Thesis

Reconnaissance Study of Selected Trace Metal Concentrations In Sediments and Vegetation of the Yukon-Kuskokwim Delta

Submitted by Mary Yunak-Martinez

In partial fulfillment of the requirements for the Degree of
Master of Science, Environmental Science
Alaska Pacific University
Anchorage, Alaska

June, 2004

Roman Dial, Committee Chairperson

Jim McCaslin Brown, Committee Member

Jeffrey Y. Foley, Committee Member

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ABSTRACT

To establish a biogeochemical baseline in the Yukon-Kuskokwim Delta (Y-K Delta) region for future environmental studies, trace metal concentrations were determined for stream sediment and vegetation samples. Selected trace metal concentrations in vegetation samples were compared to the same metal content in stream sediment samples to determine whether a correlation between plant chemistry and the underlying geology exists, whether variations in metal concentrations in sediment and vegetation samples between geographic quadrants exist and to ascertain the element concentrations by plant types.

Spearman's rank order correlation was applied to statistically determine the presence, or absence, of correlation of selected metal concentrations of arsenic, mercury, lead, selenium and zinc. The strength of significance of the results was based on a p value of 0.05 (where p is the probability of rejecting a true null hypothesis). The null hypothesis for this study is that there is no relationship between metal concentrations in vegetation and that in the sediment. When p is ≤ 0.05, the null hypothesis is rejected, indicating correlation between the parameters. Therefore, as p approaches 0, correlation between sediment and vegetation chemistry increases. Scatter plots of the concentration of metals in vegetation and the same corresponding metals in sediment show that vegetation readily absorbs the available metals at low concentrations. However, vegetation ceases to absorb metals at corresponding higher metal concentrations in sediment.

Comparison of trace metal concentrations in sediments among geographic quadrants shows that no significant ($p > 0.05$) differences exist, except in the case of lead ($p = .001$). However, significant differences in concentrations of lead, mercury and zinc in vegetation occur among geographic quadrants. Box plots show that mercury concentrations in vegetation in the southeast quadrant were low relative to the other quadrants. Analysis of element concentrations by plant type demonstrates that woody plants absorbed zinc at highest

concentrations. Peat and moss, which are essentially similar vegetation types, behave similarly to sediment in concentrating and retaining the metals in this study.

In general, metal concentrations in vegetation were within published values and contained no unusually high concentrations. Further, metal concentrations in vegetation were consistently lower than metal concentrations in sediment. The significance of these results is that metal concentrations in vegetation in the Y-K Delta are present in levels that currently pose no health concerns to the people or wildlife that consume edible vegetation.

ACKNOWLEDGEMENTS

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INTRODUCTION

Trace elements in the natural environment are known to accumulate in vegetation worldwide. Studies show that elemental composition of plants correlates with the geologic composition of the earth (Gough, 1993). Some trace elements, such as arsenic, lead, cadmium and mercury are of environmental concern, as they are known to be toxic to organisms. Two primary sources of trace elements for plants are weathered rock-forming minerals and anthropogenic activities, such as agricultural practices and atmospheric deposition of industrial pollutants (Ross, 1994).

Trace metals available to vegetation in southwest Alaska are likely to be derived from the weathering of bedrock and sediment transported from the mountainous areas of the upper Kuskokwim region, as there are currently (2003) no industrial processes in or near the region to release anthropogenic metals into the environment. Elements in the sediment become bio-available through natural mechanical and chemical weathering and are selectively absorbed by plants. Non-vascular plants, such as mosses and lichens, absorb nutrients primarily from atmospheric deposition. Likely source of trace elements in mosses and lichens are airborne particles originating from local sand dunes, glacial dust and metal-laden stream sediments. Another possible source is the long-distance transport of industrial pollutants from industrialized regions in the northern hemisphere.

In this study, sample vegetation was collected under natural environmental conditions. Analysis of the vegetation samples, on a dry-weight basis, provides an estimate of element concentration that is available to the plants, and therefore the wildlife and humans that consume the edible vegetation within the region.

Except for the mountainous areas, the bedrock geology of much of the Yukon-Kuskokwim Delta (Y-K Delta) region is not well known. Large volumes of unconsolidated sediment and overlying vegetation mat cover most of the low-lying marshy coastal plain. Metal-rich sediments in the coastal plain might be expected in the vicinity of isolated volcanic vents and local deposits of transported metal-rich sediments from the mountainous regions. The Y-K Delta is an excellent setting to examine chemical availability to vegetation, for this is a region of numerous exposed mineral occurrences in the upper Kuskokwim versus a largely low-lying flat coastal region largely devoid of outcropping bedrock.

The principal objectives of this study are to 1) determine baseline trace metal concentrations in stream sediment and vegetation; 2) determine whether or not there is a correlation between plant chemistry and the underlying geology; and 3) determine plant types that absorb certain trace metals. This information is important, as the work will generate a substantial database that will be useful as an environmental baseline database for future investigations or during future development in the Yukon-Kuskokwim Delta region. To date, only a few studies have examined metal concentrations, mainly mercury, in the upper Kuskokwim region. The present study is the most comprehensive region-wide study of multiple elements.

Sources of Trace Metals

The main sources of trace metals for sediment and plants are parent rock materials from which soil and sediment is derived and overburden transported by wind, water or glaciation. Exposed bedrock in the upper Kuskokwim region, primarily the Kuskokwim Group sedimentary sequence and younger igneous rocks, are notable for numerous sulfide mineral occurrences (J. Foley, Calista Corporation, personal communication). In addition, biogenic processes, including bacterial action, can concentrate sulfur. Natural leaching of sulfur and sulfide minerals releases metals into the environment (J. McAtee, Calista Corporation, personal communication). Other natural sources of metals are swamplands that can produce acidic water that dissolve metals and release them into the surface environment. In addition, recent human activities worldwide have contributed to the source of metals in the environment, locally increasing concentrations to levels of concern (Gough, 1993). Among others, human-related sources include mining and smelting activities, industrial emissions and vehicle emissions. Atmospheric transport can play a role in the import of trace metals from distant industrial sources. Smelters in Eurasia are major sources of air pollution in Arctic air. The Arctic Monitoring and Assessment Program (1998) further describe sources of contamination in the Arctic.

With respect to the present study area, human-related metal contaminants are believed to be minimal, as there are currently no large-scale industrial activities in the region. Effects of long-distance transport of metals on vegetation are unknown, as there have been no studies of this type in the region. Historically, gold, platinum and mercury were mined in the upper Kuskokwim and neighboring regions. Placer gold mining has taken place at various sites throughout the region, however, is not considered a source of widespread pollution. Some mercury deposits in the region were mined, including Alaska's largest mercury mine at Red Devil which operated between 1933 and 1971, producing a total of 36,000 flasks of liquid mercury (Bailey and Gray, 1997). It has since been closed due to economic factors. There are currently no operating mercury mines in southwest Alaska.

Socioeconomic Status

The Yukon-Kuskokwim region is sparsely populated and virtually isolated from the rest of the state. Residents live in 49 year-round villages scattered along the coast and major rivers, with no road connections to the outside region (Calista Corporation, 1991). There are approximately 25,000 (1999 census) predominantly Yup'ik and Cup'ik Eskimo residents in the region and more than 1,000 Athabascan people in the upper Kuskokwim villages (Alaska Department of Transportation and Public Facilities, 2002). The economy of the region is a basic subsistence lifestyle, utilizing riverboats and snow machines for subsistence activities and for commuting between villages. Subsistence activities include hunting marine mammals, moose, caribou, and waterfowl; year-round fishing; and harvesting edible vegetation and berries. There is no rail transportation in the region and roads are limited to local, unpaved village roads. In the summer months, barges transport fuel and heavy consumer items to the villages along the coast and rivers (Calista Corporation, 1991).

Commercial fishing and limited local jobs as medical aids, teachers, cashiers, postal clerks and various other government-subsidized services are major sources of monetary income. Marketable items include ivory carvings, fur apparel and grass baskets. Air transportation, largely based in Anchorage and Fairbanks, is the primary mode of access in this remote region. Natural resources have not been developed to great commercial extent. Because of the absence of large-scale development, anthropogenic effects are minimal. Therefore, metal sources are very likely to originate from local, geologically related sources.

<u>Literature Review</u>

A few biogeochemical studies in southwest Alaska examine element, mainly mercury, concentrations and distribution in sediment and vegetation samples in the Upper Kuskokwim region. In a study by Bailey and Gray (1997), total mercury concentrations in sediment at Cinnabar Creek mine measured 0.13-1,500 ppm with 20-970 ppb mercury in alder and willow leaves. Red Devil mine sediment concentration showed 0.05-1,200 ppm total mercury, and 20-900 ppb mercury in alder and willow leaves. Total mercury concentrations are higher in sediment samples from both mines than in background samples (0.10-1.2 ppm). Bailey and Gray's study found that alder and willow generally contained the highest levels of mercury, which tended to accumulate in the leaves versus stems. Mercury levels in vegetation near the Cinnabar Creek and Red Devil mercury mines were similar to concentrations in vegetation collected near the Pinchi Lake mercury mine in British Columbia. Another study in the region examined metal concentration distribution in sediments in the central Kuskokwim drainage basin (Wang, 1999). Some arsenic and mercury sediment samples from the Kuskokwim River exceeded levels where toxicology effects may occur, according to standards for selected metals established by the Canadian Council of Ministries of the Environment (Wang, 1999). The elevated values were attributed to exposed mercury ore bodies and past mining activities.

Throughout Alaska, most vegetation studies have been conducted on a local scale. One such study by Crock and others (1993) gathered baseline elemental information in moss, lichen, spruce, and surface sediments in the Wrangell-St. Elias National Park. The authors observed that baseline ranges were in agreement with those reported in literature. In another study, baseline information was given on lichen, moss, and sediment in and near Denali National Park (Crock and others, 1992). The study found high concentrations of As, Cr, Cu, Mn, Ni, and V in moss tissue compared to values reported in the literature from other locations. Mn and total sulfur were high in lichen. A few vegetation samples high in metal near Nenana were thought to be due to metal-rich wind-blown dust. In a statewide study, Gough and others (1988) investigated mean concentration of elements, excluding mercury, in sediment and surficial material from 266 locations throughout Alaska (Gough and others, 1988). A pattern in Gough's study shows generally low concentrations of multiple elements in material from tundra regions, similar to the Y-K Delta region, whereas higher concentrations were associated with mineralized regions.

Vegetation studies typically examine the effects of industry on nearby vegetation. Reports have shown elevated concentrations in moss and lichen that are attributed to anthropogenic disturbances. Pollution from smelting industries, for example, has impacted peat deposits in southwest England through Pb, Ni, and Cr contamination (Ross, 1994). Contaminants of inorganic phosphate fertilizers in agricultural sediments are mainly Cd, Cr, and Pb (12); and As, Cd, Hg, and Pb contaminants are typical mining contaminants. Studies of use of mosses and lichens as biomonitors are listed in Crock and others (1992).

Present State of Knowledge

Between 1974 and 1980, the Federal Government systematically evaluated uranium resources of the conterminous United States and Alaska through the National Uranium Resource Evaluation (NURE) program (USGS, 1974-1980). Research included hydrogeochemical, stream-sediment and rock sampling and analyses, airborne magnetic surveys and geologic mapping. The data were organized in reference to a rectangular grid system that corresponds to the National Topographic Map Series 1:250,000-scale quadrangle system used by the U.S. Geological Survey (USGS). Out of a total of 625 quadrangles nationwide, only 307 quadrangles were sampled (USGS, 1997), leaving a checkerboard pattern of completed and incomplete quadrangles and a gap in southwest Alaska. Southwest Alaska was not evaluated because of its perceived improbable mineral potential and because funding for the NURE program was abruptly terminated. In 1985, the USGS took responsibility for managing the data generated by the NURE program. To complete the work in southwest Alaska, the USGS, du Pont de Nemours and Company and Calista Corporation geologists investigated the environmental geochemistry and mineralogy of the Yukon-Kuskokwim Delta that began in summer 2001.

Continuing Geochemical Survey

The 2001 geochemical survey of the Yukon-Kuskokwim Delta by the U.S. Geological Survey was partially funded in 2001 by du Pont de Nemours and Company, a major international industrial mineral producer. Calista Corporation geologists assisted the USGS and du Pont during sample collections. The team of heavy mineral and geochemical professionals with expertise in assessing industrial mineral resources has the primary responsibility of collecting sediment and stream sediment samples for geochemical research. Having interest in potentially useful plants in Alaska, du Pont de Nemours and Co. included secondary plans to collect composite organic samples, including peat, lichen, sedge, moss and leafy plants at each sampling location during the 2001 field season. This was the first comprehensive, region-wide exploration program for heavy minerals in the Yukon-Kuskokwim Delta region. The USGS and Calista Corporation continued the geochemical survey in 2002 and 2003. Stream sediment data will become available through the USGS. This study is based only on data from the 2001 and 2002 investigations.

This study examined the concentration of chemical elements in sediments and vegetation in the Yukon-Kuskokwim Delta. The methodology used to collect the vegetation samples was not conducted ideally as scientific researchers typically collect plants by species, however, there now exists valuable comprehensive data from the Y-K Delta for study. The study of trace metals in sediment and vegetation is not new. Much effort has been expended over the past 40 years to examine and quantify the transfer of elements from sediment to plants (Banuelos and Husein, 1995). The fact that the data from the Y-K Delta is new makes this study valuable. Important to this study is that the samples were collected from randomly selected sites, which will allow valuable analysis of chemical distribution patterns on a regional scale.

Study Area Description

The Y-K Delta is a fan-shaped area covering 400 kilometers north to south, along the Bering Sea coast, and 320 kilometers inland to the Kuskokwim Mountains. Accretion of the depositional plain continues seaward since the sea reached its present level approximately 6,000 years ago (Thornsteinson, 1989). The coastal area is a large area of fluvial sedimentation formed by alternating marine and freshwater deposition. The 62,200 square kilometer delta is composed of a lake-dotted, marshy flatland (Péwé, 1975) sloping gently, approximately 1:1,000, seaward from where it begins inland (Thornsteinson, 1989). The study area includes the upper Kuskokwim River uplands area; an area known for mineral deposits.

THE PHYSICAL ENVIRONMENT

Regional Geology

The coastal plain of the Yukon-Kuskokwim Delta consists primarily of unconsolidated Quaternary sediment, including alluvial, marine, loess, and glacial deposits. This thin sediment cover is underlain by a thick section of the Cretaceous Kuskokwim Group, which consists predominantly of graywacke and mudstone deposited as turbidites in a basin adjacent to active orogenic uplifts (Decker et al., 1994, Patton et al., 1994). Overlain unconformably by the Kuskokwim Group are basement rocks consisting of pre-Cretaceous meta-sedimentary and meta-igneous rocks. Both the Kuskokwim Group and older basement rocks are intruded by Tertiary-age mafic igneous bodies, which include numerous, small volcanic cones dotting the lake-studded lowland (Cady, 1955).

In the Kuskokwim Mountains, and other upland areas surrounding the delta lowland, the Kuskokwim Group and pre-Cretaceous basement have been intensely deformed by Tertiary thrust faulting, and Tertiary to recent major regional strike-slip faulting. This area of northeast-southwest-trending deformation is bound on the north by the Kaltag Fault and the south by the Denali-Farewell Fault (Decker et al., 1994; Patton et al., 1994). Intruding the Kuskokwim Group and older basement rocks are numerous dikes, sills, volcanic-plutonic complexes, and volcanic fields of Late Cretaceous-early Tertiary age (Bundtzen and Miller, 1997). These igneous bodies have been associated with the numerous gold and mercury mineral occurrences throughout southwestern Alaska.

Mineral Occurrences

Mineral deposits, including mercury lodes and gold placers, are common in the middle to upper Kuskokwim River valley (Bundtzen and Miller, 1997; Gray and others, 1997). Mercury deposits occur along faults in greywacke, shale, granite, and dolomitized limestone host rocks, along a tectonic zone containing Late Cretaceous - early Tertiary volcanic rock (Sainsbury, 1965; Gray and others, 1997). Mercury ore consists of cinnabar (HgS) and is often accompanied by quartz, calcite, stibnite, pyrite, native mercury and small amounts of arsenic. Other metals such as molybdenum, copper, zinc, lead, silver and gold are found in varying amounts in lodes in and adjacent to veins that are also associated with Late Cretaceous – early Tertiary age igneous rocks.

Sediments

Exposed and near-surface sedimentary deposits in the coastal region consist mostly of unconsolidated Tertiary non-marine strata of deltaic origin (Plafker and Berg, 1994). A large part of the sediment in the Delta was transported from the upper Kuskokwim and Yukon Rivers (Yukon Delta National Wildlife Refuge, 1988). The deltaic sediments are poorly drained and consist of stratified loams, silt, and sands overlain with a thick layer of peat (Yukon Delta National Wildlife Refuge, 1988). Major regional groups of surficial deposits in Alaska, from which sediments are derived, are described by Péwé (1975). Permafrost persists to approximately 183 meters beneath the surface throughout much of the region (Yukon Delta National Wildlife Refuge, 1988). Drainage is slow due to the presence of permafrost and surface water is slow to evaporate because of the cool moist climate.

Climate

Three broad climatic zones in the Y-K Delta are maritime along the coast; transitional in the central region; and interior, in the upper Kuskokwim region. The climate of the Delta is influenced by the adjacent Bering Sea winds. Mean monthly air temperatures on the Yukon Delta range from 10°C in July and August to a low of -14°C during the winter months (Thornsteinson, 1989). Average annual precipitation of the maritime zone ranges from 380 to 560 millimeters. The interior generally receives 2 meters of snowfall annually. The growing season is approximately from June 1 to September 15. The Delta is largely treeless, however, alder, willows, and birch grow sparsely along major streams (McNab and Avers, 1994). The rivers of this region are brownish-gray due to large loads of sediment and dissolved organic debris.

Vegetation

The coastal area is dominated by wetland vegetation that is often inundated by tidal waters. The coastal plain is covered by lowland tundra where the dominant vegetation is wet sedge meadow consisting of *Eriophorum angustifolium* (tall cotton-grass) and *Carex aquatilis* (water sedge) (Viereck, 1992). The upland tundra area is dominated by *Europhorum vaginatum* (tussock sedges) with areas of *Dryas* dwarf shrub on dry rocky sites (Viereck, 1992). The study area is typical of complex vegetation patterns in arctic areas where there exist subtle differences in vegetation in short distances. These subtle changes are due to small changes in elevation and sediment moisture (Thornsteinson, 1989).

There are six basic community types in the Y-K Delta: wet tundra, moist tundra, alpine tundra, high brush, bottomland spruce—hardwood forest, and upland spruce—hardwood forest. Sample collection sites for this study were largely from the wet and moist tundra communities. Wet tundra is the most extensive community type in the study area, where dominant vegetation are water-tolerant sedge and cotton grass that are rooted in a mat of mosses and lichens. This community type is common to the low-lying areas on poorly drained, acidic sediments with shallow permafrost (Monz, 2001). Its associated plants include willow, Labrador tea, shrubby cinquefoil, bog cranberry, Lyme grass, lichens and mosses. Moist tundra communities occur on elevated grounds and are very productive during the growing season. Characteristic of this community is cotton grass tussocks with sedges and dwarf shrubs rooted in a mat of mosses, lichens and grasses. Associated plants are willow, dwarf birch, Labrador tea, blueberry, cotton grass, horsetail, sedges, and mosses. Very few samples were collected from alpine tundra, a community type of barren rocks with low plant mats. The remaining community types from which samples were collected are dominated by woody vegetation. Alder, willow, various berries, bluejoint grass, ferns and mosses characterize high brush communities. Bottomland spruce—hardwood forest communities contain white spruce, balsam poplar, and tall shrubs. Finally, white spruce, birch, aspen, and black spruce characterize upland spruce—hardwood forest communities (USGS, 1973). Decomposition of vegetation in arctic regions is slow, according to Gough (1988), resulting in large deposits of organic materials, such as peat, in which chemical elements may be immobilized. Peat is generally dead sphagnum moss that comprises a large portion of the vegetation samples.

METHODS

Stream sediment and vegetation samples were collected at randomly selected locations for geochemical analysis. This section discusses the methods of sample collection, preparation and analysis.

Field Methods

Geologists and geochemists relied upon helicopter transport to collect samples in the months of July and August, 2001 and 2002. Sample sites were primarily in tundra settings. Sample locations were located on a topographic map, GPS coordinates recorded, and photographs were taken at most sample sites. Sample sites were selected on the basis of a 17-km x 17-km mesh grid projected over the study area (Figure 1). The quadrant of each grid cell sampled was determined by random number generation. Vegetation samples were collected during peak seasonal vegetation biomass.

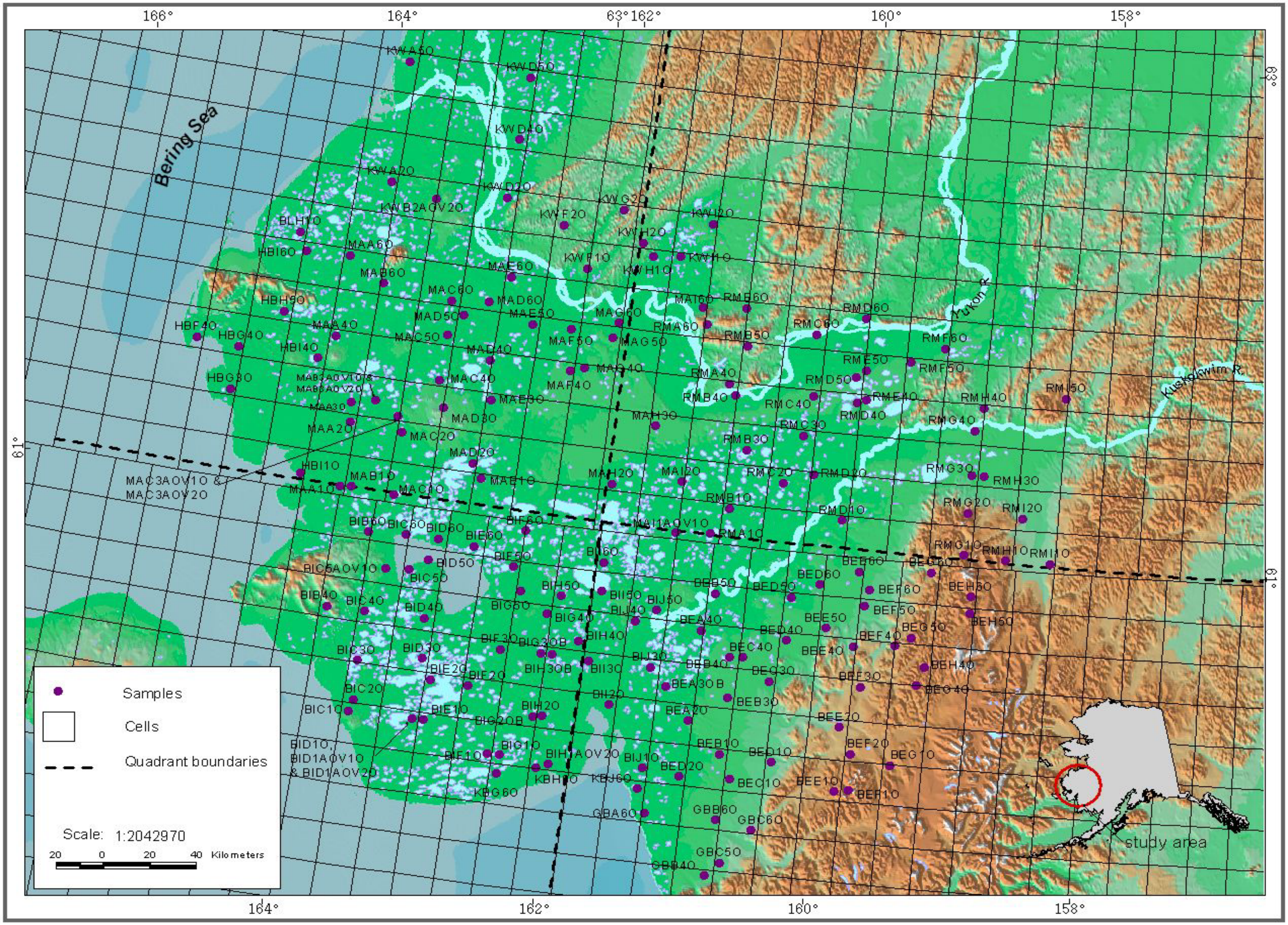

Figure 1. Sediment and vegetation sample locations.

