

Ethnolichenology of *Bryoria fremontii*: Wisdom of elders, population ecology, and
nutritional chemistry

by

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B. Sc., University of Lethbridge, 2001

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Abstract

More than 300 species of lichens are used by people across the world, mostly as dyes or medicines. Some lichens are used as food, although previous studies indicate that lichens are indigestible to humans. *Bryoria fremontii* is an example of a lichen that is an important traditional food throughout its range. A literature review and interviews with a knowledgeable Secwepemc elder reveal that this lichen is traditionally harvested, washed, and cooked in specific ways that are deeply rooted in its ecology and chemistry. A population study indicates that the traditional practice of avoiding areas with light-coloured and greenish lichen selects for locations with *Bryoria fremontii* and avoids similar-looking toxic species. A cooking experiment suggests that cooking does not make lichen carbohydrates digestible, but when the lichen is cooked with other foods it can capture digestible carbohydrates from them that would otherwise be lost, thus increasing available carbohydrates by 23–122%.

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Dedication

To Mary Thomas, whose wisdom and generosity is inspiration for us all.



Mary Thomas (1919–2007)

Chapter 1 An introduction to ethnolichenology

1.1 Abstract

The unique biology of lichens is briefly explained, and a survey of over 300 species of lichens used by people across the world is summarized. Lichens are mainly used by humans for dye, medicine, and food, but people have also found many other, more novel uses for these organisms. The secondary compounds and carbohydrates in lichens have been and are still useful to humans. The secondary compounds are used as dyes and medicines, and the carbohydrates are used in medicines and food.

People have a lot of traditional knowledge about the variation in lichens and often use several clues to select the best quality specimens. The food uses of lichens are briefly reviewed. Almost all food lichens are cooked in some way before being eaten, and the cooking process is often complex, usually involving steps to remove toxins from the lichen. Folk taxonomies of lichens across the world are reviewed, and provide insight into the human perception of lichens.

Many lichens are quite slow growing. As a result, lichen productivity is usually low, although there are some ecosystems that can produce a significant lichen biomass relatively quickly. The low productivity of lichens means that over-harvesting is a real concern when humans use lichens, and there are many cases of overexploitation of lichens.

A variety of animals eat lichens, including some rodents, ungulates, and invertebrates. Lichens produce a large number of secondary compounds that defend them against pathogens, competitors, and herbivores, as well as serving other functions. The concentration of these compounds can vary substantially along numerous ecological gradients. Many of these lichen secondary compounds have toxic effects against animals, and this toxicity has been well studied for usnic acid and vulpinic acid. Lichen secondary compounds also have a wide variety of pharmaceutical properties. They are somewhat water soluble, and quite heat stable.

Lichen carbohydrates are reviewed, and the nutritionally relevant carbohydrates in lichens are determined to be the glucans lichenin and isolichenin. Some lichens also have

significant levels of proteins and essential amino acids, as well as some minerals and vitamins, but most lichens only have minimal amounts of these nutrients. Digestion studies conducted for lichen carbohydrates over the last 135 years in humans, lab animals, and livestock are reviewed. Lichen carbohydrates are very unlikely to be digestible to humans, although some lichenivorous ruminants can digest them quite well. It can be concluded that the historical tendency to view lichens as nutritious to humans may be exaggerated.

1.2 Introduction to lichen biology

1.2.1 The lichen symbiosis

Lichens are a unique testament to the ingenuity of fungi. All fungi are incapable of photosynthesis and would therefore be unable to produce their own food from the sun, except that some of those fungi — the ones that we call lichens — have discovered how to cultivate photobionts to do the job for them (Anton de Bary 1879; Potter 1897). These photobionts are algae and/or photosynthetic cyanobacteria that grow within a mesh of fungal hyphae inside the lichen thallus. The photobiont photosynthesizes and produces sugar from the sun's energy, which the fungi absorbs from it by means of finger-like projections on its hyphae called haustoria. In return for its servitude the photobiont may receive some protection from its fungal caretaker, but some lichenologists challenge this supposed benefit and liken this relationship to a form of controlled parasitism (Schwendener 1869; Ahmadjian and Jacobs 1981). A perhaps more accurate description is used by lichenologist Trevor Goward, who calls lichens "fungi that have discovered agriculture".

Various species of green algae and cyanobacteria are the most common choice for a lichen's photobiont, although a few lichens will use golden algae or brown algae. Some lichens will even use both green algae and cyanobacteria at the same time in a three-way symbiosis. Generally a particular lichen species will always choose the same photobiont species, but there are a few lichen species, called chimeras, which have rejected this more traditional arrangement. When these lichens become bored of the monotony of their

cyanobacteria partner, they can spice up their relationship by adding an algae partner to the relationship (Armaleo and Clerc 1991).

Lichens have a very long history on our planet and may be among the first multicellular organisms to evolve on Earth. Some authors have postulated that at least some of the Ediacaran fauna may have been lichens (Retallack 1994; Peterson *et al.* 2003). These fossils date back as far as 565 million years ago, before the Precambrian Explosion in which multicellular organisms engulfed the planet. Fungi have evolved the ability to cultivate a photobiont several different times independently (as determined from ribosomal DNA by Gargas *et al.* 1995), and thus the lichens that populate the biosphere today do not form a monophyletic group that traces back to a single ancestor. Some formally lichenized fungi have secondarily lost the ability to form lichen, resulting in lineages of non-lichenized fungi with lichen ancestors. A notable example of this is *Penicillium* spp., a mold used to make penicillin as well as several tasty cheeses (Lutzoni *et al.* 2001).

1.2.2 The success and importance of lichens

The lichen growth form has afforded them the flexibility to colonize a wide variety of habitats, and the tenaciousness to thrive in some of the most inhospitable locales on the planet. There are almost 14,000 species of lichen in the world (Brodo *et al.* 2001), which dominate about 8% of the area covered by terrestrial ecosystems (Larson 1987). Lichens are found growing from the highest mountains to the driest deserts, from Antarctica to the tropics. They provide many important ecological functions, such as soil formation (Cooper and Rudolph 1953; Galvan *et al.* 1981; Jones 1988), fixing atmospheric nitrogen (Forman 1975; Kelly and Becker 1975; Crittenden 2000), nutrient cycling (Pike 1971; Pike 1978; Knops *et al.* 1996), and food for wildlife (see **Section 1.4.2 Animals that eat lichens** on page 29).

Lichens can allow their internal water content to vary with their surroundings, which is an important contribution to their hardiness. When there is not enough water to survive, lichens merely dry out and go dormant to wait for conditions to improve (Green *et al.* 1994). Many lichens can survive for months, or even years, in a desiccated state, and resume function within minutes after rewetting (Kranner *et al.* 2003). Even the little

animals that make lichens their home can do this. Franceschi (1948) added water to a dry moss specimen that had been stored in an Italian museum for 120 years, and reported that he saw a dormant tardigrade (a small, eight-legged creature that often lives on lichens) come back to life. This result has been questioned (Jönsson and Bertolani 2001), but other research has shown that tardigrades on lichens can survive in a desiccated state for at least nine years (Guidetti and Jönsson 2002).

1.2.3 Types of lichens

Lichens come in a variety of shapes, sizes, and colours, and are often classified into several different growth forms. These classifications represent broad morphological categories of convenience that often have little evolutionary basis, but can be very useful in describing and identifying lichens. The following seven categories are used by Goward (1999):

- a. **Leprose (dust) lichens** have no upper or lower cortex, and consist of just a powdery thallus directly attached to the substrate. See **Figure 1.1 (A and B)**.
- b. **Crustose (crust) lichens** are also attached directly to the substrate with no lower cortex, but they have a hard, protective upper cortex. See **Figure 1.1 (C and D)**.
- c. **Squamulose (scale) lichens** also have an upper cortex and no lower cortex, but they have partially raised and often overlapping scales. Many *Cladonia* spp. have both a squamulose primary thallus as well as fruticose club- or cup-shaped podetia. See **Figure 1.5**.
- d. **Foliose (leaf) lichens** have leaves or lobes with both an upper and lower cortex, and are usually attached to the substrate by rhizines. See **Figure 1.2** and **Figure 1.3**.
- e. **Club/cup fruticose lichens** are upright, and usually exhibit (mostly) radial symmetry in cross-section. They are sparsely branched or not branched at all, and can have clubs, cups, or points at the top. Many *Cladonia* spp. have club/cup fruticose podetia that rise out of their squamulose primary thallus. See **Figure 1.5**.

- f. **Shrub fruticose lichens** are similar to club/cup lichens, but with many branches. They are often erect, and usually bush- or shrub-like in appearance. See **Figure 1.4 (A and D)**.
- g. **Hair fruticose lichens** are similar to shrub lichens, but their branches are much finer and longer. They are also often pendant and hang from the substrate where they are attached. See **Figure 1.4 (B and C)**.

1.2.4 Where lichens can be found

This diversity of lichens has found purchase on a multitude of different substrates in many different ecosystems. Generally individual lichen species are specific to certain substrates. The most common substrates for lichens to grow on are (taken from Brodo *et al.* 2001):

- a. **Bark:** Bark of different tree species varies significantly in its characteristics, and as a result some bark lichens are specific to certain tree species or groups of tree species. In general, lichens of conifer bark are quite different than most lichens of deciduous bark.
- b. **Decaying wood:** Dead wood is similar to bark, but generally hosts very different lichens, most of which are crustose. The species of tree and state of decay both significantly affect the lichen species supported.
- c. **Mosses and dead vegetation:** Many lichen species grow on or within moss clumps, or over decaying pieces of vegetation.
- d. **Rocks:** Rocks differ significantly in their chemical characteristics, and so most rock lichens are specific to certain types of rocks. In general, calcareous rocks host different lichen communities than siliceous rocks.
- e. **Soil:** The texture, stability, and chemistry of the soil are important to lichens. Calcareous soils have different lichen communities than siliceous soils. Often lichens help to stabilize the soil.

Many species of lichen are also found growing on more novel substrates.

Lecanora vinetorum is a species of lichen that grows only on grape arbors that are regularly sprayed with copper-containing fungicides (Poelt and Huneck 1968). Some

lichens, like *Stereocaulon vulcani*, can grow on recent lava flows (Jackson 1971). Over 700 species of lichens are found growing directly on the leaves of tropical plants, mostly in Southeast Asia (Farkas and Sipman 1997; Lücking 2000). Some lichens grow exclusively on other lichens (Etayo and Diederich 2001), while others grow on non-lichenized fungi (Arvidsson 1982-1983). Decaying antlers and bones can also provide a home for many species (Steinheil 1834).

Not all lichen species are terrestrial. There are many species of freshwater lichens (Keller 2005), such as the beautiful *Ionaspis lavatum*, a pink crustose lichen found in mountain streams in British Columbia (Brodo *et al.* 2001). Other lichens are marine, such as *Coccotrema* spp. and *Verrucaria* spp. that form characteristic bands on rocky shores (Brodo *et al.* 2001).

Many lichen species can grow on artificial substrates like plastic net fences (Upreti and Dixit 2002), discarded shirts (Brodo *et al.* 2001), oil spills (Arvidsson 1982-1983), concrete (Olech 1998), old unwashed cars (Pedley 2000; Bennett 2002), and rubber (Gray 1999).

Larva of the green lacewing *Leucochrysa pavida* constructs a home for itself out of pieces of lichen that it collects, and then carries this around with it for camouflage, and later incorporates this lichen packet into its cocoon when it pupates (Skorepa and Sharp 1971; Wilson and Methven 1997). Several species of weevils and colydiid beetles in Papua New Guinea don't have to work that hard for their lichen camouflage — lichens grow right on their backs, anchored by special protuberances from the beetle's carapace. Mites and rotifers will then live on these lichens that live on the weevils that live on plants (Gressitt 1966a, 1966b).

Several species of the crustose lichen *Pyrenocollema* grow exclusively on mollusk and barnacle shells, and can be seen as small black spots. *Pyrenocollema halodytes*, or barnacle itch, is one of these species common in the Pacific Northwest of North America (McCune 1997; Tucker and Thiers 1998). The foliose lichen *Dirinaria picta*, which normally grows on bark, also grows abundantly on the carapace of the Galápagos giant land tortoise (*Geochelone elephantopus*) (Hendrickson and Weber 1964).

Lichens can even thrive in the harsh climate of Antarctica, actively photosynthesizing beneath 15 cm of snow (Pannewitz *et al.* 2003) at temperatures as low as -17°C , using fresh snow instead of liquid water (Kappen *et al.* 1996). Many Antarctica lichens survive by actually growing inside of rocks (Friedmann 1982; Hale 1987; Wynn-Williams *et al.* 2000; de los Ríos *et al.* 2005; de los Ríos *et al.* 2005). Sandstones are preferred, and the fungal hyphae either colonize small fissures or actively penetrate through the rock up to a depth of 1.5 cm. Algal cells are generally kept in a layer about 5 mm below the surface of the rock, where a thin layer of the translucent quartz crystals and fungal hyphae partially protects them from the extreme temperatures, UV radiation, and fierce winds of their environment while still allowing some light to filter through for photosynthesis.

Lichens with similar growth forms also survive inside rocks in the hot deserts of the world, like the Sonoran desert in Arizona (Bungartz *et al.* 2004) and the very driest desert of them all, the Atacama Desert of Chile (Villar *et al.* 2005).

The resilience of lichens even extends beyond the confines of challenges that can be found within our own biosphere. In 2005 the European Space Agency sent two common lichens (*Xanthoria elegans* and *Rhizocarpon geographicum*) into space as part of the Foton M2 mission (ESA 2005). Once these lichens were outside of the Earth's atmosphere their protective capsules were opened, exposing the lichens to the vacuum of space. For 14.6 days they endured solar and cosmic radiation, no atmosphere, daily temperature fluctuations of -35°C to $+30^{\circ}\text{C}$, and anything else that space had to throw at them. When the lichens were brought back to Earth they were perfectly fine, with no discernable damage from their extraplanetary travel. ESA scientists have even postulated that these lichens could survive on Mars (ESA 2005), which is not a new idea given that as recently as the 1950s it was widely thought that lichens did live on Mars (Kuiper 1952).

Unfortunately, the astounding hardiness of lichens often does not extend to anthropogenic challenges that we throw at them. Many lichens are very sensitive to air pollution (particularly lichens that protrude further from their substrate), and the decline of these lichens can be used to map out air pollution (Sharnoff 1984; Kauppi and Halonen 1992). The beautiful *Usnea longissima*, common in British Columbia's old growth

temperate rainforests, is a good example of a lichen that is very sensitive to both air pollution and clear cut logging, and as a result it has already been extirpated from some areas in Scandanavia (Esseen *et al.* 1981; Olsen and Gauslaa 1991). But some lichens can thrive despite pollution. *Lecanora conizaeoides* loves sulfur dioxide, and populations are actually in decline as a result of clean air laws in Europe (Bates *et al.* 2001).

1.2.5 The human appreciation of lichens

Although ignored by many, the beauty of lichens has always fascinated some human minds. Beatrix Potter is more famously known as the author of Peter Rabbit, but she was actually an exemplary lichenologist that only went into children's books when the world of science refused to accept her due to her unfortunate choice in gender. Potter (1897) presented the Linnean Society with some of the first research showing the symbiotic nature of lichens, but was not even allowed to attend the reading of her paper. Her work was ridiculed at the time, never published, and eventually destroyed. Her posthumously published journals (Linder 1966: pp. 423-430) and letters (Taylor 1989: pp. 39-41) both discuss her research, and the Linnean Society of London (1897) records that her paper was presented, but nothing else of this ground-breaking work has survived.

Other examples of great minds enjoying the beauty and mystery of lichens include M. C. Escher's use lichens in his artwork "Waterfall", and Wyndham (1960) in his science fiction novel "Trouble with Lichen". Even Henry David Thoreau appreciated lichens, and records in his journal for January 26th, 1853 (Thoreau 1852: pg 234):

It is good to break and smell the black birch twigs now. The lichens look rather bright today, near the town line, in Heywood's wood by the pond. When they are bright and expanded, is it not a sign of a thaw or rain? The beauty of lichens, with their scalloped leaves, the small attractive fields, the crinkled edge! I could study a single piece of bark for hours. How they flourish! I sympathize with their growth.

Some people may have elevated lichens to an even higher status. Kerpyčius is a masculine deity in Lithuanian mythology who is listed by Jan Łasicki (1615) as a forest god (although this doesn't appear to be corroborated by any other independent sources). The etymology of Kerpyčius' name implies that he is a spirit of lichens, as *kerpė* is the Lithuanian word for lichen.

1.3 Lichen use by humans

The field of ethnolichenology (the study of the relationship between lichens and humans) is especially interesting because lichens and humans have a long history together. Lichens have been enduring use by humans for millennia, which is evident even in the name *lichen*. The word originates in ancient Greece with a ringworm-like skin disease called *leichen* (literally “what eats around itself”). An unidentified “mossy plant” found on rocks was used to treat this disease, and therefore called by the same name (Booth 1836). *Leichen* was later corrupted to *lichen*, and applied to a variety of cryptogams (including lichens, liverworts, and mosses) by European academics in the 16th to 18th centuries, before settling on its current taxonomic definition¹.

A brief survey of the literature indicates that lichen use is widespread among humans across the planet. Records were found of a multitude of cultures from every continent (with the possible exception of Australia) traditionally using over 300 different species of lichen. See **Appendix X** for a complete listing of these lichen uses. The most common traditional use of lichens is for dye, with 164 species of lichen used for this purpose. Many lichens are also used as medicine (99 species) and for food (91 species). Lichens have been and are still being used for many other purposes, including alcohol production (for fermentable carbohydrates, as catalysts, and/or as flavour/preservatives); cosmetics (for hair, and/or sweet smelling powders); perfumes; decorations (including costumes and artwork); fibre (clothing, housing, cooking, sanitation); animal feed (both fodder and forage); fuel; industrial purposes (production of acid, antibiotic, carbohydrate, litmus); tanning; hunting/fishing (to find prey, or to lure them in); navigation; prospecting (for copper or gold); insect repellent/insecticide; preservatives (for food or beer); poison (arrowheads, wolves); mummies; rituals; magic; smoking; snuff; narcotics; and hallucinogens.

¹ Early botanical treatise, such as those by Clusius *et al.* (1601), Tournefort (1694), and Dilleni (1719), would lump together certain liverworts and lichens as *lichens*, call some lichens *liverworts* (particularly the culturally important *Peltigera canina*), and then omit certain other lichens (particularly fruticose ones) as something else entirely that was more closely related to mosses. Morison (1715) was the first to create our modern notion of the lichen taxon, but he called them *musco-fungi*. The modern use of *lichen* started with Micheli (1729) and Watson *et al.* (1758).

1.3.1 Important aspects of lichen chemistry for human use

The secondary chemicals of lichens make many contributions to their utility to humans. These chemicals are used as medicines and dyes, which are the two most common uses for lichens. They are also useful when lichens are occasionally used as tanning agents, poisons, and preservatives. The properties of these compounds are reviewed in **Section 1.5.1.2 Effect of lichen compounds on other organisms** on page 36.

Although most of these secondary compounds are not particularly water-soluble (see **Section 1.5.1.3.1 Solubility of lichen compounds** on page 46), they are often extracted for human use by using boiling water. A good example of this is seen in *Letharia vulpina*. This lichen is widely used as a yellow dye, and the vulpinic acid responsible for this colour is almost always traditionally extracted with boiling water. The Tlingit are an exception to this, and traditionally steep the lichen in children's urine to extract the dye (Emmons and Boas 1907). *Letharia vulpina* does not grow in Tlingit territory and therefore has to be acquired from neighboring nations. This would likely make the lichen more valuable and provide an incentive to use it more efficiently.

Although people regularly extract secondary lichen compounds using boiling water, there are many examples of more novel extractions. Santesson (1939) reports that *Letharia vulpina* must be boiled in fat to acquire adequate vulpinic acid for use as wolf poison. In Sweden, *Peltigera aphthosa* is traditionally boiled in milk to make a medicine for thrush (Lindley 1849), and in some parts of Spain, *Xanthoria parietina* is decocted in wine for menstrual complaints (González-Tejero *et al.* 1995). Some people use alcohol to make a tincture out of *Usnea* spp. before using it medicinally (Hobbs 1986). These may all be instances of people finding methods to improve the yields of desired secondary compounds despite their low solubility in water.

The carbohydrates of lichens have also proved useful to humans. Lichen carbohydrates easily form a mucilage with water. This has traditionally been used medicinally as a demulcent to relieve minor pain and inflammation of membranes (e.g. Nelson 1951). It was also often used to make jellies for tasty desserts, particularly from *Cetraria islandica* in northern Europe (e.g. Jacobj 1916). Despite the usefulness of these

lichen carbohydrates, whether or not they can actually provide nutrition to humans is a matter of debate (see **Section 1.5.5 The digestibility of lichens** on page 56).

1.3.2 Variations in lichen quality

Numerous scientific studies have shown that lichens of the same species can vary significantly in their content of secondary lichen compounds depending on many different aspects of their environment, including the amount of sunlight, temperature, elevation, location, and season. As well, the age of the lichen can have a significant effect, and different parts of the same lichen thallus can have different concentrations of secondary compounds. (See **Section 1.5.1.1 Variation in lichen compounds between and within lichens** on page 32 for more details.) Not surprisingly, lichens have been found to have characteristic antibiotic properties depending on the area that they were collected from (Burkholder *et al.* 1944).

Lichens also have seasonal variation in their content of protein (Dannfelt 1917; Scotter 1965) and minerals (Scotter 1965; Hanley and McKendrick 1983). As well, mineral concentration in lichens can vary significantly with height (Lang *et al.* 1980) and substrate (Prussia and Killingbeck 1991).

As one might expect, this variation in lichens has not gone unnoticed by the people who use these lichens for various purposes. There are numerous examples of traditional knowledge on the variation between lichens based on season, location, and substrate.

1.3.2.1 Variation according to season

The season in which a lichen is collected has occasionally been said to affect the quality of that lichen. *Parmelia saxatilis* is richest in dye content in August (Uphof 1959), whereas *Ochrolechia tartarea* was always collected in May and June for dye (Uphof 1959). *Evernia prunastri* and *Pseudevernia furfuracea* are said to be of better quality for perfume if picked in summer (Moxham 1981). Chinese herbalists would only gather *Usnea diffracta* for medicine during the fifth lunar month (Sharnoff 1997). Nganasans considered the lichen in the stomachs of reindeer to be more tasty in the winter than in the summer, when it was bitter (Eidlitz 1969).

1.3.2.2 Variation according to location

Evernia prunastri and *Pseudevernia furfuracea* are noted to be better quality for perfume if from the former Yugoslavia or Bosnia (Moxham 1981). *Pseudevernia furfuracea* is known to have different properties for perfumery if picked off pine in France instead of cedar in Morocco (Richardson 1991). *Roccella tinctoria* is said to be better for dye if collected from the Canary and Cape Verde Islands (Uphof 1959).

1.3.2.3 Variation according to substrate

Evernia prunastri from oak branches is supposed to be best for perfume (Uphof 1959), and the tree species is also said to have an unspecified affect on the quality of *Lobaria pulmonaria* for perfume (Uphof 1959). Moxham (1980) claims that *Pseudevernia furfuracea* growing on cedar has different properties for perfumery than the same lichen growing on pine.

The Nuxalk of British Columbia use *Alectoria sarmentosa* and *Usnea* spp. to poultice sores and boils only if the lichen is growing on red alder (*Alnus rubra*) (Smith 1928; Turner 1973). The Nuxalk also use *Lobaria* spp. as a tea for stomach pains, an eyewash, and a poultice, but only if the lichen is growing on certain trees (Smith 1928; Turner 1973).

Lobaria amplissima (possibly *L. quercizans*) was only eaten from certain trees. The Menomini used it only if it was growing on hard maple or hemlock (Smith 1923), and the Ojibwa ate it only from old white pine (Arnason *et al.* 1981). A different, unidentified "mossy" lichen (possibly *L. amplissima*, but this lichen is not at all mossy) was also eaten by the Ojibwa, and also only if it was growing on white pine (Arnason *et al.* 1981). The Potawatomi ate *Hypogymnia physodes* only if it was growing on spruce (Smith 1933).

1.3.2.4 Detecting substrate differences by lichen cover

There are several examples of people detecting characteristics of a lichen based on the substrate that it is growing on, but one can also detect differences in the substrate by paying attention to the lichen. The Nunamiut locate marmot burrows on talus slopes by looking for bright yellow and/or orange splotches of *Xanthoria* spp. on the rocks (Llano 1956). Similar patches of *Caloplaca* spp. and *Xanthoria* spp. on cliff faces can be

used in northeast Greenland to detect open water in the summer, as these areas have higher bird activities and thus larger growths of these copriphilous lichens (Llano 1956). In the badlands of Drumheller, Alberta, the bright orange *Xanthoria elegans* can be used to locate dinosaur fossils, as it prefers fossils over the surrounding sandstone (Crawford, pers. obs.).

1.3.3 Lichens as food

There are records of lichens being used for food by dozens of First Nations Peoples throughout Canada and the USA, as well as in Europe, Britain, Greenland, Russia, the Middle East, northern Africa, India, Nepal, China, Korea, and Japan (see **Appendix X**). Although these records encompass 90 different lichen species and numerous different cultures on four continents, there are some striking similarities in how these lichens were and are prepared and eaten.

Lichens are almost always processed in some way before they are eaten. The only exception to this appears to be in southwestern Alaska. *Lobaria scrobiculata* is eaten raw right off tree by Yup'ik in Kwethluk (near Bethel, Alaska) (Sharnoff 1997). This may also be the unidentified tree lichen eaten by the Inland Dena'ina (their neighbors to the east) that is sweet if eaten raw right off the tree (Kari 1987; Kuhnlein and Turner 1991).

1.3.3.1 Boiling lichens for food

Lichens are commonly prepared for food by boiling. In Japan *Usnea trichodeoides* and *Sulcaria sulcata* are boiled in a soup, and *Parmotrema tinctorum* is boiled to make tea (Ohmura 2003). The Potawatomi boil *Hypogymnia physodes* before eating it plain or in soup (Smith 1933). The Ojibwa, Iroquois, and Menomini boil *Lobaria amplissima* (possible *L. quercizans*) until it is "like scrambled eggs" or porridge (Yarnell 1964), and then eat it plain, as a porridge (Iroquois: Arnason *et al.* 1981), or sometimes in soup (Menomini: Smith 1923). The Ojibwa prepare another, unidentified "mossy" lichen in this same fashion (Arnason *et al.* 1981).

Often lichens are boiled with other food items to make them palatable. The Yup'ik boil *Nephroma arcticum* with crushed fish eggs, and *Cetraria ericetorum* and

Flavocetraria cucullata with fish or duck soup (Oswalt 1957). The Nipigon boiled an unidentified rock lichen with pemmican, otherwise the lichen was quite bitter (Harmon 1800-1816a, 1800-1816b). The Inland Dena'ina boiled *Alectoria* spp., *Cladina rangiferina*, and/or *Usnea* spp. with fish, fish eggs, grease, berries, or caribou blood, and maintain that the lichen will give you an upset stomach if not cooked right (Kari 1987). In Saudi Arabia, *Parmotrema austrosinensis* is boiled in meat stew (Richardson 1975).

Several lichens are eaten in southwestern China after being thoroughly boiled and soaked, as recorded by Wang *et al.* (2001). The Bai of northwest Yunnan eat *Lobaria isidiophora* and *L. kurokawae* after boiling the lichen for 10 to 30 minutes, then soaking it in fresh water for one to two days, and frying it with pork. Just to the north, Tibetans cook *L. yoshimurae* and *L. orientalis* in a similar way, but sometimes after the boiling and soaking they will serve it cold instead of frying it. The Yi and Dai of south Yunnan have a similar preparation strategy for *Ramalina conduplicans* and *R. sinensis*, except that soda is added to the boiling water, and they only need to be boiled for 10 to 20 minutes. The lichens are then soaked in new water for one to two days, and either served cold or stir fried with pork.

Umbilicaria esculenta is a delicacy in Japan that is prepared in several different ways, including being boiled with sugar and soy sauce; in a thick miso soup; and in a clear salty soup (Sato 1968).

1.3.3.2 Boiling lichens for food: The case of *Umbilicaria* spp.

Despite several published accounts to the contrary (Porsild 1953; Llano 1956; Moore and Egan 1991), *Umbilicaria* spp. were commonly eaten by indigenous peoples across northern and eastern Canada. Examples include the Inuit, Attawapiskat Cree (Honigmann 1961), Naskapi (Lips 1947), Nihithawak Cree (Leighton 1985), Huron (Parkman 1869), Algonkin (Blair *et al.* 1911), and Ojibwa (Henry 1809) (see **Appendix X**). These lichens were usually washed (occasionally with ash water), boiled with fish stew, fish eggs, caribou blood, flour, lard, or salt, and then eaten as soup. It is important to note that this lichen was not cooked alone, and was not eaten as a staple food.

There are also numerous accounts of early Europeans in North America (in particular Jesuit missionaries, fur traders, and explorers) frequently eating *Umbilicaria*

spp. as a famine food (Ragueneau 1650; Radisson 1658-1660; Lallemant 1661-1664; Allouez 1665-1667; Dablon 1671-1672; Rasles 1723; Charlevoix and Bellin 1744; Long 1778-1791; Pond 1793-1805; Hearne 1795; Heriot 1807; Henry 1809; Farnham 1839; Schoolcraft *et al.* 1851; Perrot 1864; Parkman 1869; Franklin 1910). Out of all these accounts, only one portrays the lichen favorably: "It is so palatable, that all who taste it generally grow fond of it. It is remarkably good and pleasing when used to thicken any kind of broth, but it is generally most esteemed when boiled in fish-liquor." (Hearne 1795). In this case the lichen is being boiled with something, and not eaten alone.

In most other accounts by early Europeans, the lichen is being boiled in water, without the addition of anything else, and eaten by itself as a famine food. An example of some descriptors used for this meal are: "very black and disagreeable porridge" (Rasles 1723); "One must close his eyes on first tasting it" (Dablon 1671-1672); "nauseous" (Parkman 1869); "...an insipid soup, black and viscous, that rather serves to ward off death than to impart life" (Allouez 1665-1667); and "...of a bitter and disagreeable taste" (Henry 1809). Perhaps the most in depth account is by Franklin (1910), who forced his men to live off it for two months while marching them across the high arctic, and recorded in detail the severe intestinal trauma his men were experiencing.

By all accounts, when this lichen was boiled and eaten alone, as was the habit of early Europeans, it wasn't very healthy. Usually when the Europeans resorted to this practice it was as a last resort. When they were eating these lichens they were often also eating many other things generally considered inedible, for example: moccasins (Parkman 1869); their dogs, sealskin pouches, and boiled wood (Rasles 1723); old shoes, bones and bits of rotten carcasses found on the trail (Franklin 1910); or considering or actually resorting to cannibalism of less important party members (Henry 1809; Franklin 1910). It is quite likely that the more complex preparation techniques practiced by indigenous peoples in North America were essential for the edibility of the lichen, and entirely missed by early European explorers.

1.3.3.3 Treating lichens with ash or lye in food preparation

Many lichens are also washed or soaked with ash, soda, or lye before cooking. An unidentified lichen species found on rocks and trees that was eaten by the Iroquois

was washed in ashes and water to remove bitterness before being boiled in grease (Arnason *et al.* 1981). Fernald (1958) reports that early European explorers would often steep *Umbilicaria* spp. in dilute soda water before boiling and eating them as emergency food, but I haven't found a first hand account of this.

Ramalina conduplicans, *R. farinacea*, *R. sinensis*, *R. subfarinacea*, *Everniastrum nepalense*, and *Usnea thomsonii* are called **yangben** by the Rai and Limbu (Nepal).

Yangben is cleaned with water, boiled with ash, washed, dried, and cut into small pieces before being stored for future use. It is then rehydrated before being cooked with meat, eggs, blood, or vegetables (Bhattarai *et al.* 1999). As mentioned above, the Yi and Dai of south Yunnan boil *Ramalina conduplicans* and *R. sinensis* in soda water for part of their preparation (Wang *et al.* 2001).

In Europe, *Lobaria pulmonaria* was steeped in alkali solution before being rinsed, boiled with sugar, and cooled to form a tasty brown jelly (Drummond 1861). *Peltigera aphthosa* is similarly boiled in soda water, or soaked in vinegar, before being baked in a cream dessert (Europe: Gioanetto 1993). *Cetraria islandica* was commonly eaten in northern Europe, particularly in times of famine. It was boiled in lye, rinsed with water, dried, then ground into flour. This processed lichen was then used to make soup (boiled with grain and elm cortex), porridge or gruel (boiled in water), salad (with oil, egg yolk, and sugar), jelly (with lemon juice, sugar, chocolate, and/or almonds), or bread (baked with 25% rye flour) (Jacobj 1916; Llano 1944). *Cladina* spp. were often prepared in a similar way (Porsild 1953; Eidlitz 1969).

1.3.3.4 Baking lichens for food

Sometimes lichens were baked in bread. *Cetraria islandica* and *Cladina* spp., after being prepared as above, could be mixed with one quarter rye flour and baked. In the Middle East *Aspicilia esculenta* and *Sphaerothallia affinis*, perhaps the fabled manna from heaven, were ground, mixed with one third grain meal, and baked into bread (Fernald and Kinsey 1958; Crum 1993). A bread called **shirsad** is still made in Iran from *A. esculenta* and flour and is said to be good to promote a mother's milk (Gioanetto 1993). In ancient Egypt *Evernia prunastri* and *Pseudevernia furfuracea* were also used to make bread (Perez-Llano 1944).

The Saami mix *Cladina* spp. with flour and make it into a dough (Eidlitz 1969). This dough is then placed on embers, baked, then broken open, filled with reindeer fat, and put back on the embers until the fat is cooked.

1.3.3.5 Some other food preparation techniques

There are a few other preparation techniques recorded for lichens. In Iceland *Cetraria islandica* was often also eaten whole, fried with butter and salt (Thieret 2004). Besides being boiled, in Japan *Umbilicaria esculenta* is sometimes just served with soy, vinegar, and sake; just with vinegar; or battered and deep fried (Sato 1968). In Korea this lichen is pickled in a kimchi (Thieret 2004).

Ragueneau (1650) records a novel preparation technique for *Umbilicaria* spp. that was used by some early Europeans in North America. It was first left in water to rot, after a while it became absorbant and swollen like a sponge, and was then apparently cooked.

1.3.3.6 Lichens as food spices

Lichens are often cooked as spices, particularly in India. Large quantities of *Everniastrum cirrhatum*, *E. nepalense*, *Heterodermia diademata*, *Parmotrema nilgherrense*, *P. tinctorum*, and *Rimelia reticulata* are harvested and sold in India for this purpose. Smaller amounts of many other lichen species are used to a lesser degree, including *Bulbothrix meizospora*, *Canoparmelia texana*, *Cetraria* spp., *Cetrelia collata*, *Flavopunctelia flaventior*, *Heterodermia* spp., *Hypotrachyna* spp., *Leptogium* spp., *Lobaria retigera*, *Melanelia infumata*, *Myelochroa aurulenta*, *Nephromopsis pallescens*, *Parmelaria subthomsonii*, *Parmelinella wallichiana*, *Parmotrema* spp., *Peltigera polydactylon*, *Ramalina* spp., *Stereocaulon himalayense*, *Thamnolia vermicularis*, and *Usnea* spp. (Upreti et al. 2005).

Parmotrema nilgherrense, *P. sancti-angelii*, *P. tinctorum*, *Rimelia reticulata*, *Everniastrum* spp., *Ramalina* spp., and *Usnea* spp. are called **dagad phool** and are the main ingredients in **Kabul garam masala**, a spice mixture used in Poona and Aurangabad (India) that is added at the end of cooking (Richardson 1988). These same lichens are often used throughout India to add to curry powder as a filler and preservative

(Richardson 1991). *Dagad phool* is sometimes also used in several other Indian spice mixtures, such as *Mahara goda masala* and *garam masala* (Trivedi 2002).

When *dagad phool* is used as a spice, it is fried in oil with onions to release its flavour before being added to the food dish (Trivedi 2002). This is a common practice for masala and curry in Indian cooking, and would probably apply to most of the spice uses of lichens in this area.

Heterodermia tremulans, *Rimelia reticulata*, *Parmotrema tinctorum*, *Everniastrum cirrhatum*, and *Ramalina subcomplanata* are called *jhavila*, and used by the Baiga, Bhil, Bhilala, Gond, Korka, and Muria (India) as spices for meat, vegetables, and pulses (Upreti 1996; 2001). *Usnea longissima* is used as a spice by the Bhotia and Garwalis (India) (Upreti 1996, 2001). *Parmotrema abessinicum* is highly regarded as a curry powder in Bellary (India) (Sastri 1953). As well as being used in India, *Parmotrema tinctorum* is also sold as a food spice in Saudi-Arabia under the Arabic name *al-sheba* (Abo-Khatwa *et al.* 1997).

1.3.3.7 Partially digested lichens as food

Another way lichens are eaten by indigenous peoples in northern Canada and Alaska is as “stomach icecream” (Osgood 1959) (see **Appendix X**). The partially digested lichens (often *Cladina rangiferina*, but many other lichen species are also present) found in the stomachs of freshly killed caribou are collected in a dish and mixed with raw mashed fish eggs, melted fat, or bone marrow. They are thoroughly stirred or mixed in soup before eating. Sometimes the lichens will be left in the stomach of the caribou for days after the animal is killed to allow it to ferment more.

1.3.3.8 Making lichens into molasses

In the 1940s two small factories in Kirovsk (Kola Peninsula, Russia) used lichens to make molasses, and produced as much as 360 kg per day in 1943 (Diachkov and Kursanov 1945). Several species of lichen were used, including *Alectoria ochroleuca*, *Cetraria islandica*, *Cladina stellaris*, *C. mitis*, *Cladonia deformis*, *Flavocetraria nivalis*, *Peltigera* spp., and *Stereocaulon paschale*. *Alectoria ochroleuca* was found to produce the best molasses, whereas *Cladina* spp. produced a molasses that was quite bitter. To produce the molasses, the lichen was soaked in a weak alkali solution, treated with dilute

sulfuric acid to hydrolyze the lichen carbohydrates, boiled, neutralized with chalk, and then purified with activated carbon. This produced a molasses of 65-82% glucose.

1.3.3.9 Making lichens into alcohol

In 1868 Stenberg discovered a procedure to produce alcohol from lichens, which became a significant industry in northern Europe and Russia for the next sixteen years (Stenberg 1868; Stahlschmidt 1870; Arendt 1872; Llano 1944). The carbohydrate could be extracted with three changes of boiling water, then boiled nine hours with sulfuric acid to produce a 70% yield of glucose. However a more cost effective method was to pack the lichens into a vessel with a small amount of sulfuric or hydrochloric acid, and then inject it with steam for several hours. The lichen formed a glucose-rich slurry, which was then saturated with chalk, fermented, and distilled. Using 1 kg of lichen produced 300 g of pure alcohol. Several lichens were used, including *Bryoria* spp., *Cetraria islandica*, and *Cladina rangiferina*. The highest concentration of glucose was yielded from *Bryoria* spp., but *Cladina rangiferina* was more plentiful and so it was used in greater quantities.

1.3.3.10 Some trivia related to the use of lichens for food

Cetraria islandica and *Cladina rangiferina* were fed to livestock in northern Europe, and according to some they improve the quality of cows' milk (Ahmadjian and Nilsson 1963). In some places in India *Roccella montagnei* is fed to cattle to make their milk better (Subramanian 1965).

Lichens are sometimes also used as preservatives for food. A variety of lichens, including *Everniastrum* spp., *Parmotrema* spp., *Ramalina* spp., *Rimelia reticulata*, and *Usnea* spp. are added to curry powder in India to help preserve it (Richardson 1991). *Parmotrema austrosinensis* is added to meat stew in Saudi Arabia as both a spice and preservative (Richardson 1975). *Cetraria islandica* was added to bread on ships to stop it from being attacked by weevils (Perez-Llano 1944). *Thamnolia vermicularis* is burned, and the smoke used to preserve buttermilk from getting wormy (Upreti and Negi 1996). A similar insecticidal property is attributed to *Parmotrema andinum*, which is burned as insect repellent in Mauritania (Lange 1957).

1.3.4 Folk taxonomy and identification of lichens

Over 200 folk taxa for lichens are identified in **Appendix VIII**. Berlin *et al.* (1973) proposed five universal ethnobiological taxonomic categories that can be applied to most folk taxonomies. The category at the top of the taxonomic hierarchy is the unique beginner (e.g. plant, animal), followed by life form (e.g. tree, vine, bird), generic (e.g. oak, pine, robin), and the less common but more precise categories of specific (blue spruce, white fir) and varietal.

Generally lichens are placed within the folk kingdom (unique beginner) of plants, although *Aspicilia vagrans* may be included with rocks by the Bedouin of Libya (Crum, 1993), and there are several compound names of lichens that imply an animal origin for certain lichens (see **Appendix VII Informative compound folk names for lichens** on page 250). Lichens are usually placed within a life form folk taxon that includes most or all other lichens, and often other small plant-like organisms like mosses and fungi. There may also be several generic taxa, and often one to three specific or varietal taxa for lichens of particular cultural interest.

1.3.4.1 Life form folk taxa for lichens

The Saami classify lichens as being a distinct group different from mosses, since reindeer do not like to eat moss (Perez-Llano 1944). However, usually mosses and lichens are grouped together into one general lichen/moss taxon. Some examples of this are in Ditidaht (Turner *et al.* 1983), Kwakwaka'wakw (Turner and Bell 1973), Haida (Turner 1974), Nuxalk (Turner 1974), St'at'imc (Turner 1974), Karok (Schenck and Gifford 1952), and Seri (Rea 1997). The O'odham have a similar general taxon, but it includes fungi as well as mosses and lichens (Rea 1997).

Other examples of grouping lichens with fungi include the Waorani (Ecuador) who group *Dictyonema sericeum* with mushrooms, but not mosses (Davis and Yost 1983). In Japan *Umbilicaria esculenta* is called *iwa-take* ["rock fungus"].

In these examples, although some lichens may be considered to be fungi, others may not. Often lichens do not all belong to the same higher level taxon. Foliose lichens are grouped with fungi by the Secwepemc, while beard lichens are grouped separately (Palmer 1975). Some lichens are separated from mosses in Sm'algyax (Hartley Bay),

but *Usnea* spp. (and presumably other beard lichens) are grouped with mosses, not other lichens (Turner and Clifton 2002). The Ditidaht taxon *p'u7up* includes both mosses and lichens, but not *Peltigera* spp. (Turner *et al.* 1983).

1.3.4.2 Generic folk taxa

Occasionally a culture will have several generic taxa for lichens, or for lichen/mosses. These generic taxa are generally divided up according to substrate the lichen grows on, its general appearance, or how it is used.

The most common generic taxa are ones created on the basis of the substrate that the lichen is growing on. There are several examples of this. The Ditidaht differentiate lichen-mosses by the branch on which they grow. Lichen-mosses are generally called *p'u7up*. A lichen-moss is called *tuxupati-c p'u7up* if it is growing on spruce, *q^mi(tl)'apati-c p'u7up* if growing on hemlock, and *c~absapati-c p'u7up* if growing on grand fir (Turner *et al.* 1983). The Nuxalk call lichen-mosses on the ground *ipst*, and those on tree *ipst-aak* (Turner 1974). The Dena'ina refer to tree lichens as the name of the tree plus *ilgida* or *endenghasdetlaq'i* ["stuck to"] (Kari 1987). The Lepchas and Nepalis (India), refer to lichens as *jhau*. Tree lichens are *rukhu ku jhau* and rock lichens are *dhungo ku jhau* (Saklani and Upreti 1992).

The Barrens-Keewatin Inuit (and probably most other Inuit) have several generic taxa based on the substrate and general appearance of the lichens. Some examples are (Wilson 1979):

- a. *Nagjuujaq*: Yellow-green bushy lichens with no practical use
- b. *Quajuq*: Flat foliose lichens
- c. *Tingaujaq*: Dark hairy lichens growing on the ground
- d. *Uriuqaq*: "White moss"

The Saami of northern Scandinavia also have several intermediate taxa that are based on both appearance and use of the lichens (Perez-Llano 1944):

- a. *Jaegel*: Large fruticose lichens commonly eaten by reindeer
- b. *Lappo*: Beard type lichens enjoyed by reindeer but not commonly eaten
- c. *Gadna*: Foliose lichens growing on rocks and trees not normally eaten by reindeer

More rarely generic taxa are based on how the lichens are used. The Rai and Limbu (Nepal) call *Ramalina* spp., *Everniastrum* spp., and *Usnea* spp. by the name *yangben* (Bhattarai *et al.* 1999). These lichens look distinctly different, but are all important food vegetables. The Dakota call both *Punctelia borreri* and *Usnea scabrata* *chan wiziye*, these two lichens look completely different but are both used to make dye (Gilmore 1919). In the Aryurveda, various medicinal lichens such as *Parmotrema* spp. and *Everniastrum* spp., are lumped together as *chharila* (Chandra and Singh 1971).

1.3.4.3 Specific taxa

Often a culture will recognize one to three specific taxa for lichens of particular cultural interest. These specific taxa may refer to individual species if that species is particularly distinctive, but are more likely to be at the genus range or even above. Because it is rare for an ethnographer to be able to identify a lichen even to its genus, it is usually difficult to determine the specificity of the lichen taxa being referred to in the literature.

Often northern First Peoples recognize a larger number of lichen taxa than their southern counterparts. The Saami and Barrens Keewatin, mentioned above, both have a relatively large number of lichen taxa, as do the Yup'ik (southwest Alaska) (Oswalt 1957):

- a. *Aouq*: *Cetraria crispa*
- b. *Ninguujuq* ("would like to be stretched"): *Flavocetraria cucullata*
- c. *Tuntutnuukaik* ("reindeer food"): *Cladina rangiferina*
- d. *Qelquaq*: *Lobaria scrobiculata*
- e. *Kuskoak*: *Nephroma arcticum*

There are several examples of relatively precise identifications of lichens in folk taxonomies. The Ditidaht differentiated *Usnea* spp. from *Alectoria* spp. and other arboreal hair lichens by the presence of the characteristic central cord (Turner *et al.* 1983). Only the lichens with "cream on the inside" were used for bandages. This is a valuable differentiation, because *Usnea* spp. have higher levels of the antibiotic usnic acid than other lichens in the same area.

In Japan *Usnea trichodeoides* is called *fuji saruogase* and is used to make a pleasant seaweed-tasting soup with a nice crunchiness. This lichen is differentiated from *Usnea diffracta*, called *yokowa saruogase*, which is known to be quite bitter tasting and bad for soup (Ohmura 2003).

Some lichen folk classifications even appear to approach the varietal level. In France *Diploschistes scruposus* was even differentiated beyond a species level. Depending on the age of the lichen, it was either called *la rise blanche* or *la grise noire* (Kok 1966).

1.3.4.4 Inferences from compound names

The names given to lichens are often compound terms and thus to some extent reflect how the lichen is viewed culturally. This can provide clues as to how the appropriate lichen is identified, how intermediate taxa are determined, and which characteristics of individual lichens are considered to be significant.

The most common compound names of lichens are based on where the lichen grows. The most popular name for lichens may be *rock flower*, with different lichens being called that in seven different languages across four continents (including one 'earth flower'). Interestingly, several of these lichens do not grow on rocks. In these cases 'rock' may refer to the appearance of the lichen instead of the substrate, or the lichens could have been misidentified. Many other lichen names include 'rock', 'tree', or 'ground' as part of their name.

Often lichens are named according to appearance or the folk ontogeny of the lichen. References to hair, beards, wool, or whiskers are common. In British Columbia and Washington lichens often seem to be associated with frogs, with names in four languages being some reference to anuran fashion (either a frog skin, diaper, dress, or blanket). Some names imply colourful ontogenies or metaphors for the lichen, such as 'rock dandruff', 'lizard semen', 'iguana toe', or 'whale baleen'. Some lichens have even been named according to how they look compared to another, more widely recognized lichen. In Scotland, *Variolaria orcina* is called *white crottle*. *Crottle* refers to the more commonly used dye lichens *Parmelia omphalodes* and *P. saxatilis*. The Secwepmec call

Alectoria sarmentosa 'white wila', with *wila* being the more culturally significant edible lichen *Bryoria fremontii*.

A third way lichens are sometimes named is according to use. Several lichens are named after their medicinal properties, such as 'deer snuff' (Denís: Brazil), 'Indian bandage' (Ditidaht), and 'female gauze' (China). *Letharia vulpina* is called 'yellow dye' in both Cheyenne and Niitsitapii (an obvious reference to its dye properties), and 'wolf moss' in Scandanavia (indicating its use as a wolf poison). And finally, several lichen names refer to their use as food, incorporating words for 'food', 'bread', 'grain', or 'egg'.

1.4 Lichen growth and ecology in relation to human use

1.4.1 Productivity of lichens

1.4.1.1 Growth rate of lichens

Lichens are renowned for growing rather slowly. This is generally true, particularly for crustose lichens. Crustose lichens grow by expanding radially, and they often do this very slowly. The crustose lichen *Rhizocarpon geographicum* has an annual radial growth from 0.9–0.02 mm depending on its age (Armstrong 1983; Armstrong and Smith 1987), while *Buellia canescens* grows slightly faster, up to about 1.5 mm per year (Proctor 1977).

Some foliose and fruticose lichens can grow faster. A foliose, ground-dwelling lichen from the prairies, *Xanthoparmelia chlorochroa*, grows about 2 mm per year (MacCracken *et al.* 1983). In a spruce forest in Sweden, Renhorn (1997) measured the growth of two foliose arboreal lichens in a spruce forest in Sweden and found an annual increase in biomass of 4.7% for *Platismatia glauca* and 3.3% for *Lobaria pulmonaria*. Denison (1988) measured the growth of two foliose, arboreal lichens in the laboratory and found *Lobaria pulmonaria* to have an annual increase in biomass of 8% for *Lobaria pulmonaria* and 16% for *L. oregana*.

Some fruticose lichens seem to be the fastest growing of the lot. Because of the complex shape of their thallus, the growth of fruticose lichens can only be accurately quantified as an increase in biomass. Reindeer lichens (*Cladina* spp.) can have an annual

growth rate of up to 90% when young, which slows to about 28% annually as they mature. (Kärenlampi 1970, 1971). *Usnea subfloridana* can grow 10% in a four month growing season (Stone 1986), while *Ramalina menziesii* in the coastal oak woodlands of California can grow 14.5–23.3% annually (Boucher and Nash 1990).

Renhorn (1995) tested growth rates of five alectorioid² lichens in a spruce forest in Sweden, and measured average annual biomass increases ranging from 6.3% for *Bryoria fremontii* to 16.3% for *Usnea filipendula*. Growth rates varied significantly between different lichens of the same species — different specimens of *Bryoria fremontii* varied in growth rate from 0.6–10.8% per year, while one specimen of *Alectoria sarmentosa* grew 40% in one year.

McCune (1996) found higher growth rates in epiphytic lichens in the Pacific Northwest of North America. *Evernia prunastri* grew 31% annually, while *Usnea longissima* grew 20–30% annually. In contrast to Renhorn's (1995) findings, McCune found *Alectoria sarmentosa* to be the slowest growing lichen tested; it actually shrank in biomass over the course of the study. In the same experiment, foliose epiphytic lichens had a bit slower growth rates than the fast-growing fruticose lichens: *Lobaria pulmonaria* at 12–22%, *L. oregana* at 4–11%, and *Pseudocyphellaria rainierensis* at 4–8%.

1.4.1.2 Determinants of growth rate

Younger lichens grow faster than old lichens (Arseneau *et al.* 1998), and the younger parts of the same lichen grow faster than the rest of that lichen (Kärenlampi 1970). Because of this, damage to the young, growing parts of the lichen may slow overall growth. *Bryoria* spp. may grow slower if the growing tips are removed (Arseneau *et al.* 1998), and in the crustose lichen *Rhizocarpon geographicum*, removal of parts of the lichen was found to drastically reduce growth rates (Armstrong and Smith 1987).

Renhorn (1995) found the main deterrent to growth rate to be fragmentation of the lichen — lichens do not increase in biomass very rapidly if pieces keep falling off. This could be particularly important in alectorioid lichens, because fragmentation is the main

² The alectorioid lichens are a non-phylogenetic group characterized by having a somewhat similar appearance (pendulous and hair-like, typically yellowish, greenish, or brownish) and being common forage lichens for ungulates (McCune 2007). Typical alectorioid genera include *Alectoria*, *Bryoria*, and *Usnea*.

means of reproduction for these lichens and so they fragment rather easily (Esseen and Renhorn 1998).

Lichen growth can be very seasonal, and several studies have reported lichens to accomplish most of their growth in the summer (Kärenlampi 1971; Armstrong 1973; Renhorn and Esseen 1995), although this may not be true for all ecosystems (Goward, pers. comm. 2007). Kärenlampi (1971) found rainfall to be the most important determinant of growth for reindeer lichens in Finland. No growth occurred with rainfall of less than 1 mm/day, and growth increased linearly to a maximum growth at the maximum observed rainfall of 3 mm/day. However, rain may not be as important in determining lichen growth rates in the warmer climate of British Columbia (Goward, pers. comm., 2007).

1.4.1.3 The arboreal lichen biomass of different ecosystems

See **Table 1.1** for a summary of reported arboreal lichen biomass in a range of ecosystems. The lichen biomass can range from negligible to being a significant part of the ecosystem. The highest reported biomass of arboreal lichens is 3291 kg/ha for a site in the southern interior of British Columbia (Edwards *et al.* 1960), which interestingly is in the middle of Secwepemc territory. Traditionally, the Secwepemc regularly harvested large quantities of the arboreal *Bryoria fremontii* for food (see **Chapter 2 Ethnolichenology, ecology, and chemistry of wila (*Bryoria fremontii* on page 82).**

1.4.1.4 Variation in arboreal lichen biomass

There can be a lot of variation in lichen biomass between different sites in the same general locality. In Wells Gray Park more than a tenfold difference was found in epiphytic lichen biomass between different sites, varying from 282.7 to 3291 kg/ha (Edwards *et al.* 1960). In this study, the highest lichen biomass was found at sites at the treeline. Similarly, in spruce forests in Sweden the greatest lichen growth was found at intermediate distances (2-12 m) from a forest edge (Renhorn *et al.* 1997). This indicates that proximity to an opening can be important for promoting abundant lichen growth.

The structure of the trees can also be very important. Lang *et al.* (1980) found that the number of dead branches on the tree was an important factor in determining lichen biomass, and Edwards *et al.* (1960) also found tree structure to be important. Tree

age is another important determinant of the biomass of epiphytic lichens, with older trees having more time to grow larger lichen communities (Lang *et al.* 1980; Hyvarinen *et al.* 1992). In Gaspé Provincial Park (PQ) *Bryoria nadvornikiana* and *Bryoria trichodes* took 30-40 years to reach maximum biomass, most *Usnea* spp. took 55 to 60 years, and *Alectoria sarmentosa* took 90 years (Arseneau *et al.* 1998).

Lichen biomass is also not evenly distributed on an individual tree. In balsam fir in New Hampshire, Lang *et al.* (1980) found maximum lichen biomass above 5 m. In Wells Gray Park, Edwards *et al.* (1960) found that the lower 3 m of the trees had only 2–13% of *Alectoria* spp. and *Bryoria* spp. biomass, while there was over twice as much lichen if they included the next 1.5 m, and significantly more again if they looked up to 6 m (24 to 42% of lichen biomass). This is probably both because of caribou grazing (Edwards *et al.* 1960) and tree structure, with greater substrate provided higher up in the canopy (Edwards *et al.* 1960; Lang *et al.* 1980).

1.4.1.5 Harvesting and overharvesting of lichens

The slow growth of lichens means that they are easily over-harvested when used by humans. This problem has been occurring for centuries, because the Iceland *Jónsbók* (law book) of 1280 records that *gros* (*Cetraria* spp. and *Cladina* spp.) could not be collected without landowner permission — a measure that the Icelanders enacted as a result of overharvesting (Airaksinen *et al.* 1986).

Another early example of lichen exploitation occurred in 1868 when the Swedes discovered how to produce brandy from lichens (Stenberg 1868). It was promoted as an excellent industry throughout northern Europe in the 1870s (Stahlschmidt 1870) and was adopted in Russia as well (Arendt 1872). However, by 1884 the industry had entirely collapsed due to the depletion of lichen from overharvesting (Llano 1944).

Cladina stellaris is harvested in Scandinavia and sold for wreaths, model train sets, and other ornamental uses. Between 1970 and 1975 about 17,900 tonnes of this lichen were exported from Scandinavia (Kauppi 1979). According to Kauppi (1979) this lichen can be sustainably harvested if it collected when it is wet, no more than 20% is removed at once, and an area is left for 5–6 years to replenish (Kauppi 1979). *Cladina* spp. are also traditionally collected in Scandinavia by the Saami as reindeer feed. Perez-

Llano (1944) records that the Saami harvest the lichen in wide strips when it is wet, only take 25% at a time, and leave an area for 30 years to grow back. The 30 year cycle that the Saami employ is substantially longer than the six year cycle that Kauppi recommended. Perez-Llano (1944) also notes that some Norwegian harvesters were taking 50% of the lichen at a time and depleting the resource, resulting in some tension with the Saami.

A variety of lichens are used in herbal remedies across Europe, and as a result they are often overharvested. Lange and Schippmann (1997) report that in Germany *Usnea* spp., *Cetraria islandica*, *C. ericetorum*, *Lobaria pulmonaria*, and *Parmelia* spp. have all been placed under protected status. Trade in native populations is prohibited, and a permit is required to import or export. As a result, Germany imports most of its medicinal lichens, importing 2,650 kg of *Usnea* sp. from Indonesia in 1994, and 17,300 kg of *Cetraria islandica* from Norway in 1989.

The government of Nepal has also placed two medicinal lichens, *Usnea* spp. and *Everniastrum nepalense*, under protected status, banning the unprocessed export of both lichens (Bhattarai 1999).

Alcohol extracts of *Evernia prunastri* and *Pseudevernia furfuracea* are used in a wide range of perfumes as both a fragrance and a fixative. Large quantities of these lichens are harvested across the world for this purpose, with estimates of the annual global harvest ranging as high as 10,000 tonnes (Moxham 1986). A significant percentage of this is harvested in southwestern Europe, but Richardson (1988) felt that the *Evernia prunastri* harvest in Europe was sustainable. Moxham (1980) felt that the same forest could be reharvested every 3–15 years. This is interesting, given that studies in Quebec have shown that even the relatively fast growing alectorioid lichens can take up to 90 years to reach optimum biomass (Arseneau *et al.* 1998)

Moxham (1986) seemed unconcerned with lichen exploitation when he reported that 3290 tonnes of lichen were being harvested annually from Nepal and India for the perfume industry. A decade later, Shah (1997) reported 1550 tonnes of lichen annually harvested just in India. Recently Upreti *et al.* (2005) cautioned that this over-exploitation was a major threat to lichens in India.

1.4.2 Animals that eat lichens

1.4.2.1 Small mammals

Lichens are an important food for the northern flying squirrel (*Glaucomys sabrinus*) in New York (Conner 1960), California (McKeever 1960; Hall 1991), Oregon (Maser *et al.* 1985), Idaho (Rosentreter *et al.* 1997), British Columbia (Cowan 1936), and southeast Alaska (Pyare *et al.* 2002). The most common lichen eaten is *Bryoria fremontii* (McKeever 1960; Maser *et al.* 1985; Rosentreter *et al.* 1997), which can compose up to 100% of the squirrels' diet in some locations (McKeever 1960), particularly in the winter and spring when other food sources are more scarce (McKeever 1960; Maser *et al.* 1985; Rosentreter *et al.* 1997). Occasionally *Usnea* spp. (Cowan 1936; McKeever 1960), or *Physcia* spp. and *Letharia* spp. (Hall 1991) may be eaten, although particularly in the case of *Letharia* spp. this may be a misidentification. Zabel (1997) found that *Bryoria fremontii*, along with two species of truffle, was the most preferred food of captive squirrels, while *Letharia vulpinia* (a toxic lichen containing vulpinic acid) was least preferred. Besides eating lichens, northern flying squirrels also use them for nest building, which is important for their thermoregulation (Cowan 1936; Maser *et al.* 1985; Hayward and Rosentreter 1994). The related southern flying squirrel (*Glaucomys volans volans*) is also known to eat lichens, though to a lesser extent (Conner 1960).

In northern spruce forests in Finland, the bank vole (*Clethrionomys glareolus*) eats mainly lichens, particularly *Alectoria* spp. and *Bryoria* spp. (Hansson 1979; Pulliainen and Keränen 1979; Viro and Sulkava 1985). Lichens are also an important food for the boreal red-backed vole (*Clethrionomys gapperi*) in northern Ontario (Martell 1981), and for both the boreal red-backed vole and the California red-backed vole (*C. californicus*) in Oregon and Washington, where lichens are the main winter food for inland, higher elevation populations (Ure and Maser 1982). Ure and Maser (1982) report that red-backed voles eat mainly *Usnea* spp. and *Alectoria* spp., but that probably included a lot of misidentified *Bryoria* spp. The insular meadow vole (*Microtus pennsylvanicus terraenovae*), Townsend vole (*M. townsendii*), and other vole species (*Arvicola* spp. and *Microtus* spp.) are also known to eat lichens (Sharnoff 1994).

Other small mammals known to eat lichens are (Sharnoff 1994): deer mouse

(*Peromyscus maniculatus*), collared lemming (*Dicrostonyx richardsonii*), various lemmings (*Lemmus* spp.), red squirrel (*Tamiasciurus douglassi*), arctic ground squirrel (*Spermophilus parryii*), hoary marmot (*Marmota caligata*), hares (*Lepus* spp.), North American pika (*Ochotona princeps*), shrew mole (*Neurotrichus gibbsii*), dusky shrew (*Sorex monticolus*), and Trowbridge shrew (*Sorex trowbridgeii*). Many of these species also use lichens for building nests, a use of lichens shared by many bird species and the hoary bat (*Lasiurus cinereus*) (Richardson and Young 1977; Helle and Helle 1989; Sharnoff 1994).

1.4.2.2 Ungulates

Many ungulates also eat lichens. The most widely known is the caribou or reindeer (*Rangifera tarandus*) of northern Canada and Scandinavia that forages on ground lichens, particularly *Cladina* spp., during the winter (Scotter 1967; Bergerud 1972; Danell *et al.* 1994). Semi-domestic reindeer of the Saami and Finnish reindeer herders in Scandinavia survive almost entirely on reindeer lichen (Colpaert *et al.* 2003). Although *Cladina* spp. makes up the large part of its diet, caribou and reindeer also have a high preference for *Bryoria* spp. when it is available (Danell *et al.* 1994), particularly in the early spring when thawing and freezing can make ground lichens unavailable under a crust of ice (Colpaert *et al.* 2003).

During the winter, the woodland caribou (*Rangifera tarandus caribou*) in British Columbia (Kinley *et al.* 2003) and Washington (Rominger *et al.* 1996) survives almost entirely on arboreal lichens, and *Bryoria* spp. are highly preferred over other lichen species (Rominger *et al.* 1996; Kinley *et al.* 2003). In northern Alberta the woodland caribou eats some arboreal lichen, but in the winter survives mainly on terrestrial lichen (Thomas *et al.* 1996).

The lichen *Lobaria* spp. and some alectorioid lichens composed up to 30% of the diet of mountain goats (*Oreamnos americanus*) in southeast Alaska in the winter, particularly in deep snow (Fox and Smith 1988). Pronghorn antelope (*Antilocarpa americana*) in Idaho eat vagrant ground lichens *Xanthoparmelia* spp. and *Rhizoplaca* spp. as an important forage (Thomas and Rosentreter 1992).

In some locations *Alectoria* spp. and *Bryoria* spp. lichens are important food in

winter months for Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) (Hanley *et al.* 1989), Columbian black-tailed deer (*O. hemionus columbianus*) (Stevenson 1978), white-tailed deer (*O. virginianus*) (Hodgman and Bowyer 1985; Ward and Marcum 2005), and elk (*Cervus elaphus*) (Ward and Marcum 2005). Other ungulates known to eat lichens occasionally are moose (*Alces alces*), bighorn sheep (*Ovis canadensis*), Dall's sheep (*O. dalli*), and muskox (*Ovibus moschatus*) (Sharnoff 1994).

1.4.2.3 Invertebrates

Many invertebrates also feed on lichens. Some invertebrates are lichen specialists and feed entirely, or almost entirely on lichens. Some examples of this are oribatid mites (Seyd and Seaward 1984; Reutimann and Scheidegger 1987; Meier *et al.* 2002), snails (Baur *et al.* 1992; Fröberg *et al.* 1993; Baur *et al.* 1994; Hesbacher *et al.* 1995a), and Arctiidae moth larvae (Hesbacher *et al.* 1995b; Pöykkö and Hyvarinen 2003). By providing both food and habitat for invertebrates, epiphytic lichen communities can greatly increase habitat quality for passerine birds (Pettersson *et al.* 1995).

1.5 Aspects of lichen chemistry relevant to ethnolichenology

1.5.1 Lichen secondary chemicals: possible ecological roles, variation within natural systems, effects on other organisms, and significance to humans

Lichens produce a variety of secondary metabolites, most of which are unique to lichens. Over 800 different lichen compounds have been isolated (Huneck and Yoshimura 1996), and many different ecological roles have been suggested for them (reviewed by: Rundel 1978; Lawrey 1986; Fahselt 1994). Many of these compounds are biologically active in humans, and many of these compounds will vary significantly in concentration in different lichens of the same species, or even within a single lichen thallus. Because of this, some knowledge of the nature of lichen secondary chemicals is essential for a more comprehensive understanding of the intricacies of how and why humans use lichens.

One of the most commonly suggested ecological roles of lichen secondary metabolites is that they may offer protection against UV-B radiation (Galloway 1993). There are also several other possible ecological roles of these compounds. Lichen substances such as atranorin have fluorescence spectrums similar to chlorophyll's absorption spectrum, and so may act as accessory pigments to help lichens utilize low light levels (Rao and LeBlanc 1965). Lange *et al.* (1997) have also suggested that the hydrophobic nature of many lichen compounds may help prevent the lichens from getting too soaked (most lichens photosynthesize optimally when they only contain 50% of their water maximum).

Phenolic acids can chelate cations in mineral substrates, and thus might be important for breaking down rocks that the lichen is growing on and providing nutrients to the lichen (Jones 1988). It has also been suggested that some lichen compounds may be energy sources that lichens can utilize in starvation periods (Quilhot *et al.* 1992). Some lichen compounds have been found to affect the photobiont (either algae or cyanobacteria), and thus might play a role in maintaining the symbiosis (Backor *et al.* 1998).

Many lichen compounds have also been found to have negative effects on vertebrate and invertebrate herbivores, lichen and vascular plant competitors, and bacterial, fungal, and viral pathogens. It is thus likely that many of these compounds serve to protect lichens from being eaten or being infected by pathogens, and help lichens succeed against competitors. For a more complete review of this see below.

1.5.1.1 Variation in lichen compounds between and within lichens

Some of the variation in lichen compounds within a species is known to be genetic. Huovinen (1985) found some variation in secondary chemicals within genetically identical clones of *Cladina stellaris* and *Cladina rangiferina*, but not as much as the variation between different clones. Culberson *et al.* (1983) also found that different clones of *Cladonia cristatella* had significantly different abilities to produce secondary compounds, and reacted differently to environmental variables (temperature).

Despite this genetic component, in many cases this variation in lichen compounds is not hardwired. Lichen compounds have been found to vary in concentration in

correlation with several different environmental factors. A brief review of this is provided by Vicente (1991). Factors such as amount of sunlight, temperature, season, elevation, latitude, and location have all been found to be correlated with lichen compound concentration.

Concentrations of lichen compounds can also vary across different organs of the lichen, and in different ages of tissue. Although it has been found that lichens can allocate more defense chemicals to more important parts of the lichen (Hyvarinen *et al.* 2000), I have not found any research to suggest that lichens will produce more defense compounds in response to herbivory, infection, or competition.

1.5.1.1.1 Variation in lichen compounds according to levels of sunlight

Lichen compounds have often been postulated to protect lichens from light damage. As direct evidence for this, Solhaug (1996) found that *Xanthoria parietina* was much more susceptible to damage from high light intensity if the parietin was removed from it. Bachereau and Asta (1997) found that the over all phenolic content in *Cetraria islandica* increased by 52% if it was exposed to UVB radiation, and the lichen turned a much darker brown colour.

Usnic acid has been found to increase with light levels in *Cladonia uncialis* (BeGora and Fahselt 2001) and *Cladonia subtenuis* (Rundel 1969), but not in *Cladina stellaris* (Fahselt 1981). BeGora and Fahselt (2001) found that atranorin concentrations in *Cladina rangiferina* increased at higher light levels, even though Fahselt (1981) had found no correlation in this lichen. Perlatolic acid in *Cladina stellaris* and fumaroprotocetraric acid in *Cladina rangiferina* have also been found to increase under higher light exposure (Fahselt 1981), while Stephenson and Rundel (1979) found that neither vulpinic acid or atranorin varied with light intensity in *Letharia vulpina*.

Extremely high light levels may actually reduce concentrations of some lichen compounds. BeGora and Fahselt (2001) found that atranorin levels in *Cladina rangiferina* and usnic acid in *Cladonia uncialis* would drop off again if exposed to too much UVB light, and Fahselt (1981) found that fumaroprotocetraric acid concentrations in *Cladina rangiferina* would begin to decrease again at very high light intensities.

1.5.1.1.2 Variation in lichen compounds according to temperature

Hamada (1982b) found that the amount of salazinic acid in *Ramalina siliquosa* could vary up to 20 times, increasing at higher temperatures or if the lichen was on a dark substrate. This effect was found to be independent of sunlight or precipitation. Divaricatic and salazinic acid in *Ramalina subbreviscula* (Hamada 1983), protocetraric acid in *Ramalina siliquosa* (Hamada 1985), and didymic acid in *Cladonia cristatella* (Culberson *et al.* 1983) all also increase at higher temperatures. In contrast to this, barbatic acid increased in *Cladonia cristatella* at lower temperatures (Culberson *et al.* 1983).

1.5.1.1.3 Variation in lichen compounds according to season

Swanson *et al.* (1996) found that *Umbilicaria americana* had smaller amounts of secondary compounds in the summer. Ravinskaya and Vainshtein (1975) noted that concentration of usnic acid and atranorin in various lichens is lower in the summer. BeGora and Fahselt (2001) found significantly less usnic acid in *Cladonia mitis* in spring and summer than in winter and autumn. In Antarctica, Quilhot *et al.* (1991) found highest usnic acid in *Usnea aurantiaco-atra* from January to May. Taguchi *et al.* (1969) tested the actual production of lichen acids, and found that production of usnic acid in *Parmelia caperata* and *Usnea diffracta* was lowest in July and highest from February to April, while there was no seasonal change in production of diffractaic or protocetraric acid.

1.5.1.1.4 Variation in lichen compounds according to small scale geography

Hill and Woolhouse (1966) found that *Xanthoria parietina* had four times greater parietin concentration when growing on roof tops or rocks by sea than when it was growing on trees, an effect that was perhaps related to light levels. Culberson *et al.* (1977b) found a very interesting gradient in chemistry in *Ramalina siliquosa* group lichens on coastal cliffs. The lichens lowest on the cliff and closest to the ocean contained stictic and norstictic acid. A bit higher up the lichens contained salazinic acid, and above that the lichens contained protocetraric acid.

1.5.1.1.5 Variation in lichen compounds according to elevation and large scale geography

In *Umbilicaria americana* the total amount and variation of secondary compounds increased with altitude, with average depside³ content doubling every 500m increase in elevation (Swanson *et al.* 1996). This is probably because UV-B irradiation increases at about 5-8% per vertical km (Swanson *et al.* 1996). In Scandinavia, Huovinen (1985) found that concentrations of perlatolic acid in *Cladina stellaris* and fumarprotocetraric acid in *Cladina rangiferina* increased dramatically as you move northward. Bjerke and Dahl (2002) found that, lichen species occupying high-altitude, continental areas in Greenland were all high in usnic acid. Mittal *et al.* (1952) found a large variation in usnic acid concentration in *Ramalina calicaris* collected in different geographical areas.

1.5.1.1.6 Variation in lichen compounds according to age of thallus

Stephenson and Rundel (1979) found up to 48 times more vulpinic acid in the younger parts of the thallus in *Letharia vulpina*. Both Lawrey (1983b) and Golojuch and Lawrey (1988) found the same trend with vulpinic and pinastric acid in *Vulpicida pinastri*, with concentrations being up to ten times higher in younger parts of the thallus. Other examples of lichen compounds being present in higher concentrations in younger lichen tissue include: salazinic acid in *Ramalina siliquosa* (Hamada 1982a); fumarprotocetraric acid and atranorin in *Cladina rangiferina* (Mirando and Fahselt 1978; Huovinen 1985); perlatolic acid in *Cladina stellaris* (Huovinen 1985); and usnic acid in *Parmelia caperata* and *Usnea diffracta* (3.5 times greater: Taguchi *et al.* 1969).

In other cases, lichen compounds can increase in concentration with lichen age. Examples of this include protocetraric acid in *Cladina rangiferina* (Mirando and Fahselt 1978), didymic acid in *Cladonia cristatella* (Culberson *et al.* 1983), and atranorin in *Letharia vulpina* (up to a 100 fold difference: Stephenson and Rundel 1979).

There are also instances of lichen compounds not varying with thallus age. Some examples of this are gyrophoric acid in *Lasallia papulosa* and *Umbilicaria muehlenbergii* (Culberson and Culberson 1958; Mirando and Fahselt 1978); barbatic acid in *Cladonia*

³ A class of secondary compounds particularly common in lichens, formed by the esterification of two or more phenolic benzoic acids.

cristatella (Culberson *et al.* 1983); and atranorin, a-collatolic acid, and alectoronic acid in *Tephromela atra* (Hesbacher *et al.* 1996).

1.5.1.1.7 Other variation in lichen compounds within the thallus

There are often higher concentrations of secondary metabolites in the contact zone between fungal hyphae and photobiont cells, which can result in higher concentrations in vegetative reproduction structures such as soredia (Feige and Lumbsch 1995). Hesbacher *et al.* (1996) didn't find any more atranorin, a-collatolic acid, or alectoronic acid in reproductive structures of *Tephromela atra*, but Stephenson and Rundel (1979) found significantly higher concentrations of vulpinic acid in the soredia of *Letharia vulpina* (up to 14%) and Hyvarinen *et al.* (2000) found higher concentrations in soredia for parietin in *Xanthoria parietina*, vulpinic acid in *Vulpicida pinastri*, and physodic acid *Hypogymnia physodes*.

Hyvarinen *et al.* (2000) also found that there were more of these secondary metabolites in the apothecia, and in the areas of the thallus bearing the apothecia and soredia. This indicates that the variation in lichen acid content was not just a result of more secondary metabolites around the algae cells, and that the lichens were actually producing more phenolics to protect the areas of the lichen of higher worth.

1.5.1.2 Effect of lichen compounds on other organisms

1.5.1.2.1 Effect of lichen compounds on vascular plants

Lichen compounds have been found to inhibit the growth of several vascular plants. Usnic acid inhibits root growth in onions (Huovinen and Lampero 1988); *Lasallia papulosa* extract inhibits root growth in cucumbers (Miller *et al.* 1963); and *Peltigera canina* will inhibit the germination of grass seeds for a small area around it (Pyatt, 1967).

Usnic acid from *Evernia prunastri* gets into the xylem of holm oak (*Quercus rotundifolia*) that it is growing on and decreases photosynthesis and causes defoliation (Giménez and Vicente 1989). *Ramalina tayloriana*, which also contains usnic acid, along with sekikaic acid, damages sandal-wood trees in India (Seshadri and Subramanian 1949).

Cladina spp. on the ground can drastically reduce seedling establishment and

growth for jack pine (*Pinus banksiana*) (Fisher 1979), Scotch pine (*Pinus silvestris*) (Brown and Mikola 1974), and white spruce (*Picea glauca*) (Fisher 1979; Houle and Filion 2003), but can also increase growth for the trees after the trees reach 20 cm (Houle and Filion 2003). These effects may not be direct, as lichens, particularly *Cladina arbuscula*, can inhibit the growth of ectomycorrhizae and thus phosphorus uptake in Scotch pine (Brown and Mikola 1974).

1.5.1.2.2 Effect of lichen compounds on bacteria, fungi, and other lichens

Rainfall has been found to leach atranorin and fumarprotocetaric acid out of *Cladina sandstedei* (Xavier Filho *et al.* 1985) and *Cladina sprucei* (Garcia-Junceda and Xavier Filho 1986), and usnic acid from *Cladina* spp. (Malicki 1965) to the soil underneath them. However, these compounds may actually benefit soil microbes as an energy source. An unidentified bacteria from soil in Lytton, BC was found to rapidly degrade vulpinic acid (Iijima *et al.* 1983), and usnic and perlatolic acid were found to increase growth of soil microbes (Stark and Hyvarinen 2003).

Several studies have shown that lichen compounds have anti-fungal properties. Miller *et al.* (1963) found *Lasallia papulosa* extract to inhibit a variety of fungi; Halama and van Haluwyn (1997) reported *Hypogymnia physodes*, *Evernia prunastri*, and *Cladonia portentosa* all to be anti-fungal; and Gardner and Mueller (1981) also found vulpinic acid to be very antifungal. Henningsson and Lundström (1970) treated several species of fungi with water extracts of various lichens and pure usnic acid. They found that these treatments increased the growth rate of one of the fungi species, and greatly reduced the growth of all the other species tested. Contrary to these studies, Lauterwein *et al.* (1995) reported fungi to be unaffected by usnic and vulpinic acid.

Dead wood with lichen growing on it is often more resistant to fungal decay (Henningsson and Lundström 1970), and it has been hypothesized that lichens may protect trees from fungal pathogens (Kaitera *et al.* 1996), although *Gremmeniella abietina*, a fungal pathogen of trees, was found to be unaffected by lichen compounds (Kaitera *et al.* 1996).

Lichen-specialist fungi were found to have trouble digesting *Lasallia pustulata* and *Punctelia rudecta* until secondary compounds were removed from these lichens

(Lawrey *et al.* 1994), probably because the lichen compounds inhibit the activity of cell wall degrading enzymes (Torzilli and Lawrey 1995). Vulpinic acid, evernic acid, and atranorin were found to inhibit the germination of lichen spores (Whiton and Lawrey 1984).

Both usnic acid and vulpinic acid inhibit the growth of the algae *Trebouxia irregularis* (a common photobiont in lichens), and usnic acid affects its membrane permeability (Backor *et al.* 1998). These properties may be important in subjugating the photobiont to the fungi's wishes (Backor *et al.* 1998).

Lichen extracts are well known to be active against gram-positive bacteria (Burkholder *et al.* 1944; Fujikawa *et al.* 1970b). In particular, usnic acid is strongly antibacterial (Lawrey 1989; Rowe *et al.* 1991; Lauterwein *et al.* 1995), but vulpinic acid is also active against gram-positive bacteria (Brodersen and Kjaer 1946; Benedict and Brady 1972; Lawrey 1989; Nadir *et al.* 1992; Lauterwein *et al.* 1995; Kanokmedhakul *et al.* 2003).

Lichens containing physodic and vulpinic acid strongly inhibited the activity of tyrosinase, an enzyme responsible for pigment production (Higuchi *et al.* 1993). Usnic acid is quite cytotoxic (Correche *et al.* 1998), as well as pannarin and sphaerophorin (Correche *et al.* 2002). Usnic acid, vulpinic acid, and atranorin all cause uncoupling of oxidative phosphorylation (usnic acid was the most potent, followed by vulpinic acid), thus attacking mitochondria and gram-positive bacteria (Abo-Khatwa *et al.* 1996).

1.5.1.2.3 Effect of lichen compounds on herbivores

Many lichen compounds are likely feeding deterrents for animals that would otherwise happily graze on the lichens. Many invertebrates have been shown to preferentially eat lichens without lichen compounds, or those with fewer or less toxic compounds. This selective herbivory has been shown in the slugs *Deroceras reticulatum* (Clark *et al.* 1999) and *Pallifera varia* (Lawrey 1980, 1983a, 1989), oribatid mites (Reutimann and Scheidegger 1987), and in caterpillars of *Eilema* spp., *Lymantria dispar* (Blewitt and Cooper-Driver 1990), and *Spodoptera littoralis* (Giez *et al.* 1994).

Some lichens that seem to be exceptionally edible and do not deter their invertebrate herbivores are: *Aspicilia gibbosa* (Lawrey 1980; 1983a; 1989), *Clauzadea*

metzleri (Clark *et al.* 1999), *Flavoparmelia caperata* (Blewitt and Cooper-Driver 1990), *Lasallia pustulata* (Lawrey 1980; 1983a; 1989; Clark *et al.* 1999), *Melanelia exasperata* (Pöykkö and Hyvarinen 2003), and *Staurothele caesia* (Clark *et al.* 1999). These lichens either have no secondary compounds (in the case of *Melanelia exasperata*), or more palatable ones (like *Lasallia pustulata*).

Besides just avoiding toxic lichen compounds, lichenivores may sequester them or successfully excrete them without noticeable harm. Arctiidae moth larvae commonly sequester atranorin and parietin, and sometimes vulpinic acid, usnic acid, and divaricatic acid (Hesbacher *et al.* 1995b). Some snails will also sequester various lichen compounds, and excrete usnic acid and collatolic acid in their faeces (Hesbacher *et al.* 1995a).

In a series of feeding trials, Lawrey (1980; 1983a; 1989) determined that the slug *Pallifera varia* preferred to eat the lichens *Aspicilia gibbosa* and *Lasallia papulosa* and avoided the lichens *Xanthoparmelia cumberlandia*, *Flavoparmelia baltimorensis*, *Porpidia albocaerulescens*, and *Pseudoparmelia baltimorensis*. He concluded that *Pallifera varia* would not eat stictic acid, was strongly deterred by protocetraric acid and usnic acid, and was unaffected by atranorin, gyrophoric acid, aspicilin, and norstictic acid.

Other feeding trials have also shown that atranorin and norstictic acid had no detrimental effect on oribatid mites (Reutimann and Scheidegger 1987), and that atranorin, along with evernic acid and parietin, have no negative effect on *Spodoptera littoralis* caterpillars (Giez *et al.* 1994). Parietin has also been found to be harmless to *Eilema* spp. caterpillars (Pöykkö *et al.* 2005),

In agreement with Lawrey's (1980; 1983a; 1989) findings, stictic acid has also been found to be a feeding deterrent in *Spodoptera littoralis* caterpillars (Emmerich *et al.* 1993; Giez *et al.* 1994). However, Giez *et al.* (1994) also found norstictic acid to be a strong deterrent, while Lawrey's (1980; 1983a; 1989) found it to be harmless. Giez *et al.* (1994) also found salazinic acid, psoromic acid, rhizocarpic acid, and calycin to be feeding deterrents, and Reutimann *et al.* (1987) also found protolichenesterinic acid to deter oribatid mites.

Physodic acid from *Hypogymnia physodes* was found to be a very strong feeding deterrent for *Eilema* spp. caterpillars (Pöykkö *et al.* 2005), however Giez *et al.* (1994)

found oxyphysodic acid in the same lichen to be highly toxic to *Spodoptera littoralis* caterpillars while physodic acid was harmless. Blewitt and Cooper-Driver (1990) found that water soluble extracts of *Hypogymnia physodes* strongly deterred the gypsy moth (*Lymantria dispar*), but no chemicals were differentiated.

Fumarprotocetraric acid is a bitter compound (Reutimann and Scheidegger 1987) found in several *Bryoria* spp. (Brodo and Hawksworth 1977). Two species of oribatid mite (Reutimann and Scheidegger 1987) and larvae of the arctiid moth *Eilema complana* (Hesbacher *et al.* 1995b), all lichenivores, will all avoid lichen that contains the compound. Giez *et al.* (1994) also found that the noctuid moth larvae *Spodoptera littoralis* was negatively affected by fumarprotocetraric acid.

Peake (1967) and Coker (1967) both found that snails avoided lichens with vulpinic acid. Pöykkö and Hyvarinen (2003) found that feeding *Eilema* spp. caterpillars *Vulpicida pinastri* would kill them, but when they removed the vulpinic and usnic acid from the lichen the caterpillars did fine (Pöykkö *et al.* 2005). Clark *et al.* (1999) found that as little as 0.01% vulpinic acid would deter field slugs (*Deroceras reticulatum*) from feeding, and Slansky (1979) found that 0.6% vulpinic acid would deter larvae of *Spodoptera ornithogalli*. The growth of *Spodoptera littoralis* was found to be significantly reduced at vulpinic acid concentrations of 0.55% (Giez *et al.* 1994) and 0.3% (Emmerich *et al.* 1993), and they were killed at concentrations above 3.3% (Emmerich *et al.* 1993).

Organisms adapted to eating lichens may be more resistant to vulpinic acid. Lawrey (1983b) found that the lichenivorous slug *Pallifera varia* exhibited a large preference for *Vulpicida pinastri* (vulpinic and pinastric acid) over *Cetraria oakesiana* (usnic acid and caperatic acid). A solution of 1% vulpinic acid (the same concentration as is in the lichen) did not deter the slug, but 15% vulpinic acid did. Emmerich *et al.* (1993) also found usnic acid to be a greater feeding deterrent for *Spodoptera littoralis* than vulpinic acid. Usnic acid deterred feeding at concentrations of 0.15% (half that of vulpinic acid), and also killed the larvae at lower concentrations.

1.5.1.2.4 Toxicity of lichen compounds against animals

The two most toxic lichen secondary compounds are usnic acid and vulpinic acid. Numerous experiments have been conducted on the toxicity of these two compounds, but there has been very little research as to the toxicity of other lichen compounds.

1.5.1.2.4.1 Toxicity of usnic acid

Usnic acid will kill freshwater fish at concentrations of 50mg/L (Seshadri and Subramanian 1949), and it is toxic to *Spodoptera littoralis* caterpillars at doses of 71 mg/kg of larvae, (vulpinic acid took 80 mg/kg) (Emmerich *et al.* 1993). Söderberg (1953) found that giving a cat an intravenous dose of usnic acid of 10 mg/kg caused gasping, an increase in respiration, and a drop in blood pressure. The cat returned to normal in five hours, but if he gave it any more usnic acid it died, and showed extreme rigormortis. Injecting cats with 30 mg/kg killed most of them.

Mikoshiha (1936) injected a variety of animals with usnic acid to see what dose would kill them. Mice died when injected with 25 mg/kg intravenously or 700 mg/kg subcutaneously. Both rabbits and rats died from a 30 mg/kg intravenous injection, while it took 40 mg/kg intravenously to kill a dog. A frog could survive with up to 500 mg/kg injected into its lymph sac.

Virtanen and Karki (1956) gave mice subcutaneous injections of different amounts of usnic acid, and found toxicity at much lower doses than did Mikoshiha. Virtanen and Karki started to see toxic effects at 75 mg usnic acid/kg body weight, and found the LD₅₀ (the Lethal Dose for half of the animals) to be 125 mg/kg. von Czetsch-Lindenwald (1955) found that subcutaneous injections of an even lower dose (only 50 mg/kg) could kill a mouse.

Virtanen and Karki (1956) also conducted some feeding experiments with usnic acid. Rabbits that were fed 17.9 mg/kg daily for 79 days showed some toxic effects such as respiratory difficulties, appetite loss, and stomach cramps. However, guinea pigs that were fed only 28.7 mg/kg daily for 119 days showed no toxic effects. Pättiälä *et al.* (1950) fed guinea pigs higher doses of usnic acid (50 mg/kg daily) and found that it caused them to lose a substantial amount of weight.

Pätiälä *et al.* (1948) conducted some usnic acid feeding experiments on humans and found that feeding a person 0.1–1 g of usnic acid daily showed no untoward effects, whereas 3 g daily caused indefinite pains in the region just above the liver. The length of time the trial lasted is not mentioned.

Grady (2003) reports a more recent incident that highlights the potential toxicity of usnic acid. In 2002, Jennifer Rosenthal, a 28-year old Californian, began taking 0.5 g usnic acid daily in the form of pills that she had bought over the internet. After 17 days she was in a comma with complete liver failure. Luckily, she was able to get a liver transplant and survived.

Another possible example of the toxicity of usnic acid occurred in 2004 when over 300 elk mysteriously died in Wyoming, and closer inspection indicated that they had been poisoned by eating too much *Xanthoparmelia chlorochroa* (Anonymous 2004; Gerhold 2004). In order to confirm the culprit, researchers fed the lichen to three healthy elk, and they developed toxic symptoms within ten days. The researchers concluded that the toxicity was a result of usnic acid, which is present in significant amounts in this lichen. However, there is another possible cause, as *Xanthoparmelia* spp. are known to be capable of absorbing toxic levels of selenium from the soil in certain areas (Anonymous 1936). Whatever the cause, the toxicity of *Xanthoparmelia chlorochroa* is consistent with Kingsbury (1964), who claimed that feeding a cow or sheep 3.6% of its body weight of this lichen would kill it.

1.5.1.2.4.2 Toxicity of vulpinic acid

Numerous experiments have been performed on the toxicity of vulpinic acid in a wide variety of animals. Emmerich *et al.* (1993) found vulpinic acid to be toxic to *Spodoptera littoralis* caterpillars at doses of 80 mg/kg of larvae (usnic acid only took 71 mg/kg larvae). Vulpinic acid was also found to be strongly insecticidal by von Lauger *et al.* (1944). Heal (1950) found that cockroaches will die if injected with an aqueous solution of *Letharia vulpina* (high in vulpinic acid), but milkweed bugs are apparently unaffected if immersed in it (Slansky 1979).

Santesson (1939) tested the toxicity of vulpinic acid on a variety of vertebrates. Injecting the frogs *Rana esculenta* and *R. temporaria* with doses of 88.8–428 mg vulpinic

acid / kg body weight was fatal in anywhere between 40 min and 2.5 h. Doses around 58 mg/kg weakened the frogs but they survived, and 36.6 mg/kg had only slight effects. Injections of up to 51 mg/kg into a rabbit had no effect. However, injecting vulpinic acid at 78.8 mg/kg into a cat caused the animal to begin vomiting, hyperventilate, drool, meow pitifully, then go into convulsions and die after 36 minutes. When he gave sequential injections of vulpinic acid to a mouse, it experienced difficulty breathing and convulsions and died after five injections over 3 h 18 min, reaching a cumulative dose of 190 mg/kg. However, given more time a lower dose could have easily been fatal, because even the first injection caused negative effects in the animal.

Soderberg (1952) also injected vulpinic acid into cats, as well as guinea pigs, and found it to cause hyperventilation and body temperature increase in both species, followed by difficulty breathing, then convulsions and respiratory failure. Dauriac (1974) found that high doses of vulpinic acid in mice caused muscle spasms and respiratory difficulties resulting in death in 60 minutes, but lower doses caused partial toxicity and recovery in 48 hours.

Brodersen and Kjaer (1946) found that the lethal dose for an intraperitoneal injection in mice was 75 mg/kg body weight (a 50% less dose all mice would survive, a 50% greater dose they would all die). Foden *et al.* (1975) also found that the toxic dose of vulpinic acid in rats was 75 mg/kg body weight, and noted that the rats died of hyperventilation. NIOSH Exchange Chemicals reports the LD₅₀ (the Lethal Dose for half of the animals) for intravenous injection of vulpinic acid into mice as 178 mg/kg body weight. According to Rundel (1978), the LD₅₀ for vulpinic acid ingested by squirrels is 150 mg/kg body weight, but it is unclear where he gets that figure.

