harvested seaweed in November, which Williams (1979) suspected was a species distinct from *P. abbottiae* [which he identified as *P. perforata*]. Both the Gitga'at Coast Tsimshian and the Saanich Strait Salish collected algae which they classed as either "number one" or "number two" seaweed, or as "summer seaweed" and "winter seaweed" (Turner 2003; Williams 1979). The "summer seaweed" likely referred to *P. abbottiae*, harvested from Haida Gwaii to Alaska, while "winter seaweed" may have included both *P. torta* and *P. pseudolanceolata*. The Saanich's "number one" seaweed likely referred to *P. abbottiae* (available from March to May), and "number two" (available from June to September) may refer to another species of *Porphyra* that Williams (1979) did not identify.

*Kwakwaka'wakw*

Most of the remainder of this thesis will focus on *Porphyra* use by the Kwakwaka'wakw. They have been one of the groups using this seaweed most intensively, and the major Indigenous knowledge holders in my research, *K$^{w}$axsistalla* and *Mayanił*, belong to this group.

To the Kwakwaka'wakw of northern Vancouver Island and the adjacent mainland, the seaweed *Porphyra abbottiae* is known as ***łəqq̓əstən***. This alga is a significant species in Kwakwaka'wakw culture, and has a discovery story and songs. One of the earliest written detailed descriptions of Kwakwaka'wakw seaweed harvesting and preparation techniques comes from Franz Boas, a German ethnologist who recorded this information from the wife of Mr. George Hunt, Tsukwani (Francine Hunt), from Fort Rupert, British Columbia. *P. abbottiae* growing within the boundaries of Kwakwaka'wakw territories is traditionally harvested during the spring months. In the Broughton Strait and southern Queen Charlotte Strait, the seaweed is ready for harvest by mid-May or early June.

The Kwakwaka'wakw ethnoecology of *Porphyra abbottiae* will be described in further detail in Chapter 2.

*Porphyra abbottiae in the Interior*

The historical consumption and use of *Porphyra abbottiae* was not limited to coastal First Nations. Once dehydrated the seaweed will keep well without spoiling for many months provided that it is kept dry, allowing it to be carried on long trade expeditions. Trade routes allowed inland groups with no direct access to *P. abbottiae* to obtain the seaweed for use as food and medicine (Turner and Loewen 1998). Some of these Interior Nations include the Dakelh, Gitxsan, and the Witsuwet'in. *P. abbottiae* is rich in iodine, and was valued by Interior Peoples to treat goitre (Turner 1997, 2003).[11] Some Interior groups were given permission by coastal Nations to travel to the coast to harvest seaweed. The Hanaksiala and some Haisla would sometimes join the Tsimshian for such harvests (Compton 1993). Table 1.2 summarizes the Nations whose use of *P. abbottiae* appears in the literature and notes relating to the names or uses of the seaweed.

Table 1.2. Summary of Indigenous groups in British Columbia, Alaska, and Washington that harvest or consume *P. abbottiae*. Table adapted from Turner (2003, Table 3).

| Group | Location | Notes |
|---|---|---|
| Dakelh (Carrier) | Central, interior of BC | The seaweed is known as ***lhak'us*** in the Cheslatta dialect, and as ***lhaga'as*** in the Lheidli, Saik'uz, and Nadleh–Stellako dialects [1]. They use the iodine-rich seaweed as a medicine for goitre [2]. The Dakelh would trade for the seaweed with the Nuxalk [1, 3]. |
| Ditidaht (Nitinaht) | Southwest Vancouver Island | The Ditidaht use the word ***c'aaypish*** as a generic name for all seaweed, including *P. abbottiae* [1, 4]. In the early 20th century, Ditidaht near Victoria would harvest the seaweed to sell to Japanese and Chinese merchants. Ditidaht from western Vancouver Island do not apparently include or eat *P. abbottiae* as one of their traditional foods. |
| Gitxsan | Inland region by the Skeena River, BC | The seaweed is known as ***laq'asx***$^{w}$ [1]. Obtained via trade with coastal Nations such as the Coast or Southern Tsimshian [1, 5]. |
| Haida | Haida Gwaii | The seaweed is known as ***sgiw*** by the Massett |

[11] As an example of the relatively high historical value of seaweed traded to inland groups, the cost for one seaweed cake in Sitka, Alaska, in 1890 was 25 cents. In comparison a dried salmon cost 10 cents, a gallon of ooligan oil and a dried cake of strawberries each cost $1, and half a dried deer cost $1.50 (Emmons [1991:55] *in* Turner [2003]).

| | | |
|---|---|---|
| | | and Kaigani Haida and as ***sgyuu*** by the Skidegate Haida [1, 6]. Their "summer seaweed" is likely *P. abbottiae*, while "winter seaweed" harvested prior to summer seaweed is *P. torta* and sometimes *P. lanceolata* [1]. |
| Haisla-Hanaksiala | Central BC coast, along the Douglas Channel | The seaweed is known as ***ɫaq's*** or ***ɫaq'sg*** [1]. The Haisla in Kitimaat barter ooligan (*Thaleichthys pacificus* Richardson) grease to Gitga'at in return for dried seaweed. Hanaksiala and Haisla would observe the blooming of the salmonberry (*Rubus spectabilis* Pursh) to know when the seaweed is ready for harvesting [1, 7, 8]. In some areas, Hanaksiala and sometimes Haisla would join Coast Tsimshian harvesters at shared seaweed camps [8]. Hanaksiala valued the seaweed as a medicine for any ailment and could be taken both internally or externally in the form of a poultice. Traditionally vesicular basalt boiling stones were reserved for cooking seaweed in water and ooligan grease, and at special feasts the chief's daughter's had the honour of eating the tastiest seaweed off the basalt stones. |
| Híɫx̌aqʷ (Heiltsuk) | Bella Bella and the surrounding area, central BC coast | The seaweed is known as ***ɫq'st*** [1, 9]. Heiltsuk used to travel with many trade goods, including seaweed, for trade as far south as California. [7] Continues to be a valuable trade item when bartering with neighbouring nations or in the cities. [9] |
| Kwakwaka'wakw | Northern Vancouver Island and adjacent mainland | The seaweed is known as ***lhəq'əstə´n*** [1], ***ɫəqq̓əstən***[10], ***ɫak'asdi***, or ***ɫak'ast*** [11]. Chapter 2 will discuss Kwakwaka'wakw ethnoecology of *P. abbottiae* in greater detail. |
| Nisga'a | Nass River, BC | The seaweed is known as ***ɫaq'asxʷ*** [1]. Harvested as part of the annual round by women in May at designated seaweed harvesting territories while men fished for halibut (*Hippoglossus stenolepis* Schimdt) [12]. The Nisga'a also often obtained the seaweed by trade [13]. |
| Nuu-Chah-Nulth | Western and southern Vancouver Island and northeastern Washington state | The seaweed is known as ***7umumc*** or ***k'winy'imc*** [1]. The former name can also refer to *Ulva* and similar-looking seaweeds. In Kyoquot (Kyuquot), northwestern Vancouver Island, harvesting would begin in March [12]. |

| | | |
|---|---|---|
| | | Near Victoria, they would sell the seaweed to Chinese merchants [3], however Nuu-Chah-Nulth from western Vancouver Island did not apparently eat the seaweed [1, 4]. |
| Nuxalk (Bella Coola) | Area surrounding Bella Coola and Kimsquit Rivers including head of Dean Channel | The seaweed is known as ***lhek's*** or ***łaq's*** [1, 14]. Seaweed was collected in early spring when thimbleberry sprouts (*Rubus parviflorus* Nuttall) were ready to be harvested and eaten [14]. Nuxalk would sell dried seaweed to the Dakelh (Carrier) as medicine for goiter. |
| Coast Tsimshian | Mouth of the Skeena River, BC, and adjacent coastline | The seaweed is known as ***la'ask*** [1]. Traditional Coast Tsimshian territories can sustain abundant seaweed harvesting, allowing surplus seaweed to be bartered to inland groups such as the Gitxsan. The seaweed is known is harvested in May, or ***ha'li' làx łà'àsk*** ("month for gathering seaweed") [15]. Gitga'at (Tsimshian) elder Helen Clifton states that the growth of the stinging nettle (*Urtica dioica* L.) mirrors the growth of *P. abbottiae* and is used as a phenological indicator to reckon when to travel to harvesting camps [16] (Turner and Clifton 2006). |
| Squamish | Southwestern BC mainland | The seaweed is known as ***lhék's*** [1]. |
| Straits Salish | Saanich Peninsula, Vancouver Island | The seaweed is known as ***łeq'es*** [1]. An approximation of the sound of this name, 'sluckus', also appears in literature [17]. Harvesters frequently sold seaweed to Japanese and Chinese merchants in the early 20th century [1, 2]. |
| Tlingit | Southern coastal Alaska | The seaweed is known as ***laak'usk*** [18] or ***laa'k'ask*** [1]. One elder related the emergence of brown bears (*Ursus arctos* ssp.) from their dens after hibernation to the maturation and blooming of the seaweed [19]. It is valued as a trade item, particularly by Elders [20]. |
| Witsuwet'in | Skeena River, BC, interior | The seaweed is known as ***łakits*** or ***ake'is*** in the Bulkley River and Babine dialects, respectively [1]. |

1. Turner 2003; 2. Turner 1973; 3. Turner and Loewen 1998; 4. Turner et al. 1983; 5. Halpin and Seguin 1990; 6. Norton 1981; 7. Turner 2005; 8. Compton ; 9. Mary Vickers, pers. comm. 2008; 10. *Mayanił*, pers. comm. 2008; 11. Turner and Bell 1973; 12. Kelm 1998; 13. Turner 1978; 14. Turner 1973; 15. Turner and Clifton 2009; 16. Turner and

Clifton 2006; 17. Williams 1979; 18. O'Clair and Lindstrom 2000; 19. Betts 1994; 20. Garza 2005.

## 1.5 Contaminants and Nutrition in Relation to *Porphyra* Use

### 1.5.1 *Porphyra* and metals

Besides its importance as a food, *Porphyra* is one of many genera that have been examined for its potential as an environmental indicator of metals in coastal waters. Seaweeds are known to accumulate trace nutrients and pollutants such as metals and radionuclides that originate from either anthropogenic (industry, agriculture, etc.) or natural sources (bedrock) (Johannessen et al. 2007; Peter Ross, pers. comm. 2009; Muse et al. 1999; Van Netten et al. 2000). Some species such as *P. columbina* are not suitable for use as bioindicators because the metal concentrations in the algal tissue do not reflect the metal concentrations in the seawater from different regions (Muse et al. 1999).

Metals in algae are a global concern. This can be attributed in part to the global consumption of seaweed, but also to the global distribution of dissolved metals in the marine environment. Seaweed production is touted as a necessary step to meet the food demands of the growing world population, but at the same time people wish to know that their food is safe to eat (Neori 2008; Ródenas de la Rocha et al. 2009). *Porphyra* is found and consumed around the world, making it the subject of many nutritional and contaminant studies. In British Columbia during the 1990s there were attempts to start a seaweed mariculture industry, but using Japanese species of *Porphyra* (Druehl 2000; Mumford 1990). Some like Pérez et al. (2007) in Argentina and Phaneuf et al. (1999) in Eastern Canada have little hesitation recommending their local wild species of *Porphyra* as safe for regular though moderate consumption, but the former note that not all countries have laws that specifically regulate or make recommendations for the metal content in edible seaweeds.

Metals can bioaccumulate in our tissues, and are known to cause serious organ damage with chronic exposure (e.g. Goyer 1997; Kuhnlein and Chan 2000). Chronic exposure to bioavailable[12] arsenic, cadmium, and lead can lead to cancers and brain, liver, and kidney damage (Kuhnlein and Chan 2000). Once taken up into the body, some metals can be stored in tissues such as in bones. Data on metals in *Porphyra* spp. in British Columbia is limited. Van Netten et al. (2000) have looked at metals in commercially available seaweeds in British Columbia, but did not include *Porphyra* originating from within the province.

1.5.2 Indigenous Health Issues and Traditional Foods

Health problems directly attributable to unhealthy diets have risen astronomically in First Nation communities post-Contact. Type 2 diabetes mellitus, obesity, and chronic illnesses are some of the diseases disproportionately affecting indigenous communities in North America (Gittelsohn et al. 1998; Health Canada / Santé Canada 2009; Kuhnlein et al. 2006, 2009; Young et al. 2000). Recent research has suggested that traditional foods aid in reducing the risk of these health problems in First Nations. *P. abbottiae* itself is used by Kwakwa̱ka̱'wakw elders alongside conventional medicines to help manage diabetes symptoms (*Kʷaxsistalla* and *Mayanił*, pers comm. 2008). By quantifying the nutritional values of traditional foods, First Nations are given evidence to strengthen legal arguments against policies that have restricted or eliminated access to traditional, healthy food resources, including *Porphyra* (Wahbe et al. 2007).

*Porphyra* spp. are not immune to concerns over environmental contamination. As discussed earlier, seaweeds such as *Porphyra* concentrate dissolved nutrients in the water column including metals. Concerns over possible contamination at traditional harvesting sites can lead to the abandonment of these sites for future harvests (*Ogʷiloğʷa*, pers. comm. 2007). This is a very negative outcome for two main reasons: *P. abbottiae* can provide a cost-effective source of nutrition, and the loss of harvesting sites can lead to the loss of this traditional food from the culture. *P. abbottiae* is recognized as a very nutritious food, high in iron and vitamin C. It is also culturally very important, often

[12] Bioavailable is defined here as a substance that is "freely available to cross an organism's cellular membrane from the medium the organism inhabits at a given time" (Semple et al. 2004).

being features as a food and gift item at social and cultural events like feasts and gatherings (Kuhnlein and Turner 1991). Furthermore, loss of harvesting sites also limits opportunities to teach youth about foods that are part of their cultural inheritance, including other foods such as halibut or eelgrass (*Zostera marina* L.) that were traditionally harvested alongside *P. abbottiae*.

Metals, *Porphyra abbottiae* and potential health risks will be discussed in further detail in Chapter 4.

## 1.6 Chapter 1 conclusions

*Porphyra abbottiae* Krishnamurthy is a significant food resource among coastal First Nations of western Canada and the United States from both cultural and nutritional perspectives. It is readily available each year along the rugged coastline from Alaska to northern California, and its consumption reaches inland, through trade, far beyond its coastal habitat. Lightweight and easily stored when dry, this alga has been a prized trade item and medicine throughout British Columbia. Even today this seaweed continues to be harvested and consumed by First Nation communities, but there is a marked decline in the number of harvesters and quantities collected. As with many traditional foods, *P. abbottiae* harvesting traditions are subject to a loss of traditional knowledge among the younger generations, there is a lack of time or energy for harvesting, processing and preparing this food, and may be a lack of interest or a preference for other foods, especially marketed and commercially processed foods that require less effort to obtain.

Observable changes in the appearance and taste of the seaweed have given rise to concerns of contamination of the seaweed at traditional harvesting sites. Such concerns can create a perception that wild foods can pose health risks. As a nutritious food, it is important to ensure that ***ɬəqq̓əstən*** remains safe to eat if it is to be consumed regularly. There is currently a dearth of information available on metal concentrations in *P. abbottiae* in British Columbia. With this research I hope to provide an accessible resource detailing traditional ecological knowledge of ***ɬəqq̓əstən*** and to alleviate concerns over metal contamination in the seaweed by providing information on existing levels of contamination and on safe consumption levels.

# Chapter 2 Traditional Ecological Knowledge of ***łəqq̓əstən*** (*Porphyra abbottiae* Krishnamurthy)

They remind us every time we come out. I remember that. "Don't pick out of the water, 'cause the weather's going to change."
- *K^w axsistalla* (Chief Adam Dick), May 2009

I said, "Tell him not to pick out of the water, it's going to rain!" It's a taboo, one of the taboos that they believed in, and it rained you know!
- *Mayanił*, May 2009

## 2.1 Introduction to the Kwakwaka'wakw and their relationship with ***łəqq̓əstən*** (*Porphyra abbottiae* Krishnamurthy).

*The Kwakwaka'wakw*

The Kwakwaka'wakw are one of many First Nations of northwestern North America that traditionally harvest and consume *Porphyra abbottiae*. The Kwakwaka'wakw, or K^wak'wala speakers, were actually once comprised of 17 tribes speaking nine related dialects of K^wak'wala. Of these original tribes, many of the descendants have moved together into common villages.[13] Figure 2.1 shows the extent of Kwakwaka'wakw territory and tribe boundaries during the early 19th century.

Traditional Kwakwaka'wakw territory is situated in an ideal region for a vibrant maritime economy, including harvesting and use of ***łəqq̓əstən*** (*Porphyra abbottiae*). Collectively, Kwakwaka'wakw lands include parts of northern Vancouver Island, the islands in the Queen Charlotte Strait and Johnstone Strait, and the adjacent mainland reaching into the Coast Mountains. The many inlets and channels in their territory allow access to deep-sea marine fish such as halibut or black cod, mature salmon and other schooling fish, as well

[13] Some groups relocated or merged to pursue economic opportunities, as in the case of four groups of Kwakwaka'wakw that moved to Fort Rupert in the 1850s (Masco 1995). Some also moved because of government policies that prevented access to services such as teachers or doctors in isolated communities (*Mayanił*, pers. comm. May 2011). Others changed their 'band membership' in order to continue living in a reserve after the introduction of a policy preventing individuals from living in a reserve other than their own (ibid.).

as marine mammals, while closer to shore, shallows, kelp beds, intertidal zones, and river estuaries provide habitat for salmon, clams, ooligans, eels, crabs and many other types of marine life. The waterways are also avenues for communication and trade with neighbouring Nations such as the Heiltsuk, Oweekeno, and Nuxalk to the north, Nuu-Chah-Nulth to the west and south, and the Tsilhqot'in and Coast Salish to the east and south (e.g. Compton 1993; Turner and Bell 1973; Turner and Loewen 1988). It is in this environment that the Kwakwa̲ka̲'wakw have harvested ***ɬəqq̓əstən***.

The widespread nature of the seaweed harvest and connectivity between Nations is reflected in the names for the seaweed used along the coast from Alaska to Washington State. This may reflect the nature of the trade routes and relationships established centuries ago by coastal and some inland First Nations, and how cultures exchange ideas and terms (Turner 2003; Turner 1997). Words for edible seaweed sharing a common root sound (***ɬek***-, ***ɬék***-, ***ɬəq***-, ***ɬaq***-, ***ɬaa'k***- or ***ɬq***-) appear across unrelated language families such as Tsimshianic, northern Wakashan, and Salishan (Table 1.1 in this paper; Turner 2003, Table 3). The K$^{w}$ak'wala word for the seaweed, ***ɬəqq̓əstən***, is included in this group. *Mayaniɬ* indicated that ***ɬəqq̓əstən*** derives from the word ***ɬəqqaɬɬa***, meaning 'draped.'[14] This reflects how the seaweed is 'draped' over the rocks where it grows.

[14] *Mayaniɬ*, pers. comm. May 2011.

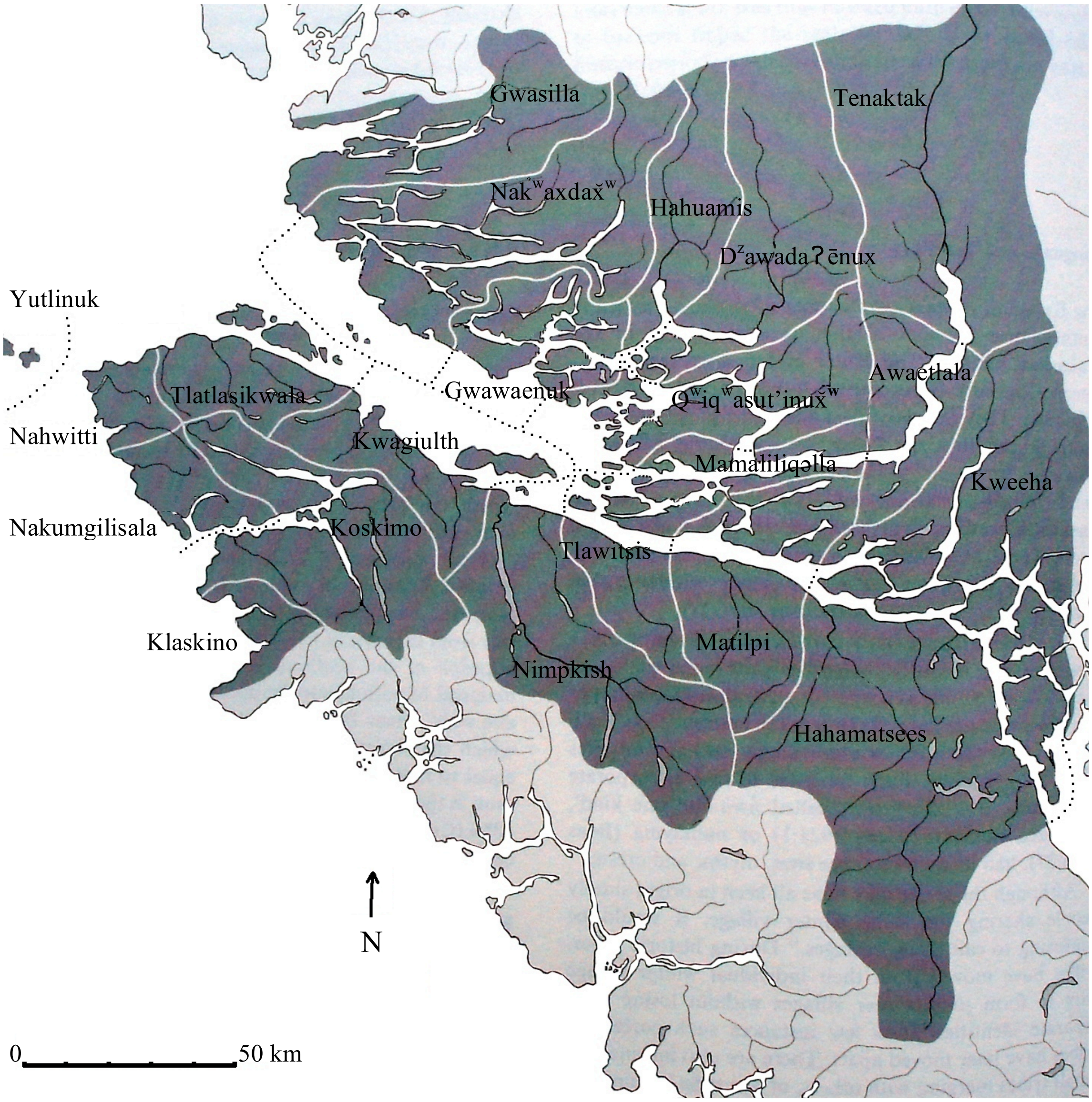


Figure 2.1. Traditional Kwakwa̱ka̱'wakw territories and tribe boundaries from the early 19th century. Adapted from Codere (1990: 360 [Figure 1]).

*Kwakwa̱ka̱'wakw Cultural Specialists*

The majority of my discussions and fieldwork took place with the guidance and participation of elders and experienced knowledge holders Clan Chief *$K^{w}$axsistalla* and *Mayanił*. They graciously permitted me to question them about traditional seaweed harvesting and preparation techniques, and I would like to explain why they are authorities in the fields of traditional Kwakwa̱ka̱'wakw history, language, and culture.

*K^w^axsistalla* was born in 1929 to Clan Chief James 'Jimmy' Dick[15] and *ʔAnicca* (Clan Chief Mary Dick, née Williams), the last female clan chief of the *Qawadiliqəlla* (Wolf) clan.[16] *Kʷaxsistalla* traces his ancestry directly to *Qawadiliqalla*, the first man to descend *ʔUgʷwx̌tollis* Mountain after the Great Flood (Lloyd 2011).[17] Prior to *Kʷaxsistalla*'s birth his mother had a prophetic dream, marking him for special training by his parents and the ***Niṅoğad*** (knowledge keepers) according to their customs (Lloyd 2011; *Ogʷiloğʷa*, pers. comm. 2011). At the age of four he was secluded by his family at Deep Harbour in Fife Sound and lived there with his grandparents over the winter months, avoiding police and Indian agent raids that took children from their families to residential school. He and his grandparents sustained themselves on traditional foods using traditional equipment, tools, and techniques. He actively participated in food harvesting activities with his family rather than learning of them from second-hand accounts. *Kʷaxsistalla* was taught in Kʷak'wala, and used little English until his 20s.

As a member of Kwakwa̱ka̱'wakw nobility, he was privy to knowledge that was not shared with non-nobility. He received direct, extensive training in the laws, rites, songs, and social and economic systems of his people in preparation to become an ***ʔuğʷamēy*** (clan chief) and Potlatch speaker. He now remains the last living, fully orally trained Potlatch speaker. He received this knowledge in a process unbroken by residential school or early cultural assimilation. By the unique circumstances of his lineage, mother's

[15] James was also named *Kʷaxsistalla*. Adam later inherited this name (Lloyd 2011).
[16] *Ogʷiloğʷa*, pers. comm. 2011; Lloyd 2011. The *Qawadiliqəlla* were one of five original clans that descended from the mountains in the Kingcome region after the Great Flood and formed a clan alliance known as the *Dᶻawada ʔēnuxʷ* tribe. *Dᶻawada ʔēnuxʷ* territory encompasses Kingcome Inlet and Kingcome River.
[17] The Great Flood is a catastrophic event found in the oral histories of First Nations along the northeast Pacific coast (Turner 2005; Turner and Clifton 2009). The Kwakwa̱ka̱'wakw traditionally used the Flood as the reference point for the timeline of their known history, comprising of the time before, during, and after the Flood) (*Mayaniɫ*, pers. comm. 2011).

prophetic dream, upbringing, and training, he is unmatched as an authority on Kwakwa̱ka̱’wakw culture.[18]

*Mayanił*, born in 1938, is the daughter of the late hereditary Clan Chief James Sewid and Flora Alfred (Alfred 2004). She traces her ancestry directly to *C̓əqaməy̓*, who survived the Great Flood by sealing himself in a giant red-cedar tree (*Thuja plicata* Donn ex D. Don; Turner 2005). Her family moved from Village Island to Alert Bay, BC, when she was a young child (*Og$^{w}$iloğ$^{w}$a*, pers. comm. June 2011). From an early age she received training in the history, stories, and language of the Kwakwa̱ka̱’wakw from her father and her grandmothers *ʔAx̌uw̓* (Agnes Alfred) and Daisy Roberts.[19] *Mayanił* fell ill with tuberculosis and spent a number of her formative years in the preventorium at Alert Bay. She did not attend residential day school because of her illness, but received tutoring while at the preventorium and later completed high school. The ***Niṅoğad*** would also visit her daily for training while she was ill. She was expected to be able to recite these cultural teachings word-for-word and without error to her teachers (*Mayanił*, pers. comm. 2010). As a member of the nobility, she had access to rites and institutions that were not shared with non-nobility. *Mayanił* has had a long career as a linguist and schoolteacher, and in 1998 was awarded an honorary doctorate in recognition of her work in teaching and documenting Kwakwa̱ka̱’wakw language and history (Turner 2005).

*K$^{w}$axsistalla* and *Mayanił* have worked together for nearly 60 years, beginning in 1952 after the repeal of the Potlatch ban (Recalma-Clutesi 2007). *K$^{w}$axsistalla* was able to publicly carry out his role as a potlatch speaker, and *Mayanił* worked as a potlatch recorder (Lloyd 2011). Since then they have used their combined training and experience to educate others on the language, history, foods, ceremonies, and traditions that were denied to the Kwakwa̱ka̱’wakw after the introduction of residential schools and the anti-

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[18] A more complete narrative of the life of *K$^{w}$axsistalla* can be found in Chapter 2 of Lloyd (2011).

[19] Alfred 2004; *Og$^{w}$iloğ$^{w}$a*, pers. comm. June 2011; Turner 2005. Children from the local band in Alert Bay were allowed to stay with their families while they attended residential day school. *Mayanił*’s family lived in Alert Bay, and so she was not separated from her family.

Potlatch laws. This study on ***łəqq̓əstən*** traditional knowledge is one of many projects with students and academics for which they have chosen to share their knowledge and experience.

*Historical ethnological work with the Kwakwa̱ka̱'wakw*

Changes in the fields of anthropology, linguistics, and botany near the end of the 19th century heralded a drive by researchers to document the languages and customs of Indigenous Peoples around the world, including those of the Kwakwa̱ka̱'wakw. Researchers from this time are among the earliest to document Kwakwa̱ka̱'wakw seaweed harvesting and preparation practises in some detail. Prominent researchers among these are German-born geographer Franz Boas, and to a lesser extent American photographer Edward S. Curtis (Cole 1999; Curtis 1915). Franz Boas conducted much of his Kwakwa̱ka̱'wakw research with the assistance of George Hunt, a Scottish-Tlingit man raised in Fort Rupert, B.C., and Hunt's wife, who spoke the *Nak̓ʷaxdax̌ʷ* dialect of Kʷak'wala.[20] Edward Curtis was a photographer, but was also employed to compile books on the practises of First Nations in North America. Curtis (1907: xvi-xvii) believed that traditional knowledge was rapidly disappearing under the influence of European society, and he sought to record as much as he could because, "The passing of every old man or woman means the passing of some tradition, some knowledge of sacred rites possessed by no other; consequently the information that is to be gathered, for the benefit of future generations, respecting the mode of life of one of the great races of mankind, must be collected at once or the opportunity will be lost for all time."

It must be acknowledged that there are problems with using information uncritically from this early ethnological work. Curtis' (1915) description of edible seaweed touches upon each stage of the seaweed harvest (harvesting, drying, storing, consumption), but does not go into great detail or offer any variations on techniques. Boas (1921) collected information on many subsistence activities, but he would not have had a chance to actually participate in seaweed harvesting had he desired to because his field expeditions

[20] *Mayanił*, pers. comm. May 2011; Cole 1999; Curtis 1915.

to Alert Bay took place during the summer and autumn months (Cole 1999: 100, 110, 116, 118). This would in some respects make his task more difficult: Boas would be unaware of variations in techniques or equipment if the informant did not think these were worth mentioning. An important detail missing from Boas' (1921) accounts is the seasonal timing of the seaweed harvest, while another is how harvesters dealt with inclement weather. The descriptions of seaweed harvesting and usage do not mention variations in practices between tribes or families, if any existed.[21] These drawbacks are mitigated by Boas' attention to detailing alternative drying and cooking techniques, which provide good insights into technologies used prior to the availability of electricity.

The issue of proprietary knowledge and special rights within communities is another consideration when embarking on a research project on Indigenous Peoples' traditional practices. It is important to note that among the Kwakwa̱ka̱'wakw, the clan owns seaweed-harvesting sites.[22] The clan chief has jurisdiction over the seaweed sites within their territory. If one wanted to harvest from a neighbouring territory, they were historically expected and required to ask permission from the clan chief of that respective territory. I did contact and seek out permission from hereditary leaders, as well as the band councils, to enter and harvest seaweed from their territories, and to document the traditional ecological knowledge of participants in this study. It is essential to obtain this permission even after having received the approval from the University's Ethics

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[21] It is important not to make sweeping generalizations for all the Kwakwa̱ka̱'wakw when reading Boas' 1921 report. In the Preface (pg. 45) to his report, Boas writes, "Much of the information in regard to cookery was obtained by Mr. Hunt from Mrs. Hunt, who was born in Fort Rupert, and who was thoroughly familiar with the duties of a good housewife." *K*$^{w}$*axsistalla*, who speaks all nine dialects of K$^{w}$ak'wala, and *Mayanił* identified the K$^{w}$ak'wala transcription regarding the seaweed processing as written in the *Nak̓*$^{w}$*alla* dialect. This corroborates the theory that George Hunt's wife, from the *Nak̓*$^{w}$*axdax̌*$^{w}$ tribe of Kwakwa̱ka̱'wakw, specifically provided the information on seaweed harvesting and processing. Boas's text does not make this immediately clear and does not give provenance to the practices. We should not assume that *Nak̓*$^{w}$*axdax̌*$^{w}$ practices are identical to those of the more southerly *Kwagiulth* of Fort Rupert, particularly when there is only one informant for seaweed harvesting and preparation practices.

[22] *Mayanił*, pers. comm May 2011. Families within the clan owned other resources such as the estuarine root gardens, crabapple trees and productive berry patches (Turner, Smith and Jones 2005: 163).

committee. As a chief and my teacher, *K$^{w}$axsistalla* took responsibility for my actions while we worked in these territories. *K$^{w}$axsistalla* distributed dried seaweed collected during the harvesting expeditions at potlatches as a sign of reciprocity to these chiefs.

*A Cultural Keystone Species*

Garibaldi and Turner (2004) introduced the concept of cultural keystone species as a metaphorical counterpart to ecological keystone species. Cultural keystone species are those whose effect on a culture is disproportionate to the frequency of their use within the culture, and that become key to the identity of that culture. As with the analogical keystone in a stone arch, a people's cultural identity can suddenly change when the keystone species is no longer in its former place as part of the culture. The keystone species may decline because it is no longer accessible to individuals in the community. This may be a result of a decline in the species' population, to regulations restricting use, to imposed restrictions in access to the places where it occurs, or to changes in a people's circumstances.

Cultures do not remain static over time. Rather, they change and adapt their practices in response to changing local conditions and resource availability. A change in cultural identity could also alter how culturally important species are used. Socioeconomic factors such as wage-labour, population shifts, children's schooling, and the introduction of new societal values from outside influences can lead to changes in how a culture or community eats, entertains, heals, creates art, and conducts ceremonies. Researching why traditional food consumption has declined, Kuhnlein (1989, 1992) found general declines in consumption of traditional foods such as wild berries and roots among the Nuxalk since the 1920s. The adoption of convenient market foods into the diet and the switch to a wage labour economic system made it inconvenient to harvest many traditional plant foods for sustenance, relegating them to occasional consumption at special events.

Biological and ecological trends can have an effect similar to these socioeconomic factors. Population declines in species such as ooligan (*Thaleichthys pacificus* Richardson) and northern abalone (*Haliotis kamtschatkana* Jonas) have made it difficult, and in some cases unfeasible, to continue harvesting some traditional foods (Turner and Turner 2008). Unpredictable weather patterns starting in the late 1990s have made planning seaweed harvesting expeditions problematic, since sufficient sunny weather is necessary both for picking and for drying the seaweed ($K^w$*axsistalla* and *Mayanił*, pers. comm. 2009; Turner and Clifton 2009). Alternatively, contamination or perceived contamination of wild foods can also prevent people from practising traditional food harvests ($K^w$*axsistalla* and *Mayanił*, pers. comm. 2009; Turner and Turner 2007, 2008). Prolonged breaks from harvesting traditional foods or materials mean fewer opportunities for the younger generation in the community to learn safe harvesting practices from elders.

The decline in use of culturally important plants or animals does not automatically mean that the community is no longer interested in resuming historical practises. There are efforts across North America and around the world to revitalize traditional food systems in order to improve health, nutrition, and reconnect with cultural identities (e.g. Kuhnlein 2009; Kuhnlein and Moody 1989; Kuhnlein et al. 2006; Turner and Turner 2008). *Porphyra abbottiae*, a cultural keystone species for coastal First Nations in British Columbia,[23] is one species whose consumption has declined after European contact[24] but there is interest in the Kwakwa̱ka̱'wakw community to revive the harvest.[25]

## 2.2 Objectives

In this chapter, I present a descriptive narrative of the oral history, terminology, technology, and practises involved in the harvesting, preparation, and consumption of *P. abbottiae* as recollected by key Kwakwa̱ka̱'wakw elders and additional informants. I evaluate how new technologies and practices have been integrated into the TEK of *P. abbottiae*. I then compare *P. abbottiae* as a "cultural keystone species" (as defined in the literature) for the Kwakwa̱ka̱'wakw in early historical and contemporary times, examining the technologies and practises involved in the harvest and preparation of this

[23] Garibaldi and Turner 2004.
[24] E.g. Turner and Turner 2008; Williams 1989.
[25] Thomas Child, pers. comm. April 2011.

alga from the past and present, and discuss what factors may have led to the development and adaptation of new technologies.

## 2.3 Methods

*Study area*

The study area is geographically situated in the Broughton and Queen Charlotte Straits north of Vancouver Island. It is a region with dynamic currents and exposed shorelines. It is also host to a great diversity of coastal and marine animal and plant species. Culturally, it is situated in traditional Kwakwa̲ka̲’wakw territories. I would like to gratefully acknowledge Dr. Daisy Sewid-Smith, *Mayanił*, for accompanying and allowing us to harvest within the traditional territory of her people, the *Mamaliliqəlla-Qʷiqʷasut̓inux̌ʷ*. I would also like to acknowledge Chief Harold Sewid (*Mamaliliqəlla-Qʷiqʷasut̓inux̌ʷ*) for granting us permission to enter and harvest from his territory.

*Interviews and documented Traditional Ecological Knowledge*

The majority of interviews, discussions, and participatory harvesting with the elders and experienced knowledge holders, *Kʷaxsistalla*, *Mayanił*, and *Ogʷiloğʷa*, took place on the waters and islands surrounding the community of Sointula on Malcolm Island, near the north end of Vancouver Island, extending up to Booker Lagoon on Broughton Island. Additional conversations about ***łəqq̓əstən*** with *Kʷaxsistalla*, *Mayanił*, and *Ogʷiloğʷa* took place at Qualicum, British Columbia. I also interviewed Mary Vickers, a member of the *Xisxis* tribe of Heiltsuk Nation from Bella Bella, British Columbia, at her home in Victoria. All interviews followed the terms of the ethics application approved by the University of Victoria Research Ethics Board. The participants’ names have been included here in this study with their permission. I have included a sample letter of informed consent for participation in this study in Appendix A. Kʷak’wala words relating to ***łəqq̓əstən*** harvesting and their translations are listed in Appendix B.

