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A Review of Lichen and Bryophyte Elemental Content Literature with Reference to Pacific Northwest Species

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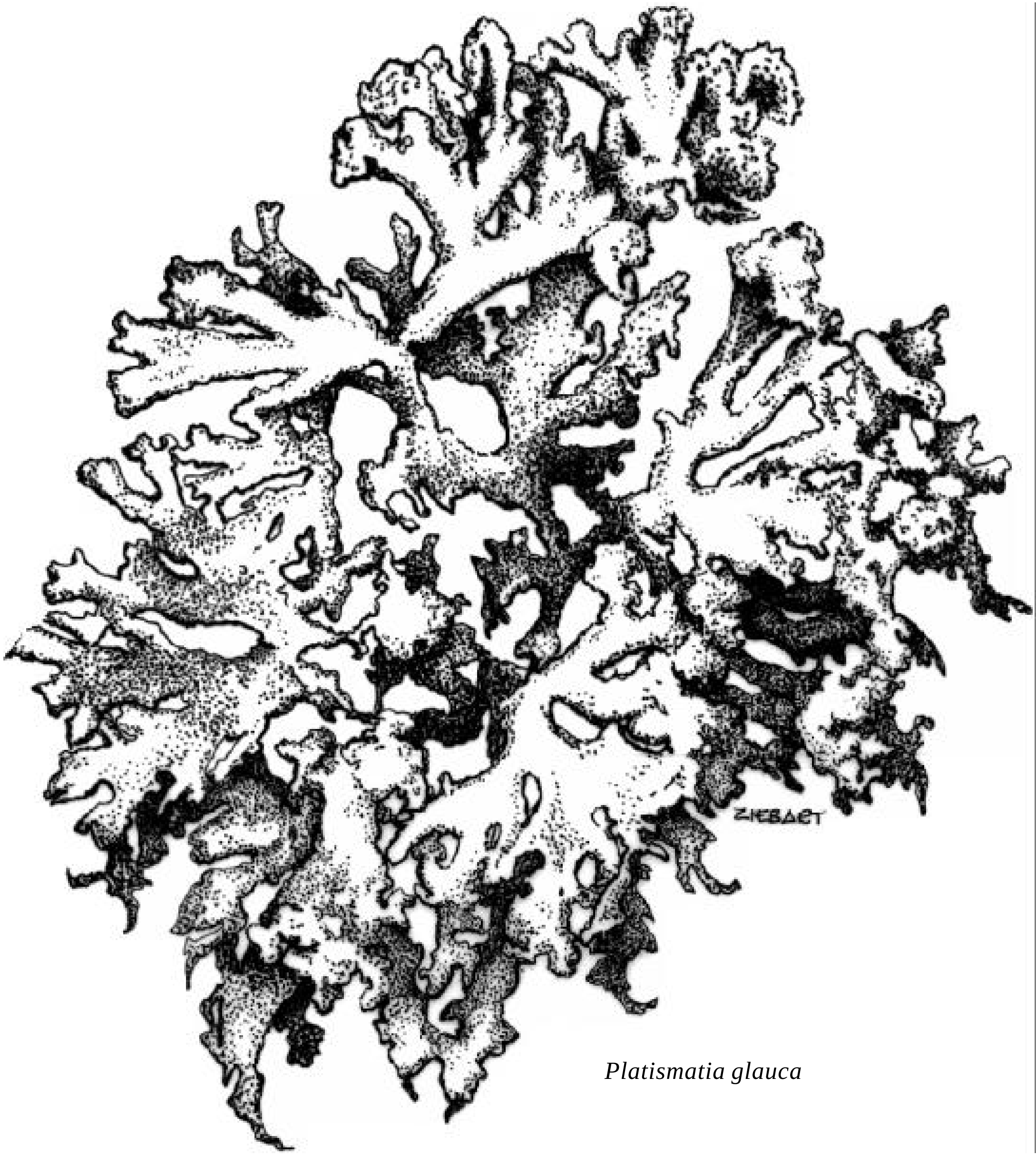

Platismatia glauca

A Review of Lichen and Bryophyte Elemental Content Literature with Reference to Pacific Northwest Species

Prepared for
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ABSTRACT

More than 500 references on the elemental content of lichens, mosses and liverworts are reviewed to facilitate the use of elemental analysis in environmental biomonitoring in the Pacific Northwest. An introductory section, four appendices, and a spreadsheet database are presented to help organize these studies: 1) an introduction to the subject, methodology, and review of the sources of elevated values for the more commonly-analyzed elements, including a table extracted from the spreadsheet database of species-specific background/enhancement levels for 8 lichen and 3 moss species of the Pacific Northwest, 2) a list of worldwide species and the studies that have used each species in elemental content work, 3) a list of common sources of enhanced levels of elements and the references referring to those sources, and 4) a matrix of elemental content for most commonly analyzed-for elements vs. Pacific Northwest species (listing reports for each species separately and including levels for other elements not in the main matrix).

TABLE OF CONTENTS

INTRODUCTION

The goal of this report and the associated appendices is to put in one place, information of use in interpreting analyses of elemental content in Pacific Northwest species of lichens and bryophytes. For the purposes of this report this region is defined as southeastern (coastal) Alaska, southern British Columbia, Washington, Idaho, western Montana, Oregon, and northern California. The separate database (Appendix C) at the end of this report (and available electronically) records levels of elements in 77 lichen and bryophyte species known to occur in the Pacific Northwest. The database matrix lists content of 17 elements commonly reported with additional records of other, less commonly reported elements. Appendix A provides cross-reference studies of species of lichens and bryophytes investigated worldwide for elemental content. Appendix B cross-references studies documenting the effects on elemental content of different potential sources of elements. The References section includes the literature cited in this report, its appendices and the database, plus other references providing background or describing techniques.

BACKGROUND

Lichens are symbiotic associations of algae and fungi that produce plant-like bodies that appear to be single organisms. Bryophytes are non-vascular plants that include mosses, liverworts and hornworts. Readers unfamiliar with the biology of these groups should consult any recent introductory botany textbook or one of the following resources for further details: Ahmadjian 1993, Hawksworth and Hill 1984, Lawrey 1984, Nash 1996, Rhoades 1995b, Schofield 1985, Schuster 1984. A number of identification manuals are available for these organisms in the Pacific Northwest (Goward and others 1994, McCune and Geiser 1997, McCune and Goward 1995, Pojar and Mackinnon 1994, Schofield 1992, Vitt and others 1988).

Many reviews have documented the use of lichens and bryophytes as indicators of environmental quality (Bates and Farmer 1992; Brown 1984; Burton 1990; Garty 1993; James 1982; LeBlanc and Rao 1974, 1975; Martin and Coughtrey 1982; Mhatre 1991; Nash and Wirth 1988; Rao 1982; Richardson 1981, 1992; Winner 1988). The literature on lichens and air pollution is periodically reviewed by Hawksworth (1974) and later, Henderson (1979). Stolte and others (1993) provide the most recent review focusing on lichens in North America.

Species respond to increasing levels of environmental chemicals by accumulating more of the chemical. More sensitive species are missing from regions with higher levels of substances to which they are sensitive. In many areas of the world, anthropogenic sources of pollutants have resulted in drastic reductions in lichen and bryophyte floras, particularly of sensitive, ecologically important, nitrogen-fixing lichen species (Henriksson and DaSilva 1978, Henriksson and Pearson 1981, Hallingbaeck 1986, Sigal and Johnston 1986, Wetmore 1989). Community inventory and analysis is an important tool for using lichens and bryophytes as environmental monitors (this topic is not dealt with further here -- consult the above general references).

More resistant species tolerate higher levels of substances that might harm other species, but the higher levels may cause changes to the resistant species. One of the changes elicited by such higher environmental levels is the increase in levels of these substances accumulated in lichen and moss tissues. Mechanisms by which elements are taken up and deposited, and their toxicity's are known but these broad topics are not further discussed in this report (see Brown 1976, 1987; Brown and Brown 1991;

Brown and Beckett 1984; Clough 1975; Garty and others 1995b; Richardson 1995; Richardson and Nieboer 1980; Takala and others 1994; Tyler 1989).

Lichens and bryophytes are affected at lower environmental concentrations of these elements than higher plants (Winner and others 1988). Therefore, enhanced concentration of these elements above background levels in resistant species of lichens and bryophytes can serve as an early-warning sign to higher plants and animals. In addition, lichens and bryophytes have important ecological roles and have been recognized by National Park Service, Forest Service, and Bureau of Land Management policies as in need of protection (Bennett 1983, Thomas and others 1993, USDA and USDI 1994).

There is a vast and growing literature devoted to some aspect of elemental content of lichens and bryophytes (the 500+ references included here attest to this). Use of elemental content in biomonitoring has a history of over 30 years, although use of the technique has expanded recently, particularly in Europe. A number of workers, primarily in the northwestern United States and Canada have begun to apply these methods in North America.

APPROACHES TAKEN IN ELEMENTAL CONTENT STUDIES

A number of resources provide overviews of the techniques and results of elemental content work (Bates and Farmer 1992; Burton 1990; Ferry and Baddeley 1976; Garty and others 1995b; Jackson and others 1993; Margot and Ramain 1976; Markert 1993; Martin and Coughtrey 1982; Nash and Gries 1995; Nieboer and others 1977, 1978; Nieboer and Richardson 1981; Pakarinen 1985; Puckett 1988; Richardson 1991; Richardson 1995; Schacklette 1965; Tuba and Csintalan 1993b; Tuba and others 1994). The goals of most studies are to provide regional baselines for long term monitoring, to assess regional environmental "loads" of elements, or to document impacts of point sources of elements. Elemental content has been shown to be correlated with the amounts of elements in the local environment (surrounding substrates, atmospheric gases and particulates, and precipitation) and to relate to sources geographically, latitudinally, altitudinally and temporally.

Elemental content can be analyzed in specimens collected from native substrates and locations (the vast majority of studies) or in transplanted material (Bartók and others 1992; Brown 1984; Gailey and others 1985; Garty 1987; Garty and Fuchs 1982; Garty and Hagemeyer 1988; Garty and others 1988; Holopainen 1984; Johnsen and others 1983; LeBlanc and others 1976; Palomäki and others 1992; Pilegaard 1979; Semadi and Deruelle 1993; Steinnes and Krog 1977; Tuba and Csintalan 1993a, 1993b). Most studies focus on elemental content in non-aquatic species, although there is a growing interest in using aquatic species, particularly bryophytes (earlier papers reviewed in Bates and Farmer 1992, Glime 1992, Johansson 1995, Mersch and Pihan 1993, Nelson and Campbell 1995, Roy and others 1996, Samecka-Cymerman and Kempers 1995, Sanchez and others 1994). Fruticose and foliose lichens are most often used in elemental content studies. Although, crustose species may be used if care is taken to remove the substrate. The general efficiency of accumulation of elements seems to be foliose > crustose > fruticose lichen species with bryophytes accumulating intermediate amounts of elements.

Lichens and bryophytes have also been used in the monitoring of environmental enhancement of other substances including radionuclides and organic compounds. These subjects are not dealt with further in this report and data from this work is not included in the database (a few of the many references considering these materials are included in Appendix B).

METHODOLOGIES

Jackson and others (1993) review the practical aspects, including study design, sample collection, preparation and analysis, and quality assurance and quality control. McCune (in Conkling and Byers 1993) provides a step-by-step description of the methodology developed for the elemental analysis indicator demonstration project for the Forest Health Monitoring program. Briefly, methodology consists of determination of the target species (based on availability of suitable amounts of a resistant species, preferably one that is easily collected and cleaned), collection and packaging (with appropriate attention to consistent sampling and proper handling), cleaning (perhaps with washing) and preparation for analysis.

A number of different analytical techniques can be used to determine levels of elements in tissues. The discussion by Jackson and others (1993) of the various techniques is particularly helpful in assessing these. A few of the most recent references for each analysis type are presented in the following list:

- **Atomic absorption spectrometry** - Sawidis and others 1995.
- **Combustion-IR analysis of total sulfur** - Jackson and others 1984.
- **Differential pulse polarography** - Flora and Nieboer 1980.
- **ICP-AES** - many papers: Geiser and others 1994, Hogan and Maynard 1985, Jackson and others 1993, Munter and others 1984.
- **Ion chromatography** - Basta and Tabatabai 1985, Busman and others 1983.
- **Neutron activation analysis** - Freitas 1993a, 1993b, 1994, 1995; Freitas and others 1993a, 1993b, 1994, 1995; Frontasyeva and Steinnes 1995; Grass and others 1994; Nazarov and others 1995; Steinnes and Njastad 1995).
- **Proton Induced X-ray or Gamma-ray Emission** - Szymczyk and others 1991.
- **SEM Electron microprobe analysis** - Asta and Garrec 1980.
- **X-ray microanalysis (X-ray fluorescence)** - Boileau and others 1982, Calliari and others 1995, Favali and others 1991, Richardson and others 1995.

Many of these methodologies have not been fully tested for accuracy and consistency. Gailey and Lloyd (1986) examined the replicability of analysis of metals in lichens. Frontasyeva and others (1995) compare the results of elemental analysis of moss tissue obtained by several different analytical methods. Recent references may use more accurate versions of the various analytical procedures and some (Calliari and others 1995, Derr 1997, Geiser and others 1994, Lodenius and Tulisalo 1995, Quevauviller and others 1993, Richardson and others 1995) include tests of the effects on the results by varying parameters of sample collection, sample preparation, and analytical procedure.

One aspect of analysis that has not been considered adequately in this country is the establishment of lichen and bryophyte standards. Such standards would provide a common reference point, rather than having to rely on higher plant standards (needles or leaves) that may contain levels of elements that differ significantly from those found in lichens and bryophytes. Some attempt has been made to develop such standards in Europe (Freitas 1993b; Freitas and others 1993b, 1994; Quevauviller and others 1996). In this country several workers (Geiser and Boyll 1994, Gladney and others 1987, Horowitz and Albert

1991, Munter and others 1984, Parr and Zeisler 1994, Stone and others 1995, Wetmore 1987d) have given thought to developing such standards.

DATA DISPLAY AND ANALYSIS

Nieboer and Richardson (1981) provide an overview of how researchers have approached data interpretation. Early papers tend to report single values or simple arithmetical means while later reports use statistical means to display and interpret complex patterns which may exist in the results. Many reports use graphical analyses or mapping to effectively display large sets of data. Data analysis falls into two categories: 1) determination of background/enhanced level cutoffs, and 2) assigning probable sources of any suspected enhanced elements.

The terms "background" and "baseline" can be confused. The term "background level" refers to the normal elemental content in a species in environments without enrichment of elements from natural or anthropogenic sources. Determination of background levels can be tricky, since natural levels vary with enrichment from wind-blown soil, marine aerosol, volcanic gases, and other natural sources, and by species. Techniques for making such determinations vary and are often somewhat subjective. Early determinations (Nieboer and others 1978, Nieboer and Richardson 1981, and LeBlanc, as cited in Winner 1988) are based on perusal of prior reports with consideration of the presence or absence of obvious sources of enhancement, and combine all species. These values are listed in the attached database and broadly define the effects of enhancements from several categories of sources on the general levels of mixed species. Recent work may determine such values objectively from means in single or mixed species. Grodzinska (1978) and Rhoades (1988) use objective multivariate range tests (following ANOVA) to determine background/enhanced cutoff values. Recent study shows that different target species accumulate substances differently. More narrowly defined ranges can be determined for many element-species combinations (see database and Table 1, below).

The term "baseline level" refers to the elemental content in collections from a given area that are being recorded as historical points of reference. Baseline levels may be higher than suspected "background" values if the given collection is subject to enrichments from natural or anthropogenic sources.

A variety of statistical techniques are useful in helping to organize, review and interpret elemental content data and to relate content to potential sources of elements. Will-Wolf (1988) presents a review of considerations in sample design that will result in data that can be appropriately analyzed with multivariate techniques (see also Hooper and Peteres 1989; Kuik and Wolterbeek 1994, 1995). Analysis of variance can help assign the variation in observed elemental levels to effects due to sampling and analytical procedures, biological differences or environmental effects (Brown and Brown 1991, McCune and others 1993, Puckett and Finegan 1980, Rhoades 1988, Sloof and Wolterbeek 1991a, Sloof and Wolterbeek 1993b). Inter-element correlation’s often show definite patterns within species (Bargagli and others 1989; Bruteig 1993; McCune and others 1993; Percy and Borland 1985; Rhoades 1988, 1995a), while interesting inter-species patterns are also shown (Folkeson 1979, Rhoades 1988, Sloof and Wolterbeek 1993a).

Ratios of one element to another may help clarify environmental sources of changes in content (Hyvärinen and Crittenden 1996). Enrichment factors may help determine nearby soil as a source for elements (Addison and Puckett 1980, Bennett 1995, Nieboer and others 1978, Nieboer and Richardson 1981, Puckett 1988, and Puckett and Finegan 1980). Enrichment factors relate tissue content to relative content in nearby soil, using the levels of an element restricted to soil, such as titanium, silicon and sometimes aluminum or iron. Isotope ratios (of iron, lead and sulfur) have been used to apportion sources of enhanced levels of elements.

Visual assessment of data often helps uncover and clarify complex relationships. In the Pacific Northwest, mapping was first used by Rhoades (1988) who combined standardized values (by dividing observed levels in each species by the background cutoff value for that species) from five species to show tissue element levels distributed around the perimeter of Olympic National Park. Geiser and others (1994) present their data from southeast Alaska using geographically oriented surface plots of lichen elemental content. The most ambitious mapping study to date combines moss data from a number of researchers to produce Europe-wide distribution maps of atmospheric heavy metal deposition (Rühling and others 1992, 1994, Wolterbeek and others 1995). Plotting of the locations of point or regional sources on mapped data is very revealing in all these studies. Graphing and regression analysis of tissue content related to distance from suspected sources is a useful tool in interpreting possible sources for enhancements (Beckett and others 1982, Dillman 1996, Rhoades 1988).

Factor analysis (Sloof 1995b) and principal components analysis (Berg and others 1995b; Puckett and Finegan 1977, 1980) have been used to apportion complex patterns of elemental content to possible source patterns. Various other multivariate methods of analysis are used by Addison and Puckett (1980), Ammann and others (1987), Aulio (1980), Berg and others (1995b), Campbell (1976), Fuchs and Garty (1983), Gough and Erdman (1977), Percy and Borland (1985), Puckett and Finegan (1980), Schaug and others (1990), Sloof and Wolterbeek (1991b), Thomas and others (1984), Zechmeister (1995).

Despite the obvious advantages of using elemental content of lichens and bryophytes to monitor environmental levels of elements, and the considerable history of this usage, the subject is not without its critics. Brown (1991b) and DeBruin (1985) discuss some of the controversy surrounding elemental content studies. Seaward (1995) describes a number of considerations that could compromise results from elemental content studies. These include difficulties in taxonomy, questions regarding the time-scales studied, consistency of habitat, standardization of techniques, and expression of results. Elemental content data can suffer from high variability and non-normal distribution. The former problem can be partially controlled by careful sample collection and preparation, and by adequate sample numbers. Rhoades (1988) documented very different uptake levels of anthropogenic elements (such as lead and sulfur) in single lichen species collected from different substrate locations (lower trunk and canopy of Douglas-fir). Restricting collections to one seasonal time frame may also help as element content is known to vary temporarily (Puckett 1985). The problem of non-normality can be controlled by data transformation (Gough and others 1977, 1985, 1987, 1988a, 1988b; McCune and others 1993; Rhoades 1995a).

SINGLE SPECIES BACKGROUND/ENHANCED CUTOFF VALUES

The separate database included with this report presents levels of elements in 77 lichen and bryophyte species known to occur in the Pacific Northwest as reported in 97 world-wide reports using those species. The database matrix lists content of 17 elements commonly reported with additional records of other, less commonly reported elements.

For each species-element where there is adequate data in the database, the reported levels were examined and estimated cutoff values between background and enhancement were determined. Table 1 extracts these estimates from the database. The determination of background/enhanced cutoff levels was done somewhat subjectively, taking into account the locations relative to sources of enhancement, the number of observations on each element and the reliability of references. Some species (e.g. *Hypogymnia physodes*, with over 30 reports) have more complete data from which to make such determinations. The enhancement status is easier to determine for some elements known to be high in environments around certain sources. Other elements are difficult to interpret because they are particularly prone to enhancement from wind-blown soil particles or their levels may decrease in environments showing enhancements of other elements (see the element-by-element discussion below for further consideration of these factors). Potential enhanced cutoff levels of some of the element/species combinations that are not in Table 1 may sometimes be determined by reference to the database.

Table 1. Estimated background/enhanced cutoff values for selected elements in selected Pacific Northwest species of lichens and mosses. All values are in parts per million (ppm).

	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn
General lichen enhancement levels[1]																		
Seashore enhanced	[2]				40000-55000			2000-3000		1000-12000	300-350		10-120		5000-9500	1000-6000		
Urban/industrial enhanced								14000-90000	100-12000		350-5000						2000-13000	1000-13000
Mine/smelter enhanced	1300-1900			30-330		25-130	15-1100	400-16000	100-12000				10-300					2000-25000
Northwest lichen species																		
Alectoria sarmentosa	50	0.50?	<2.0?	0.20?	2500	0.50	1.50	40	5	250	80		0.60	500	1500	75	350	25
Cladina rangiferina	250		<2.0?	0.20?	500	0.50	2.00	200	2.00	400	50		0.80	350	2000	60	500	20
Hypogymnia enteromorpha	500		3.0	0.25	10,000?	2	4	400	15	500	75		1.5	900	2400	200	750	35
Hypogymnia physodes	700	4.0	2.0?	0.25	5000?	3	7	800	20	800	50		4	1500	4000	100	750	60
Lobaria oregana	200		<2.0?	0.20?	600	1	5.00	100?	1.75	450	60		0.60	2000	7000	150	1200	50
Parmelia sulcata	2500	5.0		5.0	5000	30	30	4000	40	750	75	10?	25	800			1200	350
Peltigera canina	1000	5.0?		3.5?	4000	5	15	1000	50	1000?	225?		10	3000?	12000?	350?	2000?	175
Platismatia glauca	500		4.0	0.25	1500	2	3	750	25	500	150		2	1100	2500	90	600	30
General moss levels																		
Moss background[3]				0.1			2	500	30				2					30
High moss level[4]		0.81		0.8		10.8	13.5		62				6.5					83
Northwest moss species																		
Hylocomium splendens	700	0.6	40	0.5	10000?	2	10	300	20	3000?	200?		3			300?	1000?	50
Hypnum cupressiforme				1.0	10000?	3?	11	1500?	50	3000?	200?	200?	5		5000?	175?		90
Pleurozium schreberi		2.0		2		10	15	1200	60		150		4.5				1000?	80

1 Nieboer and others (1978) for undefined lichen species
2 empty cells = not determined or not enough data for a determination
"?" = estimates for element levels are very approximate because of incomplete data for element in that species
"<" = the cutoff level may be below the usual limit of detection.
3 LeBlanc (1969) as cited in Winner (1988). General background based on means from Pleurozium schreberi, Hylocomium splendens and Leucobryum glaucum from North America and Scandinavia.
4 Gydesen and others (1983). Data from various regions of Sweden presented in Table 3 of Puckett (1988).

The data in Table 1 support the view that different species retain elements in different amounts (Garty and others 1996a, Rhoades 1988, Sloof and Wolterbeek 1993a, Steinnes 1993). This is not surprising since different species likely have different physical, biological, and physiological mechanisms to uptake and hold these elements and different physiological needs for different elements. Air-pollution-sensitive, fruticose or epiphytic species (such as *Alectoria sarmentosa*, *Cladina rangiferina* and *Lobaria oregana*) show lower background levels of most elements and, hence, lower levels that indicate enhancement. On the other hand, particularly resistant epiphytes and terrestrial species (such as *Hypogymnia enteromorpha*, *Parmelia sulcata*, *Peltigera canina* and *Platismatia glauca*) show higher background loads and correspondingly higher enhancement levels. It is clear that the general levels of enhancement given by Nieboer and others (1978) are higher than shown in sensitive species (and too high for all species for elements such as Pb, S and Zn and perhaps Mg). As further observations are made and interpreted, the ranges of these enhancement cutoffs for individual species can be refined and added for other species.

NORTHWEST STUDIES

Studies of elemental content of lichen species in the Pacific Northwest have appeared periodically since the late 1970's. Fewer mosses have been used in this work and no bryophyte species have been used region-wide in the Northwest. Species of lichens most commonly used in the forested regions include the epiphytic species, *Alectoria sarmentosa*, *Hypogymnia enteromorpha*, *H. physodes* (this species has the largest use world-wide of any species -- see Appendix A and database), and *Lobaria oregana*. In terrestrial studies, *Cladina rangiferina* and *Peltigera canina* have been found most useful. Appendix A cross-references all lichen/bryophyte species world-wide with references that report elemental content. This list may be used to complete a survey of all relevant references to Northwest species when data from them is not included in the database, or to examine the results and discussions concerning related, non-Northwest species. Peterson and others (1992) provide a list of air pollution sensitivities of Northwest species that may be useful in developing and interpreting studies of interest.

