University of Alberta

A Habitat-based Approach to Rare Vascular Plant Conservation in the Northern Rocky Mountains of Alberta

by

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Abstract

The overall objective of this study was to examine patterns of distribution of rare vascular plant species of the northern Rocky Mountains of Alberta in relation to vegetation type and other rare species. Classification of vegetation was a necessary first step to build a framework upon which to test the fidelity of rare plants to vegetation type. Eight treed, 8 shrub and 45 herbaceous types were recognized. There was limited concordance between previously identified types and those of this study due in part to the area surveyed and differences in methodologies for data collection and analysis. Elevation was the main factor influencing the distribution of vegetation but the soil nutrients P and K were also important associates of vegetation type for treed sites and Ca, N and P for herbaceous types. Soil moisture and aspect were determined to be important for some herbaceous community types in the alpine. Seventy-four rare plants were identified, 19 of which had a strong association to habitat. Few plants were restricted to one vegetation type; however, some types had a high probability of capturing one or more rare species. Twenty-nine rare species were represented five or more times in the dataset and of these only one did not show a significant association with another rare species. Examination of the distribution of these species in relation to measured environmental parameters showed that co-occurring species have similar responses. There was only one pair of co-occurring rare species that had high fidelity to the same vegetation type. In summary, conservation plans that focus on vegetation type and/or suites of species may be appropriate for some taxa but single species approaches will still be required for the rarest of the rare and those for which there is no demonstrated association with other taxa or vegetation type.

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Chapter 1: General introduction and overview of thesis

Few species are common (Kunin and Gaston 1993; Bevill and Louda 1999; Magurran 1988) and emphasis on the conservation of biodiversity means that a great deal of attention is focused on the conservation of rare taxa. However, there is no consensus on how to define rarity or what causes it.

Definitions of rarity

Interest in rare species has been evident since at least the time of Darwin (Darwin 1859; Griggs 1940; Preston 1948; Drury 1974; Harper 1981; Gaston 1994; Kunin and Gaston 1997), with much attention put to understanding the role of rare taxa in relation to community structure and function (McNaughton 1978; Pimm 1984; Tilman and Downing 1994; Grime 1997; Hooper and Vitosek 1997; Mayfield et al. 2005; Tilman et al. 2006) and in the conservation of biological diversity (Harris 2002; Lozano and Schwartz 2005). In spite of this interest, we still lack of a general theory of rarity (Fiedler and Ahouse 1992; Gaston 1994) and a concise definition still defies description (Gaston 1994). Most definitions include reference to range and abundance with a rare species being one with low abundance and/or small range (Gaston 1994).

Understanding why some species are rare while others are not has been a frequent focus of rare species research. Studies have examined the potential causes of rarity, such as species traits as compared to closely related common taxa (Rabinowitz and Rapp 1981; Rabinowitz and Rapp 1985; Hodgson 1986; Buchele et al. 1991 a and b; Lahti et al. 1991; Gustafsson 1994; Kelly and Woodward 1996; Kunin and Shmida 1997; Hegde and

Ellstrand 1999; Walck et al. 2001; Cadotte and Lovett-Doust 2002), population demography (Pavlik and Manning 1993; Eisto et al. 2000), population genetics (Stebbins 1942; Medail et al. 2002), herbivory (Bruelheide and Scheidel 1999), competitive ability (Griggs 1940; Kruckeberg 1951; Rabinowitz et al.1984), habitat requirements (Hodgson 1986), range size (Kelly and Woodward 1996), taxon size (Schwartz and Simberloff 2001) and taxon age (Willis 1922; Fernald 1918; 1929; 1943; Schwartz 1993). No one parameter can be used to explain why species are rare and it is generally believed that rarity is not the result of one factor but rather is a multifactoral phenomenon (Fiedler 1986; Fiedler and Ahouse 1992; Schemske et al. 1994; Kunin 1998) operating at a range of spatial scales (Schemske et al. 1994).