Sediment Collection

At each sample site, a shovel was used to cut into the top 2 feet of sediment layer. Samples were placed in Hubco® sample bags and labeled. All sediment samples were sent to the USGS Denver laboratories for preparation and analysis. The samplers collected sediment profile information at the sample sites and digital photographs of most locations.

Vegetation Collection

At most stream sediment sample locations, vegetation samples that variously consist of moss, lichen, and leafy species were collected. In 2001, vegetation samples variously included single species and multi-species composite samples. In 2002, mostly single species plant samples were collected. Plant sample material was collected and placed into labeled Hubco® sample bags and allowed to air dry. Composite samples typically consist of mixtures of vegetation species typically found in the Delta, including: willow (*Salix sp.*), blueberry (*Vaccinium uliginosum*), dwarf birch (*Betula nana*), Labrador tea (*Ledum palustre*), cloudberry (*Rubus chamemorous*), horsetail (*Equisetum fluvatile*), lowbush cranberry (*Vaccinium vitus-idaea*), reindeer lichen (*Cladina stygia*), and moss (*Sphagnum sp.*).

<u>Sample Preparation and Analytical Methods</u>

All sediment samples were shipped to the USGS Laboratory in Denver for preparation for analysis. Methods of preparation and analysis are described and followed the procedure documented in Crock and others (1993), including analyses of laboratory-prepared duplicate samples.

Vegetation samples were air dried at room temperature. Samples collected in 2001 were separated into sub-samples by different plant types, characterized by common plant and genus names and digitally photographed. Weight percent composition of these plant types was recorded. In contrast to methods of Crock and others (1993), vegetation samples were not washed with water. Samples were ground with a Wiley Mill®, mixed after grinding and stored in labeled cardboard canisters. Splits of each sample were prepared for ashing, leaving the other split unashed. Duplicate samples were introduced along with standard reference material and control samples. Analytical procedures followed the USGS's laboratory quality assurance and quality control policies.

A portion of each ground vegetation sample was placed in a labeled crucible, weighed, then ashed in a 500°C furnace for twelve hours. The furnace was allowed to cool for approximately 8 hours before samples were removed. The ashed samples were analyzed at Bequerel Laboratories, Ontario, Canada by inductively coupled plasma mass spectrometry (ICP-MS). Elemental concentrations in this report are based on ash weight in parts per million (ppm). In order to provide values that represent whole plant, reported elemental values were multiplied by the percent ash remaining, after organic compounds were driven off as vapor in the ashing process. The unashed splits of the ground samples were chemically analyzed by cold-vapor analytical method to determine mercury concentrations.

Statistical Methods

To determine whether or not similar relations between metals in vegetation and the same metals in sediment exist in different geographic areas, the study area was divided into four quadrants. Midlines of latitude and longitude for the study area were used to determine the boundaries between quadrants. The quadrants were divided into NW, NE, SW and SE quadrants in Figure 1 and successive illustrations. Two dependent variables were used in the statistical analyses: (1) arsenic, mercury, lead, selenium and zinc concentrations in sediment and (2) the same metals in vegetation. Concentrations of these metals were compared among geographic quadrants and among general plant types (peat, moss, lichen, herbs, woody). To test correlations between the selected metals in vegetation and sediment, [1]Spearman's rank order correlation was applied using statistical software, SPSS (Statistical Package for the Social Sciences) Version 12.0. Obvious outliers were removed from the lead (one vegetation sample, BEA4O, value > 120x other vegetation values) and selenium vegetation samples (one vegetation sample, BIJ3O, > 6x other vegetation values) from the beginning. These samples contained anomalous concentrations of metals. Sample BEA4O contained an exceptionally high concentration of lead (1269.66 ppm). Concentrations for sample BIJ3O were high in arsenic (5.06 ppm), lead (10.47 ppm), selenium (3.12 ppm) and zinc (202.47 ppm). In addition, the ICP-MS analytical technique has a detection limit of 5.0 ppm for arsenic (As) in sediment and furthermore, many vegetation samples contained less than detectable levels of arsenic. Consequently, if either a vegetation or sediment sample had less than detectable levels of arsenic, that sample point was excluded from the As correlation test. With respect to the two outliers, samples BEA4O and BIJ3O are located on opposite ends of a typical lake system just south of the village of Napaskiak. The sample sites are in a wet tundra ecosystem located near the mouth of the Kuskokwim River (Figure 2). A winter trail cuts through the lake system connecting the villages of Napaskiak and Eek. It is possible that activities related to snow-machine use along the trail is the source of metal contamination in the sample location sites. Additional sampling in the vicinity could shed some light as to the actual cause of high metal concentrations in the area.

[1] Spearman's Rank Correlation is a method used for calculating correlation between variables, when the data does not follow the normal distribution. It is therefore a non-parametric test. (http://www.psybox.com/web_dictionary/Spearman.htm, 2003)

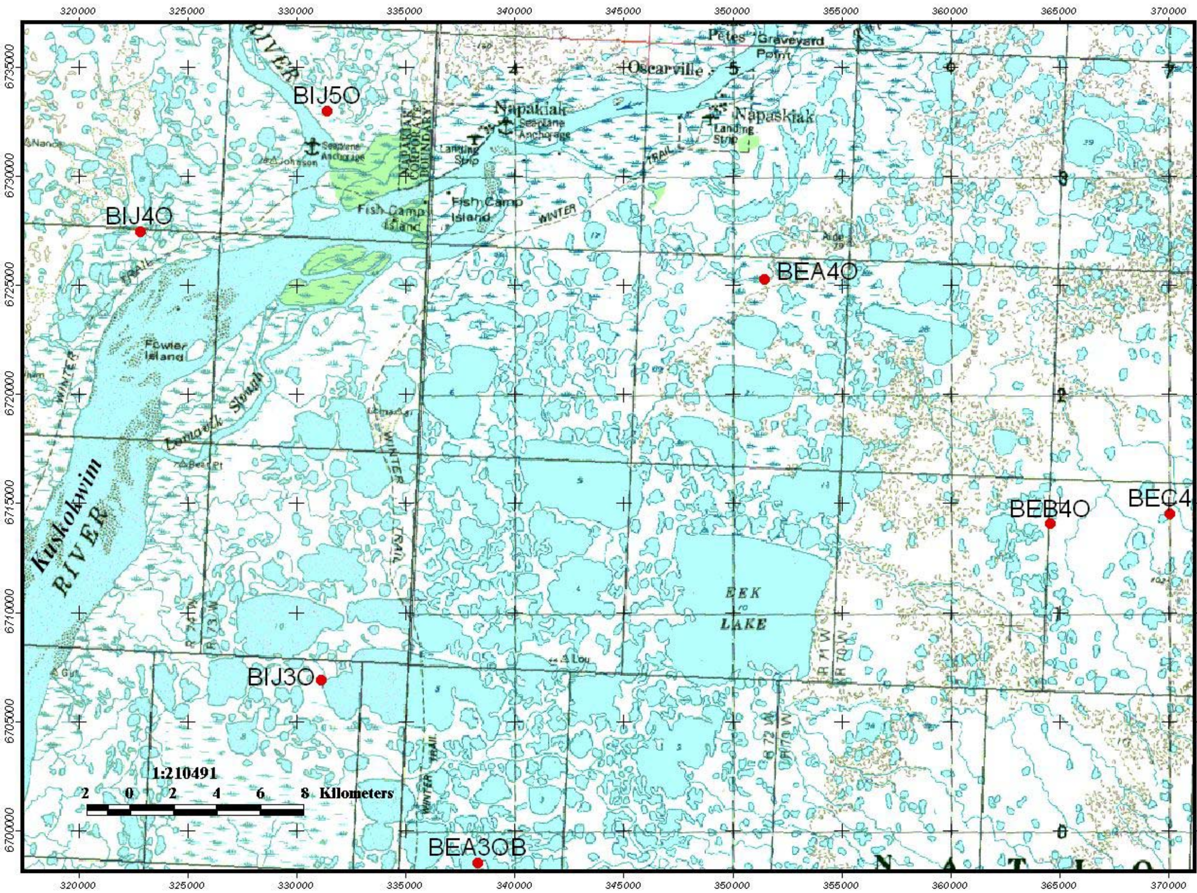

Figure 2. Locations of vegetation samples (BEA4O and BIJ3O) high in metal concentrations (map coordinates are in UTM meters).

Because literature suggests that element concentrations in plants positively correlate with element concentrations of the substrate (Gough, 1993), [2]one-tailed tests were used with a significance level set at $p = 0.05$. The null hypothesis states that there is no relationship between metal concentration in soil and the same metal concentrations in the vegetation samples. In other words, there are no significant differences between the mean metal concentrations in soil and in vegetation. The cut off point of significance used here is the 0.05 level. If the test is significant ($p \leq 0.05$), the two variances are significantly different; that is there is a relationship between metal concentrations in soil and in the

[2] This is a one-tailed test of hypothesis because the interest is whether there is a difference only. At $p \leq 0.05$, I rejected the null hypothesis and state that a relationship exists between concentration of metals in soil and the same metals in vegetation.

vegetation samples. Because Spearman's rank correlation statistic is more robust to distributions, it was used in preference to Pearson's correlation coefficient (r). This measure for linear relationship between variables ranges from –1 to +1, where a positive relationship has a value close to or equal to +1; a coefficient of 0 indicates a non-linear relationship. Boxplots were used to display variation of metal concentrations in sediment among quadrants and among plant types. Boxplots were again used to determine in which quadrants the concentrations of trace metals in vegetation were the greatest. [3]One-way ANOVA was used with [4]post-hoc comparisons using Tukey's correction factor for among region and among plant comparisons. Appendix A shows descriptions and locations of the vegetation samples statistically analyzed in this study.

RESULTS

Reference Material and Duplicates

With respect to the percent differences in the duplicate samples (Appendix B), it appears that as the values approach the detection limit, there is less precision in the measurements. In general, there were no large fluctuations in the overall duplicate samples (Appendix C), indicating a low level of analytical variance. Percent variability was greatest in arsenic at lower concentrations ($\leq$ 6 ppb). Certified and standard arsenic (As) values were below detection limits, so evaluation of reliability at these concentrations was not possible. Chemical analysis of the ashed multi-species plant material show estimates of trace metals available to plants in the Y-K Delta (mercury alone was not ashed).

[3] One way ANOVA (analysis of variance) compares three or more groups defined by a single factor (http://www.graphpad.com/instatman/IntroductiontoANOVA.htm, 1990-1998). Soil element was compared with the elements between the quadrants.
[4] A post-hoc comparison is a test of the statistical significance of differences between group means after having done an ANOVA (http://www.ithaca.edu/jwiggles/stats/notes/notes23.htm, April 2002). Tukey's HSD is the post-hoc test used in this study.

Statistical Analyses

A total of 170 vegetation and sediment samples were used in the statistical analysis. These sample population distributions are displayed in the box plots and statistical analyses that follow.

Element Concentrations by Region

Sediment

In sediments, lead was the only element that differed significantly (p = .001) among quadrants. The difference in lead in sediment between the SE and NW quadrants was significant (p = .001). Likewise, a significant difference (p = .032) was observed between the NW and NE quadrants (Figure 3). Tukey's pairwise comparison showed that the other four metals tested in sediment occur similarly in all quadrants (Figures 4-7); nor did significant differences occur for any other sediment metal among quadrants using one-way ANOVA and Tukey's post hoc comparison (p > 0.05).

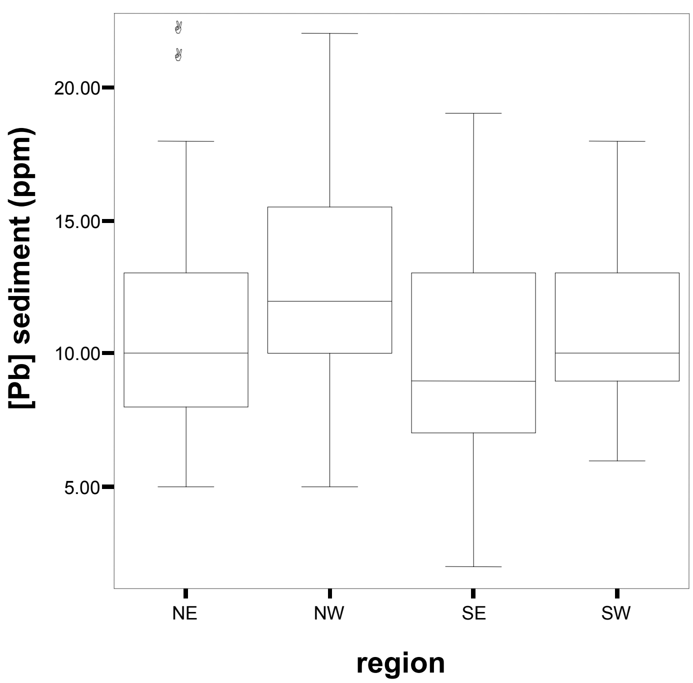

Figure 3. Boxplot of lead concentrations in sediment among quadrants.

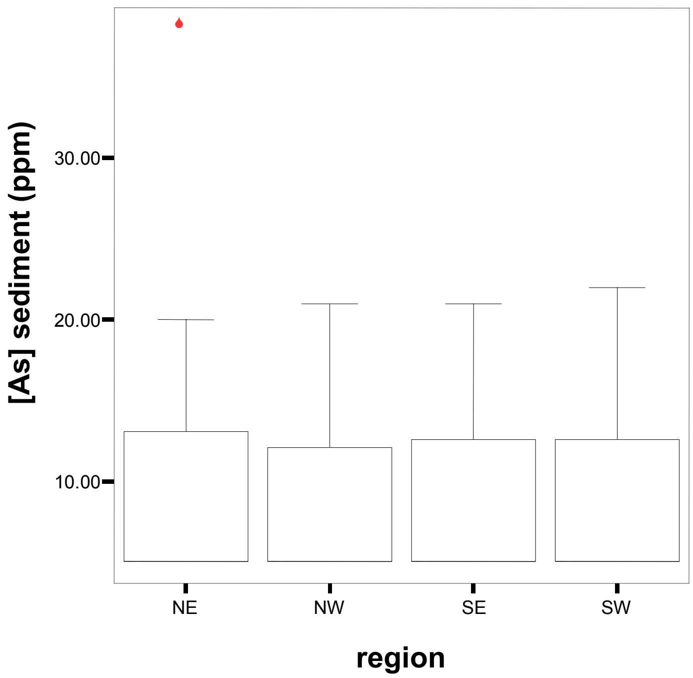

Figure 4. Boxplot arsenic concentrations in sediment among quadrants.

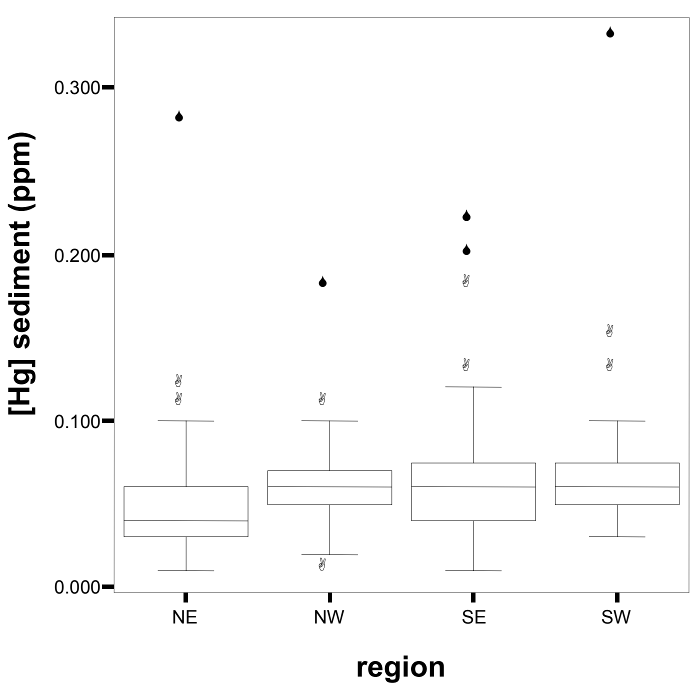

Figure 5. Boxplot of mercury concentrations in sediment among quadrants.

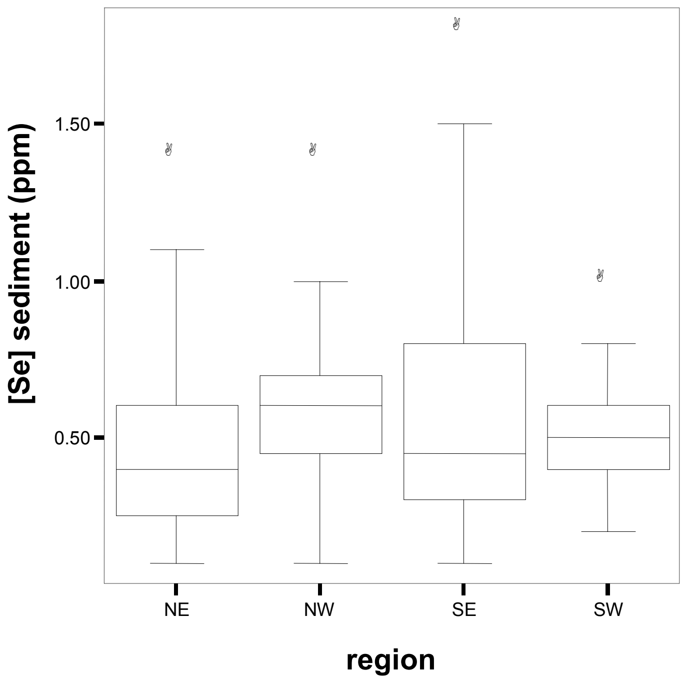

Figure 6. Boxplot of selenium concentrations in sediment among quadrants.

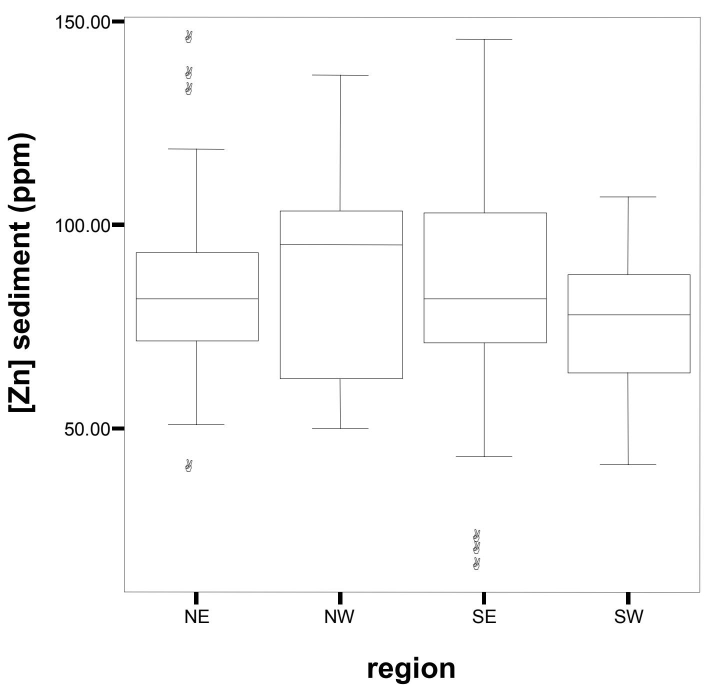

Figure 7. Boxplot of zinc concentrations in sediment among quadrants.

According to literature, zinc and lead often occur together in mineralized outcrops (Gough, 1982). In this study, correlation tests for lead and zinc in sediment showed significant ($p < 0.05$) positive correlations ($r > 0$) in all quadrants. Scatter plots between lead and zinc concentrations in sediment show positive correlation in all quadrants (Figure 8).

In the SE quadrant, correlation between lead and zinc in sediment was slightly positive [5](r = .252*) and significantly different from zero ($p = .031$). In the SW quadrant, the correlation between lead and zinc in sediment was again slightly positive (r = .326*) and significantly different from zero ($p = .049$). In the NW quadrant, the correlation between lead and zinc in sediment was slightly more positive than in the other quads (r = .529**) and significantly different from zero ($p = .001$). Finally, in the NE quad, correlation between lead and zinc in sediment was positive (r = .373**) and significantly different from zero ($p = .006$).

[5] SPSS notes a significant difference with an asterisk (*). The r value contains one asterisk (*) when $p < 0.05 > 0.01$; two asterisks (**) when $p < 0.01 > 0.001$; and three asterisks (***) when $p \leq 0.001$).

