NUNATAKS AND ISLAND BIOGEOGRAPHY IN THE ALASKA-CANADA BOUNDARY RANGE: AN INVESTIGATION OF THE FLORA AND ITS IMPLICATIONS FOR CLIMATE CHANGE

by

POLLY BASS

(Under the Direction of Elgene O. Box)

ABSTRACT

A baseline flora of the nunataks, isolated peaks and ridges protruding above glaciers, is developed for the Juneau Icefield. Nunatak and periglacial sites from adjacent areas in Alaska, northern British Columbia, and the Yukon are included. Key sites are investigated phytosociologically and biogeographically. Species richness is considered in relation to winter low temperature, dominant aspect of the study sites, growing-season length, latitude, elevation, the distance of the sites from the continuously vegetated mainland, and the surface area of the study sites. The nunatak habitats are tested against the tenets of the theory of island biogeography. Though difficult in the time frame of the study (approximately seven years) to draw conclusions on extinction and immigration rates, it is possible to identify species not observed in previous investigations. It is also possible to observe the relationship between richness and nunatak surface area, and richness and the distance of a given nunatak from the continuously vegetated mainland. Surface area of the sites is the variable most correlated with species richness. This finding is in agreement with the theory of island biogeography. Latitude, elevation, and growing-season length are further found to have a strong influence on the richness of the vascular plant assemblages. Species richness has more than doubled from 1948 to 2007, in parallel with a recorded increase in the mean annual temperature of the region over the same time period. The floristic data facilitate monitoring the region for further changes. The geobotany of the northern Alaska-Canada Boundary Range harbors significant information on the past, current and future effects of climate change on sub-Arctic and alpine vegetation.

INDEX WORDS: Nunatak, Island biogeography, Phytosociology, Floristic richness, Juneau Icefield, Alaska-Canada Boundary Range, Sub-Arctic vegetation, Alpine vegetation, Temperature change

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DEDICATION

This dissertation is dedicated to the following special friends and associates who have passed on and now belong to the ages but who have made the world a better place for their having been in it. They have enriched my life and bolstered my dedication to keep striving every day. These include Dr. James H. Anderson, Dr. Eugene Odum, Dr. Calvin J. Heusser, Mrs. Joan Miller, Mr. Tony Coburn, Dr. Molly O. Ahlgren, Dr. Arthur Gittins, Dr. George Williams, Mr. Tom Bingam, Mr. Chris Cochran, Mrs. Vivian Norris, Mr. Fred Bass, Mrs. Mabre Stephens Bass, Mrs. Rose Jones, Mrs. Mary Servella, Mr. Goran Krop, Mr. Alex Lowe, and Dr. Bruce Haines.

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CHAPTER 1

INTRODUCTION

"Alpine vegetation is often like a garden, a mosaic of beauty, a small scale multitude of ways of coping with life."

Christian Körner, Alpine Plant Life (1999)

Overview

A comprehensive flora of the Juneau Icefield nunataks is developed which tests the principles of island biogeography in application to nunatak environments. The Eskimo term, nunatak, refers to a mountain peak or rock ridge rising above the glaciers of an icefield, often serving as an ice-divide demarcating the ice flows of separate glaciers. "Nunatak" translates to "lonely rock or peak" from the Greenland Eskimo (Bates & Jackson, 1984; Molnia, 2001). The data set is compared to similar cordilleran habitats in other regions. The impact of adjacent field stations, at some locations in the alpine habitat, is considered as well as the effects and implications of climate change. The vouchers are being used to establish herbaria at Sheldon Jackson College and at the Glaciological and Arctic Sciences Institute in Atlin, British Columbia. The work provides a base for future botanical exploration and continued global change research.

Research Hypotheses

Hypothesis 1

More vascular plant species will be observed in the current investigation than in historical botanical studies. A 20% or greater increase in species richness is expected between the vascular plant species observed in the region, in all past studies, and the current study.

Justification. During the approximate 58 years since the first formal floristic investigation of the region, new plant immigrants have taken hold on the study sites. In addition, the increased time dedicated to investigating the region allows for observation of species that may have been previously overlooked.

Hypothesis 2

An increase in vascular plant species richness is observed on the maritime to continental gradient.

Justification. This hypothesis is founded on the observed greater number of clear sunny days on the continental sites as compared to the number of clear sunny days observed on the maritime perimeter of the region.

Hypothesis 3

There is a direct relationship between the mean winter low temperature on the nunataks and vascular plant species richness. As the average winter low temperature increases, the richness of vascular plant species also increases.

Justification. This hypothesis is founded on the observations of Abbott (1974).

Hypothesis 4

Opportunistic vascular plant species, not found on nunataks without field stations, will be found on nunataks with field stations. As a testable, quantitative criterion, at least three such opportunistic species are expected on nunataks with field stations, which are not present on nunataks without field stations. Therefore, the presence of human and other animal activity contributes to the richness of vascular plant species on these nunataks.

Justification. Humans are effective vectors of dispersal.

Hypothesis 5

There is a positive correlation between nunatak surface area and the number of different species on a nunatak. As nunatak surface area increases and decreases so does variation in the richness of vascular plant species.

Justification. This hypothesis is founded on the tenets of the theory of island biogeography (MacArthur & Wilson, 1967).

Hypothesis 6

There is an indirect relationship between the distance of nunataks from the continuously vegetated mainland and the number of vascular plant species. As distance from the continuously vegetated mainland increases, the number of vascular plant species decreases.

Justification. This hypothesis is founded on the laws of island biogeography (MacArthur & Wilson, 1967) that are expected to be satisfied by the distribution of species across the nunataks.

Site Description

The Juneau Icefield lies within the Tongass National Forest in southeast Alaska and stretches approximately 161 km north to south, and 72 km east to west (United States Forest Service [USFS], 1971). It is the fifth largest icefield in the Western Hemisphere with an ice-covered extent of approximately 2400 km^2. The latitudinal range of this glacierized region is 58.4 to 59.6 degrees North (Figures 1, 2, and 3).

The geology of most of the Juneau Icefield nunataks is characterized by granodiorite with associated metamorphic petrologies of the Coast Range Batholith. These rocks have been K-Ar dated at 53 million years before present (BP). Forbes (1959) estimated that the granodiorite in the batholith was formed 35 km below the surface of the earth. A lack of information exists on nunatak vegetation of the North American sub-Arctic and Arctic. The glacierized environment of southeast Alaska is in a state of increased change, making a record of the region's biota increasingly important (Miller, 1955). Plants are an especially sensitive indicator of environmental change (Walker, Theodose, & Webber, 2001). The vulnerability of alpine ecosystems makes an understanding of the biological processes and life forms of the region imperative in the presence of increased human impact on the earth (Anderson, 1991).

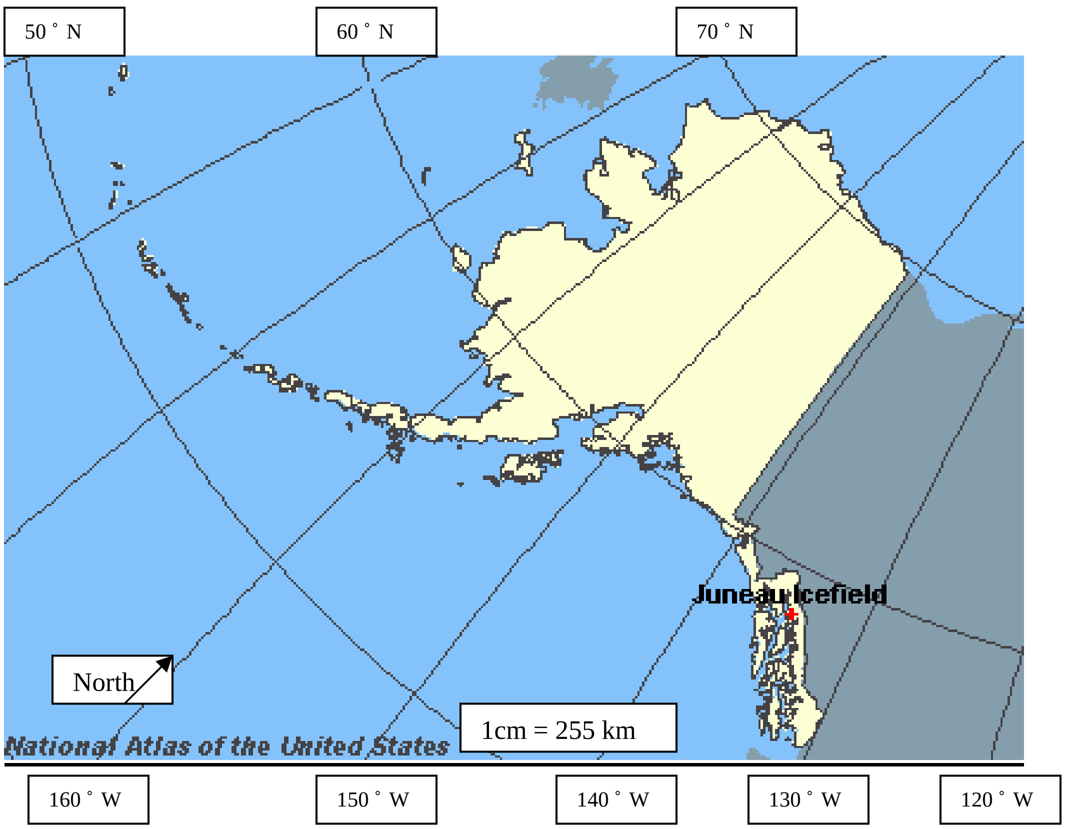


Figure 1. Juneau Icefield Index Map.

The Juneau Icefield, located in the Alaska-Canada Boundary Range, is presented above in the larger context of Northwestern North America (from:http://nationalatlas.gov/natlas/natlasstart.asp).

Figure 2. Map of the Southern Sector of the Study Region.

Alaska-Canada Boundary Range and southern study sites indicated with yellow diamonds.

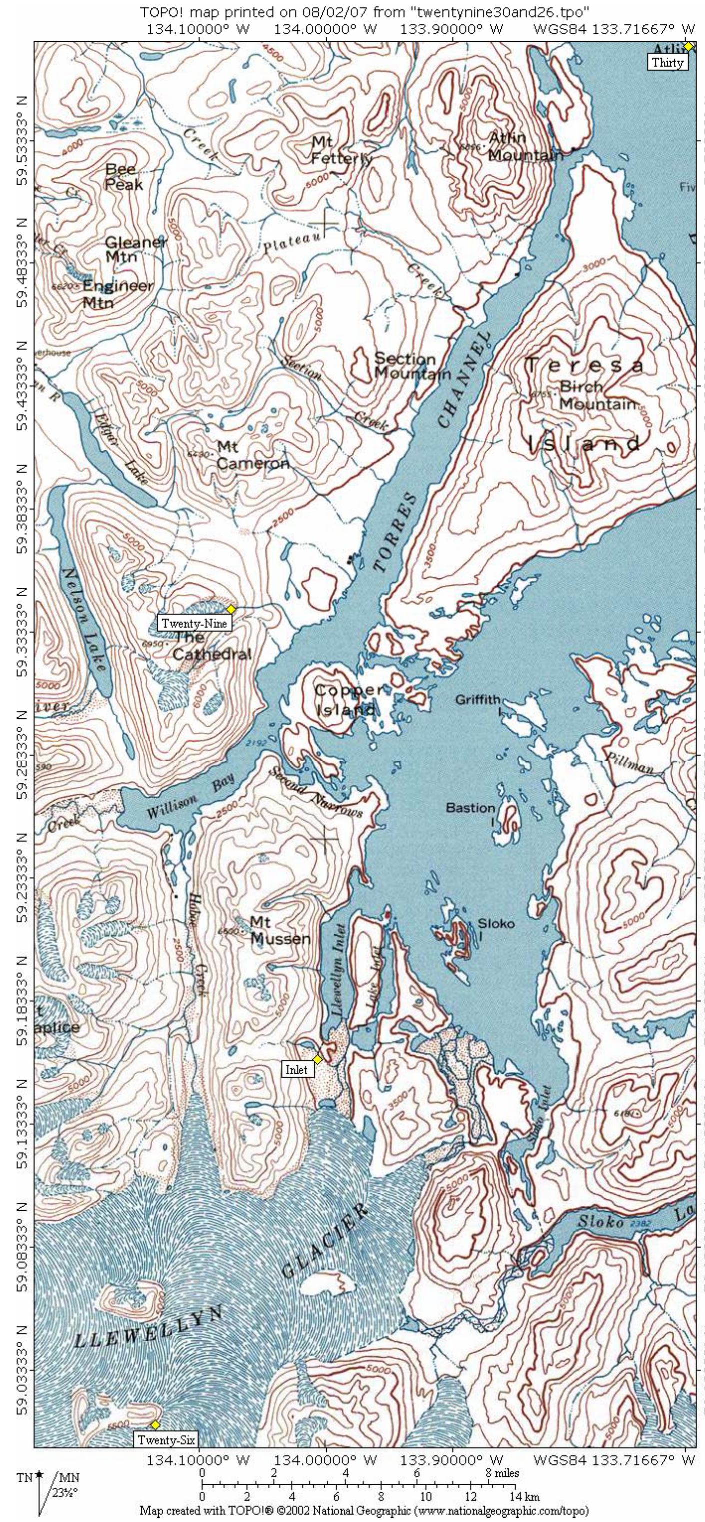


Figure 3. Map of the Northern Sector of the Study Region.

Alaska-Canada Boundary Range and northern study sites indicated with yellow diamonds, including Site Twenty-six.

In the late 1940s botanical work was carried out in the Yakutat and Icy Bay Region on the Tyndall and Malaspina Glaciers (Miller, 1955). A general floristic survey of some Juneau Icefield nunataks was also carried out in the 1950s (Heusser, 1954a, 1954b). Since then, Ward (1951) and Anderson (1970) have conducted ecological investigations on scattered Juneau Icefield nunataks and environs. Buttrick (1977) completed a thesis on the alpine flora of Birch Mountain, on Teresa Island in Atlin Lake, on the northern perimeter of the Juneau Icefield in British Columbia. Also of note is Scott's (1972) phytosociological work in the Wrangell Mountains, northwest of the Juneau Icefield.

It has been hypothesized that some nunataks remained ice-free during the Pleistocene glaciations. These nunataks may harbor plant species that were present before the Pleistocene and were largely eliminated from the surrounding ice-covered terrain during the maximum continental glaciations (Cooper, 1942; Körner, 1999; Stehlik, Schneller, & Bachmann, 2001). The nunatak hypothesis supports the isolation and preservation of species during the Pleistocene Maximum, via protection on topographic highs such as nunataks (Heusser, 1954a). This demonstration of fitness and ability to survive in an austere environment is among many attributes making alpine plants an intriguing subject of study (Körner, 1999).

Most nunatak vegetation studies have been conducted in Scandinavia, the European Alps, Greenland, and Antarctica (Buttrick, 1977; Elven, 1980; Stehlik et al., 2001). An international circumpolar vegetation survey is in progress (Walker & Markon, 1996). An effort is being made to encourage the extension of the international effort to the sub-Arctic and alpine zones of North America. Changes in sub-Arctic and circumpolar vegetation are useful indicators of human impact on the climate (Smith, Steenkamp, & Gremmen, 2001).

The vegetation on the nunataks of the Juneau Icefield developed predominately during the Thermal Maximum. The Thermal Maximum is defined as the warm and dry interval following an initial postglacial wet-cool interval of the Wisconsinan Glaciation (Heusser, 1954b; Miller & Anderson, 1974). The Thermal Maximum on the Juneau Icefield spanned from approximately 3250 to 5500 years BP (Miller, 1955; Molnia, 2001), a time of maximum warmth on the southern portion of the icefield. The Thermal Maximum is thought to have ranged from 3000 to 8000 years BP in other locations.

Price (1981) has likened nunataks and alpine environments to habitat islands. The theory of island biogeography, developed by MacArthur and Wilson (1967), proposed that large islands usually have more species than small islands, and that remote islands usually have fewer species than less remote islands. Immigration rate decreases with greater distance from a mainland. While the extinction rate on an island is caused by the replacement of prior inhabitants with new colonists, it is also related to the distance from the mainland (Shafer, 1990).

Data

Floristic inventories were carried out on nunataks across the Juneau Icefield in southeast Alaska and northern British Columbia (Table 1). Phytosociological relevés (the basic sampling unit), line transects, and data on species per unit area were collected by the author at each site over the course of approximately seven years. Data from historical studies of the region and adjacent areas were obtained through library research. The author carried out pertinent literature and specimen surveys at the Herbarium of the University of Alaska, Fairbanks, the State Museum of Alaska Herbarium, the University of Idaho Library (including the Library of the Glaciological and Arctic Sciences Institute), and the University of Washington Library and Archives.

Table 1

Study Sites with Corresponding Description, Elevation, Coordinates, Number of Plant Species and Families, and Distance from Continuously Vegetated Land

Site and Brief Description	**Elevation (m)**	**Latitude & Longitude (˚)**	**Number of Species**	**Number of Families**	**Approximate Distance from Mainland (km)**
Herbert Glacier	66. m	58.54°N 134.70°W	15	13	**
Bog Pond	462. m	58.38°N 134.41°W	10	7	**
Tarn Lake, Lemon Creek Valley, one valley west of Seventeen A	774. m	58.39˚ N 134.39˚ W	12	9	**
Seventeen A, base of Ptarmigan and Lemon Creek Glaciers	780. - 800. m	58.39°N 134.38°W	23	15	**
Ptarmigan Ridge	1142. m	58.37˚ N 134.38˚W	19	12	**
Seventeen, Cairn and Vesper Peak Ridge between Ptarmigan and Lemon Creek Glaciers	1266. - 1286. m	58.37˚ N 134.37˚ W	80	23	1. km to south
Fourteen, Rock Band above east side of Lemon Creek G1, south of Thirteen	1365. m	58.43˚ N 134.33˚ W	8	7	5. km to west
Thirteen, Ridge above Death Valley	1396. m	58.44°N 134.32°W	13	7	6. km to west
Ten, Borders Icy Basin of Upper Taku Gl.	1303. - 1168. m	58.65˚ N 134.19˚ W	71	19	31. km equidistant to south and southwest
Sunday Point, at confluence of Demorest and Taku Gl.	1067. - 1172. m	58.62˚ N 134.17˚ W	41	14	25. km to south
Taku Northwest Nunatak	1362. m	58.66˚ N 134.36˚ W	37	14	21. km to west on coast
Nina A, West Matthes Gl.	1469. m	58.70˚ N 134.17˚ W	4	3	25. km to west on coast
Eighteen, Vaughan Lewis Icefall roche moutonnee	1661. m	58.83˚ N 134.28˚ W	39	13	13. km to west
Eighteen B, below Eighteen on the Cleaver	1335. m	58.83˚ N 134.29˚ W	22	11	11. km to west, Gilkey River
Twenty-six, Northwest Llewellyn Gl.	1646. m - 1802. m	59.02˚ N 134.15˚ W	144	27	20. km to north
Twenty-nine, base of Cathedral Glacier	1357. - 1618. m	59.35°N 134.07°W	15	8	**
Inlet	438. m	59.17°N 133.99°W	10	9	**

**Connected to continuously vegetated land on ridgeline, above tree-line.
The Sites are listed as they occur from the southeast to northwest across the study region (top to bottom in table).

Expected Results

Some species are expected to be found outside of their known ranges. This is a probable consequence of increased average temperatures (Cody, Kennedy, & Bennet, 2001). Range extensions may result due to the fact that some investigated areas have not been previously botanically studied, and the true ranges of species may have been previously underestimated. Other species extensions may result from the physical extension of the range of a given species and the progression of post-glacial succession, particularly where the ice has receded on the margins of nunataks. Such findings could have implications for the rate of climate change and global environmental change in alpine plant habitats.

The distribution of plant species is expected to vary between the nunataks on the southern portion of the icefield with a maritime climate and the nunataks on the northern portion with a drier continental climate. Greater abundance of species and individuals is anticipated on the northern nunataks as a result of the generally warmer inland growing-season. The principles of island biogeography are expected to apply to nunataks in most respects.

CHAPTER 2

BACKGROUND

"Omnis vera cognito cognitione specierum innitatur"
'All truth I know begins with the knowledge of the species'

Linnaeus

The Diversity and Origin of Alpine and High Latitude Plant Species

Ward (1951) notes that many peaks of the Juneau Icefield region likely remained above the ice at the Last Glacial Maximum (LGM). The glacial maximum is currently accepted to have occurred approximately 17,000 years BP (before present) in most of southeast Alaska (Viens, 2001). At that time, the mean late-summer snowline (névé line) has been estimated to have been approximately 1768 m in the central portion of the region and 1601 m on the perimeter of the region. Plant species may have survived above the névé line. A large migration of plant species into the region likely occurred during the Thermal Maximum or Xerothermal Interval, between approximately 3250 and 8000 years BP. Also known as the Hypsithermal, this warm interval was followed by a cooling trend reaching its maximum in the Little Ice Age between 200 and 300 years ago. The subsequent retreat of ice has opened new migration corridors that had not previously been available.

Island Biogeography and Vascular Plant Species

In MacArthur and Wilson's (1967) theory of island biogeography, area is cited as the predominant influence on species richness. Abbott's (1974) work on high latitude islands included nineteen Southern Hemisphere islands and focused on avian species. Abbott (1974) found that in controlling species richness, winter low temperature was a greater influence than the surface area of an island.

The tenets of the island biogeography theory, as presented by MacArthur and Wilson (1967) and elaborated on by many others (e.g., Pielou, 1980), include: a dynamic equilibrium between immigration and extinction; a decrease in immigration rate with an increase in species richness (the number of different species) on a given island; the dependence of species richness on the distance of a given island from a mainland; an increase in extinction rate with an increase in species richness; an extinction rate which is indirectly proportional to the area of a given island; and a direct relationship between the distance of a given island from a mainland and the probability of new immigrants displacing previous inhabitants, as well as the probability of extinction for the displaced species. Additionally, mountainous islands with a greater diversity of terrain are expected to sustain greater species richness with less surface area.

Hubbel (2001) and others have augmented the work of MacArthur and Wilson (1967). A unified neutral theory is presented by Hubbel (2001), centered on drift and equilibrium in biological communities and the subsequent effect on extinction and immigration. MacArthur and Wilson (1967) have asserted that their seminal work was not meant to be an end in itself, but rather a basis for intellectual growth and a stimulus for augmentation of our understanding of the complexities of island populations and biogeography. Hubbel (2001) emphasizes the importance of the relative equivalent fitness of species at the individual level (neutrality). The unified neutral theory champions the recognition of random processes, chiefly from the dispersal-assembly view of communities, to predict the richness of populations on islands and mainlands (Hubbel, 2001).

Nunataks are surrounded by glacier ice of a solid deformable and ever-changing medium. To many organisms, ice presents a greater impediment to dispersal than water. After all, material can travel on water and via wind. Wind can carry material of light mass across a glacier, but crevasses and icefalls present a formidable and impassable barrier to most forms of ground transport and terrestrial life. Thus, the presence, location, and abundance of plant life on islands and in island like habitats, such as nunataks, are significant in the evolutionary sense. Speciation, immigration, extinction and equilibrium need more detailed study in all forms of island-like habitats.

Perspectives on Climate Change and Vegetation

The Intergovernmental Panel on Climate Change (IPCC) was formed in 1988 by the United Nations Framework Convention on Climate Change. The goal of reducing global greenhouse gas emissions to pre -1990 levels by the year 2000 was set but since then has been difficult to achieve: the framework was not ratified by key countries needed to meet the final goal (UNEP-WCMC, 2003). If greenhouse gas emissions are eventually reduced, species should be able to adapt and successional processes proceed at a natural and sustainable rate, thereby reducing the threat of endangerment and extinction of species of flora and fauna essential to global biodiversity and food production (UNEP-WCMC, 2003). The importance of investigating the effect of climate change on species geography, diversity, sensitivity and subsequent resilience was underscored by the UNEP-WCMC Framework Convention (2003). Predictions regarding the local climate of southeast Alaska include an increase in average temperature of 5.5˚ C (10º F) by 2100 (Kelly et al., 2007). Fungus and insect populations are expected to expand their ranges, exacerbating the challenges already faced by alpine plant species as lower elevation species expand their ranges to higher elevation habitats (Kelly et al., 2007).

The Center for Plant Diversity of the Americas is a division of the Smithsonian Institution and the National Museum of Natural History. The Center developed criteria for assessing the importance of regions as centers of plant diversity (Krupnick, 2001). Previously, the sheer number of different species present and the presence of endemic species were the primary characteristics used for ranking. New criteria for ranking centers of diversity include the ability of species to disperse, the importance of species in traditional use, the economic importance of species, and most significantly, the ecological relationships between species on a given site.

A convention on biological diversity held by the World Conservation Center on Biodiversity recently determined that, to designate regions as priorities for conservation, the criteria of species richness (even without a tree species count) and the number of species known to be endemic to the region, are ample. The specifications were taken a step further to consider presence of species specialized to the substrate, as well as species of importance to humans, the diversity of habitats, and imminent threats to the site (Krupnick, 2001).

For comparative considerations, a terrestrial site must have at least 1000 different vascular plant species, with 100 of these (10% of the total), known to be endemic and not occurring in any other location. The term endemic is applied broadly in this determination, to describe a species present on a specific site or in the entire phytogeographical region (Krupnick 2001). Island sites are evaluated with the criterion of 50 endemic species or 10% of the total species present. Again, at least 1000 different species must be present to qualify an island site as a priority region and a center of plant diversity (Krupnick, 2001). The Center cited the frequent occurrence of depauperate flora, with low overall species diversity, in island-like habitats as justification for the different ranking criteria (Krupnick, 2001). The above criteria established by the Center for Plant Diversity do not classify nunatak habitats, or for that matter any alpine plant habitat, as a center of plant diversity. However, in many locations, alpine plant communities served as centers of dispersal following the Last Glacial Maximum (LGM). Alpine and high latitude habitats are among the most threatened in the current global mass extinction and are among the most vulnerable to anthropogenically induced global change (Broll & Keplin, 2005). Amplified nutrient transport and anthropogenic perturbation of natural cycles have been predicted for alpine habitats by the landscape continuum model of Seastedt et al. (2004).

A reevaluation of the criteria for identifying and classifying centers of plant diversity, and thus regions for greater conservation concern, is in order. Alpine and nunatak habitats have multiple attributes, not identified by the current criteria, which make them vulnerable to environmental and anthropogenic threats. Furthermore, alpine and nunatak habitats are understudied and not thoroughly understood. They harbor species that, quite possibly, have survived the Last Glacial Maximum. The sites have the potential for having served as dispersal centers following the Last Glacial Maximum. In fact, in some mountain ranges, including the Alaska-Canada Boundary Range, probability dictates that there are post Last Glacial Maximum plant dispersal centers present. Proving the identification of a site as such is the more challenging task. Nonetheless, it does not diffuse the necessity of protecting these habitats. Current conservation practices (Krupnick, 2001) have ignored the importance of mountain summits and nunatak-like habitats. These regions need to be reevaluated and new criteria established. Needed changes to current policy include a broader definition of the term ‘island’ to include habitat islands and untraditional islands such as nunataks. In addition, more concern is needed for regions that may be considered insignificant due to their austere climates, high elevations, and general, but misguided, interpretation as inaccessible. The current interest in outdoor recreation and ecotourism brings the importance of the conservation of mountain summits to the forefront.

Climate Change and Alpine Plant Species

The potential for plant migration has been investigated in some locations experiencing an increased impact from rising temperatures, such as the Antarctic Peninsula and sub-Antarctic Islands, as well as Arctic and sub-Arctic sites (Smith et al., 2001). The freezing elevation at some mid and high latitude sites has risen by 150 m since 1970 (Krajick, 2004). In the Swiss Alps, increased species numbers have been observed in high alpine areas as a result of lower elevation species extending their altitudinal range. This leads to increased competition for the high elevation alpine plants and threatens some with extinction. Low mountains, with limited alpine habitats and a narrow altitudinal belt between the montane, subalpine and nival habitats, are especially threatened by global temperature increases. In consequence, average elevations for subalpine fir (*Abies lasiocarpa)* and Engelmann spruce (*Picea englemannii),* in the Canadian Rockies, have risen by 50 m in the last 14 years (Krajick, 2004). Changes in the tree-line may also be a result of recovery from lower pre-Little Ice Age (LIA) tree-line elevations, as well as fire, rainfall and humidity changes. All explanations and variables must be considered (Krajick, 2004).

Arguments do exist against the upward migration hypothesis. Recent studies in the Swiss Alps have established that the number of vascular plant species in the alpine zone has increased. Species observed in a 1985 study have not been displaced by new immigrants (Walther, Beiβer, & Conradin, 2005, Walther, Beiβer, & Pott, 2005a). The presence of species overlooked in historical investigations and the need for more data on species shifts in mountain regions are cited, emphasizing the importance of the current investigation in the Alaska-Canada Boundary Range (Kammer et al., 2007).

Numerous studies (e.g., Keeling, Chin, & Whort, 1996, Myeni et al., 1997, Walther et al., 2002) have focused on recent global changes and the effect on vegetation assemblages in the northern latitudes. Increased temperatures lead to earlier snowmelt, longer growing-seasons and generally increased plant growth. Such changes in turn lead to the positive feedbacks of increased carbon dioxide release to the atmosphere by vegetation and decreased albedo.

The Coast Range Mountains of southeast Alaska, northwest British Columbia, and the adjoining Yukon Territory, rise directly from sea level to high summits over a narrow horizontal distance. Alpine species of the Coast Range live at elevations between 1212 m and 2576 m (3975 – 8449 ft), where average temperatures are increasing and low elevation species are expanding their ranges to higher elevations. The most evident change in alpine regions over most of the globe is the retreat of mountain glaciers (Krajick, 2004). Glacial retreat is well evident in the mountains of southeast Alaska and is augmenting the potential habitat for alpine species as the surface area of nunataks increases.

The work of Halloy and Mark (2003) has drawn attention to the impact of climate change on alpine vegetation. The research in the Otago tussock grasslands, on the South Island of New Zealand, has focused on using species-area curves to predict the impact of increased average temperature on the migration and survival of alpine plant species (Halloy & Mark, 2003). The study predicts the addition of species (native and non-native) to the alpine regions of New Zealand, both on the South and North Islands. The islands are key regions, climatically similar to the Alaskan Panhandle. The additional species are predicted to lead to the extinction of over 70 native species, and cause major perturbations in 93% of the alpine habitat above 1000 m (3280 ft) on New Zealand's North Island. This is in response to a predicted 3º C (5.4˚ F) increase in the regional temperature (Halloy & Mark, 2003; Mark, 2004). The situation is analogous to the changes observed and predicted in southeast Alaska. One encouraging fact is that invasive non-native alpine species are, in general, not well suited to New Zealand, possibly reducing the threat they present to the native vascular alpine species.

Site Twenty-nine (Figure 3 and 4), on the Cathedral Massif Glacier, at the periphery of the Juneau Icefield in British Columbia and bordering Atlin Lake, may have been a refugium for vegetation during the austere climatic conditions of the LGM (Last Glacial Maximum), approximately 18,000 years ago. At the LGM, glaciers extended from the Juneau Icefield proper to the currently separated Cathedral Massif Glacier. That site was most likely a paleonunatak, surrounded by glacier ice at the time of the LGM, and is now connected to continuously vegetated land. The Cathedral Massif Glacier is an alpine glacier that has recessed rapidly in the last three decades but, for the first time in these decades, maintained a positive mass balance in the 2006-2007 accumulation/ablation season. This is considered an indication of the influence of inland migrating warmer climatic conditions and the related effect of greater snowfall at moderate to high elevations (Miller, personal communication, September 2006). Comparisons between the Cathedral Massif Site and nunataks on the Juneau Icefield proper can provide insight into the timing and magnitude of future changes. Study of the site, and those like it, will allow for prediction of the challenges faced by alpine vegetation as climate and habitats continue to change.

Alpine plant species (both vascular and non-vascular) are among those most threatened with extinction as global average temperatures rise. The extension of the ranges of land mammals to higher elevations, will increase grazing pressures on alpine plant species.

Observations of the vegetation on the Cathedral Glacier Massif, Site Twenty-nine, suggest that in coming years, if glacial recession continues and weather patterns continue to shift, there will be less precipitation received on the Alaskan sectors of the region and more on the inland British Columbian sectors. In addition, this is expected to lead to more sub-shrub and dense graminoid type vegetation dominating the nunatak landscapes. It is unlikely that plant life forms greater in size than the sub-shrub or shrub will take hold, due to the open and exposed nature of most nunataks and the high winds they often receive.

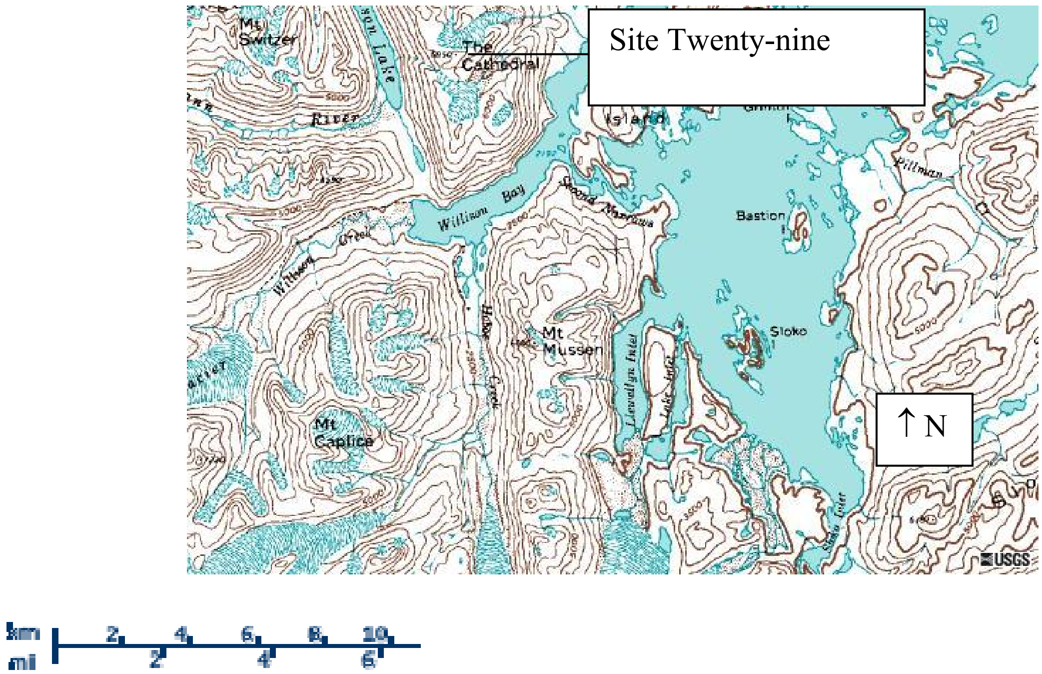


Figure 4. Site Twenty-Nine Location Map.

Site Twenty-nine is located at the terminus of the Cathedral Massif Glacier, which borders Atlin Lake in British Columbia, U.S.G.S., Terraserver.

Alpine plant assemblages found on isolated rock outcrops, such as nunataks on the Juneau Icefield, have not yet been studied in detail. Most of these species, particularly species of the Poaceae, Cryptogrammaceae, and Juncaceae, and associated lichen and bryophyte species, are considered inconsequential biota by the average person contemplating or passing through an alpine habitat. Careful observation, however, confirms that these alpine and subalpine habitats support a vast array of botanical life forms. The evolution of species and landforms on nunataks lends understanding to the future of such sites in southeast Alaska and the expected changes in vegetation assemblages.

The Nunatak Hypothesis and Tabula Rasa

The nunatak hypothesis supports the survival of species on isolated mountains above land inundated by glaciers during the Last Glacial Maximum (LGM) (Dahl, 1946; Heusser, 1989; Ives, 1974). In opposition to the survival of species on refugia is Tabula rasa, the hypothesis that supports the postglacial immigration of species to these isolated locations, which arguably may have served as refugia (Brochmann et al., 2003; Elven, 1980; Stehlik, 2003). Evidence from molecular work with the circumpolar species, Purple Mountain Saxifrage (*Saxifraga oppositifolia),* adds support to the concept of survival of some species on refugia during the Last Glacial Maximum, and the dispersal of species to their preglacial extent when conditions improved (Abbott et al., 2000). Heusser's (1972) observation of the bryophyte, *Drepanocladus berggrenii,* on the Gilkey Glacier, near Site Eighteen B of the current investigation, is further evidence for the possible survival of species in the Juneau Icefield Region during the glacial maximum.

In a recent natural history review of Iceland, Buckland and Dugmore (1991) preface their evidence for Tabula rasa with, 'If this is a refugium, why are my feet cold'. It has been a relatively short geologic span of years since the development of Iceland's modern vascular plants in, roughly the Pliocene, approximately 3mya (million years ago). In this time interval, marked changes have not occurred in the dominant climate controlling geographic variables such as latitude, aspect, and elevation. Since the Pliocene, however, isostatic rebound and denudation of the substrate have been a constant presence. The Region of greatest isostatic rebound, resulting from deglaciation, on the North American Continent, is centered 50 km directly west of the

Juneau Icefield in Glacier Bay National Park. Here the shoreline is rising 2.5 cm per year. Measurements in the Juneau region have suggested emergence rates of 1.2-1.3 cm per year (Anderson, Watts, & Motyka, 2002).

An increasing number of molecular studies now support postglacial immigration of species to regions previously purported as refugia. Most of these data are from the northern Atlantic, including Europe, Scandinavia, Iceland, Svalbard and Greenland. In the North Pacific, research supports the presence of lower elevation coastal refugia (Carrara, Ager, Baichtal, & Van Sistine, 2003; Heusser, 1989). Hultén (1937) supported a centric variation of the nunatak hypothesis and cited evidence that species had dispersed from two centers on a number of Scandinavian islands (Brochmann et al., 2003; Hultén, 1937; Scott, 1972). This line of thought is similar to that applied in Norway in the early 1900s and known as unicentric and bicentric dispersal (Dahl, 1946). Locations on the outer coast of Northwest North America, to the south and west of the current study region on the Alaska-Canada Border, have been hypothesized as likely refugia due to recently discovered geomorphological evidence (Carrara et al., 2003).

Significant genetic evidence from the Swiss Alps indicates that the natural history and survival of a given species is largely individual and based on hardiness, dispersal, pre-glacial range, and reproductive efficiency (Stehlik, 2003). The modern distribution of high latitude and alpine plants, according to Hultén (1937), is a function of reduction of the range of a species during the full glacial periods. This may have occurred during the Last Glacial Maximum, with dispersal taking place during the interglacials. Research in Scandinavia and the Urals further suggests a subset of arctic-montane plants that can survive arctic and high elevation conditions. These species were able to survive in refugia at high elevations, if not ice-covered, or at lower latitudes during the glacial maximum. The data support the argument for refugia on high mountain peaks, such as those on the Juneau Icefield, due to the presence of drier conditions at lower elevations. The shorter than usually assumed dispersal time required of most vascular plant species is cited in this argument. Some species may have survived more severe conditions in high mountain refugia, while others survived by migrating south, where conditions were similar to those known previously at higher elevations. Other species may simply have been incapable of migrating or adapting to the climate changes.

Annuals and biennials are expected to have greater adaptive capability, especially in regard to escaping ice cover to a more suitable location during glaciations. However, most Arctic and alpine species are represented by perennials. Additionally, it has been observed that species thought to have survived in periglacial locations are largely represented by plants with bulbs and rhizomes (usually perennials), and therefore a large portion of the organism is protected under the surface of the soil (Hultén, 1937). The dominance of perennials, in the vegetation assemblages of the Alaska – Canada Coast Range, makes the survival of preglacial species in refugia during the full glacial unlikely in consideration of adaptive capability (i.e., most evident in annuals and biennials), yet probable in light of the physiological suitability for survival possessed by many of the species (i.e., bulb and rhizome life forms).

A model of plant distribution as a function of equiformal areas, which are ultimately occupied by the same species as a result of radiation from a central location, has been described as an alternative postglacial dispersal pattern (Hultén, 1937). In this context, rigid species are described as those incapable of returning to their preglacial distribution, and plastic species as those that are capable of returning to their preglacial extent. The limitations in dispersal are thought to be species specific, rather than a function of the climate and other geographic variables (Hultén, 1937). This equiformal area plant distribution model strengthens the argument for species persistence in refugia and has significance for the observed geobotanical conditions and plant assemblages of the Juneau Icefield Region.

Ptarmigan Ridge Geobotany

A terrain has been observed on the Ptarmigan ridge which is unusual in the Coast Range and is one of few such locations in North America. Here there is pronounced evidence of glaciation early in the Wisconsinan, with the surfaces thereafter appearing to have remained ice-free. This permitted soil and vegetation development during the remainder of the Wisconsinan and through Thermal Maximum and Neoglacial time.

During Hypsithermal time (elsewhere in the literature termed the Thermal Maximum or Altithermal), from approximately 3250-8000 BP, the climate of the Alaska Panhandle was dominantly warm and wet, with storm tracks pushing well inland (Miller & Anderson, 1974). Over this roughly 5000 year interval, the Ptarmigan Glacier ablated and is assumed to have been fully recessed. This recession is consistent with palynological evidence that suggests there was little glacial ice on the Juneau Icefield as a whole at this time, except possibly at the highest elevations (Miller, 1956, 1963). The Ptarmigan and Lemon Creek Glaciers are middle-elevation, small alpine-scale glaciers, with their presence mainly a result of their deep and north-trending valley configurations, facilitating the accumulation of drifting snow from northerly storm winds. The lower elevation, orientation, and smaller extent of these glaciers has made them sensitive to regional storm patterns and climatic fluctuations. Their topographical location and character are key factors, serving to protect their upper sections and the adjoining Ptarmigan Ridge crestal zone from the overriding of main regional glacier ice during mid and late Wisconsinan time.

CHAPTER 3

METHODOLOGY

"…lofty mountains are most worthy of deep study. For everywhere you turn, they present to every sense a multitude of objects to excite and delight the mind. They offer problems to our intellect; they amaze our souls. They remind us of the infinite variety of creation, and offer an unequaled field for the observation of the processes of nature."

Josias Simler *De alpibus commentarius* *1574*

Methodological Background

Geobotanical collections and fieldwork are carried out on the Juneau Icefield (JIF) over the summers (mid-June through mid-August) of 2001, 2002, 2003, 2004, 2005, 2006 and 2007. Plant species are examined, studied, identified, and photographed. Representative voucher specimens are also collected. This is done sparingly to reduce the impact on the habitat. The Braun-Blanquet phytosociological approach is used, following Fujiwara (1987). Methodologies of Scott (1972), Komarkova (1979), Buttrick (1978) and Anderson (1970) are applied, all of which utilize phytosociological techniques in alpine or sub-Arctic environments. Tabular analysis of the floristic data is carried out using traditional sorting methods as well as algorithms in SAS 9.1 (2007) and JUICE software (Tichy, 2002). Nomenclature used in the study follows Hultén (1968) with updates noted in Table 2, based on ITIS (2007).

The principles of island biogeography (MacArthur and Wilson, 1967) are applied to nunataks through analysis of species richness, habitable surface area, and the distance of each nunatak from continuously vegetated land. The impact of occupied field stations on the alpine habitat is investigated through comparison of species richness on nunataks with field stations to the richness on sites without such stations.

Table 2

Nomenclatural Updates from the Integrated Taxonomic Information System (ITIS) as of 29 July 2007

Previously Accepted Name	***Newly Accepted Classification***
Achillea borealis	*Achillea millefolium* var. *borealis* (Bong.) Farw.
Agropyron violaceum	*Elymus alaskanus* ssp. *latiglumis* (Scribn. & J.G. Sm.) A. Löve
Agropyron violaceum ssp. *violaceum*	*Elymus alaskanus* ssp. *latiglumis* (Scribn. & J.G. Sm.) A. Löve
Agrostis borealis	*Agrostis mertensii* Trin.
Alnus crispa ssp. *sinuata*	*Alnus viridis* ssp. *sinuata* (Regel)A.&D. Löve
Antennaria atriceps	*Antennaria alpina* (L.) Gaertn.
Antennaria friesiana ssp. *compacta*	*Antennaria alpina* (L.) Gaertn.
Antennaria monocephala ssp. *monocephala* var. *monocephala*	*Antennaria monocephala* ssp. *monocephala* DC.
Antennaria pallida	*Antennaria alpina* (L.) Gaertn.
Arabis hirsuta ssp. *eschscholtziana*	*Arabis eschscholtziana* Andrz.
Arnica amplexicaulis ssp. *amplexicaulis*	*Arnica amplexicaulis* Nutt.
Aruncus sylvester	*Aruncus dioicus* var. *vulgaris* (Maxim.) Hara
Aster modestus	*Canadanthus modestus* (Lindl.) Nesom
Caltha palustris ssp. *asarifolia*	*Caltha palustris* var. *palustris* L.
Campanula lasiocarpa ssp. *lasiocarpa*	*Campanula lasiocarpa* Cham,
Carex atrata ssp. *atrosquamea*	*Carex atrosquama* Mackenzie
Carex dioica ssp. *gynocrates*	*Carex gynocrates* Wormsk. ex Drej.
Carex garberi ssp. *bifaria*	*Carex garberi* Fern.
Cassiope stelleriana	*Harrimanella stelleriana* (Pallas) Coville
Cladothamnus pyroliflorus	*Elliottia pyroliflorus* (Bong.) S.W. Brim & P.F. Stevens
Cryptogramma crispa ssp. *acrostichoides*	*Cryptogramma acrostichoides* R. Br.
Cryptogramma crispa var. *sitchensis*	*Cryptogramma sitchensis* (Rupr.) T. Moore
Dryas octopetala ssp. *octopetala* var. *octopetala*	*Dryas octopetala* var. *octopetala* L.
Epilobium adenocaulon	*Epilobium ciliatum* ssp. *ciliatum* Raf.
Epilobium angustifolium	*Chamerion angustifolium* ssp. *angustifolium* (L.) Holub
Epilobium glandulosum	*Epilobium ciliatum* ssp. *glandulosum* (Lehm.) Hoch & Raven
Epilobium latifolium	*Chamerion latifolium* (L.) Holub
Eriophorum scheuchzeri var. *tenuifolium*	*Eriophorum scheuchzeri* Hoppe
Fauria crista-galli	*Nephrophyllidium crista-galli* (Menzies ex Hook.) Gilg.
Festuca vipara	*Festuca viviparoidea* Krajina ex Pavlick
Gentiana propinqua	*Gentianella propinqua* ssp. *propinqua* (Richards.) J. Gillett
Heracleum lanatum	*Heracleum maximum* Bartr.
Juncus biglumis ssp. *albescens*	*Juncus biglumis* L.
Juncus triglumis ssp. *albescens*	*Juncus albescens* (Lange) Fern.
Luzula parviflora ssp. *parviflora* var. *melanocarpa*	*Luzula parviflora* ssp. *parviflora* (Ehrh.) Desv.
Luzula tundricola	*Luzula arctica* ssp. *latifolia* (Kjellm.) Porsild

Table 2 continued

Luzula wahlenbergii ssp. piperi	*Luzula piperi* (Coville) M. E. Jones
Lycopodium alpinum ssp. alpinum	*Lycopodium alpinum* L.
Lycopodium inundatum	*Lycopodiella inundata* (L.) Holub
Lycopodium sabinaefolium ssp. *sitchense* *Lycopodium selago* ssp. *appressum*	*Lycopodium sitchense* Rupr. *Huperzia selago* var. *densa* Trevisan
Lycopodium selago ssp. *selago*	*Huperzia selago* var. *selago* (L.) Bernh. ex Mart. & Schrank
Matricaria matricarioides	*Matricaria discoidea* DC.
Myosotis alpestris ssp. *asiatica*	*Myosotis alpestris* ssp. *alpestris* F.W. Schmidt
Oxycoccus palustris	*Vaccinium oxycoccos* L.
Petasites hyperboreus	*Petasites frigidus* var. *nivalis* (Greene) Cronq.
Phyllodoce aleutica	*Phyllodoce glanduliflora* (Hook.) Coville
Phyllodoce coerulea	*Phyllodoce caerulea* (L.) Bab.
Platanthera saccata	*Platanthera stricta* Lindl.
Poa alpigena	*Poa pratensis* ssp. *alpigena* (Fries ex Blytt) Hiitonen
Poa brachyanthera	*Poa pseudoabbreviata* Rosh.
Poa glauca ssp. *conferta*	*Poa glauca* ssp. *glauca* Vahl
Polypodium vulgare ssp. *occidentale*	*Polypodium glycyrrhiza* D.C. Eat.
Potentilla diversifolia var. *glaucophylla*	*Potentilla diversifolia* var. *diversifolia* Lehm.
Potentilla fruticosa	*Dasiphora floribunda* (Pursh) Kartesz, comb. nov. ined.
Sagina saginoides ssp. *acaulis*	*Sagina saginoides* (L.) Karst.
Salix arctica ssp. *crassijulis*	*Salix arctica* Pallas
Salix arctica ssp. *tortulosa (torulosa* also accepted cf. Hulten, 1968)	*Salix arctica* Pallas
Salix depressa	*Salix bebbiana* Sarg.
Salix glauca ssp. *glabrescens*	*Salix glauca* var. *villosa* (D. Don ex Hook.) Anderss.
Salix lasiandra	*Salix lucida* ssp. *lasiandra* (Benth.) E. Murr.
Salix reticulata var. *semicalva*	*Salix reticulata* ssp. *reticulata* L.
Sanguisorba stipulata	*Sanguisorba canadensis* L.
Saxifraga punctata	*Saxifraga nelsoniana* ssp. *nelsoniana* D. Don
Saxifraga punctata ssp. *pacifica*	*Saxifraga nelsoniana* ssp. *pacifica* (Hultén) Hultén
Saxifraga rivularis ssp. *flexuosa*	*Saxifraga rivularis* L.
Saxifraga rivularis var. *flexuosa*	*Saxifraga rivularis* L.
Sedum rosea ssp. *integrifolium*	*Rhodiola integrifolia* ssp. *integrifolia* Raf.
Senecio atropurpureus ssp. *tomentosus*	*Tephroseris atropurpurea* (Ledeb.) Holub
Solidago lepida	*Solidago canadensis* var. *lepida* (DC.) Cronq.
Stellaria monantha	*Stellaria longipes* Goldie
Streptopus amplexifolius ssp. *americanus*	*Streptopus amplexifolius* var. *amplexifolius* (L.) DC.
Trisetum spicatum ssp. *alaskanum*	*Trisetum spicatum* (L.) Richter
Trisetum spicatum ssp. *molle*	*Trisetum spicatum* (L.) Richter
Vaccinium uliginosum ssp. *alpinum*	*Vaccinium uliginosum* L.
Vaccinium uliginosum ssp. *microphyllum*	*Vaccinium uliginosum* L.
Vahlodea atropurpurea ssp. *latifolia*	*Vahlodea atropurpurea* (Wahlenb.) Fries ex Hartman
Veronica wormskjoldii ssp. *alternifolia*	*Veronica wormskjoldii* Roemer & J.A. Schultes
Vulpia megalura	*Vulpia myuros* (L.) K.C. Gmel.