Region-wide comparison of elemental content of lichens from the Pacific Northwest begins indirectly in the paper by Pike (1978) on mineral cycling in lichens. Pike discusses the mineral capital of the biologically-mobilized elements nitrogen, phosphorus, potassium, calcium, and magnesium in five lichens (data from three species, *Lobaria oregana*, *Usnea subfloridana* and *Alectoria sarmentosa*, are from Northwest studies). Wiersma (1981) reports on lead, copper and aluminum content in two terrestrial mosses (*Hylocomium splendens* and *Rhytidiadelphus loreus*) on the west coast of the Olympic Peninsula. Initial testing showed that elemental analysis of mosses gave more reliable and consistent results than vascular plant samples. Wiersma and others (1987) extend the earlier study, adding results from analysis for additional heavy metals and other elements. Values for *Hylocomium splendens* were among the lowest values found in any biological material to the date of that study, suggesting the pristine nature of the environment in the Western Olympics. Taylor and Bell (1983) focus on the distribution of sulfur in *Alnus* leaves downwind from a Whatcom County oil refinery. Their report includes a range of sulfur content observed in the lichen, *Hypogymnia physodes*.

Frenzel and others (1985, 1990) compare heavy metals (arsenic, zinc, copper, cadmium and lead) and sulfur content in *Alectoria sarmentosa* at high elevation sites in Mt. Rainier and Olympic National Parks. All elements but lead were higher at the Mt. Rainier sites. These high levels were attributed to downwind enhancement from the copper smelter in operation in Tacoma until 1985. The levels (except lead) in Olympic National Park were highest at the eastern-most sites, again pointing to the general influence of the Tacoma/Seattle urban air basin. Palmer (1986) analyzed elemental content (in single samples) of 16 species of lichen and moss in her study establishing baselines at forested sites in southwestern British Columbia. Gough and others (1987, 1988a) established baselines for a number of heavy metals and other elements in *Hypogymnia enteromorpha* and *Usnea* spp. from an ultramafic region of Redwood National Park.

Rhoades (1988) presents the first large-area, multisample, multielement study of element content in five epiphytic lichens on Douglas-fir around the perimeter of Olympic National Park. In this study an attempt is made to establish background levels expected in each of the five species, by statistical evaluation of the distribution of values for each species. In addition, geographical distributions of tissue levels of each element are accomplished by averaging normalized (against each species-element's background value) values for all species in all sites around the Park. In general, levels of elemental content in Olympic National Park lichen species are well below the minimum enhanced levels expected for lichens. However, maximum levels in Olympic National Park exceeded enhanced cutoff levels for lichens for the following elements: S, P, Mg, Al, Fe, Mn, Pb and Ni. With the exception of Mn, Mg and Al, the highest Olympic National Park values relative to background levels found in lichens collected along the Heart of the Hills Parkway on the north side of Olympic National Park.

Enns (1989) compared element content of species analyzed in her original baseline study (Palmer 1986) with content in newly collected samples of the same species. Despite the small sample number (one large sample per species), she demonstrates a general trend of increase in levels of many elements with anthropogenic sources. Enns and Bio (1990) report on their establishment of a biomonitoring network near a future gold-ore roaster project in northwestern British Columbia. Included in this report are values of elemental content in the terrestrial species, *Peltigera aphthosa* and *Cladina stellaris*, unfortunately reported together as "lichen". The elevated levels of a number of elements document the mineral-rich status of the area.

Considerable elemental content work has been recently finished or is on-going with support from the USDA Forest Service in southeast Alaska (Derr 1994, 1997; Geiser 1991; Geiser and others 1994), Washington (Lesher and Henderson, pers. comm.), and Oregon (Geiser 1993, Geiser and Boyll 1994). These reports establish baselines for the regions in question and begin to assess the impact of natural and anthropogenic sources on lichen elemental content. Dillman (1996) reports on the elemental content of *Rhizoplaca melanophthalma* as related to the emissions from a phosphate refinery in Idaho. Most of these studies benefit from the use of larger numbers of samples and from more complete statistical analysis of the data than were used or was carried out in earlier studies in the region.

Further discussion of the results from these studies are included in the element-by-element discussion below.

ELEMENT BY ELEMENT DISCUSSION

Assuming the levels of elements found in lichens and bryophyte species are statistically valid, the interpretation of this data may be difficult because natural and anthropogenic sources of elements vary and may be compounded for a given element, and the mechanisms of uptake and storage and levels of toxicity vary from species to species and from element to element. In as much as elements play natural roles in lichens (either as constituent parts of lichens or in nutrient cycling) it is useful to reflect on these natural roles while interpreting element content data (Brown and Brown 1991, Pike 1978, Richardson 1995, Tyler 1989). In addition, the uptake of one element can be directly influenced by the levels of others in tissues (Richardson and others 1979).

There has been particular interest in analysis for anthropogenically-enhanced elements such as sulfur, fluorine, lead and other "heavy metals". The following discussion focuses on these elements. In regards to the category, "heavy metals", Nieboer and Richardson (1980) propose that the term "heavy metals" be abandoned in favor of a classification which separates metal ions into functional groups: class A (oxygen-seeking: K^+, Ca^{++}, Sr^{++}), class B (nitrogen/sulfur- seeking: Ag^+, Hg^+, Cu^+) and borderline (or intermediate: Zn^{++}, Ni^{++}, Cu^{++}, Pb^{++}).

In the following discussion, particular reference is made to several sources of general values reported for lichens (Nieboer and others 1978, Nieboer and Richardson 1981) and for bryophytes (Gydesen and others 1983, and Winner 1988). The background/enhanced cutoff levels for individual species often can be narrowed or will differ significantly from these general values (Table 1). At this time, no effort has been made to narrow the discussion based on these species' cutoffs because of their preliminary nature. The discussion of values in Olympic National Park lichens is from Rhoades (1988, with some modification) and relates levels observed in lichens to levels in air samples from the region (Davidson and others 1985). Data from other northwest studies are included if the levels of an element were deemed enhanced. Two tables in Martin and Coughtrey (1982) cross-reference literature resources up to 1981 that deal with specific heavy metals in specific lichen and bryophyte species. Puckett (1988) provides a useful table reviewing point source studies using both mosses and lichens (see also Appendix B).

Aluminum

Aluminum generally is enhanced in lichens that have been exposed to crustal elements in local soils. Atmospheric levels near highways may be enriched due to automobile exhaust or road dust (Pacyna 1986). Industrial emissions (from aluminum smelters, coal-fired power plants, cement manufacturing plants, and waste incinerators) and general urban emissions are enriched sources of aluminum (Harte and others 1991). Aluminum may also be enriched in areas with clayey soils. Background levels of aluminum in lichens are below 400 ppm while enhanced levels are usually above 1000 ppm (Nieboer and others 1978). No background levels of aluminum in bryophytes were determined in the references reviewed.

In Olympic National Park, uptake of aluminum differs significantly within and between different species (Rhoades 1988). Levels of aluminum in *Hypogymnia enteromorpha* vary from 225 ppm to 1430 ppm. The highest values in this species near the Heart of the Hills Parkway suggest either road dust or automobile exhaust as a source. Enhanced levels in other species are in samples from northern and southern locations in the Park and do not occur at sites with high levels of anthropogenic elements such as Pb and S, suggesting that most of the enhancement in the Park is due to crustal sources.

Background aluminum for Olympic National Park were calculated at 800 ppm for *Hypogymnia enteromorpha*, 700 ppm for *Hypogymnia physodes*, 29 ppm for *Alectoria sarmentosa* and 69 ppm for *Sphaerophorus globosus*. The range in these values again suggests that the various species differ in how they take up this element. The relatively high background levels (relative to accepted literature backgrounds, at least for *Hypogymnia enteromorpha* and *Hypogymnia physodes*), points to a crustal source of this element throughout Olympic National Park. The pattern of distribution of aluminum in Olympic National Park lichens does not seem to follow the pattern of aluminum seen in airborne samples by Davidson and others (1985).

Some samples of *Peltigera aphthosa* collected to establish baseline levels of elements near a gold mine in northwestern British Columbia showed elevated levels of aluminum (Enns and Bio 1990). Geiser and others (1994) attributed higher levels of aluminum around Sitka, Alaska to the presence of this element in disturbed road dust.

Arsenic

Arsenic is emitted to the atmosphere mainly from coal combustion, locally from mining, and minor emission sources include the glass industry and uses in pesticides and wood preservatives (Rühling and others 1994). Arsenic is found associated with other metals as arsenide ores. As such it can be a serious waste product from the smelting of metals, particularly copper, nickel and chromium. Arsenic is also used in bronzing, pyrotechny and hardening of shot. Background levels of arsenic in lichens are below 1.5 ppm while potentially enhanced levels observed around urban emission sources range from 1 to 5000 ppm (Nieboer and Richardson 1981). Levels of arsenic in mosses near sites with air pollution range from 2 to 4 ppm (Winner 1988). Some samples of *Peltigera aphthosa* collected to establish baseline levels of elements near a gold mine in northwestern British Columbia showed elevated levels of arsenic (Enns and Bio 1990). Arsenic was not analyzed in Olympic National Park lichens (Rhoades 1988).

Boron

Boron may be elevated in some soils associated with volcanic springs and may be used in some manufacturing processes. Boron can be elevated in vehicular exhausts (Fuchs and Garty 1983). Background and enhanced levels of boron were not established in lichens by Nieboer and others (1978), or any general bryophyte work, but levels of 17 ppm were considered high in a study of saxicolous lichens in New Mexico (Nash and Somerfield 1981).

In Olympic National Park lichens, levels of boron ranged from 0.68 to 7.4 ppm, with the highest values seen at the north end of Olympic National Park along the Heart of the Hills Parkway (Rhoades 1988). In addition, there was a statistically significant decreasing relationship of boron content in some species with distance away from Port Angeles, suggesting that urban area as a source.

Geiser and others (1994) found elevated levels of boron throughout the region near Sitka, Alaska, with especially high values near the sulfite pulp mill.

Cadmium

Cadmium often occurs with zinc ores, is used in electroplating, and is an important component of bearing alloys. In addition, cadmium can be spread by the use of phosphate fertilizers and through the combustion of fossil fuels (Rühling and others 1994). Surface layers of the ocean are also sources for this element (Davidson and others 1985). Cadmium can be enhanced near urban and industrial areas particularly because of the use in bearings, with levels in nearby lichens of 30 to 330 ppm. Cadmium can also be released in significant quantities from volcanic eruptions and, in the emissions from municipal waste incineration from the disposal of nickel-cadmium batteries (Harte and others 1991). Background levels in lichens are between 1 and 30 ppm (Nieboer and others 1978), although Nieboer and Richardson (1981) indicate that enhanced levels of as low as 1 ppm have been observed near industrial areas. In bryophytes, levels above 0.8 ppm may be enhanced (Gydesen and others 1983).

Levels of cadmium in Olympic National Park lichens were very low (below limit of detection of ICP-AES to 0.44 ppm; Rhoades 1988). Distribution of these values did not reveal peaks. Davidson and others (1985) found cadmium to be enriched in airborne samples relative to crustal aluminum, suggesting a marine influence. The finding that lichens in Olympic National Park are not universally enhanced in cadmium suggested that the marine influence may not be effective for this element.

Some collections of *Peltigera aphthosa* collected to establish baseline levels of elements near a gold mine in northwestern British Columbia showed elevated levels of cadmium (Enns and Bio 1990). Geiser and others (1994) found elevated levels of cadmium near the sulfite pulp mill and the town incinerator of Sitka, Alaska.

Calcium

Calcium is the fifth most abundant metallic element in the earth's crust and particularly abundant in areas with limestone. However, crustal enrichment is a common source of elevated values everywhere, particularly where crustal sources are exposed as near unpaved roads. Calcium is found enriched in lichens near the seashore (Nieboer and others 1978), where levels may exceed 40,000 ppm. Nieboer and Richardson (1981) define background levels in lichens as < 1000 ppm for strictly rural areas (presumably without marine or crustal influences). Laaksovirta and Olkkonen (1979) found calcium to be a good indicator of airborne dust from roadways in Finland. An enhanced level of calcium for bryophytes has not been defined in the general references reviewed. High levels of calcium can confer protection to lichens from the damaging effects of sulfur dioxide (Nieboer and Kershaw 1983, Richardson and others 1979). Calcium levels in lichens also vary according to the status of "heavy metal" elements in the thalli (Markert and Wtorova 1992).

Levels of calcium for lichens in Olympic National Park were all within background range as defined by Nieboer and others (1978) but ranged upwards to 19,263 ppm (Rhoades 1988). The general pattern of distribution of higher values in most species suggested a marine source for calcium in Olympic National Park lichens. However, the highest value observed in *Hypogymnia physodes* in the Dungeness River area suggested high calcium in dust from a nearby logging road. Otherwise, the pattern of distribution of calcium in lichens followed the pattern of calcium seen in airborne samples by Davidson and others (1985).

Derr (1994) found some relatively high values for calcium in *Alectoria sarmentosa* throughout southeast Alaska which was attributed to the marine influence. Geiser and others (1994) found depressed levels of calcium near the sulfite pulp mill (reflecting the damaging effects of other, elevated elements) near Sitka, Alaska, but an elevated value elsewhere was interpreted as influenced by salt spray.

Chromium

Chromium resembles iron in its chemical characteristics and is often found with iron in ores. It is extremely important in the manufacture of steel alloys, and is used in catalysts, electroplating, pigment manufacture, leather tanning and some wood preservatives (Harte and others 1991). Chromium can occur as a byproduct of the combustion of coal (Rühling and others 1994). It is also used to prevent corrosion in power plant cooling towers and can be released into the atmosphere in steam released from such towers (Harte and others 1991). Chromium can be enhanced near urban/industrial areas, with levels of 25 to 130 ppm. In addition, chromium is often higher in soils in ultramafic regions (Kabata-Pendias and Pendias 1984). Background levels in lichens are between 0 and 10 ppm (Nieboer and others 1978), although Nieboer and Richardson (1981) indicate that enhanced levels of as low as 4 ppm have been observed near industrial areas. Levels of about 10 ppm in bryophytes were considered enhanced (Gydesen and others 1983).

Levels of chromium in Olympic National Park lichens were all within the first background range (below limit of detection of ICP-AES to 6.4 ppm; Rhoades 1988). Distribution of the highest values showed a similar pattern to nickel, iron and aluminum, with high values to the north and south in Olympic National Park.

Some collections of *Peltigera aphthosa* collected to establish baseline levels of elements near a gold mine in northwestern British Columbia showed elevated levels of chromium (Enns and Bio 1990). Geiser and others (1994) found elevated levels of chromium near the ferry terminal at Sitka, Alaska. Despite the ultramafic nature of the surrounding soil parent material in the northern part of Redwood National Park, chromium was not elevated in *Hypogymnia enteromorpha* and *Usnea* spp. there (Gough and others 1987, 1988a).

Copper

Copper levels are enhanced around smelters and areas where copper is mined, urban areas and in regions with marine influence (Davidson and others 1985). In addition, copper may be locally enhanced in areas where copper-containing fungicides are used (Rühling and others 1994). Nieboer and others (1978) give background ranges in lichens of 1 to 50 ppm and enhanced ranges of 15 to 1100 ppm. Levels as low as 13.5 ppm may be enhanced in bryophytes (Gydesen and others 1983).

Levels of copper in lichens in Olympic National Park were all below accepted enhanced values (highest value was 7.6 ppm in *Hypogymnia enteromorpha* along the Heart of the Hills Parkway; Rhoades 1988). As with zinc, a statistically significant negative regression slope of copper content in *Hypogymnia enteromorpha* versus distance from the Heart of the Hills Parkway suggested that higher values closer to the Parkway, though below enhanced levels, may be due to uptake of small amounts of the element from vehicular exhaust. Davidson and others (1985) found levels of copper in air in Olympic National Park sites enriched relative to values for aluminum, suggesting a noncrustal (perhaps marine) source for this element.

Enns (1989) found regional increases in copper content in a number of lichens and bryophytes sampled in southeastern British Columbia when comparing single samples of each species from 1986 and 1988. Geiser and others (1994) found elevated levels of copper near the sulfite pulp mill at Sitka, Alaska.

Fluorine

Fluorine is released into the environment in the form of fluoride in areas around aluminum smelting, brick firing, glass making, the production of fertilizers and phosphorus, and some volcanic eruptions (Richardson 1992). Fluorine is also a component of older refrigerants. Nieboer and Richardson (1981) defined levels above 12 ppm as enhanced in lichens. Levels above 6 ppm may be enhanced in bryophytes (Rao and LeBlanc 1966). Damaging effects of this element seem more localized than for sulfur dioxide emissions (LeBlanc and others 1971).

Fluorine was not analyzed in Olympic National Park lichens (Rhoades 1988), nor in any other northwestern study.

Iron

Enhanced iron, like aluminum, can indicate crustal sources, but the element is also enriched in anthropogenic sources (for example, roadside environments may be enhanced in all elements of steel because of the abrasion of the metals from automotive engines that ends up in exhaust). Iron mining and smelting and the fly ash from coal burning also release iron into the atmosphere (Rühling and others 1994). Nieboer and others (1978) give background ranges in lichens of 50 to 1600 ppm and enhanced ranges of 400 to 90,000 ppm, with the highest levels near smelters and urban/industrial areas. Nakamura and Inoue (1991) showed that stable iron ($^{54}Fe/^{58}Fe$) isotope ratios in two lichen species varied according to lichen growth activity at a site in Antarctica. Levels above 1550 ppm may be enhanced in bryophytes (Rao and LeBlanc 1967). Levels of 800 ppm iron have been shown to cause morphological damage in sensitive *Peltigera* spp. (Goyal and Seaward 1982a).

Background and enhanced levels in Olympic National Park lichens paralleled almost exactly the levels of aluminum, with highest levels to the north and south (Rhoades 1988). The two elements always showed very high correlations within a species across all sites in Olympic National Park. Highest levels ranged from 1988 ppm in *Hypogymnia enteromorpha* to 108 ppm in *Alectoria sarmentosa*. The pattern of distribution of iron in lichens does not seem to follow the pattern of iron seen in airborne samples by Davidson and others (1985).

Some collections of *Peltigera aphthosa* collected to establish baseline levels of elements near a gold mine in northwestern British Columbia showed elevated levels of iron (Enns and Bio 1990). Geiser and others (1994) attributed higher levels of iron around Sitka, Alaska to the presence of this element in disturbed road dust.

Lead

Lead may be locally enhanced around mining areas and in various industrial areas. Long-range atmospheric transport of lead from the densely populated areas has resulted in regionally enhanced levels of this element in Europe (Rühling and others 1994). Lead is also enhanced in regions with marine influence (Davidson and others 1985). There has been considerable discussion in the past about the uptake of lead in lichens along roadways. In studies analyzing the relationship of lead content in lichens to distance from roadways, content decreases rapidly and reaches regional background levels between 60 and 200 m distance. Results from recent lichen community studies and some elemental content studies (Halonen and others 1993, Lawrey 1993) document the known reductions in the amount of lead being released in vehicle exhaust from gasoline additives. However, in spite of reductions in use of leaded fuels, lead is still a component of vehicular emissions as a whole (Pacyna 1986). Background levels in lichens as given by Nieboer and others (1978) are from 5 to 100 ppm while enhanced levels are above 100 ppm. Nieboer and Richardson (1981) lowered this limit and suggest that values of lead above 15 ppm should be considered enhanced in lichens. In bryophytes, levels of 62 ppm are considered enhanced (Gydesen and others 1983).

Levels of lead in lichens in Olympic National Park were low (below limit of detection to 41 ppm) except for samples immediately along the Heart of the Hills Parkway (Rhoades 1988). Statistically significant negative slopes occurred in the regressions of lead content in *Hypogymnia enteromorpha* and *Alectoria sarmentosa* on distance from the Parkway, suggesting that higher values closer to the parkway, though below enhanced levels, may be due to uptake of the element from vehicular exhaust. The values of lead observed in *Hypogymnia physodes* were about one- half of those seen by Laaksovirta and others (1976) along roadsides in Finland and about one-third of those seen by Lawrey and Hale (1981) in rural areas of the northeastern United States. The highest values in individual samples in Olympic National Park were 10.3 ppm in *Alectoria sarmentosa* and 88.3 ppm in *Hypogymnia enteromorpha*. Solution of the regression equations for lead at 100 m distance, suggested background levels of 34 ppm in *Hypogymnia enteromorpha* and 0.4 ppm in *Alectoria sarmentosa*. The background levels calculated by comparing distribution of values from sites throughout the Park were 13 ppm and 4 ppm for these two species.

The picture of lead distribution in Olympic National Park is confusing when one compares various studies (Davidson and others 1985, Frenzel and others 1985, Frenzel and Starkey 1987, Rhoades 1988, Wiersma 1981) which have looked at the element in the Park. The influence of road traffic seems to be the most consistent factor in contributing to high lead levels in the past, although regional sources from the east may also contribute. Lead isotope ratios can be used to assess specific sources of increased levels of this element (Jaakkola and others 1983). Using lead isotope tracers (and likely true for other elements of anthropogenic origin), Fox and Ludwick (1976) show wind patterns commonly carry air from the Portland, Oregon -- Vancouver, Washington metropolitan area down the Columbia River valley, out to sea and back onto the Olympic Peninsula. Considering this fact, air masses moving over the west coast of Washington may not be as pristine as many imagine.

Most of the elevated values of lead in lichens around Sitka, Alaska were attributed to the effects of road traffic (Geiser and others 1994).

Magnesium

Like calcium, magnesium levels in lichens tend to be enriched near seashore environments. In addition, magnesium is higher in soils in ultramafic regions (Kabata-Pendias and Pendias 1984). Nieboer and Richardson (1981) suggest 1000 ppm as the cutoff between background and enhanced levels of this element in lichens. Enhanced levels of magnesium are not described for general bryophytes by the references reviewed.

Levels of magnesium in lichens in Olympic National Park showed an almost identical pattern to those of calcium, with high values on the west and north sides of Olympic National Park; the highest level (1160 ppm) was in *Hypogymnia physodes* in litterfall at the Heart of the Hills campground (Rhoades 1988).

The pattern of distribution of magnesium in lichens followed the pattern of magnesium seen in airborne samples by Davidson and others (1985).

Derr (1994) found some relatively high values for magnesium in *Alectoria sarmentosa* throughout southeast Alaska that was attributed to the marine influence. Gough and others (1987, 1988a) attributed the high values of magnesium in *Hypogymnia enteromorpha* and *Usnea* spp. in the northern part of Redwood National Park to the ultramafic nature of the surrounding soil parent material.

Manganese

Manganese can be enhanced near seashore environments, showing levels in tissues up to 350 ppm, or near urban/industrial areas, with levels in tissues up to 5000 ppm. Manganese is used in steel alloys and may be present in abraded dust from automotive engines. In addition, manganese is often higher in soils in ultramafic regions (Kabata-Pendias and Pendias 1984). Background levels in lichens are between 10 and 130 ppm (Nieboer and others 1978). Enhanced levels of manganese are not described for general bryophytes in the references reviewed.

The distribution of levels of manganese in Olympic National Park lichens is interesting, with many values exceeding the accepted background levels (Rhoades 1988). Extremely high values occurred in *Hypogymnia physodes* in litter (1257 ppm), in *Hypogymnia enteromorpha* in a lower Douglas-fir canopy (935 ppm), and in litter (752, 640 and 599 ppm), while the highest values relative to species background occurred in *Alectoria sarmentosa* on trunk (280 ppm) and *Sphaerophorus globosus* on trunk (259 and 143 ppm). John Aho (Olympic National Park, personal communication) indicates that manganese was once mined in the Morse Creek drainage near Port Angeles. The high levels of this element there and elsewhere point to a crustal source.

Some collections of *Peltigera aphthosa* collected to establish baseline levels of elements near a gold mine in northwestern British Columbia showed elevated levels of manganese (Enns and Bio 1990). Gough and others (1987, 1988a) attributed the high values of manganese in *Hypogymnia enteromorpha* and *Usnea* spp. in the northern part of Redwood National Park to the ultramafic nature of the surrounding soil parent material.

Mercury

Mercury may be enhanced in regions high in native ores or near industrial sites where it is processed. Nieboer and Richardson (1981) define levels of 8 ppm as being enhanced in lichens, while a level of 15 ppm was considered enhanced in bryophytes by Rao and LeBlanc (1967).

Mercury analyses are notoriously difficult and results are subject to the form of the analysis (Lodenius and Tulisalo 1995). Mercury was not analyzed in Olympic National Park lichens (Rhoades 1988) nor in most other northwest studies. Some collections of *Peltigera aphthosa* collected to establish baseline levels of elements near a gold mine in northwestern British Columbia showed elevated levels of mercury (Enns and Bio 1990).

Nickel

Nickel can be enhanced in lichens near seashore environments, showing levels in lichens from 10 to 120 ppm, or near urban/industrial areas, with levels in lichens up to 300 ppm. In addition nickel is often higher in soils in ultramafic regions (Kabata-Pendias and Pendias 1984). Nickel is used in making hard steel alloys and in electroplating, is present in stack gases from oil and coal burning power plants, and can be enhanced near municipal waste incinerators. Background levels in lichens are between 0 and 5 ppm (Nieboer and others 1978), but enhanced values of as low as 2 ppm have been seen in lichens near industrial areas (Nieboer and Richardson 1981). Levels as low as 6.5 ppm in bryophytes are likely to be enhanced (Gydesen and others 1983).

Levels of nickel in Olympic National Park lichens were all within the background range (below limit of detection of ICP-AES to 7 ppm; Rhoades 1988). Distribution of the highest values followed a similar pattern as iron and aluminum, with the highest values to the north and south in Olympic National Park. Statistically significant negative slopes occurred in the regressions of nickel content in *Hypogymnia enteromorpha* and *Alectoria sarmentosa* versus distance from the Heart of the Hills Parkway. Higher values closer to the Parkway, though below enhanced levels, may have been due to uptake of small amounts of the element from vehicular exhaust. Solution of the regression equations for nickel at 100 m distance, suggested background levels of 2.5 ppm in *Hypogymnia enteromorpha* and 0.2 ppm in *Alectoria sarmentosa*. The background levels calculated by comparing distribution of values from sites throughout the Park were 2.2 ppm and 0.5 ppm for these two species.