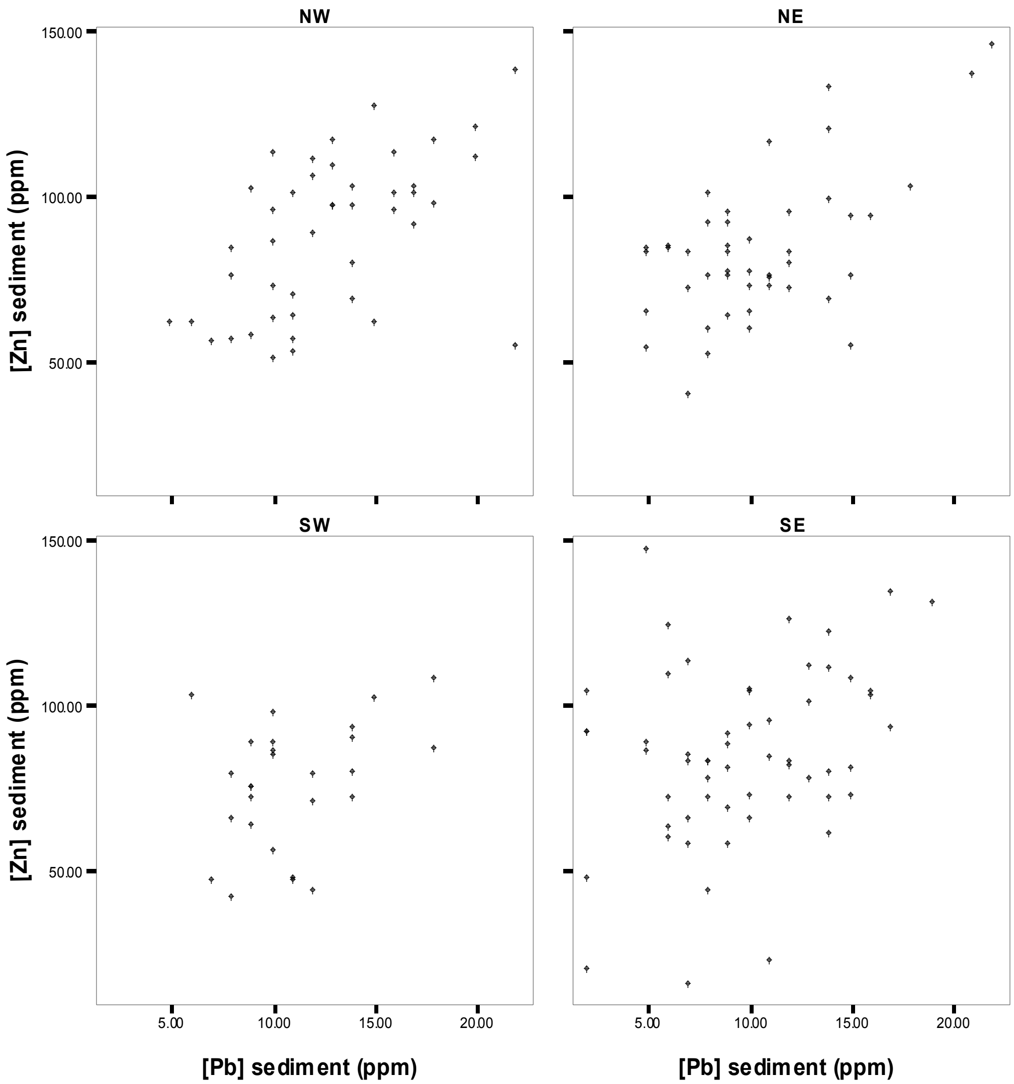

Figure 8. Scatter plot of zinc and lead in sediment for all quadrants.

Vegetation

In contrast to metals in sediment, concentrations of metals in vegetation samples showed significant differences ($p < 0.05$) among regions for lead, zinc and mercury.

One-way ANOVA test showed that lead in vegetation differed significantly ($p = .007$) among quadrants for element concentrations in vegetation. Zinc and mercury also differed significantly, ($p = .028$) and ($p = .004$), respectively, among the quadrants. No significant differences were found for arsenic or selenium in vegetation among quadrants using one-way ANOVA and Tukey's Post Hoc comparison ($p > 0.05$).

The difference in lead in vegetation between the NW and NE quadrants was significant ($p = .008$). Box plots depict lead concentration in vegetation highest in the northwest quad with mean concentrations of 1.86 ppm (Figure 9). Lead levels were also high in the southwest quadrant with a mean concentration of 1.70 ppm.

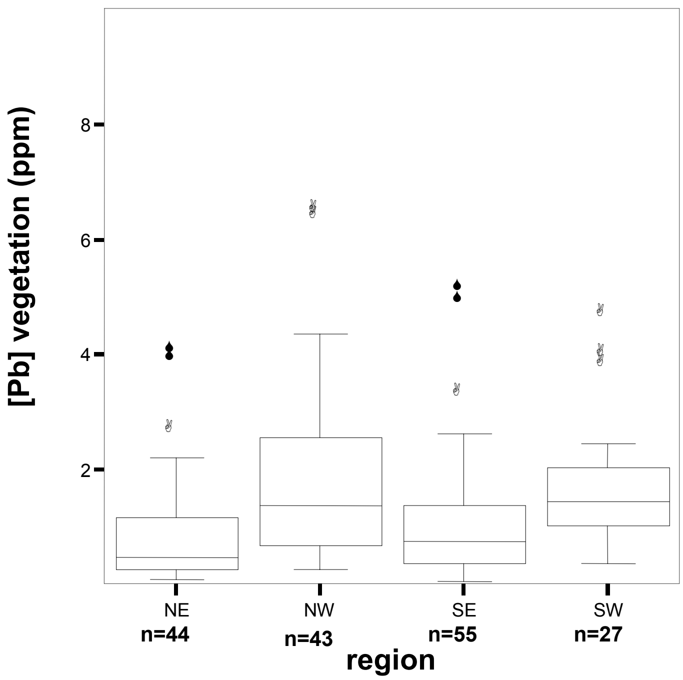

Figure 9. Lead concentrations in vegetation among quadrants.

Zinc concentrations in vegetation significantly ($p = .038$) differed in the NW and NE quadrants. Zinc concentrations in vegetation showed the greatest concentration in the northeast quad with a mean of 53.72 ppm (Figure 10).

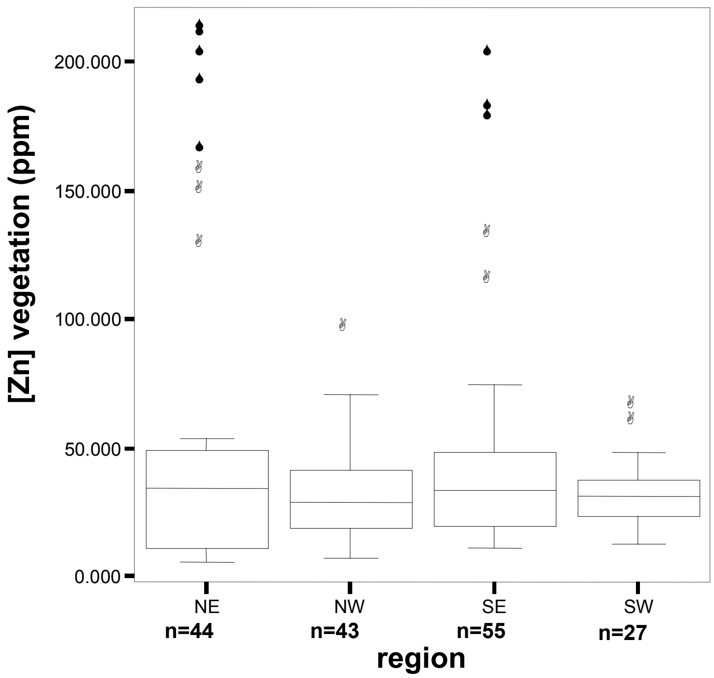

Figure 10. Zinc concentrations in vegetation among quadrants.

Mercury concentrations in vegetation differed significantly (p = .006) in the NW and NE quadrants. Box plots shows that mercury concentration levels in vegetation were high in the southwest quad (mean = 112.96 ppb) and highest in the northwest quad with a mean concentration of 125.12 ppb (Figure 11).

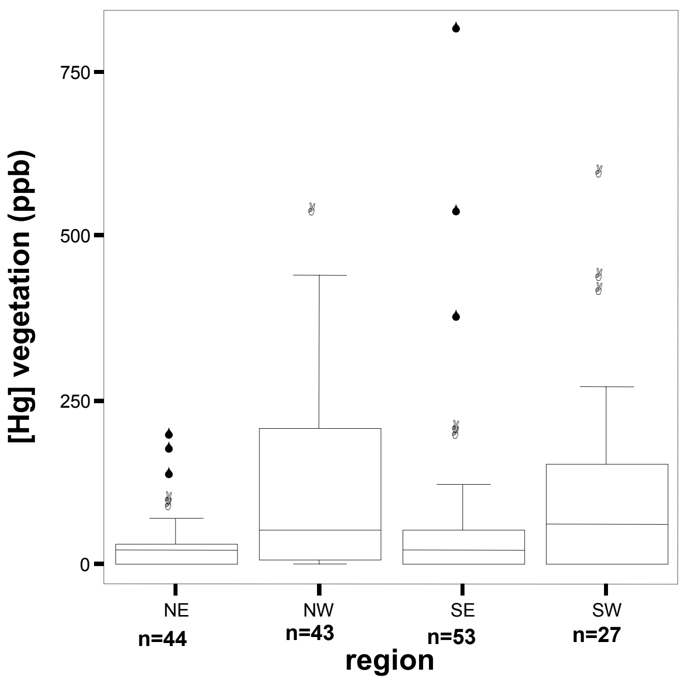

Figure 11. Mercury concentrations in vegetation among quadrants.

No significant differences were found for arsenic and selenium in vegetation among quadrants. Arsenic levels in vegetation had the highest concentration in the northwest quad having a mean concentration of 1.78 ppm (Figure 12).

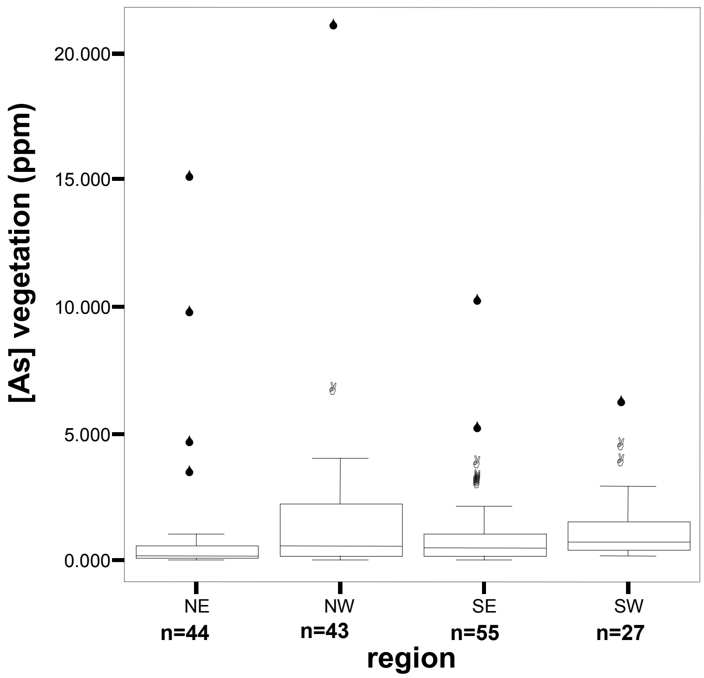

Figure 12. Arsenic concentrations in vegetation among quadrants.

Mean selenium concentration levels in vegetation had a mean of 0.14 ppm in the SE and SW quadrants with little variance throughout the region (Figure 13). In general, only concentrations of lead, zinc and mercury in vegetation varied among the quadrants.

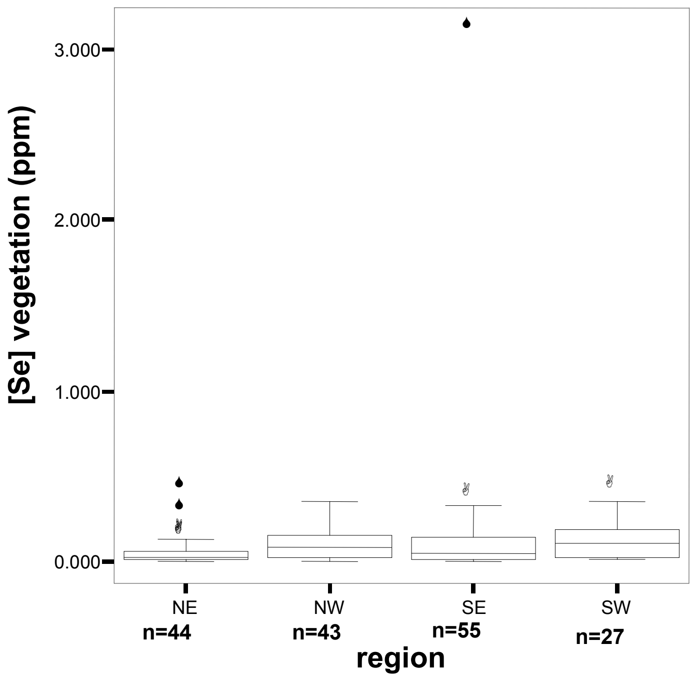

Figure 13. Selenium concentrations in vegetation between quadrants.

With respect to lead and zinc in vegetation, differences in correlation between these metals exist among quadrants. The concentration of zinc in vegetation showed a positive (r = .359**) and significant (*p* = .008) correlation with the concentration of lead in vegetation in the northwest quad. Concentration of zinc in vegetation also showed a somewhat significant (*p* = .065) correlation, although negative (r = -230), with the concentration of lead in vegetation in the northeast quad. No significant differences for lead and zinc occurred in vegetation among the remaining quadrants.

The differences seen here contrast with the strong positive correlations observed between zinc and lead concentrations in sediment between quadrants as depicted in Figure 8. Differences in zinc content in vegetation are responsible for the correlation differences among quadrants. Scatter plots of correlations between zinc and lead in vegetation between the quadrants show that correlations in the NW and SW quadrants are positive, and negative in the SE and NE (Figure 14). The scatter plot for the NE quadrant is of interest and shows that while lead and zinc are sequestered similarly in relation to one another, vegetation in this quadrant is absorbing zinc in high concentrations with a mean of 53.72 ppm.

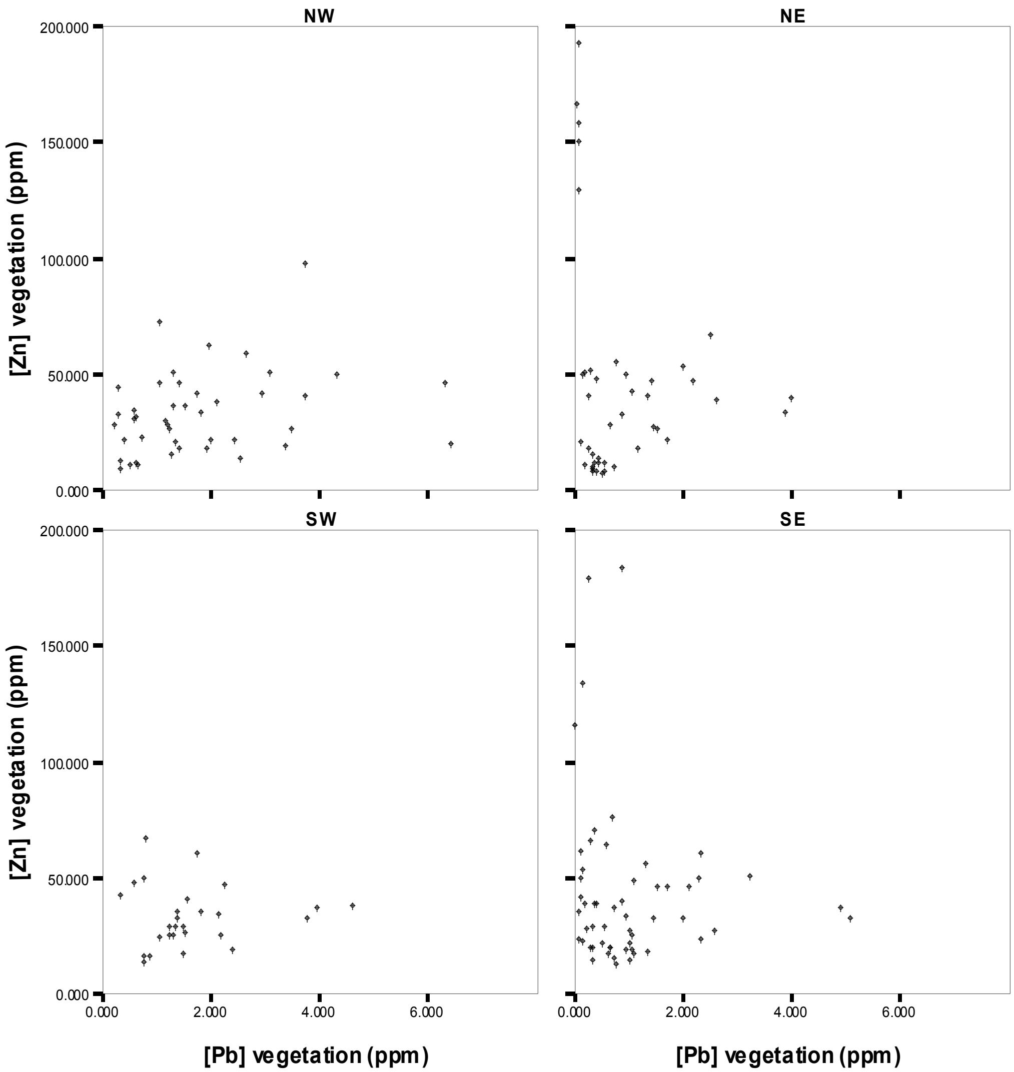

Figure 14. Scatter plot of zinc and lead in vegetation for all quadrants.

Box plot of concentration of zinc in vegetation between the quadrants confirms the highest absorption occurring in the NE quad (Figure 15).

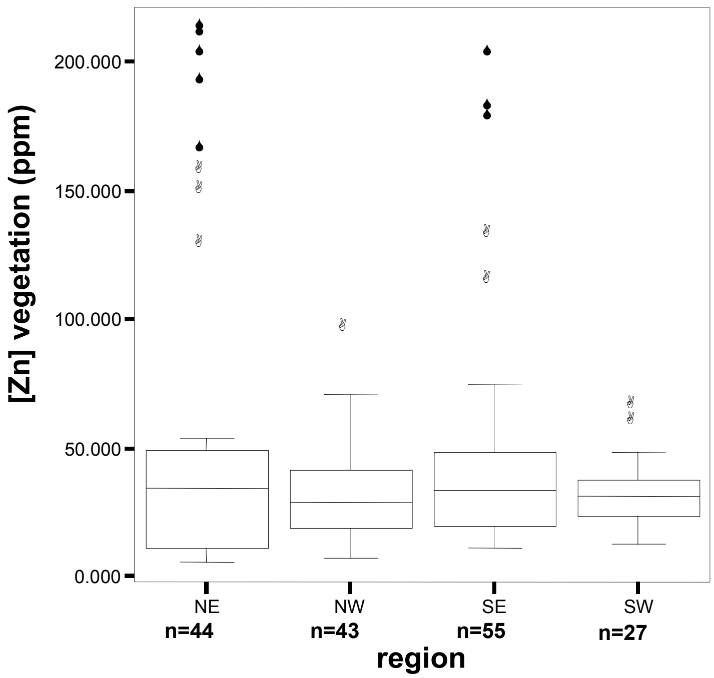

Figure 15. Box plot of highest zinc concentrations occurring in the NE quadrant.

Element Concentrations by Plant Types

Mean concentrations for each metal are listed by major plant type (mosses, grasses, peat, lichen, and woody vegetation) in Table 1. The highest concentrations of lead, mercury and arsenic were in peat; the highest concentration of selenium was in moss; and zinc was highest in woody plants. The highest metal concentration in lichen was zinc, with a mean of 25 ppm. In general, arsenic, mercury and lead, which are not essential to plant growth or health, concentrated in peat.

Table 1. Sample size and descriptive statistics given as mean (standard deviation) for concentrations for five elements by major plant type.

	PEAT N = 45	MOSS N = 32	LICHEN N = 34	HERB N = 47	WOODY N = 12
[As] (ppm)	2.10 (2.69)	1.95 (3.81)	0.34 (0.77)	0.98 (1.65)	0.24 (0.39)
[Pb] (ppm)	2.04 (1.29)	1.36 (1.41)	0.78 (0.69)	0.96 (1.09)	0.52 (0.79)
[Se] (ppm)	0.17 (0.10)	0.24 (0.15)	0.03 (0.03)	0.02 (0.03)	0.03 (0.03)
[Zn] (ppm)	30.93 (15.96)	38.80 (33.35)	25.21 (37.01)	38.87 (18.76)	146.95 (56.94)
[Hg] (ppm)	0.163 (188.16)	0.122 (140.72)	0.029 (37.58)	0.024 (20.15)	0.004 (11.65)

Box plots of metals in vegetation by plant type show which metals are absorbed to the greatest extent in each plant type. Peat, and moss absorbed higher concentrations of arsenic, a mean of 2.10 ppm, and 1.95 ppm respectively, than any other plant types (Figure 16).

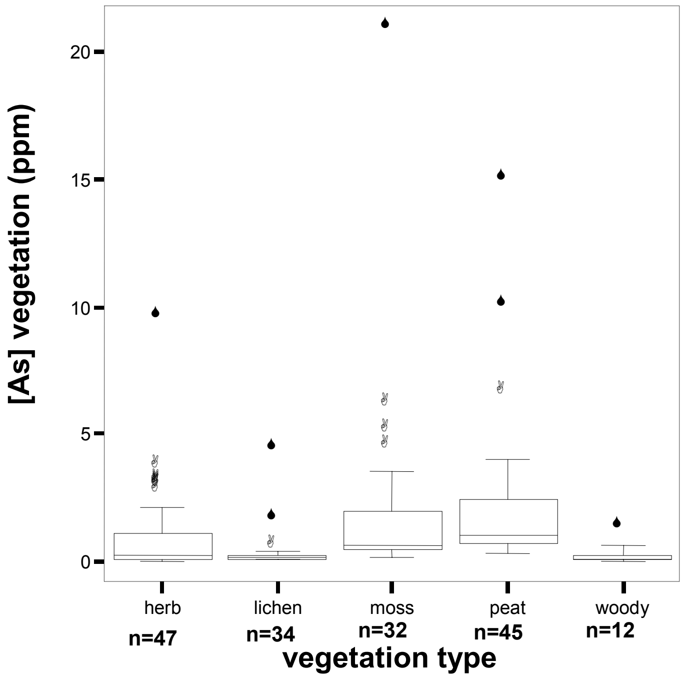

Figure 16. Arsenic concentrations in vegetation among plant types.

In Figure 17, peat absorbed a mean of 163 ppm mercury and moss absorbed a mean of 121 ppb mercury.