Updates to taxonomical nomenclature are presented in the above table. The nomenclatural style of Hultén is followed throughout with the exception of all specific epithets presented in lower case, including those derived from proper nouns.

The bulk of the data is phytosociological. This methodology is recommended by three different researchers familiar with the study region and its logistical difficulties. Information on the presence and absence of species is recorded, including the relative abundance/cover, and sociability values for each species. A frequency/constancy table and partial sorted table are developed from the data (contact author for complete information). This determines the number of sampling units or relevés in which each species is present. Species are separated by fidelity classes, i.e., the percentage of relevés in which each species occurs. The species are then separated into the categories of single occurrences, companion species, and differential species. Line transects and species-area-curves are carried out at most of the same locations where relevés are taken. The number of species on the individual nunataks is then correlated with distance of the nunataks from the continuously vegetated mainland. Additionally, the surface area of the nunataks is correlated with the number of different species on each nunatak. A regression with the response variable of richness, and the control variables of distance, area, aspect, temperature, latitude and elevation, is performed to compare the strength and influence of each control variable.

The change in species richness (number of different species per nunatak) is also correlated with recorded changes in average temperature of the study sites and region for the time periods for which the data are available, i.e., 1949, 1952, 1954, and 1978 (Anderson, 1979; Alaska Climate Research Center, 2007; Miller, 1949, 1952, 1955,1956, 1985; Miller & Anderson, 1974; Pelto & Miller, 1990; Heusser, 1954a & b; Ward, 1951). Data from the historical studies conducted in the region during these years is compared with data from the current study. A species list for each study is compiled and the average temperature for the icefield region for the time period of each of the studies is determined.

The average winter low temperature for each site is determined. The sites in the historical studies are not well noted. It is difficult, therefore, to determine whether the same nunataks were sampled as in previous studies. However, what is similar, and of significance, is that the species are limited to nunataks specifically on the Juneau Icefield, making the studies comparable.

Diversity and/or richness is considered and measured. Most diversity indices involve an actual number of individual plants of a given species in a plot. The phytosociological data do not provide absolute numbers of individuals of a single species. Rather, they provide relative abundance/cover values for each species. Richness is representative of diversity and is more defendable and clear than other measures of diversity, such as indices that use abundance variables. Diversity indices, such as those of Jaccard, Simpson, and Shannon-Weiner, incorporate an abundance or evenness variable. If equal areas or an equal number of equal-sized stands are in the site comparisons, species richness is a more than ample measure of diversity.

Phytosociological Analysis

The Braun-Blanquet relevé approach is based on the use of floristic presence, absence, and abundance data (Braun-Blanquet, Fuller, & Conrad, 1965). The method is phytosociologic and is chosen as the core of this field investigation in southeastern Alaska. Phytosociology involves grouping plant species into recognizable units which are present and identifiable across a lateral extent (Kent & Coker, 1996). The relevé method, utilized here, is that derived from Professor Braun-Blanquet and is known as the Zurich-Montpellier School of Phytosociology.

Although varying slightly in their focus and analysis techniques, many of the schools of phytosociology concentrate on the vegetation of montane, subalpine, alpine, and high-latitude regions such as those in the Central Alps, Sweden, and the Scottish Highlands. Braun-Blanquet carried out his seminal studies in the French Mediterranean Region in an effort to develop a global vegetation classification scheme (Braun-Blanquet et al., 1965). van der Maarel (1978), compares Braun-Blanquet's impact on phytosociology to the impact of J.S. Bach on the history of music.

The relevé or aufnahme is the basic sampling unit of phytosociology. Unlike most vegetation sampling techniques, the location of a relevé is non-random and based on the presence of representative vegetation units and species assemblages. The stand selected is homogenous and the size of a stand must adequately represent all of the species present in the unit (Braun-Blanquet et al., 1965; Kent & Coker, 1996; Mueller-Dombois & Ellenberg, 1974). Species-area curves are used to determine the minimal sample size for a representative vegetation unit. The procedure of physically executing the relevé and collecting the raw data includes noting both an index of abundance and sociability for each species present. Abundance values, based on percent cover, are defined in Table 3. Sociability values are defined using the scale presented in Table 4.

Table 3

Abundance Values

Abundance	Cover
1	<5%
2	5-25%
3	26-50%
4	51-75%
5	76-100%

Table 4

Sociability Values

Sociability	
1	Solitary
2	In small tufts
3	In larger patches
4	Carpet covering one-half of relevé area
5	Continuous carpet

Every sampling technique has shortcomings. Some concerns with the Braun-Blanquet approach include difficulty in defining homogenous units in mosaic-like landscapes and difficulty in defining the breaking point of species-area curves used to determine the adequate size of sample units (Kent & Coker, 1996). The practice of discarding relevés which do not fall into the determined associations is commonly criticized. These relevés represent the noda or transitional ecotones, initially described by Poore (1955). The ecotones are present between the better defined and more easily recognized plant communities. They are retained as such in this study. Relevés with several species in common are grouped into associations which define plant community types. Individual associations and communities are usually considered abstract if precise location data are not indicated (Kent & Coker, 1996).

Analysis of relevés involves tabulating and comparing stands and species within particular stands. The procedure starts with determination of the frequency of a given species in consecutive relevés, referred to as the *constancy* of a species. A raw data table is developed with the sum of the relevés for a given study or region (contact author for complete information). Species are categorized by frequency within the raw table (contact author for complete information). Differential species are those that have a medium to low level of frequency in the raw table and actually differentiate communities by their presence. Normally, two to eight differential species, identified in the raw data table, are diagnostic in grouping species. Character species are those species in abundance classes 3, 4, and 5, which normally have constancy values greater than or equal to 80% in the tabular analysis of the relevés for a given study region. Partial or extract tables are developed by grouping relevés with the same or similar differential species. The related differential species are placed next to one another to make the ordered partial table (contact author for complete information).

All species which are not differential are referred to as the companion species and are used to continue to sort the raw data table into the differentiated table. Plant communities or associations should be evident in the differentiated table. Synoptic tables summarize the information on each determined plant association. Within the synoptic table each species is described by a constancy percentage. Syntaxonomy is a set of classification rules, based on the international code of botanical nomenclature, which ranks communities on the basis of similar species and the overall relationship among determined associations. Environmental data including elevation, substrate, aspect, exposure and slope, are used to characterize the communities and to classify them in accordance with the Code of Phytosociological Nomenclature (Barkman, Moravec, & Rauschert, 1986).

Species in an association are often described by *fidelity*, or their regularity of occurrence, which is not synonymous with constancy. Degrees of fidelity are described in Table 5.

Table 5

Fidelity Values

Fidelity	Description
1	Accidental
2	Indifferent
3	Preferential
4	Selective
5	Exclusive

Many arguments exist against the concept of fidelity, in particular, its dependence on physical geography and the size of the region sampled (Kent & Coker, 1996).

Partial Table Sorting

In the process of phytosociological tabular analysis, the species matrix and analysis tables are used to pare down the data and recognize models for species associations and communities across the study region. The highest frequency species remaining in the table, after removing the initial high frequency species (present in only 61 % of the relevés), have a frequency of 37 % and are present in 37 % of the relevés. Removing the species which occur too frequently to be useful for classification results in removal of only one species. The rarest species are also removed.

All relevés are entered into one raw table, rather than sorted into tables per nunatak, to assess true communities and not simply define nunatak species assemblages. The later was considered due the geographical breadth of the region and the very different climate on the northern sector than on the southern. Sorting smaller segments of the table is one means of checking the clusters developed in the table as a whole. Greater confidence in the communities results from the presence of associations in both the whole table and the sub-tables. Grouping all of the relevés from a nunatak next to one another, and grouping species that are known to occur together, are initial sorting techniques. The relevé names are standardized and organized into groups by sites. Relevés from the same nunatak are placed next to one another and the relevés are organized from left to right in the columns as they occur on a southwest to northeast gradient across the region.

In some explanations, differential species are defined as those in frequency class III or as species which occur in 41-60% of the plots. Fujiwara (1987) states that it is possible for an association to have no character species if the sampling location is at the distributional (i.e., northern or southern) or altitudinal (i.e., in mountains) limit for a community. Additionally, successional communities may represent only fragments of associations. This variation may explain some of the initial difficulties in identifying clusters in the partial table.

Tabular Analysis and Sorting in Juice and SAS

Juice and SAS 9.1 use principal components analysis to reduce dimensionality. Eigenvalues of the correlation matrix are computed. The number of eigenvalues with magnitudes greater than one determines the number of clusters. Statistical clustering using SAS software and an algorithm with the species matrix table, has the advantage of eliminating subjectivity in the sorting process and giving an estimate of error, along with the probability of each species occurring with other species. Seventeen factor variables were used for input following the Flexible-beta method. TWINSPAN (Two-way Indicator Species Analysis) is utilized in JUICE. TWINSPAN is a numerical sorting method which utilizes a reciprocal averaging algorithm (Tichy, 2002). TWINSPAN and JUICE together use principle components analysis to derive eigenvalues and determine the number of clusters.

Cut levels, or the number of frequency categories the species fall into, are defined as three: with 0 for <5%, 5 for 5-25%, and 25 for 25-50%. Abundance 4 and 5 species are removed from the sorting process. Minimum group size is defined as 5 and the maximum level of divisions as 3. Separation among clusters is displayed in a synoptic table with percentage of constancy.

Sequential Steps Taken in Relevé Analysis

The following steps describe the procedure used, with the exception of the use of SAS 9.1 and JUICE for some of the sorting steps described in #s 20-27. The details of using SAS and JUICE are described under the corresponding sections on tabular analysis. For critical consideration, these methodological details are reviewed.

1. The primary methodologies of phytosociology, line transects and species-area curves are selected. These methods are recommended by E.O. Box, Donald Walker, J.H. Anderson, and D.F. Murray.
2. Field work is carried out in the summers of 2001, 2002, 2003, 2004, 2005, 2006 and 2007. A total of 107 relevés are carried out at more than 17 different locations across the region from southeast Alaska and northwest British Columbia.
3. Voucher specimens from relevés are pressed and dried in newspaper in the field and tentative identifications noted, usually with family, genus and tentative species names. Collection date, collector, habitat, elevation, associates, color, odor, habit, soil, aspect, slope, exposure and substrate are noted with each specimen.
4. Voucher specimens collected with field work are confirmed with experts out of the field. Species lists and identification confirmations are made and recorded with specimen numbers in species identification confirmation notebooks.
5. The raw species data table is completed with data from the species identification confirmation notebooks. For each specimen; the location, elevation, habitat, observations, associates, aspect, slope, the relevé the species is found within, plant family, plant genus, and dates of collection are included in the appropriate columns of the table.
6. A data table of peripheral relevé data is developed to include data other than species, abundance, and dispersion/sociability values. The peripheral relevé data includes the number of shrubs, herbs, and lichens in each relevé; the percent cover of each physiognomic type, the elevation of the relevé, location, aspect, slope, soil type, exposure, relevé size; the percent the relevé represents of the total stand, topography,

sun and wind exposure, soil depth, habitat disturbance, soil moisture, general vegetation type, collection date and relevé personnel.

7. Data from species checks and identification confirmations in the large species spreadsheet are organized by relevé, date and location; and then matched with the appropriate relevé sheet. This insures species noted in the field are identified correctly.
8. The species raw data spreadsheet is organized by relevés.
9. A presence/absence spreadsheet-matrix is developed with relevé numbers across the header row and species names down the header column.
10. The updated relevé sheets are used to augment the presence/absence matrix spreadsheet. Abundance and sociability values replace the presence absence data.
11. After the abundance and sociability data are included in the working raw table, the table is reorganized and alphabetized by genus and species. Duplicate species entries for a single relevé are then deleted and abundance and sociability values shifted up the columns of the table.
12. The raw table is checked for correctness of family name entries.
13. Following refinement of duplicate species listings, the working raw table is then copied to a new document where sociability values are removed, leaving an abundance only raw table. In the original raw table, the abundance values are removed to make a sociability only table.
14. The revised raw table is rechecked for duplication. Abundance values are separated from the sociability/dispersion values by rounding the cells to zero decimal places. This is possible because no dispersion/sociability values are greater than four and

therefore all numbers round to the first whole number of the previous decimal number.

15. The new raw table with abundance/cover values only, is placed in a new worksheet. A formula is then used to sum the cover values for each species. If the cover/abundance values are greater than one, the sum formula is not accurate for frequency. However, many species have multiple abundance/cover values of one. The rows are reviewed for cells with cover/abundance values greater than one and the frequency values corrected as needed.
16. A frequency table with species sorted by the total number of relevés in which they occur is developed. This is the raw table sorted vertically into descending order of species frequency (how many relevés in which a species appears). Care is taken to paste the corrected frequency value in a cell without the sum formula to avoid corrected values returning to uncorrected values. All values are re-checked to make sure the correct frequency is found. The sum values are the sum of the whole numbers. The sums are rechecked to ensure correct values. Excel Software may see values that are not visible. It is necessary to go to the ‘tools’, and then ‘options’ menu and choose ‘precision as displayed’ to avoid the decimal number from the original abundance/sociability value from being calculated with the preliminary frequency sum values. ‘Count’ may also be utilized to determine frequency. In shifting rows and columns, frequency formulas may move and some species may appear to have a frequency of ‘1’ when they do not. This is circumvented by re-entering the formulas periodically during sorting.

17. Species richness per relevé is calculated by counting the number of species per relevé using the count formula in Excel. A row is added below the last species in the table and labeled ‘species richness’. In the last cell of the first relevé column, the species richness is calculated. The whole column, minus the relevé name is included in the sum formula. The formula is then copied to the rest of the species richness rows by highlighting the row with the formula and selecting ‘fill to the right’. The table is then sorted by species richness. To do this the relevé identifiers at the top of the table are highlighted over to the frequency column, and the columns are sorted from left to right in descending order by species richness.
18. The frequency table is reduced by removing all species that occur only once (in one relevé, and have a frequency of one). These provide nothing for the clustering table (the next step). The constancy percentages are then calculated for the remaining species. They assist in determining the constancy class in which the species should be placed. This further separates the species into three categories: single occurrences, differential species, and companion species. The constancy value or percentage is determined by placing another column to the right of the frequency column and inserting the formula: (frequency/total number of relevés) x 100. The total number of relevés in the table is 107. Differential species are those which are present in 21-80% of the relevés (Fujiwara, 1987). The highest constancy value in this study is 60%. Species with constancy between 21 and 60 % are defined as the differential species.
19. The frequency table is further reduced by removing species which occur too often to be indicators, usually denoted with a frequency of > 80% (fidelity of V). The most common species in this study have a constancy of less than 80%. Rather than

omitting these species, they fall into the category of differential species. The remaining species with constancies between 20 and 1 % are identified as companion species.

20. If a species is present in several relevés in a row, an association is represented. Groups of associations represent communities. Associations define plant communities.
21. Sorting begins with the refined and smaller frequency table.
22. The frequency table is sorted for clusters to form a cluster table.
23. Relevés which do not seem to fit should not be discarded, as they likely represent noda of change or ecotones.
24. Species which are known to occur together are grouped. Differential species are used to identify groups.
25. From the frequency table, partial extract tables are made by grouping relevés with the same or similar differential species. Related differential species are placed next to one another in the partial ordered table.
26. Relevés with similar companion species are used to further sort the table.
27. A synoptic table is developed which defines communities and character species.

Line Transects

Line transects are used to augment and check the phytosociological data**.** The percent cover of species along the line transects may be compared to frequency classes in the phytosociology work. Frequency is the most straightforward means of comparing the relevés and line transects. The line transect data may be utilized in a number of applications including presence and absence of species along the transects.

The cover values are transposed to percentages of the total length of the transect and then to Braun-Blanquet cover values. Substrate is noted when the ground cover includes soil and/or rock instead of vegetative material. The values for the species and substrate percent cover are rounded for ease in summing the species present on multiple segments of the line. The data are then sorted in descending order. The sum of the percentages of the cover of a species and the cover of substrate often add up to less than 100, as a result of standard and random error. In most cases, the missing cover value is explained by unaccounted rock substrate.

Species-Area Curves

Scatter plots are produced using the number of species and the corresponding area for a given stand on a given site. A linear regression is performed to find the correlation coefficient (R^2 value), which indicates the strength of the relationship between the number of species and the area of a nunatak.

Modeling Principles

Abiding by the principle of Occam's Razor and parsimony, the model with the fewest variables is the most accurate (Motulsky, 1995). A straight line may not be the best fit for the nature of the data from the nunatak study sites. Plots of species richness versus distance, elevation, average winter low temperature, latitude, and surface area, are considered in model development. The plots allow determination of the control variables with the greatest influence on the response variable, species richness. The results and predictive value of the model are expressed in a surface graph from which the richness may be determined on a site where there has been no botanical ground truthing or surveying (Figure 21).

Some of the variables could be confounding and influence one another. For example, the surface area of a nunatak is influenced by temperature, i.e., via the ablation of the glacier surface ice and the coinciding greater surface area available on a nunatak for vegetation growth. The average temperature is influenced by elevation, latitude, and aspect. Area may be influenced by distance from the mainland. Higher temperatures may result in less snow and hence greater surface area for vegetation growth. Correlations alone can be spurious and not representative of what is truly occurring in a natural system. Because of this, it is useful to build a model which incorporates the infuence of several variables. Regression is used in constructing a model to account for the control one variable may have on another.

In building the model, it is important to observe each variable in relation to richness on a two-variable scatter plot. The correlation coefficient (R^2) indicates that the 'x' variable (independent) explains a given percent of the variation in the 'y' variable (dependent).

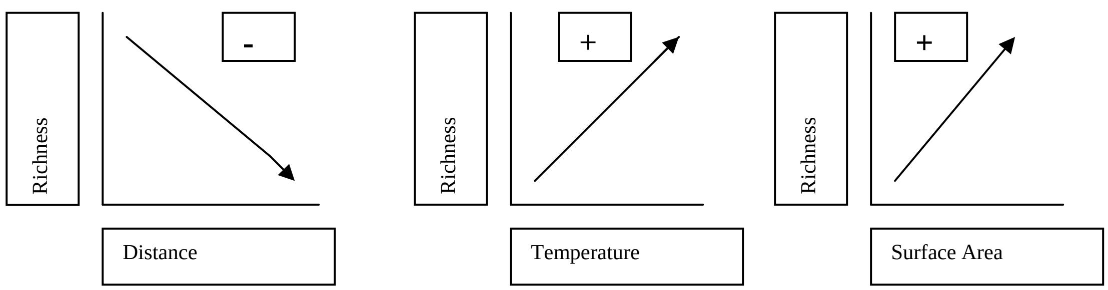


Figure 5. Hypothetical Relationships between Dependent and Independent Variables.

Finding the value of R^2, for each of the above examples, aids in determining how the variables are weighted in the developing model.

Hypothetical Models

Model 1: Richness ~ Temperature + Surface Area + Distance + Latitude + Elevation

Model 2: Richness ~ Temperature + Surface Area + Distance

Model 3: Richness ~ Elevation

The log of the linear trend line is found to represent the best fit for the richness data. Using the log function eliminates extreme values and pares down the data set, with a mathematical one-to-one relationship. Many variables contribute to species richness. The question is which variable contributes to richness to the greatest extent. In observing the effect of individual variables, it is important also to realize that a curved trend-line may be a more realistic fit to the data than a linear trend-line.

Species richness is used as a measure of diversity in this study. The choice of richness in this sense relates to its simplicity and the ease in comparing the parameter to other data sets. Variables controlling richness are temperature, distance from the continuously vegetated land, elevation, slope, aspect, soil development (texture, depth, nutrients), latitude, average winter temperature (in particular, winter low temperature), and surface area of the nunataks.

The developed model allows the prediction of species richness on an unstudied nunatak, using what has been determined about the effects of temperature, elevation, distance, and latitude. The most accurate model represents maximum variation with the fewest variables.

Latitude and Elevation Regressions

Log latitude, log elevation, and log aspect are not effective for use as control variables in the model due to the limited variability in the original form of these variables. A histogram is plotted with the values for richness (Figure 6). The histogram indicates an asymmetrical data set of non-normal data. As a result, the natural logs of richness are used.

In the model, the residuals, or the difference between the observed and predicted values, should fall between -3 and 2. The F statistic for significance should be less than 0.05 and the correlation coefficient, R^2, should be greater than 50 % (Motulsky, 1995).

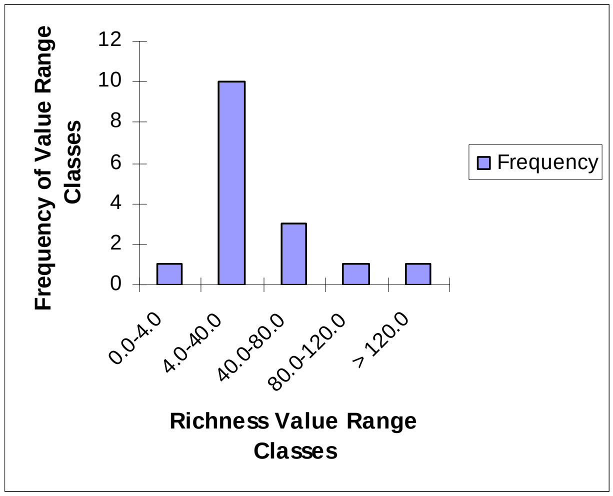


Figure 6. Histogram of Species Richness Values.

The frequency of richness values in a given range is represented.

Just as richness can be predicted from area, area may be predicted from richness. The best models were developed without inclusion of the intercept, which indicates the value of y, the response variable or richness, when x, the control variable (namely area and latitude) is near zero. The logarithmic fit to the model indicates an exponential relationship between richness and area. As the area increases, the richness increases exponentially. Although the exponential increase does not hold for larger values, the model and relationship are reasonable for the area values in this data set.

Temperature Data Formatting

The dry adiabatic lapse rate is 0.98 ° C per 100 m or 9.8 ° C per 1000 m. The dry adiabatic lapse rate is constant while the wet adiabatic lapse rate fluctuates with changes in temperature and is represented by a range; i.e., approximately 0.55 ˚ C to 0.98 ˚ C per 100 m in southeast Alaska (Ainsworth, personal communication, 2007). Each site without temperature data is compared to the nearest site with temperature data. The dry adiabatic lapse rate of 9.8˚ C per 1000 m (or the high end of the wet adiabatic lapse rate range) is used along with the elevation difference between the two sites to interpolate approximate temperature values for the sites without temperature data. This provides a reasonable estimate of the average maximum and minimum yearly temperatures at each site (Ainsworth, personal communication, 2007; Meentemeyer, personal communication, 2007; Miller, personal communication, 2007). These sites are Seventeen A, the Tarn Lake, the Bog Pond, Site Fourteen, Site Thirteen, and Site Eighteen B. An exception is Site Seventeen A, which is affected strongly by katabatic winds. The adiabatic lapse rate alone does not completely account for the temperature difference between Site Seventeen A and the nearest site at a higher elevation for which temperature data are available. Additionally, since the dry lapse rate (the high end of the wet adiabatic lapse rate range) is used, the interpolated values are assumed to be closer to the high end of the range, due to the predominace of low pressure systems and significant precipitation in southeast Alaska.

Temperature Per Site 1999-2006

The site Seventeen maximum and minimum calculations are made from data for the years 1998-1999, 1999-2000, 2000-2001, 2001-2002, 2002-2003, and 2004-2005. The 2000-2001 data include only the months of February and March. The 2005-2006 data were not collected due to instrument error.

The Site Ten averages are made from data for the years 1998-1999, 1999-2000, 2001-2002, 2002-2003, 2003-2004, 2004-2005, and 2005-2006. The Site Ten 2000-2001 data are not available due to instrument error.

The Sunday Point Site and Taku Northwest Point (TNW) data used for the maximum and minimum temperature calculations, include the years of 2003-2004, 2004-2005, and 2005-2006. Digital data-logging temperature recording devices have been placed at these sites for the purpose of this study. Temperature data has not been collected from these sites previously. To augment future studies, temperature data collection will continue at the sites beyond the time period of the current investigation.

Site Nine A minimum and maximum calculations are made using data from the years 1998-1999, 2000-2001, 2001-2002, 2002-2003, 2003-2004, and 2005-2006. The data from the years 1999-2000 and 2004-2004 are not available due to instrument error.

Site Eighteen maximum and minimum calculations are made using data from the years 1998-1999, 2000-2001, 2001-2002, 2002-2003, and 2005-2006. Data from the years 1999-2000, 2003-2005 and 2004-2005 are not available.

Site Twenty-six maximum and minimum values are calculated from temperature data from the years 1998-1999, 2000-2001, 2001-2002, 2002-2003, 2003-2004, and 2005-2006. Data from the years 1999-2000 and 2004-2005 are not available.

Site Twenty-nine maximum and minimum calculations are made from data from the years 2000-2001, 2001-2002, 2002-2003, and 2005-2006. Temperature data from the years 2003-2004 and 2004-2005 are not available.

The Site Thirty maximum and minimum values are calculated with data from the years 2000-2001, 2001-2002, 2002-2003, 2003-2004, 2004-2005, and 2005-2006. Data from the years 1998-1999 and 1999-2000 are not available.

Data for Site Thirteen are interpolated using the adiabatic lapse rate and the elevation difference between Site Thirteen and the nearest comparable site. Temperature data from Site Seventeen are used to interpolate the temperature for Sites Thirteen, Fourteen, the Bog Pond, Site Seventeen A, the Tarn Lake, and Ptarmigan Ridge.

Growing-Season Data

Length of the growing-season per site is defined as the number of days between 1 May and 31 August each year with an average daily temperature equal to or greater than 5° C (41º F). The maximum potential growing-season length is 123 days. The days meeting these requirements are not necessarily continuous days, as is often assumed in reference to the term ‘growing-season’. Most of the digital data logging temperature recorders are programmed to record either every hour or every three hours. This results in 8 to 24 readings per day and between 3000 and 8818 temperature readings per site, per year.

Each year of temperature data for each site for the last five to ten years, depending on the data available for a particular site, is reviewed with special emphasis on the recordings between 1 May and 31 August. The number of days with an average temperature equal to or greater than 5º C is determined.

Data from 2004-2005 for Site Twenty-six are not available. Site Twenty-six 2000-2001 data are used in their place. Data from 2004-2005 are not available for Site Nine A. Site Nine A 2000-2001 data are used in their place. Data from 2002-2003 and 2000-2001 are not available for Site Ten. The Site Ten 1999-2000 and 2000-2001 data are used in their place. Data from 2003-2004 for Site Eighteen are not available. Data for Site Eighteen from 1998-1999 are used in their place. Data from Site Seventeen are not available for 2005-2006. Data from Site Seventeen for 1999-2000 are used in their place.

Data from Site Twenty-nine are not available for 2003-2004 and are replaced with Site Twenty-nine 1999-2000 data. Data from Site Twenty-nine are not available for the years 2004-2006. Average growing-season length for Site Twenty-nine includes the years 2001-2003 and 1999-2000.

Data from the Sunday Point (SP) and Taku Northwest (TNW) Sites are not available for the years 2001-2003. Data loggers were first deployed at these sites in 2003. Data collection at the Sunday Point and Taku Northwest Sites continues at present. Average growing-season length for these sites is based on the years 2003-2006.

Compilation of Temperature and Richness Data for Studies from 1948- Present

Temperature data from the Alaska Climate Research Center for the city of Juneau are used to make consistent calculations for the lengthy period between 1948 and 2007. Data from Chamberlain's Study are obtained from Miller (1949, 1952). Other data utilized for historical comparisons are from Ward (1951), Heusser (1954), and Anderson (1979). Accumulation and ablation season average temperature records on the Juneau Icefield Sites are also consulted in determining the mean annual temperatures from 1948 to the present (Miller, 1985; Pelto & Miller, 1990).

Aspect Data Compilation

The dominant aspect for the relevés taken on each of the study sites is utilized in relating the variable to species richness. The quantity of degrees from south of each site’s dominant aspect is compared with the species richness of the site. The dominant azimuth direction relative to south is used in order to reduce variability and more clearly visualize the relationship between aspect and richness. A vector plot is developed in which the length of the vector corresponds to the relative species richness for the site. The vectors for each site are then organized on a plot with their orientation representing the magnitude, in degrees from south, of the dominant aspect of the site.

Comparison of Sites in Historical Studies and the Current Study

Direct comparison of two sites botanically sampled in the current study and in historical studies is possible with confidence. The historical studies do not, however, give sufficient information on the collection sites, or their specific coordinates, to know, with certainty, that the sites in the past studies are the same as those sampled in the current study. Map comparisons and narrative descriptions of the sites are used to find the commonality between the studies (Miller, 1950; Ward, 1951). For example, Sites Ten and Thirteen of the current study were botanically investigated by Ward in 1949 and 1950, providing some general comparisons with respect to the flora of the region as a whole.

Ptarmigan Ridge Geobotany

On the Juneau Icefield, the last full Pleistocene glacial maximum of the late Wisconsinan, occurred between 11,000 and 12,000 years Before Present (BP) (Miller 1956, 1963), with noted variations observed at specific localities in the region. Within the larger Pleistocene time frame, the Thermal Maximum and Neoglacial affected surfaces are the author’s primary soil and vegetation concern. Geobotanical observations on the Ptarmigan Ridge provide a documented framework for interpretation of post-glacial maximum vegetation succession at locations in the adjacent Coastal Cordillera.

CHAPTER 4

RESULTS AND ANALYSES

"A life in harmony with nature, the love of truth and virtue, will purge the eyes to understand her text. By degrees we may come to know the primitive sense of the permanent objects of nature, so that the world shall be to us an open book, and every form significant of its hidden life and cause."

Ralph Waldo Emerson from The American Scholar 1837

Phytosociology

Clusters and subsequent vegetation communities are identified following tabular analysis. A partial sorted table, with frequency and constancy values per species, and richness values per relevé, is available from the author. The Raw Table, from which the partial sorted table is derived, is also available from the author. Algorithms in SAS and JUICE Software are applied to the data from the raw and partial sorted tables to arrive at the clusters presented in Tables 6, 7, 8, and 9. Both programs define seven clusters or communities.

The JUICE cluster one (Table 8) comprises species that inhabit exposed rock outcrops such as those of Site Thirteen on the Nugget Ridge. JUICE cluster one is very similar to the SAS cluster five, and includes *Epilobium latifolium*, *Oxyria digyna*, *Phyllodoce empetriformis,* and *Epilobium anagallidifolium.*

JUICE cluster two (Table 8) is very similar to SAS cluster four and is typified by species on south aspect steep slopes on small area sites such as Taku Northwest Point and Site Eighteen. The community includes *Poa paucispicula*, *Carex pyrenaica* ssp. *micropoda, and Cassiope stelleriana.*

Table 6

Clusters Representing Communities from JUICE

Cluster 1	**cluster 4**	**cluster 5**	**cluster 6**	**cluster 7**
Antennaria pallida	Antennaria atriceps	Antennaria media	Agrostis borealis	Antennaria monocephala
Carex macrochaeta	Antennaria media	Antennaria monocephala	Antennaria atriceps	Arctostaphylos rubra
Cryptogramma crispa	Arctostaphylos rubra	Antennaria pallida	Artemisia arctica ssp. arctica	Artemisia arctica ssp. arctica
Epilobium anagalladifolium	Arnica amplexicaulis	Artemisia arctica ssp. arctica	Campanula lasiocarpa	Campanula rotundifolia
Epilobium latifolium	Artemisia arctica ssp. arctica	Campanula lasiocarpa	Cardamine bellidifolia	Cardamine bellidifolia
Juncus mertensiana	Astragalus alpinus ssp. alpinus	Campanula rotundifolia	Carex circinata	Carex circinata
Oxyria digyna	Campanula rotundifolia	Cardamine bellidifolia	Carex macrochaeta	Carex macrochaeta
Phyllodoce empetriformis	Cardamine bellidifolia	Carex circinata	Carex nardina	Carex membranacea
Poa glauca	Carex circinata	Carex macrochaeta	Carex nigricans	Carex nardina
Saxifraga lyallii	Carex macrochaeta	Carex nigricans	Carex praticola	Carex nigricans
Saxifraga oppositifolia	Carex membranacea	Cassiope stelleriana	Cassiope tetragona	Cassiope tetragona
Sedum rosea ssp. integrifolium	Carex praticola	Cassiope tetragona ssp. tetragona	Cassiope stelleriana	Cassiope stelleriana
	Carex pyrenaica ssp. micropoda	Castilleja unalaschensis	Cornus canadensis	Cryptogramma crispa
cluster 2	Cassiope tetragona	Cornus canadensis	Cryptogramma crispa	Empetrum nigrum
Poa paucispicula	Cassiope stelleriana	Cryptogramma crispa	Deschampsia danthonioides	Gentiana glauca
Carex pyrenaica ssp. micropoda	Cassiope tetragona ssp. tetragona	Deschampsia danthonioides	Deschampsia elongata	Hierochloë alpina
	Castilleja unalaschensis	Empetrum nigrum ssp. nigrum	Empetrum nigrum ssp. hermaphroditum	Juncus biglumis
cluster 3	Cerastium beeringianum	Empetrum nigrum	Empetrum nigrum ssp. nigrum	Juncus ensifolius
Achillea borealis	Cornus canadensis	Epilobium anagalladifolium	Empetrum nigrum	Juncus mertensiana
Aconitum delphinium	Cryptogramma crispa	Epilobium latifolium	Epilobium anagalladifolium	Luetkea pectinata
Astragalus alpinus ssp. alpinus	Deschampsia danthonioides	Equisetum arvense	Epilobium hornemannii	Luzula parviflora ssp. parviflora
Campanula rotundifolia	Empetrum nigrum ssp. hermaphroditum	Erigeron purpuratus	Epilobium latifolium	Luzula arcuata
Cardamine bellidifolia	Empetrum nigrum ssp. nigrum	Gentiana glauca	Heuchera glabra	Luzula arcuata ssp. unalaschensis
Carex nigricans	Empetrum nigrum	Heuchera glabra	Hierochloë alpina	Luzula multiflora ssp. kobayasii
Carex pyrenaica ssp. micropoda	Epilobium anagalladifolium	Hierochloë alpina	Juncus biglumis	Lycopodium alpinum
Cerastium beeringianum	Epilobium angustifolium	Juncus drummondii	Juncus drummondii	Lycopodium selago ssp. selago
Epilobium anagalladifolium	Epilobium hornemanni	Juncus falcatus ssp. sitchensis	Juncus ensifolius	Phyllodoce aleutica
Epilobium latifolium	Epilobium latifolium	Loiseleuria procumbens	Juncus falcatus ssp. sitchensis	Poa alpigena
Luetkea pectinata	Equisetum arvense	Luetkea pectinata	Juncus mertensiana	Poa arctica arctica
Luzula multiflora ssp. kobayasii	Erigeron purpuratus	Lupinus nootkatensis	Juncus triglumis ssp. albescens	Poa brachyanthera
Oxyria digyna	Heuchera glabra	Luzula parviflora ssp. parviflora	Loiseleuria procumbens	Poa glauca
Phyllodoce aleutica	Hierochloë alpina	Luzula arcuata ssp. unalaschensis	Luetkea pectinata	Poa paucispicula
Poa arctica arctica	Juncus biglumis	Luzula multiflora ssp. kobayasii	Lupinus nootkatensis	Potentilla villosa
Poa brachyanthera	Juncus drummondii	Luzula spicata	Luzula parviflora ssp. parviflora	Salix reticulata
Poa paucispicula	Juncus falcatus ssp. sitchenis	Luzula tundricola	Luzula arcuata ssp. unalaschensis	Saxifraga bronchialis
Poa stenantha	Juncus mertensiana	Luzula wahlenbergii	Luzula multiflora ssp. multiflora	Saxifraga ferruginea
Polemonium pulcherrimum	Juncus triglumis ssp. albescens	Lycopodium alpinum	Luzula tundricola	Saxifraga punctata
Potentilla uniflora	Loiseleuria procumbens	Lycopodium clavatum	Luzula wahlenbergii	Saxifraga punctata ssp. pacifica
Salix reticulata ssp. reticulata	Luetkea pectinata	Lycopodium selago	Lycopodium alpinum	Trientalis europaea
Saxifraga bronchialis	Lupinus arcticus	Lycopodium selago ssp. selago	Lycopodium clavatum	Trisetum spicatum
Saxifraga ferruginea	Lupinus nootkatensis	Phyllodoce aleutica	Phyllodoce aleutica	Trisetum spicatum ssp.alaskanum
Trisetum spicatum ssp. spicatum	Luzula parviflora ssp. parviflora	Poa glauca	Poa brachyanthera	Trisetum spicatum ssp. molle
Vaccinium ovalifolium	Luzula arcuata	Poa paucispicula	Polemonium pulcherrimum	Trisetum spicatum ssp. spicatum
	Luzula arcuata ssp. unalaschensis	Potentilla hyparctica	Salix arctica	Vaccinium uliginosum
	Luzula spicata	Potentilla villosa	Salix fuscescens	
	Luzula tundricola	Salix reticulata	Salix reticulata	
	Luzula wahlenbergii	Salix reticulata ssp. reticulata	Salix reticulata ssp. reticulata	
	Lycopodium alpinum	Salix stolonifera	Saxifraga bronchialis	
	Lycopodium selago ssp. selago	Saxifraga bronchialis	Saxifraga ferruginea	
	Oxyria digyna	Saxifraga ferruginea	Saxifraga punctata	
	Phyllodoce aleutica	Saxifraga lyallii	Sibbaldia procumbens	
	Phyllodoce empetriformis	Saxifraga oppositifolia	Trientalis europaea	
	Poa alpigena	Saxifraga rivularis	Trisetum spicatum	
	Poa arctica arctica	Sedum rosea ssp. integrifolium	Tsuga heterophylla	
	Poa brachyanthera	Sibbaldia procumbens	Vaccinium membraceum	
	Poa glauca	Silene acaulis ssp. acaulis	Vaccinium ovalifolium	
	Poa leptocoma	Solidago multiradiata	Vaccinium parvifolium	
	Poa paucispicula	Trientalis europaea	Vaccinium uliginosum	
	Poa pratensis	Trisetum spicatum		
	Poa stenantha	Trisetum spicatum ssp. alaskanum		
	Polemonium pulcherrimum	Trisetum spicatum ssp. spicatum		
	Potentilla villosa	Tsuga heterophylla		
	Salix arctica	Vaccinium uliginosum		
	Salix reticulata			
	Salix reticulata ssp. reticulata			
	Salix stolonifera			
	Saxifraga bronchialis			
	Saxifraga ferruginea			
	Saxifraga lyallii			
	Saxifraga oppositifolia			
	Saxifraga punctata			
	Saxifraga punctata ssp. pacifica			
	Saxifraga rivularis			
	Sedum lanceolatum			
	Sedum rosea ssp. integrifolium			
	Sibbaldia procumbens			
	Silene acaulis ssp. acaulis			
	Solidago multiradiata			
	Stellaria monantha			
	Trientalis europaea			
	Trisetum spicatum ssp. alaskanum			
	Trisetum spicatum ssp. molle			
	Trisetum spicatum ssp. spicatum			
	Vaccinium ovalifolium			
	Vaccinium uliginosum			
	Veronica arvensis			

Juice uses an algorithm and factor analysis to determine clusters from a sorted table. Species with a high probability of occurring in more than one cluster are listed in multiple clusters.

Table 7

Clusters Developed using the SAS 9.1 Algorithm

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7
Campanula rotundifolia	*Antennaria media*	*Carex praticola*	*Cardamine bellidifolia*	*Artemisia arctica* ssp. *arctica*	*Loiseleuria procumbens*	*Carex circinnata*
Carex macrochaeta	*Arctostaphylos rubra*	*Cassiope tetragona*	*Carex pyrenaica* ssp. *micropoda*	*Cornus canadensis*	*Phyllodoce aleutica* ssp. *glanduliflora*	*Luzula arcuata* ssp. *unalaschcensis*
Carex nigricans	*Castilleja unalaschcensis*	*Cassiope tetragona* ssp. *tetragona*	*Cassiope stelleriana*	*Empetrum nigrum*	*Vaccinium uliginosum* ssp. *alpinum*	*Saxifraga bronchialis* ssp. *funstonii*
Heirochloe alpina	*Cerastium beeringianum*	*Cryptogramma crispa*	*Poa paucispicula*	*Epilobium anagallidifolium*		*Saxifraga ferruginea*
Juncus biglumis	*Cryptogramma crispa* var. *acrostichoides*	*Heuchera glabra*		*Epilobium latifolium*		*Sibbaldia procumbens*
Juncus ensifolius	*Cryptogramma crispa* var. *sitchensis*	*Juncus drummondii*		*Lupinus nootkatensis*		
Luzula arcuata	*Deschampsia danthonioides*	*Juncus falcatus* ssp. *sitchensis*		*Luetkea pectinata*		
Luzula multiflora ssp. *kobayasii*	*Empetrum nigrum* ssp. *hermaphroditum*	*Oxyria digyna*		*Lycopodium alpinum*		
Poa arctica ssp. *arctica*	*Equisetum arvense*	*Phyllodoce empetriformis*				
	Juncus mertensiana	*Poa glauca*				
	Juncus triglumis ssp. *albescens*	*Polemonium pulcherimum*				
	Luzula parviflora ssp. *parviflora*	*Salix reticulata*				
	Luzula wahlenbergii ssp. *piperi*	*Saxifraga bronchialis*				
	Lycopodium clavatum	*Trisetum spicatum* ssp. *alaskanum*				
	Lycopodium selago	*Trisetum spicatum* ssp. *spicatum*				
	Lycopodium selago ssp. *selago*					
	Phyllodoce aleutica					
	Poa brachyanthera					
	Potentilla hyparctica					
	Potentilla villosa					
	Salix. reticulata ssp. *reticulata*					
	Saxifraga oppositifolia ssp. *oppositifolia*					
	Sedum lanceolatum					
	Silene acaulis ssp. *acaulis*					

Table 7 (continued)

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7
	Solidago multiradiata var. *multiradiata.*					
	Trientalis europaea ssp. *Arctica*					
	Trisetum spicatum					
	Vaccinium ovalifolium					
	Vaccinium uliginosum					
	Vaccinium uliginosum ssp. *microphyllum*					

Species with an abundance of five or less and a high probability of occurring in more than one cluster are omitted.

Table 8

Community Descriptions as Identified with JUICE and TWINSPAN

Cluster and Community	**Description of Community and Habitat**	**Dominant Aspect of Communities**	**Dominant Species**	**Soil Depth (cm)**	**Locations**	**Dominant Slope**	**Typifying Species**
Community 1, Rocky Exposed	Rocky locations with exposed soil (1365 – 1396 m elevation)	South and Southwest	*Epilobium latifolium, Oxyria digyna, Phyllodoce empetriformis, Epilobium anagalladifolium*	Shallow, Less than 5 cm, and 3 - 4 cm in most locations with vegetation	Site Thirteen, Site Fourteen	Steep, 40 - 60˚	*Epilobium latifolium, Oxyria digyna*
Community 2 Small Area-High Elevation	Small area, generally exposed sites, higher elevation (1362 - 1661m)	South and East to Southeast	*Poa paucispicula, Carex pyrenaica* ssp. *micropoda*	Shallow, Less than 2 – 5 cm	Site Eighteen, Taku Northwest	Mid to high angle, 20 - 80˚	*Carex pyrenaica* ssp. *micropoda*
Community 3 Periglacial, Well Developed	Periglacial, successional-ly advanced, maritime and continental sites, lower elevation (438 – 800 m)	West	*Cardamine bellidifolia, Epilobium anagalladifolum, Epilobium latifolium, Saxifraga bronchialis*	Deeper, 7 – 10 cm	Site Seventeen A, Bog Pond, Inlet	Gently sloping (0 - 30˚)	*Aconitum delphinifolium, Luetkea pectinata, Astragalus alpinus, Cerastium beeringianum*
Community 4 Continental, Well Developed	Higher elevation (1067 – 1802 m), continental sites, more developed vegetation	South and Southeast	*Cerastium beeringianum, Cryptogramma crispa, Phyllodoce aleutica, Salix reticulata* ssp. *reticulata, Saxifraga bronchialis, Solidago multiradiata, Vaccinium uliginosum, Campanula rotundifolia, Luzula tundricola, Cardamine bellidifolia, Sedum lanceolatum*	Shallow to medium 2 - 5 cm on average	Site Ten, Site SP, Site Twenty-six, Site Eighteen, Site Eighteen B	Mid to high angle 20 - 50˚	*Arctostaphylos rubra, Castilleja unalaschcensis, Equisetum arvense, Salix reticulata*
Community 5 Alpine to Sub-alpine Transition	Lower elevation (462 – 1286 m), alpine to sub-alpine	West	*Cryptogramma crispa, Phyllodoce aleutica, Saxifraga bronchialis, Vaccinium uliginosum*	Deeper 6 - 15 cm	Inlet, Tarn Lake, Site Seventeen, Bog Pond	Gentle 10 - 30˚	*Tsuga heterophylla, Lupinus nootkatensis, Hierochloe alpina, Heuchera glabro*

Table 8 continued

Cluster and Community	Description of Community and Habitat	Dominant Aspect of Communities	Dominant Species	Soil Depth (cm)	Locations	Dominant Slope	Typifying Species
Community 6 Large Area Central Icefield	Large area, centrally located, broadly occurring community, mammal and avian activity (1303 – 1802 m elevation)	South, West, and East	*Cryptogramma crispa, Phyllodoce aleutica, Saxifraga bronchialis, Vaccinium uliginosum*	Shallow to well developed 3 - 12 cm	Site Ten, Site Twenty-six	20 - 50˚	*Salix fuscenscens, Epilobium hornemannii, Polemonium pulcherrimum,*
Community 7 Alpine, Less Developed	Higher elevation (1266 – 1661 m), alpine	South and West	*Phyllodoce aleutica, Saxifraga bronchialis, Vaccinium uliginosum*	Shallow to well developed in pockets 2 - 12 cm	Site Seventeen, Site Eighteen	20 - 60˚	*Gentiana glauca*

The vegetation communities identified represent seven distinct habitats. Species characterizing the communities are represented by relevés taken from, on average, three sites with similar attributes, especially aspect, elevation, slope and soil development.