*Participatory traditional harvesting and preparation expeditions*

In May 2008 and May 2009, I helped organize two expeditions to Malcolm Island, British Columbia, with *K*$^{w}$*axsistalla*, *Mayanił*, and *Og*$^{w}$*iloğ*$^{w}$*a* and a group of graduate students, and others [in 2009 this included paleoethnobiologist Dr. Dana Lepofsky; a phycologist specializing in *Porphyra,* Dr. Sandra Lindstrom; my supervisor, Dr. Nancy Turner; and filmmaker Richard Boyce]. From this location, we set out to harvest *P. abbottiae* from locations on adjacent islands in the Broughton and Queen Charlotte Straits. Sites visited are shown in Figure 2.2 and coordinates are listed in Appendix C.

Each site was selected based on the knowledge and experiences of *K*$^{w}$*axsistalla* and *Mayanił* in harvesting seaweed with their parents and grandparents long ago. Prior to making any arrangements for accommodations for the expedition, we requested permission from the hereditary and elected chiefs in whose traditional territories we would be travelling through and sampling the seaweed. Harvesting at each site went on for approximately 1.5 to 4 hours, depending on the weather and tides. At one site, Bauza Island, when I was collecting samples for metal testing, harvesting was limited to less than 20 minutes due to the difficulty in manoeuvring the boat.

Upon returning to the base camp, I selected a random set of 30 *Porphyra* fronds from the quantity I collected for metal testing and set these aside to be dried in a warm-air food dehydrator. The results of the chemical analyses are presented and discussed in further detail in Chapter 4. The remainder of the seaweed was dried outdoors whenever possible, or indoors in a dehydrator during inclement weather, and was later divided among the elders and students for personal consumption and gifting.

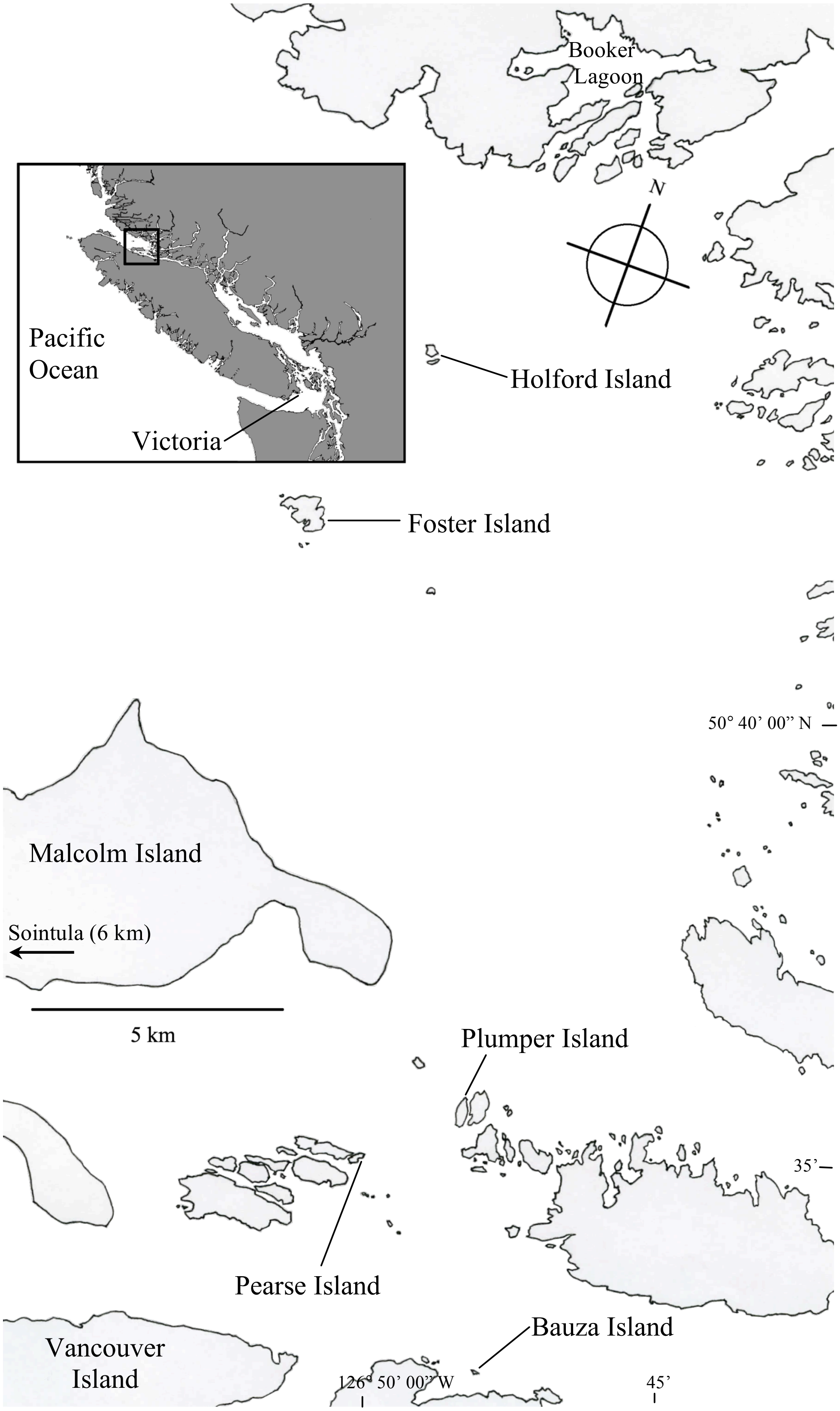


Figure 2.2. Map of the Broughton Strait and islands in Kwakwaka’wakw traditional territory where we harvested *P. abbottiae*.

## 2.4 Results

We were fortunate that the weather conditions held up well for the duration of the harvesting expeditions in May 2008 and 2009. By participating in the interviews at or near harvesting sites, the elders were able to immerse themselves within the process of harvesting as remembered from years earlier. Site-specific details emerged that might otherwise not have been brought up during interviews at home.

I will begin this section with a traditional story of why the Kwakwaka'wakw first began to harvest ***łəqq̓əstən***. I will then describe each step of the seaweed harvesting process, outlining the goals of each and the equipment used in the past and present to achieve those goals.

*Oral history of the origin of Kwakwaka'wakw use of* Porphyra abbottiae

While there is archaeological evidence for the ancient origins of *Porphyra* spp. harvesting by Indigenous peoples in South America and parts of North America,[26] I have not been able to locate in the literature reports of *Porphyra* remains at archaeological sites in coastal British Columbia. The lack of reported algal remains does not preclude the antiquity of the ***łəqq̓əstən*** harvest. Marine algae decompose readily if they are not completely dried,[27] making it difficult to find or identify remains at archaeological sites.[28] A story from the oral tradition of the Kwakwaka'wakw told by *Mayanił* places the discovery of the medicinal properties of ***łəqq̓əstən*** as a vision originating early in remembered history:

> When I was in my teens, I asked my grandmother Daisy "*Kʷəlstolił*" Roberts how our people knew that seaweed was edible. Her reply was that in ancient times we did not use seaweed as we do today. She then said, "I will tell you a story."

[26] E.g. Moseley 1975; Aaronson 1986, Dillehay et al. 2008.
[27] Chopin and Ugarte 2006.
[28] Some of the seaweed remains found by Dillehay et al. (2008) at Monte Verde in Chile were burnt, while others were found in masticated cuds. They reported some difficulties in identifying some of the more fragmented specimens from the cuds.

> Apparently a man went to his favourite fishing camp to harvest his winter supply of fish. One day he was feeling sick. He decided to rest but his fever raged on. Soon he was unable to stand and he was unable to eat or drink. He was in and out of consciousness. One day he had a vision. In this vision a man appeared to him. The man said, "Why are you just lying there suffering as you do? Why do you not go to the water's edge and pick seaweed? If you eat it, it will make you well. Go quickly while you still have the little strength remaining."
>
> The man was very weak. He could no longer walk, so he crawled to the water's edge. He gathered a few seaweed and started eating it. His strength slowly returned to his body. He gathered more seaweed and continued to eat it while he was recovering from his illness. He returned to his village and he told his people about his vision and the medicinal qualities of seaweed. The K$^{w}$ak$^{w}$akəwak$^{w}$ started harvesting seaweed for medicinal purposes. Later someone added clams to it and it became one of the staple diets for the K$^{w}$ak$^{w}$akəwak$^{w}$ people. Today we still use seaweed as food but many still use it for medicinal purposes."[29]

This story somewhat parallels another story told by a Hanaksiala elder, Gordon S. Robertson (translated by Emmon Bach and Brian Compton; see Davis et al. 1995: 22-23; Turner 2003). Compton (1993) suggests that the Hanaksiala learned about the medicinal uses of seaweed from the Tsimshian. In this story, a Tsimshian man's wife was very ill and could not swallow any food she was served. A seaweed spirit, ***Nawlakw***, appearing as a person on a rock in the ocean called out "It's me, hey! Come here!" to the Tsimshian man in his canoe while he was looking for medicine. The spirit told him to harvest the seaweed, ***lhaq'esq***, and how to prepare it for his wife. She was able to eat the seaweed and soon recovered. They invited all the village members to a big feast and the man recounted the story of how his wife had been cured. That is how the Tsimshian, and then the Hanaksiala, were made aware of the importance of laver (Turner 2003).

*Division of labour along gender lines*

Seaweed harvesting was undertaken in late spring, at the same time in the seasonal round as other food-gathering activities including halibut fishing, and sea urchin[30] and eelgrass rhizome (***ts'áts'ayem***, *Zostera marina* L.; Cullis-Suzuki 2007) harvesting. Women and children traditionally harvested seaweed while the men fished for ***p̓oy*** (halibut) to make

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[29] Originally recorded May 19, 2008, and later expanded May 2011 in a pers. comm.

[30] *K$^{w}$axsistalla* would sometimes refer to these as 'deep sea strawberries.'

into ***məlmadᶻuw*** (sun dried halibut fillets).[31] Boas' (1921) informant appeared to have travelled and harvested alone, but *Kʷaxsistalla* recalled both men and women participating in food gathering, even though both groups had separate tasks:

> And when we dropped the women off where you see the ***ɬəqq̓əstən***, we go out there and [do] halibut fishing. Yeah, then we go back and pick them [the women] up when the tide's coming up, and then we go off and spread them [seaweed] on the rock.

In *Kʷaxsistalla*'s experience, men in former times did not participate in the seaweed gathering, but both men and women might spread the seaweed after it was harvested.[32] Spreading the seaweed to dry soon after returning home or to the camp allowed harvesters to make use of the remaining sunlight and warmth radiating from the rocks that day. Today, both women and men participate in the seaweed harvest (pers. observation).[33]

*Harvest timing*

Harvesting ***ɬəqq̓əstən*** is concerned with safely acquiring good-quality seaweed in quantities sufficient to last for an entire year.[34] Efficiency is needed to maximize the seaweed harvest because the window of time in which harvesting traditionally takes place is relatively brief. *Porphyra abbottiae* usually reaches a desirable length for harvesting from May to early June, but the tides and the weather can further restrict harvesters. The harvesters must rely on their knowledge of when the low tides occur and where the seaweed grows, as well as on observations of the seaweed's development leading up to its ideal length, and on times of clear weather. If all these factors – access to growing sites, low tides at the right time of day, appropriate seaweed maturity and good weather – coincide, harvesters can begin improving efficiency by organizing equipment and planning optimal sites to harvest.

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[31] *Kʷaxsistalla*, pers. comm. 2009; *Mayaniɫ*, pers. comm. May 2011.
[32] *Kʷaxsistalla*; May 19, 2008.
[33] Mary Vickers also reported that both men and women in her home community of Bella Bella harvest and prepare seaweed. Her late father routinely harvested seaweed for their family.
[34] *Mayaniɫ*, pers. comm. 2009.

Harvesters could set out from their village, or could set up a temporary camp close by to the seaweed beds within their territory (Boas 1921; Turner 2003). Seasonal harvesting camps have the advantage of being located closer to the food resources than permanent settlements. Gatherings at camps also provide opportunities for members of the younger generation to immerse themselves in traditional food gathering activities with their family and elders.

***Łəqq̓əstən*** harvesters must take the seaweed's own schedule into consideration when planning an expedition *Porphyra abbottiae* is not picked at just any stage in its lifecycle; it is harvested only until the thallus begins to 'bloom' or 'turn' and change colour at the blade margins. The mature haploid blade is releasing spermatia from spermatangia, which appear as light green streaks along the edge of the blade. Once this process has begun, the seaweed changes flavour and is said to be unsuitable for consumption. When *Mayanił* was asked if the taste of the seaweed had changed since she and *Kʷaxsistalla* were children she replied:

> Yeah, we noticed, we noticed [that] some of the ones we bought, it's bitter. It's tasteless. And we assumed that the younger generation doesn't know the rules concerning the four-finger rule, or the rain rule, and they pick it. And therefore you end up with tasteless seaweed.[35]

*Kʷaxsistalla*'s observations mirrored *Mayanił*'s:

> I guess [X] went late last year, and they bought me some, but it's so different, it's so hard to chew at you know, they picked it real late when they get too tall, and then it's tasteless, it tastes different.

As *Kʷaxsistalla* and *Mayanił* recalled, when the seaweed was ***kʷəlxʷ ʔid*** (colour has faded), it was past the prime harvesting period and was no longer harvested. The quote above also suggests that the seaweed changes flavour when it becomes too old. Sometimes seaweed that has 'turned' – become overmature – is weeded out from the rocks while people are harvesting and discarded.[36]

The ideal length for seaweed at the time of harvest is shorter that might be expected by

[35] *Mayanił*, pers. comm. May 19, 2008.
[36] *Kʷaxsistalla*, pers. comm. May 19, 2008.

someone with no experience in seaweed harvesting. An inexperienced harvester might assume that picking longer blades of *Porphyra* is more desirable, because it will fill up the bag more quickly, requiring less effort to harvest a year's supply. However, these longer blades, as noted previously, are usually poorer in quality. When asked if the seaweed's length was important to the taste of the seaweed, *K^w^axsistalla* replied:

> Very important. [...] when it's three fingers, four fingers tall, that's when we picked them. [...] And they told me when it gets taller than that, leave it alone. It gets harder and ***wəłp̓p̓a*** [no taste] after that.

The elders emphasized that harvesting shorter, higher quality seaweed was preferable to harvesting larger quantities of inferior seaweed.[37] Neither Boas (1921) nor Curtis (1915) mentioned frond length as a factor considered by their informants while harvesting.

I considered the possibility of plant phenology[38] being used in the planning process to organize seaweed harvesting. Gitga'at elder Helen Clifton observed the growth of stinging nettles (*Urtica dioica* L.) to estimate when the seaweed located far from the camp would be ready for harvesting (Turner and Clifton 2009). The nettles, according to Mrs. Clifton, grew at approximately the same rate as the edible seaweed and were therefore used as a phenological indicator for timing the harvesting of the seaweed. When asked if they used the growth of any plants to gauge the growth of the seaweed, *K^w^axsistalla* and *Mayanił* said they did not. *K^w^axsistalla* commented, "How do I know [when the seaweed is ready]? Cause that's the only time. Not any time."

*Site identification*

Harvesters must first determine harvesting sites for the seaweed and then travel to these locations. In the energetic, dynamic waters of the Broughton and Queen Charlotte Straits, *Porphyra abbottiae* grows well on steep rocky shorelines in the intertidal zone. Islands

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[37] In May 2009, the emphasis on quality over quantity was reinforced when *Og^w^iloğ^w^a* discovered that the students had accidentally collected *P. abbottiae* that had 'bloomed' and mixed it with the 'good' seaweed. A full garbage bag of this incorrectly harvested seaweed was sorted out from the edible *P. abbottiae* and removed. This also certainly taught the students to be more observant while harvesting seaweed.
[38] Rathcke and Lacey (1985) describe phenology as the 'study of the seasonal timing of lifecycle events.'

are good sites for harvesters to look for this seaweed because of their location in channels and straits with strong currents. I also discovered that it is not as simple as just going to any rocky island to look for seaweed.

Our initial trip to Foster Island in the Queen Charlotte Strait in 2008 was the first time that most of the students working with *Kʷaxsistalla*, *Mayanił* and *Ogʷiloǧʷa*, including myself, had a chance to observe the seaweed *in situ* from a boat.[39] We did not know exactly what to look for, but relied on *Kʷaxsistalla*'s assurances, since he had harvested ***łəqq̓əstən*** from Foster Island as a child. We arrived at the island from the south and proceeded to circle the island clockwise. Neither the students nor the elders sighted the seaweed on the western or northern ends of the island. *Kʷaxsistalla* became concerned that the seaweed might no longer grow on Foster Island and that we would have to look elsewhere. This meant possibly missing the necessary window of time when the tide was low enough to harvest the seaweed. Only when we arrived at the eastern end of Foster Island did someone sight a large patch of *P. abbottiae*. At this point *Kʷaxsistalla* remembered his grandfather telling him that you look for seaweed where the island is hit by the morning sun, and found that his words were correct.[40]

*Travelling to harvesting sites*

The mode of transportation is important in determining the maximum distance that seaweed harvesters can travel from their base camp or community. It also determines how early they must set out to reach the seaweed at low tide. As indicated from the quotes at the beginning of this chapter, the seaweed cannot be harvested when it is immersed in the water, and low tide is the only time when the seaweed is exposed to the air. Boat access, even along inhabited islands, has the benefit of eliminating the need to walk long distances or traverse difficult terrain along rocky shorelines that land access – even if available – would entail. If the harvesters are planning to dry the seaweed in the sun, they might aim to pick seaweed on days when the low tide occurs sometime between

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[39] May 17, 2008.

[40] *Kwaxsistalla* repeated this memory two days later during an interview on May 19, 2008, and added that the seaweed does not grow on the dark sides of the islands.

dawn and noon. Collecting seaweed in the afternoon runs the risk of the seaweed being only partially dried before the sun starts to set and the humidity rises. Afternoon-harvested seaweed would then have to finish drying indoors.

In pre-European contact and early post-contact times, travel to harvesting sites on islands was by dugout cedar canoe (*Thuja plicata* Donn ex D. Don). Even as late as the 1930s, Gitga'at elder Helen Clifton remembered the women propelling their canoes using both paddles and sails, travelling between the Gitga'at spring harvest camp at K'yel (Princess Royal Island) and Campania Island (Turner 2003; Turner and Clifton 2006). Neither Boas (1921) nor Curtis (1915) elaborate on whether the canoes described by their Kwakwa̱ka̱'wakw informants were equipped with sails. *Kʷaxsistalla* recalled a song[41] that harvesters would sing while paddling out to harvest seaweed:

| | |
|---|---|
| *Wo hoy wo, wo I ho; wo hoy.* | Wo hoy wo, wo I ho; wo hoy. |
| *Wigga xəns sasix̌ʷwidalla* | Let us paddle faster so |
| *qəns leƛ ƛəns hiłc̓ał x̌ʷa xaď axəllax̌.* | we can catch the low tide. |
| | |
| *Ha, wo, hoy hoy hoy; wo hoy.* | Ha, wo, hoy hoy hoy; wo hoy. |
| *Qəns leƛ ƛəns k̓ʷilgalissaƛ* | So that we can pluck |
| *x̌ux̌ łaqqilla yax̌ sa məkolla.* | the seaweed growing on that island. |

The Paddling Song encouraged the paddlers to paddle harder so to arrive at the ***məkolla*** (a small island such as Cormorant Island)[42] in time for the low water when the seaweed would be exposed and ready to be picked.

*Harvesting the Seaweed*

As noted, ***łəqq̓əstən*** is harvested after it is exposed to air by the falling tide. There are two subtly different approaches to collecting the seaweed from the rocks. I was initially puzzled by Boas' (1921) brief description of a woman harvesting seaweed because he distinguishes between plucking and peeling the seaweed from the rocks, but it became clear once we arrived at the harvesting sites in May 2008. Wet *Porphyra* exposed from

[41] May 19, 2008.
[42] Both *Mayanił* and *Kʷaxsistalla* indicated that they do not harvest from ***miwella*** (large islands such as Vancouver Island) (pers. comm. May 2011).

the receding tide is plucked from the rocks by pinching the seaweed at the base. *Porphyra* that has dried under the sun after the tide has receded it becomes plastered to the rocks and must be peeled off. The harvester flicked the wrist and snapped the handful of *Porphyra* to remove any periwinkles (*Littorina* spp.) or crustaceans hidden in the folds of the seaweed. The patch of rock is cleared of *P. abbottiae* before moving on to another patch as is shown in Figure 2.3. Fronds are not 'cherry picked' or haphazardly harvested, but are instead systematically removed. Harvesters should collect *P. abbottiae* fronds that have a smooth texture and even colouration, and avoid fronds that have a rough texture or visibly discoloured patches. Generally, seaweed at the ideal stage occurs all together and can be harvested *en masse*.

The harvester requires few tools to collect ***łəqq̓əstən***. In fact, too much gear could be unwieldy while the harvester is clambering over slippery, seaweed-covered rocks. Boas (1921) does not elaborate on the equipment used by early harvesters of the past besides the large basket that the woman filled while harvesting, and a mat to cover the seaweed poured into her canoe once she filled her basket. Curtis (1915) makes no mention of any equipment in his description. The basket mentioned by Boas (1921) would almost certainly have been a ***lax̌ēy*** (a wide-mesh basket with spines formed by cedar roots or withes and woven with cedar bark).[43] The mat covering the seaweed in the canoe was likely a cedarbark mat. The mat may have been to slow the drying of the seaweed before the harvester returned home. Another reason for the mat might have been to prevent freshwater from touching the seaweed if rain or fog suddenly appeared. The seaweed piled into the canoe between loads would lay exposed to the sun or rain without a mat covering the pile. If the seaweed were partially dried it would become difficult to pry the pile apart to spread out to dry or to pack into bentwood boxes. Once home, she could

[43] Williams (1979) records a then 76-year old Coast Salish woman, Sophie Misheal from the Songhees Reserve, using a cedar basket as a youth for harvesting *Porphyra*. The author's fieldwork was completed in 1967, and so Sophie would have been born around 1891 and would have used the basket around the turn of the century. Cedar baskets would have been readily available to the Kwakwa̱ka̱'wakw when Boas (1921) conducted his fieldwork for his report around 1900. Boas spends several pages describing the construction of baskets made using cedar twigs or withes and woven with cedarbark.

process the seaweed however she wanted.

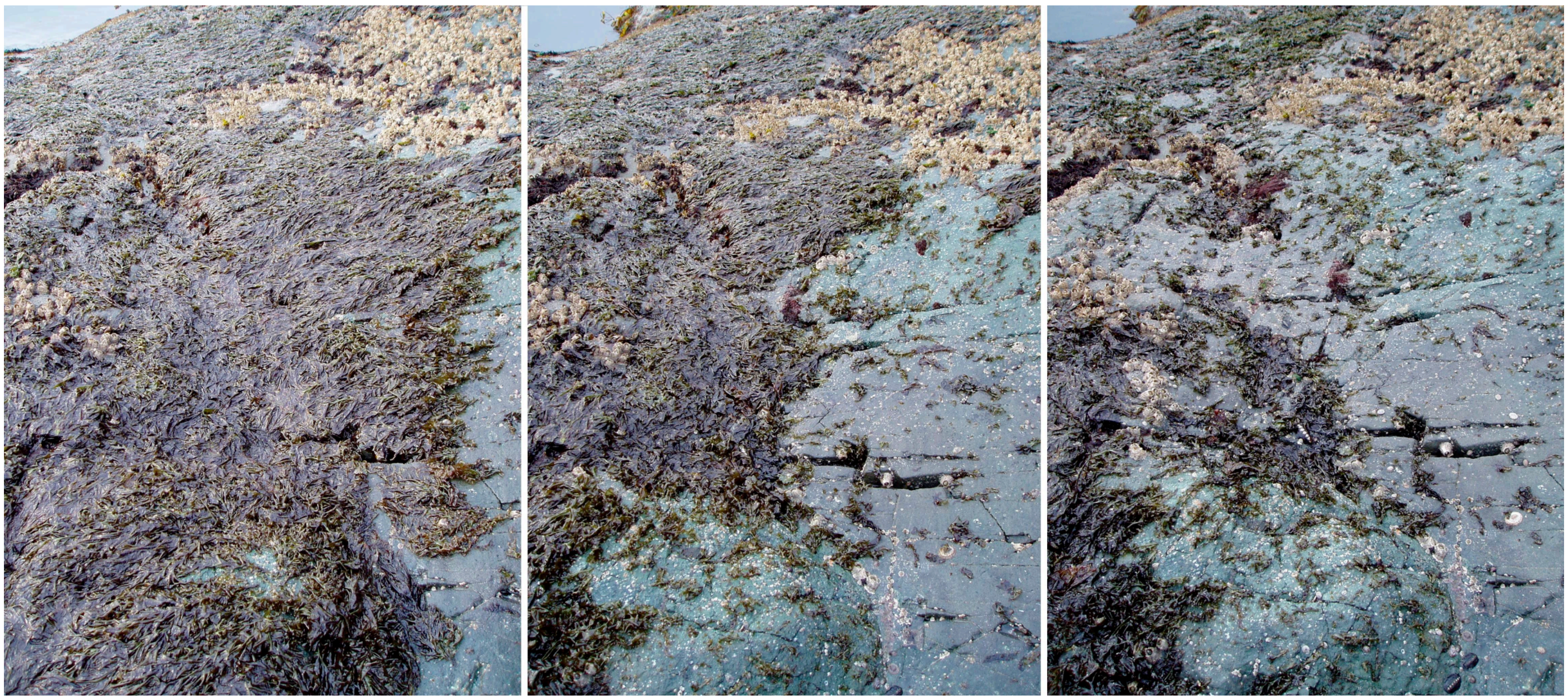

Figure 2.3. Three images taken from the same location to demonstrate how thoroughly *P. abbottiae* is removed from a harvesting site before moving on to another location [far left, not yet harvested; middle, partially harvested; far right, completely harvested].

Harvesting equipment in contemporary times is also kept to a minimum, but is enough to increase the harvester's comfort while on the rocks. A harvester might wear a pair of rubber boots so not to cut their feet on the barnacles or sharp ledges, and to provide some traction on seaweed covered rocks. Gloves are optional but useful if it is necessary to climb over barnacle-encrusted rocks. Early morning temperatures can change rapidly over the course of harvesting on the shoreline, and so warm layers of clothing are recommended. It is necessary, however, to bring bags or containers to hold seaweed as it is being harvested just as the earlier harvesters used cedar baskets. *Ogʷiloǧʷa* advised students to use clean cotton bags while harvesting. These bags are durable, will not split from the weight of the wet seaweed, and allow air to circulate around the ***łəqq̓əstən*** and excess water to drain off. Other containers that can be used are burlap sacks, netted onion bags, plastic bags, and buckets.[44]

The weather determines whether or not the harvesters are able to venture onto the rocks to pick seaweed. Seaweed harvesting is not allowed when it is raining, but may go ahead if it is overcast. Neither Boas (1921) nor Curtis (1915) indicates the type of weather required for harvesting, but the importance of good weather was strongly reinforced by *Kʷaxsistalla*, *Mayanił*, and *Ogʷiloǧʷa*. Ideally, the sky should be clear and with sun continuing to shine until harvesting is completed. When rain or any other freshwater touches the seaweed, it begins to lose its distinctive flavour.[45] Harvesting continues until the tide rises, until the sacks are full of seaweed, or if the ***ƛ̓issalla*** (sun) became hidden and it started to rain.

Sunny weather, however, can pose a problem if plastic bags are being used in the harvest. One problem that may occur is 'sweating', in which the seaweed begins to heat up or even cook inside the bag.[46] If the seaweed is kept in a plastic bag while harvesting and air does not circulate in the bag, the seaweed will 'sweat' rather than dry out. Using cedar

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[44] *Kʷaxsistalla* and *Mayanił*, pers. comm. 2008; Mary Vickers, pers. comm. 2008; Turner 2003.
[45] 'Rain Rule.' *Kʷaxsistalla* and *Mayanił*, pers. comm. 2008, 2009.
[46] *Mayanił*, pers. comm. May 17-19, 2008.

baskets and placing woven mats over the pile of seaweed avoided this problem, as did the burlap potato or onion sacks and cotton pillowcases, since these allowed air to flow through the seaweed, facilitating drying and preventing the seaweed from sweating.

Another song recalled by *Kʷaxsistalla* suggests that not everyone in the community participated in the seaweed harvest. *Kʷaxsistalla* sang a song[47] that describes a man, *K̓esugʷilakʷ* of the *Qʷiqʷasut̓inux̌ʷ*, repeating a song over and over to anyone who would listen:

> *Gax̌ nis ƛi łəqq̓əstən nas ʔiwax̌sda yas Ğʷayasdəm sa, he, ē, ya.*
> I long for the seaweed of the islands below Gilford Island (Broughton archipelago).

"They say that this guy was so lazy that he's hoping that somebody will give him ***łəqq̓əstən*** from [...] those islands (Broughton Archipelago)." It is unclear whether *K̓esugʷilakʷ* participated in halibut fishing with the men while the women and children harvested seaweed, but the song implies that he does not have a store of seaweed due to laziness.[48] *Kʷaxsistalla* and *Mayanił* indicated that *K̓esugʷilakʷ* was likely singing this in the hope that anyone passing by might take pity and offer him some of their seaweed.[49]

*Drying or Preservation*

It is one matter to harvest large quantities of seaweed, but it is another to ensure that all of the seaweed harvested can be processed adequately and will be ready for consumption throughout the year until the next harvest. Marine algae are prone to drying and decomposition once removed from saltwater. *Porphyra abbottiae* is no exception; its texture and flavour can change rapidly within days, or even hours, depending on how it is stored after harvesting and whether or not it comes into contact with fresh water. When preserving the seaweed, the primary concern is to bring it to a stable state where it will not spoil.

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[47] May 18, 2008. *Kʷaxsistalla* sang the following verse only twice, but *K̓esugʷilakʷ* would have sung it many times.

[48] Laziness was a strongly disliked trait among the First Nations in British Columbia. Their economic systems expected reciprocity to the best of one's ability (Lutz 2008: 35).

[49] *Kʷaxsistalla* and *Mayanił*, pers. comm. May 2011.

Figure 2.4. *P. abbottiae* drying in squares on Pearse Island, B.C., May 24, 2009.

The seaweed was traditionally ***ləmxʷəxʷ sa ƛisəlla*** (dried by the sun) outdoors, assuming that the weather was not cloudy or wet. Western red-cedar wooden racks, boards, or warm and flat rocks were all surfaces that could potentially be used to dry seaweed. Some measure of drying could be started during the harvesting stage. While we were harvesting seaweed in May 2009, *Kʷaxsistalla* pointed out locations on nearby rocks where his grandmother would set the seaweed in squares on the rocks as it was harvested to partially dry (Figure 2.4).

These squares were collected once harvesting was completed for the day, and brought back to the camp to finish drying. Boas (1921) reported that there were both ‘experienced’ and ‘inexperienced’ methods of drying the seaweed, but these were not universally accepted practices.[50] The inexperienced harvester would set about drying the seaweed as soon as she returned home. The seaweed would dry quickly under the sun, but it would also become tough to chew. The experienced harvester on the other hand would pile the seaweed on the beach and cover it with a mat. There she would let it sit for about four days where it would have begun to decompose, and may also have begun to ferment (Turner 1995, 2003).[51] After the harvester fermented the seaweed, the ***łəqq̓əstən*** was traditionally dried on surfaces such as flat rocks or cedar slat racks (Figure 2.5). Less traditional surfaces for drying seaweed outdoors include tarps[52] and a novel ‘wind tunnel’ formed by an open-ended tent created by a bed sheet draped over cedar slats covered in seaweed and dried by a forced air propane heater at one end.[53] The seaweed needs to be turned occasionally so that it dries completely on both sides. *Mayanił* commented that raising the cedar racks up off the ground like a table makes it much easier for her to reach and separate the seaweed than trying to work with seaweed on a tarp on the ground.[54]

Drying seaweed indoors by a fire was another traditional technique that could have been used when the weather did not permit drying outdoors. Boas (1921) recorded this method as ‘Curing Seaweed 2’, in addition to the technique of fermenting freshly harvested seaweed under a cedar mat mentioned above. The harvester constructed cedar racks for the purpose of drying the seaweed. Two large stakes set into the floor of the house would

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[50] *Kʷaxsistalla* and *Mayanił* identified the Nak̓ʷalla dialect from Boas’ (1921) Kʷak’wala transcription regarding seaweed preparation and believe Boas’ informant to have been George Hunt’s Nak̓ʷaxdax̌ʷ wife. Their knowledge of cultural ties and exchange between northerly groups of Kwakwa̱ka̱’wakw (such as the Nak̓ʷaxdax̌ʷ) and other Nations further north has led *Kʷaxsistalla* and *Mayanił* to attribute the ‘experienced’ and ‘inexperienced’ methods probably as northern concepts.

[51] Both *Kʷaxsistalla* and *Mayanił* strongly disagreed with the entire concept of leaving wet seaweed on the beach for several days (pers. comm. May 2011). They felt that this would attract maggots. They were taught by their elders to dry the seaweed as quickly as possible (pers. comm. May 2011).

[52] We used these on Malcolm Island, BC, for lack of flat rocks while staying at a working farm and guest cottage in May 2008.

[53] This invention was made necessary due to the inclement weather that prevented drying outdoors, and to the lack of space indoors from the large quantity of seaweed harvested that day.

[54] Pers. comm. May 19, 2008.

stand upright next to the fire and several smaller split cedar sticks would be lashed on horizontally, joining the stakes. The seaweed was draped over the split cedar sticks and turned over when one side was browned.[55] Once completely toasted, the sheets of ***łəqq̓əstən*** would be bundled in a deer hide and beat until it reached the desired consistency. The seaweed might also be chopped finely on a wooden block using a ***k̓əmƛayuw*** (chopper)[56]. The chopped ***łəqq̓əstən*** was then stored in tightly sealed bentwood boxes. Neither *Kʷaxsistalla* nor *Mayanił* agree with this practice of storing powdered seaweed. They indicated that seaweed cakes were only chopped as needed.[57]

A third method for drying the seaweed makes use of both indoor and outdoor space. Harvesters use cedar bentwood boxes not only for general storage, but also to make pressed seaweed ‘cakes.’ Curtis (1915) describes in brief how the Kwakwa̱ka̱’wakw spread individual blades of freshly harvested *Porphyra* into the cedar boxes until the layer is approximately two inches thick. Curtis mentions that skunk cabbage leaves (*Lysichiton americanus* Hultén & H. St. John) are used to separate each layer. Boas (1921) tells us that the ‘soft tips of cedar branches’ are used to separate layers of seaweed in the cedar boxes.[58] The seaweed is layered until the box is full. Here Boas (1921) and Curtis (1915) differ slightly in their descriptions of how a heavy weight is applied to the top of the seaweed to press it into compact cakes. From Curtis’ (1915) description it sounds as though a heavy weight is placed directly on the topmost layer of seaweed. Boas (1921) instead says that the box was filled to its brim and that the lid would be fastened securely using rope and heavy rocks to prevent the box from bursting open.[59]

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[55] *Kʷaxsistalla* and *Mayanił* did not recognize this practise and instead said that the seaweed could be brought indoors to dry but away from the direct heat of the fire so not to burn it (pers. comm. May 2011). They felt that toasting the seaweed was not desirable if it was going to be stored for later.

[56] *Kʷaxsistalla* and *Mayanił*, pers. comm. May 2011.

[57] Ibid.

[58] Others use salal leaves (*Gaultheria shallon* Pursh) as well as cedar boughs (Turner 2003).

[59] *Kʷaxsistalla* and *Mayanił* agree with Curtis’ description. The seaweed will dry more quickly with only a heavy weight on the topmost layer than in a box with a fastened lid. (pers. comm. May 2011).

Figure 2.5. *P. abbottiae* squares drying on cedar racks in Sointula, B.C., May 2009.

When the harvesters used bentwood boxes for drying they could choose to alter or add flavours to the seaweed cakes, but this was not a universal practice. *K^w^axsistalla* said that he would sometimes spray a bit of seawater onto cakes in the box to add flavour and help the seaweed stick tightly together.[60] Another technique described by Boas (1921) requires some synchronizing of chiton harvesting with bentwood box seaweed drying. After eating chitons or clams, the men would leave the house (Boas 1921; Turner 2003). A woman would collect the men's dish, saving the liquid from the chitons. She would take a mouthful of the liquid and spread it upon a layer of seaweed temporarily placed in the lid of the bentwood box (Boas 1921).[61] She would then proceed to layering the seaweed in the box, separating the layers with cedar branches or skunk cabbage leaves. According to *K^w^axsistalla*, the cedar branches between the layers also add flavour to the seaweed cakes.[62] Stewart (1984:168) remarks that the Kwakwa̱ka̱'wakw used cedar boughs for aeration between layers of seaweed in bentwood boxes.

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[60] Pers. comm. May 2011.
[61] Neither *K^w^axsistalla* nor *Mayanił* were taught to flavour seaweed with clam or chiton juices. They suggest that it was a northerly Kwakwa̱ka̱'wakw practice (pers. comm. May 2011).
[62] Pers. comm. May 19, 2008.

During the seaweed camp in May 2009, we recreated this cedar box drying technique following the instructions of *K*$^{w}$*axsistalla*. He instructed graduate student Abe Lloyd to place small handfuls of partly dried seaweed evenly into the box until the layer was about 3 centimetres thick (Figure 2.6). Abe added freshly cut cedar boughs to completely cover the seaweed below, and then began another layer. This process continued until the box was nearly full. At this point *K*$^{w}$*axsistalla* covered the final layer of seaweed with cedar boughs. Abe filled a plastic bag with sand and placed this over the cedar boughs. The sand allowed for an even distribution of weight while the seaweed below was compacted into seaweed cakes. The cakes were removed three days later[63] and were briefly toasted in the oven to ensure that all of the moisture was eliminated, before being stored away in airtight containers.