Appa Rao and Prabhakar (1988) found that the LD₅₀ for intraperitoneal injection of vulpinic acid in mice was 74.13 mg/kg body weight, the LD₁₀₀ was 90 mg/kg body weight, and that non-lethal doses over 40 mg/kg body weight produce the same toxic symptoms in mice (laboured breathing, convulsions) reported by previous authors. Intravenous injection in cats of 60-70 mg/kg body weight also caused hyperventilation, reduced blood pressure, and death by respiratory failure (Appa Rao and Prabhakar 1988). Vulpinic acid was found to slow frog hearts and causes dilation of frog blood vessels, which was probably the mechanism for the reduction in blood pressure noted in rats at

doses of 5-20 mg/kg body weight when injected intravenously (Appa Rao and Prabhakar 1988). Foden *et al.* (1975) also reports that as little as 5 mg/kg body weight in rats can have pharmaceutical activity (as an anti-inflammatory).

1.5.1.2.5 Pharmaceutical properties of lichen compounds

Recently, several authors have noted the pharmaceutical properties of lichens, and briefly reviewed some of their medicinal properties (Crittenden and Porter 1991; Huneck 1999; Muller 2001; Cocchietto *et al.* 2002). The main medicinal property of these compounds that is usually discussed is their strong anti-bacterial and anti-fungal properties that can and have been used for treating many human diseases across the world. These properties have also resulted in lichen compounds being suggested as preservatives for Japanese sake (Fujikawa *et al.* 1970b), as well as being traditionally used to preserve curry powders (Richardson 1991) and buttermilk (Upreti and Negi 1996) in India, and bread in Europe (Perez-Llano 1944).

Vulpinic acid was found to be antiviral against two influenza RNA viruses, but not against a herpes DNA virus (Rashan *et al.* 1990). Virensic acid from *Bryoria tortuosa*, as well as stictic acid and chloroparellic acid were all found to be active against HIV-1 integrase, and thus perhaps valuable for AIDS treatment (Neamati *et al.* 1997).

Several different lichen compounds have been found to be antiproliferative against human tumor cells, including: vulpinic acid (Nadir *et al.* 1992; Kanokmedhakul *et al.* 2003); obtusatic acid from *Ramalina* spp. (Kumar and Muller 2000); barbatic and diffractaic acid from *Parmelia* spp. (Kumar and Muller 1999a); lobaric acid from *Stereocaulon alpinum* (Ogmundsdottir *et al.* 1998); protolichesterinic acid from *Cetraria islandica* (Ogmundsdottir *et al.* 1998); usnic, barbatic, diffractaic, and evernic acid from *Usnea longissima* (Yamamoto *et al.* 1995); and gyrophoric, usnic, and diffractaic acid from *Parmelia nepalensis* and *Parmelia tinctorum* (Kumar and Muller 1999c).

Several lichen compounds have also been found to be anti-inflammatories, including: vulpinic acid (Foden *et al.* 1975; Appa Rao and Prabhakar 1988); 4-0-methylcryptochlorophaeic acid (Sankawa *et al.* 1982); atranorin, diffractaic acid, and protolichesterinic acid from *Parmelia nepalensis* and *Parmelia tinctorum* (Kumar and Muller 1999b); obtusatic acid from *Ramalina* spp. (Kumar and Muller 2000); and

barbatic and diffractaic acid from *Parmelia* spp. (Kumar and Muller 1999a). Because of the anti-inflammatory properties, vulpinic acid has been successfully used to treat arthritis in rats (Foden *et al.* 1975), and lichen compounds have been suggested for the treatment of psoriasis (Kumar and Muller 1999a).

Lobaric acid from *Stereocaulon alpinum* (Gissurarson *et al.* 1997) and vulpinic acid (Appa Rao and Prabhakar 1988) were both found to be muscle relaxants in guinea pigs. Diffractaic and usnic acid from *Usnea diffracta* (Okuyama *et al.* 1995) and vulpinic acid (Appa Rao and Prabhakar 1988) were all found to be analgesics on mice.

Pannarin and chloropannarin are strong anti-oxidants that protect cells from damage from free radicals, and atranorin and divaricatic acid are moderate anti-oxidants (Hidalgo *et al.* 1994). An unidentified phenolic extract from *Umbilicaria nylanderiana* was also found to be a strong antioxidant (Gulluce *et al.* 2006). Fernández *et al.* (1996) tested the UVB protective properties of several lichen compounds on albino shaved guinea pigs, and found them to be significantly better than the commercial sunscreen homomenthyl salicylate. The lichen compounds tested and their SPFs at concentrations of 0.4 mg/100mL were: gyrophoric acid (10), diffractaic acid (10), divaricatic acid (9), pannarin (9), usnic acid (8), and atranorin (6).

Usnic acid is a well-known antibiotic common in many lichens. Marshak *et al.* (1947) were the first to isolate usnic acid and show it to be antibiotic, and their work was soon confirmed by subsequent authors (Siintola *et al.* 1948; Johnson *et al.* 1950; Pätiälä *et al.* 1950). Several Finnish researchers soon developed a derivative of usnic acid under the trade name of Usno, and found it to be active against tuberculosis and various other gram-positive bacteria, as well as some fungi like *Candida* and athlete's foot (Virtanen 1954; Virtanen *et al.* 1954; Kortekangas and Virtanen 1956; Virtanen and Kilpiö 1957).

Allergic contact dermatitis from lichens is known to occur in woodcutters and workers who harvest lichen for perfume, wreaths, decorations, and other purposes (Hausen *et al.* 1993). Salo *et al.* (1981) reported that it occurs in as many as 18% of people who regularly handle lichen. Common culprits are fumarprotocetraric acid (Hausen *et al.* 1993), usnic acid (Salo *et al.* 1981), and atranorin (Dahlquist and Fregert 1980; Hausen *et al.* 1993). Evernic, stictic, and perlatolic acid are also all thought to be possible allergens (Hausen *et al.* 1993). Dahlquist and Fregert (1980) report that 1% of

people are allergic to atranorin.

1.5.1.3 Other properties of lichen compounds relevant to ethnolichenology

1.5.1.3.1 Solubility of lichen compounds

Lichen compounds are usually cited as being insoluble in water, and thus are not removed by heavy rainfall in nature, or by people washing the lichens or decocting them in boiling water. However, atranorin, fumarprotocetraric acid, and usnic acid have all been found to leach out of lichens with real or simulated heavy rainfall (Malicki 1965; Xavier Filho *et al.* 1985; Garcia-Junceda and Xavier Filho 1986), although fumarprotocetraric acid was found to leach out less than atranorin (Garcia-Junceda and Xavier Filho 1986), and Miranda and Fahselt (1978) were unable to extract fumaroprotocetraric and protocetraric acid from *Cladina rangiferina* unless the thallus was completely dry.

Water extracts of various lichens have also been found to be effective feeding deterrents against gypsy moths (Blewitt and Cooper-Driver 1990), and strongly anti-fungal (Henningson and Lundström 1970), which implies that some lichen compounds are effectively removed with water.

Lauterwein *et al.*, (1995) found that although the solubility of vulpinic and usnic acid was low, aqueous solutions of 32 ug/mL were possible. Stephenson and Rundel (1979) noted that vulpinic acid is at least four times more soluble in water than atranorin. Huovinen (1988) found that boiling *Cetraria islandica* in water to make medicinal tea would yield about 2% protocetraric acid per dry weight of lichen, which is a fairly effective extraction. Yields were higher if the lichen was finely ground and not in a tea bag (presumably the lichen polysaccharides clogged the bag).

1.5.1.3.2 Heat stability of lichen compounds

Lichen compounds are also generally thought to be very heat stable, but there is some evidence that this is not always true. Huovinen (1988) found that decocting *Cetraria islandica* in boiling water would hydrolyze the fumarprotocetraric acid into protocetraric acid. Miranda and Fahselt (1978) found that if *Cladina rangiferina* was dried at temperatures over 40°C it would significantly reduce atranorin content, and

drying at 80°C reduced all lichen compounds tested (atranorin, fumaroprotocetraric and protocetraric in *Cladina rangiferina*, usnic acid in *Cladina mitis*, and gyrophoric acid in *Lasallia papulosa* and *Umbilicaria muehlenbergii*). Culberson *et al* (1977a) also found that temperatures of 85 -105°C, resulting from either herbarium drying or volcanic activity where the lichen was growing, would degrade anziaic acid in *Hypotrachyna prolongata* and *Hypotrachyna partita*.

1.5.1.3.3 Biological activity may be affected by pH

An interesting set of experiments by Gardner and Mueller (1981) showed that pH can affect the toxicity of lichen acids towards fungi. Evernic acid was very toxic to fungi at pH 7, but much less so at a higher or lower pH. An exactly opposite effect was seen in psoromic acid, which had the least activity at pH 7. Fumaroprotocetraric acid was an effective fungicide at a lower pH, as were the less effective fungicides stictic acid, lecanoric acid, and atranorin. Usnic acid was a stronger fungicide at a higher pH. Vulpinic acid was the strongest fungicide tested, but the effects of pH on its toxicity were not as clear. Vulpinic acid inhibited fungal growth more at higher or lower pH (not at pH 7), but it was only effective at preventing spore germination at a lower pH.

1.5.2 Lichen carbohydrates

1.5.2.1 Simple carbohydrates in lichens

A variety of low molecular-weight carbohydrates are present in lichens. These include reducing monosaccharides, oligosaccharides, and polyols (sugar alcohols). Only the polyols are present in large enough quantities to potentially be nutritionally relevant. A variety of reducing monosaccharides are commonly found in lichens, as is sucrose, but they are only present in small quantities (Nishikawa *et al.* 1973; Gorin *et al.* 1993). Several oligosaccharides are occasionally found in some lichen species, but again only in small quantities (Gorin *et al.* 1993).

Lichens can, however, contain significant concentrations of polyols (sugar alcohols). Although numerous polyols have been reported in lichens in trace amounts, the most widespread and abundant polyols are mannitol and arabinitol (Lindberg *et al.*

1953; Lewis and Smith 1967). Polyol contents in lichens of 0.13–8.0% (more commonly 1–4%) are often reported (Pueyo 1960; Gorin and Iacomini 1984, 1985; Iacomini *et al.* 1985; Gorin *et al.* 1993; Armstrong and Smith 1994), although concentrations as high as 10–15% have been reported for some lichens in summer (Pueyo 1960; Miceno *et al.* 1991), and some Antarctic lichens can contain as much as 24% polyols in the spring (Miceno *et al.* 1991). Levels of polyols are much lower in the winter than in the summer, and decrease dramatically with prolonged storage (Lewis and Smith 1967).

Polyols are not particularly digestible to humans, and as a result are often used as artificial sweeteners. Mannitol and arabinitol have low digestibility, and provide less than half the calories as sucrose while causing bowel complaints in larger doses (ADA 2004).

1.5.2.2 Polysaccharides in lichens

The main carbohydrates in lichens are polysaccharides. These fall into three main categories: lichenins, isolichenins, and galactomannans. The lichenins are β -(1→3)-(1→4)-linked D-glucans that are common in Parmeliaceae lichens and dissolve in hot water but precipitate out as it cools. The isolichenins are taxonomically widespread α -(1→3)-(1→4)-linked D-glucans that remain soluble in cold water. The galactomannans are alkali-soluble carbohydrates that were previously called hemicellulose. A fourth category of lichen carbohydrates, the pustulans, are β -(1→6)-linked D-glucans that appear restricted to the Umbilicariaceae.

1.5.2.2.1 The (1→3)-(1→4)- β -D-glucans (lichenins)

The lichenins are common and well-known lichen carbohydrates that are soluble in hot water but precipitate out of cold water (although some cold-water soluble lichenins have been discovered: Takeda *et al.* 1972; Iacomini *et al.* 1988; Corradi da Silvia and Gorin 1990). Lichenin from *Cetraria islandica* was first described by Berzelius (1813), making it the first lichen carbohydrate known to science. Guérin-Varry (1834) later gave it the name *lichenin*.

Lichenin is a medium length polymer of glucose molecules connected by β -(1→3) and β -(1→4) bonds. Estimates for the length of this glucan range from 80 (Carter

and Record 1939) to 160 (Meyer *et al.* 1948) units long. The glucose molecules are arranged linearly with a ratio of (1→3) to (1→4) linkages of about 0.43 (Chanda *et al.* 1957; Nishikawa *et al.* 1973; Yokota *et al.* 1979). This ratio has been found to vary slightly in some lichen species, from 0.33–0.53 (Iacomini *et al.* 1988; Corradi da Silva and Gorin 1990; Baron *et al.* 1991), and a lichenin was isolated from *Evernia prunastri* with a (1→3) to (1→4) ratio of 3.0 (Takeda *et al.* 1972).

Lichenin seems to be a relatively regular molecule, usually consisting of a repeating pattern of two β -(1→4) bonds and then a β -(1→3) bond (Peat *et al.* 1957), although occasionally there will be three consecutive β -(1→4) bonds (Perlin and Suzuki 1962). The interspersed β -(1→3) bonds make lichenin more flexible than cellulose, which is entirely β -(1→4) bonds (Tvaroska *et al.* 1983). This flexibility is probably important for the lichen structurally, making the outer cortex and/or inner cord of the lichen strong yet flexible.

Common (1991) surveyed a multitude of species within the Parmeliaceae family for the presence of lichenin. He differentiated two different types of lichenin based on their iodine staining patterns: *Cetraria*-type lichenin and *Xanthoparmelia*-type lichenin. Within the Parmeliaceae, *Cetraria*-type lichenin was found in 197 species across 34 genera; *Xanthoparmelia*-type lichenin was found in 18 species across 5 genera; and 123 species in 25 genera did not contain any lichenin. Although it is apparent that lichenin is exceedingly common amongst the Parmeliaceae (a very large family of lichens), lichenin has often been reported to be absent from lichens belonging to other families, such as *Ramalina* (Common 1991) and *Cladina* (Person *et al.* 1975; Svihus and Holand 2000).

Table 1.2 summarizes numerous studies on the carbohydrate content in a variety of lichen species. Many authors have measured the hot-water soluble carbohydrate in lichen and reported it as lichenin, without attempting to identify it or remove other carbohydrates that were undoubtedly present. These authors have often reported much a higher lichenin content for these lichens than other, more precise studies. Although “lichenin” concentrations as high as 50% have been reported for a variety of lichens by several authors, none of them were actually differentiating water-soluble carbohydrates, so these values will be too high (e.g. Diachkov and Kursanov 1945; Lal and Rao 1956;

Källman 1988). The highest lichenin concentration recorded that was actually properly identified as lichenin is 27% for *Neuropogon aurantiacoater* (Baron *et al.* 1991).

1.5.2.2.2 The (1→3)-(1→4)- α -D-glucans (isolichenins)

The isolichenins are soluble in both hot and cold water (a few isolichenins have been discovered that are insoluble in cold water: Gorin *et al.* 1993). They were first differentiated from lichenin in extracts of *Cetraria islandica* by Mulder in 1838. This momentous achievement was apparently overshadowed when, one year later, he proposed the word *proteine* for a novel substance that he had isolated from animal tissue. Berg (1873) also differentiated lichenin and isolichenin, but it did not get a name until 1881 when Beilstein called it *isolichenin*.

Isolichenin is a medium length polymer of glucose molecules connected by α -(1→3) and α -(1→4) bonds. This glucan has been estimated to be 42–44 units long (Chanda *et al.* 1957). The glucose molecules are attached linearly, usually with slightly more (1→3) bonds than (1→4) bonds, however the ratio of (1→3) to (1→4) bonds can vary from 0.4–3.0 (Chanda *et al.* 1957; Peat *et al.* 1961; Fleming and Manners 1966; Hauan and Kjølberg 1971; Miceno *et al.* 1991). Unlike lichenin, isolichenin is a very irregular molecule. There appears to be little pattern to the bond placement, with both types of bond occurring both alone and in groups (Peat *et al.* 1961).

The occurrence and abundance of isolichenin in a variety of lichen species is summarized in **Table 1.2**. Although it is a commonly occurring carbohydrate in a wide variety of lichens, it does not usually occur in high concentrations. Isolichenin concentrations of 0–5% are most common, and the most isolichenin-rich lichen recorded to date is *Alectoria sulcata*, which contains 9.2% isolichenin (Takeda *et al.* 1972). Within the Parmeliaceae, isolichenin generally seems to be present in significantly lower concentrations than lichenin. It should also be noted that isolichenin seems to be more taxonomically widespread than lichenin, and occurs in small amounts in a variety of lichens outside of the Parmeliaceae, most notably *Cladina* spp. and *Stereocaulon* spp.

1.5.2.2.3 The (1→6)-β-D-glucans (pustulans)

The pustulans appear to be mostly restricted to the related genera *Umbilicaria* spp. and *Lasallia* spp. Lichens from these genera have been important food for several cultures, so this carbohydrate could be of nutritional interest. Like lichenin, these carbohydrates are soluble in hot water, but precipitate out in cold water.

Pustulin was first described by Drake (1942) from *Lasallia pustulata*. Further research has elucidated the pustulin content in numerous species of *Lasallia* and *Umbilicaria*, ranging from 7% in *Lasallia pustulata* (Lindberg and McPherson 1954) to 35% in *Umbilicaria muehlenbergii* (Iacomini *et al.* 1988). (See **Table 1.2.**) Interestingly, the entirely unrelated *Cladonia amaurocraea* was found to have low concentrations of this carbohydrate as well (Iacomini *et al.* 1985).

1.5.2.2.4 The galactomannans

Lichens often contain significant quantities of alkali-soluble carbohydrates, which have historically been called hemicellulose. In reality, these alkali-soluble carbohydrates probably consist of several, unrelated carbohydrates. However, the galactomannans are the only carbohydrates of this class that have been studied in lichens. The galactomannans of lichens, first isolated by Karrer and Joos (1924), are now known to consist of a (1→6)-α-D-mannopyranosyl main-chain with α-D-Manp, α-D-Galp, and/or β-D-Galp side-chains (Gorin *et al.* 1988).

Isolating galactomannans from lichens is generally accomplished by removing the alkali-soluble carbohydrates in boiling aqueous KOH, and then precipitating out the galactomannan (often by forming a copper complex using Fehling solution). A brief review of the literature, covering 23 different lichen species from a wide variety of families, shows that the average amount of galactomannan recovered from the lichen is about 4% of its dry weight (Mićović *et al.* 1969; Takahashi *et al.* 1979; Gorin and Iacomini 1984, 1985; Iacomini *et al.* 1985; Gorin *et al.* 1988; Baron *et al.* 1989; Kjølberg and Kvernheim 1989; Corradi da Silvia and Gorin 1990; Baron *et al.* 1991; Miceno *et al.* 1991; Teixeira *et al.* 1992). The highest yields of galactomannan recovered from lichens were 11% for *Usnea meridionalis* (Teixeira *et al.* 1992) and 16% for *Ramalina celastri* (Miceno *et al.* 1991).

The total amount of galactomannan recovered from the lichen via a Fehling precipitate is usually only a fraction of the amount of carbohydrate extracted in alkali solution. In the studies reviewed above, the concentration of alkali-soluble carbohydrates ranged from 3.1% to 55% (average 35%). This is probably caused by two phenomena: the presence of other, unidentified alkali-soluble carbohydrates; and the Fehling precipitation not yielding 100% of the galactomannans present. It should also be noted that some galactomannans have been discovered in lichens that are soluble in distilled water (Gorin and Iacomini 1984).

Numerous other studies that are more nutritionally-focused have reported the hemicellulose content of lichens (e.g. Yanovsky and Kingsbury 1938; Diachkov and Kursanov 1945). This should be interpreted as the alkali-soluble carbohydrate content, and values from these studies are in good agreement with those reviewed above (25–60%).

Hemicelluloses are indigestible to humans (Institute of Medicine 2002), although they can be degraded by fermentation in the lower intestine (Slavin *et al.* 1981). The digestibility of galactomannan from lichen has not been studied, but galactomannans from other sources have been found to be indigestible to humans and interfere with the digestion of other, digestible carbohydrates (Brennan *et al.* 1996).

1.5.3 Lichen proteins

1.5.3.1 The amount of protein in lichens

The lichens *Cladina* sp., *Cetraria islandica*, and *Alectoria sarmentosa* are often eaten by ungulates, and numerous tests have been done on their macronutrients. These lichens seem to be similar to each other in their protein content. Although some authors have reported protein contents as high as 5% (Dannfelt 1917), or as low as 1.3% (Scotter 1972) or even 0% (Chatfield and Adams 1940), the majority of researchers have reported values of 2–3% (Scotter 1965; Pulliainen 1971; Beeson *et al.* 1972; Scotter 1972; Jacobson and Skjenneberg 1975; Rochelle 1980; Airaksinen *et al.* 1986; Robbins 1987; Danell *et al.* 1994; Säkkinen *et al.* 1999; Svihus and Holand 2000; Storeheier *et al.*

2002). This is significantly less protein than most other forages (Beeson *et al.* 1972; Rochelle 1980).

Bryoria spp. are also often eaten by ungulates, and usually contain more protein than the above mentioned lichens. This is probably why they tend to be preferred forage lichens of caribou (Rominger and Robbins 1996). Reported values for protein in *Bryoria* spp. range from 4–8% (Dannfelt 1917; Yanovsky and Kingsbury 1938; Scotter 1965; Fujikawa *et al.* 1970a; Solberg 1970; Pulliainen 1971; Antifeau 1987; Danell *et al.* 1994; Rominger and Robbins 1996; Kirkpatrick *et al.* 2001).

Some lichens contain a lot more protein. In particular, cyanolichens (lichens that have a cyanobacteria symbiont and are thus capable of fixing nitrogen) tend to be much higher in protein (Lal and Rao 1956; Fujikawa *et al.* 1970a; Solberg 1970). The cyanolichen *Stereocaulon paschale* is often included (in small amounts) in caribou forage and contains more protein than most other forage lichens, with reported values of 5.4–7.9% (Scotter 1965; Pulliainen 1971; Svihus and Holand 2000; Storeheier *et al.* 2002). The highest protein content reported for a commonly occurring cyanolichen is for *Peltigera canina*, which contains 21–25% protein (Lal and Rao 1956; Subramanian and Ramakrishnan 1964; Scotter 1965; Solberg 1970). The much less common *Dictyonema glabratum* (a basidiomycete with a cyanobacteria symbiont), has been recorded to contain 36% protein (Iacomini *et al.* 1987).

Several other species of lichen that have a rich culinary history also have higher protein contents. Rock tripes (*Umbilicaria* spp. and *Lasallia* spp.) were found to contain 6.3–10.8% protein (Dannfelt 1917; Ilback and Kallman 1999). Three edible species of lichen from Nepal, *Everniastrum nepalensis*, *Ramalina farinacea*, and *R. conduplicans*, contain 9.0–9.6% protein (Bhattarai *et al.* 1999). A common ingredient for spices in India, *Parmotrema tinctorum*, contains 13.8% protein (Lal and Rao 1956).

To understand the nutritional value of a lichen, it is not the total amount of crude protein that is important, but rather the total digestible protein. An *in vivo* test with *Rhinopithecus bieti* (a foregut fermenting primate) found the protein in *Bryoria* spp. to be 91% digestible (Kirkpatrick *et al.* 2001). The protein in a variety of caribou forage lichens was found to be about 50% digestible using *in vitro* tests (Pulliainen 1971; Beeson *et al.* 1972), while Hawksworth (1984) found that protein in the antelope forage lichen, *Ramalina duriaei*, was only about 32% digestible (using an *in vitro* test with pepsin).

1.5.3.2 The quality of lichen proteins

Several investigators have studied the amino acid content of numerous lichens (Ramakrishnan and Sankara Subramanian 1964; Subramanian and Ramakrishnan 1964; Ramakrishnan and Subramanian 1965; Subramanian 1965; Ramakrishnan and Subramanian 1966a, 1966b; Fujikawa *et al.* 1970a; Solberg 1970; Ilback and Kallman 1999). In general, most of the lichens tested did not contain enough essential amino acids to be of significance to human nutrition. However, some lichens were particularly protein-rich and did have significant amounts of some amino acids. The lichens tended to be a particularly good source of threonine, lysine, and valine, and a particularly poor source of histidine, methionine/cysteine, and isoleucine.

Fujikawa (1970a) analyzed the amino acid content of a *Bryoria* sp. and did not find significant levels of any essential amino acid. The most significant amino acid in this lichen was threonine, and it would still require 18 kg of lichen per day to provide an average person's nutritional requirement for this amino acid (Institute of Medicine 2002). These results are very similar to what Solberg (1970) found for *Bryoria fuscescens*.

However, some lichens are much higher in protein. Ilback and Källman (1999) measured the amino acids of *Lasallia pustulata* (10.8% protein), and a mere 340 g of this lichen per day could provide an average person with adequate levels of all twelve essential amino acids (80 g provides adequate threonine). And if Subramanian and Ramakrishnan (1964) are correct (their measurements are much higher than Solberg 1970), as little as 320 g of *Peltigera canina* per day could provide the required levels of all essential amino acids (160 g provides required threonine, valine, and tryptophan). The protein-rich *Dictyonema glabratum* contains so much tyrosine that as little as 25 g could provide your daily requirement of that essential amino acid, although this lichen would be difficult to collect in any quantity.

1.5.4 Other nutrients in lichens

1.5.4.1 Minerals in lichens

Lichens contain a variety of essential minerals and vitamins. The significance of these nutrients to human nutrition depends on how much lichen you would need to eat to

get the required level of a given nutrient. This information was reviewed from numerous authors and is summarized in **Table 1.3**. It is important to note that nutrient content in lichens can vary significantly with season (Blix and Rydin 1932; Scotter 1965, 1972; Rochelle 1980; Hanley and McKendrick 1983) and substrate (Prussia and Killingbeck 1991).

Lichens could be a significant source of both calcium and iron, although no tests have been done to determine the bioavailability of any of these minerals. The concentrations of both minerals vary substantially depending on the substrate on which the lichen is growing (Prussia and Killingbeck 1991), indicating that the lichen absorbs them from its environment.

This absorptive ability of lichens can be problematic as well. In feeding experiments with rats, Airaksinen (1986) discovered that the *Cetraria islandica* he was feeding them had absorbed enough lead to be toxic. Several other lichens have also been found to absorb toxic levels of other elements from their environment: selenium in *Xanthoparmelia* sp. (Anonymous 1936), beryllium in *Parmelia saxatilis* and *Xanthoria parietina* (Fearon 1933), and chlorine in *Pseudevernia furfuracea* (Koller and Pöpe 1934). Palmer *et al.* (1963) traced the high body burdens of radioactive cesium-137 in Inupiaq in northern Alaska to the consumption of caribou that had eaten lichens which had accumulated high levels of the radioactive material.

1.5.4.2 Vitamins and other useful nutrients in lichens

Information on the vitamin content of lichens was reviewed from numerous authors and is summarized in **Table 1.3**. Some lichens contain significant amounts of vitamin B₁₂, choline, tocopherol (vitamin E), and folate (vitamin B₉) (Sjöström and Ericson 1953; DaSilva and Jensen 1971; DaSilva and Englund 1974). Some lichens may also contain significant levels of vitamin C. However, the studies quantifying vitamin C content in lichens differed in their results by orders of magnitude, making conclusions about this vitamin difficult. Eidlitz (1969) did note, however, that the Nnganasans in Siberia used stomach icecream (the half-digested *Cladina* spp. from a reindeer's stomach) as a remedy for scurvy.

Lal and Rao (1956) found that *Roccella montagnei* contained a significant amount of riboflavin, but feeding tests in rats for 22 Alaskan species of lichens failed to detect any riboflavin (Ellis *et al.* 1933). Lal and Rao (1956) may have overestimated riboflavin because of an effect of lichen carbohydrates on their detection method (Scott *et al.* 1941).

Czeczuga (1988) examined 143 species of lichen and found 42 different carotenoids in lichens, only six of which can be converted to vitamin A (Rodriguez-Amaya 2001). Certain lichens, especially orange and yellow lichens in the family Teloschistaceae, were exceptionally high in carotenoids (up to 94.7 ppm). In these cases the carotenoids were almost entirely auroxanthin or mutauxanthin, neither of which are useful as vitamin A precursors (Rodriguez-Amaya 2001). However, carotenoids (even ones that are not vitamin A precursors) are also powerful antioxidants (Fraser and Bramley 2003), and these lichens could still be nutritionally valuable for this reason. In particular, astaxanthin is a common carotenoid in many lichen species (Czeczuga 1988), and is renowned for its powerful antioxidant abilities (Palozza and Krinsky 1992).

1.5.5 The digestibility of lichens

Dr. Hansteen, the chief lecturer in the Agricultural School at Aas, Norway in 1911, prophesized that lichen was to become the great popular food of the masses, because of its cheapness and nutritive properties (Swartz 1911). Lichenin had been considered to be digestible ever since Berzelius (1808) first referred to an extract of *Cetraria islandica* as being “moss-starch”. It gained much popularity after Kütz (1874) suggested that lichen carbohydrates could be eaten by diabetics as a substitute for conventional dietary carbohydrates, and as a result numerous experiments were done in the late 19th and early 20th century on the digestibility of both lichenin and isolichenin.

In 1879, two separate physicians conducted experiments feeding *Cetraria islandica* bread to diabetics, a Norwegian (Bugge 1879) and an Italian (Cantani 1879, *cited in*: Poulsson 1906). The experiments were considered to be a success because the lichen bread did not increase sugar levels in the urine of the diabetics, a conclusion later echoed by both Voit (1881) and Poulsson (1906). This seems overly optimistic, because there was no evidence that the lichenin was actually providing any nutrient to the subjects. In fact, lichenin was not even shown to contain a digestible sugar (glucose) until 1886 when

Klason succeeded in hydrolyzing it in strong acid (Klason 1886), a fact that was later verified by Brown (1898) and Müller (1905).

1.5.5.1 *In vitro* experiments

The first experiments on the digestibility of lichenin were conducted in 1873 by Theodor Berg. He conducted *in vitro* tests and subjected lichenin to human saliva, pancreatic extract, and gastric juice, as well as malt diastase, and still could not break the lichenin down into glucose. Other researchers subsequently confirmed these results in a variety of other *in vitro* tests. Lichenin is not broken down by human saliva (Nilson 1893; Brown 1898; Saiki 1906); human gastric juice (Nilson 1893); pancreatic extracts from dogs, ox, or rabbits (Nilson 1893; Brown 1898; Saiki 1906; Shimizu 1921a); intestine extracts from dogs, pigs, or rabbits (Saiki 1906; Shimizu 1921a), *Bacillus coli* culture (Saiki 1906), or by prepared amylase (malt diastase: Brown 1898; Saiki 1906).

Jewell and Lewis (1918) continued to search for the presence of the enzyme to break down lichenin (licheninase) in a wide variety of organisms, using more *in vitro* tests to see if selected tissue from these organisms contained the enzyme to break down lichenin. All twenty species of invertebrates that they tested had licheninase, these included poriferans, annelids, echinoderms, mollusks, arthropods, crustaceans, and tunicates. However, no vertebrate tissue that they tested contained the enzyme. They tested alimentary canal tissue from a goldfish, frog, lizard, snake, and two species of turtle. They also tested the pancreas and upper portion of small intestine of a chicken and a rabbit, the pancreas of pig and a dog, the small intestine of sheep, and saliva from a human.

Some *in vitro* experiments by Saiki (1906) did find enzymes to break down lichenin in two different molds. An inulase prepared from *Aspergillus niger* and a takadiastase prepared from *Aspergillus oryzae* both broke down lichenin. Interestingly, takadiastase is a type of α -amylase, and should not be active against lichenin.

The only evidence from an *in vitro* experiment that a vertebrate tissue may produce licheninase is from von Tschermak (1912). He conducted a series of *in vitro* tests with tissue from rabbit pancreases and intestines, and found that 50% of the animals

had licheninase in one organ or the other. I am uncertain why his results differed from those of other researchers.

1.5.5.2 Feeding experiments on lab animals

1.5.5.2.1 Some early feeding trials with lab animals

Both Brown (1898) and Saiki (1906) conducted some feeding trials to confirm the results of their *in vitro* experiments mentioned above. Brown (1898) fed two starved rabbits lichenin from *Cetraria islandica*, and tested their livers to see if glycogen content increased. It did not, implying that the rabbits could not digest lichenin. Saiki (1906) fed *Cetraria islandica* to a small dog. The lichen was added to the dog's diet of meat for a two-day period, and carbohydrate levels in its feces measured before, during, and after the feeding period. High levels of lichen carbohydrates were present in the dog feces for two full days after he stopped feeding it lichen, indicating a long retention time for the lichenin in the dog's gut. About 81% of the lichen carbohydrates that the dog ingested were found in the dog's feces, indicating at best a very low digestibility.

Brown's results directly contradict those of an earlier experiment by von Mering (1877), who found significant amounts of glycogen in the livers of two rabbits after feeding them lichenin. However, it was later decided that von Mering's method of measuring glycogen levels was inaccurate (Miura 1895).

Shimizu (1921b) did some feeding experiments on dogs, and found that they more effectively absorb the protein in their diet if they are fed lichenin. Shimizu's (1921a) subsequent *in vitro* experiments failed to find licheninase in dog digestive tissue, so Shimizu (1921c) conducted another series of *in vitro* tests to provide some evidence that bacteria present in the lower intestines of mammals could be responsible for breaking down lichenin, which could explain his previous results that lichenin helped with protein absorption.

1.5.5.2.2 A flawed feeding trial with mice

Wallerstein (1925) conducted some feeding experiments with lab mice, and concluded that they could digest 53-64% of the lichenin that he fed them (a claim later immortalized by Perez-Llano 1944). However, a closer scrutiny of Wallerstein's

experimental design makes his results dubious. He fed the mice bread that had some lichenin in it for four days and measured how much carbohydrate they had in their feces. He assumed that the difference between the amount of lichenin that he fed to the mouse and the amount that he found in its feces on that same day was the amount of lichenin that was successfully digested by that mouse. This does not account for the increased retention time of indigestible foods in the gut.

Wallerstein analyzed the feces every second day, starting four days before he started feeding the mice lichenin and continuing until four days after he had stopped feeding them lichenin. On the fourth (last) day that he fed the mice lichenin, there was 28% more carbohydrate in their feces than on the second day he fed them lichenin. And on the second and fourth day after he stopped feeding the mice lichenin there was 40% more carbohydrate in their feces than there was two and four days before he fed them lichenin (found significant by a t-test, $P=0.003$). This indicates that a significant amount of the lichenin was retained in the gut for several days, and that at least part of the lichenin that Wallerstein assumed was digested by the mouse was in fact just sitting undigested in its gut.

It is apparent that even the relatively low digestibility of lichenin in a mouse gut that was reported by Wallerstein (53-64% as compared to 98.9% for wheat starch) is an over-estimation of the digestibility of lichenin. The poor digestibility of lichenin is further indicated by the fact that Wallerstein had to redesign his experiment to stop the mice from dying. He reported that his original experiment involved feeding the mice bread that contained either 33% or 66% lichenin, but that this killed too many animals. He had to reduce the lichenin content to 11.25% before enough mice survived to provide any results.

1.5.5.2.3 More recent feeding trials

Airaksinen *et al.* (1986) conducted some more recent feeding experiments on mice and rats. They fed mice a mixture that was half lichen (either *Cetraria islandica* or *Cladina* spp.) and half regular mouse food. When they used untreated lichen, all of the mice died within six days. The mice lived slightly longer if the lichen was treated before it was fed to them. Boiling the *Cetraria islandica* increased the life expectancy of the

mice to eight days, soaking it in ash lye increased it to twelve days, and doing both increased it to three to four weeks. These treatments were less effective with *Cladina* sp., which remained more toxic despite the treatments.

A second feeding experiment was then conducted by Airaksinen *et al.* (1986), where they fed rats a mixture of 25% treated *Cetraria islandica* (boiled and soaked in ash lye) and 75% regular rat food. The rats survived well over a 3-month test, although they didn't gain as well as the control group, and they showed some signs of lead poisoning (the lead was accumulated in the lichen).

Ilback and Källman (1999) also did a feeding experiment on mice. The mice were fed a diet containing 30% *Lasallia pustulata* for three weeks. The lichen was first soaked in a carbonate solution, otherwise the mice refused to eat it. At the end of the test, there was no detectable effect on the growth or health of the mice. The mice that were fed lichen did have a significant increase the activity of their spleen B-lymphocytes, perhaps indicating a stimulation of their immune system.

1.5.5.3 Human feeding experiments

1.5.5.3.1 A flawed feeding trial on two diabetics conducted 100 years ago

Poulsso (1906) tried feeding humans bread that was made with either *Cetraria islandica* or *Flavocetraria nivalis*. The *Flavocetraria nivalis* caused such intestinal disturbances that feeding trials with that lichen had to be stopped. Poulsso did, however, complete two feeding trials with *Cetraria islandica*. In each trial, the participant was fed some *Cetraria islandica* bread along with meat, wine, eggs, butter, cheese, coffee, and tea, and then the amount of carbohydrate in their feces was measured. If the carbohydrate present in their feces was less than the total amount of lichenin they were fed, Poulsso considered that they must have absorbed some of it.

The first trial involved one diabetic person for 53 hours, the second a different diabetic person for 60 hours. Poulsso does not record when in each trial the person actually ate the food. Presumably, the participants did not eat anything for the first part of the trial to allow their digestive systems to void any previous food. The actual ingestion of the food must have taken some time, because it involved about 2.5 kg of food. Therefore, the length of time between when the participants ate the last of the

lichen bread and the end of the trial must have been substantially less than the length of the trial. If the retention time of the lichenin in the human gut was longer than that, then a significant amount of lichenin may have still been in the digestive tracts of the participants at the end of the trial.

If one assumes that there was no lichenin left in the digestive tracts of the participants, then an average of 108 g lichenin was absorbed by each participant in the first trial, and 97 g in the second trial. This was 49% and 46%, respectively, of the total lichenin that the participants consumed. This digestibility of 46–49% was later cited by Llano (1944) and has become widely accepted. However, both Mendel (1908) and Swartz (1911) disagreed with Poulsson's method of carbohydrate analysis of the feces, and felt that the feces may have actually contained a lot more carbohydrate than was measured, which would reduce the estimate of how much lichenin was absorbed in the gut.

1.5.5.3.2 Some unpublished feeding trials of that era that appear more accurate

Two subsequent feeding trials were conducted on humans in two different laboratories, both of which were much more thorough in their design. One of the experiments was conducted by Dr. V. C. Meyers and preliminary results were reported by Mendel (1908). The other experiment was conducted by a Mr. S. W. MacArthur, and preliminary results of it were reported by Swartz (1911). Neither experiment appears to be published by its author in a final form. Both experiments improved on Poulsson's (1906) experimental design by allowing for a longer retention time of the lichenin in the human gut, and using a more thorough method of carbohydrate analysis. The experiments of both Meyers and MacArthur indicate that there was negligible lichen carbohydrates absorbed in the by either of their human subjects

In Meyers' experiment, the subject ate *Cetraria islandica* (along with bread) for three days, waited two days, and then ate the lichen again for one day. Carbohydrate levels in the feces were measured during the feeding trial, as well as for two days before and two days after. In total, 100 g of lichen was consumed, containing 70.5 g of lichen carbohydrate. The subject excreted a total of 80 g of carbohydrate in their feces over the eight-day period after they first ate lichen. If their feces had continued to contain the

same amount of carbohydrate as it had before they ate lichen, they would have only excreted 5.6 g of carbohydrate.

MacArthur had a similar experimental design. He fed a person *Cetraria islandica* for three days, and measured carbohydrate levels in the feces during the trial and for three days before and three days after. The subject ate 47 g of lichen, containing 34.1 g of carbohydrate. In the 6-day period after they first ate lichen, they excreted 38.7 g of carbohydrate in their feces. This is compared to the 7.9 g of carbohydrates that would have been in their feces if it had remained the same as it was before they ate lichen.

1.5.5.3.3 A more recent feeding trial by the Swedish military

The Swedish military conducted an experiment on the edibility of *Bryoria* spp. that is reported by Källman (1988). In the winter of 1985 eight soldiers were left in a taiga forest near the Arctic circle, with temperatures around -40°C , and fed only pine needles and *Bryoria* spp. for nine days while being made to march 130 km. They prepared the lichen by soaking it in sodium carbonate and washing it before cooking. Physiological changes were measured in the bodies of the soldiers to see how effective their food source was. The soldiers each lost an average of 17 pounds, or about 9% of their body weight. Their blood glucose dropped, and the ketones in their urine increased (indicating they were using their body's protein for energy). This experiment indicates that although the soldiers were obviously gaining some nutrients from *Bryoria* spp. which prevented them from starving to death, the lichen by itself was not a sustainable food source under their conditions of extreme physical exertion and cold temperatures.

1.5.5.4 The nutrient value of similar carbohydrates

There are a group of (1 \rightarrow 3)-(1 \rightarrow 4)- β -D-glucans which are found in cereals that are structurally similar to lichenin. Oats and barley contain the highest concentrations of these β -glucans, up to about 16% (Robertson *et al.* 1997), while wheat and rye contain much lower concentrations of less than 1% (Cui *et al.* 2000). These cereal β -glucans have been studied in recent years because of their potential health-promoting properties, and because of their structural similarity they may provide some insights into lichenin.

1.5.5.4.1 Structural similarity between lichenin and cereal β -glucans

Lichenin consists of cellotriose⁴ and cellotetrose⁴ units that are connected by β -(1 \rightarrow 3) bonds (Peat *et al.* 1957; Perlin and Suzuki 1962), with approximately five times as many cellotriose units as cellotetrose units (Wood *et al.* 1994). Cereal β -glucans have a similar structure, but contain relatively more cellotetrose units, as well as a few larger cellodextrins⁴. The ratio of cellotriose to cellotetrose is highest in lichenin (5), followed by wheat (4.5), barley (3), rye (2.5), and then oats (2) (Wood *et al.* 1994; Cui *et al.* 2000). Cereal β -glucans also contain some larger cellodextrins with five to nine glucose moieties, which constitute about 4–9% of the glucan (Cui *et al.* 2000; Lazaridou *et al.* 2000). These have not been reported in lichenin (Peat *et al.* 1957; Perlin and Suzuki 1962).

These structural differences result in lichenin having a slightly higher ratio of (1 \rightarrow 3):(1 \rightarrow 4) bonds than cereal β -glucans, and a more regular structure that contains more cellotriose units. Within the cereal β -glucans, an increase in cellotriose units has been hypothesized to result in poorer solubility and greater gelling properties (Cui *et al.* 2000).

Lichenin is also a smaller molecule than most cereal β -glucans. Lichenin contains 80–120 glucose moieties (Cartar and Record 1939; Meyer *et al.* 1948), while the cereal β -glucans usually contain about 1,000–6,000 glucose moieties (Robertson *et al.* 1997; Cui *et al.* 2000). Within oat β -glucans, a decrease in molecular size has been shown to result in greater gelling properties (Lazaridou *et al.* 2000).

Given the structural similarities of lichenin and cereal β -glucan, it is logical that these two classes of glucans would have similar (but not identical) physical properties. It is also likely the differences in fine structure and molecular size would both result in lichenin being an even better gelling agent than the cereal β -glucans (which are already proficient gelling agents).

⁴ Cellodextrins (cellotriose, cellotetrose, etc.) are linear glucose polymers of varying lengths where each glucose moiety is joined by β -(1 \rightarrow 4) bonds. They are identical to small fragments of cellulose, and are generally produced by cellulolysis (breakdown of cellulose). Cellotriose consists of three glucose moieties joined by two β -(1 \rightarrow 4) bonds, cellotetrose consists of four glucose moieties joined by three β -(1 \rightarrow 4) bonds, etc.

1.5.5.4.2 Value of cereal β -glucans in human health and nutrition

Oat β -glucans have been shown to cause a modest reduction in blood cholesterol in humans (Ripsin *et al.* 1992). This occurs because the oat β -glucans increase excretion of cholesterol in the feces (Lia *et al.* 1995). Barley β -glucans probably have similar properties, because they have been found to cause rats to excrete more cholesterol in their feces (Hecker *et al.* 1998; Kalra and Jood 2001).

Cereal β -glucans have also been found to reduce postprandial glycemia (the spike in blood sugar levels after a meal) by slowing the absorption of sugar into the body (Wood *et al.* 1994; Dubois *et al.* 1995; Hallfrisch *et al.* 1995). However, not all studies confirm this effect of cereal β -glucans on blood cholesterol and blood sugar, as Keogh *et al.* (2003) found no significant effect of barley β -glucans on postprandial glycemia or cholesterol levels (Keogh *et al.* 2003).

Two different mechanisms have been proposed for the ability of cereal β -glucans to reduce cholesterol. Dongowski *et al.* (2002) found that barley β -glucans promoted beneficial lactobacillus bacteria and reduced detrimental bacteria in the lower intestines of rats. They proposed that this improved bacterial community helped with the excretion of cholesterol. Wang *et al.* (1992) proposed an alternative mechanism. They thought that the ability of the cereal β -glucans to form a viscous gel could reduce cholesterol absorption in the intestine.

There has been little research on the potential caloric benefit of cereal β -glucans. Barley β -glucans are fermented in the lower intestine, which produces some short chain fatty acids which can be absorbed and provide readily available energy (Wisker *et al.* 1997). However, the ingestion of these β -glucans has other energetic costs, and Wisker *et al.* (1997) also found that the net caloric benefit of barley β -glucans in the human diet was minimal, and sometimes even negative.

1.5.5.5 The digestibility of isolichenin

The previously discussed *in vitro* digestibility experiments (Section 1.5.5.1 on page 57) all looked at lichenin, and the feeding experiments on lab animals (Section 1.5.5.2 on page 58) and humans (Section 1.5.5.3 on page 60) either used isolated lichenin

or ground *Cetraria islandica*, and virtually all of the carbohydrate in that particular lichen is lichenin. However, many lichens contain substantial amounts of a second type of lichen carbohydrate — isolichenin. Very few experiments have been done on isolichenin.

Hönig and St. Schubert (1887) did an *in vitro* experiment on isolichenin with an amylase (malt diastase), and found that the isolichenin broke down into smaller, dextrin-like molecules, but not into glucose. This experiment was later repeated by Brown (1898) and Karrer *et al.* (1924) with the same results. Brown (1898) also tried using human saliva and pancreatic extract, with an identical outcome.

These dextrin-like molecules produced from isolichenin are short-chain glucans that are probably still indigestible to most vertebrates, given that the *in vitro* tests could not break them down into glucose. It is likely that the amylase was capable of cleaving the isolichenin at some of its α -1-4 bonds, but not at its α -1-3 bonds, which would result in very small chain α -1-3 glucans, with some of them perhaps retaining a few α -1-4 bonds. Amylase would be ineffective against these α -1-3 glucans, and so they would remain undigested.

1.5.5.6 Livestock feeding experiments with lichens

In 1903, a Norwegian researcher conducted experiments on dairy cattle comparing the food value of *Cladina stellaris* and timothy hay, and in 1906 he conducted the same research comparing the lichen to turnips (Isaachsen 1906). The lichen was not utilized by the cattle as well as either of the more traditional foods, but it was found that about 55% of the organic matter of the lichen was digestible. Several feeding experiments conducted on sheep in Sweden a decade latter found that the digestibility of the organic matter in reindeer lichen (*Cladina rangiferina*) was substantially lower. In these experiments, the digestibility of the lichen was found to be 13.5% (Morgan 1916), 16.5% (Kellner 1905), and 23% for old lichen and 35% for young lichen (Honcamp and Blanck 1918).

Jacobj (1916) conducted three feeding trials on pigs. He did not measure the digestibility of the lichen, but found that pigs that were fed 500 g per day of *Cladina* spp. in addition to their regular feed grew 6–36% faster (over about a two week period). The

lichen was first treated by boiling it in ash water. He also found that he could feed rabbits and hares *Evernia prunastri* after he removed the lichen acids.

Presthegge (1954) conducted a series of lichen digestibility experiments on sheep in Norway over six years starting in 1941. He found lichen digestibility to be highly variable between trials, but on average both *Cladina stellaris* and *Cetraria islandica* were 48% digestible. *Flavocetraria nivalis* was much more digestible (74%), but it was also slightly toxic and needed to be treated with alkali. When he fed *Cladina stellaris* to dairy cattle, they produced more milk, but it was of a lower quality. Pigs refused to eat the lichen.

1.5.5.7 Lichen digestion by a ruminant primate

The Yunnan snub-nosed monkey (*Rhinopithecus bieti*) is a species of colobine (a foregut fermenting primate), which has a natural diet of about 75% lichens (Kirkpatrick *et al.* 2001). Kirkpatrick *et al.* (2001) fed five captives of this species differing amounts (16–73%) of lichen (*Bryoria* spp.) for five days, and analyzed the nutrient content and retention time of their feces. The monkeys that were fed the highest percentage of lichen were able to digest the highest percentage of their food — about 80%. The lichen had a mean retention time in their gut of 47 hours.

1.5.5.8 Lichen digestion by ungulates

Several species of ungulate eat lichens as a significant part of their diet (see **Section 1.4.2 Animals that eat lichens** on page 29). These animals are ruminants, and their specialized digestive systems appear to contain microorganisms that allow them to digest lichen carbohydrates. Aagnes *et al.* (1995) examined the rumen bacteria of free-living reindeer that were eating large amounts of *Cladina rangiferina*, and determined that 5.2–12.5% of these bacteria could digest lichenin. Although this indicates that some rumen bacteria are capable of digesting lichenin, they were much less common than one might expect from an animal living off lichen. This is possibly because, unlike many other lichens, most of the carbohydrates in *Cladina* spp. are something other than lichenin or isolichenin (Person *et al.* 1975; Svihus and Holand 2000).

1.5.5.8.1 Digestibility of lichens by lichenivorous ruminants

The hair lichens *Alectoria* spp. and *Bryoria* spp. appear to be the most digestible of the lichens that have been tested. *In vitro* and *in vivo* tests with caribou, black-tailed deer, and mule deer have shown digestibilities of 78–95% (Person 1975; Rochelle 1980; Thomas *et al.* 1984; Robbins 1987; Rominger and Robbins 1996). However, Rochelle (1980) showed that the digestibility of *Alectoria sarmentosa* to black-tailed deer dropped dramatically in the spring, to only 48.2%.

Other digestibility tests have shown that the non-alectorioid forage lichens are less digestible. *Cladina* spp. may only be 43–58% digestible (Person 1975; Person *et al.* 1980; Storeheier *et al.* 2002), but one test has shown *Cladina arbuscula* to be 70% digestible (Storeheier *et al.* 2002), and some *in vivo* tests with mixed forage lichens that were mostly *Cladina* spp. showed the lichens to be 69–81% digestible (Jacobson and Skjenneberg 1975, 1979). *Cetraria islandica* is 50–76% digestible (Person 1975; Person *et al.* 1980; Thomas and Kroeger 1980, 1981; Thomas *et al.* 1984; Storeheier *et al.* 2002). Some authors have reported *Flavocetaria* spp. as being only 36–55% digestible (Thomas and Kroeger 1980, 1981; Thomas *et al.* 1984), but there are other reports of it being 71–82% digestible (Person 1975; Person *et al.* 1980; Storeheier *et al.* 2002). *Stereocaulon* spp. may be the least digestible forage species at only 32–48% digestible (Person 1975; Person *et al.* 1980; Jacobson 1981; Thomas and Kroeger 1981; Thomas *et al.* 1984; Storeheier *et al.* 2002).

A few other lichen species that are not regular forage lichens of caribou in North America have been found to be even less digestible. *Ramalina duriaei* is only 28.7% digestible with cellulase (Hawksworth *et al.* 1984), *Usnea* sp. and *Lobaria* spp. are only 21.5% and 29.2% digestible respectively using caribou rumen fluid (Hanley and McKendrick 1983), and a mixture of *Usnea* sp. and *Evernia mesomorpha* is 43.9% digestible using white-tail deer rumen fluid (Jenks and Leslie 1988).

1.5.5.8.2 Lichen digestion requires extra effort

Although lichens are often highly digestible to lichen-eating ruminants, there is good evidence that fully digesting the lichens requires some extra effort. Many authors have reported that lichens take an exceptionally long time to digest. *In vitro* experiments

have shown that lichens continue to digest in reindeer/caribou rumen fluid for 60–72 hours (Thomas and Kroeger 1981; Thomas *et al.* 1984; Storeheier *et al.* 2002). Person *et al.* (1975) reported rumen retention times of 3–5 days for caribou if they are fed only lichens, and White and Trudell (1980) reported that rumen turn-over time for reindeer more than doubled (from 11 h to 23 h) in the winter when they eat much more lichen, and this increased digestibility of the lichen by 63%. Rochelle (1980) found that *Alectoria sarmentosa* took much longer to digest in black-tailed deer rumen fluid than any other forage. All other forage species were 75–100% digested after 24 hours, while the lichen was only 46% digested after 24 hours, and 91% digested after 36 hours.

Efficient lichen digestion also requires a well-adapted rumen. Rumen fluid from both caribou (Person 1975) and white-tailed deer (Jenks and Leslie 1988) has been found to be better at digesting lichens than cattle rumen fluid. It has also been shown that not even all caribou rumens can handle lichen. A caribou rumen cannot adequately digest lichens unless it has been eating them regularly and its rumen is adjusted to a lichenivorous diet (Trudell *et al.* 1980; Heiskari and Nieminen 1987; Rominger and Robbins 1996). A caribou that is unfamiliar with lichens must be given an adjustment period of at least one month before being made to survive off them (Rominger and Robbins 1996).

1.5.5.8.3 The synergistic properties of lichen in the diet

In a series of *in vitro* experiments using rumen fluid, Rochelle (1980) found that *Alectoria sarmentosa* increased the digestibility of diets consumed by black-tailed deer. Mixed diets that contained various proportions of lichen increased dry matter digestibilities by 6–16% above values expected from combining digestibilities of the component species. The more lichen that was in the diet, the more it increased the digestibility. This synergistic effect probably occurred because the lichen supplied the deer with a large amount of digestible carbohydrate, which then allowed the deer to more effectively process the remaining food (McCullough 1979). Three other feeding experiments using lichen species with significantly less digestible carbohydrates failed to find the same feeding synergy with lichens, using *Usnea* sp. and *Evernia mesomorpha*

with white-tailed deer (Jenks and Leslie 1988), or *Cladina* spp. with caribou (Person 1975; Storeheier *et al.* 2002).

A couple of other interesting feeding synergies have been noticed with lichens. Palo (1993) found that usnic acid, highly toxic lichen secondary compound, makes *Cladina stellaris* and *Stereocaulon paschale* more digestible to reindeer. And White *et al.* (1984) suggested that lichens might inhibit the absorption of certain essential minerals (particularly calcium and magnesium) in the gut of a reindeer. These lichens accomplished this by binding to the minerals and making them biologically inaccessible.

1.5.5.9 Conclusions about the food value of lichens to humans

A review of numerous studies on the digestibility of lichens indicates that most non-ruminant vertebrates gain very little nutritional benefit from eating most lichens. A few species of cyanolichen may be significant sources of protein and essential amino acids, and a few lichen species may be significant sources of some essential minerals and vitamins. However, the majority of lichens are not useful sources of these nutrients.

The main nutrients present in most lichens are carbohydrates, and lichens do not seem to provide significant levels of any carbohydrate that is directly digestible to vertebrates without fermentation. There is no evidence that lichenin is affected by the human digestive system. Human amylases will break apart some of the glycosidic bonds in isolichenin, but they will not fully hydrolyze isolichenin into glucose. As a result, isolichenin can be partially broken down in the human gut, but it is unlikely to be digested. Other lichen carbohydrates have not been tested for digestibility, but are likely even more difficult to digest (Svihus and Holand 2000).

1.5.5.9.1 Possible synergistic effects from eating lichens

It is possible that lichens could still be nutritionally useful to humans even though they may not provide direct nutrients. Sometimes certain foods can effect how our body deals with other nutrients, and thus provide indirect benefits. There are some examples of indirect nutritional benefits in some animals, but there is no evidence that any of these examples could apply to humans.

Some lichen species have been found to increase the digestibility of other forage species in black tailed deer (Rochelle 1980). However, it seems unlikely that the

mechanism behind this would extend to humans. Shimizu (1921b) found that dogs that were fed lichen had improved protein absorption in their guts. The mechanism for this is unknown, and it is possible that lichen ingestion may have a similar effect on humans. Palo (1993) found that usnic acid improved the efficiency of reindeer's digestion, but given the high toxicity of this compound one should probably still avoid eating it.

White *et al.* (1984) found that lichens can inhibit the absorption of certain essential minerals in the gut by binding to them and making them biologically inaccessible. It is possible that this could be useful for dealing with toxic elements in food, but it seems more likely that lichens would be a source of these toxic elements, as this has been well established in multiple cases (Koller and Pöpe 1934; Anonymous 1936; Palmer *et al.* 1963; Airaksinen *et al.* 1986).

1.5.5.9.2 Potential non-caloric health benefits of lichen carbohydrates

Lichenin and isolichenin are not digestible using human-produced enzymes, but they are probably utilized by bacteria in our lower intestine. If these lichen carbohydrates preferentially promote beneficial bacteria (like bifidobacteria and lactobacillus), they may have a significant health benefit as prebiotics⁵.

Bacteria capable of digesting lichenin obviously exist, because they are present in rumen fluid (Aagnes *et al.* 1995). Shimizu (1921c) concluded that bacteria in the lower intestines of mammals are capable of breaking down lichenin, but his evidence was ambiguous. Wisker *et al.* (1997) showed that the human intestinal flora could ferment barley β -glucans, which are structurally similar to lichenin.

⁵ The human intestine supports a diverse community of microorganisms. Our diet, lifestyle, and history affect the composition of this community, and the composition of this community in turn affects our health (Dethlefsen *et al.* 2005). Numerous studies have shown that some carbohydrates that are indigestible to humans will pass through our digestive tract and be digested by bacteria in our lower intestine. These carbohydrates can promote specific, beneficial bacteria (mainly bifidobacteria), and thus improve the microbial community in our gut. These indigestible carbohydrates that promote beneficial bacteria are called prebiotics. Most of the research on prebiotics has been done with inulin, which has been shown to be beneficial to human health by beneficially altering our intestinal microbial community (Roberfroid *et al.* 1998; Kolida *et al.* 2002). This can have many benefits, including helping with calcium absorption (Griffin *et al.* 2002).

Saiki (1906) found that an inulase prepared from *Aspergillus niger* broke down lichenin. Bifidobacteria in our lower intestine are capable of digesting inulin (Roberfroid *et al.* 1998). These bifidobacteria must produce an inulase to digest the inulin, so it is quite possible that they are also capable of digesting lichenin. If this is true, lichenin could easily act as a prebiotic in the same way as inulin. Dongowski *et al.* (2002) found that barley β -glucans (structurally similar to lichenin) act as prebiotics in the lower intestines of rats, which also indicates a possible prebiotic function of lichenin.

Lichenin may have other health benefits as well. The β -glucans present in cereals are similar to lichenin, and have been shown to reduce blood cholesterol (Ripsin *et al.* 1992) and help moderate rapid increases in blood sugar after meals (Hallfrisch *et al.* 1995). These health benefits may be caused by either the prebiotic (Dongowski *et al.* 2002) or gel-forming (Wang *et al.* 1992) properties of these β -glucans. Lichenin is likely to have similar characteristics to the cereal β -glucans in these respects.

1.5.5.9.3 The human insistence on the digestibility of lichens

In 1868, the Royal Patriotic Society of Sweden distributed 4000 free booklets to teach lower-class Swedes how to cook and eat *Cetraria islandica*, *Flavocetraria nivalis*, *Cladina* spp., *Ramalina calicaris*, *Bryoria* spp., and *Usnea* spp. (Andersson 1868). During the famines of World War I, the Finnish and Swedish governments put out numerous pamphlets recommending that their citizens eat lichens (Anonymous 1917b, 1917a; Dannfelt 1917; Lindfors 1917; Nyman 1917). The eleventh edition of the Encyclopædia Britannica (1910-1911) called *Cetraria islandica* “nutritious and easily digested”, and this is still quoted today on Wikipedia (accessed June, 2007).

Despite numerous studies providing empirical data to the contrary, lichens are still widely considered to be digestible to humans (e.g. Ilback and Kallman 1999; Thieret 2004). A few authors do question this assumption (e.g. Moore and Egan 1991), but their opinions are generally not included in popular literature. Llano (1956) reported that he was assisting the military in preparing a survival manual, and intentionally deleted all references to lichens as emergency food. The editors of the manual considered this to be an oversight and “very thoughtfully added the unnecessary data”.

1.5.5.9.4 The toxicity of lichens

The insistence of many authors that lichens are digestible, and therefore a good emergency food, is especially problematic given that numerous feeding experiments on a variety of animals have shown that many lichens are toxic if they are eaten untreated and in quantity. This has been shown for *Cetraria islandica* in mice (Wallerstein 1925; Airaksinen *et al.* 1986) and rats (Airaksinen *et al.* 1986); *Flavocetraria nivalis* in humans (Poulsso 1906) and sheep (Presthegge 1954); *Cladina* spp. in pigs (Jacob 1916; Presthegge 1954) and mice (Airaksinen *et al.* 1986); and *Lasallia pustulata* in mice (Ilback and Kallman 1999). In all cases, the animals either refused to eat the untreated lichen, or if they were forced to eat it they died in days to weeks, or became so ill that the experiment was stopped. In some cases, treating the lichen made it more palatable, but this did not always work. Often, even the treated lichen could not be fed in concentrations greater than 25%.

Further evidence from this can be seen in Sir John Franklin's journals of his first expedition, which lasted from 1819 to 1822 and attempted to map out the Northwest Passage by exploring it over land. His journals (Franklin 1910) document an intriguing lichen feeding experiment that he conducted on his men. By August 18th, 1820, Franklin and his men had reached Turnagain Point on the Kent Peninsula, but had to turn back due to lack of food and bad weather conditions. Over the next three months they walked over 700 km southwest to Fort Providence, which was the closest settlement where they could procure supplies. Franklin forced his men to carry books and other useless equipment instead of food, and refused to let them go hunting. As a result, from September 7th to November 7th, Franklin and his men were trekking across the tundra without food and resorted to eating bits of leather, scraps of carrion, and each other. Despite bitter complaints from his men, Franklin forced them to collect and eat rock tripe every day. He reported severe intestinal upset in some of his men as a result, and his men were dropping like flies from fatigue and starvation.

Chapter 1 Tables and Figures

Table 1.1. Arboreal epiphytic lichen biomass in different ecosystems across the world.

Lichen biomass (kg/ha)	Ecosystem	Researcher
7–10	Montane rainforest in Colombia, South America	(Forman 1975)
11	Higher, harsher areas in Gaspé Provincial Park, PQ	(Arseneau <i>et al.</i> 1997)
47–282	Spruce/fir forest on Cape Breton Island, NS	(Wein and Speer 1975)
564	Old-growth Douglas-fir, OR	(Pike <i>et al.</i> 1972)
754	Oak woodland, coastal CA	(Boucher and Nash 1990)
120–1603	Epiphytic (mostly foliose) lichens on balsam fir in NH	(Lang <i>et al.</i> 1980)
1200	Black spruce forest in SA	(Scotter 1962)
1306	Lower mountain areas in Gaspé Provincial Park, PQ	(Arseneau <i>et al.</i> 1997)
1200–1800	Garry oak forest, OR	(Pike 1971)
2000	Lodgepole pine forest in SA	(Scotter 1962)
282.7–3291	Douglas-fir and spruce/fir forests, Wells Gray Park, BC	(Edwards <i>et al.</i> 1960)

Table 1.2. Total concentration of glucans in various lichen species.

Species	Amount of glucan in lichen (%)			Reference ^c
	Lichenin β -glucan	Isolichenin α -glucan	Total glucan ^a	
Parmeliaceae				
<i>Alectoria</i> spp.			44	[1]
<i>Alectoria ochroleuca</i>			33.8–45.6	[2, 3]
<i>Alectoria sarmentosa</i>	15	1.7		[4]
<i>Alectoria sulcata</i>	15	9.2		[4]
<i>Bryoria</i> spp.	Present	Present	17.5–35.7	[5-7]
<i>Evernia prunastri</i>	0.6	8		[4, 8]
<i>Letharia vulpina</i>	9	4		[9]
<i>Usnea</i> sp.	5.5			[9]
<i>Usnea longissima</i>			46.3	[10]
<i>Usnea orientalis</i>			50	[10]
<i>Usnea rubrotincta</i>	11.4			[11]
<i>Usnea stirtoniana</i>			36	[10]
<i>Neuropogon aurantiacoater</i>	27	3.7		[12]
<i>Cetraria islandica</i>	0.6–9.5	0.05–0.55	26–51	[2, 3, 13-16]
<i>Flavocetraria nivalis</i>			17.3–18.8	[2, 3]
<i>Masonhalea richardsonii</i>	Present	Present		[17]
<i>Everniastrum cirrhata</i>			22.5	[10]
<i>Flavoparmelia caperata</i>		3		[4, 17, 18]
<i>Parmelina quercina</i>			25	[10]
<i>Parmotrema tinctorum</i>			25	[10]
<i>Rimelia cetratum</i>	2.2			[19]
Ramalinaceae				
<i>Ramalina australiensis</i>		2		[20]
<i>Ramalina celastri</i>		26		[21]
<i>Ramalina sinensis</i>			52	[10]
Cladoniaceae				
<i>Cladina</i> sp.			None	[2, 22]
<i>Cladina confusa</i>		0.3		[23]
<i>Cladina mitis</i>		Present		[11]
<i>Cladina rangiferina</i>		0.5	30	[11, 24]
<i>Cladina stellaris</i>		0.1		[23]
<i>Cladonia amaurocraea</i>	4 ^b			[23]
<i>Cladonia crispata</i>		0.6		[11]
<i>Cladonia squamosa</i>		0.3		[11]
<i>Cladonia gracilis</i>			30	[24]
<i>Pilophoron ocicularis</i>		5		[17]

Table 1.2 cont'ed. Total concentration of glucans in various lichen species.

Species	Amount of glucan in lichen (%)			Reference ^c
	Lichenin β -glucan	Isolichenin α -glucan	Total glucan ^a	
Stereocaulaceae				
<i>Stereocaulon exutum</i>		5.4		[25]
<i>Stereocaulon japonicum</i>		5.5		[17, 25, 26]
<i>Stereocaulon paschale</i>		0.1	None	[2, 26]
<i>Stereocaulon ramulosum</i>		4.5		[27]
<i>Stereocaulon sorediiferum</i>		1.8		[25]
Umbilicariaceae				
<i>Lasallia papulosa</i>	32 ^b			[31]
<i>Lasallia pensylvanica</i>	19.5 ^b			[30]
<i>Lasallia pustulata</i>	7 ^b		45	[28, 29]
<i>Umbilicaria angulata</i>	7.2 ^b			[32]
<i>Umbilicaria caroliniana</i>	16 ^b			[32]
<i>Umbilicaria esculenta</i>	5.2 ^b			[31]
<i>Umbilicaria muehlenbergii</i>	35 ^b			[9]
<i>Umbilicaria polyphylla</i>	28 ^b			[32]
Other families				
<i>Acrosyphus sphaerophoroides</i>		0.2		[4, 17]
<i>Lobaria isidiosa</i>			15	[24]
<i>Roccella montagnei</i>			15	[10]
<i>Sphaerophorus globosus</i>		1.9		[17]

^a Called "lichenin", but water-soluble carbohydrates not differentiated by author.

^b The β -glucan measured in these studies was the (1 \rightarrow 6)-linked pustulan, not lichenin.

^c References cited:

- | | |
|--|--|
| 1. (Stenberg 1868) | 17. (Yokota <i>et al.</i> 1979) |
| 2. (Svihus and Holand 2000) | 18. (Yokota and Shibata 1978) |
| 3. (Diachkov and Kursanov 1945) | 19. (Corradi da Silvia and Gorin 1990) |
| 4. (Takeda <i>et al.</i> 1972) | 20. (Gorin and Iacomini 1984) |
| 5. (Kirkpatrick <i>et al.</i> 2001) | 21. (Miceno <i>et al.</i> 1991) |
| 6. (Yanovsky and Kingsbury 1938) | 22. (Person <i>et al.</i> 1975) |
| 7. (Common 1991) | 23. (Iacomini <i>et al.</i> 1985) |
| 8. (Hranisavljevic-Jakovljevic <i>et al.</i> 1975) | 24. (Subramanian 1965) |
| 9. (Iacomini <i>et al.</i> 1988) | 25. (Takahashi <i>et al.</i> 1981) |
| 10. (Lal and Rao 1956) | 26. (Hauan and Kjølberg 1971) |
| 11. (Nishikawa <i>et al.</i> 1973) | 27. (Baron <i>et al.</i> 1988) |
| 12. (Baron <i>et al.</i> 1991) | 28. (Källman 1988) |
| 13. (Meyer and Gürtler 1947a) | 29. (Lindberg and McPherson 1954) |
| 14. (Meyer and Gürtler 1947b) | 30. (Nishikawa <i>et al.</i> 1974) |
| 15. (Fleming and Manners 1966) | 31. (Shibata <i>et al.</i> 1968) |
| 16. (Chanda <i>et al.</i> 1957) | 32. (Nishikawa and Ohno 1981) |

Table 1.3. Essential nutrients in lichens compared to nutrient requirements for a person.

Nutrient	DRI ^a for adults	Concentration in lichen (ppm) ^b	Lichen needed for DRI ^d	References ^c
Calcium (Ca)	1000 mg	(48) 500–17300	58–2000 g	[1-10]
Phosphorus (P)	700 mg	100–6100	115–7000 g	[1-10]
Iron (Fe)	8–18 mg	56.7–3140	2.5–141 g	[1, 2, 5, 7, 9, 11]
Zinc (Zn)	8–11 mg	6.6–45 (230)	244–1667 g	[2, 5, 7, 9, 11, 12]
Copper (Cu)	900 μ g	0.7–4.4 (80)	205–1286 g	[2, 5, 7, 9, 11, 12]
Retinol (Vit. A)	700–900 μ g	0–1 ^c	800– ∞ g	[13, 14]
Thiamine (B ₁)	1.1–1.2 mg	0.9–1.8	639–1278 g	[1, 13, 14]
Riboflavin (B ₂)	1.1–1.3 mg	0.8–7.5	160–1500 g	[14, 15]
Niacin (B ₃)	14–16 mg	22.8–50.1	299–658 g	[16]
Folate (B ₉)	400 μ g	0.32–3.51	114–1250 g	[16]
Cobalamin (B ₁₂)	2.4 μ g	0–0.035	69– ∞ g	[17, 18]
Choline	425–550 mg	300–6300	77–1625 g	[1, 7, 14, 19]
Ascorbic acid (C)	75–90 mg	27–7500	11–3056 g	[13, 17, 20-24]
Ergosterol (D ₂)	5 μ g	0–212	0.02– ∞ g	[17, 21]
Tocopherol (E)	15 mg	0–134	112– ∞ g	[13, 24-27]

^a Dietary Reference Intake: amount of nutrient required to meet the needs of most individuals. Values from the Institute of Medicine (1997; 1998; 2000; 2001).

^b Range of values reported by different authors for a variety lichen species collected from different seasons, locations, and substrates. Numbers in parentheses are values that substantially differ from other investigators, and may represent a measurement error.

^c Approximated as Retinol Activity Equivalence (RAE), carotenoids converted to RAE according to Rodriguez-Amaya (2001).

^d Grams of lichen dry weight required per day to meet DRI for an average adult. Range of values represents variation in nutrient content for different lichens.

^e References cited:

1. (Lal and Rao 1956)
2. (Prussia and Killingbeck 1991)
3. (Scotter 1972)
4. (Scotter 1965)
5. (Hanley and McKendrick 1983)
6. (Pulliainen 1971)
7. (Airaksinen *et al.* 1986)
8. (Beeson *et al.* 1972)
9. (Bhattarai *et al.* 1999)
10. (Storeheier *et al.* 2002)
11. (Scotter and Miltimore 1973)
12. (Kaznovskii 1969)
13. (Ellis *et al.* 1933)
14. (Gustafson 1954)
15. (Barberie 1946)
16. (Sjöström and Ericson 1953)
17. (DaSilva and Jensen 1971)
18. (Lindberg 1955)
19. (Bourne and Allen 1935)
20. (Blix and Rydin 1932)
21. (DaSilva and Englund 1974)
22. (Murty and Subramanian 1959d)
23. (Eidlitz 1969)
24. (Murty and Subramanian 1959b)
25. (Murty and Subramanian 1959a)
26. (Murty and Subramanian 1959c)
27. (Czeczuga 1988)

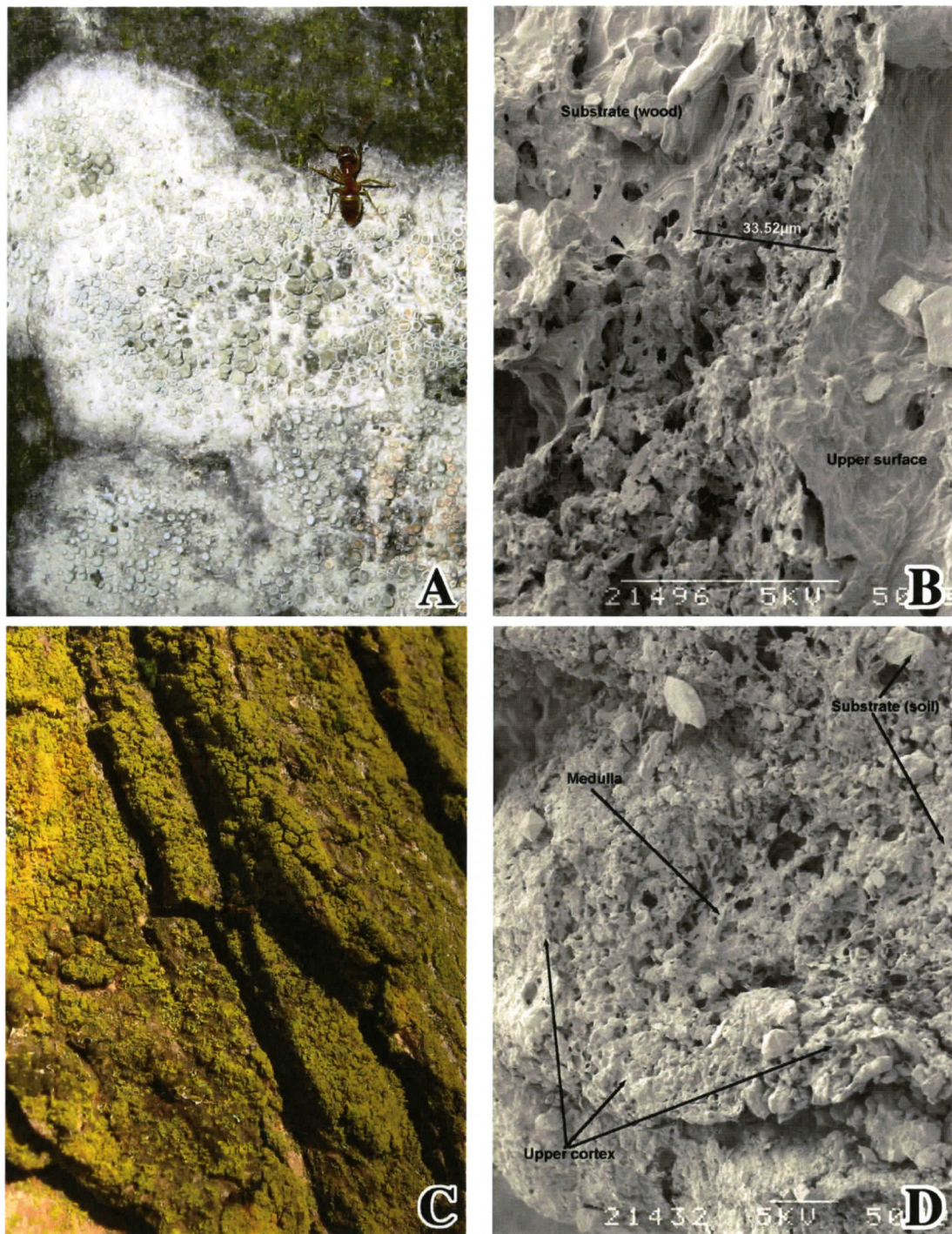


Figure 1.1. Crustose lichens: **A.** Crustose lichen growing on tree at UBC campus, Vancouver, BC; **B.** Scanning Electron Microscopy (SEM) cross-section showing lack of internal structure in crustose lichen *Icmadophila ericetorem* growing on wood; **C.** Crustose lichen on tree in west end of Vancouver; **D.** SEM cross-section showing upper cortex of crustose lichen *Diploschistes scruposus* growing on soil. (Photographs by M. Shannon, micrographs by S. Crawford.)

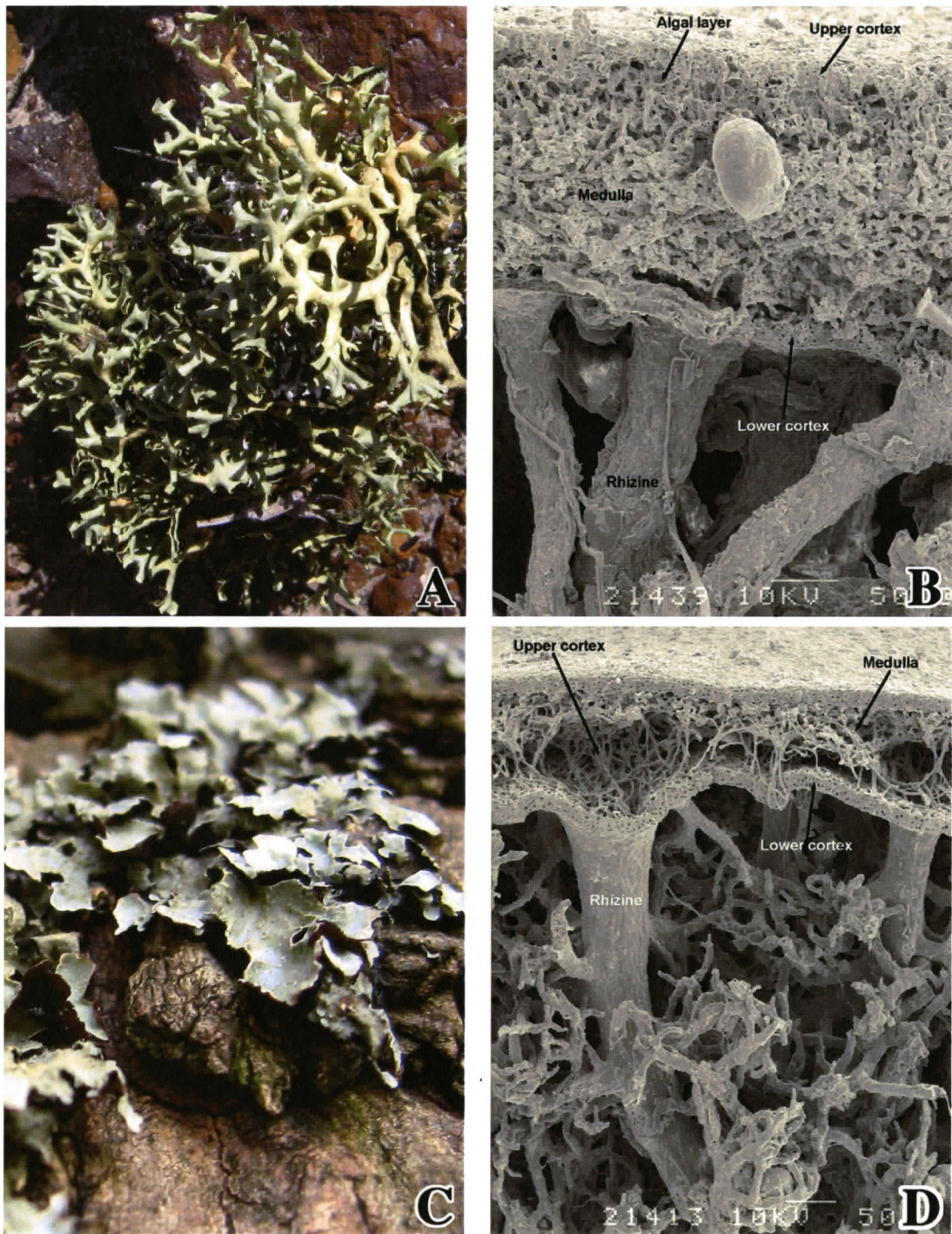


Figure 1.2. Foliose lichens. **A.** *Xanthoparmelia chlorochroa* growing on soil in Drumheller, AB; **B.** SEM cross-section of *Xanthoparmelia chlorochroa* showing upper and lower cortex, and rhizines; **C.** *Parmelia sulcata* growing on tree at UBC campus; **D.** SEM cross-section of *Parmelia sulcata* showing similar structures. (Photographs by M. Shannon, micrographs by S. Crawford.)

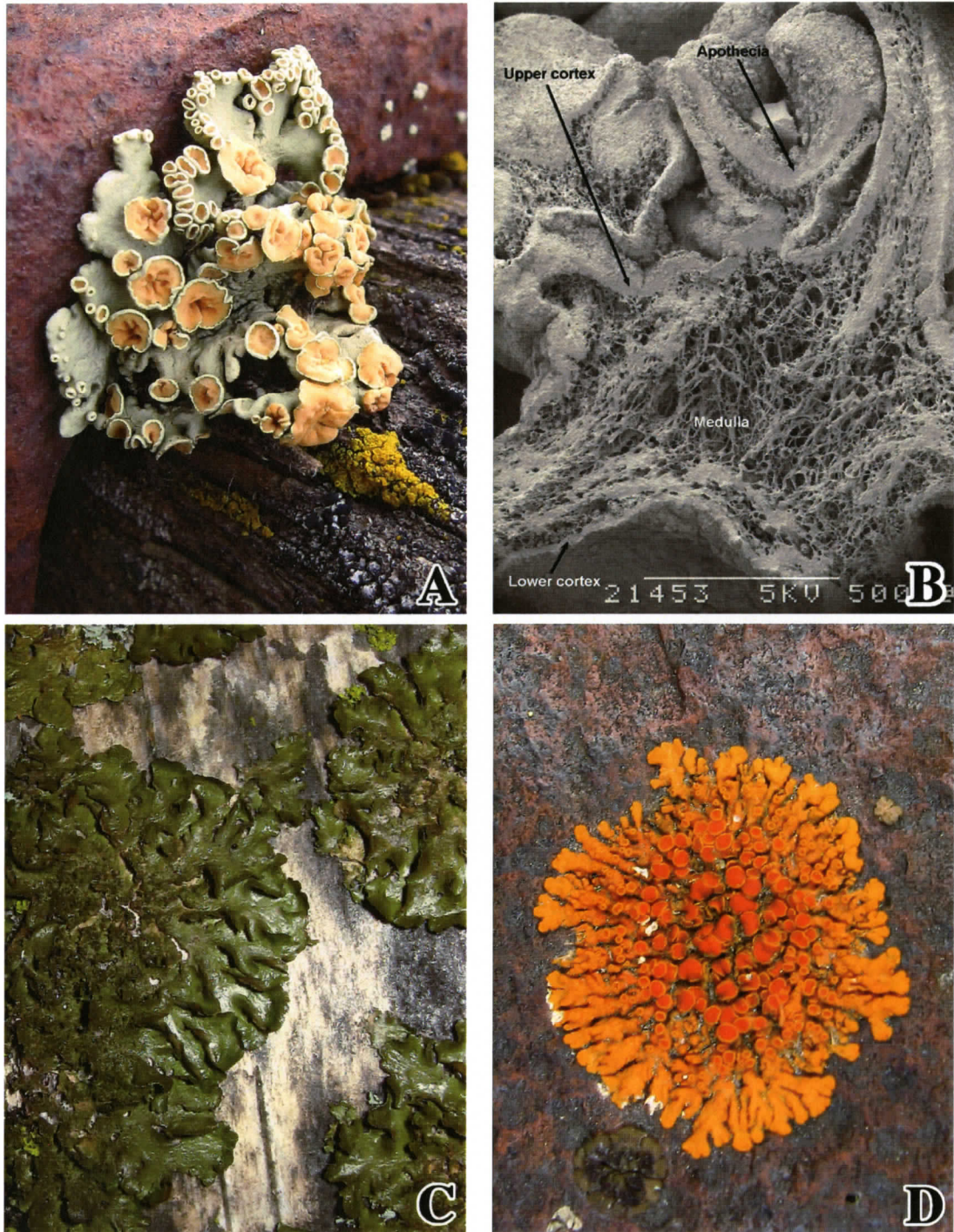


Figure 1.3. Foliose lichens: **A.** *Rhizoplaca chrysoleuca* growing on coal car in East Coulee, AB; **B.** SEM cross-section of *Rhizoplaca chrysoleuca* showing upper and lower cortex. **C.** *Melanelia* sp. growing on tree at UBC campus; **D.** *Xanthoria elegans* growing on coal car in East Coulee, AB. (Photographs by M. Shannon, micrographs by S. Crawford.)

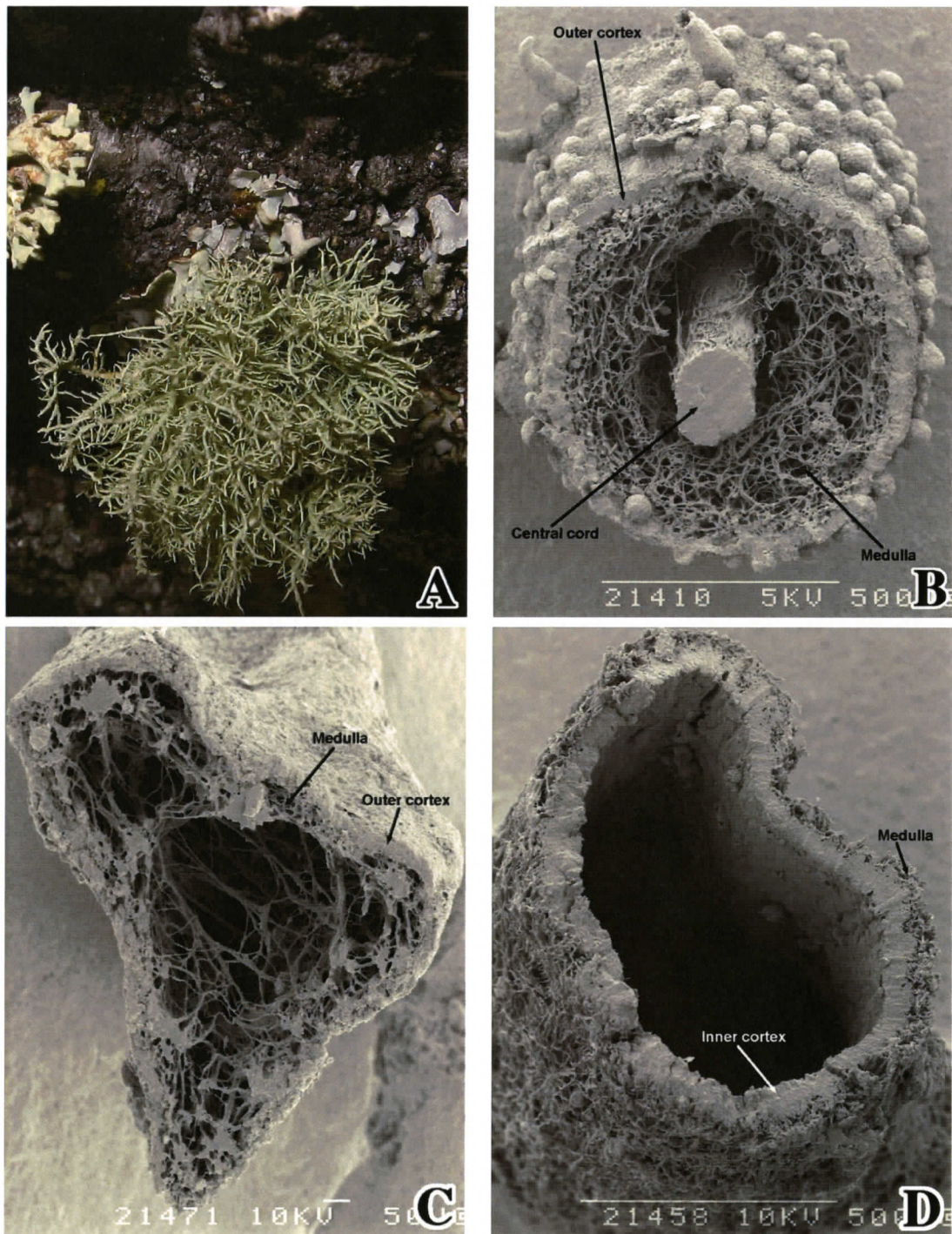


Figure 1.4. Fruticose lichens: **A.** Shubby fruticose lichen *Usnea* sp. growing on tree at UBC campus; **B.** SEM cross-section of hair fruticose lichen *Usnea* sp. showing radial symmetry and central cord; **C.** SEM cross-section of hair fruticose lichen *Alectoria imshangii* showing radial symmetry and outer cortex; **D.** SEM cross-section of shubby fruticose lichen *Cladina mitis* showing radial symmetry and stereome (inner cortex). (Photographs by M. Shannon, micrographs by S. Crawford.)

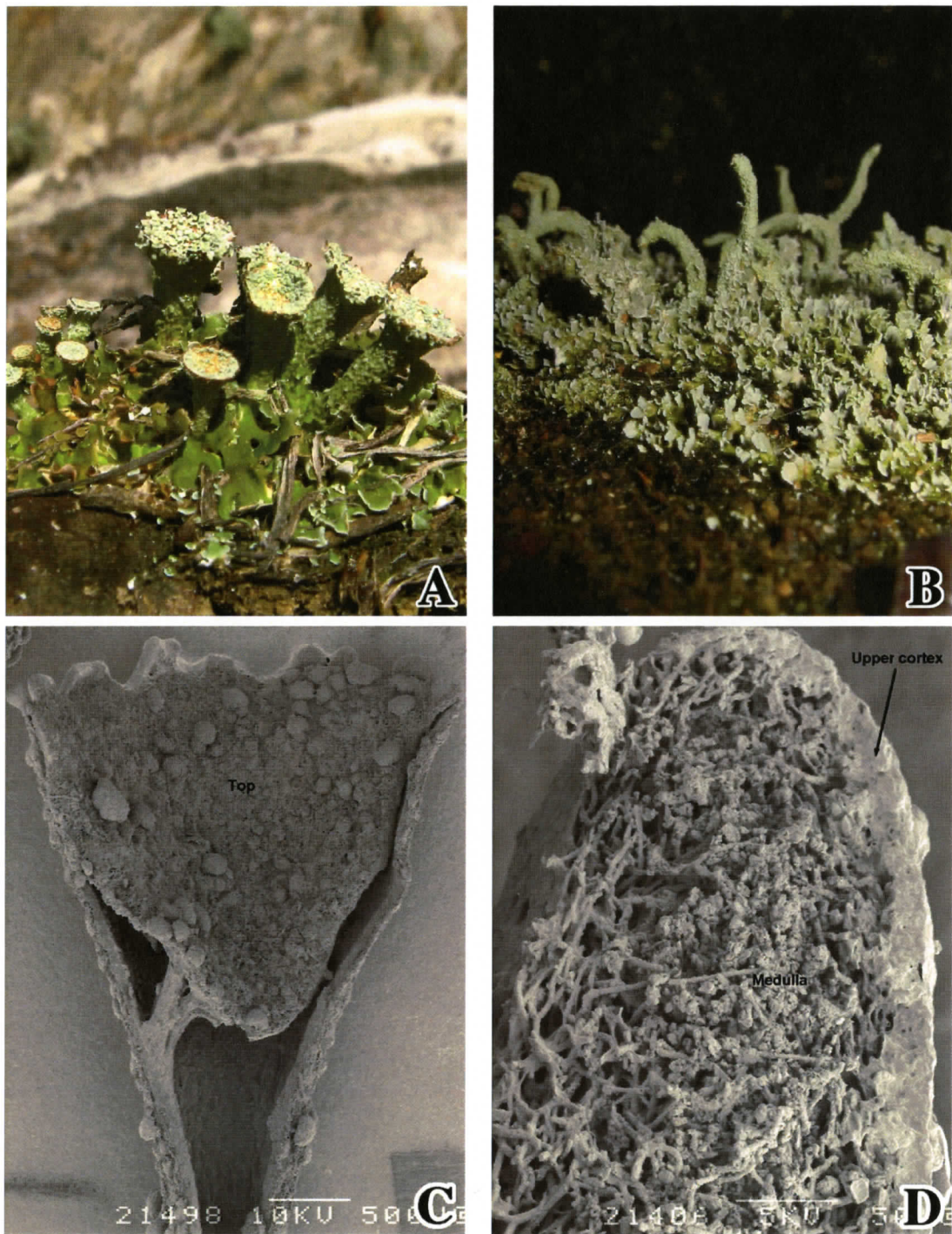


Figure 1.5. Fruticose lichens: **A.** Cup fruticose lichen *Cladonia pyxidata* showing fruticose podetia and squamulose primary thallus, on soil in Drumheller, AB; **B.** Club fruticose lichen *Cladonia* sp. growing on cedar fence at UBC campus; **C.** SEM longitudinal-section of podetia of cup fruticose lichen *C. pyxidata* showing stereome; **D.** SEM cross-section of squamulose primary thallus of *C. pyxidata* showing upper cortex and no lower cortex. (Photograph by M. Shannon, micrographs by S. Crawford.)