Attempts to characterize rare species by categorizing them according to various attributes include those of Drury (1980), Rabinowitz (1981) and Fiedler and Ahouse (1992). Drury (1980) recognized three types of rare species: 1. species of restricted distribution but with large numbers in areas where they are found, 2. species of wide distribution but with small numbers, and 3. species occurring at a few sites in small numbers or with a restricted geographic range. Rabinowitz (1981) further refined this model by adding habitat specificity and her scheme includes seven types of rarity based on differences in specificity to habitat (wide vs. narrow), local abundance (small vs. large) and geographic range (wide vs. narrow). Fiedler and Ahouse (1992) added taxon persistence (short-long) as an important attribute for characterizing rarity; however, information on taxon age is rarely available, hence this model is of limited applicability.

Rarity is scale dependant (Gaston 1994; Sætersdal 1994) and can be defined based on political boundaries, with some species being rare in one jurisdiction but not others. Such taxa are often at the edge of their range in the region where they are rare, and are generally of low priority for conservation attention (Hunter and Hutchinson 1994; Channell and Lomolino 2000). However, research has shown that many of these 'edge of range' populations have genetic (Lesica and Allendorf 1995) and ecological characteristics that distinguish them from populations at the centre of the species' range (Hunter and Hutchinson 1994). The majority of the rare vascular plant species in Alberta are at the edge of their range in the province and, while rare in Alberta, are common elsewhere. These are the "pseudo-rare" species of Rabinowitz (1981) while Schoener (1987) refers to these as species exhibiting diffusive rarity. While Rabinowitz's (1981) scheme is generally applied to globally rare taxa, it has merit for application at the regional scale as well (Sætersdal 1994). Edge of range populations of taxa may have stronger associations to particular habitats than do populations at the centre of their range; thus these edge of range situations may lend themselves to predictive modeling efforts (MacDougall and Loo 2002).

Degree of threat is sometimes incorporated into definitions of rarity (Gaston 1997) although this often confuses rather than clarifies the concept. Degree of threat is best incorporated into a "prioritization" scheme for conservation attention rather than into a definition of rarity itself. This is the approach used by various advisory bodies such as the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) prior to recommending a species for legislative designation. Such priorization schemes are based on criteria developed by the World Conservation Union (IUCN) and include: 1) declining population, 2) geographic range size and fragmentation, decline or fluctuations, 3) small population size and fragmentation, decline or fluctuations, 4) very small population or very restricted distribution and 5) quantitative analysis of risk of extinction (population viability analysis) (IUCN 2001). Note that small population size or restricted distribution, the two criteria that are typically used to define rarity, are incorporated into one of the IUCN criteria. The other criteria relate to risk of extinction.

NatureServe has developed criteria similar to those of IUCN for evaluating extinction risk and such criteria are applied at the global as well as regional (jurisdictional) scale. The assessments result in a listing of taxa (tracking list) that are considered to be rare or declining. The criteria used by NatureServe include abundance, range, threats to population and habitat, and population trends (http://www.natureserve.org/explorer/ranking.htm), although rarely is information available for criteria other than range and number of locations (occurrences). The Alberta Natural Heritage Information Centre (ANHIC) is a member of the NatureServe network and thus has adopted the criteria used for assessment of rarity of Alberta vascular plant species. The resulting list of rare species (tracking list) (Gould 2000) was used in this study to define species that were rare.

Landscape level approaches to the conservation of rare vascular plant species

In Alberta, there are over 400 species of vascular plants that are thought to be rare (Gould 2000) (about 30% of the native flora), and species-specific conservation approaches would result in the need for more assessments than either funding or available personnel would allow (Keddy 1991). Understanding how rare plants are distributed on the landscape and the factors associated with that would facilitate development of predictive models using information available at the landscape scale. Such models could then identify areas that have a high probability of harbouring rare species, thereby targeting sites for detailed on-the-ground surveys and conservation attention.