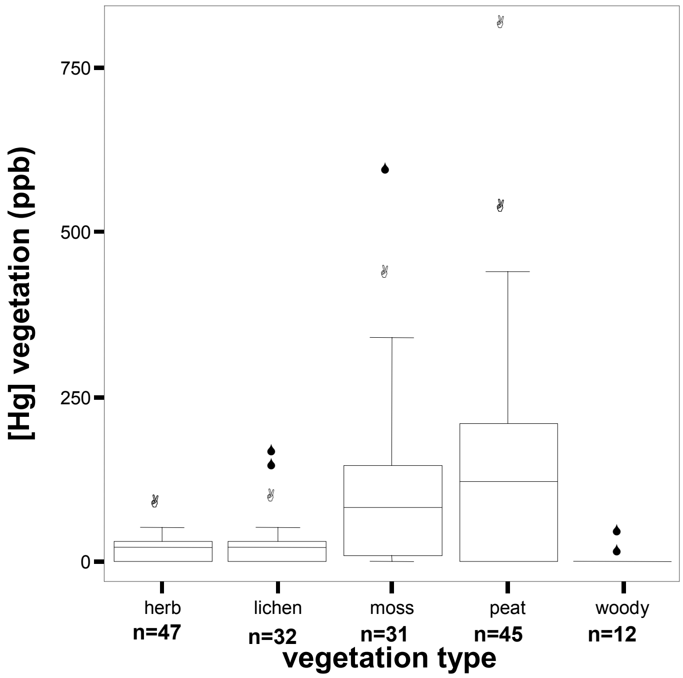

Figure 17. Mercury concentrations in vegetation among plant types.

Figure 18 shows that peat absorbed a mean of 2 ppm lead with slightly more uptake of lead in woody plants than shown in the previous figures.

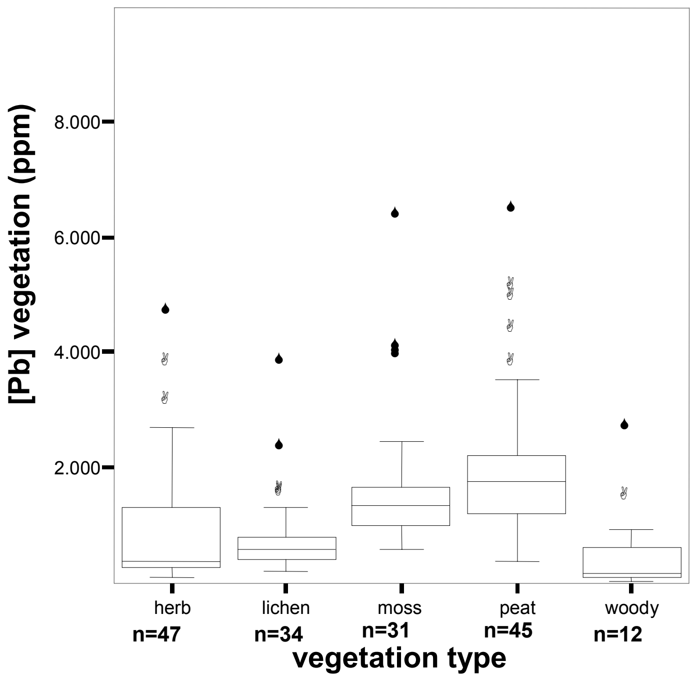

Figure 18. Lead concentrations in vegetation among plant types.

Low selenium concentrations were absorbed by peat (mean of 0.17 ppm) and moss (mean of 0.24 ppm) (Figure 19).

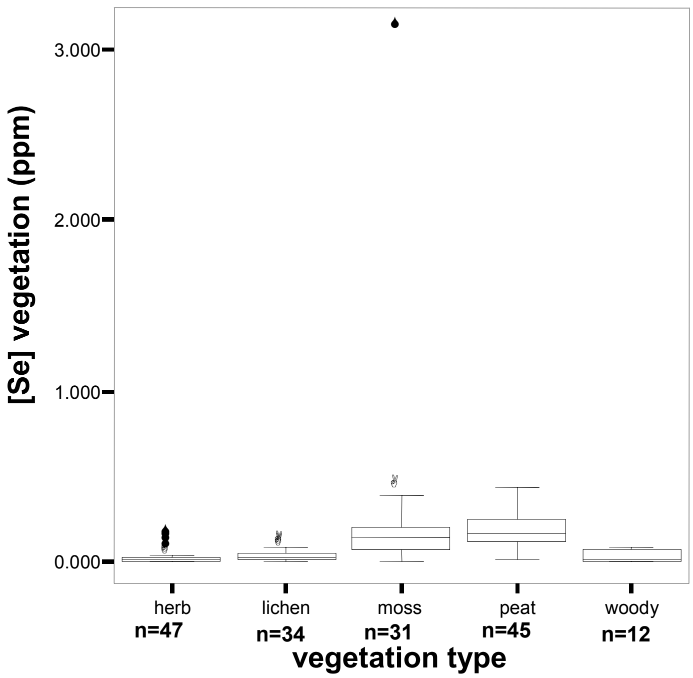

Figure 19. Selenium concentrations in vegetation among plant types.

Notable in the zinc in vegetation box plot (Figure 20) is the high zinc concentration (a mean of 146.95 ppm) that woody plants absorb.

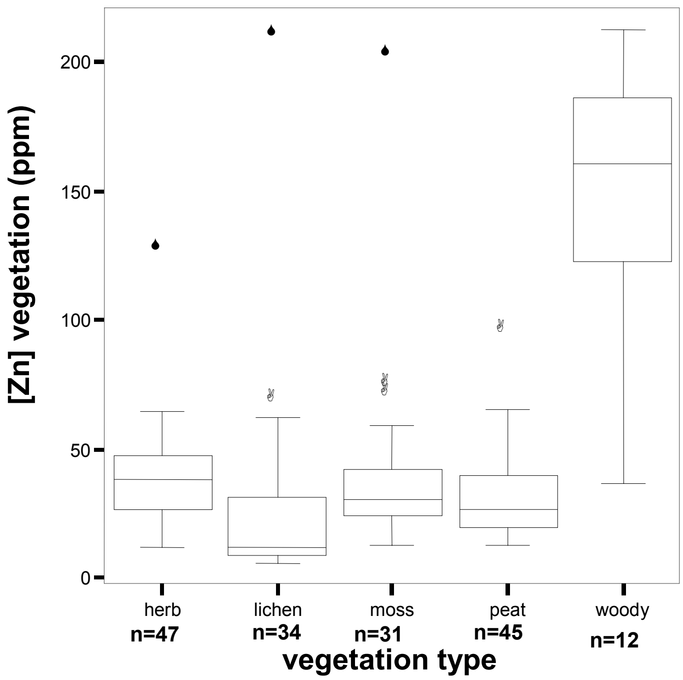

Figure 20. Zinc concentrations in vegetation among plant types.

Overall, peat and moss absorbed arsenic, mercury, lead, selenium, and zinc more than any other plant type, except in woody plants, which absorbed zinc in higher concentration. Peat and moss appear to behave similarly to sediment as they concentrate all five metal types in appreciable levels.

Distribution of sampled vegetation types is shown by region in Figure 21. Peat is the most common plant type collected from the SW, SE and NW quadrants, which are generally in the Y-K Delta lowlands, dominated by wet tundra ecosystem (USGS, 1973). Lichen is the most common plant type collected in the NE quadrant, which contains moist tundra ecosystem. Lichens, however, are commonly found in wet tundra ecosystems where associated plants are lichens, mosses, dwarf birch, and bog cranberries. Moss is ubiquitous in the wet tundra ecosystem, which dominates the SW quadrant. Herbs are abundant in the SE, where a mixture of wet and moist tundra ecosystems occurs within the quadrant.

Again, samples may have been taken largely from the moist tundra ecosystem in the SE quadrant. Woody plants occur only in the SE and NE quadrants, with the largest percentage in the NE quad. The woody plant samples were collected from the moist tundra and upland spruce ecosystems where dwarf shrubs like willow, Labrador tea and blueberry are abundant.

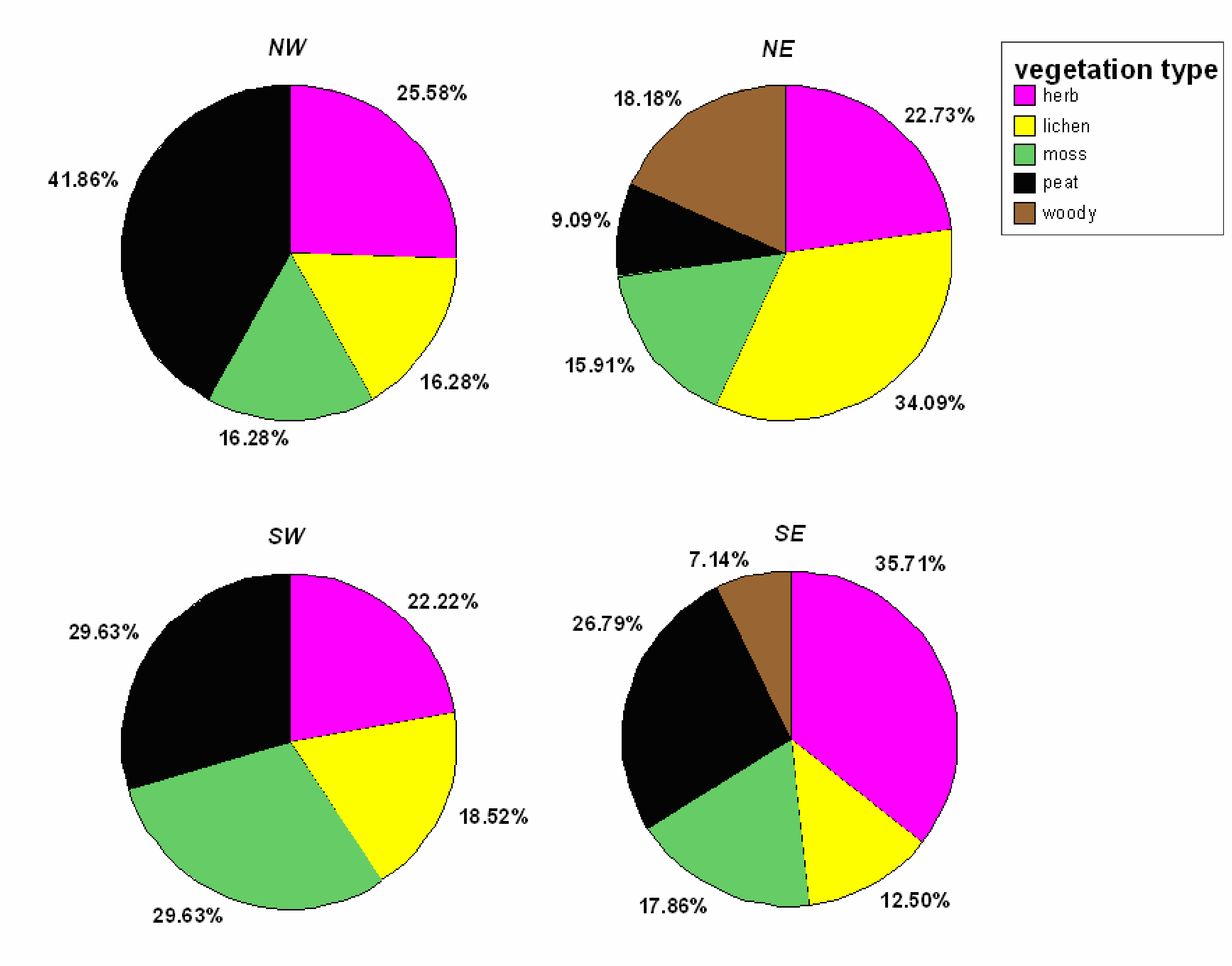

Figure 21. Percentages of vegetation types by quadrant.

Relationships Between Sediment and Vegetation Concentrations

Mercury. Mercury concentration in vegetation shows a complex relationship with mercury concentration in sediment (Figure 22). For samples with mercury concentration in sediment ≤ 0.1 ppm (100 ppb), it appears that there is a positive correlation between mercury in vegetation and sediment. In contrast, at sediment mercury concentration greater than 0.1 ppm, the relationship appears negative. Overall, the correlation between mercury in vegetation and in sediment was close to zero (r = .023) and not significantly different from zero (p = .385).

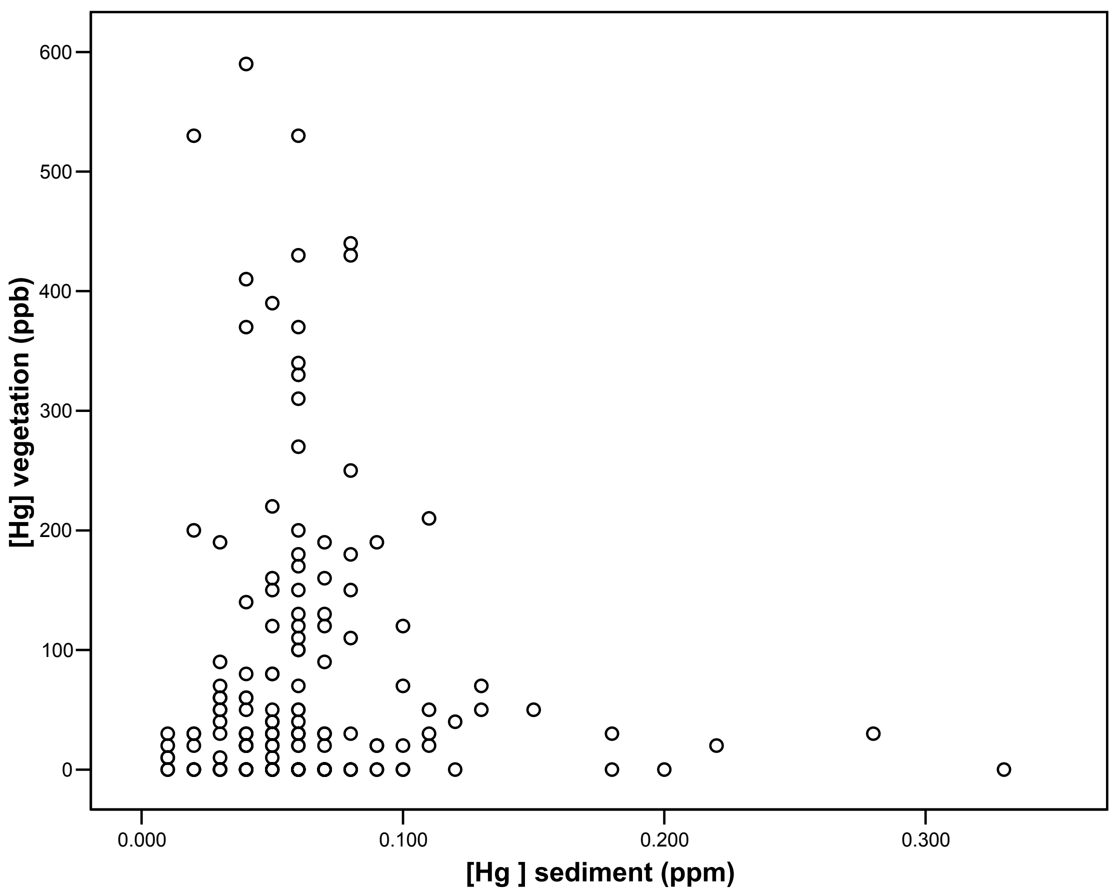

Figure 22. Correlation between mercury in vegetation and sediment.

Arsenic. The concentration of arsenic in vegetation showed a weak, positive (r = .210*) and significant (p = .041) correlation with the concentration of arsenic in sediment (Figure 23). For arsenic in sediment concentrations between 10 ppm and 20 ppm, where most data points lie, it appears that there is a slightly higher positive correlation.

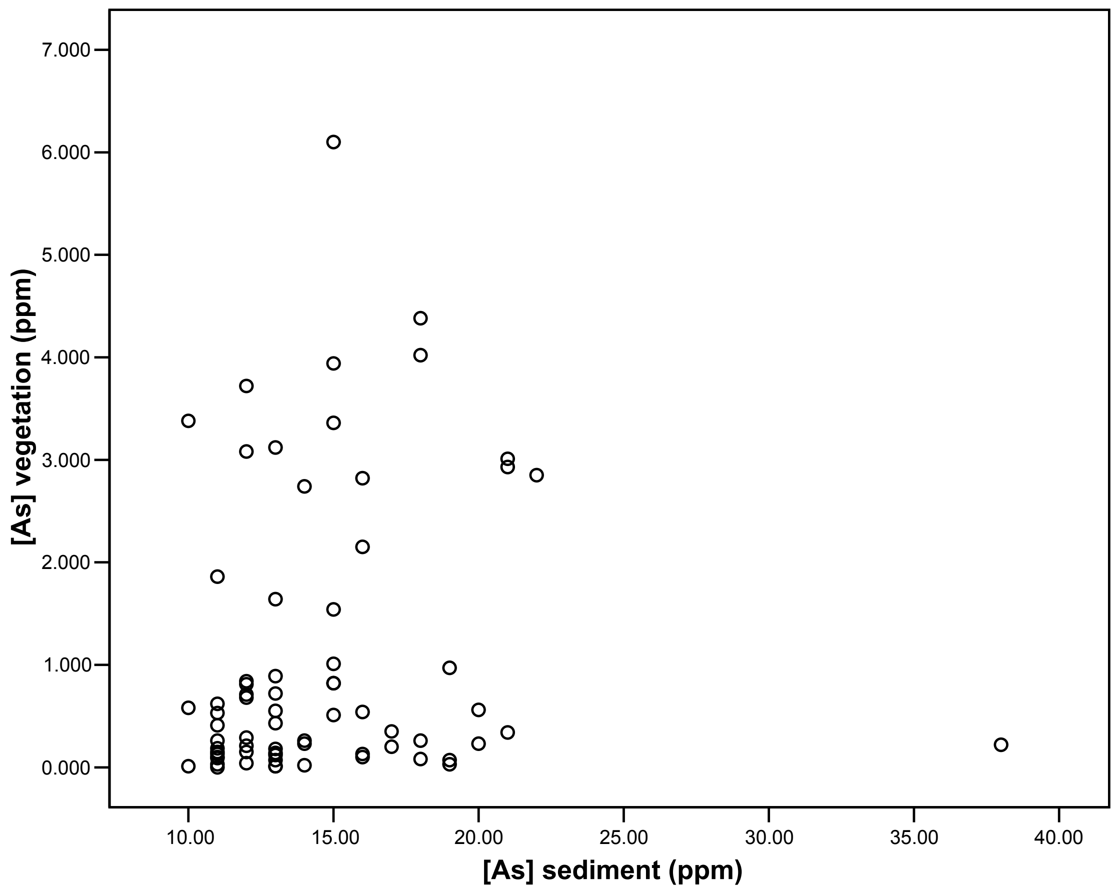

Figure 23. Correlation between arsenic in vegetation and sediment.

Lead. Lead concentration in vegetation also shows a complex relationship with lead in sediment (Figure 24). For lead in sediment ≤ 15 ppm, there is a positive correlation. For lead greater than 15 ppm, the relationship appears negative. Overall, the correlation between lead in sediment and lead in vegetation was close to zero (r = .024), not significantly different from zero (p = .378).

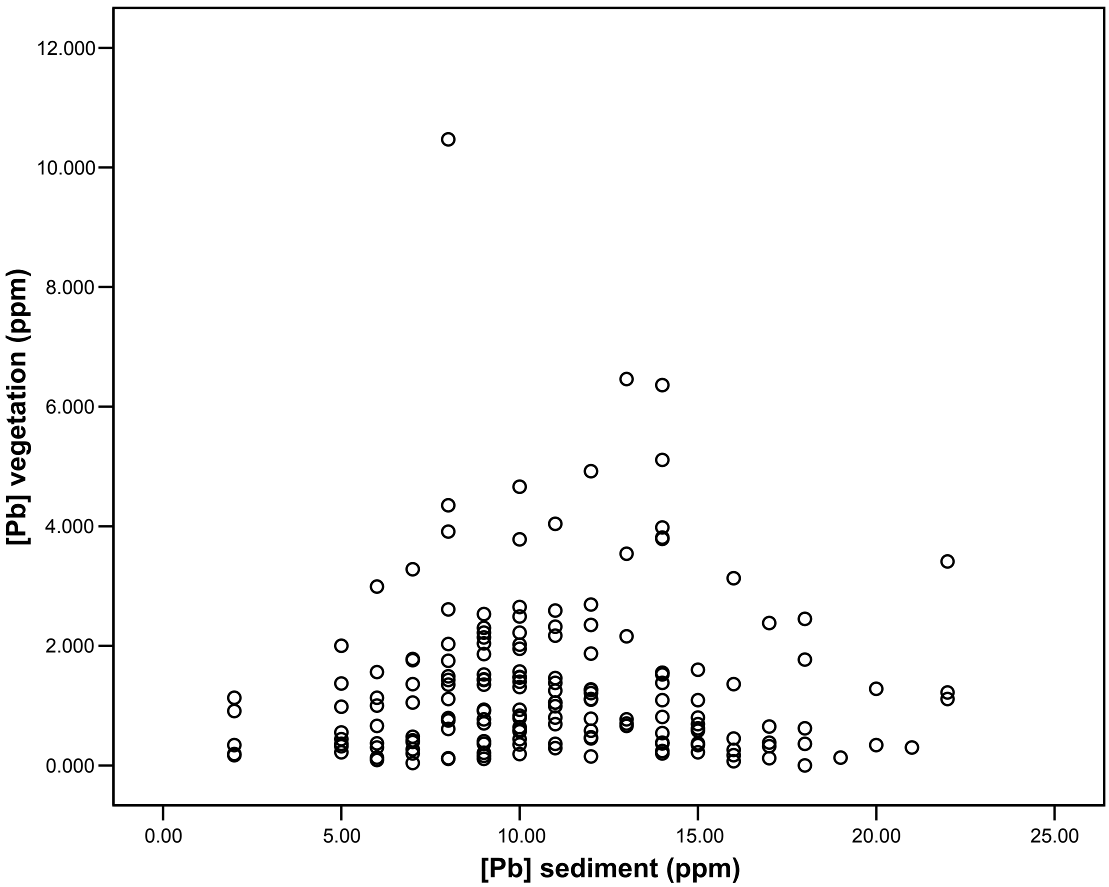

Figure 24. Correlation between lead in vegetation and sediment.

Selenium. Selenium concentration in vegetation shows a positive relationship with selenium in sediment when selenium in sediment $\leq$ .9 ppm (Figure 25). The correlation between selenium in vegetation and sediment is positive (r = .257**), and significantly different from zero (p = .001). For selenium concentration up to .9 ppm in sediment, there appears to be a gradual uptake of selenium in vegetation, from 0 ppm up to .2 ppm. In what appears to be another population of scattered samples, it appears that vegetation is absorbing selenium in soil up to 1.0 ppm, however, uptake decreases above this value.