Nickel levels were determined in several other Pacific Northwest studies. Some collections of *Peltigera aphthosa* collected to establish baseline levels of elements near a gold mine in northwestern British Columbia showed elevated levels of nickel (Enns and Bio 1990). Geiser and others (1994) found elevated levels of nickel near the sulfite pulp mill and the ferry terminal at Sitka, Alaska. Gough and others (1987, 1988a) attributed the high values of nickel in *Hypogymnia enteromorpha* and *Usnea* spp. in the northern part of Redwood National Park to the ultramafic nature of the surrounding soil parent material.

Phosphorus

Phosphorus may be locally enhanced surrounding areas rich in native rock phosphates or in areas where it is used in industry. Concentrations of 200 to 2000 ppm are given as background in lichens by Nieboer and others (1978). Neither Nieboer and others (1978) nor Nieboer and Richardson (1981) give enhanced level cutoffs for phosphorus in lichens. Enhanced levels of phosphorus are not described for general bryophytes by the references reviewed. In a number of studies (peruse the database) the levels of potassium and phosphorus are inversely correlated with the levels of pollutants that are known to cause injury to the lichen symbiosis such as sulfur and lead (Moser and others 1983). This may be because of the breakdown of membranes by the latter pollutants and subsequent loss of biologically active phosphorus and potassium.

Levels of phosphorus in all species in Olympic National Park lichens were generally within the background range (Rhoades 1988). Higher values (up to 2689 ppm in *Hypogymnia enteromorpha*) were seen in samples from Douglas-fir canopy and from trunk. The suggested background value for *Hypogymnia enteromorpha* (1300 ppm) was lower than the value observed in that species by Palmer (1986).

Some collections of *Peltigera aphthosa* collected to establish baseline levels of elements near a gold mine in northwestern British Columbia showed elevated levels of phosphorus (Enns and Bio 1990). Geiser and others (1994) found elevated levels of phosphorus near the sulfite pulp mill and the ferry terminal at Sitka, Alaska.

Potassium

Potassium is found enriched in lichens near the seashore (Nieboer and others 1978). Uptake and efflux of K^+ is variable in lichens exposed to varying amounts of SO_2 and heavy metals (Nieboer and others 1976, Nieboer and others 1979). For example, Moser and others (1983) recorded a decrease in potassium levels in *Lobaria oregana* and *Peltigera aphthosa* associated with emissions from Mt. St. Helens. Because of these complexities, it is difficult to attribute the distribution of values of this element to any simple source or cause. Background values for potassium in lichens are given as 500 to 5000 ppm, while enhanced levels in lichens are 5000 to 9500 ppm (Nieboer and others 1978). Enhanced levels of potassium are not described for general bryophytes by the references reviewed.

Levels of potassium in all lichen species in Olympic National Park are generally within the background range of concentrations for lichens (Rhoades 1988). A few values are at the high end of that range or the low end of the "high industrial" range (Nieboer and Richardson (1981); these values are in samples collected from canopy locations near the Heart of the Hills Parkway.

Levels of potassium in lichens were slightly elevated in the vicinity of Sitka, Alaska (Geiser and others 1994) but these enhanced values could not be attributed to a single source.

Sodium

Sodium, like calcium and magnesium, is shown to be enhanced in lichens near seashores. The element is also locally concentrated in desert alkali areas. Nieboer and others (1978) set background levels in lichens from 50 to 1000 ppm and enhanced levels above 1000 ppm. Enhanced levels of sodium are not described for general bryophytes in the references reviewed.

Sodium in Olympic National Park lichens showed distribution of high levels similar to the distribution of high levels of magnesium and, to a lesser extent, calcium (Rhoades 1988). However, levels observed (up to 450 ppm) were always well within the accepted background range. The pattern of distribution of sodium in lichens in Olympic National Park did not seem to follow the pattern of sodium seen in airborne samples by Davidson and others (1985).

Derr (1994) found some relatively high values for sodium in *Alectoria sarmentosa* throughout southeast Alaska which she attributed to the marine influence. Geiser and others (1994) found elevated levels of sodium near the sulfite pulp mill near Sitka, Alaska, and other elevated values attributed to uptake of salt spray.

Sulfur

After lead, sulfur has been the most important element studied in lichens and bryophytes. Sulfur is released during the combustion of sulfur-rich oils in industrial applications of all sorts and is a component of several processes used in pulping paper. Sulfur is also a by-product of automobile exhaust (Hale

1983, Pacyna 1986). Sulfur may be locally enhanced in environments surrounding volcanic areas or in areas with certain sulfide ores of metals (iron, lead, zinc, mercury and antimony). Nieboer and Richardson (1981) list background levels of sulfur in lichens in general below 1000 ppm with enhanced levels above this value, while Nieboer and others (1978) use values above 2000 ppm as enhanced. In bryophytes, Rao and LeBlanc (1967) defined levels of 1000 to 9350 ppm as enhanced. Case and Krouse (1980), Jackson and Gough (1988), and Takala and others (1991) have all used stable sulfur isotope ratios to determine the sources of the sulfur content in lichens.

In Olympic National Park, levels of sulfur were enhanced in all lichen samples from the region immediately south of Port Angeles where comparisons between sites could be made (Rhoades 1988). Because of the pattern of distribution of these values (statistically significant negative slope in the linear regression of sulfur content of trunk and litter samples to distance south of Port Angeles, and the significantly increased values in two species in the canopies studied along the Parkway a few miles south of Port Angeles and at Heart of the Hills campground), Port Angeles was deemed to be the likely source of these elevated values.

The overall pattern of distribution of sulfur in lichens in the Morse Creek drainage, south of Port Angeles, suggests a complex pattern of wind flow from Port Angeles into Olympic National Park. Comparison of samples from trunk or litter with samples from Douglas-fir canopy locations pinpoints the enhancement in a certain range of elevations, from approximately 300 m to 600+ m. This was attributed to the combined effects of 1) a plume effect from the sulfur dioxide sources in Port Angeles, similar to plume effects seen by Showman (1975, 1981) and 2) an "edge effect" where lichens in outer or upper forest canopies exposed to air with enhanced levels of pollutants have higher values of pollutants than the same lichens within or below the canopy (Hale 1983).

Values of sulfur elsewhere in Olympic National Park for all species were in the background range for lichens in general as reported by Nieboer and Richardson (1981). In particular, the values observed in *Alectoria sarmentosa* (255 ppm) and *Sphaerophorus globosus* (285), both south-rim locations in Olympic National Park, were very low for those species, indicating no effect from urban areas to the south of Olympic National Park. The values for *Alectoria sarmentosa* in other regions in Olympic National Park given by Frenzel and others (1985) are near the background value for *Alectoria sarmentosa* suggested by Rhoades (1988).

Enns (1989) found regional increases in sulfur content in a number of lichens and bryophytes sampled in southeastern British Columbia when comparing single samples of each species from 1986 and 1988. Geiser and others (1994) found elevated levels of sulfur near the sulfite pulp mill and the ferry terminal at Sitka, Alaska. Taylor and Bell (1983) found that the sulfur content observed in *Hypogymnia physodes* showed a highly significant relationship to that in *Alnus* leaves from the same location.

Titanium

Titanium is almost always present in crustal soils from rocks of igneous origin. It is used in industry to strengthen steel alloys and in the manufacture of the most common white paint pigment. Because of its crustal ubiquity, titanium is often included in analyses so that enrichment factors may be calculated (Addison and Puckett 1980, Nieboer and others 1978, Nieboer and Richardson 1981, Puckett 1988, Puckett and Finegan 1980). Background levels in lichens as given by Nieboer and others (1978) are from 6 to 150 ppm while enhanced levels are above 150 ppm. Nieboer and Richardson (1981) lowered this limit and suggest that values of titanium as low as 35 ppm may be considered enhanced in lichens. Enhanced levels of titanium are not described for general bryophytes by the references reviewed. Titanium was not analyzed in Olympic National Park lichens (Rhoades 1988) nor in other northwest studies.

Zinc

Zinc levels can be enhanced in automobile exhaust (Pacyna 1986), may be elevated near roadways due to tire wear (Harte and others 1991), urban/industrial areas in general, and areas with marine influence (Davidson and others 1985). Zinc is used in the galvanizing process and in battery manufacture. Enhanced levels in lichens are above 500 ppm (Nieboer and others 1978). Nieboer and Richardson (1981) suggest that levels as low as 30 ppm may be enhanced. For bryophytes, Rao and LeBlanc (1967) suggest enhanced levels of zinc at about 325 ppm, while Gydesen and others (1983) suggest that values as low as 83 ppm may even be enhanced.

Levels of zinc in lichens in Olympic National Park did not vary from one lichen species to another as much as other elements, and were all well below accepted enhanced values (highest values from 40 to 67 ppm; Rhoades 1988). These highest levels were seen in canopy locations along the Heart of The Hills Parkway in the north end of Olympic National Park. A statistically significant negative slope in the regression of zinc content in *Hypogymnia enteromorpha* versus distance from the Heart of The Hills Parkway suggested that higher values closer to the Parkway, though below enhanced levels, may be due to uptake of small amounts of the element from vehicular exhaust. It may be that the values given as a background range (Nieboer and Richardson 1981) are incorrect, and that levels more in the range of those given by Gydesen and others (1983) for bryophytes may be more correct. Davidson and others (1985) found levels of zinc in air enriched relative to values for aluminum, suggesting a noncrustal (possibly marine) source for this element.

Geiser and others (1994) found elevated levels of zinc near the sulfite pulp mill and the town incinerator at Sitka, Alaska.

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APPENDIX A. WORLDWIDE SPECIES REFERENCED IN ELEMENTAL CONTENT LITERATURE

Elemental content papers reference various species. The citations include papers which study effects of elemental pollutants on lichen and bryophyte health, uptake of selected natural environmental elements, selected references documenting the uptake of radionuclides and organic compounds, and a few pertinent references discussing physiological change and elemental uptake during fumigation experiments. All species reported in the various cited papers are included, whether or not they occur in the Pacific Northwest.

Species not otherwise indicated occur in the Pacific Northwest region (perhaps marginally). Species presence in North America was determined with reference to Stotler and Crandall-Stotler (1977), Anderson and others (1990), Anderson (1990) and Esslinger and Egan (1995). Lichens and bryophytes not present are noted: "[not in N.A.]". Species presence in the Pacific Northwest were determined with help from Bruce Ryan, Bruce McCune, and Trevor Goward (all personal communications) and by reference to Lawton (1971, for mosses except *Sphagnum*). Lichens and mosses not found in the region are noted: "[not in PNW]". Liverwort presence in the region is incompletely known.

Acarospora bullata, A. peliscypha, A. smaragdula (Huneck and others 1990)

Acarospora strigata (Nash and Sommerfeld 1981) [Great Basin part of PNW]

Alectoria nigricans (Freedman and others 1990, Solberg and Selmer-Olsen 1978)

Alectoria ochroleuca (Asta 1992, France and others 1993, Hoffmann and others 1993, Solberg and Selmer-Olsen 1978)

Alectoria sarmentosa (Derr 1997; Enns 1996; Frenzel and others 1985, 1990; Geiser 1991, 1993; Geiser and others 1994; Pike 1978; Rhoades 1988; Roberts and Thompson 1980; Solberg and Selmer-Olsen 1978; Wiersma 1981)

Alectoria spp. (Biazrov and Adamova 1993, Doyle and others 1973, Nieminen and Rantataro 1990, Takala and others 1994)

Allocetraria oakesiana (Lang and others 1980) [not in PNW]

Anaptychia ciliaris (Glenn and others 1995) [not in PNW; misidentification in N.A.]

Anaptychia sp. (Papastefanou and others 1992) [rare in PNW]

Brachythecium rivulare (Sanchez and others 1994)

Brachythecium rutabulum (Wolterbeek and others 1995)

Bryocaulon divergens (Freedman and others 1990, Solberg and Selmer-Olsen 1978)

Bryophytes (unspecified bryophyte, moss or liverwort) (Catarino and others 1991, Crowder 1991, Ellison and others 1976, Ford and others 1992, Heinrich and others 1989, Jackson and Ehrle 1994, Malmer and others 1992, Mankovska 1994, Nelson and Campbell 1995, Steinnes 1995, Tuba and others 1994, Turkan and others 1995, Winner and others 1988, Zechmeister 1995)

Bryoria capillaris (Holopainen 1983, 1984; Palomäki and others 1992; Ryan and Nash 1990; Solberg and Selmer-Olsen 1978)

Bryoria fremontii (Sheridan and others 1976, Solberg 1979, Solberg and Selmer-Olsen 1978)

Bryoria glabra (Skorepa and Vitt 1976)

Bryoria sp. (as *Alectoria jubata*) (Freedman and others 1990)

Bryoria spp. (Biazrov and Adamova 1993, Kortesharju and Kortesharju 1989, Nieminen and Rantataro 1990, Ramelow and others 1991, Rhoades 1988, Solberg and Selmer-Olsen 1978, Takala and others 1994)

Bryum algens (Battiston and others 1990) [not in NA]

Buellia sororia (Huneck and others 1990) [not in NA]

Caloplaca aurantia (Garty and others 1977, 1979, 1986; Galun and others 1984) [not in PNW?]

Caloplaca ehrengergii (Garty 1985) [not in N.A.]

Caloplaca trachyphylla (Nash and Sommerfeld 1981)

Calyrneferes usambaricum (Nyangababo 1987) [not in N.A.]

Candelariella aurella (Huneck and others 1990)

Candelariella vitellina (Guevara and others 1995)

Cetraria islandica (Asta 1992, Guttenberger and others 1991, Mankovska and Kyselova 1987, Solberg and Selmer-Olsen 1978)

Cetraria muricata (as *Cornicularia muricata* Rao and others 1977)

Cetraria spp. (Biazrov and Adamova 1993, Hoffmann and others 1993, Yevseev and Krasovskaya 1994)

Cetrariella delisei (Solberg and Selmer-Olsen 1978) [not in PNW]

Cetrelia cetrarioides (Adamova and Biazrov 1991)

Cladina arbuscula (Addison and Puckett 1980, Nifontova and Alexashenko 1993, Pakarinen and others 1978) as *Cladina sylvatica* (Kortesharju and others 1990, Steinnes 1993)

Cladina mitis (Biazrov 1993, 1994; Boileau and others 1982; Case 1990; Fahselt and others 1995; McIlveen and Negusanti 1994; Meland and Junttila 1992; Nieboer and others 1972; Nifontova and Alexashenko 1993; Pakarinen and others 1978; Palmer 1986; Rissanen 1992; Solberg and Selmer-Olsen 1978)

Cladina rangiferina (Albrecht 1989; Asta 1992; Boileau and others 1982; Case 1990; Derr 1997; Ellis and Smith 1987; Evans and Hutchinson 1996; Fahselt and others 1995; Folkeson 1979; Geiser and others 1994; Glenn and others 1991; Gries and others 1994; Kortesharju and others 1990; Lane and Puckett 1979; Mankovska and Kyselova 1987; Muir and others 1993; Nieboer and others 1972; Punning and others 1991; Rissanen 1992; Roberts and Thompson 1980; Scott and Hutchinson 1989; Solberg and Selmer-Olsen 1978, Steinnes 1993; Takala and others 1990; Wetmore 1989; Winner and others 1988; Zakshek and others 1986)

Cladina skottsbergii (Connor 1979) [not in N.A.]

Cladina stellaris (Aamlid 1992a, 1992b; Auclair and Rencz 1982; Doyle and others 1973; Geiser 1991; Gorshkov and Lyanguzova 1989; Huttunen and others 1992; Kortesharju and others 1990; Mattson 1975; Meland and Junttila 1992; Nieboer and others 1972; Puckett and Finegan 1980; Rissanen 1992; Roberts and Thompson 1980; Scott and Hutchinson 1989; Solberg and Selmer-Olsen 1978; Steinnes 1993; Steinnes and Njåstad 1993; Wetmore 1987d)

Cladina stygia (Wetmore 1989)

Cladina subtenuis (Lawrey and Hale 1981) [not in PNW?]

Cladina spp. (Huttunen and others 1992; Kansanen and Venetvaara 1991; McIlveen and Negusanti 1994; Nieminen and Rantataro 1990; Pakarinen 1981a; Takala and others 1991, 1994; Wetmore 1987a)

Cladonia amaurocraea (Nifontova and others 1979) [not in PNW?]

Cladonia cervicornis subsp. *verticillata* (Li 1979)

Cladonia convoluta (Lam.) P. Cout. (Brown and Beckett 1983, Farkas and others 1985, Li 1979, Martin and others 1989, Tuba and Csintalan 1993a, Tuba and others 1994) [not in N.A.]

Cladonia crispata (Biazrov 1993, 1994)

Cladonia deformis (Nieboer and others 1972, Solberg and Selmer-Olsen 1978)

Cladonia furcata (Enns 1989 ?, Gries and others 1994, Martin and others 1989, Tuba and others 1994)

Cladonia glauca (Gries and others 1994) [possibly edge of PNW?]

Cladonia gracilis (Biazrov 1993, 1994; Palmer 1986)

Cladonia gracilis var. *elongata* (Asta 1992)

Cladonia portentosa (Branquinho and Brown 1994, Farmer 1994) ? (Ertel and others 1987, Deruelle 1992, as *Cladonia imp[l?]exa*)

Cladonia pyxidata (Belandria and others 1991)

Cladonia rangiformis (Brown and Beckett 1983, Brown and Slingsby 1972, Martin and others 1989) [not in N.A.]

Cladonia sulfurina (Solberg and Selmer-Olsen 1978)

Cladonia squamosa (Palmer 1986)

Cladonia subulata (Huneck and others 1990)

Cladonia uncialis (Biazrov 1993, Nieboer and others 1972)

Cladonia spp. (Bartók 1992, Biazrov and Adamova 1993, Enns 1989, Ernst 1983, Freedman and others 1990, Goyal and Seaward 1981b, Hoffmann and others 1993, Lodenius and Malm 1990, Nieboer and others 1972, Pakarinen 1981b, Papastefanou and others 1992, Steinnes 1993, Takala and others 1985, Yevseev and Krasovskaya 1994)

Collema auriforme (Gries and others 1994) [rare in PNW]

Collema polycarpon (Fields and St. Clair 1984)

Collema tenax (Henriksson and DaSilva 1978)

Collema sp. (Papastefanou and others 1992)

Dactylina arctica (Looney and others 1986)

Dermatocarpon miniatum (Brown and Beckett 1983, Ryan and Nash 1990)

Dicranoweisia cirrata (Johnsen and others 1983, Pilegaard 1979)

Dicranum polysetum (Folkeson 1979)

Dicranum sp. (Pakarinen and Rinne 1979)

Diploschistes streppicus (Garty 1985) [not in N.A.]

Entodon schreberi (Kabata-Pendias and Pendias 1984) [not in N.A.?]

Eurhynchium praelongum (Brüning and Kreeb 1993)

Eurhynchium sp. (Enns 1989)

Evernia mesomorpha (Addison and Puckett 1980, Albrecht 1989, Bennett 1995, Huebert and others 1985, Malhotra and Khan 1980, McIlveen and Negusanti 1994, Wetmore 1989) [rare in easternmost PNW]

Evernia prunastri (Albrecht 1989; Biazrov 1993; Caniglia and others 1994; Freitas 1993a, 1993b; Freitas and others 1993a, 1993b, 1994, 1995; Gries and others 1994; Hawksworth and Rose 1976; Hoffmann and others 1993; Johnsen and others 1983; Lang and others 1980; Lounamaa 1965; Solberg and Selmer-Olsen 1978; Stone and others 1995)

Evernia sp. (Biazrov and Adamova 1993, Papastefanou and others 1992)

Flavocetraria cucullata (Asta 1992, Ford and others 1992, Freedman and others 1990, Landers and others 1995, Looney and others 1986, Puckett and Finegan 1980, Solberg and Selmer-Olsen 1978)

Flavocetraria nivalis (Asta 1992, France and others 1993, Freedman and others 1990, Heino and others 1992, Looney and others 1986, Meland and Junttila 1992, Nieminen and Rantataro 1990, Puckett and Finegan 1980)

Flavoparmelia baltimorensis (Hale and Lawrey 1985, Lawrey 1993, Lawrey and Hale 1979, 1981, Prussia and Killingbeck 1991, Schwartzman and others 1987, Schwartzman and others 1991) [not in PNW]

Flavoparmelia caperata (Adamova and Biazrov 1991; Bargagli and others 1987a, 1987c; Barghigiani and others 1990, Catarino and others 1991; Eversman and Sigal 1987; Freitas and others 1993b; Glenn and others 1991; Gries and others 1994; Loppi and Bargagli 1996; Loppi and others 1992, 1994a, 1994b, 1995; Maguas and others 1990; McCune and others 1993; Nimis and others 1993; Olmez and others 1985; Prussia and Killingbeck 1991; Rhoades 1995a; Rhoades and others 1995; Schutte 1977; Showman and Hendricks 1989) [southern edge of PNW]

Fontinalis antipyretica (Johansson 1995, Kirchman and Lambinon 1973, Mersch and Pihan 1993, Roy and others 1996)

Frullania dilatata (Maguas and others 1990) [not in PNW?]

Funaria hygrometica (Basile 1993, Brown and Buck 1978, Comeau and LeBlanc 1972, Shaw 1990)

Hylocomium splendens (Berg and others 1995a, 1995b; Brown and Brumelis 1996; Folkeson 1979; Kansanen and Venetvaara 1991; Knulst and others 1995; Lead and others 1996; Markert and others 1996; Pakarinen and Rinne 1979; Robitaille 1977; Rühling and others 1992, 1994; Rühling and Tyler 1970; Steinnes 1993; Steinnes and Njåstad 1993; Steinnes and others 1992, 1994; Thoni and Hertz 1991; Wiersma and others 1987; Wolterbeek and others 1995)

Hypnum cupressiforme (Folkeson 1979, Johnsen and others 1983, Markert and others 1996, Morosini and others 1993, Rühling and Tyler 1971, Ward and others 1977, Wolterbeek and others 1995)

Hypogymnia enteromorpha (Geiser 1991, 1993; Geiser and others 1994; Gough and others 1987, 1988a; Rhoades 1988; Sheridan and others 1976)

Hypogymnia imshaugii (Rhoades 1988, Ryan and Nash 1990)

Hypogymnia inactiva (Geiser 1993)

Hypogymnia krogiae (Lang and others 1980) [not in PNW]

Hypogymnia physodes (Aamlid 1992b; Adamova and Biazrov 1991; Addison and Puckett 1980; Bennett 1995; Biazrov 1993, 1994; Biazrov and others 1993; Bruteig 1993; Bylinska and others 1991; Comeau and LeBlanc 1972; DePreist and others 1987; Deruelle 1992; Enns 1996; Evans and Hutchinson 1996; Farkas and others 1985; Farkas and Patkäi 1989; Folkeson 1979; Gailey and others 1985; Garty and others 1996a; Gliemeroth 1994; Gorshkov and Lyanguzova 1989; Gries and others 1994; Halonen and others 1993; Hawksworth and Rose 1976; Herzig and others 1990; Hoffmann and others 1993; Holopainen 1983, 1984; Holopainen and others 1993; Jeran and others 1993, 1996; Johnsen and others 1983; Kabata-Pendias and Pendias 1984; Kanerva and others 1988; Kansanen and Venetvaara 1991; Kauppi and Halonen 1992; Kral and others 1989; Kubin 1990; Kytomaa and others 1995; Laaksovirta and Olkkonen 1977, 1979, 1983; Laaksovirta and others 1976; Lang and others 1980; Lodenius and Kumpulainen 1983; Lodenius and Laaksovirta 1979; Lodenius and Tulisalo 1995; Lounamaa 1956, 1965; Lupsina and others 1992; Markert and Wtorova 1992; Miszalski and Niewiadomska 1993; Mukherjee and Nuorteva 1994; Nifontova and Alexashenko 1993; Nygard and Harju 1983; Olkkonen and Takala 1975; Pakarinen and others 1978; Palmer 1986; Palomäki and others 1992; Paulsen 1992; Pfeiffer and Barclay-Estrup 1992; Pilegaard 1979; Punning and others 1991; Pyatt 1970, 1973; Rhoades 1988; Roberts and Thompson 1980; Robitaille 1977; Sarkela and Nuorteva 1987; Scott and Hutchinson 1989, 1990; Skácel and Pekarek 1992; Søchting 1991; Solberg 1967; Steinnes 1993; Steinnes and Njåstad 1993; Stubbs and Homola 1990; Swieboda and Kalemba 1978; Takala and Olkkonen 1981; Takala and others 1985, 1990, 1991, 1994; Taylor and Bell 1983; Vestergaard and others 1986; Wetmore 1989)

Hypogymnia spp. (Biazrov and Adamova 1993; Enns 1989; Pike 1978; Wetmore 1986, 1987a)

Hypotrachyna brevirrhiza (Guevara and others 1995) [not in N.A.]

Isopterygium elegans (Palmer 1986)

Isothecium myosuroides (Enns 1989, Farmer and others 1991, Palmer 1986)

Kiaeria starkei (Woolgrove and Woodin 1996)

Lasallia papulosa (Nash 1975)

Lasallia pensylvanica (Nifontova and others 1979) [not in PNW]

Lasallia pustulata (Ascasco and Fortun 1981, Solberg and Selmer-Olsen 1978, Tarazona Lafarga and others 1995) [not in PNW]

Lecanora argopholis (Nash and Sommerfeld 1981 as *Lecanora frustulosa*) [Great Basin part of PNW]

Lecanora conizaeoides (Gailey and Lloyd 1983; Johnsen and others 1983; Sloof and Wolterbeek 1993a, 1993b)

Lecanora muralis (Huneck and others 1990, Seaward 1973, 1974; Vincent 1994)

Lecanora novomexicana (Nash and Sommerfeld 1981)

Lecanora polytropa (Alstrup and Hansen 1977)

Lecanora subaurea (Huneck and others 1990) [not in PNW]

Lecanora subfusca (Bartók 1988) [= *Lecanora allophana* in N. A.] [not in PNW]

Lecanora. stenotropa (Huneck and others 1990) [not in N.A.]