Most landscape approaches to rare species conservation have focused on the development of predictive models for one species or for richness (Miller 1986; White and Miller 1988; Hill and Keddy 1992; McIntyre and Lavorel 1994; Hiekkinen 1998; Engler et al. 2004); few have taken a multi-species approach (but see Kintsch and Urban 2002, MacDougall and Loo 2002). The objective of such models is to identify potential habitat that can then be searched for the presence or absence of the rare species or, alternatively, to identify areas that should be removed from development plans given a high probability of occurrence of rare taxa. Most of these predictive models focus on physical attributes of the ecosystem or habitat; there are few that incorporate the use of ecological communities to determine how effective these are in predicting rare species (but see Kintsch and Urban 2002). However, this is viewed as one of the most critical tasks facing conservation biologists (Wilcove and Master 2005). An evaluation of the effectiveness of ecological communities in capturing rare species could be useful in identifying "critical habitat" as required under federal endangered species legislation (*Species at Risk Act*) and would further inform recovery plans that must follow designation. Most recovery plans are done for single species, in spite of co-occurrence of other rare taxa. The relationship of rare species to other rares is of conservation interest, especially if two or more rare species have strong fidelity to the same habitat. Such rare species groups might then lend themselves to multi-species conservation plans that focus on habitat. This could greatly reduce the time and resources needed, compared with taking a single-species approach.

Vegetation of the northern Rocky Mountains

There have been several attempts to describe and classify the vegetation of the northern Rocky Mountains of Alberta, with the primary sources being Corns and Achuff (1982), Bork (1994), Beckingham et al. (1996), Willoughby and Alexander (2003) and Willoughby et al. (2005). Each of these, however, focused on different areas. As a result, there was not one classification system for the northern Rocky Mountains of Alberta that could be used as a basis for classification of the vegetation into types or communities.

While there have been a number of studies in the Rocky Mountains of Alberta that have described the vegetation in relation to environmental parameters, few have covered a range of vegetation types across a broader landscape or across a topographic gradient (but see Hettinger 1975). As a result, an understanding of the main drivers of vegetation distribution across this landscape is lacking.

Study area

The northern Rocky Mountain region of Alberta is known as one of two areas of concentration of rare vascular plant species in the province (Ogilvie 1998), the other being the Crowsnest/Waterton area in southern Alberta. My interest in conducting research in the northern Rocky Mountain area was due, in part, to the number of rare vascular plants. Further, there is a concentration of protected landscapes (National and Provincial Parks and protected areas) in this region thus patterns of distribution of rare species likely reflect primarily ecological and historical factors rather than human-induced changes in habitat.

Thesis overview

The objective of this research was to determine whether rare vascular plant species of the northern Rocky Mountains of Alberta were distributed independently across the landscape. This was tested by first examining their fidelity to vegetation type and then looking at co-occurrence among rare vascular plant species. Species with a strong fidelity to habitat may be suitable for modeling probability of occurrence at the landscape scale as well as for the application of habitat approaches to conservation. Species with a strong association with another rare species may lend themselves to multi-species conservation approaches and if these same taxa have a strong fidelity to the same habitat, a multi-species approach that focuses on habitat may be warranted.

Given the lack of an appropriate vegetation classification scheme for the study area, and the need for such a scheme as a basis for assessing habitat fidelity, my first undertaking was to develop a classification scheme for this purpose. Chapter 2 presents this classification and description of the vegetation types of the study area as determined by cluster analysis and ordination.

The fidelity of rare vascular plant species to vegetation types was explored in Chapter 3. The distribution of rare species in relation to vegetation types and environmental gradients was also assessed.

The results of my examination of the co-occurrence of rare vascular plant species with one another is presented in Chapter 4. When rare species were found to co-occur I examined the fidelity to habitat for each of them (from Chapter 3) in order to determine whether the two co-occurring species showed fidelity to the same habitat.

In Chapter 5, I present a brief summary of the main contributions of the thesis, along with my general conclusions, and recommendations for conservation planning and future research.

Literature Cited

Beckingham, J., I. G. W. Corns and J. H. Archibald. 1996. Field guide to ecosites of west central Alberta. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. Special Report No. 9.

Bevill, R. L. and S. M. Louda. 1999. Comparisons of related rare and common species in the study of plant rarity. Conservation Biology 13:493-498.

Bork, E. 1994. Ecological Range Classification of Willmore Wilderness Park. Alberta Environmental Protection. 65 pp..

Bruelheide, H. and U. Scheidel. 1999. Slug herbivory as a limiting factor for the geographical range of *Arnica montana*. Journal of Ecology 87:839-848.

Buchele, D. E., J. M. Baskin and C. C. Baskin. 1991a. Ecology of the endangered species *Solidago shortii*. II. Ecological life cycle. Bulletin of the Torrey Botanical Club 118:281-287.