Table 9

Communities and their Dominant Species

Community	**Dominant Species**
Rocky Exposed Community	*Epilobium latifolium, Oxyria digyna*
Small Area - High Elevation Community	*Carex pyrenaica* ssp. *micropoda*
Periglacial, Well-developed Community	*Cardamine bellidifolia, Epilobium anagallidifolium, Epilobium latifolium, Saxifraga bronchialis*
Continental, Well-developed Community	*Cerastium beeringianum, Cryptogramma crispa, Phyllodoce aleutica, Salix Reticulata* ssp. *reticulata, Saxifraga bronchialis, Solidago multiradiata, Vaccinium uliginosum*
Alpine to Sub-alpine Transition Community	*Cryptogramma crispa, Phyllodoce aleutica, Saxifraga bronchialis, Vaccinium uliginosum*
Large Area-Central Icefield Community	*Cryptogramma crispa, Phyllodoce aleutica, Saxifraga bronchialis, Vaccinium uliginosum*
Alpine, Less-developed Community	*Phyllodoce aleutica, Saxifraga bronchialis, Vaccinium uliginosum*

JUICE community three (Table 8) is an assemblage of periglacial species found on the more successionally advanced portions of the region in the maritime and continental sectors, represented by *Aconitum delphinifolium, Luetkea pectinata, Astragalus alpinus,* and *Cerastium beeringianum,* among other species.

JUICE community four (Table 8) is represented by high elevation habitats on south-facing higher elevation slopes and is typified by *Campanula rotundifolia, Luzula tundricola, Cardamine bellidifolia, Solidago multiradiata*, and *Sedum lanceolatum* among other species. SAS cluster two is similar to JUICE community four, but is more typical of the continental sector of the region. Species of SAS cluster two are those that inhabit successionally well-developed habitats and include *Arctostaphylos rubra, Castilleja unalaschcensis, Equisetum arvense, Lycopodium* sp., *Vaccinium* sp., and *Salix reticulata.*

JUICE community five (Table 8) represents lower elevation habitats in the subalpine to alpine ecotone, which harbor species such *Tsuga heterophylla, Lupinus nootkatensis, Hierochloë alpina,* and *Heuchera glabra.* JUICE community six occurs broadly and typifies larger area sites with noted avian and mammal activity. The communities occur in the central to northern sectors of the region and are typified by *Salix fuscescens, Epilobium hornemannii, Polemonium pulcherrimum,* and *Phyllodoce aleutica*. JUICE community seven is similar to JUICE community five with the exception of harboring a higher elevation more alpine association of species, including *Gentiana glauca*, in addition to several herbaceous perennials and graminoids it shares with JUICE community five.

SAS cluster one (Table 8) represents communities on small area sites on the southern to central maritime portion of the region with generally low richness and species assemblages that include graminoid physiognomic forms such as *Luzula arcuata* and *Juncus ensifolius*, along with herbaceous perennials. SAS cluster six represents central icefield nunataks with avian and mammal activity, substantial soil development, and generally significant wind exposure. The species composing this community are resistant to desiccation, prostrate in habit, and include *Loiseleuria procumbens, Phyllodoce aleutica* ssp. *glanduliflora,* and *Vaccinium uliginosum* ssp.

alpinum. SAS cluster seven represents vertical exposures on mostly south-facing slopes between 1660 and 1680 m. Species composing this rock-wall community type include *Carex circinnata*, *Saxifraga bronchialis* ssp. *funstonii*, *Saxifraga ferruginea*, and *Sibbaldia procumbens*. Dominant species from each community are represented in Table 8.

Floristics

Species observed in this study and the study sites therein in formal relevé sampling units are found in Appedix F. The comprehensive specimen database, available from the author, includes species observed on the sites but not within formal sampling units, in addition to those observed in the relevés. Taxonomic nomenclature follows Hultén (1968). Nomenclatural changes identified in the ITIS Database (2007) are included in Table 2. The total number of taxa found in the study is between 297 and 318, depending on the classification of species, species with indefinite identifications (*incertae sedis)*, or identification pending. The taxa represent 43 families, 130 genera, and approximately 104 subspecies and varieties (Tables 10, 11, 12 and Figures 7, 8, 9). These results are derived from 107 relevés taken over approximately six years, from over seventeen sites, in addition to taxa observed and vouchered but not present in the formal sampling units. A comprehensive voucher specimen database is available from the author. The specimens are deposited in the herbaria of Georgia Southwestern University in Americus, Georgia and Sheldon Jackson College in Sitka, Alaska. The species per site are compiled into an interactive map on which species lists and photographs from each site may be viewed following clicking on a given site on a digital topographic map (Appendix G).

Table 10

Species Richness from Botanical Investigations in the Juneau Icefield Region

Vascular Plants of the Juneau Icefield Nunataks	Collector and Year(s) of Study				
	Chamberlain 1949	Ward 1951	Heusser 1954	Anderson 1977**	Bass 2001-2006
Families	18	19	24	19	43
Genera	34	40	58	31	130
Species	100	60	99	122	314*
Subspecies and Varieties	***	***	***	***	104

*+/- 21 specimens *incertae sedis*.,** The study of Anderson in 1977 (1979) focused on British Columbia's Tuff Nunatak, Site Twenty-six in the current study, and included Marble Mountain, which is not included in the current investigation or the other above mentioned studies. *** Information not available.

Table 11

Dominant Vascular Plant Families of the Nunataks of the Alaska-Canada Boundary Range

Family	Number of Taxa	Number of Genera within the Family
Gramineae	25	10
Compositae	24	11
Rosaceae	23	12
Cyperaceae	20	2
Juncaceae	18	2
Ericaceae	18	8
Saxifragaceae	17	5
Salicaceae	11	2
Onagraceae	10	1
Caryophyllaceae	7	4
Ranunculaceae	7	6

In this application taxa per family are given with subspecies and varieties classified as separate taxa.

Table 12

Diversity of Dominant Vascular Plant Genera of the Nunataks of the Alaska-Canada Boundary Range

Largest Genera in Order of Decreasing Abundance of Species	
Genus (Family)	Number of Species
Carex (Cyperaceae)	19
Poa (Gramineae)	16
Saxifraga (Saxifragaceae)	15
Salix (Salicaceae)	14
Luzula (Juncaceae)	11
Antennaria (Compositae)	10
Epilobium (Onagraceae)	9
Juncus (Juncaceae)	8
Potentilla (Rosaceae)	7
Lycopodium (Lycopodiaceae)	7
Vaccinium (Ericaceae)	7

In this application, varieties and subspecies are not included as separate taxa.

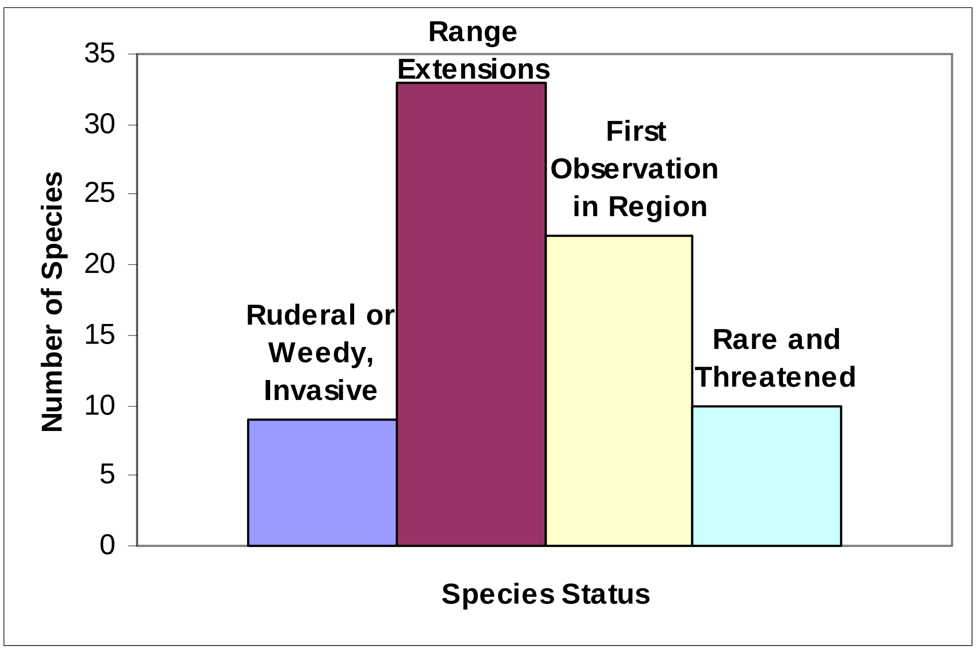
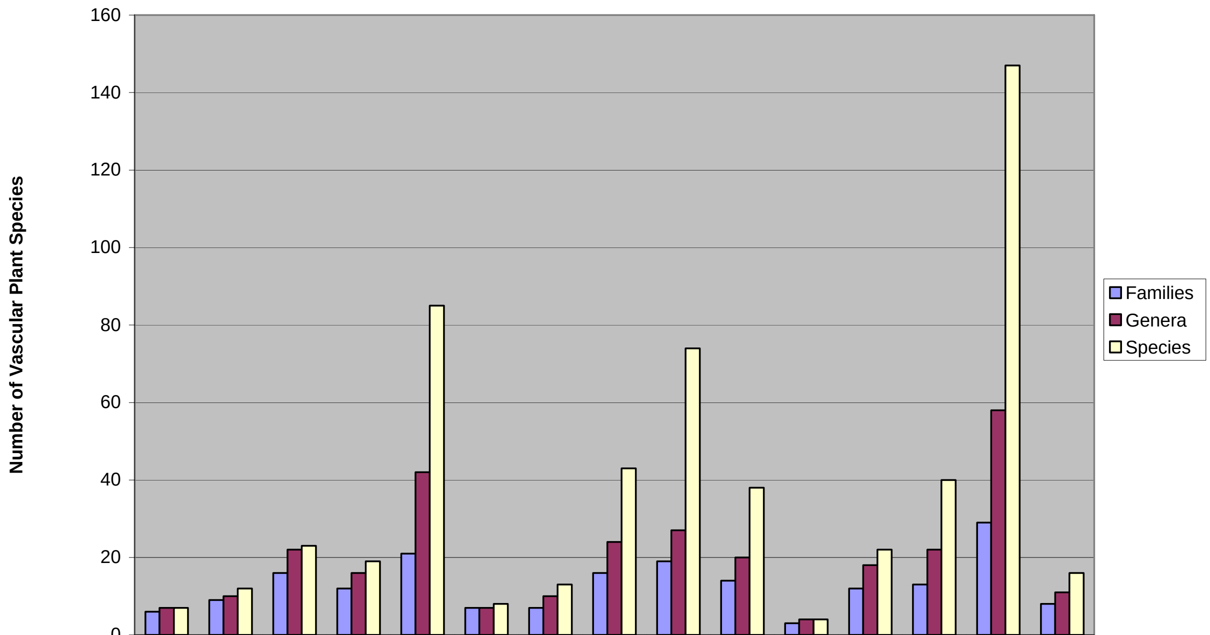


Figure 7. Special Status Species

Species identified as invasives, ruderals or weeds; range extensions; first observations on the icefield sites; and rare or threatened species are noted in Figure 7 and Table 13.

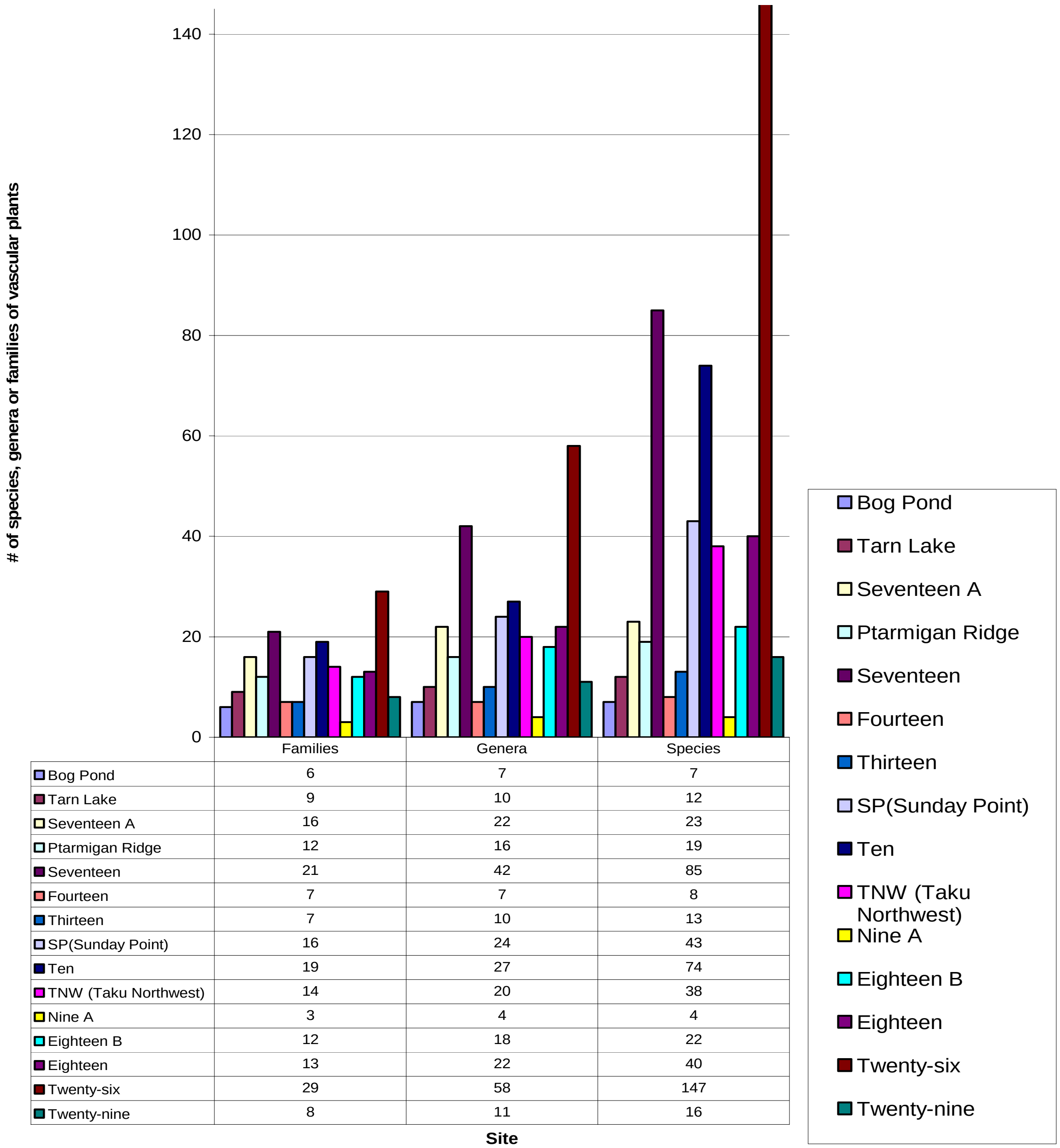


	Bog Pond	Tarn Lake	17 A	Ptarm. Ridge	17	14	13	SP	10	TNW	9 B	18 B	18	26	29
Families	6	9	16	12	21	7	7	16	19	14	3	12	13	29	8
Genera	7	10	22	16	42	7	10	24	27	20	4	18	22	58	11
Species	7	12	23	19	85	8	13	43	74	38	4	22	40	147	16

Site

Figure 8. Families, Genera and Species of Vascular Plants per Site, Emphasizing the SW to NE Transect Across the Juneau Icefield.

Sites are arranged from southwest to northeast across the study region. Generally, greater richness corresponds with higher diversity of genera and families. The largest sites, Twenty-six and Seventeen, are examples of this. The closer the three bars representing the number of families, genera, and species, the greater the diversity of the site. Some of the smaller sites have unusually high diversity, although the total number of species is low, e.g., Sites Thirteen and Nine A.



	Families	Genera	Species
Bog Pond	6	7	7
Tarn Lake	9	10	12
Seventeen A	16	22	23
Ptarmigan Ridge	12	16	19
Seventeen	21	42	85
Fourteen	7	7	8
Thirteen	7	10	13
SP(Sunday Point)	16	24	43
Ten	19	27	74
TNW (Taku Northwest)	14	20	38
Nine A	3	4	4
Eighteen B	12	18	22
Eighteen	13	22	40
Twenty-six	29	58	147
Twenty-nine	8	11	16

Figure 9. Families, Genera and Species of Vascular Plants per Site, in the Context of Taxonomic Diversity and Continentality.

Sites are arranged from southwest to northeast across the study region. An overall trend of increased diversity is evident with the increase in the continentality of climate that occurs from south to north across the region.

Table 13

Species Observations of Note: Ruderal, Invasive, Rare, First Sited, Threatened and/or Extended Range Species from Nunatak Sites

Family	Genus	Species	Subspecies or Variety	Status
Aspidaceae	*Polystichum*	*braunii*	var. *alaskense*	First observation of species on an icefield site
Boraginaceae	*Myosotis*	*alpestris*	ssp. *asiatica*	Rare species on icefield sites
Caprifoliaceae	*Sambucus*	*racemosa*	ssp. *pubens*, var. *arborescens*	Native, sometimes ruderal, weedy species, unexpected on alpine sites
Caryophyllaceae	*Stellaria*	*monantha*		First observation of species on an icefield site
Compositae	*Anaphalis*	*margaritacea*		First observation of species on an icefield site
Compositae	*Antennaria*	*friesiana*	ssp. *alaskana*	Range ext., nearest known found 574 km to NW
Compositae	*Antennaria*	*pulcherrima*		First observation of species on an icefield site
Compositae	*Antennaria*	*rosea*	var. *nitida*	First observation of species on an icefield site
Compositae	*Arnica*	*frigida*		Range ext. to border of known range
Compositae	*Erigeron*	*purpuratus*		First observation of species on an icefield site
Compositae	*Matricaria*	*matricarioides*		Introduced weed
Compositae	*Senecio*	*atropurpureus*	ssp. *tomentosus*	Range ext., nearest known found 115 km to N
Equisetaceae	*Equisetum*	*arvense*		Ruderal and often weedy
Ericaceae	*Phyllodoce*	*coerulea*		Range ext., nearest known found 1072 km to W
Ericaceae	*Phyllodoce*	*empetriformis*		Rare in SE alaska, classified as critically imperilled by the ANHP (2006)
Ericaceae	*Vaccinium*	*membranaceum*		Range ext. from B.C., not previously noted on icefield sites, nearest known found 230 km to E
Ericaceae	*Vaccinium*	*parvifolium*		Range ext. to border of known range
Gentianaceae	*Fauria*	*crista-galli*		Range ext. to border of known range
Gentianaceae	*Gentiana*	*propinqua*		Range ext. to border of known range, first observation of species on icefield sites, calciphile
Gramineae	*Agrostis*	*stolonifera*		Range ext., found 32 km to W
Gramineae	*Festuca*	*vivipara*		Range ext., nearest known found 115 km to NW
Gramineae	*Melica*	*bulbosa*		Range ext. from British Columbia, red listed in B.C. (threatened, endangered or extirpated)**
Gramineae	*Poa*	*brachyanthera*		Range ext., nearest known found 306 km to W, not observed on icefield sites previously
Gramineae	*Poa*	*leptocoma*		Rare species, threatened in Washington State, imperiled in AK (ANHP, 2004)
Gramineae	*Poa*	*pratensis*		Introduced weed
Gramineae	*Poa*	*pseudoabbreviata*		Range ext. from Northern and Western Alaska, nearest known found 536 km to NW
Gramineae	*Vulpia*	*megalura*		Range ext., nearest known found 500 km to NW, invasive garden weed
Juncaceae	*Juncus*	*castaneus*	ssp. *castaneus*	Range ext. from Northern and Western Alaska
Juncaceae	*Luzula*	*tundricola*		First observation of species on an icefield site
Leguminoseae	*Astragalus*	*alpinus*	ssp. *alpinus*	First observation of species on an icefield site
Lycopodiaceae	*Lycopodium*	*inundatum*		Range ext. fom southern panhandle of Alaska, nearest known found 345 km to SE
Onagraceae	*Epilobium*	*angustifolium*	ssp. *angustifolium*	weed common in burned areas
Onagraceae	*Epilobium*	*angustifolium*		weed common in burned areas
Onagraceae	*Epilobium*	*davuricum*		Range ext. from British Columbia and the Yukon, nearest known found 25 km NE
Onagraceae	*Epilobium*	*hornemannii*		Range ext. of habitat type, first observation of species on icefield sites
Onagraceae	*Epilobium*	*luteum*		Range ext. to border of known range, first observation of species on icefield sites
Papaveraceae	*Papaver*	*macounii*		Range ext., nearest known found 100 km NW, considered rare in BC in 1976 (BC DCC, 2006)
Polemoniaceae	Polemonium	*pulcherrimum*		Rare on icefield sites
Polemoniaceae	Polemonium	*boreale*		Rare on icefield sites
Polygonaceae	*Polygonum*	*viviparum*		Rare species on icefield sites
Ranunculaceae	*Coptis*	*trifolia*		Range ext. of habitat type
Ranunculaceae	*Ranunculus*	*glacialis*	ssp. *chamissonis*	Considerable range ext. from the north and west of Alaska, nearest known found 100 km NW
Rosaceae	*Chamaerhodos*	*erecta*		Range ext., Rare, first observation on icefield sites, nearest known found 100 km NW
Rosaceae	*Potentilla*	*flabelliformis*		Range ext. from the west and north of Alaska, nearest known found 570 km NW
Rosaceae	*Potentilla*	*norvegica*	ssp. *monspeliensis*	Range ext., nearest known found 150 km N, first of species observed on icefield sites, problem weed*
Rosaceae	*Potentilla*	*diversifolia*	var. *glaucophylla*	Range ext. to border of known range, habitat type ext., first of species observed on icefield sites
Rosaceae	*Potentilla*	*uniflora*		Range ext. to border of known range, habitat type ext., first of species observed on icefield sites
Rosaceae	*Rosa*	*rugosa*		Introduced weed, range ext. and escape from cultivation
Salicaceae	*Salix*	*arctica*	ssp. *arctica*	First observation of species on an icefield site
Salicaceae	*Salix*	*fuscescens*		Range ext., nearest known found 570 km to NW
Salicaceae	*Salix*	*phylicifolia*	ssp. *planifolia*	Range ext., nearest known found 100 km to N
Saxifragaceae	*Saxifraga*	*bronchialis*	ssp. *cherlerioides*	Rare, first observation on an icefield site
Saxifragaceae	*Saxifraga*	*caespitosa*		First observation of species on an icefield site
Saxifragaceae	*Saxifraga*	*oppositifolia*	ssp. *smalliana*	First observation of species on an icefield site
Saxifragaceae	*Saxifraga*	*punctata*	ssp. *charlottae*	Range ext., nearest known found 450 km to SE
Saxifragaceae	*Saxifraga*	*tolmiei*		First observation of species on an icefield site
Distances and directions indicated to nearest previously known occurrence of species noted as range extensions				
*Royer and Dickinson, 1999		ext.=extension	B.C.=British Columbia	** Government of British Columbia, 2006

Of the 318 taxa observed in the formal relevé sampling units, 11 are classified as ruderal weeds or invasive species; 10 are threatened species; 31 were found beyond their previously known ranges; and 22 of the species have not been previously observed in the icefield region.

Tabular Analysis of Relevés

The goal of the relevé tabular analysis is to identify plant communities or populations of species that occur together and interact with one another. In the sorted table these should appear as nearly solid blocks of numbers with few spaces. One initial consideration in sorting relevés is whether to arrange those from different nunataks in different tables (one table per nunatak). However, this would identify nunataks as communities, rather than finding true communities of plant species. The names of the relevés are standardized in the table for algorithm analysis.

Comparing the similarity of relevés is a component of finding communities. The solid blocks, which represent the communities, are developed by sorting both the columns (relevés), and the rows (species). Most of the relevés represent different nunataks, although some of the relevés are from the same nunatak. Infrequent species are not representative of the data set and skew the results when included. If a species occurs in only 1-4 relevés, of 107, it is considered a chance occurrence and affects the data set disproportionally.

Community Identification from Tabular Analysis

The clusters in Tables 6 and 7 are developed using an algorithm and process cluster in the SAS 9.1 software program. All species that occurred in less than five relevés, or had a frequency of less than five, are omitted from the species matrix for the clustering. The abundance values in the matrix are replaced with presence (1) and absence (0) data for their occurrence in each relevé. The cross validation process indicates that some species may belong to two or more clusters. The probability of a species occurring in more than one cluster and community is high and these probability values should be considered. A factor analysis is done in SAS (9.1) to determine factor values for clustering with the algorithm. The factors reduce the variability of values used in finding clusters. With factor analysis, the 107 relevés are reduced to 17 factor variables. The clustering algorithm determines seven eigenvalues greater than one, implying seven clusters. A cross validation procedure estimates the probability of each species occurring in each cluster. Approximately 12% of the species have probability estimates that suggest they may occur in more than one cluster. The developed clusters are, however, considered well defined and not fragmentary (Tables 6, 7, 8, and 9).

The process is summarized as follows:

1. Species with frequency of four or less are omitted, resulting in 75 vascular plant species with frequencies of 5 or greater.
2. The 107 possible relevés, in which each species could occur, are reduced to 17 factor input variables.
3. The 17 factor variables represent the association of each species in the relevés.
4. The factor variables account for 67.6% of the variation in the species data.
5. A clustering algorithm is applied with the 17 factor variables as input using the Flexible-beta method.
6. Seven clusters are developed which are retained and have Eigenvalues > 1.
7. A 12.9% classification error rate is indicated by cross validation.
8. The cross validation results indicate the likelihood of individual species occurring in more than one relevé. An example is *Empetrum nigrum* ssp. *hermaphroditum* with a 44% probability of being classified in cluster 2 and a 56% probability of being classified in cluster 3.

TABWIN and JUICE use an algorithm by Hill (1979) and modified by other authors (e.g., Tichy, 2002). The algorithm is similar to that used by other tabular sorting software programs such as TURBOVEG, CANACO and PC-ORD. TWINSPAN identifies species in

Table 14

Frequency Two Species Removed in Tabular Analysis Processing

	Specific Epithet	
Genus	***Species***	***Subspecies* or *Variety***
Sambucus	*racemosa*	ssp. *pubens* var. *arborescens*
Tsuga	*heterophylla*	
Dryas	*integrifolia*	ssp. *integrifolia*
Vaccinium	*caespitosum*	
Salix	*rotundifolia*	
Festuca	*brachyphylla*	
Cladothamnus	*pyrolaeflorus*	
Caltha	*Palustris*	ssp. *asarifolia*
Vahlodea	*atropurpurea*	ssp. *latifolia*
Geranium	*erianthum*	
Geum	*calthifolium*	
Carex	*Obtusata*	ssp. *obtusata*
Dryas	*integrifolia*	ssp. *sylvatica*
Equisetum	*variegatum*	
Erigeron	*Humilis*	
Poa	*Alpine*	
Polemonium	*Boreale*	
Polygonum	*viviparum*	
Salix	*niphoclada*	
Sagina	*saginoides*	
Sanguisorba	*Stipulate*	
Saxifraga	*Lyallii*	ssp. *hulténii*
Saxifraga	*tricuspidata*	
Senecio	*Lugens*	
Rubus	*parviflorus*	
Sorbus	*sitchensis*	
Trisetum	*Spicatum*	ssp. *spicatum*
Leptarrhena	*pyrolifolia*	
Luzula	*multiflora*	
Anaphalis	*margaritacea*	
Luzula	*Rufescens*	
Ranunculus	*Glacialis*	ssp. *chamissonis*
Sagina	*saginoides*	
Antennaria	*Rosea*	
Petasites	*Frigidus*	
Arabis	*Hirsute*	ssp. *eschscholtziana*
Salix	*Arctica*	ssp. *arctica*
Dryas	*octopetala*	ssp. *octopetala* var. *octopetala*
Myosotis	*Alpestris*	ssp. *asiatica*
Saxifraga	*bronchialis*	ssp. *cherlerioides*

Table 14 continued

Specific Epithet		
Genus	***Species***	***Subspecies* or *Variety***
Polemonium	*Boreale*	ssp. *boreale*
Potentilla	*Fruticosa*	
Lycopodium	*Selago*	ssp. *appressum*
Veronica	*wormskjoldii*	ssp. *alterniflora*
Sambucus	*racemosa*	ssp. *pubens*
Arnica	*cordifolia*	
Fragaria	*virginiana*	
Saxifraga	*oppositifolia*	

These taxa were omitted from the Partial Clustering Table in the Refinement Process.

terms of presence and absence. Only species with defined cut-levels, based on abundance above the defined values, are classified as 'present' (Tichy, personal communication, 2007). Principle components analysis is used in JUICE to determine the factor values used for sorting with the algorithm (Tables 6, 7, 8, 9, and 14).

Communities from Clusters

Clusters develop when relevés have species in common and when species occur together in the same relevé. Relevés with species in common are placed next to one another in the clustering tables. These species form communities. If clusters develop, it is because the relevés are more similar to one another than relevés not in the cluster. Species likely to occur together appear in the clusters (Mueller-Dombois & Ellenberg 1974). In making the raw table and subsequent partial sorting table, species with similar distributions in the relevés are evident, and relevés with similar species compositions become evident. The distinction of species and relevés that form clusters from species which are not present in the clusters, identifies the communities and associations of plants that have recurring patterns across a given lateral extent (Tables 6, 7, 8, 9, and 14).

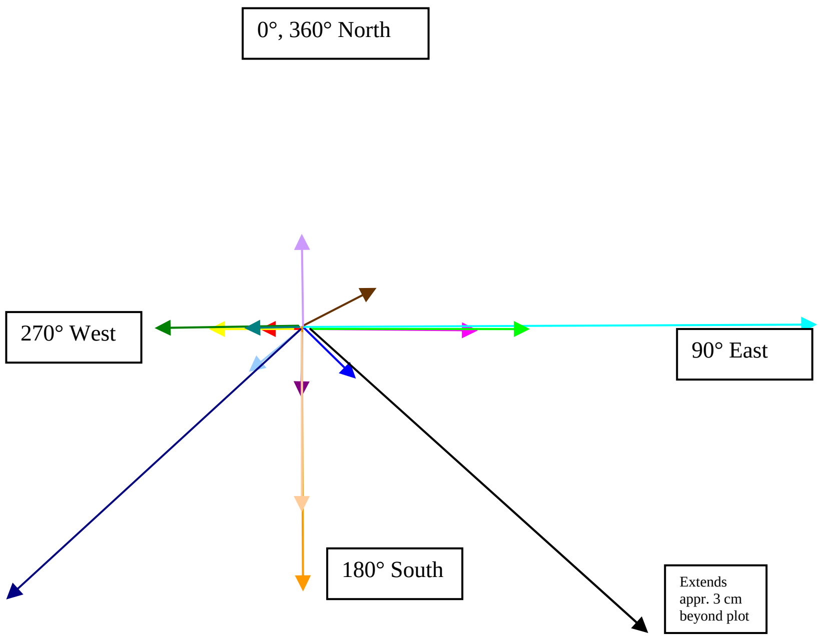
Identifying the species in common between relevés and sorting them into clusters in a partial table can be challenging with a large data set. Manual sorting has the disadvantage of subjectiveness, compared to computerized sorting, which uses algorithms to find clusters and identify species and relevés that occur together (Kent & Coker, 1996).

Compilation and Formatting of Aspect Data

Aspect is considered an important variable in controlling species richness on the nunatak sites. Plotting aspect data is difficult with traditional software programs. The dominant aspects for the relevés taken at each site are utilized in incorporating the variable into the model developed to test the strength of the control variables on the response variable, species richness (Figure 10).

Richness and Temperature from 1948-2006

Temperature data from the Alaska Climate Research Center are used with species data from the publications of Miller (1949), Ward (1951), Heusser (1954a, 1954b), and Anderson (1979) (Figure 11). Approximately ninety-percent of the variation in vascular plant species richness between the years of 1948 and 2006 may be explained by variation in temperature (Figure 12). The temperature of the Central Juneau Icefield, as observed from Site Ten meteorological records from 1948 to 2006, indicates an increasing trend (Figure 13). Particularly, the winter minimum temperatures at this central icefield site have warmed over the last six decades with accentuated increase evident since the mid-1970s (Miller, 1985). At this time, the 90 year solar cycle was no longer apparent and global temperatures exhibited the first evidence of human induced climate change (Miller, 1985) (Figure 13). Abbott (1974) observed



Aspect Data from Sites

Nunatak or Homogenous Stand	Length of Vector (1.8 cm = richness of 10)	Aspect (Azimuth direction from south (°))	Dominant Aspect
Nine A	0.4	270.0	W
Thirteen	1.3	135.0	SE
TNW (Taku Northwest)	3.8	100.0	E
Ptarmigan Ridge	1.9	90.0	E
Tarn Lake	1.2	270.0	W
Eighteen B	2.2	270.0	W
Fourteen	0.8	180.0	S
Seventeen	8.5	100.0	E
Eighteen	4.0	190.0	S
Ten	7.4	225.0	SW
Twenty-nine	1.6	55.0	NE
Twenty-six	14.7	135.0	SE
SP(Sunday Point)	4.3	200.0	S
Bog Pond	0.7	270.0	W
Seventeen A	2.3	0.0	N
Thirty	0.8	225.0	SW

Figure 10. Dominant Aspect in Relation to Magnitude of Species Richness per Site.

The length of each vector is approximate and corresponds with the magnitude of species richness at each site. The color of each vector corresponds to the site the vector represents. The orientation of the vector indicates the approximate dominant aspect of the site in degrees from the south.

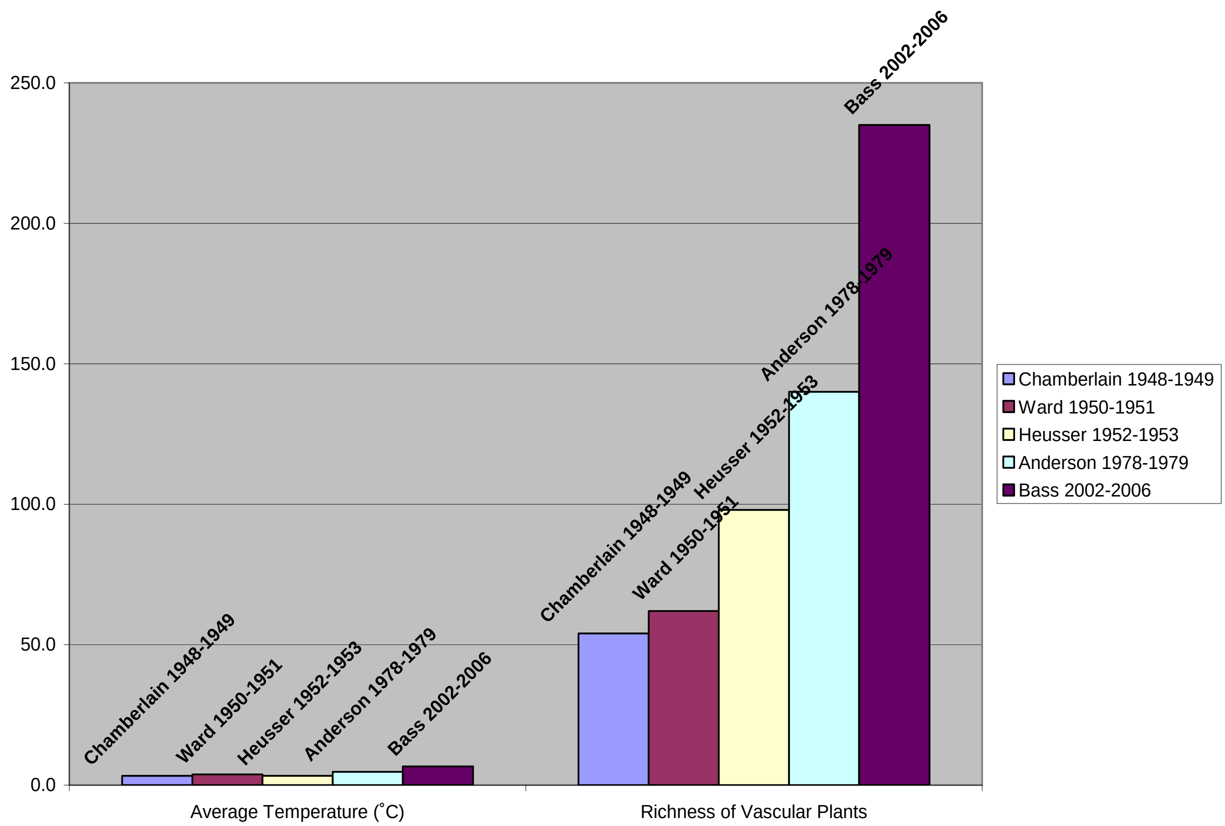


Figure 11. Bar Graph of Richness and Average Temperature 1948-2006.

A positive correlation exists between temperature and species richness from 1948-present for the study region as a whole. Temperature data from the Alaska Climate Research Center were used with species data from the publications of Miller (1949), Ward (1951), Heusser (1954), and Anderson (1979).

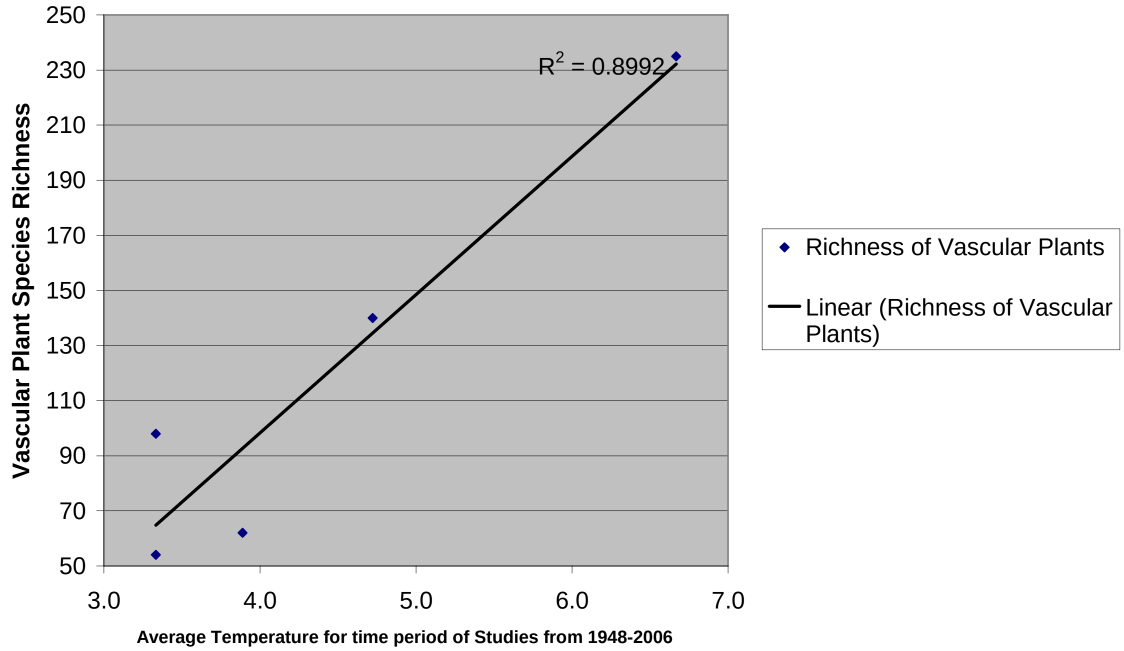


Figure 12. Richness and Temperature.

The average temperature from 1948 to the present is correlated strongly with species richness over the same time period.

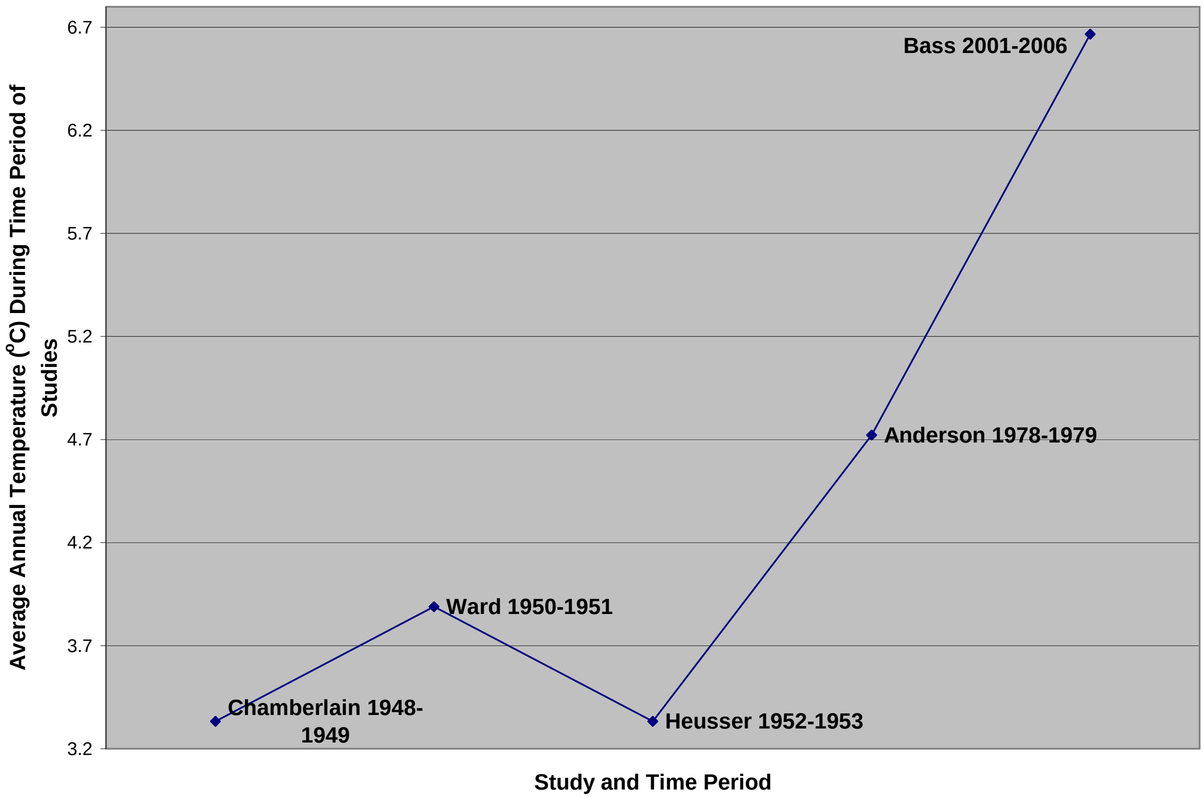
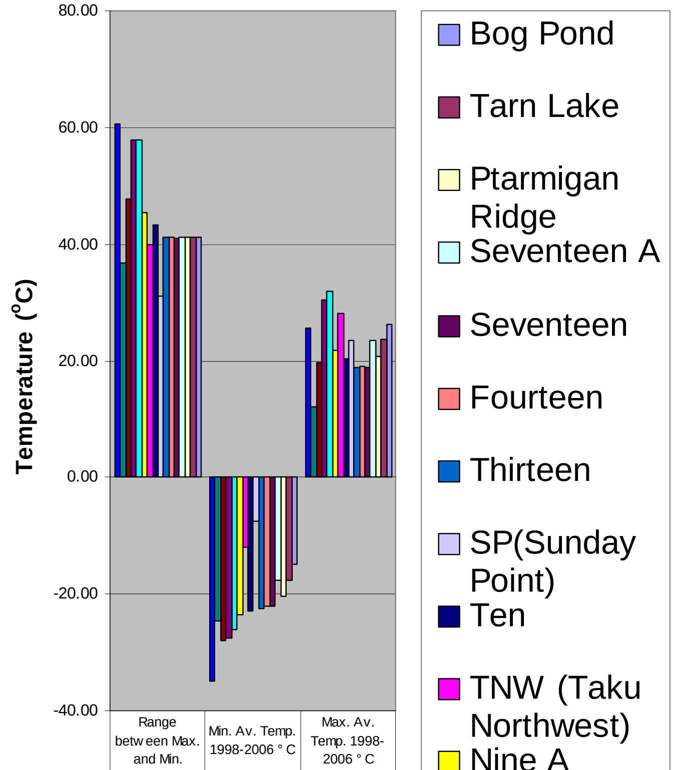


Figure 13. Average Annual Temperature on the Central Juneau Icefield, 1948-2006.

The average temperature of the Central Juneau Icefield from 1948 to 2006 indicates an increasing trend, which coincides with increases in vascular plant species richness (Figure 12).



	Range between Max. and Min.	Min. Av. Temp. 1998-2006 ° C	Max. Av. Temp. 1998-2006 ° C
Bog Pond	41.22	-15.00	26.22
Tarn Lake	41.20	-17.58	23.62
Ptarmigan Ridge	41.20	-20.44	20.77
Seventeen A	41.27	-17.70	23.57
Seventeen	40.97	-22.08	18.89
Fourteen	41.20	-22.16	19.04
Thirteen	41.20	-22.40	18.80
SP(Sunday Point)	30.97	-7.59	23.38
Ten	43.30	-22.99	20.31
TNW (Taku Northwest)	40.03	-11.97	28.06
Nine A	45.51	-23.61	21.90
Eighteen B	57.95	-26.08	31.87
Eighteen	57.95	-27.55	30.40
Twenty-six	47.70	-28.08	19.63
Twenty-nine	36.69	-24.66	12.03
Thirty	60.61	-34.95	25.67

Figure 14. Average Minimum (Winter) and Maximum Temperature per Site, 1998-2006.

Sites are arranged from the south to the north in the legend and data table. In general, a greater range between the minimum and maximum temperature corresponds with a more continental climate for a given site. Data for sites Bog Pond, Tarn Lake, Ptarmigan Ridge, Seventeen A, Fourteen, Thirteen, and Eighteen B are interpolated and therefore approximate estimates.