Modern techniques of seaweed preservation are more convenient for the harvesters since they are not limited by the sunlight available after the seaweed has been harvested, and the processing is not restricted by the narrow timeframe when the seaweed is still fresh. Drying the seaweed traditionally kept the seaweed ready for consumption throughout the year, but with the introduction of refrigeration it has become possible to freeze freshly harvested seaweed until it is ready to be used (Mary Vickers, pers. comm. 2008; Turner 2003). Electricity has thus become a boon for convenience when the weather is too humid or rainy for drying the seaweed outdoors. Ovens, food dehydrators, and even clothes dryers can be used when drying seaweed outdoors is not feasible. *K*$^{w}$*axsistalla* recalled placing seaweed in a pillowcase and drying it in an electric clothes dryer when the weather was not right for drying outdoors.[64]

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[63] The cakes would have been left to dry in the boxes longer, but the group expedition on Malcolm Island was drawing to a close.

[64] Pers. comm. May 19, 2008.


Figure 2.6. $K^w$*axsistalla* explaining to Abe Lloyd the technique for layering *Porphyra abbottiae* in a bentwood cedar box.

*Storage and Consumption*

Harvesters are concerned with keeping the seaweed in a stable state where it will not absorb moisture and spoil. The seaweed will last in good condition for at least a year (until the time of the next harvest) if kept dry (*Mayanił*, May 19, 2008; Curtis 1915). Traditionally, bentwood boxes were used for storing the drying seaweed cake only until they were fully dried at which point the cakes were bundled in a cedarbark blanket and stored away.[65] Boas (1921) recorded that the dried cakes and the chopped seaweed were also stored in boxes, but this may be a practice of the *Nak̓ʷaxdax̌ʷ* tribe.[66] The cedar branches formerly used in the drying process to separate the drying layers of seaweed were removed, and the seaweed dried thoroughly before being stored for the year (Boas 1921). People later used tin boxes for storing dried seaweed.[67] Today sealable plastic bags, totes and boxes with tightly fitting lids, and glass or plastic jars are all used for storing seaweed (pers. observations).

*Porphyra abbottiae* is a versatile food and is consumed either alone or as an accompaniment to other foods. Seaweed can be a part of many meals; today this is mostly only limited by imagination! Depending on its origin, age and the quality of its processing, ***łəqq̓əstən*** might be described ***łaxʷp̓p̓a*** (bitter), ***wəłp̓p̓a*** (no flavour), or ***ʔixp̓p̓a*** (tastes good/sweet). It can be chopped up using a ***k̓əmƛayuw*** and stewed to create a thick soup (Curtis 1915). Boas (1921) recorded dried seaweed being cut with an adze on a hemlock wood block (*Tsuga heterophylla* (Raf.) Sargent), chewed, and set in a kettle with hot water. The seaweed is stewed and mixed with ooligan grease prior to serving with spoons. ***Łəqq̓əstən*** could also be stewed with dog-salmon eggs (chum salmon; *Oncorhynchus keta* Walbaum) and ooligan grease, or stewed in clam juice and ooligan grease, halibut heads, boiled chum salmon, and salmon eggs (Boas 1921; Turner 2003).

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[65] *Kʷaxsistalla*, pers. comm. 2008, 2011.
[66] *Kʷaxsistalla* and *Mayanił*, pers. comm. May 2011. They again identified the *Nak̓ʷalla* dialect in Boas' (1921) transcription and while they do not store seaweed in bentwood boxes, they allow that it might have been a northerly practice.
[67] Mary Vickers, pers. comm. 2008.

Modern meals will still combine the seaweed with salmon or have it served in soups, but market foods have expanded the range of meals possible with *P. abbottiae*. ***Łəqq̓əstən*** can now be fried in a frying pan in hot oil, or eaten with a variety of introduced foods including root vegetables, rice, cabbage, and creamed corn (Turner 1975, 2003). *Mayanił* said that they once ate the seaweed with salmon eggs and ooligan grease, but when the eggs became scarce some people began eating *P. abbottiae* with canned creamed corn.[68]

In the past, meals made using ***łəqq̓əstən*** did follow a set of protocols, traditions, and restrictions. Curtis (1915: 61-62) described a ritual of purification for spiritual power or as preparation for hunting, ***q̓eqəlla***,[69] that he believed was becoming obsolete by the time he published his research. This ritual required ridding oneself of any odours that might be offensive to spirits, and in some cases fasting, standing in icy water, and rubbing the skin with hemlock tips to scour the skin.[70] During this period of purification, young men would abstain from a number of foods including ***łəqq̓əstən***, herring spawn (*Clupea pallasi* Valenciennes), berries, 'wild tigerlily' (likely northern rice-root, *Fritillaria lanceolata* Pursh), and silverweed roots (*Argentina egedii* (Wormskjold) Rydberg; syn. *Potentilla pacifica* Howell) as part of a taboo.[71] Boas (1921) reported that there was a set

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[68] Pers. comm. May 19, 2008.

[69] Curtis incorrectly transcribed the purification ritual as ***Kékala*** but *Mayanił* corrected the spelling in a discussion in May 2011.

[70] *Mayanił* has indicated that Curtis is mixing elements from various purification rites in his description of the ***q̓eqəlla***. Rites for those who seek spiritual power or who are preparing for hunting require scouring with hemlock tips and washing in a lake, river, or stream to eliminate odours, lest they offend the spirits or the animals. Those seeking spiritual power would also fast. Fishermen used smoke instead of water as part of the cleansing. Purification to strengthen the body and mind requires washing in glacial water, streams, rivers, or lakes during the winter. Each of these rites require meditation and prayer (pers. comm. May 2011).

[71] *Mayanił* said that those who would travel to places such as the glaciers or into the forest as part of their purification and who fasted could not bring any food with them during the journey. If they ate at all, they were only permitted to eat food harvested from the site (pers. comm. May 2011). The foods in Curtis' list are very seasonal and/or habitat-restricted. ***Łəqq̓əstən*** would not be found anywhere but the coast. This 'taboo' may reflect that these foods were simply not available for harvesting during these

order when eating seaweed with water and salmon or halibut. In the morning, a person would eat seaweed only after having finished eating dried salmon or halibut (***k̓awas***; dried salmon or halibut fillet). At noon or in the evening, the seaweed could be eaten first. They could also only drink water after eating the seaweed, not beforehand or while eating seaweed. In the morning they would drink water prior to eating dried fish, which itself was consumed prior to eating seaweed. Boas' (1921) informant also indicated that powdered ***ɬəqq̓əstən*** would only be boiled in small kettles and never in large kettles because the seaweed would be eaten directly from the kettle. The informant said that the seaweed is only good to eat when it is hot, and hot stones placed in the small kettles would keep the seaweed hot for a longer time than if placed in a large kettle. This small kettle would contain an individual portion of ***ɬəqq̓əstən***. After eating the cooked seaweed, people would 'cool off' by drinking fresh water.

Table 2.1 lists comparisons between technologies that were in general use or available to the Kwakwa̱ka̱'wakw before and after the start of the $20^{th}$ century. This comparison is meant to show general trends in technologies and equipment that became available around 1900. Some equipment such as motorized boats came to gradually replace canoes a decade or so after the turn of the century. Alternatively, traditional items such as cedar racks are still in use today alongside equipment such as food dehydrators and ovens.[72]

Table 2.1. Comparison of tools and technologies in available to and in general use by the Kwakwa̱ka̱'wakw in the harvest and preparation of *Porphyra abbottiae* prior to and after the advent of the 20th century when early ethnological studies took place.

| Aspect of seaweed harvest | Technologies in general use: | |
|---|---|---|
| | Prior to $20^{th}$ century | After advent of $20^{th}$ century |
| Transportation to and from seaweed harvest sites | Dugout canoes were paddled from spring harvesting camps or communities to seaweed | Motorized boats came into use to reach harvesting sites quickly.[2, 3, 4] These boats |

journeys and, because they could not be brought along from the village, they were excluded from the diet for the duration of the purification rite.

[72] *Kʷaxsistalla*, *Mayaniɫ* and *Ogʷiloǧʷa*, pers. comm. 2008; Mary Vickers, pers. comm. 2008.

| | | |
|---|---|---|
| | harvesting sites.[1] | began replacing dugout canoes as early as 1911 (Alfred 2004: xxxiv; Codere 1990). |
| Harvesting the seaweed | Woven cedarbark and cedar withe baskets were used to collect the seaweed as it was being picked from the rocks. When the baskets were full, they would be emptied into the canoes until the canoe was full or the harvester had to return to the camp or home.[1] | Burlap bags, plastic garbage bags, and cotton bags are all used as temporary containers while harvesting seaweed.[2, 3]<br><br>Harvesters would wear rubber boots to protect their feet from sharp rocks and cold water while harvesting. |
| Storing freshly picked seaweed until outdoor drying conditions improve | If left exposed outdoors, the harvested seaweed would risk being exposed to freshwater (e.g. fog, rain) and would lose its flavour. It could be dried indoors by a fire.[1] | Refrigeration or freezing the fresh seaweed until the weather improves sufficiently to dry the seaweed under the sun.[2, 3, 4] |
| Drying the seaweed | The seaweed was generally sun-dried on flat surfaces such as warm rocks or cedar racks.<br><br>Alternatively, ***ɬəqq̓əstən*** could be dried indoors on a rack adjacent to a fire if there were inclement weather outside.[1, 2, 3] This drying method was limited by the available space on the racks next to the fire.<br><br>Seaweed could also be pressed into square cakes, while spacing layers of seaweed using cedar boughs or skunk cabbage leaves.[1, 2, 5] The squares would be left there for a month and removed each day for four days to dry outdoors.[1] | Sun-drying seaweed on flat rocks or on cedar racks raised on a table is still a common practise.[2] A tarp is another more recent surface available for drying seaweed outdoors. Tarps have the benefit of being easily folded and portable.<br><br>Electricity has allowed use of ovens and food dehydrators when the weather does not permit drying outdoors.[2, 3, 4] Another available tool is the clothes dryer with seaweed in a pillowcase.[2] |
| Additional treatments (e.g. flavouring the seaweed, texture or shape | Prior to drying the seaweed, one treatment was to pile the wet seaweed and cover it | Today, seaweed is sometimes flavoured using clam juice produced by |

| | | |
|---|---|---|
| modifications) | with a cedar bark blanket for approximately four days.[1] The seaweed would begin to decompose. It would then be dried as it would normally, resulting in more tender seaweed than if it were dried immediately after harvesting. Neither *K^w^axsistalla* nor *Mayanił* recognize this practise but suspect this was a practise from the *Nak̓^w^axdax̌^w^*.[6]<br><br>Seaweed could be flavoured by spitting clam juice or chiton juice onto partially dried squares of seaweed inside bentwood boxes after having a meal of the boiled shellfish.[1] The saliva from this may have also helped break down and partially digest the seaweed.[7] Seaweed cakes could also be flavoured with seawater, or would be stewed with salmon eggs or clams and ooligan grease immediately before eating.[6]<br><br>To powder seaweed, toasted seaweed was bundled in a deer hide and beat with a wedge until the seaweed reached the desired size.[1] Seaweed cakes could also be placed on a wooden block and chopped as needed.[6] | boiling clams.[4]<br><br>Another treatment available after the introduction of sugar by Europeans is candying. The seaweed is sweetened by sprinkling a sugar solution onto the wet seaweed prior to drying it in the oven.[4] |
| Storing the dried seaweed | Seaweed could be stored as pressed cakes or could be crumbled or powdered inside bentwood boxes.[1] Cedar branches were removed before this final stage of storage. The box covers were tied down to the boxes, which | Airtight plastic bags, jars, or plastic boxes are now commonly used to store dried seaweed.[2, 4]<br><br>Before the introduction of plastics, tin containers could be used as an alternative to |

| | | |
|---|---|---|
| | were kept in a dry location in the house.<br><br>Neither *K<sup>w</sup>axsistalla* nor *Mayanił* recognize these methods but suspect they were *Nak̓<sup>w</sup>axdax̌<sup>w</sup>* practises. They instead recall cakes being stored while wrapped up in cedarbark blankets.[6] | bentwood boxes. This kept the dried seaweed 'fresher.'[4]<br><br>Alternatively, some people choose to freeze the wet seaweed after harvesting to dry it at a later time instead of drying immediately.[3, 4] |
| Other | Stewed seaweed would be eaten using hemlock spoons.[8] Dried seaweed would sometimes be torn into strips and cut into smaller pieces using an adze or chopper (***k̓əmƛayuw***) and block of hemlock wood.[1] | Some people enjoy making a snack like potato chips by frying the seaweed in a bit of oil over the stovetop until it is crisp.[3, 4] |

1. Boas 1921; 2. *K<sup>w</sup>axsistalla* and *Mayanił*, pers. comm. 2009; 3. Turner 2003; 4. Mary Vickers pers. comm. 2008; 5. Curtis 1915; 6. *K<sup>w</sup>axsistalla* and *Mayanił*, pers. comm. May 2011; 7. Nancy Turner, pers. comm. May 2011; 8. Codere 1957.

## 2.5 Discussion

### 2.5.1 *Porphyra abbottiae* as a cultural keystone species, past and present

From the discussions and harvesting expeditions with *K<sup>w</sup>axsistalla* and *Mayanił* I found that the importance of ***łəqq̓əstən*** to the Kwakwa̲ka̲'wakw begins with the origin story of the historic discovery of the medicinal properties of seaweed. The Kwakwa̲ka̲'wakw, as mentioned previously, share a similar story with the Hanaksiala who also considered the seaweed to be medicinal and who in turn may have received the story from the Tsimshian (Compton 1993: 132). That this discovery story and its variants are found in more than one Nation in British Columbia suggests not only cultural exchange from trade in dried seaweed along the coast, but also a widespread appreciation for the medicinal qualities of the seaweed.[73]

[73] For instance, the use of dried *Porphyra* by the Dakehl (Carrier) in treating goitre caused by iodine deficiency (Turner 2003).

In these stories the medicinal qualities of seaweed are revealed to a man by supernatural means rather than by accident or from another person sharing their knowledge. In the Kwakwa̱ka̱'wakw story the supernatural being appears in a vision while the man suffered from a fever, while in the Tsimshian/Hanaksiala story the seaweed spirit appears in plain sight to the healthy husband of the sick woman during the day. There is also an element of grave or immediate danger in both stories. The rapid recovery of the man (Kwakwa̱ka̱'wakw) and the woman (Tsimshian/Hanaksiala) emphasizes the effectiveness of the seaweed as medicine. This is consistent with the widespread belief among First Nations in British Columbia that spiritual and physical health are closely linked (Kelm 1998).

The exact cultural status of ***łəqq̓əstən*** in the past is not always immediately evident from texts such as Boas (1921) and Curtis (1915), in part because their goals were primarily to record Indigenous practices before they 'disappeared.' Nonetheless, there are clues to the historic importance of ***łəqq̓əstən*** in Kwakwa̱ka̱'wakw households. Curtis (1915) notes *Porphyra* as one of the staple foods of the Kwakwa̱ka̱'wakw.[74] Seaweed was sometimes traded or gifted, and was thus also an economic resource. The song where the lazy *K̓esug*$^{w}$*ilak*$^{w}$ longs for ***łəqq̓əstən*** also suggests that dried seaweed was a common staple in the community. He hoped that someone would eventually spare him some from their supply, which would be unlikely to happen if it were a rare treat. He was not yet resigned to the possibility that no one would give him any seaweed because he was simply being lazy! The very precise rules recorded by Boas (1921: 515) regarding when and how to eat seaweed in daily meals offer further evidence that it was not merely medicine or a food meant to satiate hunger whenever one was hungry. There was thought put into how seaweed should be eaten with respect to water and dried salmon or halibut. These rules, stories, and song were embedded in their daily lives beyond the harvesting period. These

[74] Curtis (1915: 44) states that, along with purple laver (*Porphyra abbottiae*), no family would be found without the following staples: salmon (*Onchorhynchus* spp.), halibut (*Hippoglossus stenolepis* Schimdt), springbank clover roots (*Trifolium wormskioldii* Lemh. formerly *T. fimbriatum*), silverweed rhizomes (*Potentilla pacifica* Howell formerly *P. anserina*), salal berries, elderberries (*Sambucus* spp.), and oolichan oil (*Thaleichthys pacificus* Richardson).

also meet the criteria[75] set out by Garibaldi and Turner (2004) when identifying a cultural keystone species.

How has this changed over the course of a century? The seaweed continues to be a valuable trade good to inland communities,[76] but today is also purchased by individuals and elders along the coast that do not have the opportunity to harvest it themselves, whether due to inclement weather or health issues (*Kʷaxsistalla*, *Mayanił* and *Ogʷiloǧʷa*, pers. comm. 2008; Mary Vickers, pers. comm. 2008).[77] *Kʷaxsistalla* and *Mayanił* have suggested that younger generations are no longer aware of certain aspects of seaweed harvesting, most notably the 'four finger rule' for harvesting short but high-quality seaweed, and the 'rain rule' that discourages picking seaweed that has been exposed to freshwater (pers. comm. 2008). They have observed a decline in the quality of the seaweed that they purchase compared to the seaweed they once harvested for themselves.

This apparent loss of specific harvesting knowledge among the younger generations is not an accurate indicator of the status of the seaweed in Kwakwa̲ka̲'wakw communities. Using Garibaldi and Turner's (2004) criteria, ***łəqq̓əstən*** continues to be a candidate for recognition as a cultural keystone species today. Despite a decline in traditional food consumption among many First Nations, ***łəqq̓əstən*** is accessible, continues to be traded beyond territorial boundaries, and is used both as food and as medicine. A dietary survey conducted in five communities on Vancouver Island (including two Kwakwa̲ka̲'wakw communities)[78] found that 105 of 288 respondents (36%) reported eating dried *Porphyra*

[75] These factors are 1) Intensity, type, and multiplicity of use, 2) naming and terminology in a language, 3) role in narratives, ceremonies, or symbolism, 4) persistence and memory of use in relationship to cultural change, 5) its unique position in the culture, and 6) extent to which it provides opportunities for resource acquisition from beyond the territory (Garibaldi and Turner 2004).
[76] As a trade item, there is a financial incentive to continue harvesting seaweed in Kwakwa̲ka̲'wakw communities. Seaweed may no longer be necessary as a staple for survival or to prevent goitre, but it is highly valued for its medicinal qualities and its taste.
[77] *Mayanił* has observed deteriorating weather conditions (pers. comm. 2008, 2011).
[78] Quatsino and We Wai Kum (Campbell River) First Nations.

in the previous year (Child and Ross, in preparation).[79] In the Kwakwaka'wakw communities, this proportion rose to 44% (41 of 93 respondents). ***Łəqq̓əstən*** is not as ubiquitous as Curtis (1915) suggests it once was, but its harvest and consumption has persisted despite massive cultural changes since the arrival of European settlers: the introduction of commercial convenience foods, breaks in traditional knowledge transfer as a result of residential school systems, and increasingly time-strapped lifestyles (Kuhnlein 1989).

As Garibaldi and Turner (2004) point out, the *Porphyra abbottiae* is difficult to replace with other native or imported species. The Kwakwaka'wakw do not typically harvest related species of *Porphyra* besides *P. abbottiae*. When compared to *P. laciniata*,[80] *P. abbottiae* is a better source of energy, protein, and trace nutrients (Kuhnlein and Turner 1991). Some species of *Porphyra* mature during different months and would not coincide with other seasonal activities such as halibut fishing, while taste and texture might also vary between species depending on its habitat requirements. *P. abbottiae* thus maintains a unique position in this culture.

2.5.2 Adoption of new technologies as part of the seaweed harvest

The adoption of introduced technologies in seaweed harvesting was a gradual process. Alfred (2004) confirms that there were new motorboats were available for use in Kwakwaka'wakw villages by the early 20th century when Boas and Curtis conducted their fieldwork with the Kwakwaka'wakw.[81] Neither man recorded the presence of such equipment, suggesting that either their informants did not yet have access to these new boats or that the authors omitted such references. The issue is how are the new technologies integrated into traditional ***łəqq̓əstən*** harvesting practices and if there have been any significant changes in the overall practices involved in seaweed harvesting. Why would harvesters favour new technologies over the tools that have served them very

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[79] They estimated the average quantity of seaweed eaten by consumers to be 0.74 kg dried seaweed/person/year, or the approximately ten large freezer bags loosely filled with dried seaweed.

[80] A species of *Porphyra* found in the Northern and Southern Atlantic Ocean.

[81] Motorboats began replacing dugout canoes by 1911 (Alfred 2004: xxxiv).

well in the past? Two factors that immediately appear to have improved as a result of adapting the new technologies are *convenience* and *safety*.

*Convenience*

Prior to European contact, seasonal activities and settlements were organized according to the seasonal and geographical availability of resources necessary for survival. This continued until the introduction of purchasable market foods. The establishment of the colony of Vancouver Island in 1849 heralded the beginning of a wage-based economy and labouring class among First Nations in British Columbia (Lutz 1992). Lutz (1992) points out that wage labour, with the exception of agriculture, favoured the employment of younger members of First Nations communities.[82] For the ***łəqq̓əstən*** harvest to survive, it had to accommodate the new seasonal schedule of the younger generation.

With the introduction of a wage-based economy and an institutionalized education system both working adults and young families might find it difficult or impossible to schedule a harvesting expedition away from their community at a seasonal camp to collect seaweed (Kuhnlein 1992; Lutz 1992).[83] Even if a family commits itself to a harvesting expedition on a weekend, they will have to contend with the weather, tides, and a relatively brief season when the ***łəqq̓əstən*** is at its prime. Inexpensive, store-bought foods are also an attractive alternative to time-intensive traditional foods for families that are pressed for time (Kuhnlein 1989, 1992). Any technology that increases the convenience and accessibility of seaweed harvesting (e.g. motor boats, electric drying appliances) is a tool that can be used to promote and continue the harvest.

[82] Lutz (2008: 258) cites Cowichan Indian Agent William Lomas, who witnessed the shift away from traditional foods to store-bought goods; the adoption of wage work by First Nations after the introduction of laws restricting access to traditional harvesting grounds meant that young men and women could afford to buy food, but "the very old people who formerly lived entirely on fish, berries, and roots, suffer[ed] a great deal through the settling up of the country."

[83] Statistics Canada (2008) reports that in 2006, 44.2% of Aboriginal people living on reserves in British Columbia were employed. For those living off-reserve, this figure jumps to 69.1% in 2007 (Zietsma 2010).

After the introduction of motorized boats in 1911, travelling to harvesting sites became much quicker (Alfred 2004; Codere 1990). When harvesting seaweed with *K$^w$axsistalla* and *Mayaniƚ* in May 2008 and 2009, the advantages to a motorized boat were quickly apparent. When we conducted seaweed harvests in May 2008 and 2009, we did not have all of our harvesting sites planned precisely beforehand. The motorboat allowed us to travel quickly over long distances to find locations with abundant populations of *Porphyra abbottiae*. The motorboat also allowed the elders to comfortably sit indoors and advise the students who were harvesting seaweed when corrections to their technique were necessary. Finally, the motorboat allowed us to return to our base camp sooner and allowed us to spread out our seaweed sooner to take advantage of the remaining sunlight for that day.

In recent decades the weather has become a major impediment to seaweed harvesting. Environment Canada (2011) reports that Port Hardy[84] experiences an average of 24.5 days with precipitation exceeding 0.2 mm in the month of May, and on average 7 of those days the precipitation exceeds 5 mm. Alternate modes for drying the seaweed helped traditional and contemporary harvesters work around time constraints imposed by bad weather. For harvesters prior to the introduction of electricity, drying ***ƚəqq̓əstən*** indoors by a fire would have been a time-intensive process. The seaweed had to be watched so that it would not be overly browned on either side. On a sunny day, harvesters can dry large quantities of seaweed en masse and are limited only by the available, flat spaces. Indoors, the harvesters are limited by the space on the cedar rack, and the number of racks that can be placed by the fire. Newer equipment such as dryers and ovens are still subject to the same space restrictions and require careful monitoring, while freezers delay the need to quickly dry the seaweed. Food dehydrators prevent burning, allow for flexible drying times, and even drying throughout the seaweed. Without these tools, time-strapped

[84] Port Hardy is situated in Kwagiulth band territory, approximately 40 km west of the study sites.

contemporary harvesters might be discouraged from harvesting if they felt that their freshly harvested seaweed would be wasted if bad weather arises.[85]

The equipment needed for seaweed harvesting generally consists of items conveniently available around the house (cloth bags or pillowcases, buckets, boots, flat spaces to dry outdoors or an oven for indoors drying). Besides a boat, seaweed harvesters require no specialized tools.[86] This is in marked contrast to the ***k'elpaxu*** (eelgrass-harvesting stick) for harvesting ***ts'áts'ayem***, or the ***kəllakʷ*** (digging stick) for working in the ***təkillakʷ*** (estuarine root gardens) (Cullis-Suzuki 2007; Lloyd 2011). Both of these tools require specialized knowledge for selecting and fashioning. The relative ease for acquiring and using seaweed harvesting equipment works to the harvester's advantage. It may also be a factor in understanding why the seaweed harvest has survived despite aforementioned social and economical factors, while the harvest of some traditional foods requiring more complex tools has virtually disappeared until recent revitalization projects.[87]

*Safety*

Traditional harvesters were concerned with maintaining the safety of the seaweed harvest; this concern has manifested itself into the taboos and in a song associated with the harvest. Harvesting in the rain was forbidden, and the taboo prohibiting the harvest of seaweed from below the water line warned that disobeying would create rain. This prevents further harvesting and drying. While rain was said to change the taste of the seaweed, it also creates very slippery and dangerous conditions for harvesters along the shoreline.[88] Keeping harvesters away from submerged seaweed also reduces the risk of falling into the water, injuries, and drowning. The paddling song (pg. 41) associated with

[85] Adapting seaweed preparation techniques, whether traditional or modern, to local weather conditions is reflected in other cultures that continue to harvest and consume seaweeds today. Bocanegra et al. (2009), for example, note that in Asia sheets of nori are dried under the sun or indoors using forced air depending on environmental conditions.
[86] And a boat is not always needed depending on the location of the harvesting site.
[87] For example, Northern rice-root, silverweed roots, springbank clover roots in Lloyd (2011).
[88] The Gitga'at also shared these concerns, and held similar taboos (Turner and Turner 2008).

***ƚəqq̓əstən*** also holds a clue to the importance of safety precautions when harvesting the seaweed. The song functions as a mechanism to encourage the canoe paddlers on their way to the site, and it tells the harvesters to reach the site at low tide. This refers again to the taboo restricting harvesting seaweed from the water.

With the switch to motorboats, contemporary harvesters no longer need paddling songs for encouragement. This is one less opportunity to reinforce the importance of harvesting at low tide. Safety and survival are built into the oral tradition. Contemporary harvesters, on the other hand, now have access to improved communications systems in case of distress, and tide and weather forecasting data to plan expeditions and avoid dangerously windy or wet conditions. These new safety measures provide additional security for contemporary harvesters whether or not they have learned of the taboos or the paddling song. However, good techniques for climbing onto slippery rocks or judging the height of waves when disembarking from the boat are still required for safe harvesting.

## 2.6 Chapter 2 conclusions

***Ƚəqq̓əstən*** has been a source of medicine and food to the Kwakwa̱ka̱'wakw and many other First Nations for centuries. The seaweed was one of several food species including halibut, sea urchins, and eelgrass that were harvested over a relatively brief period in the spring months. Its importance is reflected in surviving oral histories and songs that recognize how ***ƚəqq̓əstən*** was a powerful medicine and a desirable resource.

The recognition of *Porphyra abbottiae* as a cultural keystone species has the potential for assisting cultural food restoration efforts among the younger Kwakwa̱ka̱'wakw. The elders felt that the youth were not aware of certain rules for harvesting, affecting the quality of their final product. Highlighting ***ƚəqq̓əstən*** as a cultural keystone species can help educate young Indigenous and non-Indigenous people alike about the place of the seaweed in the seasonal round alongside other foods, bring about greater social acceptance of traditional foods, and encourage youth to seek out and work with elders in their community. ***Ƚəqq̓əstən*** sites are easily accessible with some planning, the seaweed is a healthy food, and the harvest can become an enjoyable family activity that includes the participation of the elders and the very young.

I accompanied knowledgeable elders and participated in seaweed harvesting under their guidance in May 2008 and 2009. The elders remembered harvesting and eating seaweed early in their childhoods, but had not been able to do so in recent years due to adverse weather conditions. I documented the seaweed harvest beginning from when the elders identified potential harvesting sites to the final stages of drying and consuming the seaweed. I found that the tools used to harvest and dry *Porphyra abbottiae* have changed, but the general practices have remained consistent. Seaweed is harvested, dried, and served in a similar manner as it was over a hundred years ago, but with the introduction of electric ovens, food dehydrators, and ovens there is now greater flexibility when working around tight work schedules and adverse weather.

While some elements of TEK such as the paddling song are in danger of being lost with the introduction of new technology, the greater part of the decline in seaweed harvesting is likely due to socioeconomic factors such as lack of time and ready availability of market foods. The technologies introduced to the contemporary seaweed harvest facilitate the harvest for families that are strapped for time as they participate in a wage-based economic system.

At the end of his paper, Williams (1979) concludes that the tradition of seaweed harvesting among Indigenous peoples on Vancouver Island, “may receive its lethal blow from Western’s culture’s most effective instrument of cultural change—technology.” He believed that the end of the seaweed harvest was inevitable. I hope that technological change will not lead to the end of seaweed harvesting, but will in fact allow the harvest to adapt to socioeconomic and environmental changes that otherwise threaten its survival.

# Chapter 3 *Porphyra abbottiae* biology and Traditional Ecological Knowledge

## 3.1 *Porphyra* biology and ecology

That's where it is. Facing east, 'cause the sun rises in the East. That's I guess where you'll find them. For some reason, I don't know, but that's what I was told. It doesn't grow in the dark sides.
- *K$^{w}$axsistalla* (Chief Adam Dick), May 2009

Human societies all around the world and throughout history have learned how to use available resources, including algae, to the best of their knowledge. This knowledge and judgement develops from a great deal of observation and interaction with their local surroundings over successive generations. From their environment, people found their means for survival and improvement of quality of life.

Today, the genus *Porphyra* is studied around the world thanks to its cosmopolitan distribution and its presence in human diets. Some species of *Porphyra* are intensively investigated in a broad range of fields; nutrition, medicine, food additives, cell physiology, genetics and phylogeny, applicability as water quality bioindicators, toxicology, and community ecology are only a few examples. Other species, such as *P. abbottiae*, have yet to reach that level of academic study. A cursory literature search using the Web of Knowledge database shows that some species, such as *Porphyra yezoensis*, *P. umbilicalis*, and *P. tenera*, each appear in hundreds of papers, while *P. abbottiae* (or *P. abbottae*) appears in just over a dozen papers.[89] While there is not a dearth of information available for *P. abbottiae*, it has yet to receive the same attention as these other species.

*Porphyra abbottiae* is an alga that occupies both an ecological niche and a cultural niche along the west coast of North America. The location of *P. abbottiae* in the intertidal zone makes it accessible to both marine and terrestrial consumers. Early Indigenous gatherers

[89] This ratio holds when conducting a similar search in Google Scholar. *Porphyra yezoensis* appears in over 4,300 articles, and *P. umbilicalis* and *P. tenera* each appear in over 2000 articles. *P. abbottiae* or *abbottae* appears in just over 150 articles.

would have encountered *P. abbottiae* as they collected coastal species such as clams, octopi, limpets, and snails, and so at some point the alga too was harvested and integrated into the traditional diet (Turner 2003). The traditional ecological knowledge (TEK) of *P. abbottiae* is based upon, by definition, the ecology of the seaweed, as known to the people who use it and interact with it. The incorporation of this alga into the Kwakwa̱ka̱'wakw diet required careful observation and a knowledge of the rapid physiological changes occurring at the time of harvest. By understanding the biology and ecology of this alga, it becomes easier to understand the development of the TEK associated with *P. abbottiae*.

## 3.2 Objectives and Methodology

In this chapter I provide a brief review on the biology and ecology of *Porphyra abbottiae* based on the literature and observations in the field. Field observations of *P. abbottiae* were conducted during two expeditions to the Broughton Archipelago, British Columbia, in May 2008 and 2009. Kwakwa̱ka̱'wakw TEK was compiled through interviews, discussions, and participatory harvesting with experienced knowledge holders *K$^{w}$axsistalla* (hereditary clan chief Adam Dick), *Mayanił* (Dr. Daisy-Sewid Smith), and *Og$^{w}$iloǧ$^{w}$a* (Kim Recalma-Clutesi). Using this knowledge, I examine the biological and ecological characteristics of *P. abbottiae* that contribute to our understanding of the development of the Kwakwa̱ka̱'wakw TEK of this useful and culturally valued seaweed.

## 3.3 Results

### *Original scientific discovery*

Prior to its identification as a separate species, *Porphyra abbottiae* was identified as *Porphyra perforata* (Turner 1975; Williams 1979). Both these species share overlapping geographical distributions (Lindstrom 2008). Dr. Vasudeva Krishnamurthy first described *P. abbottiae* as a new species in 1972 (Krishnamurthy 1972). The original spelling employed in the literature was *P. abbottae*, but this was later corrected to *P. abbottiae* (N.J. Turner, pers. comm. 2007; Cannon 1989; Krishnamurthy 1972; Lin et al. 2008; Lindstrom and Cole 1992; Turner 2003). A common name for *P. abbottiae* is laver, similar to the name 'purple laver' applied to *P. umbilicalis* and other *Porphyra* spp. in Britain (E.g. Garibaldi and Turner 2004; Turner 1975).

*Morphology*

*Porphyra abbottiae* shares some morphological characteristics with other *Porphyra* species that share its geographical range. O'Clair and Lindstrom (2000) note that it can be difficult to distinguish species of *Porphyra* on the Pacific coast based on appearance alone. The blade is reddish-purple or greenish with the consistency of cellophane, and may reach lengths of up to 150 cm.[90] In late May at the time of harvesting, the seaweed fronds intended for consumption will measure approximately 10-15 cm.[91] Figure 1.1 (see page 6) shows the typical form and size of *P. abbottiae* blades at the time of harvest in mid-May. *P. abbottiae* also occurs in a filamentous conchocelis form, as the alternate generation to the membranous form. Cells in vegetative branches of the conchocelis measure in 20-40 μm in length and 4-8 μm in diameter. Cells in sporangial branches measure 12-20 μm in diameter (Krishnamurthy 1969).

*Ecology of* Porphyra abbottiae

*Porphyra abbottiae* has an extensive geographical range, spanning from the Kodiak Archipelago in Alaska to northern California (Figure 3.1) (Lindstrom 2008). The alga typically occupies the mid and lower intertidal zones of the shoreline throughout its geographic range (McConnaughey 1985; Turner 2003). An example of this vertical stratification is shown in Figure 3.2. *P. abbottiae* does not exclusively occupy these zones in the intertidal; it is found alongside other algae including other *Porphyra* spp., *Fucus* spp., *Acrosiphonia arcta* (Dillwyn) Gain, and *Ulva lactuca* L. (Sandra Lindstrom, pers. comm. May 2009). *P. abbottiae* is epilithic,[92] but may also grow on other hard,

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[90] Turner 1975. Dr. Sandra Lindstrom (pers. comm. 2011) has suggested that this is incorrect; *P. abbottiae* is always green in the field and with a tough consistency. *Porphyra* that is red and has the consistency of cellophane may actually be *P. cuneiformis*.

[91] *K$^{w}$axsistalla*, pers. comm. 2008.

[92] Grows on rock surfaces.

immovable substrates such as shell.[93] This particular species of *Porphyra* is not known to grow on other algae or seagrasses.[94] *Porphyra* spp. are best known as sources of food for people around the world, but *P. abbottiae* is also food for marine herbivores such as limpets, chitons, and snails.[95]

Figure 3.1. Geographical range of *Porphyra abbottiae*. The shaded green area represents the known extent of the seaweed's range.

[93] Turner 2003; Williams 1979.
[94] Lindstrom 2008.
[95] Turner 2003.


Figure 3.2. Photo depicting typical seaweed distribution at Fort Rupert, Vancouver Island. In this region, *Porphyra abbottiae* occupies the mid- and lower-intertidal zones (B and C) while being mostly excluded from the upper-intertidal (A).

*Life history of* Porphyra abbottiae

Members of the Rhodophyta, or red algae, are known for having relatively complex life histories. *Porphyra abbottiae* is a typical representative species demonstrating alternation of generations; it alternates between a filamentous conchocelis phase and a membranous blade phase (Chapman and Chapman 1980; Druehl 2000; Nelson et al. 1999). This cycle is represented in Figure 3.3.