Letharia columbiana (Ramelow and others 1991, Ryan and Nash 1990)

Letharia vulpina (Geiser 1993, Goward 1987, Ryan and Nash 1990, Wetmore 1986)

Leucobryum glaucum (Solberg and Selmer-Olsen 1978) [not in PNW]

Leucodon sciuroides (Maguas and others 1990) [not in PNW]

Lichens (Crête and others 1992, France and Coquery 1996, Grass and others 1994, Pakarinen and others 1983, Parr and Zeisler 1994, Quevauviller and others 1996, Stone and others 1995, Zhang and others 1995)

Lobaria linita (Derr 1997)

Lobaria oregana (Derr 1997; Geiser 1991, 1993; Geiser and others 1994; Gries and others 1994; Moser and others 1983; Pike 1978)

Lobaria pulmonaria (Adamova and Biazrov 1991, Brown and Beckett 1983, Catarino and others 1991, Farmer and others 1991, Kabata-Pendias and Pendias 1984, Palmer 1986, Sigal and Johnston 1986)

Lobaria scrobiculata (Brown and Beckett 1983)

Lobaria spp. (Hallingbaeck 1986)

Lobothallia alphoplaca (as *Lecanora* Nash and Sommerfeld 1981; may be confused with *L. praeradiosa*) [one or both species in Great Basin part of PNW]

Lunularia cruciata (Basile 1993) [a greenhouse weed in PNW only]

Masonhalea richardsonii (Ford and others 1992, Landers and others 1995) [not in PNW]

Melanelia exasperatula (Rope and Pearson 1990)

Melanelia olivacea (Aamlid 1992b) [not in PNW]

Mnium undulatum (Türk and Wirth 1975)

Nephroma antarcticum (Garty and Delarea 1991, Wiersma and others 1992) [not in N.A.]

Nephroma arcticum (Takala and others 1985, 1994) [rare in PNW]

Nephroma laevigatum (Brown and Beckett 1983)

Parmelia cunninghamii (Guevara and others 1995) [not in N.A.]

Parmelia saxatilis (Bargagli and others 1987c, Lang and others 1980, Solberg and Selmer-Olsen 1978)

Parmelia squarrosa (Robitaille 1977)

Parmelia sulcata (Albrecht 1989; von Arb and others 1990, Bargagli 1990; Bargagli and Barghigiani 1991; Bargagli and others 1987b, 1987c, 1989; Barghigiani and others 1990; Biazrov 1993; Biazrov and others 1993; Brown and others 1994; DeBruin and Hackenitz 1986; Freitas 1994, 1995; Freitas and others 1993b, 1994; Glenn and others 1995; Gough and others 1985, 1988b; Gries and others 1994; Herzig 1993; McIlveen and Negusanti 1994; Morosini and others 1993; Pike 1978; Sloof 1995a; Sloof and Wolterbeek 1991a, 1991b, 1993a; Taylor 1978; van den Berg and others 1992)

Parmelia spp. (Bargagli and Barghigiani 1991; Bargagli and others 1987b, 1989; Kapu and others 1991; Papastefanou and others 1992; Rao and others 1977; Wetmore 1987b)

Parmeliaceae (Belandria and others 1991)

Parmelina quercina (Martin and others 1989) [southern edge of PNW]

Parmotrema chinense (Figueira and others 1994)

Parmotrema madagascariaceum (Gordon and others 1995) [not in PNW]

Parmotrema praesorediosum (Ramelow and others 1991; Thomson and others 1987; Walther and others 1990a, 1990b)

Parmotrema tinctorum (Sugiyama 1973) [not in PNW]

Peltigera aphthosa (Asta 1992; Belandria and others 1991; Brown and Beckett 1983; Enns 1989; Enns and Bio 1990; Feige 1977; Fritz-Sheridan 1985; Moser and others 1983; Takala and others 1985, 1991, 1994)

Peltigera canina (Bartók 1988; Belandria and others 1991; Enns 1989, 1996; Goyal and Seaward 1982a, 1982b; Henriksson and Pearson 1981; Kortesharju and others 1990; Nifontova and Alexashenko 1993; Nifontova and others 1979; Palmer 1986; Rao and others 1977; Seaward 1974; Solberg and Selmer-Olsen 1978)

Peltigera collina (Gries and others 1994)

Peltigera didactyla (Bylinska and others 1991)

*Peltigera horizontalis (*Brown and Beckett 1983*)*

Peltigera hymenina (Brown and Beckett 1983) [rare in PNW?]

Peltigera malacea (Li 1979)

Peltigera membranacea (Brown and Beckett 1983, Wells and others 1995)

Peltigera neopolydactyla (Fritz-Sheridan 1985)

Peltigera praetextata (Gries and others 1994)

Peltigera rufescens (Goyal and Seaward 1982a, Hawksworth and Rose 1976, James 1973)

Peltigera spp. (Bartók 1992; Beckett and Brown 1984a, 1984b; Brown and Avalos 1991; Goyal and Seaward 1981b; Papastefanou and others 1992; Richardson and Nieboer 1983)

Pohlia wahlenbergii (Solberg and Selmer-Olsen 1978)

Physcia adscendens (Guevara and others 1995)

Physcia biziana (Bargagli and Barghigiani 1991)

Physcia sp. (Papastefanou and others 1992, Vincent 1994)

Physconia distorta (as *Physconia pulverulenta* Martin and others 1989) [misidentified in N. A.]

Plagiothecium undulatum (Palmer 1986, *?*Enns 1989)

Platismatia glauca (Enns 1989, Geiser 1993, Hoffmann and others 1993, Lang and others 1980, Lounamaa 1965, Palmer 1986, Rhoades 1988, Stubbs and Homola 1990)

Platyhypnidium riparioides (Claveri and Mouvet 1995, as *Rhynchostegium*)

Pleurosticta acetabula (Martin and others 1989) [not in N.A.]

Pleurozium schreberi (Case 1990, Czarnowska and Gworek 1992, Evans and Hutchinson 1996, Folkeson 1979, Kansanen and Venetvaara 1991, Knulst and others 1995, Kuik and Wolterbeek 1995, Mankovska 1996, Markert and others 1996, Mukherjee and Nuorteva 1994, Punning and others 1991, Raeymaekers 1987, Raeymaekers and Glime 1986, Robitaille 1977, Wolterbeek and others 1995)

Pleurozium sp. (Kortesharju and others 1990, Pakarinen and Rinne 1979)

Pohlia nutans (Folkeson 1979)

Polytrichum commune Hedw. (Roberts and others 1979, Roberts and Thompson 1980, Solberg and Selmer-Olsen 1978)

Polytrichum juniperinum (Kabata-Pendias and Pendias 1984)

Polytrichum spp. (Markert and Wtorova 1992, Pakarinen and Rinne 1979, Santos and others 1993)

Pseudephebe pubescens (Alstrup and Hansen 1977)

Pseudevernia cladonia (Lang and others 1980) [not in PNW]

Pseudevernia furfuracea (Asta 1992; Calliari and others 1995; Caniglia and others 1993; Folkeson 1979; Guttenberger and others 1991; Heinrich and others 1989; Hoffmann and others 1993; Lounamaa 1965; Miszalski and Niewiadomska 1993; Solberg and Selmer-Olsen 1978; Takala and others 1985, 1990, 1991, 1994; Wetmore 1987b) [misidentifications in N. A.: Records are either *P. consocians* or *P. intensa*]

Pseudevernia intensa (Gries and others 1994, Wetmore 1987b) [not in PNW]

Pseudocyphellaria anthraspis (Gries and others 1994, Palmer 1986)

Pseudoscleropodium purum (Markert and others 1996, Wolterbeek and others 1995) [likely only an urban weed in PNW, escaped from Europe]

Ptilium crista-castrensis (Solberg and Selmer-Olsen 1978)

Punctelia hypoleucites (Wetmore 1987b) [not in PNW]

Punctelia rudecta (Olmez and others 1985, Schutte 1977, Wetmore 1989) [edge of PNW]

Punctelia subrudecta (Glenn and others 1995) [sporadic in western parts of PNW]

Racomitrium lanuginosum (Solberg and Selmer-Olsen 1978)

Ramalina calicaris (Figueira and others 1994) [not in PNW]

Ramalina duriaei (Fuchs and Garty 1983; Galun and others 1984; Galun and Ronen 1988; Garty 1987, 1988; Garty and Fuchs 1982; Garty and Hagemeyer 1988; Garty and others 1982, 1985a, 1985b, 1988, 1992, 1993; Garty and Theiss 1990; Ronen and others 1983; Semadi and Deruelle 1993) [N. A. identifications of this species are of *R. lacera*]

Ramalina ecklonii (Levin and Pignata 1995) [not in N.A.]

Ramalina farinacea (Adamova and Biazrov 1991, Bargagli and Barghigiani 1991, Semadi and Deruelle 1993, Tarazona Lafarga and others 1995)

Ramalina maciformis (Garty 1985, Garty and others 1996b) [not in N.A.]

Ramalina menziesii (Boonpragob and Nash 1990, 1991; Boonpragob and others 1989; Boucher and Nash 1990; Gries and others 1994; Handley and Overstreet 1968)

Ramalina siliquosa (Solberg and Selmer-Olsen 1978) [not in N.A.]

Ramalina stenospora (Mueller and others 1987; Ramelow and others 1991; Thomson and others 1987; Walther and others 1990a, 1990b) [not in PNW]

Ramalina spp. (Barghigiani and others 1989, McIlveen and Negusanti 1994, Papastefanou and others 1992,)

Rhizomnium glabrescens (Enns 1989, Palmer 1986)

Rhizomnium sp. (Enns 1989)

Rhizoplaca chrysoleuca (Hale 1982)

Rhizoplaca melanophthalma (Dillman 1996; Hale 1982; Nash and Sommerfeld 1981; Rope and Pearson 1990; St. Clair and others 1990, 1995)

Rhytidiadelphus squarrosus (Brüning and Kreeb 1993, Wells and Brown 1995, Wells and others 1995)

Rhytidiadelphus triquetrus (Türk and Wirth 1975)

Rimelia reticulata (McCune and others 1993, Rhoades 1995a, Rhoades and others 1995) [not in PNW]

Roccella phycopsis (Brown and Beckett 1983) [not in PNW; probably misidentifications in N. A.]

Scapania undulata (Samecka-Cymerman and Kempers 1995)

Sphaerophorus fragilis (Solberg and Selmer-Olsen 1978)

Sphaerophorus globosus (Rhoades 1988)

Sphagnum compactum (Solberg and Selmer-Olsen 1978)

Sphagnum flexuosum (Solberg and Selmer-Olsen 1978)

Sphagnum fuscum (Gorham and Tilton 1978)

Sphagnum henryense (Enns 1989, Palmer 1986)

Sphagnum magellanicum (Percy 1983, Percy and Borland 1984)

Sphagnum molle (Solberg and Selmer-Olsen 1978)

Sphagnum warnstorfii (Solberg and Selmer-Olsen 1978)

Sphagnum spp. (Aulio 1980, 1982; Ferguson and others 1984; Gignac 1989; Glooschenko and Arafat 1988; Markert and Wtorova 1992; Pakarinen 1977, 1981b, 1981c; Pakarinen and Rinne 1979; Rühling and Tyler 1973; Steinnes 1993; Steinnes and Njastad 1995; Stewart and Fergusson 1994 (peat); Wojtun 1994)

Squamarina crassa (Garty 1985) [not in N.A.]

Stereocaulon alpinum (Asta 1992)

Stereocaulon dactylophyllum (Pyatt and others 1992) [not in PNW]

Stereocaulon evolutum (Solberg and Selmer-Olsen 1978) [not in N.A.]

Stereocaulon nanodes (Huneck and others 1990, Maquinay and others 1961) [not in PNW]

Stereocaulon paschale (Lounamaa 1956, Nieboer and others 1972, Solberg and Selmer-Olsen 1978)

Stereocaulon ramulosum (Quilhot 1988) [not in N. A. north of Mexico]

Stereocaulon vesuvianum (Davies and Notcutt 1989, Jones and others 1982)

Stereocaulon vulcani (Notcutt and Davies 1993) [not in N. A. north of Mexico]

Stereocaulon spp. (Biazrov and Adamova 1993, Doyle and others 1973, McIlveen and Negusanti 1994, Nieminen and Rantataro 1990)

Sticta sylvatica (Brown and Beckett 1983) [not in PNW; misidentifications?]

Teloschistes lacunosus (Garty 1985) [not in N.A.]

Thamnolia subuliformis (Freedman and others 1990)

Thamnolia vermicularis (Asta 1992)

Tomenthypnum nitens (Solberg and Selmer-Olsen 1978) [not in PNW]

Tortula ruralis (Tuba and Csintalan 1993b)

Tuckermannopsis americana (as *Cetraria halei* Skorepa and Vitt 1976)

Tuckermannopsis chlorophylla (Rhoades 1988)

Umbilicaria aprina (Nakamura and Inoue 1991, Upreti and Pandev 1994) [not in PNW]

Umbilicaria cylindrica (Belandria and others 1991, Kwapulinski and others 1985)

Umbilicaria decussata (Bargagli 1993, Battiston and others 1990, Upreti and Pandev 1994)

Umbilicaria deusta (Kwapulinski and others 1985, Mankovska and Kyselova 1987, Nieboer and others 1972)

Umbilicaria hirsuta (Hale 1982, Kwapulinski and others 1985, Solberg and Selmer-Olsen 1978)

Umbilicaria lyngei (Alstrup and Hansen 1977)

Umbilicaria mammulata (Eversman and Sigal 1987) [not in PNW]

Umbilicaria muhlenbergii (Flora and Nieboer 1980; France and others 1993; Nieboer and others 1976, 1979; Richardson and others 1979)

Umbilicaria murina (Kwapulinski and others 1985) [not in N. A.]

Umbilicaria polyrhiza (Ryan and Nash 1990)

Umbilicaria virginis (Ryan and Nash 1990)

Umbilicaria spodochroa (Solberg and Selmer-Olsen 1978) [not in N.A.]

Umbilicaria spp. (Doyle and others 1973, Seaward and others 1981)

Usnea alpina (Skorepa and Vitt 1976) [not in PNW at least as this name]

Usnea antarctica (Olech 1991) [not in N.A.]

Usnea aurantiaco-atra (Quilhot 1988) [not in N.A.]

Usnea fastigiata (Guevara and others 1995) [not in N.A.]

Usnea filipendula (Folkeson 1979, Miszalski and Niewiadomska 1993)

Usnea hirta (Eversman 1978, Garty and others 1996a)

Usnea lapponica (Gough and others 1987)

Usnea muricata (Belandria and others 1991) [not in N.A.]

Usnea sphacelata (Nakamura and Inoue 1991)

Usnea subfloridana (Gough and others 1987, Hawksworth and Rose 1976, McIlveen and Negusanti 1994, Pike 1978, Rhoades 1988, Stubbs and Homola 1990)

Usnea tristis (Wetmore 1987b) [not in PNW]

Usnea spp. (Adamova and Biazrov 1991; Biazrov and Adamova 1993; Figueira and others 1994; Gough and others 1987, 1988a; Hale 1982; Lang and others 1980; Moore and others 1978; Solberg and Selmer-Olsen 1978; Wetmore 1987b)

Verrucaria nigrescens (Nash 1975)

Xanthoparmelia chlorochroa (Erdman and Gough 1977, Erdman and others 1977, Eversman 1978, Fields and St. Clair 1984, Gough and Erdman 1977, Gough and others 1985)

Xanthoparmelia conspersa (Bartók 1988; Lawrey and Hale 1981; Saeki and others 1975, 1977) [not in PNW]

Xanthoparmelia cumberlandia (Hale 1982, Ryan and Nash 1990)

Xanthoparmelia wyomingica (Hale 1982)

Xanthoparmelia sp. (Thomas and Ibrahim 1993)

Xanthoria calcicola (Dongarra and others 1995) [not in N.A.]

Xanthoria parietina (Bargagli and Barghigiani 1991, Barghigiani and others 1990, Bartók 1992, Bartók and others 1992, Belandria and Asta 1987, Brown and others 1994, Davies and Notcutt 1989, Garty 1993, Gasparo and others 1989, Martin and others 1989, Vincent 1994, Zanini and others 1992) [rare in western parts of PNW]

Xanthoria polycarpa (Rope and Pearson 1990)

Xanthoria sp. (Papastefanou and others 1992)

APPENDIX B. SOURCES OF ENHANCEMENTS

The following natural sources of enhancements are specifically discussed by the listed references:

Nearby soil and rock - Dongarra and others 1995; Garty and others 1995a, 1996b; Goyal and Seaward 1981b, 1982a, 1982b; Hyvärinen and Crittenden 1996; LeRoy and Koksoy 1962; Lounamaa 1956; Maquinay and others 1961; Pilegaard 1993; Prussia and Killingbeck 1991; Purvis 1984; Santos and others 1993.

Natural organic substrates (bark, rotten wood) - Prussia and Killingbeck 1991, Seaward and Bylinska 1980, Sloof and Wolterbeek 1993b, Takala and others 1990.

Precipitation (incl. fog, rain and snow) chemistry - Bosserman and Hagner 1981, Farmer and others 1991, Gordon and others 1995, Hooper and Peteres 1989, Malmer and others 1992, Pike 1978, Punning and others 1991, Takala and others 1994, Woolgrove and Woodin 1996, and Zechmeister 1995.

Marine aerosol - Bargagli and others 1987a, Boonpragob and Nash 1990, Boucher and Nash 1990, Fuchs and Garty 1983, Geiser and others 1994.

Volcanic gases - Connor 1979; Moser and others 1983; Davies and Notcutt 1989; Martin and others 1989; Barghigiani and others 1989, 1990; Bargagli and Barghigiani 1991; Notcutt and Davies 1993.

Bird excreta - Masse 1966.

Altitude (indirectly by increases in ppt with altitude) - Farmer 1994, Gordon and others 1995, Guttenberger and others 1991, Kral and others 1989, Kwapulinski and others 1985, Zechmeister 1995.

The following anthropogenic sources of enhancements are specifically discussed by the listed references:

Industrial emissions (power plants, pulp mills, other stack emissions) - Freitas 1994, 1995; Freitas and others 1993b; Garty 1988, 1993; Garty and Hagemeyer 1988; Garty and others 1988; Geiser and others 1994; Gliemeroth 1994; Gough and Erdman 1977; Halonen and others 1993; Juichang and others 1995; Kytomaa and others 1995; Mueller and others 1987; Nash and Sommerfeld 1981; Nimis and others 1993; Nygard and Harju 1983; Olmez and others 1985; Palomäki and others 1992; Pilegaard 1978; Rao and Dubey 1992; Showman and Hendricks 1989; Steinnes and Krog 1977; Tarazona and others 1995; Taylor 1978; Taylor and Bell 1983; Thomson and others 1987; Turkan and others 1995; Walther and others 1990a, 1990b.

Automobile exhaust and other automobile/combustion engine pollution - Garty 1987, 1993; Garty and Fuchs 1982; Garty and others 1982, 1995a, 1996a; Geiser and others 1994; Glenn and others 1995; Laaksovirta and Olkkonen 1979; Laaksovirta and others 1976; Lawrey 1986; Lawrey and Hale 1979, 1981; Levin and Pignata 1995; Mankovska and Kyselova 1987; Markert and others 1996; Semadi and Deruelle 1993; Tuba and Csintalan 1993a; Upreti and Pandev 1994; Vincent 1994.

Concrete (including roof tiles) - Garty and others 1986, Kortesharju and Kortesharju 1989.

Mining wastes around mines and smelters - Bargagli and others 1987b; Berrow and Reaves 1984; Dillman 1996; Fahselt and others 1995; Frontasyeva and Steinnes 1995; Jovanovic and others 1995; Kansanen and Venetvaara 1991; Lawrey 1977; Lawrey and Rudolph 1975; LeRoy and Koksoy 1962; Lodenius and Laaksovirta 1979; Lupsina and others 1992; Markert and others 1996; Mukherjee and Nuorteva 1994; Nash 1975; Nieboer and others 1982; Palomäki and others 1992; Perkins and others 1980; Pilegaard 1979; Pyatt 1970, 1973; Pyatt and others 1992; Roberts and others 1979; Roberts and Thompson 1980; Robitaille 1977; Sanchez and others 1994; Sawidis and others 1995; St. Clair and others 1995; Tomassini and others 1976; Tsai 1987; Vestergaard and others 1986; Wallin 1976; Yevseev and Krasovskaya 1994; Zanini and others 1992.

General urban air pollution - Bargagli and others 1987c; Boonpragob and Nash 1991; Brüning and Kreeb 1993; Garty and others 1977, 1993; Glenn and others 1991; Guevara and others 1995; Markert and others 1996; Rope and Pearson 1990; Saeki and others 1975, 1977; Steinnes and Njastad 1995; Takala and Olkkonen 1981; Thomson and others 1987; Vincent 1994.

Agricultural sources - Loppi and others 1994b; Søchting 1991, 1995.

Acid rain events - Case 1990, Farmer and others 1991, Freedman and others 1990, Hyvärinen and Crittenden 1996, Kubin 1990, Lodenius and Malm 1990, Raeymaekers 1987, Raeymaekers and Glime 1986, Richardson 1988.

Geothermal power generation facilities - Bargagli and Barghigiani 1991, Loppi 1995, Loppi and Bargagli 1996, Mathews 1981.

Ski areas and concentrations in snow - Moore and others 1978, Woolgrove and Woodin 1996.

Radionuclide enhancement (including natural sources) - Adamova and Biazrov 1991; Biazrov 1993, 1994; Biazrov and others 1993; Bretten and others 1992; Feige and others 1990; France and others 1993; Hanson and others 1975; Heinrich and others 1989; Hoffmann and others 1993; Nifontova 1995; Nifontova and Alexashenko 1993; Nifontova and others 1979, 1989; Nifontova and others 1979, 1989, Papastefanou and others 1992; Rahola and others 1992; Rissanen 1992; Santos and others 1993; Seaward 1991; Sloof and Wolterbeek 1992; Steinnes and Njåstad 1995; Svoboda and Taylor 1979; Thomas and Ibrahim 1995; Tuominen and Jaakkola 1973; van den Berg and others 1992.

Organic residues - Carlberg and others 1983, Focardi and others 1991, Herzig 1993, Morosini and others 1993, Muir and others 1993, Roy and others 1996, Thomas and others 1984, Villeneuve and others 1988.

APPENDIX C: DATABASE OF ELEMENT CONTENT IN LICHEN AND BRYOHYTE SPECIES FOUND IN THE PACIFIC NORTHWESTERN UNITED STATES AND CANADA

Key to interpretation of data tables

The tables present levels of elements in some 77 lichen and bryophyte species known to occur in the Pacific Northwest. The main columns list content of 17 elements commonly reported. Other less commonly reported elements are listed in the final column. Elements that may be referenced in the final column of the table include: Antimony (Sb); Barium (Ba); Beryllium (Be); Bromine (Br); Cerium (Ce); Cesium (Cs); Chlorine (Cl); Cobalt (Co); Fluorine (F); Gallium (Ga); Iodine (I); Lanthanum (La); Lithium (Li); Molybdenum (Mo); Neodymium (Nd); Nitrogen (N); Scandium (Sc); Selenium (Se); Silicon (Si); Silver (Ag); Strontium (Sr); Tin (Sn); Titanium (Ti); Vanadium (V); Tungsten (W); Uranium (U); Ytterbium (Yb); Yttrium (Y); Zirconium (Z)

Enhancement coding

Cell formats in tables indicate elemental enhancement as defined by the authors of cited papers or as determined by interpretation of discussion.

Enhanced	Partly enhanced	Possibly enhanced	Unenhanced or not evaluated

Partly - not all values making up a mean or range value were above enhanced level

Possibly enhanced - original citation does not qualify and site is urban or industrial

Additional coding used in final column of tables: po = possibly enhanced; pa = partly enhanced; en = enhanced.
"—" in cell indicates values below limit of detection.
All values in tables are in parts per million (ppm).

Forest Health Monitoring Guidelines from EPA (1992)	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn
Maximum detection limits (Table 2-2)	1.0	0.002	0.2	0.02	2	0.02	0.02	0.6	0.0	0.8	0.02	0.004	0.02	2	0.2	0.2	2	0.02
Decimal points in reports (Table 2-4)	1	2	1	1	0	2	2	1	1	0	1	3	2	0	0	1	0	1

Sources referenced in the tables are listed in Appendix D.