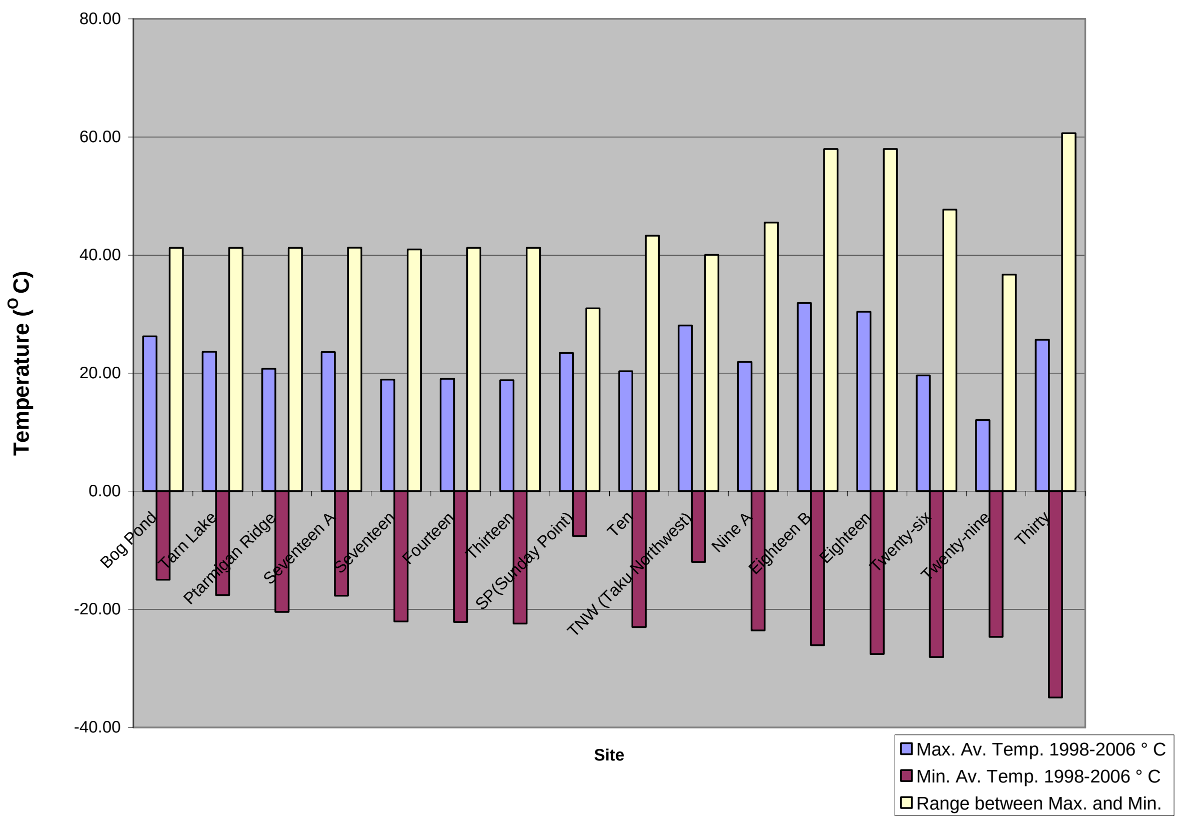


Figure 15. Maximum and Minimum Average Temperature per Site.

The sites are arranged from south to north as they occur across the study region. In general, the more continental sites manifest a greater range of temperature. Site Twenty-nine is located on Lake Atlin and may experience a slight ‘lake effect’. The Sunday Point and Taku Northwest Sites may experience a more maritime effect due to their proximity to Taku Inlet. The small size and lower elevation of the Taku Northwest Site may make it more prone to a maritime effect on temperature than Site Ten, which is actually closer to Taku Inlet, but has a larger area and a greater average elevation. Data for sites Bog Pond, Tarn Lake, Ptarmigan Ridge, Seventeen A, Fourteen, Thirteen, and Eighteen B are interpolated and therefore approximate estimates.

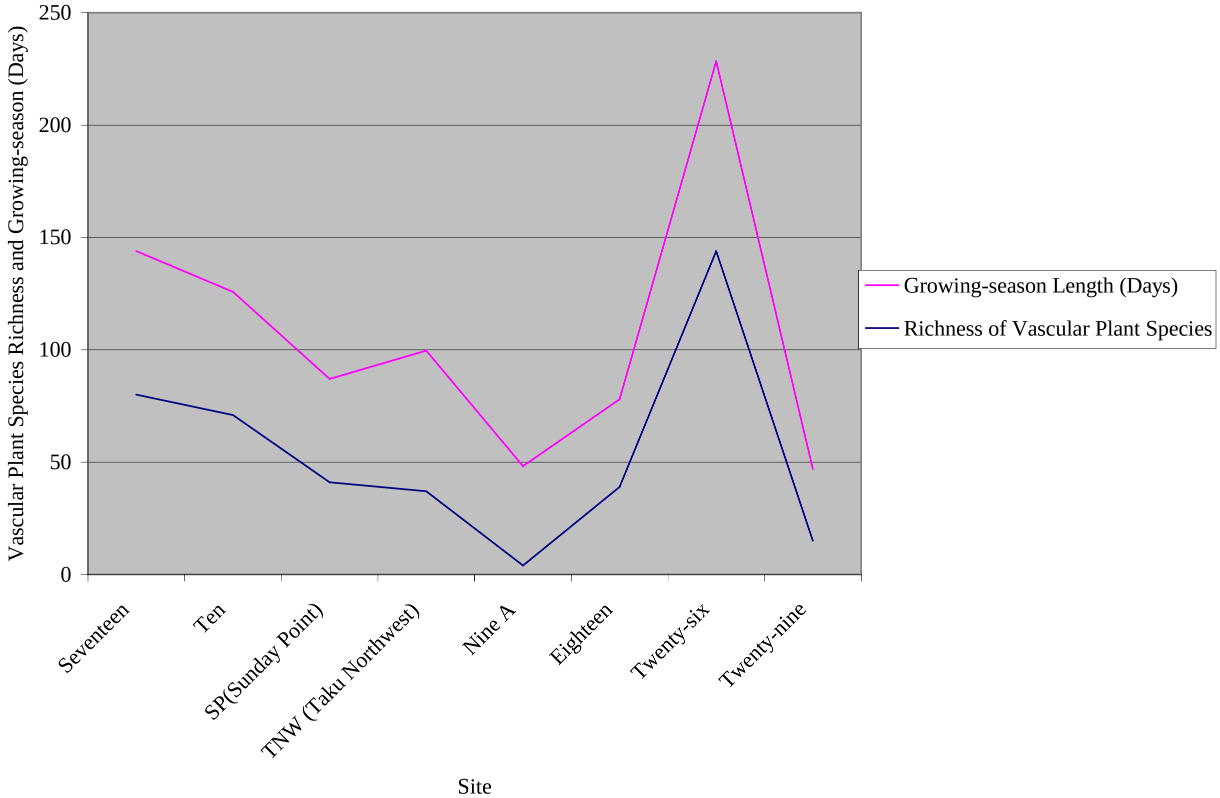


Figure 16. Species Richness and Growing-Season Length.

Growing-season is defined as the number of days between 1 May and 31 August of each year with an average temperature of 5° C or greater. Length of the growing-season is positively correlated with species richness. The sites are arranged as they occur from south to north across the study region.

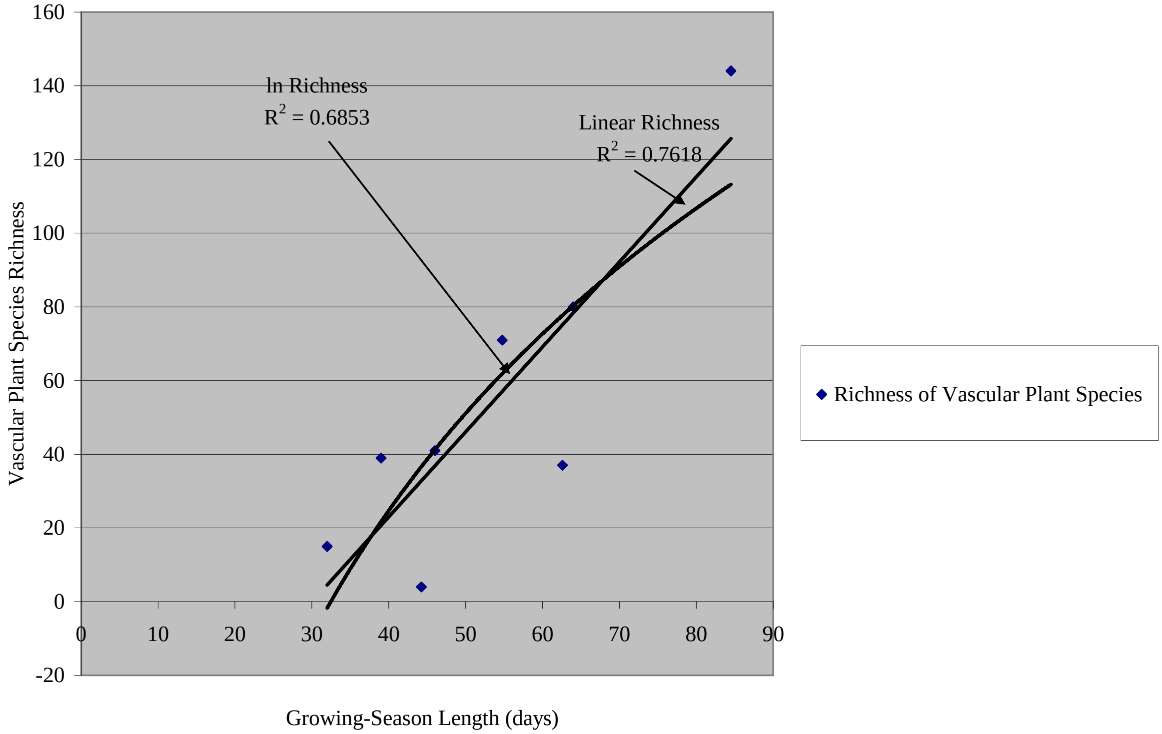


Figure 17. Correlation of Richness and Growing-Season Length.

Sixty-eight percent of the variation in the natural log of vascular plant species richness can be explained by variation in growing-season length. Seventy-six percent of the variation in the richness of vascular plant species can be explained by variation in growing-season length.

winter low temperature as the primary influence on species richness on islands in the Southern Hemisphere.

Growing-Season Results

Growing-season is defined here as the number of days with an average temperature equal to or greater than 5° C (and not necessarily continuous days) as is often assumed in ‘growing-season’ terminology. Some phytoenzymes require a threshold temperature below which they remain inactive. The value of 5° C was chosen based on accepted growth threshold temperatures for the region (Archibald, 1995; Box, E.O., personal communication, 2007). Growing-season length can be an important control on species richness and may have a greater influence than winter low temperature.

The data from the Sunday Point Site data logger, located in a rock cairn on the ground, indicate the time of snow cover and snow melt at the site. In 2003, snow cover was achieved on approximately 10 October, and snowmelt occurred in 2004 on 21 June, when the temperature rose from -0.27 to 15.5º C. In the fall of 2004, snow cover was achieved on 27 October and snowmelt in 2005 occurred on 25 July. In the fall of 2005 snow cover occurred on 8 October and snowmelt in 2006 occurred on 30 June. Snowmelt date on the cairn containing the data logger was much more defined in the temperature data than the snow cover date. The snowmelt date was marked by consistent temperatures of approximately -1° C on a given day, rising to 10° C, or even 15.5° C, the following day.

Surprisingly, few days within the growing-season, on any of the sites, are marked by daytime temperatures above freezing and nighttime temperatures below freezing. For most years, only a few such days are present in the data each fall and spring. The greatest diurnal variation is seen at the sites on the northwestern periphery of the study region, with more continental climates and a greater seasonal temperature range (Figures 14 and 15).

The line plot relating the growing-season length and vascular plant species richness indicates an overall direct relationship (Figure 17). The correlation coefficient between richness and growing-season length (see Figures 16 and 17) indicates that approximately 68 % of the variation in the natural log of species richness can be explained by variation in growing-season length. Seventy-six percent of the variation in the richness of vascular plant species can by explained by variation in growing-season length.

Originally, Site Thirty data were included in the growing-season compilation. These data comprised a smaller number of relevés than the other sites. The true species richness of Site Thirty vascular plants is not indicated by the small sample size. If the sample size for Site Thirty were comparable, the data would likely indicate a more direct relationship between species richness and growing-season length. Integrating growing-season length into the comprehensive richness model presents a challenge as a result of sites without sufficient temperature data to determine growing-season length. A regression with richness and growing-season also indicates that 76 % of the variation in richness can be explained by variation in growing-season length (Figure 17). A model developed from the regression data for predicting richness as a function of growing-season length is as follows:

Predicted Richness + 2.31(growing-season length in days) + -69.32

A regression incorporating growing-season and area to predict richness indicates that 90 % of the variation in richness may be explained by growing-season length and area. A model to predict richness using growing-season and area is as follows:

Predicted Richness = Growing-season length (2.30) + Area (33.786) + -90.05

Distance, Area, and Richness

Species richness increases with distance from the mainland. The area of the nunataks also increases with distance from the mainland, and area is likely the variable affecting the increase in richness with distance. The greater area of the nunataks farther from the periphery of the icefield may be explained by the large size of a given nunatak protecting the site from being overridden and denuded by the thicker glacier ice in the more central portions of the icefield.

On the periphery of the icefield, small nunataks are present due to reduced ice thickness and ablation. Small nunataks can not as readily remain above the thicker ice in the central portion of the icefield. It is probable that the smaller peripheral nunataks have been ice-free for a shorter duration than the large central nunataks, and this has reduced the time for colonization by species, ultimately resulting in the relatively low richness values for the peripheral sites. Large nunataks close to the periphery of the icefield likely become part of the mainland. This explains the absence of large area nunataks a short distance from the mainland in the data set of the current study. There is likely a threshold size, above which a nunatak is unlikely to be denuded and its surface area acts as a positive feedback mechanism in the site’s continued existence above the level of glacier ice. The underlying geology of the region, lithologic contacts and faults, ultimately control the location of the larger area nunataks of greater elevation on the central icefield.

Continuous land is significant because it serves as a migration conduit. The distance data were reevaluated in light of the counter-intuitive observation of increased richness with increased distance from the mainland. The original distance measurements err on the side of greater distance, to insure that the distance was to continuously vegetated mainland. In the next evaluation of distance, the focus was to measure to continuous land, whether or not the land is continuously vegetated (Table 15).

Table 15

Distance of Sites from Mainland

Nunatak or Homogenous Stand of Vegetation	Distance of Site from Mainland (km)	Re-evaluated Distances (km)	Direction to Continuous Land
Twenty-six	34	20	to North
SP(Sunday Point)	31	25	to South
Ten	29	30.6	to both South and Southwest, equidistant
Nine A	24	25	to West
TNW (Taku Northwest)	23.5	21.1	To West
Eighteen	22.5	12.9	To West
Eighteen B	22	11.29	To West
Thirteen	3.5	6.4	To West
Fourteen	3.2	4.83	To West
Seventeen	1.1	0.8	to South
Tarn Lake	0.5	0	*
Ptarmigan Ridge	0	0	*
Twenty-nine	0	0	
Bog Pond	0	0	*
Seventeen A	0	0	*
Thirty	0	0	*

* Periglacial sites connected to the continuously vegetated mainland, which have likely been nunataks previously. Sites are listed from greatest to least distance from a mainland (top to bottom).

A regular relationship between area and distance was not expected. The relationship is of geomorphological significance, but perhaps beyond the scope of this project. Local weather patterns and wind direction may also affect species richness, due to their effect on plant dispersal. Topography, elevation, relief, and area of a nunatak can affect the weather patterns and dominant wind direction in the vicinity of a nunatak. The greater the area and elevation of a nunatak, the more likely the wind patterns will be affected by the presence of the land mass.

Small nunataks near the edge of the icefield occur, most commonly, as the ice recedes, and in a relatively short period of time (geologically) become a part of the mainland. This partly explains the predominance of smaller area nunataks near the periphery of the icefield and larger area nunataks in the central icefield.

Yet another consideration, in the surface area versus distance from the mainland relationship of the nunataks, is the sample size. Nunataks occur on icefields and the Juneau Icefield is the location of the current investigation. The sample of nunataks is limited in this way (icefields are uncommon and inaccessible), perhaps biasing the sample of nunataks and their surface area - distance relationship. Additionally, the nunataks that were visited on this icefield did not include every single nunatak. The sites included were governed by logistical considerations, safety, location, and time.

Nunataks and Island Biogeography

A model was developed to test the relationship of nunataks to islands in the theory of island biogeography (MacArthur & Wilson, 1967). In the model, developed from data on the vascular plant species of the Juneau Icefield nunataks, area is still a greater influence in controlling species richness than winter low temperature (Abbott, 1974). Latitude and elevation, however, do have a strong influence, depending on the analytical parameters used in model building.

The model was developed using regression and elimination to determine the weight or strength of the variables (surface area of the nunataks, distance from continuously vegetated land, average winter low temperature of the sites, growing-season length, elevation, aspect and latitude) on the vascular plant species richness per site (Figures 18 and 19).

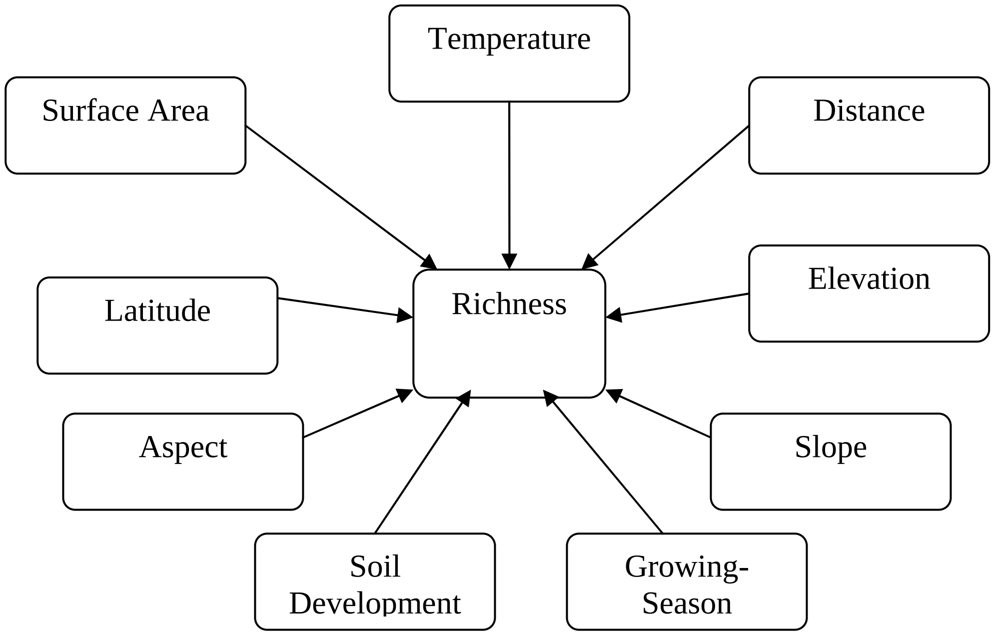


Figure 18. Variables Contributing to and Controlling Species Richness.

The above diagram depicts most of the variables that may influence species richness.

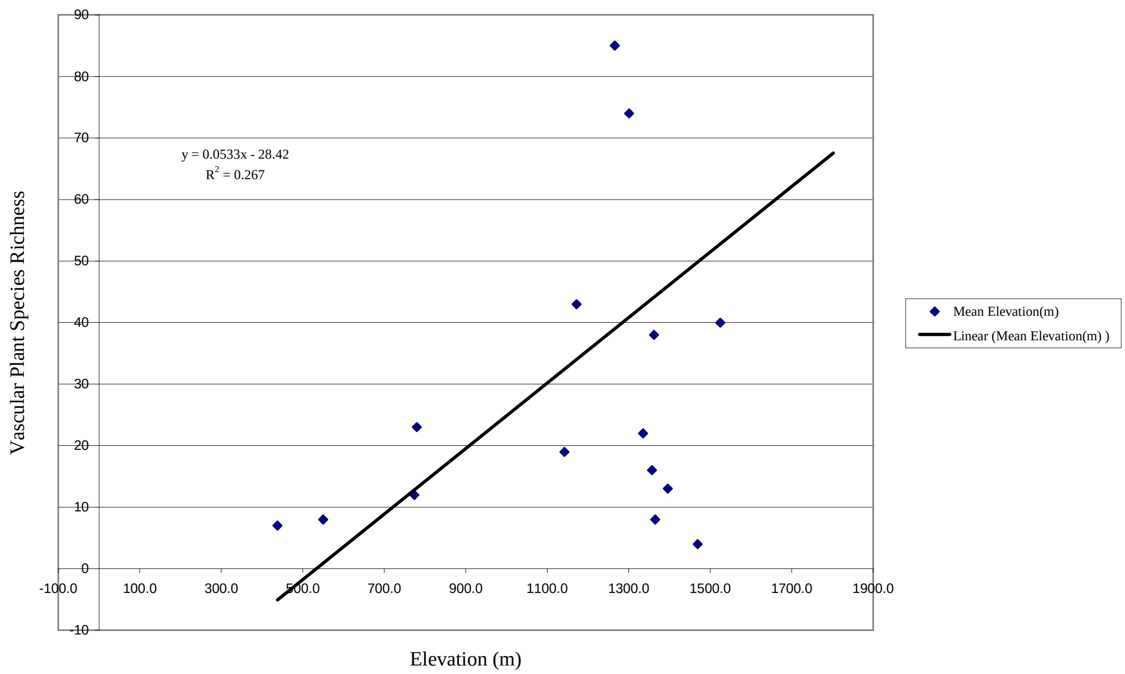


Figure 19. Richness and Elevation.

Elevation does not correlate significantly with vascular plant species richness.

Model Building

The model will be used to predict the richness on an un-studied nunatak, using what is known about the incorporated control variables and their effects on the response variable, vascular plant species richness. The residuals, which result from a regression of the control and response variables, represent the difference between the observed and predicted values. The residuals should be small for the best-fitted model.

In correlating variables in the regression, an effort is made to find an F significance statistic with a value < 0.05. The correlation coefficients (R and R^2) indicate the percentage of the response variable explained by the control variables. Residuals should be < -3 or > 2 in a well-fitted model (Motulsky, 1995).

If the correlation coefficient (R^2) is 0.34, in a model incorporating area as the dominant control variable, then 63% of the variation in richness is due to variables other than area. If this is the case, the variable of area, as expressed above, should not be used in the model (Motulsky, 1995). Latitude has an insignificant influence in the best-fit model but does allow for a better model than area alone.

Variable Coefficients for Best-Fit Model to Predict Species Richness

Latitude	Area
0.044	1.370

The best fitting model for the prediction of species richness involves the variables of latitude and area (Table 16). Area has the greatest effect. The residuals for the best-fitted model are between -2 and 2 (Figure 20). The *F* significance statistic and the *P* statistic for latitude and area in the regression are both less than 0.05. The P statistic is < 0.0001 for the latitude effect and 0.013 for the area effect. The standard F statistic should have a value greater than 1 if the model fits. With a value of 4.072, fit of the model is indicated (Motulsky, 1995). The values for F and P assess the importance of the control variables, latitude and area (Table 16).

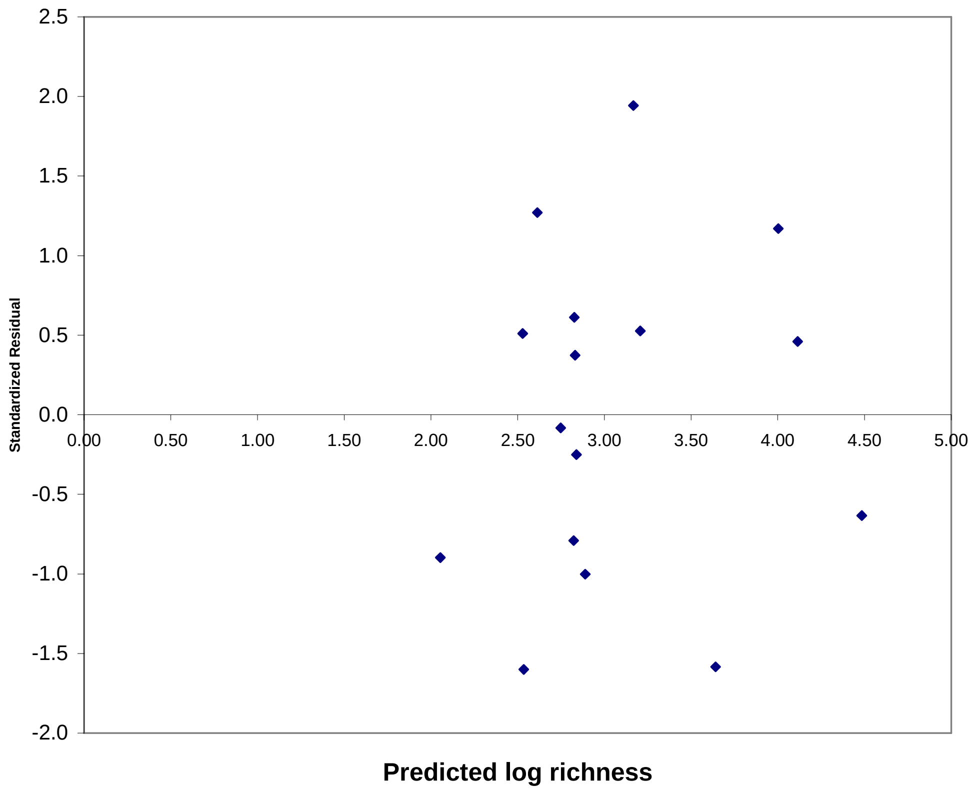


Figure 20. Residuals on Predicted Richness Values Plot for Determination of Model Fit.

The residuals represent the difference between the true observation of richness and the predicted value for richness in the regression. The residuals indicate a fit of the model with all values falling between -2.0 and 2.0.

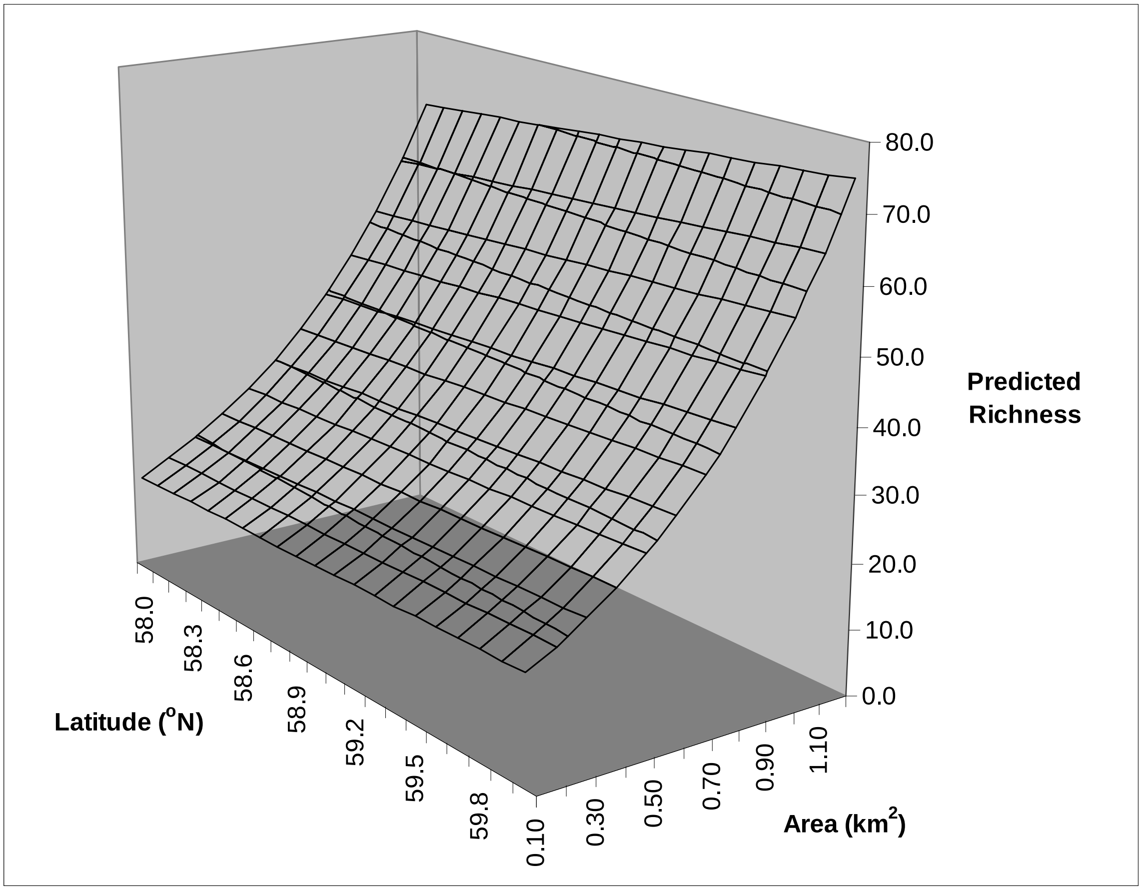


Figure 21. Predictive Richness Curve.

The relationship of area (km^2) and latitude (^{o} N) in the best-fitted model produces a curve that may be utilized to estimate the vascular plant species richness at a location that has not been botanically investigated.

Table 16

Regression Results from the Best-fitted Model for Richness Prediction

Richness ~ Latitude + Area

Regression Statistics	
Multiple R	0.61
R Square	0.37
Adjusted R Square	0.25
Standard Error	0.82
Observations	16.00

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.00	5.53	2.77	4.07	0.04
Residual	14.00	9.51	0.68		
Total	16.00	15.04			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A
Latitude (N) Decimal Degrees	0.04	0.00	9.86	0.0001	0.03	0.05
Site Area (km^2)	1.37	0.48	2.86	0.01	0.34	2.40

RESIDUAL OUTPUT

Observation	*Predicted log richness*	*Residuals*	*Standard Residuals*
1	2.62	-1.23	-1.60
2	2.63	-0.06	-0.08
3	2.66	0.98	1.27
4	2.66	0.29	0.37
5	2.68	-0.19	-0.25
6	2.70	0.39	0.51
7	2.69	-0.61	-0.79
8	2.94	1.50	1.94
9	3.28	0.41	0.53
10	3.95	0.35	0.46
11	3.99	-1.22	-1.58
12	4.09	0.90	1.17
13	4.25	-0.49	-0.63
14	2.72	-0.77	-1.00
15	2.66	0.47	0.61
16	2.77	-0.69	-0.90

PROBABILITY OUTPUT

Percentile	*log richness*
3.13	1.39
9.38	1.95
15.63	2.08
21.88	2.08
28.13	2.48
34.38	2.56
40.63	2.77
46.88	2.94
53.13	3.09
59.38	3.14
65.63	3.64
71.88	3.69
78.13	3.76
84.38	4.30
90.63	4.44
96.88	4.99

The correlation coefficient and limited deviation between predicted and observed values support the model incorporating area and latitude to predict richness.

Predicted richness = exp(latitude)(latitude influence)+(area)(area influence)

Log richness = ((latitude)(0.044)+(area)(1.370))

Richness = Exp((latitude)(0.044)+(area)(1.370))

Log Richness = 1.372 (area) + 0.044 *latitude

Richness = exp^ (1.37 (area) + 0.044*latitude)

1.37 = constant parameter estimate

The most successful model utilizes latitude and area and is made without incorporating the intercept in the regression. Distance, aspect, and temperature are removed from the model due to their insignificant correlation with richness. Elevation and latitude are tested in the final iterations of the model. Use of the heterogeneity of landscape ratio, defined as elevation/area, develops another model which does incorporate elevation.

Value of Using Log of Richness

A nonlinear curve was observed when plotting a histogram of the richness data. Linear relationships are rare in nature (Motulsky, 1995). Observation of the left skewed histogram indicates a possible exponential relationship between richness and its control variables. In experimenting with a variety of models using the control variables of latitude, area, elevation, temperature, growing-season length, aspect, and their logs, area yields the best fitting model.

Predicted Richness Curve

The plot of predicted richness values shows a fit of values along the exponential trend line. The plot of predicted richness versus area indicates the following fit of the model (Figures 20 and 21): Richness ~ (latitude)(0.044)+(area)(1.370).

Species-Area Results

The Vesper Peak species-area relationship, observed in the current study, suggests that lichen and bryophyte mat assemblages are more diverse than alpine grassland assemblages at the same location. Eighteen species were found in the alpine grassland versus twenty-one species on the lichen/bryophyte alpine mat (Figure 22).

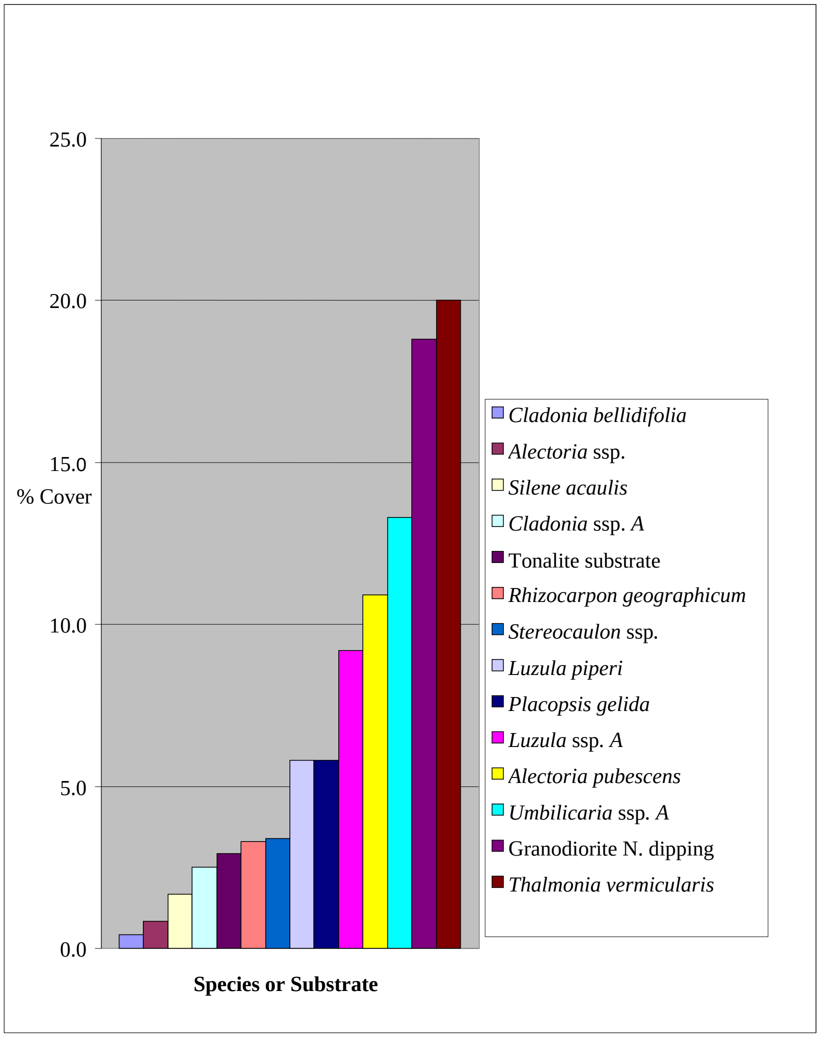


Figure 22. Percent Cover of Species and Substrate, Vesper Peak, Relevé 6.

The percent cover plots were derived from line transect data collected in conjunction with relevé and species-area analyses.

Comparison of Sites in Historical Studies and the Current Study

Sites Ten and Thirteen in the current study were investigated by Ward in 1951. There is a 124 % increase in species richness from 1951 to 2007 for Site Ten, located on the east side of the Taku Glacier. The author (Bass) identified 56 different taxa of vascular plant species at Site Ten between 2001 and 2007. Ward identified 25 different vascular plant taxa between 1950 and 1951. Twenty-eight percent of the species at Site Ten are in common between the 1951 study and the current investigation. Ward found seven species not identified in the current study. The author identified 38 species not found by Ward.

Site Thirteen is located on the Nugget Ridge above the Norris Glacier and the Dead Branch of the Norris Glacier. A 233 % increase in richness was identified from 1951 to the present for Site Thirteen. Ward identified six vascular taxa at Site Thirteeen and the author identified 20 vascular plant taxa between 2001 and 2006. Only two of the species found in the two studies for Site Thirteen are in common, giving the studies an 8 % similarity. The species in common for Site Thirteen, between the 1951 study and the current study, are *Antennaria rosea* and *Artemisia arctica*.

Ptarmigan Ridge Geobotany Results

The Ptarmigan Ridge lies immediately to the southwest of the upper Ptarmigan Glacier (Figure 23). It represents a significant glacial/geomorphological bedrock surface and geobotanical location. The feature has a glacierization history earlier than most icefield sites so far studied, and is a unique example of the earliest developed soil in the icefield area’s late glacial and climatic ground moraine sequence.

Field observations corresponding with relevés 11, 12, and 13, taken in July of 2003, identified the top of the Ptarmigan Ridge as 200 m across at an elevation of 1128 to 1174 m

(3700 to 3850 ft.), with a 10-20º easterly sloping surface above cirque levels C-3 and C-4, at 762 to 976 m (2500 to 3200 ft). The top of the ridge is characterized by an overlapping bold ground moraine on its eastern edge, which is also above the western front of the Ptarmigan Glacier (Miller, 1956, 1964). This crestal moraine is likely of early Neoglacial age (approximately 3000 – 4000 years BP) based on its form and extensive lichen cover. Immediately to the west of this moraine is a distinguishing and well-weathered tank and tor topography, evidence of an early cold dry environment in this sector (Figure 24). The ridge appears to have been overridden from the east at the height of the last Wisconsinan Maximum, and again in the early late Wisconsinan. On the Ptarmigan Valley's east wall, a tonalite sill is well exposed in association with a metamorphic gritstone and prominent cross-faults. Ultramafic horneblende schists occur in these outcrops. In addition, a prominent roche moutonée is displayed on the eastern side of the present Ptarmigan Glacier Valley. The sector is interpreted to characterize segments of the pre-glacial Taku and Stikine regional terranes (Miller, 1956 & 1964).

Figure 23. Ptarmigan Ridge Overview

The Ptarmigan Ridge as viewed from above looking west down and across the Ptarmigan Glacier from the ridge separating the Ptarmigan and Lemon Creek Glaciers.

On the eastern edge of the crestal zone of the Ptarmigan Ridge there is a notably undissected, well lichen-covered push moraine likely of early Neoglacial age, i.e., from approximately 3000 – 4000 BP. Immediately to the west, on the bordering bedrock ridge, is a dominating array of highly weathered tanks and tors, each interpreted as much older and developed in the earlier Wisconsinan. A few granite erratics lie on the surface (Figures 24 and 25), and appear to have been transported to the site by an early major glacial advance that overrode the ridge from the east. The superimposed, younger and undissected push moraine dominates the eastern edge of the ridge. At the height of the Little Ice Age (LIA), approximately 1300 – 1800 AD, this moraine was likely added by the second phase Neoglaciation when the Lemon Creek Glacier attained its most recent maximum extent and created a fresh trim-line. The trim-line creates a double pattern, replicating the most recent moraine pattern displayed at the head of the Lemon Creek Glacier. The whole valley and marginal ridge display evidence of having been overridden by earlier Pleistocene glaciations.

Figure 24. Ptarmigan Ridge Granite Erratics

Granite erratics are viewed in the foreground and a typical tor in the background.

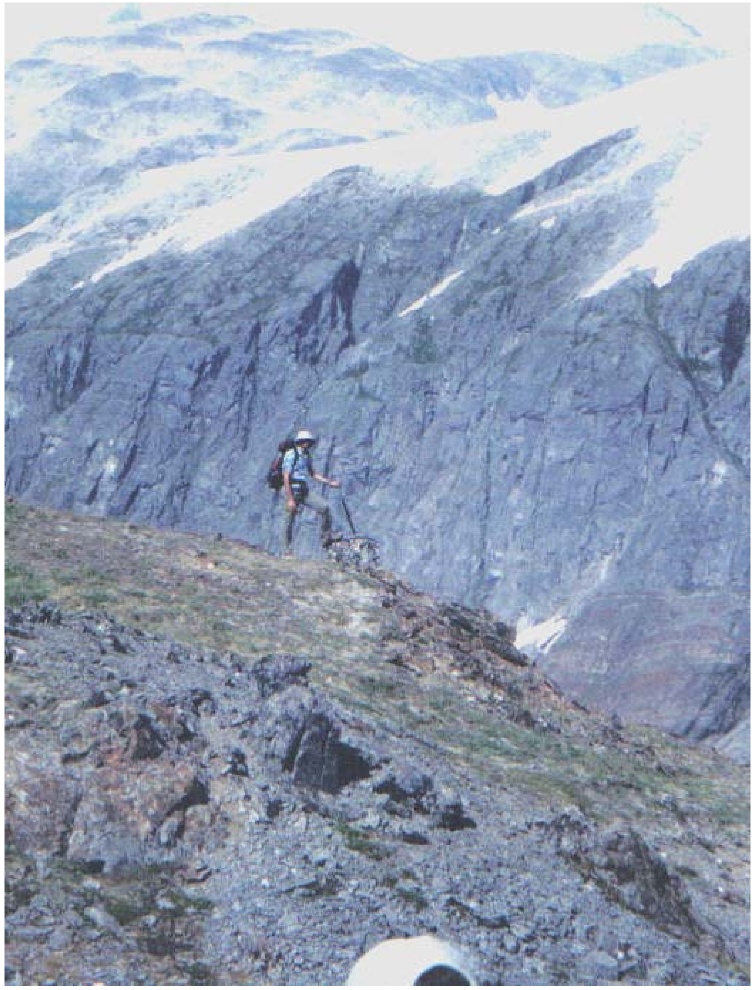


Figure 25. Ptarmigan Ridge Mid-Wisconsinan Topography

A granite erratic is emphasized by the observer. The Ptarmigan Glacier Valley is below and beyond the view.

Glacial environments are generally defined as cold and wet, with periglacial environments as generally cold and dry (Miller, 1956, 1964; Miller & Anderson, 1974). The tank and tor terrain of the Ptarmigan Ridge appears to have been affected by periglacial conditions, with superimposed subsequent glacial deposits. Remnant stone circles are further evidence of late-phase periglacial conditions on the ridge. Over the duration of the Little Ice Age (LIA), from approximately 1300 to 1800 AD and culminating in the mid to late 1600s, the Ptarmigan Ridge is interpreted to have supported dominately periglacial conditions.

Bedrock exposed on the Ptarmigan Ridge is ultramafic amphibolite-hornblendite schists with metamorphic sedimentary horizons subjected to intensive weathering. This lithology is a key regional geologic horizon. Relict solifluction lobes represent periglacial and subsequent cold-wet conditions, which have affected the top surface of the ridge. Vegetation on this exposed terrain has likely developed since early to mid Wisconsinan time. During the late Pleistocene, the location is interpreted to have served as a protective refugium for vegetation. The associated area of well-weathered tank and tor topography shows evidence of having been ice-free for at least 50,000 years BP, i.e., fitting into the North American Pleistocene Chronology of mid to late Wisconsinan time.

Soil development and extensive alpine tundra vegetation are evidence of a long deglaciation on the top section of this ridge. Confirmation is provided by abundant *Salix* spp. and *Cornus canadensis* growing in deep soil cover. These species have been observed on other nunatak sites in the Alaska-Canada Coast Mountains only where vegetation is successionally well advanced (Anderson, 1970, 1979). Additional evidence of the long integrity of this surface are the tanks and tors in the metamorphic bedrock. The tors are highly weathered and surrounded at their bases by slumped mass-wasted material, denuded from their protruding surfaces. If this sector had been overridden by early to mid Pleistocene ice, these tors could not have been retained. A few scattered, yet significant, glacial erratics found on the older tank and tor surface are composed of granodioritic rock from the Coast Range Batholith and are more resistant to weathering than the metamorphic bedrock surface of the tors which are composed of the Taku Terrane.

CHAPTER 5

INTERPRETATIONS, CONCLUSIONS, AND FUTURE RESEARCH

“With a mind eager in search, patient in doubt, fond of meditation, slow to assert, not carried away by novelty or admiration of antiquity, a mind framed in the pursuit of truth.”

Francis Bacon and motto of Molly O. Ahlgren, Ph.D.

Floristics

One-hundred-seven relevés (the basic sampling units) were completed over approximately seven years on over seventeen nunatak and periglacial sites. The taxa identified in the formal relevé sampling units, in addition those identified but not included in the relevés, include 318 taxa representing 43 families, 130 genera, and 104 subspecies and varieties. The species richness of the region as whole has more than doubled since the first floristic study in 1948 (Miller, 1949). Of the 318 taxa observed in the formal relevé sampling units; there are 11 species classified as ruderal and invasive, 31 species found beyond their previously known and accepted ranges, 22 species that have not been previously observed in the icefield sector, and 10 rare and threatened species (Table 13, Figure 7).

Phytosociology and the Identification of Communities

Seven community types were identified across the study region (Table 8). They include species assemblages representing a range of successional stages and environmental variables. Fujiwara (1987) describes the possibility of an association having no character species at the geographic extremes of the ranges of the included species. The phenomenon may explain some initial difficulties in identifying clusters in the partial table.

The seven identified communities are distinguished primarily by their elevation, maritime or continental climate, and soil development (Table 8). The communities include: the Rocky, Exposed Community with exposed young soils at elevations from 1365 – 1396 m; the Small-area, High Elevation Community representing exposed sites at 1362 - 1661 m; the Periglacial, Well-developed Community with successionally advanced vegetation and soil, present at the lowest elevations of 438 – 800 m; the Continental, Well - developed Community representing sites at higher elevations with successionally advanced substrates; the Alpine to Sub-alpine Transition Community representing lower elevation sites at 462 – 1286 m; the Large-area, Central Icefield Community on large area sites with evident avian and mammal activity; and the Alpine, Less-developed Community representing higher elevation sites located from 1266 – 1661 m with young substrates.

Evidence of Nunataks Serving as Refugia

The study region is known to have been largely overridden by ice at the last glacial maximum (LGM) (Miller, 1956, 1964; Carrara et al., 2003). The western side of Baranof Island, located to the southwest of the Juneau Icefield, was inundated with ice to the southern tip of the island. The western edge of the Cordilleran Ice sheet that filled Chatham Straight, glaciated the western side of Baranof Island. During the Late Wisconsinan (25,000-14,000 years BP), the eastern side of the island was partly a refugium. The Cordilleran Ice sheet covered most of the Boundary Range in the Coast Mountains (Carrara et al., 2003). Data derived from aerial mapping and geological investigations (Carrara et al., 2003), suggest that the presence of refugia on nunataks of the Juneau Icefield during the LGM was possible. The survival of species in isolated microhabitats and on lower elevation outer islands, such as Baranof Island, during the LGM is even more probable.

The presence of the circumpolar angiosperm, *Saxifraga oppositifolia,* and the disjunct bryophyte, *Drepanocladus berggrenii,* is evidence of species survival in microhabitats of the study area. Bryophytes, such as *Drepanocladus berggrenii*, are widely present across the globe, presumably due to the agile dispersal of their spores (Brochmann et al., 2003). As indicated by Stehlik (2003), the survival and dispersal of species in glacial and postglacial times cannot be clarified in either the 'tabula rasa' or 'nunatak' hypotheses, and must be considered in relation to the reproductive and dispersal capacity of an individual species. Also to be considered is the hardiness and adaptability of a species, i.e., its plasticity in Hultén's terms (1937), as well as multiple environmental and habitat variables. Brochmann et al. (2003) further express caution in the identification of endemic species and suggest that endemics have been overestimated in arguments for refugia in the North Atlantic region. Brochmann et al. (2003) identify the North Atlantic arctic montane species in their study as hardy and non-hardy species. The latter are considered unlikely candidates for survival. Over forty-three species were classified as 'hardy' and over thirty-four species as 'non-hardy'. The study also suggests the likelihood of some of these species returning to their current extent from periglacial refugia. Species in that study, also present in the current study in the Boundary Range, include *Luzula arcuata* and *Poa arctica,* among the hardy species, and *Juncus arcticus* among those identified as non-hardy endemics in the North Atlantic.

Dahl (1946) classifies species of the Scandinavian and European Arctic into those likely to have survived the last ice age in coastal, tundra, and Antarctic-types of refugia. Dahl identified over forty-eight species as 'coastal varieties'. These coastal habitats are usually lower elevation and have a maritime climate. Those in the current study, in common with the coastal variety of

Dahl's classification, are *Juncus arcticus, Sagina saginoides, Epilobium hornemannii, Epilobium anagallidifolium,* and *Loiseleuria procumbens*

Dahl (1946) identified over twenty-two species as the 'tundra variety'. The tundra-type refugia have a continental climate. Of those also found in the current Alaskan study, which are in Dahl's tundra category, are *Potentilla hyparctica* and *Polemonium boreale*. The Antarctic-type of refugia in Dahl's classification (1946) have a firn line that extends to sea level, while the Scandinavian-types have a firn line that never reaches sea level, with a maritime climate.