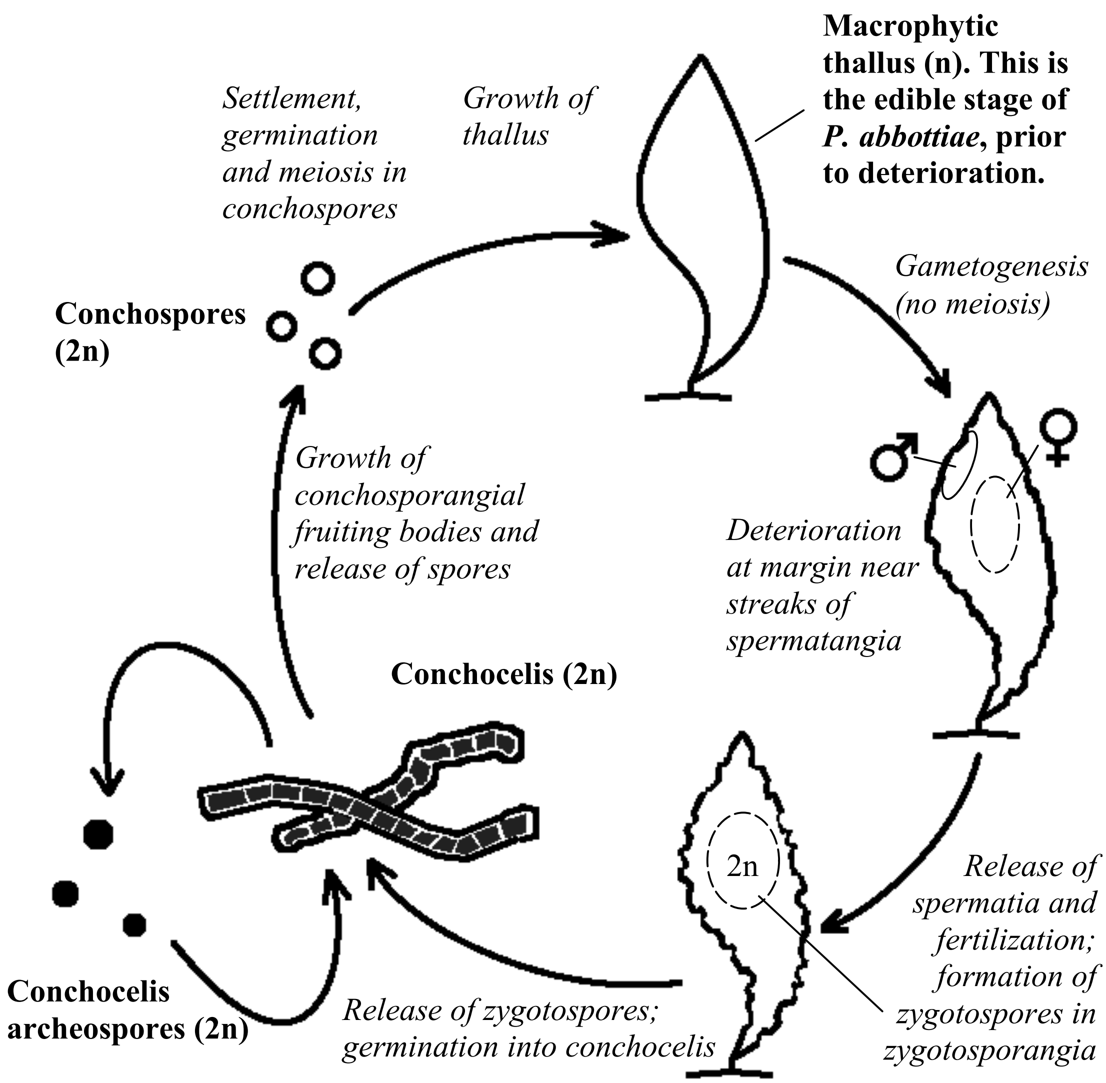


Figure 3.3. Alternation of generations in *P. abbottiae* Krishnamurthy.

*Conchospore and conchocelis phase*

The conchocelis phase of *P. abbottiae* is microscopic in size. Prior to Kathleen Drew Baker's discovery that zygotospores released by the *Porphyra* blade developed into conchocelis filaments, these filaments were misidentified as part of the genus *Conchocelis* (Krishnamurthy 1969). The conchocelis develops from diploid zygotospores released from zygotosporangia on the thallus. The zygotospores burrow into solid substrates such as shells, and proceed to germinate into conchocelis filaments (Lindstrom et al. 2008; Nelson et al. 1999). Salinity has a strong bearing on conchocelis development; filaments do not grow at salinities of 10 ppt (parts per thousand) or less, and are killed at 5 ppt Stekoll et al. 1999).

As the conchocelis matures, it forms reproductive structures at the tips of the filaments called conchosporangia. Lindstrom et al. (2008) found that *P. abbottiae* would form conchosporangia as water temperatures increased from 4-5°C to 11°C in long-day light conditions, while healthy conchospores would be released and grow into thalli when temperatures decreased from 11°C to 7°C in short-day light conditions. Waaland et al. (1990) also reported that photoperiod and temperature regulate conchospore release in the field. Conchospore maturation and release in *P. abbottiae* was optimal when temperatures decreased from 10°C to 6-8°C, and was triggered by long-day conditions[96]. Lindstrom et al. (2008) noted that conchospore release is improved with high light and high wave motion. These experiments were conducted *in vitro*, but the conditions simulate natural changes in photoperiods and temperatures experienced by *P. abbottiae* in the wild as summer changes into autumn. The authors also reported the presence of conchocelis archeospores in *P. abbottiae* that developed under different environmental conditions including exposure to decreasing temperatures while shifting from short-day to long-day photoperiods, and increasing temperatures while maintaining long-day light conditions.[97]

*Blade phase*

The blade form is the more conspicuous of the two morphologies found in *P. abbottiae*. The blade is one cell thick, and is slightly thicker in reproductive areas (56-65 µm) than in vegetative areas (52-56 µm) (Sandra Lindstrom, pers. comm. October 2011; Krishnamurthy 1972). The edges of the blade are ruffled but with a smooth margin. The blade appears green when fresh. When dried the blade appears deep purple to black. The appearance of the blade form of *P. abbottiae* is strongly affected by environmental factors. Hannach and Waaland (1989) found that, unlike in conchocelis growth and

[96] Long-day conditions are 16 hours of light, 8 hours of darkness. Short-day conditions are 16 hours of darkness, 8 hours of light.
[97] Conchocelis archeopores are formed from differentiated vegetative cells in the conchocelis; instead of developing into a thallus, they produce more conchocelis filaments (Nelson et al. 1999).

development, temperature had no significant effect on blade growth. Water motion stimulates growth of young *P. abbottiae* thalli, particularly under low-nutrient water conditions. The authors also found that growth rate decreases as the thallus increases in size.

The blade develops from conchospores released from conchosporangial fruiting bodies in the conchocelis. The diploid spores settle on a solid, stone surface, and undergo meiosis upon germination (Burzycki and Waaland 1987). Though the blade is haploid, it produces both male and female gametes. In the case of *P. abbottiae*, both types of gametes are produced on the same thallus. Haploid male and female gamete packets are produced by mitosis of blade cells rather than by meiosis (Nelson et al. 1999). In mid-May to early June, the cell walls of the male gamete packets break down and release the spermatia.[98] The spermatia fertilize female gametes in the central area of the blade. *P. abbottiae* produces zygotospores (previously known as carpospores) after fertilization (Cannon 1989; Nelson et al. 1999). It is also capable of producing pre-fertilization zygotospores (known as agamospores) from vegetative cells under short-day conditions (10 hours light, 14 hours darkness).[99] These zygotospores are released and will later germinate and produce conchocelis. Table 3.1 summarizes the basic biological description of *P. abbottiae*.

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[98] The packets of male gametes appear as pale streaks along the margin of the blade (Sandra Lindstrom, pers. comm. May 2009). As the cell wall breakdown progresses, the blade margin appears increasingly ragged.

[99] Cannon 1989. Agamospores form by mitotic division of macrophytic blade cells (Nelson et al. 1999).

Table 3.1 Summary of the biological and ecological characteristics of *P. abbottiae*.

| | |
|---|---|
| Classification | Division Rhodophyta[1]<br>Class Bangiophyceae<br>Order Bangiales<br>Family Bangiaceae<br>Genus *Porphyra* (now *Pyropia*)[2]<br>Species *Porphyra abbottiae* Krishnamurthy[3] [now *Pyropia abbottiae* (V. Krishnamurthy) S. C. Lindstrom comb. nov.][2] |
| Morphology and colour | *P. abbottiae* can take form as either an edible, macrophytic blade form and an inconspicuous, filamentous conchocelis form.<br><br>The blade is one cell (approximately 0.05 mm) thick,[4] resulting in a membranous appearance. It reaches lengths of up to 150 cm and 3-4 cm wide.[5] The edges of the blade are ruffled but with a smooth margin. The blade appears green when fresh, and when dried appears deep purple to black. In late May/early June the blade changes colour to brow-yellow begins to deteriorate at the margin, signalling the release of male gametes.<br><br>The conchocelis is much smaller than the blade form; cells in vegetative branches measure in 20-40 µm in length and 4-8 µm in diameter, sporangial branches measure 12-20 µm in diameter.[6] |
| Reproduction and lifecycle | *P. abbottiae* alternates between a free-living filamentous (conchocelis) phase and a 'fleshy,' or blade, phase.[4, 7]<br><br>The conchocelis is a diploid, microscopic form that develops from germinated zygotospores. The filamentous phase may be better at surviving harsh environmental conditions than the blade phase and be more common over the warm summer months. The conchocelis develops conchosporangial fruiting bodies at the ends of reproductive filaments. These bodies produce conchospores which settle, germinate, undergo meiosis, and re-establish the blade phase in the fall.[4, 8]<br><br>Under a very specific set of environmental conditions the *P. abbottiae* conchocelis can asexually produce and release diploid archeospores[9]. These archeospores are released from the conchosporangial bodies and germinate to produce new diploid conchocelis filaments. |
| Habitat | The thallus grows in rocky, low-intertidal[5] to mid-intertidal[10] zones. Germination and growth may improve in areas where there is energetic water motion,[9] with the best growth occurring on exposed shorelines. |
| Worldwide distribution | North-western coast of North America, from the Kodiak Archipelago in Alaska to northern California.[11] |

1.Oliveira et al. 1995; 2. Sutherland et al. 2011; 3. Krishnamurthy 1972; 4. Druehl 2000; 5. Turner 1975; 6. Krishnamurthy 1969; 7. Chapman and Chapman 1980; 8. Burzycki and Waaland 1987; 9. Lindstrom et al. 2008; 10. McConnaughey 1985; 11. Lindstrom 2008.

*Senescence or disease*

During the seaweed harvesting expeditions in both 2008 and 2009, the elders noticed that students were harvesting *P. abbottiae* blades that did not appear quite normal. When drying and sorting the seaweed we found that there were normal, ‘healthy’ thalli and yellow-brown, ‘crinkly’ thalli. Sandra Lindstrom (pers. comm. October 2011) suggests that the crinkling occurs as a result of epiphytic diatoms; the diatoms cause the thallus to crinkle as it grows with the diatoms covering the blade. In Figure 3.4, the crinkly or “curly” seaweed is distinguished from the normal seaweed by a slightly shrunken, ‘veined’ appearance. Dried crinkly seaweed did not harden and ‘crisp’ like the normal dried specimens; it instead remained pliable and slightly stretchy. It is unclear if these crinkly specimens are in an advanced stage of senescence that began earlier than most of the *P. abbottiae* population, or if they are afflicted by disease as a result of diatom loading. The crinkled specimens were found interspersed among the healthy-looking thalli on the rocks, suggesting that the cause of the crinkled appearance is either not communicable (i.e. normal senescence affecting individual specimens) or does not spread readily, leaving open the possibility of disease. Samples of this crinkly *P. abbottiae* harvested at Bauza Island in 2008 were analyzed alongside healthy-looking specimens for metal content; the results appear in Chapter 4.

Figure 3.4. Specimens of desirable fresh and dried *P. abbottiae* (top left and right, respectively), and the undesirable 'crinkly' *P. abbottiae*, both fresh and dried (bottom left and right, respectively).

## 3.4 Discussion

*Edibility*

*Porphyra abbottiae* begins releasing spermatia from late May to early June; it is also at this time when the edible thallus senesces and changes colour, texture, and flavour. During the harvesting expedition in May 2009, $Og^{w}ilo\breve{g}^{w}a$ noticed that a significant quantity of seaweed harvested by student volunteers was yellowed and ragged. *Mayanił* ate a small quantity of the yellowed seaweed and soon had an unsettled stomach. She then related to the students how she was taught as a youth not to harvest the yellowed or crinkly seaweed. This is very specific knowledge on seaweed identification that protects consumers from poor-quality seaweed and possible stomach-unsettling effects. This knowledge also helps harvesters avoid spending time – which is already limited by the tides – from inadvertently harvesting this undesirable seaweed.

*TEK and algal biology*

The entire undertaking of organizing and carrying out *P. abbottiae* harvesting requires an understanding of the biology and ecology of the alga—knowing the effects of temperature, sunlight, and precipitation on growth of the thallus allows the harvester to make decisions that affect personal safety and the quality of the finished product. The predictable lifecycle of the seaweed allows people to plan its harvest in conjunction with other important aquatic food species during the seasonal round. The quote at the beginning of this chapter is an example of TEK that relates light exposure to macrophytic *P. abbottiae* growth, even if it does not specifically mention *why* the seaweed is found on east-facing shorelines. This TEK also equips the harvester to make more efficient use of their time if seeking out new harvesting sites within their territory – they do not need to spend time at the south-, west-, or north-facing ends of the island. Identification skills are very important: there are other seaweeds that occupy a similar ecological niche or resemble *P. abbottiae* in appearance, but are different in texture and flavour, possibly even inedible. On some occasions, other species of *Porphyra* are mixed in with quantities of *P. abbottiae* harvested by coastal Indigenous peoples (Turner 2003). Finally, harvesters must be able to identify high-quality seaweed from poor-quality seaweed (i.e. the crinkly or yellowed seaweed).

Sustainability of the seaweed harvest is and has always been crucial to its continued existence. Harvesting repeatedly from the same area and managing to maintain the same harvesting sites over generations requires an understanding of both positive and detrimental factors on the population at each site. Nelson and Conroy (1989) found that Maori harvesting techniques and harvest timing of *Porphyra* spp. in New Zealand have significant impacts on population regeneration. Removing the thallus outright resulted in significantly less regeneration in the population after two months than if a basal portion is left intact on the rock at the time of harvest. *K*$^{w}$*axsistalla* and *Mayanił* (pers. comm. May 2008, 2009) taught the students at the field expeditions to pluck the seaweed near its base. The student harvesters often left behind a very small basal portion but it is unclear what effect, if any, that this may have on regeneration of the individual plant. Nelson and

Conroy (1989) suggest that species composition in *Porphyra* at each site may influence the extent of the population recovery after harvesting. Kain (1975) suggests that algal re-colonization of cleared areas is also dependent, in part, on the timing of the fertile period of the thallus with respect to harvest timing.

These findings are applicable to the *Porphyra* harvest by Indigenous Peoples in British Columbia; *P. abbottiae* is harvested just prior to the onset of its reproductive state. Removing the population of *P. abbottiae* from a site before it has the opportunity to reproduce appears, initially, to be an obstacle in maintaining a sustainable harvest. During the harvesting expeditions it was apparent that *P. abbottiae* could not be completely removed at any site; limited manpower and harvesting time between tides ensured that a significant quantity of seaweed remained in the intertidal zone. By following the Kwakwa̲ka̲'wakw protocol to avoid harvesting from below the water line, there is also a constant and close source of conchocelis and young gametophytes to regenerate the population. Furthermore, the newly cleared spaces provide habitat and an opportunity for the recruitment of a new cohort of *P. abbottiae* gameophytes.[100] Further research may be needed to ascertain the exactly process of *P. abbottiae* regeneration from harvested sites in the field; unlike the *Porphyra* harvested twice in a year by Nelson and Conroy (1989), the Kwakwa̲ka̲'wakw do not harvest *P. abbottiae* again two months after the initial harvest in mid-May. The thallus instead continues to senesce and is not recommended by Elders for consumption. However, Turner and Clifton (2006) note that the Gitga'at would harvest *P. abbottiae* twice in a year; the second harvest occurs approximately one month after the initial harvest. *P. abbottiae* is capable of regenerating from the small basal portion left on the rock. If so, it is possible that the harvesting technique has a significant effect on *P. abbottiae* regeneration and that leaving a short basal portion can delay senescence.

[100] *K$^{w}$axsistalla* (pers. comm. 2008) remarked that unwanted algae such as the yellowed or crinkly seaweed would be weeded out during harvesting. This would also in effect create more habitat for a new generation of *P. abbottiae*.

*Taboos, and safety*

Rocky and steep intertidal habitat is a risky environment for harvesters. Both the Gitga'at and the Kwakwa̱ka̱'wakw have taboos barring harvesting when it is raining (Garibaldi and Turner 2004; *K$^w$axsistalla*, pers. comm. May 2008). This is a temporal taboo that limits harvesting to exposed intertidal habitat during specific times (rainy weather) (Garibaldi and Turner 2004). It is also forbidden, as previously noted, to harvest *P. abbottiae* that is below the water line or is floating in the water. If the seaweed is harvested from the water, it is said that it will start to rain and that the seaweed will not taste very good.[101] Garibaldi and Turner (2004) call this type of taboo a habitat taboo, as harvesting below the water line is always restricted.

There is a physical danger associated with harvesting laver on wet rocks made slippery by the algae—to harvest when it is raining would greatly increase the risk of injury or possibly death by drowning. A Kwakwa̱ka̱'wakw paddling song[102] specifically encourages the harvesters to reach the harvesting site before low tide—at this time the currents are at their slowest velocity and most of the *P. abbottiae* is exposed to the air. When the tides start to rise and the seaweed becomes partially submerged, there is a real danger of one slipping off the rocks and into the surging waters. The development of these taboos and song is based on ecological knowledge of the seaweed's habitat (intertidal zone). This danger of slipping on the rocks or falling into the water has evolved into a collective group memory and become manifested into the taboos mentioned above. Taboos passed down to each new generation help protect the younger, inexperienced harvesters from accidents not witnessed in the community's collective living memory, but that may have occurred perhaps centuries earlier.

## 3.5 Chapter 3 conclusions

Environmental factors such as temperature, light intensity and frequency, salinity, and water motion are all known to affect *Porphyra* growth and development. Scientific

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[101] Garibaldi and Turner 2004; *K$^w$axsistalla*, pers. comm. May 2008. See Chapter 2 for further details surrounding the taboos.

[102] See page 41.

inquiry has been able to quantify the precise effects of each factor on the development of *P. abbottiae* conchocelis and gametophytes, while Kwakwaka'wakw TEK has displayed a qualitative understanding of these same factors. Some of the TEK may have accumulated from direct observations, while other aspects (upset stomach from poor-quality seaweed, taboos) may have arisen from personal experiences and teachings from previous generations.

*Porphyra abbottiae* is an alga that shares its ecological territory with the cultural territories of the Kwakwaka'wakw and other coastal First Nations in Northwest North America. It is harvested and consumed both as food and as medicine, but knowledge of its ecology and biology are ingrained in the traditional ecological knowledge of those people who harvest it. This biological and ecological knowledge of *P. abbottiae* is important to its inclusion in the traditional diet of the Kwakwaka'wakw – the predictable cycle of growth and senescence of the thallus allows the seaweed to form a regular rather than sporadic part of the seasonal round.

# Chapter 4 Metal concentrations in *Porphyra abbottiae* Krishnamurthy at harvesting time

## 4.1 Introduction to food contaminants and nutrition

That’s why when we started noticing the bitterness, and tastelessness of seaweed, that’s why we were wondering whether pollution was starting to spread. And we were quite worried about it because we noticed the difference in taste.
- *Mayanił*, May 2009

What is there that is not poison? All things are poison and nothing [is] without poison. Solely the dose determines that a thing is not a poison.
-Paracelsus, 1492-1541[103]

There is growing interest in the scientific community to study contaminants in traditional foods of Indigenous Peoples. At the same time, there is evidence supporting the health benefits of traditional diets. We now know that there is a close link between health and traditional foods in First Nations communities (Kuhnlein et al. 2009). Traditional foods can be instrumental in improving diets and fighting chronic illnesses that are epidemic in First Nations communities (Kuhnlein and Receveur 1996). Not only are many traditional foods rich in nutrients that are lacking in market foods commonly available to First Nations communities, but traditional foods also provide a tangible link to people’s culture and history (Kuhnlein and Chan 2000; Kuhnlein 2009). As part of my overall study of Kwakwa̱ka̱’wakw use of the edible red alga ***ɬəqq̓əstən*** (*Porphyra abbottiae* Krishnamurthy), under the guidance of Kwakwa̱ka̱’wakw leaders, *Kʷaxsistalla*, *Mayanlł*, and *Ogʷiloǧʷa*, I analyzed samples of *Porphyra abbottiae* harvested from within traditional Kwakwa̱ka̱’wakw territories for a suite of metals. This work was in response to concerns expressed by my Kwakwa̱ka̱’wakw advisors that their edible seaweed might be contaminated and therefore potentially harmful to eat.

There are a number of classes of potential food contaminants, including metals, persistent organic pollutants and radionuclides (e.g. Kuhnlein and Chan 2000). I chose metals as the target contaminants for this study for two reasons. The first was the need to narrow the scope of the study to a manageable level. Metal analysis can reveal the presence or

[103] Deichmann et al. 1986.

absence of elements in the seaweed, restricting the pool of potential contaminants from other classes of pollutants. The second was because the health effects of metals have been extensively studied around the world for many decades and, as a result of that research, guidelines have been prepared by health agencies regarding safe consumption of metals, including arsenic, cadmium, mercury, and lead, in food (Institute of Medicine of the National Academy of Sciences 2003, 2006; World Health Organization 1982, 1983, 2000, 2006, 2011). These guidelines are important for setting recommended intake quantities for foods such as *P. abbottiae* that do not appear specifically in the Canada Food Guide (Institute of Medicine of the National Academies 2003).

*Mechanism for metal uptake by marine algae*

Algae are an attractive option for scientists to study contamination in marine systems because they are known to accumulate metals dissolved in the water column. Worldwide there is a great deal of research into the uptake mechanisms and concentrations of contaminants in red, green, and brown algae (e.g. Sharp et al. 1988; Muse et al. 1999; Pan et al. 2000). Algae's lack of root systems and inability to take up solid particles in the water means that they can only take up molecules dissolved in a solution, namely seawater (Lobban et al. 1985). Seaweeds can accumulate these molecules at concentrations far greater than those found in the water column (Orduña-Rojas and Longoria-Espinoza 2006). Some algae such as *Alaria* (a type of kelp; Phaeophyta) can sequester metals at different concentrations in different sections of the thallus (e.g. stipe, outer and younger blade, inner and older blade, holdfast), resulting in variations in assessed metal concentrations if researchers are not consistent in the parts of the alga sampled (Burger et al. 2007).

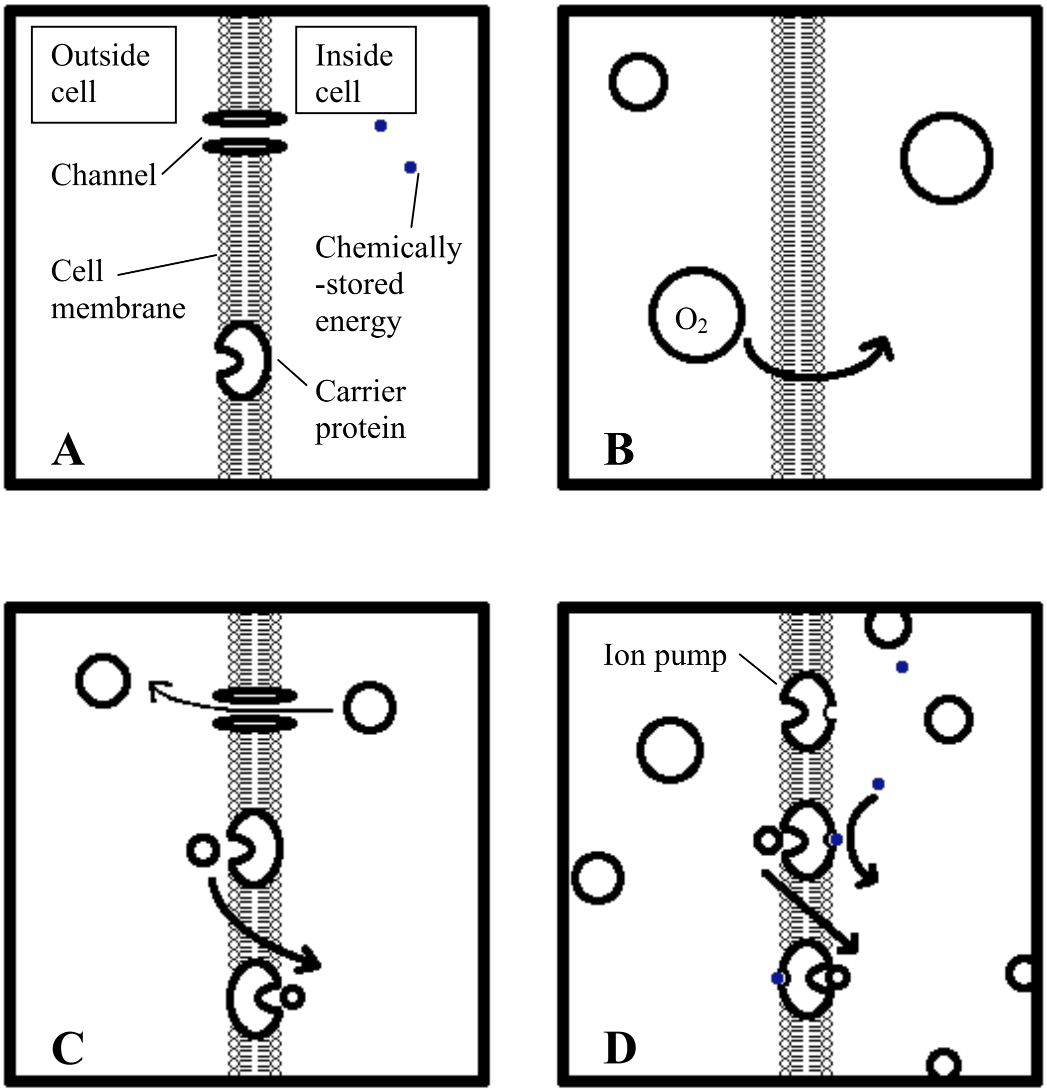


Figure 4.1. Model of types of metal uptake by an algal cell wall (A), showing passive diffusion (B), facilitated transport (C), and active transport (D).

Metals can enter algal cells by three processes: passive diffusion, exchange diffusion, and active transport (MacRobbie 1974) (see Figure 4.1.) In passive diffusion, the algal cell expends no energy in moving molecules across the cell membrane. The movement is generated by the difference in electrochemical potential between an ion and the environment on the other side of the membrane. This is a function of the ion concentration and the difference in electric potential (MacRobbie 1974). Some dissolved gases such as oxygen ($O_2$) or carbon dioxide ($CO_2$) can diffuse across the lipid bilayer of the cell membrane (Lobban et al. 1985). This process, however, would not result in an internal metal concentration significantly greater than that in the water column.

Exchange diffusion occurs when an ion in the cell membrane facilitates movement of a molecule across the membrane, but as in passive diffusion the cell exerts no energy in moving the molecule (Lobban et al. 1985). The molecule will bind to a protein in the membrane that will transfer it across the membrane, or ions will pass through protein channels. Facilitated diffusion occurs more quickly than passive diffusion. An ion of the same charge may move across the membrane in the other direction with the aid of membrane proteins, resulting in no net change in electric charge (Kolek and Holobradá 1992). McLean and Williamson (1977) found that *Porphyra umbilicalis* Kützing uptakes cadmium – a potentially harmful metal – by exchange diffusion in an anabolic process mediated by light availability. The light affects protein production, and by experimenting with light intensities and a protein production-inhibitor (cycloheximide) the authors found cadmium uptake from the solution. This suggests that the cadmium is attached to the newly made proteins before being transported into the cell, facilitated by the proteins. They also found that in *P. umbilicalis*, the cadmium appeared to be stored in the nucleus of the cell.

Active transport of molecules across the membrane occurs when a cell expends metabolic energy (for example, by the hydrolysis of adenosine triphosphate) at binding sites in ion pumps to move molecules across its cell membrane against a concentration gradient. This active process is also referred to as bioaccumulation (Shiewer and Volesky 2000). This form of transport is more rapid than either passive or facilitated diffusion (Lobban et al. 1985). Murru and Sandgren (2004) found that *Porphyra* species (*P. torta V.* Krishnamurthy*, P. papenfussii* Krishnamurthy*, P. perforata* J. Agardh*,* and *P. fucicola* Krishnamurthy) from Puget Sound actively take up carbonate ($HCO_3^-$) as a source of carbon atoms. The *Porphyra* spp. increase the pH just outside the outer cell membrane after producing hydroxide ($OH^-$) ions from the hydrolysis of the carbonate. The researchers noted that *P. torta*, found in the high intertidal zone, did not deplete inorganic carbon in the surrounding waters as efficiently as *Porphyra* species growing in the lower intertidal. The high intertidal zone species relied more on dissolved carbon dioxide from passive diffusion than on carbonate for their carbon requirements. *Porphyra abbottiae* occupies the mid-intertidal zone and is found in energetic, high-motion waters where carbon dioxide dissolves easily from the atmosphere. It is likely that it uses both active transport (bioaccumulation) to take up carbonate and passive diffusion to take up carbon dioxide. The results of Vasconcelos and Leal (2001) suggest that there was some passive diffusion of metals, including cadmium and lead, into *Porphyra* spp.

Algae do have mechanisms in place to control or mitigate the movement of elements across the cell membrane. Concentration gradients and electric potential at the cell membrane can slow the uptake of metals by passive diffusion. The phospholipids in the cell membrane itself repel ions, which are lipophobic (Lobban et al. 1985). Facilitated diffusion can similarly be slowed or blocked if transporting an ion across the membrane would go against the concentration gradient inside the cell. Facilitated diffusion can also be blocked by competitive and non-competitive inhibition, in which an inhibitor molecule reduces the function of the carrier protein (non-competitive) or prevents the binding of ions available for transport across the membrane (competitive). Active transport of molecules can be slowed or prevented by **competitive** and **non-competitive** inhibition. Antagonistic relationships between metals can also change metal concentrations in *Porphyra* spp. Andrade et al. (2006) found that algae transplanted from reference sites to waters with high concentrations of dissolved copper would suppress cadmium uptake and even decrease cadmium concentrations in their tissues while simultaneously taking up copper. Antagonistic relationships would make it difficult to predict the presence of metals in *Porphyra* based on knowledge of existing contaminant sources such as geological substrate or industrial effluents.

The intertidal ecology of *Porphyra abbottiae* means that metals can come into contact with the seaweed from two media: from the water at high tide, and from the air at low tide (see Figure 4.2). Contaminants in the air do not transfer directly into the seaweed, but are adsorbed in the layer of water on the surface of the seaweed if the *Porphyra* has not yet had a chance to dry out. As noted previously, seaweeds are unable to accumulate particulate contaminants from the air; they can only take up elements or compounds that have dissolved in a solution (Lobban et al. 1985). When *P. abbottiae* dries out during low tide, the desiccated thallus retains a thin sheen of water for some time until that too evaporates. Davison and Pearson (1996) found that intertidal seaweeds experience a decline in photosynthesis and a decrease in nutrient uptake during sublethal desiccation, though this may be a consequence of nutrient limitation.

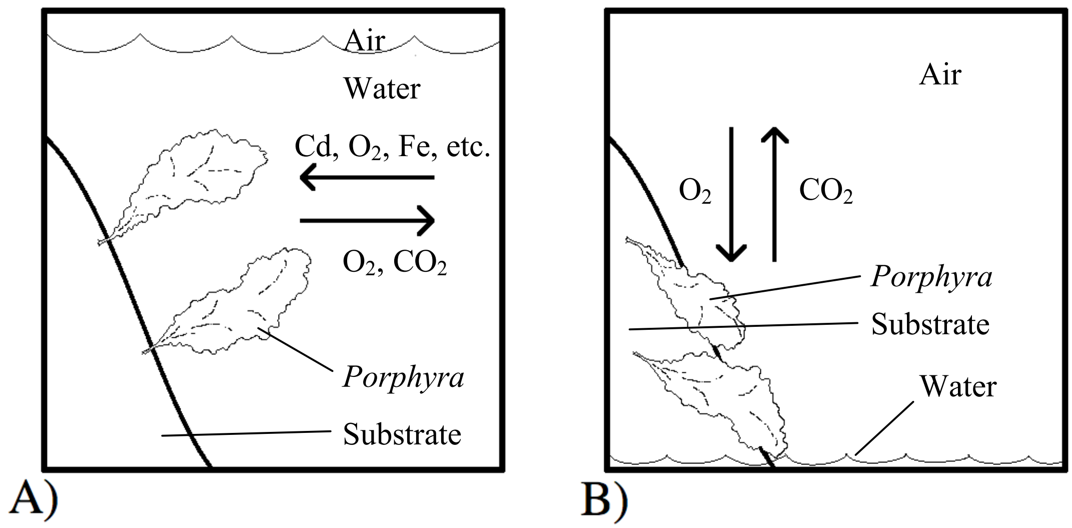


Figure 4.2. Examples of metal and gas transfer between *Porphyra* sp. and environment at A) high tide and B) low tide.

Metal uptake in seaweeds is not uniform throughout the year. Vasconcelos and Leal (2001) found seasonal variation in *Porphyra* spp. and *Enteromorpha* spp. (now *Ulva* spp.) metal uptake. Their *in situ* studies in Portugal showed that *Porphyra* increased its uptake of cadmium and lead in the winter months as compared to the summer months. The winter months were the time when the seaweed thalli are growing rapidly and increasing in surface area. The authors concluded that seasonal variation could be responsible for variations in results between independent studies on algal metal uptake and excretion. This problem in potential seasonal variation in my analysis is circumvented by the fact that the seaweed is only ever harvested for food during a very specific period of the year. Kwakwaka'wakw and other Indigenous authorities of the Northwest Coast specify that *P. abbottiae* is harvested in May or early June, every year.[104] Accounting for seasonal variability in metal concentrations would only be a problem if *P. abbottiae* destined for consumption was harvested over different periods in its lifecycle.

*Metal contamination in marine systems*

Algae have long interested scientists for their ability to accumulate and sequester both trace nutrients and metals. This ability has led to research into the potential use of algae for bioremediation, biofuel production, and multi-trophic or integrated marine aquaculture applications (e.g. Shiewer and Volesky 2000; Neori 2008; Smith et al. 2009). Anthropogenic water pollution can be a serious problem, especially near urban, agricultural, and industrial sites. Nutrients such as nitrogen and phosphorus are normally a limiting factor to algal growth in coastal waters, but excess volumes from agricultural runoff can promote phytoplankton growth and cause algal blooms, leading to eutrophication. On the other hand, by concentrating excess nutrients or metals from the water column, algae have the potential to remove surplus nutrients from agricultural runoff or finfish aquaculture operations in the Broughton Archipelago.

Marine pollution is also a concern due to the bioaccumulation and biomagnification in the food chain of substances harmful to aquatic life. Humans are also susceptible to increasing concentrations of marine contaminants, including from consuming traditional foods: harbour seals (*Phoca vitulina*) in Puget Sound have shown elevated concentrations of persistent organic pollutants (POPs), with contaminant burdens up to seven times greater than those in seals from the nearby Strait of Georgia (Ross et al. 2004). Cullon et al. (2005) estimated that the daily intake of POPs by these seals exceeded the daily-tolerable intakes under wildlife guidelines set by several federal agencies, and that younger seals may be even more vulnerable to negative health effects than adult seals. While present in the water in very low concentrations, POPs such as polychlorinated biphenyls (PCBs) and organochlorine pesticides were found at measurable but as of then not harmful levels in ooligans and ooligan grease from the Nass River, Kitimaat, Bella

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[104] This is the time just prior to the release of the seaweed's gametes. (*K$^{w}$axsistalla* and *Mayanił*, pers. comm. 2009; Turner 2003; Turner and Clifton 2006).

Coola, Kingcome Inlet, and Knights Inlet in British Columbia (Chan et al. 1996). British Columbia oyster growers at aquaculture operations around Vancouver Island and the adjacent mainland also showed measurably increasing levels of cadmium in their blood over a span of 5 years from consuming oysters (Copes et al. 2008).

Van Netten et al. (2000) analyzed several edible species of seaweed commercially available in British Columbia, including several species sourced from Bamfield, BC (*Alaria marginata* Postels & Ruprecht, *Laminaria saccharina* (L.) Lamouroux,[105] *Laminaria setchellii* P.C. Silva, *Macrocystis integrifolia* Bory de Saint-Vincent,[106] *Nereocystis leutkeana* (K. Mertens) Postels & Ruprecht). They found that three local species tended to have lower concentrations of lead than imported species, but two local species had elevated cadmium concentrations.

*Sources of pollutants*

The environmental pollutants both present and suspected in the waters off the coast of British Columbia are potentially of deep concern: besides anthropogenic and naturally occurring metals, there are persistent organic pollutants, organic metal compounds, plant hormones, and pharmaceuticals, many of which are being found in the marine food chain (E.g. Chan et al. 1996; Ross et al. 2000; Ross and Birnbaum 2003; Cullon et al. 2005; Johannessen et al. 2007; Copes et al. 2008). These pollutants can travel exceedingly long distances and arrive at apparently pristine areas though atmospheric circulation, ocean currents, and in the tissues of migratory animals. Johannessen et al. (2007) identified ten potential sources of contaminants in the Pacific North Coast Integrated Management Area (PNCIMA). The southern half of this Management Area entirely encompasses the sections of the Broughton and Queen Charlotte Straits visited in this study. The potential sources listed by Johannessen et al. (2007) are: 1) aquaculture, 2) vessel traffic including shipping and cruise ships,[107] 3) ports, harbours and marinas, 4) forestry runoff, 5) pulp and paper mill effluents, 6) mining, 7) dumping, 8) military and coast guard sites, 9)

[105] Currently *Saccharina latissima* (L.) C.E. Lane, C. Mayes, Druehl & G.W. Saunders.
[106] Currently *Macrocystis pyrifera* (L.) C. Agardh.
[107] As a personal observation, we saw both a cruise ship and a diving tour boat pass by the Pearse Island site while we were harvesting seaweed in May 2009.

offshore oil and gas, and 10) long-distance global contaminants. Of these, the authors speculate that increased vessel traffic, acid rock drainage and leaching from past mining and smelting operations, expanding aquaculture, and globally dispersed POPs pose the greatest threat to marine environmental quality in the PNCIMA.

While metals can originate from anthropogenic sources, there are also significant natural sources of metals to consider. On a global scale, metals can enter marine systems through volcanic activity, bedrock weathering, and forest fires (Nriagu and Pacyna 1988). In British Columbia, bedrock weathering has been known to release cadmium into coastal waters (Kruzynski 2000). The challenge is to distinguish between these naturally occurring, background levels of metals in the water and seaweed from anthropogenic sources of the same elements. If the sources of the metals in seaweed are identified as anthropogenic, consumers can press for source control or mitigation.