General Lichen Means

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Worldwide[1]	Enhanced - seashore	various					40000-			2000-		1000-	300-		10-120		5000-	1000-			
Worldwide[1]	Enhanced - urban/industrial	various								14000-	100-		350-						2000-	1000-	Ti 150-3800en;
Worldwide[1]	Enhanced - mine/smelter	various	1300-			30-330		25-130	15-	400-	100-				10-300					2000-	Mo 1-10en
Worldwide[1]	Background	various	300-			1-30	200-	0-10	<1-50	50-1600	5-100	100-	10-130	0-1	0-5	200-	500-	50-	50-	20-500	6
Canada[2]	Arctic, supposed background	various						2	5	160	5				1				210		Ti 5-10; V 1.00
Worldwide[2]	Background	various	<400	1.50		<30	<1000	<10	<50	<1600	<5	<1000	<130	<1	<5		<5000	<1000	<1000	<500	7
Worldwide[2]	Urban/industrial (see note with	various	7900-	1-		1-32	2800-	4-120	12-	660-	15-	710-	40-	8.000	2-120		4000-	520-	980-	30-	8
Worldwide[3]	Industrial/urban concentrations	various		128-				4	15-	200-	111-			0.40-	8-312				470-	800-	9
Worldwide[3]	Rural concentrations	various		0.06-				0.5-2	0.7-5	50-900	0.4-9.2			0.009-	~1-5.5				101-	6-55	F 2.9-7.8; Ti 7-
NM[4]	Saxicolous cr/fol - low				5.3				26.00				218.0								10
NM[4]	Saxicolous cr/fol - high				17.0				106.70				326.0								11
NM[4]	Saxicolous cr/fol - range			3.8-			28300-	9.0-	9.5-	2800-	25.1-	2500-		0.20-	3.6-	5600-	9600-	1100-		24.3-	12
WA[5]	Olympic National Park, overall max.	various	1340		7.4	0.43	19300	3.41	7.63	1850.0	128.0	1160	1130.		5.68	2690	4810	453.6	1760	65.8	
WA[5]	ONP, species showing maximum	various	HYEN		TUCH	HYPH	HYPH	HYEN	HYEN	HYEN	HYIM	HYPH	HYPH		HYPH	HYEN	HYEN	BRYO	HYEN	HYPH	
WA[5]	ONP overall minimum	various	32.6		0.7	--	501	0.18	1.02	19.6	--	201	18.3		--	327	1450	52.7	243	16.2	

1 Nieboer and others 1978
2 Nieboer and Richardson 1981
3 Nash and Gries 1995
4 Nash and Sommerfeld 1981
5 Rhoades 1988
6 Mo 0-3; N 6000-50000; Sr 0-700; Ti 6-150; V 0-10
7 Se 0.5; Sr <700; Ti <150; V <10
8 F 50-150en; Ga 3.0po; Li 2.0po; Se 1.0po; Sr 150.0po; Ti 35-3800en; U 1.0po; V 2-170en; Y 11.0po
9 F 48-940en; Ti 35-3800en; V 101-578en
10 Ba 152.00; F 45.00; Li 4.4; Mo 1.90; Se 1.0
11 Ba 228.00; F 110en; Li 11.4en; Mo 1.90en; Se 2.7en
12 Be 0.11-0.27; Co 3.6-7.7; Li 2.6-9.5en; Mo 0.5-2.0en; Si 40000-106000; Ag 0.63-1.35

General bryophyte means

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
N. America & Scandanavia[1]	Background	Various				0.10			2.00	500.0	30.0			0.100	2.00					30.0	
Various[1]	General plant enhanced	Various		8.00					30.00	800.0	50.0				30.00					250.0	F 35en
Various[2]	Mosses at sites with air pollution	Various		2-4		4.4-593			173-1340	1550	1-17320			15.00	620.0				1000-9349	323-55000	F 6-6000en
Sweden[3]	Lowest value in table	Various		0.16		0.3		0.70	4.50		11.0				1.5					47.0	V 1.40
Sweden[3]	Highest value in table	Various		0.81		0.8		10.80	13.50		62.0				6.50					83.0	V 7.20po
Canada[4]	Newfoundland	Near phosphorus plant																			F 11.3-2255pa

1 LeBlanc 1969
2 Rao and LeBlanc 1966
3 Gydesen and others 1983
4 Moore and others 1978

Alectoria spp. (ALECT3)*

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]		Low soil Mo							2.3-14.1				21-76							9.0-30.3	Mo --
Canada[1]		High acid soil Mo							3.0-5.9				9-32							6.6-17.8	Mo --

[1] Doyle and others 1973

* Species acronyms follow USDA Natural Resources Conservation Service, National Plant Center database (NRCS PLANTS database) and can be accessed via the world wide web at http://trident.ftc.nrcs.usda.gov/plants/.

Alectoria sarmentosa (ALSA9)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
WA[1]	Olympic National Park	Appleton Pass		0.26		0.01			0.59		8.2								245	9.8	
WA[1]	Olympic National Park	Deer Lake		0.22		0.01			0.69		7.3								272	9.3	
WA[1]	Olympic National Park	Hurricane Ridge		.029		0.02			0.92		7.6								348	11.5	
WA[1]	Mt. Rainier National Park	Golden Lakes		0.40		0.02			0.88		5.0								404	15.2	
WA[1]	Mt. Rainier National Park	Tolmie		0.30		0.04			1.10		8.9								448	15.3	
WA[1]	Mt. Rainier National Park	Windy Gap		0.60		0.04			1.01		6.9								431	14.5	
BC[2]	Spruce-fir Forest	52N 120W					2100					600				1400	3500				N 5500
OR[3]	Mt. Hood Wilderness	various	46.8		0.7	0.13	3107	0.69	1.2		5.1	316	105.1		0.41	473	1646	68.8	370	22.9	N 3630
Canada[4]	Newfoundland	near phosphorus plant																			F 5.9-12.6
WA[5]	Alpine Lakes Wilderness	various - range	24.8-159.4		2.0-4.6	0.14-0.44	578-6479	0.49-1.31	1.52-2.96	20.9-124.9	1.82-14.59	190-528	40.9-131.2		-- - 1.59	196-779	1040-2565	36.0-90.5	360-710	16.8-50.0	SI 47.8-201.3
WA[6]	Olympic National Park	various-background	46.7		1.5	0.04	2200	0.42	1.20	19.6	4.7	232	73.2		0.56	777	1450	67.6	245	17.4	
WA[6]	Olympic National Park	various-min	32.6		1.0		930	0.26	1.02	19.6	3.3	232	37.6			327	1450	62.8	243	17.9	
WA[6]	Olympic National Park	various-max	119.0		2.9	0.05	4210	0.64	1.37	108.0	14.4	453	268.0		1.17	1150	2700	221.0	592	44.6	
AK[7]	Tongass National Forest	various - baseline	30.4		1.2	0.18	3860	0.38	0.81	20.0	2.8	314	78.7		0.59	317	1188	125.5	320	21.4	
AK[8]	Chugach National Forest	various-mean	41.9		3.3	0.29	4482	0.65	1.6	36.5	2.2	371	51.5		0.62	366	1235	187	294	22.2	
AK[9]	SE AK peatland	various-range	12-144		0.21-16.33	0.07-0.60	603-29156	0.11-0.82	0.26-1.48	6-165	0.85-8.84	122-601	6-150		0.22-0.59	121-312	624-1372	30-3948	28-433	13-39	
AK[9]	SE AK peatland	various -median	32.0		1.6	0.21	5082	0.25	0.90	24	2.2	353	48.0		0.29	185	1047	105	257	22	
BC[10]	West Kootenay	various -range	97-230	<2.0-4.0		1.0-2.5	410-1820	<0.2-0.5	1.3-2.3	89-189	17-55	151-312	43-327		0.2-1.1	270-797	1640-2450	39.0-138	360-670	78-128	11
BC[10]	West Kootenay	various -mean	154	2.33		1.85	1096	0.34	1.8	140	30	243	170.5		0.46	463	2081	91.3	525	100	12
	Estimated Cutoff		50	0.50?	<2.0?	0.20?	2500	0.50	1.50	40	5	250	80		0.60	500	1500	75	350	25	

1 Frenzel and others 1985, 1990
2 Pike 1978
3 Geiser and Boyll 1994
4 Moore and others 1978
5 Lesher and Henderson 1992
6 Rhoades 1988
7 Geiser and others 1994
8 Derr 1997
9 Derr 1994
10 Enns 1996
11 Sb<2, Ba 4.0-9.0, Be<0.02, Bi<2.0, Co<0.1, Li<0.2, Mo<0.5, Se<2.0 , Si 51.0-85.0, Ag<0.1, Sr 2.0-6.0, Th<1.0, Sn 2.0-5.0, Ti 6.8-13.0, U<5.0, Va<0.2-0.4, Zr<0.1-0.5
12 Sb<2, Ba 6.2, Be<0.02, Bi<2.0, Co<0.1, Li<0.2, Mo<0.5, Se<2.0 , Si 65, Ag<0.1, Sr 3.7, Th<1.0, Sn 3.5, Ti 9.0, U<5.0, Va 0.28, Zr 0.19

Bryoria spp. (BRYOR2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
WA[1]	Alpine Lakes Wilderness	Various-range	64.1-249.2		2.9-5.6	-- - 0.42	767-2236	0.72-1.6	1.82-3.72	51.6-248.3	17.46-17.46	239-334	31.2-142.0		0.53-1.72	361-765	1448-2166	47.8-95.2	500-820	15.6-30.6	Si 56.9-253.7
WA[2]	Olympic National Park	Various-min	154.0		4.2	--	672	0.86	2.42	218.0	18.2	578	65.8		1.92	662	3290	261.0	705	31.2	
WA[2]	Olympic National Park	Various-max	231.0		6.2	0.13	1190	1.34	3.08	332.0	39.1	609	137.0		2.41	1310	3640	454.0	1020	43.4	

1 Lesher and Henderson 1992
2 Rhoades 1988

Bryoria capillaris (BRCA14)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
CA[1]	Marble Mt. Wilderness	~41 37'N ~123 8'W	65.3	0.27	37.7	1.71	2693	0.54	1.46	276.5	7.5	824	346.8		--	2170	4470	62.4		21.0	[2]

1 Ryan and Nash 1990
2 Ba 14.43pa, Co 0.01, Li --, Si 352, Mo 0.19, Ag 0.61, Sr 14.3, Sn 0.80, T 1.0, V 0.19.

Bryoria fremontii (BYFR60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
MT[1]	Missoula River Valley west of Missoula	46 55'N 114 05'W																	1800-2350		

1 Sheridan and others 1976

Cetraria subalpina (CESU60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
WA[1]	Alpine Lakes wilderness	Various-range	282.0-334.0		3.2-5.9	0.28-0.43	756-1068	1.16-1.82	3.67-4.22	142.8-199.0	10.09-17.40	338-436	34.3-108.2		1.24-1.87	460-606	2921-4255	134.1-166.8	590-780	49.8-59.6	

1Lesher and Henderson 1992

Tuckermannopsis (Cetraria) chlorophylla (TUCH60, CECH4)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
WA[1]	Olympic National Park near Port Angeles	one sample from canopy of Douglas-fir	765.0		7.4	--	1370	2.14	6.81	925.0	8.4	844	79.0		5.41	2150	4600	310.0	1340	31.9	

[1] Rhoades 1988

Allocetraria (Cetraria) cucullata syn.Flavocetraria cucullata (FLCU, CECU60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	Northwest Territories	mean values, various Lats 60-80+ N	633.8	0.26			7627	1.60	8.50	478.8	4.2	638	47.7		2.50		1661	233.1	233	24.1	[2]

[1] Puckett and Finegan 1980
[2] Sb 0.1, Cl 339, Co 0.5, Sc 0.18, T 62.7, V 1.78

Allocetraria (Cetraria) nivalis (FLNI, CENI62)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	Northwest Territories	mean values, various Lats 60-80+ N	369.6	0.28			9093	1.50	6.20	257.7	5.6	917	84.5		2.70		1434	213.3	191	25.0	[2]

[1] Puckett and Finegan 1980
[2] Sb 0.1, Cl 202.1, Co 0.7, Sc 0.13, T 48.1, V 1.20

Cladina sp. (CLADI3)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	British Columbia, UBC Haney 1988	49 16'N 122 34'W	310.0				1049		1.00	408.0	29.0	235	100.0			642	1394	129.0	642	42.0	
Canada[1]	British Columbia, UBC Haney 1986	49 16'N 122 34'W	222.0				1050		13.50	284.0	27.0	275	48.0			556	1280	61.0	547	25.0	

[1] Enns 1989

Cladina arbuscula (CLAR60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	northern Alberta	Athabasca oil sands area	200-1520																		Ti 20-160, V 3-140

[1] Addison and Puckett 1980

Cladina mitis (CLMI60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	Ontario	background at 30 mi. from smelter							182.7	1489	36.5		13.0		112.0					28.3	
Canada[2]	British Columbia, UBC research forest	~49 22'N ~122 32'W	310.0				1049		1.00	405.0	29.0	335	100.0		84.80	477	1394	129.0	642	42.0	N 5700
Canada[3]	Ontario, 0.5-39km S of two U mines	46 25'N 81 38'W						1.07-8.27										100-10100		11.65-43.73	4

[1] Nieboer and others 1972
[2] Palmer 1986
[3] Fahselt and others 1995
[4] Ce 0.76-13.8, Cs 0.0-0.41, La 0.22-6.76, Rb 2.93-10.92, Sc 0.10-0.30, Sm 0.05-0.77, Th 0.07-4.87pa, U 0.00-1.05pa

Cladina rangiferina (CLRA60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	Ontario	background at 30 mi. from smelter							55.60	1456	30.3				101.1					22.8	
ME[2]	Acadia National Park		71-140		0.9-1.6	0.1-0.2	197-274	0.2-0.3	1.4-2.1	73-134	3.7-11.0	287-431	5.6-30.1		<0.3-0.9	363-587	1295-2360	60.9-193.7	367-610	13.2-17.5	
Sweden[3]	surrounding brass foundry	various				0.1-1.0			4-40	160-1200	11-36				0.8-2.3					51-204	
Canada[4]	Newfoundland	near phosphorus plant																			F 5.9-52.5pa
Canada[5]	regional study	various									3.5-31								310-1140		
AK[6]	Tongass National Forest	baseline	40.4		0.7	0.23	583	0.38	0.76	50.3	1.90	429	50.9		0.52	231	931	56.8	270	11.5	
AK[7]	Chugach National Forest	various-means	321.0		1.7	0.12	914	0.82	1.91	266	1.00	424	41.6		0.79	341	658	184	313	11.6	
MI[8]	Isle Royale National Park	various	370.3		1.1	--	824	0.50	2.13	387	7.98	324	26.4		0.77	489	1578	31	379	17.6	
MN[9]	Boundary Waters Canoe Area	various	240.0		1.7	0.16	571	0.42	1.61	205	1.42	287	45.3		0.59	502	1841	29	472	15.7	
	Estimated Cutoff		250		<2.0?	0.20?	500	0.50	2.00	200	2.00	400	50		0.80	500	2000	60	500	20	

1 Nieboer and others 1972
2 Wetmore 1987c
3 Folkeson 1979
4 Moore and others 1978
5 Zakshek and others 1986
6 Geiser and others 1994
7 Derr 1997
8 Wetmore 1985
9 Wetmore 1987a

Cladina stellaris (syn. Cladina alpestris) (CLST60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	Northwest Territories	various, Lat. 60-80+ N	940.7	0.44			1013.1	2.30	6.90	568.7	4.3	351	30.2		2.90		1375	158.9	340	15.9	[6]
Canada[2]	Ontario	background at 30 mi. from smelter							95.00	1615	32.7		15.0		112.8					15.0	
Canada?[3]		Wetmore lichen standard	403.0		0.7	0.16	212.3	0.96	2.18	521.6	10.8	266	18.8		1.06	193	658	82.7	416	16.9	
Canada[4]		Low soil Mo							1.7-4.6				33-93							7.8-25.7	Mo --
Canada[4]		High acid soil Mo							0.6-8.9				17-156							6.7-32.3	Mo 0.2-2.4po
Canada[5]	Newfoundland	various around phosphorus plant																			F 5.8-686na

1 Puckett and Finegan 1980
2 Nieboer and others 1972
3 Wetmore 1987d
4 Doyle and others 1973
5 Moore and others 1978
6 Sb 0.1; CL 61; Co 0.6; Sc 0.20; Ti 68.5; V 3.98

Cladonia deformis (CLDE60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	Ontario	10 mi. from Ni smelter							270.0	5200					385.0					95.0	
Canada[1]	Ontario	background at 30 mi. from smelter							86.70	109.0	49.5		27.0		109.0					35.7	

1 Nieboer and others 1972

Cladonia furcata (CLFU3) Note: In Enns (1989), indicated as Cladonia in Appendix 2 but CLFU3 in captions to Figure 2.

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	British Columbia, UBC Haney 1988	49 16'N 122 34'W	1260				886		6.50	1372	68.0	318	30.0			486	1288	140.0	597	85.0	
Canada[1]	British Columbia, UBC Haney 1986	49 16'N 122 34'W	316.0				1000		26.00	479.0	28.2	236	36.0			412	1670	209.0	537	282.0	

1 Enns 1989

Cladonia gracilis (CLGR13)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	British Columbia, UBC Research Forest	~49 22'N ~122 32'W	521.0				989		5.50	642.0	60.0	240	43.0		2.20	350	1138	102.0	551	60.0	N 5700

1 Palmer 1986

Cladonia squamosa (CLSQ60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	British Columbia, UBC Research Forest	~49 22'N ~122 32'W	1260				886		6.50	1372	68.0	318	30.0		2.60	597	1280	140.0	597	85.0	N 6700

1 Palmer 1986

Cladonia uncialis (CLUN60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	Ontario	background at 30 mi. from smelter							71.00	1329			13.0		33.00					40.0	

1 Nieboer and others 1972

Cladonia spp. (CLADO3)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Norway[1]	mean from 1976 data compared to other spp.		712.0			0.16			2.75		13.4									23.3	

1 Steinnes 1993

Dermatocarpon miniatum (DEMI60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
CA[1]	San Gabriel Wild. 1989	~34 19'N ~117 56'W	7693	0.06	2.1	0.69	4768	31.18	21.11	3688	41.3	9555	499.9		15.52	12683	27967	9295		46.1	
UK[2]	field samples	various					2840					3035					10735			95.0	[4]
NM[3]		various		5.30				12.90	20.50		28.6			0.480						37.6	Be 0.27

1 Ryan and Nash 1990
2 Brown and Beckett 1983
3 Nash and Sommerfeld 1981
4 Ba 108.12en, Co 3.3pa, Li 5.44en, Mo 2.40pa, Si 13283en, Ag 0.03, Sr 293.7, Sn 0.78, Ti 986.83en, V 12.98en

Dicranoweisia cirrata (DICI5)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Denmark[1]		in situ				0.49					32.0										
Denmark[1]		transplanted				0.36-3.09					33-521										

1 Johnsen and others 1983

Dicranum polysetum (DIPO70)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Sweden[1]	surrounding brass foundry	various				0.4-2.2			11-68	320-1180	22-43				1.6-5.3					74-303	
MN[2]	Cedar fen	unknown	1400		9.0		9000			1700		1000	270.0			1700	2900				

1 Folkeson 1979
2 Gorham and Tilton 1978

Eurhynchium sp. (EURHY2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	British Columbia, Shawnigan Lake 1988	49 36'N 123 43'W	541.0				7230		10.60	443.0	25.8	1380	1050			1650	7280	246.0	1140	39.7	

1 Enns 1989

Evernia prunastri (EVPR2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Finland[1]										242-536			42-92							46-106	
Denmark[2]		in situ				0.2					3.2										
Denmark[2]		transplanted				0.06-1.4					9.6-300										
Scotland[3]	West Central	mean winter SO2<30 ug/m3																	382		
Scotland[3]	West Central	mean winter SO2 55 ug/m3																	1129		

1 Lounamaa 1965
2 Johnsen and others 1983
3 Hawksworth and Rose 1976

Flavoparmelia caperata (FLCA2) - background measured in Parmelia s. lato

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
N. Italy[1]	range of regional background means	~44 08'N ~9 17'E	186-427	0.57		0.33-1.22		0.32-0.87	5.7-13.4	210-700	8.9-40.0		8.1-30.0	0.10-0.24	0.27-2.11					19.6-77.3	Ti 0, V 1.71
N. Italy[1]	La Spezia range	~44 08'N ~9 17'E	271-1545	0.30-2.30		0.85-9.04		0.81-3.84	12.5-60.2	195-952	24-494		21.1-47.7	0.22-1.07	2.08-6.22					75-157	Ti 8-42pa, V 1.66-5.81pa

1 Nimis and others 1993

Hylocomium splendens (HYSP70)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Norway[1]	Regional study - 1976 means	various	890.0	0.57		0.3		2.1	6.60	663	37.0		235.0					322.0		40.0	14
Norway[1]	Regional study - 1976 ranges	various	80-5860	0.13-2.33		0.07-0.86		0.3-8.3	0.09-1.57	130-3700	6-148		30-720					83-1900		11-80	15
Norway[2]	Regional study - 1977 means	various	863.0	0.51		0.3		2.7	7.30	631.0	25.6		311.0		2.6			318		41.0	16
Norway[3]	Regional study - 1977 ranges	various	120-8970	0.05-3.54		<0.1-1.5		0.2-128	1.3-82	130-8800	1-181		22-1240		<0.5-88			40-6580		12-241	17
Norway[4]	Regional study - 1985 ranges	various	150-13700	0.1-6.2		0.03-1.64		0.3-116	2.1-265	130-19400	1-138				0.4-303					8-780	18
N. Finland[5]	Background ranges away from steel works							2.6							3-6						
WA[6]	Mean of 1-5 yr. leaves	47 50'N 123 59'W	780.0	<1.0	34.0	<3.0	3300	0.5	4.80	580.0	3.6	1200	2700		<0.5	930.0	7200	260.0		15.0	19
WA[7]	Range of 6 sites		1084-2260						2.6-7.8		0.7-10.0										
Canada[8]	Enhanced			4		8.4			173-724		93-17220								1600	304-804	F 7.0en
Sweden[9]	surrounding brass foundry	various				0.7-2.4			14-78	310-1250	22-80			2.9-8.5							V 94-315en
Canada[10]	Partial range into area around copper mine			4.0-4.0		1.1-1.5			81.0-246.0		141.0-196.5									86.0-120.0	
Italy[11]	mean of background areas		700			0.27	9800	0.90	8.60	457	17	2600	150.0	0.11	1.3		5500	154.0		32.0	Ba 14
Note: The following studies (four rows) combined Hylocomium splendens and Pleurozium schreberi																					
N. Europe[12]	Background	various				0.2		1.0	4.00	200	5.0				1.0					20.0	V 2.0
N. Europe[12]	Enhanced	various				0.8		10.0	28.00	1500	60.0				30.0					100.0	V 10.0en
Europe[13]	Background	various		<0.2-0.6		<0.2-0.5		<1.0-2	<4-10	<500-1000	<5-20				<1-3					<40-50	V<1-3
Europe[13]	Enhanced	various		>0.6		>0.5		>2.0	>10	>1000	>20				>3					>50	V>3en
	Estimated Cutoff		700	0.6	40	0.5	10000?	2.00	10	300	20	3000?	200?		3			300?	100?	50	

1 Steinnes 1993
2 Schaug and others 1990 and Steinnes 1993
3 Steinnes 1993 and Steinnes and others 1994
4 Steinnes and others 1994
5 Kansanen and Venetvaara 1991
6 Wiersma and others 1987
7 Wiersma 1981
8 LeBlanc and De Sloover 1970 and LeBlanc and others 1971
9 Folkeson 1979

10 Rao 1982

11 Bargagli and others 1995

12 Rühling and others 1992

13 Rühling and others 1994

14 Sb 0.3pa, Br 7.4pa, Cs 0.3pa, Cl 171pa, Co 0.4pa, La 0.49pa, Mo 0.1pa, Rb 9.1pa, Sc 0.2pa, Se 0.4pa, Ag 0.12pa, Sm 0.10pa, Th 0.10pa, V 3.7pa

15 Sb 0.5-0.94pa, Br 1.6-18.7pa, Cs 0.04-1.21pa, Cl 40-410pa, Co 0.09-1.5pa, La 0.08-1.51pa, Mo 0.05-0.44pa, Rb 1.1-26, Sc 0.03-107pa, Se 0.05-109pa, Ag 0.02-0.59pa, Sm 0.01-0.27, Th 0.01-0.37, V 0.3-10.1pa

16 Sb 0.3pa, Br 6.5pa, Cs 0.2pa, Cl 185pa, I 3.3pa, Co 0.3pa, La 0.60pa, Mo<0.2pa, Rb 11.2pa, Sc 0.2pa, Se 0.5pa, Ag 0.09pa, Sm 0.085pa, Th 0.113pa, V<0.5-64pa

17 Sb 0.03-1.96pa, Br 1.3-34.7pa, Cs<0.01-2.06pa, Cl 30-810pa, I<1.0-20.4, Co 0.4pa, La 0.07-15.2pa, Rb 1.2-52, Sc 0.021-2.23pa, Se<0.10-2.84pa, Ag<0.05-1.38pa, Sm 0.006-0.89, Th 0.01-2.55

18 Sb 0.3-1.40pa, Br 1.4-34.7pa, Co 0.01-12.7pa, I 0.6-47pa, Sc 0.03-4.2pa, Se 0.04-2.18pa, V 0.4-20.9pa

19 Ba 35.0, Be<0.2, Co<1.5, Li 2.9, Mo<0.2, N 8900, Si 4700, Ag<0.1, Sr 25.0, Sn<0.3, Ti 41.0, V<1

Hypnum cupressiforme (HYCU4)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Denmark[1]	cited from Pilegaard, 1979, from Tisvilde site					0.75					150.0										
England[2]	estimated backgrounds	Northeast coast				1.0			10.00	1000	40.0		75.0							50.0	
Sweden[3]	surrounding brass foundry	various				0.9-2.2			11-82	762-3230	52-175				4.0-13.0						V 105-392en
Sweden[4]	General regional background	various												90-150							
Sweden[4]	Enhanced range	various												500-15000							
New Zealand[5]	range from mineralized areas near mining					0.80-4.60			18-34		160-202									112-156	Ag 0.16-0.60
New Zealand[5]	range near treatment plants in mining areas					1.20-3.40			15-34		74-125									126-167	Ag 0.01-0.10
New Zealand[5]	mean from background areas					0.41			10.10		10.6									17.2	Ag 0.015
Sweden[6]	lowest background mean					0.68			6.80		42									82.0	
Italy[7]	mean of background areas		1600			0.30	9200	2.4	8.40	1290	15	2800	178.0	0.11	1.8		4900	156.0		26.0	Ba 32
	Estimated Cutoff		2000?			1.0	10000?	3.00?	11	1500?	50	3000?	200?	200?	2.5?			175?		90	