Chapter 2 Ethnolichenology, ecology, and chemistry of wila (*Bryoria fremontii*)

2.1 Abstract

The ethnographic literature on the traditional use of *Bryoria fremontii* is reviewed. This lichen is an important traditional food throughout most of its range in North America, although it may not be as culturally significant in southern Oregon and California, or in coastal areas. There is specific traditional knowledge relating to the harvesting and preparation of this lichen. People choose the correct lichen using clues such as colour, location, and tree species. The lichen is always thoroughly washed to remove unwanted detritus and bitterness, and usually pitcooked for at least half a day along with root vegetables. Many accounts stress the importance of proper washing and cooking. The cooked lichen is gelatinous, and either eaten fresh or dried and stored.

A variety of species of *Bryoria* coexist within the range of *Bryoria fremontii*, including many species that look very similar but are bitter and/or toxic. These include *Bryoria tortuosa*, which contains toxic levels of vulpinic acid, and numerous other species that contain other, mildly toxic secondary compounds. This makes proper species selection essential. The taxonomy of *Bryoria* species has been quite confused until recently, making it difficult to determine which species is being discussed in ethnographic literature. Although numerous *Bryoria* species coexist, many have different habitat preferences that seem mainly to correlate with the level of ventilation in their environment.

Although *Bryoria fremontii* contains small amounts of proteins, minerals, and vitamins, these are not present in high enough quantities to be nutritionally significant. *Bryoria fremontii* probably contains significant amounts of lichenin and small amounts of isolichenin. However, neither of these carbohydrates are digestible to humans without being hydrolyzed.

2.2 An overview of the traditional use of *Bryoria* species

The most important *Bryoria* species for human use is *Bryoria fremontii*, and its main traditional use is for food. Other species of *Bryoria* are used to a much lesser extent, and are often used for purposes other than eating. Ethnographic accounts usually do not record what species of *Bryoria* is being used, so one can only infer that it is likely *Bryoria fremontii*. It is therefore possible that the lichen being referred to in these accounts may include other species of *Bryoria*.

Bryoria fremontii has had a variety of inconsistently applied scientific names (see **Section 2.3.3.1** on page 112) and has been given several different English names, none of which are particularly popular or appropriate (including black moss, black tree lichen, and edible horsehair lichen). Numerous First Peoples across western North America have much more felicitous names for this lichen (see **Table 2.1**), and the Secwepemctsin name for this lichen, *wila*, will be adopted for this document.

Prior to this report, the use of *wila* (*Bryoria fremontii*) in North America was most comprehensively reviewed by Turner (1977). Several other authors in ethnobotany and/or lichenology have also reviewed the use of *wila* for food in North America, with varying degrees of completeness (Smith 1921; Richardson 1975; Sharnoff 1984; Kuhnlein and Turner 1991; Moore and Egan 1991; Turner 1997; Brodo *et al.* 2001; Upreti 2001; Ohmura 2003; Thieret 2004).

2.2.1 Geographical extent of the traditional use of *wila* in North America

Wila is traditionally eaten over most of its range in the interior of British Columbia, Washington, and northern Oregon, as well as in parts of Idaho and Montana. See **Table 2.1** and **Figure 2.1** for more details. This area includes many different cultures, most of which belong to the Plateau culture area (as defined by Driver 1964). I have not found records of Shoshoni cultures in southern Oregon and Idaho utilizing this resource, although the lichen is present within their traditional territory.

A few groups of people in northern California and southern Oregon did use *wila* for food, but in these areas it was probably only used during times of famine. The Inland Dena'ina of Alaska also traditionally use a species of *Bryoria* as a famine food. Krog (1968) lists *Bryoria fremontii* as being collected from the Kenai Peninsula close to the

territory of the Inland Dena'ina. However, the range of *Bryoria fremontii* as defined by Brodo and Hawksworth (1977) and Brodo *et al.* (2001) does not extend into Alaska, so it is likely that Krog's (1968) range for the lichen is incorrect, and based on a misidentification resulting from the taxonomic uncertainty surrounding *Bryoria* species in the pre- Brodo and Hawksworth (1977) era.

The use of wila for food is a practice noticeably absent from most coastal First Peoples' cultures. Some exceptions to this might be found in the Tsimshian, Halkomelem (Upper Sto:lo), Coast Salish of Vancouver Island, and Twana, but the veracity of some of these accounts is questionable.

Turner's (1977) interpretation of Mayne (1862) and Boas and Tate (1916), which is subsequently cited by Kuhnlein and Turner (1991), concludes that the Tsimshian may have traditionally used some species of *Bryoria* for food, but this seems unlikely, as both original references are questionable and *Bryoria fremontii* is not found in significant quantities within Tsimshian territory.

The "wet moss" (which Turner [1977] interprets to be a species of *Bryoria*) that is placed into a pit-cook along with fern roots in a Tsimshian story recorded by Boas and Tate (1916) is more likely actually moss, and it was probably merely used to line the pit, and was not eaten. Mayne (1862: pg 256) does write that indigenous peoples of coastal British Columbia cooked and ate a species of *Bryoria*, but he does not specify the nation to which he is referring. Although there does appear to be evidence for the food use of wila among coastal First Peoples, Mayne (1862) seems unable to differentiate between different cultures, often does not appear to be writing from first-hand experience, and paints such a generalized picture of First Nations in British Columbia that the ethnographic value of his writing is questionable.

Turner and Thompson (2006) report that a species of *Bryoria* may be called *whyelkine* in Tsimshian, which could imply some use for the lichen. However, this information likely originally comes from Mayne (1862: pg. 301), who was actually referring to either the Nlaka'pmx, Secwepemc, or Okanagan, none of which call the lichen by that name.

Duff (1952) claims that the Halkomelem boiled wila and dried it into cakes to make "moss bread", but the example he gives is actually from Nlaka'pmx territory.

Turner and Bell (1971) record that the Coast Salish on Vancouver Island may have eaten a species of *Bryoria*, but this is not corroborated with any other accounts. Wila is, however, traditionally pitcooked and eaten by the Skokomish (Twana), as was reported to S. Crawford by Subiyay (Bruce Miller), a Skokomish elder (pers. comm. 2003).

2.2.2 Importance of wila to First Peoples in North America

The importance of wila as a food source was often discounted by Europeans. Blankinship (1905) noted that wila was eaten in Montana, but that it was “neither palatable nor nutritious”. When Father de Smet (1847) encountered the Lower Ktunaxa eating wila, he commented that it was “...a most miserable food, which, in a brief space, reduces those who live on it to a pitiable state of emaciation”. Wilkes (1845) contended that the Okanagan were forced to eat wila in the winter because they weren’t good enough at catching fish in the summer.

Other early accounts give slightly more credit to the lichen, while still being skeptical of its significance and culinary desirability. In 1814 Franchère encountered some Coville Okanagan who were reduced to surviving off wila. Franchère (1820) writes [translated] “I had the curiosity to taste some of this bread and thought I had put a piece of soap in my mouth. However, people who had eaten this paste told me that it is quite good when cooked a while and taken with meat.” Harmon (1800-1816a; 1800-1816b) writes that “This substance is not very palatable; and it contains but little nourishment. It will, however, barely support life, for a considerable time.” According to Morice (1894), among the Dakelh the lichen “...is eaten but not prized. Claimed to be very sweet and savory when prepared like this [mixed with dough and baked].”

In 1808, David Thompson came to a camp of Lake Okanagan and Ktunaxa, and in his journal he notes the importance of wila to them: “the whole of their livelihood small Carp & a kind of Bread made of Moss from the Trees, of a lightly bitter insipid Taste” (Thompson 1784-1812a). Thompson further writes that they “received us very civilly & of such as they had they gave us to eat - Moss Bread & dried Carp”, but he was not particularly impressed with the lichen, because the next day he confides that “The Moss Bread we have traded is very dirty, & scarcely eatable at all, hungry as we are, & gives the Belly Ache.” Thompson’s opinion of this food improves two days later when he

trades with another group of Lake Okanagan for "...some Moss Bread, far superior to that made by Kootanaes and Lake Indians and very cleanly" (Thompson 1784-1812a), which he then devours with "a keen appetite" (Thompson 1784-1812b, 1784-1812c). Despite this, Thompson remains somewhat disparaging of the lichen in his narrative, writing that the lichen is "of a slightly bitter taste, but acceptable to the hungry, and in hard times, of great service to the Indians. I never could relish it, it has just nourishment enough to keep a person alive" (Thompson 1784-1812b, 1784-1812c).

Other authors have had a higher appreciation for this lichen. According to Teit, *wila* was both "much eaten, particularly by the lower division" [of the Nlaka'pmx] (1900) and "much used by both divisions of the [St'at'imc] tribe" (1906), while "a good deal of black moss ... was eaten" [by the Secwepemc] (1909). Teit (1928) also writes that the lichen was "much used long ago" by the Schitsu'umsh, and he lists it as a principal food of the Okanagan and Flathead as well. Several of Turner's (1977) consultants in British Columbia and Washington described the lichen as tasting like candy (especially when cooked with onions or saskatoon berry juice), and Turner (1977; 1978) says that bread made from *wila* is a good sustainer on long trips.

Dawson (1891) records that the lichen is "said to taste very sweet" [by the Secwepemc]. Aimee August, a Secwepemc elder, says that "It's very very good, but it doesn't look good; when you eat it, don't look at it!", but other Secwepemc elders have varying opinions and some don't like it (Turner 1998b).

Turney-High (1937) says that *wila* "is considered [by the Flathead] an excellent condiment to be used with camas. ... some twenty-five pounds of the light stuff being considered essential for a very small family." Both Stubbs (1966) and Hart (1976) note that this lichen is considered a luxury food by the Flathead.

According to L. V. McWhorter (Old Wolf) (*in* Mourning Dove 1933), "Palatable and nutritious when cooked, it [*wila*] is considered a delicacy by the [Okanagan] Indians." Ray (1932) records that among the Sanpoil-Nespelem Okanagan the lichen was an important food product and "...was one to the best liked of all vegetable preparations. The lichen is said to have sweetened the concoction" [of wild onion and/or camas]. Spier (1938) says that "when sugared it is delicious", referring to the modern Sinkaietk Okanagan practice of adding sugar to the cooked lichen.

The prominence of wila in different Interior Salish cultures also attests to its importance. Wila is featured in beliefs and stories of the Secwepemc, Okanagan, and Stl'atl'mc. Both the Secwepemc and Okanagan have origin stories for wila. A St'at'imc story recorded by Bouchard and Kennedy (1977) shows that wila was a common food, although not liked quite as much as salmon. See **Section 2.2.5 Beliefs and stories about *Bryoria* species** on page 103 for more details on these beliefs.

Another manifestation of the importance of wila is its prominence within the Nlaka'pmx and Okanagan languages. Turner *et al.* (1990) records different Nlaka'pmx names for various aspects of wila and its preparation. The lichen itself is called /wi7e/. An expedition to harvest the lichen is called /ki7/wi7e-me and the act of harvesting itself is /ki7/wi7e or /q'w'=áqs-m [lit. "break(-with-a)-hook"]. The common practice of using a hooked stick to pull down the lichen is /q'y'ú7e-me (from "the stick with a hook") or /lk'"=áqs-m (lit. "hook the nose"). Cleaning the lichen is /xp-ém or /p'ix-e-s and soaking the lichen is íxwem or /q'án'-e-s. As well, at least two locations in Nlaka'pmx territory are named after the fact that wila used to be prepared there (Turner *et al.* 1990).

Turner *et al.* (1980) records a similar phenomenon within the Okanagan language. The lichen itself is called *skwelíp*. The act of gathering the lichen is *xipm*. The stick for collecting the lichen is called *txipmn*, and using this stick to twist the lichen off the branch is *ski7alkwíkstm*. Cleaning the lichen is called *nexwkw'íw'sntm*. There are also at least two places in Okanagan territory named after wila.

Despite the derision of some of the above-mentioned authors towards this lichen, there is abundant evidence that wila did represent an important, and even desirable, food to many people (see **Table 2.1**). Wila was probably a regular food for these people, and it likely became more important during famines because of its availability. Some examples of this could be the Okanagan (Franchère 1820; Anderson 1925; Spier *et al.* 1938) and the Nimi'ipuu (Lewis and Clark 1804-1806; Spinden 1907-1915), both of which are recorded as using the lichen as both a regular food and a famine food.

Other First Peoples probably just used wila as a famine food. Wila (or some other, unidentified species of *Bryoria*) has been classified as a famine food among various groups of people by numerous authors, including the Inland Dena'ina (Kari 1987), Lower Ktunaxa (de Smet 1847), Niitsitapii in western Montana (Johnston 1970;

1982), Klamath (Coville 1897), and Wailaki (Chesnut 1902), as well as unspecified peoples in California, Oregon, and Montana (Uphof 1959). In some cases the lichen may have been a true famine food that was never eaten except in times of extreme hunger (as defined by Turner and Davis 1993), but more often it was likely a secondary food used minimally in normal circumstances and in larger quantities in times of food scarcity.

2.2.3 Harvesting wila for food

2.2.3.1 Where to collect the lichen and how to identify the right type

Many people have commented that the species of tree that the lichen is growing on is important in determining its flavor. There is, however, no consensus between on which species of tree imparts the most desirable flavor. As a result, many different tree species preferences have been recorded.

Turney-High (1937) writes that the Flathead collect the lichen off pine trees. According to Spier (1930), the Ila'xluit collect it off fir trees. Turner (1977) reports that the Nimi'ipuu prefer the lichen if growing on ponderosa pine or western larch. This agrees with Marshall (1977), who records that Nimi'ipuu prefer the lichen from larch, consider the lichen off pine to be acceptable, and view lichen collected off fir to be inedible. Dawson (1891) records that the Secwepemc collected wila off larch, while Palmer (1975) says they like it best from ponderosa pine. Turner (1998b) notes that some Secwepemc prefer the lichen on Douglas-fir in very wet sites.

Northern Okanagan elders who spoke with Turner *et al.* (1980) preferred the lichen from larch, fir, or lodgepole pine, while Sanpoil-Nespelem Okanagan elders interviewed by the same authors liked the lichen from ponderosa pine and thought larch ruined its taste.

Ray (1932) records that the Sinkaietk Okanagan collect the lichen off pine trees, but according to Spier (1938) they prefer the lichen off fir and larch, because pine trees will give the lichen an unpleasant, pitchy flavour unless the branches are dead. Turner (1977; 1978) reports that the St'at'imc also like lichen off Douglas-fir or western larch instead of pine.

Hunn (pers. comm. 2005) recorded that the Columbia River Sahaptin collected the lichen from a variety of trees, including ponderosa pine, lodgepole pine, mountain mahogany, and western juniper, with the juniper being the preferred tree simply because its smaller size makes it easier to harvest.

Sometimes environmental variables besides tree species were used to identify good lichen. The Okanagan prefer lichen off older trees, claiming that the lichen on younger trees is bitter (Turner 1977; Turner *et al.* 1980). According to the Nimi'ipuu wila tastes different depending on where it is growing, with lichen collected by river being much inferior to the delectable flavor of lichen growing at high altitudes in the mountains (Marshall 1977: 59; Turner 1977). Dawson (1891) also implies that the Secwepemc preferred lichen higher up mountains.

Turner *et al.* (1990) doesn't record any correlates that the Nlaka'pmx associated with tasty lichen, but they do note that specific places in Nlaka'pmx territory are known to be good places to collect wila, like above Spuzzum Creek, on Anderson Mountain, and at Botanie Valley. The Secwepemc also don't collect wila from just anywhere, but rather have specific places that are known to be good, like the top of the switchback road above Neskonlith Lake (Turner 1998b) and the area known as "Last Chance" (Kennedy and Bouchard 1996).

Some people will determine whether a lichen is good to eat by an investigation of the lichen itself. Turney-High (1937) reports that the Flathead allow the lichen to blacken on the tree before it is considered mature enough to harvest. While *Bryoria* species may not actually darken with age, different species are different shades of black and choosing darker lichen may be a good algorithm for selecting *Bryoria fremontii* over other *Bryoria* species like *B. capillaris* that are lighter in colour. Columbia River Sahaptin have a similar visual preference, and don't use the greenish, finer lichen for food, and instead use it as a medicine (Hunn, pers. comm. 2005).

Aimee August, a Secwepemc elder, describes another *Bryoria* species in an interview with Bouchard and Kennedy (recorded in: Turner 1998b). This lichen is called *tqwesimáka7*, and she describes it as "...black and pretty much the same as *wíla*, but finer. It hangs down as much as two feet, like *wíla*, but they grow in birch or any tree, but not cottonwood. It grows from the damp and fog, in damp places." She also noted

that wila is mostly found on fir trees, whereas *tqwesimáka7* even grows on birch, willows, around the creek where it's damp. *Tqwesimáka7* was good for starting fires, but not for food. *Tqwesimáka7* translates to "moss growing on top of branch" (Ignace, pers. comm. 2005). The description of this lichen sounds very much like *Bryoria pseudofuscescens*, another *Bryoria* species that looks quite similar to *Bryoria fremontii* except for being finer and containing bitter norstictic acid. According to Palmer (1975), *kwesimáka7* refers to *Lobaria* sp. or *Parmelia* sp., but Ignace (pers. comm. 2005) disagrees with this assessment.

Often taste is used to investigate the lichen as well. Among the Okanagan, young hunters would collect small pieces of *Bryoria* from different mountain slopes during their travels and bring them back for their grandmothers or mothers to taste. If the lichen was sweet and not bitter, the family would claim the area where it was growing and collect as much of the lichen as possible from the trees in the vicinity (Turner 1977; Turner *et al.* 1980). Palmer (1975) also records that among the Secwepemc the old people will chew on the lichen to see if it tastes good before it is harvested.

Chamberlain (1892) identifies the tree lichen that is pitcooked by the Ktunaxa as *Letharia vulpina*, while others have identified it as a species of *Bryoria* (Thompson 1784-1812b; de Smet 1847; Hart 1974; Keddie 1988). This could indicate that the two lichens were used interchangeably, but this seems very odd given the high toxicity of *Letharia vulpina* and the vastly different appearances of the two lichens (*Letharia vulpina* is bright yellow). It is more likely that Chamberlain is mistaken.

2.2.3.2 When to collect the lichen

The general consensus is that it doesn't matter when you collect wila, it doesn't vary through the seasons. This has been recorded for the Secwepemc (Dawson 1891; Turner 1998), Nlaka'pmx (Turner *et al.* 1990), Okanagan (Turner *et al.* 1980), Sanpoil-Nespelem (Ray 1932), Sinkaietk (Spier *et al.* 1938), and Ila'xluit (Spier and Sapir 1930). However, for logistical reasons the Secwepemc (Turner 1998), Nlaka'pmx (Turner *et al.* 1990), Okanagan (Turner *et al.* 1980), Sinkaietk (Spier *et al.* 1938), and Ila'xluit (Spier and Sapir 1930) would generally harvest the lichen in the fall after work with other foods is completed. The Flathead may be a bit earlier than most, because Turney-High (1937)

records that they gather the lichen in July. This may correspond to their camas harvest, because Turney-High (1937) also records that the Flathead considered wila to be a necessary condiment when pitcooking camas.

2.2.3.3 How to collect the lichen

Wila is often collected using a long stick to reach up into the tree, twisting the lichen around the stick, and then pulling it down. The Secwepemc, Nlaka'pmx (Turner *et al.* 1990), and Okanagan (Turner *et al.* 1980) all use this method. The Lakes Okanagan have a hook on the end of the stick to help with this process (Elmendorf 1935-1936), and this may be a common feature elsewhere as well. This process was sometimes recorded as being entirely a woman's job (Secwepemc: Dawson 1891), but according to Turner (1977) whole families, men, women and children, often partook in harvesting.

Sometimes trees would be climbed to collect the lichen. Spier (1938) recorded that the Sinkaietk would send young boys to climb high into the trees to collect the lichen. Columbia River Sahaptin will also climb to get the lichen if it is growing on ponderosa pine (Hunn, pers. comm. 2005).

Another method, which may be more modern in origin, is to just cut down the tree. Turner (1980) noted that the Sanpoil-Nespelem Okanagan cut the trees with power saws and then picked off the lichen. Kennedy and Bouchard (1996) also commented on this practice with the Secwepemc. In these cases, the stick method of harvesting would be used first to sample the lichen to see if it was any good (Turner 1977). In a good area with abundant lichen, cutting down five to six trees would supply enough lichen for an entire family (Turner 1977).

2.2.4 Cooking the lichen

Pitcooking is the standard way to cook wila, and is described in some detail by Turner (1977, 1978). Minor variations of this method are seen among the:

- Dakelh (Kane 1846-48);
- Secwepemc (Dawson 1891; Palmer 1975; Turner 1998b);
- St'at'imc (Turner and Davis 1993);
- Nlaka'pmx (Teit and Boas 1900; Turner *et al.* 1990);

- Okanagan, including the Northern, Sinkaietk, Sanpoil-Nespelem, Lakes, and Coville (Wilkes 1845; Ray 1932; Mourning Dove 1933; Spier *et al.* 1938; Gabriel and White 1954; Turner *et al.* 1980);
- Ktunaxa (de Smet 1847; Chamberlain 1892; Keddie 1988);
- Twana (Subiyay, pers. comm. 2003);
- Schitsu'umsh (Teit and Boas 1928);
- Flathead (Turney-High 1937; Stubbs 1966; Hart 1976);
- Spokane (Douglas 1914);
- Ila'xluit (Spier and Sapir 1930);
- Umatilla, Cayuse, Yakima, and perhaps other Sahaptin along the Columbia River (Hunn, pers. comm. 2005);
- Nimi'ipuu (Marshall 1977; Turner 1977);
- Unspecified peoples along the Columbia River (Harmon 1800-1816a; 1800-1816b; Morse 1822; Parry 1871)

The general process of pitcooking involves washing the lichen very thoroughly and then steaming it underground in a pit heated by large, red-hot rocks. The rocks are heated by a large fire and then placed in the bottom of the pit. The hot rocks may have some sand put on top of them, then a layer of wet vegetation (perhaps moss, fern fronds, skunk cabbage leaves, bark, grass, or conifer needles). The wila is piled on top of the vegetation, usually with layers of root vegetables or other food. The lichen is covered with more wet vegetation, and then some earth. Water is usually added through holes in the covering, and a fire lit on top. The lichen is left to cook for anywhere from overnight to several days: When it is dug up it has formed a black, gelatinous dough about a quarter of its original volume that can be eaten fresh or dried into cakes to store for future use.

2.2.4.1 Importance of proper cooking

Several accounts stress the importance of proper cooking. Franchère's (1820) comment that the lichen tasted like soap, but could be quite good if cooked right, as well as Morice's (1894) comment that the lichen could be "sweet and savory" if prepared right both highlight the importance of cooking. Thompson notes that the first lichen bread he

eats is “scarcely eatable at all”, but several days later trades for some new lichen bread from a different group of Lake Okanagan which is “well made” that he devours “with a keen appetite” (Thompson 1784-1812a, 1784-1812b, 1784-1812c).

According to Spier (1938) the Sinkaietk might eat the lichen raw, but then it was very bitter and turned your saliva green. Because of this it was probably only eaten raw in a famine when people were too weak to boil it (Spier *et al.* 1938). This may also illustrate the importance of washing the lichen, which could remove the yellow (often described as green) and bitter toxin vulpinic acid. Both the Secwepemc (Turner and Davis 1993) and Okanagan (Turner *et al.* 1980) would also only eat the lichen raw in times of famine, otherwise it would be washed and cooked first to make it palatable.

Several contemporary wila experts (Turner’s (1977; Turner *et al.* 1990) maintain that slow cooking in an earth oven is essential for making the lichen edible, and that trying to cook the lichen quickly in a pressure cooker does not work. Turney-High (1937) reports that the lichen was only a good food when cooked properly with camas, and when it was baked by itself it was considered more of a tonic for the sick than a food.

2.2.4.2 The cleaning of the lichen

The lichen was usually cleaned very thoroughly before being cooked. The lichen would first be cleaned by removing twigs, dirt, other lichens, sap, etc. by hand. It would then soaked several hours to overnight in water, often in running water like a creek. It would sometimes be worked by hand, or pounded with a paddle-shaped tool while being soaked. Authors have reported on the importance of this washing among the Dakelh (Morice 1894), Ila’xluit (Spier and Sapir 1930), Secwepemc (Dawson 1891), Nlaka’pmx (Turner *et al.* 1990), Flathead (Stubbs 1966; Hart 1976), Ktunaxa (de Smet 1847), Okanagan (Thompson 1784-1812b, 1784-1812c; Wilkes 1845; Turner *et al.* 1980), Spokane (Douglas 1914), and the Umatila, Cayuse, and Yakima Sahaptin (Hunn, pers. comm. 2005).

Annie York, a Nlaka’pmx elder interviewed by Turner *et al.* (1990), gave a thorough description of the process and necessity of washing the lichen.

They have it in bags... And then they clean it like this [taking all the sticks and debris out]...and then they put it into the creek. And you leave it in the creek... you have to

soak it good. And then you take it, you get this nice smooth rock, and then you hit it like this [beating it with a stick] and the green stuff goes out like this. That's what makes it bitter, if you don't do it. ...You keep turning it and hitting it and the green stuff just comes out of it... Then they take it and wash it several times.

Morice (1894) comments that "It is thoroughly washed [by the Dakelh] until it loses its outer colouring matter." Turner *et al.* (1980) also stress the importance of washing the lichen among the Okanagan. The lichen is washed repeatedly in cold water while working it with the hands. Thompson writes that the lichen is washed and beaten before being baked (Thompson 1784-1812b, 1784-1812c), and seems to attribute this cleanliness to the tastiness of the finished product, commenting that the dirty lichen cakes they try first were bitter, insipid, scarcely edible, and gave his men belly aches (Thompson 1784-1812a), while the clean lichen cakes he tries later were "by far the best we had had" (Thompson 1784-1812b, 1784-1812c).

The Secwepemc have a specific word for cleaning wila — they call this process *kálka*. The wila is carefully cleaned of twigs and other inedibles and then soaked and kneaded in fresh water to get rid of the bitter tasting compounds (Turner 1998b).

One anomaly to this practice may be among the Sanpoil-Nespelem Okanagan, for Ray (1932) reports that extraneous matter was picked out of the lichen, but it was not washed or soaked.

2.2.4.3 Building the oven to cook the lichen

The pit that is dug for cooking wila would generally be quite large. Some reported sizes for the pit are 300 cm square and 60 cm deep (Secwepemc: Dawson 1891); 300 to 370 cm in diameter and 90 cm deep (Sinkaietk Okanagan: Spier *et al.* 1938); 150 cm by 300 cm and 120 cm deep (Lakes Okanagan: Elmendorf 1935-1936), 120 cm by 180 cm and 60 cm deep (Flathead: Stubbs 1966), and 75 cm in diameter and 75 cm deep (Sanpoil-Nespelem Okanagan: Turner *et al.* 1980).

The rocks to heat the pit are generally heated by a large fire at the bottom of the pit. There are, however, some variations to this. Both the Secwepemc (Turner 1998b) and Okanagan (Turner *et al.* 1980) may light the fire on logs laid across the opening of the pit. The fire will burn for quite a while with an ample supply of oxygen, and when the logs finally burn through the rocks will fall down into the pit. The Nlaka'pmx

sometimes heat the rocks on a fire outside of the pit, and move them when they are hot enough (Turner *et al.* 1990).

The pit would always be lined with layers of vegetation to prevent dirt from getting into the lichen. Many different plants could be used to line the pit, depending on who was preparing it and where they were. Some different methods and materials for lining the pit that have been reported include:

- In layers on top of the hot rocks: sand, 30 cm of maple and alder boughs, skunk cabbage, sheets of larch bark, lichen and bulbs, boughs and leaves, bark, and then a few inches of sand (Secwepemc: Dawson 1891).
- Wild rosebushes, dogwood, cherry, saskatoon, or fir branches, pine needles, and/or timber grass used to line pit. Lichen put in woven trays of Rocky Mountain maple bark, or wrapped in tule reeds. (Secwepemc: Turner 1998b).
- Line the pit with sod and grasses (Flathead: Turney-High 1937).
- In layers on top of the hot rocks: Five to eight cm of green sticks and leaves, slough grass, camas bulbs, lichen, slough grass, green leaves, dirt (Flathead: Stubbs 1966).
- In layers on top of hot rocks: grass or leaves, lichen, more grass or leaves, dirt (Spokane: Douglas 1914).
- In layers on top of the hot rocks: dirt, conifer boughs (either ponderosa pine or Douglas-fir), lichen, conifer boughs, lichen, conifer boughs (up to four layers), then yellow glacier lily bulbs, conifer boughs, and earth. Sometimes fern fronds used in place of conifer boughs. (Nlaka'pmx: Turner *et al.* 1990).
- In layers on top of the hot rocks: green leaves, grass, lichen, grass, leaves, and a foot of earth (Sinkaietk: Spier *et al.* 1938).
- Line the pit with grass (Dakelh: Kane 1846-48).
- Line the pit with pine needles (Ila'xluit: Spier and Sapir 1930).
- In layers on top of the hot rocks: grass, lichen and roots, grass, bark, then earth (Schitsu'umsh: Teit and Boas 1928).
- In layers on top of the hot rocks: rosebush branches, lichen, rosebush branches, grass, then earth (Okanagan: Gabriel and White 1954).

- In layers on top of the hot rocks: green grass or leaves, green twigs, camas bulbs, lichen, green grass or leaves, tule-reed matting, dirt (Okanagan: Mourning Dove 1933).
- In layers on top of hot rocks: 18 cm dirt and 18 cm vegetation (timothy, quack grass, wild rye grass, bracken fern fronds, bunch grass, bark, pine needles, skunk cabbage leaves, or thimbleberry leaves), then feel for right amount of heat through vegetation with feet. Cotton sacks full of the lichen and root vegetables placed on top and surrounded with alfalfa to sweeten it. Cover with large, open sack or skunk cabbage leaves, then more grass, and ten inches dirt. Before cotton sacks, more vegetation was used instead. (Okanagan: Turner *et al.* 1980).

2.2.4.4 Food that the lichen is cooked with

Almost invariably wila was not pitcooked alone, and other foods would be mixed in with it. The Schitsu'umsh may be the one exception to this practice, as Teit (1928) claims that in previous times they did not mix anything with the lichen while it was being cooked, although at the time he was observing the cooking they would put camas, onions, and other roots in with the lichen.

According to Turney-High (1937), the Flathead never cook either camas or wila by themselves, both of these items are only cooked blended together. The lichen is said to sweeten the mixture, and is considered a necessary condiment for camas.

The Okanagan have also often been recorded to mix other foods with wila while it is being pitcooked. Okanagan often cook the lichen with dried or fresh saskatoon berries, or just with the berry juice (Gabriel and White 1954; Turner 1977; Turner *et al.* 1980), and in recent times, apples or other fruit might be included (Mourning Dove 1933; Turner 1977, 1978; Turner *et al.* 1980). The Okanagan also sometimes add roots of false Soloman's seal (Turner 1977, 1978), blue camas (Mourning Dove 1933; Turner *et al.* 1980), Douglas wild onions (Turner *et al.* 1980), nodding onions (Turner *et al.* 1980), or *Lomatium* spp. (Turner *et al.* 1980) to the lichen. Ray (1932) records that the Sanpoil-Nespelem Okanagan would always cook the lichen with unidentified species of wild onion and camas, or with just the onion alone.

There are many other examples of wila being cooked with other foods. Nlaka'pmx usually cook the lichen with the roots of balsamroot, yellow glacier lily, or nodding onions, or they add saskatoon berries or deer grease (Teit and Boas 1900; Turner *et al.* 1990). The Secwepemc traditionally cook the lichen with bulbs (Dawson 1891), and will sometimes also mix in mashed saskatoon berries, yellow glacier lily bulbs, wild celery, wild onions braided by their leaves, cactus, and all kinds of other foods (Turner 1998b).

The Ila'xluit traditionally mix the lichen with wild onions to cook it (Spier and Sapir 1930), while the Nimi'ipuu use Geyer's onions (Turner 1977). Other First Peoples add nodding onions or blue camas (Turner 1977). Unspecified people in Montana add camas or Douglas onion (Hart 1976). Uphof (1959) notes that wila is cooked with camas. A Twana elder now adds sweet onions and anise to the lichen to cook it (Subiyay, pers. comm. 2003).

Often after the lichen has been cooked, dried, and stored for up to three years, it will be re-cooked again with food plants before it is eaten. See **Section 2.2.4.8 What to do with the cooked lichen** on page 98.

2.2.4.5 Water added to the pit for cooking

Water is usually added to help the lichen steam cook in the pit. Both the Flathead (Turney-High 1937) and Ila'xluit (Spier and Sapir 1930) add this water by thoroughly drenching the vegetation surrounding the lichen with water before it is buried. A more common method is to add the water after the cook pit is covered. This is accomplished by burying one or more large sticks in the pit vertically that go right from the bottom to above ground level. After the pit is completely covered, these sticks are removed, leaving holes going down to the bottom of the pit. Water is poured into these holes and hits the hot rocks at the bottom. This method is used by the Okanagan (Mourning Dove 1933; Spier *et al.* 1938; Gabriel and White 1954; Turner *et al.* 1980), Nlaka'pmx (Teit and Boas 1900; Turner *et al.* 1990), Dakelh (Kane 1846-48), and Secwepemc (Turner 1998b). As always, there may be exceptions to this. Teit (1928) reports that the Schitsu'umsh did not add any water when pitcooking lichen.

2.2.4.6 A fire built on top of the pit

After the pit was covered up and water added, a fire would often be lit on top and kept burning for the duration of the cooking. This helps to keep the pit hot enough to cook the lichen. The practice of starting a fire on top of the pit is seen among the Secwepemc (Dawson 1891; Turner 1998b), Flathead (Turney-High 1937; Stubbs 1966), Nlaka'pmx (Teit and Boas 1900), Okanagan (Mourning Dove 1933; Turner *et al.* 1980), Ktunaxa (Chamberlain 1892), Dakelh (Kane 1846-48), Ila'xluit (Spier and Sapir 1930), and Schitsu'umsh (Teit and Boas 1928).

2.2.4.7 Length of time to cook the lichen

Pitcooking wila was generally an activity that took a substantial length of time. There are reports of this process taking anywhere from twelve hours to four days. Different lengths of time reported in the literature are: One night (Spokane: Douglas 1914); overnight to overnight plus a day (Secwepemc: Dawson 1891); 12 to 24 hours (Sinkaietk: Spier *et al.* 1938); 24 hours (Okanagan: Wilkes 1845; Nlaka'pmx: Turner *et al.* 1990); one to two days (Montana: Hart 1976); one plus days (Umatilla, Cayuse, and Yakima: Hunn, pers. comm. 2005); some days (Ktunaxa: Chamberlain 1892); two days and one night (Sanpoil-Nespelem Okanagan: Turner *et al.* 1980); two days (Schitsu'umsh: Teit and Boas 1928; Ila'xluit: Spier and Sapir 1930; Twana: Subiyay, pers. comm. 2003); two to three days (Sanpoil-Nespelem: Ray 1932); three days (Lakes Okanagan: Elmendorf 1935-1936; Flathead: Stubbs 1966) and three to four days (Okanagan: Mourning Dove 1933). There is one report of this process taking about an hour (Harmon 1800-1816a; 1800-1816b), but he seems to be referring to a very different preparation technique (see **Section 2.2.4.9 Other traditional methods for preparing the lichen for food** on page 100).

2.2.4.8 What to do with the cooked lichen

The cooked lichen can then be cooled and eaten fresh, or dried to store for future use. Sugar is often added to it when it is eaten fresh (Turner 1977), a practice has been recorded for the Okanagan (Mourning Dove 1933; Turner *et al.* 1980), Sinkaietk

Okanagan (Spier *et al.* 1938), Nlaka'pmx (Turner *et al.* 1990), and Columbia River Sahaptin (Hunn, pers. comm. 2005). Brown sugar is preferred by some people (Nlaka'pmx: Turner *et al.* 1990; Sahaptin: Hunn, pers. comm. 2005). Some people will now add sugar and cream to the lichen (Nimi'ipuu: Hart 1976; Columbia: Turner 1977). In the past, Douglas-fir sugar (a sweet, crystalline trisaccharide produced rarely on interior Douglas-fir branches) was sometimes used instead of commercial sugar (Turner 1977). Grease (Nimi'ipuu: Hart 1976) or berries (Nlaka'pmx: Turner *et al.* 1990) were also sometimes added for flavouring.

The Secwepemc have several tasty ways to eat the freshly cooked lichen (recorded by: Turner 1998b). Saskatoon berries and fish eggs can be mixed in with the cooked lichen for flavour. Sugar can be worked into the cooked lichen until it sets like jello and is then eaten like a dessert. Recently commercial sugar was used for this, in the past Douglas-fir sugar or huckleberry juice would have been used.

If the cooked lichen was to be stored, it would be either molded into cakes, or pressed into a thin sheet and cut into bricks. These cakes can range in size from small cubes 0.5–1 inch across (Sinkaietk: Spier *et al.* 1938) to larger squares an inch thick and several inches across (Nlaka'pmx: Turner *et al.* 1990). These cakes are then dried, sometimes by smoking them on a fire (Nlaka'pmx: Turner *et al.* 1990). The Nlaka'pmx sometimes mix cooked Saskatoon berry juice with the cakes before they are dried (Turner *et al.* 1990)

This practice of drying out lichen cakes for storage is reported among Okanagan (Wilkes 1845; Turner *et al.* 1980), Northern Okanagan (Gabriel and White 1954), Sinkaietk (Spier *et al.* 1938), Sanpoil-Nespelem (Ray 1932), Secwepemc (Dawson 1891), Nlaka'pmx (Turner *et al.* 1990), Schitsu'umsh (Teit and Boas 1928), and Ila'xluit (Spier and Sapir 1930). The Flathead have a slightly different method of preserving the cooked lichen. The lichen is dried and then pulverized into a fine powder for storage (Turney-High 1937; Hart 1976). Wilkes (1845) reports that the Okanagan washed the lichen again after it was cooked and before it was dried, but the utility of washing a gelatinous substance seems dubious.

Estimates of how long the cooked, dried lichen will keep range from “a long time” (Dawson 1891), to three years (Spier *et al.* 1938), to “indefinitely” (Mourning

Dove 1933). A Secwepemc elder noted that the lichen does not last as long if cooked with other foods (Turner 1998b). The dried lichen can be prepared for eating by boiling the dried cakes by themselves in water or in a soup with other ingredients (Sanpoilnespelem: Ray 1932; Okanagan: Mourning Dove 1933; Sinkaietk: Spier *et al.* 1938). Turner *et al.* (1990) note that Nlaka'pmx sometimes chew the dried lichen first to soften it before it is boiled. If boiled by itself, the rehydrated lichen resembles molasses (Mourning Dove 1933).

Turner *et al.* (1990) report several Nlaka'pmx recipes for preparing the cooked, dried lichen. The lichen cakes can be boiled in a soup with dried Indian carrots, saskatoon berries, yellow glacier lily corms, tiger lily bulbs, or dried venison. Cooking the dried lichen with bitter-root, dough, and fresh salmon eggs is also apparently a tasty dish (Turner *et al.* 1990). It can be mixed with fish oil and eaten for breakfast after a main course of dried fish. The lichen is also cooked with a pudding called *ngéxw* that is made out of fermented salmon eggs which have been buried in the ground for a period of time, saskatoon berries, deer fat, yellow glacier lily corms, and bitter-root or tiger lily bulbs. The lichen added to this pudding helps to thicken it, although flour can be used instead.

An Okanagan recipe for the dried lichen cakes is to boil them in water with flour (or tapioca) and butter to make a pudding that is mixed with other foods, like bitter-root, yampah, Douglas-fir sugar, raisins, apples, or brown sugar (Turner *et al.* 1980). Alternative Okanagan ways of eating dried lichen cakes are to soak them in cold water overnight, or to dip them in soup and eat them like bread or crackers, or to mix them with dry meat as flavoring (Turner *et al.* 1980).

A Flathead method to eat the dried cooked lichen powder is to mix it with powdered camas, and boil it into a thick mush and eat it with a spoon (Hart 1976). Turner (1977, 1978) reports that dried lichen cakes can also be marinated in saskatoon berry juice and then eaten.

2.2.4.9 Other traditional methods for preparing the lichen for food

Although wila was generally pitcooked, several other preparation methods have been recorded. Most of these alternative recipes generally involve boiling the lichen.

Several of these alternative recipes were done by people who would normally pitcook the lichen. They may have reserved these unconventional methods for occasions when there wasn't time to do a proper pitcook. Examples of groups of people who would normally pitcook the lichen occasionally using a different recipe are found in the Dakelh, Okanagan, Ktunaxa, and Nimi'ipuu.

The Ktunaxa traditionally pitcook wila (de Smet 1847), but in times of famine they would sometimes also boil it with the stomach contents or droppings of spruce grouse (Hart 1976). Keddie (1988) reports another interesting cooking method among the Ktunaxa. The lichen is first moistened, and the beaten with a flat, paddle-shaped, stone hand-maul. The beaten lichen is then formed into cakes and baked. These stone mauls are found as far back as 1500 BCE in Ktunaxa territory. Keddie proposes that they were mostly used for pounding lichen, but could have had other uses as well.

Teit (1900) records that the Nlaka'pmx will occasionally just boil wila together with bitter-root, saskatoon berries, and deer grease until it turns into a thick paste, and then eat it with a spoon. Teit (1900) is probably referring to the pudding *ngéxw*. Turner *et al.* (1990) report the Nlaka'pmx adding pitcooked lichen cakes to this pudding, so perhaps either fresh or pitcooked lichen could be used for this purpose.

The Nimi'ipuu were recorded to sometimes just boil the lichen and eat it (Lewis and Clark 1804-1806; Spinden 1907-1915). The Okanagan sometimes just roast the lichen on a stick over hot coals, turning it frequently. When the lichen is crumbly it is then boiled to the consistency of molasses. This method of preparation is called *spatkán* (Turner 1977; Turner *et al.* 1980).

Morice (1894) reports that the Dakelh would sometimes use wila to bake a fruitcake. The lichen was mixed with dough like one would do with raisins, and the loaf was baked. This was said to help the bread rise. Morice (1894) also tells us that prior to introduction of flour the lichen was cooked with grease.

Mayne (1862) records a variation on the pitcooking method that was used by an unspecified First Nation of coastal British Columbia to cook a species of *Bryoria*, but his accuracy may be questionable. According to Mayne, any debris is picked from the lichen, which is then steeped in water until soft. It is then wrapped in grass and leaves

and cooked between hot stones for ten to twelve hours, and then pressed into cakes while still hot.

Several First Nations for whom wila was not an important food apparently did not ever pitcook it. Examples of this are the Inland Dena'ina, Halkomelem, and people in northern California. As both northern California and Alaska appear to be disjunct with other cultures that pitcook lichens, this may be a result of a lack of contact with people who know of a better preparation technique.

The Halkomelem traditionally boil fresh wila in baskets or wooden troughs and dry it into cakes (Duff 1952). The Inland Dena'ina boil a species of *Bryoria*, and mix it with fish, berries, or grease (Kari 1987). In northern California, wila was dried, ground, and made into soup, which was said to taste like acorns (Murphey 1959).

There is a possibility that some people in North America may have fermented wila before eating it. Uphof (1959) mentions this, but his source is unclear. Blankinship (1905) cites Parry (1871) who cites Morse (1822) who cites Harmon (1800-1816a; 1800-1816b) who gives this first-hand account of a very unique preparation of wila which may be the source of Uphof's information:

On the Columbia River they gather it from the trees, and lay it in a heap, on which they sprinkle a little water, and then leave it, for some time, to ferment. After that, they roll it up into balls, as large as a man's head, and bake them in ovens, well heated, which are constructed in the earth. After having been baked about an hour, they are taken out for use. A kind of bread.

Harmon is probably referring to a pitcook, but the fact that it only lasted an hour and was preceded by a lengthy fermentation of the lichen makes this a very different process from other pitcooks recorded by different authors. Harmon may have misinterpreted some parts of the preparation, but given that he appears to have been watching the process himself it seems unlikely that he could confuse a process that normally takes at least a day for one that only takes an hour. It therefore seems possible that he may have observed an otherwise unrecorded preparation method for the lichen.

2.2.4.10 A few modern methods for cooking the lichen

A few modern methods have been experimented with for a more convenient way to cook wila. Several contemporary wila experts have noted that cooking the lichen in a pressure cooker doesn't work very well (Turner 1977; Turner *et al.* 1990), but Subiyay

(pers. comm. 2003) reports that using a crockpot is quite effective. The crockpot probably more closely mimics the slow cooking of a pitcook. Hunn (pers. comm. 2005) reports that some Columbia River Sahaptin elders will use a microwave or oven to cook the lichen.

2.2.5 Beliefs and stories about *Bryoria* species

There are several Okanagan beliefs regarding the preparation and eating of wila. Turner *et al.* (1980) report that men are not allowed near the pitcook when the lichen is cooking or it will turn out badly. Menstruating women apparently have a similar effect and are also not allowed near the cooking pit (Lakes Okanagan: Elmendorf 1935-1936). Elmendorf (1935-1936) also notes that Lakes Okanagan women prepare themselves for cooking wila by fasting and tying their hair back with vermilioned buckskin, or carrying a piece of it around with them. There is also an Okanagan belief that pregnant women should not eat the lichen because it will make their baby dark (Lerman 1952-1954).

Teit (1900) reports a Nlaka'pmx belief that a bereaved spouse should not eat lichen cake for a full year after the death of their partner.

Wila is also featured in several Interior Salish stories. Mourning Dove (1933) records an Okanagan story about how wila originated from Coyote's hair (similar Okanagan stories recorded by: Spier 1938; Turner *et al.* 1980). In the story Coyote tries to catch some swans, but they fool him by playing dead. Not realizing that the swans are just faking, Coyote unwittingly ties them to his son and crawls up a pine tree to get a pitch top for kindling. The swans then flew away with his son, and in Coyote's haste to get down to save him his long hair got caught in the tree. The swans drop Coyote's son to his death, and Coyote has to cut off his hair to get free. Coyote then transformed his hair into tree lichen, saying (quoted from Mourning Dove 1933):

“You shall not be wasted, my valuable hair. After this you shall be gathered by the people. The old women will make you into food,” he said.

That was Coyote's ruling near the Beginning. That is why his hair, the long black timber-hair, hangs from trees in the mountains. It is called squil-lip. It is the black moss that the people cook in pit ovens.

Bouchard and Kennedy (1979) record a similar lichen origin story told by Secwepemc elder Ike Willard:

While Coyote was hunting he saw something moving at the top of a tree, so he stopped to watch. Soon he saw that it was Spider lying on his back and turning very, very slowly. "Spider, hey Spider! What are you doing up there?" asked Coyote.

"I'm just looking at the scenery," replied Spider.

"Come down here and we will have a friendly chat," suggested Coyote. So Spider slid down to the ground on a strand of his web.

Coyote was amazed that Spider was able to travel on his web. "How do you do that?" asked Coyote. Spider explained that he had a ball of web which he let out to climb on. "I'm going to try to imitate him," thought Coyote to himself.

Coyote climbed up the tree and lay on his back on the top of the branches. He turned around and around, until he had enough of looking at the scenery. Coyote used his fur as a web and started to slide down it, but when he was halfway down, he became stuck.

Just then, Spider came along and saw Coyote dangling in the tree. "Coyote, why do you always try to copy other people? I know how to slide on my web because I have been doing it for a long time!"

Spider unhooked Coyote from the tree and helped him back to the ground. "Coyote, when the coming people live on this land, your fur that is still hanging from the branches will be black tree moss. The people will gather it and cook it to eat."

Turner (1990) records an amusing Nlaka'pmx story about a young girl who was told to go up into the mountains to collect wila. The Nlaka'pmx word that is used to describe the collection of wila is /q'w'=áqs-m, which approximately translates to mean "to gather with a hook" (a hooked stick is used to pull down the lichen). This same word could also mean "break one's nose", so the unfortunate, and somewhat literal-minded, girl of this story misunderstood her instructions and went up to the mountains and repeatedly beat her face against a lichen laden tree until her nose broke. She returned without lichens and was much ridiculed for her stupidity.

Wila is also featured in a St'at'imc story told by Charlie Mack and recorded by Bouchard and Kennedy (1977). In this story a chief's son is abandoned by his village for being greedy and is forced to get his own food. The son of the sun visits him and gives him a gift of a magic robe that can catch salmon. Raven notices the new found success of the chief's son, and starts stealing some of his many fish to feed to his family. When the chief's son's old village notices all the food that Raven is bringing back, Raven tries to hide it by claiming it is merely lichen cakes. But the people quickly discover Raven's deception and hurry back to rejoin the chief's son. The chief's son is understandably annoyed at his village for abandoning him to die, and only allows his village to come back when someone offers him their daughter to take as a wife.

2.2.6 Other uses for *Bryoria* species

Besides being an important food for many people, wila and other species of *Bryoria* have several other uses. The Secwepemc rarely eat wila raw for food, but chewing on the raw lichen is a good thirst quencher (Turner 1998b). There are also several medicinal uses for *Bryoria* species. Some of these uses may be related to an antibiotic function, as at least one *Bryoria* species (*Bryoria fuscescens*) has been found to inhibit gram-positive bacteria (Aslan *et al.* 2001).

The Okanagan have a couple of pediatric uses for *Bryoria* species. The fresh lichen is dried, powdered, and mixed with grease to form a salve to rub on the navels of newborn babies to prevent infection (Turner 1977; Turner *et al.* 1980). After babies are weaned from the breast they are given a syrup made from melting *Bryoria* species in berry juices. This syrup is said to be good for them (Gabriel and White 1954).

The Nlaka'pmx use *Bryoria* species for removing warts in a method described by Teit (1900). Warts are removed from the hands, fingers, or arms by cutting them off close to the skin. The lichen is exposed to a fire until hot and then placed on the fresh wound. The Atsugewi of northeastern California also use a species of *Bryoria* as a kind of poultice. The lichen is dried and pounded, and then either used dry or boiled to make a poultice to reduce swellings (Garth 1953). The Secwepemc use *Bryoria* species as part of a cast for broken bones, and may also use it as a bandage (Turner 1998b).

Wennekens (1985) reports a similar medicinal use for the lichen among the Sugpiaq of Alaska. They collect large quantities of *Bryoria trichodes* and probably other species of *Bryoria* to pile on a sick person in the steam bath to hold the heat on his body. This lichen was also used as a bandage to staunch the blood from a wound.

Nimi'ipuu use *Bryoria* species as a treatment for upset stomach, indigestion, and diarrhea (Hart 1976), and the Flathead use the lichen baked by itself (instead of with camas) as a tonic for the sick (Turney-High 1937). When used in this way it was only baked for one day instead of three days (Stubbs 1966).

Some *Bryoria* species are also used for pigments. The Haisla use several *Bryoria* species (including *B. glabra*, *B. capillaris*, and *B. trichodes*) for paint. The lichen is burned into a powder and made into a black paste (Compton 1993). The Lummi use a lichen that is quite possibly a species of *Bryoria* to make a dark green dye for patterns on

mountain goat wool blankets (Stern 1934). Subiyay (pers. comm. 2003), a Skokomish elder, mixed a species of *Bryoria* with *Letharia vulpina* to make a green dye for wool. Turner (1977) reports that the Coast Salish on Vancouver Island may have used *Bryoria* species to make a yellow dye, but the original source (Ravenhill 1938) is ambiguous and probably actually referring to *Letharia vulpina*. Uphof (1959) reports that in England *Bryoria* species are used to stain wool a pale green to brown-red colour, as well as being used in perfumery.

Brough (1984) tested the dye characteristics of various species of *Bryoria* in British Columbia. *Bryoria abbreviata*, *B. pseudofuscescens*, and *B. vrangiana* all produced excellent yellow-brown to brown dyes when prepared with an ammonia fermentation, and poorer dyes of a similar colours when prepared with boiling water. *Bryoria capillaris* and *B. fuscescens* both produced similar yellow-brown dyes, but were better in boiling water. *Bryoria fremontii* was an anomaly and produced a green coloured dye with boiling water.

The St'at'imc (Turner 1998a), Nlaka'pmx (Teit and Boas 1900; Newcombe 1901-1913; Turner *et al.* 1990), and possibly other Interior Salish (Turner 1998a) traditionally made clothing out of *Bryoria* species. Lichen garments were usually only worn by poorer people (Teit and Boas 1900), as their wooly texture quickly absorbed water and made them unsuitable in wet weather (Turner 1977). To make lichen cloths, long, 1.5 cm ropes of lack tree lichen are slightly twisted, laid side by side, and intertwined with strands of silverberry bark (*Elaeagnus commutata*), Indian hemp (*Apocynum cannabinum*), or some other plant fibre (Newcombe 1901-1913; Turner 1998a). Vests, ponchos or capes, shoes, and leggings can be made in this manner (Newcombe 1901-1913).

The fibrous properties of *Bryoria* species lend them to other uses as well. The Nlaka'pmx (Turner *et al.* 1990), Secwepemc (Turner 1998b), and possibly other Interior Salish use *Bryoria* species mixed with mud for chinking cracks in houses. The Secwepemc also use the lichen for moccasin liners and diapers, and children will use it for fake whiskers and hair (Turner 1998b). The Kwakwa'wakwa call *Bryoria* species and other alectorioid lichens *p'elems*, and use them as household material for activities such

as lining steaming pits and wiping blood and slime off salmon (washing or scraping the fish ruins its taste). Various Inuit groups use *Bryoria* species as tinder (Wilson 1979).

People have also noticed the palatability of *Bryoria* species to animals. The Secwepemc recognize *wila* as being food for deer (Palmer 1975). *Bryoria* species and other dark coloured alectorioid lichens are called *tingaujaq* by North Slope, Barrens-Keewatin, Baffin Island, Ungava-Labrador, and Greenland Inuit. *Tingaujaq* is known to be the favorite food of young caribou, and children will use it to lure fawns in to touch them (Wilson 1979). *Bryoria* species and other alectorioid lichens are called *lappo* by the Saami of northern Scandinavia. The Saami recognize that *lappo* is quite liked by reindeer, even though it doesn't form a major part of their diet (Lynge 1921). A contradiction to this is Blankinship's (1905) claim that in Montana, cattle are said to be poisoned by feeding upon excess of *Bryoria* in the early spring.

2.2.7 Use of *Bryoria* species in the rest of the world

Bryoria fremontii is not limited in distribution to North America. It is also common in boreal forests of northern Europe and Asia (Ahlner 1948). As a result, it is also traditionally used by people in these areas.

Andersson (1868) wrote a booklet for distribution to Swedish peasants to teach them how to eat lichens in times of need. He did include *Bryoria* species as one of six recommended edible species, but focused more on promoting *Cetraria islandica*. Eidlitz (1969) reports that during the famines in the 1860s in Jämtland and Dalarna (Sweden), the authorities were very insistent in their attempts to get the poor people to eat lichen as a solution to the food shortages. Government employees traveled around the countryside teaching people how to cook and eat *Cetraria islandica*. Other lichens were not recommended for food. But the people were suspicious of eating *Cetraria islandica*, and the practice never caught on. The fact that several people died from eating this particular lichen also increased reluctance. Instead of eating *Cetraria islandica*, the locals preferred to eat *Bryoria* species collected off spruce or birch trees, choosing the blacker lichens over the more yellow lichens and then baking it into a bread. This confused the authorities, who couldn't understand why the silly locals wouldn't use the "highly

nutritious” *Cetraria islandica* (which happens to contain fairly high concentrations of the very bitter and slightly toxic fumarprotocetraric acid).

Eidlitz (1969) also records that the Saami used *Bryoria* species along with *Cetraria islandica* to make bread, porridge, blood-sausage, and blood-pancakes. Swedes in Västerbotten (Sweden) also sometimes use *Bryoria* species to make bread (Eidlitz 1969).

Bryoria species were also one of the preferred lichens for use in northern Europe and Russia for production of brandy from 1868-1884, and in northern Russia for production of molasses in 1940s. The suitability of *Bryoria* species for these applications was related to their high yield in glucose and their lack of bitterness. In both cases the lichen was prepared by steaming it with a small amount of acid. See **Section 1.3.3.8 Making lichens into molasses** on page 18 and **Section 1.3.3.9 Making lichens into alcohol** on page 19 for more details on this preparation.

A disjunct population of *Bryoria fremontii* has also been reported from the Canary Islands, off the west coast of Africa (Hawksworth 1982). I have, however, been unable to determine any traditional use for the lichen from this area. Rivera Núñez and Obon de Castro (1991) list 280 edible plant species and Darias *et al.* (1993b) list 37 unusual edible plant species, but both only deal with vascular plants and do not include any lichens or fungi. None of Bramwell and Bramwell (1974), Pérez de Paz and Medina Medina (1988), or Pérez de Paz and Hernández Padrón (1999) list anything besides vascular plants. Darias *et al.* (1986; 1989; 1993a) do report some lichens, but deal mostly with medicinal and dye species. Manual Pardo de Santayana (pers. comm. 2006) is unaware of any edible lichen from the Canary Islands, and reports that *B. fremontii* is not found there.

2.3 Ecology, spatial distribution, and taxonomy of *Bryoria* species

2.3.1 Where *Bryoria fremontii* grows

Bryoria species are mainly boreal lichens with a circumpolar distribution, as well as being found in Southeast Asia (Jorgensen and Galloway 1983), and Antarctica (Olech

and Bystrek 2004). Brodo and Hawksworth (1977) review the distribution of *Bryoria fremontii* in North America (see **Figure 2.1**). *Bryoria fremontii* is found throughout most of the interior of British Columbia, but is less common or absent in the northern third of the province. Some coastal populations exist in the south of the province, and it is found on Vancouver Island, although uncommon and restricted to open dry sites (Szcawinski 1953).

Bryoria fremontii is also present in the Albertan Rockies, down into Montana, Idaho, and Wyoming, as well as being found in Washington, Oregon, and California (Brodo and Hawksworth 1977). *Bryoria fremontii* has been reported from the Kenai Peninsula in Alaska (Krog 1968), although this may be a result of a misidentification, because it is not corroborated by Brodo and Hawksworth (1977).

Bryoria fremontii also grows in northern Europe (Motyka 1962) and Russia (Kravchenko 2003). Hawksworth (1982) reported *Bryoria fremontii* as growing on the Canary Islands (west coast of Africa), but a lichen expert of that area did not agree (Manuel Pardo de Santayana, pers. comm. 2006).

2.3.2 Population ecology of *Bryoria* species

A variety of *Bryoria* species are present in traditional territories where *Bryoria fremontii* would be collected as food in the interior Pacific Northwest. Virtually all other species of *Bryoria* in these areas contain secondary lichen compounds that are bitter or toxic to eat. Most of these species can grow in the same areas, but do have distinctive ecological tendencies (see **Table 2.2**).

2.3.2.1 Importance of ventilation in determining distributions of *Bryoria* species

Humidity and ventilation seem to be important factors in determining *Bryoria* species distributions. Prolonged wetting under a snow pack appears to kill all species of *Bryoria* (Goward 1998), and shorter periods high humidity also have a negative impact, with some species being more susceptible than others (Goward 2003). Furthermore, open areas with greater ventilation tend to support a larger biomass of *Bryoria* species (Goward 1998; 2003), and this trend seems to be related to ventilation levels independent of light intensity (Goward 1998).

Most alectorioid lichens (including most *Bryoria* species) tend to reproduce by fragmenting instead of with soredia⁶. These fragments are much larger than soredia, as a result, these non-sorediate species require stronger winds for dispersal and are slower to colonize new areas (Esseen and Renhorn 1998). The non-sorediate *Bryoria* species are relatively slow to disperse, but still do tend to colonize faster than *Alectoria sarmentosa* and some other alectorioid lichens (Esseen and Renhorn 1998). Given the limitation imposed by their mode of reproduction, it is not surprising that the sorediate species of *Bryoria* (such as *B. fuscescens* and *B. glabra*) tend to dominate areas with less ventilation, while non-sorediate species (most other *Bryoria* species, including *B. fremontii*) are limited to areas with more ventilation (Goward 2003; Goward and Campbell 2005).

Environmental differences are often apparent at different heights on the same tree. In particular, lower down the tree is usually more shaded with less ventilation, while higher up the tree is more open with more ventilation. Several researchers have noted that when *Bryoria fremontii* and *Alectoria sarmentosa* are present on the same tree, *B. fremontii* always occurs above *A. sarmentosa* (Edwards *et al.* 1960; Arseneau *et al.* 1997; Campbell and Coxson 2001).

Goward (2003) more carefully observed this tendency, and categorized three distinct vertical zones of *Bryoria* growth on trees. Zone A is the lowest part of the tree that is under snow pack for part of the year, and it supports very little *Bryoria*. Zone B is above this, and is partially shaded. It is dominated by the sorediate species *B. fuscescens* and *B. glabra*. The highest part of the tree, Zone C, is more open and well ventilated and has a much higher *Bryoria* biomass, primarily the non-sorediate species *B. fremontii* and *B. pseudofuscescens*. The Zone B/C boundary (and thus the occurrence of *B. fremontii*) tends to occur lower on trees that are at a higher elevation, and thus there is a tendency for *B. fremontii* to be more accessible from the ground at higher elevations.

Goward's (2003) characterization of the vertical zonation of *Bryoria* may partially contradict Edwards *et al.* (1960), who said that the tops of trees are too windy for *Bryoria fremontii*, but other *Bryoria* species can survive there. Goward (2003) is consistent with

⁶ Soredia are asexual reproductive structures of lichens, consisting of small granules of a few algal and fungal cells that dispersed by wind to a new site.

Arseneau *et al.* (1997), who also found that the zone of highest lichen biomass was lower on the tree at higher elevations.

Goward and Campbell (2005) expanded on Goward's (2003) model of *Bryoria* zonation, providing more evidence of the trend and showing that it also occurs between sites, and not just within individual trees. More open stands of trees usually support a larger *Bryoria* biomass that is mostly *B. fremontii* and *B. pseudofuscescens*, while *B. fuscescens* and *B. glabra* dominate more closed stands.

Within the non-sorediate *Bryoria* species, *Bryoria fremontii* in particular may be one of the least tolerant species in the genus to poor ventilation. Goward (1992) noted that in the interior of British Columbia *Bryoria fremontii* prefers more open, well-ventilated sites than other *Bryoria* species, and Szczawinski (1953) noted that on Vancouver Island *B. fremontii* was restricted to only the most open and dry sites. *Bryoria capillaris*, on the other hand, is also a non-sorediate species but seems more tolerant to humidity than other non-sorediate species of *Bryoria* (Goward, pers. comm. 2006).

2.3.2.2 Other factors determining the abundance of different *Bryoria* species

Goward (1998) examined the biomass of *B. fremontii* and *B. pseudofuscescens* in different habitats, and noted that in addition to being more abundant in more open forests, they were also more abundant on the inner, defoliated parts of branches, and on older, senescent trees. Edwards *et al.* (1960) observed that *Bryoria* species are found in lower abundance on lodgepole pine than on other tree species, despite the fact that lodgepole pine stands tend to be more open. They attributed this to the shape of these trees not providing as much surface area to colonize, however Goward (pers. comm, 2007) points out that their research was soon after a major fire in Wells Gray Park, and the lichen may not have had enough time to reach its peak abundance.

Many *Bryoria* species tend to be restricted to specific elevations (Brodo and Hawksworth 1977), which are summarized in **Table 2.2**. Brodo and Hawksworth (1977) state that *B. fremontii* is normally found about 1200 m in elevation, and only rarely as low as 700m. However, Edwards *et al.* (1960) claim that *B. fremontii* is unique for a *Bryoria* species and does not have these altitudinal restrictions, being found in lower forests as well as higher in the mountains.

2.3.3 *Bryoria* species taxonomy

2.3.3.1 The creation and development of the taxon *Bryoria fremontii* in scientific literature

The first scientific classification of lichens was completed by Carl von Linnaeus when he included all lichens in the single genus *Lichen*. All *Bryoria* species were lumped together as the species *Lichen jubatus* L. (1753: pg 1155). Erik Acharius, a student of Linnaeus, did the first comprehensive taxonomy of lichens and divided up Linnaeus' *Lichen* genus into many new genera. Acharius created the genus *Alectoria* Ach. (1810: pg 120, 592), and placed all *Bryoria* species into a single species *Alectoria jubata* (L.) Ach. (1814: pg 291), although he recognized eight different varieties within this species (none of which were synonymous with the lichen currently called *Bryoria fremontii*).

Bryoria fremontii remained lumped in the collective species *Alectoria jubata* along with all other *Bryoria* species until Edward Tuckerman (1872) identified *Alectoria fremontii*⁷ and *Alectoria oregana* as being distinctive species of their own. Subsequent authors identified more varieties of *Alectoria jubata* as distinct species, the most significant being Motyka (1964) who named six new *Alectoria* spp. that were previously included in the collective species *Alectoria jubata*.

Although many different species of *Bryoria* were being identified as individual species within the genus *Alectoria*, Tuckerman (1872), Motyka (1964), and other authors kept the taxon *Alectoria jubata*, which served as a repository for a number of different *Bryoria* species that could not be differentiated from each other (which did not include *Bryoria fremontii*). The popular *Alectoria jubata* (L.) Ach. taxon has also been called *Bryopogon jubatus* (L.) Link (1833) and *Setaria jubata* (L.) Samp. (1923).

It is important to note that after 1872 many authors continued to call *Bryoria fremontii* by the name *Alectoria jubata*, even though it was properly called *Alectoria fremontii*. This is unfortunate, as this name confuses *Bryoria fremontii* with many other species of *Bryoria*.

⁷ Named after John Charles Fremont, an American explorer who led several expeditions into the American West in the 1840s (Frémont 1887).

The taxonomy of *Bryoria fremontii* changed once more when Brodo and Hawksworth (1977) divided the genus *Alectoria* into four distinct, well-defined genera (*Alectoria*, *Bryoria*, *Pseudephebe*, and *Sulcaria*). The *Alectoria* spp. originally encompassed in the single species complex *Alectoria jubata* (L.) Ach were assigned to their own genus *Bryoria*, resulting in the creation of *Bryoria fremontii* (Tuck.) Brodo & D. Hawksw. (1977). Brodo and Hawksworth (1977) rejected the taxon *Alectoria jubata* as being an artificial collection of unidentified *Bryoria* species, but the name *Bryoria jubata* still continues to be used by some authors (e.g. Bystrek 1986).

The genus *Bryoria* was later subdivided by Common and Brodo (1995) and three distinctive *Bryoria* species were placed in their own genus, *Nodobryoria*. This included *Alectoria* [*Bryoria*] *oregana* originally identified by Tuckerman, but did not affect the classification of *Bryoria fremontii*.

The lichen *Bryoria fremontii* has also been referred to as: *Bryopogon fremontii* (Tuck.) Rabenh. (1874); *Alectoria jubata* var. *fremontii* (Tuck.) Boistel (1896); *Alectoria corneliae* Gyeln. (1931); and *Alectoria tenerrima* Mot. (1964).

2.3.3.2 The creation and development of the taxon *Bryoria tortuosa* in scientific literature

Merrill (1909) first described *Bryoria tortuosa* (which he named *Alectoria tortuosa* G. Merr.) from a specimen collected in New Westminster, BC, and noted that this lichen was very similar to *Bryoria fremontii* (then named *Alectoria fremontii*) except for being more yellow. Since then *Bryoria tortuosa* has also been called: *Eualectoria tortuosa* (G. Merr.) Gyeln., (1934); *Bryopogon tortuosus* (G. Merr.) Bystrek (1971: pg 273); and according to Esslinger (2006) it has been misidentified in North America as the European lichen *Alectoria virens* Taylor (1847). Brodo and Hawksworth (1977) renamed this lichen *Bryoria tortuosa* (G. Merr.) Brodo & Hawksw. and placed it in *Bryoria* sect. *tortuosa* along with *Bryoria fremontii*.

2.3.3.3 The distinction between *Bryoria fremontii* and *Bryoria tortuosa*

Ever since the creation of the taxon *Bryoria tortuosa*, it has been considered to usually be more yellowish in colour than the similar-looking *Bryoria fremontii* (Merrill 1909). However, many *Bryoria tortuosa* specimens do not appear yellowish to the naked

eye, and thus cannot be differentiated in this manner (Crawford, pers. obs.; Goward, pers. comm.; Brodo and Hawksworth 1977). A more reliable species distinction is that *Bryoria tortuosa* has more abundant pseudocyphellae that are large and yellow, while *B. fremontii* has no pseudocyphellae or sparse, small white ones (see **Table 3.2** and **Figure 3.6**).

The taxonomy proposed by Brodo and Hawksworth (1977) is still currently accepted by lichenologists — *Bryoria fremontii* and *B. tortuosa* are considered to be distinct species, and the only two members of *Bryoria* sect. *tortuosa*. However, recently some lichenologists have proposed that there exists a continuum of morphologies between *B. fremontii* and *B. tortuosa*, and that they represent two chemotypes of the same species (Goward and Ahti 1992; Halonen, pers. comm. 2005).

2.3.3.4 The current taxonomic placement of *Bryoria* species

Hale (1983) considered the genera *Alectoria* and *Bryoria* to be closely related and placed both genera (along with the other alectorioid genera *Coelocaulon* Link, *Cornicularia* (Schreb.) Ach., *Pseudephebe* M. Choisy, and *Sulcaria* Bystr.) within the family Alectoriaceae. Later taxonomies (Eriksson and Hawksworth 1985; 1986; 1993; 1998) included only the genera *Alectoria*, *Oropogon* Th. Fr., and *Sulcaria* within the family Alectoriaceae, and placed *Bryoria* within the larger family Parmeliaceae.

Kärnefelt and Thell (1992) also supported a narrower definition of Alectoriaceae. Based on morphological characteristics, particularly the shape and colour of asci and ascospores, they concluded that *Bryoria* species appear to be very similar to species of *Pseudephebe* and *Bryocaulon*, but quite different from *Alectoria* species and the other genera in the Alectoriaceae family. They suggest that the three *Bryoria*-like genera should either be left in the family Parmeliaceae or put in their own family.

Recent studies using ribosomal DNA (Mattsson and Wedin 1998, 1999; Wedin *et al.* 1999) have suggested that the family Alectoriaceae should be eliminated and all of the alectorioid lichens should be placed within the family Parmeliaceae, a large family containing about 2000 species and 80 genera of foliose and fruticose lichens. The alectorioid lichens do not form a monophyletic group within this large family (Mattsson

and Wedin 1999), and thus the close historical link between *Alectoria* and *Bryoria* may have no evolutionary basis.

2.4 Chemistry of *Bryoria* species in relation to its toxicity and nutrition

2.4.1 Lichen secondary compounds in *Bryoria* species and their potential toxicity

2.4.1.1 The secondary chemistry of *Bryoria fremontii* and *Bryoria tortuosa*

In North America, the only lichen compound found in either *Bryoria tortuosa* or *Bryoria fremontii* is vulpinic acid (Brodo and Hawksworth 1977). Vulpinic acid is found throughout the thallus of *Bryoria tortuosa*, but only in the soralia and apothecia of *Bryoria fremontii* (Brodo and Hawksworth 1977). Vulpinic acid concentration can vary considerably in both *Bryoria tortuosa* (Brodo and Hawksworth 1977) and *Bryoria fremontii* (from 0.004% in Sequoia National Park to 0.23% in Carmel Valley, CA: Stephenson and Rundel 1979). *Bryoria fremontii* can contain vulpinic acid in Britain as well (Hawksworth 1972), and in Norway it can contain vulpinic acid along with alectoralic acid and thamnolic acid (Huneck and Follmann 1970).

2.4.1.1.1 The occurrence of vulpinic acid among fungi

Bebert (1832) isolated a yellow pigment from *Letharia vulpina* and named it vulpinic acid. The structure of this compound was later determined by Spiegel (1880a, 1880b, 1881, 1883) and is shown in **Figure 2.2**. Vulpinic acid ($C_{19}H_{14}O_5$) is a vulpinic acid derivative, a class of common lichen secondary compounds that are produced through the shikimate pathway (Huneck 1999).

Vulpinic acid is exceptionally abundant in *Letharia vulpina*, and can constitute up to 5% of the weight of the lichen (Solberg and Remedios 1978; Stephenson and Rundel 1979). Vulpinic acid has since been discovered in a variety of other fungi, particularly lichens in the Parmeliaceae family (which includes *Letharia vulpina*). Other Parmeliaceae lichens with vulpinic acid include *Vulpicida pinastri*, which contains between 0.5 to 3% vulpinic acid (Golojuch and Lawrey 1988; Hyvarinen *et al.* 2000; Pöykkö *et al.* 2005), and several other members of that genus, such as *V. juniperinus*

(Hesse 1898a) and *V. tubulosus* (Zopf 1902). *Alectoria virens* Tayl. and *Alectoria sulcata* (Lev.) Nyl., two Parmeliaceae lichens from Southeast Asia, both contain vulpinic acid (Hawksworth 1970; 1971; 1972). The related *Bryoria fremontii* and *Bryoria tortuosa* are the only alectorioid lichens in North America with vulpinic acid (Brodo and Hawksworth 1977).

Vulpinic acid is also found in several unrelated species of lichen. *Sporopodium lucidum* Aptroot & Sipman (1993), a bright yellow lichen from the family Ectolechiaceae that grows on understory leaves in tropical rainforests in Papua New Guinea, is high in vulpinic acid (Lücking and Lumbsch 2001). *Pseudocyphellaria encoensis*, a large leafy lichen with yellow pseudocyphellae, contains vulpinic acid (Garbarino *et al.* 1991), as do *Chaenotheca chrysocephala* and *Chrysothrix chlorina*, two yellow dust lichens (Zopf 1895; Hesse 1898b).

Some non-lichenized fungi also contain vulpinic acid. Earthballs (*Scleroderma citrinum*) are puffball-like basidiomycetes related to *Boletes* that contain vulpinic acid and are mildly toxic (Kanokmedhakul *et al.* 2003). The edible basidiomycete mushroom *Pulveroboletus ravenelii* also contains large amounts of vulpinic acid (Marumoto *et al.* 1986; Quang *et al.* 2003).

2.4.1.1.2 Variation in vulpinic acid concentrations

Contrary to Galloway (1993), there seems little evidence that vulpinic acid plays a role in protecting the lichen from UV-B or other environmental stresses. Many studies have shown that vulpinic acid is highly toxic to most herbivores, gram-positive bacteria, and fungi, and it thus seems much more likely that it serves an ecological function of protecting the lichen against herbivory, infection, or perhaps even lichen competitors (Whiton and Lawrey 1984).

Probably as a result of this, variation in concentration of vulpinic acid has not been found to be correlated with any environmental factors measured (Stephenson and Rundel 1979; Golojuch and Lawrey 1988). However, Stephenson and Rundel (1979) found that the concentration of vulpinic acid could vary 50 fold between different individuals of *Bryoria fremontii*, and the concentration of vulpinic acid can also vary significantly within the same individual lichen: 50 fold in *Letharia vulpina* (Stephenson

and Rundel 1979) and tenfold in *Vulpicida pinastri* (Golojuch and Lawrey 1988). Within a lichen thallus, vulpinic acid is concentrated in younger tissue (Stephenson and Rundel 1979; Lawrey 1983b; Golojuch and Lawrey 1988), soredia (Stephenson and Rundel 1979; Hyvarinen *et al.* 2000), and apothecia (Hyvarinen *et al.* 2000).

Hyvarinen *et al.* (2000) also found more vulpinic acid in the regions of the *Vulpicida pinastri* thallus that had apothecia and soredia. This implies that the lichen was allocating more defense chemicals to more valuable parts of the lichen. However, there is no research so far to suggest that lichens may produce more vulpinic acid in response to increased risk of predation or infection, or increased competition.

2.4.1.1.3 Biological activity of vulpinic acid

Many studies have shown vulpinic acid (along with usnic acid) to be one of the most potent lichen compounds in its toxicity to animals, fungi, and bacteria. Tests on various vertebrates indicate that about 3 mg of vulpinic acid would begin to show toxic effects on a 70 kg person (see **Section 1.5.1.2.4 Toxicity of lichen compounds against animals** on page 41). Using the concentrations of vulpinic acid reported for various specimens of *Bryoria fremontii* and/or *B. tortuosa* by Stephenson and Rundel (1979), this could be anywhere from 1.3 g to 75 g of lichen. In a particularly potent specimen of *Letharia vulpina*, a mere 53 mg of lichen would begin to be toxic (using concentrations reported by Stephenson and Rundel 1979). This toxicity could further be amplified because vulpinic acid is not particularly water soluble and very lipophilic (Abo-Khatwa *et al.* 1996), so it is possible that it may bioaccumulate.

Besides being quite toxic, vulpinic acid has been found to possess several other pharmaceutical properties (see **Section 1.5.1.2.5 Pharmaceutical properties of lichen compounds** on page 44). It has been found to be antiviral (Rashan *et al.* 1990), antiproliferative against tumor cells (Nadir *et al.* 1992; Kanokmedhakul *et al.* 2003), anti-inflammatory (Foden *et al.* 1975; Appa Rao and Prabhakar 1988), muscle relaxant (Appa Rao and Prabhakar 1988), and an analgesic (Appa Rao and Prabhakar 1988).

2.4.1.2 The secondary chemistry of related species of *Bryoria* possibly collected for food with *Bryoria fremontii*

2.4.1.2.1 Secondary chemistry of related species of *Bryoria*

The most common *Bryoria*-like species of lichen to co-occur with *Bryoria fremontii* and *Bryoria tortuosa* in the interior Pacific Northwest fall into three groups. The first group is the *Bryoria fuscescens* sensu lato species, which includes *B. fuscescens*, *B. glabra*, and *B. lanestris*. These lichens all contain fumarprotocetraric acid (Brodo and Hawksworth 1977). The second group of relevant *Bryoria* species is *Bryoria* sect *implexae*, particularly *B. capillaris* and *B. pseudofuscescens*. *Bryoria capillaris* contains barbatolic acid, and *B. pseudofuscescens* contains norstictic acid (Brodo and Hawksworth 1977). The third group are the *Nodobryoria* species, which are less abundant and contain no lichen substances (Brodo and Hawksworth 1977). See **Table 2.2** for a complete listing of secondary lichen compounds present in these species.

2.4.1.2.2 Biological activity of secondary compounds in related species of *Bryoria*

Fumarprotocetraric acid has a bitter taste (Reutimann and Scheidegger 1987), and numerous studies have shown the compound to be a feeding deterrent for a variety of invertebrates (Reutimann and Scheidegger 1987; Giez *et al.* 1994; Hesbacher *et al.* 1995b). Norstictic acid has also been found to be a strong feeding deterrent (Giez *et al.* 1994). See **Section 1.5.1.2.3 Effect of lichen compounds on herbivores** on page 38 for more details. I have found no tests on the effect of barbatolic acid on herbivores, but in general most lichen secondary compounds are at least slightly toxic (see **Section 1.5.1.2 Effect of lichen compounds on other organisms** on page 36), so it is quite likely that one would want to avoid eating barbatolic acid as well.

2.4.2 The nutritional value of *Bryoria*

Many lichen species contain small quantities of a variety of nutrients (see **Section 1.5.4 Other nutrients in lichens** on page 54). Although some species of lichen can contain significant quantities of vitamin B₁₂, choline, tocopherol (vitamin E), and folate (vitamin B₉), *Bryoria* species have been tested for all of these nutrients and have not

contained significant amounts of any of them (Sjöström and Ericson 1953; DaSilva and Jensen 1971; DaSilva and Englund 1974). *Bryoria fremontii* contains more protein than most other chlorolichens (i.e. lichens without a cyanobacteria symbiont), but this is still not enough protein to be nutritionally significant to humans (see **Section 1.5.3 Lichen proteins** on page 52). As a result, carbohydrates are likely to be the main component of *Bryoria fremontii* to be relevant to human nutrition.

2.4.2.1 Carbohydrates in *Bryoria*

Very little work has been done on the carbohydrates of *Bryoria* species. Yanovsky and Kingsbury (1938) tested two separate samples of *Bryoria* species, and found them to contain 17.7–24.8% water-soluble carbohydrate and 35.4–51.7% alkali-soluble carbohydrate. Kirkpatrick *et al.* (2001) found a *Bryoria* species to contain 35.7% water-soluble carbohydrate. The water-soluble carbohydrates are likely either lichenin or isolichenin. The alkali-soluble fraction could contain galactomannans, as well as a variety of other carbohydrates, all of which are entirely indigestible to humans.

The only other lichens similar to *Bryoria* that have been analyzed for carbohydrates are some species of *Alectoria*. Stenberg (1868) found some *Alectoria* species to contain 44% hot water-soluble carbohydrate. *Alectoria ochroleuca* was analyzed by Diachkov and Kursanov (1945), who found it to contain 45.6% water-soluble and 34.6% alkali-soluble carbohydrate, and by Svihus and Holand (2000), who found 33.7% water-soluble glucan. A more precise carbohydrate analysis was conducted on *Alectoria sarmentosa* and *A. sulcata* by Takeda *et al.* (1972). They found both of these lichens to contain 15.0% lichenin, but they differed in concentration of isolichenin (1.7% and 9.2% respectively).

Common (1991) used iodine staining techniques to qualitatively examine the lichenin and isolichenin content of the alectorioid lichens. He found lichenin in relatively high concentrations in almost all of the alectorioid lichens. Isolichenin was also present in many of the species, but often in very low concentrations. All species of *Bryoria* had high concentrations of *Cetraria*-type lichenin, but lichenin was absent from *Nodobryoria*. All species of *Bryoria* also contained isolichenin, but it was only present in low

concentrations in most species. *Bryoria capillaris* had particularly high concentrations of isolichenin, while *Bryoria implexa* had particularly low concentrations.

The water-soluble carbohydrates identified in *Bryoria* species by Yanovsky and Kingsbury (1938) and Kirkpatrick *et al.* (2001) are probably mostly, but not entirely, lichenin. Based on the limited data available, it seems reasonable to guess that *Bryoria* species probably contain 15–30% lichenin, and that *Bryoria fremontii* probably contains less than 5% isolichenin.

2.4.2.2 The digestibility of *Bryoria*

Various species of *Bryoria* and *Alectoria* have been found to be the most digestible of all forage lichens to lichenivorous ruminants (see **Section 1.5.5.8 Lichen digestion by ungulates** on page 66). This is probably because of their high lichenin content relative to other lichens (see **Table 1.2**). However, numerous digestibility experiments have shown that it is very unlikely that humans can digest lichenin (see **Section 1.5.5 The digestibility of lichens** on page 56). These studies have also shown that isolichenin probably has a very low digestibility, if it is digestible at all. It seems that the carbohydrates of *Bryoria* species would provide little nutrition to a person.

The Swedish military conducted an experiment on the edibility of *Bryoria* species that is reported by Källman (1988). Eight soldiers survived on *Bryoria* species and pine needles for nine days while engaging in strenuous physical exercise and enduring harsh environmental conditions in the high arctic. Although all participants survived, they lost considerable weight, indicating that the lichen was not a sustainable food source under the conditions tested. See **Section 1.5.5.3.3 A more recent feeding trial by the Swedish military** on page 62 for more details.

2.4.3 The possible effects of proper harvesting and preparation on the nutritional chemistry of *Bryoria*

It is apparent that unprocessed *Bryoria* species do not represent an easily accessible nutritional source with no risk of toxicity. Utilizing these lichens as a major food source, as was done by many First Nations in the past, requires careful selection and processing. As would be expected, eating wila traditionally includes specific knowledge

on how to select the correct lichen (see **Section 2.2.3 Harvesting wila for food** on page 88) and on how to wash and cook it (see **Section 2.2.4 Cooking the lichen** on page 91). It is very likely that these practices affected the nutrition of the lichen.

2.4.3.1 The proper selection of *Bryoria* for food

The secondary chemistry of the various species of *Bryoria* makes it essential to select the correct lichens for eating (see **Section 2.4.1 Lichen secondary compounds in *Bryoria* species and their potential toxicity** on page 115). The highly toxic vulpinic acid may have a 50-fold variation in concentration between different individual specimens of *Bryoria fremontii* (Stephenson and Rundel 1979). As a result, it may be important to avoid these particularly potent specimens of *B. fremontii*. The closely related (and very similar looking) *Bryoria tortuosa* always has higher levels of vulpinic acid, and should always be avoided when eating lichen. As well, there are several other *Bryoria* species that commonly occur with *Bryoria fremontii* and that contain other bitter tasting and/or slightly toxic secondary compounds. One would probably want to avoid these species as well when selecting lichen to eat.

Traditional harvesting practices can selectively collect edible *Bryoria fremontii* and avoid *Bryoria* species with toxic and/or bitter lichen secondary compounds. Clues such as colour and location are particularly important for this. See **Chapter 3** on page 130 for a more complete analysis of this topic.

2.4.3.2 Washing the lichen

Most lichen secondary compounds are slightly water-soluble (see **Section 1.5.1.3.1 Solubility of lichen compounds** on page 46). Vulpinic acid in particular has been found to be slightly water-soluble (Stephenson and Rundel 1979; Lauterwein *et al.* 1995), and will form an aqueous solution up to 32 mg/L (Lauterwein *et al.* 1995). This low but non-zero solubility means that although the bitter and/or toxic lichen acids will not easily wash out of a lichen thallus, they will probably leach out to some degree if enough water is used to wash them over a long enough period of time.

Most lichen carbohydrates have a low solubility in water (see **Section 1.5.2 Lichen carbohydrates** on page 47). Isolichenin is the most water-soluble polysaccharide commonly found in lichens. Although most isolichenins are highly soluble in cold water,

they are only soluble after they are extracted from the lichen thallus, and will not dissolve out of an intact thallus (Common 1991). Melick and Seppelt (1994) did find that polyols could be leached out of lichens, noting that if *Umbilicaria decussata* was soaked in water it lost about 5% of its polyol content in the first half hour, although carbohydrate loss stopped after that. This may not be significant, as lichen polyols probably have little relevance to human nutrition (see **Section 1.5.2.1 Simple carbohydrates in lichens** on page 47).

2.4.3.3 Cooking the lichen

Complex carbohydrates can often be broken down into simpler, more digestible forms by cooking (Wandsnider 1997). In particular, pitcooking some traditional root vegetables can break down inulin (an indigestible polysaccharide) into fructose (a digestible monosaccharide) (Konlande and Robson 1972; Peacock 1998). It is possible that cooking could degrade indigestible lichen carbohydrates into more digestible forms. See **Chapter 4** on page 164 for an exploration of this possibility.

Cooking can also be used to detoxify some foods (Wandsnider 1997). Although most lichen secondary compounds are quite heat stable, some have been known to be degraded by heat (see **Section 1.5.1.3.2 Heat stability of lichen compounds** on page 46). It is possible that cooking lichen could help detoxify certain secondary compounds.

Chapter 2 Tables and Figures

Table 2.1. Use of *Bryoria* species by First Peoples in North America.

People	Uses for <i>Bryoria</i> species	References
Sugpiaq	Called <i>nakuraartum nuyii</i> or <i>napam ungagua'i</i> . Includes all <i>Bryoria</i> spp. Medicine, used in steam bath and as bandage	(Wennekens 1985)
Inland Dena'ina	Called <i>dehtsighu</i> ("branch hair") or <i>ch'vala andaz'i</i> ("spruce hair"). Includes other alectorioid lichens. Famine food. Boiled, mixed with berries, fish, or grease.	(Kari 1987)
Sekani	Unconfirmed food use	(Turner 1977)
Dakelh	Called <i>teh-ra</i> ("above hair"). Food, pitcooked, or baked with flour, or cooked with grease.	(Kane 1846-48; Dawson 1891; Morice 1894)
Wet'suwet'en	Unconfirmed food use	(Dawson 1891; Morice 1894; Turner 1977)
Tsilhqot'in	Possibly the Tinneh referred to by Dawson. Other citations of uncertain source.	(Dawson 1891; Turner 1977; Kuhnlein and Turner 1991)
Haisla	Paint, burned to powder, made into black paste.	(Compton 1993)
Kwakwaka'wakwa	Called <i>p'elems</i> . Includes other alectorioid lichens. Fibrous material for household activities.	(Turner and Bell 1973)
Gitksan	Unconfirmed food use	(Turner 1977)
Tsimshian	May be called <i>whyelkine</i> , likely a misinterpretation of Mayne (1862). Reference to food use more likely refers to moss being used to line a pitcook.	(Boas and Tate 1916; Turner 1977; Kuhnlein and Turner 1991; Turner and Clifton 2002)
Secwepemc	Called <i>wila</i> or <i>wile</i> . Major food. Pitcooked, sometimes with berries, roots, or wild celery. Fibre: moccasin lining, diapers, casts, bandages. Featured in traditional stories.	(Dawson 1891; Teit 1909; Palmer 1975; Kennedy and Bouchard 1996; Turner 1998b)
Stl'atl'imc	Called <i>a.wi'.a</i> . Major food. Pitcooked. Made into clothing. Featured in traditional stories.	(Teit 1906; Turner and Bouchard 1974; Bouchard and Kennedy 1977; Turner 1977, 1978; Turner and Davis 1993; Turner 1998a)

Table 2.1 cont'd. Use of *Bryoria* species by First Peoples in North America.