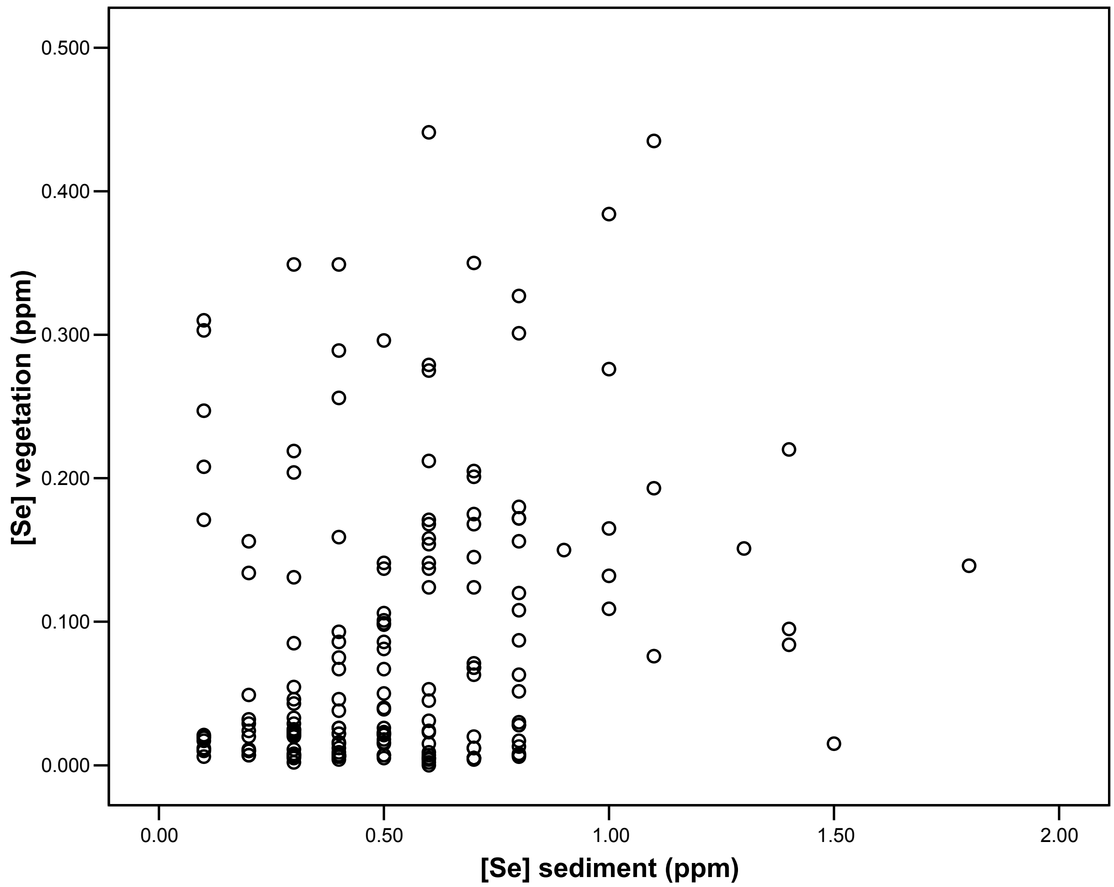

Figure 25. Correlation between selenium in vegetation and sediment.

Zinc. Zinc concentration in vegetation has no apparent relationship with zinc in sediment (Figure 26). The data points for zinc concentrations in sediment fall between 20 and 140 ppm and generally have no corresponding value in vegetation. The majority of the vegetation samples are concentrating up to 60 ppm zinc. Some vegetation samples appear to be absorbing high concentrations of zinc, although corresponding zinc concentrations in sediment are lower. The correlation between zinc in sediment and zinc in vegetation was slightly negative (r = -.010), however, not significantly different from zero (p = .449).

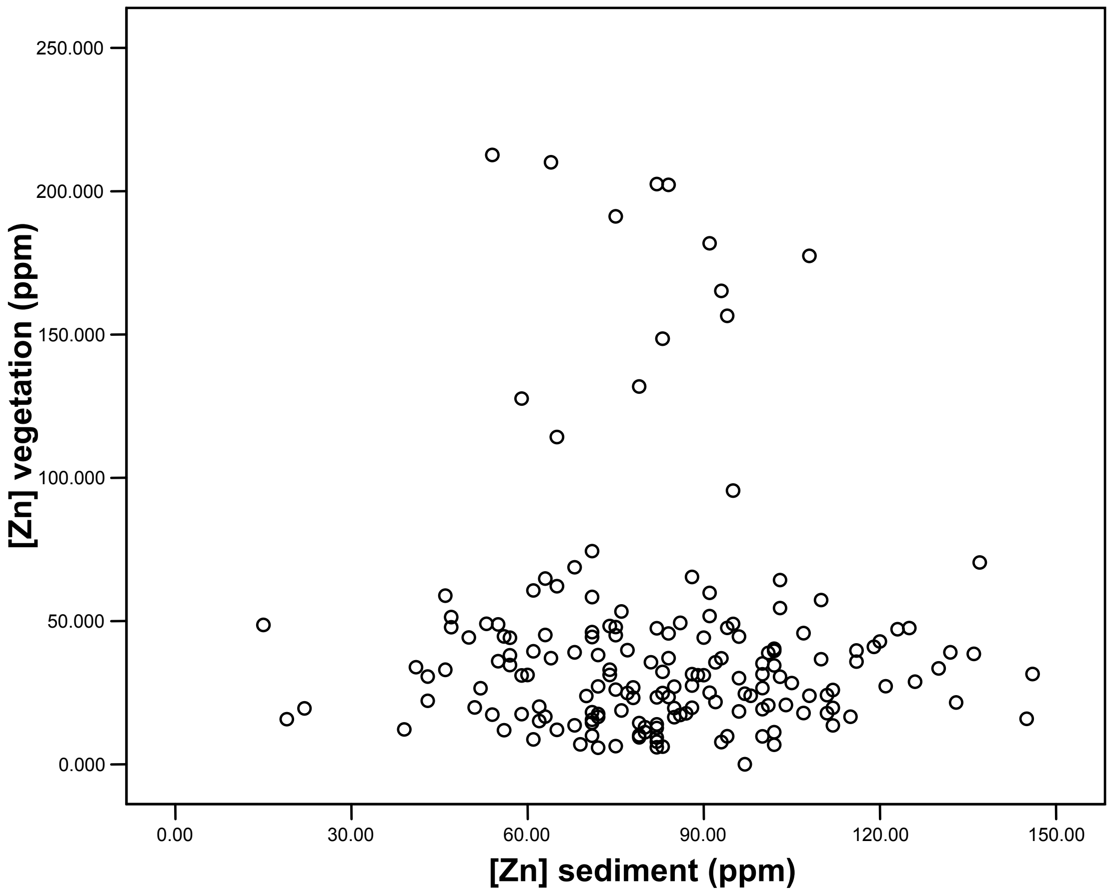

Figure 26. Correlation between zinc in vegetation and sediment.

Lead-Zinc. The concentration of zinc in sediment had a positive relationship with lead in the sediment (Figure 27). Overall, the correlation between zinc in sediment and lead in sediment was slightly positive (r = .393**) and significantly different from zero (p = .001). These data indicate that there is a positive correlation between zinc in sediment and lead in sediment.

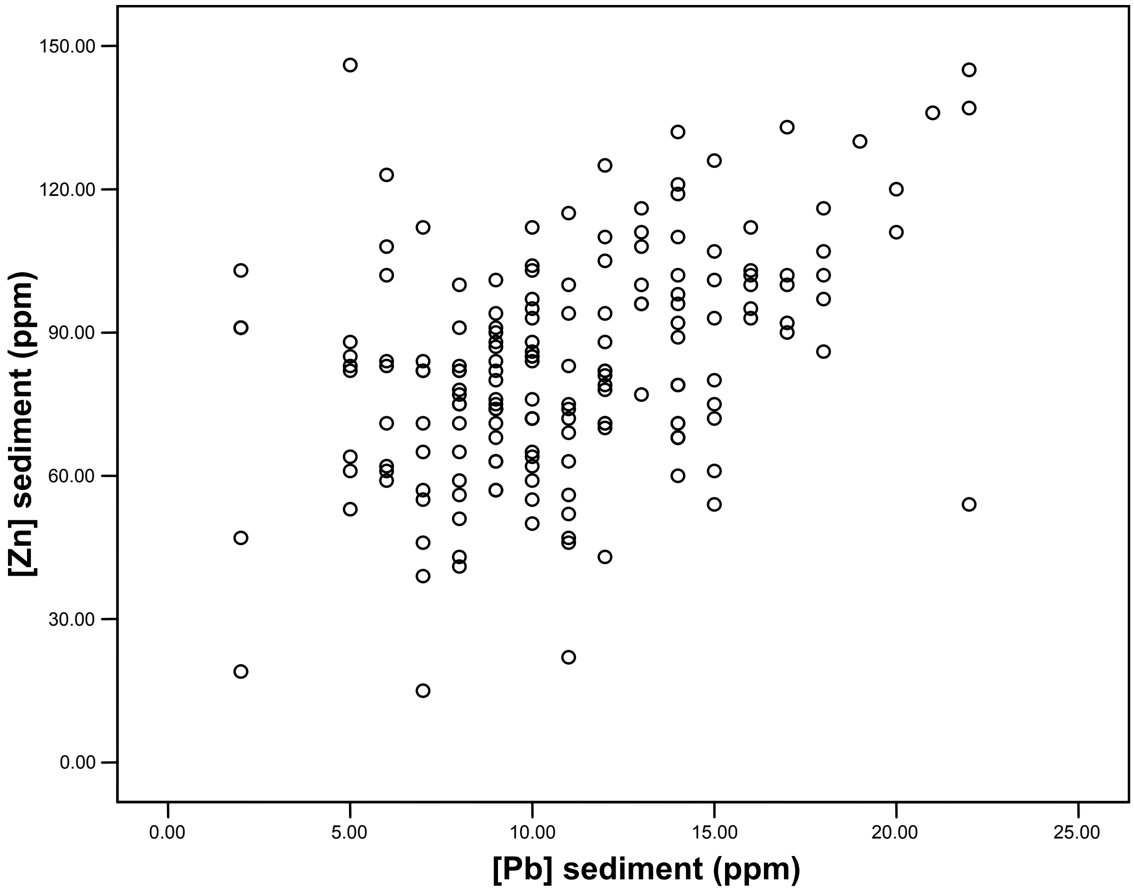

Figure 27. Correlation between zinc in sediment and lead in sediment.

These scatterplots of metals in sediment and vegetation show that at $\leq$ .1 ppm mercury concentration in sediment, mercury in vegetation and sediment show positive correlation. Between 10 ppm and 20 ppm sediment, there is a weak positive correlation between arsenic in vegetation and sediment. At $\leq$ 15 ppm lead in sediment, vegetation and sediment show positive correlation. Selenium in vegetation and sediment show positive correlation at $\leq$ .9 ppm selenium concentration in sediment. There was no apparent correlation between zinc in vegetation and sediment. In general, at low levels (Hg: $\leq$ .1 ppm, As: 10 ppm – 20 ppm, Pb: $\leq$ 15 ppm and Se: $\leq$ .9 ppm), there is good correlation between vegetation and sediment chemistry.

Correlation between the selected metals in vegetation and the same metals in sediment among the plant types resulted in a mixture of correlations:

Arsenic. Arsenic concentration in vegetation showed weak positive relationship with arsenic concentration in sediment in moss and peat plant types (Figure 28). Correlation of arsenic in vegetation and sediment were close to zero in the herb (r = .014), lichen (r = .021), and moss (r = .053) plant types, with weak negative correlations in peat (r = -.002) and woody plants (r = -.105). Overall, the correlation between arsenic in vegetation and in sediment was close to zero in all plant types and not significantly different from zero ($p > 0.05$).

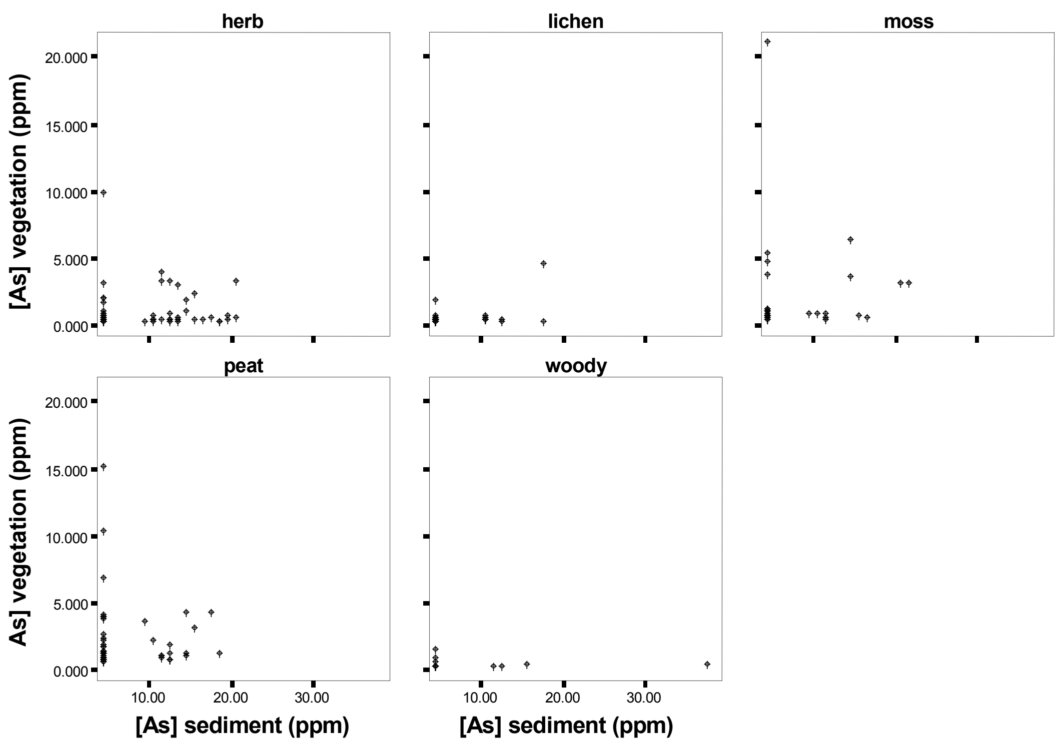

Figure 28. Scatter plot of arsenic concentrations in vegetation and in sediment between plant types.

Mercury. Correlation of mercury concentration in vegetation shows positive correlation in moss and negative correlation in peat with mercury concentration in sediment

(Figure 29). Correlation of mercury in vegetation and sediment were close to zero in herbs (r = .020) and slightly positive in moss (r = .285). Slightly negative correlation occurred in peat (r = -127) and woody plants (r = -154). Negative correlation occurred in the lichen plant (r = -324*) significantly different from zero (p = .035).

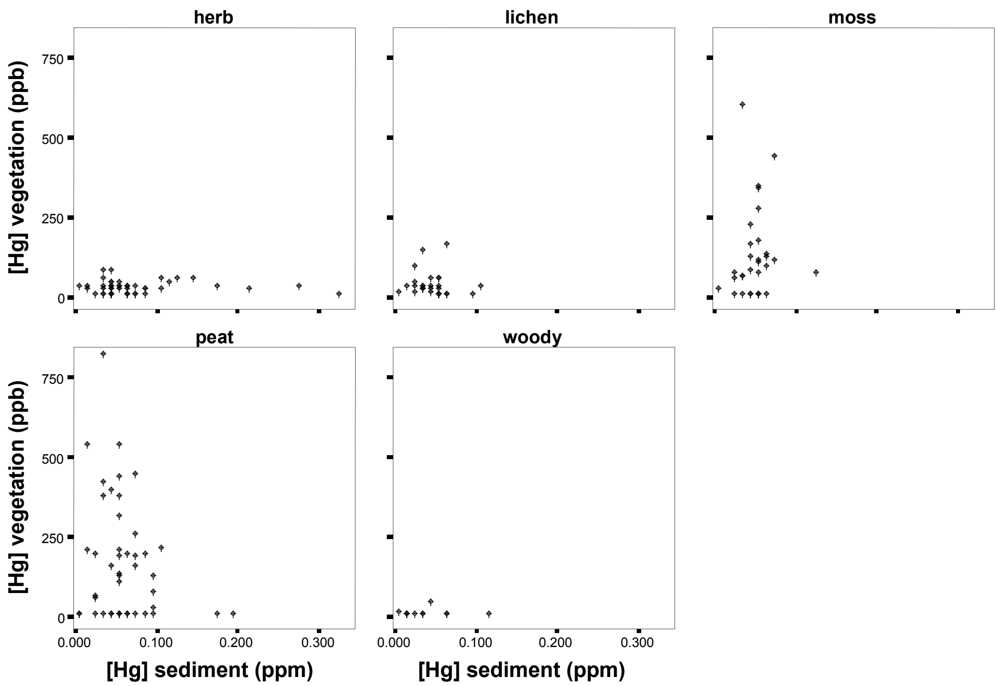

Figure 29. Scatter plot of mercury concentrations in vegetation and in sediment between plant types.

Lead. Lead concentration in vegetation had no apparent relationship with lead in sediment in the plant types (Figure 30). Moss and peat appeared to absorb more lead than the other plant types. Little to no relationship with sediment levels occurred in the woody plants. Overall, the correlation between lead in vegetation and sediment in all plant types was close to zero (r < 1) and not significantly different from zero ($p > 0.05$).

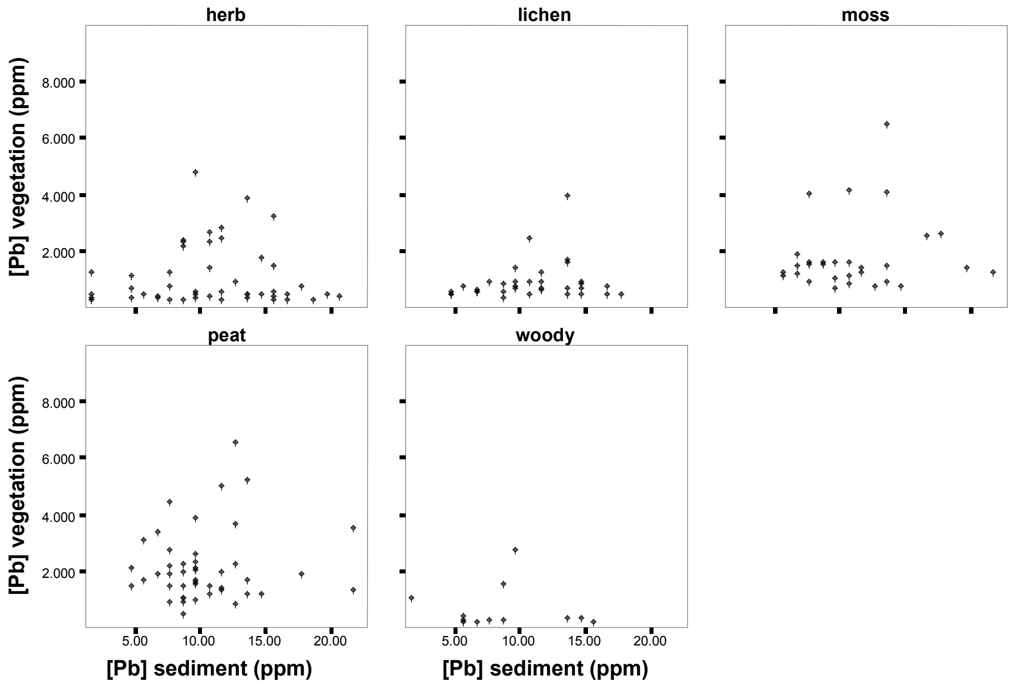

Figure 30. Scatter plot of lead concentrations in vegetation and in sediment between plant types.

Selenium. Selenium concentration in vegetation had no apparent relationship with selenium concentration in sediment for all plant types (Figure 31). A weak positive correlation appeared to occur in moss. Lead in vegetation and in sediment slightly correlated in moss (r = .258) and woody plants (r = .358) and appears to be positive in lichen (r = .357*) and significantly different from zero (p = .019). Negative correlation occurred in herb (r = -.028) and peat (r = -115), however, the correlation was not significantly different from zero in both cases ($p > 0.05$).

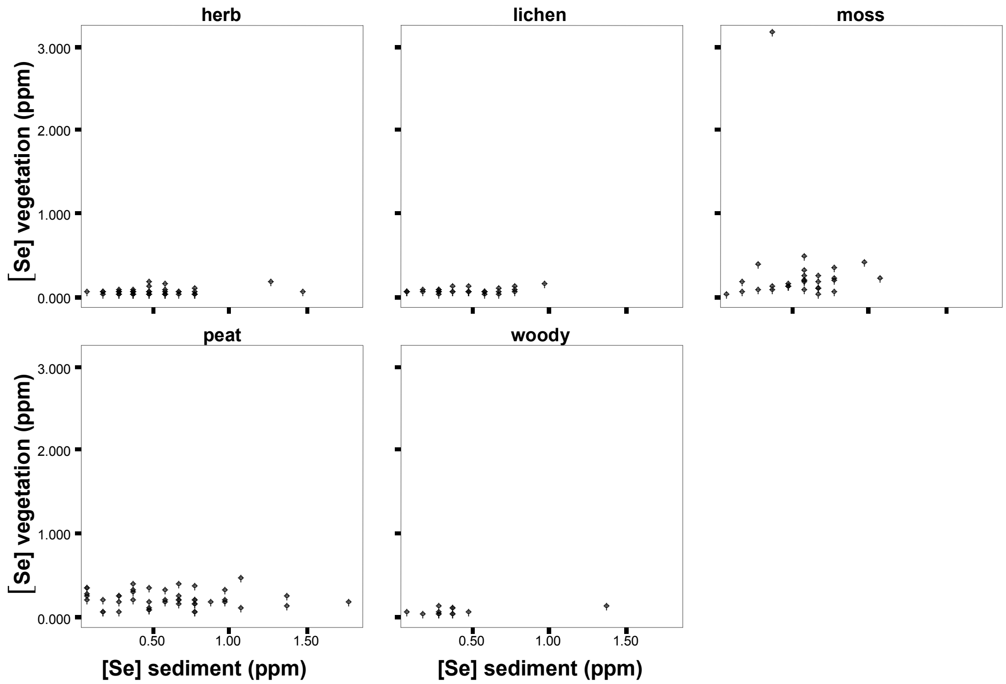

Figure 31. Scatter plot of selenium concentrations in vegetation and in sediment between plant types.

Zinc. Zinc concentration in vegetation had no apparent relationship with zinc in sediment among the plant types, except for woody plants. It appears that there is a slightly positive correlation in woody plants between 50.0 ppm and 100.0 ppm (Figure 32). Correlation of zinc in vegetation and in sediment was negative in herb (r = -.102), lichen (r = -.226), and peat (r = -.119), however, it was not significantly different from zero ($p > 0.05$). Correlations in moss and woody plants were slightly positive, however, not significantly different from zero ($p > 0.05$).