Buchele, D. E., J. M. Baskin and C. C. Baskin. 1991b. Ecology of the endangered species *Solidago shortii*. III. Seed germination ecology. Bulletin of the Torrey Botanical Club 118:288-291.

Cadotte, M. W. and J. Lovett-Doust. 2002. Ecological and taxonomic differences between rare and common plants of southwestern Ontario. Ecoscience 9:397-406.

Channell, R. and M. V. Lomolino. 2000. Dynamic biogeography and conservation of endangered species. Nature 403:84-86.

Corns, I. G. W. and P. L. Achuff. 1982. Ecological (Biophysical) Land Classification of Banff and Jasper National Parks. IN: Volume 2: Soil and Vegetation Resources. (Holland, W. D. and G. M Coen editors). Alberta Institute of Pedology Publication No. SS-82-44. pp. 71-142.

Darwin, C. 1859. The Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life. (J. W. Burrow ed.) Penguin Books, New York. 477 pp.

Drury, W. H. 1974. Rare species. Biological Conservation 6:162-169.

Dufrêne, M. and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetric approach. Ecological Monographs 67:345-366.

Eisto, A.-K., M. Huitunen, A. Lammi, V. Saari, J. Suhonen, S. Syrjasuo and P. M. Tikka. 2000. Population persistence and offspring fitness in the rare bellflower *Campanula cervicaria* in relation to population size and habitat quality. Conservation Biology 14:1413-1421.

Engler, R., A. Guisan and L. Rechsteiner. 2004. An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. Journal of Applied Ecology 41:263-274.

Fernald, M. L. 1918. The geographic affinities of the vascular flora of New England, the Maritime Provinces and Newfoundland. American Journal of Botany 5:219-247.

Fernald, M. L. 1929. Some relationships of the floras of the Northern Hemisphere. Proceedings of the International Congress of Plant Sciences 2:1487-1507.

Fernald, M. L. 1943. *Scirpus longii* in North Carolina. Rhodora 45:55-65.

Fiedler, P. L. 1986. Concepts of rarity in vascular plant species, with special reference to the genus *Calochortus* Pursh (Liliaceae). Taxon 35:502-518.

Fielder, P. L. and J. J. Ahouse. 1992. Hierarchies of cause: toward an understanding of rarity in vascular plant species. IN: Conservation Biology: the Theory and Practice of Nature Conservation, Preservation and Management (eds. P. L. Fiedler and S. K. Jain). Chapman and Hall, London. pp. 23-47.

Gaston, K. J. 1994. Rarity. Chapman and Hall, New York, New York. 205 pp.

Gaston, K. J. 1997. What is rarity? IN: The Biology of Rarity: Causes and Consequences of Rare-Common Differences. Population and Community Biology Series, Chapman and Hall, New York. pp. 30-47.

Gould, J. 2000. Alberta Natural Heritage Information Centre—Tracking and Watch Lists for Vascular Plants, Mosses, Liverworts and Hornworts. Alberta Environmental Protection, Edmonton, Alberta.

Griggs, R. F. 1940. The ecology of rare plants. Bulletin of the Torrey Botanical Club 67:575-594.

Grime, J. P. 1997. Biodiversity and ecosystem function: the debate deepens. Science 277:2360-1261.

Gustafsson, L. 1994. A comparison of biological characteristics and distribution between Swedish threatened and non-threatened forest vascular plants. Ecography 17:39-49.

Harper, J. L. 1981. The meanings of rarity. IN: The Biological Aspects of Rare Plant Conservation. (H. Synge ed.). John Wiley and Sons Ltd. pp. 189-203.

Harris, S. A. 2002. Biodiversity of the vascular timberline flora in the Rocky Mountains of Alberta, Canada. IN: Mountain Biodiversity: a Global Assessment. (ed. C. Körner and E. M. Spehn). Parthenon Publishing, New York. pp. 49-57.

Hegde, S. G. and N. C. Ellstrand. 1999. Life history differences between rare and common flowering plant species of California and the British Isles. International Journal of Plant Science 160:1083-1091.

Hettinger, L. R. 1975. Vegetation of the Vine Creek basin, Jasper National Park. PhD thesis, University of Alberta. 276 pp..