1 Johnsen and others 1983
2 Ellison and others 1976
3 Folkeson 1979
4 Doyle and others 1973
5 Ward and others 1977
6 Rühling and Tyler 1971
7 Bargagli and others 1995

Hypogymnia "enteromorpha" (HYEN60) -- Note this may also include reference to Hypogymnia apinnata

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
MT[1]	Missoula River Valley west of Missoula	46 55'N 114 05'W																	700-1900		
CA[2]	Redwood NP	41 46'N 124 02'W	1100			--	3800	4.90	3.70	850.0	12.0	1300	89.0		11.00	670	1800	320.0	470	25.0	[8]
CA[3]	Little Bald Hills	41 45'N 124 05'W	300-1800			<0.08-0.33	12-13000	2.4-13	1.3-9.9	360-1900	3.6-20	340-1800	40-250		5.0-26	230-1200	620-2300	120-490	60-640	9.1-51	[9]
OR[4]	Mt. Hood Wilderness	various	596.3		1.9	0.16	6384	1.36	4.00		10.4	561	128.7		1.08	1033	2309	187.1	520	31.7	N 4520
Note: The following record was given as Hypogymnia spp. in Enns (ne Palmer) 1989, Appendix 2, but were indicated as being HYEN in captions to Figure 2 and Table 1. (another record from this Table was HYPH from Palmer 1986 and is included below)																					
Canada[5]	British Columbia, Saltspring Island, 1988	48 48'N 123 31'W	1530				2290		13.20	2020	63.5	907	194.0			1320	1530	--	852	39.2	
WA[6]	Olympic National Park	background	803.0		2.7	0.09	8420	1.87	5.55	1040	16.5	742	75.8		1.82	1270	2640	112.0	723	33.7	
WA[6]	Olympic National Park	max	1340		6.8	0.33	18200	3.41	7.63	1850	109.0	1130	935.0		5.50	2690	4810	242.0	1760	48.5	
WA[6]	Olympic National Park	min	207.0		1.4	--	1460	0.54	3.52	141.0	--	422	27.9		--	1040	2270	54.9	440	24.9	
AK[7]	Tongass National Forest	baseline	275.8		3.7	0.26	12168	0.73	3.52	266.5	4.8	1115	231.0		1.12	878	2213	258.8	590	34.2	
	Estimated Cutoff		500		3.0	0.25	10000?	2.00	4	400	15	500	75		1.5	900	2400	200	750	35	

1 Sheridan and others 1976
2 Gough and others 1987
3 Gough and others 1988a
4 Geiser and Boyll 1994
5 Enns 1989
6 Rhoades 1988
7 Geiser and others 1994
8 Ba 24.00, Ce 0.55, Co 0.3 Ga 0.3 La 0.37, Li 0.33, Mo --, Nd 0.3, Sc 0.26, Sr 18.0, Sn --, Ti 51.0, V 2.50, Y 0.22
9 Ba 10-110, Ce<0.18-0.89, Co 0.15-0.72, Ga<0.18-0.49, La 0.09-0.68, Li<0.9-0.55 Mo<0.09-0.18, Nd<0.18-0.50, Sc<0.09-0.46, Sr 5.5-40, Sn<0.9-4.4, Ti 16-88, V 0.73-6.3, Y<0.09-0.37

Hypogymnia imshaugii (HYIM60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
CA[1]	Sequoia and Kings Canyon NPs	~36 46'N ~118 57'W	928-1497		5.0-6.3	-- - 0.3	10404-12275	1.2-1.7	4.5-5.5	668-1184	12-15	957-1147	124.6-181.3		2.0-2.9	1260-1727	4127-5140	84.9-86.9	1345-1682	24-31	
CA[2]	San Gabriel Wilderness 1987	~34 19'N ~117 56'W	2221.7	-- ?	3.4	0.87	7277	4.40	17.48	2866.7	45.4	2330	248.2		1.63		13433	1913.0		57.5	[4]
WA[3]	Olympic National Park	one sample	912.0		3.8	0.20	697	3.31	6.17	1320.0	128.0	363	18.3		3.75	788	2490	129.0	1540	41.7	

1 Wetmore 1986
2 Ryan and Nash 1990
3 Rhoades 1988
4 Ba 56.53en, Co 0.88, Li 2.8en, Mo 1.81, Si 4437en, Ag 0.03pa, Sr 27.5, Sn 0.33, Ti 81.4, V 2.62

Hypogymnia inactiva (HYIN2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
OR[1]	Mt. Hood Wilderness	various	582.4		1.6	0.22	4741	1.93	3.60		11.6	601	181.7		1.34	819	2675	144.0	600	28.5	N 5180

1 Geiser and Boyll 1994

Hypogymnia physodes (HYPH60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	BC, Salt Spring Island	~ 48 50'N ~ 123 31'W	1948.0				13513		2.60	1549.0	60.0	680	162.0		4.10	1027	2472	120.0	505	38.0	N 5200
Canada[2]	northern Alberta	Athabasca oil sands area	2000->5000																1000->2500		V 100 - >250
Denmark[3]		in situ				0.46					46										
Denmark[3]		transplanted				0.21-1.53					45-273										
S. Finland[4]	ranges around Valkeakoski	urban area					1197-2287			823-7200							1600-4157		532-1673	160-266	Ti 446-6820; V 24-578
Finland[5]										850-1621			23-133							74-154	
WA[6]	sites around oil refinery	various																	139-1204		
Denmark[7]		background				0.58-0.74		2.2-5.0	8.4-10.6	1100-1700	44-76		24-38		0.11-0.12					85-100	
Denmark[7]		transplanted				4.0-7.4		80-82	117-240	28000-31000	574-1600		293-686		35-46					1530-2220	
Norway?[8]		transplants																	3000		
Poland?[9]																			1440		
Poland[10]	Pine and birch forest				2.4	0.40		3.20	5.00	1100.0	17.0		62.0		4.80					78.0	
NH[11]	Balsam Fir						26900			581.0			339.0			1200	4500			112.0	Mo 1.12; N 7900
N. Finland[12]	away from steel works	Background						4-5							3.3-3.8						
S. Finland[13]	20 m from hwy.	various									195.0										
S Finland[13]	100 m from hwy.	various									80.0										
MN[14]	Boundary Waters Area	various	480		4.16	0.84	23614	0.87	3.38	490	19.5	695	205		1.54	703	3301	31.2	951	66.5	
ME[15]	Acadia NP		163-230		1.3-3.1	0.4-0.7	6795-7910	0.4-0.7	2.8-3.2	151-263	30.8-44.1	905-1407	82.6-178.9		1.1-2.2	417-758	2496-3109	77.8-470.3	533-667	45.2-66.4	
Canada[16]	Ontario, ranges around Thunder Bay	~ 48 20' N ~ 89 10'W	185-706	0.9-7.1		0.2-1.2			0.8-6.0	114-601	3.9-48			0.6-5.8					42-434	7-92	
Canada[17]	British Columbia, Saltspring Island 1986	48 48'N 123 31'W	1948.0				13515		2.60	1549.0	60.0	680	162.0		4.10	1027	2472	120.0	505	38.0	N 5200
Norway [18]	mean from 1976 data compared to other spp.					0.74			7.77		62.8									95.0	
Norway [19]	lowest 10% mean	regional																	550		N 4600
Norway [19]	highest 10% mean	regional																	1330		N 14300en
Sweden[20]	surrounding brass foundry	various				0.4-1.7			11-79	290-1200	14-33				1.7-2.0					93-450	

Hypogymnia physodes (HYPH60) (continued)

Scotland[21]	surrounding steel foundry	various						1.4-17.0	10-15.6	724.6-1104.0	17.8-25.1		43.1-66.4		1.7-7.5					58.0-94.5	
Canada[22]	Newfoundland	Various around phosphorus plant																			F 15.9-1094en
Finland[23]	Regional	various								2830-4140									1090-2220		
WA[24]	Olympic National Park	"Background"	743.0		1.6	0.22	14500	1.87	4.71	754.0	38.3	834	255.0		3.97	1080	2810	111.0	574	53.0	
WA[24]	Olympic National Park	Max	918.0		5.0	0.43	19300	3.19	7.35	1390.0	121.0	1160	1130		5.68	2360	4700	277.0	1460	65.8	
WA[24]	Olympic National Park	Min	471.0		1.4	0.22	8220	1.11	3.78	545.0	17.6	610	35.1		2.72	933	2370	83.6	535	39.2	
West Central Scotland[25]	Mean winter SO2 < 30 ug/m3																		537		
West Central Scotland[25]	Mean winter SO2 60-70 ug/m3																		1509		
Canada[26]	British Columbia, west Kootenay - mean	various	440	3.83		3.48	2400	3.05	13.7	833	205	403	67.0		2.40	1472	4498	46.5	978	330	30
Canada[26]	British Columbia, west Kootenay - range	various	320 - 549	<2.0 - 6.0		2.9 - 4.0	1940 - 3360	1.2 - 5.8	8.8 - 22.2	600 - 1000	178 - 232	367 - 445	47 -83		1.1 - 3.9	1410 - 1550	4040 - 4790	41.0 - 52	860 - 1100	290 - 377	31
Finland[27]	Rural areas	various	480			0.70	3340	2.1	7.3	540	18	400	131		2.6		2750		1090	86.0	N 13000; Ti 25.9
Finland[28]	Urban and suburban sites in Oulu	various	1040			0.28	1420	7.5	10.1	2120	22.7	730	61.6		4.1		2740		2500	88.3	N 27800; Ti 115.2
Finland[29]	Rural areas outside Oulu	various	440			0.32	2190	1.7	5.9	530	9.7	410	68.5		1.1		2310		1130	61.0	Ti 20.8
Finland[29]	range - "pre & early operational"	various	440-1020			0.02-0.97	1290-5840	0.8-2.7	3.4-8.6	390-1440	8.1-18.3	290-540	35.6-87.6		0.0-1.3		1570-2620		720-1390	58.7-91.7	N 5000-9700; Ti 19.7-47.8
Finland[29]	range - post operational	various	360-940			0.00-2.23	770-4820	0.7-5.3	4.3-12.7	380-1540	5.8-67.9	270-690	28.3-125.3		0.0-5.5		1140-2650		740-2530	59.8-196.6	N 6700-24200; Ti 19.7-105.1
	Estimated Cutoff		700	4.0	2.0?	0.25	5000?	3.0	7	800	20	800	50		4	1500	4000	100	750	60	

1 Palmer 1986
2 Addison and Puckett 1980
3 Johnsen and others 1983
4 Laaksovirta and Olkkonen 1979
5 Lounamaa 1965
6 Taylor and Bell 1983
7 Vestergaard and others 1986
8 Steinnes and Krog 1977
9 Swieboda and Kalemba 1978
10 Kabata-Pendias and Pendias 1984
11 Lang and others 1980
12 Kansanen and Venetvaara 1991
13 Laaksovirta and others 1976

14 Wetmore 1987a
15 Wetmore 1987c
16 Pfeiffer and Barclay-Estrup 1992
17 Palmer 1986 and Enns 1989
18 Steinnes 1993
19 Bruteig 1993
20 Folkeson 1979
21 Gailey and others 1985
22 Moore and others 1978
23 Takala and others 1994
24 Rhoades 1988
25 Hawksworth and Rose 1976
26 Enns 1996
27 Kubin 1990
28 Kauppi and Halonen 1992
29 Halonen and others 1993
30 Sb 2.50; Ba 24.7; Be <0.02; Bi <2.00; Co 0.27; Li 0.22; Mo 0.52; Se <2.00; Si 183; Ag 0.33; Sr 11.8; Th <1.00; Sn 1.83; Ti 38.4; U <5.00; Va 1.23; Zr 0.60
31 Sb <2.0 -4.0; Ba 12-36; Be <0.02-<0.02; Bi <2.0-<2.0; Co <0.1-0.3; Li <0.2-0.3; Mo <0.5-0.6; Se <2.0-<2.0; Si 163-199; Ag 0.2-0.4; Sr 8.0-14.0; Th <1.0-<1.0; Sn <1.0-2.0; Ti 28.3-52; U <5.0-<5.0; Va 0.9-1.6; Zr 0.4-0.8

Hypogymnia spp (HYPOG2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
NH[1]	Balsam fir	44N 72W					2000					400				1900	5300				N 16900
Canada[2]	BC, Shawnigan L. 1988	49 36'N 123 43'W	329.0				3300		10.50	411.0	10.2	744	173.0			2050	4430	105.0	2050	46.5	
WA[3]	Alpine Lakes Wilderness	various	117.5-1257		2.73-6.13	0.21-0.61	1296-16979	1.25-3.01	4.52-9.55	388.1-1269	6.58-70.97	319-822	45.6-442.7		1.49-2.95	372-1152	1221-3187	82.8-142.8	590-1000	24.7-76.8	Si 310-621

1 Pike 1978
2 Enns 1989
3 Lesher and Henderson 1992

Isopterygium elegans (ISEL)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
British Col[1]	Coquitlam L. North	~ '49 25'N ~ '122 45'W	1138				4264		34.10	13364	169.0	1570	313.0		8.30	710	2046	297.0	983	76.0	N 14100

1 Palmer 1986

Isothecium myosuroides (ISMY2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
British Col[1]	Coquitlam L. West 1986	49 21'N 122 48'W	949.0				4742		16.60	905.0	118.0	797	543.0		6.10	1322	2719	88.0	1484	56.0	N 12200
British Col[2]	Coquitlam L. West 1988	49 21'N 122 48'W	910.0				4540		46.00	1080	122.0	916	470.0			1220	3540	527.0	2010	61.0	

1 Palmer 1986 and Enns 1989
2 Enns 1989

Lasallia papulosa (LAPA13)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
ME[1]	Acadia NP		113-209		1.3-2.0	0.3-0.5	59-126	0.3-0.4	2.4-2.9	126-215	17.8-33.1	280-513	6.1-14.2		0.7-0.9	382-853	3197-4232	47.5-131.7	1127-1370	126.8-178.4	

1 Wetmore 1987c

Lecanora conizaeoides (LECO17)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Netherlands/ Belgium[1]	Regional study	various		9.50		4.50		30.00	40.00	6200										430.0	[2]

[1] Sloof and Wolterbeek 1993a
[2] Sb 10.7en; Br 43.00en; Co 4.7en; La 4.60en; Se 2.3en; W 1.20en; V 32.0en

Letharia spp. (LETHA) [combined data for both L. columbiana and L. vulpina from these sites]

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
CA[1]	Desolation Wild.	~ 38 52' N ~ 120 9' W	269.1	0.28	12.5	0.5	3221	0.84	1.49	439.1	7.3	558	118.9		0.05	2129	3629	95.8		17.0	[2]
CA[1]	Emigrant Wild.	~ 38 7' N ~ 119 54' W	439.2	0.29	9.5	2.04	1344	1.18	3.14	651.3	5.0	727	66.7		0.13	2612	3862	114.8		21.8	[3]
CA[1]	Marble Mt. Wild.	~ 41 37' N ~ 123 8' W	94.8	0.25	12.9	0.74	1780	1.36	0.43	335.1	7.3	1165	77.7		0.21	1674	3018	42.7		12.2	[4]

[1] Ryan and Nash 1990
[2] Ba 12.96; Co 00; Li 0.14; Mo 0.24; Si 1783pa; Ag 0.5; Sr 10.5; Sn 0.67; Ti 28.4; V 0.87
[3] Ba 11.30pa; Co --; Li 0.01; Mo 0.35; Si 2680pa; Ag 0.45; Sr 4.1; Sn 0.84; Ti 33.6; V 0.86
[4] Ba 15.02; Co 0.04; Li 0.09; Mo 0.23; Si 888; Ag 0.58; Sr 2.9; Sn 0.64; Ti 2.8; V 0.33

Letharia columbiana (LECO26)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
CA[1]	Desolation Wild.	~ 38 52' N ~ 120 9' W	329.8	0.28	13.3	1.30	1910	0.84	2.76	514.8	6.2	743	276.8		0.10	2260	3383	113.7		17.8	[2]
CA[1]	Emigrant Wild.	~ 38 7' N ~ 119 54' W	621.0	0.29	10.4	2.34	1111	1.70	5.02	834.8	4.4	793	76.8		0.27	3043	3900	147.1		22.8	[3]
CA[1]	Marble Mt. Wild.	~ 41 37' N ~ 123 8' W	104.3	0.24	14.4	1.10	1248	1.76	0.45	397.2	8.6	1485	47.3		0.40	1718	3097	41.5		5.6	[4]
CA[1]	San Gabriel Wild. 1987	~ 34 19' N ~ 117 56' W	417.3	--	1.6	0.11	991	1.68	4.97	644.7	8.0	573	60.6		0.28	278	7393	161.7		19.0	[5]
CA[1]	San Gabriel Wild. 1989	~ 34 19' N ~ 117 56' W	1507.8	0.24	4.1	1.29	3798	1.85	10.67	1124.7	22.0	1547	166.8		0.39	4387	5155	489.0		35.9	[6]

[1] Ryan and Nash 1990
[2] Ba 12.16; Co --; Li 0.12; Mo 0.31; Si 2268en; Ag 0.49; Sr 4.3; Sn 0.79; Ti 39.1; V 0.86
[3] Ba 14.72pa; Co --; Li --; Mo 0.41; Si 3640en; Ag 0.43; Sr 3.6; Sn 0.91; Ti 53.4; V 1.10
[4] Ba 5.75; Co 0.07; Li 0.15; Mo 0.24; Si 1148; Ag 0.6; Sr 2.6; Sn 0.66; Ti 2.3; V 0.46
[5] Ba 10.28; Co 0.22; Li 0.79pa; Mo 0.10; Si 2253pa; Ag 0.01; Sr 9.1; Sn 0.09; Ti 6.2; V --
[6] Ba 46.4en; Co 0.14; Li 0.99en; Mo 0.55; Si 5533en; Ag 0.28; Sr 89.6; Sn 0.80; Ti 138.2pa; V 0.96

Letharia vulpina (LEVU2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
CA[1]	Sequoia and Kings Canyon NPs	~ 36 46' N ~ 118 57' W	322-362		3.9-4.9	-- - 0.2	1986-2848	0.6-0.7	2.4-2.4	225-266	8.3-9.5	648-686	93.5-105.4		0.8-1.1	952-1110	3522-3353	52.4-77.7	885-910	18.8-20.6	
CA[2]	Desolation Wild.	~ 38 52' N ~ 120 9' W	238.7	0.29	12.1	0.2	3876	0.84	0.84	401.2	5.6	465	40.0		0.03	2056	3752	86.8		16.7	3
CA[2]	Emigrant Wild.	~ 38 7' N ~ 119 54' W	257.3	0.28	8.6	1.7	1577	0.66	1.26	467.7	5.7	662	56.5		--	2180	3823	82.6		20.8	4
CA[2]	Marble Mt. Wild.	~ 41 37' N ~ 123 8' W	85.2	0.27	11.4	0.4	2312	0.96	0.41	273.0	6.0	845	108.0		0.03	1630	2940	43.9		18.8	5
CA[2]	Aqua Tibia Wild.	33 23' N 117 57' W	716.2	0.28	11.9	2.4	2210	0.82	2.87	688.5	5.5	917	106.7		0.12	3075	5162	339.8		40.7	6
CA[2]	San Gabriel Wild. 1987	~ 34 19' N ~ 117 56' W	732.2	--	3.1	0.5	1670	0.79	9.12	1026.6	51.0	984	83.0		0.62	534	7321	403.2		32.1	7

1 Wetmore 1986
2 Ryan and Nash 1990
3 Ba 13.37pa; Co --; Li 0.16; Mo 0.21; Si 1569pa; Ag 0.45; Sr 13.6; Sn 0.60; Ti 23.1; V 0.87
4 Ba 10.04; Co --; Li 0.02; Mo 0.30; Si 1720; Ag 0.47; Sr 4.6; Sn 0.78; Ti 11.8; V 0.62
5 Ba 24.3en; Co 0.01; Li 0.04; Mo 0.22; Si 629; Ag 0.56; Sr 3.3; Sn 0.62; Ti 3.2; V 0.24
6 Ba 24.33; Co --; Li 0.22; Mo 0.41; Si 3878en; Ag 0.42; Sr 18.9; Sn 0.83; Ti 74.2; V 0.26
7 Ba 26.72en; Co 0.32; Li 1.52en; Mo 0.58; Si 3971en; Ag 0.01; Sr 14.4; Sn 0.43; Ti 18.8; V 0.04

Lobaria oregana (LOOR60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
OR[1]	Douglas-fir	44N 122W					1700					300				2400	5700				N 17300
OR[2]	Mt. Hood Wilderness	various	160.6		1.49	0.08	588	0.58	4.40		1.43	415	60.1		0.53	1777	6909	122	1070	29.8	N 19780
AK[3]	Tongass Nat. Forest	Baseline	44.2		1.61	0.14	479	0.38	4.26	71.6	1.62	493	60.0		0.61	1800	6634	103	1090	40.4	
AK[4]	Chugach National Forest mean	various	349.0		3.26	0.19	827	1.47	7.25	417	0.83	547	49.3		1.29	1850	6022	296	1262	54.2	
	Estimated Cutoff		200		<2.0?	0.20?	600	1.00	5.00	100?	1.75	450	60		0.60	2000	7000	150	1200	50	

1 Pike 1978
2 Geiser and Boyll 1994
3 Geiser and others 1994
4 Derr 1997

Lobaria linita (LOLI60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
AK[1]	Kenai Peninsula	Chugach NF - mean	131		2.05	0.278	2431	0.461	3.69	164	<1.68	567	15.8		1.03	1177	4227	55	933	33.0	

1 Derr 1997

Lobaria pulmonaria (LOPU60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Poland[1]		Pine and birch forest			2.4	0.50		3.20	7.50	1450	28.0		66.0		2.40					74.0	
UK[2]		field samples - various					3180					365					8350			105.0	
Canada[3]	British Columbia	"GOLD" Plot	295.0				1113		1.50	299.0	14.0	474	30.0		2.40	2484	5635	86.0	2036	36.0	N 23900
Canada[3]	British Columbia	"WAIN" Plot	296.0				1389		0.30	301.0	24.0	616	38.0		0.90	2263	6284	107.0	1633	21.0	N 22900

1 Kabata-Pendias and Pendias 1984
2 Brown and Beckett 1983
3 Palmer 1986

Lobaria scrobiculata (LOSC60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
UK[1]	field samples	various					3950					950					7490			130.0	

1 Brown and Beckett 1983

Nephromataceae (includes Pseudocyphellaria anthraspis, Nephroma parile, Lobaria oregana and Lobaria pulmonaria) -- these are samples that were collected from Wain Road, N. Saanich, B. C. on Holodiscus discolor branches and transplanted (or kept as controls)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
British Col.[1]	N. Saanich Ctrl 1986		389.0				2053		1.80	405.0	30.5	769	55.5			2848	6251	118.0	1898	28.0	
British Col.[1]	N. Saanich Ctrl 1988		344.0				2360		15.60	434.0	22.0	855	59.0			1880	6660	209.0	2230	28.2	
British Col.[1]	Shawnigan L. 1988 1	49 36'N 123 43'W	659.0				4820		14.70	934.0	173.0	1320	242.0			1790	4090	269.0	1800	33.2	
British Col.[1]	Shawnigan L. 1988 2	49 36'N 123 43'W	325.0				3300		10.00	411.0	10.0	744	173.0			2050	4430	105.0	2050	46.0	
British Col.[1]	Saltspring I. 1988	48 48'N 123 31'W	441.0				2290		14.20	616.0	12.0	840	141.0			2700	5840	75.0	2400	43.6	

1 Enns 1989

Nephroma laevigatum (NELA3)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
UK[1]	field samples	various					3070					1255					9985			140.0	

1 Brown and Beckett 1983

Orthotrichum obtusifolium (OROB70)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	Quebec	Region around aluminum smelter																			F 20-600en

1 LeBlanc and others 1971

Parmelia saxatilis (PASA60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
NH	Balsam Fir						2500			951.0			181.0			1500	4900			97.0	Mo 1.88; N 13300

1 Lang and others 1980

Parmelia sulcata (PASU63)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
NH[1]	Northern Hardwood	44N 72W					5400									1600	6000				N 17200
ND[2]	T. Roosevelt NP ranges	~47 30'N ~103 25'W	1300-3000	0.60-1.5	<0.4-<0.4		2700-7500	5.6-11	12-120	1600-3900	21-38	540-1000	57-110	<0.12-0.16	<4-17	560-1600			920-1700	60-320	8
ND[2]	T. Roosevelt NP geometric means	~47 30'N ~103 25'W	2000	0.97	--		4400	7.30	24.00	2700	26.0	730	72.0	0.140	6.60	790			1200	95.0	9
Netherlands[3]	Regional study	various		0.5-17		0.6-21		4.0-270		720-30000	3.1-367			0.1-36	1.9-57					61-1100	10
Italy[4]	Mt. Amiata - cinnabar mine		69.0						141.0	25.8			1.0	11.30						957.0	
Italy[4]	Mt. Etna - active volcanic region								512.0	50.1			1.9	0.900							
Netherlands/Belgium[5]	Regional study	various		10.90		5.00		29.00	49.00	4000										540.0	11
Quebec[6]	Region around aluminum smelter																				F 70-990en
Spain[7]	Montseny Biosphere Reserve	various							10-24		27-46									100-240	
	Estimated Cutoff		2500	5.0		5.0	5000	30.00	30	4000	40	750	75	10?	25	800			1200	200 ?	