Ward (1951) describes the Juneau Icefield vegetation as developed post LGM, citing the unlikely survival of species on most nunataks due to the generally low mountains, thick ice-cover, and geomorphologic evidence of glacial ice at high elevations, as exemplified by the abundant grooves, striations, and polished rock on Taku B Peak. This terrain is extremely varied, and although the probability of plant species surviving full glacial conditions on the nunataks is low, the variety and diversity of landscapes and protected pockets in the terrain suggest the possibility of some hardy species having survived in these locations.

Considerations of Succession

Soil type and depth are integral in supporting vascular plant species abundance and richness. Ward (1951) observed a pattern in the xerarch phase of the successional process in which circular patterns developed with a center of bare rock, surrounded radially by lichens and bryophytes in a thin veneer of soil. Progressively outward from the center of these circles, soil depth thickened and supported more advanced plant forms. Erosional processes and ablation on the peripheral sectors of such sites should also be considered. Heath were not present until the soil depth was at least 2.5 cm. Ward (1951) observed this at a location on the west side of the Taku Glacier terminus, now cited as Camp 12, which was his Station 1. The author visited Camp

12 on Grizzly Bar in 1994 in conjunction with the research of Dr. Arnie Friedman who was investigating teleconnections between the recession of the Taku and Norris Glaciers. In Ward's (1951) description of the radial xerarch successional pattern, he mentions the presence of liverworts near the center of the circles. Liverworts have been observed on the icefield at only a few locations that are directly influenced by human activity. In general, it is thought that liverworts require a more moist and protected environment than that of most locations on the central icefield. The presence of liverworts at Ward's described Station 1, 'Camp 12' confirms the site's identification as Ward's Grizzly Bar site on the west side of the Taku Glacier terminus. In the present study, the same successional pattern was observed at a location four miles from the Taku terminus, on a nunatak on the eastern side of the glacier, comprised of Taku A and Taku B Peaks.

Modeling of the Controls on Species Richness and Distribution Across the Nunataks

From some standpoints, it is logical that higher elevation sites should have greater species richness than lower elevation sites on an icefield inundated by glaciers. The higher the elevation of a site, the more likely it will be ice free, and the more likely that it has been ice free for a longer period of time. Elevation is a strong predictor of winter low temperature, and in many respects is a more static and dependable variable than winter low temperature. The confounding influence of these variables must be considered. For example, elevation and latitude greatly influence temperature. In turn elevation, latitude, and temperature are integral in defining the growing-season. In a similar manner, the aspect of a site, contributes to the insolation received and, ultimately, the temperature and growing-season. The slope of a particular site is also important. Beyond a given slope, the likelihood of plant life to take hold decreases.

The influence of Site Twenty-six (Figures 20 and 26) on the model is of note. This nunatak has the second highest latitude, the greatest richness, the greatest surface area, and the greatest predicted richness of any site in the study. Its temperature, area, and richness vary substantially from the other sites. Site Twenty-six is an outlier and made for difficulties in the modeling process.

Sites with a predicted richness value near zero, and outliers with richness values near ninety, are significant, as seen in the Residuals on Predicted Richness Plot, and the Predicted Richness Curve (Figures 20 and 21). Sites with small areas and low richness values can be explained by their location near the periphery of the icefield. The size of the nunataks suggests that the sites have been exposed recently by ice recession. Therefore, less time has been available for colonization of the sites by vegetation. Such sites soon become continuous with the mainland and their richness then increases rapidly. Site Twenty-six is one of the northernmost sites in the current study (Figures 19 and 20), and is an outlier at the upper end of the plotted values, with a richness of 89 and an area of 1.2 km^2. Its size and relief have protected it from denudation by glacier ice and have allowed it to foster a variety of vascular plant species.

Area as a Dominant Variable in Controlling Species Richness

Why is area the dominant variable in determining species richness? One immediate explanation is the extended time on large area sites for the development of soil, the immigration of species, and successional processes. A large area site has more surface ice free than smaller area sites, which allows more time for the above-mentioned processes. The next question is why are the nunataks with a greater distance from the mainland larger. This is of geomorphological significance and is likely a result of the size of the nunatak. The size contributes to protecting the land mass from being overridden by the thicker ice at the center of the icefield. Small nunataks near the edge of the icefield are usually younger in age, having been free of ice for less time, and therefore, they have had less time for colonization by plants.

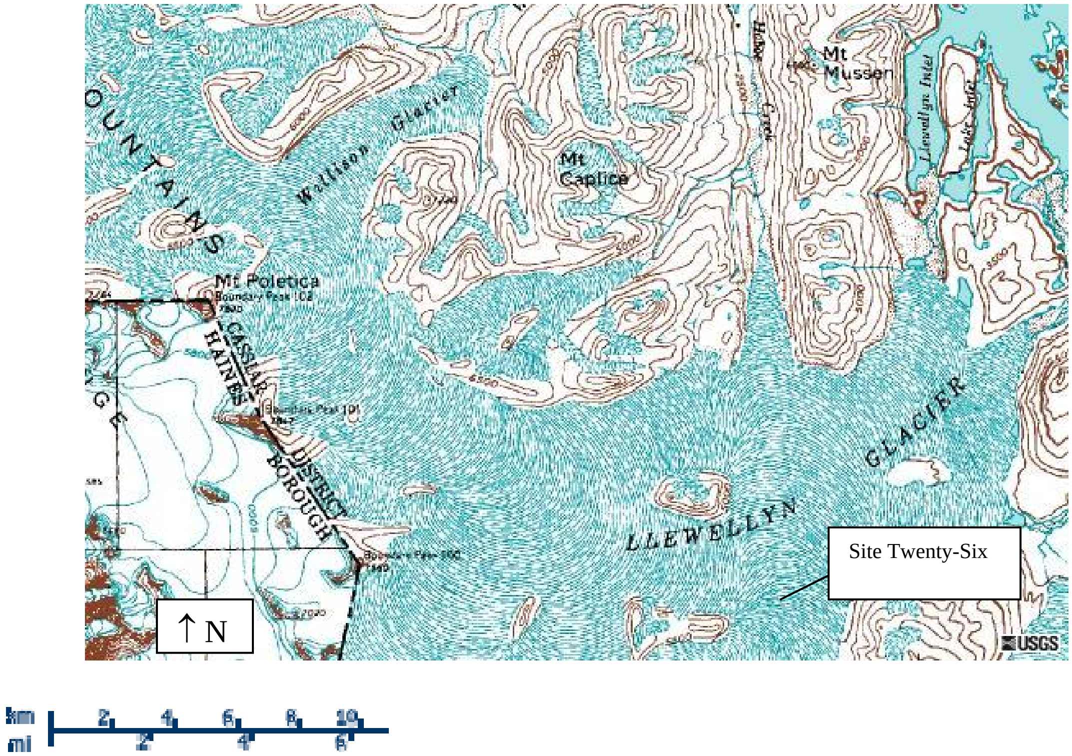


Figure 26. Site Twenty-Six Location Map.

Site Twenty-Six is located on the Llewellyn Glacier in British Columbia, U.S.G.S. Terraserver.

An observation counterintuitive to the low species richness, on the small nunataks near the periphery of the ice, is the close proximity to an influx of species and seeds from the continuously vegetated mainland. Landscape heterogeneity is expected to be greater on larger area nunataks and is expected to influence richness. The heterogeneity of larger area nunataks may be an important variable contributing to greater richness at these sites.

The Influence of Aspect

Ward (1951) noted a substantial variation in vegetation coverage on different nunataks. Southwest aspect slopes were identified as the most vegetated and well-developed in terms of successional processes. At high latitudes, the sun is low in the sky in both summer and winter. Due to the tilt of the earth on its axis, day length is also significantly reduced in the winter months and is greater in the summer months in the sub-Arctic high latitudes. In this study region, day length varies from an extreme of 5 hours of daylight at the winter solstice to 19 hours at the summer solstice. In the summer, the sun trends to the northeast and northwest in rising and setting in the Northern Hemisphere, and to the southeast and southwest in rising and setting in the winter months. The operative factor is the longer length of the winter season and the predominance of light on south aspect slopes. Latitudes south of the study region receive more sunlight, as a result of Earth's inclination. South aspect slopes, within the study region, receive more daylight annually than north aspect slopes.

More insolation, on south aspect slopes annually, increases the likelihood of successional processes leading to soil development. In this regard, richness would be expected to be greater on south aspect slopes (Miller, personal communication, 2007b), as is observed in the aspect plot. Please refer to the Aspect and Richness plot (Figure 10). The best example of this phenomenon in the current study is the Cathedral Glacier Massif, Site Twenty-nine, which is almost exclusively north-facing. Site Twenty-six also has a preponderance of north aspect slopes in comparison to other stations in this investigation. North aspect nunatak slopes do appear to have enhanced growing-seasons partly due to increased insolation during the summer months. Although north aspect slopes receive more hours of sunlight in the growing-season, the sun is higher in the sky on the south aspect slopes, and therefore, they receive more total radiation (Box, personal communication, 2007).

Considering the above example, a threshold may exist beyond which north aspect slopes have a greater influence on richness. The threshold occurs when enough soil has developed to support plant populations. This may be important on north aspect slopes receiving more insolation during the growing-season in the summer months.

Distribution of Species Across the Nunataks and the Theory of Island Biogeography

The observation of area as a stronger variable than overwinter low temperature in controlling species richness (Abbott, 1974) is significant because it emphasizes that nunataks behave as islands in the theory of island biogeography, despite being connected to the mainland by a medium with greater structural integrity than water, as in true oceanic islands (MacArthur & Wilson, 1967).

The distribution of species on nunataks follows, in part, that described by Guar, Raturi, & Bhatt (2005) in the Central Himalaya. In that study, katabatic winds are observed as influencing the habitation of lower elevation slopes closest to the glacier surface, and plant associations are related to their interdependence on each other for substrate development and for protection from the elements.

Growing-Season

Taku Northwest Point is the only site for which an increase in growing-season length does not correspond with an increase in species richness (Figure 16). This variation is likely a result of the small surface area of the site and the substantial vertical terrain. The relatively few days with night-time temperatures below freezing and day-time temperatures above freezing is a result of the strong maritime influence on the climate of a large portion of the study region. Area is not considered in the context of growing-season, although it does have an indirect influence on a nunatak’s temperature and species richness (Figures 16 and 17). At Site Nine A, the growing-season is shorter and vascular plant assemblages negligible. This is largely a result of katabatic winds flowing down the uppermost Demorest Glacier and extensive snow cover that cools the air, contributing to the retention of firn, further limiting the growing-season. In contrast, Figure 16 reveals a maximum growing-season length at Site Twenty-six, a consequence of its reduced firn cover, its inland location, and its predominance of south and east aspect slopes. Site Twenty-nine is located approximately 15 km north of the main icefield and is not as comparable from an analytical standpoint.

Richness and Temperature from 1948-2006

The increase in species richness from 1948 to 2006 can be attributed to the longer period of investigation of the current study. Some of the increase is attributable to successional processes and the corresponding increase in temperature over the time interval. Additional considerations are the inclusion of nunataks mainly from the western or Alaskan side of the region in the earlier three studies of Chamberlain (Miller, 1949), Ward (1951) and Heusser (1954b), and the addition of nunataks from the more northern, British Columbia, side in the later two studies of Anderson (1979) and Bass (the current study). Approximately 90 % of the variation in richness can be explained by variation in temperature. However, the variables of study length, rate and magnitude of successional processes, and other variations in the sites must also be considered (Figure 18).

It should be noted that taxonomic changes have taken place in the last half-century. In Heusser and Ward's applications, species and subspecies are included which are no longer accepted (ITIS, 2007). Therefore, these taxa are not incorporated into the counts for interpreting specific change from 1948 to the present. For example, the species *Salix crassijulis* and *Salix* *torulosa* are listed as subspecies of *Salix arctica* by Hultén (1968). They have recently been delisted and are now included within *Salix arctica* (see Table 2).

Comparison of Sites in Historical Studies and the Current Study

A significant increase in species richness was identified from 1951 to the present on Sites Thirteen (233 % increase) and Ten (124 % increase). These increases can be explained by successional processes, plant immigration, and the cumulative length of time over which the region has been investigated. At Site Ten, 56 species were observed in the current study. Ward observed 25 species at Site Ten in 1951. There is 25 % similarity between the species observed at Site Ten in 1951 and in the current study. Species observed by Ward in 1951 and not found at the same locations in the current study are of interest. At Site ten, these included *Juncus mertensiana*, *Carex praticola, Carex pribylovensis*, and *Saxifraga oppositifolia.* At Site Thirteen, 20 species were observed in the current study. Ward observed 6 species at Site Thirteen in 1951. There is 8% similarity between the species observed at Site Thirteen in 1951 and in the current study. Species observed in 1951 at Site Thirteen and not observed at the same location today include *Carex anthoxanthea, Cassiope mertensiana, Luzula wahlenbergii,* and *Potentilla emarginata.* Most of the sites in the studies of Ward (1951), Chamberlain (Miller,1949), and Heusser (1954b) are not described in sufficient detail to locate on a map and permit direct comparisons of richness on a site-by-site basis. Therefore, the species richness for the region as a whole is considered. The current study includes sites at Taku Northwest Point and Site Twenty-six. Ward and Heusser did not investigate these sites. Ward (1951) and Heusser (1954b) did include sites at Juncture Peak and the Twin Glaciers. The current study did not include these sites due to logistical and safety complications. The sites included in the current study, but excluded from the earlier studies, along with those included in the early work, but not included in the current study, balance the comprehensive data set for a general comparison of species richness across the Boundary Range.

Ptarmigan Ridge Geobotany

Cirque level C-5, with a mean floor elevation of 975 m (3200 ft) lies just below the Site Seventeen ridge and is at the level of the current uppermost névé of the Ptarmigan and Lemon Creek Glaciers. The ice eroded and highly-weathered ridge top appears to have been exposed for at least 50,000 years after glacierization in the early to middle Wisconsinan. This interpretation is based on alliance to the North American Centered Pleistocene stratigraphic chronology (Miller, 1964, 1985). The presence of glacial erratics, rounding of bedrock hummocks, and associated soil and alpine tundra vegetation, are further evidence of the long exposure of this surface. In this sequence, the Mendenhall and Herbert Glaciers are presumed to have occupied cirque levels C-1 and C-2 (i.e., at mean elevations of 91 m and 305 m (300 and 1000 ft) in Pleistocene Maximum time. This interpretation is based on the approximately 213 m (700 ft) spacing between cirque floor elevations on the northwest coast of North America, which pertains to this coastal sector of the Juneau Icefield, the accompanying Alaska Panhandle and the islands of the Alexander Archipelago (Miller, 1956).

Vegetation assemblages on the Ptarmigan Ridge have features that distinguish them from observed younger icefield surfaces. They represent a more advanced and mature vegetation association than elsewhere on the adjoining periphery of the icefield. The Ptarmigan Ridge is a prime example of late-Pleistocence soils and plant development in the icefield region, upon which an understanding of subsequent vegetation and natural history in other segments of the glacierized region depends. Implications for plant dispersal and species richness are evident from field study of this ridge. Key plant species observed and vouchered on the Ptarmigan Ridge Site, which typify the successionally advanced vegetation assemblage, include *Empetrum nigrum, Castilleja unalaschcensis*, *Menziesia ferruginea*, *Oxycoccus palustris*, *Salix stolonifera,* and *Tsuga heterophylla.*

Research Hypotheses Revisited

Hypothesis 1

More vascular plant species will be observed in the current investigation than in historical botanical studies. A 20% or greater increase in species richness is expected between the vascular plant species observed in the region in all past studies and the current study.

Justification. During the approximately 58 years since the first formal floristic investigation of the region, new plant immigrants have taken hold on the study sites. The increased time dedicated to investigating the region allows for the observation of species that may have been previously overlooked.

Accepted. The vascular plant species richness is observed to have more than doubled between 1948 and 2006. Many variables are responsible, including rise in average temperature, longer growing-season, successional processes, species range extensions, the longer length of the current investigation, and the total time that has now been devoted to studying the region's flora.

Hypothesis 2

An increase in vascular plant species richness is observed on the maritime to continental gradient.

Justification. This hypothesis is founded on the observed greater number of clear days on the continental sites as compared to the clear days observed on the maritime perimeter of the region.

Accepted. The sites with the greatest species richness are those with the most continental climates and are located the greatest distance from the coast. Exceptions do exist and other variables besides continentality contribute to richness, including landscape heterogeneity and area. However, the sites with more continental climates do exhibit higher average temperatures in the summer, which is the essential growing-season for the region.

Hypothesis 3

There is a direct relationship between the mean winter low temperatures on the nunataks and vascular plant species richness. As the average winter low temperature increases, the richness of vascular plant species also increases.

Justification. This hypothesis is based on the observations of Abbott (1974).

Rejected. The sites with the lowest winter temperatures are not those with the lowest species richness. This counters what is known about continentality and summer and winter extreme temperatures. Abbott's study (1974) is based on Southern Hemisphere islands, precluding sites with a continental character.

Hypothesis 4

Opportunistic vascular plant species not found on nunataks without field stations will be found on nunataks with field stations. As a testable, quantitative criterion, at least three such opportunistic species are expected on nunataks with field stations, which are not present on nunataks without field stations. Therefore, the presence of human and animal activity contributes to the richness of vascular plant species on these nunataks.

Justification. Humans are effective vectors of dispersal.

Accepted. Eleven ruderal and invasive plant species, not typical of the alpine habitat of the Boundary Range, are observed and have been vouchered on sites with field stations. These species include *Veronica arvensis*, *Sambucus racemosa*, and *Solidago multiradiata.*

Hypothesis 5

There is a positive correlation between nunatak surface area and the number of different species on a nunatak. As nunatak surface area increases and decreases so does variation in the richness of vascular plant species.

Justification. This hypothesis is based on the tenets of the theory of island biogeography (MacArthur & Wilson, 1967).

Accepted. Area is determined to be among the most influential variables controlling species richness. Area and species richness are correlated strongly. Area, in conjunction with latitude and growing-season length, produces a model for the prediction of richness with the least variation between observed and predicted values.

Hypothesis 6

There is an indirect relationship between the distance of nunataks from the continuously vegetated mainland and the number of vascular plant species. As distance from the continuously vegetated mainland increases, the number of vascular plant species decreases.

Justification. This hypothesis is based on the laws of island biogeography (MacArthur & Wilson, 1967), which are expected to be satisfied by the distribution of species across the nunataks.

Rejected. The richness of vascular plant species is not observed to decrease regularly with increased distance from the mainland. The sites in the data set manifest greater area with greater distance from the mainland. The influence of the local geology and positive feedback mechanisms, governing the persistence of large-area nunataks above the surface of the ice, contribute to this phenomenon.

Future Research

The influence of north versus south aspect slopes should be investigated further with instrumentation to quantify solar radiation at specific sites and, subsequently, to assess the effects on soil development and vegetation succession. Radiation received and the number of days with temperatures above a growth-threshold temperature at Sites Twenty-nine and Twenty-six should be investigated in more detail, ideally with permanent year-round radiometers, actinographs or pyroheliometers.

The use of comparative mountain studies will bring attention to the global application of the current work. The author plans to expand this research through wider-area and more detailed studies in Alaska and British Columbia, with comparative work in other locations including South America, New Zealand, the Himalayan Ranges, and Scandinavia. This research, on the alpine plant species of the Tongass National Forest and Atlin Provincial Park, will draw attention to the importance of mountains and nunataks in the conservation of sub-Arctic and high-latitude flora and fauna.

Recently exposed nunataks near the edge of the icefield provide a natural laboratory for the observation of successional processes in-habitat. Study of the threshold size of nunataks should be pursued. This is the size beyond which large-area nunataks are not inundated by ice and provide habitat for high diversity plant communities. Such large area sites will inherently become even larger, more soil will develop, and more extensive plant cover will follow. The decreased albedo will create the positive feedback of greater species diversity and enhance successional processes. The relationship of nunatak surface area and the distance of the nunataks from the mainland was not expected and deserves more study.

Future studies should incorporate a means of measuring dominant wind direction on the sites. This could be accomplished with establishment of permanent weather stations deployed on key sites. The author hopes to investigate lichens and bryophytes in more detail, especially to note the effects of on-going climate change. The incorporation of population genetics will allow for better understanding of the dispersal centers of the regional plant populations and the intraspecific relationships of plants on different nunataks. Radiocarbon dating will allow the determination of surface exposure dates.

In future studies, species diversity on nunataks in the Alaska Range and in the Canadian Rockies can be compared to that on the Coast Range and Juneau Icefield nunataks. Such comparisons are especially interesting in consideration of the proximity of the Alaska Range to the Ice-free Corridor and the connectivity of the Canadian Rockies and the Coast Range with lower contiguous North America. The data will elucidate the migration routes and origin of the current Coast Range species assemblages. In particular, these data could allow for investigation of plant species of the Juneau Icefield having immigrated from Beringia, from more northern locations, and from more southerly, less severe climates along the coast. Future studies will also clarify questions on the extent of ice inundation of the Juneau Icefield nunataks during the Little Ice Age and Hypsitermal.

The relationship between richness and temperature from 1948 to the present is especially significant and should be considered in more detail. Future analyses, with a larger data set, should be designed to test the influence of control variables within a framework of temperature, presumably one of the more influential of the variables. Continuation of this study will provide an extensive data set, making possible more adequate tests of the extinction, immigration and equilibrium tenets, originally presented by MacArthur and Wilson (1967), as well as the dynamic drift implications presented by Hubbel (2001).

The author will continue the development and maintenance of educational herbaria for the Sitka Native Education Program, the Taku River First Nation, and for the Glaciological and Arctic Sciences Institute in Atlin, British Columbia.

Nunatak vegetation is a harbinger of the greater global changes the region is experiencing and is paramount in understanding the changes at hand now and in the future. Regional botanical investigations of the nunatak and periglacial regions in the northern Alaska-Canada Boundary Range demand and deserve continued research emphasis.

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APPENDIX A

GLOSSARY

Ablation: Removal by melting of glacier ice, firn and snow, erosion, evaporation, and sublimination.

Abundance: The number of individuals of a particular species in a population or community. Abundance is not synonymous with dominance, which is dependent on ecologic control of the habitat and coverage.

Albedo: The reflectivity of a surface or the ability of a surface medium to reflect and deflect incoming solar insolation and associated heat energy.

Bergschrund: A large crevasse that forms at a high angle between rock and ice near the crest of a mountain slope and is augmented by differential stress between the ice and rock surfaces (Bates & Jackson, 1976).

Berm Level: The elevation of successive excavations at marginal bedrock zones by glacier ice. The lowest berm level corresponds to the lowest elevation cirque, formed when ice levels are the most extensive. The highest berm level and cirque are excavated when ice cover is the least extensive (Miller, 1964).

Bølling-Allerød: A warming period in the general cooling of the Younger Dryas in the Wisconsinan Epoch, approximately 14,600-14,100 BP, based on oxygen isotope records from the Greenland ice cores.

Character Species: Species in fidelity classes 3, 4, and 5 in Braun-Blanquet's phytosociological system. Species in class 5 occur almost exclusively in one community type. Species in class 4 have a preferential occurrence in a given community type, and those in class 3 occur in several community types but grow most efficiently in only one community type. Generally, character species will have a constancy above 80% (Hanson, 1962).

Cinder Cone: As in the Atlin area of the study region, a lava flow pushing through the earth's crust and accumulating in mounds of scoria (Bates & Jackson, 1976).

Cirque: A glacially eroded depression in mountainous terrain. In northwest North America, cirques developed from the Pleistocene to the present day have been observed to have approximately 700 ft. between successive levels. In southeast Alaska, cirque levels one and two are slightly above sea level, with the Herbert and Mendenhall Glaciers serving as examples. An example of cirque level two is the current study's Bog Pond Site. An example of cirque level three is the Tarn Lake Site. An example of cirque level four and five, in the current study, are on the Ptarmigan ridge and the headwall of the Lemon Creek Glacier, respectively. Cirque level one is generally sea level to 213 m. Level two is 214 to 548 m. Level three is 549 to 762 m. Level four is 763 m to 975 m, and level five is 976 m to 1067 m.

Cluster: A group of species which occur together, and are identified as such in classic phytosociological tabular analysis.

Coast Range Batholith: The granitic bedrock unit comprising many of the nunataks of the Juneau Icefield (JIF). The Coast Range Batholith rocks have been K/Ar dated at 53 million years before present. It has been estimated that the batholith was formed 35 km below the surface of the earth.

Companion Species: In Braun-Blanquet's fidelity classification, companion species may occur in a number of community types and are not differential. Companion species are used to sort the raw data table into the differentiated table (Hanson, 1962; Kent & Coker, 1996).

Constancy: The occurrence or presence of a species as present in a percentage of the total number of relevés or sampling units (Hanson, 1962).

Cutlevel: In tabular phytosociological analyses using JUICE and TWINSPAN Software, the number of frequency categories the species fall into, frequently defined as three, with cutlevel 0 for frequency <5%, cutlevel 5 for frequency 5-25%, and cutlevel 25 for frequency 25-50%.

Depauperate: Describes a population or an individual of a species that is dwarfed and stunted as a result of environmental and geographic stresses.

Differential Species: Species used to distinguish community types due to their regularity of occurrence in a particular plant community (Hanson, 1962).

Disjunct: The occurrence of a species in a location without evident geographic links to a distribution source or immigration route; often referred to as a gap in distribution (Hanson, 1962).

Diversity: Diversity in this investigation is represented as richness and is defined as the number of different species.

Eigenvalue: Special values of variable parameters in an equation, which produce nontrivial solutions only when the special value is used. The values may be used in linear, differential, or integral equations (McGraw Hill, 1971).

Endemic: A species found only in a given region or country and with an overall narrow range of occurrence (Hanson, 1962).

Fidelity: The regularity with which a species occurs in a given community type. A ranking system is used: 5 - exclusive, 4 - selective, 3 - preferential, 2 - companion and, 1 - accidental (Hanson, 1962).

Firn: cf. névé. A morphogenic stage between snow and glacier ice, normally referring to late stage ‘old snow’ that is at least one year old, has changed in crystal form, and has become markedly granular in comparison to fresh snow as a result of multiple freeze/thaw cycles. Firn usually has a bulk density of 0.60 g/cm^3 (Trowbridge, 1957).

Firn limit: cf. névé, snow line, firn line, regional snow line, equilibrium line elevation. The demarcation between the accumulation and ablation zones on a glacier, with the accumulation zone covered with firn, and the ablation zone (at a lower elevation) with exposed glacier ice from which the firn has ablated.

Flora: In the context of this project, “flora” refers to vascular and nonvascular vegetation including: angiosperms (monocots and dicots), pteridophytes, lichens, and bryophytes. This study does emphasize vascular species.

Glacial: Referring the cold wet climatic conditions, as typified by the later Wisconsinan time and following the Two Creeks Interglacial and the resurgent Valders Substage of the Wisconsinan Stage of the Pleistocene Epoch.

Glaciated: Refers to a landscape that has been formerly covered by active glaciers.

Glacier: Specifically, a perennial mass of ice, snow, rock, sediment, and included liquid, which originates on land and flows down-slope (Molnia, 2001).

Glacierized: Refers to a landscape that is currently covered with active glaciers.

Growing-Season: In the context of this study, the growing-season is defined as the number of days with an average temperature at or above 5 ° C, or 41° F, between 1 May and 31 August of each year. These days may not be consecutive.

Hydrosere: All of the stages in a successional sequence collectively, and beginning in water (Hanson, 1962).

Icefield: An area where the lower parts of tributary valley glaciers converge, with nunataks protruding above the ice surface; usually at least 500 square miles in area (Molnia, 2001).

Katabatic Wind: A strong down-valley wind common in orographic belts, and formed by the inversion and deflected, down-slope movement of cold and warm air masses.

Last Glacial Maximum (LGM): The time of the last major glacial advance in the Northern Hemisphere, also known as the Wisconsinan Glaciation, generally dating from approximately 18,000 to 20,000 BP (Before Present).

Little Ice Age: (LIA) A cooling period within the latest warm interglacial of Neoglacial time**.** Matthes (1930) first classified the time period based on his work in the Yosemite area, California, as approximately 3000 yr BP. Today the term is generally used for describing a markedly cooler interval between the 15th and 18th century (Pittock et al., 1978). The LIA climatic cold period of the late 1800s saw a temporary glacial advance in the North American Arctic and sub-Arctic.

*Medieval Warm Period***:** A warming period identified in the north Atlantic between 800 and 1300 AD, pre - Little Ice Age.

Nunatak: A mountain peak or rock ridge rising above glaciers of an icefield and often serving as an ice-divide demarcating the ice flows of separate glaciers. “Nunatak” literally means “lonely rock or peak” from the Greenlandic Eskimo (Bates & Jackson, 1984; Molnia, 2001).

Nunatak Hypothesis: The hypothesis supporting the isolation and preservation of species during the maximum of the Pleistocene Glaciation, via protection on topographic highs such as nunataks (Heusser, 1954a).

Plant Association: The species composing a plant community. The species characteristically occur together and define a habitat and physiognomic type; more indicative and characterizing than the general term, plant community. Relevés with overlapping species form associations and define communities. Associations and communities are abstract spatial entities representing uniformity of composition and habitat over a spatial extent.

Plant Assemblage: Representative species that occur together, often dominantly, and define communities.

Plant Community: A number of plant populations composed of species known to occur together and interact with one another.

Pleistocene: The epoch of geologic time beginning 1.6 million years ago, and ending approximately 10,000 years ago in most locations, followed by the Holocene, which began approximately 11,000 years BP, depending on the location. During the Pleistocene, large continental ice sheets covered much of the earth. The Holocene and Pleistocene Epochs together comprise the Quaternary Period of geologic time (Molnia, 2001).

Positive feedback: A condition that augments itself and related conditions. An example is the reduction of ice and snow cover on a surface. This reduces the albedo of the surface, leading to greater vegetation growth and soil development, further reducing albedo.

Primary Succession: Generally, referring to the habitation of, and subsequent presence of, more advanced organisms, in particular vegetation, on a bare area not previously occupied by life forms.

Protalus Rampart: An apron of periglacial debris, terraced above the periphery of a glacier and wedged between a talus slope and lateral moraine. Usually unsorted, non-stratified, coarse angular rock debris forming arcuate low ridges and present with perennial snow banks on shaded sites (Hall, 2002).

Refugia: Areas that preserve species through isolation via altitude, distance, and protection from environmental forces. Species not protected in such areas are at risk of extinction.

Relict Vegetation: Referring to a vegetation community that has survived austere environmental conditions (for example; climate change, glaciation, or a natural disaster), when most related species have not survived. The relict community has survived due to some form of protection, usually related to geographic location, and is a fragment of a previously more widespread community.

Richness: In the context of this investigation, *Richness* refers to the number of different vascular plant species.

Relevé: cf. Aufname, the sampling unit or stand in the Braun-Blanquet methodology and School of Phytosociology.

Roches moutonnées: Glacially denuded bedrock structures, typically with glacial polish, striations, crescentic gauges, and pressure forms. In most cases, a roche moutonnée will have a gradually sloped up-glacier stoss side and a steeply plucked down-glacier lee side (Trowbridge, 1957).

Sere: The series of stages following one another in ecological succession (Hanson, 1962).

Species Complex: A species complex describes intergrades and possible forms between the subspecies and varieties present within a species, and describes a group of related species that may or may not be reproductively isolated from one another. If isolated, each species breeds only with its own species. If not isolated, the species may breed with other species and form hybrids.

Subsere: The series of stages (succession) taking place following disturbance of natural vegetation, usually by humans (Hanson, 1962).

Subspecies: In this study, a subspecies is considered a geographically separate part of the species, while a variety is a part of the species' population that crops up within the species in a given location. Varieties may occur without any subspecies designation. Subspecies commonly intergrade with one another and are not always isolated.

Tank and Tor Topography: A landscape created in periglacial, cold dry conditions, usually originated in bedrock of differential resistance, and forming high points that are more resistant (tors), and depressions (tanks), often water filled, in locations of less resistant rock. The origin of the tanks and tors is deep overriding glacier ice and glacierization followed by terrestrial weathering processes. These are equivalent to knob and kettle topography in a continental glaciation. Knobs and kettles are the counterpart depositional and erosional features formed in softer glacially deposited sediments.

Teleconnection: In the context of this investigation, a broad scale relationship across time and distance.

Thermal Maximum: The warm and generally dry interval following the postglacial wet - cool climate interval of the Wisconsinan Glaciation, via the Cordillera Ice Sheet in northwestern North America (Heusser, 1954b; Miller & Anderson, 1974). The Thermal Maximum was a time of maximum warmth on the southern portion of the Juneau Icefield (J.I.F.), and a time of increased moisture and storminess on the northern end of the J.I.F. The Thermal Maximum spanned between 3250 - 5500 years ago on the Juneau Icefield, with 4000 to 8000 years BP noted for the interval in other locations (Miller, 1955). Synonyms for the Thermal Maximum include the following: altithermal, Holocene climatic optimum, Hypsithermal, Holocene thermal maximum, and Holocene megathermal.

Variety: A varying taxonomic group within a species or subspecies but differing from, and being of lesser rank than, the species or subspecies occurring within a given population.

Xerarch: A successional sequence or sere commencing in a dry habitat (Hanson, 1962).

Younger Dryas: Refers to the European cool period following the warmer Bølling-Allerød and generally accepted as about 10,500 years ago, at the end of the Wisconsinan. The interval was prior to the preboreal, and is identified by a cooling climatic trend when glaciers expanded and there was a pause in the overall pattern of retreat (Iverson, 1954).

APPENDIX B

2002-2004 REPORT

Preliminary Report

2002-2004 Botanical Research on the Juneau Icefield

Nunataks and Island Biogeography: Implications for Plant Geography in the Alaska-Canada Boundary Range

Primary Investigator: Polly Bass

with support from the Foundation for Glacier and Environmental Research and the Juneau Icefield Research Program

Polly Bass

December 24th, 2004

Introduction

Thirteen sites were botanically investigated between 18 July and 25 August 2003. Four of the thirteen had not been botanically studied in the field season of 2002. Among the highlights of the field season were the observations of bird and mammal species on the field sites, the collection of modern pollen rain, and the deployment of digital data logging thermometers at two sites. More time was spent at most sites in the field season of 2003 than in the 2002 season. This allowed for more thorough surveys to be carried out. Three sites which were not visited in the 2002 field season were added to the study in the 2003 field season. Site numbers given to locations in 2002 were maintained and any new sites were given a number above the thirteen labeled in 2002. Site One and Site Three from the 2002 field season were not investigated in 2003 due to logistical complications and time constraints.

The 2004 field season involved work at several of the sites visited in 2003 in addition to work at five new sites, mostly on the southern sector of the study region. Eleven sites in total were surveyed between 9 July and 1 August 2004. At most of the sites, species/area curves were carried out, as well as line transects and relevés. A new site, at the base of the Ptarmigan Glacier, and along the stream that originates from the glacier, was added to the study. Another new site is a location on the ridge above the upper Lemon Creek Glacier, Ptarmigan Glacier and Salmon Valley. Sites on Vesper Peak, Cairn Peak and a location above Blackerby Ridge were also included. A site, which was surveyed in 2002, located at the Tarn lake, one valley south and west of the Ptarmigan glacier, was again investigated in 2004. A site along the central portion of the Taku Glacier, just below the Taku B peak was also added to the study.

Project Overview

Nunataks and island biogeography: Implications for plant geography in the Alaska-Canada Boundary Range

A comprehensive flora of the Juneau Icefield nunataks will be developed, while testing the principles of island biogeography in application to nunatak environments. The data set will be compared to similar habitats in other regions. Additionally, the impact of field stations on the alpine habitat will be considered. The collections and data will be used to assist in the formation of a herbarium and educational opportunities for the Taku River Tlingit First Nation Tribe. This study will be based on the nunataks of the Juneau Icefield (JIF).

The JIF lies within the Tongass National Forest in southeast Alaska and stretches approximately 161 km north to south, and 72 km east to west (USFS, 1971). It is the fifth largest icefield in North America and covers approximately 2400 km^2. A nunatak is a mountain peak or rock ridge rising above the glaciers of an icefield, and often serving as an ice-divide demarcating the ice flows of separate glaciers. “Nunatak” translates to “lonely peak” from the Greenland Eskimo (Bates & Jackson, 1984).

The geological formation composing most of the JIF nunataks is the Coast Range Batholith. These rocks have been K-Ar dated at 53 million years BP. It has been estimated that the batholith was formed 35 km below the surface of the earth (Forbes, 1959). A lack of information exists on nunatak vegetation of the North American sub-Arctic. Additionally, the glacierized environment of southeast Alaska is in a state of increased change, making a record of the region’s biota important (Miller, 1955). Plants are a sensitive indicator of environmental change (Walker, et. al. 2001). The sensitivity of the alpine ecosystem makes an understanding of the biological processes and life forms of the region imperative in the presence of increased human impact on earth (Anderson, 1991).

Expected Results for the Study

Some species are expected to be found outside of their known ranges. This is an expected consequence of increased average temperatures (Cody, et al. 2001). Species extensions could result due to the fact that some investigated areas have not been botanically studied prior. Other species extensions may result from the physical extension of the range of a given species and the progression of postglacial succession, particularly where the ice has receded on the margins of nunataks. Such findings could have implications for the rate of climate change in alpine plant habitats.

The distribution of plant species is likely to vary between the nunataks on the southern portion of the icefield with a maritime climate and the nunataks on the northern portion of the icefield with a drier continental climate. Greater abundance of species and individuals is expected on the northern nunataks. The principles of island biogeography are expected to apply to nunataks in most respects.

Brief Overview of the 2002 Field Season

In the field season of 2002, thirteen separate sites were visited and botanically surveyed. These included 11 different nunataks and one alpine periglacial ridge connected to continuously vegetated land. Six of the nunataks investigated have field stations which are occupied for a period of one to three weeks between 5 July and 24 August of each year.

Sites Visited in 2003 and Activities at Each

<u>Site Two, C17</u>: The site was visited on 18 July 2003. It is technically a paleonunatak

and is connected to the mainland by a ridgeline. In 2003, three hours were spent on the site. Modern pollen rain samples, soil samples and floristic vouchers were collected. Four relevés were completed.

Site Three, C13 and Rock Band: The site was visited on 18 July 2003. One relevé was completed on this precarious and steep location located on the north side of the Lemon Creek Glacier and south of the Nugget Glacier and Nugget Mountain ridge. *Saxifraga oppositifoia* L., which is fairly infrequent on the icefield nunataks, is found at this location (Hultén, 1968).

Site Four, Nugget Mountain Ridge C14: The site was visited on 18 July 2003. One relevé was completed. Soil samples, modern pollen rain samples and floristic vouchers were collected.

Site Five, C10: The site was visited on 25 July – 29 July 2003. Six relevés were completed. A long-term ecological monitoring site for lichens was developed. Modern pollen rain samples, soil samples and floristic vouchers were collected. Multiple ptarmigan hens, roosters and chicks were observed eating *Cassiope mertensiana* (Bong.) D. Don and *Luzula wahlenbergii* Rupr. ssp. *piperi* (Cov.) Hult. (Hultén, 1968). An interesting scat specimen was collected and may be from a fox, however, further analysis is needed.

Site Nineteen, C18N: The site was visited on 4 August 2003. The site is located on iron and coal bearing outcrops. One relevé was completed. Modern pollen rain samples and floristic vouchers were collected. Soil and water samples were tested for pH and found to be moderately acidic.

Site Twelve, C8: The site was visited on 4 August 2003. It is located on the west facing slope of Mt. Moore. Two relevés were completed. Lichen vouchers and modern pollen rain samples were collected.

Site Thirteen, C26: The site was visited on 11 August – 15 August 2003. Eleven relevés were completed. The east, northeast and southeast facing slopes of the nunatak were thoroughly investigated. Modern pollen rain samples, soil samples and floristic vouchers were collected.

Site Twenty-nine, C29: The site was visited on 26 August 2003. The site is a paleonunatak and located adjacent to the terminal lake of Cathedral Glacier. One relevé was completed. Mountain goats were observed in the vicinity. Modern pollen rain samples and floristic vouchers were collected.

Sites Visited in 2004 and Activities at Each

Site Fourteen, C17A: The site was visited on 9 July 2004. Two relevés were carried out at this site at the base of the Ptarmigan and Lemon Creek Glaciers along Lemon Creek. Floristic vouchers were collected.

Site Two, C17: The site was visited from 11 July – 13 July 2004. Two species area curves, two lines transect and fourteen relevés were completed.

Site Twenty-two, Ptarmigan Ridge: The site was visited on 12 July 2004. It is located to the west of the Ptarmigan glacier, which is a snowdrift glacier. Soil samples and floristic vouchers were collected. Four relevés were completed.

Site Sixteen, Cairn Peak: The site was visited on 11 July 2004. Two relevés, two line transects and two species area curves were completed. Floristic vouchers were collected.

Site Fifteen, Vesper Peak: The site was visited on 12 July 2004. Two relevés, two line transects and two species area curves were completed. Floristic vouchers were collected.

Site Four, Nugget Ridge: The site was visited on 18 July 2004**.** One relevé, one species area curve and one line transect were completed. Floristic vouchers were collected.

Site Five, C10: The site was visited on 20 July 2004. Five relevés, three line transects and three species area curves were completed. Floristic vouchers were collected.

Site Eighteen, Taku B: The site was visited on 27 July 2004. One relevé, one species area curve and one line transect were completed. Floristic vouchers were collected.

Sites Six and Seven, Sunday Point North and South: The site was visited on 21 July 2004. Ten relevés, five species area curves and five line transects were completed. A HOBO digital data logging temperature monitoring device was downloaded and re-deployed to collect data over the 2004 - 2005 winter at one hour intervals. Floristic vouchers were collected.

Site Eight, Taku Northwest: The site was visited on 23 July 2004. Six relevés, two species area curves and two line transects were completed. Floristic vouchers were collected. A HOBO digital data logging temperature monitoring device was downloaded and re-deployed to collect data over the 2004-2005 winter at one hour intervals.

Site Eleven, C18: The site was visited on 30 July 2004. Six relevés, three species area curves and three line transects were completed. A long term lichen monitoring plot, initiated in 2003, was evaluated. Floristic vouchers were collected.

Discussion

Digital data logging temperature recording devices were deployed in the field season of 2003 at two sites without meteorological stations. During the 2004 season the devices were downloaded and re-deployed. They will be downloaded again during the summer of 2005.

An unusual situation regarding habitat and floristic diversity was observed at one of the sites added to the study in 2004. At the Taku B site on the central Taku Glacier, greater diversity of plant species, including cryptogams and bryophytes, was observed at a higher elevation, overall inhospitable site, than at lower adjacent and seemingly more habitable locations. The species area curves, line transects and relevés will confirm the observations.

An additional observation of interest on the same nunatak, located on the central Taku Glacier, was the presence of what is presumed to be a dimorphism in the capsule of *Cassiope mertensiana* (Bong.) D. Don (Hultén, 1968). The appendage may be a variant form of the capsule which appeals to rodents or ptarmigan, which eat the capsules and subsequently disperse the seeds. The other observed form of the capsule is five-chambered, round and dry. Both appear to contain seeds.

Goals for the Spring Semester of 2005

During the spring semester of 2005 the author will teach four labs and three lectures (Physics laboratory, Geology lecture and laboratory, General Chemistry lecture and laboratory and Systematic Botany lecture and laboratory) at Sheldon Jackson College in Sitka, AK. Teaching Systematic Botany in an environment very near and similar to the study sites will be conducive to making progress toward dissertation completion.

Additionally, a trip to the University of Georgia in the spring will lend itself to analysis of relevé data, constructive meetings with the dissertation advisor and committee members and creation of a GIS database. During the spring semester, the author plans to complete data entry for the completed relevés, species/area curves and line transects. Indices of similarity may be carried out with comparisons between nunataks, sites, and data from other geobotanical studies in similar regions around the world. There has been some concern over the issue of repeating relevés in the same locations in consecutive years. This problem will be discussed with the dissertation advisor.

The author is considering travel to New Zealand in May and June of 2005, which could allow for incorporation of floristic data from sites on the southwest side of the South Island of New Zealand for comparative mountain studies. Relevés, line transects and species area curves will not require collection or damage to habitats and will be conducted at sites with elevations and conditions similar to those on the sites in southeast Alaska.

Goals for the 2005 Field Season

In the field season of 2005, more work may be done on the Juneau Icefield. However, there is a large body of material and data yet to be analyzed and in some respects, organizing the previously collected data may be the most prudent use of time. If more field work on the Juneau Icefield is carried out, the HOBOs will be collected, downloaded and re-deployed at TNW and Sunday Point on the Taku glacier, sites seven and eight. A method will be devised to monitor increase in land surface area on the studied nunataks. This may consist of use of satellite data or placement of permanent monitoring stakes on the edge of nunataks where the permanent snowline appears to be receding.

Granted logistics and conditions allow, the author would like to visit sites on the Twin Glaciers and on Juncture Peak in the field season of 2005. These sites were included in Ward's 1951 study. Dangerous bergschrunds and terrain have been the limiting factors in accessing the sites. Additionally, if time permits, a site on the Gilkey Glacier and two sites on the Llewellyn Glacier (Marble Mountain and Red Mountain) both in British Columbia will be visited. Although it is not likely to be logistically feasible, visiting Birch Mountain, on Teresa Island in Lake Atlin, would allow for investigation of species composition changes since Buttrick's study (1977) and comparison of the nunatak sites to a true island at a similar latitude.

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APPENDIX C

2005 REPORT

2005 Botanical Research Report

Nunataks and Island Biogeography: Implications for Plant Geography in the Alaska-Canada Boundary Range with Teleconnections to the Glacierized and Glaciated Portions of New Zealand's North Island

Primary Investigator: Polly Bass

with support from the Foundation for Glacier and Environmental Research and

the Juneau Icefield Research Program

Polly Bass

August 7, 2006

Introduction:

Seven sites on the Juneau Icefield were botanically investigated between 18 July and 1 August 2005. Species area curves, line transects, and relevés were conducted at each field site. Permanent plots were established, and a mechanism for determining increase in land surface area was employed. Three sites on the North Island of New Zealand were investigated between 13 June and 20 June 2005. The New Zealand component of the investigation allowed for teleconnections and comparative mountain biogeography. Approximately seven weeks of herbarium work and processing of collections and data were carried out between 6 August and 16 August 2005; 22 December and 3 January 2006; 7 March to 25 March 2006; and 3 July to 15 July 2006.

A very hot and early spring in the vicinity of the Juneau Icefield during the months of May and June 2005 resulted in most species having bloomed prior to the author's arrival in the field. Species on some field sites, Sunday Point and Taku Northwest in particular, which were visited on 25 July and 23 July 2005, respectively, showed signs of heat stress. Record high temperatures were recorded in Juneau during the first and second week of June 2005. The high temperatures appeared to have affected the majority of the species observed on the five sites visited on the central Alaskan side of the Juneau Icefield from 19 July through 28 July 2005. In late July of 2005, some species appeared to have succumbed to heat stress, while others were only beginning to green up. Although counterintuitive, the heat stress may also delay blooming. In a typical field season, the majority of observed species are in bloom or past bloom in late July.

Among the highlights of the field season were sightings of the following species, which were unusual and new to the nunatak locations: a Water Pipit, *Anthus spinolett,* and a Gray-crowned Rosy Finch, *Leucosticte tephrocota*, on the lower Taku Glacier. Crowberry, *Empetrum* *nigrum* ssp. *hermaphroditum,* with flowers, and *Trientalis europaea,* were observed on the east side of the lower Taku Glacier. Elderberry, *Sambucus racemosa*, and Early blueberry, *Vaccinium ovalifolium*, were observed on the east side of the Central Taku Glacier.

Intensive Herbarium Work:

Approximately 15 sites in Alaska and British Columbia have been botanically investigated by the author during the field seasons of 2002, 2003, 2004 and 2005. The specimens have been collected over four field seasons, with the primary purpose of serving as vouchers of species' presence at the investigated locations.