People	Uses for <i>Bryoria</i> species	References
Nlaka'pmx	Called /wi7e. Major food. Pitcooked with roots; or boiled with roots, berries, meat, or grease. Lichen cake called Itxwa . Medicine, poultice. Made into clothing.	(Teit and Boas 1900; Newcombe 1901-1913; Turner 1977, 1978; Turner <i>et al.</i> 1990; Turner 1998a)
Okanagan (including Northern, Sinkaietk, Sanpoil-Nespelem, Lakes, and Coville)	Called skwelip . Major food. Pitcooked with camas, onions, or berries; or roasted over coals then boiled. Medicine, for babies. Featured in traditional stories.	Northern (Gabriel and White 1954; Turner <i>et al.</i> 1980); Sinkaietk (Spier <i>et al.</i> 1938); Sanpoil-Nespelem (Ray 1932; Turner <i>et al.</i> 1980); Lakes (Thompson 1784-1812a: pp. 85-89; 1784-1812b: pp. 388-392; 1784-1812c: pp. 282-285; Elmendorf 1935-1936); Coville (Franchère 1820; Turner <i>et al.</i> 1980); Spokane (Carlson and Flett 1989); Unspecified (Wilkes 1845; Teit and Boas 1928; Dumbeck 1945; Lerman 1952-1954)
Columbia and Wenatchi	Food	(Turner 1977)
Kalispel and Spokane	Called saw'-t-m=qn , s-q''l-Ap-qn , or s-q''l'=ap=qn . Pitcooked for food.	(Douglas 1914: pg. 171; Turner <i>et al.</i> 1980; Carlson and Flett 1989)
Schitsu'umsh	Called sä'tc'Etct . Major food. Pitcooked with camas and onions.	(Teit and Boas 1928)
Flathead	Called caúmtemkan , st'telu , skola'pkEn , or squatlo . Major food. Pitcooked with roots. Medicine, tonic if cooked alone.	(Teit and Boas 1928; Turney-High 1937; Stubbs 1966; Hart 1976)
Ktunaxa	Perhaps called ä'ttla or emgo'tlna (may refer to <i>Letharia vulpina</i>). Famine food. Pitcooked; or boiled with grouse stomach contents or droppings; or pounded with stone maul into cake and baked.	(Thompson 1784-1812a: pp. 85-89; 1784-1812b: pp. 388-392; 1784-1812c: pp. 282-285; de Smet 1847; Chamberlain 1892; Hart 1974, 1976; Keddie 1988)
Niitsitapii (MT)	Famine food	(Johnston 1970; 1982)
Unspecified interior peoples of BC, east of the Fraser River	Called whyelkine . Major food.	(Mayne 1862)

Table 2.1 cont'd. Use of *Bryoria* species by First Peoples in North America.

People	Uses for <i>Bryoria</i> species	References
Unspecified coastal peoples of British Columbia and Vancouver Island	Baked between hot rocks, wrapped in vegetation. Questionable account.	(Mayne 1862)
Coast Salish (V. I.)	Unconfirmed food use	(Turner 1977)
Lummi	Dye, dark green	(Stern 1934)
Halkomelem	Called <i>sqwelíp</i> ("hair dirt"). Boiled and dried into cakes, or pitcooked into lichen loaf	(Duff 1952; Galloway 1982)
Twana	Pitcooked for food. Dye, dark green	(Subiyay, pers. comm. 2003)
Ila'xluit	Called <i>ik!u'nuc</i> . Major food. Pitcooked.	(Spier and Sapir 1930)
Tenino	Called <i>wa-kamwa</i> . Unspecified food use	(Murphey 1959)
Umatilla, Cayuse, Yakima, and unspecified Sahaptin	Called <i>kw"u'nch</i> . Pitcooked for food.	(Hunn 1997; Hunn, pers. comm. 2005)
Nimi'ipuu	Called <i>/ho.póp/</i> . Regular food and famine food. Boiled; or pitcooked with roots. Medicine, upset stomach and diarrhea	(Lewis and Clark 1804-1806; Spinden 1907-1915; Hart 1976; Marshall 1977; Turner 1977)
Klamath	Famine food	(Coville 1897)
Modoc	Called <i>qa'l</i> . Unspecified food use	(Ray 1963)
Shasta	Unconfirmed food use	(Turner 1977)
Atsugewi	Medicine, poultice.	(Garth 1953)
Wailaki	Famine food	(Chesnut 1902)

Table 2.2. Ecology and chemistry of *Bryoria* species of the interior Pacific Northwest (summarized from: Brodo and Hawksworth 1977; Goward and Ahti 1992; McCune 1997; Goward 1999; Brodo *et al.* 2001).

Species	Elevation	Ecology	Chemistry
<i>Bryoria glabra</i>		Often grows on subalpine fir and spruce. Uncommon and sporadic in moist low forests in Rockies, common in Wells Gray. Likes moister, shadier areas.	Fumarprotocetraric acid
<i>Bryoria lanestris</i>	1300-2300m Rarely as low as 700m	Grows on coniferous trees, especially lodgepole pine, also in grand fir-cedar forests. Common.	Fumarprotocetraric acid
<i>Bryoria fuscescens</i>		Grows on conifers, mostly pine and Douglas-fir. Likes moister, shadier areas. Ubiquitous but seldom dominant.	Fumarprotocetraric acid
<i>Bryoria simplicior</i>		Often found on lodgepole pine. Uncommon in Rockies and Wells Gray.	No lichen products
<i>Bryoria fremontii</i>	1200-2300m Rarely as low as 700m	Grows mainly on ponderosa pine, lodgepole pine, Douglas-fir, and larch. Likes open, dry areas.	Vulpinic acid only in soralia and apothecia
<i>Bryoria tortuosa</i>		Grows on exposed trees.	Variable amounts of vulpinic acid
<i>Bryoria capillaris</i>		Grows on all trees, especially understory of spruce, Douglas-fir, fir, cedar, and hemlock. More tolerant of humidity than other non-sorediate species.	Barbatolic acid; sometimes alectorialic acid
<i>Bryoria pseudofuscescens</i>	1100-2350m Rarely as low as 700m	Grows on white spruce, subalpine fir, whitebark pine	Norstictic acid; rarely connorstictic acid
<i>Bryoria implexa</i>		Grows on conifers in boreal spruce-fir forest. Rare.	Psoromic acid
<i>Bryoria friabilis</i>	0-1500m	Prefers exposed habitats. Rare in Rockies and Wells Gray, common in Cascades.	Gyrophoric acid in cortex; alectorialic acid in apothecia
<i>Bryoria chalybeiformis</i>	1400-2700m	Usually grows on rocks and soil, only rarely on trees.	Fumarprotocetraric acid
<i>Nodobryoria oregana</i>	1500-2300m Rarely as low as 600m	Grows on subalpine fir, spruce, pine, Douglas-fir, cedar.	No lichen substances
<i>Nodobryoria abbreviata</i>	700-2100m	Grows on ponderosa pine, Douglas-fir, cedar.	No lichen substances

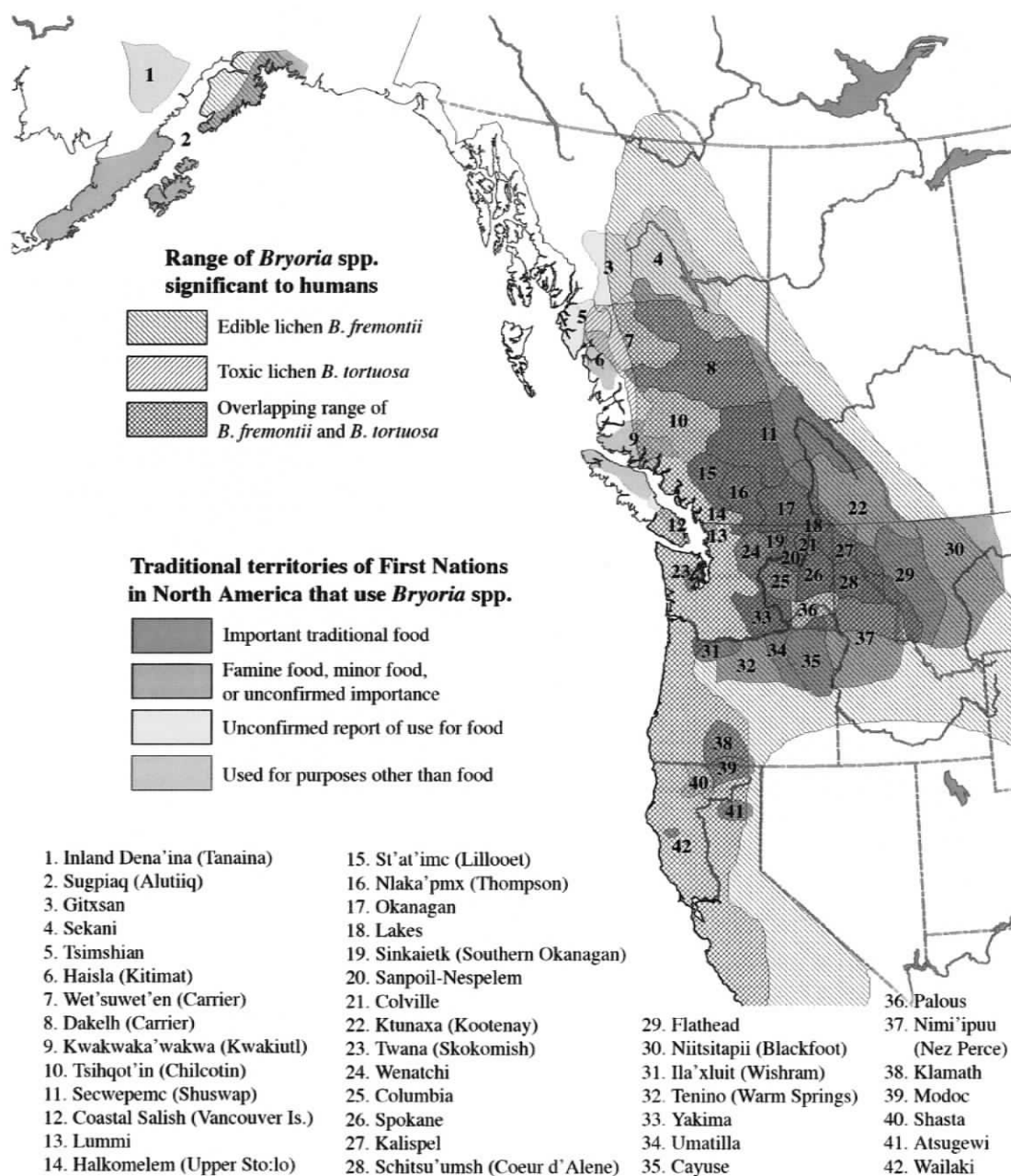


Figure 2.1. Map showing traditional territories of First nations that traditionally use *Bryoria* species, and range of *Bryoria fremontii* and *B. tortuosa*.

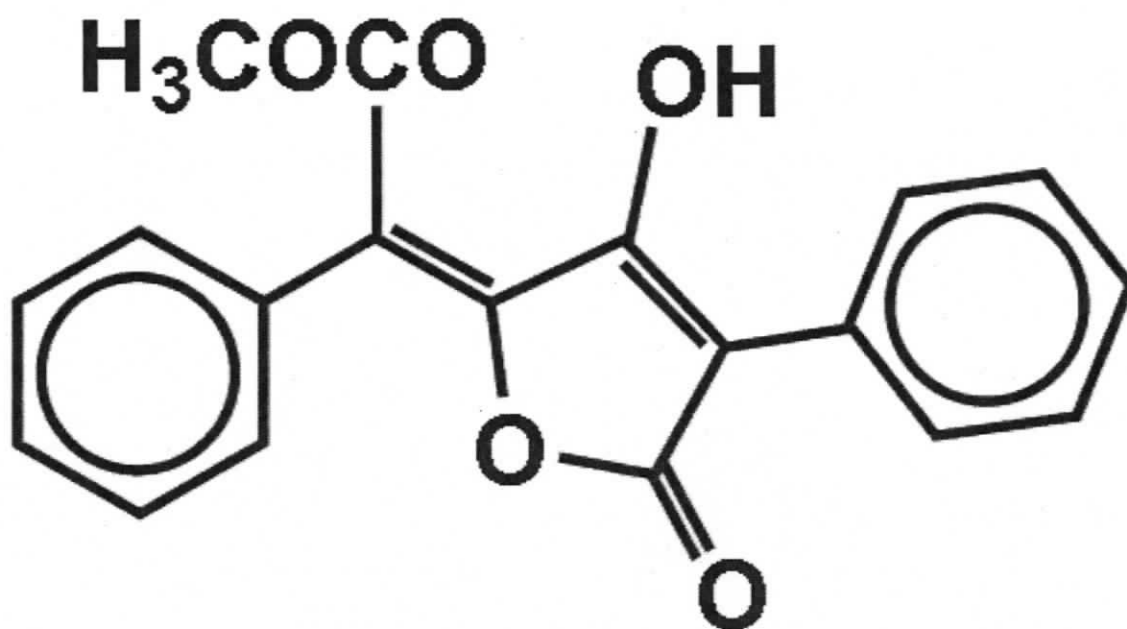


Figure 2.2. The structure of vulpinic acid ($C_{19}H_{14}O_5$), a pulvinic acid derivative. The pulvinic acids are common lichen secondary compounds produced through the shikimate pathway. Vulpinic acid is bright yellow, toxic, and abundant in *Bryoria tortuosa*, *Letharia vulpina*, and several other lichens and fungi.

Chapter 3 Population ecology of *Bryoria* species growing on trees in Secwepemc territory and relevance to the proper selection of edible *Bryoria fremontii*

3.1 Abstract

Successfully eating *Bryoria fremontii* requires selectively harvesting it while avoiding the toxic *Bryoria tortuosa* and several other bitter *Bryoria* species. Many indigenous lichen experts traditionally use colour to differentiate the appropriate *Bryoria* species for harvest. However, colour is insufficient to reliably differentiate individual *Bryoria* specimens.

Bryoria species were harvested from 80 trees at eight different sites in Secwepemc traditional territory. Secwepemc elder and lichen expert Dr. Mary Thomas examined selected samples and determined which were good for eating. *Bryoria* species composition was determined for each tree, and species associations between and within sites were investigated. Mary Thomas preferentially selected *Bryoria* samples with more *Bryoria fremontii* and less *Bryoria* sect. *implexae*.

Species composition was highly correlated within sites, so the edibility of lichen from a single tree is a good indication of the suitability of that entire area for harvest. The abundance of brown-coloured *Bryoria tortuosa* was positively correlated with yellow-coloured *B. tortuosa*, and the abundance of light-coloured *B. fremontii* was positively correlated with dark-coloured *B. fremontii*. *Bryoria* sect. *implexae* was negatively correlated with *Bryoria fremontii* and uncorrelated with *B. tortuosa*. As a result of these correlations, if lichen is only harvested from trees with darker lichen, avoiding lighter-coloured and yellowish lichen, *Bryoria fremontii* is preferentially selected and *Bryoria tortuosa* is avoided, even though many *Bryoria fremontii* and *Bryoria tortuosa* specimens are indistinguishable from each other by quick visual inspection.

3.2 Introduction

Wila (*Bryoria fremontii*) is a widespread and important traditional food throughout much of its range in North America (see **Section 2.2 An overview of the traditional use of *Bryoria* species** on page 83). This lichen usually contains no secondary lichen compounds, and thus has no bitterness or toxicity. However, there are several other species of *Bryoria* co-occurring with wila that contain toxic secondary compounds, and some specimens of *Bryoria fremontii* may contain elevated levels of the toxin vulpinic acid. This issue is detailed in **Section 2.4.1 Lichen secondary compounds in *Bryoria* species** on page 115. In summary, there are three groups of *Bryoria* species that should be avoided:

- (1) Specimens of *Bryoria fremontii* with exceptionally high levels of vulpinic acid,
- (2) The closely related *B. tortuosa* (which always has toxic levels of vulpinic acid),
- (3) Any other *Bryoria* or *Nodobryoria* species encountered when collecting *Bryoria fremontii* (probably mostly *Bryoria* sect. *implexae* and *Bryoria fuscescens* s. l., which both contain other secondary compounds that are bitter and mildly toxic).

Correctly distinguishing edible *Bryoria fremontii* from these inedible groups of *Bryoria* species can be difficult, and conventional lichen identification keys employed by lichenologists use characters that may require a hand lens and/or chemical tests. Indigenous lichen experts did not traditionally have either of these tools, and yet were still able to select tasty and non-toxic lichen.

The main characteristics traditionally used by Indigenous lichen experts to identify edible lichens (as reviewed in **Section 2.2.3 Harvesting wila for food** on page 88) are the colour of the lichen, and the environment where the lichen is growing (both the general location and the specific substrate). Unfortunately, neither of these characteristics is adequate to consistently differentiate specific *Bryoria* specimens to the level necessary to distinguish edible *Bryoria fremontii* from the inedible groups of *Bryoria* listed above. However, both the colour of a lichen and the environment where it is growing do reveal some information about that lichen, and this may be useful in determining its edibility.

3.2.1 Using colour to determine edibility

The toxin vulpinic acid is bright yellow, and *Bryoria tortuosa* (which has high levels of vulpinic acid) tends to be more yellow than *Bryoria fremontii* (which has lower levels of vulpinic acid). However, this is not always the case. *Bryoria tortuosa* often contains significant amounts vulpinic acid in its outer cortex and thus appears yellow. However, in many specimens the vulpinic acid restricted to the medulla, and the yellow colour cannot be seen without dissection and magnification (Crawford, pers. obs.; Goward, pers. comm.; Brodo and Hawksworth 1977). See **Figure 1.4 C** for an explanation of these lichen organs.

Other species of *Bryoria* are often different shades of brown. *Bryoria capillaris* (*Bryoria* sect. *implexae*) is almost always much lighter in colour than *B. fremontii*. *Bryoria pseudofuscescens* (also *Bryoria* sect. *implexae*) is much more variable in colour, but can also be lighter in colour than *B. fremontii*.

3.2.2 Using environmental cues to identify edible lichen

Some species of *Bryoria* prefer relatively open, well-ventilated habitats while others are dominant in more sheltered habitats with less ventilation (see **Section 2.3.2 Population ecology of *Bryoria* species** on page 109), and there are likely numerous other examples of habitat differentiation within the genus *Bryoria* that have yet to be described. Of particular significance is the possibility that the vulpinic acid rich *Bryoria tortuosa* may be restricted to more open, sunny areas while *Bryoria fremontii*, with very little vulpinic acid, is much more widespread (Goward and Ahti 1992; Goward, pers. comm. 2007). Although most of these habitat preferences are not absolute, habitat type can be a good indication of the relative abundance of certain species of *Bryoria*.

There is substantial intraspecific variation in vulpinic acid concentration (and thus toxicity) in both *Bryoria fremontii* and *B. tortuosa* (see **Section 2.4.1.1 The secondary chemistry of *Bryoria fremontii* and *Bryoria tortuosa*** on page 115). It is possible that this variation may be correlated to habitat type, as intraspecific variation in lichen secondary compounds is often correlated to environmental factors (see **Section 1.5.1.1 Variation in lichen compounds between and within lichens** on page 32). If *B. tortuosa* (which is almost identical to *B. fremontii*, except for having much higher

vulpinic acid concentrations) prefers more sunny habitats, it seems possible that vulpinic acid concentration within each species could also vary according to levels of sunlight. Unfortunately, there is no published evidence for this correlation.

3.2.3 Identifying populations of edible *Bryoria fremontii*

Indigenous lichen experts often do not categorize lichens at the scale of individual lichen thalli. Instead, large clumps of lichen that contain many similar-looking thalli are identified as edible or inedible. Although neither colour nor habitat choice are sufficient to reliably determine the edibility of individual lichen thalli, at larger scales (e.g. all the lichens on a single tree) these characters may be a good indication of the presence or abundance of certain species of *Bryoria* and of the concentrations of secondary compounds in those species, and thus the edibility of that lichen community.

3.2.4 Objectives

I undertook the following study to help elucidate how traditional identification methods are successful in differentiating edible and inedible *Bryoria* species. Two traditional identification techniques were examined: using colour to determine edibility; and using the lichens on one tree to determine the edibility of lichens on nearby trees.

This study examined *Bryoria* species at the spatial scales that are encountered by traditional harvesters (eg. all the lichen that can be collected from one tree). This was done for two reasons. First of all, considering the lichen at the same level of precision as is employed by traditional wila experts is perhaps more directly applicable to trying to understand their traditional techniques. Secondly, a more precise study was not possible using the resources available to me.

This study does not have a high enough level of precision to allow for deciphering the complex ecology of *Bryoria*. I am attempting to investigate how the quality of collectable lichen from a given tree is correlated with traditionally observed characteristics. I cannot, however, determine the ecological causes of those correlations. I am therefore trying to understand how, but not why, traditional identification methods are successful.

3.3 Methods

3.3.1 Lichen collection

Lichen was collected from eight sites in traditional Secwepemc territory near Salmon Arm, BC. These sites were specifically selected to be located in possible traditional harvesting areas for wila (*Bryoria fremontii*). All sites had abundant growth of *Bryoria* species and were close to Secwepemc communities, and they were all in areas that Secwepemc community members had recommended as good places to go looking for wila. The sites ranged over an area 40 km across. They varied in elevation from 550 m to 1310 m, and were all dominated by Douglas-fir (*Pseudotsuga menziesii*). The locations of the eight collection sites are listed in **Table 3.1**, and mapped in **Figure 3.1**.

Lichen was collected from ten trees at each site. As much lichen was harvested from each tree as was practical by employing several different collection methods that would have been available to indigenous lichen harvesters in the past (pictured in **Figure 3.2**). Lichen was pulled off from any low hanging branches by hand. If the tree was climbable without using tree climbing equipment, it would be climbed to access more lichen. In these cases arborist safety equipment was used to secure the harvester to the tree for safety, but it was not used to aid in climbing. A lichen-collecting stick was used to pull down lichen hanging from branches, as is a common traditional practice (see **Section 2.2.3.3 How to collect the lichen** on page 91). This stick was also used to knock down dead branches so lichen could be collected from them on the ground.

3.3.2 Lichen identification by traditional methods

Six *Bryoria* species samples were shown to Dr. Mary Thomas, a Secwepemc elder of the Neskonlith community and respected expert on collecting, preparing, and eating wila (*Bryoria fremontii*). Each lichen sample is all the *Bryoria* species that could be harvested from an individual tree in the process described above. The six lichen samples were chosen to be representative of the visual variation present in the 80 lichen samples collected. Mary Thomas' comments on each lichen sample were audio recorded and transcribed.

3.3.3 Lichen identification by scientific methods

Each lichen sample is the total amount of lichen that could be harvested from an individual tree employing traditional harvesting techniques, and not the total amount of lichen that was growing on that tree. Lichen was only collected from an individual tree as long as further harvesting efforts continued to obtain significant amounts of lichen, which was a subjective decision for each tree.

Obtaining a value for the total abundance for each lichen species on each tree would have required collecting all the lichen from every tree, separating and identifying every individual piece of lichen, and then weighing the total amount of each lichen species. This was logistically impossible, so instead the relative abundance of each lichen species on each tree was recorded as a percentage of the total lichen collected from that tree.

Each lichen sample was moistened to make it more pliable, and spread out evenly over a 1 m² area of the workbench in a layer approximately one thallus thick. Representative lichen thalli were pulled out of the sample and identified using a dissecting scope and chemical tests. A visual estimation was then made of the percent of the 1 m² of workbench that was covered by each lichen species. Voucher specimens were taken of each species.

Numerous arboreal species of *Bryoria* are present in the study area (see **Table 3.2** for a summary of the relevant species and their identifying characters). However, given the specific objectives of this study, not all were identified to species, and some lichens were identified past the species level. The taxonomy used for classifying the *Bryoria* species in each sample is described below.

3.3.3.1 Classification of *Bryoria fremontii* and *Bryoria tortuosa*

The accepted convention in *Bryoria* taxonomy is to follow the proposal of Brodo and Hawksworth (1977) and divide *Bryoria* sect. *tortuosa* into two species, *B. tortuosa* and *B. fremontii*. More recently, however, some lichenologists have contended that there is a continuum of morphologies between *B. fremontii* and *B. tortuosa*, and that this species distinction may not be valid (Goward and Ahti 1992; Halonen, pers. comm. 2005).

The species distinction between *Bryoria tortuosa* and *B. fremontii* as defined by Brodo and Hawksworth (1977) is based mainly on the nature of their pseudocyphellae (size, abundance, and colour, see **Figure 3.6**) and their chemistry (concentration of vulpinic acid). Indigenous lichen experts traditionally do not directly use either of these characters, and instead rely on colour as a main defining character for hair lichen taxa (along with substrate and location, see **Section 1.3.4 Folk taxonomy and identification of lichens** on page 20 for more details).

The issues mentioned in the preceding two paragraphs create two taxonomic problems: The current species distinction between *Bryoria tortuosa* and *B. fremontii* is inadequate to clearly delineate the two species, and the classification system used by lichenologists conflicts with the one used by indigenous lichen experts who are familiar with edible lichen. I attempted to account for both of these problems by dividing these two species into five categories based on both the criteria of Brodo and Hawksworth (1977) and on colour criteria compatible with the traditional classification by indigenous lichen experts. It is important to note that there is no simple chemical test to determine vulpinic acid concentration. As a result, conventional lichen identification keys do not directly measure this character to differentiate *Bryoria tortuosa* and *B. fremontii* (Brodo and Hawksworth 1977). I also did not directly measure vulpinic acid concentration.

The five categories created for *Bryoria* sect. *tortuosa* (*B. fremontii* and *B. tortuosa*) are outlined below. Colour definitions follow Kornerup and Wanscher (1967), and are detailed in **Table 3.3**.

- *Bryoria fremontii*: Main branches less twisted than *B. tortuosa*. Pseudocyphellae are often absent, but when they are present they are small, sparse, and white (see **Figure 3.6**). Representative colour morphotypes are pictured in **Figure 3.3**.
 - (1) *Bryoria fremontii* **morph. dark**: Mostly soot brown with some darker strands, and some lighter strands of dark blond.
 - (2) *Bryoria fremontii* **morph. light**: Mostly khaki, with some lighter strands of absinthe yellow and some darker strands of bronze.
- *Bryoria tortuosa*: Specimens do not get as large as *B. fremontii*, but the old branches can still get very thick and often very twisted and furrowed. Pseudocyphellae are abundant, large, long, and often spiraling around the

branches (see **Figure 3.6**). The majority of the pseudocyphellae are yellow, but some white ones may be present as well. Representative colour morphotypes are pictured in **Figure 3.4**.

- (3) *Bryoria tortuosa* **morph. yellow**: Mostly olive yellow to chartreuse, with some darker strands of olive.
- (4) *Bryoria tortuosa* **morph. brown**: Mostly olive brown, with some lighter strands of khaki and honey yellow, and some darker strands of sepia.
- Intermediate: Pseudocyphellae are absent or sparse, when they are present they are small and usually white, with occasionally a few yellow ones.
- (5) *Bryoria tortuosa* x *fremontii* **intermediate**: Absinthe yellow with some darker strands of olive.

3.3.3.2 Classification of other *Bryoria* species

Several other species of *Bryoria* were collected along with *Bryoria fremontii* and *B. tortuosa*. These other species can be grouped into two categories: *Bryoria* sect. *implexae* (which includes *B. capillaris* and *B. pseudofuscescens*, see **Figure 3.5**), and *Bryoria fuscescens* sensu lato (which includes *B. fuscescens*, *B. glabra*, and/or *B. lanestris*). These two groupings, *B. implexae* and *B. fuscescens* s. l., make both ecological and taxonomic sense (see **Section 2.3.2 Population ecology** on page 109). Because of this, I acknowledged these groupings in both identifying the lichens and the subsequent statistical analysis.

I identified the two *Bryoria* sect. *implexae* lichens (*B. capillaris* and *B. pseudofuscescens*) to the species level because they are easily differentiated via chemical tests. The *Bryoria fuscescens* sensu lato lichens (*B. fuscescens*, *B. glabra*, and *B. lanestris*) are more difficult to differentiate. They are also not particularly culturally important and only present in small quantities, while having identical chemistry (and thus similar nutrition/toxicity) and very similar ecology. Therefore I deemed it unnecessary to identify them to the species level and called them all *Bryoria fuscescens* s. l.

The different taxa of *Bryoria* that were identified in the current study, as described above, are listed in **Table 3.4**.

3.3.4 Statistical methods used for determining community associations

3.3.4.1 Use of relative abundance data

Statistical analysis on relative species abundance brings with it some unique considerations. The data matrix is actually a profile of relative abundances (also called compositional data) instead of raw abundance data. Euclidean-based ordination methods such as principal-component analysis (PCA) and redundancy analysis (RDA) can be performed on this compositional data matrix, comparing the distance between species profiles (Legendre and Gallagher 2001). Using the profile of relative abundances for these tests instead of the raw abundance data can provide a more accurate measure of similarity/dissimilarity between species, particularly if the data is not normally distributed, has many rare species, and/or has many sites where certain species are absent (Legendre and Gallagher 2001).

Legendre and Gallagher (2001) recommend that in most cases, these Euclidean-based ordination methods provide an even more accurate measure of similarity/dissimilarity if the Hellinger distance (Rao 1995) is used instead of the distance between species profiles. The data transformation necessary to use the Hellinger distance is merely the square root of the relative abundance, and thus a Hellinger transformed data matrix can easily be obtained from the current data set.

According to Legendre (2005b), the Hellinger transformation also provides acceptable projections of the correlations among species in principal component space, and he therefore recommends it for finding species associations in communities, because community species composition data typically contains many zeros (species that are absent from specific sites). Legendre (2005b) uses Kendall's Coefficient of Concordance (W), Spearman's rank correlation coefficient, and principal components analysis (PCA) on Hellinger transformed species abundance data to look for species associations. The square root part of the Hellinger transformation has no effect on the Kendall W or Spearman correlation, as both these tests use ranks, but it does affect the PCA (reducing the influence of highly abundant species).

3.3.4.2 Determining differences between sites

In order to determine if the eight sites where lichen was collected are significantly different from each other, an analysis of variance is required to test if variation between the sites is significant compared to the variation found between individual trees within the same site. This test will decide if there is more similarity between the communities of *Bryoria* species on nearby trees (trees from the same site) than on distant trees (trees from different sites).

The abundance of one lichen species on a tree will likely have a strong effect on the abundance of another lichen species on that same tree. Because of this, the abundances of different lichen species collected from the same tree are not independent and cannot be used as independent samples. Both parametric and non-parametric analyses of variance require independent samples. To overcome this limitation, the species composition of each tree can either be summarized by a single value (possibly generated by a principal components analysis), or each species can be analyzed separately. Because of the relatively small number of species involved, the latter option was adopted for the current analysis.

A Kruskal-Wallis (1952) one-way analysis of variance by ranks was chosen for this purpose. Varga and Delaney (1998) contend that this test requires equal variances in ranks between different groups, and in cases of unequal variances they recommend a robust ANOVA alternative using a Welch-Satterthwaite (1947) approximate. However, many other authors do not consider unequal variances to be important in a Kruskal-Wallis test (e.g. Siegel and Castellan 1988), and even Varga and Delaney (1998) conclude that the Kruskal-Wallis test is particularly robust to unequal variances as long as each group contains the same number of data points. In the current data set there is some variation in the rank variances between groups, but all groups have the same number of samples, so it was decided that the Kruskal-Wallis test was applicable.

A Kruskal-Wallis statistic (KW) is calculated for each individual lichen species by assigning a rank to each tree based on the abundance of that lichen species on that tree compared to its abundances on all other trees. These ranks are then averaged for each site, and KW is calculated as a measure of disparity between these averaged rankings. A

P-value can then be calculated from KW to determine if the difference between sites is significant for that particular lichen species.

3.3.4.3 Method for understanding the species associations

3.3.4.3.1 Confirming the existence of species associations

Kendall's Coefficient of Concordance (W) (described by: Siegel and Castellan 1988; Legendre 2005b) was used to test if some of the *Bryoria* species were associated with each other. Legendre (2005b) recommends using this test with relative species abundance data to find species associations, making it ideal for the current data set. A disadvantage of this test is that it only detects positive correlations between species. Negative correlations not only remain undetected, they also reduce the power of the test to detect positive correlations.

To calculate Kendall's W, each site is given a rank for each lichen type according to that lichen type's relative abundance in that site compared to the other sites (i.e. the site with the highest relative abundance of species A will be given a rank of 1 for species A). The rankings are then summed for each site. A Kendall's Coefficient of Concordance (W) is calculated as a measure of the variation in these summed rankings. A larger variation shows that the different species are less independent in their relative abundances. A lack of independence indicates that the abundances of certain species are correlated (e.g. sites where the relative abundance of species A is higher than average also have a relative abundance of species B that is a higher than average).

A chi square value can be calculated from W, but with this test the chi square statistic is known to be overly conservative if there are ≤ 20 species or ≤ 7 sites (Siegel and Castellan 1988). In these situations, a probability value can instead be calculated by using an *a posteriori* permutations test (Legendre 2005b). For this test, random values are assigned for each species abundance, and the W is calculated. This is repeated a large number of times, and it is determined how often the actual value for W can occur by chance alone.

3.3.4.3.2 Locating and characterizing the species associations

The method described above calculates a global Kendall's W from the summed rankings for each site to look for overall concordance between all species. This does not indicate *which* species are in concordance, only whether or not there is significant concordance between at least two species. Another *a posteriori* permutations test must be used to decide which species are in concordance (Legendre 2005b). This test looks at each species individually to determine if that species is in concordance with the rest. To test an individual species, random values are assigned for that species' abundances at each site, while all other species are left with their actual abundances, and the new W is calculated. This is repeated a large number of times and the contribution of that species to the actual W is determined. This is then repeated for each species.

Kendall's W and its *a posteriori* permutations test do not determine if there is more than one group of correlated species (e.g. species A & B are correlated, and species C & D are correlated, but species A & B are not correlated with species C & D), it only tests for which species are concordant. Likely groups of correlated species must be determined by other methods, but they can then be tested with Kendall's W to determine their significance. To do this, an *a posteriori* permutations test for Kendall's W is conducted for just the group of species of interest, and the test reports the concordance of each of those species to the other species in that grouping (Legendre 2005b).

Determining the most likely groups of correlated species is most easily done with a Spearman (1904) rank correlation table (Legendre 2005b). By itself, the Spearman's test is not very powerful because it tests each interaction separately, and the likelihood of committing a Type I error increases with multiple testing (as more tests are performed, it becomes more likely that a significant correlation will be falsely shown for variables that are not actually correlated). To solve this problem, the Spearman correlation table needs a multiple testing correction, which significantly reduces its power to find real effects. The Bonferroni (1936) adjustment is commonly used to correct for multiple testing, however Wright (1992) concludes that this is too conservative for sets of non-independent tests like these, and recommends the Holm (1979) adjustment instead.

3.4 Results

3.4.1 Traditional identification compared to species composition

As described by Dr. Mary Thomas, the most important characteristic for determining the quality of each *Bryoria* species sample for eating was the colour of the sample. Mary Thomas considered lichen samples that were darker in colour to be preferable for eating, while lighter coloured samples would be bitter tasting. Her comments on the individual lichen samples are tabulated and compared to the species composition of each sample in **Table 3.5**.

Only samples that were almost entirely *Bryoria fremontii* were identified as being ideal for eating. If each lichen sample is given a score of 1–4 based on Mary Thomas' comments as to their quality, an ordinal logistic regression shows that the percent of *B. fremontii* had a significant effect on the quality rating of the lichen sample ($X^2 = 11.19$, $P = 0.0008$, $R^2 = 0.75$), as did the percent of *B. sect. implexae* ($X^2 = 8.57$, $P = 0.0034$, $R^2 = 0.58$), but the percent of *B. tortuosa* did not ($X^2 = 1.34$, $P = 0.2463$, $R^2 = 0.09$). It appears that Mary Thomas identified tasty lichen samples as being those with a greater abundance of *B. fremontii* and a lower abundance of *B. sect. implexae*, while the abundance of *B. tortuosa* may not have been as important for her decision.

3.4.2 Differences between sites

Figure 3.7 compares the relative abundance of the different *Bryoria* species at each of the eight sites, and shows that the composition of the lichen community varied greatly between sites. To determine if this between-site variation was significantly greater than variation between trees within each site, XLStat (2007) was used to conduct a series of Kruskal-Wallis tests on the abundances of all eight lichen species on the 80 trees across the eight sites (**Table 3.6**). The sites were significantly different in relative species abundance for all species present, so it is easily concluded that the sites are significantly different from one another in their composition of *Bryoria* species.

Individual trees cannot be considered as independent samples because the site where an individual tree was located has a significant effect on its lichen community.

Subsequent analysis on the associations between lichen species was therefore only conducted on the variation in average relative species abundances between the eight sites. The values for each site are an average of the ten trees that were at that site.

3.4.3 Associations between different *Bryoria* species

3.4.3.1 Existence of species associations in the data set

The procedure from Legendre (2005b) was used to calculate a global Kendall's coefficient of concordance (W) of $0.144_{(n=8,p=8)}$ as a measure of the level of association between the different lichen species across the eight sites. Because there were fewer than 20 species being tested, a probability value was calculated with an *a posteriori* permutations test, using a program by Legendre (2005a). One million permutations were used to calculate a P-value of 0.325. The concordance (positive association) between all the lichen species was therefore insignificant, probably a result of negative correlations between species obscuring the positive correlations.

A Spearman rank correlation table was calculated to look for associations between the different lichen species across the different sites, using XLStat (2007). See **Table 3.7**. As explained above, this method lacks power for hypothesis testing, but it is appropriate as an exploratory statistical method to determine which lichen species may be correlated with each other.

The negative correlation between *Bryoria fremontii* (dark and light morphotypes) and *Bryoria* sect. *implexae* (*B. capillaris* and *B. pseudofuscescens*) that is suggested by the Spearman test would help obscure any concordance between the other species. To mitigate this effect, Kendall's W was recalculated omitting *Bryoria* sect. *implexae*. A significant concordance was then found between the remaining species ($W=0.382_{(n=8,p=6)}$, $P=0.0145$), using the *a posteriori* test to one million permutations to calculate the P-value.

3.4.3.2 Arranging lichen species into concordant groups

The Spearman test further suggests that the lichen taxa could be divided into four concordant groups (**Table 3.8**). A computer program by Legendre (2005a) was used to

test each of these groups separately for concordance with Kendall's W, as was recommended in Legendre (2005b). All groups were found to have a highly significant level of concordance, with the P-value determined by one million permutations of the *a posteriori* test (**Table 3.8**). When the *a posteriori* test was further used to determine which lichens were concordant with the rest of their group, all individual group members were found to be significantly concordant (**Table 3.8**). When Kendall's W was calculated for any of these four groups plus a random outside lichen, the outsider was always found to be not significantly concordant. This indicates that **Table 3.8** is an accurate way to group the concordant lichen species.

3.4.3.3 Correlations between lichen groups

Spearman's rank correlation test was used to test for correlations between the lichen groups shown in **Table 3.8**. Kendall's W was inappropriate for this test, as it cannot detect negative correlations. The power of the Spearman test was increased by lumping the lichens into their groups and thus reducing the multiple testing correction. Despite this increase in power, no statistically significant correlations were found between groups after applying a multiple testing correction (see **Table 3.9**). However, there was a negative correlation of $r=-0.857$ between *Bryoria fremontii* and *Bryoria* sect. *implexae* which had a P-value approaching alpha ($P=0.064$, $\alpha=0.05$). This may indicate an important negative correlation that could be observed with a larger sample size. If *Bryoria fuscescens* is removed from the test to further increase its power, the P-value of the negative correlation between *Bryoria fremontii* and *Bryoria* sect. *implexae* improves to $P=0.032$ and is significant. Removing *Bryoria fuscescens* from the test might be justified because it was only present in very low abundances at all sites, it does not appear to be correlated with any other *Bryoria* species, and it is not a species of interest.

3.4.3.4 Non-significant but interesting associations between different morphotypes of *Bryoria fremontii* and *Bryoria tortuosa*

There are some relationships between species that are not statistically significant, but nonetheless may be worth considering. A principal components analysis (PCA) using Hellinger transformed species abundances (calculated with XLStat 2007) is shown in **Figure 3.8** and corroborates with the above findings. The PCA visually shows the

groupings confirmed in **Table 3.8** while also showing the negative correlation between *Bryoria fremontii* and *Bryoria* sect. *implexae*, and no correlation with *Bryoria tortuosa* (**Figure 3.8**). However, this PCA also shows another interesting trend that has no quantitative significance.

If the five morphotypes of *Bryoria* sect. *tortuosa* (which includes *B. tortuosa* and *B. fremontii*) were placed on a gradient, with the most yellow *Bryoria tortuosa* type-specimen at one end, and the darkest brown *Bryoria fremontii* type-specimen at the other end, they would be ordered as follows: *Bryoria tortuosa* morph. *yellow* \Leftrightarrow *B. tortuosa* morph. *brown* \Leftrightarrow *B. tortuosa* x *fremontii* intermediate \Leftrightarrow *B. fremontii* morph. *light* \Leftrightarrow *B. fremontii* morph. *dark*. This gradient makes morphological sense, and probably makes chemical sense, given that colour is a likely indication of vulpinic acid concentration.

The relationship between the lichen morphotypes in this gradient is mimicked in the correlations between the abundances of each lichen morphotype shown in the PCA. Each lichen morphotype is more likely to be found in a higher abundance in sites where its most similar lichen morphotype is also found in a higher abundance (see **Figure 3.8**).

3.5 Discussion

Differentiating edible *Bryoria fremontii* from toxic species of *Bryoria* is very important when collecting wila for food. Traditional wila experts are able to cook a tasty, non-toxic meal from the lichen, so they are obviously able to successfully differentiate the correct species, even though they do not use a hand lens or chemical tests. They often cite colour as being an important character to identify edible lichen, despite the fact that any particular specimen of *Bryoria* cannot be specified by colour alone. Their identification method seems to work because colour can be used to identify *Bryoria* communities that are exceptionally high in *Bryoria fremontii* and low in other *Bryoria* species contaminants.

3.5.1 Using *Bryoria* sect. *implexae* to identify edible lichen

The abundance of *Bryoria fremontii* was negatively correlated with the abundance of *B. sect. implexae*, while the abundance of *B. tortuosa* was not correlated with either *B.*

fremontii or *B. sect. implexae*. Because of this, avoiding trees with abundant *B. sect. implexae* populations will tend to increase the abundance of the edible *Bryoria fremontii* while having no effect on the abundance of the the toxic *B. tortuosa*. This could increase the amount of *Bryoria fremontii* relative to *B. tortuosa*.

The two *Bryoria sect. implexae* species present in the study area were *B. capillaris* and *B. pseudofuscescens*. *Bryoria capillaris* is exceptionally light-coloured for a *Bryoria* species, and is thus very easy to differentiate visually. *Bryoria pseudofuscescens* can be very dark, even darker than *B. fremontii*, but is also often very light-coloured. As a result of this, lichen samples with a high proportion of *B. sect. implexae* are usually immediately obvious because they have a lot of exceptionally light coloured *Bryoria* in them.

Although *Bryoria fremontii* can be very difficult to visually distinguish from *B. tortuosa*, it is usually quite easy to determine if a lichen population on an individual tree has a high proportion of *B. sect. implexae*. The abundance of *B. sect. implexae* can therefore be used as a simple visual proxy to preferentially select edible *Bryoria fremontii* over the toxic *B. tortuosa*.

This suggestion to avoid *Bryoria sect. implexae* when collecting wila appears to be consistent with the expertise of a variety of indigenous lichen experts. Dr. Mary Thomas uses the abundance of *Bryoria sect. implexae* as an important criterion for selecting tasty wila when she avoids lighter-coloured lichens, and there are numerous reports in the literature of lighter-coloured *Bryoria* being avoided when collecting lichens for food (see **Section 2.2.3.1 Where to collect the lichen and how to identify the right type** on page 88). It is possible that *Bryoria sect. implexae* is an even greater deterrent than *Bryoria tortuosa* for Mary Thomas when she is selecting edible wila, because this appeared to be the case for the six lichen samples that she examined in **Table 3.5**.

Some indigenous lichen experts may have used more characteristics than just colour to avoid *Bryoria sect. implexae*. Aimee August, a Secwepemc elder, described another species of *Bryoria* that she called *tqwesimáka7* (in an interview with Bouchard and Kennedy recorded in: Turner 1998): "...black and pretty much the same as *wíla* [*Bryoria fremontii*], but finer. It hangs down as much as two feet, like *wíla*, but they grow in birch or any tree, but not cottonwood [instead of growing on just Douglas-fir,

like wila]. It grows from the damp and fog, in damp places.” She also noted that *tqwesimáka7* was good for starting fires, but not for food. (See **Section 2.2.3.1** on page 88 for more details.)

Aimee August’s description of *tqwesimáka7* sounds like an accurate description of *Bryoria* sect. *implexae*. If this is true, then Aimee August was also recommending avoiding *Bryoria* sect. *implexae* when collecting wila for food. She was also using some additional characters to identify it, including the fineness of individual branches of the thallus, and the substrate on which it was growing.

3.5.2 Distinguishing cryptic *Bryoria tortuosa* from *Bryoria fremontii*

There are many specimens of *Bryoria tortuosa* that are brown in colour and visually indistinguishable from *Bryoria fremontii* without the use of a hand lens (see **Figure 3.3** and **Figure 3.4**). Some specimens of *Bryoria tortuosa* are bright yellow in colour (see **Figure 3.4**) and very easy to visually differentiate from *Bryoria fremontii*, but these lichens account for substantially less than half of the *Bryoria tortuosa* specimens that were found in the current study (see **Figure 3.7**).

Fortunately for lichen connoisseurs, the abundance of the indistinguishable *Bryoria tortuosa* morph. *brown* is strongly correlated with the abundance of the very distinctive *Bryoria tortuosa* morph. *yellow*. Therefore, although *Bryoria tortuosa* morph. *brown* cannot be easily identified by merely glancing at the colour of the *Bryoria* species growing on a tree, if you avoid collecting lichen from trees that have significant amounts of the very distinctive *Bryoria tortuosa* morph. *yellow* growing on them, you will also avoid the majority of the difficult to detect *Bryoria tortuosa* morph. *brown*.

Indigenous wila experts are probably aware of this handy indication of toxic lichen. Mary Thomas recommends avoiding greenish lichen when harvesting wila, a recommendation that is often echoed in ethnographic accounts of the lichen (see **Section 2.2.3.1** on page 88).

Some specimens of *Bryoria fremontii* are very dark while others are lighter in colour (see **Figure 3.3**). The dark morphotype of *Bryoria fremontii* is much easier to differentiate from *Bryoria tortuosa* than is the light morphotype. Both morphotypes of *Bryoria fremontii* were quite abundant in the study sites (see **Figure 3.7**).

The abundance of *Bryoria fremontii* morph. *dark* is strongly correlated with the abundance of *Bryoria fremontii* morph. *light*. Therefore, if a tree has lots of the relatively distinctive *Bryoria fremontii* morph. *dark* growing on it, then the lighter-coloured *Bryoria* species on the tree is more likely to be *Bryoria fremontii* morph. *light* than the toxic but difficult to distinguish *Bryoria tortuosa* morph. *brown*. The traditional preference for darker *Bryoria* species, as is discussed above, would likely result in this preferential selection.

3.5.3 A proposal for identifying edible *Bryoria fremontii* by proxy

The lighter coloured specimens of the edible *Bryoria fremontii* are very common and very difficult to visually differentiate from the brown specimens of the toxic *Bryoria tortuosa*, which are also very common. However, if you avoid trees that have lots of the distinctively bright yellow specimens of *Bryoria tortuosa* and/or the distinctively lighter coloured specimens of *Bryoria* sect. *implexae*, and prefer trees that have lots of the distinctively darker coloured specimens of *Bryoria fremontii*, you will end up with lots of *Bryoria fremontii* and not much *Bryoria tortuosa*. This avoidance of the yellowish (greenish) and/or lighter-coloured *Bryoria* species and the preference of the really dark-coloured lichen appears to be a common traditional practice, as recommended by Mary Thomas and many other knowledgeable elders.

3.5.4 Using lichens from one tree to successfully identify larger areas suitable for harvesting wila

The *Bryoria* species composition on individual trees was strongly correlated within sites. As a result, if a particular species of *Bryoria* is abundant on an individual tree, it is likely to be abundant on neighboring trees. The edibility of a lichen sample from an individual tree is therefore a good indication of the suitability of that entire area for harvesting wila for food. The traditional practice of determining a good wila harvesting area by having young hunters bringing back samples of lichen from a variety of areas to be inspected by knowledgeable elders (reviewed in **Section 2.2.3.1** on page 88) would therefore be an effective strategy, as would be expected.

3.5.5 Using other indications to identify edible *Bryoria fremontii*

There are many reports in the literature of other cues besides colour traditionally being used to identify the appropriate *Bryoria* species for eating (see **Section 2.2.3.1** on page 88). These include the tree species on which the lichen is growing, the geographic location, environmental factors (like proximity to a river), and the taste of the lichen. These characteristics may be important in some areas or for some wila experts. However, Mary Thomas did not feel that these criteria were important for selecting the right kind of *Bryoria*, and many other wila experts have also indicated that colour is an important indication of the edibility of the lichen (see **Section 2.2.3.1** on page 88).

3.5.6 Some possible ecological and taxonomic suggestions

It is not possible to draw any conclusions from this study as to the causes of the observed species associations. However, some hypotheses lend themselves well to the data and could perhaps be pursued in future studies.

Bryoria tortuosa and *B. fremontii* are very similar except for their concentrations of vulpinic acid. The continuum of morphologies between these two species that was observed in the current study lends credence to the previously suggested hypothesis that they are in fact different chemotypes of the same species. The current study identified *Bryoria* sect. *tortuosa* along the continuum of *Bryoria tortuosa* morph. *yellow* \Leftrightarrow *B. tortuosa* morph. *brown* \Leftrightarrow *B. tortuosa* x *fremontii* intermediate \Leftrightarrow *B. fremontii* morph. *light* \Leftrightarrow *B. fremontii* morph. *dark*, but there was a continuous gradient of individual specimens between each identified morphotype. The fact that the abundance of each morphotype was most closely correlated with the abundance of the morphotypes most similar to it (see **Figure 3.8**) suggests that this may be a morphological variation induced by some environmental factor.

Chapter 3 Tables and Figures

Table 3.1. Lichen collection sites in Secwepemc territory near Salmon Arm, BC. Collection site locations are mapped in **Figure 3.1**.

Site number	Elevation	General location	Specific location	Coordinates
1	550 m	5.9 km west of Chase	Neskonlith Lk Rd at north park boundary	50° 48' 44.8" N 119° 46' 18.3" W
2	600 m	2.6 km southeast of Chase	Chase Landfill turnoff on Chase-Falkland Rd	50° 48' 19.4" N 119° 39' 37.8" W
3	560 m	6.4 km south of Chase	At first junction on Harper Lake Rd	50° 45' 53.7" N 119° 42' 46" W
4	600 m	7.2 km south of Chase	Dandlicker Rd junction on Harper Lk Rd	50° 45' 28.5" N 119° 42' 41.1" W
5	640 m	7.5 km south of Chase	Matthews Rd intersection above Dandlicker Rd	50° 45' 15.8" N 119° 42' 12.6" W
6	700 m	8.6 km south of Chase	End of public road on Harper Lk Rd	50° 44' 39.4" N 119° 42' 37.1" W
7	870 m	9.6 km southwest of Salmon Arm	Below CP 640-1-43 on southwest face of Mt. Ida	50° 36' 59.4" N 119° 19' 19.6" W
8	1310 m	8.2 km southwest of Salmon Arm	Above CP 640-1-1 on southwest face of Mt. Ida	50° 37' 34.1" N 119° 17' 36.9" W

Table 3.2. *Bryoria* spp. of the interior Pacific Northwest and their identifying characteristics (summarized from: Brodo and Hawksworth 1977; Goward and Ahti 1992; McCune 1997; Goward 1999; Brodo *et al.* 2001).

Species	Thallus length	Branch thickness	Soredia	Pseudocyphellae	Chemistry	Colour and Texture	Other notes
<i>Bryoria glabra</i>	10-15 cm	0.2-0.4 mm	White. Fissural, rare tuberculate. To 1 mm long. Most narrower than branch.	Absent	Soralia PD+ red	Even olive-brown to greenish-black. Smooth, often translucent appearance.	Branching wide, even, U-shaped.
<i>Bryoria lanestris</i>	5-10 cm Rarely to 15 cm	0.1-0.25 mm	Sparse/abundant, occasional absent. Fissural. White often w/ blk flecks To 0.3 mm long.	Absent	Soralia PD+ red	Even brown-black to olive-black, darker and duller, rarely shiny in parts. Brittle branches.	Branching uneven, V-shaped w/ acute angles.
<i>Bryoria fuscescens</i>	5-15 cm Rarely to 30 cm	0.3-0.4 mm Rarely 0.2-0.6 mm	White. Fissural, often tuberculate or spinulose.	Absent	Soralia PD+ red; Cortex usually PD- occasionally PD+ faint to bright red	Dark fuscous-brown, base paling almost white; or entirely pale fuscous. Branches (especially base) often flat, twisting. Often spiny side branches.	Variable. Branching even to uneven, acute to obtuse.
<i>Bryoria simplicior</i>	2-4 cm Rarely to 5 cm	0.2-0.4 mm	Greenish black, occasional white to brownish black. Abundant. Most wider than branch.	Absent	All reactions negative	Even cervine to dark brown or almost black. Shiner. Sparse/frequent lateral spinules with slightly constricted base.	Branching usually even, acute, wider than <i>lanestris</i> . Rare.
<i>Bryoria fremontii</i>	20-45 cm Rarely to 90 cm	Main branch 0.4-1.5 mm Rare 4 mm	Rare. Bright yellow, wart-like.	Sparse or absent. White.	All reactions negative	Yellowish to reddish brown or dark brown. Usually shiny. Uneven branches become twisted, foveolate, often flattened.	Apothecia rare, brown w/ bright yellow pruina
<i>Bryoria tortuosa</i>	to 30 cm	Main branch 0.4-1.0 mm	Rare. Bright yellow.	Usually abundant. Bright yellow. Twists around branches.	PD+ pale to bright yellow; or PD- yellow;	Dark red-brown to dusky yellow. brown, occasional bright yellow. Usually dull. Uneven branches become twisted, foveolate, flat.	Apothecia rare, brown w/ bright yellow pruina

Table 3.2 cont'ed. *Bryoria* spp. of the interior Pacific Northwest and their identifying characteristics.

Species	Thallus length	Branch thickness	Soredia	Pseudocyphellae	Chemistry	Colour and Texture	Other notes
<i>Bryoria capillaris</i>	10-15 cm Rarely to 30 cm	0.1-0.3 mm Rarely 0.5	Absent	White, faint on pale lichens. Fusiform. 0.1-0.25 mm long.	Medulla & cortex PD+ deep yellow, K+ yellow, KC+ red, C+ pink or C-	Pale greenish grey to grey; or a darker uneven, dull smoky brown or brownish grey.	Usually paler than other <i>Bryoria</i> .
<i>Bryoria pseudo-fuscescens</i>	5-10 cm	0.15-0.35 mm. Rarely 0.8 mm w/ branch pits, contorted	Absent	Usually abundant. White. Fusiform to elongate, often spiral partly around branch	Medulla & cortex PD+ yellow, K+ yellow changes to dull reddish brown	Very pale grayish brown to almost black. Branches slender, usually uneven, often twisted.	Generally darker than other <i>Bryoria</i> .
<i>Bryoria implexa</i>	6-15 cm	0.1-0.3 mm	Absent	Sparse-abundant, white, conspicuous, elongate fusiform, usually depressed. To 1.5 mm.	PD+ bright yellow, K-		Rare
<i>Bryoria friabilis</i>	to 15 cm			Abundant. Brown to white. Broadly fusiform.	Apothecia PD+ deep yellow, KC+ pink; Cortex KC+ pink, C+ red/pink, but hard to detect	Very pale cervine brown, often olive coloured. Very brittle. Branches usually uneven, very contorted, wrinkled, foveolate.	Rare
<i>Bryoria chalybeiformis</i>	8-15 cm Rarely to 20 cm	0.5-1.0 mm Rarely 0.3-2	Absent/ sparse	Absent	Soralia PD+ red Medulla very PD+ red in parts	Brown to dark brown or olive-black, often paler base. Usually shiny, smooth. Main branches usually twisted, foveolate, often channelled.	Usually on rocks and soil, rare on trees.
<i>Nodobryoria oregana</i>	to 17 cm	Base 0.25-0.4 mm. Pendant branch 0.1-0.2 mm	Absent	Absent	All reactions negative	Reddish brown. Dull. Branches channelled, foveolate, angular. Brittle, jigsaw puzzle surface.	Apothecia infrequent, lateral.
<i>Nodobryoria abbreviata</i>	to 2.5 cm	Base 0.3-1.0 mm. Main stem 0.2-0.4 mm	Absent	Absent	All reactions negative	Same as <i>N. oregana</i> .	Apothecia common, subterminal, rarely lateral.

Table 3.3. Colour definitions used for differentiating different colour morphologies of *Bryoria fremontii* and *B. tortuosa* according to the Methuen (Kornerup and Wanscher 1967) and Munsell (1929) colour systems.

Colour	Methuen colour code	Munsell colour code
Soot brown	5F5	9YR 3.5/2.0
Bronze	5E5	8.5YR 4.5/3.1
Dark blond	5D4	8.5YR 5.5/2.8
Sepia	4F5	6.5Y 3.4/1.9
Olive brown	4E5	5Y 4.8/3.1
Khaki	4D5	5.5Y 5.9/4.1
Honey yellow	4D6	5.5Y 5.8/5.6
Olive	3F5	8.5Y 3.4/1.9
Olive yellow	3D6	7Y 5.8/5.6
Absinthe yellow	3C5	6.5Y 6.9/4.7
Chartreuse	2C6	9.5Y 6.9/6.8

Table 3.4. Taxonomy of *Bryoria* species collected and identified from trees in Secwepemc traditional territory around Salmon Arm, BC.

Section	Species	Colour morphology
	<i>Bryoria fremontii</i>	<i>Bryoria fremontii</i> morph. dark <i>Bryoria fremontii</i> morph. light
<i>Bryoria</i> sect. <i>tortuosa</i>	<i>Bryoria tortuosa</i>	<i>Bryoria tortuosa</i> morph. yellow <i>Bryoria tortuosa</i> morph. brown
	<i>Bryoria tortuosa</i> x <i>fremontii</i> intermediate	
<i>Bryoria</i> sect. <i>implexae</i>	<i>Bryoria capillaris</i> <i>Bryoria pseudofuscescens</i>	
<i>Bryoria fuscescens</i> sensu lato	<i>Bryoria fuscescens</i> , <i>B. glabra</i> , and/or <i>B. lanestris</i>	

Table 3.5. A Secwepemc elder's evaluation of the quality of six different samples of raw lichen, compared to the species composition of each sample. The suitability of each lichen sample for cooking was evaluated by Dr. Mary Thomas, a Secwepemc elder and respected expert on collecting, preparing, and eating wila. Each lichen sample was in its raw, unprocessed form and represented all the lichen that could be harvested from an individual tree using traditional harvesting methods. The trees were selected to have abundant growth of *Bryoria* species and were growing at various sites in Secwepemc traditional territory by Salmon Arm, BC (see **Table 3.1** and **Figure 3.1** for the locations of each site).

Collection Site #	Lichen Quality	Percent composition of different <i>Bryoria</i> species			
		<i>B. fremontii</i>	<i>B. tortuosa</i>	<i>B. implexae</i>	<i>B. fuscescens</i>
8	Excellent	98%	0.5%	1%	0.5%
4	Edible if you pull out the lighter bits of lichen	33%	41%	25%	1%
5	Preferably don't eat	35%	0%	60%	5%
3	Bad	15%	34.5%	50%	0.5%
3	Bad	5%	30%	60%	5%
7	Bad	0%	0%	97%	3%

Table 3.8. Concordant groupings of lichen taxa as suggested by Spearman's rank coefficients and determined by Kendall's coefficient of concordance. A global Kendall's W is calculated for each group, and the P-value determined by one million permutations of an *a posteriori* test. A Kendall's W and associated P-value is also calculated for each individual species' concordance to the other members of its group by one million permutations of an *a posteriori* test. P-values for individual species' concordance are adjusted for Holm's correction for multiple testing. n = 8 sites for all tests.

Lichen taxa groupings: Individual species	Within-group global test for concordance		Concordance of individual species to the rest of the group		
	W	P	W _(i)	P	P _{adj}
<i>Bryoria fremontii</i> :	0.940	0.004			
<i>B. f. morph. dark</i>			0.940	0.004	0.007
<i>B. f. morph. light</i>			0.940	0.004	0.007
<i>Bryoria tortuosa</i> :	0.884	<0.0001			
<i>B. t. morph. yellow</i>			0.841	0.016	0.016
<i>B. t. morph. brown</i>			0.913	0.001	0.003
<i>B. t. x f. inter.</i>			0.897	0.002	0.005
<i>Bryoria</i> sect. <i>implexae</i> :	0.893	0.014			
<i>B. capillaris</i>			0.893	0.014	0.028
<i>B. pseudofuscescens</i>			0.893	0.014	0.028
<i>Bryoria fuscescens</i> s. l.					

Table 3.9. Spearman correlation table for relative abundances of lichen species across eight collection sites, after the lichen taxa lumped into concordant groups (as determined by Kendall's W): r = Spearman's rank correlation coefficient, P = P-value, P_{adj} is the P-value adjusted for Holm's multiple testing correction. **Bold** indicates significance before correcting for multiple testing, no correlations are significant after correction.

Species		Correlated with		
		<i>tortuosa</i>	<i>implexae</i>	<i>fuscescens</i>
<i>B. fremontii</i>	r	-0.048	-0.857	-0.619
	P	0.935	0.011	0.115
	P _{adj}	0.935	0.064	0.575
<i>B. tortuosa</i>	r		-0.310	0.238
	P		0.462	0.582
	P _{adj}		1.847	1.164
<i>B. sect. implexae</i>	r			0.286
	P			0.501
	P _{adj}			1.502



Figure 3.1. Lichen collection sites in Secwepemc territory near Salmon Arm, BC.



Figure 3.2. Collecting *Bryoria* species in Secwepemc traditional territory on Mt. Ida by Salmon Arm, BC: **A.** Climbing a tree to get lichen; **B.** Using a lichen-collecting stick; **C.** Mt. Ida in the winter, as seen from the Fly Hills.

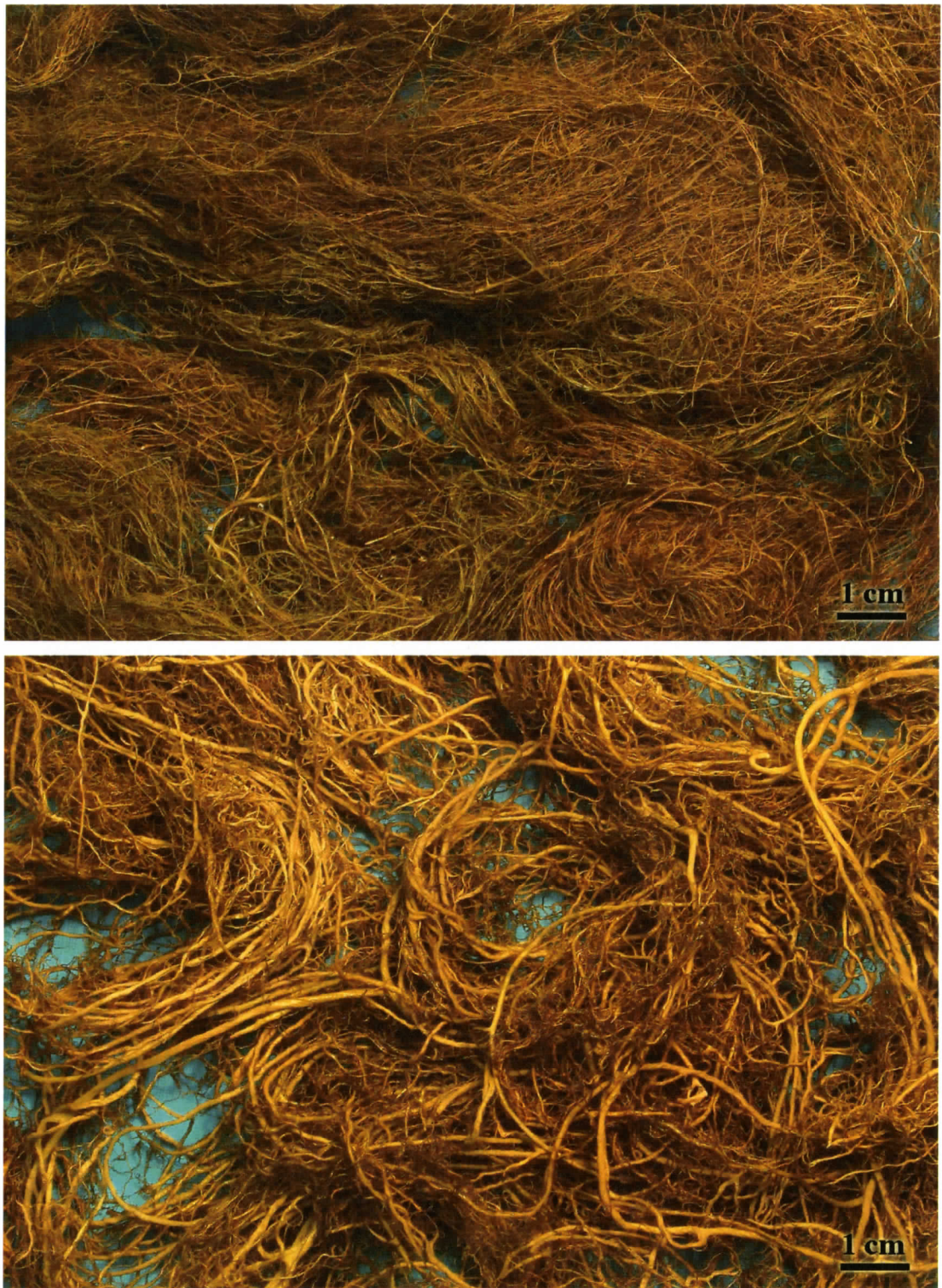


Figure 3.3. Two different colour morphologies of edible lichen *Bryoria fremontii* that grow on trees where wila might be collected for food. Collected off Douglas-fir by Salmon Arm, BC. **Top:** dark brown. **Bottom:** light brown.

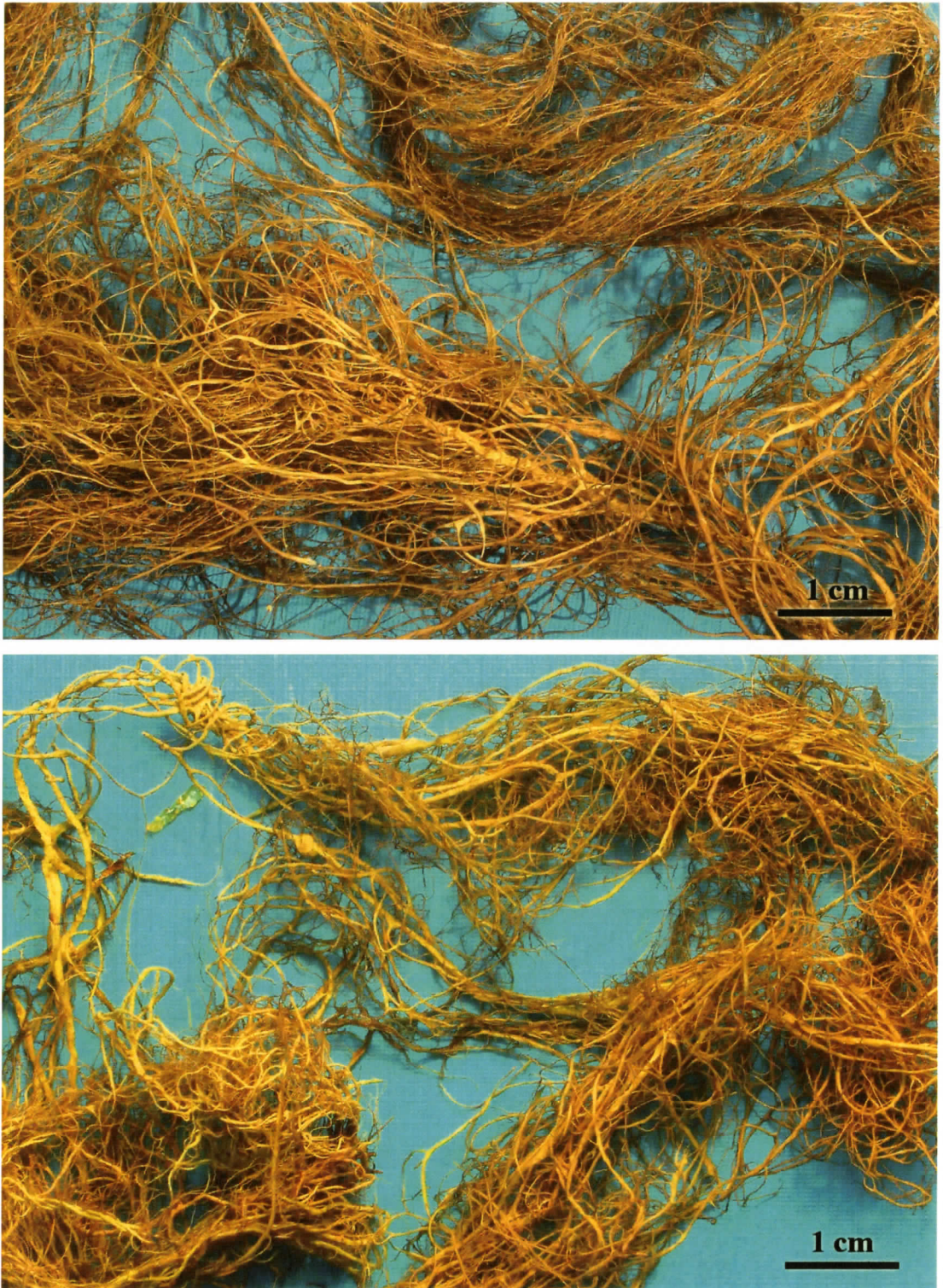


Figure 3.4. Two different colour morphologies of toxic lichen *Bryoria tortuosa* that grow on trees where wila might be collected for food. Collected off Douglas-fir by Salmon Arm, BC. **Top:** brown. **Bottom:** yellow.



Figure 3.5. Bitter lichen *Bryoria pseudofuscescens*, another species of *Bryoria* that grows on trees where wila might be collected for food. Collected off Douglas-fir by Salmon Arm, BC.

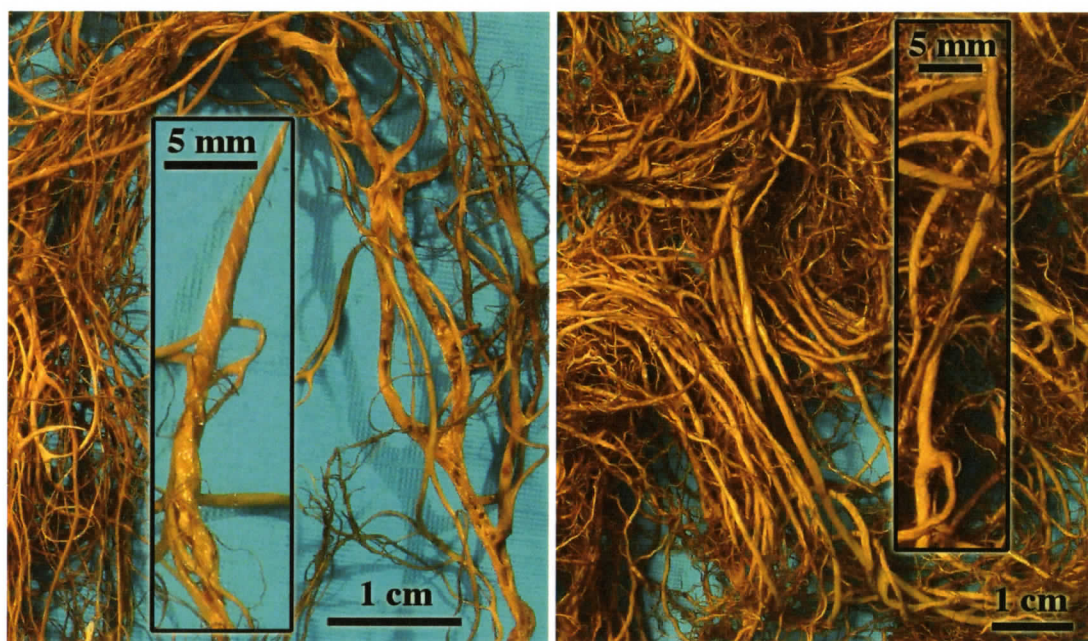


Figure 3.6. Contorted, pitted main branches with prominent yellow pseudocyphellae typical of *Bryoria tortuosa*, (left), and smoother main branches without pseudocyphellae typical of *Bryoria fremontii* (right). Both collected off Douglas-fir by Salmon Arm, BC.

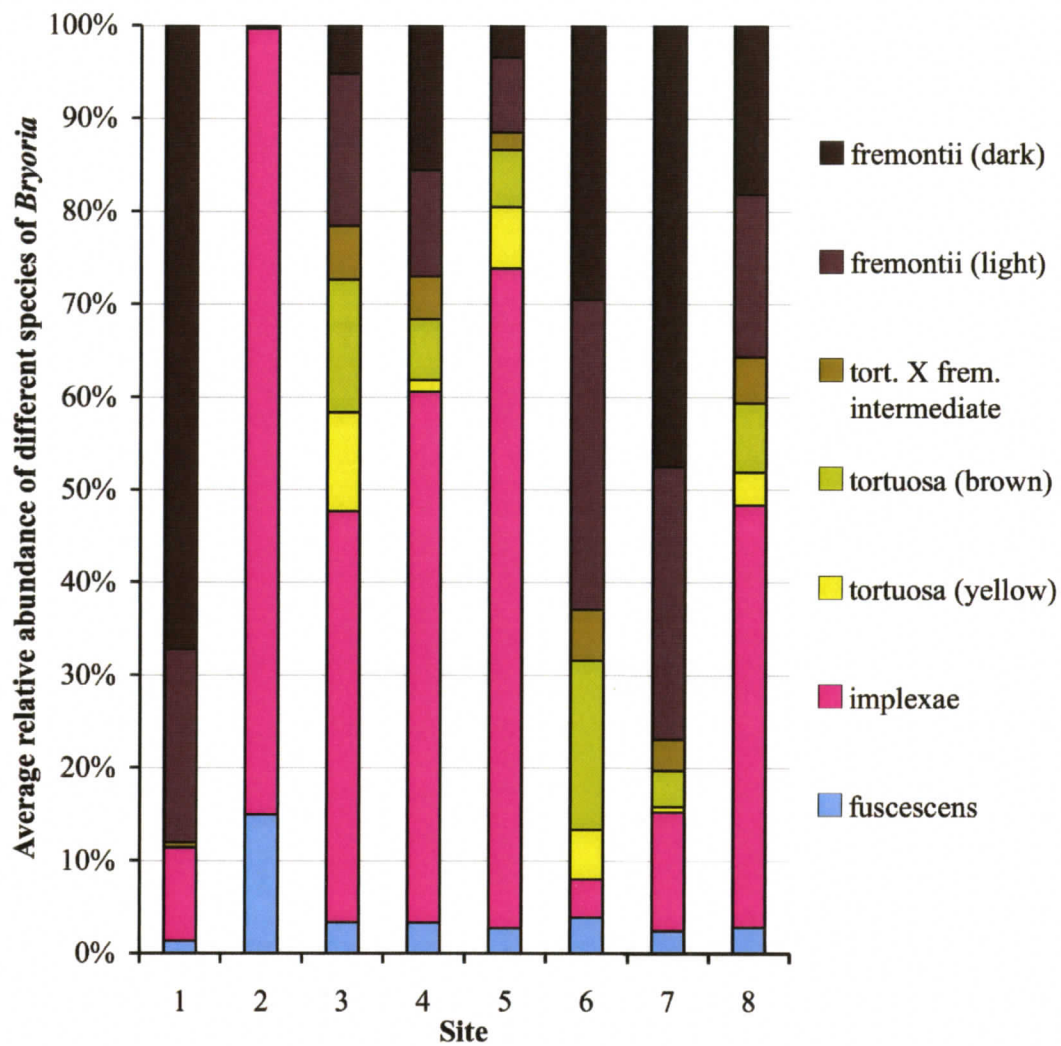


Figure 3.7. The relative abundance of the different *Bryoria* species present on trees from the eight collection sites. Relative abundance at each site is reported as the average for the ten trees.

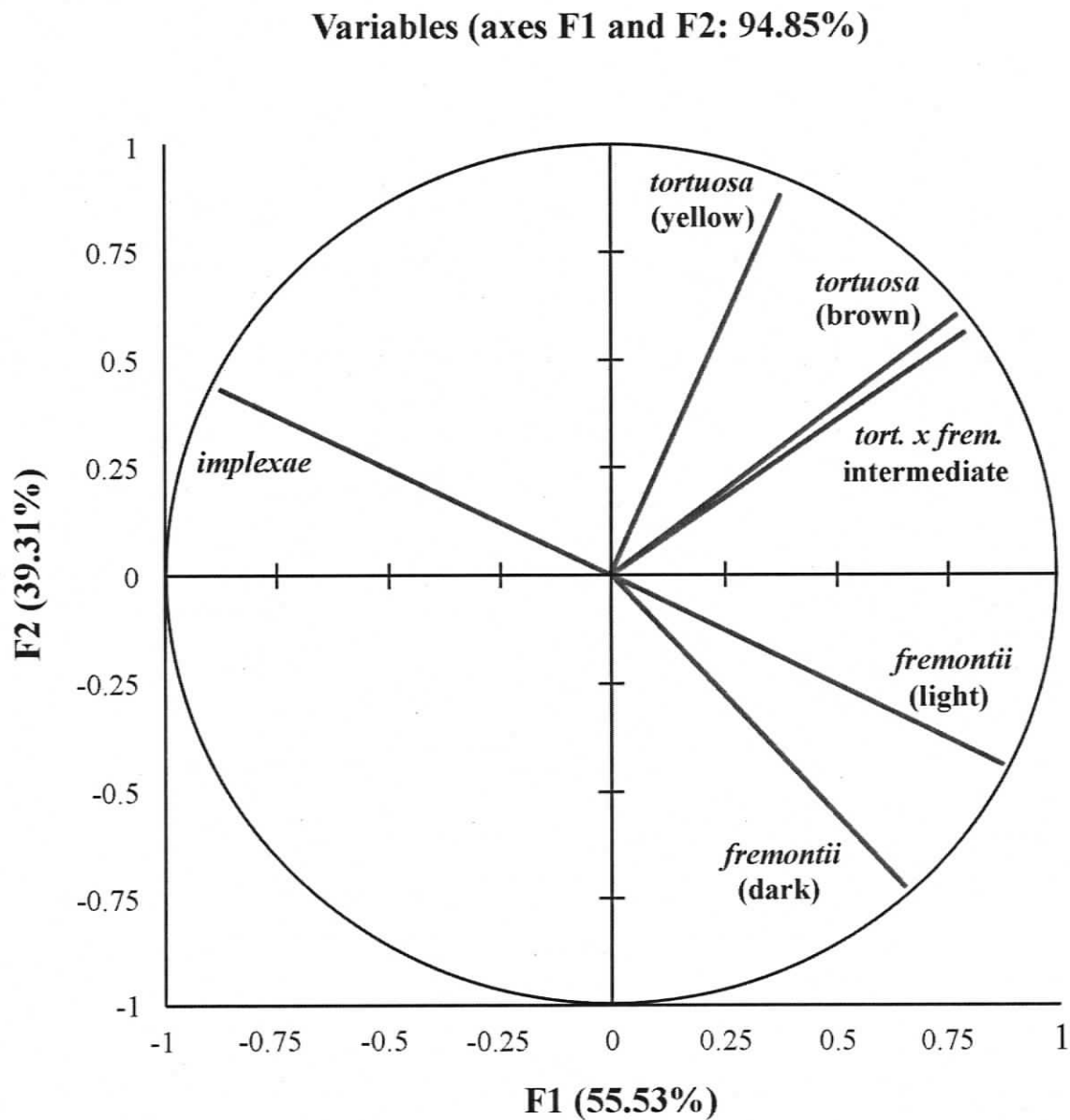


Figure 3.8. Principal Components Analysis (PCA) of Hellinger transformed species abundance for all *Bryoria fremontii* and *B. tortuosa* morphs, as well as *Bryoria* sect. *implexae*. This figure gives a visual representation of how the abundances of different species are correlated across sites. Species that are closer together are more closely positively correlated. Species perpendicular to each other are completely uncorrelated, and species opposite to each other are negatively correlated.

Chapter 4 The effect of traditional cooking methods on the nutritional value of wila (*Bryoria fremontii*)

4.1 Abstract

Wila (*Bryoria fremontii*) is traditionally used for food throughout much of the interior Pacific Northwest, with considerable effort is put into harvesting and preparing this lichen. In apparent contradiction to this, the major nutrients in wila are indigestible carbohydrates. Wila is traditionally pitcooked with root vegetables. It seems very likely that this process contributes significantly to the nutritional value of this lichen. The objective of the following experiment was to elucidate any potential nutritional benefit of cooking wila.

I estimated the most probable conditions in an actual wila pitcook from empirical pitcook data and theoretical models. I used this information to simulate pitcooks in the lab and cooked wila for varying durations ranging from 6 hours to 34 hours. I tested several cooking treatments, including different cooking acidities as well as cooking the lichen with or without camas. I also cooked camas alone to compare to the camas cooked with the lichen. I used a colorimetric microtitre plate enzymatic assay to measure the concentrations of glucose and fructose, which are the breakdown products of lichen and camas storage carbohydrates.

Cooking did not alter the lichen carbohydrates, indicating that lichen is not made digestible by traditional cooking methods. Cooking the lichen and camas together did result in the lichen capturing a significant quantity of digestible camas carbohydrates that would otherwise be lost into the inedible surrounding material of the pitcook. Because of this phenomenon, cooking the lichen with the camas could almost double the amount of available digestible carbohydrate. I suggest that this is the true nutritional value of wila.

4.2 An introduction to the mechanics and importance of pitcooking

4.2.1 Pitcooking lichens to improve their nutritional value

Many lichen species contain small quantities of a variety of nutrients, but carbohydrates are the only nutrient present in *Bryoria* species in quantities large enough to be nutritionally relevant (see **Section 2.4.2 The nutritional value of *Bryoria*** on page 118). The main carbohydrate in *Bryoria fremontii* is lichenin, with isolichenin and a few other carbohydrates possibly present in small amounts (see **Section 2.4.2.1 Carbohydrates in *Bryoria*** on page 119). This is problematic when considering value of this lichen for human nutrition, because it is unlikely that humans can digest lichenin or isolichenin to any useful extent (see **Section 1.5.5 The digestibility of lichens** on page 56). However, both of these carbohydrates are polymers of glucose, and glucose is highly digestible. Many polysaccharides are known to hydrolyze into smaller, more digestible carbohydrates when they are cooked or otherwise processed (Wandsnider 1997; Barham 2001).

Pitcooking is the standard technique for cooking wila among the Salishan and other First Nations of British Columbia (see **Section 2.2.4 Cooking the lichen** on page 91). Many other foods are also traditionally pitcooked by these peoples, as well as those of many other cultures around the world (Sheldon 1905; Ellis 1997; Wandsnider 1997; Dering 1999; Thoms 1999; Brink and Dawe 2003). There are numerous minor variations in the process, but the basic process of burying food with hot rocks and leaving it for several hours to days to cook is quite common, with water often being added to the pitcook after it is buried (Ellis 1997; Wandsnider 1997).

Cooking foods can be important to both detoxify them and to break down nutrients into more digestible forms (Wrangham and Conklin-Brittain 2003). Different cooking styles can alter food in characteristic ways, and pitcooking can have a distinct effect on the nutrients of some foods when compared to other cooking methods (Kumar and Aalbersberg 2006a, 2006b). Pitcooking can induce both chemical (i.e. hydrolyze carbohydrates into smaller molecules) and physical (i.e. rupture starch granules) changes in complex carbohydrates to make them more digestible, with some carbohydrates requiring higher temperatures for longer periods of time to achieve this result

(Wandsnider 1997). Many plant foods are traditionally pitcooked for only 18 hours or less, but some are cooked for longer. The maximum recorded duration for a pitcook is 60 hours to cook the bulbs of sotol (*Dasyilirion wheeleri*), a monocot shrub from southern USA and Mexico (Wandsnider 1997).

Pitcooking can be very successful in breaking down complex plant carbohydrates. Peacock (1998) found that 70% of the inulin⁸ in balsamroot (*Balsamorhiza sagittata*) was broken down into simple sugars after 20 hours in a cooking pit. The temperature of this cooking pit appears to be very important, because a very similar cooking pit conducted at a slightly cooler temperature had very little effect on the inulin (Peacock 1998).

Pitcooking for a longer duration of time may be even more effective at breaking down inulin, because when Konlande and Robson (1972) baked camas bulbs for two days and two nights in a traditional cooking pit (with a fire built on top of the pit at night), as is the traditional Flathead practice as outlined by Malouf (1979), they found that almost 100% of the inulin had broken down into fructose.

Temperature and acidity may be somewhat interchangeable in their effect on plant polysaccharides. Konlande and Robson (1972) found that boiling camas bulbs in water for 80 minutes had effect similar to soaking the bulbs in cold water with hydrochloric acid (at a pH of 2) for 24 hours, both treatments breaking down about 15% of the inulin into fructose. Combining the high temperatures with a lower pH appears to be even more effective, because Yamazaki and Matsumoto (1993) found that 86% of the complex carbohydrates (mostly inulin) in Jerusalem artichoke (*Helianthus tuberosus*) broke down into simple sugars after only 15 minutes at 100°C and a pH of 2.5.

It is possible that the traditional practice of pitcooking wila helps to break down the lichen's carbohydrates into digestible forms. Wila was almost always traditionally pitcooked with other types of food, particularly root vegetables (see **Section 2.2.4.4 Food that the lichen is cooked with** on page 96). It is possible that when these different foods are cooked together they have a significant effect on each other.

⁸ Inulin is an indigestible polymer consisting of a chain of 2–200 fructose moieties linked by β -(2→1) bonds. It may have some branching, as well as a single glucose moiety at one end (Franck and de Leenheer 2002).

To understand the nutritional value of *B. fremontii* for humans, it is necessary to determine what effect the traditional method of pitcooking this lichen has on its carbohydrate content. This includes ascertaining if there is any synergistic effect of pitcooking the lichen with other foods.

4.2.2 The essential parameters of a pitcook

Cooking is a chemical reaction. The chemical changes that occur in the food are dependent on the temperature and pH of the cooking environment, and the length of time the food is subjected to it. Furthermore, particularly with traditional cooking methods, temperature and pH are often not constant over the entire period of cooking. This temporal variation in temperature and pH may also affect how the food cooks.

4.2.3 The thermal dynamics of pitcooks

Knowing the temperature of a pitcook and understanding how that changes over time is the essential first step in deciphering what effect pitcooking has on the food that is being cooked. The factors determining the temperature in the pitcook are outlined below; they are complex and poorly understood.

4.2.3.1 Experimental data on pitcook temperature

Peacock (1998) constructed two roasting pits to cook balsamroot roots, and measured the temperature of these pits over time with two temperature probes per pit. For the first pit she employed the traditional Secwepemc (Shuswap) method of leaving the rocks in a fire at the bottom of the pit until they were red-hot. The second roasting pit was conducted using an apparently more modern Secwepemc method of heating the rocks over a fire beside the pit, and putting them into the pit when they were hot enough. The first, more traditional method of the rocks being heated in a fire at the bottom of the pit has more similarities to pitcooking methods reported for cooking wila by the Secwepemc and other Interior Salish groups (see **Section 2.2.4 Cooking the lichen** on page 91), and was found by Peacock (1998) to get the pit hotter and be much more effective in breaking down balsamroot storage carbohydrates into digestible forms. The roasting pit using this method will therefore be considered to be a better approximation of

a pitcook for wila. In this pitcook, the temperature stayed between 97°C and 98°C for two hours, and then began to rapidly cool, dropping to 58°C after 20 hours (see **Figure 4.1**).

Pagoulatos (2005) also conducted a series of pitcooks and measured their temperatures over time. He did a total of twelve pitcooks, ranging in length from 6 hours to 48 hours. Although his procedure was similar to Peacock's, there were some notable differences between the two experiments. The Pagoulatos pitcooks were conducted in Texas where different materials were available. Pagoulatos used limestone cobbles (instead of igneous cobbles standard in a Secwepemc pitcook) and layers of yucca (*Yucca rupicola*) to protect the food, which was prickly pear (*Opuntia phaeacantha*). Pagoulatos described the soil type as a clayey earthen loam, and used oak as fuel to heat the rocks. Although Peacock did not record her fuel type, given the location of her experiment it was most likely a conifer wood.

Theoretically the igneous rocks of the Peacock pitcook should have been better suited for pitcooking (Buckley 1990), however Pagoulatos seems to have gotten his pitcooks hotter than Peacock. This is possibly a result of using a hardwood fuel. There was considerable variation between Pagoulatos' twelve pitcooks (see **Figure 4.3**, **Figure 4.4**, and **Figure 4.5**), but although the initial temperature of the hot rocks ranged from 598°C to 828°C, the food was usually maintained at a relatively constant temperature, somewhere between 100°C and 120°C, for about 24 hours, and then dropped to about 60°C over the next 24 hours. In some cases the food got much hotter, and in one pitcook the food was over 200°C when it was dug up after 24 hours. In the Peacock pitcooks, in contrast, the temperature began to drop after only two hours from an initial temperature just shy of 100°C and was below 60°C after only 20 hours.

Leach *et al.* (1998) also conducted an experimental pitcook and measured temperatures. Their pitcook was within 30 km of the site Pagoulatos used for his pitcooks, and as a result the two experiments used similar materials. Both the Leach *et al.* and Pagoulatos cooking pits were in clayey loam and used limestone cobbles for heating. Two minor differences between the two experiments are that Leach *et al.* used sotol leaves instead of yucca leaves to protect the food, and that Leach *et al.* cooked both sotol bulbs and prickly pear (instead of just prickly pear). Perhaps a more major difference is

that Leach *et al.* used mainly mesquite (*Prosopis* sp.) as fuel to heat the rocks, which may explain why the Leach *et al.* (1998) pitcook started out with cooler rocks (initial temperature of 583°C), and the food took longer to heat up (maximum temperature of 109°C reached after 12.5 hours) and longer to cool down (not dropping below 100°C until after 34 hours, see **Figure 4.2**).

4.2.3.2 A theoretical model of the thermal dynamics of a pitcook that ignores water

4.2.3.2.1 The mathematics of basic heat flux by conduction from a hot object

When food is added to the cooking pit and buried, the source of heat for the pitcook is the hot rocks at the bottom of the pit. Unless a fire is built on top of the pit, no additional heat energy is created and the temperature dynamics of the pitcook should be continuous heat loss via conduction. A very simplified model of heat loss by conduction from an object can be calculated using Fourier's law (Incropera and DeWitt 1990), where the heat flux (q''_x) is the heat transfer rate in the x direction per unit area perpendicular to the direction of transfer:

$$q''_x = -k \cdot (dT/dx)$$

The thermal conductivity (k) is a measure of how well the material conducts heat, and is usually assumed to be a constant for the material, although in reality it can change as the material changes temperature. The temperature gradient (dT/dx) is the change in temperature (dT) divided by the distance (dx) that this temperature change occurs over.

Immediately after the hot rocks are buried, they will begin to cool, and the surrounding soil will begin to heat up. This both decreases the temperature difference between the rocks and soil, and increases the distance over which that difference occurs. Both of these factors will serve to decrease the temperature gradient, and thus the heat flux away from the pit.