## 4.2 Objectives

This chapter examines the results of the metal analysis performed on samples of *Porphyra abbottiae* collected at traditional harvesting sites in the Broughton Strait in May 2008 and 2009. The primary objectives here are to observe whether there are any discernable differences in metal concentrations among sites, to identify the primary factors responsible for such differences, and to consider potential risks arising from consumption of *P. abbottiae* from this region. I will examine the results of the metal analyses from two perspectives: 1) health risks from metal consumption as a result of eating *P. abbottiae* on a regular basis; and 2) potential risks to people's health and well-being incurred if they stop harvesting and consuming the seaweed. The long-term health risks are assessed using Health Canada and World Health Organization guidelines for upper metal intake levels. I then compare risks and benefits of continued harvesting and consumption of *P. abbottiae* from the perspectives of health and culture.

## 4.3 Methods

### *Study area*

Samples of *P. abbottiae* were collected in May 2008 and 2009 at several sites in the Broughton and southern Queen Charlotte Straits between the northeast coast of

Vancouver Island and the adjacent mainland of British Columbia, within Kwakwa̱ka̱'wakw traditional territories. These sites lie across a landscape with chemically and chronologically diverse geological strata (Province of British Columbia 1996). The collection sites were identified through discussions with *K^w^axsistalla* and *Mayanił*. Most of them were at locations that they remembered visiting for seaweed harvesting, during their lifetimes, in some cases as children. Other sites were selected for proximity to the base camp and to achieve a broader representation of samples from different areas of the Broughton and Queen Charlotte Straits. A map of the study area and sites is shown in Figure 2.1. In addition to the analysis samples of *P. abbottiae* with the prime appearance and texture for consumption, I included *P. abbottiae* collected from Bauza Island in 2008 with a yellow-brown colour and crinkly, rough texture.[108] I also included in my analyses one sample collected from the area of Bella Bella to the north, in Heiltsuk territory.[109]

Harvesting of samples paralleled traditional harvesting methods, as described by *K^w^axsistalla* and *Mayanił*, and was timed to coincide with the earliest low tide each day so that the seaweed would be exposed to the air. I randomly selected samples from the *P. abbottiae* harvested at these sites by blindly picking individual blades from a bag containing the freshly collected seaweed after harvesting was completed. Sites, coordinates, and site-years sampled are listed in Appendix C.

*Laboratory methods*

From July 27 to July 31, 2009, all *Porphyra abbottiae* samples collected in May 2008 and May 2009 were prepared for metal analysis in Dr. Hing Man (Laurie) Chan's

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[108] The elders advised that *P. abbottiae* destined for consumption should have a smooth texture and green colour, with no fraying at the margins that indicate the frond has entered a reproductive state. I wanted to see how this 'crinkly' *P. abbottiae* differs chemically from edible *P. abbottiae*.

[109] The Bella Bella seaweed was a gift from Mary Vickers and was not collected during the Malcolm Island seaweed expeditions of 2008 and 2009. It was already shredded and consisted of multiple blades from a single site, and so the five sub-samples I took were all from this site.

laboratory at University of Northern British Columbia (UNBC), Prince George. Andrew MacKinnon assisted me in the laboratory with the sample digestions.

I followed a modified nitric acid digestion protocol from Chan et al. (1995) for the samples. Blades of *Porphyra abbottiae* fell within the range of required sample for analysis (0.3 to 0.5 g dried tissue). Individual blades of *P. abbottiae* did not have the mass necessary to provide two or more subsamples (>0.8 g). For this reason it was not possible to prepare replicates of individual blades collected. Instead we prepared 10 randomly chosen specimens from each site to represent the within-site variation. Each site was identified using prefixes (see Table 4.1). Three sites (Bauza, Pearse, and Foster islands) were sampled in both 2008 and 2009.

The blades were shredded manually using sterile latex gloves into small pieces (approximately 1 cm x 1 cm) to homogenize each sample. This was done to avoid any bias from variable metal concentrations within different parts of the blade. At least 5 pieces of each shredded blade were used when weighing out the 0.3 - 0.5 grams required. Three samples from each location (with the exception of the Bella Bella samples) were prepared daily to reduce the risk of any error affecting results for an entire site. On the final day of processing, one sample from each site was processed.

As a quality control check, three replicates of standard reference apple leaves (91515 Apple Leaves, NIST Standard Reference Material® [National Institute of Standards and Technology 1993]) and one blank sample were also digested using the same protocol and included with each daily batch to be processed. Each sample was weighed in glass reflux tubes to four decimal places.

Table 4.1. Sample identifiers from sample sets collected in May 2008 and May 2009.

| Island Sample Set | Year | Sample Prefix Identifier |
|---|---|---|
| Bauza Island (yellow) | 2008 | BY08 |
| Bauza Island | 2008 | Z08 |
| Foster Island | 2008 | F08 |
| Pearse Island | 2008 | P08 |
| Bella Bella | 2008 | L08 |

| | | |
|---|---|---|
| Bauza Island | 2009 | A09 |
| Foster Island | 2009 | S09 |
| Pearse Island | 2009 | C09 |
| Holford Island | 2009 | H09 |
| Plumper Island | 2009 | M09 |

While working inside a fumehood, I added 4.0 mL nitric acid ($HNO_3$) to each sample to begin pre-digestion. Tubes were covered with glass reflux bulbs and allowed to pre-digest overnight at room temperature for 15 hours after adding the $HNO_3$. The following day we added 1.00 mL hydrochloric acid (HCl; >30% pure) and 0.10 mL gold chloride ($AuCl_3$; 500 μg/mL in 2% $HNO_3$) to each tube. Tubes were immediately re-covered and placed in a dry bath. Samples were heated to 100° C within 2-3 hours, and left at 100° C in the bath for a total of 7 hours. Tubes were removed from the bath and allowed to cool to room temperature.

The contents of each tube were decanted into 50 mL plastic graduated centrifuge tubes. Tubes were rinsed out using Nanopure water, or ultra-pure water with a water electrical resistance value of 18.2 MOhm-cm, filtered in a Barnstead EASYpure® II LF ultrapure water system. The wash was also transferred to the centrifuge tubes. We then added 1.0 mL hydrogen peroxide ($H_2O_2$; 35% pure). The centrifuge tubes were filled to 50 mL using nanopure water. The full chemical list can be found in Appendix D.

Samples were centrifuged using an Allegra™ 25R Centrifuge for 10 minutes at 3000 rpm, RCF 1912 using Rotor ST 5.1-500 to remove any floating particles from the column and compress them into pellets. Each tube was then decanted into a new 50 mL graduated tube. Any volume lost from the removal of the pellet was made up with nanopure water. I set aside the samples at room temperature until analysis.

During sample preparation, samples S09-1 and S09-2 collected from Foster Island in May 2009 were accidentally combined while decanting the samples from the glass tubes into the graduated tubes prior to adding $H_2O_2$. S09-2 was repeated from the remaining material, but there was an insufficient quantity of tissue to repeat S09-1. The tube containing both samples S09-1 and S09-2 (original sample) was therefore discarded from the analysis.

All glassware used during sample preparation was acid-washed to remove any contaminants. After rinsing with 70% isopropyl alcohol to remove any markings and 2% Decon (also known as Contrad® 70 [Contrad® 70 MSDS 2008], a glassware cleaning agent), the glassware was rinsed several times under hot tap water and then with distilled water. Glassware was then left fully submerged in a Decon bath overnight, after which it was rinsed again several times under hot tap water, distilled water, and nanopure water. Glassware was moved to a 20% HCl bath for at least 4 hours, and then rinsed under nanopure water. The glassware was then moved into a final 10% $HNO_3$ bath, left for at least 4 hours, and then rinsed under nanopure water before being dried in the oven.

Samples were run through an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) at University of Northern British Columbia by laboratory technician Allen Esler. The target elements were: arsenic, calcium, cadmium, cobalt, chromium, copper, iron, mercury, manganese, lead, selenium, and zinc. Element concentrations determined by the chemical analysis are presented in Appendix E.

*Statistical analyses*

The data were normalized for the analysis by mean adjustment. This was accomplished by dividing the data in each row by the sum of the metal concentrations across the row. These resulting values in each column were then divided by the geometric mean of the column, normalizing the data by chemical element and by site location.

The data were initially explored using Pirouette® modelling software to conduct Principal Component Analyses (PCA). The first PCA included only the metal concentrations across sites and elements. The second PCA added a set of independent variables derived from geographical features that may be driving differences in metal concentrations between sites. These variables were: latitude, longitude, distance to nearest largest land mass (either Vancouver Island or the mainland), distance to nearest island >10 $km^2$, number of islands in a 1 and 2 kilometre radius, distance to nearest community, channel width,[110] shoreline length within 1 km radius, and distance to 100 m and 200 m water depth.[111] Both PCA tests were run using autoscale preprocessing and $\log_{10}$ transformation of the data, and normal rotation of the principal components.

Systat 13 was used to carry out ANOVA, t-tests, correlation, and regression. I performed single-factor ANOVA tests (level of significance=0.05) to assess the variance in metal concentrations between islands. The same independent variables included in the PCA analysis were used for the correlation and regression tests. Sites that were sampled both in 2008 and 2009 (Foster, Pearse, and Bauza Islands) were included in the analysis using both years as separate 'sites.' I ran post hoc Tukey tests to identify sites with significantly different mean metal concentrations in their *P. abbottiae* populations. Differences in metal concentrations were considered significant when $p<0.05$.

*Risk quantification*

To quantify risk from ingesting metals in *P. abbottiae*, I first had to understand: 1) how much seaweed, on average, is normally consumed, and 2) at what concentrations do metals begin to cause health problems in people. To establish an average consumption rate, I used the pooled data obtained from a dietary survey conducted in five First Nation communities on Vancouver Island including two Kwakwa̱ka̱'wakw communities, Quatsino and We Wai Kum (Campbell River) First Nations (Child and Ross, pers. comm.).

I used average consumption rates and mean & maximum element concentrations to determine the expected exposure to these elements through normal consumption of *P. abbottiae*. Tolerable Daily Intake (TDI) values set by Health Canada and the World Health Organization (WHO) were used to rank metals and trace elements according to relative health risk by dividing the average concentration of the elements by the TDI

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[110] Defined as the distance to the point facing across the channel along the sampling site.
[111] Distances to the nearest buildings, communities, and largest landmasses were obtained using the topographic map of Canada in the Atlas of Canada found online at http://atlas.nrcan.gc.ca/site/english/maps/topo/map.

values.[112] These allow me to identify potential contaminants of concern based on standard guidelines. Hazard quotients (HQ) calculated from the mean element concentrations in *P. abbottiae* and TDI values were used to gauge probable health risk from consumption independently the consumer's body mass following Chan et al. (2011) (Laurie Chan, pers. comm. May 2011). Appendix F lists the current, accepted TDI limits recommended by Health Canada and the WHO.

## 4.4 Results

### 4.4.1 Inter- and intra-site metal trends

Two-sample t-tests performed on the sites sampled in both 2008 and 2009 (Pearse Island, Foster Island, and Bauza Island ) showed few significant intra-site differences in metal concentrations between sampling years, with the exception of Foster Island (Table 4.2). When sites sampled in both 2008 and 2009 were analyzed separately, ANOVA tests showed that chromium ($p$=0.14), lead ($p$=0.62) and copper ($p$=0.44) were not significantly different between sites. These elements along with manganese ($p$=0.24) and mercury ($p$=0.12) also showed no significant differences between sites when those sites sampled both years were treated as a single site.

Table 4.2. Significant temporal changes in mean intra-site element concentrations between 2008 and 2009.

| Site | Element | Net change (mg/kg dry seaweed) | $p$ |
|---|---|---|---|
| Pearse Island | Calcium | -150 | 0.01 |
| | Lead | +0.2 | 0.01 |
| Foster Island | Manganese | -2.9 | 0.01 |
| | Iron | -19.0 | 0.00 |
| | Zinc | -4.3 | 0.00 |
| | Arsenic | -4.3 | 0.03 |
| | Chromium | +0.3 | 0.05 |
| | Selenium | +0.1 | 0.02 |
| Bauza Island | Calcium | +165 | 0.00 |
| | Lead | -0.3 | 0.00 |

[112] Health Canada and the Institute of Medicine of the National Academy of Sciences in the United States have not set a tolerable upper limit value for chromium due to a lack of data on chronic chromium intake. For this metal, Health Canada recommends being careful when consuming this element in excess of the Adequate Intake (AI) of 35 µg/day (Institute of Medicine of the National Academies 2006).

*Principal Component Analysis (PCA)*

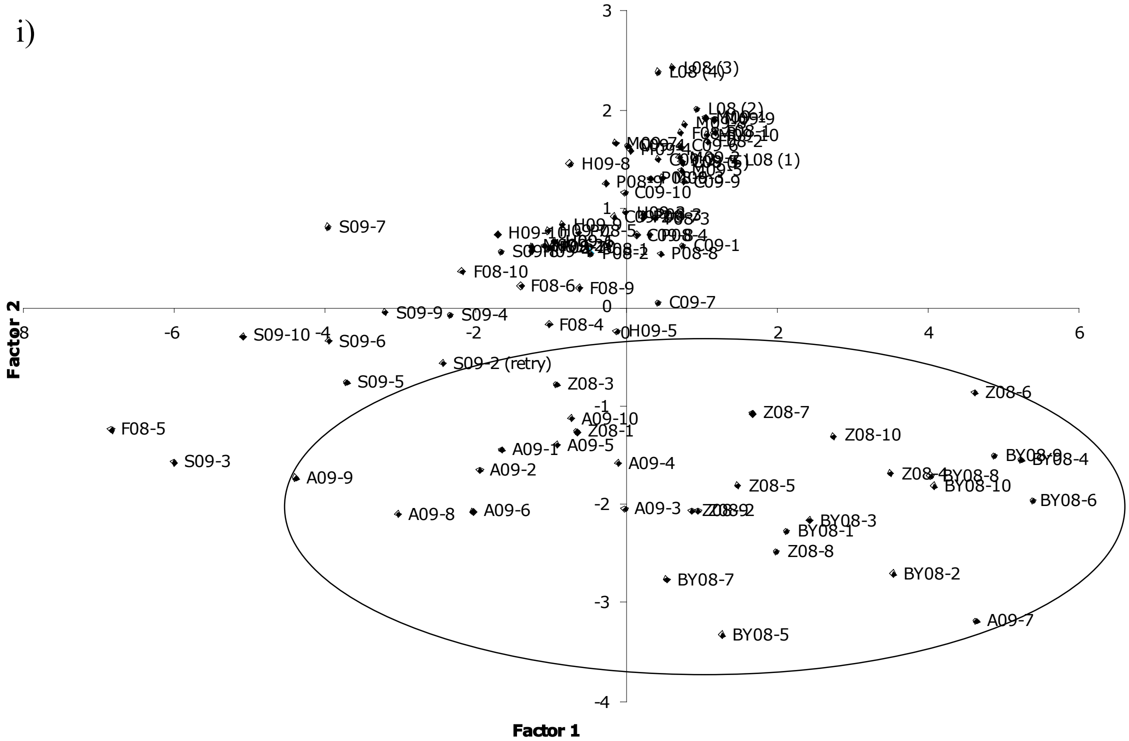
The initial PCA suggested that one sample, A09-7, was an outlier in the data. I excluded this data point from further PCA runs for further exploration, but it was not excluded from the univariate statistical tests. The PCA revealed that there are two well-defined components in the chemical analysis data. In Figure 4.3 i), many of the Bauza Island samples (Z08, BY08, and A09) lie horizontally across Factor 1, while most of the other samples lie vertically along Factor 2. When viewed in a three-dimensional graph a single data point, A09-7, was an outlier among the Bauza samples. A closer look at the data showed that A09-7's copper, zinc and lead concentrations were much higher compared to other samples within the same site and from samples at all other sites. Removing the Bauza samples from the PCA resulted in a more even distribution of the samples across Factors 1 and 2, with some of the Foster Island samples (S09 and F08) pulling away from the Pearse, Plumper, Holford, and Bella Bella samples (Figure 4.3 [ii]).

Three factors explained 71.4% of the variation in metal concentration trends. PCA factor 1 (PC1) explained 42.4% of the variation, PC2 explained 17.8%, and PC3 explained 11.2%. When I repeated the procedure on the data that excludes the Bauza Island samples, factors 1-3 accounted for 75.0% of the variation. PC1 rose to 55.3%, while PC2 and PC3 fell to 11.0% and 8.7%, respectively.

I correlated the PCA factor loadings from the first analysis against the element concentrations to see which elements most likely explain the variance in the principal components. PC1 had a moderate but significant negative correlation[113] with calcium in *P. abbottiae* ($R^2$= 0.527, $p$= 0.00). PC2 correlated most strongly with cadmium ($R^2$= 0.728, $p$= 0.00) and arsenic ($R^2$= 0.638, $p$= 0.00). PC3 showed the weakest relationship to an element among the three PCA factors; at best it had a moderate negative correlation to lead concentrations in the seaweed ($R^2$= 0.426, $p$= 0.00). The full table of Pearson correlation coefficients and correlation $p$-values can be found in Appendix G.

[113] The Pearson correlation coefficient is represented by $r$, and the coefficient of determination is represented as $R^2$. A correlation will be considered strong if $r \geq 0.8$, moderate if $0.8 < r > 0.5$ and weak if $r \leq 0.5$.

i)




ii)

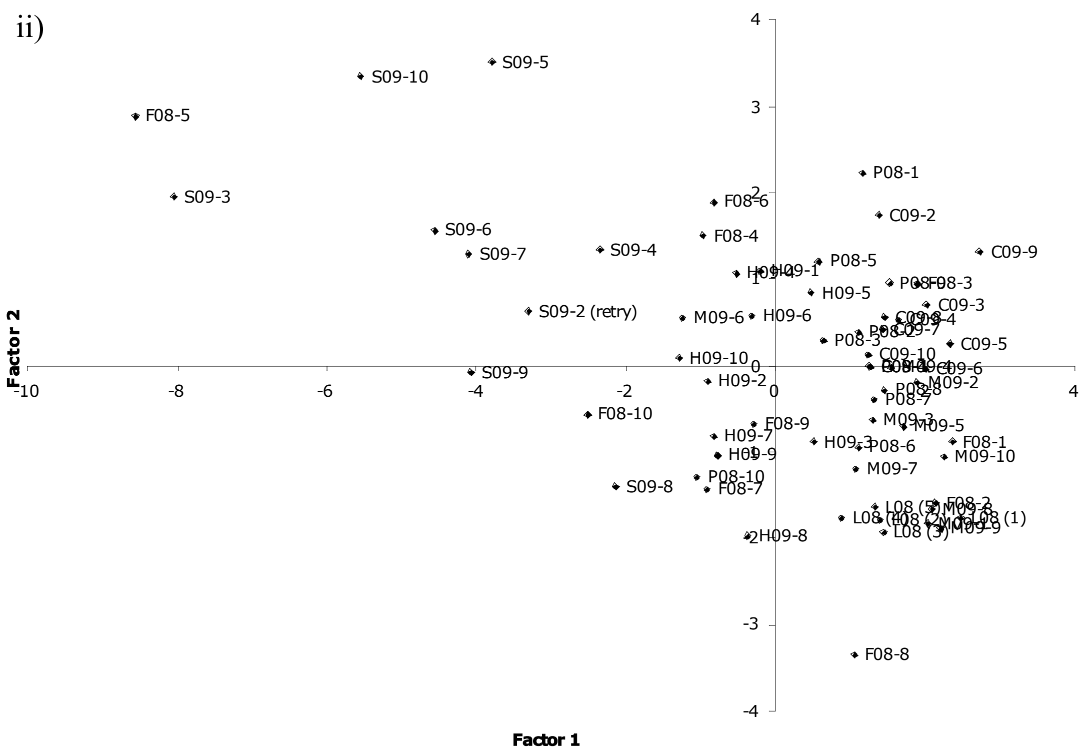



Figure 4.3. PCA loadings graphs showing the relationships between the samples with i) the full data set with the Bauza Island samples (circled) and ii) after the Bauza Island samples are excluded.

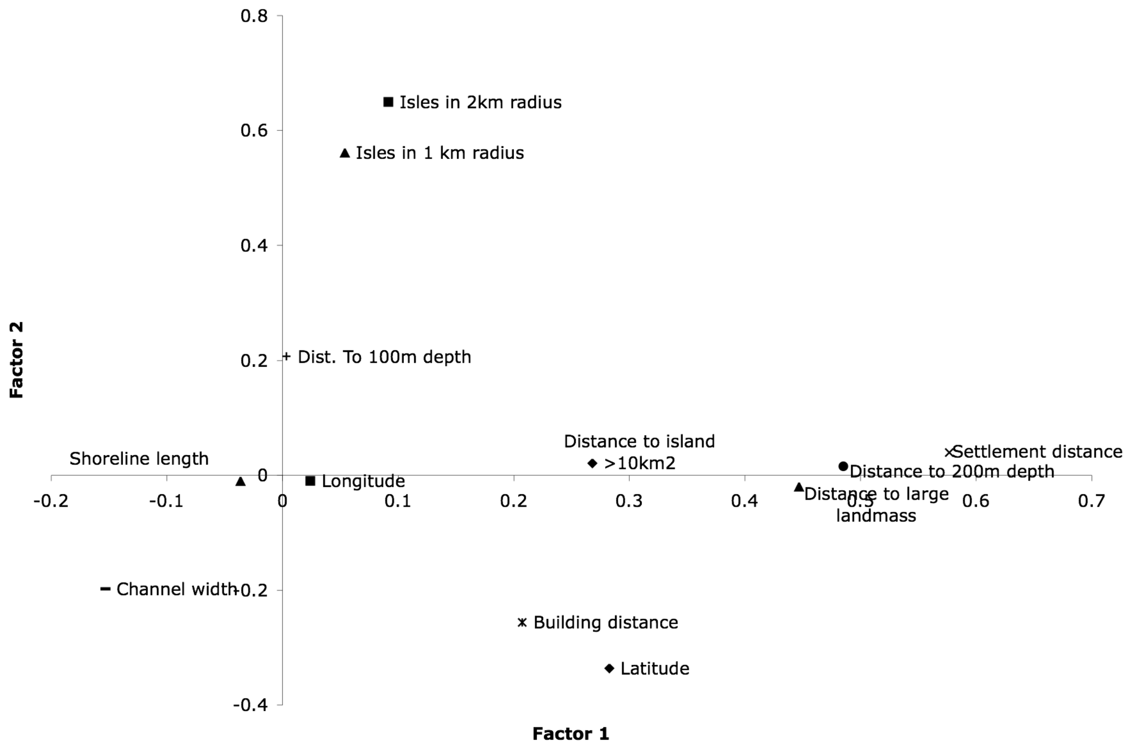



Figure 4.4. PCA loadings graph showing the relationship between the geographical factors with respect to metal concentrations in the seaweed samples.

In Figure 4.4, PC1 appears to be best explained by the distance to the nearest settlement, distance to 200 m water depth, and the distance to the nearest large landmass. The nearest distance to 100 m water depth in a nearby channel best represents PC2.[114]

[114] Two geographical factors (number of islands within a 1 and 2 km radius) had high $R^2$ values from a least squares regression discussed below (0.818 and 0.805, respectively), but these measures were not counted because the island sizes were not uniform and thus introduce an unknown variable.

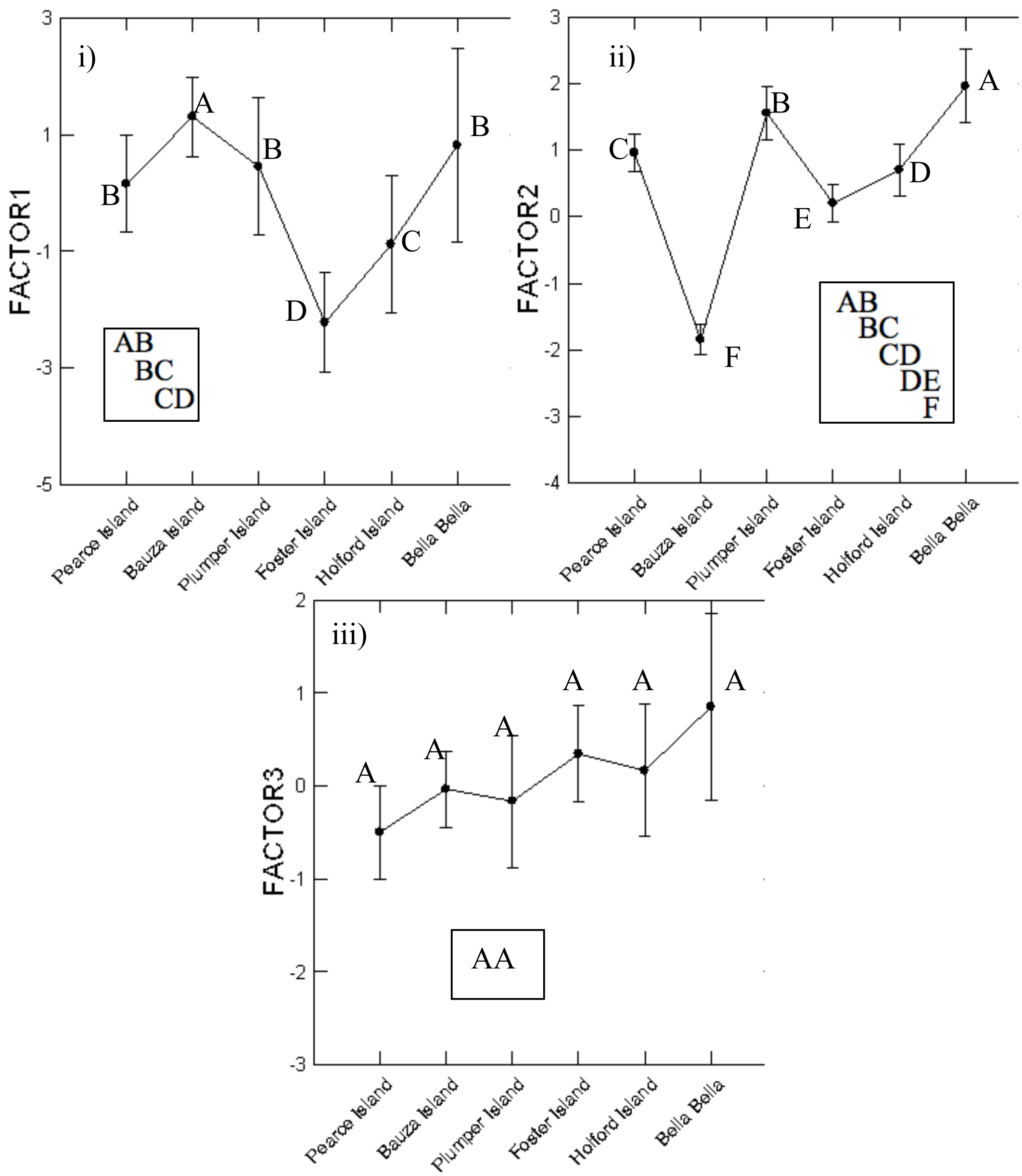



Figure 4.5. Means and 95% confidence intervals of (i) PC1, (ii) PC2, and (iii) PC3 grouped by harvesting site. Sampling sites that share a letter are not significantly different ($p$>0.05). Each row in the inset shows groups of sites that are not significantly different.

Figure 4.5 shows the grouping of sampling sites along the principal component analysis factors. The islands did not consistently group together in the PCA according to geographical factors such as latitude or proximity to other islands sampled. Figure 4.5 i) shows that Bella Bella, a site further north and outside of the Broughton Strait, is not significantly different from the Pearse, Plumper, Bauza, and Holford sites. In Figure 4.5 ii) Bauza stands out as being significantly different from all other sites. There were no significant differences between any of the sites along PC3 (Figure 4.5 [iii]). When testing PCA factors against the suite of possible geographical factors using least-squares regression, I found that variance in PC1 was weakly explained by the distance to the nearest large landmass ($R^2$= 0.295, $p$= 0.00; Table 4.3). This is in contrast to Figure 4.4, which suggested that distance to the nearest settlement might be a better predictor for PC1. The distance of the harvesting site to the nearest point where the water reached a depth of 100 m best explained the variance in PC2 ($R^2$= 0.502, $p$= 0.00), which is in agreement with Figure 4.4. None of the geographical factors could be significantly correlated to PC3 ($p$> 0.05). After removing the Bauza sites from the correlation, PC1 continued to be best correlated to the distance to largest landmass; $R^2$ increased to 0.358 ($p$= 0.00). PC2 was now best correlated to longitude ($R^2$= 0.135) instead of distance to the nearest 100 m water depth, but this was not significant ($p$= 0.33). PC3 was again not significantly correlated to any of the geographical variables.

Table 4.3. Regression $p$-values and $R^2$ values for the PCA factors tested against site-specific factors.

| | | All sites | | | Bauza removed | | |
|---|---|---|---|---|---|---|---|
| | | PC1 | PC2 | PC3 | PC1 | PC2 | PC3 |
| Latitude | $p$ | 0.00 | 0.00 | 0.14 | 0.00 | 0.51 | 0.99 |
| | $R^2$ | 0.278 | 0.211 | 0.025 | 0.317 | 0.008 | 0.000 |
| Longitude | $p$ | 0.00 | 0.00 | 0.91 | 0.01 | 0.00 | 0.74 |
| | $R^2$ | 0.171 | 0.116 | 0.000 | 0.102 | 0.134 | 0.002 |
| Distance to large landmass | $p$ | 0.00 | 0.00 | 0.13 | 0.00 | 0.44 | 0.96 |
| | $R^2$ | 0.295 | 0.209 | 0.027 | 0.358 | 0.010 | 0.000 |
| Distance to 200 m depth | $p$ | 0.00 | 0.00 | 0.19 | 0.00 | 0.86 | 0.99 |
| | $R^2$ | 0.228 | 0.242 | 0.020 | 0.201 | 0.001 | 0.000 |
| Distance to 100 m depth | $p$ | 0.00 | 0.00 | 0.28 | 0.04 | 0.12 | 0.67 |
| | $R^2$ | 0.068 | 0.502 | 0.014 | 0.074 | 0.042 | 0.003 |
| Number islands in 1 km radius | $p$ | 0.00 | 0.00 | 0.23 | 0.00 | 0.24 | 0.90 |
| | $R^2$ | 0.334 | 0.818 | 0.064 | 0.309 | 0.024 | 0.000 |
| Number islands in 2 km radius | $p$ | 0.00 | 0.00 | 0.17 | 0.00 | 0.35 | 0.99 |
| | $R^2$ | 0.333 | 0.805 | 0.058 | 0.360 | 0.015 | 0.000 |
| Distance to nearest settlement | $p$ | 0.00 | 0.00 | 0.29 | 0.00 | 0.71 | 0.95 |
| | $R^2$ | 0.207 | 0.353 | 0.013 | 0.212 | 0.002 | 0.000 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Shoreline length 1km radius | $p$ | 0.15 | 0.00 | 0.68 | 0.74 | 0.89 | 0.76 |
| | $R^2$ | 0.024 | 0.155 | 0.002 | 0.002 | 0.000 | 0.002 |
| Channel width | $p$ | 0.00 | 0.00 | 0.45 | 0.05 | 0.54 | 0.75 |
| | $R^2$ | 0.139 | 0.167 | 0.007 | 0.066 | 0.007 | 0.002 |
| Distance to island >10 km$^2$ | $p$ | 0.00 | 0.00 | 0.49 | 0.21 | 0.37 | 0.55 |
| | $R^2$ | 0.300 | 0.407 | 0.005 | 0.027 | 0.014 | 0.006 |

I used correlation and regression to test the geographical factors against the element concentrations between sites. Arsenic proved to have a correlation to the distance to the nearest large island >10 km$^2$ ($R^2$= 0.560, $p$= 0.00). Cadmium likewise had a positive correlation to distance to nearest large island >10 km$^2$ ($R^2$= 0.502, $p$= 0.00). The remainder of the elements were weakly correlated to the geographical factors ($R^2$< 0.300). Chromium, manganese, cobalt, copper, mercury, and lead were not significantly correlated to any of the geographical factors. The full table of the ANOVA results and regressions is found in Appendix H.

Table 4.4. Bonferroni-corrected $p$-values from correlations between the concentrations of elements across all sites (excluding Bella Bella). Significant values ($p$< 0.05) are indicated in bold font.

| | **Ca** | **Cr** | **Mn** | **Fe** | **Co** | **Cu** | **Zn** | **As** | **Se** | **Cd** | **Hg** | **Pb** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ca** | 0.00 | | | | | | | | | | | |
| **Cr** | 1.00 | 0.00 | | | | | | | | | | |
| **Mn** | 1.00 | 1.00 | 0.00 | | | | | | | | | |
| **Fe** | 1.00 | 1.00 | **0.00** | 0.00 | | | | | | | | |
| **Co** | 1.00 | 1.00 | **0.00** | **0.00** | 0.00 | | | | | | | |
| **Cu** | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | | | | | | |
| **Zn** | 1.00 | 1.00 | 1.00 | 0.28 | 1.00 | **0.00** | 0.00 | | | | | |
| **As** | 1.00 | 1.00 | **0.00** | **0.00** | 1.00 | 1.00 | **0.00** | 0.00 | | | | |
| **Se** | 1.00 | 1.00 | **0.00** | **0.00** | **0.00** | 1.00 | 1.00 | **0.00** | 0.00 | | | |
| **Cd** | 1.00 | 0.34 | 1.00 | 1.00 | 0.61 | 1.00 | **0.01** | **0.00** | 1.00 | 0.00 | | |
| **Hg** | 1.00 | 1.00 | 0.32 | 1.00 | 0.06 | 1.00 | 1.00 | 0.87 | **0.00** | 1.00 | 0.00 | |
| **Pb** | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | **0.00** | **0.00** | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 |

I then correlated the metals across all sites to each other to discern whether or not there may be relationships between metal concentrations. The $p$-values were adjusted using the Bonferroni correction to decrease the likelihood of a false positive error. Table 4.4 shows the $p$-values from these correlations. Copper and lead show a strong positive correlation in *P. abbottiae*, with $R^2$= 0.899 (Table 4.5). Copper and zinc also have a strong, positive correlation ($R^2$= 0.697). Zinc and lead have a moderate correlation ($R^2$= 0.594). The remainder of significant correlations show moderate to weak $R^2$ values explaining the variance between the elements.

Table 4.5. Pearson correlation coefficients (*r*) of significantly correlated element-element pairings ($p < 0.05$).

| | **Mn** | **Fe** | **Co** | **Cu** | **Zn** | **As** | **Se** |
|---|---|---|---|---|---|---|---|
| **Fe** | 0.589 | - | - | - | - | - | - |
| **Co** | 0.540 | 0.510 | - | - | - | - | - |
| **Zn** | - | - | - | 0.835 | - | - | - |
| **As** | -0.419 | -0.435 | - | - | -0.412 | - | - |
| **Se** | 0.569 | 0.548 | 0.617 | - | - | -0.567 | - |
| **Cd** | - | - | - | - | -0.396 | 0.666 | - |
| **Hg** | - | - | - | - | - | - | 0.548 |
| **Pb** | - | - | - | 0.948 | 0.771 | - | - |

4.4.2 Health risks related to ingestion of metals

I ranked the metals according to their relative risk in an average sample of seaweed by dividing the mean element concentration by the tolerable daily intake (TDI). This ranking is relative because it is independent of the quantities of seaweed consumed; it shows the order in which elements will meet their TDI with unrestricted consumption of the seaweed. Table 4.6 shows that arsenic and cadmium rank first and second, respectively, as the contaminants of concern in *P. abbottiae* from this study. Their relative risk quotients are two orders of magnitude greater than those of manganese, lead, iron, chromium, calcium, zinc, copper, and selenium. The elements of least concern in this ranking are mercury and cobalt.

The average yearly consumption of *P. abbottiae* among the 5 communities surveyed by Child and Ross (pers comm.) was estimated at 16.3 meals/year or approximately 0.74 kg/year. This would average out to approximately 2 g/day. One full portion (one cup) measures approximately 7 g.[115] I first looked at establishing an absolute estimate of risk

[115] I obtained this value from a loosely packed measuring cup filled with *P. abbottiae*. It is important distinguish between portions and meals. Respondents were asked to estimate portion sizes using cups or parts of cups. Meal sizes were not standardized. Respondents

for a theoretical, 60 kg adult consumer of *P. abbottiae*. I used the tolerable daily intakes for arsenic and cadmium, which were identified as the elements of most concern. The mean concentration of arsenic was 19.0 ± 9.8 mg/kg dry seaweed. Yearly consumption of 0.74 kg dry seaweed would result in the consumer being exposed, on average, to 14.1 ± 7.3 mg arsenic/year. The tolerable dietary intake of arsenic for a 60 kg adult according to the WHO is 0.18 mg/day or 65.7 mg/year. This theoretical 60 kg adult would ingest 21.4% of their yearly tolerable intake of arsenic by eating 0.74 kg dry seaweed/year. The same adult would also ingest 9.6% of their yearly limit of cadmium. The remainder of the elements surveyed fell well below tolerable dietary intake levels (< 0.3% TDI) for a 60 kg as set by Health Canada and the WHO.