The specimens are composed primarily of vascular plants including Pteridophytes (ferns, club mosses, and spike mosses) and Angiosperms (monocots and dicots). Cryptogams (mosses, lichens and liverworts) have also been collected. At the present time, the author does not plan to include the cryptogams in this project, but rather return to them as a post-thesis project, following thorough analysis of the vascular species of the region.

As of 23 March 2006, every specimen collected on the Juneau Icefield nunataks and on adjacent, continuously vegetated land, has been keyed at least to family level with most specimens confirmed to species level. Additionally, those collected on the volcanic plateau of the North Island of New Zealand have been keyed and their identifications confirmed, most to species level. The collection comprises more than 1233 specimens.

Collected and identified specimens have been separated into family, genus, and species folders during the August 2005, December 2005, January 2006, March 2006, and July 2006 herbarium work at the Georgia Southwestern University Herbarium. The taxonomical organization allows the identified species to be readily available and accessible for comparison and establishment of relationships. The organized collection facilitates new insights regarding the similarities and differences of species present at different locations. A mounting technique involving the adherence of small specimens to cards is being utilized. Note-cards and envelopes are used for recording annotations and additional information on the specimens. The collection will serve as an excellent educational resource.

The specimens represent approximately 37 plant families, 65 genera, and 168 different species. The largest families are Saxifragaceae with 16 species, Compositae with 17 species, Rosaceae with 17 species, and Poaceae with 15 species. The herbarium work has been carried out at The University of Georgia Herbarium with Herbarium Curator and Director, Dr. Wendy B. Zomlefer, and at the Georgia Southwestern University Herbarium with Herbarium Director, Dr. Robert A. Norris.

Field Investigations on New Zealand's North Island:

The New Zealand segment of field work involved work in Ruapehu National Park. At each site species-area curves were carried out, as well as line transects and relevés. On 14 June, 15 June, 16 June and 17 June 2005, the region of Tongariro National Park on New Zealand's Central North Island was investigated. The last major eruption of Ruapehu occurred after the Last Glacial Maximum (LGM) (Cox, 1989). A volcanic cinder cone, known as Pukeonake, was chosen as a site for field investigations. Pukeonake is interpreted as a parasitic lava tube feeding off of the main volcanic center from the Ruapehu Crater. This scoria cone, as well as others neighboring it, such as Pukekaikiore, were present prior to the LGM. Their rounded topography is largely a result of glacial scouring. Whether the scoria cones were completely covered with glacial ice is undetermined. The sites may have been refugia for vegetation during the austere climatic conditions which occurred at the LGM, when glaciers filled the Magnetepopo Valley. The sites are interpreted as paleonunataks which were surrounded or possibly covered by glacier ice at the time of the LGM, approximately 18,000 years ago in New Zealand, but are now connected to continuously vegetated land. A similar situation exists with the Cathedral Glacier Massif Site, bordering the Juneau Icefield in British Columbia. Comparisons between the two sites may yield insight into the timing and magnitude of future changes in the environments. The upper slopes of the Ruapehu and Ngarahue Volcanoes are currently glacierized. The substrate on Mount Pukeonake is predominately scoria and pumice with some minor soil development.

Studies of paleonunataks, such as Pukeonake, could allow for prediction and mitigation of the challenges which alpine vegetation will face if the climate continues to change, temperatures continue to rise, and species ranges extend, pushing the alpine species out of their specialized niche, with few options for other habitable landscapes. Alpine plant species (both vascular and non-vascular) are among those most threatened with extinction as climate and global average temperatures change. Additionally, the extension of the ranges of land mammals to higher elevation sites, as temperatures rise, will increase the grazing pressure on alpine species. Again, the species inhabiting isolated rock outcrops, such as nunataks, have not been studied in detail. Most of the species, particularly members of the Poaceae, Cryptogrammaceae, and Juncaceae families, as well as the lichen and bryophyte species, are often considered inconsequential biota by the average person passing through an alpine habitat. Careful observation confirms that these alpine and subalpine habitats support a vast array of botanical life forms.

Field Work on the Nunataks of the Juneau Icefield

Inversion of Habitats:

During the 2005 field season, an interesting inversion of phenology, or flowering times, was recognized and observed on the Sunday Point field sites on the lower east side of the Taku

Glacier, Site 7. The same species, which were not in bloom at the lowest elevations adjacent to the glacier, were in bloom at higher elevations. The site has a southwest aspect with significant slope. The species most prominently demonstrating this inversion of phenology included *Vaccinium uliginosum, Lupinus nootkatensis* and *Luetkea pectinata.* The author hypothesizes that the katabatic down-glacier winds near the glacier inhibit plant growth at the lowest elevation portions of the site, closest to the ice surface. Thermal warming of the upper steep, south and west facing slopes creates a noticeably warmer microclimate at the higher elevation portions of the site. As the vegetation takes hold in the spring, a positive feedback is present as the sub-shrub habitat provides insulation and retains warmth. This also may partly explain the phenomenon noted on Taku B in the field season of 2004. A seemingly inhospitable site high on Taku B's west slope, at an elevation above those of more habitable sites at lower elevations, is home to a diverse bryophyte, lichen, grass and sedge community. The site of the phenomenon on Sunday Point station is diverse in species and has a hummocky, organic-rich moss mat substrate. The vegetation assemblage is advanced successionally with a variety of animal and bird life.

Dimorphism Observation at Lower Taku Glacier Site

A dimorphism, or the presence of two morphologically different examples of specimens that otherwise appear to be the same species, was observed in specimens of Bog Blueberry, *Vaccinium uliginosum,* on the Sunday Point Station located on the east side of the lower Taku Glacier on 28 July 2005. Some specimens exhibited large bright red leaves. Other specimens of *Vaccinium uliginosum* exhibited smaller green leaves. There are three possible explanations for the dimorphism. 1)The red leaves may indicate older growth and the green leaves new growth. 2) A dimorphism within the species may be present, or 3) the variation may indicate a possible new variety. Varieties may occur within a given population while subspecies are, generally, geographically distinct. Mountain Azaelea, *Loiseleuria procumbens,* was observed to occur in two forms with white and pink inflorescences on separate plants. Abrams (1964) and Gleason (1968) do recognize this species as having white or pink varieties. However, the variation is not noted in other floras and appears to be unusual.

Uredinales within Dominant Species:

An unusual bulbet-like formation on *Cassiope mertensiana* was observed at multiple sites on the Central Juneau Icefield, bordering the Taku Glacier. The affected leaves are succulent, red, and dry to a dark black color (see Fig. 1).

All of the *Cassiope* specimens observed in 2005 from stations C10, Sunday Point, and Taku Northwest were confirmed as *Cassiope mertensiana* and not *Cassiope tetragona*. *Cassiope tetragona* has a prominent slit on the back of the needle leaf and has been observed in the icefield region twice previously with specimens from stations C26 (specimen # 256, NE aspect, 17 August 2002, and #487 E. aspect, 12 August 2003) in British Columbia and station C10 (specimen # 432, 24 July 2002). *Cassiope tetragona* (L.) D. Don. ssp. *tetragona* Hult. P. 724, known by the common name, Lapland Cassiope, is a relatively rare heather. *Cassiope tetragona* is rare at the C10 site and has greater abundance at station C26 in British Columbia. Other than this, it has been observed on no other nunataks or sites on the Juneau Icefield. James H. Anderson observed the species at C10 on the central Taku Glacier in 1973. *Cassiope tetragona* is expected to hybridize with *Cassiope mertensiana*. The observations suggest that *Cassiope tetragona* has lost dominance, may be losing its niche to *Cassiope mertensiana*, and is worthy of consideration for special conservation measures.

The swollen leaf of *Cassiope mertensiana* is now known to be infected with a rust of the Uredinales, first determined by J.P. Anderson (1952). Work at the Alaska State Museum

Herbarium on 27, 28 and 29 June 2006, unearthed a paper by J.P. Anderson, describing the Uredinales in Alaska. The Uredinales are an order of parasitic fungus with several families and genera infecting a variety of species throughout Alaska. Previously all inquiries with experts, the Forest Service, and literature searches, were unsuccessful in explaining the presence of the deformed leaves of *Cassiope mertensiana*. The condition is also observed in specimens of *Cassiope mertensiana* found on Baranof Island and in the leaves of *Cassiope tetragona* (specimen # 561) from the Coast Range study region.

Fig. 1 *Cassiope mertensiana* with Uredinales rust observed on Sunday Point, E. side of Taku Glacier, 27 July 2005, P.B.

Viviparous Poaceae Members:

Several of the Poaceae members from the nunatak sites are viviparous, which literally means “live bearing”. Viviparous graminoids produce a germinated plant at the apex of the inflorescence of the parent plant. Viviparity, or a plant growing out of a few floral parts of a member of the Poaceae, is found in seven species in Alaska and British Columbia. This habit is not unlike that of the mangrove tree of the estuarine southeast United States. Viviparous specimens include specimen # 453, on Ridges 1 and 2 of the Lemon Creek Glacier.

Poa lanata variety *vivipara* was observed and a voucher collected on the Lemon Creek Glacier, specimen # 694. The species is relatively infrequent, but was observed by

Anderson in the1970s. *Poa stenantha*, specimen #s 360 and # 345, were observed adjacent to the Llewellyn Glacier and have not been noted previously.

Viviparous plants carry out a variety of asexual reproduction and produce vegetative parts from flowers that are caducous. These reproductive parts fall to the ground, take root and grow into new plants of the species. According to Zomlefer (1994), viviparous individuals are seeds which germinate while on the parent plant. Six of the seven viviparous members of Poaceae present in Alaska and British Columbia are present at station C26 (Site 13). They include: *Poa arctica; Poa alpina; Poa lanata; Poa hispidula, Festuca vivipara* and *Poa stenantha*. *Poa stenantha* Trin. specimen #330, was collected on 13 August 2003 in British Columbia on the Llewellyn Glacier at 1494 m, on an east aspect slope (Ref. p.142 of ID confirmation book 1). *Poa stenantha* was also observed on a northeast aspect slope, at 1524 m on 14 August 2003 at C-26. *Poa alpina* is present in the collection as specimen #s 288, 153, and 238, all collected at C-26 (Site 13). *Festuca vivipara*, spec. # 720, p. 168 Hultén, is yet another viviparous grass observed on the C17 study site.

Rare Grass Noted on Nunataks:

Poa leptocoma Trin. (Hultén p. 145), a rare grass, as determined by Heusser in 1954, is classified as threatened in the state of Washington, U.S., and is imperiled on the Alaska Natural Heritage Program vascular plant tracking list (2006). *Poa leptocoma* was located in British Columbia adjacent to the Llewellyn Glacier on 16 August 2003, collection #343. The specimen has a red/purple inflorescence, a medium green central culm and red lower culm. *Poa leptocoma* was found with *Sedum rosea, Epilobium latifolium, Erigeron* sp*., Castilleja* sp., and *Veronica arvensis.* The collection site was at 1524 m elevation, on a NE aspect, 45˚ slope. Heusser (1954), Ward (1951) and Anderson (1973) observed the species at unspecified locations on the Alaska side of the icefield. It was not observed on the Alaska side of the icefield in this investigation, suggesting a reduction in population for the species.

Threatened Species observed in British Columbia:

Specimen #239* from site 13 or station C26 on the Llewellyn Glacier in British Columbia, *Melica bulbosa* Geyer, is a member of the Poaceae. The specimen was observed on a NE aspect slope. *Melica bulbosa* is a small grass with glumes present but with florets largely or wholly shed. Genus *Melica* is not typical of Alaska and is not listed in Hultén (1968) or in J.P. Anderson (1959). *Melica bulbosa* may be a new species to Alaska, and certainly is new to the Juneau Icefield region. The species is referenced in Abrams (1964). The species and genus are typical of the western lower 48 United States and Western Canadian Provinces, such as Alberta and Saskatchewan. *Melica bulbosa* is classified as "red" status in British Columbia, which means it is, or is a candidate to be, listed as endangered, extirpated or threatened (Government of British Columbia, 2006).

* The specimen's (#239) rachilla is absent and the upper floret is enclosed by the glumes of the floret below it. The rachilla disarticulates above the glumes and is prolonged beyond the perfect florets, with stout pedicels, and a columnar sheath, which is not split, as in most grasses.

Observations of Interest within the Empetraceae:

Two subspecies of *Empetrum nigrum* were determined on separate nunatak stations. The subspecies of *Empetrum nigrum* (*nigrum* and *hermaphroditum*) are observed to be geographically separated with subspecies *hermaphroditum* occurring on stations C13, C14, Sunday Point, Taku Northwest (specimen # 66), and C10. Subspecies *nigrum* was observed only at station C26 (specimen # 368), adjacent to the Llewellyn Glacier.

Subspecies *hermaphroditum* has male and female flowers present on the same plant, and is monoecious. The presence of flowers in *Empetrum nigrum* is rare; they are caducous and quickly fall away for the expanded ovary and berry to dominate. Subspecies *nigrum* is dioecious, with staminate and pistillate flowers on separate plants, while subspecies *hermaphroditum* has staminate and pistillate flowers present on the same plant. Sterile specimens of *Empetrum nigrum* are easily confused with *Cassiope stelleriana*. Separate petals on the flowers of the *Empetrum* species distinguish it from the Ericads.

Observations of possible Hybridization:

An unusual form of *Phyllodoce aleutica* ssp. *glanduliflora* was observed at the Sunday Point station. A notable size variation in the needles of different specimens, and even on the needles of the same plant, of what otherwise appeared to be the same species, was observed in *Phyllodoce aleutica* ssp. *glanduliflora.* The specimen is suspected to be a hybrid between *Phyllodoce aleutica* ssp. *glanduliflora* and *Cassiope tetragona*. An alternative hypothesis is that the specimen is an immature form; however other immature specimens of similar habit were not observed.

New Plant Families Observed on the Juneau Icefield Nunataks:

During March 2006 herbarium work, the confirmation of *Papaver macounii* Greene, Macoun's Poppy, spec. # 1155, Hult. p. 491, was a particular highlight. Members of the Papaveraceae are rare in SE Alaska. Although, in the last year, there have been reports of isolated populations of members of the Papaveraceae on Baranof and Chichagof Islands by Forest Service technicians (pers. Comm. Brad Kriekhaus). This is a major range extension and is the first poppy observed on a Juneau Icefield nunatak. The specimen of *Papaver macounii* was observed in British Columbia, where the species was considered rare as of 1976 (BC Data Conservation Center, 2006).

Papaver macounii was found high on a nunatak bordering the west side of the Llewellyn Glacier, at 1829 m, near the summit of the nunatak on an exposed SE aspect slope. Associates included *Solidago multiradiata*, *Silene acaulis*, and *Arnica amplexicaulis*. The *Papaver macounii* voucher specimen was collected on 15 August 2003. *Papaver* genus members usually have a distinctive capsule, but not always, especially when immature, as this specimen was. Also, the capsule of *P. macounii* is narrow and elongated compared to most members of the genus. *Papaver macounii* is the first member of the Papaveraceae to be noted in a floristic investigation in the regions of the Juneau Icefield.

Two members of the Polemoniaceae have been identified on the Juneau Icefield nunataks, *Polemonium pulcherrimum* and *Polemonium boreale.* The two members of the Polemoniaceae, or Phlox Family, are the only members observed in four field seasons. Prior to this study no members of this family had been observed on the nunataks. The lack of Polemoniaceae may relate to species' habitat preference and insufficient time for successional processes and migration. The species favor damp habitats and have been observed in the melt-water streams on the east aspect slopes of Site 13 along the Llewellyn Glacier, a generally drier site with a continental climate. The author observed *Polemonium pulcherrimum* at three different elevations on the C26 nunatak bordering the Llewellyn Glacier, (reference specimen #s 318 and 322, Hult. p. 769, Abrams p. 398 - 401). Abrams notes that *P. pulcherrimum* is a frequent inhabitant of volcanic soils, which are present on the C26 site. The lowest elevation specimen was found at approximately 1457 m on an east aspect slope. The other examples of *Polemonium pulcherrimum* were found at 1860 m on a southeast aspect slope, and at 1491 m on an east aspect slope near an ephemeral snow-melt stream running over a moss mat on the border of the Llewellyn Glacier. The elevation of the second specimen of *P. pulcherrimum,* 1491 m, corresponds with what Lietzke (1982) determined as berm level one. Berm level one refers to the most recent sediment apron remaining along the edge of the Llewellyn Glacier, following the last major recession of the glacier, presumably following the Little Ice Age advance. *Polemonium boreale* was sited for the first time in the region, in close proximity to the locality of *Polemonium pulcherrimum*, on one of the most biotically diverse and successionally advanced field sites.

Assistance in Evaluation of Recreational Use Permit:

The author was able to assist a U.S. Forest Service Botanist, Ellen Anderson, in evaluating the appropriateness of granting a recreational use permit to a commercial guiding vendor, to use a helicopter for hiking and climbing access to three sites within the southwestern portion of the study region. Mount Wrather, Mount Stroller-White, and Split Thumb were proposed as locations for guided climbs and hikes. In the region of Split Thumb, some species of interest are *Trientalis* e*uropaea* ssp. *arctica, Epilobium latifolium, Saxifraga oppositifolia,* and the lichen *Solarina crocea.* The author recommended that the permit be denied on the basis of the sensitivity of the habitats and what is known about the species assemblages on similar adjacent sites.

Cathedral Glacier Massif, B.C. Represents New Study Site:

The Cathedral Glacier Massif borders Lake Atlin, B.C. on the northwest edge of the Juneau Icefield, and is denoted as station C29. The location is rich with Quaternary geomorphologic features, including strand lines and stone stripes. A site at the terminus of the Cathedral Massif Glacier was botanically investigated on 26 August 2003. The site had not been included in previous Icefield region floristic studies. The location is considered to be a paleonunatak, which is currently separated from the main icefield, but was connected in the past. A paleonunatak is a rock knob that has been isolated by surrounding glacier ice, but is now connected to continuously vegetated land due to the retreat and ablation of glacier ice. The vegetation species assemblages on the paleonunatak may have intermixed with species from the continuously vegetated land if significant time, post-isolation, has passed. A paleonunatak may harbor some species not present in the adjacent territories from which it has been isolated. Plant immigration and changes in species assemblages are dependent on the duration of time post-ice retreat and post-isolation, among other variables.

Three range extensions within the Poaceae were observed at the site. *Vulpia megalura* (Nutt.) Rydb., spec. #833, p. 171 Hultén, was observed as a major range extension. *Vulpia megalura* was not found in other studies on the Juneau Icefield. The ‘megalura’ species name refers to the long tail-like awns of the lemmas. *Poa alpigena* (E. Fries) Lindm.(Spec. # 828), p.135 Hult., and *Agrostis stolonifera* L., p.100 Hult., were also observed as range extensions. For the Caryophyllaceae, *Cerastium beeringianum* Cham. & Schlecht. var. *beeringianum*, p. 421 Hult., is a range extension on the C29 site.

Invasive Species Observation:

An invasive species, *Veronica arvensis,* a member of the Scrophulariaceae, was found at C26 (Site 13) on the Llewellyn Glacier. The species is ever present over a large portion of the lower 48 states. Great variation is observed within specimens of *Veronica arvensis,* i.e. # 569 and 563. However, both of the specimens of this common invasive are from the same nunatak on the Llewellyn Glacier. One specimen is 5.0 cm tall and the other is 15.0 cm tall, while both appear to be mature.

Rare species and Range Extensions

Rosaceae

Chamaerhodos erecta (L.) Bunge, a member of the Rosaceae, specimen # 1114, was collected on C26, at approx. 1645.6m above sea level (asl) and at 59.02N, 134.14W, on 17 August 2003. The species' common name is American Chamaerhodos.

The first member of the *Potentilla* genus of the Rosaceae family to be sited in this study was *Potentilla norvegica* (L.) Aschers & Graebn. Hult. p. 614, observed adjacent to the Lemon Creek Glacier on Site C17 on 18 July 2004. The species was not observed in previous studies of the region.

Potentilla diversifolia Lehm. var. *glaucophylla* Lehm. (spec. #266) is the first of its species sited in the region, and was observed on the border of the Llewellyn Glacier at station C26, at 4900 ft. on a NE aspect, 45 degree slope on 13 August 2003. *Potentilla uniflora* Ledeb., p.612 Hult., specimen # 1081, was observed for the first time in the icefield region on 17 July 2004, west of Cairn Peak, on station C17, separating the Lemon Creek and Ptarmigan Glaciers. It is a highly variable species and often hybridizes with *Potentilla villosa* as well as other *Potentilla* species.

Gentianaceae

Specimen # 1113, *Gentiana propinqua* Richards., p. 760 Hult., Four-parted Gentian (a member of the Gentian Family), was collected at station C26 on 13 August 2004. *Gentiana propinqua* is usually associated with limestone or calcareous deposits.

Onagraceae

Epilobium luteum Pursh, spec. #568, was collected on 15 August 2002, Hult. p.687, on a NE aspect slope on the C26 site adjacent to the Llewellyn Glacier. *E. glandulosum* Lehm., p. 690

Hult., was observed at the same location on 15 August 2002, for the first time in the region and is suspected to be a possible hybrid between *E. luteum* and *E. glandulosum* (p.690 Hultén) because of the yellow and purple corolla. Such hybrids occur, see Hult. p. 687. *Eplilobium hornemannii* Rchb., spec. # 630, was observed on 28 July 2003, on a protalus rampart above Icy Basin on the Taku Glacier.

Gramineae

Poa brachyanthera Hult., spec. # 822, (relevé 35). Hult. p. 146, was observed for the first time on 27 July 2004, and has not been previously noted in other studies of the region. This specimen was found in a microhabitat high on Taku B Peak, along the East side of the Taku Glacier, on a glacial polished felsenmeer, which is snow covered most of the year. Specimen # 1129 of *P. brachyanthera* was observed on the Taku Northwest Site on 23 July 2004.

Festuca vivipara, spec. # 720, p. 168 Hult., is a viviparous grass observed on the C17 study site on 17 July 2004, and represents a range extension from that previously known for the species.

Juncaceae

Luzula tundricola Gorodk., Spec. # 604 (p. 300 Hult.) was observed for the first time on a Juneau Icefield nunatak, at Sunday Point on a SW aspect slope, on the lower Taku Glacier on 22 July 2003. Specimen # 451 was observed at station C17 on 15 July 2002 on a SE aspect slope. Specimen # 143 of this species was observed on 6 August 2003, in relevé 1, at site C18B, adjacent to the lower Vaughan Lewis Icefall at the juncture of the Vaughan Lewis Glacier and Gilkey Glaciers in a semi-protected valley. The three locations where the species was observed are widely separated, suggesting that the species’ members have migrated to the sites from areas not on the icefield, rather than having migrated from one of the described sites to the others.

Compositae

***Se**necio atropurpureus* (Ledeb.) Fedtsch., Hult. ssp. *tomentosus* (Kjellm.) Hult., spec. # 1015. Hult. p. 928, is a range extension observed on the periphery of the Llewellyn Glacier, station C26. The specimen was found at around 1829 m on a southwest aspect slope on 15 August of 2003 with *Salix reticulata* and *Epilobium angallidifolium*. In the vicinity of *Senecio atropurpureus*, but at a lower elevation. *Arnica frigida* C.A. Mey. Hult. p. 917, spec. # 1033, was observed at 1829 m on a SE aspect slope on 15 August 2003. *A. frigida*, spec. # 1072, was observed on station C17, South of Cairn Pk., high above the Salmon Valley Reservoir in relevés 13,14, and 15, on 17 July 2004.

Antennaria pulcherrima (Hook.) Greene, specimen # 958, p. 872 Hult., was observed at the Tarn Lake near the base of the Ptarmigan and Thomas Glaciers on 8 July 2004. This species was not noted in previous studies of the region. *Antennaria rosea* Greene var. *nitida* (Greene) Breitung, specimen #578, p. 880 Hult., was sited in the region for the first time at station C13 on 18 July 2003.

Anaphalis margaritacea (L. Benth. & Hook.) spec. # 629, p. 882 Hult., was sited for the first time in the region on a protalus rampart appr. 30 ft. above the Taku Glacier's surface in Icy Basin on 28 July 2004. *Erigeron purpuratus* Greene, P. 863 Hult., specimen # 646 was sited for the first time in the Juneau Icefield Region, at the terminus of the Cathedral Massif Glacier, station C29, on 26 August 2003.

Leguminosae

Astragalus alpinus L. ssp. *alpinus,* spec.# 1021 p. 649 Hult., was observed at station C26 on 15 August 2003 at approximately 1829 m, with *Senecio atropurpureus* and is not known from previous studies of the region.

Ericaceae

A range extension was observed in *Vaccinium membranaceum* Dougl., spec. # 1103, Hult. p. 732, in Relevé 21, found at Sunday Point, on the east side of the lower Taku Glacier, on 22 July 2004. This species of *Vaccinium* has not been noted in previous J.I.F. nunatak studies.

Vaccinium parvifolium Sm., spec. # 998, Hult. p. 733, was sited on Taku B, station C10, in Relevés 18 and 19 on 20 July 2004 with *Loiseleuria procumbens* and *Empetrum nigrum.*

Phyllodoce empetriformis (Sm.) D. Don, p. 722 Hult., specimen # 654, is rare and unusual in southeast Alaska and was found on an exposed ridge separating the Lemon Creek Glacier from Death Valley and the Dead Branch of the Norris Glacier, on 18 July 2003. This species is normally found in more continental climates. *Phyllodoce empetriformis* is classified as critically imperiled by the Alaska Natural Heritage Program (2006).

Aspidiaceae

Polystichum braunii (Spenn.) Fee var. *alaskense* (Maxon) Hult., spec. # 181, Hult., p. 54, was observed on the C26 station at 1707 m on a SE aspect slope on 15 August 2003 and is the first observation of the species for the Juneau Icefield.

Boraginaceae

Myosotis alpestris F.W. Schmidt ssp. *asiatica* Vestergr. spec.#283, p.779 Hult., was observed at station C26, on 14 August 2003 on a SE aspect, 40 degree slope, at 1707 m, bordering the Llewellyn Glacier, as an associate of *Oxyria digyna, Silene acaulis, Saxifraga bronchialis*, and *Epilobium latifolium*.

Polygonaceae

Polygonum viviparum L., Hult. p.385 (ref spec.#s1018 and 1026), was observed at station C26, on a SE aspect slope at 1829 m, bordering the Llewellyn Glacier, on 15 August 2003 with *Salix reticulata* and *Myosotis alpestris.*

Saxifragaceae

Saxifraga bronchialis ssp*. cherlerioides* (D. Don) Hult. Spec. # 575, p. 570 Hult., was observed on a NE aspect slope bordering the Llewellyn Glacier on 15 August 2002 and is the first known occurrence in the region. *S. bronchialis* ssp. *cherlerioides* is a rare subspecies of Saxifrage and is similar to *S. bronchialis* ssp. *funstonii*; however the petals are not clawed at the base, the stamens are shorter than the petals, and the leaves are obtuse-mucronate (coming to a narrow abrupt point).

Saxifraga tolmiei Torr. and Gray, spec. #674 (Alpine Saxifrage) p. 567 Hult., was found at the ridge separating the Lemon Creek and Ptarmigan Glaciers on 14 July 2004 and was the first of its species noted on the icefield nunataks.

Saxifraga caespitosa L. specimen # 1025, p. 583 Hult, was observed for the first time in the region on the margin of the Llewellyn Glacier on 13 August 2003, at 1829 m on a SE aspect slope.

Caryophyllaceae

A member of the Caryophyllaceae, *Stellaria monantha* Hult., spec. # 580, p. 418 Hultén, was a first observation for the species on the Juneau Icfield. *S. monantha* was observed at Site 13, adjacent to the Llewellyn Glacier on a NE aspect slope on 15 August 2002.

Species with Evident Population Changes Between Previous Studies and the Current Study:

Carex macrochaeta, spec. #801 (in Relevé 31) C.A. Mey., was observed by J.H. Anderson in the 1970s on the east side of the Central Taku Glacier. The species was first observed in the current study on 27 July 2004 on the Northwest Branch of the Taku Glacier and appears to be rare in the current nunatak flora. The flowers of *Carex macrochaeta* are incomplete with the staminate flowers above the pistillate flowers, although it is not entirely androgenous (Norris, Dec. 31, 2005).**

Two infrequent and rare species observed as associates of *Senecio atropurpureus* and *Astragalus alpinus* L. ssp. *alpinus*, at C26 bordering the Llewellyn Glacier, are *Myosotis alpestris* and *Polygonum viviparum*. These species were noted in historical investigations; however, their abundance was not noted.

Salix arctica Pall. ssp. *arctica,* specimen # 1094, Hult. p. 340, was present in Relevés 13, 14, and 15, taken on 14 July 2004, on Cairn Peak separating the Lemon Creek and Ptarmigan Glaciers. *S. arctica* was observed by Chamberlain in 1948, but was not noted by Heusser (1954), Ward (1951), or Anderson (1973). Two preliminary hypotheses for the decrease in frequency of *Salix arctica* is the increased average over-winter temperature on the study sites between 1950 and the present, and the decrease in winter snow cover which results in less protection for the species from wind and ice.

Saxifraga punctata L. ssp. *pacifica* Hult. was observed at one site in this investigation and is present in less abundance than in the 1950s. Heusser noted the species in his 1954 study, present between 3500 and 5600 feet, as a widely distributed, early successional species.

** Since the time of this report's publication, specimens of *Carex macrochaeta* have been vouchered from Site Seventeen.

Campanula rotundifolia L. was observed in the current study and was observed by Heusser (1954) between 4900 and 5900 ft. *Luzula arcuata* (wahlenb.) Sw. ssp. *unalaschcensi*s (Buchenau) Hult. is ever present across the icefield. The species has been observed and vouchers collected on nunataks on the Northwest Branch of the Taku Glacier, the Central Taku Glacier, and the Lemon Creek Glacier. Heusser observed *Luzula arcuata*, not the subspecies *unalaschcensis,* present between 4900 and 5900 ft. (1954), with no specific loations given.

Trientalis europaea L., p. 751 Hultén, specimen # 672, of the Primulaceae, is present at Sunday Point (Site 7), adjacent to the lower Taku Glacier. In previous field seasons, the author has observed *Trientalis europaea* adjacent to the Tarn Lake, one valley west of the Ptarmigan Glacier, a site which is connected to continuously vegetated land. *Trientalis europaea* has also been observed by the author on the rock bands on the west side of the Lemon Creek Glacier. *Trientalis europaea* L. ssp. *arctica* (Fisch.) was noted by Heusser at one locality with an elevation of 4000 ft. in his 1954 investigation, and by Ward (1951) at an unspecified location on the Alaska side of the icefield.

Primula cuneifolia Ledeb. ssp. *saxifragifolia* (Lehm.) Sm. & Forrest, specimen # 698; *Gentiana glauca* Pall., specimen #702; and *Petasites hyperboreus* Rydb. were observed in the vicinity of Vesper Peak adjacent to the Lemon Creek Glacier. Heusser's work identified the above species at unspecified locations on the Alaska side of the icefield (1954). Ward (1951) observed *Primula cuneifolia* ssp. *saxifragifolia,* but no *Gentiana* or *Petasites.*

Observations of Vegetational Assemblages on Periglacial Regions Connected to Continuously Vegetated Land:

On the Southwest periphery of the icefield *Sorbus sitchensis* Roem; *Menziesia ferruginea* Sm; and *Cladothamnus pyrolaeflorus* Bong., Spec. # 973, p. 717 Hult., were observed on the continuously vegetated land adjacent to the Ptarmigan and Lemon Creek Glaciers, on 8 July 2004. Also sighted with the above species, was *Oxycoccus palustris* Pers., spec.# 972, Hult. P. 735.

Other Notes on the Vegetation of the Icefield Nunataks:

An interesting note in terms of the alpine-subalpine vegetation assemblages of southeast Alaska is the occurrence of only Lycopodiaceae family members (club mosses) and no Selaginellaceae (spike mosses) on the nunatak sites. No Selaginellaceae family members have been observed, although they are a frequent occurrence at slightly lower elevations throughout southeast Alaska. Many species descriptions in Eric Hultén's Flora of Alaska and Neighboring Territories state that total range is unknown, as is the case for several species found in this study.

Observations of Island Biogeography and Suggestions of Early Speciation:

On 18 July 2004, Nugget Ridge, separating the Lemon Creek Glacier, Norris Glacier Valley and Death Valley, was traversed. *Saxifraga oppositifolia* ssp. *smalliana* (Engler & Irmsch.) Hult., p. 565 Hult., was observed for the first time in the region. The Nugget Ridge is separate from the other sites where *Saxifraga oppositifolia* has been observed, including stations C26 and C10, to the north and east.

Luzula multiflora (Retz.) Lej., specimen #546, is possibly one of four subspecies of a *L. multiflora* complex observed on the study sites. A species complex describes intergrades and possible hybrid forms between the subspecies and varieties present within a species. The specimen has a squat habit and was observed in rocks adjacent to the east side of the Taku glacier on a SW aspect, 10˚ slope, on the Sunday Point station.

Certain species have been sighted only on selected nunataks. An example is *Cardamine bellidifolia* L., which has been found on four sites: Sunday Point, C10, C18, and Taku

Northwest. It is not unforeseen that the species may have migrated from a central location, such as Sunday Point, to the other sites.

Alnus species have been suggested to be absent at Station C26 in Canada, due to the poor drainage properties of the substrate. Most sites are not successionally advanced enough with soil development to support large woody species. Soil horizons have not developed in most locations in the region of site 13 (C26). However, a significant organic stratum is present in most localities on the C26 nunatak. Site 13 is one of the few sites with *Salix* present. Other sites with *Salix* include the Cathedral Massif Glacier, Station C29, Station C17A, and Station C17. All three stations are possible paleonunataks, currently connected to continuously vegetated land, but isolated by glacier ice in the recent geologic past.

Variation in *Silene acaulis* L. was observed on two sites, one adjacent to the Llewellyn Glacier and the other adjacent to the Lemon Creek Glacier. Specimen # 663, from the Lemon Creek site, has a longer broader corolla while specimen #s 585 and 571, from the Llewellyn Glacier, have small light yellow corollas.

Evidence of Successional Processes:

Epilobium angustifolium L., specimen # 789; *Vaccinium ovalifolium* Sm., p. 733 Hultén; and *Sambucus racemosa* L. were observed near Taku B Peak on the Taku Glacier. These species are infrequent at this site. Their presence suggests that succession is advancing on the site and that these species are most likely migrating up-glacier from the lowlands at the terminus.

Work at the Alaska State Museum Herbarium:

On the 27, 28, and 29 of June 2006, the author was able to work in the herbarium of the Alaska State Museum in Juneau. Donna Barron, Museum Registrar, and Steve Henrikson, Curator, were knowledgeable and helpful. The collection contains approximately 6000 specimens and is largely a result of the work of the Juneau Botanical Club, which was organized in the late 1940s to develop a state herbarium collection. According to Barron, the collection has had no new additions since approximately the year 1967. Wendy P. Sweddell wrote a history of the Juneau Botanical Club and organized the majority of the collection in 1986. J.P. Anderson worked closely with the Juneau Botanical Club.

The author was aware of specimens in the collection from the Juneau Icefield as a result of a museum publication which mentioned that some specimens from Calvin J. Heusser's investigations were donated to the museum. Each specimen in the collection with location or collector data indicating that it might be from the Juneau Icefield region was pulled and examined while at the State Museum. Unfortunately, the specimens were lacking in detailed labels and only a few had habitat information included. A publication made at the time of Heusser's small donation to the State Museum includes some information on his Juneau Icefield collections. The specimens collected by Heusser are all from the Alaska side of the Icefield. A list of the species collected by Heusser is included in Table 3. All of the specimens collected by Heusser and donated to the Juneau Botanical Club and subsequently donated to the Alaska State Museum, were observed in the museum cases by the author with the exceptions of *Carex scirpoidea* Michx. Heusser did collect in some locations which were not logistically accessible in the most recent study.

Over all, several additions, in terms of species, families and genera, have been made to the flora of the Juneau Icefield Region (see Tables 1, 2, and 3). The collections of Huesser, Ward and Chamberlain all focused on the Alaska side of the Icefield, while the current study includes sites from the British Columbia side of the Juneau Icefield.

Table 1

Species from botanical investigations conducted in the Juneau Icefield Region.

Vascular Plants of the Juneau Icefield Nunataks

	Collector and Year(s) of Study			
	Chamberlain 1949	Ward 1951	Heusser 1954	Bass 2001-2005
Families	*	19	24	37
Genera	*	40	58	65
Species	100	60	99	168

*Yet to be determined.

Table 2

Quantitative Summary of Juneau Icefield Nunatak Species as of Field Season 2005

Largest Families: in order of decreasing abundance in terms of species #s	
Family	# of Taxa (including species and subspecies)
Saxifragaceae	17
Compositae	16
Rosaceae	16
Poaceae	14
Juncaceae	11
Ericaceae	10
Cyperaceae	8
Caryophyllaceae	7
Onagraceae	6

Table 3

Species from Juneau Icefield Region in Alaska State Museum Herbarium Collection

Genus	**species**	**ssp. or var.**	**Authority**	**Family**	**Juneau Botanical Club #, Accession #**	**Collection Date**	**Found by PB 2001-2005**
Artemesia	*arctica*		Less.	Compositae	25	Jul-52	Yes
Carex	*aenea*		Fern.	Cyperaceae	47,6	Jul-52	No
Carex	*macrochaeta*	C.A. Mey.	Cyperaceae		Jul-52	Yes	
Carex	*nardina*		Fr.	Cyperaceae	7	Jul-52	Yes
Carex	*pyrenaica*		Wahl.	Cyperaceae	9	Jun-52	Yes
Carex	*scirpoidea*	Michx.	Cyperaceae		Jul-52	No	
Cassiope	*tetragona*		(L.) D. Don	Ericaceae	s.n.,16	Jun-52	Yes
Cassiope	*lycopodioides*	(Pall.) D. Don	Ericaceae		Jun-52	No	
Erigeron	*humilis*		Grah.	Compositae	1	Jul-52	Yes
Festuca	*brachyphla*	Schult.	Poaceae		Jul-52	Yes	
Hierochloë	*alpina*		(Sw.) Roem &Schult.	Poaceae	5	Jul-52	Yes
Leptarrhena	*pyrolifolia*		(D.Don) Ser.	Saxifragaceae	29	Jul-52	Yes
Luzula	*parviflora*		(Ehrh.)Desv.	Juncaceae	17	Aug-51	Yes
Lutkea	*pectinata*		(Prush)Kuntze	Rosaceae	31	Jul-52	Yes
Parnassia	*fimbriata*		Konig.	Saxifragaceae	30	Jul-52	Yes

Petasites	*hyperboreus*	Rydb.	Compositae		Jul-52	Yes	
Potentilla	*emarginata*	*var. nana*	Pursh (Willd.)Comb. Nov.	Rosaceae	22	Aug-51	No
Primula	*cuneifolia*	*ssp. Saxifragaefolia*	(Lehm.) Hult.	Primulaceae	11	Jul-52	Yes
Salix	*stolonifera*	(Col.)	Salicaceae		Jul-52	Yes	
Saxifraga	*bronchialis*	*ssp. funstonii*	L. (Small)Hult.	Saxifragaceae	26	Jul-52	Yes
Saxifraga	*ferruginea*	*var. macounii*	Gra.Engl. Irmsch.	Saxifragaceae	20		Yes
Saxifraga	*punctata*	*ssp. Pacifica*	L. Hult.	Saxifragaceae	15	Jun-52	Yes
Scirpus	*caespitosus*	*var. callous*	L. Bigel	Poaceae	10	Jul-52	no
Sedum	*roseus*	*ssp. Integrifolium*	(L.) Swp. (Raf.)Hult.	Crassulaceae	22	Aug-51	yes
Sibbaldia	*procumbens*	L.	Rosaceae		Jun-52	Yes	
Solidago	*multiradiata*	*arctica*	Ait. (DC)Fern.	Compositae	28	Jul-52	no
Stellaria	*calycantha*	Bong.	Caryophyllaceae		Aug-51	No	
Trisetum	*spicatum*		(L.) Richter	Poaceae	8	Jun-52	yes
Vaccinium	*uliginosum*	L.	Ericaceae		Aug-51	Yes	
Veronica	*wormskjodii*	*nutans*	R&S (Bong. Pennell	Scrophulariaceae	23	Aug-51	yes
Cassiope	*tetragona*		(L.) D. Don	Ericaceae	s.n.	Jun-52	yes
Carex	*bigellowii*		Torr.	Cyperaceae	4c	Jul-55	no

Some Goals for Future Writing and Analysis:

Efforts are underway to use Image Mapper HTML (Hyper Text Mark Up Language) to create an interactive map of the study region. The result will be a map on which placement of a cursor on a site will allow for data to be accessed, such as a list of species observed at the site, and photographs of the study site.

Range maps with vectors to a species' nearest expected location are a goal of the current project or a post thesis project. Indices of diversity and similarity will be carried out. Hypotheses on the most probable causes of species' range extensions will be explored. Tests of some of the tenets of island biogeography will be carried out with the data, and the data will be used to classify the habitats into vegetation types using the Braun-Blanquet Phytosociological technique.

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APPENDIX D

2006 REPORT

PEO Scholar Award Progress Report I

January 5, 2007

Grantee: Polly Bass

Project: Ph.D. Dissertation, Nunataks and Island Biogeography: Implications for Vegetation Dynamics in a Changing Environment.

It has been a productive summer and fall. I wish you all a happy new year. I thank you for giving me this opportunity to research the subject I love. Thank you for making this research possible. Much has been accomplished since June 2006.

Summer 2006 Progress:

In May 2006, I visited the University of Idaho, Moscow. My initial visit was for an unfortunate reason, the death of one of my longtime mentors, Joan Miller. Mrs. Miller served as the logistics director of the Juneau Icefield Research Program, which has supported my field work, since its inception. While in Moscow, Idaho, for the memorial service, I was able to visit and research in the library of the Glaciological and Arctic Sciences Institute. The University of Idaho, Moscow, has served as the base institution for Dr. Maynard M. Miller, Director of the Juneau Icefield Research Program and the Glaciological and Arctic Sciences Institute (the overseeing board), since the late 1970s.

In June, I visited Juneau and made a brief excursion into the field prior to traveling to Georgia for work in the Georgia Southwestern University herbarium with Dr. Robert Norris. While in Juneau, I visited and researched the herbarium of the former Juneau Botanical Club housed in the archival collections of the Alaska State Museum. I investigated some specimens in the herbarium that were collected in the Juneau Icefield Region in the early 1950s. There were some manuscripts in the herbarium cabinets which I have not seen elsewhere. Some of these manuscripts were written by Jacob Peter Anderson, the author of the first Flora of Alaska and Adjacent Territories. Anderson worked closely with the Juneau Botanical Club, which donated their herbarium collection to the Alaska State Museum in 1976. J.P. Anderson taught at Iowa State University in Ames until his death.

I was aware of specimens in the collection, from the Juneau Icefield, as a result of a publication which mentioned that some specimens from Calvin J. Heusser's investigations were donated to the museum (1954). While at the State Museum, I pulled and examined each specimen in the collection with location or collector data indicating that it might be from the Juneau Icefield. Unfortunately, the specimens were lacking in detailed labels and only a few had habitat information included. The specimens collected by Heusser are all from the United States (Alaska) side of the Icefield.

I spent a large part of the summer of 2006 working with Dr. Robert A. Norris in the Georgia Southwestern University Herbarium, where most of my voucher specimens are currently stored. Identification confirmations of all of the field collections were completed. The voucher collection was further organized. The field data for each specimen was entered into a database. Edits to the existing draft of my thesis were completed, and a report and presentation for the 16 August 2006, committee meeting at the University of Georgia were prepared.

On 16 August 2006, I met with my five professor committee in Athens, Georgia, U.S., and discussed my progress to date. I presented a report and discussed questions and concerns I have about how to tie my data together into the final dissertation. I received much useful feedback and took extensive notes on the comments and suggestions of the committee. The committee consists of the chair/advisor, Dr. Elgene O. Box, Plant Geographer; Dr. Vernon Meentemeyer, Biogeographer and Climatologist; Dr. Fausto Sarmiento, Mountain Biogeographer; Dr. Wendy B. Zomlefer, Director of the UGA Herbarium and Plant Taxonomist; and Dr. Ervin Garrison, Quaternary Geologist and Archaeogeologist.

Among the suggestions of the committee was the unanimous vote on removal of the component on comparative biogeography with New Zealand, which was added to the study in spring 2005. This component of the study will be best set aside for a post-dissertation project. A stronger argument will be made for the current work by keeping it focused on the dynamics and change in the vegetation communities of the southeast Alaska nunataks. The committee also suggested adherence to an organization of pure chapters. They commended the research which has been done and the possibility for augmentation of the work, but said it would be best saved for a post-dissertation book, with the dissertation focusing on my new contributions, and not as much on the review of related literature and research.

Another important and surprisingly challenging aspect of the meeting was attempting to set a date for the dissertation defense. Post-meeting e-mail communications led to the date of 8 May 2007, at 2 p.m. at the University of Georgia Geography Department, Athens, Georgia, U.S.

Fall 2006 Progress:

Identification confirmations of voucher specimens collected during field work were continued with experts. These were recorded with specimen numbers in identification confirmation notebooks.

Following identification confirmations on the last of the field specimens, a large database was created. For each specimen in the database; the location, elevation, habitat, observations, associates, aspect, slope, the identification number of the relevé the species was found within, family, genus, species, subspecies, and/or variety, and the date of collection were recorded in the appropriate columns.

The sampling units or quadrats, known as relevés, were entered into the database and transposed in various ways through a process known as phytosociological tabular analysis. Tabular analysis identifies representative community types using species associations evident in the relevés or sampling units.

One component of the tabular analysis is development of a ‘raw table’ which includes all of the species in the study organized in rows and all of the sampling units, or relevés, organized in columns. A frequency table was then developed which calculated how many times each species was present in separate sampling units. Species richness, or how many different species were present in each sampling unit, was also calculated.

Student workers assisted with data entry in the fall 2006 semester. For each species and each of the sampling units, both abundance and dispersion information were recorded. A presence-absence table was developed as a component of the tabular analysis. This table will lend itself well to comparison studies with other alpine regions.

A data table of peripheral relevé data was developed which includes data other than species, abundance and dispersion. These data include the number of shrubs, herbs, and lichens in each relevé, the percent cover of each physiognomic type, the elevation of the relevé, the location, aspect, slope, relevé size, the percent relevé of the total stand, topography, sun and wind exposure, soil type, soil depth, disturbance, soil moisture, date, and relevé personnel.

On Christmas day, 2006, I helped serve at the Sitka Pioneer’s Home and had the honor of meeting Bob DeArmond, a historian, journalist, and long time Sitkan, who is 95 years old. I enjoyed talking with Mr. DeArmond about his writing. He volunteered to read and assist in editing some of my writing. I am going to take him up on this. I think we will both benefit from the discussions.

The methodological chapter was updated significantly and a methodological verbal flow chart is in production. In considering analysis of my data set, I have become aware of the intricacies in defining and measuring biological diversity. Richness is often a more clear, simple, and defendable measure of diversity than the indices of Shannon-Weiner, Simpson, and Jacquard. The three aforementioned indices incorporate an abundance or evenness variable. If equal areas or an equal number of equal sized stands are used in the comparison of sites, species richness is an appropriate measure of diversity.

Plan for Spring 2007 Progress and Beyond:

This fall I requested one-half time status again for the spring 2007 semester. The request was granted. Additionally, the spring class schedule is such that it will allow me two full research and writing days during the school week. The primary objectives of the spring 2007 semester include final editing and chapter organization as well as final analyses with the data set. Tables and analysis in the outline developed early in the fall 2006 semester will be completed. I may utilize student workers for input of data from other studies in order to compare those studies to mine.