4.2.3.2.2 The Lovering model of heat loss

Expanding Fourier's law into a usable model for heat flux from a pitcook is extremely complicated. Lovering (1935) recommended several simplified models of heat loss for geological applications, based on work of Ingersoll and Zobel (1913) and later

recommended by Carslaw and Jaeger (1986). One of the Lovering models is for heat loss from a laccolith, which is a spherical intrusion of hot igneous rock into bedrock. The thermal dynamics of this should be similar to a pitcook.

$$\text{Lovering model of heat loss: } \theta_{xt} = \theta_s + 0.5 \cdot (\theta_r - \theta_s) \cdot \left(\text{erf}(a) + \text{erf}(b) + \frac{(e^{-a^2} - e^{-b^2}) \cdot 2 \cdot h \cdot t^{0.5}}{d \cdot \pi^{0.5}} \right)$$

$$\text{where: } a = \frac{r - d}{2 \cdot h \cdot t^{0.5}} \quad \text{and} \quad b = \frac{r + d}{2 \cdot h \cdot t^{0.5}}$$

$$\text{erf is the error function: } 2\pi^{-0.5} \int_0^\beta e^{-\beta^2} d\beta$$

$$\text{and } \beta \text{ is a function in the form: } \frac{\pm 1 \mp x}{2 \cdot h \cdot t^{0.5}}$$

Definitions:

θ_{xt} is the temperature ($^{\circ}\text{C}$) at distance x and time t

d is distance (cm) from the center of the hot rock

t is the length of time (s) since the introduction of the hot rock

θ_r is the initial temperature ($^{\circ}\text{C}$) of the hot rock

θ_s is the initial temperature ($^{\circ}\text{C}$) of the surrounding soil

r is the radius (cm) of the hot rock

h^2 is the thermal diffusivity of the material (cm^2/s)

It is apparent from this that the rate of heat loss is not directly proportional to the thermal conductivity of the material, but rather the thermal diffusivity (h^2). The thermal diffusivity of a material is a ratio of its thermal conductivity to how much heat that material can hold ($h^2 = k/(\rho \cdot c_p)$, where k is thermal conductivity; c is specific heat; and ρ is the density of the substance).

4.2.3.2.3 Limitations of the Lovering model applied to pitcooks

The Lovering model assumes a greatly simplified situation in order to be able to calculate the change in temperature over time and space. Some of these simplifications may affect the accuracy of the model. The main assumptions are:

- (a) All materials involved have an identical thermal diffusivity;
- (b) Thermal diffusivity remains constant as the material changes in temperature;
- (c) The heat source is a single, perfectly spherical rock;
- (d) This spherical rock is initially uniformly heated;
- (e) The burial of the rock is instantaneous;
- (f) The latent heat of vaporization of the water in the pit has no effect on the temperature.

All six of these assumptions are not met by a standard pitcook, and will have varying effects on the accuracy of its predictions. Lovering (1935) assumes that breaking assumption (a) will only have a small effect on accuracy, as long as the thermal diffusivities are somewhat similar. However, in a pitcook the thermal diffusivities may vary by up to an order of magnitude (see **Section 4.2.3.2.4.3 Thermal diffusivity of pitcook materials** on page 172). Breaking assumptions (b)-(e) may only have a small effect on the outcome of the model. However, assumption (f) is likely a major flaw in this model because the latent heat of vaporization of the water in the pit will have a significant moderating influence on the temperature of the food, as is explained in **Section 4.2.3.3 Including water into the equation** on page 176.

4.2.3.2.4 Application of the Lovering heat flux model to a standard pitcook

4.2.3.2.4.1 Initial temperature of hot rocks

The initial rock temperatures in Pagoulatos' (2005) pitcooks ranged from 598°C to 828°C, with an average of 685°C. Leach *et al.* (1998) measured the initial maximum temperature of the hot rocks in their experimental pitcooks as 583°C. The initial temperatures of the hot rocks in Peacock's (1998) pitcooks are unknown (she only recorded food temperature), but the rocks were likely not as hot as in the Pagoulatos pitcooks because the food didn't get as hot. Peacock (1998) did report that the rocks were heated until they were red hot. This is a commonly recorded practice in traditional pitcooks. Lintz (1989) reported that caliche rocks, commonly used for pitcooks in Eastern New Mexico, did not glow red until they were heated to temperatures above 800°C.

The maximum temperatures achieved using wood fuel to fire pottery by the Tewa and Keresan Pueblos was reported at 625°C to 962°C (average 778°C) (Shepard 1968). Black *et al.* (1997) recorded that a hot rock bed used in a rock lined hearth was 650°C to 900°C during initial firing.

4.2.3.2.4.2 Soil temperature

Wila is traditionally usually pitcooked in the fall at an average depth of 30 cm to 60 cm below ground level. The pitcooks conducted by Peacock (1998) were done at a similar depth, in August, in Wells Gray Park. Using a soil temperature model developed by Nofziger *et al.* (2000), I calculated the soil temperature at a depth of 45 cm in Wells Gray in August to be 24°C. This is calculated using the daily minimum and maximum temperatures (1.5°C and 28.1°C) recorded at nearby Williams Lake in 2005 (Environment Canada 2005a). Using the same model, and temperature data for Salmon Arm, BC (Environment Canada 2005b), I calculated the soil temperature at a depth of 45 cm in September in Salmon Arm (a likely time and place for wila to be cooked) to be 18°C.

The Nofziger *et al.* (2000) model can be tested against actual soil temperature data that was recorded in Summerland, BC over a 20 year period (Phillips and Aston 1979). At a depth of 50 cm in Summerland in September, the Nofziger *et al.* (2000) model predicts a soil temperature of 21°C, while Phillips and Aston (1979) report this temperature to actually be 19.3°C. This suggests that the soil temperatures calculated above may be accurate to within a few degrees centigrade.

4.2.3.2.4.3 Thermal diffusivity of pitcook materials

The thermal diffusivity of rock is generally around 0.01. Reported values for a typical igneous rock that might be used in a pitcook range from 0.007 (Maqsood *et al.* 2004) to 0.016 (Lovering 1935). The thermal diffusivity of soil ranges from 0.002 to 0.013, with sandy soils and wetter soils tending to have a higher diffusivity than finer soils and dryer soils (Baver *et al.* 1972; Nofziger *et al.* 2000; Tessy Chacko and Renuka 2002). Water has a relatively low thermal diffusivity (0.0014), but increasing the water content in soil will increase its thermal diffusivity dramatically at low soil moisture contents (up to five fold: Nofziger *et al.* 2000). As the soil moisture content approaches saturation, the thermal diffusivity of the soil will plateau or slowly decrease (Nofziger *et*

al. 2000; Tessa Chacko and Renuka 2002). Wood has a thermal diffusivity of 0.0012 – 0.0016, with greener wood having a higher diffusivity (Steinhagen 1977).

Thermal diffusivity will also change as the temperature changes. Maqsood (2004) found that in granite at temperatures of -20°C to 60°C there was about a 0.002 drop in diffusivity per 10°C increase in temperature. In contrast, the diffusivity of wood increases only slightly with temperature (Steinhagen 1977).

Models of heat conduction must assume a constant and uniform diffusivity. In cases where the diffusivity varies between the different materials and temperatures involved, Lovering (1935) recommends that taking the average value will give the most accurate solution. Assuming a pitcook to be a mixture of igneous rock, soil, green woody material, and water, a reasonable diffusivity value should be between 0.0012 and 0.016.

4.2.3.2.4.4 Theoretical temperatures of a standard pitcook using the Lovering model

I calculated pitcook temperature dynamics using the Lovering model (see **Section 4.2.3.2.2 The Lovering model of heat loss** on page 169) with the following parameters, which seem reasonable for a typical pitcook:

- Rock size: A single spherical rock 20 cm in diameter;
- Distance between rock and food: 10 cm;
- Initial rock temperature: uniformly 650°C;
- Soil temperature: 20°C;
- Average thermal diffusivity: 0.01 cm²/s.

The results of my calculations suggest that the food would not reach its maximum temperature until 5.6 hours after it was buried on top of the rocks, and this maximum temperature would be 312.5°C. Temperature would then begin to drop slowly, but would remain above 100°C for nine days, and above 50°C for over two months.

This result seems rather unlikely, as the actual experiences show that cooking pits do not take that long to heat up once built, and do not remain hot for that long. Perhaps something about the nature of pitcooks results in the average thermal diffusivity of the pitcook being higher than one might expect from merely looking at the materials involved. It is likely that there is a significant amount of air in the pit even after it is

buried. Air has a much higher thermal diffusivity of $0.349 \text{ cm}^2/\text{s}$ at 100°C (Ierardi 2000), and could increase the thermal diffusivity of the pit. Another possibility is that convection of air, steam, and/or liquid water could be occurring within the pit, which could increase the rate of heat transfer.

4.2.3.2.5 Testing models against the data

The statistical computing program R was used to compare theoretical models of heat loss to the actual data collected by Peacock (1998), Pagoulatos (2005), and Leach *et al.* (1998). A linear response, two Type II responses, two Type III responses, and the Lovering model were tested. The models tested are:

- (a) Linear model: $\theta_t = \theta_i + a \cdot t$
- (b) Type II response: $\theta_t = \theta_s + (\theta_i - \theta_s) \cdot e^{-at}$
- (c) Type II response: $\theta_t = \theta_i + (\theta_s - \theta_i) \cdot t / (a + t)$
- (d) Type III response: $\theta_t = \theta_i - (\theta_i - \theta_s) \cdot t^a / (b^a + t^a)$
- (e) Type III response: $\theta_t = \theta_i - (\theta_i - \theta_s) \cdot ((1 + a \cdot e^{-t/c}) / (1 + b \cdot e^{-t/c}))$
- (f) The Lovering model of heat loss (see **Section 4.2.3.2.2 The Lovering model of heat loss** on page 169)

For models (a)-(e):

θ_t is the temperature ($^\circ\text{C}$) at time t ;

t is the length of time (s) since the food was buried;

θ_i is the initial temperature ($^\circ\text{C}$) of the food;

θ_s is the initial temperature ($^\circ\text{C}$) of the surrounding soil;

a - c are variables.

4.2.3.2.5.1 An information criterion approach to model selection

Akaike's Information Criterion (AIC) was used to find the best model to fit the data. Using this approach, the best model is the model that can minimize the residual of sums of squares using the fewest variables. Because of the relatively small number of observations as compared to parameters for many of the models, a corrected AIC (AICc) was calculated from the AIC to help prevent bias against parsimonious models.

4.2.3.2.5.2 Problems optimizing the Lovering model

Because of the large number of variables in the Lovering model, many local minima can be found for the residual sums of squares. To overcome this, each the Lovering model was run eight times for each data set with different starting parameters for each trial, and the results with the most reasonable parameter values and lowest AIC were used. Also, constraints were added to the possible parameter values to prevent nonsensical results. The constraints were:

- The spot where the temperature is being measured cannot be inside the rock
- The rock must be a reasonable size ($1 \text{ cm} < x < 100 \text{ cm}$)
- The soil temperature must be a reasonable value ($0^\circ\text{C} < x < 40^\circ\text{C}$)
- The initial rock temperature has to be reasonable value (maximum recorded temperature for that pitcook $\leq x < 1000^\circ\text{C}$)
- The thermal diffusivity must be positive

The Lovering model assumes instantaneous burial of the pit. In reality, burial could take several minutes. This assumption has a major effect on the first data point (temperature at time 0), and a more minimal effect after that. If burial was instantaneous, the food should initially be at the ambient air temperature (close to the soil temperature). However, in all the data sets the food is already very hot (usually above 100°C) at the first data point. A time lag can be added to the equation, so that the data point for time 0 is actually calculated for a point in time several minutes after time 0. However, this creates an infinite number of local minima and makes the equation impossible to optimize. Instead, the first data point was merely omitted from the analysis.

4.2.3.2.5.3 Best fit for models tested

For the Peacock data, an optimal fit for the Lovering model was found using a soil temperature of 20°C , initial rock temperature of 115°C , food sitting directly on the rock, which has a diameter of 50 cm, and a thermal diffusivity of $0.048 \text{ cm}^2/\text{s}$. However, a Type III functional response version (d) [model (d), see **Section 4.2.3.2.5 Testing models against the data** on page 174] actually fit the data better than the Lovering model and produced the lowest AICc of any model tested (see **Table 4.1** and **Figure 4.1**).

Using model (d), a soil temperature of 20.7°C is predicted, which is fairly close to the estimated value of 24°C using Nofziger *et al.*'s (2000) soil temperature model (see **Section 4.2.3.2.4.2 Soil temperature** on page 172).

Because of the hotter temperature of the Pagoulatos (2005) pitcooks, the latent heat of vaporization of water had a much larger dampening effect on the temperature of the food, and as a result the Lovering model could not be fitted to the food temperature data with any reasonable parameters (as outlined in **Section 4.2.3.2.4 Application of the Lovering heat flux model to a standard pitcook** on page 171). The Lovering model can, however, be applied to the temperature of the hot rocks. Modeling the heat loss of the rocks, the thermal diffusivity of the Pagoulatos pits is calculated to be an order of magnitude greater than the Peacock pit, the average for twelve pitcooks is 0.43 cm²/s (with a 95% confidence limit of ± 0.26). In the Pagoulatos pitcooks, model (d) still provided the best fit for both rock temperature and food temperature, providing a better fit than the Lovering model and all other models tested.

For the Leach *et al.* (1998) experimental pitcook, the Lovering model provided the smallest AICc of all models tested, indicating that it is the model that best fits the data for that experiment (see **Figure 4.2**). This best fit is achieved at a soil temperature of 36°C, initial rock temperature of 186°C, a rock with a diameter of 48 cm, the food 25 cm from the rock, and a thermal diffusivity of 0.017 cm²/s. This predicted initial temperature for the hot rocks is obviously much lower than the actual maximum measured temperature of 583°C. The predicted model also seems to fall apart for the last two data points (at hours 37 and 39). This could indicate an inaccuracy of the model, or could be a result of a cooling effect of the heavy rains that Leach *et al.* (1998) recorded at the end of their pitcook.

4.2.3.3 Including water into the equation

The latent heat of vaporization of the water in the pit will likely have a major effect on the temperature of the pit and the food inside it. Once water has been heated to the boiling point (generally around 100°C) it needs to change state from a liquid to a gas before it can continue to increase in temperature. During this phase change the water will continue to absorb energy while maintaining a constant temperature. The amount of

energy required to raise the temperature of water (specific heat capacity) is only 4.186 J/(g·°C), while the amount of energy required to convert that water from a liquid to a gas (specific latent heat of vaporization) is 2257 J/g. This means that once the water hits its boiling point at around 100°C, the amount of energy it will absorb before being able to increase in temperature again is the same amount of energy that would be required to raise the temperature of that water by 539°C.

4.2.3.3.1 The effect of the latent heat of vaporization of water on the temperature of food in a cooking pit

As a result of the high latent heat of vaporization for water, any water in a cooking pit will make it more difficult to raise the temperature of that pit much above 100°C, and it will maintain that pit at around 100°C for longer once that temperature is achieved. Because of this, any water in the pit will strongly regulate the temperature of that pit. Furthermore, the food itself almost always also contains a high concentration of water, which will further regulate the temperature of that food even if the temperature of the pit surrounding it succeeds in increasing significantly above 100°C. A moist food item cannot be raised above the boiling point of water until all the water in it has been boiled away, at which point the food is probably a charred inedible mass.

4.2.3.3.2 Variation in the boiling point of water

The latent heat of vaporization of water will tend to maintain the temperature of the pit at the temperature at which water boils. However, the boiling point of water is not constant and can be changed by two factors: the surrounding air pressure and the presence of solutes in the water.

4.2.3.3.2.1 Air pressure inside the cooking pit

The vapour pressure of water increases as it heats up, and the liquid boils when its vapour pressure equals the surrounding air pressure. As a result, the boiling point of water is dependent on the surrounding air pressure in a relationship that is approximately logarithmic. At pressures near one atmosphere, this relationship can be approximated by the equation $T_b = 27.3 \cdot \ln(P) - 26.1$, where T_b is temperature in °C and P is pressure in

kPa. To calculate the boiling point with more accuracy, or for different ranges of pressures, a table of critical values should be consulted (Lide *et al.* 2006).

Air pressure normally varies with elevation and local weather patterns. Air pressure at sea level commonly varies anywhere between 97.0 kPa and 104.0 kPa depending on the weather (Morgan and Morgan 1996). Salmon Arm, BC (a representative location in Secwepemc territory, one place where wila would traditionally have been cooked) is at about 330 m elevation, which under normal conditions should make air pressure roughly 4 kPa lower than at sea level. As a result, the boiling point in areas where wila might be cooked could range anywhere between 97.7°C and 100.7°C. The boiling point can be further elevated if the water is contained in a pressurized vessel. At a pressure of 1.5 atmospheres water boils at 112°C, at two atmospheres it boils at 120°C, and at three atmospheres it boils at 134°C (Lide *et al.* 2006). Stenberg (1868) found that lichen carbohydrates broke down most efficiently at three atmospheres pressure, which could have corresponded to heating the lichen to 134°C.

In a cooking pit, the food is covered with layers of vegetation and perhaps soil (see **Section 2.2.4.3 Building the oven to cook the lichen** on page 94). The weight of this material will contribute to the pressure being experienced by the cooking food. The maximum depth of soil reported for covering the pit was 30 cm, which would weigh approximately 500 kg/m² (using average density reported by: Walker 2004). This would generate an additional 5 kPa of pressure inside the pit, and raise the boiling point of water by about 1.3°C.

In a pitcook the liquid water is boiled by contact with the hot rocks and expands as water vapour. This expansion may increase the pressure within the pit if it functions as a sealed vessel. The amount of pressure created would depend on the amount of water vapour produced and the porosity of the walls and covering of the pit. If this could generate a significant amount of pressure, it is possible that the food inside the pit could be heated to a temperature significantly hotter than 100°C. Unfortunately I am unaware of any empirical data on pressure increase inside a pitcook. This possibility needs to be investigated further.

4.2.3.3.2.2 Boiling point elevation from increasing solute concentration

The boiling point of any solvent increases as the concentration of solutes in that solvent increases. This phenomenon is known as boiling point elevation, and depends only on the concentration of the solute and not on what type of solute is present (a colligative property). Boiling point elevation is a product of the ebullioscopic constant (K_b) of the solvent and the molality (m) of the solution ($\Delta T = K_b \cdot m$). However, the K_b for water is very low, approximately $0.512 \text{ }^\circ\text{C}\cdot\text{kg}\cdot\text{mol}^{-1}$, making this effect very minimal, even under conditions of relatively high concentrations of solute.

Cooking lichen contains about 80% water and 20% solutes (see **Section 4.4.2.7 The hydrophilic nature of cooked lichen** on page 202). Lichenin and isolichenin constitute the bulk of this material (see **Section 1.5.2 Lichen carbohydrates** on page 47). If the cooking lichen contained only lichenin and isolichenin, it would have a molality of about 0.03 mol/kg of water. The molality would increase if these polysaccharides began to break down into their component monosaccharides, but even if they were entirely hydrolyzed into glucose (which is unlikely to happen from pitcooking, see **Section 4.4.2.2 Sugars in lichen** on page 195), the molality would still only be about 1.4 mol/kg of water. This would still result in a boiling point elevation of less than 1°C .

4.2.3.3.3 Empirical data for the effect of water on food temperature in a pitcook

The temperature regulating properties of water are readily apparent in the Pagoulatos (2005) pitcooks. Although the hot rocks in his pitcooks started at $600\text{-}800^\circ\text{C}$, in the majority of the trials the food was maintained at about 100°C (generally between 95°C and 120°C) for about 24 hours. An exception to this is that many pitcooks showed an initial peak in the temperature of the food immediately after burial (as high as 406°C in one instance), before it immediately dropped in temperature to around 100°C for the next reading one hour later. It is unclear what may have caused this phenomenon, but perhaps the hot rocks initially forced the water out of the food and allowed them to become superheated, before water from the rest of the pit began to seep down and control the temperature. Another exception is seen in one pitcook where Pagoulatos succeeded in heating the rocks to the exceptionally hot temperature of 828°C (The hottest temperature he reached in twelve separate experiments). In this experiment, the food was maintained

at around 100°C for about twelve hours, and then the temperature shot up to above 250°C where it stayed for the remainder of the 24-hour experiment. This is likely because the rocks were so hot they finally succeeded in vaporizing all of the water in the pit.

Although the Pagoulatos (2005) pitcooks indicate that water is regulating cooking temperature, the food was not always maintained at exactly 100°C, and commonly ranged as high as 120°C. The possible causes of this are:

- Experimental error in measuring the temperature;
- The food was completely dried out;
- The pit was experiencing pressures of about two atmospheres.

It is unlikely that the food was completely dried out, as this would likely result in a spike in the temperature of the food (as seen in the trial mentioned above), instead of maintaining the food at the relatively constant temperature that was observed. It is therefore possible that the pit was becoming pressurized. The Leach *et al.* (1998) pitcook similarly got the food significantly above 100°C (to a maximum of 109°C). This would require pressures of about 1.4 atmospheres.

4.2.3.4 Conclusions about the temperature dynamics of pitcooking

It can be concluded from the data of Peacock (1998), Pagoulatos (2005), and Leach *et al.* (1998) that the temperature dynamics of pitcooking can vary greatly depending on how the pitcook is set up and many other variables outside of human control. **Table 4.2** outlines some of the variables determining thermal dynamics of a pitcook. All of these variables will affect the maximum temperature of the food, how long it takes to reach that temperature, how long it is maintained close to that temperature, and how rapidly it cools down. Some of these factors listed in **Table 4.2** are directly under human control (e.g. distance from hot rocks to food), but in many cases human choice is limited by the geology, climate, and ecology of the area.

Both the empirical data and theoretical models indicate that the cooking food can be maintained at about 100°C for up to 24 hours before it begins to cool off, although depending on the conditions of the pit it can cool off much sooner. The food can also be maintained at above 100°C (around 120°C in some cases), which may be a result of pressurizing the pit.

Different temperature dynamics of the pitcook will have an effect on how the food is cooked. Maintaining all the parameters of a pitcook to produce properly cooked food would take an experienced pitcooking chef who was knowledgeable about both the food being cooked, the fuel, the rocks and other materials used, and the area where the pitcook was being conducted. Without having temperature data from a lichen pitcook done by a person skilled in pitcooking wila, it is impossible to know the ideal (or even typical) temperature dynamics of such a pitcook.

4.2.4 The pH of a pitcook

The pH of the cooking environment may have a significant effect on the cooking food. Complex carbohydrates will hydrolyze more readily if cooked in a low pH environment. This has been shown for breaking down inulin in Jerusalem artichoke tubers (Yamazaki and Matsumoto 1993) (pH 2.5), and for breaking down lichen carbohydrates to produce alcohol (Stenberg 1868; Stahlschmidt 1870; Arendt 1872; Pain 2005) or molasses (Diachkov and Kursanov 1945).

Many plant materials are slightly acidic. It is possible that vegetation used above and below the food in a pitcook (see **Section 2.2.4.3 Building the oven to cook the lichen** on page 94) may contribute to acidifying the cooking environment and help break down the carbohydrates in the food. Certain root vegetables commonly cooked in pitcooks may also be slightly acidic, which could help break down the carbohydrates in those foods and in foods that they are cooked with.

4.2.4.1 Possible sources of acidity in a cooking pit

Conifer boughs are commonly used in cooking pits as the material above and/or below the food. Conifer needles are acidic, and could acidify the water while pitcooking. Pfeifhofer (1999) found that extracting 2 g of Norway spruce needles (*Picea abies*) in 12 mL of water produced a pH of around 4, and if various salt solutions were used for the extraction a pH as low as 3.5 could be reached.

The leaves of broadleaf trees, shrubs, and herbaceous plants are also often used in pitcooks instead of conifer boughs, and these leaves may not be as acidic. Haas (1941)

found that the leaves of one species of broadleaf tree (the avocado, *Persea americana*) had a pH of 5.5.

The food being cooked may also contribute acidity. There is very little information available on the acidity of traditional foods, but we know the pH of many of the common foods from a grocery store. Carrots and beets can have a pH as low as 4.9 (NIRC 2001), while potatoes have a pH of 5.6 (Bickelhaupt 2007). Cabbage has a pH of 5.3 (Bickelhaupt 2007) and white mushrooms have a pH of 6.0 to 6.5 (NIRC 2001). Acidic fruits like grapes and peaches can have a pH as low as 3.0 (NIRC 2001).

Soils may be either acidic or alkaline, and so it is possible that the ground in which the cooking pit is dug could also contribute to the acidity of the pit. In some situations extremely acidic soils can have a pH as low as 4.5, but generally even acidic soil doesn't have a pH below 5.0, and if it does it will seriously effect plant growth (Bickelhaupt 2007).

4.2.4.2 A wild but educated guess as to the pH in a typical cooking pit

Most of the materials used for pitcooking are slightly acidic, so it is likely that most cooking pits represent a slightly acidic cooking environment. I am unaware of any empirical data on the pH of cooking pits. However, looking at the pH of relevant materials, I would hypothesize that it is quite possible that many cooking pits have a pH as low as 5.0, it might be possible for the pH to get as low as 4.0, but it is unlikely for the pH to get any lower than 3.0.

4.2.5 Conclusions on the mechanics and importance of cooking pits

Pitcooking can be essential for breaking down some indigestible complex carbohydrates into simple sugars that are digestible to humans. The temperature, acidity, and duration of pitcooking are important for its value in cooking food. It appears that a cooking pit can maintain food at about 100°C for up to 24 hours before it begins to cool off, although depending on the conditions of the pit it can cool off much sooner. The food can also be maintained at above 100°C (around 120°C in some cases), which may be a result of pressurizing the pit. The pH of a cooking pit could easily be acidic. A pit pH

of 5.0 seems very possible, but it is difficult to imagine how a cooking pit could produce a pH below 3.0.

4.3 A method for conducting experimental pitcooks and measuring their efficacy

4.3.1 Simulating pitcooking in the lab

4.3.1.1 The advantage of an artificial pitcook

Mimicking the temperature dynamics of a proper lichen pitcook is difficult when that temperature dynamics are only poorly understood. This difficulty holds true regardless of whether one attempts an actual pitcook or merely tries to mimic the pitcook in an artificial setting in the lab. However, the time, labor, and resources necessary to conduct even one pitcook make the artificial pitcook an attractive option if numerous tests are to be performed.

There is a high degree of variation between individual pitcooks, even if one attempts to conduct them all identically. Pagoulatos (2005) attempted to keep all conditions identical for four of his experimental pitcooks, but the average temperature of the food varied between them by more than 50°C over the first six hours (not all pitcooks were continued past this). This inherent variation makes it difficult to differentiate the effects of different variables. Artificial pitcooks conducted in a lab allow for much tighter control than is possible with actual pitcooks, and make it possible to focus on the effects of specific factors of the pitcook.

4.3.1.2 Using temperature models to decide how hot to keep the artificial pitcooks

Theoretical models and empirical data show that in most cases the food in a pitcook rapidly reaches a maximum temperature close to 100°C and maintains that temperature an extended period of time before it begins to cool off. The duration of this stable thermal maximum can be as short as two hours (Peacock 1998) or as long as 24 hours (Leach *et al.* 1998; Pagoulatos 2005). The food then begins to cool down, and the rate of this cooling is also highly variable.

The food is often left in the pit during the cooling down phase, and as a result the food is not always kept at a constant temperature for the entire cooking duration. It is possible that this temporal variation in cooking temperature has an effect on how the food cooks, but the chemical changes that occur in food as a result of cooking happen faster at hotter temperatures (Wandsnider 1997; Barham 2001), so the duration of the stable thermal maximum in the pitcook is probably more important than the cooling down phase.

Including different rates of cooling in the artificial pitcooks would add an entire set of additional variables that would be time consuming to test and are probably not very important. Because of this, I decided to keep the food in my artificial pitcooks at their thermal maximum for their entire duration. This is a situation that would sometimes occur in traditional pitcooks, but not always because sometimes the food would enter the cool down phase before it was dug up. When cooking food, a longer period of time at a cooler temperature is usually equivalent to a shorter period of time at a hotter temperature (Wandsnider 1997), so although it is possible that the cool down phase that I have omitted might have a unique effect on the food, it is more likely that leaving food in the pitcook into the cool down phase is equivalent to having a slightly longer duration of the stable thermal maximum.

4.3.1.3 The experimental design

4.3.1.3.1 Testing the effect of cooking duration on lichen and camas and for possible interactions between food ingredients

Food samples were cooked at 100°C in simulated pitcooks for five different durations of time: 6, 10, 18, 26, and 34 hours. These food samples were of three different types: lichen samples, camas (*Camassia quamash*) samples, or samples of both lichen and camas cooked together. All lichen samples were 10.00 g, and all camas samples were ≈15 g, regardless of whether they were cooked together or separately. One replicate was done for every combination of cooking duration and food type, resulting in 15 simulated pitcooks to test for the effect of cooking duration on lichen and on camas, and for any synergistic effect of the two foods being cooked together.

4.3.1.3.2 Controlling for the effect of the lichen on the cooking camas

In the samples of camas that were cooked alone the 10 g of lichen was replaced with 10 g of clean cotton felt to make the cooking environment as equivalent as possible for both camas treatments.

A pairwise experimental design was used to better elucidate the effect on the camas of cooking it with or without lichen. Each sample of camas that was cooked wrapped in cotton was paired with the corresponding treatment of camas cooked wrapped in lichen for the same cooking duration, and every effort was made to reduce all other sources of variation within these pairs. Within each pair, the variation in the moisture content and mass of the camas bulbs was reduced as much as possible (see **Section 4.3.1.5.1 Sample preparation** on page 186), and the samples were cooked at the same time in the same oven to reduce any variation in temperature dynamics (see **Section 4.3.1.5.3 Temperature regulation** on page 188).

4.3.1.3.3 Control samples of raw lichen, camas, and cotton

The cooked samples of lichen, camas, and cotton were compared to control samples of those substances that were never cooked. The control samples were of the same weight as the experimental samples (10.00 g for lichen and cotton, \approx 15 g for camas), and were taken from the same population as their respective experimental samples. The control samples were in all discernable respects identical, or represented identical variation, and are thus likely a good representation of the initial moisture and carbohydrate content of the cooked samples.

I analyzed five control samples of camas, three of lichen, and two of cotton. There were fewer control samples of lichen and cotton analyzed because the variation between them was found to be lower.

4.3.1.3.4 Testing for the effect of pH on cooking lichen

Lichen samples (10.00 g) were cooked at 100°C in simulated pitcooks for ten hours at three different acidities to test for the effect of pH on cooking lichen. The acidities tested were a pH of 7.0, 5.0, and 3.0. Only one replicate was done of each pH

because this initial test showed no effect of pH on the carbohydrate content of the cooked lichen so further tests were not pursued.

4.3.1.4 Specimens used for pitcooking experiments

All of the lichen used for these experiments was collected from the same tree, a 483 mm DBH Douglas-fir (*Pseudotsuga menziesii*) growing at 1310 m on Kela7scen, close to Salmon Arm, BC in Secwepemc traditional territory. Only using lichen from one tree reduced many potential sources of variation that may have confounded the effect of the cooking method. This tree had abundant lichen growth that was 99% *Bryoria fremontii*, and was in an area with lots of *Bryoria fremontii* growing on neighboring trees. This made the area a desirable place to collect wila, and thus a likely place for wila to have been traditionally collected.

All of the camas bulbs used for these experiments were collected from one field in Victoria, BC. The bulbs were dug up, washed, dried off, and stored in a refrigerator for no longer than four days before being used.

4.3.1.5 The recipe for simulated pitcooking

4.3.1.5.1 Sample preparation

The lichen was not oven dried before cooking, as this is not a traditional practice and could have affected cooking. The lichen was instead dried at ambient room temperature and moisture, resulting in a moisture content of 13.3% ($\pm 3.5\%$) water. Following traditional practice, the dry lichen was carefully picked through by hand removing any debris such as sticks, needles, sap, or other lichens. It was then divided into 10.00 g samples of clean, dry lichen. The lichen was not washed with water, although this is the traditional practice. I concluded that washing the lichen would introduce too many other variables, and thus should be tested separately in future experiments.

The camas bulbs used for the experiment were freshly dug up, washed, and their surface dried, but they were not desiccated. Traditionally, fresh camas bulbs would often be used for pitcooking, and I thought a desiccated bulb might cook differently. As a result, the exact moisture content of each raw sample of camas bulbs is not known and

not identical between samples (the moisture content of the five uncooked control samples of camas bulbs varied between 64.3% and 76.4%).

I thought that cutting a camas bulb in half might affect how it cooked and how it leached carbohydrates, so I used only entire bulbs for the experiments. Because of this, it was impossible to exactly match the raw weight of the sample of camas bulbs in every trial. This variation in both the initial moisture content and weight of the camas bulbs introduces some inherent variation into the cooking trials. Therefore, the cooking trials were done in pairs in an attempt to better ascertain the effect of cooking camas with lichen by reducing other sources of variation (see **Section 4.3.1.3.2 Controlling for the effect of the lichen on the cooking camas** on page 185).

The camas samples within each pair were matched as closely as possible. For each camas bulb in one sample, a sister bulb was selected for the other sample that was the most similar in both mass and appearance out of all the camas bulbs harvested. The total mass of the camas bulbs within each sample was also matched as closely as possible. The largest variation between camas sample weights within a pair was 2%, with an average of a 0.7% difference.

The camas bulbs could not be matched as closely between pairs as they were within pairs. Although within each pair there was always the same number of bulbs, samples in different pairs varied from two bulbs to five bulbs. The weights of camas samples between pairs also varied much more, from 14.41 g to 17.72 g.

4.3.1.5.2 Building the pitcook

Each pitcook was simulated by wrapping a food sample (lichen and/or camas) in cotton gauze and placing it in the middle of a clay baker stuffed with soaked cotton felt. Two simulated pitcooks were heated simultaneously in the same oven for each cooking trial, while the temperature was continuously monitored both in the oven and inside each sample using temperature probes (see **Figure 4.6**).

Two small (2.5 L) Schlemmer-Topf clay bakers with glazed bottoms (Scheurich Home Design) were used for this experiment. A small groove was filed into the base and lid of each baker to allow for passage of the temperature probe cord while still

maintaining a snug fit for the lid. The bakers were soaked in cold water for 30 minutes before each cooking trial.

The 10.00 g lichen sample was moistened with water, wrapped around the temperature probe of a TruTemp Digital cooking thermometer (Taylor), and then thoroughly wrapped in a 50 cm x 50 cm piece of cotton gauze. In cooking trials utilizing camas, the camas bulbs were wrapped up with the temperature probe in 10.00 g of either lichen or cotton felt, and then wrapped in the cotton gauze. The temperature probe was only placed next to the camas bulbs and not inserted into them because I thought that a metal probe inside the bulbs might change how they cooked.

Clean, dry cotton upholstery felt was weighed, and 350 g was soaked in water to use for stuffing the baker. Several layers of soaked cotton felt were put into the bottom of the baker and the wrapped lichen sample was placed on top, with the cord from the temperature probe exiting the clay baker through the filed groove. The remainder of the soaked cotton felt was then packed around and on top of the wrapped lichen sample, and the lid of the clay baker was fitted over top.

The packed baker was weighed and the wet weight was compared to the initial dry weight of all the components in order to measure its water content. Additional water was added to ensure that each baker initially contained exactly 3.0 L of water.

In the cooking trials testing for the effect of pH, citric acid used to acidify 3.0 L of water to a pH of 5.0 for the slightly acidic cooking trial, and to a pH of 3.0 for the strongly acidic cooking trial. This acidified water was then used as the 3.0 L of water necessary to soak the cotton felt for stuffing inside the clay baker, as per the recipe outlined above.

4.3.1.5.3 Temperature regulation

Two simulated pitcooks were prepared at a time and heated simultaneously in the same oven for each cooking trial in a pairwise experimental design to better determine the effect of lichen on cooking camas (see **Section 4.3.1.3.2 Controlling for the effect of the lichen on the cooking camas** on page 185). The pair of simulated pitcooks were placed side-by-side in a cold oven. The temperature probe in each sample, and a temperature probe dangling in the middle of the oven were all connected to digital

readouts outside the oven to allow for continuous monitoring of the temperature of the oven and the food samples.

After the simulated pitcooks were in place, the oven was heated to 190°C. The oven used for the experiments reached this temperature within 15 minutes, and maintained it within $\pm 5^\circ\text{C}$. The temperature of the oven and each sample was recorded every five minutes. The oven was turned down to 120°C after both samples had reached 99.0°C to prevent the bakens from drying out unnecessarily. Getting both samples to this temperature took about 119 minutes (± 6 minutes) from the start of the trial. Within a given trial the samples would usually reach 99.0°C within 6.5 minutes (± 5 minutes) of each other. The duration of each cooking trial was measured starting after both samples had reached 99°C (either 6, 10, 18, 26, or 34 hours).

The temperature of each sample was very stable once it reached its maximum, usually fluctuating only a few tenths of a degree over a period of several hours. Paired samples that were cooked together had concordant temperatures, and were usually within 0.2°C to 0.3°C of each other, with a maximum recorded discrepancy of 0.5°C. Throughout all of the trials, the coolest recorded temperature for a sample to stabilize at was 99.1°C, and the hottest 100.5°C. The temperatures of a representative cooking trial are shown in **Figure 4.7**.

4.3.1.6 Preparation of the cooked samples

The cooked samples were immediately removed from the simulated pitcooks at the end of the cooking period. The camas and lichen were carefully separated in the treatments where they were cooked together. This could be done with relative precision, although some cross-contamination was evident. The separated samples were sliced to facilitate drying, and weighed. They were then left in a drying oven at 60°C for one week. When selected samples were dried for an additional week, they lost only an additional 0.2% of their mass, indicating that one week was adequate drying time. The dried samples were weighed to determine the moisture content of the cooked samples.

The dried samples of raw and cooked camas, and cooked lichen, were ground to a fine powder with an electric grinder. Raw lichen was soaked in liquid nitrogen and ground with a mortar and pestle.

The cotton could not be ground, so extractions of the entire samples were prepared in the following way. The cotton was boiled in 300 mL of water for one hour, the water was then decanted, and the cotton wrung out. The extraction was repeated a second time and the two fractions added together. The extract was then topped up to exactly 600 mL. The extraction used the entire 10 g sample of cotton, so 1 mL of extract represents the water-soluble constituents of 16.7 mg of cotton.

4.3.2 Measuring the effect of cooking

The main storage carbohydrates present in wila are glucans (polymers of glucose), which will produce smaller glucans and/or glucose as they begin to break down (see **Section 1.5.2 Lichen carbohydrates** on page 47). The major carbohydrate in camas is inulin which comprises 12 ± 22 % of the fresh weight of a camas bulb (van Loo *et al.* 1995). Inulin is a fructan (polymer of fructose), which will produce smaller fructans and/or fructose when it breaks down. Neither the glucans of the lichen (see **Section 1.5.5 The digestibility of lichens** on page 56) nor the inulin of the camas (Franck and de Leenheer 2002) are digestible to humans. However, the final breakdown products, glucose and fructose respectively, are both highly digestible, and the possible intermediate breakdown products of smaller glucans and fructans may be digestible.

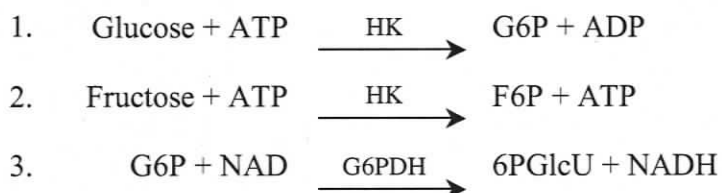
Because of this, the total amount of glucose and fructose in the cooked samples was used as a measure of how much the indigestible lichen and camas polysaccharides had begun to break down into digestible forms. Colorimetric microtitre plate enzymatic assays were used to measure glucose and fructose concentrations for each sample of cooked lichen, camas, and cotton, as well as for the raw control samples of all three materials.

This enzymatic assay method for measuring carbohydrates is outlined by Campbell *et al.* (1999) and Yip (pers. comm. 2006). The appropriate enzymes are utilized to oxidize any glucose in the sample by reducing NAD to NADH. The amount of NADH produced by this reaction is measured by its absorbance at 340 nm and is a direct measure of glucose content. Any fructose in the sample is then converted to glucose by the addition of another enzyme. The new glucose is subsequently oxidized by

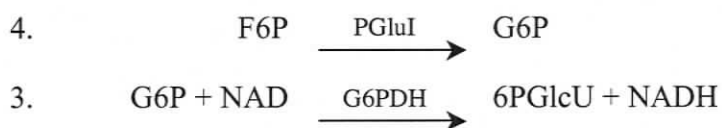
the previously added enzymes, producing more NADH. The NADH concentration is again measured, and the increase is a direct measure of fructose content.

4.3.2.1 The chemistry behind the colorimetric microtitre plate enzymatic assay to measure glucose and fructose

Hexokinase uses ATP to phosphorylate glucose and produces glucose-6-phosphate (G6P) and ADP (equation 1). The hexokinase also phosphorylates any fructose into fructose-6-phosphate (F6P) (equation 2). G6P dehydrogenase oxidizes the G6P to gluconate-6-phosphate (6PGlcU) by reducing NAD⁺ to NADH (equation 3). The F6P is unaffected by the G6P dehydrogenase. The amount of NADH can then be measured by its absorbance at 340 nm to quantify the total amount of glucose that was present in the original sample.



Phosphoglucose isomerase (PGluI) is then added to the mixture, which converts the F6P to G6P (equation 4). The G6P dehydrogenase then converts this new G6P to 6PGlcU by reducing more NAD⁺ to NADH (equation 3). The increase in NADH quantifies the total amount of fructose that was present in the original sample.



Abbreviations:

ADP = Adenosine diphosphate

NAD = Nicotinamide adenine dinucleotide

G6P = Glucose-6-phosphate

6PGlcU = Gluconate-6-phosphate

PGluI = Phosphoglucose isomerase

G6PDH = Glucose-6-phosphate dehydrogenase

ATP = Adenosine triphosphate

NADH = Reduced NAD

F6P = Fructose-6-phosphate

HK = Hexokinase

4.3.2.2 Carbohydrate analysis protocol

Three separate extracts were prepared from each sample to be analyzed. Each extract was analyzed separately, and an average of the three replicates was used to characterize the true carbohydrate content of the sample. The extraction procedure was adapted from Yip (pers. comm. 2006) and is outlined in **Appendix I**. The colorimetric microtitre plate enzymatic assay used to measure glucose and fructose concentration in each extraction followed Yip's adaptation (pers. comm. 2006) of Campbell *et al.*'s (1999) protocol, and is outlined in **Appendix II**. Although only glucose and fructose concentrations were measured for the current analysis, this procedure could be adapted to measure concentrations of many other, more complex carbohydrates, as outlined in **Appendix II**.

4.4 Results for the simulated pitcooking experiments

4.4.1 An information criterion approach to determine the effect of cooking time

An information criterion approach was used to determine the best model of how the amount of sugar in camas and lichen increased over time as it was cooked. The statistical computing program R was used to compare five different response models, including a linear model, two Type II functional responses, and two Type III functional responses. These models were:

Type I functional response (linear model):

$$(a). \quad S = S_{init} + a \cdot t$$

Type II functional response:

$$(b). \quad S = S_{end} + (S_{init} - S_{end}) \cdot e^{-a \cdot t / S_{end}}$$

$$(c). \quad S = S_{init} + \frac{(S_{end} - S_{init}) \cdot t}{a + t}$$

Type III functional response:

$$(d). \quad S = S_{init} + \frac{(S_{end} - S_{init}) \cdot t^a}{b^a + t^a}$$

$$(e). \quad S = S_{\text{init}} + \frac{(S_{\text{end}} - S_{\text{init}}) \cdot (1 + a \cdot e^{-tc})}{1 + b \cdot e^{-tc}}$$

Explanation of variables:

S = Amount of sugar present after cooking for t hours

S_{init} = Initial amount of sugar before cooking

S_{end} = Maximum amount of sugar possible after cooking

t = Length of time in hours for which the food is cooked

a , b , and c = Additional parameters determining shape of the function

The initial amount of sugar (S_{init}) was constrained to be the average of the raw samples. The model was free to determine a value for the maximum (S_{end}) amount of sugar (except for the linear model which has no maximum) and one to three additional parameters (a , b , and c) that would minimize the residual sums of squares for that model. Akaike's Information Criterion (AIC) was then used to determine which model produced the best fit to the data (see **Section 4.2.3.2.5.1 An information criterion approach to model selection** on page 174).

4.4.2 Analysis of the results of the simulated pitcooks

4.4.2.1 The sugars in camas

Raw camas contained very little fructose and even less glucose (**Figure 4.8** and **Figure 4.9**). When the bulbs were cooked, the concentration of both fructose and glucose increased substantially over time, as would be expected from the storage carbohydrates breaking down into their component monosaccharides. Cooking the camas produced much more fructose than glucose, which is consistent with camas using inulin (a fructose-based polysaccharide) as a primary storage carbohydrate.

4.4.2.1.1 Effect of lichen on the fructose concentration in cooked camas

The presence of lichen appears to have no significant effect on the fructose concentration in the cooked camas. Camas cooked with lichen had on average a 5.8% higher concentration of fructose than camas cooked alone, but a paired t-test showed this difference to be insignificant ($t_{0.5,4} = -0.749$, $P=0.496$). However, this test assumes that

both camas cooking treatments (cooked with lichen and cooked alone) respond the same to cooking over time, and only looks for a consistent trend of one treatment tending to be higher or lower in fructose concentration over all the cooking times.

The response of fructose concentration to length of time cooked is not linear (see **Section 4.4.2.1.3 The effect of cooking time on the fructose concentration in camas** on page 194), so the data was first transformed to be linear before an ANCOVA was used to compare the two camas cooking treatments while controlling for the effect of time. The data was transformed according to $y' = \ln(y - S_{\text{end}})$, which is derived from the best fitting model **(b)** shown in **Section 4.4.2.1.3** below. An ANCOVA on the transformed fructose concentrations showed no significant interaction between hours cooked and cooking treatment ($F_{1,6}=0.205$, $P=0.666$), and a subsequent ANCOVA showed no significant effect of the presence of lichen on the fructose concentration of cooked camas ($F_{1,7}=0.257$, $P=0.628$).

4.4.2.1.2 Effect of lichen on the glucose concentration in cooked camas

The presence of lichen also appears to have no significant effect on the glucose concentration in the cooked camas. Camas cooked with lichen had on average a 1.8% higher concentration of glucose than camas cooked alone, but a paired t-test showed this difference to be insignificant ($t_{0.5,4} = 0.107$, $P=0.920$). Because the glucose concentration of the camas was linearly related to the length of time cooked (see **Section 4.4.2.1.4 The effect of cooking time on the glucose concentration in camas** on page 195), an ANCOVA was used to test for the effect of the presence of lichen on the glucose concentration of the camas as it was cooked. No significant difference was found in the response to cooking time between the two cooking treatments ($F_{1,7}=0.573$, $P=0.478$).

4.4.2.1.3 The effect of cooking time on the fructose concentration in camas

The fructose concentration in camas obviously increased dramatically over time as it was cooked (see **Figure 4.8**). All five models listed above were tested to see which one best described this response. All models were compared looking at the data separately for the two cooking treatments (camas cooked alone and camas cooked with lichen), and again with the all the data lumped together. The increase in fructose concentration was best modeled with either a Type II functional response version **(b)** or a

Type III functional response version (**d**). The AICc values for the models using all the data lumped together were significantly lower than the sum of the AICc values for the data modeled separately, implying that a better fitting model is achieved by lumping the two cooking treatments together. See **Table 4.3** for a summary of the quality of fit of the relevant models.

The Type III functional response version (**d**) provided a much better fit for camas cooked with lichen, and for both treatments lumped together, but because of the small sample size the corrected AIC chooses the more parsimonious Type II functional response version (**b**) as the best model (see **Table 4.3**). However, the Type III functional response version (**d**) should still be considered as a possible alternative.

4.4.2.1.4 The effect of cooking time on the glucose concentration in camas

The glucose concentration in camas also increased over time as it was cooked (see **Figure 4.9**). All five models listed above were tested to see which one best described this response, and the linear model produced the best fit according to the AICc. When models looking at the data split into the two cooking treatments were compared to models using all the data lumped together, the AICc values for the lumped models were significantly lower than the sum of the AICc values for the split models, implying that a better fitting model is achieved by lumping the two cooking treatments together.

4.4.2.2 Sugars in lichen

4.4.2.2.1 Sugar concentration in lichen cooked alone

The raw lichen contained no fructose, and none accumulated when the lichen was cooked alone. See **Figure 4.10**. This is to be expected, as lichen storage carbohydrates are glucans.

The raw lichen did contain a small amount of glucose but this concentration appeared to change very little when the lichen was cooked by itself (see **Figure 4.11**). On average, when the lichen was cooked alone it contained 14.4% less glucose than when it was raw. This decrease in glucose was found to be significant with a two-sample t-test ($t_{0.5,6} = -2.56$, $P=0.034$). A linear decrease in glucose concentration over time was found to be the most parsimonious model according to AIC. (The inversed hump model $S = S_{init}$

- $b \cdot t \cdot (1 - t/c)$ actually scored a better AIC, but given that there is no *a priori* reason to assume such a relationship, this model was rejected).

4.4.2.2 Sugar concentration in lichen cooked alone at different acidities

The initial pilot test for the effect of cooking pH on lichen carbohydrates indicates that pH has no effect on glucose concentration. Altering the pH of two lichen samples cooked for ten hours to a pH of 5.0 and 3.0 lowered their glucose concentration by 11.4% and 17.8% respectively. This variation appears to be well within the natural variation observed in glucose concentration of lichen cooked alone (see **Figure 4.11**), consequently the two trials of lichen cooked at different acidities were lumped together with the other trials of lichen cooked alone to increase sample size for subsequent analysis.

4.4.2.3 Sugar concentration in lichen cooked with camas

The lichen contained a substantial higher concentration of both glucose and fructose when it was cooked with camas, with concentrations of both sugars appearing to increase over time, and accumulating to significant levels after ten or more hours (notably, sugar concentration after only six hours was not particularly high). A linear response was the best fit for both glucose and fructose increase over time when the possible models were compared with AIC. See **Figure 4.10** and **Figure 4.11**. A more intuitive model of sugar increase in the lichen cooked with camas would probably be in the form of:

$$S = L(t) + \int_0^t C(t) \cdot A(t) \, d(t)$$

Where L is the function describing lichen derived sugar, C is the function describing the amount of sugar in the camas, and A is the function describing the net flux of sugar into the lichen from the camas, all in respect to time (t). However, according to AIC there are too few data points and too much variation around any trend to opt for any model more complicated than a linear model.

It is important to note that the dry mass of the lichen in each sample is roughly twice that of the camas. Because of this, a given sugar concentration in the lichen

represents more total sugar than the same concentration in the camas, which must be accounted for when trying to understand how much of the camas' sugar is being absorbed by the lichen.

4.4.2.3 Mass loss in camas and lichen as they were cooked

A change in sugar concentration was not the only effect of cooking. Both the camas and the lichen appeared to lose mass steadily over time as they were cooked (see **Figure 4.12** and **Figure 4.13**). Because the samples could not be dried before cooking, the original dry weight must be estimated based on the moisture content of the uncooked control samples. Because of natural variation in moisture content of raw samples there is some inaccuracy inherent to this method that will likely partially obscure any trend. This is particularly true for raw camas, which varied from 64.3% to 76.4% water in this experiment (which is still substantially less variable than the 69 ± 50 % reported by van Loo *et al.* 1995). Nonetheless, there appears to be a trend that both lichen and camas lost mass over time, and a trend that both the lichen and the camas lost less mass when they were cooked together.

This mass loss that is occurring in the camas and lichen during cooking is important to consider when attempting to understand the nutritional value of cooking. Any materials being lost that are nutrients (glucose and/or fructose in the current analysis) represent a negative effect of cooking. Any materials being lost that are not nutrients will increase the concentration of nutrients (which is what is being measured) without increasing the total amount of nutrients (which is the nutritionally relevant value), and thus confound the current analysis.

4.4.2.3.1 Mass loss in camas

A linear decrease in mass over time was found to be the most parsimonious model according to AICc (see **Figure 4.12** and **Table 4.4**). When the data for the two cooking treatments (camas cooked alone or with lichen) was lumped together it had a better AICc than when the data was split into treatments, implying that a more accurate model is achieved by lumping together the two cooking treatments for camas (see **Table 4.4**). Although the linear model had the best AICc, the difference between the AICc of the linear model and the AICc of the Type II version (c) model was less than one, indicating

that there was not a significant difference between the two and that the Type II version (c) model should also be considered as a possible model for the mass loss of camas.

On average, the camas retained 6.5% more of its mass when it was cooked with lichen instead of being cooked alone, but a paired t-test found this difference to be not quite significant ($t_{0.05,4} = 2.38$, $P=0.075$). Lumping the two treatments together, a simple linear regression shows that the reduction in mass with increased cooking time was significant ($R^2=0.68$, $t_{0.05,8}=-4.09$, $P=0.0035$).

4.4.2.3.2 Mass loss in lichen

According to AIC, the mass loss over time of lichen cooked alone was best modeled with a Type II response version (c) (see **Table 4.4**). For lichen cooked with camas, both the linear model and the Type II (c) model scored within one for their AICc, indicating that they were not significantly different. When the data for the two treatments were lumped together the Type II (c) model scored significantly better, but the summed AICc for the treatments considered separately was better than the lumped AICc, indicating that the data are best modeled by considering the two treatments separately (see **Figure 4.13**). This would be expected, given that the treatments were found to be significantly different (as shown below).

Although the mass loss of lichen over time as it was cooked was not necessarily linear (see **Figure 4.13** and **Table 4.4**), this non-linearity is mostly caused by constraining the lichen to be at 100% of its weight at hour zero (a logical necessity). If one just considers the data points of the actual experiment (from 6 hours to 34 hours), a linear regression is the best fitting model according to AICc. Because of this, an ANCOVA is appropriate to test how the masses of lichens in the two different treatments (cooked alone and cooked with camas) changed over time, as long as the raw lichen is not included in this test.

If the lichen was cooked with camas, it was on average 5.6% heavier than if it was cooked alone. This suggests that that the lichen lost mass faster when cooked alone, but an ANCOVA found that the interaction between the length of time cooked and cooking treatment (whether it was cooked alone or with camas) was not quite significant ($F_{1,9}=4.10$, $P=0.077$). The reduction in the mass of the lichen over time between 6 hours

and 34 hours was significant ($F_{1,10}=17.5$, $P=0.002$), as was the effect of cooking treatment on this mass reduction ($F_{1,10}=13.1$, $P=0.006$).

4.4.2.4 Total sugar content in cooked camas and lichen

It is not the concentration of digestible carbohydrate in the cooked product that is important, but rather the total amount of digestible carbohydrate produced from the initial food stuff. Cooking does increase the concentration of both sugars, but also decreases the total mass. A more relevant measure to compare the effectiveness of the different cooking methods in creating digestible carbohydrates is to relate the total mass of sugar present in the food after cooking to the initial mass of that food before cooking.

4.4.2.4.1 Standardization necessary to compare camas and lichen samples

There are two main confounding factors that make it difficult to compare between individual camas samples or between individual lichen samples: the initial samples of raw food did not start out at identical raw weights, nor did they start at identical moisture contents. Both these factors result in the samples not having identical initial raw dry weights. This was particularly a problem with the camas bulbs, as they had greater variation in initial wet weight and moisture content. Every effort was made to ensure that both of these sources of error were reduced within each pair of samples that were cooked for the same length of time, but variation between samples that were cooked for different lengths of time could not be controlled to the same extent.

This variation necessitates that the actual dry weight of the cooked samples be standardized before comparing the total sugar contents of different samples. To compare samples that were cooked for different lengths of time, this standardization was accomplished by multiplying the actual sugar concentration of each sample by the estimated amount of mass remaining from the raw weight.

Although a Type II functional response was also a good model for mass loss over time (see **Table 4.4**), this is only because the models were constrained so that the items started at 100% of their weight at hour zero, which is essential for a holistic model of mass loss. If the intent is just to allow for comparisons between the five data points over time (from 6 hours to 34 hours), the model does not need to be concerned with what happens at hour zero. This allows for an even better fit to be achieved using four separate

linear models for camas and lichen, both cooked separately and together, as is confirmed by AIC. The four linear regressions reported in **Table 4.5** were therefore used to estimate the mass loss for each sample and generate a standardized value for the total amount of sugar produced per initial dry weight.

The total sugar content of the lichen and camas when they were cooked together as opposed to being cooked separately can best be compared by looking at each pair of samples individually because there was less variation in sample mass and moisture content in samples within pairs than there was between pairs. In this case the sample weights are only standardized within each pair (a maximum adjustment of 1%), and the actual dry weight is used instead of the theoretical one calculated by the linear regression.

4.4.2.4.2 Total sugar content in cooked camas bulbs

Even though fructose concentration in camas bulbs increased over time for the entire period of the test (**Figure 4.8**), because mass was slowly lost over time the maximum total amount of fructose was achieved at 18 hours (**Figure 4.14**). Although the fructose concentration continues to slowly rise, this is counteracted by the slow decrease in mass.

There also appears to be a trend that camas cooked with lichen contains more total fructose than camas cooked alone. The camas that was cooked with lichen contained on average 27.7% more fructose than camas cooked alone, but because of the high variability a paired t-test showed no significant difference ($t_{0.05,4}=-1.33$, $P=0.255$).

The total amount of glucose in the camas appears to begin to level off after 18 hours (**Figure 4.15**), although the glucose concentration continues to rise for the 34 hours of the test (**Figure 4.9**). The glucose content is still too variable to see any other distinct trends.

4.4.2.4.3 Total sugar content in cooked lichen

The total amount of fructose and glucose in cooked lichen (**Figure 4.16** and **Figure 4.17**) shows a trend similar to that of the fructose and glucose concentration in cooked lichen (**Figure 4.10** and **Figure 4.11**), although the decrease in glucose content is more pronounced (**Figure 4.17**).

4.4.2.5 Total sugar produced by the different cooking methods

The total amount of sugar produced by a cooking method (either cooking the lichen and camas together or separately) is the sum of the total sugar in both the lichen sample and the camas sample from that cooking method. The total fructose content was always higher when the camas and lichen were cooked together (**Figure 4.18**), and the total glucose content was higher with the camas and lichen cooked together when they were cooked for ten hours or longer (**Figure 4.19**). The total sugar content (fructose plus glucose) was always higher when the lichen and camas were cooked together. The effect was not as pronounced at six hours, but from ten hours onward there is an average increase in total sugars of 74.2%, ranging from 26% to 122%.

Figure 4.20 and **Figure 4.21** show the theoretical curves of sugar accumulation in camas and lichen when they are cooked together and separately. The theoretical curves are calculated from the best fit models for the actual data. It is apparent that cooking lichen and camas together produces substantially more total sugar.

4.4.2.6 Using cotton instead of lichen to cook with camas

When camas was cooked alone, it was wrapped in 10 g of cotton instead of 10 g of raw lichen. When the cotton was baked around the camas, it had an average increase in mass of 2.0%, but an independent samples t-test found this difference to be not quite significant ($t_{0.5,5} = 2.36$, $P = 0.068$).

A linear model for change in both fructose and glucose concentration over time in the cotton as it was cooked with camas was confirmed by AICc to be the best fit out of all models tested (see **Figure 4.22**). A simple linear regression showed that the change in glucose concentration in the cotton as it was cooked with the camas was not significant ($R^2 = 0.27$, $t_{0.5,5} = 1.35$, $P=0.235$, power=0.64), but the increase in fructose concentration was significant ($R^2 = 0.91$, $t_{0.5,5} = 7.16$, $P=0.0008$).

This indicates that the cotton was absorbing some of the fructose that was being lost from the camas as it cooked. This sugar that was collected by the cotton is represented in **Figure 4.18** and **Figure 4.19** by the white sections of the bar graph, and is sugar that has been lost from the food and is therefore nutritionally unavailable. But even if this amount of sugar is included, there is still considerably more sugar present when the

lichen and camas are cooked together (**Figure 4.18** and **Figure 4.19**). This is at least partially because the lichen seems to be about six times better at absorbing sugars than the cotton (see **Figure 4.23**).

4.4.2.7 The hydrophilic nature of cooked lichen

When the lichen cooks it absorbs moisture from its environment and swells up into a black, licorice-like substance. There seems to be a very specific amount of water that the cooked lichen absorbs from its environment, and this does not appear vary with the moisture content of the lichen's environment, or with how long it was cooked. The cotton that surrounded the cooking lichen in the simulation pitcooks varied greatly in water content between the different cooking trials, containing between 6% and 46% of its weight in water at the end of the trial when the lichen was removed and weighed. A simple linear regression showed that this variation in the water content of the lichen's cooking environment had no significant effect on the water content of the lichen ($R^2 = 0.01$, $t_{0.5,11} = 0.38$, $P = 0.714$, power=0.70, see **Figure 4.24**). A simple linear regression also showed no significant effect of cooking time on the water content of the cooked lichen ($R^2 = 0.06$, $t_{0.5,11} = 0.79$, $P = 0.450$, power = 0.62, see **Figure 4.25**).

The moisture content was affected by whether or not the lichen was cooked with camas (see **Figure 4.24** and **Figure 4.25**). When the lichen was cooked alone it was 83.2% (± 0.8) water, and when it was cooked with camas it contained 3.0% less water, which was found to be significant by an independent samples t-test ($t_{0.5,10} = 3.08$, $P = 0.012$). The six-hour cooking trial was the only instance when the lichen cooked with camas contained as much water as lichen that was cooked alone. It is quite possible that six hours was not long enough to see a significant effect from the presence of the camas, because this was also the case for glucose and fructose content for both the lichen and the camas. Lichen that was cooked with camas for ten hours or longer was 79.8% (± 0.9) water, 3.8% less than when it was cooked alone.

4.4.3 Summary of results

4.4.3.1 The effect of cooking on lichen

1. The lichen lost mass over time as it cooked (see **Figure 4.13**).
2. The lichen absorbed four to five times its weight in water sometime within the first six hours of cooking and retained that amount water throughout the cooking process, regardless of how long it was cooked or the moisture content of its surroundings.
3. Lichen did not contain any fructose when raw, and did not gain any when cooked alone (see **Figure 4.10** and **Figure 4.16**).
4. Lichen contained a small amount of glucose when raw, and this amount decreased by an average of 14.4% when it was cooked alone (see **Figure 4.11** and **Figure 4.17**). This decrease was significant ($t_{0.5,6} = -2.56$, $P=0.034$).
5. Acidifying the cooking environment to a pH of 5.0 or 3.0 appears to have no effect on the cooking lichen.

4.4.3.2 The effect of cooking on camas

1. The camas lost mass over time as it cooked (see **Figure 4.12**).
2. The raw camas contained a small amount of fructose. This increased dramatically over time as it was cooked. Initially the concentration of fructose increased rapidly with cooking, and then more slowly after 18 hours (see **Figure 4.8**). Although fructose concentration increased continually over time as it cooked, the total amount fructose was highest at 18 hours and then slowly decreased because the camas was also losing mass (see **Figure 4.14**).
3. The raw camas contained a small amount of glucose, which increased slightly over time as it cooked (see **Figure 4.9** and **Figure 4.15**). However, there was much less glucose than fructose in the camas, raw or cooked.

4.4.3.3 The effect on the lichen of cooking the lichen and camas together

1. When the lichen was cooked with camas, the dry mass of the cooked lichen was 5.6% heavier, which was found to be significant ($F_{1,10}=13.1$, $P=0.006$). The lichen was either losing less mass, or gaining some additional material.

2. Lichen cooked with camas had a significantly higher concentration of glucose (about double if cooked for ten or more hours). This concentration increased over time the longer the lichen and camas were cooked. See **Figure 4.11**.
3. Lichen cooked with camas had a significantly higher concentration of fructose (several hundred times greater if cooked for ten or more hours). This concentration increased over time the longer the lichen and camas were cooked. See **Figure 4.10**.
4. The lichen cooked with camas captured six times more fructose from the camas carbohydrate than was captured by the same amount of cotton (see **Figure 4.23**).
5. Lichen cooked with camas stabilized at a moisture content that was 3-4% lower than when it was cooked alone (79.8% water instead of 83.2% water, or absorbing four times its weight in water instead of five times). This difference was significant ($t_{0.5,10}=3.08$, $P=0.012$).
6. All of these effects were much less evident (or non-existent) when the lichen and camas were cooked for only six hours, but very apparent when cooked for ten or more hours.

4.4.3.4 The effect on the camas of cooking the camas and lichen together

1. The glucose and fructose concentrations of the camas were unaffected by cooking it with lichen.
2. When camas was cooked with lichen the dry mass of the cooked camas was found to be slightly heavier, but this difference was not significant in this experiment.
3. Although the concentration of fructose in the camas did not increase when the camas was cooked with lichen, there was less dry material lost, and therefore a higher total fructose content. There was, on average, 27.7% more fructose in the camas bulbs when they were cooked with lichen, but because of the high variation in the samples this difference was not statistically significant.

4.4.3.5 The result of cooking lichen and camas together

1. Cooking lichen and camas together produced substantially more glucose and fructose than cooking them separately. The total amount of these simple sugars present when the foods were cooked together increased by an average of 74.2%

(range 26% to 122%). See **Figure 4.18**, **Figure 4.19**, **Figure 4.20**, and **Figure 4.21**.

2. A cooking duration of six hours was not long enough to see a significant effect of cooking the foods together. The maximum reward for cooking the lichen and camas together appears to occur at the 18 and 26 hour cooking durations.

4.5 Discussion

The use of *Bryoria fremontii* for food was widespread throughout the interior Pacific Northwest, and the people who traditionally used this lichen for food put considerable effort into harvesting and preparing it (see **Section 2.2 An overview of the traditional use of *Bryoria* species** on page 83). This indicates that the lichen had a significant nutritional value to the people who were eating it. The major nutrients in this lichen are carbohydrates (see **Section 2.4.2 The nutritional value of *Bryoria*** on page 118), but these carbohydrates are indigestible to humans in their raw state (see **Section 1.5.5 The digestibility of lichens** on page 56). Virtually all of the First Peoples who traditionally ate *Bryoria fremontii* as an important vegetable used a very similar, time consuming procedure for preparing and cooking this lichen (see **Section 2.2.4 Cooking the lichen** on page 91). It thus seems very likely that this procedure for preparing and cooking the lichen contributes significantly to its nutritional value for humans.

4.5.1 Cooking the lichen does not make it edible

It appears that cooking *Bryoria fremontii* does not contribute in any way to making the lichen's carbohydrates digestible to humans. It is possible that traditional pitcooks were capable of maintaining the lichen at a hotter temperature than was used in the experimental trials, and that this hotter temperature was capable of breaking down the lichen carbohydrates. It is also possible that traditional pitcooks had a low enough pH to help significantly the breakdown of the lichen carbohydrates. Both these possibilities, however, seem unlikely for the reasons explained below.

4.5.1.1 The possibility that the pitcooks should have been hotter

The cooked lichen has often been likened in appearance to black licorice (e.g. Turner 1998). The cooked lichen from the current cooking trials was very reminiscent of black licorice: it was pure black and had a rubbery, gooey texture (see **Figure 4.6 F**). This characteristic of the cooked lichen is a result of it absorbing four to five times its weight in water and holding that water as a gel. It is impossible to raise the temperature of this lichen gel above the boiling point of water without boiling off all the water in the gel, which would not produce the desired or characteristic end product of a traditional wila pitcook.

It is possible that the traditional wila pitcook pressurized itself enough (perhaps to double atmospheric pressure) to significantly raise the boiling point of water, and thus heat the lichen significantly above 100°C. Although there may be evidence of this occurring in some experimental pitcooks conducted in Texas (Leach *et al.* 1998; Pagoulatos 2005), these types of temperatures were not reached by an experimental pitcook conducted in Secwepemc territory that is a more likely representation of a traditional wila pitcook (Peacock 1998). The 100°C temperatures used in the current experiment were therefore probably quite representative of the maximum temperature reached a traditional wila pitcook.

4.5.1.2 The possible contribution of pitcook acidity

The pilot test conducted to see if acidifying the cooking environment helped to break down the lichen carbohydrate indicates that there is no effect of acidity even after reaching a pH of 3.0. It seems highly unlikely that a pitcook could reach a pH lower than 3.0 (see **Section 4.2.4 The pH of a pitcook** on page 181). It therefore seems unlikely that the acidity of a pitcook is significantly contributing to any breakdown of the lichen carbohydrates.

4.5.2 An alternative role for lichen carbohydrates

Lichen storage carbohydrates, particularly lichenin, are known for their ability to form gels with water. *Cetraria islandica* has traditionally been used throughout northern Europe to make a variety of pudding-like desserts for this very reason (for examples see

Jacobj 1916). This property of lichen carbohydrates is undoubtedly the cause of the very unique, black, licorice-like gel formed when *Bryoria fremontii* is pitcooked. The undeniable aesthetic appeal of *Bryoria fremontii* when it has been cooked in this fashion may have contributed somewhat to its widespread use, but this gel may also play a more utilitarian role in capturing digestible carbohydrates from accompanying food that would otherwise be lost due to the cooking process.

Lichen definitely captured a significant amount of digestible carbohydrate from the camas when they were cooked together. It seems likely that the formation of the lichen gel contributes to this ability of the lichen, although the two phenomena may be entirely unrelated. The lichen does not appear to be removing carbohydrate from the camas, because the carbohydrate content of the camas did not decrease with the presence of the lichen, but rather slightly increased (although this increase was not significant). It therefore seems that these camas carbohydrates would have been otherwise lost if not for the presence of the lichen.

Inulin, the major carbohydrate present in camas bulbs, is somewhat water soluble (Yanovsky and Kingsbury 1933), while both fructose and glucose are entirely water soluble. A likely scenario is that steam from the pitcook is allowing carbohydrates from the camas bulbs to leach into their environment. Without the presence of wila, these carbohydrates are lost into the inedible materials surrounding the camas in the pitcook. In the presence of the lichen, however, the unique properties of the lichen carbohydrate-water gel allowed the lichen to capture these leaching camas carbohydrates. The lichen was six times better at capturing the leaching camas carbohydrate than the same amount of cotton (see **Figure 4.23**).

The optimum cooking time for cooking wila together with camas was found to be 18 to 26 hours (see **Figure 4.19** and **Figure 4.20**). This is comparable to common cooking times reported in the literature for traditional wila pitcooks (see **Section 2.2.4.7 Length of time to cook the lichen** on page 98).

It is also interesting to note that the β -glucans in cereals (which are structurally very similar to lichenin) are known for their ability to help moderate the increase in blood sugar after meals by slowing the absorption of sugars into the body (Wood *et al.* 1994; Dubois *et al.* 1995; Hallfrisch *et al.* 1995), and that this ability has been linked to the gel-

forming properties of these β -glucans (Wang *et al.* 1992). It may be the case that cereal β -glucans and lichenin both have a strong affinity for holding onto simple sugars, regardless of whether or not it is in a cooking pit or in your gut. If this is true, after the lichenin captures the digestible carbohydrates that were otherwise being lost from the cooking root vegetables, it may also help our body to assimilate those carbohydrates in a more efficient manner.

4.5.3 Quantifying this benefit to people

It appears that the lichen *Bryoria fremontii* contains minimal nutrients of value to humans. The main storage carbohydrates of this lichen, lichenin and isolichenin, are indigestible to humans, and do not appear to break down with traditional cooking practices. But, even though it remains indigestible, this lichen may still confer a significant nutritional benefit in traditional cooking.

When *Bryoria fremontii* was cooked with camas bulbs, the digestible carbohydrate content of the food was increased by an average of 74.2% (range 26% to 122%). It is conceivable that with enough practice to perfect the pitcooking recipe, one could use the lichen to double the amount of available digestible carbohydrates produced by cooking the camas. This is a substantial increase in the nutrition of this root vegetable. Given the effort involved in harvesting camas and other root vegetables, if wila can be used to halve the number of bulbs necessary fulfill a person's calorie requirement, then the lichen would be very useful indeed.

The value of cooking camas and wila together is further corroborated by Turney-High's (1937) report on the traditional cooking practices of the Flathead. Apparently the Flathead never cook either camas or wila alone. Both of these items are only cooked blended together, and the lichen is said to sweeten the mixture and is considered a necessary condiment for camas.

Wila is almost always traditionally cooked with a root vegetable (see **Section 2.2.4.4 Food that the lichen is cooked with** on page 96), so capturing root vegetable carbohydrates could be the main nutritional use of the lichen. Edible blue camas is traditionally a common root vegetable to be cooked with the lichen (particularly among

the Flathead), but Douglas wild onions, nodding onions, Geyer's onions, *Lomatium* spp., balsamroot, yellow glacier lily, and false Solomon's seal are also traditionally used in different areas. The current experiment tested only one of these species of root vegetable, but it seems likely that the other species are also enhanced by cooking with lichen, particularly because several of them are similar to camas in having inulin as their major storage carbohydrate.

Chapter 4 Tables and Figures

Table 4.1. The optimal parameter values that minimize residual sum of squares for the Peacock (1998) experimental pitcook data using five different models of heat loss. Corrected Akaike's Information Criterion (AICc) values are calculated to determine that the best model is model (d).

Model	# Obs.	# Par.	Parameter values					RSS	AIC	AICc
			θ_i	θ_s	a	b	c			
I (a)	16	2	99.3	•	-2.12	•	•	14.0	1.88	2.81
II (b)	16	3	100	-116	0.0109	•	•	11.2	0.27	2.27
III (d)	16	4	98.3	20.4	1.50	19.3	•	3.38	-16.9	-13.2
III (e)	16	5	99.9	49.7	-0.907	3.93	6.32	4.58	-10.0	-4.01
			θ_r	θ_s	d	r	h			
Lovering model (f)	15	5	115	20.0	25.0	25.0	0.220	62.6	31.8	37.8

Table 4.2. Some factors affecting the thermal dynamics of a pitcook.

Pitcook parameter	Effect on thermal dynamics
Thermal diffusivity of the pit wall (depends on the soil type and moisture content)	How long the pit takes to heat up and cool down
Heat capacity of the hot rocks (depends on rock type and size)	Amount of energy available to heat pit
Thermal conductivity of rocks (depends on rock type, size, and shape)	Rate at which the rocks transfer heat into the pit.
Distance from hot rocks to food	How heat is transferred from the rocks to the food
Ambient temperature of soil (depends on season, recent weather, and pit depth)	How rapidly the pit will cool down
Thermal diffusivity of materials inside pit	How long the food takes to heat up and cool down
Structure of materials inside pit	Allows for convection of water, air, or steam which could greatly increase thermal diffusivity of pit
Amount of water in pit	Latent heat of vaporization of the water will help to maintain the pit at the boiling point of water
Initial temperature of hot rocks (depends on fuel source, technique, and duration of fire)	Amount of energy available to heat pit
Weight of material on top of pitcook	More weight increases pressure and boiling point of water, which increases temperature that food is maintained at
Porosity of pit walls and covering	Allows for increased pressure with boiling of water, same effect as above

Table 4.3. Fructose concentration of cooked camas in simulation pitcooks compared to theoretical models for increase in fructose concentration over time. Models are Type II functional response version **(b)** and Type III functional response version **(d)**. The optimal parameter values minimize residual sum of squares for the experimental data compared to the models. Corrected Akaike's Information Criterion (AICc) values are calculated to determine the best model. Data sets for camas cooked alone and camas cooked with lichen are analyzed separately, and lumped together. The best fitting model is achieved by lumping the data together and using model II **(b)**.

Model	Data set	# Obs.	# Par.	Parameter values				RSS	AIC	AICc
				S_{init}	S_{end}	a	b			
II (b)	cooked alone	5	2	4.33	40.5	0.058	•	29.0	12.8	18.8
III (d)	cooked alone	5	3	4.33	39.8	1.68	11.3	26.0	14.2	38.2
II (b)	with lichen	5	2	4.33	34.0	0.099	•	29.7	12.9	18.9
III (d)	with lichen	5	3	4.33	33.4	3.40	7.42	2.16	1.8	25.8
II (b)	all data	10	2	4.33	37.3	0.076	•	72.1	23.8	25.5
III (d)	all data	10	3	4.33	35.4	2.25	8.60	52.6	22.6	26.6

Table 4.4. Weight loss over time of camas and lichen as they are cooked separately and together in simulation pitcooks compared to theoretical models of weight loss over time. The two best fitting models are reported: Type I functional response (linear) and Type II functional response version (c). The optimal parameter values minimize residual sum of squares for the experimental data compared to the models. Corrected Akaike's Information Criterion (AICc) values are calculated to determine the best model. Data sets for camas/lichen cooked separately and cooked together are analyzed separately, and lumped together.

Model	Data set	# Obs	# Par	Parameter values			RSS	AIC	AICc
				M_{init}	M_{end}	a			
I	camas (alone)	5	1	1.00	•	-0.016	0.58	-20.3	-19.0
II (c)	camas (alone)	5	2	1.00	0.30	18.4	0.033	-21.1	-15.1
I	camas (w/ lichen)	5	1	1.00	•	-0.014	0.015	-27.2	-25.8
II (c)	camas (w/ lichen)	5	2	1.00	-2.18	208	0.014	-25.3	-19.3
I	camas (all data)	10	1	1.00	•	-0.015	0.078	-46.5	-46.0
II (c)	camas (all data)	10	2	1.00	0.07	37.0	0.061	-47.0	-45.3
I	lichen (alone)	7	1	1.00	•	-0.014	0.117	-26.6	-25.8
II (c)	lichen (alone)	7	2	1.00	0.67	1.90	0.001	-57.4	-54.4
I	lichen (w/ camas)	5	1	1.00	•	-0.011	0.028	-24.0	-22.6
II (c)	lichen (w/ camas)	5	2	1.00	0.65	6.81	0.008	-28.0	-22.0
I	lichen (all data)	12	1	1.00	•	-0.012	0.155	-50.2	-49.8
II (c)	lichen (all data)	12	2	1.00	0.67	2.76	0.020	-72.9	-71.6

Table 4.5. Linear regressions relating the percentage of dry mass of camas or lichen remaining after cooking to the length of time it was cooked (in hours).

Data set	R^2	P	Intercept	Slope
Camas cooked alone	0.6	0.126	84.8%	-0.946%
Camas cooked w/ lichen	0.85	0.025	95.3%	-1.164%
Lichen cooked alone	0.73	0.015	74.5%	-0.211%
Lichen cooked w/ camas	0.79	0.045	85.4%	-0.496%

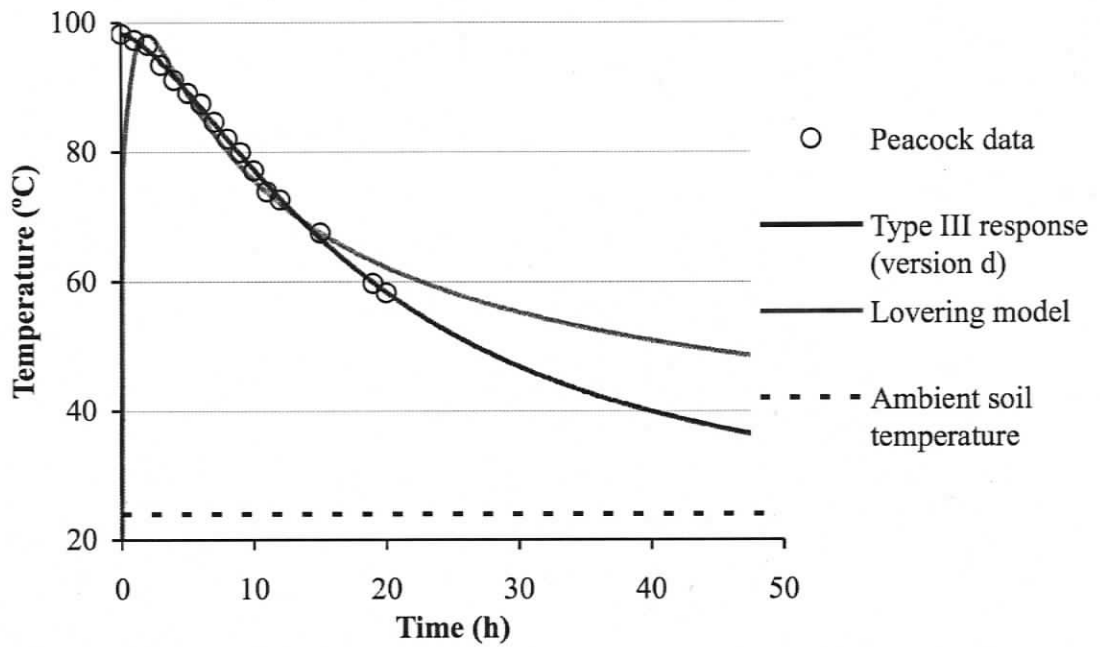


Figure 4.1. Temperature of the Peacock (1998) experimental pitcook over time, compared to two models of heat loss.

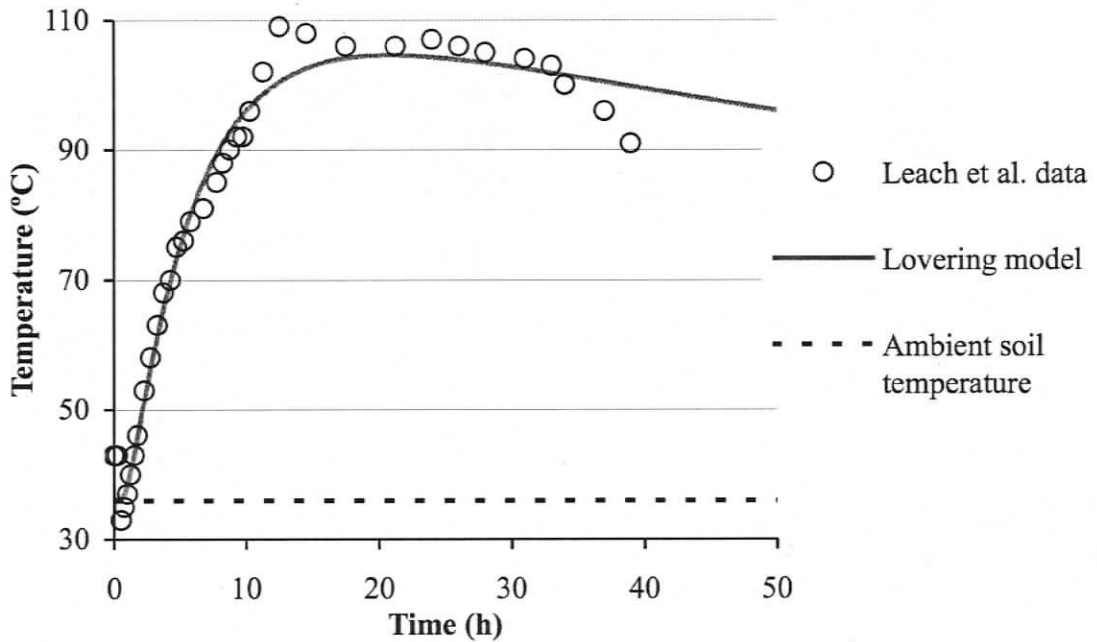


Figure 4.2. Temperature of the Leach *et al.* (1998) experimental pitcook over time, compared to the Lovering model of heat loss (RSS= 388; AICc=97.7).

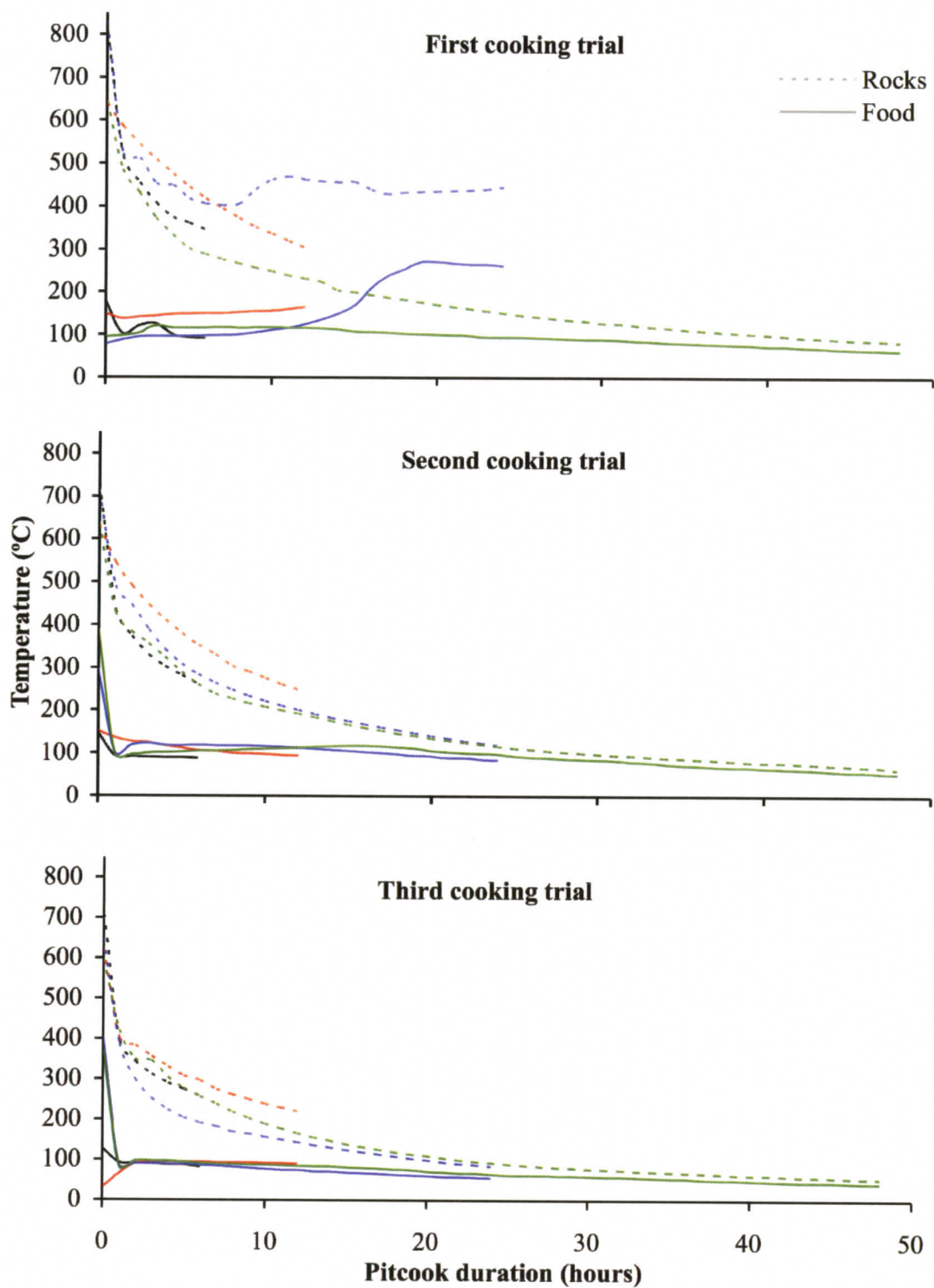


Figure 4.3. Temperature of rocks and food in Pagoulatos (2005) experimental pitcooks. Second and third trials reuse the limestone cobbles from the previous trial (cobbles cracked with use). Lines of the same colour represent the same pitcook.

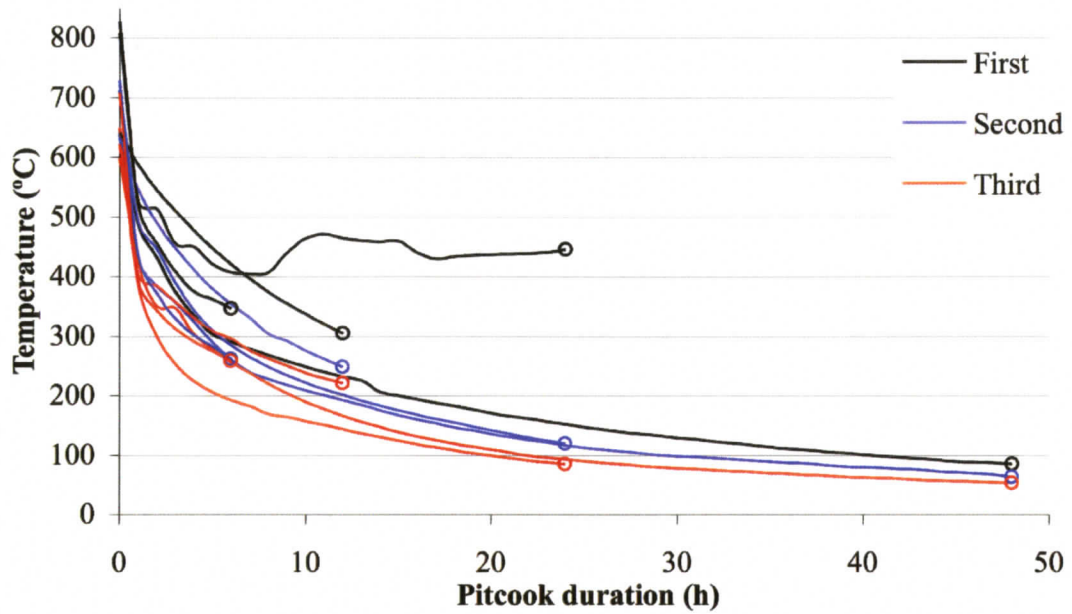


Figure 4.4. Temperature of rocks over time in Pagoulatos (2005) experimental pitcooks left for different periods of time. Second and third trials conducted in the same pit as the previous trial of that duration and reuse the limestone cobbles (which cracked with use).

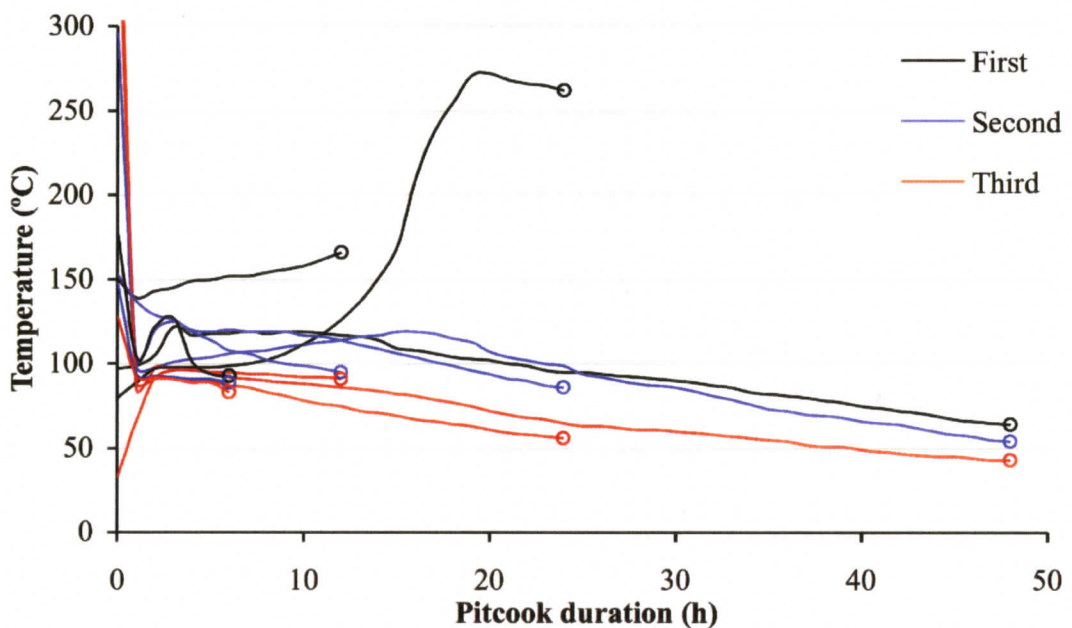


Figure 4.5. Temperature of food over time in Pagoulatos (2005) experimental pitcooks left for different periods of time. Second and third trials conducted in the same pit as the previous trial of that duration and reuse the limestone cobbles (which cracked with use).



Figure 4.6. Simulation pitcooks for cooking wila: **A.** Supplies used for cooking each sample; **B.** Camas bulbs and temperature probe will be completely wrapped in wila, then cotton gauze; **C.** Cotton gauze wrapped sample on cotton felt in clay baker, to be covered with more soaked cotton and the clay baker lid; **D.** Two samples are cooked simultaneously for each trial; **E.** Temperature continuously monitored in oven and inside each sample; **F.** Cooked lichen sample.