1 Pike 1978
2 Gough and others 1988b
3 Sloof and Wolterbeek 1991a
4 Bargagli and others 1989
5 Sloof and Wolterbeek 1993a
6 LeBlanc and others 1971
7 Glenn and others 1995
8 Ba 60-100; Sr 18-42; Ti 12-19; V 2.7-5.7; Y 1.3-3.8
9 Ba 79.00; Sr 28.0; Ti 16.0; V 4.40; Y 2.50
10 Sb 0.3-12pa; Br 15-170pa; Cs 0.2-5.3pa; La 0.8-64pa; Se 0.4-7.5pa; W 0.1-10pa; V 5.7-99pa
11 Co 3.5en; Sb 4.6en; Br 43.00en; La 3.80en; Se 2.0en; W 0.80en; V 29.0en

Parmelia spp. (PARME2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
GA/FL[1]	Okefenokee Swamp		760		32.0	0.30	2000	0.80	5.60	370.0	31.0	410	71.0		1.30	320	2000	160.0		31.0	Si 360; Sr 10.0
ME[2]	Acadia NP		163-217		1.3-3.1	0.4-0.7	6795-7171	0.4-0.7	2.8-3.2	151-263	31-44	905-1407	140-179		1.1-1.8	417-647	2496-3109	143-470	533-667	45-61	

1 Bosserman and Hagner 1981
2 Wetmore 1987c

Peltigera aphthosa (PEAP60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Note: following four sample sites may also have included other species																					
N. BC[1]	transect A	~ 57 50'N ~ 137 30'W	4576.0	4.00		--	6950	13.80	19.60	4548	--	2300	191.6	--	9.20	2974			1396	44.8	[4]
N. BC[1]	transect B	~ 57 50'N ~ 137 30'W	5216.0	16.80		1.20	7572	45.20	34.20	6504	--	5020	239.0	0.064	25.00	2468			1378	45.4	[5]
N. BC[1]	transect C	~ 57 50'N ~ 137 30'W	4820.0	2.20		1.20	8650	24.60	31.40	5350	--	3534	265.0	0.128	14.20	2546			1350	42.8	[6]
N. BC[1]	grab sample.	~ 57 50'N ~ 137 30'W	2907.9	2.72		1.15	6117	12.65	20.05	3312	1.3	2536	184.4	0.084	8.90	2675			1431	52.9	[7]
UK[2]	field samples	various					2430					1270					6795			150.0	
Canada[3]	Newfoundland	Various around phosphorus plant																			F 268-1243en

1 Enns and Bio 1990
2 Brown and Beckett 1983
3 Moore and others 1978
4 Ba 71.2; Co --; Mo --; Se --; Sr 17.2; V 14.8
5 Ba 102.4; Co 10.2; Mo --; Se --; Sr 25.8; V 18.2
6 Ba 94.8; Co 10.4; Mo --; Se --; Sr 48.8; V 15.4
7 Ba 42.15; Co --; Mo --; Se --; Sr 19.0V 7.85

Peltigera canina (PECA60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
BC[1]	Saltspring I. 1986	48 48'N 123 31'W	628.0				2113		0.01	525.0	7.0	598	221.0		4.40	1622	6236	269.0	1154	17.0	N 38900
BC[2]	Saltspring I. 1988	48 48'N 123 31'W	294.0				1890		9.10	367.0	9.7	616	337.0			1610	6260	237.0	1190	317.0	
UK[3]	"background" sites	various						6.2-11.3	16.0-35.3	930-12716	28-2072		41-217		10.0-17.5					75-881	
UK[3]	"enhanced" sites	various						2.5-12.3	8.3-10.3	190-1511	8.2-20.0		29-275		2.6-9.0					50-131	
BC[4]	west Kootenay - mean	various	825	3.88		3.00	3563	1.92	9.4	855	40.9	970	268.9		2.87	2853	9670	301.7	1984	148	[5]
BC[4]	west Kootenay - range	various	183 - 3740	<2.0 - 10.0		0.8 - 5.2	1520 - 6710	<0.3 - 9.9	4.6 - 14.9	222 - 2200	10 - 110	510 - 2070	72 - 726		0.5 - 11.8	1740 - 4570	5980 - 15100	87.0 - 645	1170 - 2750	48 - 307	[6]
	Estimated Cutoff		1000	5.0 ?		3.5 ?	4000	5.00	15	1000	50	1000?	225 ?		10	3000?	12000?	350?	2000?	175	

1 Palmer 1986 and Enns 1989
2 Enns 1989
3 Goyal and Seaward 1982a
4 Enns 1996
5 Sb 2.36; Ba 68.8; Be 0.04; Bi 2.36; Co 0.52; Li 0.45; Mo 0.63; Se 2.45; Si 271; Ag 0.13; Sr 30.7; Th 1.24; Sn 2.39; Ti 44.9; U 6.11; Va 1.49; Zr 0.65
6 Sb <2.0 -10.0; Ba 31-133; Be <0.02-0.14; Bi <2.0-10.0; Co <0.1-1.7; Li <0.2-2.5; Mo <0.5-2.0; Se <2.0-10.0; Si 89.0-682; Ag <0.1-0.5; Sr 10.0-58.0; Th <1.0-5.0; Sn <1.0-6.0; Ti 9.5-170; U <5.0-20.0; Va 0.3-4.3; Zr <0.1-3.0

Peltigera horizontalis (PEHO60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
UK[1]	field samples	various					5640					640					12115			105.0	

1 Brown and Beckett 1983

Peltigera membranacea (PEME60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
UK[1]	field samples	various					8025					1645					11460			105.0	

1 Brown and Beckett 1983

Peltigera rufescens (PERU60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
England[1]	Lincolnshire - 1907 control							25.81	16.14	14150	78.7		371.7		10.30				6220		
England[1]	Lincolnshire - range of sites away from steel smelters							24.8-127.4	20.3-914	1517-90380	58.8-454.4		386-5000		26-38				5876-8762		
UK[2]	"enhanced" sites	various						6.0-13.3	19.5-30.0	994-6072	225-1560		53-145		7.6-90.0					180-790	

1 Seaward 1973 (also reported in Hawksworth and Rose 1976)
2 Goyal and Seaward 1982a

Plagiothecium undulatum (PLUN4) Note: In Enns (1989), indicated as *Plagiothecium* sp. in Appendix 2 but Plaund in captions to Fig. 2

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
BC[1]	Coquitlam L. North 1986	49 22'N 122 46'W	1250				4462		20.60	885.0	170.0	1120	321.0		7.30	1046	6492	187.0	1330	107.0	N 15500
BC[2]	Coquitlam L. North 1988	49 22'N 122 46'W	1060				6520		43.80	1320	247.0	1820	299.0			1600	9120	341.0	1980	151.0	

1 Palmer 1986 and Enns 1989
2 Enns 1989

Platismatia glauca (PLGL60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
ME[1]	Acadia NP		95-232		1.6-2.7	0.2 - 0.2	390-682	0.4-0.9	2.1-2.9	87-233	11.3-20.0	374-539	27.1-60.9		0.8-1.0	366-517	1746-2209	66.5-206.7	563-757	18.1-29.7	
NH[2]	Balsam Fir						1200			482.0			125.0			1200	5100			72.0	Mo 0.81; N 10100
BC[3]	Saltspring I. 1986	48 48'N 123 31'W	1398				1748		1.70	1069.0	40.0	499	93.0			924	2540	133.0	558	39.0	N 5400
BC[4]	Saltspring I. 1988	48 48'N 123 31'W	1590				1770		27.00	2070.0	39.8	744	99.0			1130	2800	87.0	784	24.3	
OR[5]	Mt. Hood Wilderness	various	343.8		1.3	0.15	1620	1.54	2.20		5.6	432	105.3		0.99	733	1834	97.7	470	26.2	N 3640
Finland[6]										591-981			35-89							52-128	
WA[7]	Alpine Lakes Wilderness		291.6-606.3		2.30-5.24	0.16-0.58	1014-1597	1.33-3.30	2.51-5.17	190.9-528.6	4.55-24.06	214-490	54.9-319.8		1.04-3.26	304-1001	1284-2932	58.6-101.3	470-780	21.7-40.9	Si 179.5-499.0
WA[8]	Olympic National Park	Max	692.0		5.9	0.26	2070	2.44	6.18	823.0	28.0	912	544.0		5.17	2380	4610	193.0	1240	40.5	
WA[8]	Olympic National Park	Min	230.0		1.9	--	953	0.93	2.64	221.0	6.4	313	36.7		1.46	1030	1850	63.7	460	20.8	
	Estimated Cutoff		500		4.0	0.25	1500	2.00	3	750	25	500	150		2	1100	2500	90	600	30	

1 Wetmore 1987c
2 Lang and others 1980
3 Palmer 1986 and Enns 1989
4 Enns 1989
5 Geiser and Boyll 1994
6 Lounamaa 1965
7 Lesher and Henderson 1992
8 Rhoades 1988

Pleurozium schreberi (PLSC70)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	mostly enhanced			2.00		4.40			1340	1550	1-1160								1000	323.0	F 6.00en
Sweden[2]	surrounding brass foundry	various				0.2-2.3			10-64	203-1500	15-70				1.3-4.6					85-280	
Poland[3]	background levels in national park	~52 15' N ~20 45' E				0.6-0.9			10-15		60-80									80-120	
Note: following study combined values from Pleurozium schreberi and Hylocomium splendens																					
Poland[4]	National Parks	low range - various				~ 1.0		3.0-4.8	7.0-8.5	~1000	37-78		79-135		2.7-4.2					65-87	Co 0.9-1.6
Poland[4]	National Parks	high range - various				1.9-6.3		8.7-13.3	15-26	~3000	140-274		439-880		5.9-8.0					142-307	Co 1.4-2.5po
Canada[5]	Partial range into area around copper mine			3.0-2.5		0.5-0.5			45.0-236.5		15.0-62.5									46.0-89.0	
	Estimated Cutoff			2.0		2		10.00	15	1200	60		150		4.5				1000?	80	

1 LeBlanc and De Sloover 1970 and LeBlanc 1969
2 Folkeson 1979
3 Czarnowska and Gworek 1992
4 Grodzinska 1978
5 Rao 1982

Pohlia nutans (PONU70)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Sweden[1]	surrounding brass foundry	various				1.0-3.1			12-145	572-2900	30-148				3.3-7.0					99-543	

1 Folkeson 1979

Polytrichum juniperinum (POJU70)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Poland[1]	Pine and birch forest				3.4	0.80		2.00	9.20	800.0	22.4		176.0		2.00					69.0	

1 Kabata-Pendias and Pendias 1984

Pseudocyphellaria anthraspis (PSAN61)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
BC[1]		"GOLD" Plot	489.0				4206		2.30	521.0	61.0	1147	57.0		2.50	3433	6209	142.0	1767	27.0	N 28300
BC[1]		"WAIN" Plot	512.0				1503		3.20	499.0	23.0	839	97.0		4.10	3433	6877	139.0	2158	29.0	N 33300

1 Palmer 1986

Punctelia rudecta (PURU2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
OH[1]	Cuyahoga Val. NRA Furnace Run		198.0		1.6	0.70	37047	0.70	3.90	265.0	55.5	527	16.9		1.10	1315	4078	9.6	1353	29.2	
OH[1]	Cuyahoga Val. NRA O'Neil Woods		292.0		4.0	0.20	4344	1.40	4.90	394.0	10.4	418	78.8		1.20	1032	2893	17.3	2393	50.5	

1 Wetmore 1989

Punctelia subrudecta (PUSU5)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Spain[1]	Montseny Biosphere Reserve	various							9-22		34-54									70-125	

1 Glenn and others 1995

Ramalina menziesii (RAME60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
CA[1]		Blue oak					1720					680				1790		340.0			N 9280

1 Boucher and Nash 1990

Rhizomnium glabrescens (RHGL70)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
BC[1]	Coquitlam L. West 1986	49 21'N 122 48'W	1406				7128		24.30	1278	155.0	983	743.0		8.90	820	4089	141.0	1551	62.0	N 14700
BC[2]	Coquitlam L. West 1988	49 21'N 122 48'W	1530				6970		69.90	2020	250.0	1030	717.0			813	3440	438.0	2120	77.0	
Note: the following two samples indicated as Rhizomnium in Appendix 2 but R. glabrescens in caption to Figure 2																					
BC[2]	Coquitlam L. North 1986	49 22'N 122 46'W	1458				6898		22.10	1256	163.0	754	455.0			775	2961	121.0	1147	59.0	
BC[2]	Coquitlam L. North 1988	49 22'N 122 46'W	2960				8940		70.10	4150	169.0	1040	550.0			1110	4710	179.0	1880	54.0	

1 Palmer 1986 and Enns 1989
2 Enns 1989

Rhizoplaca melanophthalma (RHME2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
NM[1]	From Tables 2 & 3	various		3.80			56400	9.00	9.50	2800	32.8	2500		0.23-0.32	3.60	5600	9600	1100		24.3	[4]
ID[2]	1 km cross wind of phosphate refinery		493.0		3.2	4.72	13119	2.11	3.77	466.0	5.9	535	20.0		1.01	1806	3161	82.0		81.0	
ID[2]	60 km upwind of phosphate refinery		611.0		2.4	2.00	22995	0.87	2.73	519.0	13.0	402	26.0		0.88	896	2317	58.0		29.0	
Note: In the following, samples combined R. chrysoleuca and R. melanophthalma																					
WY[3]	Sites 5, 16, & 17		2362		23.0		25164		24.00	1799	36.0	1006	39.0			765	2402	125.0		31.0	

1 Nash and Sommerfeld 1981
2 Dillman 1996
3 Hale 1982
4 Be 0.11; Co 3.6; Li 2.6; Mo 0.5; Si 40000; Ag 0.63

Rhytidiadelphus spp. (RHYTI2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
WA[1]		Range of 2 sites	1516-1540						2.8-5.3		0.7-2.2										

1 Wiersma 1981

Sphaerophorus globosus (SPGL60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
WA[1]	Olympic National Park	"Background"	81.6		1.1	0.04	677	0.37	1.44	50.9	1.1	216	56.2		0.44	826	1560	57.2	305	18.2	
WA[1]	Olympic National Park	Max	140.0		7.1	0.03	1030	0.53	2.38	114.0	2.7	291	259.0		1.00	1350	2470	113.0	620	28.5	
WA[1]	Olympic National Park	Min	65.3		0.7	--	501	0.18	1.26	44.3	--	201	46.1		--	752	1520	52.7	280	16.2	

[1] Rhoades 1988

Sphagnum fuscum (SPFU70)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
MN[1]	Boundary Waters Canoe Area	~ 48 05'N ~ 90 20'W	280		2		1100			360		450	57			570	3900				
WI[1]	Near Milwaukee	~ 43 00'N ~ 87 55'W	860		4		4400			950		1400	48			780	3400				

[1] Gorham and Tilton 1978

Sphagnum henryense (SPHE4)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
BC[1]	Coquitlam L. West 1986	49 21'N 122 48'W	629.0				4240		10.50	573.0	62.0	860	385.0		6.00	778	5182	240.0	1166	36.0	N 12600
BC[2]	Coquitlam L. West 1986	49 21'N 122 48'W	743.0				3800		25.00	655.0	42.0	1400	465.0			890	6860	1130	2120	47.9	
BC[3]	Coquitlam L. North	~ 49 25'N ~ 122 45'W	1458				6898		22.20	1256	163.0	754	455.0		7.00	775	2961	121.0	1147	59.0	N 16100

[1] Palmer 1986 and Enns 1989
[2] Enns 1989
[3] Palmer 1986

Sphagnum magellanicum (SPMA70)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	Maritime Provinces	various-mean values				0.17	2003	1.24	2.54	352.8	9.4	1089	244.6	0.310	1.51		5227	387.7	1105	24.1	Co 0.6; N 8607
Canada[1]	Northern Ontario	various						3.30	12.00	344.0	23.0		89.0	13.00						39.0	
Canada[1]	Northwest Territories	various						3.60	13.00	2835	8.0		383.0	108.0						37.0	
MN[2]		various	250.0		5.0		1400			310.0		550	74.0			640	2500				
S. Sweden[1]		various				1.15		2.97	5.05	1416	79.8		65.0		3.37					89.3	Co 0.6
S. Finland[1]		various							5.10	395.0			76.2							56.8	

[1] Percy 1983 and Percy and Borland 1985

2 Percy 1983, Percy & Borland 1985 and Gorham & Tilton 1978

Sphagnum spp. (including S. fuscum, S. capillaceum and S. fallax) (SPHAG2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	lowest in range					1.00		8.00	4.00		15.0				--					21.0	
Canada[1]	highest in range					2.90		35.00	124.0		78.0				59.00					57.0	
Poland[2]	ombrotrophic sites - 11 spp mean	~ 50 30'N ~ 16 30'E					1240			410.0		480				360	4800	440.0			N 11500
Poland[2]	minerotrophic sites- 10 spp mean	~ 50 30'N ~ 16 30'E					1850			280.0		660				720	9400	570.0			N 14100
Norway[3]	mean from 1976 data compared to other spp		385.0			0.27			4.29		25.8		101.0					761.0		28.6	4

1 Glooschenko and others 1981
2 Wojtun 1994
3 Steinnes 1993
4 Br 12.6pa; Cl 740pa; V 2.36pa

Stereocaulon paschale (STPA60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Ontario[1]	10 mi. from Ni smelter								500.0	3300					290.0					65.0	
Ontario[1]	asymptotic background								< 30	<500					< 25					30.0	

1 Nieboer and others 1972

Stereocaulon sp. (STERE2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]	Low soil Mo								3.00				27.0							22.7	Mo --
Canada[1]	High acid soil Mo								3.00				32.0							19.7	Mo --

1 Doyle and others 1973

Tortula ruralis var. ruralis (TORU70)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Hungary[1]	control mean	~47 20' N ~18 55' E	1270			0.83		2.50	9.93	1775	25.0				5.78					65.5	V 4.79pp
Hungary[1]	transplanted range	~47 20' N ~18 55' E	986-2292			0.59-1.21		2.38-4.96	8.40-13.30	1476-3920	17.95-43.74				4.98-39.81					48.1-99.8	V 7.20-94.80pa

1 Tuba and Csintalan 1993b

Umbilicaria cylindrica (UMCY60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Poland[1]	SW region near Sudety							4.70	7.90	1468	33.9		21.4		2.3					40.5	

1 Seaward and others 1981

Umbilicaria deusta (UMDE61)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Ontario[1]	10 mi. from Ni smelter								270.0	4000					390.0					170.0	
Ontario[1]	asymptotic background								< 90	2000					<100					<80	
Poland[2]	SW region near Sudety							7.10	18.10	3720	84.2		43.4		4.40					129.7	

1 Nieboer and others 1972
2 Seaward and others 1981

Umbilicaria hirsuta (UMHI60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Wyoming[1]	Sites 2 & 17		2924		32.0		1777		63.00	1783	24.0	2147	66.0			1245	3809	597.0		74.0	
Poland[2]	SW region near Sudety							4.70	12.80	1727	34.7		33.8		5.00					260.6	

1 Hale 1982
2 Seaward and others 1981

Umbilicaria polyphylla (UMPO60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Poland[1]	SW region near Sudety							7.30	16.80	1915	67.6		24.0		3.50					176.5	

[1] Seaward and others 1981

Umbilicaria polyrhizza (UMPO2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
CA[1]	Emigrant Wild.	~ 38 7' N ~ 119 54' W	796.0	0.24	10.6	1.97	1307	1.74	7.85	1025.2	11.7	1548	90.1		0.50	4295	7148	278.3		197.2	[2]

[1] Ryan and Nash 1990
[2] Ba 21.05en; Co 0.14; Li 1.00en; Mo 0.72; Si 4107en; Ag 0.31; Sr 5.5; Sn 0.88; Ti 79.0pa; V 1.55

Umbilicaria virginis (UMVI60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
CA[1]	San Gabriel Wild.	~ 34 19' N ~ 117 56' W	1252.5	0.25	14.5	0.39	928	2.29	16.33	1418.3	11.9	2210	100.8		0.20	4468	6215	649.3		71.9	[2]

[1] Ryan and Nash 1990
[2] Ba 19.68en; Co 0.04; Li 1.25en; Mo 0.94; Si 6487en; Ag 0.45; Sr 8.1; Sn 1.02; Ti 89.6; V 0.17

Umbilicaria sp. (UMBIL2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Canada[1]		High acid soil Mo							3.7-10.3				7-30							20.3-24.1	Mo 0.3-1.0po

[1] Doyle and others 1973

Usnea filipendula (USFI61)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
Sweden	surrounding brass foundry	various				0.4-1.0			7-48	250-1400	15-40				1.7-4.1					82-200	

[1] Folkeson 1979

Usnea subfloridana (USSU60)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
OR[1]	Oak Woodland	44N 123W					5200					900				2000	5000				N 14800
NM[2]	Along roadside near Santa Fe Ski Basin						9900		12.00	1040	55.0	710	119.0				4830	520.0		35.0	
WA[3]	Olympic National Park	one sample	122.0		1.7	0.17	2270	0.87	2.24	95.3	36.7	952	129.0		2.12	1390	3210	140.0	650	31.0	
West Central Scotland[4]	Mean winter SO2 < 30 ug/m3																		254		
West Central Scotland[4]	Mean winter SO2 40-50 ug/m3																		1101		

1 Pike 1978
2 Moore and others 1978
3 Rhoades 1988
4 Hawksworth and Rose 1976

Usnea spp. (UNEA2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
GA and FL[1]	Okefenokee Swamp		440.0		13.0	0.30	3600	1.00	4.70	290.0	29.0	810	64.0		1.20	190	1500	240.0		23.0	[6]
NH[2]							2500			374.0			135.0			1200	5500			84.0	[7]
WY[3]		Sites 3, 10 and others	944.0		24.0		6812		16.00	378.0	22.0	640	72.0			1285	3677	103.0	1400	34.0	
Note: The following said to include predominantly U. lapponica and U. subfloridana																					
CA[4]	Redwood NP	41 46'N 124 02'W	260.0			--	3300	1.00	2.60	170.0	7.5	1600	97.0		6.00	420	1800	300.0	380	21.0	[8]
Note: The following said to include these species: U. subfloridana, U. lapponica, U. comosa, U. dasypoga																					
CA[5]	Little Bald Hills	41 45N 124 05W	100-700			<0.05-0.20	1900-8700	0.34-2.7	1.3-10	60-400	5.5-15	1200-2600	40-330		3.4-15	270-860	1200-2700	190-560	220-580	14-38	[9]

1 Bosserman and Hagner 1981
2 Lang and others 1980
3 Hale 1982
4 Gough and others 1987
5 Gough and others 1988a
6 Co 0.3; Si 310; Sr 15.0
7 Mo 0.91; N 12000
8 Ba 16.0; Ce 0.22; Co 0.2; Ga --; La 0.11; Li 0.097; Mo --; Nd --; Sc 0.08; Sr 18.0; Sn --; Ti 16.0; V 0.53; Y 0.10
9 Ba 10-44; Ce <0.13-0.59; Co 0.12-0.35; Ga 0.09-0.19; La <0.05-0.40; Li <0.36-0.26; Mo <0.05-<0.11; Nd <0.09-0.26; Sc <0.06-0.18; Sr 12-30; Sn <0.5-3.4; Ti 5.6-43; V 0.21-1.4; Y<0.06-0.24

Xanthoparmelia chlorochroa (XACH3)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
WY and MT[1]		background?	38000	0.92		4.00	280000	33.00	70.00	14000	110.0	6400	270.0	0.098	10.00	7400		400.0	670	210.0	[3]
WY[2]		influenced by coal-burning power plant?	3000-13000	0.6-2.4	3.8-16.0		19000-73000	5.2-15.0	5.1-12.0	1100-4600	11-25	600-1600	15-51	0.08-0.16	1.1-2.9	700-1100	1700-2700	44-92		25-40	[4]

1 Erdman and Gough 1977
2 Gough and Erdman 1977
3 Ba 370.0; Co 3.5; F 25.0; I 4.5; Li 6.3; Se 0.4; Si 90000; Sr 350.0; Ti 1700; U 1.3; V 58.0; Y 32.00; Z 77.00
4 Ba 22-130; F 20-50; Ga 1.1-3.6; Li 0.6-2.1; Sc 0.5-1.7; Se 0.35-1.40; Sr 22-150; Ti 110-330; U 0.27-0.70; V 8-23; Yb 0.4-1.3; Y 5.2-13.0; Z 5.2-23.0

Xanthoparmelia cumberlandia (XACU2)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
CA[1]	San Gabriel Wild. 1987	~ 34 19' N ~ 117 56' W	1970	--	1.9	1.84	17053	3.40	10.20	2246.7	57.4	1803	177.3		1.34	1113	9440	1103.7		37.2	[3]
WY[2]		other sites	5176		41.0		23776		43.00	3492.0	51.0	2242	116.0			1251	3327	207.0	1400	56.0	
WY[2]	Mt. Zirkel		4519		31.0		16629		37.00	2908.0	55.0	1472	90.0			1250	3561	126.0	1150	65.0	

1 Ryan and Nash 1990
2 Hale 1982
3 Ba 43.13en; Co 0.62; Li 2.93en; Mo 1.02; Si 7503en; Ag 0.01; Sr 53.0; Sn --; Ti 58.4; V 1.74