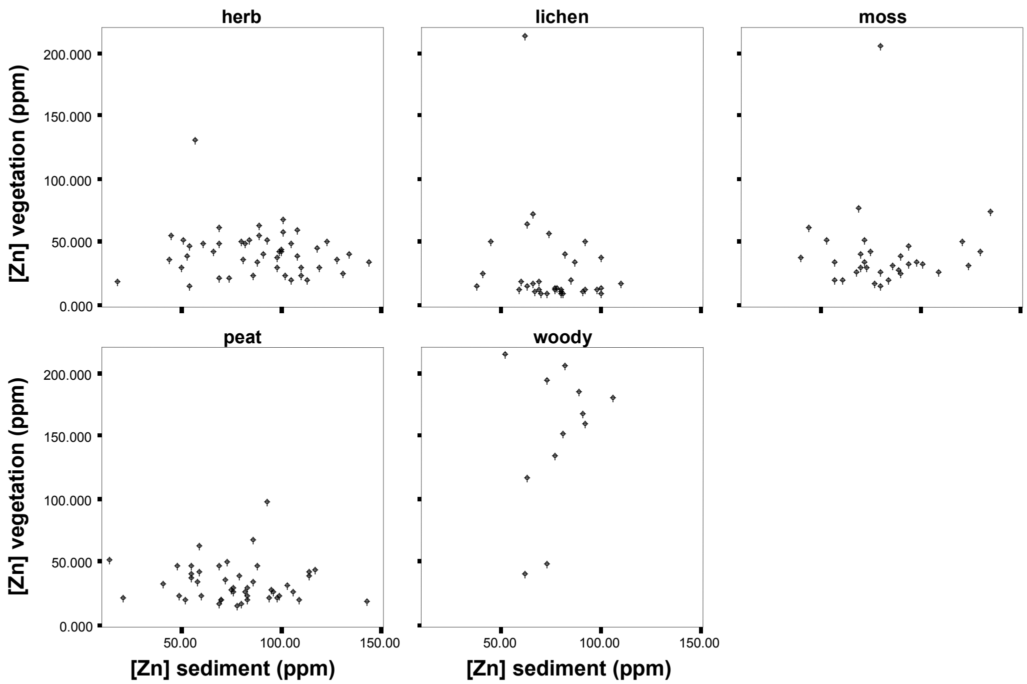

Figure 32. Scatter plot of zinc concentrations in vegetation and in sediment between plant types.

In general, correlation of arsenic in vegetation and in sediment had a positive relationship in all plant types. Correlation of mercury and selenium in vegetation had positive relationships with the same metals in sediment for lichen plants. Lead in vegetation and in sediment showed no correlation for all plant types. And, although it appears that zinc in vegetation had no correlation with zinc in sediment, high concentrations of zinc in vegetation occurred in woody plants.

Results show that lead concentration in vegetation had a positive relationship with zinc concentration in vegetation for lichen (r = .393*) and peat (r = .337*) and was significantly different from zero ($p < 0.05$) in both cases (Figure 33). No correlations were apparent for the metals in herb and moss. Correlation between lead and zinc in vegetation was slightly negative (r = -.231) in woody plants, however it was not significantly different from zero (p = .235). Woody plants appear to be selectively absorbing zinc and a small concentration of lead. Scatter plots of lead and zinc in vegetation for woody plants show that zinc and lead are not being absorbed simultaneously in woody plants.

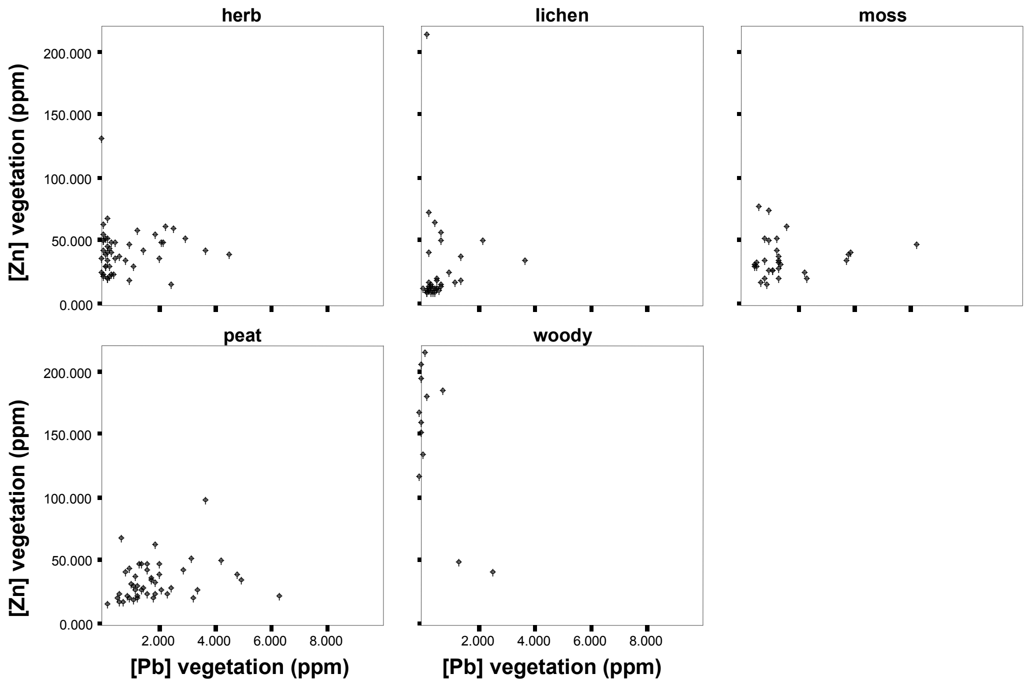

Figure 33. Scatter plot of correlations between lead and zinc in vegetation among plant types.

With respect to zinc and lead in sediment, lead concentrations had a positive relationship with zinc for sediment in all plant types except sediments that support woody plants (Figure 34). The correlation between sediment lead and zinc for woody plants in sediment was slightly negative (r = .352), however not significantly different from zero (p = .131).

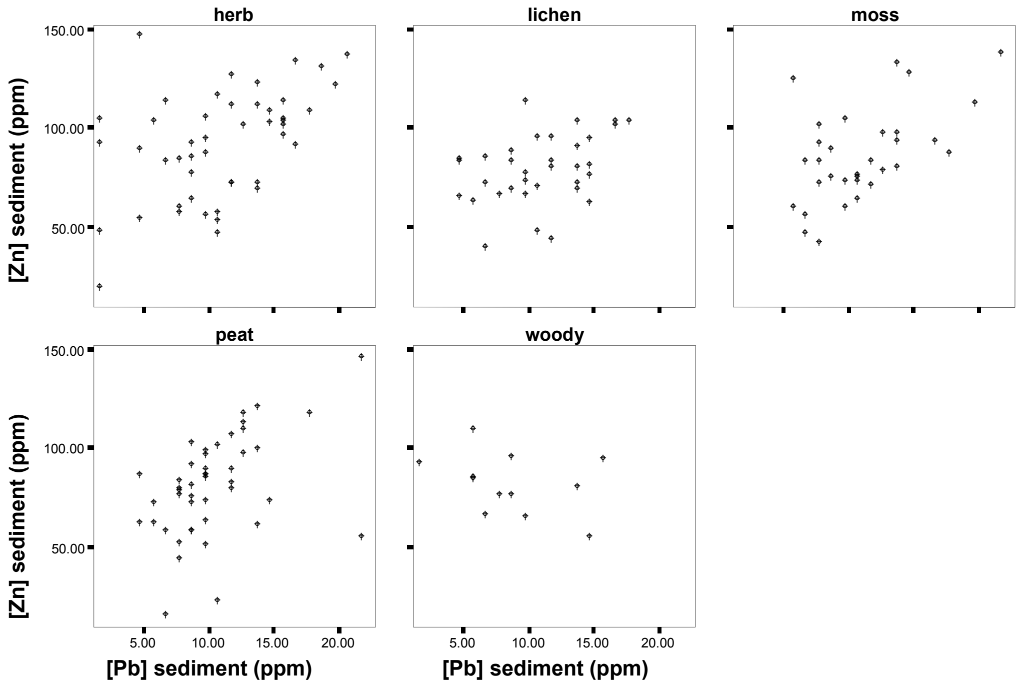

Figure 34. Scatter plot of correlations between lead and zinc in sediment among plant types.

DISCUSSION

Trace metal concentrations in sediment are generally uniform throughout the Y-K Delta. Metal concentrations in vegetation, however, vary across the region. Results show that peat and moss behave like sediments by retaining As, Hg, Pb and Se, while woody plants sequester zinc. In addition, there is a positive, however, low level, correlation between vegetation and sediment chemistry.

With the exception of lead, box plots show that variations of metals in sediment generally did not occur among quadrants. Lack of variation in sediment between geographic quadrants may result from sample collection from primarily one material type that dominates the region. The region is dominated by sedimentary material of Quaternary age consisting of alluvial deposits. Sediment samples collected near igneous rocks and sediment originating from glacial deposits did not cause large differences between the quadrants. Lead concentrations greater than 20 ppm occur in the NW quadrant, approximately 30 kilometers south east of the village of Chevak. This sample location is east of a volcanic center from which eroded material may have been collected. Lead concentrations greater than 20 ppm in sediment also occurred in the NE quadrant near an area of mineral prospects near the village of Marshall.

There was a positive correlation in all quadrants for lead and zinc in sediment. Samples in the SE quadrant were collected in the Kilbuck Mountains, which are of Cretaceous age, and consists of exposed graywacke, mudstone and sandstone deposits eroded from volcanic and intrusive rocks. Samples from the SW quadrant were collected from Nelson Island, where Cretaceous age sedimentary rock is intruded and capped by Quaternary and Tertiary age volcanic rocks. In the NW quadrant, samples were collected north of an intrusive body of Cretaceous age forming a prominent topographic feature, the Askinuk Mountains near the village of Scammon Bay. Other samples with elevated levels of lead and zinc were collected from sites west of old sand dune deposits located south of the village of St. Mary's. Finally, samples from the NE quadrant were collected near mineral prospect sites at Marshall. These findings agree with literature that zinc and lead often occur together in mineralized outcrops (Gough, 1982).

With respect to trace metal variations in vegetation, box plots show that lead, mercury and zinc differed by the greatest amounts among quadrants. Lead concentrations in vegetation were highest in the NW quadrant. Vegetation samples in this quadrant may be absorbing lead from metal-rich sediment originating from rocks of volcanic origin east of Chevak. Zinc concentrations in vegetation were high in the NE quadrant where samples were collected near mineral prospect sites on the upper Yukon River. Mercury concentration levels greater than 20 ppm occurred in the NW quadrant on the edge of volcanic rocks southeast of Chevak and in the NE quadrant near prospect sites on the Yukon River. In the SW quadrant, mercury concentrations of 10-20 ppm occurred on Nelson Island. Box plots show that mercury concentrations in vegetation in the SE quadrant were low relative to the other quadrants. One reason for low metal concentrations in vegetation in the SE quadrant is that the majority of the elements such as arsenic and mercury are bound in sulfide minerals. Mercury studies in the Y-K Delta are localized in the upper Kuskokwim. Gray and others (1994), for example, studied mercury in water, stream sediment and fish tissue in southwest Alaska where the authors found elevated mercury in fish near Mountain Top, a mercury-rich area, where there had been no history of mining production.

Scatter plots of lead and zinc concentrations in vegetation among quadrants show positive correlation in the NW and NE quadrants. Scatter plots of correlations between lead and zinc in vegetation revealed an interesting finding indicating that vegetation in the NE quadrant is sequestering zinc in higher concentrations, while uptaking little lead.

Box plots of the selected metals in vegetation by plant type showed that peat and moss absorbed arsenic, mercury, lead, selenium and zinc to greater extent than any other plant type. Only woody plants absorbed zinc at higher concentrations in the zinc in vegetation test. A study by Berg (2001) shows that peat bogs are excellent long-term sinks for anthropogenic elements, such as carbon, in the atmosphere. Approximately 10% of the carbon fixed in a peat bog is permanently retained as peat deposits (Berg). Similarly, it can be suggested that peat is retaining metals, such as those in this study, absorbed from the environment. This retention of metals in peat explains why peat and moss behave similarly to sediment in retaining the trace metals in this study.

Variations in trace metals in vegetation among quadrants occur because the study area is composed of many ecosystems. Pie charts of the percentages of vegetation type by region show that each vegetation type (peat, moss, lichen, herb, and woody) occurs in the quadrant(s) with the ecosystem that typically contains these vegetation types and their associated plant species. For example, the percentage of peat, by sample, was greatest in the NW and SW quadrants. Mixtures of wet and moist tundra ecosystems occur in these quads, with wet tundra ecosystem dominating. Associated vegetation in the wet tundra ecosystem are: lichens, mosses, dwarf birch, Labrador tea and low bush cranberries. It was also apparent that woody vegetation occurs mainly in the SE and NE quadrants, with the largest percentage in the NE quadrant. Associated woody vegetation in the alpine ecosystem of the NE quadrant are crowberry, bog blueberry and dwarf willows. Similarly, woody vegetation in the upland spruce ecosystem of the NE quadrant in this study are willow, and high and low bush cranberries. These are the vegetation types absorbing zinc in the NE quadrant. It is apparent that vegetation samples were collected from different vegetation communities or ecosystems in the Delta. This is cause for differences between metal concentrations in vegetation among quadrants.

With respect to the relationship between vegetation and sediment metal concentrations, vegetation absorbs trace metals at low sediment concentrations and drops concentration levels at higher sediment levels. For example, vegetation absorbed mercury in soil at concentrations of less than 0.1 ppm. At greater than 0.1 ppm, little mercury was absorbed. Similar occurrences were observed for arsenic and lead.

Correlation between the selected metals in vegetation and the same metals in sediment among vegetation types show that peat and moss absorb arsenic in small concentrations and woody vegetation absorbs large amounts of zinc. Lead, which is one of the more persistent metals, is typically not incorporated in vegetation to any large degree, while other trace metals, such as zinc and selenium, are plant-essential and are readily absorbed by vegetation. In addition, certain species are known accumulators of certain metals; for example, birch (a woody vegetation) accumulates zinc (Verry & Vermette, 1991). This preferential uptake of metals explains why the woody vegetation in the NE quadrant of this study had especially high concentrations of zinc.

Concentrations of the selected metals in vegetation in this study were generally within the reported range values of the same metals in vegetation in baseline studies of vegetation in and near Wrangell-Saint Elias National Park and Preserve, Denali National Park and Preserve, the Fortymile River Watershed in east-central Alaska and the Kenai Peninsula, in Alaska. With the exception of the noted outliers, metal concentrations in vegetation in this study were close to published values and had no unusual high concentrations of any of the selected elements. The analytical data on a dry-weight basis for the selected metals used for statistical analysis in this study are in Appendix D. The following compares trace metal concentrations in vegetation in this study with the same metal concentrations from other studies in Alaska.

Lichen vegetation samples

Mean arsenic concentration in this study was 0.34 ppm and within the range of arsenic values (0.09 – 0.38 ppm) for *Peltigera aphthosa*, a type of lichen, in the Denali National Park. Therefore arsenic values in this study are in agreement with literature values. Literature suggests that arsenic concentration greater than 5.0 ppm in Navel oranges is excessive (Gough, et al., 1982).

Mean lead concentration in lichen was 0.78 ppm, which is in agreement with values in the Denali National Park (0.2 – 3.3 ppm) and Wrangell-Saint Elias (0.4 – 1.1 ppm) studies (Crock, et al., 1993). Plants in mineralized outcrops may absorb high concentrations of lead without showing toxicity symptoms, and shrubs may contain as high as 350.0 ppm lead in ashed samples without visible toxic symptoms (Gough, et al., 1982).

Mercury concentration had a geometric mean of 0.03 ppm in this study, which is in line with mercury concentration ranges in the two National Parks previously mentioned. Observed baseline ranges for mercury in Denali National Park was 0.02 – 0.12 ppm and 0.04 – 0.12 ppm in Wrangell-Saint Elias.

Mean concentration for selenium in lichen in this study was 0.03 ppm. In the Denali National Park study, concentration range of selenium in *Peltigera aphthosa* was < 0.03 – 0.07 ppm.

As for the concentration ranges for zinc in lichen, literature showed a range of 21 – 50 ppm in Wrangell-Saint Elias, and 20 – 95 ppm in Denali National Park. Mean zinc concentration in this study gives 25.21 ppm, well within the reported ranges.

Moss vegetation samples

Once again, element concentration values in this study are compared to concentration levels in vegetation studies in Denali National Park, Kenai Peninsula, and Wrangell-Saint Elias National Park. The following are observed baseline ranges in ppm for element concentrations for *Hylocomium splendens*, a type of moss that may have been included in the vegetation samples identified as moss in this study (Crock, et al., 1992).

	Denali	Kenai Peninsula	Wrangell-Saint Elias
As	0.1 – 5.6	0.05 – 0.36	no data
Hg	< 0.02 – 0.13	0.04 – 0.17	0.04 – 0.12
Pb	0.7 – 4.7	0.6 – 7.0	< 0.6 – 3.2
Se	< 0.03 – 0.62	< 0.03 – 0.18	no data
Zn	22 – 81	16 – 77	24 – 60

Mean concentrations (in ppm) for each of the selected elements in the moss plant type in this study are as follows: As (1.95); Hg (0.12); Pb (1.36); Se (0.24); and Zn (38.80). Studies in northern Germany showed that typical range for arsenic in moss is 0.07 – 0.6

ppm. With respect to lead in moss, studies in Scandinavia show values > 60 – 80 ppm is considered contaminated (Crock, 1992). By comparison, all other trace metal concentrations in this study for moss are in agreement with other studies in Alaska and therefore with published values. Mosses are able to accumulate metals at higher levels than their physiological requirements. Like soil, the metals remain in the plant throughout its lifetime (Crock, 1992).

Peat vegetation samples

Concentration levels for the same metals in peat were similar to values in moss. The following are mean concentrations in ppm for peat in this study: As (2.10); Hg (0.16); Pb (2.04); Se (0.17); and Zn (30.93). It is no surprise that the mean concentration for moss and peat are similar, as peat is generally dead Sphagnum (moss), which comprises a large portion of the vegetation in the Y-K Delta.

Woody vegetation samples

Woody plant concentration values are compared to concentrations in the twigs of Grayleaf Willow (*Salix glauca*) from a study on the Fortymile River Watershed in East-Central Alaska by Crock, et al. (1999). Grayleaf Willow was the most similar plant type to the woody plant type in this study. All concentrations are in ppm.

	Fortymile River	Y-K Delta
As:	< 0.03 - 0.09	0.24
Hg:	< 0.02 – 0.02	0.004
Pb:	0.02 – 0.11	0.52
Se:	no data	0.03
Zn:	71 – 271	146.95

Arsenic and lead values in the woody samples are somewhat higher than those in other parts of Alaska. This could be due to samples collected from or near exposed or eroded mineralized rocks.

As to sources of trace metals in vegetation in this study, there are no industrial processes in the Yukon-Kuskokwim region from which transportable contaminants could originate. The trace metals are likely to originate from underlying weathered minerals in the bedrock and sediment, of which there are generally higher quantities of metals in igneous than in sedimentary rocks (Ross, 1994). Many trace metals are commonly found in sulphide ores, which are prevalent in the upper Kuskokwim mineral belt district. Ross noted that trace metal total concentrations could vary widely in different sediments from different parent materials. Vegetation and sediment samples were collected from the Y-K Delta, a region of mostly alluvial deposits with little exposed bedrock.

Another source of trace metal is aerial deposition of anthropogenic sources. Literature states that a major source of atmospheric arsenic is coal combustion, which does not occur in the region. Lead originates from fuel combustion. It is also known to be transported great distances in the atmosphere. Zinc, mercury and selenium in the atmosphere originate in the emissions of base metal industries, such as the nickel smelting industries in northern Russia. Even if the method may be aerial deposition, Ross (1994) has shown that short distance transport of metals is more common than long distance transport, concentrating metals locally near industrial sources. Evidence of transported pollution has been found in arctic regions and polar sea ice.

CONCLUSIONS

This paper presents the first region-wide study of trace metal concentrations in vegetation and sediment in the Y-K Delta. Metal concentration in sediment and vegetation in geographic quadrants was investigated to determine whether there is variation in metal concentrations among the quadrants and among plant types within the quadrants. The conclusions derived from this study include:

- Vegetation absorbs trace metals at low concentrations. Concentrations of metals in vegetation are well within the ranges of values found in studies of other parts of Alaska. In general, metal concentrations in vegetation in the Y-K Delta are below contamination levels.
- The variation of metal concentration in vegetation in the Y-K Delta is a function of vegetation type. Element concentration levels in vegetation decrease progressively in peat, moss, lichen, herb, and woody vegetation types with peat and moss mimic sediment in retaining higher concentration levels than other vegetation types.
- Vegetation from the Kuskokwim mercury province does not contain unusually high concentrations of mercury. Higher mercury concentrations occur at or near mineral properties such as those near mineral prospects and in areas of exposed bedrock throughout the region.

Diets of Native people include edible vegetation and berries in the region. Trace metals have been known to bioaccumulate to levels that can cause harm in animals higher in the food chain. In his study on traditional foods, Bradley (2002) provides information on amounts of terrestrial mammals harvested annually in the Yukon-Kuskokwim region. Existing studies of contaminants in ungulates are mainly of persistent organic pollutants in Arctic caribou. Currently, no information exists about the biological effects of organic contaminants in caribou or reindeer, however, the levels are lower than those expected to cause harmful effects (AMAP, 1998).

This study shows that vegetation, such as lichen, that caribou and reindeer eat do not contain contaminated levels of trace metals of environmental concern (arsenic, lead and mercury). No information is available for contaminant levels of these trace metals for caribou or reindeer in the Y-K Delta. The toxicity of trace metal accumulation in wildlife in the Y-K Delta is an important topic for future study.

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APPENDICES

Appendix A. Description and locations of vegetation samples analyzed.