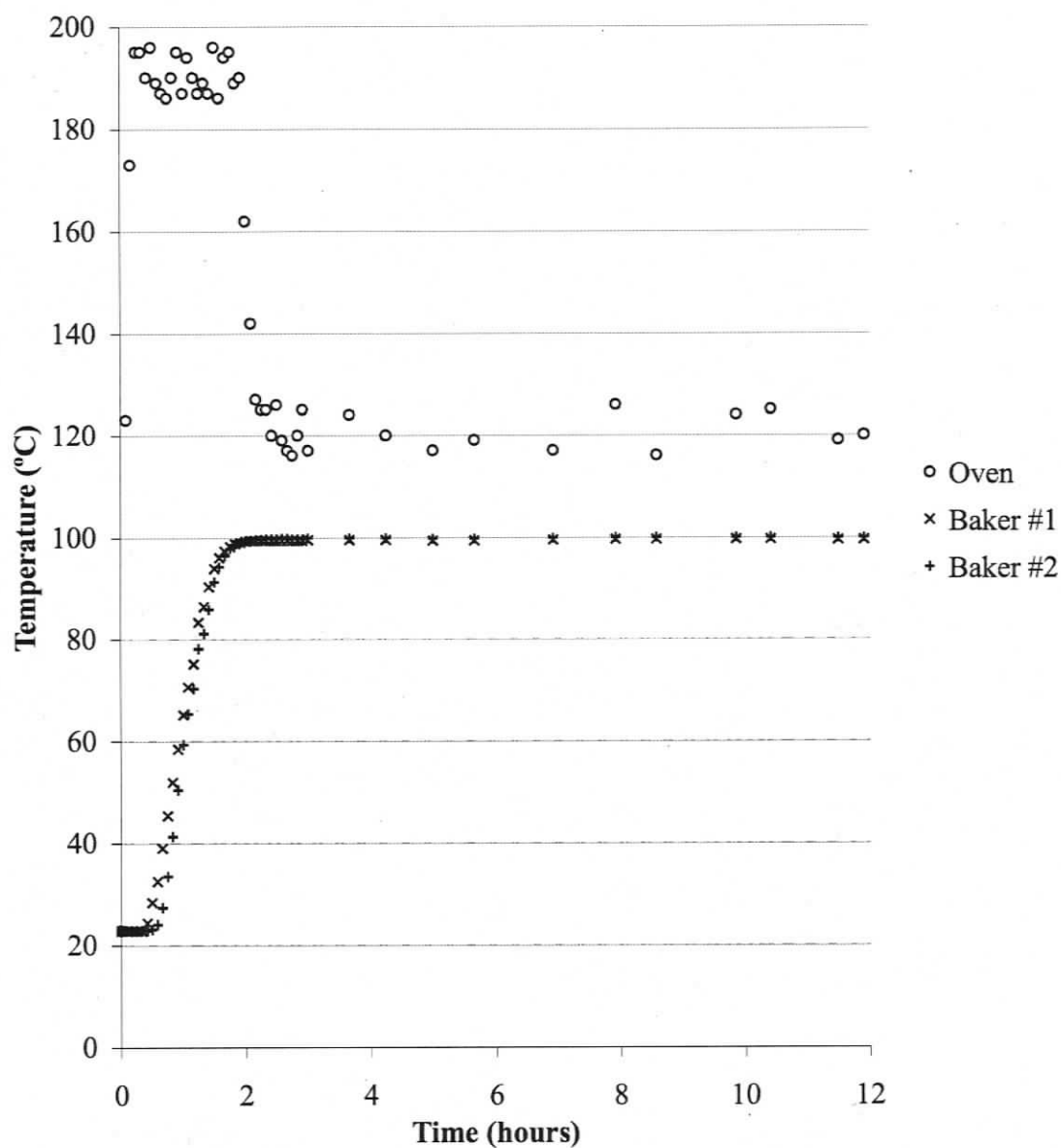


Figure 4.7. Temperatures of two lichen samples in two different clay bakers being heated in an oven to simulate pitcooking compared to the ambient air temperature in the oven for a ten hour cooking trial.

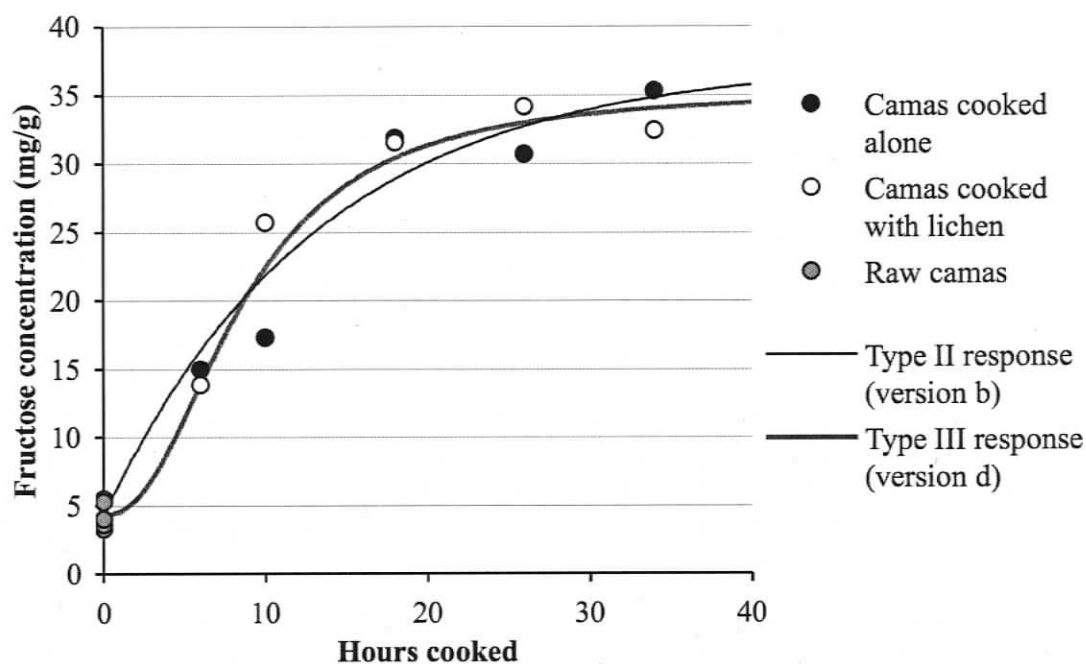


Figure 4.8. Fructose concentration in camas bulbs cooked for different lengths of time, both alone and with lichen. Camas cooked with lichen was not significantly different from camas cooked alone (paired t-test: $t_{0.5,4} = -0.749$, $P=0.496$). Fitted lines are for two different best fit models as determined by Akaike's Information Criterion (AIC).

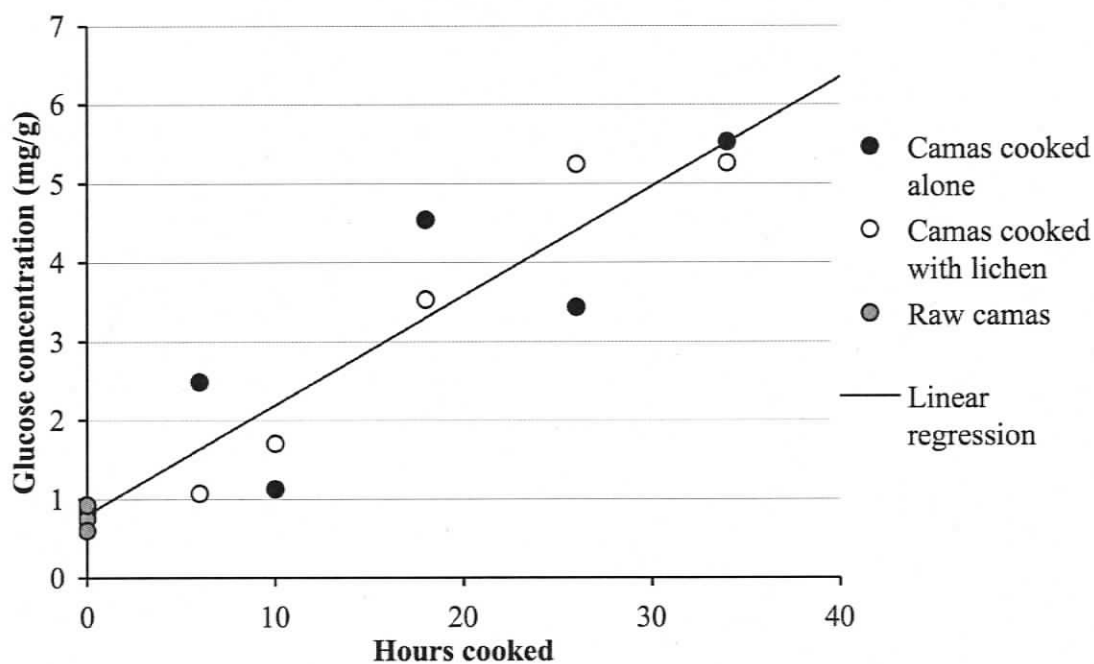


Figure 4.9. Glucose concentration in camas bulbs cooked alone or with lichen for different lengths of time. Lichen did not significantly affect camas glucose concentration (paired t-test: $t_{0.5,4} = 0.107$, $P=0.920$). Fitted line is best fit model as determined by AIC.

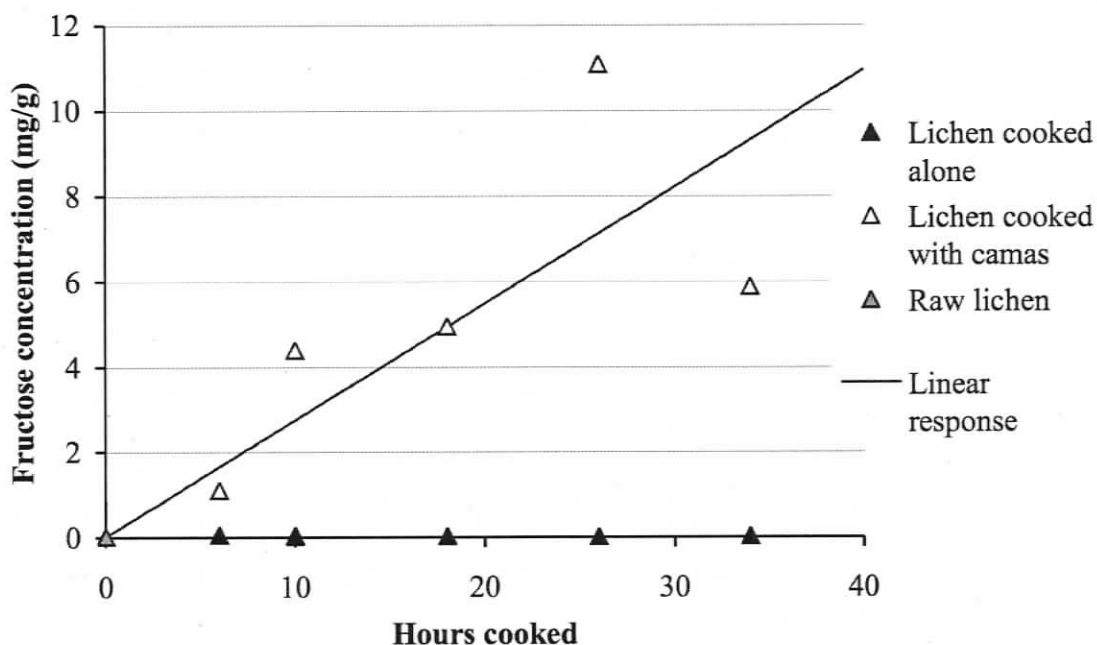


Figure 4.10. Fructose concentration of *Bryoria fremontii* cooked for different lengths of time, both alone and with camas. Fitted line is the best fit model as determined by Akaike's Information Criterion (AIC).

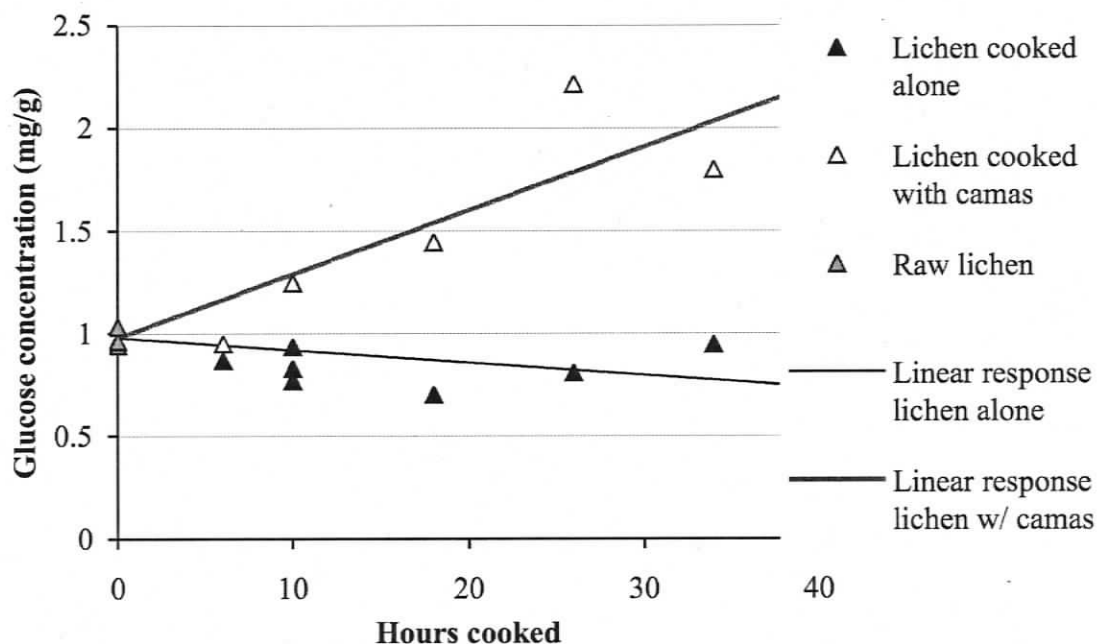


Figure 4.11. Glucose concentration of *Bryoria fremontii* cooked for different lengths of time, both alone and with camas. Glucose concentration was significantly less in lichen cooked alone than in raw lichen (two-sample t-test: $t_{0.5,6} = -2.56$, $P=0.034$). Fitted lines are the best fit models as determined by Akaike's Information Criterion (AIC).

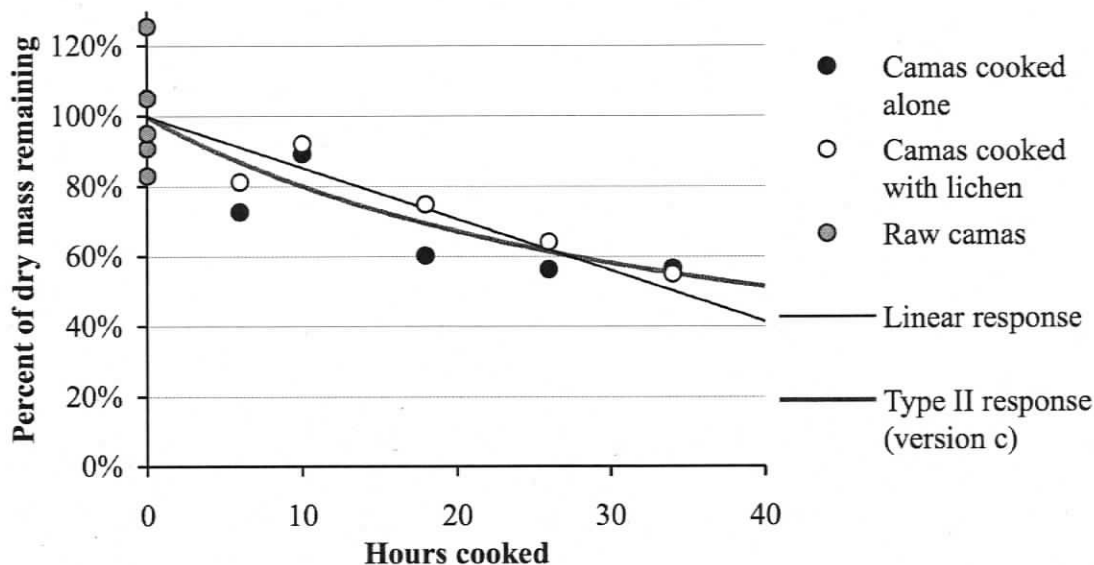


Figure 4.12. Mass loss of camas bulbs cooked alone and with lichen for different lengths of time. Original dry mass of camas estimated from wet weight, using the average moisture content of five raw camas samples. Lichen did not significantly effect mass loss (paired t-test: $t_{0.05,4} = 2.38$, $P=0.075$). Mass decreased significantly over time (linear regression: $t_{0.05,8} = -4.09$, $P=0.0035$). Fitted lines are for two different best fit models as determined by Akaike's Information Criterion (AIC).

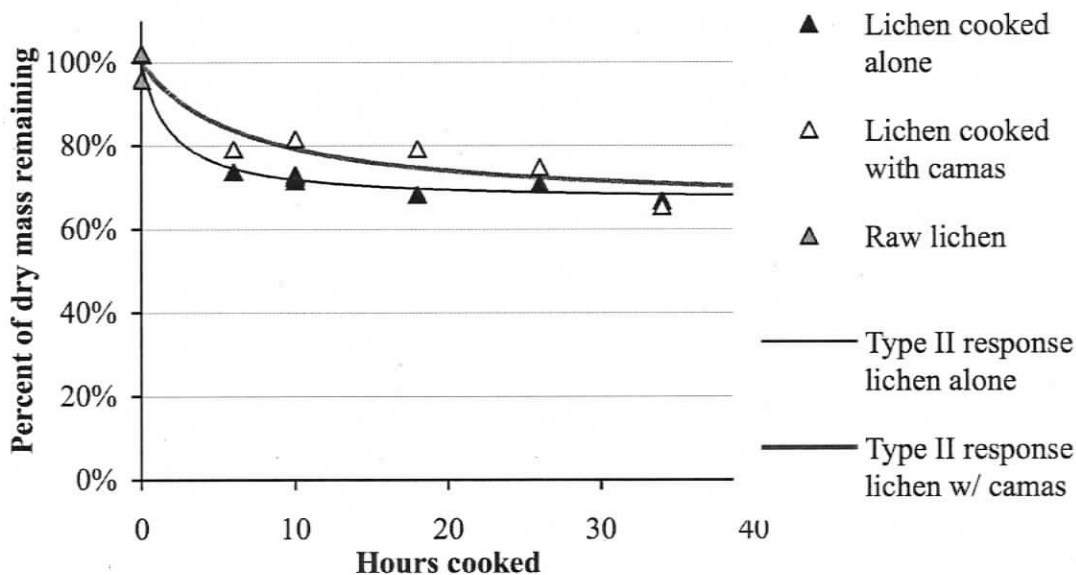


Figure 4.13. Mass loss of *Bryoria fremontii* cooked alone and with camas for different lengths of time. Original dry mass of lichen estimated from wet weight, using average moisture content of three raw lichen samples. Mass loss from 6–34 hours is significantly affected by both cooking duration (ANCOVA: $F_{1,10}=17.5$, $P=0.002$) and presence of camas ($F_{1,10}=13.1$, $P=0.006$). Fitted lines are best fit models as determined by AIC.

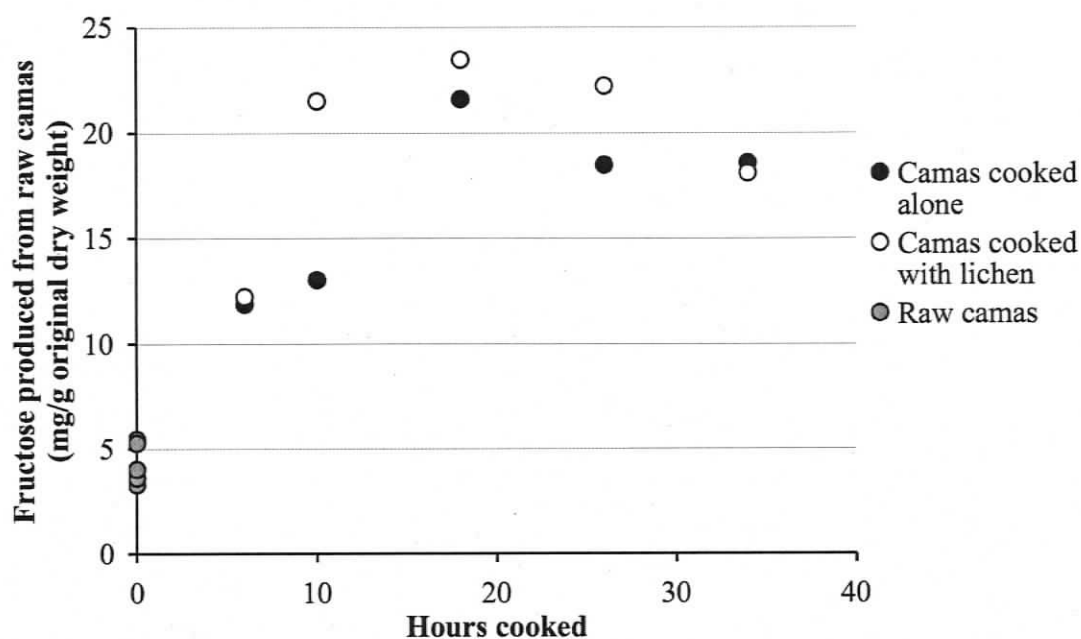


Figure 4.14. The amount of fructose in cooked camas bulbs relative to the dry mass of those bulbs before they were cooked. The dry mass before cooking is estimated from the dry mass after cooking using a linear regression of mass loss over time. The presence of lichen has no significant effect on fructose content (paired t-test: $t_{0.05,4} = -1.33$, $P = 0.255$).

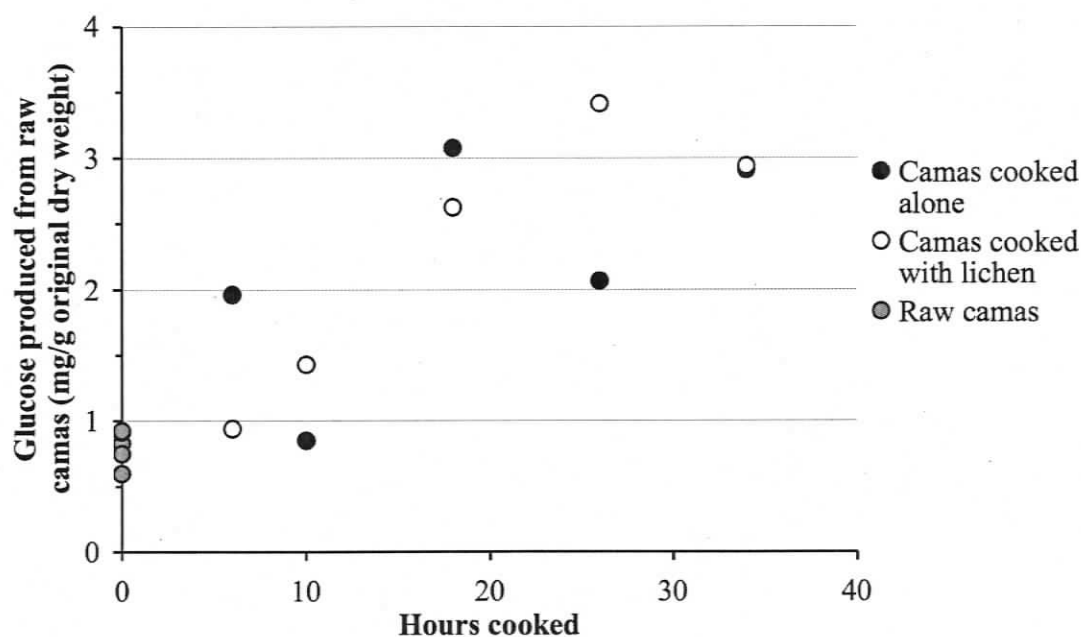


Figure 4.15. The amount of glucose in cooked camas bulbs relative to the dry mass of those bulbs before they were cooked. The dry mass before cooking is estimated from the dry mass after cooking using a linear regression of mass loss over time.

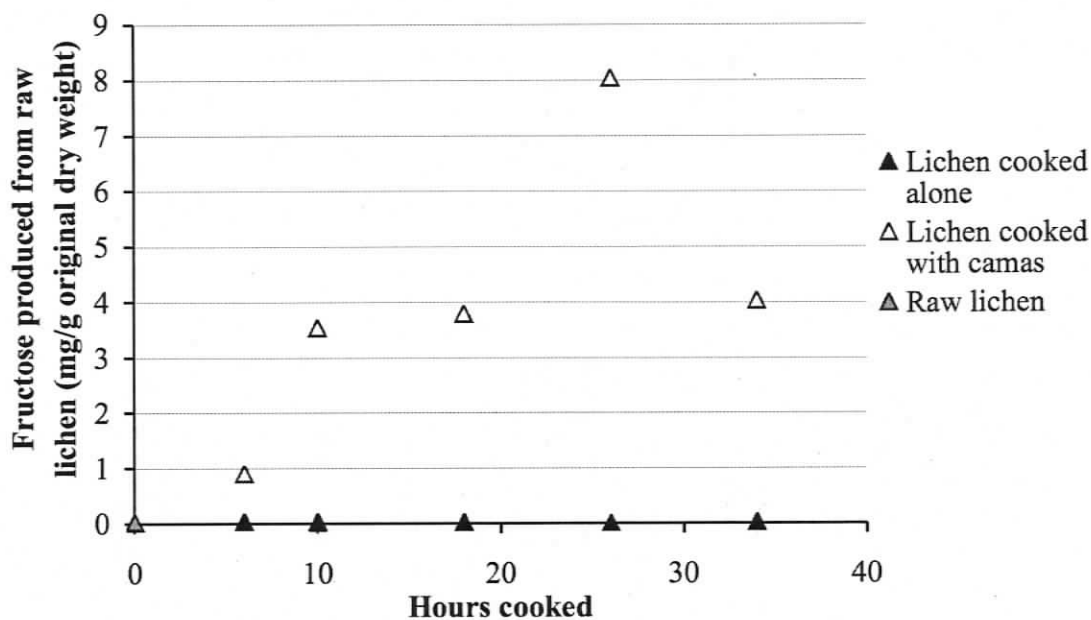


Figure 4.16. The amount of fructose in cooked *Bryoria fremontii* relative to the dry mass of the lichen before it was cooked. The dry mass before cooking is estimated from the dry mass after cooking using linear regressions of mass loss over time.

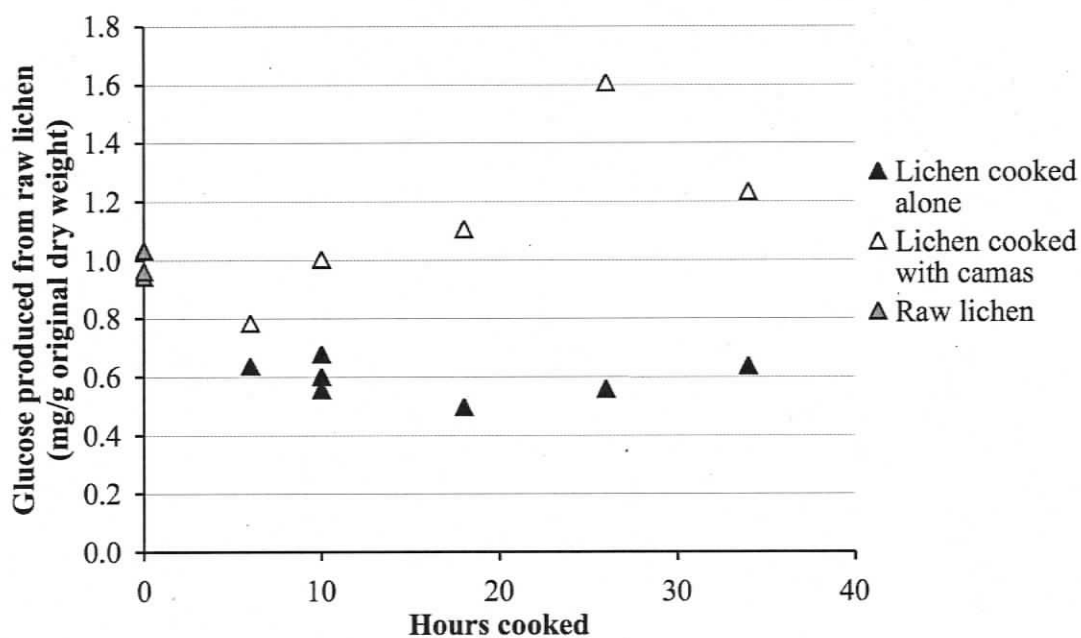


Figure 4.17. The amount of glucose in cooked *Bryoria fremontii* relative to the dry mass of the lichen before it was cooked. The dry mass before cooking is estimated from the dry mass after cooking using linear regressions of mass loss over time.

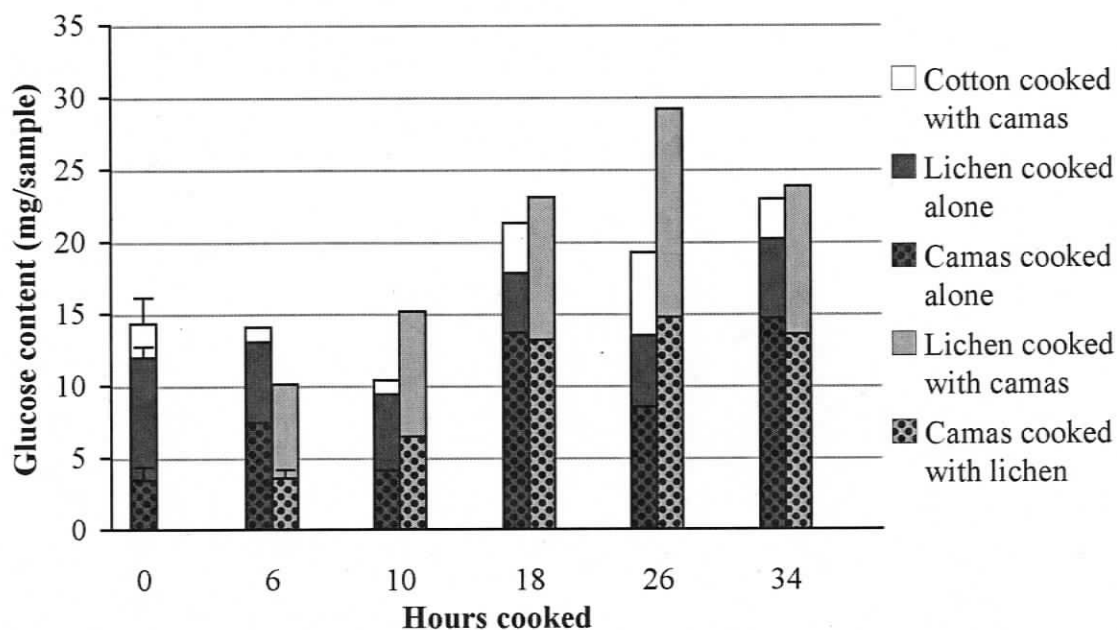


Figure 4.18. The total glucose content of camas bulbs and *Bryoria fremontii* cooked separately and together. Camas samples averaged 15.4 g and lichen averaged 9.9 g before cooking (wet weight). Sample weights standardized within pairs, but varied between pairs by up to 2%. Glucose in cotton was lost from the food.

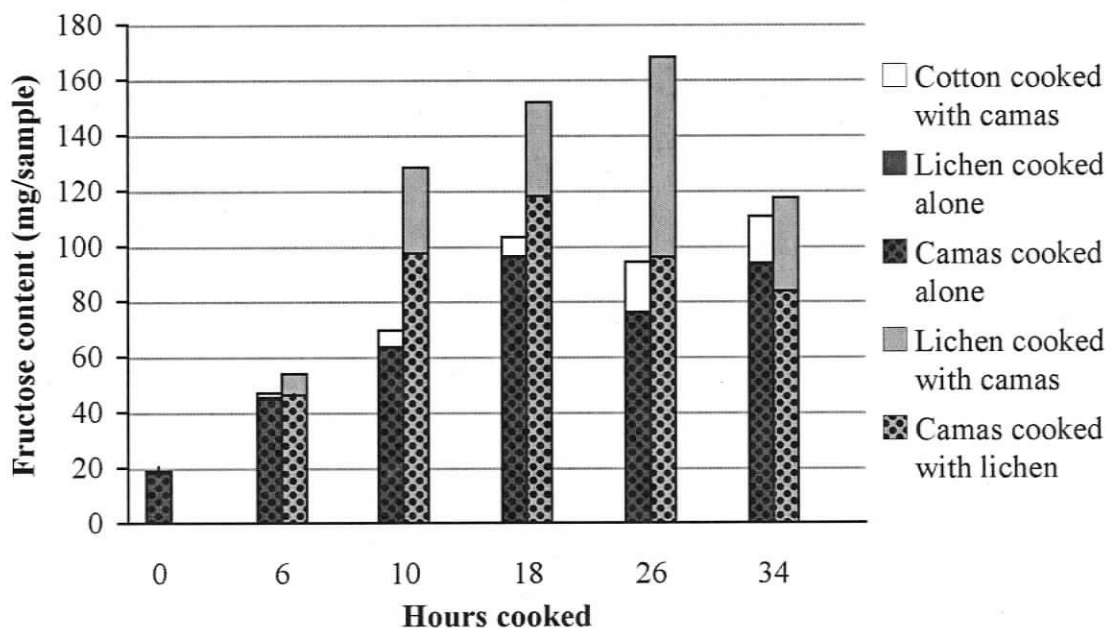


Figure 4.19. The total fructose content of camas bulbs and *Bryoria fremontii* cooked separately and together. Camas samples averaged 15.4 g and lichen averaged 9.9 g before cooking (wet weight). Sample weights standardized within pairs, but varied between pairs by up to 2%. Fructose in cotton was lost from the food.

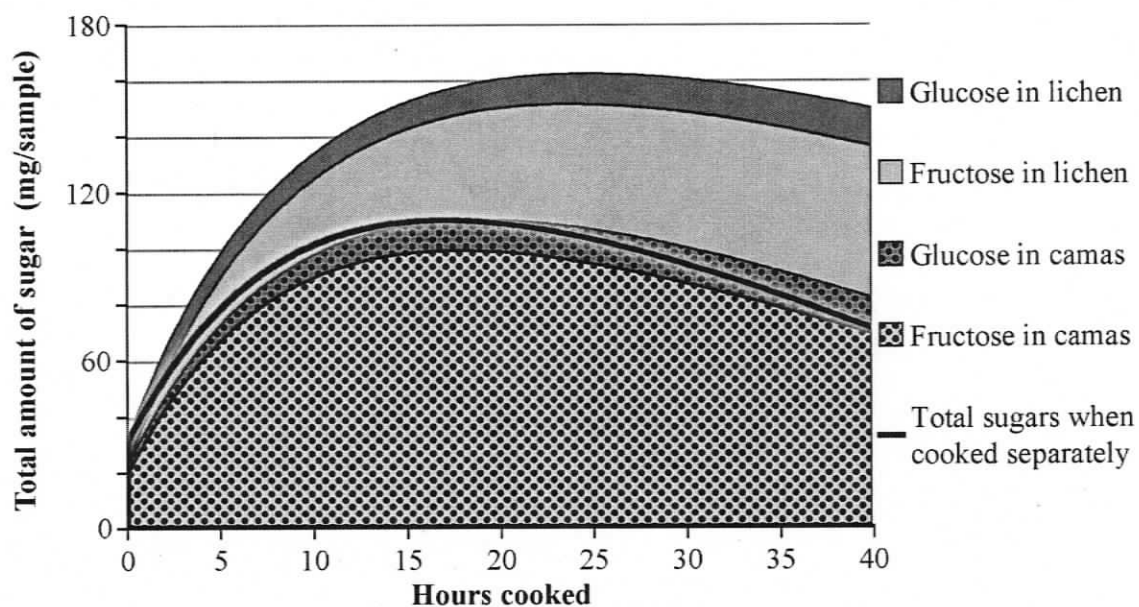


Figure 4.20. Contribution of glucose and fructose from camas bulbs and *Bryoria fremontii* to the total amount of sugar produced by cooking the camas and lichen together compared to the total amount of sugar produced when they are cooked separately, as calculated from best fit models for actual data using an average sample size of 15.4 g camas and 9.9 g lichen, raw wet weight.

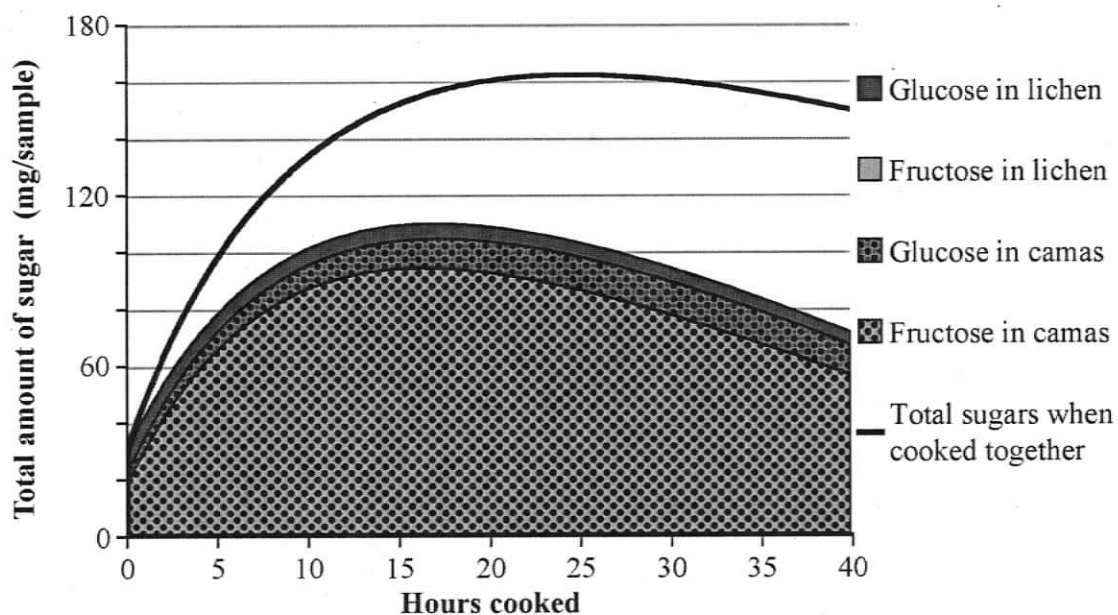


Figure 4.21. Contribution of glucose and fructose from camas bulbs and *Bryoria fremontii* to the total amount of sugar produced by cooking the camas and lichen separately compared to the total amount of sugar produced when they are cooked together, as calculated from best fit models for actual data using an average sample size of 15.4 g camas and 9.9 g lichen, raw wet weight.

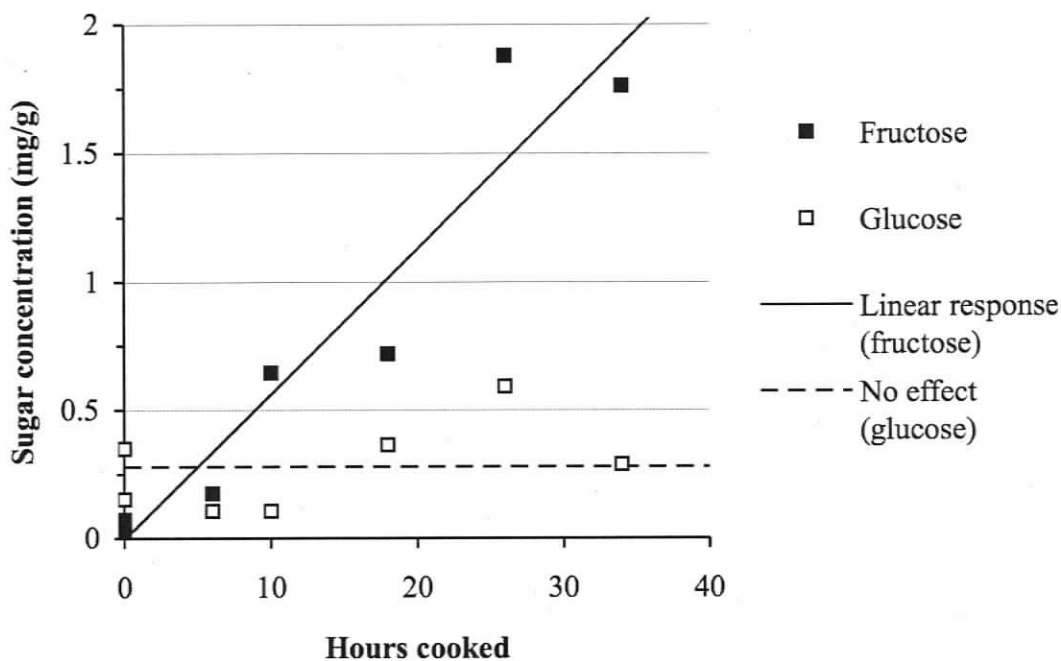


Figure 4.22. Glucose and fructose accumulation in 10 g cotton samples that surrounded the camas bulbs when they were cooked without lichen. Fitted lines are the best fit models as determined by Akaike's Information Criterion (AIC).

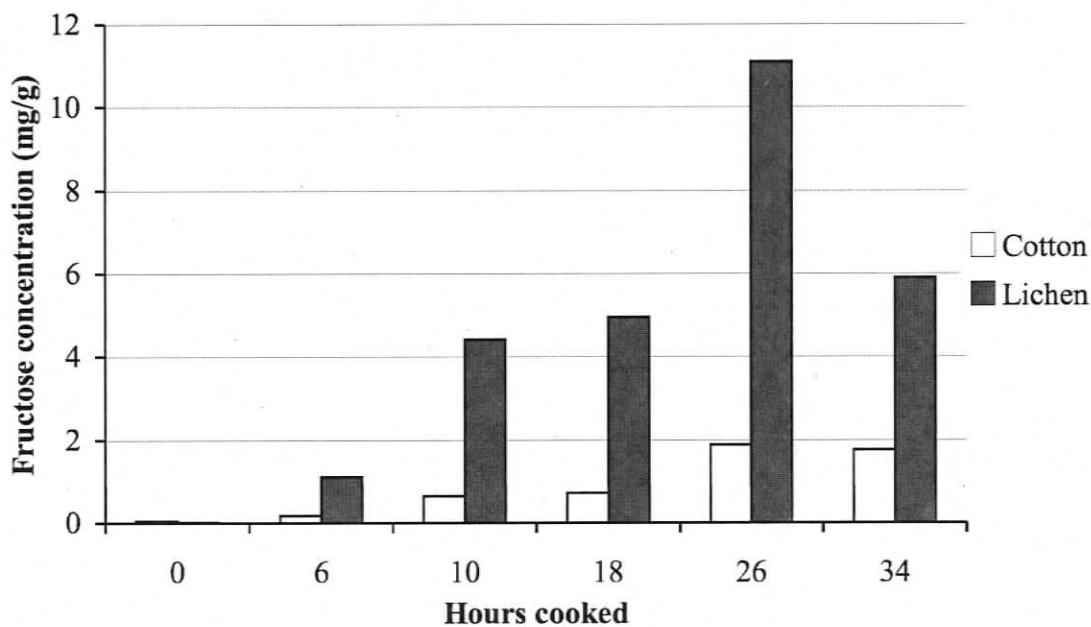


Figure 4.23. Fructose accumulation in 10 g samples of either cotton or lichen that surrounded the samples of camas bulbs when they were cooked.

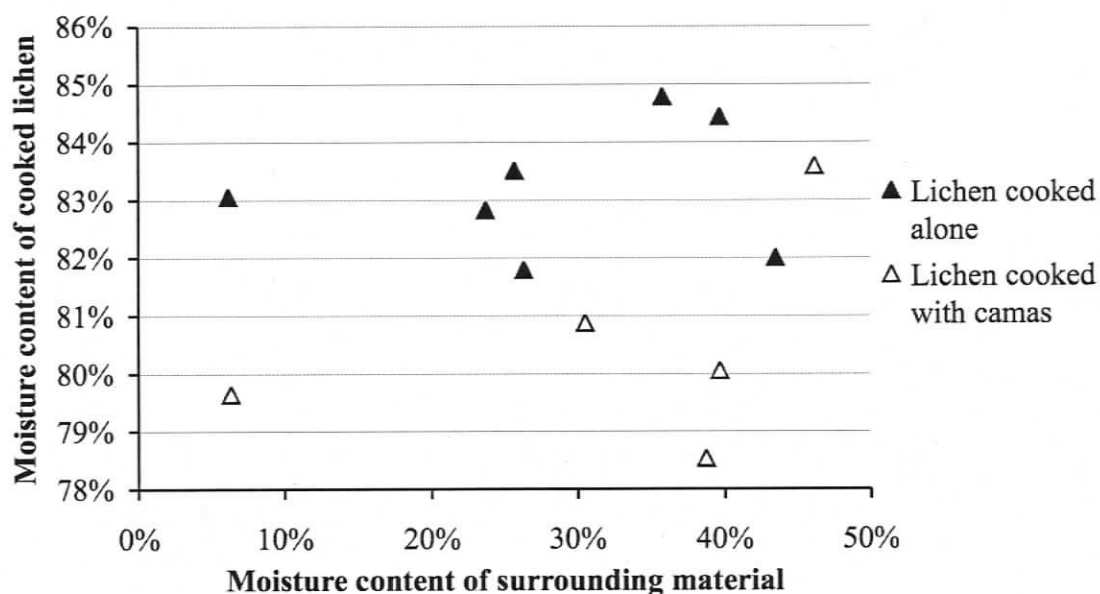


Figure 4.24. Moisture content of lichen cooked alone or with camas in simulated pitcooks with varying amounts of water in the material surrounding the cooking lichen. The presence of camas significantly affected the moisture content of the cooked lichen (independent samples t-test: $t_{0.5,10}=3.08$, $P=0.012$), but the moisture content of the surrounding material did not (linear regression: $t_{0.5,11} = 0.38$, $P = 0.714$, power=0.70).

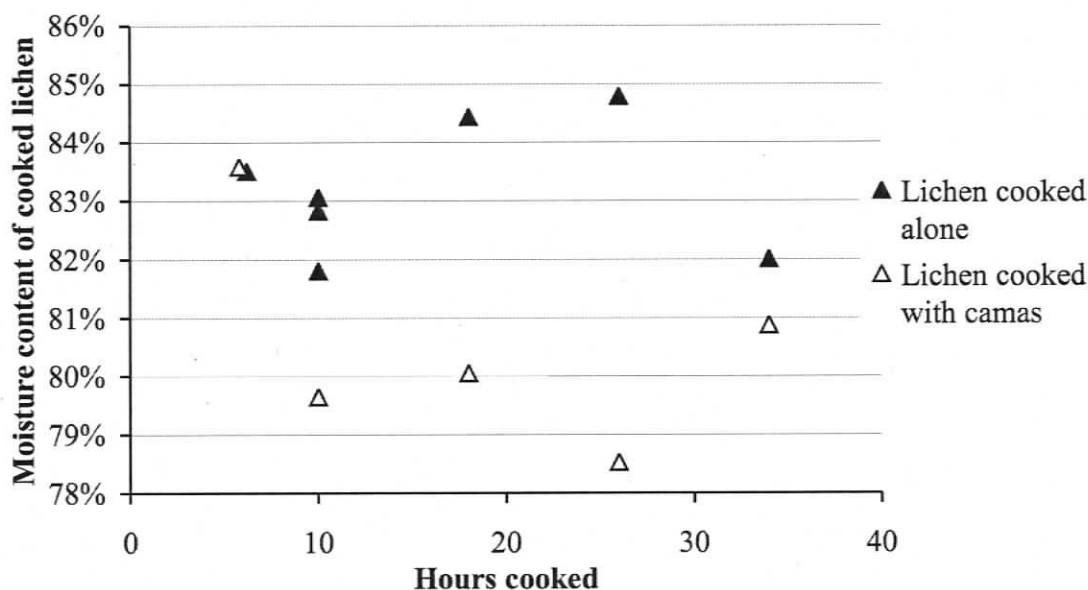


Figure 4.25. Moisture content of lichen cooked alone or with camas for different periods of time. The presence of camas significantly affected the moisture content of the cooked lichen (independent samples t-test: $t_{0.5,10}=3.08$, $P=0.012$), but the cooking duration did not (linear regression: $t_{0.5,11} = 0.79$, $P = 0.450$, power = 0.62).

Chapter 5 Conclusions on the ethnolichenology of wila (*Bryoria fremontii*)

5.1 Wila is an important traditional food

The traditional use of wila (*Bryoria fremontii*) is reviewed in **Chapter 2**. This lichen is an important traditional food throughout its range. Although its current culinary use is limited, in the past it was a major food for several First Nations. There is specific traditional knowledge about the harvesting, washing, and cooking of this lichen that is undoubtedly related to its ecology and chemistry. In particular, the traditional harvesting and preparation of this food involves:

- Collecting methods that select edible *Bryoria* species and avoid toxic ones
- Thorough washing techniques that remove any lichen toxins that were present
- An involved cooking process that renders a nutritional benefit from the lichen, although this benefit may not be a direct one.

5.2 Some comments from an expert on using wila for food

Dr. Mary Thomas is a respected Secwepemc elder of the Neskonlith community, and an expert on the harvesting and collection of wila. She shared some of her knowledge about this lichen with me. Mary Thomas stressed several aspects of wila ethnolichenology, particularly how to collect the right lichen, wash it properly, and cook it hot enough. Some of her wisdom is detailed below.

5.2.1 Collecting the right lichen

Selecting the right lichen is important to avoid bitter and potentially toxic lichen. This is discussed in some detail in **Chapter 3**. Mary Thomas stressed the importance of picking the right lichen, and detailed the use of colour in this determination. Darker specimens of *Bryoria* are better for eating, and ones that look greenish will be bitter and should be avoided.

When they're green like that [*Bryoria tortuosa*] don't bother with it. Leave it. ... That one looks better [points to *B. fremontii*]. The darker the better. ... I would take these [*B.*

fremontii]. That's a dandy one. ... Yes, this is the best one [*B. fremontii*]. The green ones tends to get bitter. It's not as nice as this one here.

That one wouldn't pass [a sample of *Bryoria fremontii* with lots of *B. tortuosa*, *B. capillaris*, and *B. pseudofuscescens* mixed in]. That wouldn't taste so good. Look for where you can find real dark stuff.

I don't know, that's one thing I don't know [is] what difference the tree [makes as to the quality of the lichen]. My mother, as long as it's dark, real dark, that's all she'd look for. And, our granny, we used to go with her. And if she couldn't reach way up, and it was really good, she'd take a long stick with a Y on the end, and she'd go push it in there, and turn, and pull it down. You didn't have to climb a tree, just use a fork.

5.2.2 Washing the lichen thoroughly

Washing the lichen is important for removing bitter and toxic lichen compounds like vulpinic acid (see **Section 2.4.3.2 Washing the lichen** on page 121). Mary Thomas detailed the careful washing that is necessary for the proper preparation of *wila*.

When you go to wash it you take all these little things [other lichen species and bits of twig] out of there. You wash it clean, take all this out ... I usually like to soak mine for a while, then ... you can tell ... it's kind of slippery. You know, after it's been soaked and it's been washed... That's when you take it and you work it with your hand like that, and it packs it and then it's ready to bake in a pit cookin'. And when it's done ... it'll look like licorice, just all caked up.

...

If you could take it, put it in a bucket, and pull out all of the no-nos in it, and wash it clean, squeeze, you'd squeeze. Change the water about two or three times, then put ... it in a cotton cloth and ... don't dry it too much, but if you can take it and you work it like that in the cotton cloth, and it starts to form like a piece of dough. It's ready to cook. And I leave it in the cotton and I put it in the pit cook'n.

...

[How long you have to wash it before it turns slippery] ... just depends on if you use warm water. It's better. Nice lukewarm water. Just put your hand and just keep working it, and then pull all the pieces that you [don't want], the light green, and piece of sticks, whatever. And you change it, put some more water, and you can finally feel it like wetted dough. And then you just put it on a — I usually have a cotton piece of white cotton, just the cotton that'll let the water drain through easier, coarse kind of cotton — you put it in that, and you fold it and just squeeze, squeeze, squeeze, squeeze. Get all the water out of it and it forms like a dough, that's when it's ready to bake. I usually bake mine right with — The way my granny used to do it, she used to have mats made out of the inner bark of the maple. She used to weave it, and put the cooking in and flop it over like that, and cook it in a pit cookin'. [Then] she'd wash it and hang it for another cookin'. But now I use just ordinary cloth — White cotton cloth I use.

5.2.3 Cooking the lichen properly

After the lichen has been washed, it needs to be properly cooked to result in a tasty product. The lichen is traditionally cooked by being buried in a pit with hot rocks (see **Section 2.2.4 Cooking the lichen** on page 91 for a complete description of this process). The most important part of the pitcook that Mary Thomas talked about was

getting the rocks hot enough to properly cook the lichen. She stressed the importance of this by recounting a mistake she made in preparing her first *wila* pitcook. In the process she describes, logs are laid across a pit, a fire is started on top of the logs, and rocks are placed in the fire. By the time the logs burn through and the rocks fall down into the pit, the rocks are supposed to be hot enough for cooking.

The secret is your rocks have to be good and hot. If they're not hot enough it will not bake it. The first one I did I was in a hurry, I had to get back to Kelowna. And I used 2x4s on top of a [pit, and had the] fire [on top of the 2x4s] and I put my rocks on it. And hear my mother, I heard that "Oh well" and I thought "Uh oh, I pulled a booboo". Next day when I came to look at my cooking, I brought it out of the pit and I put it on the table, and I looked at it, and it looked like something that a little animal like coyote ate and... I told my mother, I wouldn't eat that, what did I do wrong? And she said "Since when did the Indians have 2x4's?" You're supposed to put a log about this big [6 inches in diameter], green, and put your rocks on, and it takes longer [to burn through], that way your rocks are good and hot. They have to be good and hot, that's the secret.

5.3 *Bryoria* ecology and chemistry, and the wisdom of elders

The traditional practices of harvesting and preparing *wila* are deeply rooted in its ecology and chemistry. The wisdom of Mary Thomas and many other elders knowledgeable about *wila* corroborates the current scientific understanding of *wila* ecology and chemistry, as well as with the results of the current study. Some key points of *Bryoria* ethnolichenology are reviewed below.

5.3.1 Traditional harvesting collects edible lichens and avoids toxic ones

The importance of harvesting the appropriate species of *Bryoria* if you are planning on eating it is made clear by Dr. Mary Thomas, and there are reports in ethnographic literature of numerous other elders saying similar things (as is summarized in **Section 2.2.3 Harvesting *wila* for food** on page 88). This is entirely logical, given that there are several other species of *Bryoria* that look very similar to the edible *Bryoria fremontii*, but contain potentially significant amounts of bitter and/or toxic secondary compounds (see **Section 2.4.3.1 The proper selection of *Bryoria* for food** on page 121).

Many elders, including Mary Thomas, have said that light-coloured and greenish lichens should be avoided. The selection criterion does not identify individual lichens, but the results of **Chapter 3** show that it could still be very effective in selecting for

edible *Bryoria fremontii* while avoiding other *Bryoria* species that are bitter/toxic. Although colour cannot identify individual specimens, it can identify lichen communities that are likely to contain large quantities of bitter/toxic lichens. This may be because the different species of *Bryoria* have different habitat preferences. The presence of a significant quantity of light-coloured or greenish *Bryoria* may indicate an environment that is not conducive to the growth *Bryoria fremontii*, and is therefore not a good place to harvest lichen for food.

Stephenson and Rundel (1979) reported a wide variation in the concentration of the toxic vulpinic acid in *Bryoria fremontii*, so it is possible that some populations of this lichen are potentially toxic. If the selection criterion discussed above is successful in identifying edible species of *Bryoria* because of the difference in habitat preference between those *Bryoria* species without secondary compounds (*Bryoria fremontii*) and those with bitter/toxic secondary compounds (e.g. *B. tortuosa*), it is also possible that this same criterion could be used to differentiate edible populations of *B. fremontii* from potentially toxic populations of the same species.

Unfortunately, the current study did not address the possibility of using colour to differentiate edible and inedible populations of *Bryoria fremontii*. Future investigation would be required, and vulpinic acid concentrations would have to be measured in the samples of *Bryoria fremontii*. I have worked out a protocol for easily measuring the relative vulpinic acid concentrations of different samples of *Bryoria fremontii* and *Bryoria tortuosa*. The protocol is as follows:

1. Finely ground lichen (0.03 g) is extracted in 5 mL of boiling methanol for 30 min in a 15 mL centrifuge tube
2. The extract is centrifuged, decanted, and topped up to 5 mL
3. The absorbance of this extract is measured at 291 nm using a spectrophotometer

Vulpinic acid has a peak in absorbance at 290–291 nm (Huneck and Yoshimura 1996), so this effectively measures vulpinic acid concentration. This process is relatively fast and simple, and numerous samples could be analyzed in a short period of time. If the vulpinic acid concentration was measured for *Bryoria fremontii* and *B. tortuosa* samples in a study like the one outlined in **Chapter 3**, it could provide informative results.

5.3.2 Washing the lichen is important

Just about every ethnographic account of eating wila mentions the importance of thoroughly washing the lichen before it is cooked (see **Section 2.2.4.2 The cleaning of the lichen** on page 93). Mary Thomas also thought that washing the lichen was very important. This process is likely important to remove the bitter/toxic secondary compounds from the lichens. Numerous elders have said that washing removes the bitterness (see **Section 2.2.4.2**), and it is quite likely that the slightly soluble secondary compounds could be leached out by sufficient washing (see **Section 1.5.1.3.1 Solubility of lichen compounds** on page 46).

Although the utility of washing the lichen seems relatively obvious, I did not test this assumption. This could be easily tested by measuring the vulpinic acid concentration of *Bryoria fremontii* and/or *B. tortuosa* before and after washing, using the procedure outlined in the above section. This could be a short project for future investigation.

5.3.3 Cooking the lichen is important but may not make it edible

The proper cooking of wila is essential for it to realize its full culinary potential. The traditional cooking of wila invariably involves pitcooking it, as is reviewed in **Section 2.2.4 Cooking the lichen** on page 91. Mary Thomas also talked of the importance of cooking, and pointed out that it was very important that the rocks be hot enough to properly cook the lichen.

An extensive literature survey on lichen digestibility experiments (see **Section 1.5.5 The digestibility of lichens** on page 56) indicates that humans probably cannot digest raw lichen carbohydrates. The results of the cooking experiments conducted in **Chapter 4** suggest the possibility that traditional cooking techniques do not break down lichen polysaccharides into digestible carbohydrates. It is therefore possible that even properly cooked lichen may not be digestible to humans.

Cooking wila does succeed in turning it into a tasty gelatinous substance reminiscent of black licorice. This is recounted by numerous elders (including Mary Thomas), and was seen in the current cooking experiment. However, given the large number of First Nation communities that traditionally invested a large amount of work in harvesting and preparing this lichen, it seems unlikely that wila was prepared only for its

delectable appearance. If it is true that lichen carbohydrates are not rendered digestible by traditional cooking, I can think of two other possible values of eating the lichen: wila may improve the nutrition of other foods, or lichen carbohydrates may have other, non-caloric health benefits.

5.3.3.1 Wila may increase the nutrition of other foods

The results from **Chapter 4** indicate that when wila is cooked with other foods it may capture significant amounts of nutrients that would otherwise be lost during the cooking process. Wila is traditionally cooked with other foods, in particular a variety of root vegetables (see **Section 2.2.4.4 Food that the lichen is cooked with** on page 96). Many of these root vegetables contain the indigestible inulin, which is broken down into the digestible, but highly water-soluble, fructose as it is cooked. The cooking experiments described in **Chapter 4** used camas bulbs and showed that a significant quantity of this fructose was lost into the environment as the root vegetables were cooked. When the camas bulbs were surrounded with wila, the lichen absorbed this fructose that would have otherwise been lost. As a result, when the camas bulbs were cooked with wila there was 26–122% more digestible carbohydrates available for human consumption. This could provide a substantial nutritional benefit.

5.3.3.2 Wila may have health benefits

Bryoria fremontii likely contains relatively high quantities of lichenin (see **Section 2.4.2.1 Carbohydrates in Bryoria** on page 119). There is some evidence to suggest that lichenin may have several different health benefits (described in **Section 1.5.5.9.2 Potential non-caloric health benefits of lichen** on page 70). Lichenin could act as a prebiotic (stimulate beneficial bacteria in the lower intestine), lower blood cholesterol, and/or moderate blood sugar levels after meals. In this way, although wila may not provide direct calories, it could still be a valuable component in a healthy diet.

Appendices

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Appendix I. Procedure for sample extraction for carbohydrate analysis

Three separate extracts are prepared from each sample to be analyzed for glucose and fructose concentration (as outlined in **Appendix II**). Each extract is analyzed separately, and an average of the three replicates is used to characterize the true carbohydrate content of the sample. The following extraction procedure was adapted from Yip (pers. comm. 2006):

1. Thoroughly stir the dried, ground sample and measure 30.0 mg into a 1.5 mL boilable Eppendorf tube.
2. Add 1 mL of 80% ethanol and vigorously shake twice, 5 seconds each time.
3. Incubate at 75°C for about 4 hours.
4. Vigorously shake, then centrifuge (2 minutes at 10,000 rpm).
5. Decant extract with pipettor into a fresh 1.5 mL boilable Eppendorf tube
6. Repeat extraction steps 2 and 3 with the residue in the original Eppendorf tube.
7. Vigorously shake, then centrifuge (4 minutes at 10,000 rpm).
8. Decant completely with pipettor and add this fraction of the extract to the first fraction.
9. Speed vac the extract to less than 20% of its volume to remove the ethanol
10. Measure the volume of the remaining extract with a 200 μ L pipettor
11. Add water to the extract to bring it to a volume of 200 μ L
12. Prepare a 1:4 dilution of this extract by combining 10 μ L extract with 40 μ L water in a 1 mL Eppendorf tube.
13. This diluted sample extract is used for analysis, and has a concentration of 30 mg plant material / mL water.

Appendix II. Procedure for measuring carbohydrate content in extracted samples

The following procedure for a colorimetric microtitre plate enzymatic assay to measure glucose and fructose follows Yip's adaptation (pers. comm. 2006) of Campbell *et al.*'s (1999) protocol. This procedure was used to measure the glucose and fructose content of three separate extracts from each sample (as prepared in **Appendix I**).

Solutions prepared ahead of time and stored for future use

A buffer is prepared that is 50 mM triethanolamine-HCl, 5 mM MgSO₄, 0.02% bovine serum albumin, and 0.5 mM dithiothreitol (Cleland's reagent). The pH of this buffer solution is then adjusted to 7.6 with 0.5 M NaOH.

A solution of the disodium salt of adenosine-5-triphosphate (ATP) is prepared by dissolving 300 mg of ATP and 300 mg Na₂CO₃ in 6 mL water. The ATP solution is frozen in 1-2 mL aliquots to preserve for future use.

Preparing the reagent mixture for the analysis

The recipe below is for enough reagent mixture to fill one 96 well microtitre plate (enough for 88 sample extracts, 5 standards, and 3 blanks). If a fewer number of extracts are to be analyzed, the amounts can be adjusted accordingly.

1. Thaw an aliquot of the prepared ATP solution in an ice bath.
2. Dissolve 15.3 mg of NAD in 7 mL of prepared buffer.
3. Add 14 mL water and 700 μ L of prepared ATP solution
4. Add 40 activity units (U) of hexokinase (HK). This analysis used 33 μ L of Sigma H5625.
5. Add 21 activity units (U) of glucose-6-phosphate dehydrogenase (G6PDH). This analysis used 3.5 μ L of Sigma G8494.
6. Thoroughly mix the reagent mixture.

Measuring glucose concentration

7. Put 5 μ L of each diluted sample extract into its own well in the 96 well microtitre plate, using no more than 88 wells.

Appendix II cont'ed. Procedure for measuring carbohydrates in extracted samples

8. Put 5 μL of five different glucose standards into their own wells, using prepared solutions of known concentrations of glucose of 0.1, 0.25, 0.35, 0.5, and 0.75 mg/mL.
9. Three wells have neither samples nor standards put into them and are used as blanks.
10. Care must be taken to record which sample extract and standard is in each well.
11. Add 200 μL of reagent mixture to each well that has a sample extract or glucose standard in it, and to the three blank wells. Thoroughly mix the wells using a multi-pipettor.
12. Incubate the microtitre plate at room temperature for 15 minutes
13. Measure and record the absorbance of each well at 340 nm using a spectrophotometer with a 96 well microtitre plate reader to determine the NADH production, thus quantifying the glucose content of each sample extract. Do not dump out the microtitre plate, as these same sample extracts are used for measuring fructose concentration (outlined below).

Measuring fructose concentration

14. Mix 140 activity units (U) of phosphoglucose isomerase (PGluI) (200 μL if using Boehringer Mannheim 128 139) in 1 mL of water.
15. Add 12 μL of PGluI solution to each well of the microtitre plate, which still have the reagent mixture and sample extracts in them from step 13.
16. Thoroughly mix the wells, and incubate at room temperature for 15 minutes.
17. Measure and record the absorbance of each well at 340 nm using a spectrophotometer to determine the NADH production. The increase in NADH since the previous measurement quantifies the initial fructose content.

Interpreting the measurements

18. The absorbances measured in step 13 are used to calculate the glucose concentrations of the extracts by subtracting the average absorbance of the three blank wells from the absorbances of each of the extracts. This value is then

Appendix II cont'ed. Procedure for measuring carbohydrates in extracted samples

multiplied by an absorbance constant of 0.4564 for glucose (as calculated by Campbell *et al.* 1999) to get the glucose concentration of each extract in mg glucose / mL extract.

19. A value for the glucose content of each original sample is obtained by averaging the values for each replicate extraction (three in the current analysis) and dividing by 0.03 g to get mg glucose / g original material (if the extract concentration was 30 mg/mL, as per the extraction procedure outlined above).
20. The glucose concentrations calculated in step 18 for the five glucose standards are used to double check the efficacy of the analysis.
21. The fructose concentrations of the extracts are calculated from their absorbances as measured in step 17 by subtracting their absorbances as measured in step 13, then multiplying it by the absorbance constant of 0.4403 for fructose (as calculated by Campbell *et al.* 1999) to get the fructose concentration of each extract in mg glucose / mL extract.
22. A value for the fructose content of each original sample is obtained from the fructose concentrations of the extracts in the same way as it was for glucose in step 19.

Potential for measuring other carbohydrates

Although only glucose and fructose concentrations were measured for the current analysis, this procedure could be adapted to measure concentrations of many other, more complex carbohydrates. To do this, you would have to initially measure the concentrations of the relevant monosaccharide breakdown products by the procedure outlined above, then add the appropriate enzymes to hydrolyze a more complex polysaccharide into these monosaccharides, and then measure the concentrations of those monosaccharides a final time. The increase in the concentration of the monosaccharides would be a direct measure of the concentration of the complex polysaccharide. A protocol using this method has been developed for sucrose (Campbell *et al.* 1999) and starch (Hendrix 1993), and one could easily be developed for many other polysaccharides.

Appendix III. Common and scientific names of species mentioned in text

Common name	Scientific name
Alder	<i>Alnus</i> P. Mill. spp.
Alfalfa	<i>Medicago</i> L. spp.
Avocado	<i>Persea americana</i> Mill.
Balsamroot	<i>Balsamorhiza sagittata</i> (Pursh.) Nutt.
Bitter-root	<i>Lewisia rediviva</i> Pursh
Blue camas	<i>Camassia quamash</i> (Pursh) Green
Bracken fern	<i>Pteridium aquilinum</i> (L.) Kuhn
Bunch grass	<i>Pseudoroegneria spicata</i> (Pursh) A. Löve
Cherry	<i>Prunus emarginata</i> (Dougl.) Walp. & <i>P. pensylvanica</i> L.
Dogwood, red-osier	<i>Cornus stolonifera</i> Michx. (<i>C. sericea</i> L.)
Douglas wild onions	<i>Allium douglasii</i>
Douglas-fir	<i>Pseudotsuga menziesii</i> (Mirbel) Franco
Fir	<i>Abies</i> P. Mill. spp.
Geyer's onions	<i>Allium geyeri</i> S. Wats.
Indian carrot	<i>Lomatium macrocarpum</i> (Nutt.) Coult. & Rose
Indian hemp	<i>Apocynum cannabinum</i> L.
Jerusalem artichoke	<i>Helianthus tuberosus</i> L.
Larch	<i>Larix</i> P. Mill. spp.
Larch, western	<i>Larix occidentalis</i> Nutt.
Lodgepole pine	<i>Pinus contorta</i> Dougl. ex Loud.
Mesquite	<i>Prosopis</i> L. spp.
Mountain mahogany, curl-leaf	<i>Cercocarpus ledifolius</i> Nutt.
Nodding onions	<i>Allium cernuum</i> Roth.
Norway spruce	<i>Picea abies</i> (L.) Karst
Oak	<i>Quercus</i> L. spp.
Ponderosa pine	<i>Pinus ponderosa</i> P. & C. Lawson
Prickly pear	<i>Opuntia phaeacantha</i> Engelm.
Quack grass	<i>Elymus repens</i> (L.) Gould
Rocky Mountain maple	<i>Acer glabrum</i> Torr.
Rose	<i>Rosa</i> L. spp.
Saskatoon	<i>Amelanchier alnifolia</i> Nutt.
Silverberry	<i>Elaeagnus commutata</i>
Skunk cabbage	<i>Lysichiton americanus</i> Hultén & St. John
Slough grass	<i>Carex</i> L. spp.
Sotol	<i>Dasyilirion wheeleri</i> S. Wats.

Appendix III cont'ed. Common and scientific names of species mentioned in text

Common name	Scientific name
Spruce grouse	<i>Falcapennis canadensis</i> (L.)
Thimbleberry	<i>Rubus parviflorus</i> Nutt.
Tiger lily	<i>Lilium columbianum</i> Hanson
Timber grass	<i>Calamagrostis rubescens</i> Buckl.
Timothy	<i>Phleum pratense</i> L.
Tule	<i>Schoenoplectus acutus</i> (Muhl. ex Bigelow) A.& D. Löve
Western juniper	<i>Juniperus occidentalis</i> Hook.
Wild celery	<i>Lomatium nudicaule</i> (Pursh) Coult. & Rose
Wild rye grass	<i>Leymus cinereus</i> (Scribn. & Merr.) A. Löve
Yampah	<i>Perideridia gairdneri</i> (H.& A.) Mathias
Yellow glacier lily	<i>Erythronium grandiflorum</i> Pursh
Yucca, twisted leaf	<i>Yucca rupicola</i> Scheele

Appendix IV. Synonyms of accepted names for different cultural groups that use lichens.

Name of cultural group used in literature	Name used in this document
Alutiiq (Port Graham, Kenai)	Chugach
Bella Coola	Nuxalk
Blackfoot	Niitsitapii
Carrier	Dakelh
Chilcotin	Tsilhqot'in
Chipewyan Dene	Denesuline
Coeur d'Alêne	Schitsu'umsh
Eskimo, Western (Alaska)	Yup'ik and Iñupiaq
Gros Ventre	A'aninin
Ingalik	Deg Hit'an
Innu; Innu Aimuun; Naskapi-Innu	Naskapi
Inupiaq, Inland (Anaktuvuk)	Nunamiut
James Bay Cree	Attawapiskat
Kawawachikamach	Naskapi
Kootenay	Ktunaxa
Kutchin	Gwich'in
Kwakiult, Southern	Kwakwaka'wakw
Laplander	Saami
Lillooet	St'at'imc
Lutuami	Modoc
Nanénot	Naskapi
Nez Perce	Nimi'ipuu
Nitinaht	Ditidaht
Nlaka'pamux	Nlaka'pmx
Northern Paiute	Paviotso
Nunatarmiut;	Nunamiut
Oweekano	Wuikinuxv
Pima	O'odham
Pit River Indians	Atsugewi
Sanikiluaq-Qikirtait	Belcher Island Inuit
Santo Domingo Pueblo	Khe-wa
Shuswap	Secwepemc
Sioux (Missouri River area)	Dakota
South Haisla	Hanaksiala
South Maidu	Nisenan
Stl'atl'imx	St'at'imc

Appendix IV cont'ed. Synonyms of names of different cultural groups

<u>Name of cultural group used in literature</u>	<u>Name used in this document</u>
Stolo, Upper	Halkomelem
Tanaina (Lime Village)	Inland Dena'ina
Tete-de-Boule	Attikamekw Cree
Thompson	Nlaka'pmx
Warm Springs	Tenino
Wishram	Ila'xluit
Wood Cree (east-central SK)	Nihitahawak

Appendix V. Synonyms of accepted names for lichens traditionally used by people.

Names in literature	Accepted name
<i>Acarospora chlorophana</i>	<i>Pleopsidium chlorophanum</i> (Wahlenb.) Zopf
<i>Actinogyra muehlenbergii</i>	<i>Umbilicaria muehlenbergii</i> (Ach.) Tuck
<i>Actinogyra muhlenbergii</i> [sic]	<i>Umbilicaria muehlenbergii</i> (Ach.) Tuck
<i>Actinogyra</i> spp.	<i>Umbilicaria</i> spp. Hoffm.
<i>Alectoria abbreviata</i>	<i>Nodobryoria abbreviata</i> (Müll. Arg.) Common & Brodo
<i>Alectoria ambigua</i>	<i>Bryoria trichodes</i> subsp. <i>americana</i> (Mot.) Brodo & D. Hawksw.
<i>Alectoria americana</i>	<i>Bryoria trichodes</i> subsp. <i>americana</i> (Mot.) Brodo & D. Hawksw.
<i>Alectoria californica</i>	<i>Kaernefeltia californica</i> (Tuck.) Thell & Goward
<i>Alectoria capillaris</i>	<i>Bryoria capillaris</i> (Ach.) Brodo & D. Hawksw.
<i>Alectoria cetrariza</i>	<i>Kaernefeltia californica</i> (Tuck.) Thell & Goward
<i>Alectoria corneliae</i>	<i>Bryoria fremontii</i> (Tuck.) Brodo & D. Hawksw.
<i>Alectoria fremontii</i>	<i>Bryoria fremontii</i> (Tuck.) Brodo & D. Hawksw.
<i>Alectoria jubata</i>	<i>Bryoria</i> spp. Brodo & D. Hawksw.; OR <i>Bryoria fremontii</i> (Tuck.) Brodo & D. Hawksw.
<i>Alectoria nitidula</i>	<i>Bryoria nitidula</i> (Th. Fr.) Brodo & D. Hawksw.
<i>Alectoria setacea</i>	<i>Bryoria capillaris</i> (Ach.) Brodo & D. Hawksw.
<i>Alectoria tenerrima</i>	<i>Bryoria fremontii</i> (Tuck.) Brodo & D. Hawksw.
<i>Allocetraria cucullata</i>	<i>Flavocetraria cucullata</i> (Bellardi) Kärnefelt & Thell
<i>Allocetraria nivalis</i>	<i>Flavocetraria nivalis</i> (L.) Kärnefelt & Thell
<i>Aspicilia alphoplaca</i>	<i>Lobothallia alphoplaca</i> (Wahlenb.) Hafellner
<i>Biatorrella simplex</i>	<i>Polysporina simplex</i> (Davies) Vezda
<i>Borrera flavicans</i>	<i>Teloschistes flavicans</i> (Sw.) Norman
<i>Borrera furfuracea</i> var. <i>nuda</i>	<i>Pseudevernia furfuracea</i> var. <i>furfuracea</i> (L.) Zopf
<i>Bryoria abbreviata</i>	<i>Nodobryoria abbreviata</i> (Müll. Arg.) Common & Brodo
<i>Bryoria vrangiana</i>	<i>Bryoria implexa</i> (Hoffm.) Brodo & D. Hawksw. [if not in Europe]
<i>Caloplaca murorum</i>	<i>Caloplaca saxicola</i> (Hoffm.) Nordin
<i>Canomaculina subtinctoria</i>	<i>Parmotrema subtinctorium</i> (Zahlbr.) Hale
<i>Catapyrenium plumbeum</i>	<i>Verrucaria inficiens</i> Breuss
<i>Cetraria californica</i>	<i>Kaernefeltia californica</i> (Tuck.) Thell & Goward
<i>Cetraria canadensis</i>	<i>Vulpicida canadensis</i> (Räsänen) J.E. Mattsson & M. J. Lai
<i>Cetraria ciliaris</i>	<i>Tuckermannopsis ciliaris</i> (Ach.) Gyelnik
<i>Cetraria collata</i>	<i>Cetrelia collata</i> (Nyl.) W.L. Culb. & C.F. Culb.
<i>Cetraria commixta</i>	<i>Melanelia commixta</i> (Nyl.) Thell
<i>Cetraria crispa</i>	<i>Cetraria ericetorum</i> Opiz subsp. <i>ericetorum</i>
<i>Cetraria cucullata</i>	<i>Flavocetraria cucullata</i> (Bellardi) Kärnefelt & Thell
<i>Cetraria delisei</i>	<i>Cetrariella delisei</i> (Bory ex Schaerer) Kärnefelt & Thell
<i>Cetraria fahlunensis</i>	<i>Melanelia commixta</i> (Nyl.) Thell
<i>Cetraria glauca</i>	<i>Platismatia glauca</i> (L.) Culb. & C. Culb.

Appendix V cont'ed. Lichen name synonyms.

Names in literature	Accepted name
<i>Cetraria hiascens</i>	<i>Cetrariella delisei</i> (Bory ex Schaerer) Kärnefelt & Thell
<i>Cetraria juniperina</i>	<i>Vulpicida canadensis</i> (Räsänen) J.E. Mattsson & M. J. Lai
<i>Cetraria nivalis</i>	<i>Flavocetraria nivalis</i> (L.) Kärnefelt & Thell
<i>Cetraria orbata</i>	<i>Tuckermannopsis orbata</i> (Nyl.) M. J. Lai
<i>Cetraria pinastri</i>	<i>Vulpicida pinastri</i> (Scop.) J. E. Mattsson & M. J. Lai
<i>Cetraria richardsonii</i>	<i>Masonhalea richardsonii</i> (Hook.) Kärnefelt
<i>Cetrariastrum nepalense</i>	<i>Everniastrum nepalense</i> (Taylor) Hale ex Sipman
<i>Chiodecton sanguineum</i>	<i>Phanerochaete sanguinea</i> (Fr.) Pouzar; OR <i>Cryptothecia rubrocincta</i> (Ehrenb.) G. Thor
<i>Cladina alpestris</i>	<i>Cladina stellaris</i> (Opiz) Brodo
<i>Cladina silvatica</i>	<i>Cladina arbuscula</i> (Wallr.) Hale & Culb.
<i>Cladina sylvatica</i>	<i>Cladina arbuscula</i> (Wallr.) Hale & Culb.
<i>Cladonia alpestris</i>	<i>Cladina stellaris</i> (Opiz) Brodo
<i>Cladonia alpestris</i>	<i>Cladina stellaris</i> (Opiz) Brodo
<i>Cladonia arbuscula</i>	<i>Cladina arbuscula</i> (Wallr.) Hale & Culb.
<i>Cladonia sanguinea</i> var. <i>anaemica</i>	<i>Cladonia anaemica</i> (Nyl.) Ahti
<i>Cladonia silvatica</i>	<i>Cladina arbuscula</i> (Wallr.) Hale & Culb.
<i>Cladonia sylvatica</i>	<i>Cladina arbuscula</i> (Wallr.) Hale & Culb.
<i>Cladonia vermicularis</i>	<i>Thamnotia vermicularis</i> (Sw.) Schaer.
<i>Coelocaulon divergens</i>	<i>Bryocaulon divergens</i> (Ach.) Kärnefelt
<i>Cornicularia californica</i>	<i>Kaernefeltia californica</i> (Tuck.) Thell & Goward
<i>Cornicularia divergen</i>	<i>Bryocaulon divergens</i> (Ach.) Kärnefelt
<i>Dermatocarpon mouslinsii</i> [sic]	<i>Dermatocarpon moulinsii</i> (Mont.) Zahlbr.
<i>Dermatocarpon plumbeum</i>	<i>Verrucaria inficiens</i> Breuss
<i>Endocarpon miniatum</i>	<i>Dermatocarpon reticulatum</i> H. Magn.
<i>Endocarpon wilmsoides</i>	<i>Staurothele drummondii</i> (Tuck.) Tuck.
<i>Endopyrenium plumbeum</i>	<i>Verrucaria inficiens</i> Breuss
<i>Evernia furfuracea</i>	<i>Pseudevernia furfuracea</i> (L.) Zopf
<i>Evernia sarmentosa</i>	<i>Alectoria sarmentosa</i> Ach.
<i>Evernia thamnoides</i>	<i>Evernia mesomorpha</i> Nyl.
<i>Evernia vulpina</i>	<i>Letharia vulpina</i> (L.) Hue
<i>Gyrophora cylindrica</i>	<i>Umbilicaria cylindrica</i> (L.) Delise ex Duby
<i>Gyrophora deusta</i>	<i>Umbilicaria deusta</i> (L.) Baumg.
<i>Gyrophora dillenii</i>	<i>Umbilicaria mammulata</i> (Ach.) Tuck.
<i>Gyrophora dillenni</i> [sic]	<i>Umbilicaria mammulata</i> (Ach.) Tuck.
<i>Gyrophora esculenta</i>	<i>Umbilicaria esculenta</i> (Miyoshi) Minks
<i>Gyrophora lecanocarpoides</i>	<i>Umbilicaria virginis</i> Schaer.
<i>Gyrophora muehlenbergii</i>	<i>Umbilicaria muehlenbergii</i> (Ach.) Tuck
<i>Gyrophora papillosa</i>	<i>Lasallia papulosa</i> (Ach.) Llano
<i>Gyrophora proboscidea</i>	<i>Umbilicaria proboscidea</i> (L.) Schrader

Appendix V cont'ed. Lichen name synonyms.

Names in literature	Accepted name
<i>Gyrophora</i> spp.	<i>Umbilicaria</i> spp. Hoffm.
<i>Gyrophora pustulata</i>	<i>Lasallia pustulata</i> (L.) Mérat
<i>Gyrophora pustulata</i> var. <i>papulosa</i>	<i>Lasallia papulosa</i> (Ach.) Llano
<i>Gyrophora vellea</i> [sic]	<i>Umbilicaria vellea</i> (L.) Hoffm.
<i>Gyrophora vellea</i>	<i>Umbilicaria vellea</i> (L.) Hoffm.
<i>Lecanora affinis</i>	<i>Sphaerothallia affinis</i> (Eversm.) Follmann & A. Crespo
<i>Lecanora alphoplaca</i>	<i>Lobothallia alphoplaca</i> (Wahlenb.) Hafellner
<i>Lecanora calcarea</i>	<i>Aspicilia calcarea</i> (L.) Mudd
<i>Lecanora esculenta</i>	<i>Aspicilia esculenta</i> (Pall.) Flagey
<i>Lecanora frustulosa</i>	<i>Lecanora argopholis</i> (Ach.) Ach. (if in NA excluding Greenland)
<i>Lecanora pallescens</i>	<i>Ochrolechia parella</i> (L.) A. Massal.
<i>Lecanora parella</i>	<i>Ochrolechia parella</i> (L.) A. Massal.
<i>Lecanora tartarea</i>	<i>Ochrolechia tartarea</i> (L.) A. Massal.
<i>Lecanora thamnoplaca</i>	<i>Lobothallia alphoplaca</i> (Wahlenb.) Hafellner
<i>Lecidea coroniformis</i>	<i>Psora crenata</i> (Taylor) Reinke
<i>Lecidea crenata</i>	<i>Psora crenata</i> (Taylor) Reinke
<i>Lepraria chlorina</i>	<i>Chrysothrix chlorina</i> (Ach.) J. R. Laundon
<i>Lepraria iolithus</i>	Name used by University of Oslo herbarium, but no published record
<i>Lichen calcaris</i>	<i>Ramalina siliquosa</i> (Huds.) A.L. Sm.
<i>Lobaria acetabulum</i>	<i>Pleurosticta acetabulum</i> (Neck.) Elix & Lumbsch
<i>Lobaria gyrophorica</i>	<i>Lobaria yoshimurae</i> Kurok. & Kashiw.
<i>Melanelia acetabulum</i>	<i>Pleurosticta acetabulum</i> (Neck.) Elix & Lumbsch
<i>Lobaria laetevirens</i>	<i>Lobaria virens</i> (With.) J.R. Laundon
<i>Lobaria lataevirens</i> [sic]	<i>Lobaria virens</i> (With.) J.R. Laundon
<i>Melanelia fuliginosa</i>	<i>Melanelixia fuliginosa</i> (Fr. ex Duby) O. Blanco <i>et al.</i>
<i>Melanelia olivacea</i>	<i>Melanohalea olivacea</i> (L.) O. Blanco <i>et al.</i>
<i>Melanelia subolivacea</i>	<i>Melanohalea subolivacea</i> (Nyl.) O. Blanco <i>et al.</i>
<i>Parmelia subolivacea</i>	<i>Melanohalea subolivacea</i> (Nyl.) O. Blanco <i>et al.</i>
<i>Nephroma parilis</i>	<i>Nephroma parile</i> (Ach.) Ach.
<i>Paraplacodium</i> <i>alphoplacum</i>	<i>Lobothallia alphoplaca</i> (Wahlenb.) Hafellner
<i>Parmelia abessinica</i>	<i>Parmotrema abessinicum</i> (Nyl. ex Kremp.) Hale
<i>Parmelia acebatulum</i> [sic]	<i>Pleurosticta acetabulum</i> (Neck.) Elix & Lumbsch
<i>Parmelia acetabulum</i>	<i>Pleurosticta acetabulum</i> (Neck.) Elix & Lumbsch
<i>Parmelia aleuritica</i>	<i>Arctoparmelia centrifuga</i> (L.) Hale
<i>Parmelia alphoplaca</i>	<i>Lobothallia alphoplaca</i> (Wahlenb.) Hafellner
<i>Parmelia andina</i>	<i>Parmotrema andinum</i> (Müll. Arg.) Hale
<i>Parmelia austrosinensis</i>	<i>Parmotrema austrosinensis</i> (Zahlbr.) Hale
<i>Parmelia borreri</i>	<i>Punctelia borreri</i> (Sm.) Krog

Appendix V cont'ed. Lichen name synonyms.

Names in literature	Accepted name
<i>Parmelia caperata</i>	<i>Flavoparmelia caperata</i> (L.) Hale
<i>Parmelia centrifuga</i>	<i>Arctoparmelia centrifuga</i> (L.) Hale
<i>Parmelia cirrhata</i>	<i>Everniastrum cirrhatum</i> (Fr.) Hale ex Sipman
<i>Parmelia conspersa</i>	<i>Xanthoparmelia conspersa</i> (Ehrh. ex Ach.) Hale
<i>Parmelia fuliginosa</i>	<i>Melanelixia fuliginosa</i> (Fr. ex Duby) O. Blanco <i>et al.</i>
<i>Parmelia furfuracea</i>	<i>Pseudevernia furfuracea</i> (L.) Zopf
<i>Parmelia glabratula</i>	<i>Melanelixia fuliginosa</i> (Fr. ex Duby) O. Blanco <i>et al.</i>
<i>Parmelia hottentotta</i>	<i>Xanthomaculina hottentotta</i> (Ach.) Hale
<i>Parmelia isidiata</i>	<i>Xanthoparmelia conspersa</i> (Ehrh. ex Ach.) Hale
<i>Parmelia kamtschadalis</i> (Mont.) Mont.	<i>Everniastrum cirrhatum</i> (Fr.) Hale ex Sipman; OR <i>Xanthoparmelia camtschadalis</i> (Ach.) Hale [if misspelled <i>P. camtschadalis</i>]
<i>Parmelia molliuscula</i>	<i>Xanthoparmelia molliuscula</i> (Ach.) Hale
<i>Parmelia molluscula</i> [sic]	<i>Xanthoparmelia molliuscula</i> (Ach.) Hale
<i>Parmelia nepalensis</i>	<i>Everniastrum nepalense</i> (Taylor) Hale ex Sipman
<i>Parmelia olivacea</i>	<i>Melanohalea olivacea</i> (L.) O. Blanco <i>et al.</i>
<i>Parmelia oregana</i>	<i>Hypogymnia physodes</i> (L.) Nyl.
<i>Parmelia paraguariensis</i> Lynge	<i>Parmotrema andinum</i> (Müll. Arg.) Hale
<i>Parmelia parella</i>	<i>Ochrolechia parella</i> (L.) A. Massal.
<i>Parmelia parietina</i> var. <i>ectanea</i> Ach.	<i>Xanthoria parietina</i> (L.) Th. Fr.
<i>Parmelia perforata</i>	<i>Parmotrema reticulatum</i> (Taylor) M. Choisy
<i>Parmelia perlata</i>	<i>Parmotrema chinense</i> (Osbeck) Hale & Ahti
<i>Parmelia physodes</i>	<i>Hypogymnia physodes</i> (L.) Nyl.
<i>Parmelia pseudoborreri</i>	<i>Punctelia borreri</i> (Sm.) Krog
<i>Parmelia reticulata</i>	<i>Rimelia reticulata</i> (Taylor) Hale & Fletcher
<i>Parmelia sancti-angelii</i>	<i>Parmotrema sancti-angelii</i> (Lynge) Hale
<i>Parmelia saxicola</i>	<i>Lecanora muralis</i> (Schreb.) Rabenh. [syn. with <i>P. s.</i> var. <i>areolata</i> Leight.]; OR <i>Parmelia saxicola</i> Ach. [Incertae sedis]; OR <i>Parmelia saxatilis</i> (L.) Ach. [if misspelled]
<i>Parmelia stygia</i>	<i>Melanelia stygia</i> (L.) Essl.
<i>Parmelia substygia</i>	<i>Melanelia tominii</i> (Oksner) Essl.
<i>Parmelia tinctorum</i>	<i>Parmotrema tinctorum</i> (Delise ex Nyl.) Hale
<i>Parmelia trichotera</i>	<i>Parmotrema chinense</i> (Osbeck) Hale & Ahti
<i>Parmelia zollingeri</i>	<i>Parmotrema zollingeri</i> (Hepp) Hale
<i>Parmotrema acetabulum</i>	<i>Pleurosticta acetabulum</i> (Neck.) Elix & Lumbsch
<i>Parmotrema reticulatum</i>	<i>Rimelia reticulata</i> (Taylor) Hale & Fletcher
<i>Peltigera aphthosa</i>	<i>Peltigera aphthosa</i> (L.) Willd.; OR <i>Peltigera britannica</i> (Gyelnik) Holt. Hartw. & Tønsberg [on Vancouver Is.]

Appendix V cont'ed. Lichen name synonyms.