Soil analyses of samples from the nunataks were begun in spring 2006 and will continue this spring. Efforts are underway to use Image Mapper HTML (Hyper Text Mark Up Language) to create an interactive map of the study region. The result will be a map on which placement of a cursor on a site will allow for data to be accessed, such as a list of species observed at the site and photographs of the particular site. Range maps with vectors to a species' nearest expected location are a goal of the current project or a post-thesis project.

I will defend my dissertation on 8 May 2007. Presumably, after the defense, there will be more edits required prior to the final submission of the dissertation. These edits will need to be completed by mid-July in order for the manuscript to be submitted by the deadline for summer 2007 graduation.

Summary:

Overall, several additions of species, families, and genera have been made to the flora of the Juneau Icefield Region in this study. Twice as many species have been identified in the region than the number found in the most recent study. The collections of Heusser, Ward, and Chamberlain all focused on the Alaska side of the Icefield, while the current study includes sites from both the British Columbia and the United States sides of the Juneau Icefield. Following input of all of the data on the field specimens, it was determined that this study of the Juneau Icefield Region has yielded a total of 297 vascular plant species from 43 plant families and 130 genera. These species were found in 107 sampling units across the icefield, stretching from the United States (Alaska), to Canada (British Columbia). The species come from over thirty-four formal sampling sites on over thirteen separate nunataks.

The current study is rich with contributions to our knowledge of high-latitude alpine plant habitats. These contributions spur me on and energize my work. The species richness, determined in this study to date, is greater than that found in any of the three other floristic studies of the region. No previous study of the region has included abundance information. Other strengths of the work include the establishment of permanent plots, the identification of range extensions, the identification of invasive species on the field sites, the use of permanent stakes to monitor the increase in land surface area, and the use of digital data logging temperature recording devices. Advantages of permanent plots include the ability to return to the same site for more thorough investigation, as well as contributing to ease in monitoring phenological, physiological and successional changes in the habitats. Additionally, changes resulting from climate perturbations or mass wasting events may be monitored (Walker, 2002).

Several observations of interest have been made, including an inversion of phenology or flowering times. The author hypothesizes that the katabatic down glacier winds, near the glacier, inhibit plant growth at the lowest elevation portions of some sites. Thermal warming of the upper, steep, south and west facing slopes creates a noticeably warmer microclimate on the higher elevation portions of these sites. As the vegetation takes hold in spring, a positive feedback is present as the subshrub habitat provides insulation and retains warmth.

A dimorphism, or the presence of two morphologically different examples of specimens, that otherwise appear to be the same species, was observed in Bog Blueberry, *Vaccinium uliginosum* and Mountain azalea, *Loiseleuria procumbens*.

An unusual bulb-like structure on *Cassiope mertensiana* was observed at multiple sites on the Central Juneau Icefield, bordering the Taku Glacier. The affected leaves are succulent, red, and dry to a dark black color. The swollen leaf of *Cassiope mertensiana* is now known to be infected with a rust of the Uredinales, first determined by J.P. Anderson (1952). Work at the Alaska State Museum Herbarium on 27, 28, and 29 June 2006, unearthed a paper by J.P. Anderson, describing the Uredinales in Alaska. The Uredinales are an order of parasitic fungus with several families and genera infecting a variety of species throughout Alaska.

Several members of the Poaceae from the nunatak sites are viviparous, which literally means “live bearing”. They include: *Poa arctica, Poa alpina, Poa lanata, Poa hispidula,* *"Festuca vivipara,"** and *Poa stenantha* (cf. Hultén, 1968). Observations of possible speciation have also been made and will be investigated further.

I have determined that one of the grasses, *Poa leptocoma,* or Bog Bluegrass, from a nunatak field site, is threatened in Washington State. Another new finding is a member of the poppy family. Macoun's Poppy, or *Papaver macounii*, is considered rare in British Columbia, where it was found. *Melica bulbosa*, or onion grass, was observed in British Columbia where it is red listed, meaning it is threatened, endangered or extirpated. Knowledge of these species adds even more relevance to the work as a whole.

* *F. vivipara* is a questionable species, often identified as *F. brachyphylla*, cf. Hultén p. 168.

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"Climb the mountains and get their good tidings. Nature's peace will flow into you as sunshine flows into trees. The winds will blow their freshness into you and the storms their energy, while cares will drop off like autumn leaves."

John Muir

APPENDIX E

2007 REPORT

Abbreviated Narrative Portion of Final Report Submitted to the

Philanthropic Educational Organization

PEO Scholar Award Progress Report II

June 2007

Grantee: Polly Bass

Project: Ph.D. Dissertation, Nunataks and Island Biogeography in the Alaska-Canada Boundary Range: Examples from the Flora with Implications for Climate Change

Summary and Narrative Overview:

It has been a very productive year. I am extremely grateful to PEO for supporting me and seeing me through this exciting and exhausting time in my life. Since January, tremendous progress has been made in spite of multiple unexpected challenges. New software was required for analyzing the data set. The challenge was met and the goal accomplished. The interactive map project was completed – a project that previously had to be postponed due to time constraints. Temperature data were analyzed. Comparisons of studies from 1948 to the present were completed. The growing-season was calculated for each study site. A model was developed to test the controls on species richness and evaluate the nunatak sites in relation to islands in the theory of island biogeography. Aspect, elevation, temperature, growing season, latitude, and surface area were evaluated for their influences on species richness and utilized in a number of predictive models. Communities were identified through phytosociological analysis. The copious species-area and line-transect data gathered in the last several years were analyzed and molded into a presentable format. Soil data were analyzed and molded into a presentable format.

Originally, the dissertation defense was scheduled for 8 May 2007. I did meet with the committee members in Athens during the week of May 5-10. It was a productive week which produced greater organizational clarity. During the second half of May 2007 and the present month of June, I have been revising drafts of the dissertation and will submit the pre-defense draft to my committee on 2 August 2007. The defense will be held on 16 August 2007 at 2 p.m. I have worked in the Georgia Southwestern University Herbarium, where my voucher collections are currently housed, and will work with the Juneau Icefield Research Program in mid-July, presenting two lectures on the vegetation of the icefield and ground truthing the developed richness models.

In the spring of 2007, I consulted a statistician for use of an algorithm to sort the phytosociological data using SAS 9.1 computer software. In the coming year, I will revise the dissertation to submit subsets of the work to peer-reviewed journals. I have been in communication with the editors of a few journals which are likely venues for the work. I plan to attend a meeting of the World Conservation Union Commission on Protected Areas (IUCN, WCPA) in Nepal in 2008 and present a talk on the importance of nunataks in the conservation of mountains. In May, a report was released which predicted a temperature increase of 10° C for the Juneau region by the year 2100. This report further justifies the importance of the current investigation. I have been asked to assist in hosting an international forum on climate change as part of the ‘Focus the Nation’ initiative in January 2008. Two researchers, one from Norway and another from Western Alaska, investigating the genetic relationships among plant species in arctic and alpine regions, have consulted with me regarding specimens. I was able to help them and hope to collaborate with them more in the future and fully utilize the potential for phytogeographical research now available through plant genomics.

Below I have included an abstract and synopsis of results focusing on the salient findings of the dissertation to date. I extend my sincere thanks to P.E.O. for the time they have invested in me. Polly Bass

Abstract

A baseline flora of nunataks, isolated peaks protruding above glaciers, on the Juneau Icefield is presented. Nunatak and periglacial sites from Alaska and Canada are included. The floristic data will allow monitoring of the region for further changes. The sites were investigated phytosociologically and biogeographically. Species richness was considered in relation to winter low temperature, dominant aspect of the study sites, growing-season length, latitude, elevation, the distance of the sites from the continuously vegetated mainland, and the surface area of the study sites. The nunatak habitats were tested against the tenets of the theory of island biogeography. Though difficult in the time frame of this study (approximately five years) to make conclusions on extinction and immigration rates, it has been possible to identify species not observed in previous investigations. It is also possible to observe the relationship between richness and nunatak surface area, and richness and the distance of a given nunatak from the continuously vegetated mainland. Surface area of a site is the most influential variable controlling species richness. This finding is in agreement with the theory of island biogeography. Latitude, elevation, and growing season length also have a strong influence on the richness of vascular plant species on the nunatak study sites. An increase in species richness from 1948 to the present parallels an increase in average temperature for the same time period. Between 1948 and 2006, there has been a 68% increase in vascular plant species richness for the icefield region.

Synopsis of Results

A model was developed to test the relationship of nunataks to islands in the theory of island biogeography. In MacArthur and Wilson's theory of island biogeography (1967) area is cited as the predominant and overarching influence on the presence of species. Abbott (1974) studied nineteen southern hemisphere islands focusing on avian species and found that winter low temperature was a greater influence than the surface area of an island in controlling species richness.

In the model developed from data on the vascular plant species of the Juneau Icefield nunataks, area is still a greater influence than over-winter low temperature. However, latitude and elevation do have a strong influence, depending on the parameters used in model building. This is significant because it suggests that nunataks do behave as islands in the theory of island biogeography, despite being connected to the mainland by a medium with greater structural integrity than water (as in true islands). Nunataks are surrounded by glacier ice of a solid medium. But to many organisms, ice presents a greater impediment to travel than water. After all, material can travel on water via wind and currents. Wind can carry material of a light enough mass across a glacier, but crevasses and icefalls present a formidable and impassable barrier to most forms of material transport and terrestrial life.

APPENDIX F

SPECIES LIST

43 families	**130 genera**		
301 species by cell +/-22 incertae sedis and not to species level specimens were found in formal relevé sampling units and are listed below.			
Taxa in this Appendix include only those in formal releve sampling units.			
Taxa observed and vouchered in this study but not present in the relevé sampling units are included in the comprehensive specimen database, available from the author, and comprise an additional 16 taxa.			
Family	**Genus**	**Species**	**Subspecies or Variety**
Aspidiaceae	*Polystichum*	*braunii*	var. *alaskense*
Aspidiaceae	*Polystichum*	*lonchitis*	
Athyriaceae	*Cystopteris*	*fragilis*	ssp. *fragilis*
Betulaceae	*Alnus*	*crispa*	ssp. *sinuata*
Betulaceae	*Alnus*	*incana*	ssp. *tenuifolia*
Boraginaceae	*Myosotis*	*alpestris*	ssp. *asiatica*
Campanulaceae	*Campanula*	*lasiocarpa*	ssp. *lasiocarpa*
Campanulaceae	*Campanula*	*rotundifolia*	
Caprifoliaceae	*Sambucus*	*racemosa*	ssp. *pubens* var. *arborescens*
Caprifoliaceae	*Sambucus*	*racemosa*	ssp. *pubens*
Caryophyllaceae	*Cerastium*	*beeringianum*	var. *beeringianum*
Caryophyllaceae	*Cerastium*	*beeringianum*	
Caryophyllaceae	*Sagina*	*saginoides*	
Caryophyllaceae	*Silene*	*acaulis*	ssp. *acaulis*
Caryophyllaceae	*Silene*	*acaulis*	
Caryophyllaceae	*Stellaria*	*calycantha*	
Caryophyllaceae	*Stellaria*	*longifolia*	
Caryophyllaceae	*Stellaria*	*longipes*	
Caryophyllaceae	*Stellaria*	*monantha*	
Compositae	*Achillea*	*borealis*	
Compositae	*Achillea*	*millefolium*	
Compositae	*Anaphalis*	*margaritacea*	
Compositae	*Antennaria*	*atriceps*	
Compositae	*Antennaria*	*friesiana*	ssp. *compacta*
Compositae	*Antennaria*	*media*	
Compositae	*Antennaria*	*monocephala*	
Compositae	*Antennaria*	*pallida*	
Compositae	*Antennaria*	*pulcherrima*	
Compositae	*Antennaria*	*rosea*	var. *nitida*
Compositae	*Antennaria*	*friesiana*	ssp. *alaskana*
Compositae	*Antennaria*	*media*	
Compositae	*Antennaria*	*monocephala*	var. *monocephala*
Compositae	*Antennaria*	*monocephala*	
Compositae	*Antennaria*	n.d.	
Compositae	*Arnica*	*amplexicaulis*	ssp. *amplexicaulis*
Compositae	*Arnica*	*cordifolia*	
Compositae	*Arnica*	*frigida*	
Compositae	*Artemisia*	*arctica*	ssp. *arctica*
Compositae	*Aster*	*modestus*	
Compositae	*Erigeron*	*humilis*	
Compositae	*Erigeron*	*purpuratus*	
Compositae	*Erigeron*	sp.	
Compositae	*Matricaria*	*matricarioides*	
Compositae	*Petasites*	*frigidus*	
Compositae	*Petasites*	*hyperboreus*	
Compositae	*Senecio*	*atropurpureus*	ssp. *tomentosus*
Compositae	*Senecio*	*lugens*	
Compositae	*Solidago*	*lepida*	
Compositae	*Solidago*	*multiradiata*	var. *multiradiata*
Compositae	*Solidago*	*multiradiata*	var. *scopulorum*

Cornaceae	*Cornus*	*canadensis*				
Crassulaceae	*Sedum*	*lanceolatum*				
Crassulaceae	*Sedum*	*rosea*	ssp. *integrifolium*			
Cruciferae	*Arabis*	*hirsuta*	ssp. *eschscholtziana*			
Cruciferae	*Cardamine*	*bellidifolia*				
Cryptogrammaceae	*Cryptogramma*	*crispa*	var. *acrostichoides*			
Cryptogrammaceae	*Cryptogramma*	*crispa*	var. *sitchensis*			
Cryptogrammaceae	*Cryptogramma*	*crispa*				
Cyperaceae	*Carex*	*atrata*	ssp. *atrosquamea*			
Cyperaceae	*Carex*	*circinnata*				
Cyperaceae	*Carex*	*dioica*	ssp. *gynocrates*			
Cyperaceae	*Carex*	*garberi*	ssp. *bifaria*			
Cyperaceae	*Carex*	*lachenalii*				
Cyperaceae	*Carex*	*laeviculmis*				
Cyperaceae	*Carex*	*macrochaeta*				
Cyperaceae	*Carex*	*membranacea*				
Cyperaceae	*Carex*	n.d.				
Cyperaceae	*Carex*	*nardina*				
Cyperaceae	*Carex*	*nigricans*				
Cyperaceae	*Carex*	*obtusata*				
Cyperaceae	*Carex*	*praticola*				
Cyperaceae	*Carex*	*pyrenaica*	ssp. *micropoda*			
Cyperaceae	*Carex*	*rupestris*				
Cyperaceae	*Carex*	sp.				
Cyperaceae	*Carex*	sp.				
Cyperaceae	*Carex*	*krausei*				
Cyperaceae	*Carex*	*phaeocephala*				
Cyperaceae	*Carex*	sp.				
Cyperaceae	*Carex*	sp.				
Cyperaceae	*Eriophorum*	*scheuchzeri*	var. *tenuifolium*			
Cyperaceae	sp.	sp.				
Empetraceae	*Empetrum*	*nigrum*	ssp. *nigrum*			
Empetraceae	*Empetrum*	*nigrum*	ssp. *hermaphroditum*			
Equisetaceae	*Equisetum*	*arvense*				
Equisetaceae	*Equisetum*	sp.				
Equisetaceae	*Equisetum*	*variegatum*	ssp. *variegatum*			
Equisetaceae	*Equisetum*	*variegatum*				
Ericaceae	*Arctostaphylos*	*rubra*				
Ericaceae	*Cassiope*	*mertensiana*				
Ericaceae	*Cassiope*	sp.				
Ericaceae	*Cassiope*	*tetragona*	ssp. *tetragona*			
Ericaceae	*Cassiope*	*stellariana*	ssp. *tetragona*			
Ericaceae	*Cassiope*	*stelleriana*				
Ericaceae	*Cladothamnus*	*pyroliflorus*				
Ericaceae	*Loiseleuria*	*procumbens*				
Ericaceae	*Menziesia*	*ferruginea*				
Ericaceae	*Oxycoccus*	*palustris*				
Ericaceae	*Phyllodoce*	*aleutica*	ssp. *glanduliflora*			
Ericaceae	*Phyllodoce*	*coerulea*				
Ericaceae	*Phyllodoce*	*empetriformis*				
Ericaceae	*Vaccinium*	*parvifolium*				
Ericaceae	*Vaccinium*	*caespitosum*				
Ericaceae	*Vaccinium*	*membranaceum*				
Ericaceae	*Vaccinium*	*ovalifolium*				
Ericaceae	*Vaccinium*	*uliginosum*				
Ericaceae	*Vaccinium*	*uliginosum*	ssp. *alpinum*			
Ericaceae	*Vaccinium*	*uliginosum*	ssp. *alpinum,* var. *salicinum*			
Ericaceae	*Vaccinium*	*uliginosum*	ssp. *microphyllum*			

Gentianaceae	*Fauria*	*crista-galli*				
Gentianaceae	*Gentiana*	*glauca*				
Gentianaceae	*Gentiana*	*propinqua*	ssp. *arctophila*			
Gentianaceae	*indefinite*	*indefinite*				
Geraniaceae	*Geranium*	*bicknellii*				
Geraniaceae	*Geranium*	*erianthum*				
Gramineae	*Agropyron*	*violaceum*	ssp. *violaceum*			
Gramineae	*Agrostis*	*borealis*				
Gramineae	*Agrostis*	*stolonifera*				
Gramineae	*Deschampsia*	*caespitosa*	ssp. *caespitosa*			
Gramineae	*Deschampsia*	*danthonioides*				
Gramineae	*Deschampsia*	*elongata*				
Gramineae	*Festuca*	*brachyphylla*				
Gramineae	*Festuca*	*vivipara*				
Gramineae	*Hierochloë*	*alpina*				
Gramineae	*Melica*	*bulbosa*				
Gramineae	*Poa*	*alpigena*				
Gramineae	*Poa*	*alpina*				
Gramineae	*Poa*	*arctica*				
Gramineae	*Poa*	*arctica*	ssp. *arctica*			
Gramineae	*Poa*	*brachyanthera*				
Gramineae	*Poa*	*glauca*	var. *conferta*			
Gramineae	*Poa*	*glauca*				
Gramineae	*Poa*	*lanata*	var. *vivipara*			
Gramineae	*Poa*	*leptocoma*				
Gramineae	*Poa*	*paucispicula*				
Gramineae	*Poa*	*pratensis*				
Gramineae	*Poa*	sp.				
Gramineae	*Poa*	*stenantha*				
Gramineae	*Poa*	*pseudoabreviata*				
Gramineae	*Trisetum*	*spicatum*				
Gramineae	*Trisetum*	*spicatum*	ssp. *spicatum*			
Gramineae	*Trisetum*	*spicatum*	ssp. *alaskanum*			
Gramineae	*Trisetum*	*spicatum*	ssp. *molle*			
Gramineae	*Vahlodea*	*atropurpurea*	ssp. *latifolia*			
Gramineae	*Vulpia*	*megalura*				
Juncaceae	*Juncus*	*arcticus*	ssp. *alaskanus*			
Juncaceae	*Juncus*	*biglumis*	ssp. *albescens*			
Juncaceae	*Juncus*	*biglumis*				
Juncaceae	*Juncus*	*castaneus*	ssp. *castaneus*			
Juncaceae	*Juncus*	*drummondii*				
Juncaceae	*Juncus*	*ensifolius*				
Juncaceae	*Juncus*	*falcatus*	ssp. *sitchensis*			
Juncaceae	*Juncus*	*mertensianus*				
Juncaceae	*Juncus*	sp.				
Juncaceae	*Juncus*	*triglumis*	ssp. *albescens*			
Juncaceae	*Luzula*	*arcuata*	ssp. *unalaschcensis*			
Juncaceae	*Luzula*	*arcuata*				
Juncaceae	*Luzula*	*multiflora*	ssp. *multiflora*			
Juncaceae	*Luzula*	*multiflora*				
Juncaceae	*Luzula*	*multiflora*	ssp. *kobayasii*			
Juncaceae	*Luzula*	*parviflora*	ssp. *parviflora*			
Juncaceae	*Luzula*	*parviflora*	*ssp. parviflora var. melanocarpa*			
Juncaceae	*Luzula*	*rufescens*				
Juncaceae	*Luzula*	*spicata*				
Juncaceae	*Luzula*	*tundricola*				
Juncaceae	*Luzula*	*wahlenbergii*	ssp. *piperi*			
Juncaceae	sp.	sp.				
Leguminosae	*Astragalus*	*alpinus*	ssp. *alpinus*			
Leguminosae	*Astragalus*	sp.				
Leguminosae	*Lupinus*	*arcticus*				
Leguminosae	*Lupinus*	*nootkatensis*				
Liliaceae	*Streptopus*	*amplexifolius*	var. *americanus*			
Liliaceae	*Tofieldia*	*pusilla*				

Lycopodiaceae	*Lycopodium*	*alpinum*				
Lycopodiaceae	*Lycopodium*	*annotinum*	ssp. *annotinum*			
Lycopodiaceae	*Lycopodium*	*clavatum*				
Lycopodiaceae	*Lycopodium*	*inundatum*				
Lycopodiaceae	*Lycopodium*	*sabinaefolium*	ssp. *sitchense*			
Lycopodiaceae	*Lycopodium*	*selago*	ssp. *selago*			
Lycopodiaceae	*Lycopodium*	*selago*				
Lycopodiaceae	*Lycopodium*	*selago*	ssp. *appressum*			
Lycopodiaceae	*Lycopodium*	sp.				
Onagraceae	*Epilobium*	*adenocaulon*				
Onagraceae	*Epilobium*	*anagallidifolium*				
Onagraceae	*Epilobium*	*angustifolium*	ssp. *angustifolium*			
Onagraceae	*Epilobium*	*angustifolium*				
Onagraceae	*Epilobium*	*davuricum*				
Onagraceae	*Epilobium*	*glandulosum*				
Onagraceae	*Epilobium*	*homemannii*				
Onagraceae	*Epilobium*	*latifolium*				
Onagraceae	*Epilobium*	*leptocarpum*				
Onagraceae	*Epilobium*	*luteum*				
Onagraceae	*Epilobium*	sp.				
Orchidaceae	*Platanthera*	*saccata*				
Orobanchaceae	*Boschniakia*	*rossica*				
Papaveraceae	*Papaver*	*macounii*				
Pinaceae	*Picea*	*sitchensis*				
Pinaceae	*Tsuga*	*heterophylla*				
Pinaceae	*Tsuga*	*mertensiana*				
Polemoniaceae	*Polemonium*	*boreale*				
Polemoniaceae	*Polemonium*	*boreale*	ssp. *boreale*			
Polemoniaceae	*Polemonium*	*pulcherrimum*				
Polygonaceae	*Oxyria*	*digyna*				
Polygonaceae	*Polygonum*	*viviparum*				
Polypodiaceae	*Polypodium*	*vulgare*	ssp. *occidentale*			
Primilaceae	*Trientalis*	*europaea*	ssp. *arctica*			
Primulaceae	*Primula*	*cuneifolia*	ssp. *saxifragifolia*			
Pyrolaceae	*Pyrola*	*grandiflora*				
Pyrolaceae	i.s.	sp.				
Pyroleaceae	*Pyrola*	sp.				
Ranunculaceae	*Aconitum*	*delphinifolium*	ssp. *delphinifolium*			
Ranunculaceae	*Anemone*	*sp*				
Ranunculaceae	*Caltha*	*palustris*	ssp. *asarifolia*			
Ranunculaceae	*Coptis*	*aspleniifolia*				
Ranunculaceae	*Coptis*	*trifolia*				
Ranunculaceae	*Ranunculus*	*glacialis*	ssp. *chamissonis*			
Ranunculaceae	*Trollius*	sp.				

Rosaceae	*Aruncus*	*sylvester*				
Rosaceae	*Chamaerhodos*	*erecta*	ssp. nuttallii			
Rosaceae	*Dryas*	*drummondii*				
Rosaceae	*Dryas*	*integrifolia*				
Rosaceae	*Dryas*	*integrifolia*	ssp. *integrifolia*			
Rosaceae	*Dryas*	*integrifolia*	ssp. *sylvatica*			
Rosaceae	*Dryas*	*octopetala*	ssp. *octopetala* var. *octopetala*			
Rosaceae	*Dryas*	*octopetala*	ssp. *octopetala*			
Rosaceae	*Fragaria*	*virginiana*				
Rosaceae	*Fragaria*	*virginiana*	ssp. *glauca*			
Rosaceae	*Geum*	*calthifolium*				
Rosaceae	*Geum*	*macrophyllum*	ssp. *macrophyllum*			
Rosaceae	*Geum*	sp.				
Rosaceae	*Luetkea*	*pectinata*				
Rosaceae	*Potentilla*	*diversifolia*	var. *glaucophylla*			
Rosaceae	*Potentilla*	*flabelliformis*				
Rosaceae	*Potentilla*	*fruticosa*				
Rosaceae	*Potentilla*	*hyparctica*				
Rosaceae	*Potentilla*	*norvegica*	ssp. *monspeliensis*			
Rosaceae	*Potentilla*	*uniflora*				
Rosaceae	*Potentilla*	*villosa*				
Rosaceae	*Rosa*	*nutkana*				
Rosaceae	*Rosa*	*rugosa*				
Rosaceae	*Sanguisorba*	*stipulata*				
Rosaceae	*Sibbaldia*	*procumbens*				
Rosaceae	*Sorbus*	*sitchensis*				
Rosaceae	*Potentilla*	sp.				
Salicaceae	*Populus*	*balsamifera*				
Salicaceae	*Salix*	*alaxensis*	ssp. *alaxensis*			
Salicaceae	*Salix*	*arctica*				
Salicaceae	*Salix*	*arctica*	ssp. *arctica*			
Salicaceae	*Salix*	*arctica*	ssp. *crassijulis*			
Salicaceae	*Salix*	*arctica*	ssp. *tortulosa*			
Salicaceae	*Salix*	*depressa*				
Salicaceae	*Salix*	*fuscescens*				
Salicaceae	*Salix*	*glauca*	ssp. *glabrescens*			
Salicaceae	*Salix*	*lasiandra*				
Salicaceae	*Salix*	*niphoclada*				
Salicaceae	*Salix*	*phylicifolia*	ssp. *planifolia*			
Salicaceae	*Salix*	*reticulata*				
Salicaceae	*Salix*	*reticulata*	ssp. *reticulata* var. *semicalva*			
Salicaceae	*Salix*	*reticulata*	var. *semicalva*			
Salicaceae	*Salix*	*reticulata*	ssp. *reticulata*			
Salicaceae	*Salix*	*rotundifolia*				
Salicaceae	*Salix*	sp.				
Salicaceae	*Salix*	*stolonifera*				
Salicaceae	*Salix*	n.d.				
Salicaceae	*Salix*	sp.				

Saxifragaceae	*Chrysosplenium*	*tetrandrum*				
Saxifragaceae	*Heuchera*	*glabra*				
Saxifragaceae	*Leptarrhena*	*pyrolifolia*				
Saxifragaceae	*Parnassia*	*fimbriata*				
Saxifragaceae	*Parnassia*	*kotzebuei*				
Saxifragaceae	*Saxifraga*	*bronchialis*				
Saxifragaceae	*Saxifraga*	*bronchialis*	ssp. *funstonii*			
Saxifragaceae	*Saxifraga*	*bronchialis*	ssp. *cherlerioides*			
Saxifragaceae	*Saxifraga*	*caespitosa*				
Saxifragaceae	*Saxifraga*	*davurica*				
Saxifragaceae	*Saxifraga*	*ferruginea*				
Saxifragaceae	*Saxifraga*	*flagellaris*	ssp. *setigera*			
Saxifragaceae	*Saxifraga*	*lyallii*				
Saxifragaceae	*Saxifraga*	*lyallii*	ssp. *hulténii*			
Saxifragaceae	*Saxifraga*	*mertensiana*				
Saxifragaceae	*Saxifraga*	*oppositifolia*	ssp. *oppositifolia*			
Saxifragaceae	*Saxifraga*	*oppositifolia*	ssp. *smalliana*			
Saxifragaceae	*Saxifraga*	*oppositifolia*				
Saxifragaceae	*Saxifraga*	*punctata*				
Saxifragaceae	*Saxifraga*	*punctata*	ssp. *charlottae*			
Saxifragaceae	*Saxifraga*	*punctata*	ssp. *pacifica*			
Saxifragaceae	*Saxifraga*	*rivularis*	var. *flexuosa*			
Saxifragaceae	*Saxifraga*	sp.				
Saxifragaceae	*Saxifraga*	sp.				
Saxifragaceae	*Saxifraga*	sp.				
Saxifragaceae	*Saxifraga*	sp.				
Saxifragaceae	*Saxifraga*	*tolmiei*				
Saxifragaceae	*Saxifraga*	*tricuspidata*				
Scrophulariaceae	*Castilleja*	*unalaschcensis*				
Scrophulariaceae	*Mimulus*	*guttatus*				
Scrophulariaceae	*Veronica*	*arvensis*				
Scrophulariaceae	*Veronica*	*wormskjoldii*	ssp. *alterniflora*			
Scrophulariaceae	*Veronica*	*wormskjoldii*	ssp. *wormskjoldii*			
Umbelliferae	*Heracleum*	*lanatum*				

APPENDIX G

DATA TABLES FOR INTERACTIVE MAP, SPECIES PER SITE

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
58.834	134.28	1670	Eighteen	Campanulaceae	*Campanula*	*lasiocarpa*	*lasiocarpa*
58.834	134.28	1660	Eighteen	Caryophyllaceae	*Silene*	*acaulis*	*acaulis*
58.834	134.28	1670	Eighteen	Compositae	*Antennaria*	*friesiana*	*alaskana*
58.834	134.28	1433	Eighteen	Compositae	*Antennaria*	*media*	
58.834	134.28	1670	Eighteen	Compositae	*Antennaria*	*monocephala*	*monocephala* var. *monocephala*
58.834	134.28	1660	Eighteen	Compositae	*Antennaria*	*monocephala*	
58.834	134.28	1670	Eighteen	Compositae	*Antennaria*	n.d.	
58.834	134.28	1660	Eighteen	Compositae	*Artemisia*	*arctica*	*arctica*
58.834	134.28	1670	Eighteen	Crassuleaceae	*Sedum*	*rosea*	*integrifolium*
58.834	134.28	1660	Eighteen	Cruciferae	*Cardamine*	*bellidifolia*	
58.834	134.28	1660	Eighteen	Cyperaceae	*Carex*	*circinnata*	
58.834	134.28	1670	Eighteen	Cyperaceae	*Carex*	n.d.	
58.834	134.28	1670	Eighteen	Cyperaceae	*Carex*	*lachenalii*	
58.834	134.28	1670	Eighteen	Cyperaceae	sp.		
58.834	134.28	1670	Eighteen	Ericaceae	*Cassiope*	*stelleriana*	
58.834	134.28	1433	Eighteen	Ericaceae	*Vaccinium*	*uliginosum*	*alpinum*
58.834	134.28	1660	Eighteen	Gramineae	*Deschampsia*	*danthonioides*	
58.834	134.28	1670	Eighteen	Gramineae	*Poa*	*glauca*	
58.834	134.28	1670	Eighteen	Gramineae	*Poa*	*paucispicula*	
58.834	134.28	1660	Eighteen	Gramineae	*Poa*	*pratensis*	
58.834	134.28	1660	Eighteen	Gramineae	*Trisetum*	*spicatum*	*spicatum*
58.834	134.28	1670	Eighteen	Gramineae	*Trisetum*	*spicatum*	*alaskanum*
58.834	134.28	1670	Eighteen	Gramineae	*Vulpia*	*megalura*	
58.834	134.28	1670	Eighteen	Juncaceae	*Luzula*	*arcuata*	*unalaschcensis*
58.834	134.28	1660	Eighteen	Juncaceae	*Luzula*	*spicata*	
58.834	134.28	1660	Eighteen	Juncaceae	*Luzula*	*wahlenbergii*	*piperi*
58.834	134.28	1670	Eighteen	Lycopodiaceae	*Lycopodium*	*selago*	*selago*
58.834	134.28	1670	Eighteen	Rosaceae	*Fragaria*	*virginiana*	
58.834	134.28	1670	Eighteen	Rosaceae	*Luetkea*	*pectinata*	
58.834	134.28	1660	Eighteen	Rosaceae	*Potentilla*	*hyparctica*	
58.834	134.28	1660	Eighteen	Rosaceae	*Potentilla*	*villosa*	
58.834	134.28	1670	Eighteen	Rosaceae	*Sibbaldia*	*procumbens*	
58.834	134.28	1670	Eighteen	Salicaceae	*Salix*	*n.d.*	
58.834	134.28	1670	Eighteen	Salicaceae	*Salix*	*reticulata*	
58.834	134.28	1670	Eighteen	Saxifragaceae	*Saxifraga*	*bronchialis*	
58.834	134.28	1670	Eighteen	Saxifragaceae	*Saxifraga*	*bronchialis*	*funstonii*
58.834	134.28	1660	Eighteen	Saxifragaceae	*Saxifraga*	*ferruginea*	
58.834	134.28	1670	Eighteen	Saxifragaceae	*Saxifraga*	*mertensiana*	
58.834	134.28	1660	Eighteen	Saxifragaceae	*Saxifraga*	*rivularis*	*flexuosa*
58.834	134.28	1433	Eighteen	Saxifragaceae	*Saxifraga*	sp.	

Site Pictures

Cassiope stelleriana, Sibbaldia procubens — Vaughan Lewis Icefall, glacial tank

Campanula lasiocarpa — GilkeyTrench

Glacial Groove — Vaughan Lewis Icefall

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
58.432	134.33	1463	Fourteen	Empetraceae	*Empetrum*	*nigrum*	
58.432	134.33	1309	Fourteen	Onagraceae	*Epilobium*	*anagallidifolium*	
58.432	134.33	1309	Fourteen	Onagraceae	*Epilobium*	*leptocarpum*	
58.432	134.33	1309	Fourteen	Gramineae	*Poa*	*pratensis*	
58.432	134.33	1309	Fourteen	Primulaceae	*Trientalis*	*europaea*	*arcticus*
58.432	134.33	1463	Fourteen	Rosaceae	*Potentilla*	*novegica*	*monspeliensis*
58.432	134.33	1309	Fourteen	Salicaceae	*Salix*	*glauca*	*glabrescens*
58.432	134.33	1431	Fourteen	Saxifragaceae	*Saxifraga*	*oppositifolia*	*oppositifolia*

Site Pictures

Folded migmatitic quartzite and marble gneiss subsr

Folded quartz monzonite and marble gneiss

Split Thumb from Fourteen Ridge with weathered horn

Nugget Ridge, Split Thumb

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
59.174	134	732	Inlet Llewellyn, terminal moraine,	Betulaceae	*Alnus*	*incana*	*tenuifolia*
59.174	134	732	Inlet Llewellyn, terminal moraine,	Compositae	*Arnica*	*cordifolia*	
59.174	134	732	Inlet Llewellyn, terminal moraine,	Cornaceae	*Cornus*	*canadensis*	
59.174	134	732	Inlet Llewellyn, terminal moraine,	Equisetaceae	*Equisetum*	*variegatum*	*variegatum*
59.174	134	732	Inlet Llewellyn, terminal moraine,	Juncaceae	*Juncus*	*arcticus*	*alaskanus*
59.174	134	732	Inlet Llewellyn, terminal moraine,	Juncaceae	sp.		
59.174	134	732	Inlet Llewellyn, terminal moraine,	Lycopodiaceae	*Lycopodium*	*annotinum*	*annotinum*
59.174	134	762	Inlet Llewellyn, terminal moraine,	Onagraceae	*Epilobium*	*anagallidifolium*	*angustifolium*
59.174	134	732	Inlet Llewellyn, terminal moraine,	Pinaceae	*Tsuga*	*mertensiana*	
59.174	134	732	Inlet Llewellyn, terminal moraine,	Rosaceae	*Dryas*	*drummondii*	
59.174	134	762	Inlet Llewellyn, terminal moraine,	Rosaceae	*Dryas*	*octopetala*	*octopetala* var. *octopetala*

Site Pictures

Alnus incana tenuifolia

Llewellyn Inlet terminus, Tsuga mertensiana

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
58.37	134.38	1000	Ptarmigan Ridge	Compositae	*Antennaria*	*pulcherrima*	
58.37	134.38	1000	Ptarmigan Ridge	Cornaceae	*Cornus*	*canadensis*	
58.37	134.38	1000	Ptarmigan Ridge	Crassulaceae	*Sedum*	*rosea*	*integrifolium*
58.37	134.38	1364	Ptarmigan Ridge	Empetraceae	*Empetrum*	*nigrum*	
58.37	134.38	1000	Ptarmigan Ridge	Ericaceae	*Cassiope*	*mertensiana*	
58.37	134.38	1364	Ptarmigan Ridge	Ericaceae	*Loiseleuria*	*procumbens*	
58.37	134.38	1000	Ptarmigan Ridge	Ericaceae	*Menziesia*	*ferruginea*	
58.37	134.38	1000	Ptarmigan Ridge	Ericaceae	*Oxycoccus*	*palustris*	
58.37	134.38	1000	Ptarmigan Ridge	Ericaceae	*Vaccinium*	*uliginosum*	*alpinum*
58.37	134.38	1286	Ptarmigan Ridge	Ericaceae	*Vaccinium*	*uliginosum*	
58.37	134.38	1364	Ptarmigan Ridge	Juncaceae	*Luzula*	*parviflora*	*parviflora var. melanocarpa*
58.37	134.38	1286	Ptarmigan Ridge	Lycopodiaceae	*Lycopodium*	*clavatum*	
58.37	134.38	1286	Ptarmigan Ridge	Lycopodiaceae	*Lycopodium*	*selago*	
58.37	134.38	1000	Ptarmigan Ridge	Pinaceae	*Tsuga*	*heterophylla*	
58.37	134.38	1286	Ptarmigan Ridge	Rosaceae	*Potentilla*	*hyparctica*	
58.37	134.38	1000	Ptarmigan Ridge	Rosaceae	*Potentilla*	*villosa*	
58.37	134.38	1364	Ptarmigan Ridge	Salicaceae	*Salix*	*stolonifera*	
58.37	134.38	1364	Ptarmigan Ridge	Saxifragaceae	*Saxifraga*	*ferruginea*	
58.37	134.38	1000	Ptarmigan Ridge	Scrophulariaceae	*Castilleja*	*unalaschcensis*	

Site Pictures

Horneblendites and cross faults

Ptarmingan Ridge

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
58.388	134.38	780	Seventeen A	Compositae	*Aster*	*modestus*	
58.388	134.38	780	Seventeen A	Compositae	*Petasites*	*frigidus*	
58.388	134.38	780	Seventeen A	Compositae	*Petasites*	*hyperboreus*	
58.388	134.38	780	Seventeen A	Cyperaceae	*Carex*	*macrochaeta*	
58.388	134.38	780	Seventeen A	Ericaceae	*Cassiope*	*mertensianus*	
58.388	134.38	780	Seventeen A	Ericaceae	*Loiseleuria*	*procumbens*	
58.388	134.38	780	Seventeen A	Geraniaceae	*Geranium*	*erianthum*	
58.388	134.38	780	Seventeen A	Gramineae	*Deschampsia*	*caespitosa*	*caespitosa var. caespitosa*
58.388	134.38	780	Seventeen A	Gramineae	*Trisetum*	*spicatum*	*alaskanum*
58.388	134.38	780	Seventeen A	Juncaceae	*Juncus*	*biglumis*	*albescens*
58.388	134.38	780	Seventeen A	Juncaceae	*Juncus*	*falcatus*	*sitchensis*
58.388	134.38	780	Seventeen A	Juncaceae	*Juncus*	*mertensiana*	
58.388	134.38	780	Seventeen A	Leguminosae	*Lupinus*	*nootkatensis*	
58.388	134.38	780	Seventeen A	Lycopodiaceae	*Lycopodium*	*selago*	*appressum*
58.388	134.38	780	Seventeen A	Onagraceae	*Epilobium*	sp.	
58.388	134.38	780	Seventeen A	Orchidaceae	*Platanthera*	*saccata*	
58.388	134.38	780	Seventeen A	Pinaceae	*Tsuga*	*heterophylla*	
58.388	134.38	780	Seventeen A	Pyrolaceae	*Pyrola*	sp	
58.388	134.38	780	Seventeen A	Ranunculaceae	*Anemone*	sp	
58.388	134.38	780	Seventeen A	Ranunculaceae	*Coptis*	*trifolia*	
58.388	134.38	780	Seventeen A	Ranunculceae	*Caltha*	*palustris*	*asarifolia*
58.388	134.38	780	Seventeen A	Rosaceae	*Geum*	*calthifolium*	
58.388	134.38	780	Seventeen A	Rosaceae	*Luetkea*	*pectinata*	
58.388	134.38	780	Seventeen A	Rosaceae	*Sorbus*	*sitchensis*	
58.388	134.38	780	Seventeen A	Saxifragaceae	*Saxifraga*	*davurica* (i.s.)	

Site Pictures

Carex macrochaeta, Epilobium latifolium — *Petasites frigidus*

Carex macrochaeta — View to Thomas and Lemon Creek Glaciers

Luetkea pectinata

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
58.393	134.39	774	Tarn Lake	Cornaceae	*Cornus*	*canadensis*	
58.393	134.39	774	Tarn Lake	Cyperaceae	*Carex*	sp.	
58.393	134.39	774	Tarn Lake	Cyperaceae	*Carex*	*macrochaeta*	
58.393	134.39	774	Tarn Lake	Cyperaceae	*Eriophorum*	*Scheuchzeri*	var. *tenuifolium*
58.393	134.39	774	Tarn Lake	Ericaceae	*Vaccinium*	*uliginosum*	*alpinum*
58.393	134.39	774	Tarn Lake	Leguminosae	*Lupinus*	*nootkatensis*	
58.393	134.39	774	Tarn Lake	Geraniaceae	*Geranium*	*bicknellii*	
58.393	134.39	774	Tarn Lake	Juncaceae	*Juncus*	*biglumis*	
58.393	134.39	774	Tarn Lake	Juncaceae	*Juncus*	*triglumis*	*albescens*
58.393	134.39	774	Tarn Lake	Onagraceae	*Epilobium*	*latifolium*	
58.393	134.39	774	Tarn Lake	Polypodiaceae	*Polypodium*	*vulgare*	*occidentale*
58.393	134.39	774	Tarn Lake	Salicaceae	*Salix*	*niphoclada*	

Site Pictures

Lupinus nootkatensis, Cassiope mertensiana

Lupinus nootkatensis

Tarn Lake

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
58.437	134.32	1431	Thirteen	Compositae	*Antennaria*	*rosea*	
58.437	134.32	1463	Thirteen	Compositae	*Artemisia*	*arctica*	*arctica*
58.437	134.32	1463	Thirteen	Cryptogrammaceae	*Cryptogramma*	*crispa*	var. *sitchensis*
58.437	134.32	1309	Thirteen	Cyperaceae	*Carex*	*circinnata*	
58.437	134.32	1463	Thirteen	Cyperaceae	*Carex*	*pyrenaica*	*micropoda*
58.437	134.32	1463	Thirteen	Ericaceae	*Phyllodoce*	*empetriformis*	
58.437	134.32	1463	Thirteen	Gramineae	*Poa*	*stenantha*	
58.437	134.32	1431	Thirteen	Gramineae	*Trisetum*	*spicatum*	*spicatum*
58.437	134.32	1463	Thirteen	Juncaceae	*Juncus*	*drummondii*	
58.437	134.32	1463	Thirteen	Juncaceae	*Luzula*	*arcuata*	*unalaschcensis*
58.437	134.32	1463	Thirteen	Saxifragaceae	*Saxifraga*	*bronchialis*	*cherlerioides*
58.437	134.32	1463	Thirteen	Saxifragaceae	*Saxifraga*	*bronchialis*	*funstonii*
58.437	134.32	1463	Thirteen	Saxifragaceae	*Saxifraga*	*oppositifolia*	*smalliana*

Site Pictures

Nugget Ridge marble intercalated granodiorites

Thirteen

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
58.663	134.36	1408	TNW	Campanulaceae	Campanula	lasiocarpa	lasiocarpa
58.663	134.36	1408	TNW	Compositae	Antennaria	friesiana	compacta
58.663	134.36	1408	TNW	Compositae	Artemisia	arctica	arctica
58.663	134.36	1408	TNW	Cruciferae	Cardamine	bellidifolia	
58.663	134.36	1408	TNW	Cryptogrammaceae	Cryptogramma	crispa	var. acrostichoides
58.663	134.36	1408	TNW	Cryptogrammaceae	Cryptogramma	crispa	sitchensis
58.663	134.36	1408	TNW	Cyperaceae	Carex	circinnata	
58.663	134.36	1408	TNW	Cyperaceae	Carex	nardina	
58.663	134.36	1408	TNW	Cyperaceae	Carex	praticola	
58.663	134.36	1408	TNW	Cyperaceae	Carex	macrochaeta	
58.663	134.36	1408	TNW	Cyperaceae	Carex	pyrenaica	micropoda
58.663	134.36	1408	TNW	Cyperaceae	Carex	sp.	
58.663	134.36	1408	TNW	Empetraceae	Empetrum	nigrum	
58.663	134.36	1408	TNW	Empetraceae	Empetrum	nigrum	hermaphroditum
58.663	134.36	1408	TNW	Empetraceae	Empetrum	nigrum	nigrum
58.663	134.36	1408	TNW	Ericaceae	Arctostaphylos	rubra	
58.663	134.36	1408	TNW	Ericaceae	Cassiope	mertensiana	
58.663	134.36	1408	TNW	Ericaceae	Cassiope	stelleriana	
58.663	134.36	1408	TNW	Ericaceae	Cassiope	stelleriana	tetragona
58.663	134.36	1408	TNW	Ericaceae	Phyllodoce	aleutica	glanduliflora
58.663	134.36	1408	TNW	Ericaceae	Vaccinium	ovalifolium	
58.663	134.36	1408	TNW	Ericaceae	Vaccinium	uliginosum	microphyllum
58.663	134.36	1408	TNW	Ericaceae	Vaccinium	uliginosum	alpinum
58.663	134.36	1408	TNW	Gramineae	Hierochloë	alpina	
58.663	134.36	1408	TNW	Gramineae	Poa	brachyanthera	
58.663	134.36	1408	TNW	Gramineae	Poa	pseudobreviata	
58.663	134.36	1408	TNW	Gramineae	Trisetum	spicatum	molle
58.663	134.36	1408	TNW	Juncaceae	Luzula	arcuata	unalaschcensis
58.663	134.36	1408	TNW	Juncaceae	Luzula	arcuata	
58.663	134.36	1408	TNW	Juncaceae	Luzula	parviflora	parviflora
58.663	134.36	1408	TNW	Lycopodiaceae	Lycopodium	selago	appressum
58.663	134.36	1408	TNW	Lycopodiaceae	Lycopodium	selago	selago
58.663	134.36	1408	TNW	Onagraceae	Epilobium	latifolium	
58.663	134.36	1408	TNW	Rosaceae	Potentilla	villosa	
58.663	134.36	1408	TNW	Salicaceae	Salix	reticulata	
58.663	134.36	1408	TNW	Saxifragaceae	Saxifraga	bronchialis	funstonii
58.663	134.36	1408	TNW	Saxifragaceae	Saxifraga	ferruginea	

Site Pictures

Lycopodium selago — Saxifraga ferruginea

Taku NW Point — Taku NW Point (II)