Sample No.	Site Description	Latitude	Longitude
BEA2O	Lake bluff with 2' vegetation mat over 6' organic layer and 8' of medium-grained sand to silt with moderate sorting and thin upper oxidation layer.	60.2632	-161.7337
BEA3OB	Gray soil with silt, clay, mud and organics; two vegetation samples: one of green leafy plants and the second of lichen.	60.3920	-161.9340
BEB1O	Meadow on Eek River; brown course sand and silt soil sample; dominated by tall grass and willows; whole plant willow sample.	60.1403	-161.4624
BEB3O	Brittle, gray silt clay with minor organics in sample; tundra vegetation dominated by grass, moss and reindeer lichen; peat and sedge vegetation sample.	60.3755	-161.4457
BEB4O	Brown soil with silt, clay, mud and organics; moss vegetation sample.	60.5415	-161.4684
BEB5O	Grass vegetation sample.	60.7919	-161.6386
BEC1O	Soil contains silt, clay and organics, no well-defined silt layer, large amount of organic material in sample; peat vegetation sample; separate salmon berry sample.	60.0440	-161.3621
BEC3O	Brown soil with silt, clay, mud and organics, silty 2' below vegetation mat; site dominated by moss, lichen and spruce trees, largely peat and some sedge in vegetation sample.	60.4575	-161.1417
BEC4O	Brown soil with sand, silt, clay, mud and organics; grass and berries dominate sample site; peat vegetation sample.	60.5474	-161.3687
BED1O	Brown soil with silt, clay and organics; dry pond bottom with mud cracks, no evident organic layer; tall grass surrounding pond edge; horsetail vegetation sample.	60.1275	-161.0537
BED2O	Sample collected from valley between mountains; brown soil with silt, clay and organics; vegetation sample is a mixture of reindeer lichen, peat and Labrador tea.	60.0317	-161.7491
BED4O	Peat and sedge vegetation sample.	60.6319	-161.0431
BED5O	Kasigluk River; eight-foot channel, soil composite of silty sand from cut bank; site dominated by moss, dwarf birch, small spruce and willow; moss vegetation sample.	60.8092	-161.0412
BED6O	Small bluff next to lake; two-foot thick peat over silty sand; sampled top foot, frozen, inaccessible below; site dominated by dwarf birch, Labrador tea and sedge; grass vegetation sample.	60.8717	-160.8337
BEE1O	Site contains graywacke, micaceous sandstone, tuffaceous sandstone and black shale; soil is gray brown, medium-grained sand and silt; site dominated by willow and grass; moss vegetation sample.	60.0342	-160.5454
BEE2O	Open tundra site; small stream with reddish-brown tan water, cobbles of quartz-feldspar porphyry, graywacke sandstone and greenstone; site dominated by grass and willow; grass vegetation sample.	60.2976	-160.5626
BEE4O	Sloughed bank on small tundra lake; gray fine to medium-grained sand beneath one to two feet of peat; site dominated by tundra tussocks and dwarf birch; dwarf birch vegetation sample.	60.6320	-160.5186
BEE5O	Small lowland stream that drains into Columbia Creek; streambed composed of mud; site dominated by sedge and willow; sedge vegetation sample.	60.6968	-160.7476
BEE6O	Gravel bar below beaver dam; sample is gray-brown coarse sand with very little silt, notable heavy minerals; vegetation dominated by willow, sedge and spruce stands; grass vegetation sample.	60.9390	-160.5314
BEF1O	Small valley stream in Eek mountains; coarse graywacke, polymict siliceous conglomerate, micaceous sandstone; sample is brown gray coarse sand; tundra vegetation of willow and grass; moss vegetation sample.	60.0440	-160.4378
BEF2O	Eek River gravel bar; graywacke, chert pebble conglomerate; sample is gray brown medium coarse sand; river grass and shrub willow on hilly topography; grass vegetation sample.	60.1927	-160.4515
BEF3O	Meadow/mountainous setting; site composed of grass and spruce; grass vegetation sample.	60.4701	-160.4308
BEF4O	Iron oxide stained sand, limonitic muddy sand and silt washed to gray-brown sandy silt; site dominated by grass and willows; grass vegetation sample.	60.6490	-160.1980
BEF5O	Abandoned channel alluvial gravel bar; no water nearby, well-rounded cobbles and pebbles of volcanic origin, meta-sediments, quartz; tundra vegetation dominated by spruce and willows; moss vegetation sample.	60.8001	-160.4614
BEF6O	Fog River; gray silty sand in vegetated riverbank in low tundra; site contains willows along banks; willow vegetation sample.	60.8704	-160.4401
BEG1O	Broad mountain pass in Kwethluk River area; dacite porphyry, graywacke, greenstone; sample of brown gray medium coarse sand, visible heavy minerals; site contains river grass and scrub willow; grass vegetation sample.	60.1608	-160.1407
BEG4O	Moderate hilly river valley; slate, sandstone, shale, greenstone; vegetation consists of sedge and willows; sedge vegetation sample.	60.4969	-159.9956
BEG5O	Area of moderate hills; cobbles of graywacke, slate and micaceous sandstone, all lower greenschist facies; many beaver dam signs; vegetation composed of grass and minor willows; grass vegetation sample.	60.6887	-160.0769
BEG6O	Slate Creek; broad mountain valley; greywacke, green volcanics, volcaniclastics, granite, quartz-feldspar porphyry, trace quartz float; spruce, willow and grass; grass vegetation sample.	60.9596	-159.9655
BEH4O	Mountainous setting; cobbles of metasediments (greenstone, shale, slate) minor mica schist on gravel bar; site vegetation dominated by sedge and willow; sedge vegetation sample.	60.5726	-159.9490
BEH5O	Fisher Creek gravel bar; cobbles of granite porphyry, quartz-feldspar porphyry, graywacke sandstone, quartz vein; site dominated by grass, willow and sparse spruce; grass vegetation sample.	60.8075	-159.6357
BEH6O	Wilhelmina Creek; mountainous area; graywacke sandstone, andesite(?), quartz-feldspar porphyry, shale; site contains grass, willows and sparse spruce; grass vegetation sample.	60.8759	-159.6383
BIB4O	Common wormwood and grass vegetation sample.	60.5383	-164.6459
BIB6O	Marshy area; soil contains silt, clay, mud and organics; collected from 3-4' depth, sediment from 2-3'; grass vegetation sample.	60.8629	-164.4219
BIC1O	Analysis of variance cell; tundra area with low grass; soil contains sand, silt, mud and organics; reindeer lichen and peat vegetation sample.	60.1275	-164.3433
BIC2O	Water-saturated peat bog; difficult to land and find sampling location; sample from lake bank; silty clay mud in sample; site dominated by moss, tundra and marsh; reindeer lichen vegetation sample.	60.1762	-164.3160
BIC3O	Moss vegetation sample.	60.3366	-164.3433
BIC4O	Muddy creek bank; soil contains silt, clay, mud and organics; site dominated by high grass; sedge vegetation sample.	60.5401	-164.3523
BIC5AOV1O	Basalt dome at edge of bay; organic rich mud; frozen ground at 1.5'; site dominated by moss, lichen and tundra; reindeer lichen and peat vegetation sample.	60.7240	-164.2410
BIC5O	Fine sand from 6' bank, soil contains sand, silt, clay, mud and organics; site dominated by moss, lichen and tundra; cotton grass and crowberry vegetation sample.	60.7343	-164.0571
BIC6O	Gray soil contains sand, silt, clay, mud and organics; rye grass and saw grass vegetation at sample site; vegetation sample of grass and sedge.	60.8738	-164.1256
BID1AOV1O	Vegetation sample of moss and some sedge.	60.1343	-163.8480
BID1AOV2O	Reindeer lichen and moss vegetation sample.	60.1343	-163.8480

Sample No.	Site Description	Latitude	Longitude
BID1O	Cotton grass and reindeer lichen vegetation sample.	60.1343	-163.8480
BID3O	Moss vegetation sample.	60.3817	-163.8430
BID4O	Moss vegetation sample.	60.5457	-163.8755
BID5O	Sample from Baird Inlet; site dominated by tundra, moss and lichen; peat vegetation sample.	60.7859	-163.9204
BID6O	Sample collected from bank of a lake on a 6' bluff; brown soil mixture of silt, clay, mud, organics and peat; Labrador tea and reindeer lichen vegetation sample.	60.8745	-163.8685
BIE1O	Reindeer lichen vegetation sample.	60.1343	-163.7570
BIE2O	Moss vegetation sample.	60.3009	-163.7570
BIE6O	Gray soil mixture of silt, clay, mud and organics; peat and sedge vegetation sample.	60.8639	-163.5773
BIF1O	Marsh and tundra setting; gray soil contains silt, clay, mud and organics, large amount of organic material in sample; vegetation sample largely of moss and some Labrador tea and sedge.	60.0333	-163.2343
BIF2O	Gray soil mixture of silt, clay, mud and organics; site dominated by small brush and marsh; vegetation sample largely of peat, and some common wormwood, grass and horsetails.	60.2958	-163.4581
BIF3O	Gray soil contains sand, silt, clay, mud and organics; peat vegetation sample.	60.4622	-163.2557
BIF5O	Gray soil contains silt, clay, mud and organics; moss vegetation sample.	60.8041	-163.2488
BIF6O	Typical lake shoreline breach in peat terrace; brown soil contains silt, clay, mud and organics; site consists of peat, grass and moss; peat vegetation sample.	60.9552	-163.1974
BIG1O	Brown soil contains silt, clay, mud and organics; site composed of grass and berries; large amount of organic material in soil sample; vegetation sample of peat and some reindeer lichen.	60.0334	-163.1418
BIG2OB	Organic rich silt clay material with small amount of sand; site composed of grass, moss and lichen; vegetation sample largely of red bearberry and some reindeer lichen and moss.	60.2040	-162.9280
BIG3OB	Brown soil contains silt, clay, mud and organics; vegetation site composed of low grass and tundra; vegetation sample largely of reindeer lichen and some Labrador tea.	60.4680	-162.9390
BIG4O	Brown soil contains silt, clay, mud and organics; site dominated by grass, moss and tundra; vegetation sample largely of moss and some reindeer lichen, Labrador tea and cotton grass.	60.6291	-162.9313
BIG5O	Brown soil contains silt, clay, mud and organics; vegetation sample largely of moss and reindeer lichen with minor Labrador tea.	60.7082	-163.1599
BIH1AOV2O	Gray soil contains silt, clay, mud and organics; site composed of grass marsh; grass vegetation sample.	60.0211	-162.7552
BIH1O	Brown soil contains silt, clay, mud and organics; Analysis of variance cell; two organic samples, one of moss, lichen, salmon berries and Labrador tea; site dominated by grass, moss, lichen and tundra; second vegetation sample of cloudberries, reindeer lichen and Labrador tea.	60.0376	-162.8530
BIH2O	Brown soil contains silt, clay, mud and organics; site dominated by moss, lichen and tundra; vegetation sample largely of moss and some reindeer lichen and dwarf birch.	60.2135	-162.8614
BIH4O	Marshy peat bog, over old lakebed; little sand and sediment; peat vegetation sample.	60.5360	-162.6584
BIH5O	Gray soil contains silt, clay, mud and organics; site dominated by grass, moss and tundra; peat vegetation sample.	60.7093	-162.8420
BII2O	Brown soil contains silt, clay, mud and organics; water inundated marsh from surface to 1'; moss vegetation sample.	60.2923	-162.3537
BII3O	Brown soil mixture of silt, clay, mud and organics; marshy site is dominated by tall grass; large amount of organic material in bulk sediment sample; vegetation consists of grass and flowers; vegetation sample is composed largely of horsetail and some reed.	60.4605	-162.5621
BII5O	Soil is brown with sand, silt, clay and organics; site dominated by grass, moss, berries and tundra; vegetation sample is largely peat with some reindeer lichen.	60.7481	-162.5350
BII6O	Brown soil with sand, silt, clay, mud and organics, west of Kasigluk Lake; sand deposits, including dunes, visible along numerous lake shorelines and trails; site contains moss and lichen; vegetation sample consists of peat and some grass.	60.8670	-162.5471
BIJ1O	Brown soil contains silt, clay, mud and organics; tundra vegetation dominated by grass and moss; vegetation sample largely of crowberries and some reindeer lichen.	60.0487	-162.0372
BIJ4O	Gray soil with silt, clay and mud; vegetation sample is largely of peat with some grass and sedge.	60.6449	-162.2397
BIJ5O	Soil with silt, clay and organics; large amount of organic material in sediment; vegetation sample is largely of peat with some reindeer lichen.	60.6984	-162.0881
BLH1O	Gray soil with sand, silt, mud and organics; site dominated by marsh and grass; silty organic unit under 2-3’ layer of loosely compacted peat; soil sample from edge of stream bank; vegetation sample of peat and some sedge.	62.0335	-165.3832
GBA6O	Brown soil with silt, clay, mud and organics; vegetation sample mostly of moss with some cotton grass.	59.8681	-161.9778
GBB4O	Meadow setting; willow vegetation sample.	59.6382	-161.4664
GBB6O	Sand and silt beneath 5' tundra vegetation; brown soil with sand, silt and organics; vegetation sample of moss, peat and Labrador tea.	59.8704	-161.4302
GBC5O	Brown soil contains silt, clay, mud and organics; site of grass and moss vegetation, vegetation sample largely of sedge with some reindeer lichen and cotton grass.	59.6970	-161.3599
GBC6O	Gravel and coarse sand from foothills to mountains, to the east possible ancient river channel; brown soil contains gravel, coarse sand, sand and silt; vegetation includes moss and lichen; vegetation sample largely of peat and some reindeer lichen.	59.8434	-161.1500
HBF4O	Grass vegetation sample.	61.5399	-166.0524
HBG3O	Poorly drained flat terrain; gray soil contains silt, clay, mud and organics; organic mud material dominates in swampy marsh; grab soil sample of mud and organics; sedge vegetation sample.	61.3556	-165.7027
HBG4O	Muskeg and wet tundra with thin vegetation mat; reddish brown soil with sand and silt; lichen, dwarf birch, crowberry: vegetation sample largely of moss and some reindeer lichen and crowberry.	62.5297	-165.7073
HBH5O	Grassy marsh, typical lakeside peat ledge; gray soil with silt, clay and mud; peat, reindeer lichen, salmon berry and crowberry vegetation sample.	61.7022	-165.3950
HBI1O	Gray soil with silt, clay, mud and organics from inter-tidal zone; grass vegetation sample.	61.0601	-165.0299
HBI4O	Small pond bank with grass and small brush; brown soil with sand, silt, mud and organics; peat vegetation sample.	61.5373	-165.0594
HBI6O	Lake edge exposure; black brown soil contains silt, clay and mud; vegetation sample largely of peat and some cotton grass.	61.9608	-165.3045
KBG6O	Brown soil with silt, clay, mud and organics; site consist of tall grass and berries; vegetation sample is largely of peat with some grass, sedge and crowberries.	59.9558	-163.1386

Sample No.	Site Description	Latitude	Longitude
KBH6O	Brown soil with silt, clay, mud and organics; site consists of grassy marsh and tundra; peat vegetation sample.	59.9992	-162.8482
KBJ6O	Marsh with high grass; brown soil with silt, clay, mud and organics; vegetation sample largely of marsh grass and some fescue.	59.9626	-162.0508
KWA2O	Tundra; gray soil with silt, mud and organics; grass, moss and peat vegetation sample.	62.2930	-164.7189
KWA5O	River bank. Gray soil with sand, silt and mud; visible heavy minerals in sediment; 2 bulk sample bags of green grass collected from banks and peat vegetation sample.	62.7917	-164.7346
KWB2AOV2O	Brown sand with silt, mud and organics; sample site composed of grass and small brush; peat vegetation sample.	62.2523	-164.3279
KWD2O	Marsh area; brown soil with sand, silt, mud and organics; soil sample from bottom of dry pond; vegetation sample largely of peat with some grass.	62.2980	-163.7470
KWD4O	Lake bank non-composite grab sample, 2 bulk samples collected, 2-3 alternating layers of clay and organic rich units; peat vegetation sample.	62.5387	-163.7248
KWD5O	Lake shore with lichen and moss; organic rich silty clay grab sample; vegetation; peat vegetation sample.	62.7948	-163.7155
KWE1O1/2	Meadow setting, small mound near lake; brown gray muddy silt; moss, grass, dwarf birch and dwarf willows; grass vegetation sample.	62.0360	-163.5303
KWF1O	Lakeside slump lowland tundra setting; gray brown silt; site dominated by moss, berries, low alder and tundra; moss vegetation sample.	62.0515	-163.0098
KWF2O	Gravel layer on silty sand (flood gravel?); cobbles of graywacke, sandstone, and trace metavolcanics. Gold visible in pan concentrate; site dominated by willow and grass; grass vegetation sample.	62.2149	-163.2561
KWG2O	Small tributary to Andreafsky River; cobbles of wackestone, sandstone, volcanics and rhyolite porphyry; fines contain heavy minerals; site dominated by willow and grass; grass vegetation sample.	62.3077	-162.7841
KWH1O	Dry lake sediment with gray green soil in marsh setting; site consists of pine, alder, grass and shrub vegetation; grass vegetation sample.	62.1328	-162.4874
KWH2O	Beaver dams throughout, poor stream sediments, sloughed bank, steeply cut channel; site vegetation dominated by spruce, alder and grass; grass vegetation sample.	62.1844	-162.5902
KWI1O	Lakeside slump site, grayish brown soil; site dominated by berry, moss and scrub pine trees, moss vegetation sample.	62.1481	-162.2690
KWI2O	Lakeside slump site with reddish brown soil; site consists of berries and moss; moss vegetation sample.	62.2942	-162.0355
MAA1O	Marsh and tundra setting; brown soil with silt, clay, mud and organics; organic rich material; peat vegetation sample.	61.0326	-164.7026
MAA2O	Gray soil with silt, clay, mud and organics; vegetation sample largely of moss and some cloudberries.	61.2977	-164.7124
MAA3O	Frozen ground at 2.5’, little sediment in this area, vegetation mat over permafrost layer, gray soil with silt, clay, mud and organics; site dominated by grass and tundra; moss vegetation sample.	61.3777	-164.7353
MAA4O	Sample from small lake bank; organic rich gray brown silty material; tundra setting, largely peat and some reindeer lichen vegetation sample.	61.6373	-164.9471
MAA6O	2' gray clay, medium brown lake sediment, silty clay; tundra setting, peat vegetation sample.	61.9693	-164.9458
MAB1O	Gray soil with silt, clay, mud and organics; organic rich bulk sample; site dominated by grass and tundra; peat vegetation sample.	61.0386	-164.6149
MAB3AOV1O	Highland setting, grab sample from river bank sediment; gray soil contains silt, clay, mud and organics; moss vegetation sample.	61.4017	-164.5403
MAB3AOV2O	Highland setting, grab sample river bank sediment; gray soil contains silt, clay, mud and organics; peat with sedge vegetation sample.	61.4017	-164.5403
MAB6O	Lake shore soil sample; brownish gray silty clay, light brown, brown organics 5 ft thick, top 1 ft sampled; vegetation sample consists of reindeer lichen, moss, Labrador tea with some sedge and low-bush cranberry.	61.8782	-164.6378
MAC1O	Gray soil from grass and tundra setting contains silt, clay, mud and organics; vegetation sample largely of peat with some Labrador tea, reindeer lichen and low-bush cranberries.	61.0282	-164.2698
MAC2O	Gray soil from marsh and tundra setting contains silt, clay, mud and organics; vegetation sample consists largely of moss and reindeer lichen with some Labrador tea, dwarf birch and leafy lichen.	61.2858	-164.2890
MAC3AOV1O	Organic rich brown silty clay near outer boundary of marsh and tundra setting; moss vegetation sample with some reindeer lichen.	61.3484	-164.3398
MAC3AOV2O	Frozen ground beneath organic layer near edge of marsh and tundra setting; black brown soil with silt, clay, mud and organics; peat and some cotton grass vegetation sample.	61.3484	-164.3398
MAC4O	Lowland tundra setting proximal to volcanic cones; frozen reddish silty mud lake sediment; grass vegetation sample.	61.5178	-164.0616
MAC5O	Brown gray silt and silty mud with about 5 percent organics in a meadow setting; vegetation dominated by grass, birch, berries and caribou moss.	61.7085	-164.0523
MAC6O	Small mound in tundra setting; brown gray silty muck; vegetation dominated by birch, berry, grass and willows; grass vegetation sample.	61.8485	-164.0666
MAD2O	Organic rich sediment material, from 6 ft bluff at large Aropuk Lake; brown soil with silt, clay, mud and organics; grass and tundra vegetation at site, peat vegetation sample.	61.2010	-163.6921
MAD3O	Dry lake near many small volcanic cones; lake sediment, upper foot sampled, reddish brown soil; berry, moss and tundra grass; moss vegetation sample.	61.4096	-163.9943
MAD4O	Meadow setting; brown gray silt with about 10 percent organics; berry, birch and moss dominate site; caribou moss vegetation sample.	61.6287	-163.6858
MAD5O	Tundra lake setting; brown gray muddy silt with about 5 percent organics; site dominated by tundra vegetation mat with caribou moss, dwarf birch and grass; caribou moss vegetation sample.	61.7973	-163.9483
MAD6O	Brown silty muck next to small lake, meadow setting; vegetation dominated by moss, grass and birch; moss vegetation type.	61.8660	-163.7676
MAE1O	Brown soil with silt, mud and organics, silty unit in lake bank; grass and tundra dominate site; peat vegetation sample.	61.1441	-163.6103
MAE3O	Organic rich sediment on Aropuk Lake shore; chocolate brown muddy silt; tundra setting; caribou moss vegetation sample.	61.1824	-163.6348
MAE5O	Brown gray muddy silt; site dominated by willow, birch, grass, berries and mosquitoes; grass vegetation sample.	61.7967	-163.3860
MAE6O	Low tundra lake setting; brown to gray brown muddy silt with about 15 percent organics; vegetation site dominated by moss, birch, willow and grass; grass vegetation sample.	61.9777	-163.6197
MAF3O	Brown soil with sand, silt, clay, mud and organics; lake sediment, dry lake margin; mare’s tail vegetation sample.		
MAF4O	Tundra lake shore; dark brown muddy silt with about 15 percent organics; vegetation at site consists of grass, tundra and marsh; grass vegetation sample.	61.6274	-163.0276
MAF5O	Lake-dotted lowland; brown silt to muddy silt with about 10 percent organics from 15 ft bluff next to lake; site dominated by grass, willow and birch; grass vegetation sample.	61.7978	-163.0730
MAG4O	Hill next to tundra lake; dark brown muddy silt with about 20 percent organics; vegetation consists of tundra grass, dwarf birch and marsh; moss vegetation sample.	61.6494	-162.9211
MAG5O	Hillside slope; sample from mountainous setting; light brown tan silt clay under 1 ft of peat, soil frozen beneath 1 ft depth; alder and moss at vegetation site; moss vegetation sample.	61.7830	-162.7236
MAG6O	Yukon River floodplain; silty sandy gray clay from beneath peat; salmon berries, moss and alder at vegetation site; moss vegetation sample.	61.8466	-162.6925
MAH2O	Break in peat/moss adjacent to lake, gray brown soil contains silt, clay, mud and organics; peat vegetation sample.	61.1891	-162.5721
MAH3O	Animal barrow at crest of old lake shore bluff, oxidized silty soil; site dominated by moss, berry and lichen, crowberry, moss, reindeer lichen, Labrador tea and leafy lichen vegetation sample.	61.4471	-162.2890