Table 4.6. Ranking of elements by relative health risk posed by elements found in *P. abbottiae*, where 1= greatest risk and 12= lowest risk. All TDI values are from the WHO unless indicated as being sourced from Health Canada by an asterix (*).

| Element | Mean concentration (mg/kg dry seaweed) | Standard deviation (mg/kg dry seaweed) | TDI (mg/kg b.w./day) | Relative risk (concentration/ TDI) | Relative risk/lowest risk element (cobalt) | Rank |
|---|---|---|---|---|---|---|
| Arsenic | 19.0 | 9.8 | $3x10^{-3}$ | 6338.2 | 2560.9 | 1 |
| Calcium | 1445.2 | 614 | 41.7 | 34.7 | 14.0 | 7 |
| Cadmium | 2.8 | 1.1 | $1x10^{-3}$ | 2835.0 | 1145.5 | 2 |
| Cobalt | 0.1 | 0.03 | $4x10^{-2}$ | 2.5 | 1.0 | 12 |
| Chromium | 0.2 | 0.2 | $4x10^{-3}$ | 45.0 | 17.7 | 6 |
| Copper | 3.6 | 1.2 | 0.2* | 21.4 | 8.7 | 9 |
| Iron | 41.9 | 15.6 | 0.8 | 52.4 | 21.2 | 5 |
| Mercury | 0.004 | 0.004 | $6x10^{-4}$ | 6.4 | 2.6 | 11 |
| Manganese | 14.2 | 4.1 | 0.2 | 77.7 | 31.4 | 3 |
| Lead | 0.3 | 0.1 | $4x10^{-3}$ | 74.9 | 30.6 | 4 |
| Selenium | 0.1 | 0.1 | $7x10^{-3}$ | 12.9 | 5.2 | 10 |
| Zinc | 17.3 | 4.6 | 0.7* | 25.8 | 10.4 | 8 |

I produced hazard quotient (HQ) values as a relative predictor of risk independent of the consumer's body mass, as opposed to an absolute measure of risk that incorporates and is

reported portions as small as 1/16th cup (one tablespoon) eaten 300 times over the preceding year, up to 6 cups eaten twice in a year.

specific to an individual's body mass.[116] Table 4.7 shows the HQ values for a single cup of *P. abbottiae* based on average element concentrations. Consumption of a single 7 g portion of *P. abbottiae* resulted in HQ> 1 for arsenic and cadmium. The remainder of the elements had HQ< 0.6, with cobalt (HQ= 0.0) and mercury (HQ= 0.1) demonstrating the lowest hazard quotients.

I then produced HQ values based on mean daily consumption of *P. abbottiae*. At maximum element concentrations, *P. abbottiae* had HQ values greater than 1 for arsenic, cadmium, and lead. Chromium and copper had HQ values of approximately 1, while the remainder of the elements had HQ< 0.3. Table 4.8 shows the HQ values for the seaweed under mean and maximum element concentrations.

Table 4.7. Hazard quotients (HQ) for one portion (7 g) of *P. abbottiae* using average metal concentrations.

| Element | TDI (mg/kg b.w./day) | Exposure (mg) | HQ (Exposure / TDI) |
|---|---|---|---|
| Arsenic | $3x10^{-3}$ | 0.1 | 44.4 |
| Calcium | 41.7 | 10.1 | 0.2 |
| Cadmium | $1x10^{-3}$ | $2x10^{-2}$ | 19.9 |
| Cobalt | $4x10^{-2}$ | $7x10^{-4}$ | 0.0 |
| Chromium | $4x10^{-3}$ | $1x10^{-3}$ | 0.3 |
| Copper | 0.2 | $3x10^{-2}$ | 0.2 |
| Iron | 0.8 | 0.3 | 0.4 |
| Mercury | $6x10^{-4}$ | $3x10^{-5}$ | 0.1 |
| Manganese | 0.2 | 0.1 | 0.5 |
| Lead | $4x10^{-3}$ | $2x10^{-3}$ | 0.5 |
| Selenium | $7x10^{-3}$ | $6x10^{-4}$ | 0.1 |
| Zinc | 0.7 | 0.1 | 0.2 |

Table 4.8. Hazard quotients (HQ) for *P. abbottiae* based on mean and maximum element concentrations. Exposure is based on mean daily consumption of *P. abbottiae* (2 g) harvested during the study.

| Element | TDI (mg/kg b.w./day) | Mean exposure (mg/day) | Max exposure (mg/day) | $HQ_{mean}$ (Mean/TDI) | $HQ_{max}$ (Max/TDI) |
|---|---|---|---|---|---|
| Arsenic | $3x10^{-3}$ | $4x10^{-2}$ | $6x10^{-2}$ | 12.9 | 20.9 |
| Calcium | 41.7 | 2.9 | 7.4 | 0.1 | 0.2 |
| Cadmium | $1x10^{-3}$ | $6x10^{-3}$ | $1x10^{-2}$ | 5.8 | 10.1 |

[116] Chan et al. (2011) state that the toxicity risk posed by the elements is negligible if the HQ is 1 or less.

| | | | | | |
|---|---|---|---|---|---|
| Cobalt | $4x10^{-2}$ | $2x10^{-4}$ | $4x10^{-4}$ | 0.0 | 0.0 |
| Chromium | $4x10^{-3}$ | $4x10^{-4}$ | $4x10^{-3}$ | 0.1 | 1.0 |
| Copper | 0.2 | $7x10^{-3}$ | 0.2 | 0.0 | 1.0 |
| Iron | 0.8 | 0.1 | 0.2 | 0.1 | 0.2 |
| Mercury | $6x10^{-4}$ | $7x10^{-6}$ | $6.1x10^{-5}$ | 0.0 | 0.1 |
| Manganese | 0.2 | $3x10^{-2}$ | $5x10^{-2}$ | 0.2 | 0.3 |
| Lead | $4x10^{-3}$ | $6x10^{-4}$ | $8x10^{-3}$ | 0.2 | 2.3 |
| Selenium | $7x10^{-3}$ | $2x10^{-4}$ | $8x10^{-4}$ | 0.0 | 0.1 |
| Zinc | 0.7 | $4x10^{-2}$ | 0.1 | 0.1 | 0.2 |

## 4.5 Discussion

### 4.5.1 Identifying the factors behind the trends

*Sources of metals*

The strongest metal-metal correlations observed in *P. abbottiae* were copper-lead ($r$= 0.948) and copper-zinc ($r$= 0.835), with a weaker relationship between zinc and lead ($r$= 0.771). The strong correlation of these sets of metals across all sites suggests that physiological processes are specifically regulating their uptake across the cell membrane; their relative concentrations in *P. abbottiae* remain roughly the same between samples despite site differences in water currents and exposed geological strata, whose erosion provide molecules in the water column for uptake (Foreman et al. 2006; Province of British Columbia 1996). Active and facilitated transport may explain the hyper-accumulation of copper, zinc, and lead observed in the outlier sample A09-7. This outlier may also reflect genetic adaptation to local rock composition, similar to some plant species' adaptation to serpentine soils (Brady et al. 2005). Over half of copper uptake in *Porphyra* is intracellular while the remainder is extracellular adsorption, suggesting that copper is transported against a concentration gradient at the cell membrane (Vasconcelos and Leal 2001). Zinc uptake in *Porphyra* occurs partly through non-metabolic exchange processes (facilitated diffusion) (Gutknecht 1963). While copper is known to inhibit cadmium uptake in algae, there is little information available on copper facilitating zinc or lead uptake (Andrade et al. 2006). Aquaculture operations in the Broughton Archipelago are known to enrich copper and zinc concentrations in sediment, but this is only observed in the immediate vicinity of the net-pens (Sutherland et al. 2007). None of the samples were collected from within 300 m of a pen,[117] the point at which Sutherland et al. (2007) no longer observed copper-zinc enrichment originating from fish farm activity. It is unlikely that aquaculture activities are a source of copper and zinc or any other contaminants at the seaweed harvesting sites.

The patterns in the PCA suggest that there may be oceanographic and geological features driving the variation between sites, but these could not be positively identified. Figure 4.4 suggested that distance to the nearest settlement might be associated with PC1, but this may actually be tied to another factor, distance to the nearest large landmass; most settlements identified as closest in proximity to the harvesting sites also occurred on the nearest large landmass, Vancouver Island. Shoreline length within a 1 km radius did not significantly correlate to metal concentrations or to the PCA factors. There was no clear relationship between shoreline (whose erosion provides material for uptake from the water column) and metal concentrations in *P. abbottiae*. Geologically, there are abundant natural sources for metals in the water column. Sediment in the Broughton Archipelago is known to contain cadmium at background concentrations of 0.1-0.2 ppm (Copes et al. 2008; Kruzynski 2000). These are thought to be primarily naturally occurring[118] in the absence of obvious cadmium inputs. Harvesting sites are in close proximity to plutonic rock,[119] a possible non-anthropogenic source of metals (Province of British Columbia 1996).

Another possibility is that some metals are transported from greater distances or upwelling in the channels. A water flow simulation by Foreman et al. (2006 [Figure 7]) shows that the harvesting sites are exposed to water currents from different channels. Foster and Holford Islands are exposed to water flow from the southern Queen Charlotte

[117] With the possible exception of the Bella Bella seaweed, for which there is no information on harvesting location or proximity to aquaculture operations.
[118] Natural sources of heavy metals include volcanic activity, bedrock weathering, and atmospheric gases originating from forest fires (Nriagu and Pacyna 1988).
[119] Plutonic rocks are intrusions of igneous or volcanic origin. The types of rocks found within these plutonic formations near the harvesting sites may include but are not limited to basaltic and pillow lava, breccia, quartz, diorite, amphibolite, granodiorite, gneiss, and argillite (Province of British Columbia 1996).

Strait and, in the case of Holford Island, from Fife Sound. Plumper and Pearse Islands face currents from both the southern Queen Charlotte and northern Johnstone Straits from their location in Weyntone Passage. Bauza Island alone is exposed primarily to currents from the Broughton and Johnstone Straits. These island groupings are reflected in Figure 4.5 ii) depicting similarities along PC2; Bauza is significantly different from all other islands, while Foster-Holford and Plumper-Pearse-Bella Bella form separate clusters along PC2. Variation in PC2 was best explained by cadmium ($r$=0.853, $p$= 0.00) and arsenic ($r$= 0.799, $p$= 0.00) concentrations. It is possible that these concentrations are related to water flow; islands from the same group are more likely to be exposed to similar element concentrations in water from the same channels. Computer modelling and simulations may be useful in predicting which islands will show similar element concentrations, but will require direct observations in the field to confirm the models.

There are a few problems with identifying the factors affecting metal concentrations in *P. abbottiae*. For example the significant, positive correlation of arsenic and cadmium (Appendix H) to distance to the nearest large island >10 $km^2$ suggests that the further away the seaweed is from a large island, the higher the concentration of arsenic and cadmium in *P. abbottiae*. While this does support the idea that water channels are conduits for long distance transport of certain metals (particularly arsenic and cadmium), it fails to explain why these metal concentrations are lower at harvesting sites near these large landmasses. The bioavailability of dissolved metals in water column is important for uptake by algae; large landmasses may be influencing bioavailability and speciation of some elements through a combination of factors including salinity gradients near freshwater discharges, metal binding to sediments, and presence of organic matter (Du Laing et al. 2009; Vasconcelos and Leal 2001). The further the harvesting site is from a large landmass, the weaker its effects are on dissolved metal bioavailability. Environmental and water conditions such as genetics, water temperature, light intensity, pH, and algal exposure to fresh and salt water are also important factors in explaining year-to-year growth and metal uptake, but this study did not incorporate measurements of these variables during the sampling period (Brady et al. 2005; Davison and Pearson 1996; Kim et al. 2007; McLean and Williamson 1977).

4.5.2 Physical and cultural health

While calcium dominated the elements sampled in *P. abbottiae* in terms of concentration, arsenic dominated the risk inherent in the seaweed (Table 4.6). Hazard quotients for arsenic and cadmium exceed 1.0 under average consumption levels and mean element concentrations (Table 4.8), making them the primary contaminants of concern (CoC) in *P. abbottiae*.[120] However, most arsenic in seaweed is not bioavailable and poses a lower actual health risk than the HQ suggests (Chan et al. 2011). Lead becomes the third greatest CoC when calculating HQ values using maximum element concentrations. Mercury concentrations fell below the detection limit of 0.01 ng/mL in 28 of 112 samples; its potential for health risks is negligible at both mean and maximum mercury concentrations (Table 4.8).

HQ rankings are not an absolute measurement of risk. For example, The WHO recommends that a 60 kg adult should not ingest arsenic exceeding approximately 65.7 mg/year. The seaweed from the Broughton and southern Queen Charlotte Strait averages 19.01 mg As/kg dried seaweed; this 60 kg person should be able to safely consume 3.4 kg *P. abbottiae* from this region over the course of a year, or approximately 9.4 grams per day. 3.4 kg dry seaweed/yr is four and a half times the average seaweed consumption rate among those surveyed in First Nations by Child and Ross (pers. comm.). For the average adult arsenic from *Porphyra* should not pose a problem, regardless of the variation between individual specimens. An undetermined portion of the arsenic in *P. abbottiae* is in an organic form (and is not bioavailable or acutely toxic) (Smith et al. 2010). Arsenic in *Porphyra* can be made more bioaccessible[121] to humans by baking; however, boiling seaweed may remove inorganic arsenic from the tissue and thus reduce the potential health risk from its consumption (Laparra et al. 2003). Individuals consuming a portion of approximately 1 cup (7 g) of loosely packed dried seaweed per day will fall below the

[120] This also includes the seaweed from Bella Bella, BC.

[121] Bioaccessible is here defined as a substance that is "available to cross an organism's cellular membrane from the environment, if the organism has access to the chemical." (Semple et al. 2004). Laparra et al. (2003) consider bioaccessibility to be the "maximum soluble concentration in gastrointestinal medium."

recommended upper intake limits currently set by the World Health Organization and Health Canada. This is a conservative estimate for safe seaweed consumption. Figure 4.6 shows 7 g or approximately one cup of dried seaweed.

Figure 4.6. Seven grams or approximately one cup of dried *Porphyra abbottiae* as it might appear in a bowl.

Arsenic, lead, and mercury concentrations in *P. abbottiae* compare favourably to those in other *Porphyra* species. Wild *Porphyra* sampled in New Zealand by Smith et al. (2010) contained, on average, ten times more mercury and nearly four times the lead concentration of *P. abbottiae* from this study. *P. abbottiae* contained approximately 5 mg/kg dried seaweed more lead than the *Porphyra* from New Zealand. Similar studies on *Porphyra* from Spain, Venice, and Japan show metal concentrations in the same order of magnitude as *P. abbottiae* with some exceptions; *P. abbottiae* generally had lower iron concentrations than *Porphyra* spp. from these other studies (Caliceti et al. 2002; Rupérez 2002; Van Netten et al. 2000).

First Nations are at higher risk of chronic health problems than the general population in Canada (Health Canada / Santé Canada 2009). Some of this risk can be attributed to a radical change in lifestyles and socioeconomic conditions for Indigenous Peoples in North America since the arrival of non-Indigenous peoples. Free access to traditional hunting, fishing, and gathering grounds became limited by imposed regulations, and the extent and quality of these lands have diminished due to development and privatization (Kuhnlein 1989; Turner and Turner 2008). Reserves were established and a wage-labour economic system was set up, further limiting time spent or incentive to harvest traditional foods (Kuhnlein 1992; Lutz 1992, 2008; Turner and Turner 2008). Residential schools exacerbated the problem by removing children from their families and culture, thus interfering with the transfer of knowledge necessary to continue harvesting traditional foods that could supplement contemporary diets and improve overall health (Kuhnlein 1992; Turner and Turner 2008). Indigenous Peoples are also at high risk of poverty, and poverty limits the food choices available, consequently increasing the likelihood that people will choose low-cost, but nutrient-poor, foods (Collin and Jensen 2009; Turner and Turner 2008).

Chronic illnesses and conditions of particular concern for Indigenous Peoples in Canada include: obesity, diabetes mellitus, and cardiovascular disease. These are among the major health issues facing contemporary First Nation communities across Canada (Health Canada / Santé Canada 1995). Illnesses such as type 2 diabetes mellitus in First Nations communities are thought to stem from a combination of genetic factors, obesity, decline in physical activity, and the change from traditional foods to market foods (Young et al. 2000). Off-reservation Indigenous people are also disproportionately more affected by chronic health issues relative to non-Indigenous Canadians (Health Canada / Santé Canada 2010). The eating habits of Indigenous Peoples in western Canada do not align well with the standards set in the Canada Food Guide, and include a high proportion of foods from the “Other Foods” category (e.g. candy, soft drinks, salty and high-fat snack foods). This factor, coupled with high rates of obesity,[122] highlights the need for a

[122] In Canada, 64% of off-reserve indigenous women and 71% of off-reserve indigenous men are either overweight or obese. Among non-indigenous Canadians, this falls to 47%

focused effort from communities and governments to change current dietary patterns associated socioeconomic factors. Increasing interest in traditional foods is one approach toward improving health when obtaining high quality non-traditional foods is not financially feasible (Willows 2005).

As with many traditional foods under threat of contamination, consumption of *P. abbottiae* requires weighing the risks and benefits (Kuhnlein and Chan 2000). Seaweed harvesting risks injury on slippery rocks and falling in the water. Consumption of *P. abbottiae* raises the possibility of chronic exposure to metals, depending on levels and frequency of consumption. Despite such risks, there are also clear benefits to incorporating traditional foods into the diets of contemporary First Nations communities. Dried *Porphyra* is a source of protein, fibre, vitamin C, iron, and trace minerals (Kuhnlein and Turner 1991; Turner 2003). A diet consisting solely of store-bought foods can lead to deficiencies in several essential nutrients including copper, iron, calcium, folate, ascorbate, and vitamins E and D (Kuhnlein 1984; Kuhnlein et al. 2004; Receveur et al. 1997). Traditional foods tend to be eaten not alone but as part of a complex, mixed diet that is ultimately more nutritionally diverse than one based solely on store-bought, industrially produced foods (Church and Doughty 1976; Receveur et al. 1997). Loss of traditional foods from the diet due to contamination or fear of contamination may be as damaging, or more damaging, to people's health than continuing reasonable consumption of the traditional foods. Wiseman and Gobas (2002) estimated that increased incidence of coronary disease from replacing shellfish with store-bought foods in coastal First Nations diets is on par with cancers and chronic illnesses from consuming the shellfish contaminated by dioxins. Traditional food consumption can also benefit low-income households through lower expenditures on food (Kuhnlein and Chan 2000). Reincorporating *P. abbottiae* into the diet may also inspire coastal First Nations communities in British Columbia to resume harvesting other traditional plant foods, helping people to fill these nutritional deficiencies and attain better overall health.

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(women) and 62% (men) (Health Canada / Santé Canada 2010).

When considering the benefits of *P. abbottiae* consumption, we must also take into account the traditional use of seaweed as a medicine. Elders *K$^{w}$axsistalla* and *Mayanił* identified *P. abbottiae* as a medicine to treat very serious fevers and other illnesses, and recalled an origin story linking its discovery as a medicine to a supernatural event.[123] In recent years, Kwakwa̱ka̱'wakw elders have used dried seaweed to manage fluctuating blood sugar levels that arise from diabetes.[124] Lee et al. (2010) found some evidence that *Porphyra* consumption may decrease the incidence of diabetes mellitus, while Kim et al. (2008) found that seaweed supplements may be effective in lowering blood sugar levels and blood cholesterol in patients with diabetes mellitus. Both studies recommend further investigation into the mechanisms responsible for these results. Continued consumption of *P. abbottiae* despite fears over contamination emphasizes the importance of this alga to First Nations in British Columbia. Fortunately *Porphyra* poses minimal risk of metal contamination in the area of this study, though this is not always the case with aquatic food resources. An elder from the Swinomish Coast Salish community in Washington State acknowledges that there are health risks associated with consuming foods that are not tested regularly for contaminants, but states that spiritual nourishment is more important than physical nourishment (Donatuto et al. 2011).

Using traditional foods can pose a problem when considering the possibility of food-related health risks. While some foods such as fish, shellfish, and terrestrial game have been scrutinized and are closely monitored for signs of chemical contamination,[125] not all traditional foods come with recommended guidelines for consumption. The majority of Canadians are unaware of many of the plant foods traditionally eaten by First Nations peoples in British Columbia such as northern rice-root, camas bulbs (*Camassia* spp.), or springbank clover roots. As a result, regulating bodies responsible for food testing and safety could easily miss some of these foods or choose a related, representative species to stand in when deciding on serving sizes or guidelines. Health Canada (1995) describes

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[123] Pers. comm. May 2009, 2011. The origin story as told by *Mayanił* is found in Chapter 2, pages 34-35.
[124] *Mayanił and Og$^{w}$iloǧ$^{w}$a*, pers. comm. May 2011.
[125] E.g. Humphrey 1987 and persistent organic pollutants (POPs) in fish in the Great Lakes; Chan et al. 1996 and POPs in ooligan grease.

seaweeds as being rich in minerals and some vitamins, but suggests that they should be consumed in moderation so as to avoid a deficiency or excess of iodine intake because either of these states can cause goitre. The guidelines do not specify what constitutes a moderate quantity. Health Canada (2008) estimates a household serving of "dulse seaweed" (likely *Palmaria palmata* L.) to be 60 mL or ¼ cup, but does not provide similar estimates for laver (*Porphyra* spp.), kelps (*Alaria* spp., *Laminaria* spp. and related species) or other edible seaweed species consumed in Canada. The lack of precise information from an accessible public resource such as Health Canada or the Canada Food Guide makes it harder to make informed decisions on seaweed consumption.

Steps can be taken to minimize health risks from contaminants in traditional foods in First Nations communities; these include education, diet modification, and involvement in the management of traditional food resources (Kuhnlein and Chan 2000). There is growing recognition of the importance of Indigenous ecological knowledge and harvesting practices in environmental monitoring (Stevenson 1996). For example, in the Broughton Archipelago the Kwakwa̲ka̲'wakw have worked in collaboration with scientists to monitor changes in clam and sustenance fisheries in areas near finfish aquaculture operations (Heaslip 2008). Involving First Nations in the management of natural resources and industries in their traditional lands allows them to have a say in decisions that directly impact their livelihoods, culture, and health. As Kelm (1998: 86) observed, many rules, taboos, and practices concerning traditional resource management developed with the intention to preserve collective, community health. This involvement permits people to share their worldview, philosophies, and traditional knowledge with those with the power to change regulations or practises having a potentially negative impact (Heaslip 2008; Stevenson 1996). This also enables individuals to make informed decisions on the safety and viability of the consumption of their traditional foods, and to manage their risks.

## 4.6 Chapter 4 conclusions

Indigenous peoples in Canada are statistically at higher risk than non-Indigenous peoples of suffering from obesity, malnutrition, and poverty as a consequence of numerous socioeconomic factors that developed post-Contact (E.g. Collin and Jensen 2009; Gittelsohn et al. 1998; Health Canada / Santé Canada 1995, 2010; Turner and Turner 2008). While addressing these problems will require significant reform at the community, societal, and government levels, supplementing contemporary diets with traditional foods is gaining support for tackling malnutrition, obesity, and overall quality of health (E.g. Kuhnlein and Chan 2000; Kuhnlein et al. 2004, 2006; Receveur et al. 1997). Across North America Indigenous peoples are exposed to higher levels of contaminants in food than non-Indigenous peoples, due in part to greater reliance on species that biomagnify and bioaccumulate pollutants in the environment (Donatuto et al. 2011; Kuhnlein and Chan 2000).

In recent years the proliferation of aquaculture operations in the Broughton and Queen Charlotte straits region, and long-standing industrial activities including mining, forestry and pulp mill operations, have engendered concerns of marine food contamination, and in particular, contamination of traditional foods of Indigenous peoples of the region. These concerns have resulted in attention from researchers looking at water quality, sediment composition, and contaminants in aquatic organisms. My research examined the potential for contaminants in *Porphyra abbottiae* – an important and nutritious traditional food – from the Broughton and Queen Charlotte Straits. This study showed that while there are some metals of concern in *P. abbottiae* in the southern Queen Charlotte Strait and Broughton Strait, they do not exceed WHO and Health Canada guidelines provided that the seaweed is consumed in moderation (a conservative estimate is ≤ 9.4 g dry seaweed/day, or approximately one cup daily). I found no obvious evidence of local anthropogenic contamination of the seaweed at the study sites in this region during usual harvesting season. Slightly elevated levels of arsenic and cadmium in my samples suggest long-distance transport of dissolved metals in water currents and naturally-occurring metals from local bedrock. The study was too short to determine whether metal concentrations in edible seaweed can vary significantly at any single site from year to year. Future studies on *P. abbottiae* in the Broughton and Queen Charlotte Straits could incorporate more comprehensive environmental data including water temperature, salinity, and currents.

Harvesting this seaweed for food provides opportunities for physical activity and fresh air, as well as the potential for positively impacting the collective health of the community as a whole. Seaweed harvesting is a multi-generational activity; elders as well as youth can participate and work together. Harvesting and consuming seaweed as part of a traditional diet provides Kwakwaka'wakw, Heiltsuk and other First Nations youth and adults alike with tangible and intangible benefits such as physical exercise, nutrition, and a chance for people to connect with their culture. Seaweed consumption in Kwakwaka'wakw and other communities can potentially also lead to increased consumption of other traditional foods. As Kuhnlein and Chan (2000) conclude, store-bought foods or nutritional supplements cannot substitute for the nutritional, physical, and cultural benefits that many traditionally harvested foods bring to First Nations communities.

# Chapter 5 Conclusions to the study

## 5.1 Summary

This study highlights how *Porphyra abbottiae* as a valuable resource to the Kwakwa̱ka̱'wakw and other First Nations in British Columbia for nutritional, medicinal, cultural, and physical reasons. This marine alga is easy to dry and transport, enabling coastal First Nations to trade dried seaweed centuries ago along the coast and inland. Seaweed harvesting by First Peoples has persisted despite the wide availability of convenience foods, massive changes in economic and education systems, and concerns over coastal pollution. It is significant that an alga harvested during a brief, two-week period each spring can be classified as a cultural keystone species.

While the Kwakwa̱ka̱'wakw have adopted new technologies for their seaweed harvest, it has not led to a radical change of its associated practices. *P. abbottiae* continues to be harvested and dried manually much in the same way as it was prior to the arrival of non-native settlers. Kwakwa̱ka̱'wakw harvesters now have greater flexibility when balancing the time-intensive harvesting process with the demands of their work and school commitments. It is not necessary to choose between taking time away from work or school and taking part in the seaweed harvest; both can be incorporated into a modern lifestyle.

Fear about the safety of seaweed consumption appear to be a greater problem than the actual risk of acute or chronic metal contamination in *P. abbottiae*. The presence of these metals measured in the seaweed can most likely be attributed to natural rather than anthropogenic sources. When the seaweed eaten in moderation, the metals it contains fall within acceptable health guidelines for daily consumption determined by the World Health Organization and Health Canada. As a trade-off the seaweed harvesters benefit from physical exercise, greater food security and sovereignty, a tangible connection to their culture and traditional territories, and time spent with family, community elders, and friends.

## 5.2 Challenges

The greatest challenge I encountered during the study was arriving as an outsider to Kwakwa̲ka̲'wakw culture, unaware of the history, values, and traditions of a culture foreign to my own experiences. I had to learn 'how to ask the right question with the right words.' A question worded another way at another time could elicit a different response from the same person. Changing how a question was asked also included changing the setting or circumstances in which the question was posed. In some cases it took a very specific set of events to occur for the TEK holder to remember particular details regarding the harvest, and required that the TEK holder believed that the knowledge was relevant to my interests as an interviewer.

An example of this occurred on May 17, 2008 at Foster Island--the first site visited in this study. Prior to that point, only the Elders in our group had experience in identifying ***ɬəqq̓əstən*** from a distance on a boat. Adam had clearly remembered harvesting seaweed at Foster Island with his family as a child, and was certain that he could find it there again. We had arrived at the southern face of the island and, upon finding no *Porphyra abbottiae*, proceeded to circle the island in a clockwise direction. We were prepared to concede defeat until finally sighting the seaweed as we arrived at the eastern face of the island. At that moment Adam remembered and relayed that his grandfather told him that the seaweed grows where the island faces the morning sun. Adam had not mentioned his grandfather's words as we identified locations for the study during discussions at his home in Qualicum. Had we not arrived at the wrong face of the island, we may not have heard these words at all!

## 5.3 Future study

While working on this study I encountered interesting questions that were peripheral to my research questions but nonetheless relevant to gaining a better understanding of Kwakwa̲ka̲'wakw TEK and use of ***ɬəqq̓əstən***. One such question that could benefit from further research is the effects of flavouring treatments on the nutrition and quality of the seaweed. I thought it was curious that, according to Franz Boas (1921), the juice of boiled, chewed chitons (*Cryptochiton stelleri* Middendorff [giant gumboot chiton]) would sometimes be used to flavour the seaweed. It is possible that the digestive enzymes from this gastropod as well as the periodic drying under the sun have some chemical effect on the chemical composition of the seaweed. Research such as that by Barry (1945) found that laminarin, a glucose polymer and algal polysaccharide, was hydrolysed or broken into simpler sugars by an enzyme found in snail juice and the common limpet. This hydrolysis broke the laminarin polysaccharides down into smaller, simpler sugars that the snails and limpets could use. Turner (2003) suggests that at least some seaweed treatments including fermentation and flavouring with shellfish juices could alter the seaweed's nutrition and digestibility. Hotz and Gibson (2007) similarly found that some traditional food preparation techniques including fermentation increase bioavailability of micronutrients in plant foods. It may be worth investigation to see if the addition of chiton juice catalyses a chemical reaction for the might alter the algal polysaccharides or other nutritional components of *P. abbottiae*.

Another point that I believe could benefit from future research is the effects of annual harvesting on patch density, quality, and regeneration. Three of the study sites (Bauza, Pearse, and Foster) were visited consecutively for two years, but no measurements on frond stand density, length or abundance were taken. *P. abbottiae* fronds may benefit from the removal of neighbours competing for space, light, and nutrients.[126] Harvesting techniques can significantly change regeneration rates in *Porphyra*, depending on whether or not the entire plant is removed or if some basal portion is left intact (Nelson and Conroy 1989). Laver-harvesting sites in British Columbia were generally places where harvesting took place routinely and traditionally, year after year. People would return to these sites and intensively harvest from these sites (*K$^{w}$axsistalla*, pers. comm.

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[126] Stackhouse (1801) remarks that people in Brittany harvested *Dilsea carnosa* for fertilizer twice a year, and that the alga was always abundant. Some First Nations such as the Straits Salish would harvest *Porphyra* twice in the same year (Turner 2003; Williams 1989). These sustainable harvests, however, may be artefacts of the implementation of traditional ecological and social knowledge. This traditional knowledge is linked to the ecology and culture of a specific area. When a newcomer is unfamiliar with the ecology and TEK of a region, their use of its resources may or may not be sustainable over the long term. (Marshall and Foster 2002).

May 2008). Understanding the ecological effects of the seaweed harvest will be another tool to ensure that the harvest continues to be sustainable and carefully managed.

## 5.4 Conclusion

When knowledgeable members of a community choose to share their traditions with outsiders, the researcher can choose either to observe and document, or to physically participate in the traditional practices. Our participation in the seaweed harvest with elders has resulted in unexpected but very welcome benefits to this study: first, this reconnection with a traditional activity and food from their youth greatly lifted their spirits. The elders enjoyed teaching young people such as myself and the other students how to harvest and dry seaweed, and were delighted to have a fresh supply of dried seaweed for personal consumption. Secondly, it would be hard to imagine how labour intensive this activity is by simply listening to an interview or reading a written description of the harvest. Participatory fieldwork helped refine the questions posed during interviews, and brought to light new questions that required further exploration. Thirdly, participation increased awareness and appreciation for traditional knowledge to guide the harvest as the elders made sure that we followed traditional protocols. It is humbling to think of a time when most people living by the coast knew the tide cycle and water currents intimately prior to the introduction of tide charts and maps. It is an honour to participate, listen to, and observe the elders and teachers involved with this study.

*Literature Cited*

Aaronson, S. 1986. A Role For Algae as Human Food in Antiquity. Food and Foodways, **1**: 311-315.

Aaronson, S. 2000. II.C.1: Algae. *In* The Cambridge World History of Food. Cambridge University Press: Cambridge, UK.

Abbott, I. A. 1996a. Limu, An Ethnobotanical Study of Some Hawaiian Seaweeds. National Tropical Botanical Garden: Lawai, Hawaii.

Abbott, I. A. 1996b. Ethnobotany of seaweeds: clues to uses of seaweeds. Hydrobiologia, **326/327**: 15-20.

Agardh, C. A. 1824. Systema Algerum. Literis Berlingianis: Lundæ [Lund, Sweden]. Pp. 190-191.

Alfred, A. 2004. Paddling to Where I Stand: Agnes Alfred, Qwiqwasutinuxw noblewoman / as told to Martine J. Reid and Daisy Sewid-Smith. Reid, M. J. (ed.). UBC Press: Vancouver. [Translated from Kwakwaka'wakw by D. Sewid-Smith.]

Allen, D. E., and Hatfield, G. 2004. Medicinal Plants in Folk Tradition, An Ethnobotany of Britain and Ireland. Timber Press: Portland, Oregon.

Andrade, S., Medina, M. H., Moffett, J. W., and Correa, J. A. 2006. Cadmium – Copper Antagonism in Seaweeds Inhabiting Coastal Areas Affected by Copper Mine Waste Disposals. Environmental Science & Technology, **40**: 4382-4387.

Barnett, H. G. 1938. The Coast Salish of Canada. American Anthropologist, **40**: 118-141.

Barry, V. J. 1945. Recent Investigations on the Chemistry of Seaweed. Journal and Proceedings of the Royal Institute of Chemistry of Great Britain and Ireland, **69**: 35-36.

BC Stats. 2007. British Columbia's Fisheries and Aquaculture Sector. http://www.env.gov.bc.ca/omfd/reports/BC-Fisheries-Aquaculture-Sector-2007.pdf, accessed October 6, 2010.

Betts, M. F. 1994. The Subsistence Hooligan Fishery of the Chilkat and Chilkoot Rivers. Technical Paper Number 213. Alaska Department of Fish and Game: Juneau, Alaska.

Bickford, D., Lohman, D. J., Sodhi, N. S., Ng, P. K. L., Meier, R., Winker, K., Ingram, K. K., and Das, I. 2007. Cryptic species as a window on diversity and conservation. Trends in Ecology and Evolution, **22**: 148-155.

Boas, F. 1921. Ethnology of the Kwakiutl: based on data collected by George Hunt. *In* Thirty-Fifth Annual Report of the Bureau of American Ethnology to the Secretary of the Smithsonian Institution, 1913-1911, In Two Parts – Part 1. Government Printing Office: Washington, D.C.

Bocanegra, A., Bastida, S., Benedí, J., Ródenas, S., and Sánchez-Muniz, F. J. 2009. Characteristics and Nutritional and Cardiovascular-Health Properties of Seaweeds. Journal of Medicinal Food, **12**: 236-258.

Brady, K. U., Kruckeberg, A. R., and Bradshaw Jr., H. D. 2005. Evolutionary Ecology of Plant Adaptation to Serpentine Soils. Annual Review of Ecology, Evolution, and Systematics, **36**: 243-266.

Brodie, J., Mortensen, A. M., Ramirez, M. E., Russell, S., and Rinkel, B. 2008. Making the links: towards a global taxonomy for the red algal genus *Porphyra* (Bangiales, Rhodophyta). Journal of Applied Phycology, **20**: 939-949.

Burger, J., Gochfeld, M., Jeitner, C., Gray, M., Shukla, T., Shukla, S., and Burke, S. 2007. Kelp as a Bioindicator: Does it Matter Which Part of 5 M Long Plant is Used for Metal Analysis? Environmental Monitoring and Assessment, **128**: 311-321.

Burzycki, G. M., and Waaland, J. R. 1987. On the Position of Meiosis in the Life History of *Porphyra torta* (Rhodophyta). Botanica Marina, **30**: 5-10.

Caliceti, M., Argese, E., Sfriso, A., and Pavoni, B. 2002. Heavy metal contamination in the seaweeds of the Venice lagoon. Chemosphere, **47**: 443-454.

Cannon, M. 1989. Cell Division Patterns and Diurnal Cycle of *Porphyra abbottae* (Rhodophyta, Bangiales) Carpogonial and Carpospore Development. Journal of Phycology, **25**: 612-615.

Carmichael, A. 1928. Carmina Gadelica: Hymns and Incantations Collected in the Highlands and Islands of Scotland in the Last Century, Vol. 2. Oliver and Boyd: Tweeddale Court, Edinburgh. Pp. 281-283.

Chan, H. M., El Khoury, M., Sedgemore, M., Sedgemore, S., and Kuhnlein, H. V. 1996. Organochlorine Pesticides and Polychlorinated Biphenyl Congeners in Ooligan Grease: A Traditional Food Fat of British Columbia First Nations. Journal of Food Composition and Analysis, **9**: 32-42.

Chan, H. M., Kim, C., Khoday, K., Receveur, O., and Kuhnlein, H. V. 1995. Assessment of Dietary Exposure to Trace Metals in Baffin Inuit Food. Environmental Health Perspectives, **103**: 740-746.

Chan, L., Receveur, O., Sharp, D., Schwartz, H., Ing, A., and Tikhonov, C. 2011. First Nations Food, Nutrition and Environment Study (FNFNES): Results from British Columbia (2008/2009). University of Northern British Columbia: Prince George, BC.

Chapman, V. J., and Chapman, D. J. 1980. Seaweeds and Their Uses. Chapman and Hall: New York.

Child, T. R., and Ross, P. S. In preparation. Dietary survey for 306 First Nation respondents on Vancouver Island.

Church, M., and Doughty, J. 1976. Value of traditional food practices in nutrition education. Journal of Human Nutrition, **30**: 9-12.

Chopin, T., and Ugarte, R. 2006. The seaweed resource of Eastern Canada. *In* World Seaweed Resources. An Authoritative Reference System. Critchley, A. T., Ohno, M., and Largo, D. B. (eds.). DVD-ROM. ETI BioInformatics Publishers: Amsterdam. 46 pp.

Codere, H. 1957. Kwakiutl Society: Rank without Class. American Anthropologist, **59**: 473- 486.

Codere, H. 1990. Kwakiutl: Traditional Culture. *In* Handbook of North American Indians, Volume 7. Suttles, W. (ed.) Smithsonian Institute: Washington. Pp. 259-390.

Cole, D. 1999. Franz Boas; The Early Years, 1858-1906. University of Washington Press: Seattle.

Collin, C., and Jensen, H. 2009. A Statistical Profile of Poverty In Canada. Parliamentary Information and Research Service. Library of Parliament: Canada.