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
59.015	134.16	1707	Twenty-Six Llewellyn Gl. BC	Aspidaceae	Polystichum	braunii	var. alaskense
59.015	134.16	1433	Twenty-Six Llewellyn Gl. BC	Aspidaceae	Polystichum	lonchitus	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Boraginaceae	Myosotis	alpestris	asiatica
59.015	134.16	1494	Twenty-Six Llewellyn Gl. BC	Campanulaceae	Campanula	rotundifolia	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Campanulaceae	Campanula	lasiocarpa	lasiocarpa
59.015	134.16	1457	Twenty-Six Llewellyn Gl. BC	Caryophyllaceae	Cerastium	beeringianum	var. beeringianum
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Caryophyllaceae	Cerastium	beeringianum	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Caryophyllaceae	Sagina	saginoides	
59.015	134.16	1493	Twenty-Six Llewellyn Gl. BC	Caryophyllaceae	Sagina	saginoides	acaulis
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Caryophyllaceae	Silene	acaulis	acaulis
59.015	134.16	1626	Twenty-Six Llewellyn Gl. BC	Caryophyllaceae	Stellaria	longifolia	
59.015	134.16	1490	Twenty-Six Llewellyn Gl. BC	Caryophyllaceae	Stellaria	longipes	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Caryophyllaceae	Stellaria	monantha	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Caryophyllaceae	Stelleria	calycantha	
59.015	134.16	1494	Twenty-Six Llewellyn Gl. BC	Compositae	Antennaria	atriceps	
59.015	134.16	1660	Twenty-Six Llewellyn Gl. BC	Compositae	Antennaria	media	
59.015	134.16	1626	Twenty-Six Llewellyn Gl. BC	Compositae	Antennaria	pallida	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Compositae	Antennaria	rosea	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Compositae	Arnica	amplexicaulis	amplexicaulis
59.015	134.16	1626	Twenty-Six Llewellyn Gl. BC	Compositae	Arnica	frigida	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Compositae	Artemisia	arctica	arctica
59.015	134.16	1616	Twenty-Six Llewellyn Gl. BC	Compositae	Erigeron	humilis	
59.015	134.16	1626	Twenty-Six Llewellyn Gl. BC	Compositae	Erigeron	sp.	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Compositae	Senecio	atropurpureus	tomentosus
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Compositae	Senecio	lugens	
59.015	134.16	1660	Twenty-Six Llewellyn Gl. BC	Compositae	Solidago	multiradiata	var. multiradiata
59.015	134.16	1463	Twenty-Six Llewellyn Gl. BC	Compositae	Solidago	multiradiata	var. scopulorum
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Crassulaceae	Sedum	lanceolatum	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Crassulaceae	Sedum	rosea	integrifolium
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Cruciferae	Arabis	hirsuta	eschoItziana
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Cryptogrammaceae	Cryptogramma	crispa	sitchensis var. acrostichoides
59.015	134.16	1616	Twenty-Six Llewellyn Gl. BC	Cryptogrammaceae	Cryptogramma	crispa	acrostichoides

59.015	134.16	1626	Twenty-Six Llewellyn Gl. BC	Cyperaceae	*Carex*	*atrata*	*atrosquamea*
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Cyperaceae	*Carex*	*garberi*	*bifaria*
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Cyperaceae	*Carex*	*lachenalii*	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Cyperaceae	*Carex*	*membranacea*	
59.015	134.16	1707	Twenty-Six Llewellyn Gl. BC	Cyperaceae	*Carex*	*obtusata*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Cyperaceae	*Carex*	*praticola*	
59.015	134.16	1463	Twenty-Six Llewellyn Gl. BC	Cyperaceae	*Carex*	*rupestris*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Cyperaceae	*Carex*	sp.	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Cyperaceae	*Carex*	*krausei*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Cyperaceae	*Carex*	*phaeocephala*	
59.015	134.16	1493	Twenty-Six Llewellyn Gl. BC	Empetraceae	*Empetrum*	*nigrum*	*nigrum*
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Empetraceae	*Empetrum*	*nigrum*	*hermaphroditum*
59.015	134.16	1457	Twenty-Six Llewellyn Gl. BC	Empetraceae	*Empetrum*	*nigrum*	
59.015	134.16	1494	Twenty-Six Llewellyn Gl. BC	Equisetaceae	*Equisetum*	*arvense*	
59.015	134.16	1494	Twenty-Six Llewellyn Gl. BC	Equisetaceae	*Equisetum*	*variegatum*	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Ericaceae	*Arctostaphylos*	*rubra*	
59.015	134.16	1707	Twenty-Six Llewellyn Gl. BC	Ericaceae	*Cassiope*	*stelleriana*	
59.015	134.16	1707	Twenty-Six Llewellyn Gl. BC	Ericaceae	*Cassiope*	*tetragona*	*tetragona*
59.015	134.16	1585	Twenty-Six Llewellyn Gl. BC	Ericaceae	*Cassiope*	*mertensiana*	
59.015	134.16	1626	Twenty-Six Llewellyn Gl. BC	Ericaceae	*Phyllodoce*	*aleutica*	*glanduliflora*
59.015	134.16	1626	Twenty-Six Llewellyn Gl. BC	Ericaceae	*Phyllodoce*	*empetriformis*	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Ericaceae	*Vaccinium*	*uliginosum*	*microphyllum*
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Ericaceae	*Vaccinium*	*uliginosum*	*alpinum*
59.015	134.16	1463	Twenty-Six Llewellyn Gl. BC	Gentianaceae	*Gentiana*	*propinqua*	*arctophila*
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Gentianaceae	*indefinite*	*indefinite*	
59.015	134.16	1494	Twenty-Six Llewellyn Gl. BC	Gramineae	*Agropyron*	*violaceum*	*violaceum*
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Gramineae	*Festuca*	*brachyphylla*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Gramineae	*Melica*	*bulbosa*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Gramineae	*Poa*	*alpina*	
59.015	134.16	1494	Twenty-Six Llewellyn Gl. BC	Gramineae	*Poa*	*arctica*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Gramineae	*Poa*	*glauca*	
59.015	134.16	1585	Twenty-Six Llewellyn Gl. BC	Gramineae	*Poa*	*glauca*	*conferta*
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Gramineae	*Poa*	*leptocoma*	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Gramineae	*Poa*	*paucispicula*	
59.015	134.16	1494	Twenty-Six Llewellyn Gl. BC	Gramineae	*Poa*	*pratensis*	
59.015	134.16	1707	Twenty-Six Llewellyn Gl. BC	Gramineae	*Poa*	*sp.*	
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Gramineae	*Poa*	*stenantha*	
59.015	134.16	1626	Twenty-Six Llewellyn Gl. BC	Gramineae	*Trisetum*	*spicatum*	*spicatum*
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Juncaceae	*Juncus*	*biglumis*	
59.015	134.16	1493	Twenty-Six Llewellyn Gl. BC	Juncaceae	*Juncus*	*castaneus*	*castaneus*
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Juncaceae	*Juncus*	*drummondii*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Juncaceae	*Juncus*	*falcatus*	*sitchensis*
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Juncaceae	*Juncus*	*mertensianus*	
59.015	134.16	1585	Twenty-Six Llewellyn Gl. BC	Juncaceae	*Juncus*	sp.	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Juncaceae	*Luzula*	*arcuata*	*unalaschcensis*
59.015	134.16	1494	Twenty-Six Llewellyn Gl. BC	Juncaceae	*Luzula*	*spicata*	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Leguminosae	*Astragalus*	*alpinus*	*alpinus*
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Leguminosae	*Astragalus*	*sp.*	
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Leguminosae	*Lupinus*	*arcticus*	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Leguminosae	*Lupinus*	*nootkatensis*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Liliaceae	*Tofieldia*	*pusilla*	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Lycopodiaceae	*Lycopodium*	*alpinum*	
59.015	134.16	1835	Twenty-Six Llewellyn Gl. BC	Lycopodiaceae	*Lycopodium*	*inundatum*	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Lycopodiaceae	*Lycopodium*	*selago*	*selago*
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Onagraceae	*Epilobium*	*anagallidifolium*	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Onagraceae	*Epilobium*	*angustifolium*	*angustifolium*
59.015	134.16	1860	Twenty-Six Llewellyn Gl. BC	Onagraceae	*Epilobium*	*glandulosum*	
59.015	134.16	1463	Twenty-Six Llewellyn Gl. BC	Onagraceae	*Epilobium*	*latifolium*	
59.015	134.16	1860	Twenty-Six Llewellyn Gl. BC	Onagraceae	*Epilobium*	*luteum*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Onagraceae	*Epilobium*	sp.	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Papaveraceae	*Papaver*	*macounii*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Polemoniaceae	*Polemonium*	*boreale*	
59.015	134.16	1615	Twenty-Six Llewellyn Gl. BC	Polemoniaceae	*Polemonium*	*boreale*	*boreale*
59.015	134.16	1860	Twenty-Six Llewellyn Gl. BC	Polemoniaceae	*Polemonium*	*pulcherrimum*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Polygonaceae	*Oxyria*	*digyna*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Polygonaceae	*Polygonum*	*viviparum*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Ranunculaceae	*Ranunculus*	*glacialis*	*chamissonis*
59.015	134.16	1494	Twenty-Six Llewellyn Gl. BC	Ranunculaceae	*Trollius*	sp.	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Rosaceae	*Chamaerhodos*	*erecta*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Rosaceae	*Dryas*	*integrifolia*	*integrifolia*
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Rosaceae	*Dryas*	*integrifolia*	*octopetala* var. *octopetala*
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Rosaceae	*Dryas*	*integrifolia*	*sylvatica*
59.015	134.16	1491	Twenty-Six Llewellyn Gl. BC	Rosaceae	*Dryas*	*octopetala*	*octopetala*
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Rosaceae	*Luetkea*	*pectinata*	

59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Rosaceae	*Potentilla*	*diversifolia*	var. *glaucophylla*
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Rosaceae	*Potentilla*	*flabellifolia*	
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Rosaceae	*Potentilla*	*fruticosa*	
59.015	134.16	1494	Twenty-Six Llewellyn Gl. BC	Rosaceae	*Potentilla*	*villosa*	
59.015	134.16	1707	Twenty-Six Llewellyn Gl. BC	Rosaceae	*Sanguisorba*	*stipulata*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Rosaceae	*Sibbaldia*	*procumbens*	
59.015	134.16	1519	Twenty-Six Llewellyn Gl. BC	Salicaceae	*Salix*	*alaxensis*	*alaxensis*
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Salicaceae	*Salix*	*arctica*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Salicaceae	*Salix*	*arctica*	*arctica*
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Salicaceae	*Salix*	*arctica*	*crassijulis*
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Salicaceae	*Salix*	*arctica*	*torulosa*
59.015	134.16	1494	Twenty-Six Llewellyn Gl. BC	Salicaceae	*Salix*	*depressa*	
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Salicaceae	*Salix*	*lasiandra*	
59.015	134.16	1463	Twenty-Six Llewellyn Gl. BC	Salicaceae	*Salix*	*niphoclada*	var. *muriei*
59.015	134.16	1519	Twenty-Six Llewellyn Gl. BC	Salicaceae	*Salix*	*phylicifolia*	*planifolia*
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Salicaceae	*Salix*	*reticulata*	
59.015	134.16	1524	Twenty-Six Llewellyn Gl. BC	Salicaceae	*Salix*	*reticulata*	*reticulata* var. *semicalva*
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Salicaceae	*Salix*	*reticulata*	*semicalva*
59.015	134.16	1626	Twenty-Six Llewellyn Gl. BC	Salicaceae	*Salix*	*rotundifolia*	
59.015	134.16	1707	Twenty-Six Llewellyn Gl. BC	Salicaceae	*Salix*	*stolonifera*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Saxifragaceae	*Chrysosplenium*	*tetrandrum*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Saxifragaceae	*Heuchera*	*glabra*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Saxifragaceae	*Parnassia*	*fimbriata*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Saxifragaceae	*Parnassia*	*kotzebuei*	
59.015	134.16	1860	Twenty-Six Llewellyn Gl. BC	Saxifragaceae	*Saxifraga*	*bronchialis*	*cherlerioides*
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Saxifragaceae	*Saxifraga*	*bronchialis*	*funstonii*
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Saxifragaceae	*Saxifraga*	*caespitosa*	
59.015	134.16	1494	Twenty-Six Llewellyn Gl. BC	Saxifragaceae	*Saxifraga*	*ferruginea*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Saxifragaceae	*Saxifraga*	*lyallii*	*hulténii*
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Saxifragaceae	*Saxifraga*	*oppositifolia*	*oppositifolia*
59.015	134.16	1626	Twenty-Six Llewellyn Gl. BC	Saxifragaceae	*Saxifraga*	*punctata*	*charlottae*
59.015	134.16	1835	Twenty-Six Llewellyn Gl. BC	Saxifragaceae	*Saxifraga*	*rivularis*	*flexuosa*
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Saxifragaceae	*Saxifraga*	sp.	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Saxifragaceae	*Saxifraga*	*tricuspidata*	
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Scrophulariaceae	*Castilleja*	*unalaschcensis*	
59.015	134.16	1645	Twenty-Six Llewellyn Gl. BC	Scrophulariaceae	*Veronica*	*arvensis*	
59.015	134.16	1585	Twenty-Six Llewellyn Gl. BC	Scrophulariaceae	*Veronica*	*wormskjoldii*	*alternifolia*
59.015	134.16	1829	Twenty-Six Llewellyn Gl. BC	Scrophulariaceae	*Veronica*	*wormskjoldii*	*wormskjoldii*

Site Pictures

Saxifraga bronchialis, Epilobium latifolium	Potentilla diversifolia	Salix reticulata
Castilleja unalaschcensis	Potentilla villosa	Saxifraga bronchialis, Silene acaulis
Castilleja unalaschcensis (II)	Epilobium latifolium	Salix arctica
Epilobium latifolium vertical	Juncus mertensiana	Saxifraga bronchialis
Dryas integrifolia	Parnassia fibriata	Salix phylicifolia

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
58.388	134.41	990	Bog Pond	Cyperaceae	*Carex*	*nigricans*	
58.388	134.41	990	Bog Pond	Ericaceae	*Cassiope*	*stelleriana*	
58.388	134.41	1100	Bog Pond	Ericaceae	*Cladothamnus*	*pyrolaeflorus*	
58.388	134.41	990	Bog Pond	Gentianaceae	*Fauria*	*crista-galli*	
58.388	134.41	1100	Bog Pond	Pinaceae	*Tsuga*	*heterophylla*	
58.388	134.41	1100	Bog Pond	Pinaceae	*Tsuga*	*mertensiana*	
58.388	134.41	990	Bog Pond	Primilaceae	*Trientalis*	*europaea*	*arctica*
58.388	134.41	990	Bog Pond	Rosaceae	*Potentilla*	*villosa*	
58.388	134.41	1100	Bog Pond	Rosaceae	*Sorbus*	*sitchensis*	
58.388	134.41	1100	Bog Pond	Umbelliferae	*Heracleum*	*lanatum*	

Site Pictures

Tsuga mertensiana
Sorbus sitchensis
Bog Pond2
Bog Pond3
Tsuga mertensiana

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
58.834	134.29	1316	Eighteen B	Compositae	*Antennaria*	*atriceps*	
58.834	134.29	1660	Eighteen B	Compositae	*Artemisia*	*arctica*	*arctica*
58.834	134.29	1368	Eighteen B	Cruciferae	*Cardamine*	*bellidifolia*	
58.834	134.29	1660	Eighteen B	Cyperaceae	*Carex*	*dioica*	*gynocrates*
58.834	134.29	1316	Eighteen B	Ericaceae	*Cassiope*	*mertensiana*	
58.834	134.29	1316	Eighteen B	Ericaceae	*Cassiope*	*stelleriana*	
58.834	134.29	1281	Eighteen B	Ericaceae	*Loiseleuria*	*procumbens*	
58.834	134.29	1660	Eighteen B	Ericaceae	*Vaccinium*	*uliginosum*	*alpinum*
58.834	134.29	1316	Eighteen B	Ericaceae	*Vaccinium*	*uliginosum*	
58.834	134.29	1316	Eighteen B	Gramineae	*Deschampsia*	*danthonioides*	
58.834	134.29	1660	Eighteen B	Juncaceae	*Juncus*	*falcatus*	*sitchensis*
58.834	134.29	1316	Eighteen B	Juncaceae	*Luzula*	*parviflora*	*parviflora*
58.834	134.29	1660	Eighteen B	Juncaceae	*Luzula*	*tundricola*	
58.834	134.29	1660	Eighteen B	Leguminosae	*Lupinus*	*nootkatensis*	
58.834	134.29	1316	Eighteen B	Lycopodiaceae	*Lycopodium*	*alpinum*	

58.834	134.29	1281	Eighteen B	Lycopodiaceae	*Lycopodium*	*selago*	
58.834	134.29	1316	Eighteen B	Onagraceae	*Epilobium*	*anagallidifolium*	
58.834	134.29	1316	Eighteen B	Rosaceae	*Geum*	*calthifolium*	
58.834	134.29	1660	Eighteen B	Rosaceae	*Geum*	sp.	
58.834	134.29	1660	Eighteen B	Rosaceae	*Luetkea*	*pectinata*	
58.834	134.29	1316	Eighteen B	Rosaceae	*Sibbaldia*	*procumbens*	
58.834	134.29	1660	Eighteen B	Saxifragaceae	*Saxifraga*	*mertensiana*	
Site Pictures							
Vaughn Lewis Icefall							
Soil sampling above Vaughan Lewis Icefall							
Y Latitu	**X Long**	**Eleva**	**Location**	**Family**	**Genus**	**Species**	**Sub. Species**
58.708	134.17	2109	Nine A	Cyperaceae	*Carex*	*pyrenaica*	*micropoda*
58.708	134.17	2109	Nine A	Gramineae	*Festuca*	*brachyphylla*	var. *brachyphylla*
58.708	134.17	2109	Nine A	Gramineae	*Poa*	*paucispicula*	
58.708	134.17	2109	Nine A	Saxifragaceae	*Saxifraga*	sp.	
Y Latitu	**X Long**	**Eleva**	**Location**	**Family**	**Genus**	**Species**	**Sub. Species**
58.388	134.38	780	Seventeen A	Compositae	*Aster*	*modestus*	
58.388	134.38	780	Seventeen A	Compositae	*Petasites*	*frigidus*	
58.388	134.38	780	Seventeen A	Compositae	*Petasites*	*hyperboreus*	
58.388	134.38	780	Seventeen A	Cyperaceae	*Carex*	*macrochaeta*	
58.388	134.38	780	Seventeen A	Ericaceae	*Cassiope*	*mertensiana*	
58.388	134.38	780	Seventeen A	Ericaceae	*Loiseleuria*	*procumbens*	
58.388	134.38	780	Seventeen A	Geraniaceae	*Geranium*	*erianthum*	
58.388	134.38	780	Seventeen A	Gramineae	*Deschampsia*	*caespitosa*	*caespitosa* var. *caespitosa*
58.388	134.38	780	Seventeen A	Gramineae	*Trisetum*	*spicatum*	*alaskanum*
58.388	134.38	780	Seventeen A	Juncaceae	*Juncus*	*biglumis*	*albescens*
58.388	134.38	780	Seventeen A	Juncaceae	*Juncus*	*falcatus*	*sitchensis*
58.388	134.38	780	Seventeen A	Juncaceae	*Juncus*	*mertensianus*	
58.388	134.38	780	Seventeen A	Leguminosae	*Lupinus*	*nootkatensis*	
58.388	134.38	780	Seventeen A	Lycopodiaceae	*Lycopodium*	*selago*	*appressum*
58.388	134.38	780	Seventeen A	Onagraceae	*Epilobium*	sp.	
58.388	134.38	780	Seventeen A	Orchidaceae	*Platanthera*	*saccata*	
58.388	134.38	780	Seventeen A	Pinaceae	*Tsuga*	*heterophylla*	
58.388	134.38	780	Seventeen A	Pyroleaceae	*Pyrola*	sp.	
58.388	134.38	780	Seventeen A	Ranunculaceae	*Anemone*	sp.	
58.388	134.38	780	Seventeen A	Ranunculaceae	*Coptis*	*trifolia*	
58.388	134.38	780	Seventeen A	Ranunculceae	*Caltha*	*palustris*	*asarifolia*
58.388	134.38	780	Seventeen A	Rosaceae	*Geum*	*calthifolium*	
58.388	134.38	780	Seventeen A	Rosaceae	*Luetkea*	*pectinata*	
58.388	134.38	780	Seventeen A	Rosaceae	*Sorbus*	*sitchensis*	
58.388	134.38	780	Seventeen A	Saxifragaceae	*Saxifraga*	*davurica*	
Site Pictures							
Carex macrochaeta, Epilobium latifolium					*Petasites frigidus*		
Carex macrochaeta					View to Thomas and Lemon Creek Glaciers		
Luetkea pectinata							
Y Latitu	**X Long**	**Eleva**	**Location**	**Family**	**Genus**	**Species**	**Sub. Species**
58.653	134.19	1371	Ten	Caprifoliaceae	*Sambucus*	*racemosa*	*pubens*
58.653	134.19	1768	Ten	Caprifoliaceae	*Sambucus*	*racemosa*	*pubens* var. *arborescens*
58.653	134.19	1768	Ten Taku B	Caryophyllaceae	*Silene*	*acaulis*	
58.653	134.19	1768	Ten Taku B	Caryophyllaceae	*Silene*	*acaulis*	*acaulis*
58.653	134.19	1768	Ten	Compositae	*Anaphalis*	*margaritacea*	
58.653	134.19	1463	Ten	Compositae	*Antennaria*	*media*	
58.653	134.19	1768	Ten Taku B	Cruciferae	*Cardamine*	*bellidifolia*	
58.653	134.19	1168	Ten	Cryptogrammaceae	*Cryptogramma*	*crispa*	var. *acrostichoides*
58.653	134.19	1371	Ten	Cryptogrammaceae	*Cryptogramma*	*crispa*	*sitchensis*
58.653	134.19	1768	Ten Taku B	Cryptogrammaceae	*Cryptogramma*	*crispa*	
58.653	134.19	1168	Ten	Cyperaceae	*Carex*	*circinnata*	
58.653	134.19	1768	Ten Taku B	Cyperaceae	*Carex*	*laeviculmis*	
58.653	134.19	1168	Ten	Cyperaceae	*Carex*	*nardina*	
58.653	134.19	1168	Ten	Cyperaceae	*Carex*	*praticola*	
58.653	134.19	1168	Ten	Cyperaceae	*Carex*	*pyrenaica*	*micropoda*
58.653	134.19	1768	Ten Taku B	Empetraceae	*Empetrum*	*nigrum*	*nigrum*
58.653	134.19	1768	Ten	Empetraceae	*Empetrum*	*nigrum*	
58.653	134.19	1168	Ten	Empetraceae	*Empetrum*	*nigrum*	*hemaphroditum*
58.653	134.19	1168	Ten	Ericaceae	*Cassiope*	sp.	
58.653	134.19	1168	Ten	Ericaceae	*Cassiope*	*stelleriana*	
58.653	134.19	1168	Ten	Ericaceae	*Cassiope*	*mertensiana*	
58.653	134.19	1168	Ten	Ericaceae	*Cassiope*	*tetragona*	*tetragona*
58.653	134.19	1768	Ten	Ericaceae	*Loiseleuria*	*procumbens*	
58.653	134.19	1768	Ten	Ericaceae	*Phyllodoce*	*aleuctica*	*glanduliflora*
58.653	134.19	1168	Ten	Ericaceae	*Vaccinium*	*parvifolium*	
58.653	134.19	1168	Ten	Ericaceae	*Vaccinium*	*uliginosum*	*microphyllum*
58.653	134.19	1168	Ten	Ericaceae	*Vaccinium*	*ovalifolium*	
58.653	134.19	1168	Ten	Ericaceae	*Vaccinium*	*uliginosum*	*alpinum* var. *salicinum* (l.s.)

58.653	134.19	1168	Ten	Ericaceae	*Vaccinium*	*uliginosum*	*alpinum*
58.653	134.19	1168	Ten	Ericaceae	*Vaccinium*	*uliginosum*	*microphyllum*
58.653	134.19	1050	Ten	Ericaceae	*Vaccinium*	*uliginosum*	
58.653	134.19	1168	Ten Vantage Peak	Gramineae	*Agrostis*	*borealis*	
58.653	134.19	1768	Ten Taku B	Gramineae	*Poa*	*brachyanthera*	
58.653	134.19	1524	Ten Taku B	Gramineae	*Poa*	*leptocoma*	
58.653	134.19	1168	Ten	Gramineae	*Poa*	*trisetum*	*spicatum*
58.653	134.19	1768	Ten Taku B	Gramineae	*Poa*	*glauca*	
58.653	134.19	1463	Ten	Gramineae	*Trisetum*	*spicatum*	
58.653	134.19	1768	Ten Taku B	Gramineae	*Trisetum*	*spicatum*	*molle*
58.653	134.19	1768	Ten Taku B	Gramineae	*Trisetum*	*spicatum*	*spicatum*
58.653	134.19	1768	Ten	Juncaceae	*Juncus*	*biglumis*	
58.653	134.19	1168	Ten	Juncaceae	*Juncus*	*drummondii*	
58.653	134.19	1168	Ten	Juncaceae	*Juncus*	*ensifolius*	
58.653	134.19	1168	Ten	Juncaceae	*Juncus*	*falcatus*	*sitchensis*
58.653	134.19	1768	Ten Taku B	Juncaceae	*Juncus*	*triglumis*	*albescens*
58.653	134.19	1168	Ten	Juncaceae	*Luzula*	*arcuata*	*unalaschcensis*
58.653	134.19	1168	Ten	Juncaceae	*Luzula*	*multiflora*	*multiflora*
58.653	134.19	1768	Ten Taku B	Juncaceae	*Luzula*	*parviflora*	*parviflora*
58.653	134.19	1768	Ten Taku B	Juncaceae	*Luzula*	*rufescens*	
58.653	134.19	1168	Ten	Juncaceae	*Luzula*	*wahlenbergii*	*piperi*
58.653	134.19	1768	Ten Taku B	Juncaceae	*Luzula*	*parviflora*	*parviflora*
58.653	134.19	1768	Ten	Leguminosae	*Lupinus*	*nootkatensis*	
58.653	134.19	1768	Ten Taku B	Lycopodiaceae	*Lycopodium*	*alpinum*	
58.653	134.19	1168	Ten	Lycopodiaceae	*Lycopodium*	*clavatum*	
58.653	134.19	1371	Ten	Lycopodiaceae	*Lycopodium*	*sabinaefolium*	*sitchense*
58.653	134.19	1768	Ten Taku B	Onagraceae	*Epilobium*	*anagallidifolium*	
58.653	134.19	1768	Ten Taku B	Onagraceae	*Epilobium*	*angustifolium*	*angustifolium*
58.653	134.19	1768	Ten Taku B	Onagraceae	*Epilobium*	*angustifolium*	
58.653	134.19	1168	Ten	Onagraceae	*Epilobium*	*davuricum*	
58.653	134.19	1168	Ten	Onagraceae	*Epilobium*	*hornemannii*	
58.653	134.19	1768	Ten	Onagraceae	*Epilobium*	*latifolium*	
58.653	134.19	1768	Ten Taku B	Pinaceae	*Picea*	*sitchensis*	
58.653	134.19	1768	Ten Taku B	Polemoniaceae	*Polemonium*	*pulcherrimum*	
58.653	134.19	1768	Ten Taku B	Polygonaceae	*Oxyria*	*digyna*	
58.653	134.19	1168	Ten	Rosaceae	*Luetkea*	*pectinata*	
58.653	134.19	1768	Ten	Rosaceae	*Sibbaldia*	*procumbens*	
58.653	134.19	1768	Ten Taku B	Salicaceae	*Salix*	*rotundifolia*	
58.653	134.19	1768	Ten Taku B	Saxifragaceae	*Saxifraga*	*bronchialis*	*funstonii*
58.653	134.19	1768	Ten	Saxifragaceae	*Saxifraga*	*ferruginea*	
58.653	134.19	1168	Ten	Saxifragaceae	*Saxifraga*	*flagellaris*	*setigera*
58.653	134.19	1768	Ten	Saxifragaceae	*Saxifraga*	*lyallii*	
58.653	134.19	1371	Ten	Saxifragaceae	*Saxifraga*	*mertensiana*	
58.653	134.19	1768	Ten Taku B	Saxifragaceae	*Saxifraga*	*punctata*	

Site Pictures

Taku Towers	*Epilobium latifolium*
Cassiope mertensiana with infestation	*Luzula Wahlenbergii*
Cryptogramma crispa	

Y Latit	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
58.663	134.36	1408	TNW	Campanulaceae	*Campanula*	*lasiocarpa*	*lasiocarpa*
58.663	134.36	1408	TNW	Compositae	*Antennaria*	*friesiana*	*compacta*
58.663	134.36	1408	TNW	Compositae	*Artemisia*	*arctica*	*arctica*
58.663	134.36	1408	TNW	Cruciferae	*Cardamine*	*bellidifolia*	
58.663	134.36	1408	TNW	Cryptogrammaceae	*Cryptogramma*	*crispa*	var. *acrostichoides*
58.663	134.36	1408	TNW	Cryptogrammaceae	*Cryptogramma*	*crispa*	*sitchensis*
58.663	134.36	1408	TNW	Cyperaceae	*Carex*	*circinnata*	
58.663	134.36	1408	TNW	Cyperaceae	*Carex*	*nardina*	
58.663	134.36	1408	TNW	Cyperaceae	*Carex*	*praticola*	
58.663	134.36	1408	TNW	Cyperaceae	*Carex*	*macrochaeta*	
58.663	134.36	1408	TNW	Cyperaceae	*Carex*	*pyrenaica*	*micropoda*
58.663	134.36	1408	TNW	Cyperaceae	*Carex*	sp.	
58.663	134.36	1408	TNW	Empetraceae	*Empetrum*	*nigrum*	
58.663	134.36	1408	TNW	Empetraceae	*Empetrum*	*nigrum*	*hermaphroditum*
58.663	134.36	1408	TNW	Empetraceae	*Empetrum*	*nigrum*	*nigrum*
58.663	134.36	1408	TNW	Ericaceae	*Arctostaphylos*	*rubra*	
58.663	134.36	1408	TNW	Ericaceae	*Cassiope*	*mertensiana*	
58.663	134.36	1408	TNW	Ericaceae	*Cassiope*	*stelleriana*	
58.663	134.36	1408	TNW	Ericaceae	*Cassiope*	*stelleriana*	*tetragona*
58.663	134.36	1408	TNW	Ericaceae	*Phyllodoce*	*aleutica*	*glanduliflora*
58.663	134.36	1408	TNW	Ericaceae	*Vaccinium*	*ovalifolium*	
58.663	134.36	1408	TNW	Ericaceae	*Vaccinium*	*uliginosum*	*microphyllum*
58.663	134.36	1408	TNW	Ericaceae	*Vaccinium*	*uliginosum*	*alpinum*
58.663	134.36	1408	TNW	Gramineae	*Hierochloë*	*alpina*	
58.663	134.36	1408	TNW	Gramineae	*Poa*	*brachyanthera*	

58.663	134.36	1408	TNW	Gramineae	*Poa*	*pseudobreviata*	
58.663	134.36	1408	TNW	Gramineae	*Trisetum*	*spicatum*	*molle*
58.663	134.36	1408	TNW	Juncaceae	*Luzula*	*arcuata*	*unalaschcensis*
58.663	134.36	1408	TNW	Juncaceae	*Luzula*	*arcuata*	
58.663	134.36	1408	TNW	Juncaceae	*Luzula*	*parviflora*	*parviflora*
58.663	134.36	1408	TNW	Lycopodiaceae	*Lycopodium*	*selago*	*appressum*
58.663	134.36	1408	TNW	Lycopodiaceae	*Lycopodium*	*selago*	*selago*
58.663	134.36	1408	TNW	Onagraceae	*Epilobium*	*latifolium*	
58.663	134.36	1408	TNW	Rosaceae	*Potentilla*	*villosa*	
58.663	134.36	1408	TNW	Salicaceae	*Salix*	*reticulata*	
58.663	134.36	1408	TNW	Saxifragaceae	*Saxifraga*	*bronchialis*	*funstonii*
58.663	134.36	1408	TNW	Saxifragaceae	*Saxifraga*	*ferruginea*	
Site Pictures							
Lycopodium selago					*Saxifraga ferruginea*		
Taku NW Point					Taku NW Point (II)		
Y Latitu	**X Long**	**Eleva**	**Location**	**Family**	**Genus**	**Species**	**Sub. Species**
58.834	134.28	1670	Eighteen	Campanulaceae	*Campanula*	*lasiocarpa*	*lasiocarpa*
58.834	134.28	1660	Eighteen	Caryophyllaceae	*Silene*	*acaulis*	*acaulis*
58.834	134.28	1670	Eighteen	Compositae	*Antennaria*	*friesiana*	*alaskana*
58.834	134.28	1433	Eighteen	Compositae	*Antennaria*	*media*	
58.834	134.28	1670	Eighteen	Compositae	*Antennaria*	*monocephala*	*monocephala* var. *monocephala*
58.834	134.28	1660	Eighteen	Compositae	*Antennaria*	*monocephala*	
58.834	134.28	1670	Eighteen	Compositae	*Antennaria*	n.d.	
58.834	134.28	1660	Eighteen	Compositae	*Artemisia*	*arctica*	*arctica*
58.834	134.28	1670	Eighteen	Crauleaceae	*Sedum*	*rosea*	*integrifolium*
58.834	134.28	1660	Eighteen	Cruciferae	*Cardamine*	*bellidifolia*	
58.834	134.28	1660	Eighteen	Cyperaceae	*Carex*	*circinnata*	
58.834	134.28	1670	Eighteen	Cyperaceae	*Carex*	n.d.	
58.834	134.28	1670	Eighteen	Cyperaceae	*Carex*	*lachenalii*	
58.834	134.28	1670	Eighteen	Cyperaceae	sp.		
58.834	134.28	1670	Eighteen	Ericaceae	*Cassiope*	*stelleriana*	
58.834	134.28	1433	Eighteen	Ericaceae	*Vaccinium*	*uliginosum*	*alpinum*
58.834	134.28	1660	Eighteen	Gramineae	*Deschampsia*	*danthonioides*	
58.834	134.28	1670	Eighteen	Gramineae	*Poa*	*glauca*	
58.834	134.28	1670	Eighteen	Gramineae	*Poa*	*paucispicula*	
58.834	134.28	1660	Eighteen	Gramineae	*Poa*	*pratensis*	
58.834	134.28	1660	Eighteen	Gramineae	*Trisetum*	*spicatum*	*spicatum*
58.834	134.28	1670	Eighteen	Gramineae	*Trisetum*	*spicatum*	*alaskanum*
58.834	134.28	1670	Eighteen	Gramineae	*Vulpia*	*megalura*	
58.834	134.28	1670	Eighteen	Juncaceae	*Luzula*	*arcuata*	*unalaschcensis*
58.834	134.28	1660	Eighteen	Juncaceae	*Luzula*	*spicata*	
58.834	134.28	1660	Eighteen	Juncaceae	*Luzula*	*wahlenbergii*	*piperi*
58.834	134.28	1670	Eighteen	Lycopodiaceae	*Lycopodium*	*selago*	*selago*
58.834	134.28	1670	Eighteen	Rosaceae	*Fragaria*	*virginiana*	
58.834	134.28	1670	Eighteen	Rosaceae	*Luetkea*	*pectinata*	
58.834	134.28	1660	Eighteen	Rosaceae	*Potentilla*	*hyparctica*	
58.834	134.28	1660	Eighteen	Rosaceae	*Potentilla*	*villosa*	
58.834	134.28	1670	Eighteen	Rosaceae	*Sibbaldia*	*procumbens*	
58.834	134.28	1670	Eighteen	Salicaceae	*Salix*	n.d.	
58.834	134.28	1670	Eighteen	Salicaceae	*Salix*	*reticulata*	
58.834	134.28	1670	Eighteen	Saxifragaceae	*Saxifraga*	*bronchialis*	
58.834	134.28	1670	Eighteen	Saxifragaceae	*Saxifraga*	*bronchialis*	*funstonii*
58.834	134.28	1660	Eighteen	Saxifragaceae	*Saxifraga*	*ferruginea*	
58.834	134.28	1670	Eighteen	Saxifragaceae	*Saxifraga*	*mertensiana*	
58.834	134.28	1660	Eighteen	Saxifragaceae	*Saxifraga*	*rivularis*	*flexuosa*
58.834	134.28	1433	Eighteen	Saxifragaceae	*Saxifraga*	sp.	
Site Pictures							
Cassiope stelleriana, Sibbaldia procubens					Vaughan Lewis Icefall glacial tank		
Campanula lasiocarpa					GilkeyTrench		
Glacial Groove					Vaughan Lewis Icefall		
Y Latitu	**X Long**	**Eleva**	**Location**	**Family**	**Genus**	**Species**	**Sub. Species**
58.536	134.7	152	Herbert Gl	Betulaceae	*Alnus*	*crispa*	*sinuata*
58.536	134.7	152	Herbert Gl	Caprifoliaceae	*Sambucus*	*racemosa*	*pubens* var. *arborescens*
58.536	134.7	152	Herbert Gl	Compositae	*Achillea*	*borealis*	
58.536	134.7	152	Herbert Gl	Cruciferae	*Arabis*	*hirsuta*	*eschscoltziana*
58.536	134.7	152	Herbert Gl	Cryptogrammaceae	*Cryptogramma*	*crispa*	*acrostichoides*
58.536	134.7	152	Herbert Gl	Equisetaceae	*Equisetum*	*arvense*	
58.536	134.7	152	Herbert Gl	Equisetaceae	*Equisetum*	sp.	
58.536	134.7	152	Herbert Gl	Equisetaceae	*Equisetum*	*variegatum*	
58.536	134.7	152	Herbert Gl	Leguminosae	*Lupinus*	*nootkatensis*	
58.536	134.7	152	Herbert Gl	Liliaceae	*Streptopus*	*amplexifolius*	*americanus*
58.536	134.7	152	Herbert Gl	Onagraceae	*Epilobium*	*latifolium*	
58.536	134.7	152	Herbert Gl	Orobanchaceae	*Boschniakia*	*rossica*	
58.536	134.7	152	Herbert Gl	Pyrolaceae	*Pyrola*	*grandiflora*	
58.536	134.7	152	Herbert Gl	Rosaceae	*Aruncus*	*sylvester*	
58.536	134.7	152	Herbert Gl	Rosaceae	*Geum*	*macrophyllum*	*macrophyllum*
58.536	134.7	152	Herbert Gl	Salicaceae	*Populus*	*balsamifera*	
Site Pictures							
Herbert Glacier Terminus							

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
58.37	134.38	1000	Ptarmigan Ridge	Compositae	*Antennaria*	*pulcherrima*	
58.37	134.38	1000	Ptarmigan Ridge	Cornaceae	*Cornus*	*canadensis*	
58.37	134.38	1000	Ptarmigan Ridge	Crassulaceae	*Sedum*	*rosea*	*integrifolium*
58.37	134.38	1364	Ptarmigan Ridge	Empetraceae	*Empetrum*	*nigrum*	
58.37	134.38	1000	Ptarmigan Ridge	Ericaceae	*Cassiope*	*mertensiana*	
58.37	134.38	1364	Ptarmigan Ridge	Ericaceae	*Loiseleuria*	*procumbens*	
58.37	134.38	1000	Ptarmigan Ridge	Ericaceae	*Menziesia*	*ferruginea*	
58.37	134.38	1000	Ptarmigan Ridge	Ericaceae	*Oxycoccus*	*palustris*	
58.37	134.38	1000	Ptarmigan Ridge	Ericaceae	*Vaccinium*	*uliginosum*	*alpinum*
58.37	134.38	1286	Ptarmigan Ridge	Ericaceae	*Vaccinium*	*uliginosum*	
58.37	134.38	1364	Ptarmigan Ridge	Juncaceae	*Luzula*	*parviflora*	*parviflora var. menanocarpa*
58.37	134.38	1286	Ptarmigan Ridge	Lycopodiaceae	*Lycopodium*	*clavatum*	
58.37	134.38	1286	Ptarmigan Ridge	Lycopodiaceae	*Lycopodium*	*selago*	
58.37	134.38	1000	Ptarmigan Ridge	Pinaceae	*Tsuga*	*heterophylla*	
58.37	134.38	1286	Ptarmigan Ridge	Rosaceae	*Potentilla*	*hyparctica*	
58.37	134.38	1000	Ptarmigan Ridge	Rosaceae	*Potentilla*	*villosa*	
58.37	134.38	1364	Ptarmigan Ridge	Salicaceae	*Salix*	*stolonifera*	
58.37	134.38	1364	Ptarmigan Ridge	Saxifragaceae	*Saxifraga*	*ferruginea*	
58.37	134.38	1000	Ptarmigan Ridge	Scrophulariaceae	*Castilleja*	*unalaschcensis*	

Site Pictures

Horneblendites and cross faults

Ptarmingan Ridge

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
58.623	134.17	1067	SP	Compositae	*Artemisia*	*arctica*	*arctica*
58.623	134.17	1067	SP	Cryptogrammaceae	*Cryptogramma*	*crispa*	*acrostichoides*
58.623	134.17	1067	SP	Cryptogrammaceae	*Cryptogramma*	*crispa*	*sitchensis*
58.623	134.17	1067	SP	Cyperaceae	*Carex*	*circinnata*	
58.623	134.17	1067	SP	Cyperaceae	*Carex*	*macrochaeta*	
58.623	134.17	1067	SP	Cyperaceae	*Carex*	*nigricans*	
58.623	134.17	1067	SP	Empetraceae	*Empetrum*	*nigrum*	*hermaphroditum*
58.623	134.17	1067	SP	Empetraceae	*Empetrum*	*nigrum*	
58.623	134.17	1067	SP	Ericaceae	*Cassiope*	*stelleriana*	
58.623	134.17	1067	SP	Ericaceae	*Cassiope*	*mertensiana*	
58.623	134.17	1067	SP	Ericaceae	*Loiseleuria*	*procumbens*	
58.623	134.17	1067	SP	Ericaceae	*Phyllodoce*	*aleutica*	*glanduliflora*
58.623	134.17	1067	SP	Ericaceae	*Vaccinium*	*uliginosum*	*microphyllum*
58.623	134.17	1067	SP	Ericaceae	*Vaccinium*	*uliginosum*	*alpinum*
58.623	134.17	1067	SP	Ericaceae	*Vaccinium*	*caespitosum*	
58.623	134.17	1067	SP	Ericaceae	*Vaccinium*	*membraceum*	
58.623	134.17	1067	SP	Ericaceae	*Vaccinium*	*uliginosum*	
58.623	134.17	1050	SP	Gramineae	*Agrostis*	*borealis*	
58.623	134.17	1067	SP	Gramineae	*Deschampsia*	*danthonioides*	
58.623	134.17	1050	SP	Gramineae	*Deschampsia*	*elongata*	
58.623	134.17	1067	SP	Gramineae	*Hierochloë*	*alpina*	
58.623	134.17	1067	SP	Gramineae	*Trisetum*	*spicatum*	
58.623	134.17	1067	SP	Gramineae	*Vahlodea*	*atropurpurea*	*latifolia*
58.623	134.17	1067	SP	Juncaceae	*Juncus*	*biglumis*	
58.623	134.17	1067	SP	Juncaceae	*Juncus*	*drummondii*	
58.623	134.17	1067	SP	Juncaceae	*Juncus*	*ensifolius*	
58.623	134.17	1067	SP	Juncaceae	*Juncus*	*falcatus*	*sitchensis*
58.623	134.17	1067	SP	Juncaceae	*Luzula*	*arcuata*	*unalaschcensis*
58.623	134.17	1067	SP	Juncaceae	*Luzula*	*parviflora*	*parviflora var. melanocarpa*
58.623	134.17	1067	SP	Juncaceae	*Luzula*	*tundricola*	
58.623	134.17	1067	SP	Juncaceae	*Luzula*	*wahlenbergii*	*piperi*
58.623	134.17	1067	SP	Leguminosae	*Lupinus*	*nootkatensis*	
58.623	134.17	1067	SP	Lycopodiaceae	*Lycopodium*	*alpinum*	
58.623	134.17	1050	SP	Lycopodiaceae	*Lycopodium*	*clavatum*	
58.623	134.17	1050	SP	Lycopodiaceae	*Lycopodium*	*inundatum*	
58.623	134.17	1067	SP	Polemoniaceae	*Polemonium*	*pulcherrimum*	
58.623	134.17	1067	SP	Primulaceae	*Trientalis*	*europaea*	*arctica*
58.623	134.17	1067	SP	Rosaceae	*Luetkea*	*pectinata*	
58.623	134.17	1067	SP	Salicaceae	*Salix*	*fuscescens*	
58.623	134.17	1067	SP	Salicaceae	*Salix*	*reticulata*	
58.623	134.17	1050	SP	Saxifragaceae	*Heuchera*	*glabra*	

Site Pictures

Lupinus nootkatensis, Vaccinium uliginosum	*Vaccinium uliginosum*	*Lupinus nootkatensis (V)*
Cassiope tetragona, Cassiope mertensiana	*Lupinus nootkatensis (III)*	Above Taku Glacier
Lupinus nootkatensis	*Lupinus nootkatensis (IV)*	*Carex nigricans*
Vaccinium caespitosum	*Vaccinium caespitosum (II)*	
Lupinus nootkatensis (II)	*Vaccinium membraceum*	
Loiseleuria procumbens	*Juncus drummondii*	

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
58.437	134.32	1431	Thirteen	Compositae	*Antennaria*	*rosea*	
58.437	134.32	1463	Thirteen	Compositae	*Artemisia*	*arctica*	*arctica*
58.437	134.32	1463	Thirteen	Cryptogrammaceae	*Cryptogramma*	*crispa*	var. *sitchensis*
58.437	134.32	1309	Thirteen	Cyperaceae	*Carex*	*circinnata*	
58.437	134.32	1463	Thirteen	Cyperaceae	*Carex*	*pyrenaica*	*micropoda*
58.437	134.32	1463	Thirteen	Ericaceae	*Phyllodoce*	*empetriformis*	
58.437	134.32	1463	Thirteen	Gramineae	*Poa*	*stenantha*	
58.437	134.32	1431	Thirteen	Gramineae	*Trisetum*	*spicatum*	*spicatum*
58.437	134.32	1463	Thirteen	Juncaceae	*Juncus*	*drummondii*	
58.437	134.32	1463	Thirteen	Juncaceae	*Luzula*	*arcuata*	*unalaschcensis*
58.437	134.32	1463	Thirteen	Saxifragaceae	*Saxifraga*	*bronchialis*	*cherlerioides*
58.437	134.32	1463	Thirteen	Saxifragaceae	*Saxifraga*	*bronchialis*	*funstonii*
58.437	134.32	1463	Thirteen	Saxifragaceae	*Saxifraga*	*oppositifolia*	*smalliana*

Site Pictures

Nugget Ridge marble intercalated granodiorites

Thirteen

Y Latitu	X Long	Eleva	Location	Family	Genus	Species	Sub. Species
59.349	134.08	1618	Twenty-Nine	Caryophyllaceae	*Cerastium*	*beeringianum*	var. *beeringianum*
59.349	134.08	1618	Twenty-Nine	Compositae	*Erigeron*	*humilis*	
59.349	134.08	1618	Twenty-Nine	Compositae	*Erigeron*	*purpuratus*	
59.349	134.08	1618	Twenty-Nine	Gramineae	*Agrostis*	*stolonifera*	
59.349	134.08	1618	Twenty-Nine	Gramineae	*Poa*	*alpigena*	
59.349	134.08	1618	Twenty-Nine	Gramineae	*Poa*	*glauca*	
59.349	134.08	1618	Twenty-Nine	Gramineae	*Trisetum*	*spicatum*	*alaskanum*
59.349	134.08	1618	Twenty-Nine	Gramineae	*Trisetum*	*spicatum*	*spicatum*
59.349	134.08	1618	Twenty-Nine	Onagraceae	*Epilobium*	sp.	
59.349	134.08	1618	Twenty-Nine	Polygonaceae	*Oxyria*	*digyna*	
59.349	134.08	1618	Twenty-Nine	Rosaceae	*Sibbaldia*	*procumbens*	
59.349	134.08	1618	Twenty-Nine	Salicaceae	*Salix*	sp.	
59.349	134.08	1618	Twenty-Nine	Salicaceae	*Salix*	*reticulata*	
59.349	134.08	1618	Twenty-Nine	Saxifragaceae	*Saxifraga*	*bronchialis*	*funstonii*
59.349	134.08	1618	Twenty-Nine	Saxifragaceae	*Saxifraga*	*oppositifolia*	

Site Pictures

Cathedral Massif	*Oxyria digynia*
Cathedral Glacier	*Oxyria digynia (II)*
Salix sp.	