Names in literature	Accepted name
<i>Peltigera canina</i>	<i>Peltigera canina</i> (L.) Willd.; OR <i>Peltigera membranacea</i> (Ach.) Nyl. [on Vancouver Is.]
<i>Peltigera parilis</i>	<i>Nephroma parile</i> (Ach.) Ach.
<i>Peltigera polydactyla</i>	<i>Peltigera polydactylon</i> (Neck.) Hoffm.
<i>Pertusaria communis</i>	<i>Pertusaria pertusa</i> (Weigel) Tuck.
<i>Physcia pulverulenta</i>	<i>Physconia distorta</i> (With.) J. R. Laundon
<i>Platysma collatum</i>	<i>Cetrelia collata</i> (Nyl.) W.L. Culb. & C.F. Culb.
<i>Pseudevernia moliuscula</i>	<i>Xanthoparmelia molliuscula</i> (Ach.) Hale
<i>Pseudoparmelia caperata</i>	<i>Flavoparmelia caperata</i> (L.) Hale
<i>Placodium</i> spp.	<i>Xanthoria</i> spp.
<i>Ramalina bourgeana</i>	<i>Niebla bourgeana</i> (Mont. ex Nyl.) Rundel & Bowler
<i>Ramalina flaccescens</i>	<i>Niebla flaccescens</i> (Nyl.) Rundel & Bowler
<i>Ramalina scopulorum</i>	<i>Ramalina siliquosa</i> (Huds.) A.L. Sm.
<i>Sarcogyne simplex</i>	<i>Polysporina simplex</i> (Davies) Vezda
<i>Scyphophorus cocciferus</i>	<i>Cladonia coccifera</i> (L.) Willd.
<i>Scyphophorus pyxidatus</i>	<i>Cladonia pyxidata</i> (L.) Hoffm.
<i>Sticta amplissima</i>	<i>Lobaria amplissima</i> (Scop.) Forss.; OR <i>Lobaria quercizans</i> Michaux [in eastern Canada?]
<i>Sticta aurata</i>	<i>Pseudocyphellaria aurata</i> (Ach.) Vainio
<i>Sticta crocata</i>	<i>Pseudocyphellaria crocata</i> (L.) Vainio
<i>Sticta glomerulifera</i> (Hoffm.) Delise	<i>Lobaria amplissima</i> (Scop.) Forss.; OR <i>Lobaria quercizans</i> Michaux [in eastern Canada?]
<i>Sticta pulmonacea</i> (Ach.) Ach.	<i>Lobaria pulmonaria</i> (L.) Hoffm. [??]
<i>Sticta pulmonaria</i>	<i>Lobaria pulmonaria</i> (L.) Hoffm.
<i>Teloschistes parietinus</i>	<i>Xanthoria parietina</i> (L.) Th. Fr.
<i>Teloschistes vermicularis</i>	No record of this lichen!!
<i>Toninia caeruleonigricans</i>	<i>Fuscopannaria praetermissa</i> (Nyl.) P. M. Jørg. [in N.A.]
<i>Tuckermannopsis canadensis</i>	<i>Vulpicida canadensis</i> (Räsänen) J. E. Mattsson & M. J. Lai
<i>Tuckermannopsis pinastri</i>	<i>Vulpicida pinastri</i> (Scop.) J. E. Mattsson & M. J. Lai
<i>Umbilicaria pustulata</i>	<i>Lasallia pustulata</i> (L.) Mérat
<i>Urceolaria calcarea</i>	<i>Aspicilia calcarea</i> (L.) Mudd
<i>Urceolaria cinerea</i>	<i>Aspicilia cinerea</i> (L.) Körb.
<i>Urceolaria scruposa</i>	<i>Diploschistes scruposus</i> (Schreber) Norman
<i>Usnea barbata</i>	<i>Usnea scabrata</i> Nyl. [if in N.A.]; OR <i>Usnea filipendula</i> Stirt. [if in Britain]; OR <i>Usnea barbata</i> (L.) Weber ex F.H. Wigg. [if elsewhere?]
<i>Usnea dasypoga</i>	<i>Usnea filipendula</i> Stirt. [if in NA, Britain]; OR <i>Usnea dasypoga</i> (Ach.) Röhl. [if elsewhere?]
<i>Usnea florida</i>	Questionable in NA; <i>Usnea florida</i> (L.) F. H. Wigg. [elsewhere?]
<i>Usnea hieronymi</i>	<i>Usnea densirostra</i> Taylor

Appendix V cont'ed. Lichen name synonyms.

Names in literature	Accepted name
<i>Usnea lacunosa</i> Willd. ex Delise	<i>Usnea cavernosa</i> Tuck. [in N. A.]
<i>Usnea plicata</i>	<i>Usnea filipendula</i> Stirton [in N. A.]; OR <i>Usnea plicata</i> (L.) Weber [elsewhere?]
<i>Usnea sikkimensis</i> Biswas sp. nov.	Taxon created by Biswas in his medicinal plant treatise, not published elsewhere (Biswas 1956).
<i>Usnea variolosa</i>	<i>Usnea hirta</i> (L.) F. H. Wigg.
<i>Variolaria communis</i>	<i>Pertusaria pertusa</i> (Weigel) Tuck.
<i>Variolaria dealbata</i>	<i>Pertusaria dealbata</i> (Ach.) Cromb.
<i>Variolaria discoidea</i>	<i>Pertusaria albescens</i> (Hudson) M. Choisy & Werner
<i>Variolaria faginea</i>	<i>Pertusaria amara</i> (Ach.) Nyl.
<i>Variolaria orcina</i>	Incertae sedis
<i>Variolaria</i> spp.	<i>Pertusaria</i> spp. DC. [partial syn.]
<i>Xanthoparmelia centrifuga</i>	<i>Arctoparmelia centrifuga</i> (L.) Hale
<i>Xanthoria parietina</i> subsp. <i>ectanea</i>	<i>Xanthoria parietina</i> (L.) Th. Fr.

Appendix VI. Higher level folk taxonomies of lichens.

Folk name	People	Scientific taxa	Reference
<i>P'u7up</i>	Ditidaht, Hesqiat	Mosses and lichens, not including <i>Peltigera</i> spp.	(Turner <i>et al.</i> 1983)
<i>P'elems</i>	Kwakwaka'wakw	Mosses and lichens	(Turner and Bell 1973)
<i>K'inxaan</i> or <i>k'innaan</i>	Haida	Mosses and lichens	(Turner 1974)
<i>Ipst</i>	Nuxalk	Mosses and lichens on ground	(Turner 1974)
<i>Ipst-aak</i>	Nuxalk	Mosses and lichens on tree	(Turner 1974)
<i>MELax'â'EstL</i>	Tsimshian	Lichens	(Boas 1902)
<i>MELax'â'EstL gan</i>	Tsimshian	Lichens on a tree	(Boas 1902)
<i>Pá7sem</i>	St'at'imc	Mosses and lichens	(Turner 1974)
' <i>Asaxxé'm</i>	Karok	Mosses and lichens	(Schenck and Gifford 1952)
<i>Melx7aest</i>	Sm'algyax (Hartley Bay)	Lichens	(Turner and Clifton 2002)
<i>Blaax</i>	Sm'algyax (Hartley Bay)	Mosses and <i>Usnea</i> spp.	(Turner and Clifton 2002)
<i>Ha'ichu vuushdag</i> ['things that grow up']	O'odham	Mosses, lichens, fungi, lower plants	(Rea 1997)
<i>Jewed eldag</i> ['earth skin']	O'odham	Mosses and lichens on ground	(Rea 1997)
<i>Hodai eldag</i> ['rock skin']	O'odham	Lichens on rock	(Rea 1997)
'Soil its skin'	Seri	Lichens and mosses	(Rea 1997)
	Saami	Lichens different from mosses	(Perez-Llano 1944)
<i>Gadna</i>	Saami	Lichens similar to <i>Parmelia</i> spp. and <i>Umbilicaria</i> spp., not commonly eaten by reindeer.	(Perez-Llano 1944)
<i>Lappo</i>	Saami	Lichens similar to <i>Alectoria</i> spp. and <i>Usnea</i> spp., enjoyed by reindeer but not commonly eaten	(Perez-Llano 1944)
<i>Jaegel</i>	Saami	Lichens similar to <i>Cladina</i> spp., <i>Cetraria</i> spp., and <i>Stereocaulon</i> spp., commonly eaten by reindeer.	(Perez-Llano 1944)
<i>Kwesáy</i>	Secwepemc	<i>Lobaria pulmonaria</i> , <i>Cladonia</i> spp., <i>Parmelia</i> -like lichens, and small mushrooms	(Palmer 1975)
<i>Chharila, Shipal, Jhoola</i>	Aryurveda (India:Sanskrit)	Medicinal lichens, mainly <i>Parmotrema chinense</i> , <i>P. perforatum</i> , <i>Everniastrum cirrhata</i> , and <i>E. nepalense</i>	(Chandra and Singh 1971; Kumar <i>et al.</i> 1996; Upreti <i>et al.</i> 2005)
<i>Chan wiziye</i> ['grows on trees, yellow']	Dakota	Dye lichens: <i>Punctelia borreri</i> ; <i>Usnea scabrata</i>	(Gilmore 1919)
<i>Yanben</i>	Rai, Limbu (Nepal)	Food lichens <i>Ramalina</i> spp., <i>Everniastrum</i> spp., and <i>Usnea</i> spp.	(Bhattarai <i>et al.</i> 1999)

Appendix VII. Informative compound folk names for lichens

Folk name	English translation	People	Lichen	Reference
<i>Lichens named according to substrate</i>				
<i>Flor de piedra</i>	Stone flower	Spain	<i>Xanthoria parietina</i> ; <i>Niebla flaccescens</i>	(González-Tejero <i>et al.</i> 1995)
<i>Klipbolm</i>	Rock flower	Afrikaans	<i>Parmelia</i> spp	(van Wyk and Gericke 2000)
<i>Gul-i-sang</i>	Stone flowers	Afghanistan	<i>Lobaria pulmonaria</i>	(Hunte <i>et al.</i> 1975)
<i>Rathipuvvu</i>	Rock flower	Bellary District: India	<i>Parmotrema abessinicum</i>	(Sastri 1953)
<i>Dagad phool</i>	Stone flower	Marathi: India	<i>Parmotrema nilgherrense</i> ; <i>P. sancti-angelii</i> ; <i>P. tinctorum</i> ; <i>Rimelia reticulata</i> ; <i>Everniastrum</i> spp.; <i>Ramalina</i> spp.; <i>Usnea</i> spp.	(Richardson 1991)
<i>Shila pushp</i>	Rock flower	Sanskrit	Lichens	(Upreti <i>et al.</i> 2005)
<i>Jievut hiawsik</i>	Earth flower	O'odham	<i>Xanthoparmelia conspersa</i>	(Rea 1997)
<i>Barba de piedra</i>	Stone beard	Argentina	<i>Usnea campestris</i> ; <i>U. densirostra</i>	(Garcia <i>et al.</i> 1990)
	Wool of Rocks	Tarahumara: Mexico	<i>Usnea</i> spp.	(Brough 1988)
<i>Yerba de la piedra</i>	Stone grass	Uruguay	<i>Usnea densirostra</i>	(Osorio 1982)
<i>Rompepiedra</i>	Stone breaker	Spain	<i>Xanthoria parietina</i>	(González-Tejero <i>et al.</i> 1995)
<i>(Tl)'a(tl)'x7a'7aq</i>	Flat against rock	Ditidaht	<i>Peltigera</i> spp.	(Turner <i>et al.</i> 1983)
<i>T'it'idic'c'7a'</i>	Rocks growing on rocks	Ditidaht	<i>Peltigera aphthosa</i>	(Turner <i>et al.</i> 1983)
<i>Didi'dichia</i>	Growing on rocks	Makah	<i>Lobaria</i> spp.	(Turner <i>et al.</i> 1983)
<i>Wakoonapishkuts</i>	Span of the rocks	Naskapi	<i>Umbilicaria</i> spp.	(Lips 1947)
<i>Pen'pen'emekx'sxn'</i>	Liver on rocks	Okanagan	<i>Cladonia chloropheae</i>	(Turner <i>et al.</i> 1980)
<i>As-se-ne wa-quon-uck</i>	Eggs of the rock	Nipigon	Unidentified rock lichen	(Harmon 1800-1816)
<i>Iwa-take</i>	Rock mushroom	Japan	<i>Umbilicaria esculenta</i>	(Kawagoe 1925)
<i>Tripe de roche</i>	Rock tripe	Europeans	<i>Umbilicaria</i> spp.	(Lindley 1838)
<i>Hodai eldag</i>	Rock skin	O'odham	Lichens on rock	(Rea 1997)
<i>Jewed eldag</i>	Earth skin	O'odham	Mosses and lichens on ground	(Rea 1997)
	Soil its skin	Seri	Lichens	(Rea 1997)

Appendix VII cont'ed. Informative compound folk names for lichens

Folk name	English translation	People	Lichen	Reference
<i>Lichens named according to substrate</i>				
<i>Qalnigi jegha</i>	Rock ear	Dena'ina	Foliose rock lichen	(Kari 1987)
<i>limx ga gan</i>	Whiskers of the tree	Tsimshian	<i>Usnea longissima</i>	(Turner and Thompson 2006)
<i>Teh-ra</i>	Above hair	Dakelh	<i>Bryoria fremontii</i>	(Morice 1894)
<i>Dehtsighu</i>	Branch hair	Dena'ina	Alectorioid lichens	(Kari 1987)
<i>Ch'vala andaz'i</i>	Spruce hair	Dena'ina	Alectorioid lichens	(Kari 1987)
<i>Sqwelip</i>	Hair dirt	Halkomelem	<i>Bryoria fremontii</i>	(Galloway 1982)
<i>Máqelhp or máqenelhp</i>	Hair-	Halkomelem	White lacy lichen	(Galloway 1982)
<i>Mousse d'arbre</i>	Treemoss	Europe	<i>Pseudevernia furfuracea</i>	(Coppins and Watling 1994)
<i>Mousse chène, eichenmoss</i>	Oakmoss	Europe	<i>Evernia prunastri</i>	(Uphof 1959)
<i>Tkwelmáka7</i>	Green limb	Secwepemc	<i>Letharia vulpina</i>	(Palmer 1975)
<i>Manil maashaxaeme</i>	Mountain moss	Karok	<i>Letharia vulpina</i>	(Schenck and Gifford 1952)
<i>Torba</i>	Dirt	Libya	<i>Aspicilia esculenta</i>	(Crum 1993)
<i>Trub</i>	Dirt	Bedouin	<i>Aspicilia esculenta</i>	(Crum 1993)
<i>K'áma páka</i>	Dry needles mold	Secwepemc	<i>Cetraria</i> spp.	(Palmer 1975)
<i>Lichens named according to appearance or folk ontogeny</i>				
	Frog-skin lichen	Quileute	<i>Lobaria pulmonaria</i>	(Forlines <i>et al.</i> 1992)
<i>Gwilehl ganaa'w</i>	Frog blankets	Gitksan	<i>Lobaria pulmonaria</i>	(Main-Johnson 1997)
<i>Nagaganaw</i>	Dress of the frog	Tsimshian	<i>Lobaria oregana</i>	(Turner and Clifton 2002; Turner and Thompson 2006)
<i>X^w q'él'ted 7e welis</i>	Diaper of frog	Samish-Lummi	Unidentified lichens	(Hess 1976)
	Grandma's hair	Gwich'in	<i>Usnea</i> spp.	(Holloway and Alexander 1990)
<i>Ha'ichu vuushdag</i>	Things that grow up	O'odham	Mosses, lichens, fungi, lower plants	(Rea 1997)
	Rock dandruff	Tsilhqot'in	Lichens on rocks	(Turner, pers. comm. 2007)
<i>Lexlek'is</i>	Echo	Kwakwaka'wakw	Grey <i>Peltigera</i> spp.	(Turner and Bell 1973)
<i>Tl'extl'ekw'és</i>	Seaweed of the ground	Kwakwaka'wakw	Grey <i>Peltigera</i> spp.	(Turner and Bell 1973)
<i>(Tl)i-(tl)i-dqwaqsibakkw</i>	Like whale baleen	Ditidaht	<i>Peltigera</i> spp.	(Turner <i>et al.</i> 1983)
<i>Ninguujuq</i>	Would like to be stretched	Yup'ik	<i>Flavocetraria cucullata</i>	(Oswalt 1957)
	Lao-tzu's beard	China	<i>Usnea diffracta</i>	(Sharnoff 1997)

Appendix VII cont'ed. Informative compound folk names for lichens

Folk name	English translation	People	Lichen	Reference
<i>Lichens named according to appearance or folk ontogeny</i>				
<i>Odoche jupacua</i>	Iguana toe	Piaroa: Amazon	<i>Parmelia</i> spp	(Azenha <i>et al.</i> 1998)
	Lizard semen	Paiute	Orange and yellow crustose lichens	(Sharnoff 1997)
<i>Tpkáka7 tl'e wila</i>	White wila	Secwepemc	<i>Alectoria sarmentosa</i>	(Palmer 1975)
<i>White crottle</i>		Scotland	<i>Variolaria orcina</i>	(Kok 1966)
<i>Chan wiziye</i>	Grows on trees, yellow	Dakota	Dye lichens: <i>Punctelia borreri</i> ; <i>Usnea scabrata</i>	(Jones, pers. comm. 2005)
<i>Lichens named according to use</i>				
<i>Baduhu-tsinā</i>	Deer snuff	Denis: Brazil	Unidentified tree lichen	(Prance 1972)
	Indian bandage	Ditidaht	<i>Usnea</i> spp.	(Turner <i>et al.</i> 1983)
	Pine gauze, female gauze	China	<i>Usnea diffracta</i>	(Sharnoff 1997)
<i>Mathaghasa</i>	rub on skull	Pudocherry: India	<i>Rocella fuciformis</i>	(Biswas 1948)
<i>E-simatch-sis</i>	Yellow dye	Niitsitapii	<i>Letharia vulpina</i>	(McClintock 1910)
<i>Hehyowo'ists</i>	Yellow dye	Cheyenne	<i>Letharia vulpina</i>	(Grinnell 1905)
<i>Ulf-mossa</i>	Wolf moss	Sweden	<i>Letharia vulpina</i>	(Teit and Steedman 1928)
<i>Wa'kwūnūk</i>	Egg bush	Potawatomi	<i>Hypogymnia physodes</i>	(Smith 1933)
<i>Jīngwakons wakun</i>	Little white pine and row of [fish] eggs	Ojibwa	<i>Lobaria amplissima</i>	(Smith 1932)
<i>Jīngwa'kwak</i>	Pine [fish] egg	Ojibwa	<i>Lobaria amplissima</i>	(Smith 1932)
<i>Tuntutnuukaik</i>	Reindeer food	Yup'ik	<i>Cladina</i> spp.	(Oswalt 1957)
	Wonder grain	Eastern Turkey	<i>Aspicilia esculenta</i>	(Sharnoff 1984)
	Bread from heaven	Kurds	<i>Aspicilia esculenta</i>	(Sharnoff 1984)
<i>Brødmore</i>	Bread moss	Norway	<i>Cetraria islandica</i>	(Airaksinen <i>et al.</i> 1986)
<i>Broedmāsā</i>				
<i>Matmāsā</i>	Food moss	Norway	<i>Cetraria islandica</i>	(Airaksinen <i>et al.</i> 1986)
<i>Svinmāsā</i>	Swine moss	Norway	<i>Cetraria islandica</i>	(Airaksinen <i>et al.</i> 1986)

Appendix VIII. Folk names and taxa for lichens used by people across the world. Language families taken from Gordon (2005).

People and language family	Folk Name	Lichen	Reference
Eskimo-Aleut: Eskimo: Yup'ik: Alaskan	Yup'ik	<i>Kusskoak</i>	<i>Nephroma arcticum</i> (Oswalt 1957)
	Yup'ik	<i>Qelquaq</i>	<i>Lobaria scrobiculata</i> <i>Ibid.</i>
	Yup'ik	<i>Aouq</i>	<i>Cetraria ericetorum</i> <i>Ibid.</i>
	Yup'ik	<i>Ninguujuq</i> ['would like to be stretched']	<i>Flavocetraria cucullata</i> <i>Ibid.</i>
	Yup'ik	<i>Tuntutnuukaik</i> ['reindeer food']	<i>Cladina</i> spp. <i>Ibid.</i>
	Chugach	<i>Nakuraartum nuyii</i> ; or <i>napam ungagua'i</i>	<i>Alectoria ochroleuca</i> ; <i>Bryoria trichodes</i> (Wennekens 1985)
Eskimo-Aleut: Eskimo: Inuit	Barrens-Keewatin Inuit	<i>Nagijuujaq</i>	Unused yellow-green bushy lichens: <i>Dactylina arctica</i> ; <i>Flavocetraria nivalis</i> (Wilson 1979)
	Barrens-Keewatin	<i>Uriugaq</i>	White "moss" <i>Ibid.</i>
	Barrens-Keewatin	<i>Quajuq</i>	Flat foliose lichens: <i>Parmelia saxatilis</i> ; <i>Peltigera aphthosa</i> ; <i>Stereocaulon paschale</i> <i>Ibid.</i>
	Barrens-Keewatin, North Slope, Ungava-Labrador, Baffin Island, and Greenland (Inuit)	<i>Tingaujaq</i>	Dark hair lichens on ground: <i>Alectoria nigricans</i> ; <i>A. ochroleuca</i> ; <i>Bryocaulon divergens</i> ; <i>Bryoria nitidula</i> <i>Ibid.</i>
	Ungava-Labrador	<i>Niqagasak</i>	<i>Cladina rangiferina</i> <i>Ibid.</i>
	Na-Dene: Nuclear: Athapaskan: Tanaina-Ahtna	Dena'ina	<i>K'udyi</i>
Dena'ina		<i>Qalnigi jegha</i> ['rock ear']	Foliose rock lichen <i>Ibid.</i>
Dena'ina		<i>K'udyika'a</i>	<i>Peltigera</i> sp. <i>Ibid.</i>
Dena'ina		<i>Dehsighu</i> ['branch hair'] or <i>ch'vala andaz'i</i> ['spruce hair']	Alectorioid lichens <i>Ibid.</i>
Dena'ina		Tree name plus <i>endenghasdetlaq'i</i> or <i>ilgida</i> ['stuck to']	Lichens on bark <i>Ibid.</i>
Na-Dene: Nuclear: Athapaskan: Canadian	Gwich'in	'Grandma's hair'	<i>Usnea</i> spp. (Holloway and Alexander 1990)
	Dakelh	<i>Teh-ra</i> ('above hair')	<i>Bryoria fremontii</i> (Morice 1894)
Na-Dene: Nuclear: Tlingit	Chilkat Tlingit	<i>Sekhone</i>	<i>Letharia vulpina</i> (Niblack 1888)
Na-Dene: Haida	Haida	<i>K'inxaan</i> or <i>k'innaan</i>	<i>Mosses and lichens</i> (Turner 1974)

Appendix VIII cont'ed. Lichen folk taxa.

People and language family		Folk Name	Lichen	Reference
Penutian:	Gitksan	<i>Gwilehl ganaa'w</i>	<i>Lobaria pulmonaria</i>	(Main-Johnson 1997)
Tsimshian:		['frog blankets']		
Gitksan	Gitksan	<i>Claanisis skinisht</i>	<i>Vulpicida canadensis</i>	<i>Ibid.</i>
	Tsimshian	<i>Melx7aest, mELax'â'Est</i>	Lichens	(Boas 1902; Turner and Thompson 2006)
	Tsimshian	<i>MELax'â'EstL gan</i>	Lichens on a tree	(Boas 1902)
Penutian:	Tsimshian	<i>Nagaganaw</i>	<i>Lobaria oregana</i>	(Turner and Thompson 2006)
Tsimshian:		['frog's dress']		
Tsimshian	Tsimshian	<i>Iimx ga gan</i>	<i>Usnea longissima</i>	<i>Ibid.</i>
	Tsimshian	<i>Blaax</i>	Mosses and <i>Usnea</i> spp.	<i>Ibid.</i>
	Tsimshian (??), or unknown east of Fraser R. (BC)	<i>Whyelkine</i>	<i>Bryoria fremontii</i>	(Mayne 1862; Turner and Clifton 2002)
	Nimi'ipuu	<i>/ho.pópl</i>	<i>Bryoria fremontii</i>	(Marshall 1977)
	Umatilla and Cayuse Sahaptin	<i>K'u'nch</i>	<i>Bryoria fremontii</i>	(Hunn, pers. comm. 2005)
Penutian:	Umatilla and Cayuse Sahaptin	<i>maxa'hl</i>	Unidentified	<i>Ibid.</i>
Plateau:	Umatilla and Cayuse Sahaptin	<i>Laxpt</i> or <i>mak+'hl</i>	Green alectoroid lichens and <i>Letharia vulpina</i>	<i>Ibid.</i>
Sahaptin	Quinalt	<i>Ts'o'o'tc</i>	Unidentified, on trees	(Gunther 1945)
	Tenino	<i>Tama muklth muklth</i>	<i>Letharia vulpina</i>	(Murphey 1959)
	Tenino	<i>Wa-kamwa</i> or <i>wa kam wa</i>	<i>Bryoria fremontii</i>	<i>Ibid.</i>
Penutian:	Klamath	<i>Shwa'-wi-säm</i>	<i>Letharia vulpina</i>	(Coville 1897)
Plateau:	Modoc	<i>Ga'da</i>	<i>Letharia vulpina</i>	(Ray 1963)
KL./Modoc	Modoc	<i>Qa'l</i>	<i>Bryoria fremontii</i>	<i>Ibid.</i>
Penutian:	Ila'xluit	<i>Ik!u'nuc</i>	<i>Bryoria fremontii</i>	(Spier and Sapir 1930)
Chinookan	Wasco	<i>Yugar sanibe</i>	<i>Letharia vulpina</i>	(Murphey 1959)
	Wasco	<i>Luke komo</i>	<i>Letharia vulpina</i>	<i>Ibid.</i>
Penutian:	Nishinam	<i>Wa'-hat-tak</i>	<i>Lecanora muralis</i>	(Powers 1877)
	Ditidaht, Hesquiat	<i>P'u7up</i>	Mosses/lichens, but not <i>Peltigera</i> spp.	(Turner <i>et al.</i> 1983)
	Hesquiat	<i>(Tl)'ac(tl)'astuphc'um</i>	<i>Lobaria pulmonaria</i>	(Turner & Efrat 1982)
Wakashan:	Ditidaht	<i>(Tl)'a(tl)'x7a'7aq</i>	<i>Peltigera</i> spp.	(Turner <i>et al.</i> 1983)
Southern:		['flat against rock']		
Nuu-chah-nulth	Ditidaht	<i>(Tl)i'(tl)i'dqwaqsibakkw</i>	<i>Peltigera</i> spp.	<i>Ibid.</i>
		['like whale baleen']		
	Ditidaht	<i>T'it'idic'c'7a'</i>	<i>Peltigera aphthosa</i>	<i>Ibid.</i>
		['rocks growing on rocks']		
	Ditidaht	'Indian bandage'	<i>Usnea</i> spp.	<i>Ibid.</i>
Wakashan:	Makah	<i>Didi'dichia</i>	<i>Lobaria</i> spp.	(Turner <i>et al.</i> 1983)
Southern		['growing on rocks']		

Appendix VIII cont'ed. Lichen folk taxa.

People and language family		Folk Name	Lichen	Reference
Wakashan: Northern	Kwakwaka'wakw	<i>Tl'extl'ekw'és</i> ['ground seaweed']	Grey <i>Peltigera</i> spp.	(Turner & Bell 1973)
	Kwakwaka'wakw	<i>Lexlek'is</i> ['echo']	Grey <i>Peltigera</i> spp.	<i>Ibid.</i>
	Kwakwaka'wakw	<i>P'elems</i>	Mosses and lichens	<i>Ibid.</i>
Chimakuan	Quileute: WA	'Frog-skin lichen'	<i>Lobaria pulmonaria</i>	(Forlines <i>et al.</i> 1992)
Salishan: Bella Coola	Nuxalk	<i>Ipst</i>	Ground moss & lichen	(Turner 1974)
	Nuxalk	<i>Ipst-aak</i>	Tree moss & lichen	<i>Ibid.</i>
	Nuxalk	<i>Sts'wakt-aak</i>	<i>Lobaria</i> & <i>Usnea</i> spp.	(Turner 1973)
Salishan: Central Salish	Halkomelem	<i>Sqwelíp</i> ['hair dirt']	<i>Bryoria fremontii</i>	(Galloway 1982)
	Halkomelem	<i>Mext'éles</i>	Grey, green tree lichen	<i>Ibid.</i>
	Halkomelem	<i>Máqelhp</i> or <i>mágenelhp</i> ['hair-']	White lacy lichen	<i>Ibid.</i>
	Samish-Lummi	<i>X^wq'él'ted 7e welis</i> ['diaper of frog']	Unidentified lichens	(Hess 1976)
	Secwepemc	<i>Kwesáy</i>	<i>Lobaria pulmonaria</i> ; <i>Cladonia</i> & <i>Parmelia</i> spp; small mushrooms	(Palmer 1975)
	Secwepemc	<i>Tkwelmáka7</i> ['yellow on wood']	<i>Letharia vulpina</i>	<i>Ibid.</i>
Secwepemc	<i>Qwesimáleq^w</i>	<i>Letharia vulpina</i>	(Turner 1998)	
Secwepemc	<i>K'áma páka</i> ['dry needles mold']	<i>Cetraria</i> spp.	(Palmer 1975)	
Salishan: Interior	Secwepemc	<i>Tpkáka7 tl'e wíla</i> ['white wila']	<i>Alectoria sarmentosa</i>	<i>Ibid.</i>
Salish: Northern	Secwepemc	<i>Wíla</i> or <i>wíle</i>	<i>Bryoria fremontii</i>	(Turner 1998)
	St'at'imc	<i>a.wi'.a</i>	<i>Bryoria fremontii</i>	(Turner and Bouchard 1974)
	St'at'imc	<i>Pá7sem</i>	Mosses and lichens	(Turner 1974)
	Nlaka'pmx	<i>lwí7e</i>	<i>Bryoria fremontii</i>	(Turner <i>et al.</i> 1990)
	Nlaka'pmx	<i>Itxwa</i>	<i>B. fremontii</i> cakes	(Newcombe 1901-1913)
	Nlaka'pmx	<i>Kolomé'ka</i> or <i>kwalá'uk</i> ['yellow on wood']	<i>Letharia vulpina</i>	(Teit and Steedman 1928)
	Okanagan	<i>Pen'pen'emekx'sxn'</i> ['liver on rocks']	<i>Cladonia chloropheae</i>	(Turner <i>et al.</i> 1980)
Salishan: Interior Salish: Southern	Okanagan	<i>Kware'uk</i>	<i>Letharia vulpina</i>	(Teit & Boas 1928)
	Okanagan	<i>Kwerníkw</i>	<i>Letharia vulpina</i>	(Turner <i>et al.</i> 1980)
	Okanagan	<i>Skwelíp</i>	<i>Bryoria fremontii</i>	<i>Ibid.</i>
	Schitsu'umsh	<i>Sä'tc'Etct</i>	<i>Bryoria fremontii</i>	(Teit & Boas 1928)
	Spokane	<i>S'áw'-t-m=qn,</i> or <i>s-q^wl'=áp=qn,</i>	<i>Bryoria fremontii</i>	(Carlson and Flett 1989)
	Spokane	<i>S-c^w-k^wr-n=éc'st</i> or <i>S-k^wali=ó7=álq^w</i>	<i>Letharia vulpina</i>	<i>Ibid.</i>
Int. Salish: Southern OR L. I.	Flathead (Salish, Ktunaxa)	<i>Caúntemkan,</i> <i>st'telu, skola'pkEn,</i> or <i>sqatlo</i>	<i>Bryoria fremontii</i>	(Turney-High 1937)
Language isolate	Ktunaxa	<i>Ä'tila</i> or <i>emgo'tl^{na}</i>	<i>Letharia vulpina</i> [perhaps <i>Bryoria</i> sp.]	(Chamberlain 1892)

Appendix VIII cont'ed. Lichen folk taxa.

People and language family		Folk Name	Lichen	Reference
Iroquoian	Iroquois	<i>Gustaot one''ta'</i>	Unidentified rock/tree lichen	(Parker 1910)
Siouan: Proper: Central	Dakota	<i>Chan wiziye</i> [grows on trees – yellow']	Dye lichens: <i>Punctelia borreri</i> , <i>Usnea scabrata</i>	(Gilmore 1919)
Unknown	Unspecified N.A.	<i>O shaw shaú kon ug</i>	Umbilicaria spp.	(Schoolcraft and Swan 1855)
Algic: Algonquian: Plains	Niitsitapii	<i>E-simatch-sis</i> ['yellow dye']	<i>Letharia vulpina</i>	(McClintock 1910)
	A'aninin	<i>Otsahaa</i>	<i>Letharia vulpina</i>	(Johnston 1982)
	Cheyenne	<i>Hehyowo'ists</i> ['yellow dye']; or <i>He-ho-wa-ins'-tots</i> ['yellow root']	<i>Letharia vulpina</i>	(Grinnell 1905)
Algic: Algonquian: Central: Cree-Montagnais-Naskapi	Nihithawak	<i>Mithapakwan</i>	<i>Usnea</i> spp.	(Leighton 1985)
	Attawapiskat	<i>Wa'kana a'pisk</i>	<i>Umbilicaria</i> spp.	(Honigmann 1961)
	Naskapi	<i>Wakoonapishkuts</i> ['span of the rocks']	<i>Umbilicaria</i> spp.	(Lips 1947)
	Attikamekw	<i>Asine-wakunik</i>	<i>U. mammulata</i>	(Raymond 1945)
Algic: Algonquian: Central: Ojibwa	Nipigon	<i>As-se-ne wa-quon-uck</i> ['eggs of the rock']	Unidentified rock lichen	(Harmon 1800-1816)
	Ojibwa	<i>Asa' gûniñk'</i>	<i>Cladina rangiferina</i>	(Smith 1932)
	Ojibwa	<i>Jîngwakons wakun</i> ['white pine & row of eggs']; or <i>jîngwa'kwak</i>	<i>Lobaria amplissima</i>	(Yarnell 1964)
	Ojibwa	<i>Waac</i>	<i>Umbilicaria</i> spp.	(Henry 1809)
Algic: Algonquian: Central: Potawatomi	Potawatomi	<i>Wa'kwûnûk</i> ['egg bush']	<i>Hypogymnia physodes</i>	(Smith 1933)
Algic: Algonquian: Central: Menominee	Menominee	<i>Wakûn</i>	<i>Lobaria amplissima</i>	(Smith 1923)
Algic: Yurok: Yurok	Yurok	<i>Mece'n</i>	<i>Letharia vulpina</i>	(Mead 1972)
Hokan: Northern	Karok	<i>'Asaxxé'm</i>	Mosses and lichens	(Schenck and Gifford 1952)
	Karok	<i>Ashaxaeme</i>	<i>Usnea scabrata</i>	(Schenck and Gifford 1952)
	Karok	<i>Manil maashaxaeme</i> ['mountain moss']	<i>Letharia vulpina</i>	(Schenck and Gifford 1952)
	Pomo	<i>Kôchih;</i> or <i>qoci</i>	<i>Usnea californica</i>	(Gifford 1967)
Hokan: Seri	Seri	'Soil its skin'	Lichens	(Rea 1997)
Yuki	Yuki	<i>Ol-gât'-i</i>		(Chesnut 1902)
Uto-Aztecan: Northern:	Shoshone	<i>Yugar sanibe</i>	<i>Letharia vulpina</i>	(Murphey 1959)
	Paiute	<i>Wapi-tonega</i>	<i>Letharia vulpina</i>	(Murphey 1959)
Numic	Paviotso	'Lizard semen'	Orange and yellow crustose rock lichens	(Sharnoff 1997)

Appendix VIII cont'ed. Lichen folk taxa.

People and language family	Folk Name	Lichen	Reference
Uto-Aztecan: Southern: Sonoran	O'odham	<i>Ha'ichu vuushdag</i> ['things that grow up']	Mosses, lichens, fungi, lower plants (Rea 1997)
	O'odham	<i>Jewed eldag</i> ['earth skin']	Mosses and lichens on ground (Rea 1997)
	O'odham	<i>Hodai eldag</i> ['rock skin']	Lichens on rock (Rea 1997)
	O'odham	<i>Jievut hiawsik</i> ['earth flower']	<i>Xanthoparmelia</i> <i>conspersa</i> (Rea 1997)
	Tarahumara (Mexico)	<i>Reté cajera</i>	<i>Flavoparmelia</i> <i>caperata</i> ; <i>Usnea</i> <i>variolosa</i> ; <i>U. subfusca</i> (Pennington 1963)
	Tarahumara	'Wool of rocks'	<i>Usnea</i> spp. (Brough 1988)
Language isolate	Waorani: Ecuador	<i>Nel/nelndapel</i>	<i>Dictyonema sericeum</i> (Davis and Yost 1983)
Quechuan	Quechua: Peru	<i>Papel-papel</i>	<i>Niebla flaccescens</i> (Velasco- Negueruela <i>et al.</i> 1995)
Tupi	Mbyá Guaraní: Brazil	<i>memby rakú í ja</i>	<i>Usnea barbata</i> (Cadogan 1949)
Arauan	Dení: Brazil	<i>Baduhu-tsinā</i> ['deer snuff']	Unidentified tree lichen (Prance 1972)
Salivan	Piaroa: Venezuala	<i>Odoche jupacua</i> ['iguana toe']	<i>Parmelia</i> spp. (Azenha <i>et al.</i> 1998)
Indo-European: Italic: Latino- Faliscan	Latin	<i>Muscus pulmonarius</i>	<i>Lobaria pulmonaria</i> (Uphof 1959)
	Latin	<i>Lichen cinereus</i> <i>terrestris</i>	<i>Peltigera canina</i> (Dampier and Sloane 1698)
	Latin	<i>Pulvis antilyssus</i>	<i>P. canina</i> /pepper mix (Mortimer 1735)
Indo-European: Italic: Romance: Gallo-Iberian: Ibero-Romance: West Iberian	Brazil (Portugese)	<i>Candúá</i>	<i>Cladonia miniata</i> (Mors and Rizzini 1966)
	Portugal	<i>Urzela</i>	<i>Roccella tinctoria</i> (Kok 1966)
	S. America (Spanish)	<i>Contrayerba blanca</i>	<i>Thamnotia vermicularis</i> (Lindley 1838)
	Uruguay (Spanish)	<i>Yerba de la piedra</i> ['stone grass']	<i>Usnea densirostra</i> (Osorio 1982)
	Argentina (Spanish)	<i>Barba de piedra</i> ['stone beard']	<i>Usnea densirostra</i> ; <i>U. campestris</i> (Garcia <i>et al.</i> 1990)
	Spain	<i>Orciglia</i> ; or <i>orchilla</i>	<i>Roccella tinctoria</i> (Kok 1966)
	Spain	<i>Flor de piedra</i> ['stone flower']	<i>Xanthoria parietina</i> ; <i>Niebla flaccescens</i> (González-Tejero <i>et al.</i> 1995)
	Spain	<i>Rompepiedra</i> ['stone breaker']	<i>Xanthoria parietina</i> <i>Ibid.</i>
	Granada	<i>Musgo</i>	<i>Pseudevernia</i> <i>furfuracea</i> <i>Ibid.</i>
	Canary Is. (Spanish)	<i>Barbas</i>	<i>Usnea</i> spp. and <i>Usnea atlantica</i> (Darias <i>et al.</i> 1986)
Canary Is.	<i>Orchilla</i>	<i>Roccella canariensis</i> , <i>R.</i> <i>tuberculata</i> , & <i>R.</i> <i>vicentina</i> (Darias <i>et al.</i> 1993)	
Canary Is.	<i>Alican</i> or <i>jaican</i>	<i>Roccella fuciformis</i> <i>Ibid.</i>	

Appendix VIII cont'ed. Lichen folk taxa.

People and language family	Folk Name	Lichen	Reference
Explorers in N. America	<i>Tripe de roche</i> ['rock tripe']	<i>Umbilicaria</i> spp.	(Lindley 1838)
Indo-European: Italic: Romance:	Europe (French) <i>Mousse d'arbre</i> ['treemoss']	<i>Pseudevernia furfuracea</i>	(Coppins and Watling 1994)
Gallo-Iberian:	Europe <i>Mousse chêne</i>	<i>Evernia prunastri</i>	(Uphof 1959)
Gallo-Romance:	Europe <i>Barbefine</i>	<i>Variolaria orcina</i>	(Kok 1966)
Gallo-Rhaetian:	France <i>Perelle</i>	<i>Variolaria orcina</i>	<i>Ibid.</i>
Oïl: French	France <i>La pommelée</i> ['dappled one']; or <i>perelle</i>	<i>Ochrolechia parella</i>	<i>Ibid.</i>
	France <i>Orseille</i> ; or <i>orchal</i>	<i>Roccella tinctoria</i>	<i>Ibid.</i>
	Sweden (Svenska) <i>Ulf-mossa</i> ['wolf moss']	<i>Letharia vulpina</i>	(Teit and Steedman 1928)
Indo-European: Germanic:	Sweden <i>Stenlav</i>	<i>Parmelia saxatilis</i>	(Ahmadjian and Nilsson 1963)
North: East Scandinavian: Danish-Swedish	Sweden <i>Tousch</i>	<i>Umbilicaria deusta</i>	(Uphof 1959)
	Norway (Bokmål) <i>Broedmåså</i> ; or <i>brødmose</i> [bread moss]	<i>Cetraria islandica</i>	(Airaksinen <i>et al.</i> 1986)
	Norway <i>Matmåså</i> [food moss]	<i>Cetraria islandica</i>	<i>Ibid.</i>
	Norway <i>Svinmåså</i> [swine moss]	<i>Cetraria islandica</i>	<i>Ibid.</i>
	Scotland <i>Crottle</i>	<i>Parmelia omphalodes</i> ; <i>Parmelia saxatilis</i>	(Mabey 1977)
	Scotland <i>Light crottle</i>	<i>Parmelia saxatilis</i>	(MacIntyre 1999)
	Scotland <i>Dark crottle</i>	<i>Parmelia omphalodes</i>	<i>Ibid.</i>
	Scotland <i>White crottle</i>	<i>Variolaria orcina</i>	(Kok 1966)
Indo-European: Germanic: West: English	Scotland <i>Corkir</i> ; <i>corcur</i> ; <i>corklit</i> ; or <i>cudbear</i>	<i>Ochrolechia tartarea</i> ; and <i>O. androgyna</i>	(Coppins and Watling 1994)
	England <i>Orchil</i>	<i>Roccella tinctoria</i>	(Kok 1966)
	England <i>Ash colored ground liverwort</i>	<i>Peltigera canina</i>	(Layard 1757)
	Derbyshire <i>Grey moss</i>	<i>Parmelia saxatilis</i>	(Vickery 1975)
	Derbyshire <i>Gold moss</i>	<i>Xanthoria parietina</i>	<i>Ibid.</i>
Indo-European: Germanic: West: High German	Europe (German) <i>Eichenmoss</i> ['oakmoss']	<i>Evernia prunastri</i>	(Uphof 1959)
	Germany <i>Persis</i>	<i>Roccella tinctoria</i>	(Kok 1966)
Indo-European: Germanic: West: Low Franconian	Afrikaans: South Africa <i>Klipbolm</i> ['rock flower']	<i>Parmelia</i> spp	(van Wyk and Gericke 2000)
Indo-European: Indo-Iranian: Iranian	Kabul: Afghanistan <i>Gul-i-sang</i> ['stone flowers']	<i>Lobaria pulmonaria</i>	(Hunte <i>et al.</i> 1975)
	Kurdish Bread from heaven	<i>Aspicilia esculenta</i>	(Sharnoff 1984)
	Persian <i>Shirsad</i>	Bread from <i>A. esculenta</i>	(Gioanetto 1993)
	Sanskrit (Aryurveda: India) <i>Chharila</i>	<i>Parmotrema chinense</i> ; <i>P. perforatum</i> ; <i>Everniastrum cirrhata</i> ; <i>E. nepalense</i>	(Chandra and Singh 1971)
Indo-European: Indo-Iranian: Indo-Aryan	Sanskrit <i>Jhoola</i>	Same as <i>chharila</i>	(Kumar <i>et al</i> 1996)
	Sanskrit <i>Shailaya</i> ; or <i>shila pushp</i> [rock flower]	Lichens	(Upreti <i>et al.</i> 2005)
	Sanskrit <i>Shipal</i>	Same as <i>chharila</i>	<i>Ibid.</i>

Appendix VIII cont'ed. Lichen folk taxa.

People and language family	Folk Name	Lichen	Reference
	Garhwal: India	<i>Maidu</i>	<i>Buellia subsororioides</i> (Upreti 2001)
Indo-European: Indo-Iranian: Indo-Aryan: Northern zone	Gaddi: India	<i>Budu</i>	<i>Everniastrum cirrhatum</i> ; <i>Cetrelia collata</i> ; <i>Melanelia infumata</i> ; <i>Parmotrema nilgherrense</i> <i>Ibid.</i>
	Nepali (& Lepcha): India	<i>Rukhu-ku-Jau</i>	<i>Everniastrum cirrhatum</i> (Saklani and Upreti 1992)
	Nepali	<i>Dhungo ku seto jhua</i>	<i>Heterodermia diademata</i> <i>Ibid.</i>
Indo-European: Indo-Iranian: Indo-Aryan: East	Bengal	<i>Darimataghosa</i>	<i>Usnea sikkimensis</i> (Biswas 1956)
	Bengal	<i>Patamataghosa</i>	<i>Peltigera canina</i> <i>Ibid.</i>
	Bengal	<i>Golmataghosa</i>	<i>Lobaria pulmonaria</i> <i>Ibid.</i>
Indo-European: Indo-Iranian: Indo-Aryan: South	Marathi: India	<i>Dagad phool</i> ['stone flower']	<i>Parmotrema nilgherrense</i> ; <i>P. sancti-angelii</i> ; <i>P. tinctorum</i> ; <i>Rimelia reticulata</i> ; <i>Ramalina</i> , <i>Everniastrum</i> , <i>Usnea</i> spp. (Richardson 1991)
Indo-European: Indo-Iranian: Indo-Aryan: East Central	Baiga, Bhil, Bhilala (& Korku, Gond, Muria): India	<i>Jhavila</i>	<i>Everniastrum cirrhatum</i> ; <i>Heterodermia tremulans</i> ; <i>Parmotrema sancti-angelii</i> ; <i>P. tinctorum</i> ; <i>Rimelia reticulata</i> , <i>Ramalina subcomplanata</i> (Lal and Upreti 1995)
Dravidian: South	Bellary District: India (Kannada)	<i>Rathipuvvu</i> ['rock flower']	<i>Parmotrema abessinicum</i> (Sastri 1953)
	Tamil	<i>Mathaghosa</i> ['to rub on skull']	<i>Roccella fuciformis</i> (Biswas 1948)
Dravidian: South-Central: Gondi	Gond, Muria (& Baiga, Bhil, Bhilala,, Korku): India	<i>Jhavila</i>	<i>Everniastrum cirrhatum</i> ; <i>Heterodermia tremulans</i> ; <i>Parmotrema sancti-angelii</i> ; <i>P. tinctorum</i> ; <i>Rimelia reticulata</i> , <i>Ramalina subcomplanata</i> (Lal and Upreti 1995)
Austro-Asiatic: Munda: North: Korku	Korku (& Gond, Muria, Baiga, Bhil, Bhilala): India	<i>Jhavila</i>	<i>Everniastrum cirrhatum</i> ; <i>Heterodermia tremulans</i> ; <i>Parmotrema sancti-angelii</i> ; <i>P. tinctorum</i> ; <i>Rimelia reticulata</i> , <i>Ramalina subcomplanata</i> <i>Ibid.</i>
Sino-Tibet: Tibeto-Burman: Bai	Bai: nw Yunnan, China	<i>Qingwapi</i>	<i>Lobaria isidiophora</i> and <i>L. kurokawae</i> (Wang <i>et al.</i> 2001)
	Yi: cent. Yunnan	<i>shihuacai</i>	<i>Ramalina conduplicans</i> <i>Ibid.</i>
	Yi: s. Yunnan	<i>Shouxu</i> or <i>shikuacai</i> ,	<i>Ramalina conduplicans</i> <i>Ibid.</i>
Sino-Tibet: Tibeto-Burman: Lolo-Burmese	Yi: south Yunnan	<i>shuhua</i>	<i>Ramalina conduplicans</i> and <i>R. sinensis</i> <i>Ibid.</i>
	Naxi: nw Yunnan	<i>Luxingcha</i> or <i>hongxuecha</i>	<i>Lethariella cashmeriana</i> , <i>L. sernanderi</i> , and <i>L. sinensis</i> <i>Ibid.</i>
	Naxi: nw Yunnan	<i>Xuecha</i> [tea ingred. from high elevation]	<i>Thamnolia subuliformis</i> and <i>T. vermicularis</i> <i>Ibid.</i>

Appendix VIII cont'ed. Lichen folk taxa.

People and language family	Folk Name	Lichen	Reference
Sino-Tibet: Tibeto-Burman: Himalayish: Tibeto-Kanauri	Tibetan: Yunnan	<i>Qinwapi</i> or <i>shuhudie</i>	<i>Lobaria yoshimurae</i> and <i>L. orientalis</i> (Wang <i>et al.</i> 2001)
	Tibetan: Sichuan	<i>Laolongpi</i>	<i>Lobaria yoshimurae</i> and <i>L. orientalis</i> <i>Ibid.</i>
	Lepcha: India	<i>Jhau</i>	<i>Peltigera polydactylon</i> (Upreti 1996)
	Lepcha (& Nepali): India	<i>Rukhu-ku-jau</i>	<i>Everniastrum cirrhatum</i> (Saklani and Upreti 1992)
	Lepcha: India	<i>Dhungo-ku-jhau</i>	<i>Stereocaulon himalayense</i> (Upreti 1996)
Sino-Tibet: Tibeto-Burman: Himalayish: Mahakiranti	Bhotia: India	<i>Chhai dhoop</i>	<i>Thamnia vermicularis</i> (Upreti 2001)
	Kathmandu: Nepal (Newar?)	<i>Kalo jhyau</i>	<i>Everniastrum nepalense</i> (Kumar <i>et al.</i> 1996)
Sino-Tibet: Chinese	Rai, Limbu: Nepal	<i>Yangben</i>	<i>Everniastrum nepalense</i> ; <i>Ramalina subfarinacea</i> ; <i>R.</i> <i>farinacea</i> ; <i>R. conduplicans</i> ; <i>R. sinensis</i> ; <i>Usnea thomsonii</i> (Bhattarai <i>et al.</i> 1999)
	China	<i>Kabuto-goke-modoki</i>	<i>Lobaria kurokawae</i> (Ohmura 2003)
	China	<i>Su lo</i>	<i>Usnea</i> spp. (Lee <i>et al.</i> 1977)
	China	'Pine gauze'; or 'female gauze'	<i>Usnea diffracta</i> (Sharnoff 1997)
Tai-Kadai, Tai,	China	'Lao-tzu's beard'	<i>Usnea diffracta</i> <i>Ibid.</i>
	Dai: south Yunnan, China	<i>shuhua</i>	<i>Ramalina conduplicans</i> and <i>R. sinensis</i> (Wang <i>et al.</i> 2001)
Japanese: Japanese (perhaps related to Altaic & Korean)	Dai	<i>shouxu</i> or <i>shikuacai</i>	<i>Ramalina conduplicans</i> <i>Ibid.</i>
	Japan	<i>Yokowa saruogase</i>	<i>Usnea diffracta</i> (Ohmura 2003)
	Japan	<i>Fuji saruogase</i>	<i>Usnea trichodeoides</i> <i>Ibid.</i>
	Japan	<i>Bandai-kinori</i>	<i>Sulcaria sulcata</i> <i>Ibid.</i>
	Japan	<i>Konahaimatsu-goke</i>	<i>Vulpicida pinastri</i> <i>Ibid.</i>
	Japan	<i>Umenoki-goke</i>	<i>Parmotrema tinctorum</i> <i>Ibid.</i>
	Japan	<i>Ookami-goke</i>	<i>Letharia vulpina</i> <i>Ibid.</i>
	Japan	<i>Kett-goke</i>	<i>Dictyonema sericeum</i> <i>Ibid.</i>
	Japan	<i>Nayonayo saruogase</i>	<i>Usnea himalayana</i> <i>Ibid.</i>
Language isolate	Japan	<i>Iwa-take</i> ['rock mushroom']	<i>Umbilicaria esculenta</i> (Kawagoe 1925)
	Korea	<i>Song-nag</i>	<i>Usnea diffracta</i> (Lee 1966)
Altaic: Turkish	Korea	<i>Seog-eui-beo-seod</i>	<i>Umbilicaria esculenta</i> <i>Ibid.</i>
	eastern Turkey	'Wonder grain'	<i>Aspicilia esculenta</i> (Sharnoff 1984)
Afro-Asiatic: Cushitic	Iraqw: Tanzania	<i>Hewas</i>	<i>Usnea africans</i> and <i>Usnea flavescens</i> (Kokwaro 1976)
	Unani (Arabic)	<i>Ushna</i>	<i>Usnea longissima</i> (Razzack and Fazal 1993)
Afro-Asiatic: Semitic: Arabic	Arabic	<i>Al-sheba</i>	<i>Parmotrema tinctorum</i> (Abo-Khatwa <i>et al.</i> 1997)
	Bedouin (Libya)	<i>Trub</i> ['dirt']	<i>Aspicilia esculenta</i> (Crum 1993)
	Libya	<i>Torba</i> ['dirt']	<i>Aspicilia esculenta</i> <i>Ibid.</i>
	Saudi Arabia	<i>Shaybah</i>	<i>Parmotrema austrosinensis</i> (Richardson 1975)

Appendix VIII cont'ed. Lichen folk taxa.

People and language family	Folk Name	Lichen	Reference
Khoisan: South Africa: Nama	Nama: Namibia	<i>Khaob</i>	<i>Xanthomaculina hottentotta</i> (van Wyk and Gericke 2000)
Niger-Congo: Bantoid: Nguni	Xhosa: South Africa	<i>Mthafathafa</i>	Unidentified rock lichen (Matsiliza and Barker 2001)
Austronesian: Polynesian: Tahitic	Maori	<i>Angiangi</i> ; or <i>kohukohu</i>	<i>Usnea barbata</i> (Brooker and Cooper 1962)
Austronesian: Malayo-Polynesian:	Ati: Philippines	<i>Tagahumok-puti</i>	<i>Usnea barbata</i> (Madulid <i>et al.</i> 1989)
Bisayan	Ati: Philippines	<i>Kalas</i>	<i>Parmotrema zollingeri</i> <i>Ibid.</i>
Trans-New Guinea: Wissel Lakes-Kemandoga	Ekari: New Guinea	<i>Ato</i>	<i>Lobaria pulmonaria</i> (Yoshimura 1970)
	Saami		Lichens different from mosses (Perez-Llano 1944)
	Saami	<i>Gadna</i>	Lichens similar to <i>Parmelia</i> spp. and <i>Umbilicaria</i> spp., reindeer don't commonly eat <i>Ibid.</i>
Uralic: Finno-Lappic: Lappic	Saami	<i>Lappo</i>	Lichens similar to <i>Alectoria</i> spp. and <i>Usnea</i> spp., reindeer like but don't usually eat <i>Ibid.</i>
	Saami	<i>Jaegel</i>	Lichens similar to <i>Cladina</i> spp., <i>Cetraria</i> spp., and <i>Stereocaulon</i> spp., commonly eaten by reindeer. <i>Ibid.</i>
Yukagir	Yukagir (Siberia)	<i>Mo'niol</i>	Lichens in reindeer stomach (Eidlitz 1969)

Appendix IX. Index of lichens by type of use.

Alcohol

Aspicilia esculenta
Bryoria spp.
Cetraria islandica
Cladina rangiferina
Cladina stellaris
Lobaria pulmonaria
Usnea subfusca
Usnea variolosa

Cosmetics

Anaptychia ciliaris
Evernia prunastri
Lobaria pulmonaria
Pseudevernia furfuracea
Parmotrema andinum
Ramalina calicaris
Ramalina farinacea
Ramalina fraxinea
Ramalina siliquosa
Usnea spp.
Usnea barbata
Usnea sikkimensis [??]
Xanthomaculina hottentotta

Decoration

Alectoria sarmentosa
Cladia aggregata
Cladina stellaris
Cladonia furfuracea
Cladonia pyxidata
Heterodermia lutescens
Hypotrachyna protenta
Hypotrachyna sp.
Parmelia saxatilis
Parmotrema dilatatum
Parmotrema flavescens
Parmotrema maclayanum
Parmotrema wainii
Rimelia cetrata
Sphaerophorus globosus
Usnea spp.
Usnea longissima
Xanthoria parietina

Dye

Acarospora smaragdula
Alectoria sarmentosa
Arctoparmelia centrifuga
Aspicilia calcarea
Aspicilia cinerea
Bacidia spp.
Bryoria spp.
Bryoria capillaris
Bryoria fremontii
Bryoria fuscescens
Bryoria glabra
Bryoria implexa
Bryoria pseudofuscescens
Bryoria trichodes
Buellia subsororioides
Caloplaca saxicola
Caloplaca trachyphylla
Candelariella rosulans
Candelariella vitellina
Cetraria aculeata
Cetraria islandica
Chrysothrix chlorina
Cladina rangiferina
Cladonia coccifera
Cladonia fimbriata
Cladonia gracilis
Cladonia miniata
Cladonia pyxidata
Dermatocarpon miniatum
Dermatocarpon reticulatum
Diploschistes scruposa
Evernia prunastri
Everniastrum cirrhatum
Flavocetraria nivalis
Flavoparmelia caperata
Flavopunctelia soledica
Fulgensia bracteata
Fuscopannaria praetermissa
Hypogymnia enteromorpha
Hypogymnia heterophylla
Hypogymnia physodes

Appendix IX cont'ed. Index of lichens by type of use.

Dye continued

Kaernefeltia californica
Lasallia spp.
Lasallia pustulata
Lasallia papulosa
Lecanora argopholis
Lecanora muralis
Lecidella stigmata
Lepraria iolithus
Letharia columbiana
Lobaria isidiosa
Lobaria pulmonaria
Lobaria retigera
Lobaria scrobiculata
Lobothallia alphoplaca
Melanelia commixta
Melanelia stygia
Melanelia tominii
Melanelixia fuliginosa
Melanohalea olivacea
Melanohalea subolivacea
Nephroma helveticum
Nephroma parile
Nodobryoria abbreviata
Ochrolechia androgyna
Ochrolechia frigida
Ochrolechia parella
Ochrolechia tartarea
Parmelia spp.
Parmelia omphalodes
Parmelia saxatilis
Parmelia sulcata
Parmotrema chinense
Peltigera aphthosa
Peltigera canina
Peltigera rufescens
Peltigera venosa
Pertusaria dealbata
Phanerochaete sanguinea
Physcia spp.
Physconia distorta
Platismatia glauca
Platismatia herrei
Pleopsidium chlorophanum

Dye continued

Pleurosticta acetabulum
Polysporina simplex
Pseudephebe pubescens
Pseudevernia furfuracea
Pseudocyphellaria anomala
Pseudocyphellaria aurata
Pseudocyphellaria crocata
Psora crenata
Punctelia borrieri
Ramalina spp.
Ramalina calicaris
Ramalina cuspidata
Ramalina farinacea
Ramalina pollinaria
Ramalina siliquosa
Ramalina subfarinacea
Ramalina thrausta
Rhizocarpon geographicum
Rhizoplaca chrysoleuca
Rhizoplaca melanophthalma
Rhizoplaca peltata
Rinodina bischoffii
Roccella spp.
Roccella babingtonii
Roccella canariensis
Roccella fimbriata
Roccella fuciformis
Roccella montagnei
Roccella peruensis
Roccella phycopsis
Roccella portentosa
Roccella sinensis
Roccella tinctoria
Roccella tuberculata
Roccella vicentina
Solorina crocea
Sphaerophorus globosus
Squamarina lentigera
Staurothele drummondii
Stereocaulon paschale
Stereocaulon tomentosum
Teloschistes spp.

Appendix IX cont'ed. Index of lichens by type of use.

Dye continued

Teloschistes flavicans
Teloschistes vermicularis [??]
Tuckermannopsis ciliaris
Tuckermannopsis orbata
Umbilicaria spp.
Umbilicaria cylindrica
Umbilicaria deusta
Umbilicaria phaea
Umbilicaria vellea
Umbilicaria virginis
Usnea spp.
Usnea barbata
Usnea ceratina
Usnea filipendula
Usnea florida
Usnea glabrata
Usnea longissima
Usnea plicata
Usnea scabrata
Usnea subfloridana
Usnea subfusca
Usnea variolosa
Variolaria orcina [i. c.]
Verrucaria inficiens
Vulpicida canadensis
Vulpicida pinastri
Xanthoparmelia chlorochroa
Xanthoparmelia conspersa
Xanthoparmelia lineola
Xanthoparmelia mexicana
Xanthoparmelia molliuscula
Xanthoparmelia sp.
Xanthoria sp.
Xanthoria candelaria
Xanthoria elegans
Xanthoria parietina
Xanthoria polycarpa
 Unidentified, black & yellow
 Unidentified, misc. lichen
 Unidentified, tree hair

Fibre

Alectoria sarmentosa
Alectoria spp.
Dermatocarpon mouslinsii
Letharia vulpina
Lobaria spp.
Parmelia saxatilis
Peltigera spp.
Peltigera aphthosa
Ramalina menziesii
Stereocaulon paschale
Usnea spp.
Usnea barbata
Usnea californica
Usnea cavernosa
Usnea longissima
 Unidentified, on trees

Fodder

Alectoria nigricans
Alectoria ochroleuca
Aspicilia esculenta
Bryocaulon divergens
Bryoria nitidula
Cetraria islandica
Cladina spp.
Cladina arbuscula
Cladina rangiferina
Cladina stellaris
Roccella montagnei
Sphaerothallia affinis

Food

Alectoria ochroleuca
Alectoria spp.
Aspicilia esculenta
Bulbothrix meizospora
Bryoria fremontii
Bryoria spp.
Canoparmelia texana
Cetraria sp.
Cetraria ericetorum

Appendix IX cont'ed. Index of lichens by type of use.

Food continued

Cetraria islandica
Cetrelia collata
Cladina arbuscula
Cladina mitis
Cladina rangiferina
Cladina spp.
Cladina stellaris
Cladonia deformis
Dermatocarpon reticulatum
Evernia prunastri
Everniastrum spp.
Everniastrum cirrhatum
Everniastrum nepalense
Flavocetraria cucullata
Flavocetraria nivalis
Flavopunctelia flaventior
Heterodermia diademata
Heterodermia leucomela
Heterodermia tremulans
Hypogymnia physodes
Hypotrachyna sp.
Leptogium sp.
Letharia vulpina
Lobaria amplissima
Lobaria isidiophora
Lobaria kurokawae
Lobaria orientalis
Lobaria pulmonaria
Lobaria quercizans
Lobaria retigera
Lobaria scrobiculata
Lobaria yoshimurae
Melanelia infumata
Myelochroa aurulenta
Nephroma arcticum
Nephromopsis pallescens
Parmelaria subthomsonii
Parmelia spp.
Parmelinella wallichiana
Parmotrema abessinicum
Parmotrema austrosinensis

Food continued

Parmotrema chinense
Parmotrema hababianum
Parmotrema nilgherrense
Parmotrema perforatum
Parmotrema praesorediosum
P. pseudonilgherrense
Parmotrema sancti-angelii
Parmotrema subtinctorium
Parmotrema tinctorum
Peltigera spp.
Peltigera aphthosa
Peltigera canina
Peltigera polydactylon
Pseudevernia furfuracea
Ramalina spp.
Ramalina calcaris
Ramalina conduplicans
Ramalina farinacea
Ramalina fraxinea
Ramalina sinensis
Ramalina subcomplanata
Ramalina subfarinacea
Rimelia reticulata
Sphaerothallia affinis
Stereocaulon paschale
Sulcaria sulcata
Umbilicaria spp.
Umbilicaria cylindrica
Umbilicaria esculenta
Umbilicaria muehlenbergii
Umbilicaria proboscidea
Usnea spp.
Usnea diffracta
Usnea longissima
Usnea thomsonii
Usnea trichodeoides
 Unidentified, foliose tree lichen
 Unidentified, misc. lichen
 Unidentified, on rocks
 Unidentified, on rock & trees
 Unidentified, on white pine

Appendix IX cont'ed. Index of lichens by type of use.

Forage

Alectoria spp.
Bryoria spp.
Cetraria ericetorum
Cetraria islandica
Cetrariella delisei
Cladina spp.
Cladina arbuscula
Cladina rangiferina
Cladina stellaris
Flavocetraria cucullata
Nephroma arcticum
Parmelia spp.
Stereocaulon spp.
Stereocaulon himalayense
Thamnolia vermicularis
Umbilicaria spp.
Usnea spp.
Usnea austroindica
Usnea longissima
Usnea orientalis

Fuel

Cladina rangiferina
Masonhalea richardsonii
Usnea spp.
 Unidentified, grey-green

Hunting/Fishing

Letharia vulpina
Xanthoria spp.

Industrial

Pertusaria spp.
 Unidentified, misc. lichens

Insect repellent

Parmotrema andinum
Thamnolia vermicularis

Magic

Dictyonema sericeum
Niebla flaccescens
Parmelia omphalodes
Parmelia saxatilis
Peltigera canina
Peltigera membranacea
Ramalina menziesii
Xanthoparmelia conspersa

Medicine

Alectoria ochroleuca
Alectoria sarmentosa
Alectoria spp.
Anaptychia spp.
Aspicilia esculenta
Bryoria fremontii
Bryoria trichodes
Cetraria islandica
Cladina spp.
Cladina rangiferina
Cladina stellaris
Cladonia spp.
Cladonia anaemica
Cladonia chloropheae
Cladonia coccifera
Cladonia pyxidata
Dictyonema sericeum
Evernia prunastri
Everniastrum cirrhatum
Everniastrum nepalense
Flavocetraria nivalis
Flavoparmelia caperata
Heterodermia diademata
Hypogymnia physodes
Lecanora muralis
Leptogium spp.
Letharia vulpina
Letharia vulpina
Lethariella cashmeriana
Lethariella sernanderi
Lethariella sinensis

Appendix IX cont'ed. Index of lichens by type of use.

Medicine continued

Lobaria spp.
Lobaria amplissima
Lobaria oregana
Lobaria pulmonaria
Lobaria quercizans
Lobaria virens
Nephroma arcticum
Niebla bourgeana
Niebla flaccescens
Parmelia spp.
Parmelia aquila
Parmelia hyporysalea
Parmelia saxatilis
Parmotrema abessinicum
Parmotrema chinense
Parmotrema perforatum
Parmotrema reticulatum
Parmotrema sancti-angelii
Parmotrema zollingeri
Peltigera spp.
Peltigera aphthosa
Peltigera britannica
Peltigera canina
Peltigera membranacea
Peltigera polydactylon
Pertusaria albescens
Pertusaria amara
Pertusaria pertusa
Physcia spp.
Pseudevernia furfuracea
Ramalina spp.
Roccella spp.
Roccella fuciformis
Roccella tinctoria
Stereocaulon himalayense
Sticta spp.
Thamnolia subuliformis
Thamnolia vermicularis
Umbilicaria esculenta
Umbilicaria mammulata
Umbilicaria spp.

Medicine continued

Usnea barbata
Usnea spp.
Usnea africana
Usnea articulata
Usnea campestris
Usnea dasypoga
Usnea densirostra
Usnea diffracta
Usnea filipendula
Usnea flavescens
Usnea florida
Usnea hirta
Usnea longissima
Usnea plicata
Usnea sikkimensis [??]
Usnea trichodea
Xanthomaculina hottentotta
Xanthoparmelia conspersa
Xanthoria parietina
 Unidentified, black foliose rock
 Unidentified, "moss"
 Unidentified, misc. lichen
 Unidentified, north side trees
 Unidentified, on rocks
 Unidentified, orange & yellow
 Unidentified, pyrenocarpous
 Unidentified, yellow on rocks

Mummies

Pseudevernia furfuracea

Narcotic

Dictyonema sericeum
Xanthoparmelia conspersa

Navigation

Caloplaca spp.
Xanthoria spp.

Appendix IX cont'ed. Index of lichens by type of use.

Perfume

Anaptychia ciliaris
Bryoria spp.
Cladina arbuscula
Cladina rangiferina
Cladina stellaris
Evernia mesomorpha
Evernia prunastri
Everniastrum spp.
Everniastrum cirrhatum
Heterodermia spp.
Lobaria pulmonaria
Parmotrema andinum
Parmotrema nilgherrense
Pseudevernia furfuracea
Ramalina spp.
Ramalina fraxinea
Usnea spp.
Usnea longissima

Prospecting

Lecanora cascadiensis
Usnea aurantiaco-atra

Poison

Dictyonema sericeum
Letharia vulpina
Teloschistes flavicans
Usnea spp.
Vulpicida canadensis
Vulpicida pinastri

Ritual

Cetrelia collata
Dictyonema sericeum
Everniastrum cirrhatum
Melanelia infumata
Niebla flaccescens
Parmotrema nilgherrense
Ramalina conduplicans
Ramalina sinensis
Thamnolia vermicularis
 Unidentified, grey-green
 Unidentified, *Parmelia*-like

Tanning

Cetraria islandica
Lobaria pulmonaria
Usnea spp.
Usnea cavernosa
 Unidentified

Tobacco

Parmelia saxatilis
Parmotrema andinum
Ramalina siliquosa
Usnea himalayana
 Unidentified, north side trees

Appendix X. Summary of human uses of lichens across the world.

Lichen	Summary of uses	Reference
<i>Acarospora smaragdula</i> (Wahlenb.) Massal	<u>Dye</u> : Tawny-olive dye with boiling water and ammonia fermentation (Arizona)	1
<i>Alectoria</i> spp. Ach.	Called lappo (Saami); p'elems (Kwakwaka'wakw); laxpt or mak+'hl (Cayuse & Umatilla Sahaptin); dehtsighu ["branch hair"] or ch'vala andaz'i ["spruce hair"] (Dena'ina). <u>Food</u> : Emergency food, boiled, and mixed with fish, berries, or grease (Inland Dena'ina). <u>Medicine</u> : Perhaps boiled, applied as a compress for open sores, arthritis, and eye problems (more likely <i>Usnea</i> spp.) (Cayuse & Umatilla). <u>Forage</u> : Liked by reindeer but not large part of diet (Saami). <u>Fibre</u> : Used for lining steaming pits and wiping off salmon (Kwakwaka'wakw)	2-6
<i>Alectoria nigricans</i> (Ach.) Nyl.	Called tingaujaq (Inuit) <u>Fodder</u> : Known as favorite food of caribou, used by children to lure fawns close to touch them (Inuit).	7
<i>Alectoria ochroleuca</i> (Hoffm.) A. Massal.	Called nakuraartum nuyii or napam ungagua'i (Chugach); tingaujaq (Inuit). <u>Medicine</u> : Piled on sick person in steam bath to hold heat, also used to staunch blood from wounds (Chugach). <u>Fodder</u> : Known as favorite food of caribou, used by children to lure fawns close to touch them (Inuit). <u>Food</u> : Analyzed for making molasses, best of any lichen (Kola Penn. Russia)	7-9
<i>Alectoria sarmentosa</i> Ach.	Called tpkaka7 tl'e wila ['white wila'] (Secwepemc); suts'wakt or ipts-aak ['limb moss'] (Nuxalk); p'u7up (Ditidaht). <u>Decoration</u> : Artificial hair for masks (Secwepemc, Nuxalk) <u>Medicine</u> : If growing on alder used to poultice sores and boils (Nuxalk). Wound dressing (Ditidaht). Straining hot pitch for medicine (Haida) <u>Fibre</u> : Baby diapers, sanitary napkins, wiping salmon, lining cooking pits, making fires smoke (Ditidaht, Sechelt). Interwoven with silverberry bark fibres and made into ponchos and footwear (St'at'imc, Oregon) <u>Dye</u> : Very dark brown dye with ammonia fermentation (BC)	10-15
<i>Anaptychia</i> spp. Körber	<u>Medicine</u> : Occasional adulterant in chharila (see: <i>Parmotrema chinense</i>)	16
<i>Anaptychia ciliaris</i> (L.) Körber	<u>Perfume</u> : In Russia. <u>Cosmetics</u> : Hair powder (NW Himalaya)	17-19
<i>Arctoparmelia centrifuga</i> (L) Hale	<u>Dye</u> : Red-brown dye for wool (Great Britain)	20
<i>Aspicilia calcarea</i> (L.) Mudd	<u>Dye</u> : Red-brown dye for wool (Sweden). Used to make purple Cudbear dye, an orchil substitute from Britain.	20, 21
<i>Aspicilia cinerea</i> (L.) Körb.	<u>Dye</u> : Red crimson dye for wool (England).	20
<i>Aspicilia esculenta</i> (Pall.) Flagey	Called 'wonder grain' (eastern Turkey); 'bread from heaven' (Kurds); torba ['dirt'] (Libya); trub ['dirt'] (Bedouin). <u>Food</u> : Famine food in Libya, Algeria, Turkey, Armenia, and ancient Persia. Ground and mixed with grain meal. May be "Manna from Heaven" mentioned in bible. Still sold in bazaars in Tehran, ground, mixed with flower, and made into bread called shirsad (Persian). <u>Alcohol</u> : Ingredient in mead (Cyrenaica), wine (Arabic) <u>Medicine</u> : 9 th to 13 th century (Arabic). Stimulate mother's milk (Iran). <u>Fodder</u> : Horse, sheep (Libya, Bedouin)	22-25, 5, 20, 26-28

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Bacidia</i> spp. De Not.	<u>Dye</u> : Red dye for wool (England).	20
<i>Bryocaulon divergens</i> (Ach.) Kärnefelt	Called <i>tingaujaq</i> (Inuit). <u>Fodder</u> : Known as favorite food of caribou, used by children to lure fawns close to touch them (Inuit).	7
<i>Bryoria</i> spp. Brodo & D. Hawksw.	Called <i>dehtsighu</i> ["branch hair"] or <i>ch'vala andaz'i</i> ["spruce hair"] (Dena'ina); <i>lappo</i> (Saami) <u>Dye</u> : Yellow dye (Coast Salish); pale green to brown-red colour dye for wool (England). <u>Food</u> : Emergency food, boiled, and mixed with fish, berries, or grease (Dena'ina). Perhaps used as food (Coast Salish). Recommended as food for poor people (Sweden). <u>Forage</u> : Liked by reindeer but not large part of diet (Saami). <u>Perfumery</u> : Unspecified use. <u>Alcohol</u> : Used to produce alcohol by Stenberg, like <i>Cladina rangiferina</i> .	3, 5, 20, 29- 33
<i>Bryoria capillaris</i> (Ach.) Brodo & D. Hawksw.	<u>Dye</u> : Burned into black powder for paint for wood (Haisla, Hanaksiala). Yellow-brown to orange dye with boiling water, brown with ammonia fermentation (BC).	15, 34
<i>Bryoria fremontii</i> (Tuck.) Brodo & D. Hawksw.	<u>Food</u> : Both regular food (generally pitcooked with root vegetables) and famine food for indigenous groups in BC, WA, ID, MT, OR, and CA. See review of <i>B. fremontii</i> ethnolichenology. <u>Medicine</u> : Dried and pounded, then either used dry or boiled for poultice to reduce swellings (Atsugewi). Treat digestive ailments (Nimi'ipuu). Lichen syrup mixed with saskatoon juice and fed to babies after weaned, salve to protect navels of newborns (Okanagan). <u>Dye</u> : Grey-green to grey dye with boiling water, brown with ammonia fermentation (BC)	4, 10, 15, 20, 23, 26, 28, 35- 76
<i>Bryoria fuscescens</i> (Gyelnik) Brodo & D. Hawksw.	<u>Dye</u> : Yellow-brown to brown dye with boiling water, brown with ammonia fermentation (BC).	15
<i>Bryoria glabra</i> (Mot.) Brodo & D. Hawksw.	<u>Dye</u> : Burned into black powder for paint for wood (Haisla, Hanaksiala)	34, 77
<i>Bryoria implexa</i> (Hoffm.) Brodo & D. Hawksw.	<u>Dye</u> : Brown dye with boiling water (BC).	15
<i>Bryoria nitidula</i> (Th. Fr.) Brodo & D. Hawksw.	Called <i>tingaujaq</i> (Inuit). <u>Fodder</u> : Known as favorite food of caribou, used by children to lure fawns close to touch them (Inuit).	7
<i>Bryoria pseudofuscescens</i> (Gyelnik) Brodo & D. Hawksw.	<u>Dye</u> : Yellow-brown dye with boiling water, brown with ammonia fermentation (BC).	15
<i>Bryoria trichodes</i> (Michaux) Brodo & D. Hawksw.	Called <i>nakuraartum nuyii</i> , <i>napam ungagua'i</i> (Chugach). <u>Dye</u> : Burned into black powder for paint for wood (Haisla, Hanaksiala). Yellow-brown dye with boiling water, pink-brown with ammonia fermentation (BC). <u>Medicine</u> : Piled on sick person in steam bath to hold heat, also used to staunch blood from wounds (Chugach).	9, 15, 34
<i>Buellia subsororioides</i> S.R. Singh & Awasthi	Called <i>maidu</i> (Garhwal: India). <u>Dye</u> : Spit on lichen, work into paste, used like henna to make orange designs on lips and palms (Garhwal).	26, 78- 80

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Bulbothrix meizospora</i> (Nyl.) Hale	<u>Food</u> : Sold as spice (Uttaranchal, Uttar Pradesh: India).	80
<i>Caloplaca</i> spp. Th. Fr.	<u>Navigation</u> : Bright yellow-orange blotches on cliff faces indicate open water in summer, result of bird activity (northeast Greenland).	81
<i>Caloplaca saxicola</i> (Hoffm.) Nordin	<u>Dye</u> : Yellow dye for wool (Sweden).	20
<i>Caloplaca trachyphylla</i> (Tuck.) Zahlbr.	<u>Dye</u> : Chamois dye with boiling water, red-purple with ammonia fermentation (Arizona, Utah).	1
<i>Candelariella rosulans</i> (Müll. Arg.) Zahlbr.	<u>Dye</u> : Yellow dye with boiling water and ammonia fermentation (Arizona).	1
<i>Candelariella vitellina</i> (Hoffm.) Müll. Arg.	<u>Dye</u> : Yellow dye with boiling water and ammonia fermentation (Utah). Yellow dye for wool (Sweden).	1, 20
<i>Canoparmelia texana</i> (Tuck.) Elix	<u>Food</u> : Sold as spice (Uttaranchal, Uttar Pradesh: India).	80
<i>Cetraria</i> spp. Ach.	Called <i>k'áma páka</i> ['dry needles mold'] (Secwepemc). <u>Food</u> : Sold as spice (Karnataka, Tamil Nadu: India).	10, 80
<i>Cetraria aculeata</i> (Schreber) Fr. Syn.	<u>Dye</u> : Red-brown dye for wool (Scotland, Canary Islands).	20
<i>Cetraria ericetorum</i> Opiz subsp. <i>ericetorum</i>	Called <i>aouq</i> (Yup'ik); <i>jaegel</i> (Saami). <u>Food</u> : Chopped, added to soups for flavour (Yup'ik, Iñupiaq). <u>Forage</u> : Preferred forage of reindeer (Saami).	4, 5, 7, 82
<i>Cetraria islandica</i> (L.) Ach.	Called <i>jaegel</i> (Saami); <i>islandslav</i> ; <i>brødmose</i> or <i>broedmåsa</i> ['bread moss'], <i>matmåsa</i> ['food moss'], or <i>svinmåsa</i> ['swine moss'] (Norway). <u>Food</u> : Boiled in lye, soda, or ash, rinsed with water, dried, then ground into flour. Used to make bread (baked with 25% rye flour, or potatoes), pancakes, thicken soup (boiled with grain and elm cortex), porridge or gruel (boiled in water, add milk), salad (with oil, egg yolk, and sugar), blood pudding, and dessert jelly (with white wine, lemon juice, sugar, chocolate, and/or almonds). Also cooked as vegetable with butter and salt (Iceland). Preserves bread and prevents weevil attack. Tastes like wheat bran with hot flavour. More commonly used in famines, but also as regular food in past, currently health food ingredient, soup thickener (northern Europe, mostly Iceland and Norway). Made into bread, porridge, blood-sausage, and blood-pancakes (Saami). Boiled with fish roe and fat for soup (Nivkhi: Russian Far East). Used for molasses (Kola; Russia). <u>Medicine</u> : Common throughout Europe and Greenland, mostly pulmonary and digestive. Used for salves, to reduce bitterness of some drugs, and as mild mucilaginous tonic. Used as nerve excitant, laxative, and to treat phthisis, chronic catarrh, dyspepsia, and chronic dysentery. In throat lozenges (Swiss), toothpaste. Treat catarrh, asthma, inflammation (Spain). Used since 16 th century in Sweden, decoction for appetite stimulant, diet food, coughs, colds, asthma, inflammation, catarrh, diabetes, nephritis, tuberculosis, cancer. Decoction for coughs (Kets: Siberia). <u>Fodder</u> : Fed to pigs, cattle, reindeer, makes cow's milk better. <u>Forage</u> : Preferred forage of reindeer. Usually about 700kg/km ² (Saami). <u>Tanning</u> : Useful because of astringent property of depsides. <u>Alcohol</u> : Used to produce alcohol by Stenberg, like <i>Cladina rangiferina</i> . <u>Dye</u> : Brown dye for wool (Iceland).	5, 8, 20, 24, 26- 28, 30, 32, 33, 62, 83- 101

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Cetrariella delisei</i> (Bory) Kärnefelt	Called <i>jaegel</i> (Saami) <i>Forage</i> : Preferred forage of reindeer (Saami)	5
<i>Cetrelia collata</i> (Nyl.) W.L. Culb. & C.F. Culb.	Called <i>budu</i> (Gaddi: India). <i>Ritual</i> : Incense for sacrificial fire in Havan ritual (also <i>Everniastrum cirrhatum</i> , <i>Melanelia infumata</i> , and <i>Parmotrema nilgherrense</i>) (Gaddi). <i>Food</i> : Sold as spice (Himachal Pradesh).	26, 80, 102
<i>Chrysothrix chlorina</i> (Ach.) J. R. Laundon	<i>Dye</i> : Brown dye for wool (Scandinavia).	20
<i>Cladia aggregata</i> (Sw.) Nyl.	<i>Decoration</i> : Sold as <i>silver moss</i> in Copenhagen, imported from Brazil.	103
<i>Cladina</i> spp. Nyl.	Called <i>tuntutnu'kaik</i> ['reindeer food'] (Yup'ik); <i>k'udyi</i> (Den'ina); <i>nexa'yasuk</i> or <i>nunaxu'tuk</i> (Labrador Inuit); <i>jaegel</i> (Saami); <i>mo'niol</i> (Yukagirs: Siberia). <i>Food</i> : Famine food (Scandinavia, Labrador Inuit, perhaps Ojibwa). Parboiled in soda water, dried, powdered; soaked in water for pudding, soup; mixed with wheat flour for bread (Scandinavia). Used for blood puddings (Sweden). Left in ash lye for days, mixed with flour into dough, placed on embers, baked, broken open, filled with reindeer fat, and put back on the embers until fat is cooked (Saami). Dry lichen smashed, boiled until soft, mixed with berries, fish eggs, or grease, eaten, sometimes boiled with caribou blood, especially important in famine or for dog food, if not cooked well causes upset stomach (Inland Dena'ina). Eaten as "stomach icecream" (Deg Hit'an, Inland Dena'ina, Inuit, Denesuline: N. A.; Nganasans, Yukagirs, Chukchi, Koryaks, Dolgans, Evenks, Oroks: Siberia). Lichens found in caribou stomachs, sometimes left in stomach to ferment for a while, sometimes liver added, then put in dish, mixed with raw mashed fish eggs, melted fat, or bone marrow, and thoroughly stirred, or put in soup (N. A.). Tastes strong but is a favorite dish, still occasionally eaten. Dried over a fire to store (Chukchi and Yukagirs). Hot soup of stomach contents for breakfast, mixed with blood for soup for children (Chukchi). Mixed with blood and pieces of the stomach and eaten as a tasty gruel (Yukagirs). Considered more tasty in winter than summer (Nganasans). <i>Medicine</i> : Taken as tea for chest pain, also eaten by hunters who are climbing hills to maintain their wind (Aluet). Medicinal decoction (Saami). Remedy for scurvy (Nganasans). Decoction for diarrhoea (Dena'ina). <i>Forage</i> : Used for grazing domestic reindeer, must keep them moving during winter to prevent overgrazing, recognize changes in lichen species with grazing pressure (Saami, n. Scandinavians). Government attempted to have Indigenous Alaskans herding reindeer, lichen was overgrazed. <i>Fodder</i> : Used for dog food (Dena'ina). Harvested when wet in broad strips to increase production take 25%, leave for 30 years (Saami, n. Scandinavians). Gather 50-100kg per day by hand or 300-400kg with implements. If fed to cattle soaked for 24 h (perhaps adding potassium carbonate) to remove bitterness. Mixed with hot water and straw before fed.	3, 5, 27, 32, 33, 81, 82, 86, 88, 93, 94, 99, 104- 107
<i>Cladina arbuscula</i> (Wallr.) Hale & Culb.	Called <i>jaegel</i> (Saami). <i>Food</i> : Occasionally used as famine food (Scandinavia). <i>Fodder</i> : Scandinavia. <i>Forage</i> : Preferred forage of reindeer (Saami). <i>Perfume</i> : Essential oils.	5, 20, 87, 88
<i>Cladina mitis</i> (Sandst.) Hustich	<i>Food</i> : Analyzed for making molasses (Kola: Russia).	8

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Cladina rangiferina</i> (L.) Nyl.	Called <i>asa' gûniñk'</i> (Ojibwa); <i>jaegel</i> (Saami); <i>tuntutnuukaik</i> ['reindeer food'] (Yup'ik); <i>niqagasak</i> (Ungava-Labrador Inuit). <u>Food</u> : Famine food (Ojibwa, Labrador Inuit, Scandanavia). Powdered with flour for bread, boiled for soup (Europe). <u>Medicine</u> : Boiled and water used to wash newborn baby (Ojibwa). Boiled and eaten for diarrhea (Inland Dena'ina). <u>Fodder</u> : Fed to livestock (Scandanavia), when fed to cattle they have better milk and meat. Cooked and fed to dogs (Inland Dena'ina). <u>Forage</u> : Preferred forage of reindeer (Saami). <u>Alcohol</u> : Booming industry in 1883, crashed in 1884 when lichen was used up (Sweden). Process adopted in Russia. Carbohydrate extracted with 3 changes of boiling water, then boiled 9 hours with sulfuric acid to produce glucose, 70% yield. More cost effective method to pack lichen into vessel with small amount of sulfuric or hydrochloric acid, then inject with steam for several hours. Forms glucose rich slurry, saturated with chalk, fermented, then distilled. 250g lichen produces 75g pure alcohol. <u>Dye</u> : Yellow-tan dye with boiling water, yellow-brown with ammonia fermentation (BC). Iron-red dye for wool (Europe). <u>Fuel</u> : Burned with intense, short-lived flame (Belcher Is. Inuit). <u>Perfume</u> : Essential oil.	4, 5, 7, 15, 20, 24, 30, 62, 83, 86- 88, 92, 93, 98- 100, 108- 116
<i>Cladina stellaris</i> (Opiz) Brodo	Called <i>jaegel</i> (Saami) <u>Food</u> : Famine food (Sweden, Finland). Analyzed for making molasses (Kola: Russia). <u>Medicine</u> : For intestinal worms (Nitihawak). Source of usnic acid (Europe). <u>Forage</u> : Preferred forage of reindeer, deceiver under grazing pressure, usually about 1500kg/1000m ² (Saami). <u>Fodder</u> : Sweden, Finland. <u>Decoration</u> : For wreaths, floral decorations, and architect's models. Between 1970 and 1975 about 17,900 tonnes were exported from Scandanavia. To maintain high production, 20% of the lichen should be removed every 5-6 years. <u>Dye</u> : Iron-red dye for wool (Europe). <u>Perfume</u> : Essential oil. <u>Alcohol</u> : Like <i>C. rangiferina</i> .	5, 8, 20, 87, 88, 117, 118
<i>Cladonia</i> spp. P. Browne	Called <i>kwesáy</i> (Secwepemc). <u>Medicine</u> : Used according to Doctrine of Signatures in 1400s Europe, obsolete by 1800. Used for inveterate coughs in children (Europe).	5, 10, 119
<i>Cladonia anaemica</i> (Nyl.) Ahti	<u>Medicine</u> : Rubbed down with sugar and water and used as a remedy for mouth ulcers.	92
<i>Cladonia chlorophaea</i> (Flörke) Sprengel	Called <i>pen'pen'emekx'sxn'</i> ['liver on rocks'] (Okanagan-Colville). <u>Medicine</u> : Decoction to wash hard to heal sores (Okanagan-Colville).	64
<i>Cladonia coccifera</i> (L.) Willd.	<u>Dye</u> : Soaked in urine to make a red orchil dye for wool (Scotland). <u>Medicine</u> : Astringent and febrifugal	20, 92, 120, 121
<i>Cladonia deformis</i> (L.) Hoffm.	<u>Food</u> : Analyzed for making molasses (Kola: Russia)	8
<i>Cladonia fimbriata</i> (L.) Fr.	<u>Dye</u> : Red dye for wool.	20
<i>Cladonia furfuracea</i> Vain.	<u>Decoration</u> : Sold as <i>silver moss</i> in Copenhagen, imported from Brazil.	103

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Lichen	Summary of uses	Reference
<i>Cladonia gracilis</i> (L.) Willd.	<u>Dye</u> : Ash-green dye for wool	20
<i>Cladonia miniata</i> G. Mey	Called <i>canduá</i> (Brazil). <u>Dye</u> : Tinting baskets and mats (Brazil).	122
<i>Cladonia pyxidata</i> (L.) Hoffm.	<u>Decoration</u> : Sold as <i>silver moss</i> in Copenhagen, imported from Brazil. <u>Medicine</u> : 1 teacup for whooping cough (Scotland). Astringent and febrifugal. Unspecified medicine (Europe). <u>Dye</u> : Perhaps a Cudbear lichen, used to make red-purple orchil dye (Scotland,Britain). Ash-green dye for wool (Europe).	20, 21, 28, 92, 103, 121, 123- 125
<i>Dactylina arctica</i> (Richardson) Nyl.	Called <i>nagijuujaq</i> (Barrens-Keewatin Inuit).	7
<i>Dermatocarpon miniatum</i> (L.) Man.	<u>Dye</u> : Tawny-olive dye with boiling water and ammonia fermentation (AZ). Ash-green dye for wool (Europe).	1, 20
<i>Dermatocarpon mouslinsii</i> (Mont.) Zahlbr.	<u>Fibre</u> : Substitute for cork in lining entomological collecting boxes (India).	19
<i>Dermatocarpon reticulatum</i> H. Magn.	<u>Food</u> : Eaten (Japan). <u>Dye</u> : Buff boiling water dye, tawny-olive ammonia fermentation dye (UT).	1, 124, 126
<i>Dictyonema sericeum</i> (Sw.) Berk.	Called <i>ne/ne/ndapel</i> (Waorani: Ecuador), <i>kett-goke</i> (Japan). <u>Magic, Hallucinogen</u> : Infusion made with other bryophytes that causes hallucinations, used by shaman to call on malevolent spirits. Causes sterility.	26, 127- 129
<i>Diploschistes scruposa</i> (Schreber) Norman	Called <i>la rise blanche</i> or <i>la grise noire</i> , depending on lichen age (France). <u>Dye</u> : Ingredient in purple pallelle dye, orchil dye from France. Red brown dye for wool (England). Brown dye for calico printing (Sri Lanka).	19- 21
<i>Evernia mesomorpha</i> Nyl.	<u>Perfume</u> : Europe, Russia.	17, 20
<i>Evernia prunastri</i> (L.) Ach.	Called <i>mousse chène, eichenmoss, oakmoss</i> . <u>Perfume</u> : Fixative, essential oil for particular perfumes, used 12 th century to present (Europe, Russia). Gathered in large quantities (Italy, Dalmatia, Morocco, Yugoslavia). Used with <i>Pseudevernia furfuracea</i> , 10,000 tons processed annually. Gathered from forests, takes 3 years to replentish. Better quality if picked in summer, or in Yugoslavia or Bosnia. Collected with lichen scraper on long pole with canvas bag attached. <u>Cosmetics</u> : Used in sweet pots and ladies' sachets to imbibe and retain odours. Used as Cyprus powder for hair and wigs in Europe (1600s), compressed with alternating layers of rose and jasmine, flowers renewed daily until lichen impregnated, then crushed. Impalpable powder or resin for soap (Europe). <u>Medicine</u> : For pulmonary affections, astringent, febrifuge, tonic for intestinal weakness (Europe). Ingredient in Lichen Quercinus Virides, a drug used in 15 th century Europe, obsolete by 1800. <u>Dye</u> : Golden-brown dye with boiling water, orange-brown with ammonia fermentation (BC). Red-purple orchil dye for wool (historical Sotland, Europe). Yellow, pink-purple, coffee-coloured, yellowish fawn dye, depending on mordant (contemporary Scotland). <u>Food</u> : Used for jelly (Turks). Leavening agent for bread (ancient Egypt, Arabs, Copts). <u>Alcohol</u> : Imported from Europe as fermentative agent (Egypt).	5, 15, 17, 20, 21, 23, 27, 28, 83, 89, 92, 93, 120, 123, 125, 130- 136