Compton, B.D. 1993. Upper North Wakashan and Southern Tsimshian Ethnobotany: The Knowledge and Usage of Plants and Fungi Among the Oweekeno, Hanaksiala (Kitlope and Kemano), Haisla (Kitamaat) and Kitasoo Peoples of the Central and North Coasts of British Columbia. Ph.D. dissertation. Department of Botany, University of British Columbia. Vancouver, B.C.

Contrad® 70 MSDS [Online]; Decon Laboratories, Inc.: King of Prussia, Pennsylvania; August 8, 2008, http://www.deconlabs.com/msds/Contrad%2070.pdf (accessed April 30, 2010)

Copes, R., Clark, N. A., Rideout, K., Palaty, J., and Teschke, K. 2008. Uptake of cadmium from Pacific oysters (*Crassostrea gigas*) in British Columbia oyster growers. Environmental Research, **107**: 160-169.

Cullis-Suzuki, S. 2007. Tending the meadows of the sea: Traditional Kwakwaka'wakw harvesting of *Ts'áts'ayem* (*Zostera marine* L.; Zosteraceae). M. Sc. Thesis. School of Environmental Studies, University of Victoria, British Columbia.

Cullon, D. L., Jeffries, S. J., and Ross, P. S. 2005. Persistent Organic Pollutants in the Diet of Harbour Seals (*Phoca vitulina*) Inhabiting Puget Sound, Washington (USA), and the Strait of Georgia, British Columbia (Canada): a Food Basket Approach. Environmental Toxicology and Chemistry, **24**: 2562-2572.

Curtis, E. S. 1907. The North American Indian, Being a Series of Volumes Picturing and Describing the Indians of the United States, the Dominion of Canada, and Alaska. Volume One. The University Press: Cambridge, U.S.A.

Curtis, E. S. 1915. The North American Indian, Being a Series of Volumes Picturing and Describing the Indians of the United States, the Dominion of Canada, and Alaska. Volume Ten. The Plimpton Press: Norwood, Massachusetts.

Davison, I. R., and Pearson, G. A. 1996. Stress Tolerance in Intertidal Seaweeds. Journal of Phycology, **32**: 197-211.

Davis, A., Wilson, B., and Compton, B. 1995. Salmonberry blossoms in the New Year; Some culturally significant plants of the Haisla known to occur within the Greater Kitlope ecosystem. The Kitimaat Village Council. Nanakila Press and Ecotrust Canada: Kitimaat, BC.

Deichmann, W. B., Henschler, D., Holmstedt, B., and Keil, G. 1986. What is there that is not poison? A study of the *Third Defense* by Paracelsus. Archives of Toxicology, **58**: 207-213.

DFO (Department of Fisheries and Oceans). 2008. Canadian Fisheries Statistics 2006. Fisheries and Oceans Canada: Ottawa.

Dillehay, T. D., Ramírez, C., Pino, M., Collins, M. B., Rossen, J., and Pino-Navarro, J. D. 2008. Monte Verde: Seaweed, Food, Medicine, and the Peopling of South America. Science **320**: 784-786. DOI: 10.1126/science.1156533.

Donatuto, J. L., Satterfield, T. A., and Gregory, R. 2011. Poisoning the body to nourish the soul: Prioritising health risks and impacts in a Native American community. Health, Risk & Society, **13**: 103-127.

Drew, K.M. 1949. *Conchocelis*-phase in the life-history of *Porphyra umbilicalis* (L.) Kütz. Nature, **164**: 748.

Druehl, L. D. 2000. Pacific Seaweeds; A Guide to Common Seaweeds of the West Coast. Harbour Publishing: Madeira Park, British Columbia.

Du Laing, G., Rinklebe, J., Vandecasteele, B., Meers, E., and Tack, F. M. G. 2009. Trace metal behaviour in estuarine and riverine floodplain soils and sediments: A review. Science of the Total Environment, **407**: 3972-3985.

Ellis, E. C., and Ramankutty, N. 2008. Putting people in the map: anthropogenic biomes of the world. Frontiers in Ecology and the Environment, **6**: 439-447.

Emmons, G. T. 1991. The Tlingit Indians. De Laguna, F. (ed.). University of Washington Press: Seattle, and the American Museum of Natural History: New York.

Environment Canada. 2011. Canadian Climate Normals 1971-2000; Port Hardy, British Columbia [online]. National Climate Data and Information Archive. URL: http://climate.weatheroffice.gc.ca/climate_normals/results_e.html?Province=BC%20%20&StationName=&SearchType=&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber=&IDType=MSC&CityName=&ParkName=&LatitudeDegrees=&LatitudeMinutes=&LongitudeDegrees=&LongitudeMinutes=&NormalsClass=A&SelNormals=&StnId=202&start=1&end=6&autofwd=0, accessed March 21, 2011.

Environment Canada/Health Canada. 2011. Screening Assessment for the Challenge; Cobalt (Elemental cobalt) Chemical Abstracts Service Registry Number 7440-48-4, Cobalt chloride Chemical Abstracts Service Registry Number 7646-79-9, Sulfuric acid, cobalt (2+) salt (1:1) (Cobalt sulfate) Chemical Abstracts Service Registry Number 10124-43-3, Sulfuric acid, cobalt salt (Cobalt sulfate) Chemical Abstracts Service Registry Number 10393-49-4; Batch 10. [online] URL: http://www.ec.gc.ca/ese-ees/8E18277B-457E-4073-8F27-EF5878648820/batch10_4substances%281%29_en.pdf, accessed March 3, 2011.

Eppley, R. W., and Cyrus, C. C. 1960. Cation Regulation and Survival of the Red Alga, *Porphyra perforata*, in Diluted and Concentrated Sea Water. Biological Bulletin, **118**: 55-65.

FAO (Food and Agriculture Organization). 2010. FAO Yearbook; Fishery and Aquaculture Statistics 2008. Food and Agriculture Organization of the United Nations: New York.

Foreman, M. G. G., Stucchi, D. J., Zhang, Y., and Baptista, A. M. 2006. Estuarine and Tidal Currents in the Brouton Archipelago. Atmosphere-Ocean, **44**: 47-63.

Gardner, M., MacAskill, G., and DeBow, C. 2009. Economic impact of the Nova Scotia ocean sector 2002-2006. Gardner Pinfold Consulting Economists Ltd.: Halifax, Nova Scotia.

Garibaldi, A. and Turner, N. 2004, Cultural Keystone Species: Implications for Ecological Conservation and Restoration. Ecology and Society, **9**: 1 [online] URL: http://www.ecologyandsociety.org/vol9/iss3/art1

Garza, D. 2005. Common Edible Seaweeds in the Gulf of Alaska. Alaska Sea Grant College, University of Alaska: Fairbanks, Alaska.

Gittelsohn, J., Wolever, T. M. S., Harris, S. B., Harris-Giraldo, R., Hanley, A. J. G., and Zinman, B. 1998. Specific Patterns of Food Consumption and Preparation Are Associated with Diabetes and Obesity in a Native Canadian Community. The Journal of Nutrition, **128**: 541-547.

Goyer, R. A. 1997. Toxic and Essential Metal Interactions. Annual Reviews in Nutrition, **17**: 37-50.

Grimes, M. K. 2011. On Shifting Roles and Responsibilities in Canadian Indigenous Community-Based Language Research. M. A. Thesis. Department of Linguistics, University of Victoria, British Columbia.

Gunther, E. 1973. Ethnobotany of Western Washington; The Knowledge and Use of Indigenous Plants by Native Americans. University of Washington Press: Seattle.

Gutknecht, J. 1966. $Zn^{65}$ Uptake by Benthic Marine Algae. Limnology and Oceanography, **8**: 31-38.

Hallsson, S. V. 1961. The Uses of Seaweeds in Iceland. Fourth International Seaweed Symposium 1961 France. http://www.noamkelp.com/technical/iceland6.0.doc

Halpin, M. M., and Seguin, M. 1990. Tsimshian Peoples: Southern Tsimshian, Coast Tsimshian, Nishga, and Gitksan. *In* Handbook of North American Indians, Volume 7: Northwest Coast. *Edited by* W. Suttles. Smithsonian Institution: Washington DC.

Hannach, G., and Waaland, J. R. 1989. Growth and Morphology of Young Gametophytes of *Porphyra abbottiae* (Rhodophyta): Effects of Environmental Factors in Culture. Journal of Phycology, **25**: 247-254.

Harris, S. G., and Harper, B. L. 1997. A Native American Exposure Scenario. Risk Analysis, **17**: 789-795.

Health Canada / Santé Canada. 1995. Native Foods and Nutrition; An Illustrated Reference Manual. Minister of National Health and Welfare: Ottawa.

Health Canada /Santé Canada. 2008. Nutrient Value of Some Common Foods. Minister of Health: Ottawa.

Health Canada / Santé Canada. 2009. A Statistical Profile on the Health of First Nations in Canada; Self-rated Health and Selected Conditions, 2002 to 2005. Minister of Health: Ottawa.

Health Canada / Santé Canada. 2010. Eating habits and nutrient intake of Aboriginal adults aged 19-50, living off-reserve in Ontario and the western provinces. Health Canada: Ottawa.

Heaslip, R. 2008. Monitoring salmon aquaculture waste: The contribution of First Nations' rights, knowledge, and practices in British Columbia, Canada. Marine Policy, **32**: 988-996.

Holland, P. 2000. Cultural landscapes as biogeographical experiments: a New Zealand perspective. Journal of Biogeography, **27**: 39-43.

Hotz, C. and Gibson, R. S. 2007. Traditional Food-Processing and Preparation Practices to Enhance the Bioavailability of Micronutrients in Plant-Based Diets. The Journal of Nutrition, **137**: 1097-1100.

Humphrey, H. E. B. 1987. The human population - An ultimate receptor for aquatic contaminants. Hydrobiologia, **149**: 75-80.

Hunn, E. 2007. Ethnobiology In Four Phases. Journal of Ethnobiology, **27**: 1-10.

Idyll, C. P. 1970. The Sea Against Hunger. Thomas Y. Crowell Company: New York. Pp. 47-50.

Indergaard, M., and Minsaas, J. 1991. Animals and Human Nutrition. *In* Seaweed Resources in Europe; Uses and Potential. Guiry, M.D., and Blunden, G. (eds.). John Wiley & Sons: Chichester, England. Pp. 21-64.

Institute of Medicine of the National Academies. 2003. Dietary Reference Intakes: Applications in Dietary Planning. National Academies Press: Washington, D.C.

Institute of Medicine of the National Academies. 2006. Dietary Reference Intakes: The Essential Guide to Nutrient Requirements. Otten, J. J., Hellwig, J. P., and Meyers, L. D. (eds.). National Academies Press: Washington, D.C.

Johannessen, D. I., Macdonald, J. S., Harris, K. A., and Ross, P. S. 2007. Marine Environmental Quality in the Pacific North Coast Integrated Management Area (PNCIMA), British Columbia, Canada: A Summary of Containment Sources, Types, and Risks. Canadian Technical Report of Fisheries and Aquatic Sciences 2716. Fisheries and Oceans Canada.

Kain, J. M., and Dawes, C. P. 1987. Useful European seaweeds: past hopes and present cultivation. Hydrobiologia, **151/152**: 173-181.

Kain, J. M. 1975. Algal Recolonization of Some Cleared Subtidal Areas. Journal of Ecology, **63**: 739-765.

Kelm, M. E. 1998. Colonizing Bodies. UBC Press: Vancouver.

Kenicer, G., Bridgewater, S., and Milliken, W. 2000. The Ebb and Flow of Scottish Seaweed Use. Botanical Journal of Scotland, **52**: 119-148.

Kim, J. K., Kraemer, G. P., Neefus, C. D., Chung, I. K., and Yarish, C. 2007. Effects of temperature and ammonium on growth, pigment production and nitrogen uptake by four species of *Porphyra* (Bangiales, Rhodophyta) native to the New England coast. Journal of Applied Phycology, **19**: 431-440.

Kim, M. S., Kim, J. Y., Choi, W. H., and Lee, S. S. 2008. Effects of seaweed supplementation on blood glucose concentration, lipid profile, and antioxidant enzyme activities in patients with type 2 diabetes mellitus. Nutrition Research and Practice, **2**: 62-67.

Kolek, J., and Holobradá, M. 1992. Ion Uptake and Transport. *In* Physiology of the Plant Root System. Kolek, J., and Kozinka, V. (eds.) Klewer Academic Publishers: Dordrecht, The Netherlands.

Krishnamurthy, V. 1969. The *Conchocelis* Phase of Three Species of *Porphyra* in Culture. Journal of Phycology, **5**: 42-47.

Krishnamurthy, V. 1972. A Revision of the Species of the Algal Genus *Porphyra* Occurring on the Pacific Coast of North America. Pacific Science, **26**: 24-49.

Kruzynski, G. M. 2000. Cadmium in BC farmed oysters: a review of the available data, potential sources, research needs and possible mitigation strategies. Canadian Stock Assessment Secretariat. Research Document 2000/104.

Kruzynski, G. M. 2004. Cadmium in oysters and scallops: the BC experience. Toxicology Letters, **148**: 159-169.

Kruzynski, G. M., Addison, R. F., and Macdonald, R. W. 2002. Proceedings of a Workshop on Possible Pathways of Cadmium into the Pacific Oyster *Crassostrea gigas* as Cultured on the Coast of British Columbia, Institute of Ocean Sciences, March 6-7, 2001. Canadian Technical Report of Fisheries and Aquatic Sciences 2405; vi + 65pp.

Kuhnlein, H. V. 1984. Traditional and Contemporary Nuxalk Foods. Nutrition Research, **4**: 789-809.

Kuhnlein, H. V. 1989. Factors Influencing Use of Traditional Foods Among the Nuxalk People. Journal of the Canadian Dietetic Association, **50**: 102-106.

Kuhnlein, H. V. 1992. Change In The Use Of Traditional Foods By The Nuxalk Native People of British Columbia. Ecology of Food and Nutrition, **27**: 259-282.

Kuhnlein, H. V. 2009. Introduction; Why are Indigenous Peoples' food systems important and why do they need documentation? *In* Indigenous Peoples' food systems: the many dimensions of culture, diversity and environment for nutrition and health. Kuhnlein, H. V., Erasmus, B., and Spigelski, D. (eds.) Food and Agriculture Organization of the United Nations Centre for Indigenous Peoples' Nutrition and Environment: Rome. Pp. 1-7.

Kuhnlein, H. V., and Chan, H. M. 2000. Environment and Contaminants in Traditional Food Systems of Northern Indigenous Peoples. Annual Review of Nutrition, **20**: 595-626.

Kuhnlein, H. V., and Receveur, O. 1996. Dietary Change and Traditional Food Systems of Indigenous Peoples. Annual Reviews in Nutrition, **16**: 417-442.

Kuhnlein, H. V., and Turner, N. J. 1991. Traditional Plant Foods of Canadian Indigenous Peoples; Nutrition, Botany and Use. Food and Nutrition in History and Anthropology, Volume 8. Gordon and Breach Publishers: Amsterdam, Netherlands.

Kuhnlein, H. Erasmus, B., Creed-Kanashiro, H., Englberger, L., Okeke, C., Turner, N., Allen, L., and Bhattacharjee, L. 2006. Indigenous peoples' food systems for health: finding interventions that work. Public Health Nutrition, **9**: 1013-1019.

Kuhnlein, H. V., Receveur, O., Soueida, R., and Egeland, G. M. 2004. Arctic Indigenous Peoples Experience the Nutrition Transition with Changing Dietary Patterns and Obesity. The Journal of Nutrition, **124**: 1447-1453.

Landsborough, D. 1851. Popular History of British Sea-Weeds, Comprising Their Structure, Fructification, Specific Characters, Arrangement, And General Distribution, With Notices of Some of the Fresh-Water Algæ. Reeve and Benham: London. Pp. 54-55.

Laparra, J. M., Vélez, D., Montoro, R., Barberá, R., and Farré, R. 2003. Estimation of Arsenic Bioaccessibility in Edible Seaweed by an in Vitro Digestion Method. Journal of Agriculture and Food Chemistry, **51**: 6080-6085.

Lee, H. J., Kim, H. C., Vitek, L., and Nam, C. M. 2010. Algae Consumption and Risk of Type 2 Diabetes: Korean National Health and Nutrition Examination Survey in 2005. Journal of Nutritional Science and Vitaminology, **56**: 13-18.

Lertzman, D. A. 2003. A Caveat on Consilience: Barriers and Bridges for Traditional Knowledge and Conservation Science. *In* Experiments in Consilience; Integrating Social and Scientific Responses to Save Endangered Species. Westley, F. R. and Miller, P. S. (eds.) Island Press: Washington, DC. Pp. 284-297.

Lertzman, D. A. 2010. Best of two worlds: Traditional ecological knowledge and Western science in ecosystem-based management. BC Journal of Ecosystems and Management, **10**: 104-126.

Lin, R. and Stekoll, M. S. 2007. Effects of Plant Growth Substances on the Conchocelis Phase of Alaskan *Porphyra* (Bangiales, Rhodophyta) Species in Conjunction With Environmental Variables. Journal of Phycology, **43**: 1094-1103.

Lindstrom, S. C. 2008. Cryptic diversity, biogeography and genetic variation in Northeast Pacific species of *Porphyra* sensu lato (Bangiales, Rhodophyta). Journal of Applied Phycology, **20**: 501-512. DOI 10.1007/s10811-008-9313-9.

Lindstrom, S. C., and Cole, K. M. 1992. A revision of the species of *Porphyra* (Rhodophyta: Bangiales) occurring in British Columbia and adjacent waters. Canadian Journal of Botany, **70**: 2066-2075.

Lindstrom, S. C., Conitz, J. M., Hall, S., and Stekoll, M. S. 2008. Induction of conchospore release: ecotypic variation in northeast Pacific species of *Porphyra*. Journal of Applied Phycology, **20**: 331-340.

Lloyd, T. A. 2011. Cultivating the t'əkkillak$^{w}$, the ethnoecology of ƛəksəm, Pacific silverweed or cinquefoil [*Argentina egedii* (Wormsk.) Rydb.; Rosaceae]: lessons from K$^{w}$axsistalla, Clan Chief Adam Dick, of the Qawadiliqəlla Clan of the

D$^{z}$awadaʔēnux$^{w}$ of Kingcome Inlet (K$^{w}$ak$^{w}$aka'wak$^{w}$ ). M. Sc. Thesis. School of Environmental Studies, University of Victoria, British Columbia.

Lobban, C. S., Harrison, P. J., and Duncan, M. J. 1985. The Physiological Ecology of Seaweeds. Cambridge University Press: Cambridge.

Lutz, J. 1992. After the fur trade: the aboriginal labouring class of British Columbia 1849-1890. Journal of the Canadian Historical Association / Revue de la Société Historique du Canada, **3**: 69-93.

Lutz, J. S. 2008. Makúk, A New History of Aboriginal-White Relations. UBC Press: Vancouver.

MacRobbie, E. A. C. 1974. Ion Uptake. *In* Algal Physiology and Biochemistry. Stewart, W. D. P. (ed.) Blackwell Scientific Publications: Oxford, UK. Pp. 676-713.

Madlener, J. C. 1977. The Sea Vegetable Book. Clarkson N. Potter: New York.

Martin, M. 1716. A Description of the Western Islands of Scotland. London.

Marshall, J., and Foster, N. 2002. "Between Belnging": Habitus and the migration experience. The Canadian Geographer, **46**: 63-83.

Masco, J. 1995. "It is a Strict Law That Bids Us Dance": Cosmologies, Colonialism, Death, and Ritual Authority in the Kwakw*aka*'wakw Potlatch, 1849 to 1922. Comparative Studies in Society and History, **37**: 41-75.

McConnaughey, E. 1985. Sea Vegetables; Harvesting Guide & Cookbook. Naturegraph Publishers: Happy Camp, California. Pp. 159-190.

McLean, M. W., and Williamson, F. B. 1977. Cadmium Accumulation by the Marine Red Alga *Porphyra umbilicalis*. Physiologia Plantarum, **41**: 268-272.

Moerman, D. E. 1998. Native American Ethnobotany. Timber Press: Portland, Oregon.

Mos, L., Jack, J., Cullon, D., Montour, L, Alleyne, C., and Ross, P. 2004. The Importance of Marine Foods to a Near-Urban First Nation Community in Coastal British Columbia, Canada: Toward a Risk-Benefit Assessment. Journal of Toxicology and Environmental Health, Part A, **67**: 791-808.

Moseley, M. E. 1975. The Maritime Foundations of Andean Civilization. Cummings Publishing Company: Menlo Park, California.

Mumford, T. F. 1990. Nori cultivation in North America: growth of the industry. Hydrobiologia, **204/205**: 89-98.

Mumford, T. F., and Miura, A. 1988. *Porphyra* as Food: Cultivation and Economics. *In* Algae and Human Affairs. Lembi, C. A., and Waaland, J. R. (eds.) Cambridge University Press: Cambridge, UK. Pp. 88-117.

Murru, M., and Sandgren, C. D. 2004. Habitat Matters for Inorganic Carbon Acquisition in 38 Species of Red Macroalgae (Rhodophyta) From Puget Sound, Washington, USA. Journal of Phycology, **40**: 837-845.

National Institute of References and Technology. 1993. Certificate of Analysis Standard Reference Material 1515 Apple Leaves. United States Department of Commerce, Washington, DC.

Nelson, W. A., Brodie, J., and Guiry, M. D. 1999. Terminology used to describe reproduction and life history stages in the genus *Porphyra* (Bangiales, Rhodophyta). Journal of Applied Phycology, **11**: 407-410.

Nelson, W. A., and Conroy, A. M. 1989. Effect of harvest method and timing on yield and regeneration of Karengo *(Porphyra* spp.) (Bangiales, Rhodophyta) in New Zealand. Journal of Applied Phycology, **1**: 277- 283.

Neori, A. 2008. Essential role of seaweed cultivation in integrated multi-trophic aquaculture farms for global expansion of mariculture: an analysis. Journal of Applied Phycology, **20**: 567-570.

Norton, H. H. 1981. Plant Use in Kaigani Haida Culture: Correction of an Ethnohistorical Oversight. Economic Botany, **35**: 434-449.

Nriagu, J. O., and Pacyna, J. M. 1988. Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature, **333**: 134-139.

O'Clair, R. M., and Lindstrom, S. C. 2000. North Pacific Seaweeds. Plant Press: Auke Bay, Alaska. Pp. 65-73.

Oliveira, M. C., Kurniawan, J., Bird, C. J., Rice, E. L., Murphy, C. A., Singh, R. K., Gutell, R. R., and Ragan, M. A. 1995. A Preliminary Investigation of the Order Bangiales (Bangiophycidae, Rhodophyta) Based on Sequences of Nuclear Small-Subunit Ribosomal RNA Genes. Phycological Research, **43**: 71–79.

Ollson, C. A., Koch, I., Smith, P., Knopper, L. D., Hough, C., and Reimer, K. J. 2009. Addressing Arsenic Bioaccessibility in Ecological Risk Assessment: A Novel Approach to Avoid Overestimating Risk. Environmental Toxicology and Chemistry, **28**: 668-675.

Orduña-Rojas, J., and Longoria-Espinoza, R. M. 2006. Metal Content in *Ulva lactuca* (Linnaeus) from Navachiste Bay (Southeast Gulf of California) Sinaloa, Mexico. Bulletin of Environmental Contamination and Toxicology, **77**: 574-580.

Pan, J.-F., Lin, R.-G., and Ma, L. 2000. Review of Heavy Metal Adsorption by Marine Algae. Chinese Journal of Oceanology and Limnology, **18**: 260-264.

Pérez, A. A., Farías, S. S., Strobl, A. M., Pérez, L. B., López, C. M., Piñeiro, A., Roses, O., and Fajardo, M. A. 2007. Levels of essential and toxic elements in *Porphyra columbina* and *Ulva* sp. from San Jorge Gulf, Patagonia Argentina. Science of the Total Environment, **376**: 51-59.

Platten, S. and Henfrey, T. 2009. The Cultural Keystone Concept: Insights from Ecological Anthropology. Human Ecology, **37**: 491-500.

Province of British Columbia. 1996. Minfile Map 092L & 102I, Alert Bay and Cape Scott Mineral Occurrence Map, 1:250 000. Ministry of Energy, Mines and Petroleum Resources.

Rathcke, B., and Lacey, E. P. 1985. Phenological Patterns of Terrestrial Plants. Annual Review of Ecology and Systematics, **16**: 179-214.

Recalma-Clutesi, K. 2007. Smoke From His Fire [documentary]. Recalma-Clutesi, K., and Szimanski, A. (directors). Produced in association with APTN and Knowledge Network: Canada. 48 minutes.

Receveur, O., Boulay, M., and Kuhnlein, H. V. 1997. Decreasing Traditional Food Use Affects Diet Quality for Adult Dene/Métis in 16 Communities of the Canadian Northwest Territories. The Journal of Nutrition, **127**: 2179-2186.

Ródenas de la Rocha, S., Sánchez-Muniz, F. J., Gómez-Juaristi, M., and Larrea Marín, M. T. 2009. Trace elements determination in edible seaweeds by an optimized and validated ICP-MS method. Journal of Food Composition and Analysis, **22**: 330-336.

Ross, P. S., and Birnbaum, L. S. 2003. Integrated Human and Ecological Risk Assessment: A Case Study of Persistent Organic Pollutants (POPs) in Humans and Wildlife. Human and Ecological Risk Assessment, **9**: 303-324.

Ross, P. S., Ellis, G. M., Ikonomou, M. G., Barrett-Lennard, L. G., and Addison, R. F. 2000. High PCB Concentrations in Free-Ranging Pacific Killer Whales, *Orcinus orca*: Effects of Age, Sex and Dietary Preference. Marine Pollution Bulletin, **40**: 504-515.

Ross, P. S., Jefferies, S. J., Yunker, M. B., Addison, R. F., Ikonomou, M. G., and Calambokidis, J. C. 2004. Harbor seals (*Phoca vitulina*) in British Columbia, Canada, and Washington State, USA, reveal a combination of local and global polychlorinated biphenyl, dioxin, and furan signals. Environmental Toxicology and Chemistry, **23**: 157-165.

Rupérez, P. 2002. Mineral content of edible marine seaweeds. Food Chemistry, **79**: 23-26.

Scagel, R. F. 1990. Seaweeds, then and now. Hydrobiologia, **204/205**: 1-5.

Schiel, D. R., and Nelson, W. A. 1990. The harvesting of macroalgae in New Zealand. Hydrobiologia, **204/205**: 25-33.

Schiewer, S., and Volesky, B. 2000. Biosorption by Marine Algae. *In* Bioremediation. Valdes, J. J. (ed.) Kluwer Academic Publishers: Dordrecht, The Netherlands. Pp. 139-169.

Semple, K. T., Doick, K. J., Jones, K. C., Burauel, P., Craven, A., and Harms, H. 2004. Defining Bioavailability and Bioaccessibility of Contaminated Soil and Sediment is Complicated. Environmental Science & Technology, **38**: 228A-231A.

Sharp, G. J., Samant, H. S., and Vaidya, O. C. 1988. Selected Metal Levels of Commercially Valuable Seaweeds Adjacent to and Distant from Point Sources of Contamination in Nova Scotia and New Brunswick. Bulletin of Environmental Contamination and Toxicology, **40**: 724-730.

Smith, J. L., Summers, G., and Wong, R. 2010. Nutrient and heavy metal content of edible seaweeds in New Zealand. New Zealand Journal of Crop and Horticultural Science, **38**: 19-28.

Smith, V. H., Sturm, B. S. M., deNoyellles, F. J., and Billings, S. A. 2009. The ecology of algal biodiesel production. Trends in Ecology and Evolution, **25**: 301-309.

Statistics Canada. 2008. 2006 Census Data Table; Labour Force Activity (8), Aboriginal Identity (8B), Age Groups (13A), Sex (3) and Area of Residence (6A) for the Population 15 Years and Over of Canada, Provinces and Territories, 2001 and 2006 Censuses - 20% Sample Data. Catalogue No. 97-559-XCB2006008. Statistics Canada: Ottawa.

Stevenson, M. G. 1996. Indigenous Knowledge in Environmental Assessment. Arctic, **49**: 278-291.

Stewart, H. 1984. Cedar. Douglas & McIntyre: Vancouver, B.C.

Sutherland, J. E., Lindstrom, S. C., Nelson, W. A., Brodie, J., Lynch, M. D. J., Hwang, M. S., Choi, H.-G., Miyata, M., Kikuchi, N., Oliveira, M. C., Farr, T., Neefus, C., Mols-Mortensen, A., Milstein, D., and Müller, K. M. 2011. A New Look at an Ancient Order: Generic Revision of the Bangiales (Rhodophyta). Phycological Society of America, **47**: 1131-1151.

Sutherland, T. F., Petersen, S. A., Levings, C. D., and Martin, A. J. 2007. Distinguishing between natural and aquaculture-derived sediment concentrations of heavy metals in the Broughton Archipelago, British Columbia. Marine Pollution Bulletin, **54**: 1451-1460.

Thompson, J. C. 2004. Gitga'at Plant Project: The Intergenerational Transmission of Traditional Ecological Knowledge Using School Science Curricula. M.Sc. Thesis. School of Environmental Studies, University of Victoria, British Columbia.

Tseng, C. K. 1992. Mariculture on Coastal China and Biodiversity. *In* Diversity of Oceanic Life; An Evaluative Review. Peterson, M. N. A. (ed.) Center for Strategic and International Studies: Washington, D.C. Pp. 76-79.

Tseng, C.K. 2001. Algal biotechnology industries and research activities in China. Journal of Applied Phycology, **13**: 375-380.

Turner, N. J. 1973. Ethnobotany of the Bella Coola Indians of British Columbia. Syesis, **6**: 193–220.

Turner, N. J. 1975. Food Plants of Coastal First Peoples. Royal British Columbia Museum. UBC Press: Vancouver. Pp. 21-22.

Turner, N. J. 1978. Food Plants of British Columbia Indians. Part II. Interior Peoples. B.C. Provincial Museum Handbook No. 36. Victoria.

Turner, N. J. 1997. Food Plants of Interior First Peoples. Royal British Columbia Museum Handbook. UBC Press: Vancouver, B.C.

Turner, N. J. 2003. The Ethnobotany of Edible Seaweed (*Porphyra abbottae* and Related Species; Rhodophyta: Bangiales) and its Use by First Nations on the Pacific Coast of Canada. Canadian Journal of Botany, **81**: 283-293.

Turner, N. J. 2004. Plants of Haida Gwaii. Sono Nis Press: Winlaw, B.C.

Turner, N. J. 2005. The Earth's Blanket: Traditional Teachings for Sustainable Living. Douglas & McIntyre: Vancouver, B.C.

Turner, N. J. 2007. Plant Technology of First Peoples in British Columbia. Royal BC Museum Handbook. Royal BC Museum: Victoria, B.C.

Turner, N. J., and Clifton, H. 2006. "The Forest and the Seaweed": Gitga'at Seaweed, Traditional Ecological Knowledge and Community Survival. (Chapter published in two books) *In* Eating and Healing; Traditional Food as Medicine. Pieroni, A. and Price, L.L. (eds.) Haworth Press: USA. Pp. 153-178. *And In* Traditional Ecological Knowledge and Natural Resource Management. Menzies, C. (ed.) Lincoln: University of Nebraska. Pp. 65-86.

Turner, N. J., and Clifton, H. 2009. ''It's so different today'': Climate change and indigenous lifeways in British Columbia, Canada. Global Environmental Change, **19**: 180-190.

Turner, N. J., and Loewen, D. C. 1998. The Original "Free Trade": Exchange of Botanical Products and Associated Plant Knowledge in Northwestern North America. Anthropologica, **40**: 49-70.

Turner, N. J., Smith, R., and Jones, J. T. 2005. "A Fine Line between Two Nations" Ownership Patterns for Plant Resources among Northwest Coast Indigenous Peoples. *In* Keeping It Living; Traditions of Plant Use and Cultivation on the Northwest Coast of North America. Deur, D., and Turner, N. J. (eds.) University of Washington Press: Seattle, and UBC Press: Vancouver.

Turner, N. J., Thomas, J., Carlson, B. F., and Ogilvie, R. T. 1983. Ethnobotany of the Nitinaht Indians of Vancouver Island. British Columbia Provincial Museum Occasional Paper No. 24. Victoria, B.C.

Turner, N. J., and Turner, K. L. 2007. “Rich in food”: Traditional food systems, erosion and renewal in Northwestern North America. Indian Journal of Traditional Knowledge, **6**: 57-68.

Turner, N. J., and Turner, K. L. 2008. “Where our women used to get the food”: cumulative effects and loss of ethnobotanical knowledge and practice; case study from coastal British Columbia. Canadian Journal of Botany, **86**: 103-115.

Van Netten, C., Hoption Cann, S. A., Morley, D. R., van Netten, J. P. 2000. Elemental and radioactive analysis of commercially available seaweed. The Science of the Total Environment, **255**: 169-175.

Vasconcelos, M. T. S. D., and Leal, M. F. C. 2001. Seasonal variability in the kinetics of Cu, Pb, Cd and Hg accumulation by macroalgae. Marine Chemistry, **74**: 65-85.

Waaland, J. R., Dickson, L. G., and Duffield, E. C. S. 1990. Conchospore production and seasonal occurrence of some *Porphyra* species (Bangiales, Rhodophyta) in Washington State. Hydrobiologia, **204/205**: 453-459.

Wahbe, T. R., Jovel, E. M., Silva García, D. R., Pilco Llagcha, V. E., and Point, N. R. 2007. Building International Indigenous People’s Partnerships for Community-Driven Health Initiatives. EcoHealth, **4**: 472-488.

Williams, M. D. 1979. The harvesting of “sluckus” (*Porphyra perforata*) by the Straits Salish Indians of Vancouver Island, British Columbia. Syesis, **12**: 63-69.

Willows, N. D. 2005. Determinants of Healthy Eating in Aboriginal Peoples in Canada; The Current State of Knowledge and Research Gaps. Canadian Journal of Public Health, **96**: S32-S36.

Wiseman, C. L. S., and Gobas, F.A.C.P. 2002. Balancing risks in the management of contaminated first nations fisheries. International Journal of Environmental Health Research, **12**: 331-342.

World Health Organization (WHO). 1982. Evaluation of certain food additives and contaminants; Twenty-sixth report of the Joint FAO/WHO Expert Committee on Food Additives. WHO Technical Report Series no. 683. World Health Organization: Geneva.

World Health Organization (WHO). 1983. Evaluation of certain food additives and contaminants; Twenty-seventh Report of the Joint FAO/WHO Expert Committee on Food Additives. WHO Technical Report Series no. 696. World Health Organization: Geneva.

World Health Organization (WHO). 1996. Trace elements in human nutrition and health. World Health Organization: Geneva.

World Health Organization (WHO). 2000. Evaluation of Certain Food Additives and Contaminants; Fifty-third report of the Joint FAO/WHO Expert Committee on Food Additives. WHO Technical Report Series no. 896. World Health Organization: Geneva.

World Health Organization (WHO). 2006. Evaluation of Certain Food Contaminants; Sixty-fourth report of the Joint FAO/WHO Expert Committee on Food Additives. WHO Technical Report Series no. 930. WHO Press: Geneva.

World Health Organization (WHO). 2011. Evaluation of Certain Contaminants in Food; Seventy-second report of the Joint FAO/WHO Expert Committee on Food Additives. WHO Technical Report Series no. 959. WHO Press: Geneva.

World Health Organization and Food and Agriculture Organization of the United Nations (WHO and FAO). 2004. Vitamin and mineral requirements in human nutrition; Second edition. World Health Organization: Geneva.

Young, T. K., Reading, J., Elias, B., and O'Neil, J. D. 2000. Type 2 diabetes mellitus in Canada's First Nations: status of an epidemic in progress. Canadian Medical Association Journal, **163**: 561-566.

Zemke-White, W. L., and Ohno, M. 1999. World seaweed utilization: An end-of-century summary. Journal of Applied Phycology **11**: 369-376.

Zietsma, D. 2010. Aboriginal People Living Off-reserve and the Labour Market: Estimates from the Labour Force Survey, 2008-2009. Catalogue no. 71-588-X, no. 2. Statistics Canada, Labour Statistics Division: Ottawa.

Appendix A. Example Form of Informed Consent

**School of Environmental Studies**
**University of Victoria**
**PO Box 3060 STN CSC**
**Victoria BC V8W 2Y2**
**Canada**

**Informed Consent Form**

You are invited to participate in a study entitled 'Traditional Kwakwa̲ka̲'wakw Use of *Porphyra abbottiae* and the Changes in the Perception of Its Quality and Abundance' that is being conducted by Amy E. Deveau, Dr. Nancy J. Turner, and Dr. John P. Volpe. I, Amy Deveau, am a graduate student in the School of Environmental Studies at the University of Victoria and you may contact me if you have further questions by phone or by email. Once this consent form is signed, you will be given a copy and I will keep the other copy.

As a graduate student, I am required to conduct research as part of the requirements for a degree in a Masters of Science in Environmental Studies. It is being conducted under the supervision of Dr. Nancy Turner and Dr. John Volpe. You may contact my supervisors. This research is being funded by the Natural Sciences and Engineering Research Council (NSERC).

**Purpose and Objectives**

The purpose of this research project is to document traditional and modern ecological knowledge and practices regarding the harvesting and preparation of *Porphyra abbottiae* (Kwakwa̲ka̲'wakw: łəqq'əstən). An important part of this research is the interviewing of Kwakwa̲ka̲'wakw adults that have memories, stories, or experiences with this edible seaweed. From these interviews I hope to get a complete story of how Kwakwa̲ka̲'wakw traditional ecological knowledge of *Porphyra abbottiae* has changed over time. I also hope to learn if the Kwakwa̲ka̲'wakw have observed any changes in the appearance, quality, abundance, and overall ecology of the seaweed.

**Importance of this Research**

Research of this type is important because *Porphyra abbottiae* is a definitive food plant for many First Nations in coastal British Columbia. It has historically been very important to the Kwakwa̲ka̲'wakw both as a food and as a key component of Kwakwa̲ka̲'wakw culture. The research will document the traditional ecological knowledge of *Porphyra abbottiae* and help preserve it for younger generations of Kwakwa̲ka̲'wakw. Furthermore, the research will also affirm that the Kwakwa̲ka̲'wakw traditionally accessed and used this coastal resource, and that these practices exist to this day.