Xanthoparmelia wyomingica (XAWY)

State/Area	Vicinity	Site	Al	As	B	Cd	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Na	S	Zn	Other
WY[1]		Site 2	3816		46.0		31351		22.00	3730	34.0	2013	87.0			1114	2730	130.0		42.0	

1 Hale 1982

APPENDIX D: SOURCES REFERENCED IN THE DATABASE TABLES ALONG WITH A BRIEF BACKGROUND OF THE STUDY

Reference	Analytical Method
Addison and Puckett 1980. Values for *Hypogymnia physodes* from figure legends: tabular presentation as enrichment factors only. Values for *Cladina arbuscula* from Table 1, include samples from a range of distances (up to 85 km) away from Suncor Ltd. oil sands refinery plant.	Modified Johnson-Nishita method (S); AAS on solubilized sample (K); INAA (rest)
Bargagli, Barghigiani, Siegel, and Siegel 1989. Mercury and other metals in PASU63 at mine site and volcanic area in Italy. Examined contents vs. elevation and enrichment over soil in areas. Data from Table V.	AAS following sulfuric/nitric digestion
Bargagli, Brown and Nelli 1995. Metal biomonitoring with mosses in Italy and Antarctica (only Italian species used). Includes background levels in several species (HYCU4, HYSP70) normalized by subtracting substratum concentrations.	AAS following HNO_3 digestion
Bosserman and Hagner 1981. Okefenokee Swamp. *Usnea spp*. and *Parmelia spp*. (latter under HYPH) means for all locations and substrates (from Table 1).	AAS on HNO_3 digest
Boucher and Nash 1990. *Ramalina menziesii* on *Quercus douglasii* (Blue oak) from area near Hastings Natural History Reservation, Monterey County (36 23'N, 121 33'W)	TrAAcs autoanalysis of H_2SO_4 digest (N); Optical Emission Spectroscopy on aqua regia digestion (rest)
Brown and Beckett 1983. Study of toxic effects of Cd and Cu on photosynthesis in chlorophycean vs. cyanobacterial lichens. Distinction not related to Zn, Mg, Ca or K concentrations Also looked at relative uptake of Zinc (greater in chloro vs cyano).	AAS on HNO_3 digest
Bruteig 1993. Regional study of nitrogen and sulphur content in HYPH in Norway. Data from Table I: lowest and highest 10% means.	ICP (sulfur) following Mg(NP3)2/nitric digestion and Kjeltec (nitrogen)
Czarnowska and Gworek 1992. Heavy metal content in *Pleruozium schreberi* from a Polish national park just west of Warsaw. Data from abstract. Highest values (from SE part of park) were deemed enhanced and lowest values more of (at least a regional) background.	AAS following HCl dissolution
Derr 1994. *Pinus contorta* peatland sites in SE Alaska. Data from table III.5 The data used partially overlaps that used by Geiser and others 1994 (12 sites of the 43 were in common).	S: IRA following dry combustion; remaining elements: ICP-AES.
Derr 1997. Air quality biomonitoring on the Chugach National Forest: Methods and baselines using lichens. For ALSA9, CLRA60 and LOOR60, values given are geometric means of all values, despite location. They are likely enriched in marine elements. Data for LOLI60 are from the mean of three collected from one site, a *Populus balsamifera/trichocarpa* wet meadow on the Kenai Peninsula.	S: IRA following dry combustion; N: micro-Kjeldahl; remaining elements: ICP-AES.
Dillman 1996. Ranges of values for RHME2 near phosphate refineries in Idaho. Means from 1 km S (close, cross wind) and 60 km NE (upwind) from pollution point sources from Table 2.	ICP-AES after dry ash and HCl equilibrium
Doyle, Fletcher, and Brink 1973. Comparison of content of soils and a variety of plant materials (including 4 lichens) from areas with various soil enrichment of Mo. Ranges (single value for STERE2) from Table 2. Higher numbers in range may be enhanced.	Dithiol method (Mo) and AAS (other elements) following nitric/perchloric acid digestion
Ellison, Newham, Pinchin, and Thompson 1976. Heavy metal content of HYCU4 around a center of iron and steel manufacture. Estimated background levels from Table 2.	AAS (Cu, Fe, Pb, Zn, Mn and Mg), Tantalum boat (Cd), ASV (Pb and Cu) following nitric/perchloric digestion
Enns, K. 1989. Analysis of grab samples of selected lichen and bryophyte species and of transplanted "Nephromataceae" from two years. Data from Tables 1 and 3, Appendix 2 (pp33-35) with reference to Figure captions for Fig 2a-2d. Print was light so there are some possible mis-transcriptions.	Induction furnace (S) and ICP (rest)
Enns, K.; and Bio, R.P. 1990. Target species was *Peltigera aphthosa*. In 3 transects of 5 samples each and one grab sample series of 20 samples, *P. aphthosa* was the dominant species, but *P. rufescens* and *Cladina stellaris* are also an undefined percentage.	Induction furnace (S) and ICP (rest)
Enns, K. 1996. Personal communication. Data for ALSA9 (12 samples), HYPH (6 samples) and PECA60 (94 samples) from Celgar mining region in south-central British Columbia, stretching from Nelson to Lower Arrow Lake. This area is "in the west Kootenay, one of the most metals-enhanced areas of B.C., with all sorts of enrichment in sites, as well as ambient influences from past smelting". To arrive at means, cutoff values were used for measurements below limit of detection (listed "<" in ranges). High end of ranges are assumed to be above the enhanced values cutoff for all elements and species. Estimated cutoff for PECA60 set to about 25% higher.	ICP
Erdman and Gough 1977. *Xanthoparmelia chlorochroa* throughout Powder River Basin in Wyoming and Montana. Data geometric means from Table 2 and Table 3.	Mostly semi-quantitative emission-spectrographic procedure of Neiman; some: specific ion electrode (F), titration

	(S), fluorometirc methods (Se, U), AAS (rest)
Fahselt and others 1995. Eleven trace elements in Cladina mitis collected along transects extending from mines in Ontario, Canada. Because of pattern in distance away from mine, highest levels of U and Th are considered enhanced.	INAA on ground material
Folkeson 1979. Interspecies calibration of heavy metal content in lichens and mosses from area around a brass foundry in Sweden. Calibration factors given for estimating HYSP70 and PLSC70 from DIPO70, HYCU4, PONU70, CLRA60, HYPH, PSIN5, USFI61. Ranges of metal concentrations from Table 1. At least the upper values should be considered enhanced.	AAS following nitric/perchoric digestion
Frenzel, Witmer, and Starkey 1985, 1990. Concentrations of metals and sulfur in ALBA needles and ALSA in Olympic National Park and Mount Rainier National Park. Geometric means of 70 samples each. Second paper has only metal levels.	ICP following ashing and nitric digestion
Gailey, Smith, Rintoul, and Lloyd 1985. Patterns of metal content in HYPH in central Scotland surrounding Armadale, a town with a steel foundry. Data are low to high value ranges from Table VIII. Highest value is likely enhanced.	AAS following digestion in nitric acid
Geiser and Boyll 1994. Preliminary results from Mt. Hood Wilderness. Means of all samples given; report discusses enhanced levels.	Various - several labs used and results compared
Geiser, Derr, and Dillman 1994. Elemental baselines in several lichen species from the Tongass National Forest in southeast Alaska.	S: IRA following dry combustion; N: micro-Kjeldahl; remaining elements: ICP-AES.
Glenn, Gomez-Bolea and Lobello 1995. Metal content in PASU63 and PUSU5 related to vehicular traffic. Data transferred from Figures 3 and 4 which related observations according to thallus weight and whether samples were roadside or interior. Ranges given for each species are approximate means of data points on graphs for interior (background) to roadside (enhanced) sites.	Flame aas on nitric/ 60% perchloric digestion
Glooschenko, Sims, Gregory, and Mayer 1981. Metal content of *Cladina* and *Spagnum spp*. related to distance from Sudbury, Ontario. Data are from ranges for *Spagnum spp*. from Table II.	AAS on nitric:perchloric digested, ground material
Gorham and Tilton 1978. Mineral content of *Sphagnum fuscum*. Data from Table 1, summarizes data for area not affected by wind-blown soil and affected by such soil (main cause of enhancement). Data for *S. magellanicum* and *Dicranum polysetum* from Table 3.	Spark-emission spectrograph on Li_2CO_3/HCL solution of ash
Gough and Erdman 1977. Content of *Xanthoparmelia chlorochroa* around a coal-fired plant near Powder River Basin in Wyoming. Ranges for each element of individual values for all samples in transect from Table 2. Six elements (Ca, F, Li, Se, Sr, U) showed significant relationship with distance from the power plant.	Emission spectrography, AAS & other techniques (probably similar to LeBlanc and De Sloover, 1970 and LeBlanc and others 1971.)
Gough, Jackson, and Sacklin 1988a. Determining baseline element composition of lichens. II. *Hypogymnia enteromorpha* and *Usnea spp*. at Redwood National Park, California. Samples collected from trees on ultamafic terrain. Baseline in the sense of what was observed in 1984 collections as derived by statistical analysis of data. The values given are the observed ranges. Slightly larger, 95% confidence ranges are given in paper.	Not given; probably same as Gough, Jackson, and Sacklin 1988a.
Gough, Jackson, Peard, [and others]. 1987. Elemental baselines for Redwood National Park. Geometric means from Tables 2 and 3.	Combustion infrared photometry on dry powder (S); ICP on acid digest (rest)
Gough, Severson, and Jackson 1988b. Determining baseline element composition of P. sulcata in Theodore Roosevelt National Park, North Dakota. Baselines and geometric means from Table 1.	Flame AAS (As); flameless AAS (Hg); combustion-infrared photometry (S); ICP (rest)
Goyal and Seaward 1982a. Analysis of *Peltigera spp*. from "enhanced" and "background" sites (differences between these sites explained in Goyal and Seaward 1981b).	AAS on HNO3/perchloric acid digest
Grodzinska 1978. Heavy metal content in PLSC70 and HYSP70 in Polish National Parks. Compares differential uptake among species (not different for Co, Cr, Ni and Mn; significantly different for Pb, Zn, Fe, Cd and Cu). Data mapped by standardized values. In chart above, combined low and high ranges are given from discussion in papers text (p. 87).	AAS following nitric/perchloric digestion
Gydesen, Pilegaard, Rasmussen, and Rühling 1983. As cited in Puckett 1988. Data for various regions in Sweden, presented in Table 3 of Puckett 1988.	Unknown
Hale 1982. Preliminary measurements of species from Flat Tops Wilderness. Values from Tables, pp. 67-73. Sulfur values are from a different table, p. 73.	Unknown
Halonen, Hyvärinen and Kauppi 1993. Temporal change of elemental content in HYPH at sites near where steam power plant and sulphate pulp mill were opened (in 1974 and 1977 respectively). Data compiled from Table 2. Background from rural sites outside of Oulu, Finland. "Pre and early-operational" ranges from 1974-1975 samples. Post-operational ranges from 1982-1989 samples.	ICP-ES except Kjeldahl method for N
Hawksworth and Rose 1976. The early classic guide to "Lichens as Pollution Monitors". Table 1 presents one of the few sets of data relating thallus sulfur content in EVPR2, HYPH, and USSU60 to SO_2 levels in air. Table 3 presents ranges of metal content in PERU60 from Seaward 1973 (related to distance from steel refinery).	Unknown
Johnsen, Pilegaard and Nymand 1983. Values in and about Copenhagen, Denmark on in situ and	AAS on HNO_3 digest

transplanted HYPH. Authors' values only.	
Kabata-Pendias and Pendias 1984. From pine and birch forest near Warsaw, Poland.	Unknown
Kansanen and Venetvaara 1991. Paper showed log-linear relationships of Ni and Cr content versus distance from steel mill. The data provided here are the presumed background ranges at distances away from the mill where concentrations leveled out. The moss analyzed was almost always *Hylocomium splendens*. When not available, *Pleurozium schreberi* was used.	Flame AAS on HCl digest and ICP (some samples)
Kauppi and Halonen 1992. Data for HYPH in urban and suburban sites in Oulu, Finland from Halonen and others 1993, Table 2.	Unknown
Kubin 1990. Data for HYPH in general rural area background levels in Finland from Halonen and others 1993, Table 2 (means of 2,385 samples).	Unknown
Laaksovirta and Olkkonen 1979. Elemental content of HYPH (and pine needles) S. Finland.	Unknown
Laaksovirta, Olkkonen and Alakuijala 1976. Lead content in HYPH adjacent to a four lane highway in S. Finland. Values are means of about 10 observations at each distance from highway (20m and 100m) estimated from graph in Figure 2.	Isotope-excited X-ray fluorescence
Lang, Reiners and Pike 1980. Dominant foliose and fruticose epiphytic lichens from boles and branches = 2 m. above ground.	Micro-Kjeldahl (N); AAS after HNO_3 digestion (Mg); Jarrell-Ash Emission Spectroscopy (rest)
LeBlanc and De Sloover 1970 and LeBlanc and others 1971. (In Winner 1988. Table 2) Data for *Hylocomium splendens* from sites with air pollution.	Unknown
LeBlanc and De Sloover 1970 and LeBlanc 1969. (In Winner 1988. Table 2) Data for *Pleurozium schreberi* from sites with air pollution.	Unknown
LeBlanc, Comeau, and Rao 1971. Fluoride in PASU63 and OROB70 in region around an aluminum smelter in Quebec and related environmental levels and injury symptoms. Data from Table 2: low value is control and high value is the highest level for each species in table.	Method of Greenhalgh and Riley (1961)
LeBlanc 1969 as cited in Winner 1988. General background for mosses based on means from: *Pleurozium schreberi*, *Hylocomium splendens* and *Leucobryum glaucum* collected from North America and Scandinavia.	Various
Lesher and Henderson 1992 (personal communication). Data from analyses of lichen and other material from Alpine Lakes Wilderness. Ranges of non-duplicate values.	ICP on dry ash, except S (Leco SC-132 furnace)
Lounamaa 1965. Content given as percent of ash and ash as a percent of dry weight. Values here equal (percent ash of dry weight x percent in ash) x 100.	Unknown
Moore, Gosz and White 1978. *Usnea spp*. metal content along roadside to ski area and Mountain Watershed near Santa Fe, NM. Data from Table VII.	AAS following nitric/hydrochloric digestion
Nash and Sommerfeld 1981. Elemental content of a variety of dry-land, saxicolous, foliose and crustose lichen species. near Four Corners power plant, NM. For low/high values (general lichen mean area of this chart), data are from Table 1 (all species were lumped at each site). "Low" value for each element is the lowest site mean. "High" (enhanced) value given is the lowest value from the insignificantly different high site means (determined by Tukey's w multirange tests). The ranges given for the larger set of elements are from among the dominant species (Tables 2 [1976 data] and 3 [1979 data]). DEMI60 and RHME2 were the only semifoliose species included.	1976: AAS after acidic digestion, except flameless AAS (Hg), thermal neutron-prompt gamma ray spectroscopy (B); 1979: AAS after acidic digestion (As, Se, Hg); optical emission spectroscopy on powdered sample (rest)
Nash and Gries 1995. Table 1 from this report compares industrial/urban elevated levels with rural levels (reverences papers 1983 and prior).	Various
Nieboer & Richardson 1981. More recent review. Data from Table V, reviewing many lichen species from a variety of cited sources, many reviewed elsewhere in the present database. "High: urban/industrial" is the range of values near urban or industrial sources in Table V. If only one source provided a value, the value is marked "possibly enhanced". Otherwise, at least the upper value in each range is considered to be enhanced.	Various
Nieboer, Ahmed, Puckett and Richardson 1972. Heavy metal content of lichens related to distance from nickel smelter in Sudbury, Ontario. Values given are estimated by reference to Table 3 (30 km "background") and from Figures 2-4 (closest collections of each species and asymptotic backgrounds).	Unknown
Nieboer, Richardson & Tomassini 1978. Classic paper reviewing elemental content in lichens.	Various
Nimis, Castello and Perotti 1993. Multivariate analysis of heavy metals in Northern Italy. Compared levels in *Flavoparmelia caperata* in La Spezia region to "background" levels in *Parmelia sensu lato* throughout Italy. They define high contamination as greater than 7 times background level, medium contamination as 4 to 7times background level, and weak or no contamination as less than 4 times background levels.	AAS following HNO3 mineralization
Palmer 1986. ARNEWS plots in coniferous forests in BC, Canada. Each record is for one collection made in August and September, 1986.	ICP following perchloric acid digestion except for N (Techator Kjeltec 10-30 Autoanalyzer)

Percy 1983, and Percy and Borland 1985. Heavy metal and sulphur content of SPMA70. A regional survey of the Maritime Provinces, Canada. Regional mean data from Percy 1983, Table I. Comparison data from other regions of the world from Percy 1983, Table II.	PES (most elements) following nitric digestion, cold vapor AAS (Hg) following modified UV digestion, magnesium nitrate fusion (S)
Pfeiffer and Barclay-Estrup 1992. Ranges of values in H. physodes collected along highways radiating out from Thunder Bay, Ontario, Canada. Values from Table 2.	ICP on HCl/HNO_3 digest
Pike 1978. HYPH is given as *Hypogymnia spp*. on Balsam Fir, NH; USSU in Oak Woodland, OR; ALSA in spruce-fir forest, BC.	Various
Puckett and Finegan 1980. Paper also calculates enrichment factors for three species	X-ray fluorescence (Cu, Pb, Ni, S); INAA (rest)
Rao and LeBlanc 1966 as cited in Winner 1988 (HOWEVER, SEE NOTE BELOW). Contamination above normal levels (for a wide range of plants from many habitats) from Ontario Ministry of the environment, as reported in Winner 1988. This paper was cited wrong by Winner, as: Rao and LeBlanc 1966. Influence of iron-sintering plant on the epiphytic vegetation in Wawa, Ontario. Bryologist 69:69-75. (The paper at this location has a different title and the paper with approx. this title is Rao and LeBlanc 1967. Bryol. 70:141-157 however neither paper contains data in Winners Table 2 attributed to Rao and LaBlanc.	Various
Rao 1982. Heavy metal content of two mosses (HYSP70 and PLSC70) as related to Index of Atmospheric Purity scores in a zone around the Murdochville copper mine area in Canada. Ranges presented are control value-zone V (lowest level of pollution). Data modified from LeBlanc and others, 1974 and presented in Rao's Table 12.5.	Unknown
Rhoades 1988. Various sites and species on Douglas-fir trunks (or litter under Douglas-fir) around Olympic National Park.	ICP; Leco Furnace/IRAA (Sulfur)
Roberts and Thompson 1980. Fluoride in lichens and bryophytes near a phosphorus plant, Newfoundland, Canada. Ranges of F in various lichen and bryophyte species from Tables 3, 4 and 5. Highest values were in areas where vegetation damage was greatest, usually closest to plant and are considered enhanced. Lowest values were from zones where vegetation damage was the least, generally furthest from plant, or controls.	Radiometer pH meter and a specific ion electrode using method of Buck and Reusmann
Rühling and Tyler 1971. In Ward and others 1977, Table 1. Lowest background mean for *Hypnum cupressiforme* in Sweden.	Unknown
Rühling and others 1992. Heavy metal deposition in northern Europe 1990. Used last three years of growth of fronds from either or both *H. splendens* and *P. shreberi* in wide-region mapping of number of metals. Background and enhanced values obtained from element-by-element discussion and in reference to Figures 6-13 (if not explicitly stated in discussion, enhanced values were taken to be highest category in each Figure's legend).	Various
Rühling and others 1994. Atmospheric heavy metal deposition in Europe 1994. An expanded version of Rühling and others 1990. Used last three years of growth of fronds from *H. splendens* or *P. shreberi* or other species outside the range of the two target species. Background and enhanced values obtained from element discussion and in reference to Figures 2-10 (if not explicitly stated in discussion, enhanced values were taken to be highest category in each Figure's legend.	various: AAS, Plasma spectrometry, or Neutron activation analysis
Ryan, B. D.; and Nash, T.H. 1990. Epiphytic and lithophilic species in southern California Wildernesses.	Optical Emission Spectroscopy
Schaug, Rambaek, Steinnes and Henry 1990. Mean 1977 data from regional study of heavy metal content in Norway in the moss, HYSP70. Data from same study as Steinnes 1980 and Steinnes and others 1994. Country-wide means from Table 2. Paper also contains principal component analysis of this data.	INAA and AAS
Seaward, Bylinska, and Goyal 1981. Heavy metals in a range of Umbilicaria species from Poland.	Same as Kabata-Pendias and Pendias, 1994.
Seaward 1973 -- as cited in Hawksworth and Rose 1976, and James 1973: ranges given show increase from 1907 control and increases with decreasing distance from a steel works.	Unknown
Sheridan, Sanderson, and Kerr 1976. Missoula Valley, MT as affected by a pulp mill.	Leco
Sloof and Wolterbeek 1991a. National trace-element survey in The Netherlands using *P. sulcata*. Range values for 1986-1987 survey in Table 3. Highest value in range can be considered enhanced, while lowest value is likely to be close to background. Not included here is interesting table (2) showing differences on different substrate tree species.	INAA on ground material & AAS following nitric digestion
Sloof and Wolterbeek 1993a. Comparison of metal uptake in PASU63 and LECO17 in an area known to be heavily polluted by metals released from industries in and out of region (border of Netherlands and Belgium). Data from Table I. All levels considered enhanced.	INAA on ground material
Steinnes and Krog 1977. Industrial area studied with lichen transplants.	Unknown
Steinnes, Hanssen, Rambaek, and Vogt 1994. Regional study of trace content in *Hylocomium splendens* with excellent discussion of possible sources for higher levels.	AAS flame furnace (Cu, Pb); AAS graphite furnace (Ni, Cd); INAA (rest)

Steinnes 1993. Comparison of 1976, 1977 means and ranges for *Hylocomium splendens* across Norway. Also discusses the relative uptake of selected elements by *Hypogymnia physodes* > *Hylocomium* > *Sphagnum* > *Cladonia*.	AAS (Pb, Zn, Cu, Cd) and INAA (other elements)
Swieboda and Kalemba 1978. HYPH listed as *Parmelia physodes*. In an area impacted by Fluorine and SO2 emissions.	Unknown
Takala, Olkkonen, and Salminen 1994. Relationship of Fe content in HYPH to S, Ti in Finland. Data from Table 5. Highest in range enhanced, lowest close to background.	X-ray fluorescence analysis
Taylor and Bell 1983. On Alnus at various sites around ARCO oil refinery, Whatcom County, WA.	Parr bomb and Ba++ titration method of Krouse (S)
Tuba and Csintalan 1993b. Transplanted *Tortula ruralis* in an area of Hungary with petroleum refinery and petroleum-fired power plant and urban sources. Compared to a control from a less-polluted area described in Tuba and Csintalan 1993a.	as described in Tuba and Csintalan 1993a
Vestergaard, Stephansen, Rasmussen and Pilegaard 1986. Transplanted near a Danish Steel mill: 1977-1982 estimates from regression equations: lowest is given background, highest estimate at 0.2 km from source.	AAS on HNO3 digest
Wallin 1976. Mercury content of HYCU4 related to Swedish chlor-alkali plants.	INAA on ground material
Ward and others 1977. Heavy metals in bryophytes near mining areas in New Zealand. Data from Table 1.	AAS (Cd, Cu, Pb and Zn); Carbon Rod Atomizer (Ag)
Wetmore 1985. Report to National Park Service on lichens and air quality in Isle Royale National Park. Data summarized from CLRA60 samples in Table 1.	ICP and Leco (S)
Wetmore 1986. Sequoia NP and Kings Canyon NP. Ranges are from Table 3 (grand means from 1984 and 1985 separate analyses of the same samples (12 collections each species)).	ICP all elements but S (IRA)
Wetmore 1987a. Report to National Park Service on lichens and air quality in Boundary Waters Canoe Area of the Superior National Forest. Data summarized from CLRA60 and HYPH samples in Table 1.	ICP and Leco (S)
Wetmore 1987c. Personal communication on lichens of Acadia NP. Ranges are of means for 5 localities each species (4 localities for *Lasallia papulosa*) from Table 2 (3 samples each locality).	ICP and Leco (S)
Wetmore 1987d. Personal communication on long-term mean of his *Cladina stellaris* standard (20 separate analyses through his run # 86-20)	ICP all elements but S (IRA)
Wetmore 1989. Data on content of *Punctelia rudecta* in Cuyahoga Valley National Recreation Area, Ohio. Table I. Elements indicated as possibly enhanced were indicated as such in his discussion.	ICP all elements but S (IRA)
Wiersma, Harmon, Baker and Greene 1987. Mean (25 samples = 5 each x 5 age class fronds [1-5]) from Twin Creek Research Natural Area, 1984.	Spark source emission spectroscopy
Wiersma 1981. Trace element levels in mosses from several sites around Olympic National Park. From Table 7.	Spark source emission spectroscopy
Winner 1988. Review of excessive levels in a variety of mosses from a variety of sources. From Table 2.	Various
Wojtun 1994. Concentrations of 7 elements in 21 species of Sphagnum, many from the Pacific Northwest. This multivariate study looked at the relationship of content to the type of species (ombrotrophic or minerotrophic).	Flame photometry (Ca, N, Na); AAS (MG, Fe); colorometric methods for N and P.
Zakshek, Puckett, and Percy 1986. Levels of sulphur and lead in CLRA60 across Canada. Lowest in range (from Northwest Territories) can be considered as background. Highest in range (from central Ontario and Quebec) considered to be enhanced. Values estimated from Figures 2 and 3.	X-ray fluorescence on ground, pelletized material