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Everniastrum</i> spp. Hale ex Sipman	Called <i>dagaful</i> ['stone flowers'] (Poona, Aurangabad: India). <u>Food</u> : Main ingredient of <i>Kabul garam masala</i> , spice mixture added at the end of cooking (Poona, Aurangabad). Bulking agent for curry with mild preservative (India). Exported (Saudi Arabia, London). <u>Perfume</u> : Grade II (of IV) perfume lichen harvested in India and exported.	28, 137- 139
<i>Everniastrum cirrhatum</i> (Fr.) Hale ex Sipman	Called <i>chharila</i> (India); <i>budu</i> (Gaddi: India); <i>rukhu-ku-jau</i> (Lepchas, Nepalese: India); <i>jhavila</i> (Baiga, Bhil, Bhilala, Gond, Korka, Muria: India). <u>Medicine</u> : Used in <i>chharila</i> along with <i>Parmotrema chinense</i> and <i>P. perforatum</i> , SEE: <i>P. chinense</i> . Burned, smoke relieves headache, powdered for good cephalic snuff (India). <u>Food</u> : Lichen boiled then fried as vegetable (Lepchas, Nepalese). Used as spice for meat and vegetables (Baiga, Bhil, Bhilala, Gond, Korka, Muria), large quantities sold in Uttaranchal, Uttar Pradesh, Sikkim (India). <u>Ritual</u> : Burned as incense in Havan ritual (also <i>Cetrelia collata</i> , <i>Melanelia infumata</i> , and <i>Parmotrema nilgherrense</i>) (Gaddi). <u>Dye</u> : Infusion used for beige-yellow dye for traditional textiles (Peru). Pale rose dye to print and perfume calico cloth (India).	16, 19, 20, 26, 79, 80, 102, 140, 141
<i>Everniastrum nepalense</i> (Taylor) Hale ex Sipman	Called <i>yangben</i> (Rai, Limbu: Nepal); <i>kalo jhyau</i> (India) <u>Food</u> : Eaten like <i>Ramalina farinacea</i> (Rai, Limbu). Large quantities sold as spice (Uttaranchal, Uttar Pradesh: India). <u>Medicine</u> : Used for toothache, soreness of throat, and pain (India). Endangered medicinal lichen banned from raw export (Nepal). Sometimes also included in <i>chharila</i> (SEE: <i>Parmotrema chinense</i>).	80, 126, 142, 143
<i>Flavocetraria cucullata</i> (Bellardi) Kärnefelt & Thell	Called <i>ninguujq</i> ['would like to be stretched'] (Yup'ik). <u>Food</u> : Used as condiment for fresh fish or duck soup (Yup'ik, Iñupiaq). <u>Forage</u> : Known as caribou food (Yup'ik).	4, 7, 82
<i>Flavocetraria nivalis</i> (L.) Kärnefelt & Thell	Called <i>nagjuujaq</i> (Barrens-Keewatin Inuit). <u>Food</u> : May have been collected with <i>Cetraria islandica</i> as food (Scandinavia). Analyzed for making molasses (Kola: Russia). <u>Dye</u> : Poor for dye (BC). Violet dye for wool (Europe). <u>Medicine</u> : Similar properties as <i>C. islandica</i>	7, 8, 15, 20, 32, 33, 88, 92, 98
<i>Flavoparmelia caperata</i> (L.) Hale	Called <i>reté cajera</i> (Tarahumar: Mexico). <u>Dye</u> : Occasionally used as crottle, a brown orange to lemon yellow boiling water dye for wool (Isle of Man, Manx, Scotland). <u>Medicine</u> : Dried, crushed, dusted on burns (Tarahumar).	20, 120, 144, 145
<i>Flavopunctelia flaventior</i> (Stirton) Hale	<u>Food</u> : Sold as spice (Uttaranchal, Uttar Pradesh: India).	80
<i>Flavopunctelia soledica</i> (Nyl.) Hale	<u>Dye</u> : "Flesh-color" dye (Navajo).	146
<i>Fulgensia bracteata</i> (Hoffm.) Räsänen	<u>Dye</u> : Chamois boiling water dye, vinaceous-buff with ammonia fermentation (UT).	1
<i>Fuscopannaria praetermissa</i> (Nyl.) P. M. Jørg.	<u>Dye</u> : Tawny-olive boiling water dye (UT).	1
<i>Heterodermia</i> spp. Trevis.	<u>Perfume</u> : Grade III and IV (of IV) perfume lichen harvested in India, exported for resinoids.	139

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Lichen	Summary of uses	Reference
<i>Heterodermia diademata</i> (Taylor) D. D. Awasthi	Called <i>dhungo ku seto jhua</i> (Nepali). <u>Medicine</u> : Paste of lichen thalli spread on cuts to protect from water and infection. <u>Food</u> : Large quantities sold as spice (Uttaranchal, Uttar Pradesh, Sikkim: India).	26, 79, 80, 141
<i>Heterodermia leucomela</i> (L.) Poelt	<u>Food</u> : Sold as spice (Uttaranchal, Uttar Pradesh: India).	80
<i>Heterodermia lutescens</i> (Kurok.) Follmann	<u>Decoration</u> : Sold as <i>silver moss</i> in Copenhagen, imported from Brazil.	103
<i>Heterodermia tremulans</i> (Müll. Arg.) W.L. Culb.	Called <i>jhavil</i> (Baiga, Bhil, Bhilala, Gond, Korka, Muria: India). <u>Food</u> : Used as spice for meat, pulse, and vegetables (Baiga, Bhil, Bhilala, Gond, Korka, Muria), sold in Madhya Pradesh (India).	26, 79, 80
<i>Hypogymnia enteromorpha</i> (Ach.) Nyl.	<u>Dye</u> : Bright yellow-brown dye with boiling water, dark brown with orange tint with ammonia fermentation (BC).	15
<i>Hypogymnia heterophylla</i> L. Pike	<u>Dye</u> : Yellow-brown dye with boiling water, pink-brown with ammonia fermentation (BC).	15
<i>Hypogymnia physodes</i> (L.) Nyl.	Called <i>wa'kwûnûk</i> ['egg bush'] (Potawatomi). <u>Food</u> : Soaked or boiled and eaten, has pleasant flavour when boiled in soup, only used if growing on spruce (Potawatomi). Substitute for gum Arabic (NW Himalaya). <u>Medicine</u> : Eaten raw to cure constipation (Potawatomi). Ingredient in Lichen Quercinus Virides, a drug used in 1400s Europe, obsolete by 1800. <u>Dye</u> : Yellow-brown dye with boiling water (BC). Brown dye for wool (Scotland, Scandanavia), and for calico printing (NW Himalaya).	4, 5, 15, 19, 20, 27, 114, 115, 147
<i>Hypotrachyna</i> sp.	<u>Decoration</u> : Sold as <i>silver moss</i> in Copenhagen, imported from Brazil. <u>Food</u> : Sold as spice (Karnataka, Tamil Nadu: India).	80, 103
<i>Hypotrachyna protenta</i> Hale	<u>Decoration</u> : Sold as <i>silver moss</i> in Copenhagen, imported from Brazil.	103
<i>Kaernefeltia californica</i> (Tuck.) Thell & Goward	<u>Dye</u> : Light brown dye with ammonia fermentation (BC).	15
<i>Lasallia</i> spp. Mérat	<u>Dye</u> : Used for orchil dyes (Europe).	89
<i>Lasallia papulosa</i> (Ach.) Llano	<u>Dye</u> : red brown dye (NW Himalaya).	19
<i>Lasallia pustulata</i> (L.) Mérat	<u>Dye</u> : Substitute for Cudbear (Europe). Pulped with water and ammonia, let ferment for 2 to 3 weeks. Red, purple, and brown dye for wool.	20, 21, 120, 125
<i>Lecanora argopholis</i> (Ach.) Ach.	<u>Dye</u> : Yellow dye with boiling water, tawny-olive with ammonia fermentation (AZ, UT).	1
<i>Lecanora cascadiensis</i> Lynge & H. Magn.	<u>Prospecting</u> : Turns green if copper in substrate (CA).	148
<i>Lecanora muralis</i> (Schreb.) Rabenh.	Called <i>wa'-hat-tak</i> (Nishinam). <u>Medicine</u> : Made into tea to treat colic (Nishinam). <u>Dye</u> : Tawny-olive boiling water dye, brown w/ ammonia fermentation (AZ).	1, 149

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Lecidella stigmatea</i> (Ach.) Hertel	<u>Dye</u> : Yellow dye with boiling water, cream coloured with ammonia fermentation (UT)	1
<i>Lepraria iolithus</i>	<u>Dye</u> : Brown dye for wool (Scandinavia).	20
<i>Leptogium</i> spp. (Ach.) Gray	<u>Medicine</u> : Occasional adulterant in <i>chharila</i> (SEE: <i>Parmotrema chinense</i>). <u>Food</u> : Sold as spice (Uttaranchal, Uttar Pradesh: India).	16, 80
<i>Letharia</i> <i>columbiana</i> (Nutt.) J. W. Thomson	<u>Dye</u> : Bright yellow dye with boiling water, slightly browner yellow with ammonia fermentation (BC).	15
<i>Letharia vulpina</i> (L.) Hue	Called <i>manil maashaxaeme</i> ['mountain moss'] (Karuk); <i>ga'da</i> (Modoc); <i>mece'n</i> (Yoruk); <i>wapi-tonega</i> (Paiute); <i>ol-gät'-i</i> (Yuki); <i>tama muklth muklth</i> (Tenino); <i>yugar sanibe</i> (Shoshone, Wasco); <i>luke komo</i> (Wasco); <i>shwa'-wi-säm</i> (Klamath); <i>laxpt</i> or <i>mak+'hl</i> (Cayuse & Umatilla Sahaptin); <i>hehyowo'ists</i> [yellow dye] or <i>he-ho-wa-ins'-tots</i> [yellow root] (Cheyenne); <i>s-c-k~r-n=ecst</i> (Spokane); <i>e-simatch-sis</i> ['yellow dye'] (Niitsitapii); <i>otsahaa</i> (A'aninin); <i>kware'uk</i> or <i>kwernikw</i> (Okanagan); <i>s-c~k~r-n=éc'st</i> or <i>s-k~ali=07=álq~</i> (Spokane); <i>tkwel máka7</i> ['yellow/green (on) wood] or <i>qwesimáleqw</i> (Secwepemc); <i>kolomê'ka</i> or <i>kwalä'uk</i> ['yellow (on) wood'] (Nlaka'pmx); <i>sekhone</i> (Tlingit); <i>ulf-mossa</i> (Sweden); <i>ookami-goke</i> (Japan). <u>Dye</u> : Bright yellow dye boiling water with some green, slightly greener and browner with ammonia fermentation. Used as boiling water dye by Hupa, Modoc, Wintun, Paviotso, Yoruk, Karuk, Atsugewi, Klamath, Tenino, Cheyenne, Niitsitapii, A'aninin, Secwepemc, Okanagan, Skokomish, Coast Salish, Oweekeno, Ktunaxa, and Flathead. Used as ammonia fermentation dye by Tlingit, who traded for it from Nuxalk, who got it from Ulkatcho Dakelh. Also dye in Norway, Sweden. Used as paint (Yuki, Nlaka'pmx). <u>Medicine</u> : Drying up running sores and relieving inflammation (Yuki, Wailaki). Infusion of lichen and bone marrow for stomach disorders like ulcer, blackened in fire and rubbed on rash, eczema, and wart sores, used for headache (Niitsitapii). Weak decoction drank for internal problems, strong decoction to wash external sores and wounds (Okanagan). Boiled, applied as compress for open sores, arthritis, eye problems, and saddle sores on horses (Cayuse & Umatilla). Placed on woman to help during difficult labour (Flathead). <u>Fibre</u> : Making clothing, bedding (Yuki, perhaps MT). <u>Food</u> : Unspecified use (Modoc). <u>Fishing</u> : Tied to fishing platforms for salmon to see (Karuk). <u>Poison</u> : To make poison arrows, the tips were imbedded in masses of the wet lichen and left for up to a year, rattlesnake venom sometimes added (Achomawi). For wolf poison in Sweden, pulverized lichen mixed with fat and flesh and warmed in pan over fire. After add fresh blood and cheese to create odor. Sometimes mix with powdered glass or strychnine. Then put under skin of carcass, wolf will die within 24h of ingestion. Older, drier lichen is more potent.	2, 10, 13, 15, 20, 23, 27, 29, 34- 36, 38- 40, 42, 46, 47, 52, 55, 58, 64, 67, 68, 76, 128, 150- 163
<i>Lethariella</i> <i>cashmeriana</i> Krog	Called <i>luxingcha</i> or <i>hongxuecha</i> (Naxi, nw Yunnan, China). <u>Medicine</u> : Traditional Tibetan medicine for reducing blood pressure, body fat, and inflammation, also drank non-medicinally (Naxi).	164
<i>Lethariella</i> <i>sernanderi</i> (Mot.) Obermayer	Called <i>luxingcha</i> or <i>hongxuecha</i> (Naxi, nw Yunnan, China). <u>Medicine</u> : Traditional Tibetan medicine for reducing blood pressure, body fat, and inflammation, also drank non-medicinally (Naxi).	164
<i>Lethariella sinensis</i> Wei & Jiang	Called <i>luxingcha</i> or <i>hongxuecha</i> (Naxi, nw Yunnan, China). <u>Medicine</u> : Traditional Tibetan medicine for reducing blood pressure, body fat, and inflammation, also drank non-medicinally (Naxi).	164

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Lobaria</i> spp. (Schreber) Hoffm.	Called <i>sts'wakt-aak</i> (Nuxalk); <i>p'elems</i> (Kwakwaka'wakw); <i>didi'dichia</i> ['growing on rocks'] (Makah). <i>Medicine</i> : Used as medicine only from certain trees, drink decoction for stomach pains, also for eyewash and poultice (Nuxalk). Mashed for poultice for running sores (Makah). <i>Fibre</i> : Lining steaming pits and wiping off salmon (Kwakwaka'wakw).	6, 11, 12, 165
<i>Lobaria amplissima</i> (Scop.) Forss.	Called <i>jǐngwakons wakun</i> or <i>jǐngwa'kwak</i> (Ojibwa); <i>wakûn</i> (Menomini) <i>Food</i> : Collected from only old white pine (Ojibwa), or only hard maple and hemlock (Menomini) Dried, stored, boiled until like scrambled eggs, eaten as favorite old food (Menomini, Ojibwa). Cooked and reduced to porridge (Iroquois), cooked in soups (Menomini), fish or meat broth (Ojibwa). <i>Medicine</i> : Tonic effect on the system and the blood (Menomini).	4, 20 109, 114- 116, 166, 167
<i>Lobaria isidiosa</i> (Müll. Arg.) Vain.	<i>Food</i> : <i>qingwapi</i> (Bai: nw Yunnan, China) Famine food in past, now widely available in market for US\$7/kg, boiled for 10–30 minutes, soaked in fresh water 1–2 days, then fried with pork (Bai). <i>Medicine</i> : Used in Chinese traditional medicine.	164, 168
<i>Lobaria kurokawae</i> Yoshim.	Called <i>kabuto-goke-modoki</i> (China); <i>qingwapi</i> (Bai: nw Yunnan, China) <i>Food</i> : Prepared same as <i>L. isidiosa</i> (Bai).	128, 164
<i>Lobaria oregana</i> (Tuck.) Müll. Arg.	Called <i>nagaganaw</i> ['frog's dress'] (Tsimshian), <i>sts'wakt-aak</i> (Nuxalk). <i>Medicine</i> : Maybe same use as <i>Sticta</i> (Nuxalk). Boiled for sore throat medicine (perhaps <i>Peltigera</i>) (Tsimshian).	11, 31
<i>Lobaria orientalis</i> (Asah.) Yoshim.	Called <i>qinwapi</i> or <i>shuhudie</i> (Tibetan: nw Yunnan, China), and <i>laolongpi</i> (Tibetan: south Sichuan, China). <i>Food</i> : Boiled in water for 30 minutes, soaked in fresh water for 1–2 days, then fried or served in cold dish with condiments (Tibetan: NW Yunnan).	164
<i>Lobaria pulmonaria</i> (L.) Hoffm.	Called 'frog-skin lichen' (Quileute); <i>gwilehl ganaa'w</i> ['frog blankets'] (Gitxsan); <i>kwesáy</i> ['mossy plants'] (Secwepemc); <i>sts'wakt-aak</i> (Nuxalk); <i>(tl)'ac(tl)'astuphc'um</i> (Hesquiat); <i>gul-i-sang</i> ['stone flowers'] (Afghanistan); <i>golmataghosa</i> (Bengal); <i>ato</i> (Kapaukoe: New Guinea); <i>muscus pulmonarius</i> (Europe). <i>Medicine</i> : Boiled to make nutrient, demulcent, or tonic for asthma, lung ulcers, spitting blood, hemorrhages, consumption, and other lung diseases (15 th century Europe; modern Spain; Sikkim and Darjeeling: India). Also excitant, astringent, and applied externally to wounds (Europe). Fed to cattle and sheep for epidemic catarrh (Europe). Used for lung diseases and in ointments (Scottish Highlands). Cure for eczema on the head (Sikkim and Darjeeling). Medicine for children with sunburned faces (Hesquiat), maybe same medicinal use as <i>Sticta</i> spp. (Nuxalk). Often used to heal navel of newborn child (Afghanistan). Used as contraceptive: consumed during menstrual period with water or dry as snuff, consumed 24h after giving birth, or consumed by men (Afghanistan). <i>Dye</i> : Produces excellent orange-brown boiling water dye (BC, Quileute, Herfordshire, Scotland, Scandanavia). Yellow ammonia fermentation dye (Scotland, Europe). Yellow dye, unspecified process (Gitxsan). <i>Food</i> : Steep in alkali solution, rinse, boil with sugar, cool to form brown jelly, add flavour and eat (Europe). Byproduct of using lichen for hops was a yellow, nearly insipid mucilage which was eaten with salt (Siberia). Perhaps used as food (Coast Salish). <i>Alcohol</i> : Used as hops for beer (Siberia monks), unspecified brewing (India) <i>Perfume</i> : Essential oil for perfume (Europe, Sikkim, Darjeeling). <i>Cosmetics</i> : Strengthening and cleaning hair (Sikkim, Darjeeling). <i>Tanning</i> : Astringent property of depsides (Europe; Sikkim, Darjeeling).	5, 10, 11, 15, 19- 21, 24, 26- 29, 85, 89, 92, 93, 119, 120, 169- 179

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Lobaria quercizans</i> Michaux	<u>Food</u> : May be lichen eaten by Ojibwa, Menomini, Iroquois (SEE: <i>L. amplissima</i>). <u>Medicine</u> : May be medicinal lichen of Menomini (SEE: <i>L. amplissima</i>).	4, 109, 114, 115, 166
<i>Lobaria retigera</i> (Bory) Trevis.	<u>Medicine</u> : Used in Chinese traditional medicine. <u>Food</u> : Sold as spice (Uttaranchal, Uttar Pradesh: India).	80, 168
<i>Lobaria scrobiculata</i> (Scop.) DC.	Called <i>qelquaq</i> (Yup'ik) <u>Food</u> : Eaten raw right off tree (Yup'ik: Kwethluk) <u>Dye</u> : Brown dye for wool (Scotland, England).	20, 146
<i>Lobaria virens</i> (With.) Laundon	<u>Medicine</u> : Unspecified (Europe).	28
<i>Lobaria yoshimurae</i> Kurok. & Kashiw.	Called <i>qinwapi</i> or <i>shuhudie</i> (Tibetan: nw Yunnan, China), and <i>laolongpi</i> (Tibetan: south Sichuan, China). <u>Food</u> : Boiled in water for 30 minutes, soaked in fresh water for 1–2 days, then fried or served in cold dish with condiments (Tibetan: NW Yunnan).	164
<i>Lobothallia alphoplaca</i> (Wahlenb.) Hafellner	<u>Dye</u> : Isabella colour dye with boiling water, light russet-vinaceous with ammonia fermentation (UT).	1
<i>Masonhalea richardsonii</i> (Hook.) Kärnefelt	<u>Fuel</u> : Tinder for fires (Yup'ik, Iñupiaq).	81
<i>Melanelia commixta</i> (Nyl.) Thell	<u>Dye</u> : Red-brown dye for wool (Europe).	20
<i>Melanelia infumata</i> (Nyl.) Essl.	Called <i>budu</i> (Gaddi: India). <u>Ritual</u> : Incense for sacrificial fire in Havan ritual (Gaddi). <u>Food</u> : Sold as spice (Himachal Pradesh: India).	26, 80, 102
<i>Melanelia stygia</i> (L.) Essl.	<u>Dye</u> : Brown dye for wool (Britain).	20
<i>Melanelia tominii</i> (Oksner) Essl.	<u>Dye</u> : Tawny-olive dye with boiling water, vinaceous brown with ammonia fermentation (AZ).	1
<i>Melanelixia fuliginosa</i> (Fr. ex Duby) O. Blanco	<u>Dye</u> : Contains purple dye.	21
<i>Melanohalea olivacea</i> (L.) O. Blanco <i>et al.</i>	<u>Dye</u> : Brown dye for wool (Britain). Dye for calico printing (NW Himalayas)	19, 20
<i>Melanohalea subolivacea</i> (Nyl.) O. Blanco <i>et al.</i>	<u>Dye</u> : Tawny-olive dye with boiling water and ammonia fermentation (AZ).	1
<i>Myelochroa aurulenta</i> (Tuck.) Elix & Hale	<u>Food</u> : Sold as spice (Uttaranchal, Uttar Pradesh: India).	80
<i>Nephroma arcticum</i> (L.) Torss.	Called <i>kusskoak</i> (Yup'ik). <u>Food</u> : Boiled with crushed fish eggs for food (Yup'ik). <u>Medicine</u> : Infusion fed to person in weak condition to make him strong (Yup'ik). <u>Forage</u> : Reindeer food (Saami).	4, 7, 82, 87
<i>Nephroma helveticum</i> Ach.	<u>Dye</u> : Brown boiling water dye, better with ammonia fermentation (BC).	15

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Nephroma parile</i> (Ach.) Ach.	<u>Dye</u> : Blue dye for wool (Scotland).	20
<i>Nephromopsis pallescens</i> (Schaer.) Park.	<u>Food</u> : Sold as spice (Uttaranchal, Uttar Pradesh, Himachal Pradesh: India).	80
<i>Niebla bourgeana</i> (Mont. ex Nyl.)	Called <i>flor de piedra</i> ['stoneflower'] (Spain).	26,
Rundel & Bowler	<u>Medicine</u> : Cup of decoction taken daily as diuretic for treating renal lithiasis, until patient is better (Viso, Nijar, Almeria: Spain).	180,
<i>Niebla flaccescens</i> (Nyl.) Rundel & Bowler	Called <i>papel-papel</i> (Quechua: Peru).	182
<i>Nodobryoria abbreviata</i> (Müll. Arg.) Common	<u>Medicine</u> : Infusion drank as antitussive (Quechua). <u>Ritual</u> : Thallus chewed with coca leaves for magic rituals (Quechua).	15
<i>Ochrolechia androgyna</i> (Hoffm.) Arnold	<u>Dye</u> : Light brown dye with boiling water, brown with ammonia fermentation (BC).	21,
<i>Ochrolechia frigida</i> (Sw) Lyngé	Called <i>corkir</i> (Scotland).	89
<i>Ochrolechia parella</i> (L.) A. Massal.	<u>Dye</u> : Lacmus, red dye exported from Norway to England, Germany in 14 th century. Used to make Cudbear, orchil dye substitute, in 1700s Scotland.	21
<i>Ochrolechia tartarea</i> (L.) A. Massal.	<u>Dye</u> : Contains purple dye.	21,
<i>Parmelaria subthomsonii</i> D. D. Awasthi	Called <i>la pommelée, perelle</i> (France).	21,
<i>Parmelia</i> sp.	<u>Dye</u> : Violet dye (Orseille d'Auvergne), may be ingredient of pabelle, orchil dye from France. Soaked in urine to make reddish orchil dye for Harris tweed (Scotland). Used for litmus paper.	120,
<i>Parmelia aquila</i> Ach.	Called <i>corcur, corklit, or cudbear</i> (Scotland)	123,
<i>Parmelia hyporyslea</i> Vain.	<u>Dye</u> : Lacmus, red dye exported from Norway to England and Germany in 14 th century. Used to make Cudbear, purple Orchil dye substitute, in 18 th century Scotland. Collected May/June by rural collectors with iron scraping hoop, dried in sun, pulverized, steeped in stale urine and chalk for 3-6 weeks in airtight vessel until forms blue-black mass, made into cakes, and dried in peat smoke, boiled with yarn. In 19 th century urine collectors gathered 3000 gallons daily from Glasgow suburbs. Also used for litmus paper.	125
	<u>Food</u> : Sold as spice (Uttaranchal, Uttar Pradesh: India).	19-
	Called <i>odoche jupacua</i> ['iguana toe'] (Piaroa: Amazon); <i>kwesáy</i> (Secwepemc); <i>gadna</i> (Saami); <i>klipbolm</i> ['rock flower'] (Afrikaans).	21,
	<u>Medicine</u> : Tea drank 3-4 times daily for a week for gonorrhoea (Piaroa). Boiled and thallus applied to insect bites, cuts, or wounds (Guahibo: Amazon). Treatment for amenorrhoea (India). Infusion to treat cough, sore throat, fertility, oral thrush in infants, abdominal pain, backache, and kidney and bladder diseases (Khoi: Africa). Crottle lichens sprinkled on feet before journey stop inflammation (Scotland).	89,
	<u>Forage</u> : Eaten by reindeer when nothing else available (Saami).	120,
	<u>Dye</u> : Produces range of dyes, including shades of orange, rust, or brown, used for wool, no mordant required (Africa). Used for brown crottle dyes for Harris tweed (Scotland).	179,
	<u>Food</u> : Curry powder (India).	186-
	<u>Medicine</u> : Astringent for asthma and old coughs	185
	<u>Medicine</u> : Occasional adulterant in <i>chharila</i> (SEE: <i>Parmotrema chinense</i>)	80

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Parmelia omphalodes</i> (L.) Ach.	Called <i>crottle</i> or <i>dark crottle</i> (Scotland). <u>Dye</u> : A main crottle lichen, reddish-brown boiling water dye for socks and Harris tweed since 1500s, scraped off rocks with shell (Scotland). Called <i>dark crottle</i> , lichen is darker than <i>P. saxatilis</i> , but produces lighter dye. <u>Magic</u> : Socks dyed in crottle will protect the wearer's feet on long journeys by foot, if sailor wears crottle it will bring bad luck "what comes from the rocks returns to the rocks" (Scotland).	20, 89, 120, 183, 190- 192
<i>Parmelia saxatilis</i> (L.) Ach.	Called <i>stenlav</i> (Sweden), <i>crottle</i> or <i>light crottle</i> (Scotland), <i>grey moss</i> (England), <i>quajuq</i> (Barrens-Keewatin Inuit). <u>Medicine</u> : To remove warts (Sweden). Worth its weight in gold as epilepsy cure if growing on human skull (15 th century Europe, obsolete by 1800). <u>Dye</u> : A main crottle lichen, deep reddish-brown boiling water dye for socks and Harris tweed since 16 th century, scraped off rocks with shell (Scotland, Ireland, Sweden). Called <i>light crottle</i> , lichen is lighter than <i>P. omphalodes</i> , but produces darker dye (Scotland). Gives characteristic scent, collected in August when richest in dye. Dye for calico printing (NW Himalaya). <u>Tobacco</u> : Smoked (Shetland Islands). <u>Decoration</u> : Minature scenes constructed in large trays using plants and lichens, and placed on top of well during well-dressing festival in summer (Derbyshire, since 19 th century). <u>Fibre</u> : Stuff caribou skins for rafts (Barrens-Keewatin). <u>Magic</u> : Socks dyed in crottle will protect the wearer's feet on long journeys by foot, if sailor wears crottle it will bring bad (Scotland).	5, 7, 19, 20, 27, 87, 89, 90, 120, 145, 190, 191, 193
<i>Parmelia sulcata</i> Taylor	<u>Dye</u> : A crottle lichen, reddish-brown boiling water dye for socks and Harris tweed since 16 th century, scraped off rocks with a shell (Scotland).	190
<i>Parmelinella wallichiana</i> (Taylor) Elix	<u>Food</u> : Sold as spice (Maharashtra: India).	80
<i>Parmotrema abessinicum</i> (Nyl. ex Kremp.) Hale	Called <i>rathipuvvu</i> ['rock flower'] (India). <u>Food</u> : Collected April, May, highly regarded curry powder (Bellary: India). <u>Medicine</u> : Eaten medicinally (India).	93, 123, 135
<i>Parmotrema andinum</i> (Müll. Arg.) Hale	<u>Tobacco</u> : Lichen imported from 750km to the NW and saturated with rose oil to give it its fragrance. Mixed one part crushed lichen to ten parts tobacco, then smoked in pipe (Mauritania). <u>Perfume</u> : Women put powdered lichen in hair for perfume (Mauritania). <u>Insecticide</u> : Burned as an insect repellent (Mauritania).	90, 194
<i>Parmotrema austrosinensis</i> (Zahlbr.) Hale	Called <i>shaybah</i> (Saudi Arabia). <u>Food</u> : Sold as spice (Maharashtra: India). Imported from India and Iran, cooked in meat stews as preservative and flavoring (Saudi Arabia).	80, 195
<i>Parmotrema chinense</i> (Osbeck) Hale & Ahti	<u>Medicine</u> : Mixture of <i>Parmotrema chinense</i> , <i>P. perforatum</i> , <i>Everniastrum cirrhata</i> , and <i>E. nepalense</i> is called <i>chharila</i> or <i>jhoola</i> , sold as crude drug in bazaars (Ayurvedic and Unani medicine: India). Used as aphrodesiac, carminative, diuretic, sedative, astringent, demulcent, bitter, and resolvent. Smoked to relieve headaches. Powdered and applied on wounds, and used as cephalic snuff. Also useful in dyspepsia, spermatorrhoea, amonorrhoea, calculi, diseases of the blood and heart, stomach disorders, enlarged spleen, bronchitis, bleeding piles, scabies, leprosy, excessive salivation, soreness of the throat, toothache, and pain in general. <i>Chharila</i> is ingredient in <i>spemen</i> , which was found very effective for treating infertility in men. <u>Dye</u> : Orchil dye (purple), imported from Ceylon when Canary, Cape Verde supply of orchil declined (Europe).	16, 19, 21, 142, 196, 197

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Parmotrema dilatatum</i> (Vainio) Hale	<u>Decoration</u> : Sold as <i>silver moss</i> in Copenhagen, imported from Brazil.	103
<i>Parmotrema flavescens</i> (Kremp.) Hale	<u>Decoration</u> : Sold as <i>silver moss</i> in Copenhagen, imported from Brazil.	103
<i>Parmotrema hababianum</i> (Gyeln.) Hale	<u>Food</u> : Sold as spice (Andman Islands: India).	80
<i>Parmotrema maclayanum</i> (Müll. Arg.) Hale	<u>Decoration</u> : Sold as <i>silver moss</i> in Copenhagen, imported from Brazil.	103
<i>Parmotrema nilgherrense</i> (Nyl.) Hale	Called <i>budu</i> (Gaddi: India); <i>dagaful</i> ['stone flowers'] (Poona, Aurangabad). <u>Ritual</u> : Incense for sacrificial fire in Havan ritual (Gaddi). <u>Food</u> : Main ingredient of <i>Kabul garam masala</i> , spice mixture added at the end of cooking (Poona, Aurangabad). Bulking agent for curry with mild preservative (India), large quantities sold as spice (Uttaranchal, Uttar Pradesh, Himachal Pradesh: India). Exported (Saudi Arabia, London). <u>Perfume</u> : Highest grade of perfume lichen harvested in India, exported.	26, 80, 102, 137- 139
<i>Parmotrema praesorediosum</i> (Nyl.) Hale	<u>Food</u> : Sold as spice (Karnataka, Tamil Nadu: India).	80
<i>Parmotrema perforatum</i> (Jacq.) A. Massal.	<u>Medicine</u> : Used in <i>chharila</i> (SEE: <i>P. chinense</i>)	16
<i>Parmotrema pseudonilgherrense</i> (Asahina) Hale	<u>Food</u> : Sold as spice (Himachal Pradesh: India).	80
<i>Parmotrema reticulatum</i> (Taylor) M. Choisy	<u>Medicine</u> : Diuretic (India).	19
<i>Parmotrema sancti-angelii</i> (Lyngé) Hale	Called <i>jhavila</i> (Gond, Oran: India); <i>dagaful</i> ['stone flowers'] (Poona, Aurangabad: India). <u>Medicine</u> : 30-50g burned, ash mixed with mustard or linseed oil, salve to treat skin disease called <i>sem</i> (Gond, Oran). <u>Food</u> : Main ingredient of <i>Kabul garam masala</i> , spice mixture added at the end of cooking (Poona, Aurangabad). Bulking agent for curry with mild preservative (India), sold as spice (Maharashtra, Karnataka, Tamil Nadu, Madhya Pradesh: India). Exported (Saudi Arabia, London).	26, 78- 80, 137, 138
<i>Parmotrema subtinctorium</i> (Zahlbr.) Hale	<u>Food</u> : Sold as spice (Uttaranchal, Uttar Pradesh, Karnataka, Tamil Nadu: India).	80
<i>Parmotrema tinctorum</i> (Delise ex Nyl.) Hale	Called <i>al-sheba</i> (Arabic); <i>jhavila</i> (Baiga, Bhil, Bhilala, Gond, Korka, Muria: India); <i>dagaful</i> ['stone flowers'] (Poona, Aurangabad: India); <i>umenoki-goke</i> (Japan). <u>Food</u> : Food spice (Arabic). Main ingredient of <i>Kabul garam masala</i> , spice mixture added at the end of cooking (Poona, Aurangabad). Spice for meat and vegetables (Baiga, Bhil, Bhilala, Gond, Korka, Muria). Bulking agent for curry with mild preservative (India). Large quantities sold as spice (Uttaranchal, Uttar Pradesh, Maharashtra, Karnataka, Tamil Nadu, Madhya Pradesh, Andman Islands: India). Exported (Saudi Arabia, London). Make tea, tastes like seaweed (Japan).	26, 79, 80, 128, 137, 138, 198

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Parmotrema wainii</i> (A.L. Sm.) Hale	<u>Decoration</u> : Sold as <i>silver moss</i> in Copenhagen, imported from Brazil.	103
<i>Parmotrema zollingeri</i> (Hepp) Hale	Called <i>kalas</i> (Ati: Philippines). <u>Medicine</u> : Burned and smoke inhaled to treat children with high fever and convulsions (Ati).	199
<i>Peltigera</i> spp. Willd.	Called <i>k'udyika'a</i> (Dena'ina); <i>(tl)'a(tl)'x7a-7aq</i> ['the ones flat against the rock'] or <i>(tl)'i-(tl)'i-dqwaqsibak'kw</i> ['resembling whale's baleen'] (Ditidaht); <i>p'elems</i> (Kwakwaka'wakw). <u>Medicine</u> : Grey species washed, squashed, eaten to make one urinate (Ditidaht). Pounded, mixed w/ spruce pitch to poultice wound (Oweekeno). Decoction drunk for tuberculosis and prolonged bleeding (Dena'ina). <u>Fibre</u> : Lining steaming pits and wiping off salmon (Kwakwaka'wakw). <u>Food</u> : Analyzed for making molasses (Kola: Russia).	3, 6, 8, 12, 34
<i>Peltigera aphthosa</i> (L.) Willd.	Called <i>quajuq</i> (Barrens-Keewatin Inuit); <i>t'it'idic'c'7a'</i> ['rocks growing on rocks'] (Ditidaht). <u>Medicine</u> : Purgative and anthelmintic, boil in milk for thrush (Sweden). Chewed and eaten for tuberculosis, poultice for sores on legs (Ditidaht). <u>Food</u> : Boil, then cook in galette (cream dessert) (Europe). <u>Dye</u> : Pink-brown ammonia fermentation dye (BC). <u>Fibre</u> : Stuff caribou skins for rafts (Barrens-Keewatin).	7, 12, 15, 20, 28, 92, 123
<i>Peltigera britannica</i> (Gyelnik) Holt. Hartw. & Tønsberg	<u>Medicine</u> : Possibly lichen used by Ditidaht (SEE: <i>P. aphthosa</i>).	12
<i>Peltigera canina</i> (L.) Willd.	Called <i>tl'extl'ekw'és</i> ['seaweed of the ground'] or <i>lexlek'is</i> ['echo'] (Kwakwaka'wakw); <i>patamataghosa</i> (Bengal); <i>ash colored ground liverwort</i> (England); <i>lichen cinereus terrestris</i> (Europe); <i>pulvis antilyssus</i> when mixed with pepper (Europe). <u>Medicine</u> : Tonic, and for liver complaints (Himalayas). Unspecified medicine (Hesquiat Nootka). Mixed with pepper and milk or broth and used to cure rabies and thrush 1700s in Europe, obsolete by 1800. Cure for rabies and jaundice (Darjeeling and Sikkim: India). <u>Food</u> : Eaten (Himalayas). <u>Dye</u> : Light tan dye with boiling water or ammonia fermentation (BC). Iron red or yellow dye for wool (Europe). <u>Magic</u> : Love charm (Kwakwaka'wakw).	5, 6, 15, 19, 20, 27, 89, 119, 125, 173, 175, 178, 200- 207
<i>Peltigera membranacea</i> (Ach.) Nyl.	<u>Medicine</u> : Possibly lichen used by Hesquiat Nuu-chah-nulth (SEE: <i>Peltigera canina</i>); Ditidaht (SEE: <i>Peltigera</i> spp.). <u>Magic</u> : Possibly lichen used by Kwakwaka'wakw (SEE: <i>Peltigera canina</i>).	6, 12, 173
<i>Peltigera polydactylon</i> (Neck.) Hoffm.	Called <i>jhau</i> (Lepchas: India). <u>Medicine</u> : Paste of thalli applied to cut, stops bleeding, antiseptic (Lepchas). <u>Food</u> : Sold as spice (Sikkim: India).	26, 79, 80, 141
<i>Peltigera rufescens</i> (Weiss) Humb.	<u>Dye</u> : Pink-tan ammonia fermentation dye (BC).	15
<i>Peltigera venosa</i> (L.) Hoffm.	<u>Dye</u> : Pink-grey ammonia fermentation dye (BC).	15
<i>Pertusaria</i> spp. DC	<u>Industrial</u> : Yields 29.4% oxalic acid, used to manufacture the acid (France).	93
<i>Pertusaria albescens</i> (Hudson) Choisy & Werner	<u>Medicine</u> : Very bitter, treatment for intermittent fevers.	92

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Pertusaria amara</i> (Ach.) Nyl.	<u>Medicine</u> : Very bitter, treatment for intermittent fevers.	92, 124
<i>Pertusaria dealbata</i> (Ach.) Cromb.	<u>Dye</u> : Contains purple dye.	21
<i>Pertusaria pertusa</i> (Weigel) Tuck.	<u>Medicine</u> : Cure for intermittent fever, more effective for men (15 th century Europe, obsolete by 1800).	5
<i>Phanerochaete sanguinea</i> (Fr.) Pouzar	<u>Dye</u> : Unspecified (Brazil).	122
<i>Physcia</i> spp. (Schreber) Michaux	<u>Dye</u> : Ground, mixed with pine resin for deep yellow paint (Acoma, Laguna). <u>Medicine</u> : According to Doctorine of Signatures (1400s Europe, obsolete by 1800).	1, 5
<i>Physconia distorta</i> (With.) Laundon	<u>Dye</u> : Yellow dye for wool (Europe).	20
<i>Platismatia glauca</i> (L.) Culb.	Yellow brown boiling water dye, poorer brown dye with ammonia fermentation (BC). Chamois dye for wool (Europe).	15, 20
<i>Platismatia herrei</i> (Imshaug) Culb.	<u>Dye</u> : Orange-brown dye with boiling water, brown with ammonia fermentation (BC).	15
<i>Pleopsidium chlorophanum</i> (Wahlenb.) Zopf	<u>Dye</u> : Yellow dye with boiling water and ammonia fermentation (AZ).	1
<i>Pleurosticta acetabulum</i> (Neck.) Elix	<u>Dye</u> : Orange-brown dye for homespuns, Harris Tweed (Northern Ireland).	20
<i>Polysporina simplex</i> (Davies) Vezda	<u>Dye</u> : Tawny-olive boiling water dye (AZ).	1
<i>Pseudephebe pubescens</i> (L.) M. Choisy	<u>Dye</u> : Burned into black powder for paint for wood (Haisla, Hanaksiala)	77
<i>Pseudevernia furfuracea</i> (L.) Zopf	Called <i>mousse d'arbre</i> , <i>cedarmoss</i> (if growing on cedar), or <i>treemoss</i> (if growing elsewhere) (Europe); <i>musgo</i> (Granada: Spain). <u>Perfume</u> : Oleo-resin, fixative for particular perfumes (1100s to present, Europe, Russia). Gathered in large quantities from forests, takes 3 years to replentish (Italy, Dalmatia, Morocco), 10,000 tons processed annually (with <i>Evernia prunastri</i>). Better quality if picked in summer, or in Yugoslavia or Bosnia, tree affects perfume characteristics. <u>Food</u> : Used to make bread (ancient Egypt). <u>Alcohol</u> : Fermentative agent (Egypt). <u>Mummies</u> : Stuffing for embalming mummies (Ancient Egypt), identified in mummy from 500-800 BC, and 18 th Dynasty vase (1700-1600BC). <u>Medicine</u> : Thallus boiled for considerable time, decoction drunk for respiratory ailments (Granada, Alfacar, Viznar: Spain). Ingredient in drug Lichen Quercinus Virdes (1400s Europe, obsolete by 1800). Astringent and febrifuge. Unspecified medicine (Egypt). <u>Dye</u> : Red dye (19 th century Scotland).	5, 17, 20, 26, 89, 92, 93, 130- 132, 134, 145, 180, 208
<i>Pseudocyphellaria anomala</i> Brodo	<u>Dye</u> : Orange-brown dye with boiling water, brown with ammonia fermentation (BC).	15
<i>Pseudocyphellaria aurata</i> (Ach.) Vainio	<u>Dye</u> : For wool (Britain, Scandanavia).	20

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Pseudocyphellaria crocata</i> (L.) Vainio	<u>Dye</u> : Brown dye for wool.	20
<i>Psora crenata</i> (Taylor) Reinke	<u>Dye</u> : Tawny-olive with boiling water, cream coloured with ammonia fermentation (Utah).	1
<i>Punctelia borreri</i> (Sm.) Krog	Called chan wiziye ['grows on trees – yellow'] (Dakota). <u>Dye</u> : Boiling water dye for porcupine quills (Dakota).	209, 210
<i>Ramalina</i> spp. Ach.	Called dagaful ['stone flowers'] (Poona, Aurangabad: India). <u>Food</u> : Main ingredient of Kabul garam masala , spice mixture added at the end of cooking (Poona, Aurangabad). Bulking agent for curry with mild preservative (India). Sold as spice (Uttaranchal, Uttar Pradesh: India). Exported (Saudi Arabia, London). <u>Dye</u> : Produce yellow dye (Peru). <u>Medicine</u> : Occasional adulterant in chharila (SEE <i>Parmotrema chinense</i>). <u>Perfume</u> : Unspecified (Russia). Grade III and IV (of IV) perfume lichen harvested in India, exported for resinoids.	16, 17, 80, 137- 140
<i>Ramalina calicaris</i> (L.) Fr.	<u>Food</u> : Food for poor people (Sweden). <u>Cosmetics</u> : Powdered and used to dye perukes and wigs (Europe, India). <u>Dye</u> : Yellow-red dye for wool (Europe).	18- 20, 27, 32, 33
<i>Ramalina conduplicans</i> Vain.	Called yangben (Rai, Limbu: Nepal); shouxu , shikuacai , and shuhua (Yi, Dai: south Yunnan, China); shihuacai (Yi: central Yunnan). <u>Food</u> : Eaten like <i>R. farinacea</i> (Rai, Limbu). Sold as spice (Himachal Pradesh: India). Boiled in water with soda for 10–20 minutes and then soaked in new water for 1–2 days, sometimes used with chili powder, salt, and other seasonings, then served in cold dish at marriage banquets (Yi, Dai: south Yunnan) or stir-fried with pork and eaten any time (Yi: centr. Yunnan) <u>Ritual</u> : Since ancient times, eaten by couples at their marriage banquet so they will love each other more and never separate (Yi, Dai: south Yunnan).	80, 126, 164
<i>Ramalina cuspidata</i> (Ach.) Nyl.	<u>Dye</u> : Light brown dye for wool (Europe).	20
<i>Ramalina farinacea</i> (L.) Ach.	Called yangben (along with, <i>R. subfarinacea</i> , <i>R. conduplicans</i> , <i>R. sinensis</i> , <i>Everniastrum nepalensis</i> , and <i>Usnea thomsonii</i>) (Rai, Limbu: Nepal). <u>Food</u> : Yangben cleaned w/ water, boiled w/ ash, washed, dried, cut to small pieces, stored. Rehydrated before cooking with meat, egg, blood, or veggies <u>Dye</u> : Light brown dye for wool (Europe), pinkish w/ ammonia fermentation. <u>Medicine</u> : Yields mucilage like gum Arabic. <u>Cosmetics</u> : India.	15, 18- 20, 123, 126
<i>Ramalina fraxinea</i> (L.) Ach.	<u>Perfume</u> , <u>Cosmetics</u> : Unspecified use (Europe, India). <u>Food</u> : Substitute for gum Arabic (NW Himalaya).	18- 20
<i>Ramalina menziesii</i> Taylor	<u>Magic</u> : Brought rain if put in water, weighed down with stone. Rain stopped when lichen removed. Thunder and lightning stopped if lichen thrown in fire. (Kawaiisu: California). <u>Fibre</u> : Baby diapers (Kashawa Pomo: California).	23, 152
<i>Ramalina pollinaria</i> (Westr.) Ach.	<u>Dye</u> : Brown-pink dye with ammonia fermentation (BC).	15
<i>Ramalina siliquosa</i> (Huds.) A.L. Sm.	<u>Dye</u> : Lichens boiled for one day, then wool put in and left until desired colour (yellow-brown to red-brown) (Scotland). <u>Tobacco</u> : Smoked (Shetland Islands). <u>Cosmetics</u> : Hair powder for wigs (18 th century Scotland).	20, 90, 125, 190, 211

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Ramalina sinensis</i> Jatta	Called yangben (Rai, Limbu: Nepal); shuhua (Yi, Dai: south Yunnan). Food: Eaten like <i>R. farinacea</i> (Rai, Limbu). Sold as spice (Uttaranchal, Uttar Pradesh, Himachal Pradesh: India). Boiled in water with soda for 10–20 minutes and then soaked in new water for 1–2 days, sometimes used with chili powder, salt, and other seasonings, then served in cold dish at marriage banquets (Yi, Dai: south Yunnan). Ritual: Since ancient times, eaten by couples at their marriage banquet so they will love each other more and never separate (Yi, Dai).	80, 126, 164
<i>Ramalina subcomplanata</i> (Nyl.) Zahlbr.	Called jhavila (Baiga, Bhil, Bhilala, Gond, Korka, Muria: India). Food: Spice for meat and vegetables (India), sold in Madhya Pradesh (India).	26, 79, 80
<i>Ramalina subfarinacea</i> (Nyl. ex Cromb.) Nyl.	Called yangben (Rai, Limbu: Nepal). Food: Eaten like <i>R. farinacea</i> (Rai, Limbu). Dye: Purple orchil dye (Scotland).	126, 178
<i>Ramalina thrausta</i> (Ach.) Nyl.	Dye: Light tan dye with ammonia fermentation (BC).	15
<i>Rhizocarpon geographicum</i> (L.) DC.	Dye: Brown dye for wool (Scandinavia).	20
<i>Rhizoplaca chrysoleuca</i> (Sm.) Zopf	Dye: Yellow dye with boiling water, olive-buff with ammonia fermentation (AZ).	1
<i>Rhizoplaca melanophthalma</i> (DC.) Leuckert	Dye: Yellow dye with boiling water and ammonia fermentation (AZ).	1
<i>Rhizoplaca peltata</i> (Ramond) Leuckert	Dye: Yellow dye with boiling water and ammonia fermentation (AZ).	1
<i>Rimelia cetrata</i> (Ach.) Hale	Decoration: Sold as silver moss in Copenhagen, imported from Brazil.	103
<i>Rimelia reticulata</i> (Taylor) Hale & Fletcher	Called jhavila (Baiga, Bhil, Bhilala, Gond, Korka, Muria: India); dagaful ['stone flowers'] (Poona, Aurangabad: India). Food: Main ingredient of Kabul garam masala , spice mixture added at the end of cooking, bulking agent for curry with mild preservative (India). Spice for meat and vegetables (Baiga, Bhil, Bhilala, Gond, Korka, Muria). Large quantities sold as spice (Uttaranchal, Uttar Pradesh, Maharashtra, Karnataka, Tamil Nadu, Himachal Pradesh, Madhya Pradesh, Andman Islands: India). Exported (Saudi Arabia, London).	26, 79, 80, 137, 138
<i>Rinodina bischoffii</i> (Hepp) A. Massal.	Dye: Tawny-olive dye with boiling water, yellow with ammonia fermentation (AZ).	1
<i>Roccella</i> spp. DC.	Dye: Orchil dyes (Europe). Imported in large quantities from 16 th to 18 th centuries. 1 tonne used annually in Holland to make litmus until 1980s. Medicine: Used according to Doctrine of Signatures (15 th century Europe, obsolete by 1800).	5, 89, 212
<i>Roccella babingtonii</i> Mont.	Dye: Used for purple-red orchil dye in Europe, when supplies exhausted imported from California.	15
<i>Roccella canariensis</i> Darb.	Called orchilla (Canary Islands). Dye: Exported for purple dye, very important commercially 15 th – 17 th centuries, several places named orchilla , islands were sometimes called Islas Purpurarias (Canary Islands).	213, 214
<i>Roccella fimbriata</i> Darbish.	Dye: Used for purple-red orchil dye in Europe, when supplies exhausted imported from California.	15

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Roccella fuciformis</i> (L.) DC.	Called <i>alican</i> or <i>jaican</i> (Canary Islands), <i>mathaghasa</i> ["to rub on skull"] (Puducherry: India). <u>Dye</u> : Purple orchil dye for silk, wool, carpet yarns, wood, marble (Europe). Important export from Canary Islands and Cape Verde 1400-1600s, imported from Ceylon when supply declined. Litmus. <u>Medicine</u> : Clean hair and cure eczema on skull and back of ear (India).	18- 21, 213, 214
<i>Roccella montagnei</i> Bél.	<u>Fodder</u> : Fed to milk cows to yield better milk (India). <u>Dye</u> : Orchil dye (purple) (Italy, Germany, Europe), imported from India, Madagascar when Canary, Cape Verde supply of orchil declined.	20, 21, 215
<i>Roccella peruensis</i> Kremp.	<u>Dye</u> : Contains purple dye.	21
<i>Roccella phycopsis</i> (Ach.) Ach.	<u>Dye</u> : Blue dye for British Broadcloth. Tincture with alcohol used in thermometers.	20
<i>Roccella portentosa</i> (Mont.) Darb.	<u>Dye</u> : Contains purple dye.	21
<i>Roccella sinensis</i> Nyl.	<u>Dye</u> : Contains purple dye.	21
<i>Roccella tinctoria</i> DC.	Called <i>orcigilia</i> , <i>orchilla</i> (Spain); <i>urzela</i> (Portugal); <i>orseille</i> , <i>orchal</i> (France); <i>persis</i> (Germany); <i>orchil</i> (England). <u>Dye</u> : Mentioned in bible as purple dye, rediscovered 1300AD Netherlands, named Orseille. Imported from Cape Verde, Canary Islands. Dye for silk and wool, wine and liquer, and laundry. Limus <u>Medicine</u> : For coughs. Yields erythrityl tetranitrate, lowers blood pressure	19- 21, 25, 27, 123
<i>Roccella tuberculata</i> Vain.	Called <i>orchilla</i> (Canary Islands). <u>Dye</u> : Exported from Canary Islands for purple dye, very important there commercially 1400-1600s, several places named <i>orchilla</i> , islands were sometimes called <i>Islas Purpurarias</i> .	213, 214
<i>Roccella vicentina</i> (Vain.) Follmann	Called <i>orchilla</i> (Canary Islands). <u>Dye</u> : Exported from Canary Islands for purple dye, very important there commercially 1400-1600s, several places named <i>orchilla</i> , islands were sometimes called <i>Islas Purpurarias</i> .	213, 214
<i>Solorina crocea</i> (L.) Ach.	<u>Dye</u> : Brown ammonia fermentation dye (BC). Yellow dye for wool (Scotland).	15, 20
<i>Sphaerophorus globosus</i> (Hudson) Vainio	<u>Decoration</u> : Grotto-work in summer houses, garden retreats and gazebos (18 th century Scotland). <u>Dye</u> : Tan ammonia fermentation dye (BC).	15, 125
<i>Sphaerothallia affinis</i> (Eversm.) Follmann	<u>Fodder</u> : Fed to sheep (Algeria to Tartary). <u>Food</u> : Made into bread in famine (Algeria to Tartary).	24
<i>Squamarina lentigera</i> (Weber) Poelt	<u>Dye</u> : Yellow dye with boiling water and ammonia fermentation (UT).	1
<i>Staurothele drummondii</i> (Tuck.) Tuck.	<u>Dye</u> : Tawny-olive dye with boiling water, chamois with ammonia fermentation (AZ).	1
<i>Stereocaulon</i> spp. Hoffm.	Called <i>jaegel</i> (Saami), <u>Forage</u> : Preferred forage of reindeer, increases under grazing (Saami).	5, 87
<i>Stereocaulon himalayense</i> Asahina & I.M. Lamb	Called <i>dhungo-ku-jhau</i> (Lepchas: India) <u>Medicine</u> : Thalli pounded and boiled, for blisters on tongue, or 100mL twice daily after meals for urinary trouble (Lepchas). <u>Food</u> : Sold as spice (Sikkim: India).	26, 79, 80, 141

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Stereocaulon paschale</i> (L.) Hoffm.	Called <i>quajuq</i> (Barrens-Keewatin Inuit). <u>Food</u> : Analyzed for making molasses (Kola, Russia). <u>Dye</u> : Ash green dye for wool (Europe). <u>Fibre</u> : Stuff caribou skins for rafts (Barrens-Keewatin).	7, 8, 20
<i>Stereocaulon tomentosum</i> Fr.	<u>Dye</u> : Light yellow-brown boiling water dye (BC).	15
<i>Sticta</i> spp. (Schreber) Ach.	Called <i>didi'dichia</i> ['growing on rocks'] (Makah); <i>sts'wakt-aak</i> (Nuxalk). <u>Medicine</u> : Mashed for poultice for running sores (Makah). Only used from certain trees, drink decoction for stomach pains, also for eyewash and poultice (Nuxalk).	11, 12
<i>Sulcaria sulcata</i> (Lév.) Bystrek	Called <i>bandai-kinori</i> (Japan). <u>Food</u> : Makes soup that tastes like seaweed (Japan).	128
<i>Teloschistes</i> spp. Norman	<u>Dye</u> : Unspecified.	27
<i>Teloschistes flavicans</i> (Sw.) Norman	<u>Poison</u> : For wolves (unspecified location).	123
<i>Teloschistes flavicans</i> (Sw.) Norman	<u>Dye</u> : Yellow to orange dye (Peru, Germany).	20, 140
<i>Teloschistes vermicularis</i> ??	<u>Dye</u> : Yellow to orange dye for weavers (San Pedro de Cajas: Junin: Peru).	140
<i>Thamnolia subuliformis</i> (Ehrh.) W. Culb.	Called <i>xuecha</i> ['tea ingredient found at high elevations'] (Naxi: nw Yunnan) <u>Medicine</u> : Traditional Chinese remedy for inflammation, boiling water is added to dry thalli in cup, infusion drank after 3-5 minutes, called snow tea (Naxi). Exported to Japan.	164
<i>Thamnolia vermicularis</i> (Sw.) Ach. ex Schaerer	Called <i>chhai dhoop</i> (Bhotia: India); <i>contrayerba blanca</i> (South America); <i>xuecha</i> ['tea ingredient found at high elevations'] (Naxi: nw Yunnan, China). <u>Insecticide</u> : Smoke from burning thalli kills worms in buttermilk (Bhotia). <u>Ritual</u> : In Hawan Samagri, a sacrificial offering to gods/goddesses (Bhotia). <u>Medicine</u> : Stomachic (South America). Traditional Chinese remedy for inflammation, boiling water is added to dry thalli in cup, infusion drank after 3-5 minutes, called snow tea (Naxi). Exported to Japan. <u>Food</u> : Sold as spice (Uttaranchal, Uttar Pradesh: India).	26, 80, 92, 164, 216
<i>Tuckermannopsis ciliaris</i> (Ach.) Gyelnik	<u>Dye</u> : Tan dye with boiling water (BC).	15
<i>Tuckermannopsis orbata</i> (Nyl.) Lai	<u>Dye</u> : Poor for dye (BC).	15
<i>Umbilicaria</i> spp. Hoffm.	Called <i>gadna</i> (Saami); <i>wa'kana a'pisk</i> (Attawapiskat Cree); <i>wakoonapishkuts</i> ['span of the rocks'] (Naskapi); <i>waac</i> (Ojibwa); <i>o shaw shaú kon ug</i> (unspecified N. A.); <i>tripe de roche</i> ; <i>rock tripe</i> (early Europeans in N. A.). <u>Food</u> : Washed, broken up, boiled for hour in soup with fish, fish roe, or caribou blood, becomes gelatinous when cooled (Inuit). Boiled for half hour with flour, lard, and salt (Attawapiskat Cree). Dried, boiled 2-3 hours until thick syrup, or boiled down longer until paste and eaten like pancake (Naskapi). Fish stew thickened with rock tripe, collected year round (Nihithawak). Boiled for food, smaller ones preferred, less bitter and tough (Huron, Nipissing). Important famine food (Algonkins). Eaten by Ojibwa (perhaps <i>Cladina</i> sp.). Boiled in soup, good taste (indigenous people, west coast Hudson Bay). Emergency food of early Europeans in N. A. (Jesuits,	4, 5, 24, 27, 62, 89, 93, 94, 99, 100, 105, 114, 115, 118,

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Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Umbilicaria</i> spp. Hoffm.	fur traders, explorers), often steeped in dilute soda water, sometimes pounded, then boiled until thick black gruel, or added to thicken soups, often with fish broth. Some liked it, but in general not highly thought of, most report mild or severe stomach upset, disgusting taste and texture, and scant nutrition. When eating this lichen, often also resorting to cannibalism, and eating shoe leather, dung, and old bones. Often reported as not eaten by indigenous peoples. <i>Medicine</i> : Cooked with fish broth for upset stomach (Nihithawak). <i>Forage</i> : Eaten by reindeer when nothing else available (Saami). <i>Dye</i> : Orchil dye (Europe). Lacmus dye, exported from Norway to England, Germany in 14 th century.	217- 240
(cont'd from previous page)		
<i>Umbilicaria cylindrica</i> (L.) Delise ex Duby	Called <i>tripe de roche</i> . <i>Food</i> : Eaten in emergencies, nutritious but bitter, produces severe colic and other complaints. <i>Dye</i> : Green-brown dye for wool (Iceland).	20, 92.
<i>Umbilicaria deusta</i> (L.) Baumg.	Called <i>tousch</i> (Sweden). <i>Dye</i> : Violet dye for wool, violet paint (Sweden).	20
<i>Umbilicaria esculenta</i> (Miyoshi) Minks	Called <i>iwa-take</i> (Japan); <i>seog-eui-beo-seod</i> (Korea). <i>Food</i> : Sold in markets (Japan, China, Korea). Expert lichen hunters lowered down cliff faces in baskets to pick lichen, dangerous so expensive (\$100/lb). Soaked overnight before cooking, several recipes (Japan): Boiled with sugar and soy; thick miso soup; clear salty soup; vinegared; with soy, vinegar, and sake; or battered and deep fried. In kimchi (Korea). <i>Medicine</i> : For dysentery (Korea). Promotes longevity when eaten (Japan).	20, 26, 28, 62, 128, 241- 244
<i>Umbilicaria mammulata</i> (Ach.) Tuck.	Called <i>asine-wakunik</i> (Attikamekw Cree). <i>Food</i> : An edible species of <i>Umbilicaria</i> (Huron, early Europeans in N. A.) <i>Medicine</i> : During difficult childbirth, lichen boiled and placed on woman's genitals (Attikamekw).	109, 224, 245, 246
<i>Umbilicaria muehlenbergii</i> (Ach.) Tuck	<i>Food</i> : Eaten in soup (Nihithawak). Claimed as the only <i>Umbilicaria</i> spp. eaten by indigenous peoples in N. A.	26, 118, 218
<i>Umbilicaria phaea</i> Tuck.	<i>Dye</i> : Drab-grey boiling water dye, light brownish vinaceous with ammonia fermentation (UT).	1
<i>Umbilicaria proboscidea</i> (L.) Schrader	Called <i>tripe de roche</i> . <i>Food</i> : Eaten in emergencies, nutritious but bitter, produces severe colic and other complaints.	92
<i>Umbilicaria vellea</i> (L.) Hoffm.	<i>Dye</i> : Violet dye for wool (Sweden). Red-brown dye (Himalaya).	19, 20
<i>Umbilicaria virginis</i> Schaer.	<i>Dye</i> : Red brown dye (Himalaya).	19
<i>Usnea</i> spp. Dill. ex Adans.	Called <i>dehtsighu</i> ["branch hair"] or <i>ch'vala andaz'i</i> ["spruce hair"] (Dena'ina); <i>suts'wakt</i> or <i>ipts-aak</i> ['limb moss'] (Nuxalk); <i>p'u7up</i> (Ditidaht); <i>laxpt</i> or <i>mak+'hl</i> (Cayuse & Umatilla Sahaptin); 'grandma's hair' (Gwich'in); <i>mithapakwan</i> (Nihithawak); 'wool of rocks' (Tarahumara: Mexico); <i>su lo</i> (China); <i>lappo</i> (Saami); <i>dagaful</i> ['stone flowers'] (Poona, Aurangabad: India); <i>barbas</i> (Canary Islands). <i>Medicine</i> : If growing on alder used to poultice sores and boils (Nuxalk). Medicine for boils (Makah). Wound dressing (Ditidaht). Straining hot pitch for medicine (Haida). Boiled, applied as a compress for open sores, arthritis, and eye problems (possibly <i>Alectoria</i> sp.) (Cayuse & Umatilla). For nosebleed (Nihithawak). Treat stomach aches (East Africa). Disinfectant (Canary Islands). Treat colds (Malaysia). Unspecified medicine (Uruguay).	1-5, 11- 13, 16, 23, 27, 29, 32, 33, 87, 89, 90,
(cont'd next page)		

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Usnea</i> spp. Dill. ex Adans. (cont'd from previous page)	To induce menstruation (New Ireland). For foot blisters (Sweden). Antibiotic salves (Europe). Scalp disorders and strengthening hair (15 th century Europe). For gynecological disorders (ancient Greece, China). For fever and skin infection (ancient China). Dust powdered herb on wound, strong decoction, alcohol tincture, salve with fat, to treat ringworm, athletes foot, yeast infection, chlamydia, trichomonas, bacterial infection, and as immune booster (Unspecified peoples). Mentioned in Formulary of Al-kindī in 850AD. Occasional adulterant in <i>chharila</i> (SEE: <i>Parmotrema chinense</i>). Medicinal tablets shown to cause poisoning (USA). <i>Perfume</i> : Grade III and IV (of IV) perfume lichen harvested in India. <i>Cosmetics</i> : Cyprus powder for hair and wigs (17 th century Europe). <i>Dye</i> : Dark green dye (Coast Salish). Tan dye for blankets (Tarahumara). Yellow dye (Makah). <i>Fuel</i> : Firestarter (Nihithawak). Collected off spruce, dried, used as tinder (Gwich'in). Making fires smoke (Sechelt). <i>Fibre</i> : Baby diapers, sanitary napkins, wiping salmon (Ditidaht, Sechelt). Interwoven with silverberry bark fibres and made into ponchos and footwear (Stl'atl'imx). Mattresses (Haida). Lining food pits (BC). Stuff pillows (Makah, Simla: India). <i>Food</i> : Emergency food, boiled, and mixed with fish, berries, or grease (Inland Dena'ina). Main ingredient of <i>Kabul garam masala</i> , spice mixture added to cooked food (Poona, Aurangabad). Bulking agent, preservative for curry (India), export to Saudi Arabia, London. Food for peasants (Sweden). <i>Forage</i> : Liked by reindeer but not large part of diet (Saami). <i>Decoration</i> : Artificial hair to decorate masks (Secwepemc, Nuxalk).	118, 137- 139, 213, 247- 252
<i>Usnea africana</i> Motyka	Called <i>hewas</i> (Iraqw: East Africa). <i>Medicine</i> : Chewed fresh, juice swallowed for stomachache (Iraqw).	253
<i>Usnea articulata</i> (L.) Hoffm.	<i>Medicine</i> : Wounds and shin bruises (Samoa)	254
<i>Usnea atlantica</i> Vain.	Called <i>barbas</i> (Canary Islands). <i>Medicine</i> : Disinfectant (Canary Islands).	213
<i>Usnea aurantiaco-atra</i> (Jacq.) Bory	<i>Prospecting</i> : Accumulates gold from environment (Antarctica).	255
<i>Usnea austroindica</i> G. Awasthi	<i>Food</i> : Sold as spice (Uttaranchal, Uttar Pradesh: India).	80
<i>Usnea barbata</i> (L.) Weber ex F.H. Wigg.	Called <i>angiangi</i> or <i>kohukohu</i> (Maori); <i>tagahumok puti</i> (Ati: Philippines); <i>memby rakú í ja</i> (Mbya-Guarani: Brazil). <i>Medicine</i> : Endangered medicinal lichen banned from raw export (Nepal). Cow udder washed several times with decoction of lichen to treat infection (Xhosa: South Africa). In humans, tincture or decoction is taken orally several times a day to treat ingestion and catarrh or the stomach (Xhosa). Infusion used externally for venereal diseases, also crushed, applied to wounds and cutaneous eruptions (Maori). Chopped and mixed with coconut oil to put on wounds, boiled and concoction drunk for epigastric/abdominal pain (Ati). For colds and strengthening after confinement (Malay Peninsula). For uterine ailments (Hippocrates). For headache, sunstroke. Cure sterility in women (Mbya-Guarani). <i>Dye</i> : Dark blue dye (Peru). Orange-red dye for wool (Europe). <i>Fibre</i> : Used as wrappers, absorbants, menstrual pads (Maori). <i>Cosmetics</i> : Strengthening hair (Malay, 15 th century Europe). Cyprus Powder (powder for hair and wigs in 7 th century Europe).	5, 20, 123, 135, 140, 143, 199, 248, 256- 258

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Usnea californica</i> Herre	Called <i>kôchih</i> or <i>qoci</i> (Pomo). <i>Fibre</i> : Baby diapers, "toilet chips" (Pomo).	259
<i>Usnea campestris</i> R. Sant.	Called <i>barba de piedra</i> (Argentina). <i>Medicine</i> : Unspecified use (Argentina).	260
<i>Usnea cavernosa</i> Tuck.	<i>Tanning</i> : Wrap brains in lichen to form brick, rub it crumbling into hide (Wylackie: CA). <i>Fibre</i> : Sometimes used as bedding (Yuki, Pomo, and/or Yokia: CA).	39, 55
<i>Usnea ceratina</i> Ach.	<i>Dye</i> : Yellow brown boiling water dye (BC).	15
<i>Usnea dasypoga</i> (Ach.) Röhl.	<i>Medicine</i> : Unspecified use (Java).	20
<i>Usnea densirostra</i> Taylor	Called <i>yerba de la piedra</i> ['stone grass'] (Uruguay); <i>barba de piedra</i> ['stone beard'] (Argentina). <i>Medicine</i> : Antiseptic, antiflogistic (Argentina). Unspecified use (Uruguay).	260, 261
<i>Usnea diffracta</i> Vain.	Called <i>yokowa saruogase</i> (Japan); <i>song-nag</i> (Korea); 'Lao-tzu's beard', 'pine gauze', or 'female gauze' (China). <i>Medicine</i> : For menostasis and scrofula, to induce menstration (Korea). In earliest herbal (500 AD), picked in 5th lunar month, dried in shade, stops sweating, dizziness, cold, pain, phlegm, benefits urinary tract and stops swelling in female genitalia (China). <i>Food</i> : Bitter to eat (Japan)	128, 146, 242, 251
<i>Usnea filipendula</i> Stirt.	<i>Medicine</i> : For balding and thinning hair (Europe). Astringent for haemorrhages and ruptures (Scotland). <i>Dye</i> : Excellent bright orange boiling water dye, brown with ammonia fermentation (BC).	15, 28, 125
<i>Usnea flavescens</i> Motyka	Called <i>hewas</i> (Iraqw: East Africa). <i>Medicine</i> : Chewed fresh, juice swallowed for stomachache (Iraqw).	253
<i>Usnea florida</i> (L.) F. H. Wigg.	<i>Medicine</i> : Antibiotic, and for tuberculosis. <i>Dye</i> : Green-yellow or red-brown dye for wool (Europe).	20, 123, 248
<i>Usnea glabrata</i> (Ach.) Vainio	<i>Dye</i> : Excellent bright orange-brown dye with boiling water, grey-green with ammonia fermentation	15
<i>Usnea himalayana</i> G. Awasthi	Called <i>nayonayo saruogase</i> . <i>Tobacco</i> : Burned as lichen cigarette.	128
<i>Usnea hirta</i> (L.) F. H. Wigg.	<i>Medicine</i> : Antibiotic, especially sodium salts.	123, 248
<i>Usnea longissima</i> Ach.	Called <i>ushna</i> (Unani); 'Indian bandage' (Ditidaht); <i>blaax</i> or <i>iimx ga gan</i> ['whiskers of the tree'] (Tsimshian). <i>Dye</i> : Poor light brown dye (BC). <i>Medicine</i> : Expectorant. Poultice for bone fractures (Bhotia, Garhwali: India). Eaten or inserted into vagina as abortifacient, eaten or used as douche for emmenagogue, ingredient in two compound drugs that are eaten as emmenagogues (Unani). Wrapped around wound for a while (Ditidaht). <i>Decoration</i> : Fake whiskers for masquerading (Tsimshian). <i>Food</i> : Spice (Bhotia, Garhwali), sold in Himachal Pradesh (India). <i>Fibre</i> : Stuffing for pillows and cushions (Bhotia, Garhwali). Wiping slime off salmon (Oweekeno). Mattresses at seasonal camps (Hanaksiala). <i>Forage</i> : Staple food of musk der (Bhotia, Garhwali). <i>Perfume</i> : Grade III and IV (of IV) perfume lichen harvested in India.	12, 15, 26, 31, 34, 78- 80, 123, 139, 248, 262
<i>Usnea orientalis</i> Mot.	<i>Food</i> : Sold as spice (Uttaranchal, Uttar Pradesh, Himachal Pradesh: India).	80

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Usnea plicata</i> (L.) Weber	<u>Medicine</u> : Whooping cough. Astringent for haemorrhages, ruptures (Scotland). <u>Dye</u> : Green or yellow dye for wool (Europe).	20, 92, 123, 125
<i>Usnea scabrata</i> Nyl.	Called <i>chan wiziye</i> (Dakota); <i>ashaxaeme</i> (Karak). <u>Dye</u> : Boiling water yellow dye for porcupine quills (Dakota).	158, 209
<i>Usnea sikkimensis</i> Biswas sp. nov.	Called <i>darimataghosa</i> (Bengal). <u>Cosmetics</u> : Powdered lichen to strengthen hair (Darjeeling, Sikkim: India). <u>Medicine</u> : For lung troubles, haemorrhage, asthma (Darjeeling, Sikkim).	175
<i>Usnea subfloridana</i> Stirton	<u>Dye</u> : Orange-brown dye with boiling water, brown with ammonia fermentation (BC). Pale yellow, copper, or olive green dye (Scotland).	15, 120, 178
<i>Usnea subfusca</i> Stirt.	Called <i>reté cajéra</i> (Tarahumar). <u>Dye</u> : Crushed, alum added, boiled several hours, wool added and simmered several days, dried in sun, rust-coloured dye (Tarahumar: Mexico). <u>Alcohol</u> : Important catalyst to make fermented corn beverages (Tarahumar).	144
<i>Usnea thomsonii</i> Stirt.	Called <i>yangben</i> (Rai, Limbu: Nepal). <u>Food</u> : Eaten like <i>Ramalina farinacea</i> (Nepal). Sold as spice (Uttaranchal, Uttar Pradesh: India).	80, 126
<i>Usnea trichodea</i> Ach.	<u>Medicine</u> : Used to promote growth of hair on head ("Native Americans").	155
<i>Usnea trichodeoides</i> Motyka	Called <i>fuji saruogase</i> (Japan). <u>Food</u> : Mild flavour, tastes better than <i>U. diffracta</i> , middle stem gives crunchy texture, tastes like seaweed (Japan).	128
<i>Usnea variolosa</i> Motyka	Called <i>reté cajéra</i> (Tarahumar). <u>Dye</u> : Crushed, alum added, boiled several hours, wool added and simmered several days, dried in sun, rust-coloured dye (Tarahumar: Mexico). <u>Alcohol</u> : Important catalyst to make fermented corn beverages (Tarahumar).	144
<i>Variolaria orcina</i> [Incertae sedis]	Called <i>white crottle</i> (Scotland), <i>perelle</i> (France), <i>barbefine</i> . <u>Dye</u> : Purple dye, may be source or pabelle, orchil dye from France.	20, 21
<i>Verrucaria inficiens</i> Breuss	<u>Dye</u> : Tawny-olive boiling water dye, cream with ammonia fermentation	1
<i>Vulpicida canadensis</i> (Räsänen) J. E. Mattsson & Lal	Called <i>claanisis skinisht</i> (Gitxsan, perhaps <i>hla'anisihl sginist</i> [pine branch]) <u>Dye</u> : Yellow boiling water dye, yellow-green with ammonia fermentation. Yellow dye for mountain goat wool (Gitxsan), sheep wool (Scandinavia). <u>Poison</u> : Used to poison wolves by mixing with ground glass (Scandinavia).	5, 15, 20, 172
<i>Vulpicida pinastri</i> (Scop.) Mattsson	Called <i>konahaimatsu-goke</i> (Japan). <u>Dye</u> : Yellow dye with boiling water (BC). Green dye for wool (Europe). <u>Poison</u> : Used to poison wolves by mixing with ground glass (pinastri acid).	5, 15 20, 128
<i>Xanthomaculina hottentotta</i> (Ach.) Hale	Called <i>khaob</i> (Nama: Namibia). <u>Medicine</u> : Decoction drunk for coughs, stomach and chest pain (Namibia) <u>Cosmetics</u> : Powdered, used as deodorant or perfume (Topnaar: Namibia).	188
<i>Xanthoparmelia</i> sp.	<u>Dye</u> : Saxicolous species, yellow tan dye for wool (Navajo),	1
<i>Xanthoparmelia chlorochroa</i> (Tuck.) Hale	<u>Dye</u> : Russet dye with boiling water, brown with ammonia fermentation (AZ). Reddish tan dye for wool (Navajo)	1
<i>Xanthoparmelia conspersa</i> (Ehrh. ex Ach.) Hale	Called <i>jievut hiawsik</i> ['earth flower'] (O'odham: AZ). <u>Magic</u> : Carried and/or smoked as powerful good luck charm, love charm (O'odham, similar uses by Maricopa, Papago, Mohave, and Kiowa) <u>Medicine</u> : Ground, sprinkled on cuts, sores; also rattlesnake bites (O'odham) <u>Hallucinogen</u> : Smoked as narcotic, hallucinogen (O'odham) <u>Dye</u> : Red-brown boiling water dye for wool (Europe).	20, 90, 178, 263- 265

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
<i>Xanthoparmelia lineola</i> (Berr.) Hale	<u>Dye</u> : Russet dye with boiling water, tawny-olive with ammonia fermentation (AZ).	1
<i>Xanthoparmelia mexicana</i> (Gyelnik) Hale	<u>Dye</u> : Ochraceous-tawny dye with boiling water, brown with ammonia fermentation (AZ).	1
<i>Xanthoparmelia molliuscula</i> (Ach.) Hale	<u>Dye</u> : Fine red dye, non-fading, no mordant (CA, OR).	55
<i>Xanthoria</i> spp. (Fr.) Th. Fr.	<u>Hunting</u> : Locate marmot burrows on talus slopes by bright yellow lichen around entrance (Nunamiut). <u>Navigation</u> : Bright yellow-orange blotches on cliff faces indicate open water in summer, result of bird activity (Northeast Greenland). <u>Dye</u> : Unspecified.	27, 81
<i>Xanthoria candelaria</i> (L.) Th.	<u>Dye</u> : Light grey-tan dye with boiling water, light brown with ammonia fermentation (BC). Yellow dye for wool (Sweden).	15, 20
<i>Xanthoria parietina</i> (L.) Th. Fr.	Called <i>flor de piedra</i> ['stone flower'] or <i>rompepiedra</i> ['stone breaker'] (Spain); <i>gold moss</i> (Derbyshire: England). <u>Medicine</u> : Bitter, cure for intermittent fevers. For jaundice (15 th century Europe, obsolete by 1800). Decoction of thallus with wine used for menstrual complaints, decoction with water to treat kidney disorders (renal lithiasis), as antidontalgic, analgesic for several pains, ingredient in cough syrup (Spain). Medicine for hepatitis (Europe). <u>Dye</u> : Yellow or orange boiling water dye for wool and for painting Easter eggs (Scotland, England, Sweden). Blue dye also reported (Scotland). <u>Decoration</u> : Minature scenes constructed in large trays using plants and lichens, and placed on top of well during well-dressing festival in summer (Derbyshire, 1800s to present).	5, 20, 26, 28, 89, 92, 120, 125, 178, 180, 181, 193
<i>Xanthoria elegans</i> (Link) Th. Fr.	<u>Dye</u> : Face paint (Haisla, Hanaksiala). Yellow paint (Kitasoo).	77
<i>Xanthoria polycarpa</i> (Hoffm.) Rieber	<u>Dye</u> : Yellow dye with boiling water, purple-pink with ammonia fermentation (BC, AZ)	1, 15
Unidentified	Called <i>maxa'hl</i> (Umatilla and Cayuse Sahaptin). <u>Tanning</u> : Used to smoke hides (Umatilla and Cayuse)	2
Unidentified, "moss"	<u>Medicine</u> : Nineteenth century wonder cure called Ti-ta contained a "moss", claimed to cure anything (Australia).	266
Unidentified, black & yellow	<u>Dye</u> : Powdered, mixed with salmon eggs, used to paint spoons, bowls, and totem poles (Haisla).	13
Unidentified, black foliose rock lichen	<u>Medicine</u> : Decoction drunk for tuberculosis and prolonged bleeding (Dena'ina)	3
Unidentified, foliose tree lichen	Called by tree name plus <i>ilgida</i> or <i>endenghasdetlaq'i</i> ["stuck to"]. <u>Food</u> : Sweet snack eaten raw off tree, or eaten with lard (Inland Dena'ina).	3, 4
Unidentified, grey-green	<u>Fuel, Ritual</u> : Medicine man climbs mountain in the second half of World Renewal Ceremony, builds a fire using dry "grey-green moss" (Karuk).	155
Unidentified, hair lichen	Called <i>ma haak</i> (Tsimshian).	31
Unidentified, misc foliose rock lichen	Called <i>qalnigi jegha</i> ["rock ear"] (Dena'ina)	3

Appendix X cont'ed. Summary of human uses of lichens across the world

Lichen	Summary of uses	Reference
Unidentified, misc. lichen	Called 'soil its skin' (Seri); <i>asaxxé'm</i> (Karak); <i>pá7sem</i> (St'at'imc); <i>ha'ichu vuushdag</i> ['things that grow up'] (O'odham); <i>k'ínxaan</i> or <i>k'ínnaan</i> (Haida); <i>melx7aest</i> (Tsimshian); <i>x"q'él'ted 7e welis</i> ['diaper of frog'] (Samish-Luumi). <i>Food</i> : Lichen starch in chocolates, pastries, confectionaries (France). <i>Medicine</i> : Usnic acid from lichen marketed for bacterial and fungal skin diseases, tuberculosis: tradenames Usno (Finland), Usniplant (Germany), Binan (Russia). Exploring genetic engineering to harvest lichen products. <i>Dye</i> : Black or yellow for mountain goat wool (Sm'algyax). <i>Forage</i> : Mountain goat food (Sm'algyax). <i>Industrial</i> : Patented use of vulpinic acid (TerraGen Discovery Inc, USA).	31, 87, 93, 158, 265, 267- 270
Unidentified, misc. lichen on ground	Called <i>ipst</i> (Nuxalk); <i>jewed eldag</i> ['earth skin'] (O'odham).	265, 269
Unidentified, misc. lichen on rocks	Called <i>hodai eldag</i> ['rock skin'] (O'odham).	265
Unidentified, misc. tree lichens	Called <i>ipst-aak</i> (Nuxalk).	269
Unidentified, north side of trees	<i>Medicine</i> : Dried, powdered lichens, put on teething infants' gums, or abscesses (Kiowa). <i>Tobaccos</i> : In smoking mixture (Kiowa).	271
Unidentified, on rock & trees	Called <i>gustaot one'ta'</i> (Iroquois). <i>Food</i> : Famine food, scraped from rocks and trees, washed in ashes and water to remove bitterness, and boiled in grease, or just boiled in emergency (Iroquois).	4, 109, 272
Unidentified, on rocks	Called <i>as-se-ne wa-quon-uck</i> ['eggs of the rock'] (Nipigon); <i>mthafathafa</i> (Xhosa: South Africa). <i>Food</i> : Very palatable when boiled with pemmican into a gelatinous substance, otherwise quite bitter (Nipigon). <i>Medicine</i> : Fresh lichen crushed, mixed with water, and infusion drank for gonorrhoea, also dried over fire, crushed, and powder applied to infected wounds (Xhosa).	43, 44, 273
Unidentified, on trees	Called <i>ts'o'o'ic</i> (Quinault) <i>Fibre</i> : Wipe salmon when they are cleaned (Quinault)	274
Unidentified, on white pine	<i>Food</i> : Ate "moss" growing on white pine. Dried, boiled, and used in fish or meat broth (Ojibwa).	109
Unidentified, orange and yellow on rocks	Called 'lizard semen' (Pavlotso). <i>Medicine</i> : Very important antibiotics and fungicides. Name derives from little pushups western fence lizards do on rocks.	146
Unidentified, <i>Parmelia</i> -like lichen	<i>Ritual</i> : Ceremonial smudge to purify and remove fear of thunder.	210
Unidentified, pyrenocarpous lichen on trees	Called <i>baduhu-tsinā</i> ['deer snuff'] (Denís: Brazil). <i>Medicine</i> : Yellow powder collected off surface of lichen and used as snuff, used frequently and induces sneezing (Denís).	275
Unidentified, tree hair	<i>Dye</i> : Dark green boiling water dye for mountain goat wool for blankets (Lummi).	276
Unidentified, white "moss"	Called <i>uriuqaq</i> (Barrens-Keewatin Inuit).	7
Unidentified, yellow on rocks	<i>Medicine</i> : Applied to the cheeks to reduce swelling for toothache and swelling in mouth (Hopi).	277

Appendix X cont'ed. Summary of human uses of lichens across the world

References cited in table

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|---------------------------------|-------------------------------------|-------------------------------------|
| 1. (Brough 1988) | 53. (Morice 1894) | 105. (Reagan 1928) |
| 2. (Hunn, pers. comm. 2005) | 54. (Morse 1822) | 106. (Hawkes 1916) |
| 3. (Kari 1987) | 55. (Murphey 1959) | 107. (Sinclair 1953) |
| 4. (Kuhnlein and Turner 1991) | 56. (Parry 1871) | 108. (Arendt 1872) |
| 5. (Perez-Llano 1944) | 57. (Ray 1932) | 109. (Arnason <i>et al.</i> 1981) |
| 6. (Turner and Bell 1973) | 58. (Ray 1963) | 110. (Freeman 1967) |
| 7. (Wilson 1979) | 59. (Spier and Sapir 1930) | 111. (Osgood 1959) |
| 8. (Diachkov & Kursanov 1945) | 60. (Spinden 1907-1915) | 112. (Stahlschmidt 1870) |
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| 10. (Palmer 1975) | 62. (Thieret 2004) | 114. (Yarnell 1964) |
| 11. (Turner 1973) | 63. (Turner 1977) | 115. (Black 1980) |
| 12. (Turner <i>et al.</i> 1983) | 64. (Turner <i>et al.</i> 1980) | 116. (Smith 1932) |
| 13. (Turner 1998) | 65. (Turner and Davis 1993) | 117. (Kauppi 1979) |
| 14. (Newberry 1887) | 66. (de Smet 1847) | 118. (Leighton 1985) |
| 15. (Brough 1984) | 67. (Dawson 1891) | 119. (Watson 1756) |
| 16. (Chandra and Singh 1971) | 68. (Stubbs 1966) | 120. (MacIntyre 1999) |
| 17. (Karavaeb 1950) | 69. (Marshall 1977) | 121. (Grierson 1986) |
| 18. (Biswas 1951) | 70. (Mayne 1862) | 122. (Mors and Rizzini 1966) |
| 19. (Biswas 1948) | 71. (Galloway 1982) | 123. (Hobbs 1986) |
| 20. (Uphof 1959) | 72. (Douglas 1914) | 124. (Smith 1921) |
| 21. (Kok 1966) | 73. (Thompson 1784-1812a) | 125. (Lightfoot 1777) |
| 22. (Crum 1993) | 74. (Thompson 1784-1812b) | 126. (Bhattarai <i>et al.</i> 1999) |
| 23. (Sharnoff 1984) | 75. (Thompson 1784-1812c) | 127. (Davis and Yost 1983) |
| 24. (Fernald and Kinsey 1958) | 76. (Carlson and Flett 1989) | 128. (Ohmura 2003) |
| 25. (Nelson 1951) | 77. (Moerman 1998) | 129. (Schultes & Raffaui 1990) |
| 26. (Upreti 2001) | 78. (Lal and Upreti 1995) | 130. (Moxham 1986) |
| 27. (Fink 1906) | 79. (Upreti 1996) | 131. (Moxham 1980) |
| 28. (Gioanetto 1993) | 80. (Upreti <i>et al.</i> 2005) | 132. (Moxham 1982b) |
| 29. (Turner and Bell 1971) | 81. (Llano 1956) | 133. (Moxham 1981b) |
| 30. (Stenberg 1868) | 82. (Oswalt 1957) | 134. (Moxham 1981a) |
| 31. (Turner & Thompson 2006) | 83. (Jacobj 1916) | 135. (Sastri 1953) |
| 32. (Andersson 1868) | 84. (Berzelius 1808) | 136. (Moiseeva 1961) |
| 33. (Hult 1918) | 85. (Piorkowski 1916) | 137. (Richardson 1988) |
| 34. (Compton 1993) | 86. (Eidlitz 1969) | 138. (Richardson 1991) |
| 35. (Subiyay, pers. comm. 2003) | 87. (Ahmadjian & Nilsson 1963) | 139. (Shah 1997) |
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| 37. (Anderson 1925) | 89. (Coppins and Watling 1994) | 141. (Saklani & Upreti 1992) |
| 38. (Blankinship 1905) | 90. (Hawksworth 2003) | 142. (Kumar <i>et al.</i> 1996) |
| 39. (Chesnut 1902) | 91. (Kartnig 1980) | 143. (Bhattarai 1999) |
| 40. (Coville 1897) | 92. (Lindley 1838) | 144. (Pennington 1963) |
| 41. (Cutright 1969) | 93. (Llano 1944) | 145. (Lindsay 1856) |
| 42. (Garth 1953) | 94. (Porsild 1953) | 146. (Sharnoff 1997) |
| 43. (Harmon 1800-1816a) | 95. (Rink and Lindorff 1856) | 147. (Smith 1933) |
| 44. (Harmon 1800-1816b) | 96. (Søchting 1990) | 148. (Czehura 1977) |
| 45. (Hunn 1997) | 97. (Wheelwright 1935) | 149. (Powers 1877) |
| 46. (Johnston 1970) | 98. (Presthegge 1954) | 150. (Emmons 1905) |
| 47. (Johnston 1982) | 99. (Heller 1981) | 151. (Emmons and Boas 1907) |
| 48. (Källman 1988) | 100. (Porsild 1945) | 152. (Anderson 2005) |
| 49. (Kane 1846-48) | 101. (Tychsen 1799) | 153. (Grinnell 1905) |
| 50. (Keddie 1988) | 102. (Singh <i>et al.</i> 2000) | 154. (Hellsen and Gadd 1974) |
| 51. (Lewis & Clark 1804-1806) | 103. (Christensen & Sipman 1998) | 155. (Hendryx & Davis 1991) |
| 52. (Mead 1972) | 104. (Smith 1973) | 156. (McClintock 1910) |

Appendix X cont'ed. Summary of human uses of lichens across the world

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| 163. (Turner 1998) | 204. (Mortimer 1735) | 244. (Sato 1968) |
| 164. (Wang <i>et al.</i> 2001) | 205. (Dampier and Sloane 1698) | 245. (Raymond 1945) |
| 165. (Parkinson & Cotes 1640) | 206. (Gourdon 1687) | 246. (Blair <i>et al.</i> 1911) |
| 166. (Smith 1923) | 207. (Steward 1738) | 247. (Gill 1983) |
| 167. (Stowe 1940) | 208. (Baumann 1960) | 248. (Cabrera 1996) |
| 168. (Hu <i>et al.</i> 1980) | 209. (Gilmore 1919) | 249. (Grady 2003) |
| 169. (Drummond 1861) | 210. (Jones, pers. comm. 2005) | 250. (Holloway & Alexander 1990) |
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| 172. (Main-Johnson 1997) | 213. (Darias <i>et al.</i> 1986) | 253. (Kokwaro 1976) |
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| 178. (Bolton 1960) | 219. (Shufer 2003) | 259. (Gifford 1967) |
| 179. (Cameron 1883) | 220. (Hearne 1795) | 260. (Garcia <i>et al.</i> 1990) |
| 180. (González-Tejero <i>et al.</i> 1995) | 221. (Parkman 1869) | 261. (Osorio 1982) |
| 181. (Martínez-Lirola <i>et al.</i> 1996) | 222. (Radisson 1668-1685) | 262. (Razzack and Fazal 1993) |
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