**Participants Selection**

You are being asked to participate in this study because I was informed by word of mouth that you are a member of the Kwakwa̱ka̱'wakw Nation with knowledge or experience in the use of *Porphyra abbottiae*.

**What is Involved**
If you agree to voluntarily participate in this research, any travel expenses incurred will be reimbursed to you. You will be interviewed at your home or at another location of your choice and at your convenience. The interview will be conducted as a conversation, and will include the interview questions found on the sheets given to you for review before you consent to the study. The interviews should require 1-2 hours of your time. As compensation, I would like to give you a small drawing or painting of your choosing. You have the right to pause or end the interview at any time you wish. If the interview is recorded using a voice recorder or video camcorder, it will be transcribed shortly afterward onto paper or onto a computer. You will get to review all of the information collected from our interview(s) before it is used in the dissertation, presentations, or any other publications. You have the right at any time to withdraw any or all information in the interview from the study.

**Inconvenience**
Participation in this study may cause some inconvenience to you. This will include the time spent conducting the interview, which we will try to arrange to your schedule.

**Risks**
There are no known or anticipated risks to you by participating in this research. Any risks will not be outside of those expected in everyday life.

**Benefits**
I hope that your participation in this will benefit you by allowing your heritage and traditions to be recognized, and to help you voice any thoughts or concerns about *Porphyra abbottiae* populations in Kwakwa̱ka̱'wakw traditional territories. You will also be ensuring that your knowledge will be documented and available to Kwakwaka'wakw communities for future generations. You will receive full credit for your contributions if they are used in any presentation or publications. You will receive copies of the transcripts, video or audio recordings, and of the dissertation, along with any other publications that will result from the research. This knowledge may also be useful to other coastal First Nations in British Columbia who wish to document their traditional knowledge of *P. abbottiae*.

**Voluntary Participation**
Your participation in this research must be completely voluntary. You are never obligated to participate. If you do decide to participate, you may withdraw at any time without any consequences or any explanation. If you do withdraw from the study, your data will only be used in the study with your permission. If you choose to withhold your permission, your data will be destroyed and will not be used in the study. You will get to keep your compensation even if you withdraw from the study.

**Anonymity**
In terms of protecting your anonymity, I would like to request permission to use your name in the dissertation, presentations, and any other publications that may result from this study. If you wish to remain anonymous, your name will not be used at any time to identify the source of the information in the study. Please refer below to the **Participant's Terms of Consent**, letter "a", to indicate whether or not you wish to remain anonymous.

**Confidentiality**
Your confidentiality and the confidentiality of the data will be protected by storing the digital data on my password-protected computer. Paper copies of the data will be stored in a locked cabinet in my locked office. Only myself and my supervisors will have access to your personal information. The computer will be kept at my locked office or at my home. Your information will only be shared with others with your consent.

**Dissemination of Results**
It is anticipated that the results of this study will be shared with others in the following ways: I will produce posters detailing the results of the study to be distributed to the Kwakwaka'wakw community through community centres. I may present the research to a class at University of Victoria or at a scholarly meeting. Furthermore, I will also organize at least one information session within the community to discuss the results of the analyses. Finally, I will make copies of my thesis available to all of the participants in the study.

**Disposal of Data**
You will receive your own copies of the data (transcripts, videos, photographs) that you have contributed to the study. At the end of the study and once the dissertation has been completed, your data from this study remaining in my possession will be disposed of at your request. Paper notes or transcripts will be shredded. Digital copies of interviews, notes, and transcripts will be deleted. If you do not wish for the destruction of your data in my possession, digital files (audio, video, electronic transcripts) will be stored onto DVDs for safekeeping. Papers and notes will be filed into a cabinet into the Ethnoecology Lab at UVic, or into the offices of Dr. Nancy Turner or Dr. John Volpe. These rooms are kept locked at all times.

**Participant's Terms of Consent**

You, ____________________________________, do hereby:
(*Participant's full name*)

a) ☐ consent / ☐ not consent (*please check one box*) to Amy Deveau identifying you by name to indicate the source of information in the dissertation, presentations, or any publications that may result from this study. You understand that you are under no obligation to be identified by name or to remain anonymous, and have the right to change your choice at any time.

b) ☐ agree / ☐ not agree (*please check one box*) that Amy Deveau has ongoing consent to use your information if multiple meetings or interviews are needed. This means that you will not need to fill out another consent form if we need to meet more than once for the purposes of the study. You understand that you are under no obligation to agree to ongoing consent. If you wish to end your ongoing consent, please contact me by telephone, mail, email, or in-person to let me know of your choice.

*c)* ☐ consent / ☐ not consent (*please check one box*) that this interview with Amy Deveau may be recorded on audio cassette. You are aware that the interview can go ahead without the interview being recorded using a voice recorder. Even if you do consent to have this interview audio-recorded, you are aware that you are free to request that the audio recording be turned off at any point during the interview. You are also free to request at any time that any segment of this recording will be excluded from the study.

*d)* ☐ consent / ☐ not consent (*please check one box)* that video clips from this interview may be used in presentations related to this study. You are aware that these clips are not necessary for the presentations. You are free to request that any of these audio clips will not be used in any presentation.

*e)* ☐ consent / ☐ not consent (*please check one box*) that this interview with Amy Deveau may be recorded using a video camcorder. You are aware that the interview can go ahead without the interview being recorded on video. Even if you do consent to have this interview video-recorded, you are aware that you are free to request that the video recording be turned off at any point during the interview. You are also free to request at any time that any segment of this recording will be excluded from the study.

*f)* ☐ consent / ☐ not consent (*please check one box)* that video clips from this interview may be used in presentations related to this study. You are aware that these clips are not necessary for the presentations. You are free to request that any of these video clips will not be used in any presentation.

*g)* ☐ consent / ☐ not consent (*please check one box)* that this interview with Amy Deveau be photographed. You are aware that these photographs may be used in the final dissertation. Even if you do consent to have this interview photographed, you are aware that you are free to request that photographs not be taken at any point during the interview. You are also free to request at any time that any of these photographs will be excluded from the study.

*h)* ☐ consent / ☐ not consent (*please check one box)* that photographs from this interview may be used in presentations and other publications related to this study. You are aware that these photographs are not necessary for the presentations. You are free to request that any photograph will not be used in any presentations or publications.

i) ☐ consent / ☐ not consent (*please check one box)* that the data collected in this study may be used for future publication or studies by Amy Deveau. These publications or studies will be based upon the same themes as this study, including traditional ecological knowledge, resource management, and *Porphyra abbottiae* ecology. You understand that you are under no obligation to agree to allow your information to be used after the completion of the study. If you wish to change your consent, please contact me by telephone, mail, email, or in-person to let me know of your choice.

j) ☐ consent / ☐ not consent (*please check one box)* that the data collected in this study may be used for future publication or studies by persons other than Amy Deveau. You understand that you are under no obligation to agree to allow your information to be used after the completion of the study. If you wish to change your consent, please contact me by telephone, mail, email, or in-person to let me know of your choice.

**Contacts**

Individuals that may be contacted regarding this study include Amy Deveau, Dr. Nancy Turner, and Dr. John Volpe. Please refer to the contact information at the beginning of the consent form. If you would like to exclude some of your contributions to the study or would like to withdraw completely from the study, please contact myself or one of my supervisors. In addition, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria (250-472-4545 or ethics@uvic.ca).

Your signature below indicates that you have read and understood the above conditions of participation in this study, and that you have had the opportunity to have your questions answered by the researchers.

| ____________________ | ____________________ | ____________________ |
|---|---|---|
| *Name of Participant* | *Signature* | *Date* |

Appendix B. Kʷak’wala terminology associated with seaweed harvesting and related seasonal activities. Orthography and spelling were provided by *Mayanił* (pers. comm. May 2011).

| | |
|---|---|
| ***ʔixp̓p̓a*** | Tastes good or sweet. |
| ***k̓awas*** | Any dried fish fillet. |
| ***k̓əmƛayuw*** | Seaweed chopper for powdering seaweed. |
| ***kʷəlxʷ ʔid*** | The colour [of the seaweed] has faded. |
| ***lax̌ēy*** | Wide mesh baskets used for clams, roots and seaweeds. |
| ***ləmxʷəxʷ sa ƛ̓isəlla*** | Dried by the sun. |
| ***łaxʷp̓p̓a*** | Tastes bitter. |
| ***łəqq̓əstən*** | *Porphyra abbottiae*, an edible intertidal red seaweed harvested and consumed by the Kwakwa̱ka̱’wakw. Found from Alaska to northern California. Derives from ***łəqqałła*** (draped), describing how the seaweed is, “drapped over the rocks.” |
| ***ƛ̓isəlla*** | Sun. |
| ***ƛ̓issalla*** | Sun or sunny weather. |
| ***makolla*** | Small island. |
| ***miwella*** | Large island (such as Vancouver Island). |
| ***məlmadᶻuw*** | Sun dried halibut fillet. |
| ***p̓oy*** | Halibut. |
| ***q̓eqəlla*** | Purification rites meant to strengthen or cleanse the body, mind and spirit. There are rites to achieve different purposes, including spiritual power, hunting, fishing, and strength. |
| ***wəłp̓p̓a*** | Having no taste. |

Appendix C. Site locations.

| **Site name** | **Years sampled** | **Latitude** | **Longitude** |
|---|---|---|---|
| Bauza Island | 2008, 2009 | 50° 32.845’ N | 126° 48.221’ W |
| Bella Bella | 2008 | Unavailable | Unavailable |
| Foster Island | 2008, 2009 | 50° 42.232’ N | 126° 50.383’ W |
| Holford Island | 2009 | 50° 43.99’ N | 126° 48.35’ W |
| Pearse Island | 2008, 2009 | 50° 35.235’ N | 126° 49.995’ W |
| Plumper Island | 2009 | 50° 35.836’ N | 126° 47.823’ W |

Appendix D. Chemical list.

| **Chemical name** | **Abbreviation** | **Producer** | **Use** |
|---|---|---|---|
| Hydrochloric Acid (>30%) TraceSelect | HCl | Fluka®, Germany | Sample digestion |
| Hydrochloric Acid (20%) | HCl | Fluka®, Germany | Glassware cleaning |
| Gold Chloride | $AuCl_3$ | In-lab | Sample digestion |
| Nitric Acid (67-70%) Trace Metal grade | | Fisher®, Canada | Sample pre-digestion |
| Nitric Acid (10%)_ | $HNO_3$ | Fisher®, Canada | Glassware cleaning |
| Dihydrogen dioxide (peroxide) (35%) | $H_2O_2$ | Emprove® | Sample digestion |
| Contrad® 70 (Decon) | KOH solution | Decon Labs, Inc. | Glassware cleaning |

Appendix E. ICP-MS results from *Porphyra abbottiae* digests. Values are represented in milligrams or nanograms per kilogram of dried seaweed.

| Sample Id | **Ca** mg/kg | **Cr** mg/kg | **Mn** mg/kg | **Fe** mg/kg | **Co** mg/kg | **Cu** mg/kg | **Zn** mg/kg | **As** mg/kg | **Se** mg/kg | **Cd** mg/kg | **Hg** mg/kg | **Pb** mg/kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P08-1 | 1289 | 0.17 | 12.7 | 38.7 | 0.08 | 1.73 | 13.8 | 23.8 | 0.01 | 2.78 | 0.007 | 0.25 |
| P08-3 | 1287 | 0.04 | 14.6 | 36.9 | 0.10 | 1.80 | 17.2 | 25.8 | 0.08 | 3.58 | 0.014 | 0.31 |
| P08-2 | 1576 | 0.17 | 19.0 | 35.5 | 0.12 | 3.07 | 15.7 | 26.5 | 0.08 | 3.92 | 0.007 | 0.37 |
| P08-4 | 1217 | 0.15 | 12.8 | 37.7 | 0.08 | 1.95 | 15.0 | 22.2 | 0.06 | 2.75 | 0.001 | 0.36 |
| P08-5 | 1388 | 0.21 | 12.2 | 39.9 | 0.09 | 1.84 | 17.1 | 21.2 | 0.02 | 2.93 | 0.002 | 0.20 |
| P08-6 | 1352 | 0.14 | 13.7 | 48.5 | 0.11 | 2.62 | 15.6 | 23.7 | 0.03 | 3.13 | 0.001 | 0.17 |
| P08-7 | 1252 | 0.14 | 14.0 | 36.9 | 0.09 | 1.77 | 16.5 | 29.4 | 0.05 | 2.91 | 0.003 | 0.11 |
| P08-8 | 1212 | 0.20 | 13.0 | 33.1 | 0.08 | 1.84 | 17.0 | 23.5 | 0.07 | 2.73 | 0.002 | 0.17 |
| P08-9 | 1255 | 0.16 | 12.7 | 39.6 | 0.08 | 1.95 | 15.8 | 26.2 | 0.01 | 2.94 | 0.003 | 0.13 |
| P08-10 | 1527 | 0.14 | 11.6 | 50.8 | 0.09 | 2.57 | 12.9 | 24.1 | 0.08 | 2.82 | 0.001 | 0.15 |
| Z08-1 | 1318 | 0.13 | 10.2 | 42.8 | 0.08 | 3.41 | 18.4 | 18.4 | 0.01 | 1.14 | 0.006 | 0.16 |
| Z08-2 | 1406 | 0.15 | 16.2 | 58.8 | 0.08 | 3.27 | 24.5 | 4.1 | 0.05 | 1.69 | 0.005 | 0.25 |
| Z08-3 | 1284 | 0.14 | 10.5 | 36.6 | 0.08 | 3.17 | 13.9 | 22.6 | 0.01 | 1.10 | 0.003 | 0.31 |
| Z08-4 | 1107 | 0.21 | 15.9 | 73.9 | 0.09 | 4.93 | 22.2 | 3.1 | 0.06 | 1.74 | 0.003 | 0.23 |
| Z08-5 | 1261 | 2.07 | 9.8 | 41.3 | 0.08 | 2.99 | 24.9 | 23.2 | 0.03 | 1.14 | 0.001 | 0.38 |
| Z08-6 | 1095 | 0.16 | 20.9 | 81.4 | 0.10 | 5.25 | 31.9 | 3.5 | 0.04 | 2.24 | 0.002 | 0.25 |
| Z08-7 | 1276 | 0.14 | 18.4 | 61.7 | 0.08 | 3.58 | 25.5 | 3.9 | 0.05 | 1.88 | 0.001 | 0.14 |
| Z08-8 | 1077 | 0.61 | 9.0 | 46.9 | 0.08 | 3.56 | 16.9 | 15.6 | 0.09 | 0.95 | 0.009 | 0.16 |
| Z08-9 | 1337 | 0.17 | 15.8 | 46.6 | 0.07 | 2.65 | 26.3 | 4.0 | 0.08 | 1.75 | 0.005 | 0.19 |
| Z08-10 | 1039 | 0.13 | 14.9 | 56.9 | 0.07 | 3.59 | 25.9 | 3.4 | 0.05 | 1.64 | 0.001 | 0.25 |
| BY08-1 | 1400 | 0.19 | 19.5 | 48.7 | 0.13 | 4.53 | 17.0 | 4.0 | 0.33 | 1.95 | 0.014 | 0.27 |
| BY08-3 | 1356 | 0.21 | 18.6 | 47.2 | 0.13 | 3.69 | 20.8 | 4.0 | 0.37 | 1.96 | 0.010 | 0.28 |
| BY08-2 | 1393 | 0.29 | 20.6 | 61.3 | 0.15 | 5.24 | 21.0 | 3.8 | 0.37 | 1.99 | 0.030 | 0.42 |
| BY08-4 | 1160 | 0.22 | 22.5 | 78.1 | 0.15 | 5.36 | 21.8 | 3.8 | 0.39 | 2.25 | 0.007 | 0.36 |
| BY08-5 | 1817 | 0.23 | 17.7 | 72.3 | 0.13 | 7.72 | 20.1 | 3.1 | 0.33 | 1.75 | 0.011 | 0.25 |
| BY08-6 | 1045 | 0.25 | 18.8 | 69.4 | 0.11 | 6.84 | 24.8 | 3.9 | 0.29 | 2.00 | 0.005 | 0.35 |
| BY08-7 | 1934 | 0.24 | 18.1 | 56.8 | 0.12 | 4.26 | 25.2 | 4.1 | 0.35 | 2.00 | 0.004 | 0.62 |
| BY08-8 | 1189 | 0.19 | 19.7 | 69.2 | 0.13 | 5.46 | 24.0 | 3.6 | 0.28 | 2.02 | 0.005 | 0.12 |
| BY08-9 | 1062 | 0.36 | 19.6 | 62.2 | 0.11 | 3.48 | 25.2 | 4.7 | 0.36 | 2.11 | 0.004 | 0.25 |
| BY08-10 | 1232 | 0.29 | 17.5 | 92.4 | 0.13 | 3.77 | 24.1 | 4.4 | 0.37 | 1.88 | 0.005 | 0.10 |
| A09-1 | 1426 | 0.13 | 10.0 | 25.4 | 0.09 | 2.55 | 13.9 | 19.1 | 0.07 | 1.22 | 0.006 | 0.21 |
| A09-2 | 1364 | 0.13 | 8.8 | 22.4 | 0.09 | 2.31 | 12.9 | 16.3 | 0.09 | 1.09 | 0.006 | 0.13 |
| A09-3 | 1381 | 0.13 | 15.5 | 35.6 | 0.08 | 3.24 | 19.1 | 2.3 | 0.07 | 1.94 | 0.004 | 0.14 |
| A09-4 | 1266 | 0.16 | 14.9 | 29.7 | 0.06 | 2.62 | 23.0 | 2.8 | 0.04 | 1.85 | 0.001 | 0.15 |
| A09-5 | 1453 | 0.13 | 16.9 | 29.7 | 0.07 | 2.87 | 21.2 | 2.5 | 0.05 | 2.06 | 0.001 | 0.10 |
| A09-6 | 1354 | 0.19 | 7.1 | 25.5 | 0.07 | 2.82 | 14.4 | 11.2 | 0.03 | 0.92 | 0.001 | 0.35 |
| A09-7 | 1274 | 0.18 | 8.8 | 30.0 | 0.08 | 83.92 | 72.0 | 17.8 | 0.06 | 1.40 | 0.001 | 4.07 |
| A09-8 | 1409 | 0.21 | 7.2 | 24.1 | 0.06 | 2.35 | 12.7 | 10.2 | 0.05 | 0.98 | 0.002 | 0.06 |
| A09-9 | 1519 | 0.15 | 7.6 | 20.9 | 0.05 | 1.97 | 12.2 | 14.4 | 0.03 | 0.95 | 0.001 | 0.06 |
| A09-10 | 1402 | 0.12 | 17.2 | 24.9 | 0.07 | 2.32 | 24.4 | 3.1 | 0.05 | 2.37 | 0.001 | 0.16 |
| C09-1 | 1234 | 0.14 | 11.6 | 66.6 | 0.08 | 1.70 | 13.0 | 18.3 | 0.05 | 3.18 | 0.003 | 0.30 |
| C09-2 | 1164 | 0.14 | 11.6 | 30.6 | 0.07 | 1.87 | 12.9 | 19.5 | 0.02 | 3.12 | 0.002 | 0.55 |
| C09-3 | 1178 | 0.13 | 13.2 | 34.9 | 0.09 | 2.07 | 13.6 | 23.0 | 0.02 | 3.50 | 0.002 | 0.37 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C09-4 | 1131 | 0.13 | 12.6 | 24.3 | 0.08 | 1.53 | 15.9 | 23.1 | 0.03 | 3.62 | 0.001 | 0.26 |
| C09-5 | 1154 | 0.14 | 13.6 | 35.5 | 0.09 | 1.92 | 15.9 | 23.9 | 0.03 | 3.31 | 0.001 | 0.36 |
| C09-6 | 1146 | 0.15 | 16.0 | 33.8 | 0.09 | 1.89 | 12.9 | 20.7 | 0.03 | 3.33 | 0.001 | 0.38 |
| C09-7 | 1211 | 0.15 | 12.2 | 35.0 | 0.07 | 2.21 | 13.8 | 25.0 | 0.08 | 2.88 | 0.009 | 0.25 |
| C09-8 | 1213 | 0.15 | 12.6 | 28.5 | 0.08 | 2.01 | 16.1 | 23.5 | 0.05 | 3.31 | 0.002 | 0.29 |
| C09-9 | 1180 | 0.15 | 13.2 | 31.9 | 0.08 | 1.85 | 18.0 | 25.0 | 0.03 | 3.53 | 0.002 | 0.64 |
| C09-10 | 1244 | 0.14 | 13.1 | 30.6 | 0.08 | 1.68 | 16.6 | 25.9 | 0.06 | 3.45 | 0.001 | 0.31 |
| M09-1 | 1214 | 0.14 | 17.7 | 36.6 | 0.11 | 2.65 | 11.7 | 25.0 | 0.06 | 3.89 | 0.001 | 0.16 |
| M09-2 | 1130 | 0.16 | 16.0 | 25.9 | 0.08 | 1.66 | 13.8 | 20.0 | 0.07 | 3.88 | 0.001 | 0.32 |
| M09-3 | 1175 | 0.16 | 16.0 | 24.4 | 0.09 | 2.03 | 12.7 | 19.1 | 0.08 | 3.69 | 0.001 | 0.23 |
| M09-4 | 1153 | 0.13 | 12.3 | 26.6 | 0.09 | 1.79 | 14.0 | 26.5 | 0.03 | 3.25 | 0.001 | 0.23 |
| M09-5 | 1191 | 0.13 | 13.8 | 36.5 | 0.10 | 2.26 | 14.0 | 22.2 | 0.05 | 3.37 | 0.001 | 0.31 |
| M09-6 | 1805 | 0.17 | 15.4 | 50.2 | 0.10 | 1.83 | 15.7 | 22.4 | 0.08 | 3.63 | 0.001 | 0.42 |
| M09-7 | 1253 | 0.14 | 14.6 | 31.3 | 0.08 | 2.30 | 14.7 | 25.8 | 0.04 | 3.92 | 0.001 | 0.08 |
| M09-8 | 1114 | 0.14 | 13.9 | 30.5 | 0.10 | 2.21 | 15.3 | 24.5 | 0.04 | 3.73 | 0.001 | 0.07 |
| M09-9 | 1299 | 0.15 | 15.1 | 49.7 | 0.13 | 2.87 | 13.4 | 28.5 | 0.05 | 3.93 | 0.001 | 0.17 |
| M09-10 | 1239 | 0.14 | 15.6 | 36.5 | 0.12 | 2.77 | 14.1 | 24.8 | 0.05 | 3.97 | 0.001 | 0.29 |
| F08-1 | 1323 | 0.15 | 16.6 | 45.1 | 0.14 | 2.21 | 15.7 | 30.8 | 0.05 | 3.45 | 0.001 | 0.28 |
| F08-2 | 1315 | 0.14 | 15.6 | 50.7 | 0.12 | 2.29 | 16.4 | 30.9 | 0.05 | 3.66 | 0.002 | 0.13 |
| F08-3 | 1395 | 0.14 | 14.3 | 45.2 | 0.10 | 2.18 | 20.2 | 28.8 | 0.02 | 3.48 | 0.008 | 0.21 |
| F08-4 | 1470 | 0.12 | 16.5 | 44.5 | 0.06 | 2.18 | 9.9 | 15.7 | 0.04 | 2.99 | 0.009 | 0.31 |
| F08-5 | 3677 | 0.12 | 13.6 | 44.4 | 0.09 | 2.50 | 16.1 | 23.6 | 0.04 | 2.88 | 0.004 | 0.20 |
| F08-6 | 1644 | 0.14 | 13.1 | 41.2 | 0.09 | 1.85 | 15.8 | 24.3 | 0.04 | 2.84 | 0.003 | 0.50 |
| F08-7 | 1625 | 0.17 | 12.9 | 54.4 | 0.11 | 2.55 | 14.8 | 26.5 | 0.05 | 3.20 | 0.003 | 0.04 |
| F08-8 | 1316 | 0.11 | 14.8 | 56.3 | 0.12 | 2.50 | 15.3 | 28.6 | 0.08 | 3.55 | 0.001 | 0.04 |
| F08-9 | 1658 | 0.15 | 20.7 | 51.9 | 0.08 | 3.20 | 22.6 | 23.7 | 0.04 | 2.46 | 0.001 | 0.08 |
| F08-10 | 1925 | 0.14 | 15.8 | 54.9 | 0.09 | 2.35 | 17.6 | 24.8 | 0.05 | 2.93 | 0.001 | 0.07 |
| H09-1 | 1548 | 0.14 | 13.3 | 34.7 | 0.11 | 2.19 | 15.3 | 24.3 | 0.03 | 3.53 | 0.006 | 0.23 |
| H09-2 | 1578 | 0.13 | 12.7 | 43.3 | 0.11 | 2.67 | 13.3 | 22.6 | 0.04 | 3.20 | 0.004 | 0.12 |
| H09-3 | 1360 | 0.13 | 13.4 | 36.1 | 0.11 | 2.38 | 14.5 | 24.9 | 0.08 | 3.29 | 0.002 | 0.17 |
| H09-4 | 1431 | 0.13 | 13.2 | 25.8 | 0.09 | 1.68 | 15.1 | 24.3 | 0.04 | 3.19 | 0.008 | 0.12 |
| H09-5 | 1528 | 0.22 | 12.1 | 38.2 | 0.10 | 2.42 | 17.9 | 23.7 | 0.09 | 2.94 | 0.005 | 0.38 |
| H09-6 | 1529 | 0.13 | 12.2 | 40.4 | 0.11 | 2.38 | 13.7 | 25.3 | 0.04 | 3.18 | 0.003 | 0.24 |
| H09-7 | 1480 | 0.14 | 11.3 | 41.5 | 0.11 | 2.77 | 14.0 | 21.5 | 0.04 | 2.75 | 0.001 | 0.11 |
| H09-8 | 1490 | 0.16 | 13.9 | 41.0 | 0.12 | 2.64 | 14.3 | 25.7 | 0.04 | 3.38 | 0.001 | 0.04 |
| H09-9 | 1633 | 0.15 | 13.6 | 46.7 | 0.11 | 2.71 | 15.0 | 24.6 | 0.07 | 3.30 | 0.001 | 0.16 |
| H09-10 | 1453 | 0.12 | 11.9 | 27.6 | 0.09 | 2.13 | 14.2 | 23.3 | 0.04 | 2.71 | 0.001 | 0.17 |
| S09-2 (retry) | 2205 | 0.23 | 17.1 | 36.5 | 0.11 | 2.37 | 12.7 | 21.3 | 0.17 | 3.89 | 0.013 | 0.12 |
| S09-3 | 2651 | 0.15 | 10.0 | 29.6 | 0.07 | 2.22 | 9.5 | 16.2 | 0.11 | 2.22 | 0.002 | 0.27 |
| S09-4 | 1793 | 0.15 | 12.4 | 33.0 | 0.10 | 1.80 | 12.1 | 26.7 | 0.08 | 3.05 | 0.008 | 0.21 |
| S09-5 | 2148 | 0.23 | 13.4 | 19.0 | 0.08 | 1.85 | 14.2 | 18.7 | 0.07 | 3.59 | 0.007 | 0.51 |
| S09-6 | 2135 | 0.14 | 10.4 | 32.3 | 0.09 | 2.16 | 10.9 | 23.2 | 0.08 | 3.13 | 0.003 | 0.32 |
| S09-7 | 1785 | 0.13 | 12.5 | 19.1 | 0.08 | 1.28 | 12.9 | 20.6 | 0.04 | 3.03 | 0.001 | 0.13 |
| S09-8 | 1823 | 0.19 | 14.1 | 36.2 | 0.12 | 2.55 | 13.4 | 24.6 | 0.16 | 3.71 | 0.001 | 0.09 |
| S09-9 | 2086 | 0.17 | 11.0 | 44.4 | 0.10 | 2.65 | 10.9 | 21.5 | 0.09 | 3.16 | 0.001 | 0.18 |
| S09-10 | 2144 | 0.13 | 11.7 | 18.6 | 0.08 | 1.11 | 13.1 | 20.8 | 0.05 | 2.98 | 0.004 | 0.23 |

Appendix F. TDI values obtained from Health Canada (HC), who uses values determined by the Institute of Medicine, and the World Health Organization. Values are based on an average 60 kg adult. Discrepancies in values between organizations are noted in brackets.

| Element | Tolerable daily intake (mg/kg b.w./day) |
|---|---|
| Arsenic | 0.003 [1] |
| Calcium | 41.7 [2] |
| Cadmium | 0.001 [3] |
| Cobalt | 0.04 [4] |
| Chromium | 0.0041 [5] |
| Copper | 0.5 [6] (HC: 0.167 [2]) |
| Iron | 0.8 [2, 7] |
| Mergury | 0.00057 [1] |
| Manganese | 0.183 [2] |
| Lead | 0.00357 [8] |
| Selenium | 0.00667 [2, 9] |
| Zinc | 1 [6] (HC: 0.67 [2]) |

1. WHO 2011; 2. Institute of Medicine of the National Academies 2006; 3. WHO 2006; 4. Environment Canada/Health Canada. 2011; 5. WHO 1996; 6. WHO 1982; 7. WHO 1983; 8. WHO 2000; 9. WHO and FAO 2004.

Appendix G. Pearson correlation coefficient (*r*) and *p*-values (Bonferroni-corrected) for PCA factors against element concentrations.

| | PC1 | | PC2 | | PC3 | |
|---|---|---|---|---|---|---|
| | *r* | *p* | *r* | *p* | *r* | *p* |
| Ca (mg/kg) | -0.726 | 0.000 | -0.161 | 0.000 | 0.186 | 0.000 |
| Cr (mg/kg) | 0.174 | 0.000 | -0.26 | 1.000 | -0.264 | 1.000 |
| Mn (mg/kg) | 0.561 | 1.000 | -0.082 | 1.000 | 0.512 | 0.972 |
| Fe (mg/kg) | 0.623 | 0.000 | -0.302 | 1.000 | 0.322 | 0.000 |
| Co (mg/kg) | 0.393 | 0.000 | 0.064 | 0.315 | 0.508 | 0.164 |
| Cu (mg/kg) | 0.294 | 0.011 | -0.307 | 1.000 | -0.564 | 0.000 |
| Zn (mg/kg) | 0.551 | 0.407 | -0.485 | 0.268 | -0.45 | 0.000 |
| As (mg/kg) | -0.402 | 0.000 | 0.799 | 0.000 | -0.233 | 0.001 |
| Se (mg/kg) | 0.469 | 0.007 | -0.525 | 0.000 | 0.554 | 1.000 |
| Cd (mg/kg) | -0.155 | 0.000 | 0.853 | 0.000 | 0.155 | 0.000 |
| Hg (mg/kg) | 0.178 | 1.000 | -0.412 | 0.000 | 0.463 | 1.000 |
| Pb (mg/kg) | 0.253 | 1.000 | -0.239 | 0.005 | -0.653 | 0.000 |

Appendix H. ANOVA *p*-values and regression *r* and $R^2$ values for the metal and trace element concentrations tested against site-specific factors. The largest $R^2$ values for each element are indicated in bold font.

| | | Ca | Cr | Mn | Fe | Co | Cu | Zn | As | Se | Cd | Hg | Pb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Latitude | *p* | 0.000 | 0.203 | 0.206 | 0.015 | 0.104 | 0.305 | 0.000 | 0.000 | 0.000 | 0.000 | 0.075 | 0.670 |
| | $R^2$ | 0.255 | 0.031 | 0.024 | 0.043 | 0.032 | 0.024 | 0.137 | 0.353 | 0.079 | 0.300 | 0.010 | 0.024 |
| | *r* | 0.505 | -0.176 | -0.155 | -0.207 | 0.179 | -0.155 | -0.370 | 0.594 | -0.281 | 0.548 | -0.101 | -0.154 |
| Longitude | *p* | 0.000 | 0.203 | 0.206 | 0.015 | 0.104 | 0.305 | 0.000 | 0.000 | 0.000 | 0.000 | 0.075 | 0.670 |
| | $R^2$ | 0.146 | 0.020 | 0.019 | 0.020 | 0.015 | 0.020 | 0.077 | 0.232 | 0.059 | 0.154 | 0.000 | 0.003 |
| | *r* | 0.382 | -0.143 | -0.138 | -0.141 | -0.122 | -0.141 | -0.277 | 0.482 | -0.243 | 0.392 | -0.013 | -0.056 |
| Distance to | *p* | 0.000 | 0.203 | 0.206 | 0.015 | 0.104 | 0.305 | 0.000 | 0.000 | 0.000 | 0.000 | 0.075 | 0.670 |
| large | $R^2$ | **0.282** | 0.031 | 0.022 | 0.043 | 0.029 | 0.025 | 0.140 | 0.358 | 0.078 | 0.308 | 0.010 | **0.024** |
| landmass | *r* | 0.531 | -0.176 | -0.148 | -0.205 | 0.173 | -0.158 | -0.374 | 0.594 | -0.277 | 0.551 | -0.100 | -0.154 |
| Distance to | *p* | 0.000 | 0.203 | 0.206 | 0.015 | 0.104 | 0.305 | 0.000 | 0.000 | 0.000 | 0.000 | 0.075 | 0.670 |
| 200m depth | $R^2$ | 0.180 | 0.032 | 0.029 | 0.048 | **0.038** | 0.024 | 0.135 | 0.350 | 0.086 | 0.310 | 0.014 | **0.024** |
| | *r* | 0.424 | -0.179 | -0.170 | -0.219 | 0.195 | -0.155 | -0.367 | 0.596 | -0.293 | 0.557 | -0.118 | -0.155 |
| Distance to | *p* | 0.000 | 0.203 | 0.206 | 0.015 | 0.104 | 0.305 | 0.000 | 0.000 | 0.000 | 0.000 | 0.075 | 0.670 |
| 100m depth | $R^2$ | 0.003 | 0.044 | 0.031 | **0.080** | 0.020 | **0.039** | 0.153 | 0.463 | **0.155** | 0.448 | **0.028** | 0.004 |
| | *r* | 0.050 | -0.210 | -0.176 | -0.283 | -0.141 | -0.197 | -0.391 | 0.680 | -0.394 | 0.669 | -0.167 | -0.063 |
| # islands in | *p* | 0.000 | 0.203 | 0.206 | 0.015 | 0.104 | 0.305 | 0.000 | 0.000 | 0.000 | 0.000 | 0.075 | 0.670 |
| 1km radius | $R^2$ | 0.183 | 0.002 | 0.003 | 0.015 | 0.025 | 0.002 | 0.006 | 0.017 | 0.013 | 0.069 | 0.027 | 0.002 |
| | *r* | -0.428 | -0.048 | 0.051 | -0.122 | -0.159 | -0.046 | -0.077 | 0.131 | -0.114 | 0.262 | -0.164 | 0.046 |
| # islands in | *p* | 0.000 | 0.122 | 0.273 | 0.007 | 0.222 | 0.183 | 0.000 | 0.000 | 0.000 | 0.000 | 0.084 | 0.532 |
| 2km radius | $R^2$ | 0.143 | 0.013 | 0.001 | 0.042 | 0.025 | 0.011 | 0.039 | 0.120 | 0.057 | 0.203 | 0.040 | 0.000 |
| | *r* | -0.378 | -0.114 | -0.035 | -0.206 | -0.159 | -0.105 | -0.198 | 0.346 | -0.239 | 0.450 | -0.201 | 0.013 |
| Distance to | *p* | 0.000 | 0.203 | 0.206 | 0.015 | 0.104 | 0.305 | 0.000 | 0.000 | 0.000 | 0.000 | 0.075 | 0.670 |
| nearest | $R^2$ | 0.132 | 0.039 | 0.029 | 0.067 | 0.038 | 0.030 | 0.166 | 0.432 | 0.111 | 0.416 | 0.027 | 0.025 |
| settlement | *r* | 0.363 | -0.197 | -0.170 | -0.259 | 0.195 | -0.173 | -0.407 | 0.657 | 0.333 | 0.645 | -0.164 | -0.160 |
| Shoreline in | *p* | 0.000 | 0.203 | 0.206 | 0.015 | 0.104 | 0.305 | 0.000 | 0.000 | 0.000 | 0.000 | 0.075 | 0.670 |
| 1km radius | $R^2$ | 0.012 | 0.011 | 0.003 | 0.023 | 0.012 | 0.011 | 0.052 | 0.120 | 0.027 | 0.198 | 0.020 | 0.000 |
| | *r* | 0.110 | -0.105 | 0.055 | -0.152 | -0.110 | -0.105 | -0.228 | 0.346 | -0.166 | 0.445 | -0.141 | -0.022 |
| Channel | *p* | 0.000 | 0.203 | 0.206 | 0.015 | 0.104 | 0.305 | 0.000 | 0.000 | 0.000 | 0.000 | 0.075 | 0.670 |
| width | $R^2$ | 0.080 | 0.024 | **0.049** | 0.034 | 0.019 | 0.018 | 0.086 | 0.256 | 0.074 | 0.174 | 0.005 | 0.015 |
| | *r* | 0.283 | -0.153 | -0.221 | -0.184 | 0.138 | -0.132 | -0.293 | 0.506 | -0.272 | 0.417 | -0.069 | -0.123 |
| Distance to | *p* | 0.000 | 0.203 | 0.206 | 0.015 | 0.104 | 0.305 | 0.000 | 0.000 | 0.000 | 0.000 | 0.075 | 0.670 |
| isle >10km² | $R^2$ | 0.215 | **0.050** | 0.031 | 0.074 | 0.002 | 0.043 | **0.206** | **0.560** | 0.142 | **0.502** | 0.019 | 0.019 |
| | *r* | 0.464 | -0.224 | -0.176 | -0.272 | 0.040 | -0.207 | -0.454 | 0.748 | -0.377 | 0.709 | -0.138 | -0.138 |