Sample No.	Site Description	Latitude	Longitude
MAI1AOV1O	Gray sand, silt and clay, typical breached peat, moss, terrace edge of adjacent to lake shoreline; vegetation sample largely of peat with some reindeer lichen.	61.0221	-162.0139
MAI2O	Lake edge break in tundra mat, cotton grass, dwarf birch, lichen, gray silt, clay, mud and organics; moss, peat ad lichen dominate vegetation site, peat vegetation sample.	61.2320	-162.0170
MAI6O	Organic mud with gray silt, no sand or gravel, marsh setting; site dominated by willow, grass, moss, cotton grass and tussocks, moss vegetation sample.	61.9496	-162.0317
RMA1O	Breached peat moss at lake shore, gray brown soil contains silt, clay, mud and organics; site consists of moss, lichen and peat, vegetation sample consists largely of moss and some cotton grass, Labrador tea and dwarf birch.	61.0375	-161.7421
RMA4O	Lake edge slump, sample 1 ft of sediment under 6+ feet of peat, frozen, gray brown soil, lowland tundra; site consists of sedge, grass, moss and dwarf birch, sphagnum moss vegetation sample.	61.6508	-161.7392
RMA6O	Wilson Creek near Marshall; metavolcanics, silicified sandstone and chert, green volcaniclastics, dacite porphyry, meadow setting; site dominated by grass and willows, willow vegetation sample.	61.8824	-161.9736
RMB1O	Open tundra, small knoll next to lake, about 20 percent organics, lowland tundra setting; vegetation site dominated by berry, moss, birch and willows, caribou moss vegetation sample.	61.1436	-161.6128
RMB3O	Minor amount of sand in gray marshed direct clay, gray soil contains sand, silt and clay, vegetation sample consists largely of peat with some reindeer lichen.	61.3906	-161.5316
RMB4O	Abandoned Yukon River channel, frozen ground 1 ft below surface, reddish brown gray soil, meadow setting; sedge grass at site, grass vegetation sample.	61.6059	-161.6773
RMB5O	Gray brown organic-rich "mucky" silt; vegetation at site consists of dwarf birch, willow, Labrador tea and tundra moss, moss vegetation sample.	61.8133	-161.6314
RMB6O	East Fork Kuyukutuk River gravel bar in meadow setting; granitic porphyry, green metasediments and metavolcanics; reddish brown silty coarse sand sediment sample with visible gold; willow vegetation sample.	61.9667	-161.6731
RMC2O	Lakeside slump exposure about 8 ft tall in lowland tundra setting; gray micaceous clayey silt; tundra and berries dominate vegetation; moss vegetation sample.	61.2699	-161.2086
RMC3O	10 to 12 ft high lakeside slump in lowland tundra setting; gray brown clayey silt; moss and sedge grass, moss vegetation sample.	61.4720	-161.0921
RMC4O	Small tree-covered hill in Portage Lake area; Yellow-brown organic-rich silt with gray loess; meadow setting adjacent to forest; vegetation site dominated by spruce, aspen, willow, berries, Labrador tea, dwarf birch and moss; moss vegetation sample.	61.6375	-161.0506
RMC6O	Yukon River sandbar; fine silty sand, well-sorted, no gravel; vegetation dominated by small willows; willow vegetation sample.	61.8893	-161.0776
RMD1O	Lowland tundra setting; silt sample with about 30 to 40 percent organics; site dominated by tussock grass, cotton grass, dwarf birch and moss; caribou moss vegetation sample.	61.1418	-160.7097
RMD2O	Small terrace on tundra; peaty silt, with about 50 percent organics; vegetation includes grass, willow, birch and moss; alder vegetation sample.	61.3176	-160.9781
RMD4O	Tundra setting near Portage Lake; brown peaty silt with about 40 percent organics; site dominated by dwarf birch, caribou moss, Labrador tea and berries; peat vegetation sample.	61.6289	-160.6898
RMD5O	Small tree-covered knob (sand dune?) north of Kulik Lake in Portage Lake area; gray to yellow gray brown silty sand; site dominated by spruce, aspen, willow, tamarack, berries, moss and Labrador tea; moss vegetation sample.	61.7285	-160.7229
RMD6O	Marsh setting over abandoned slough (channel) in Tucker Slough area; river silt beneath peat, frozen at 1 ft depth, brown gray muddy silt; site consists of grass, willows and spruce; grass vegetation sample.	61.9730	-160.6920
RME4O	Tundra setting in Portage Lake area; organic peaty silt soil from 1 to 3 feet depth beneath peat layer; site vegetation dominated by moss, small spruce, Labrador tea, salmon berries and dwarf birch; moss vegetation sample.	61.6431	-160.6232
RME5O	Birch woods on small ridge; gray brown sandy silt about 1 ft beneath tundra vegetation mat; site dominated by birch, spruce, grass and equisetum (horsetail); equisetum vegetation sample.	61.7623	-160.6502
RMF5O	Small terrace above tundra lake; tan gray silt with about 20 percent brown organics; vegetation at site consists of aspen, spruce, birch, Labrador tea, moss and grass; moss vegetation sample.	61.8114	-160.2966
RMF6O	Low ridge next to Portage Mountains. Gray brown muddy silt; vegetation at site consists of moss, caribou moss, small spruce, willow and dwarf birch; caribou moss vegetation sample.	61.8778	-160.0271
RMG1O	Hilly setting on Myrtle Creek, near Nyac; granitic rocks, Kuskokwim Group greywacke and shale; brown coarse sand; vegetation dominated by willow, birch, moss, spruce and blueberries; willow vegetation sample.	61.0448	-159.7402
RMG2O	Discovery Creek drainage with beaver dams, in wooded hilly area of hornfels, feldspar porphyry, dacite(?) porphyry; brown sand; site consists of grass, willow and spruce; willow vegetation sample.	61.2269	-159.7349
RMG3O	Hillside slope with frost at 1 ft depth; gray brown silty mud, clay and organics; vegetation includes cotton grass, caribou moss, Labrador tea and berries; cotton grass vegetation sample.	61.3670	-159.6890
RMG4O	Hillcrest near slough; gray-brown clayey silt; spruce, Labrador tea, berries and moss; moss vegetation sample.	61.5081	-159.7088
RMH1O	Hilly setting on second order tributary to Salmon River; greywacke, sandstone, mudstone, shale (Kuskokwim Group sediments?); brown sand and silt; site consists of grass, alder, spruce, willow, moss and dwarf birch; moss vegetation sample.	61.0244	-159.3565
RMH3O	Gray brown silt, clay and mud; site consists of scrub spruce, cotton grass and berries; moss vegetation sample.	61.3725	-159.6147
RMH4O	Small stream in hilly setting; organic-rich muddy silt, no gravel or sand; vegetation dominated by grass, willow, moss, birch and cotton grass; moss vegetation sample.	61.6499	-159.6645
RMI1O	Small gravel bar in hilly setting on Aniak River tributary; quartz-feldspar porphyry, greenstone, slate, greywacke and andesite; gray brown sand and silt; vegetation dominated by dwarf birch, spruce, cotton grass and willow; grass vegetation sample.	61.0464	-159.0574
RMI2O	Wooded gravel bar on Swift River; granite, chert, vein quartz, granitic porphyry, sandstone, slate; gray brown mixture of coarse sand and sand; site consists of willow, spruce and river grass; willow vegetation sample.	61.1808	-159.2807
RMI5O	Beaver dammed stream, northwest side of Russian Mountains; quartz-monzonite, basalt, diorite, quartz cobbles; brown silty coarse sand; vegetation site contains reed, grass, willows, spruce forest; reed vegetation sample.	61.7133	-159.0113

Appendix B. Range and detection limits for selected vegetation samples

Sample	Range (ppm)	Detection Limit (ppm)
Arsenic	<0.2-148.2	<0.2
Lead	0.8-21928.48	0.8
Selenium	<0.2-10.8	<0.2
Zinc	53.8-11553.8	53.8
Mercury	0.01-0.81	0.01

Appendix C. Percent difference in duplicates and standard reference materials

Duplicates								
SAMPLES	As ppm	% difference	Pb ppm	% difference	Se ppm	% difference	Zn ppm	% difference
RME5O	0.1	0.00	0.8	16.09	0.1	0.00	873.9	1.10
RME5O Duplicate	0.1		0.94		0.1		864.3	
BIC6O	11.8	5.76	9.15	7.47	0.1	0.00	179.2	7.29
BIC6O Duplicate	12.5		9.86		0.1		166.6	
BEG1O	26.2	10.87	8.52	1.74	0.7	13.33	274	2.63
BEG1O Duplicate	23.5		8.67		0.8		281.3	
BID3O	31.9	2.22	20.83	5.01	0.9	11.76	186.1	1.02
BID3O Duplicate	31.2		21.9		0.8		188	
MAI2O	12.9	2.35	16.27	0.12	2.2	4.65	211.3	0.86
MAI2O Duplicate	12.6		16.29		2.1		209.5	
RMG1O	4.4	33.96	2.24	16.43	1.7	5.71	3180.3	4.03
RMG1O Duplicate	6.2		1.9		1.8		3054.7	
BIC2O	20.1	4.58	17.51	3.31	0.1	0.00	142.9	1.73
BIC2O Duplicate	19.2		16.94		0.1		145.4	
Standard Reference Materials								
SAMPLES	As ppm		Pb ppm		Se ppm		Zn ppm	
*SRM 1515	0.18	127.27	0.43	8.89	0.07	33.33	13.01	4.00
certified SRM 1515	0.04		0.47		0.05		12.50	
ICP-MS Analyzed								
42211	0.54		3.18		0.44		41.27	
42215	0.05		0.28		0.03		3.64	
42214	0.89		3.82		0.61		41.81	
42223	0.82		3.80		0.30		41.27	

*Standard Reference Material

Appendix D. Chemical results for analyses of selected vegetation samples (dry-weight basis)

Sample No.	As (ppm)	Pb (ppm)	Se (ppm)	Zn (ppm)	Hg (ppm)	Lat	Long
BEA2O	1.66	2.32	.02	47.60	nd	60.263	-161.734
BEA3OB	.26	.62	.10	14.42	.08	60.392	-161.934
BEB1O	1.34	.92	.09	181.76	.04	60.140	-161.462
BEB3O	.50	1.09	.16	17.56	nd	60.375	-161.446
BEB4O	1.02	.60	.05	27.20	.10	60.541	-161.468
BEB5O	2.15	1.37	.05	54.51	nd	60.792	-161.639
BEC1O	.54	1.06	.25	19.48	nd	60.044	-161.362
BEC3O	.77	1.37	.31	16.45	.20	60.458	-161.142
BEC4O	.55	.77	.22	13.93	.81	60.547	-161.369
BED1O	.38	.19	.02	51.37	nd	60.128	-161.054
BED2O	1.58	1.77	.07	44.16	nd	60.032	-161.749
BED4O	1.03	.93	.27	38.04	nd	60.632	-161.043
BED5O	.26	.80	.01	11.20	.02	60.809	-161.041
BED6O	.21	.55	.01	19.74	.03	60.872	-160.834
BEE1O	.15	1.14	.19	47.11	.07	60.034	-160.545
BEE2O	.10	.18	.01	59.81	.02	60.298	-160.563
BEE4O	.04	.21	.02	131.84	nd	60.632	-160.519
BEE5O	.57	.37	.01	18.17	.03	60.697	-160.748
BEE6O	.26	.15	.01	47.57	.03	60.939	-160.531
BEF1O	.68	1.48	.38	30.54	.05	60.044	-160.438
BEF2O	.53	.35	.01	64.29	.04	60.193	-160.452
BEF3O	.07	.35	.00	17.88	.03	60.470	-160.431
BEF4O	.13	.37	.01	27.22	.03	60.649	-160.198
BEF5O	2.93	2.39	.06	21.75	.12	60.800	-160.461
BEF6O	.01	.30	.07	177.42	nd	60.870	-160.440
BEG1O	3.01	.98	.08	31.51	.05	60.161	-160.141
BEG4O	.01	.14	.01	33.45	.02	60.497	-159.996
BEG5O	.09	.28	.01	25.94	.03	60.689	-160.077
BEG6O	.01	.24	.01	36.67	.02	60.960	-159.965
BEH4O	.03	.12	.00	21.55	.02	60.573	-159.949
BEH5O	.26	.17	.01	39.59	.02	60.807	-159.636
BEH6O	.02	.20	.01	20.69	.03	60.876	-159.638
BIB4O	.26	.38	.03	40.33	nd	60.538	-164.646
BIB6O	1.54	1.60	.02	38.88	.05	60.863	-164.422
BIC1O	.19	.80	.11	47.81	nd	60.127	-164.343
BIC2O	4.38	3.81	.02	31.11	.16	60.176	-164.316
BIC3O	.55	1.28	.44	23.86	.16	60.337	-164.343
BIC4O	3.72	4.67	.03	35.96	nd	60.540	-164.352
BIC5AOV1O	.37	1.11	.09	22.14	nd	60.724	-164.241
BIC5O	1.76	2.17	.02	32.96	nd	60.734	-164.057
BIC6O	2.97	2.30	.03	45.12	.05	60.874	-164.126
BID1AOV1O	.40	.82	.28	14.39	.11	60.134	-163.848

Sample No.	As (ppm)	Pb (ppm)	Se (ppm)	Zn (ppm)	Hg (ppm)	Lat	Long
BID1AOV2O	.41	1.52	.10	15.55	nd	60.134	-163.848
BID1O	.18	.63	.06	45.77	nd	60.134	-163.848
BID3O	6.10	3.98	.17	35.58	.11	60.382	-163.843
BID4O	.87	1.79	.14	58.85	.27	60.546	-163.875
BID5O	1.07	2.22	.35	23.46	.15	60.786	-163.920
BID6O	.82	1.41	.04	27.10	nd	60.875	-163.868
BIE1O	.30	.79	.03	12.02	.14	60.134	-163.757
BIE2O	2.85	2.46	.20	17.20	.09	60.301	-163.757
BIE6O	1.45	1.26	.13	26.83	.41	60.864	-163.577
BIF1O	.65	1.52	.35	27.47	nd	60.033	-163.234
BIF2O	.71	.83	.02	65.37	.06	60.296	-163.458
BIF3O	.28	.91	.17	14.47	.12	60.462	-163.256
BIF5O	.80	1.44	.09	33.86	.59	60.804	-163.249
BIF6O	.67	1.86	.16	32.98	.43	60.955	-163.197
BIG1O	.71	1.35	.26	23.19	nd	60.033	-163.142
BIG2OB	.05	.27	.04	91.37	nd	60.204	-162.928
BIG3OB	.19	.57	.03	15.10	nd	60.468	-162.939
BIG4O	.18	1.01	.10	17.49	nd	60.629	-162.931
BIG5O	.45	1.43	.21	31.16	nd	60.708	-163.160
BIH1AOV2O	3.12	2.35	.02	58.35	.05	60.021	-162.755
BIH1O	.51	1.06	.05	24.84	.15	60.038	-162.853
BIH2O	.15	.75	.07	74.36	nd	60.213	-162.861
BIH4O	2.82	.70	.08	17.81	.12	60.536	-162.658
BIH5O	2.04	2.61	.15	24.86	.37	60.709	-162.842
BII2O	.62	1.06	.01	12.66	.08	60.292	-162.354
BII3O	.72	.45	.03	36.98	nd	60.461	-162.562
BII5O	.99	1.57	.12	44.40	nd	60.748	-162.535
BII6O	1.04	3.28	.21	48.61	.53	60.867	-162.547
BIJ1O	.07	.66	.07	15.09	nd	60.049	-162.037
BIJ4O	10.06	4.93	.03	35.61	.19	60.645	-162.240
BIJ5O	3.66	5.11	.33	31.15	.29	60.698	-162.088
BLH1O	1.86	2.03	.30	20.10	.37	62.034	-165.383
GBA6O	.54	1.10	.30	23.35	.12	59.868	-161.978
GBB4O	.07	.05	.01	114.19	.01	59.638	-161.466
GBB6O	1.39	2.15	.10	44.19	nd	59.870	-161.430
GBC5O	.47	1.14	.15	15.76	nd	59.697	-161.360
GBC6O	.81	2.04	.14	30.61	nd	59.843	-161.150
HBF4O	1.37	1.25	.02	26.51	.03	61.540	-166.052
HBG3O	3.08	2.69	.02	57.28	nd	61.356	-165.703
HBG4O	.46	1.47	.15	16.63	nd	61.530	-165.707
HBH5O	.43	2.16	.13	35.83	nd	61.702	-165.395
HBI1O	2.74	3.13	.02	49.00	.04	61.060	-165.030
HBI4O	.65	1.36	.22	34.60	.44	61.537	-165.059
HBI6O	1.64	1.47	.18	44.25	nd	61.961	-165.305
KBG6O	.89	1.58	.17	24.62	.15	59.956	-163.139

Sample No.	As (ppm)	Pb (ppm)	Se (ppm)	Zn (ppm)	Hg (ppm)	Lat	Long
KBH6O	.84	.36	.29	12.93	.02	59.999	-162.848
KBJ6O	.82	.78	.01	35.18	nd	59.963	-162.051
KWA2O	3.94	6.46	.14	18.45	.19	62.293	-164.719
KWA5O	3.79	2.00	.17	60.66	.05	62.792	-164.735
KWB2AOV2O	1.77	2.59	.14	11.90	nd	62.252	-164.328
KWD2O	3.64	4.35	.03	47.85	nd	62.298	-163.747
KWD4O	1.99	1.96	.11	16.55	.21	62.539	-163.725
KWD5O	1.05	1.88	.28	31.44	.25	62.795	-163.716
KWE1O 1/2	.00	.00	.00	.00	nd	62.036	-163.530
KWF1O	.06	.55	.02	9.42	.01	62.051	-163.010
KWF2O	.23	.45	.01	19.68	.02	62.215	-163.256
KWG2O	.23	.29	.00	16.60	.03	62.308	-162.784
KWH1O	.11	.22	.01	49.05	.03	62.133	-162.487
KWH2O	.15	.17	.01	18.79	.02	62.184	-162.590
KWI1O	.06	.36	.01	5.93	.03	62.148	-162.269
KWI2O	.10	.44	.01	6.17	.03	62.294	-162.036
MAA1O	4.02	3.41	.02	17.29	.10	61.033	-164.703
MAA2O	.74	1.12	.15	70.45	.33	61.298	-164.712
MAA3O	.29	.63	.16	28.82	.43	61.378	-164.735
MAA4O	1.01	1.77	.20	39.68	nd	61.637	-164.947
MAA6O	3.38	3.78	.02	95.52	.18	61.969	-164.946
MAB1O	.56	1.21	.14	28.37	.53	61.039	-164.615
MAB3AOV1O	20.94	6.36	.10	44.56	.22	61.402	-164.540
MAB3AOV2O	6.58	3.55	.04	23.94	.20	61.402	-164.540
MAB6O	.52	1.56	.09	34.48	nd	61.878	-164.638
MAC1O	.32	.77	.20	20.60	.39	61.028	-164.270
MAC2O	.31	.66	.09	30.07	nd	61.286	-164.289
MAC3AOV1O	.48	1.36	.17	48.81	.34	61.348	-164.340
MAC3AOV2O	3.61	3.00	.35	39.41	.13	61.348	-164.340
MAC4O	.07	1.12	.02	44.64	.08	61.518	-164.062
MAC5O	.09	1.31	.01	13.55	.05	61.709	-164.052
MAC6O	.34	.26	.02	26.60	.04	61.848	-164.067
MAD2O	2.42	1.39	.16	19.23	.31	61.201	-163.692
MAD3O	.05	.37	.03	6.95	.02	61.410	-163.994
MAD4O	.12	.65	.03	9.73	nd	61.629	-163.686
MAD5O	.15	.38	.00	11.19	.05	61.797	-163.948
MAD6O	.35	1.28	.00	24.13	.07	61.866	-163.768
MAE1O	.97	2.50	.12	19.60	.18	61.144	-163.610
MAE3O	.09	.70	.01	8.67	nd	61.182	-163.635
MAE5O	.14	.35	.03	42.87	.03	61.797	-163.386
MAE6O	.03	.32	.00	31.10	.03	61.978	-163.620
MAF3O	2.21	2.54	.02	64.80	.06	61.377	-162.957
MAF4O	.20	.62	.01	32.25	.04	61.627	-163.028
MAF5O	.04	3.79	.01	39.05	.02	61.798	-163.073
MAG4O	.23	.78	.03	7.86	.02	61.649	-162.921

Sample No.	As (ppm)	Pb (ppm)	Se (ppm)	Zn (ppm)	Hg (ppm)	Lat	Long
MAG5O	.15	.48	.00	12.14	.02	61.783	-162.724
MAG6O	.18	.58	.00	9.78	.03	61.847	-162.693
MAH2O	1.05	1.56	.44	23.94	.19	61.189	-162.572
MAH3O	.54	1.00	.01	48.25	nd	61.447	-162.289
MAI1AOV1O	14.98	1.75	.30	19.86	nd	61.022	-162.014
MAI2O	.97	1.22	.17	15.89	.07	61.232	-162.017
MAI6O	.99	.94	.02	30.99	.06	61.950	-162.032
RMA1O	.58	1.50	.18	24.98	.13	61.037	-161.742
RMA4O	.09	.39	.02	13.60	.02	61.651	-161.739
RMA6O	.07	.12	.01	191.17	nd	61.882	-161.974
RMB1O	.08	.37	.02	6.81	.03	61.144	-161.613
RMB3O	.55	1.10	.17	40.99	nd	61.391	-161.532
RMB4O	.20	.30	.00	38.54	.02	61.606	-161.677
RMB5O	.79	.69	.04	26.06	.07	61.813	-161.631
RMB6O	.04	.09	.03	202.18	nd	61.967	-161.673
RMC2O	.22	.59	.03	6.35	.03	61.270	-161.209
RMC3O	.12	.38	.02	7.76	.02	61.472	-161.092
RMC4O	.26	.80	.05	53.34	.09	61.637	-161.051
RMC6O	.06	.32	.01	210.05	.01	61.889	-161.078
RMD1O	.11	.57	.02	5.80	.03	61.142	-160.710
RMD2O	.06	.23	.02	212.59	nd	61.318	-160.978
RMD4O	.84	2.22	.12	45.64	nd	61.629	-160.690
RMD5O	.60	2.66	.07	37.02	nd	61.728	-160.723
RMD6O	9.57	2.04	.04	51.71	nd	61.973	-160.692
RME4O	.45	1.38	.07	39.06	.17	61.643	-160.623
RME5O	.01	.12	.01	127.59	nd	61.762	-160.650
RMF5O	.32	1.44	.01	45.01	nd	61.811	-160.297
RMF6O	.10	.22	.01	9.35	.04	61.878	-160.027
RMG1O	.22	.11	.08	156.47	nd	61.045	-159.740
RMG2O	.13	.08	.01	165.22	nd	61.227	-159.735
RMG3O	.07	.21	.01	47.47	.02	61.367	-159.689
RMG4O	.07	.42	.02	9.97	.01	61.508	-159.709
RMH1O	3.36	3.92	.13	31.40	.02	61.024	-159.357
RMH3O	.12	.47	.02	10.13	.03	61.372	-159.615
RMH4O	4.48	4.04	.11	38.13	.06	61.650	-159.664
RMI1O	.53	.45	.01	46.11	.08	61.046	-159.057
RMI2O	.01	.14	.01	148.52	nd	61.181	-159.281
RMI5O	.56	.35	.01	49.33	.03	61.713	-159.011

Note: nd = no data