Hiekkinen, R. K. 1998. Can richness patterns of rarities be predicted from mesoscale atlas data? A case study of vascular plants of the Kevo reserve. Biological Conservation 83:133-143.

Hill, N. M. and P. A. Keddy. 1992. Prediction of rarities from habitat variables: coastal plain plants on Nova Scotian lakeshores. Ecology 73:1852-1859.

Hodgson, J. G. 1986. Commonness and rarity in plants with special reference to the Sheffield flora. Part I: the identity, distribution and habitat characteristics of the common and rare species. Biological Conservation 36:199-252.

Hooper, D. U. and P. M. Vitosek. 1997. The effects of plant composition and diversity on ecosystem processes. Science 277:1302-1305.

Hunter, M. L., Jr. and A. Hutchinson. 1994. The virtues and shortcomings of parochialism: conserving species that are locally rare but globally common. Conservation Biology 8:1163-1165.

IUCN. 2001. IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK. ii + 30 pp.

Keddy, P. 1991. Biological monitoring and ecological prediction: from nature reserve management to national state of the environment indicators. IN: Monitoring for conservation and ecology (ed. F. B. Goldsmith). pp. 249-267.

Kelly, C. K. and F. I. Woodward. 1996. Ecological correlates of plant range size: taxonomies and phylogenies in the study of plant commonness and rarity in Great Britain. Philosophical Transactions of the Royal Society of London B 351:1261-1269.

Kintsch, J. A. and D. L. Urban. 2002. Focal species, community representation, and physical proxies as conservation strategies: a case study in the Amphibolite Mountains, North Carolina, U.S.A. Conservation Biology 16(4):936-947.

Kruckeberg, A. R. 1951. Intraspecific variability in the response of certain native plants to serpentine soils. American Journal of Botany 38:408-419.

Kunin, W. E. 1998. Extrapolating species abundance across spatial scales. Science 281:1513-1515.

Kunin, W. E. and K. J. Gaston. 1993. The biology of rarity: patterns, causes and consequences. Trends in Ecology and Evolution 8:298-301.

Kunin, W. E. and K. J. Gaston. 1997. The Biology of Rarity: Causes and Consequences of Rare-Common Differences. Chapman and Hall, New York. 280 pp.

Kunin, W. E. and A. Shmida. 1997. Plant reproductive traits as a function of local, regional and global abundance. Conservation Biology 11:183-192.

Lahti, T., E. Kemppainen, A. Kurtto and P. Uotila. 1991. Distribution and biological characteristics of threatened vascular plant species in Finland. Biological Conservation 55:299-314.

Legendre, P. and M. Anderson. 1999. Distance-based redundancy analysis: testing multispecies response in multifactorial ecological experiments. Ecological Monographs 69(1):1-24.

Lesica, P. and F. W. Allendorf. 1995. When are peripheral populations valuable for conservation? Conservation Biology. 9:753-760.

Lozano, F. D. and M. W. Schwartz. 2005. Patterns of rarity and taxonomic group size in plants. Biological Conservation 126:146-154.

MacDougall, A. S. and J. A. Loo. 2002. Predicting occurrences of geographically restricted rare floral elements with qualitative habitat data. Environmental Review 10:167-190.

Magurran, A. E. 1988. Ecological Diversity and its Measurement. Princeton University Press, Princeton, N. J. 179 pp.

Mayfield, M. M., M. F. Boni, G. C. Daily and D. Ackerly. 2005. Species and functional diversity of native and human-dominated plant communities. Ecology 86:2365-2372.

McIntyre, S. and S. Lavorel. 1994. Predicting richness of native, rare, and exotic plants in response to habitat and disturbance variables across a variegated landscape. Conservation Biology 8:521-531.

McNaughton, S. J. 1978. Stability and diversity of ecological communities. Nature 274:251-253.

Medail, F., S. Ziman, M. Boscaiu, J. Riera, M. Lambrou, E. Vela, B. Dutton, F. Ehrendorfer. 2002. Comparative analysis of biological and ecological differentiation of *Anemone palmata* L. (Ranunculaceae) in the western Mediterranean (France and Spain): an assessment of rarity and population persistence. Botanical Journal of the Linnean Society 140:95-114.

Miller, R. I. 1986. Predicting rare plant distribution patterns in the southern Appalachians of the south-eastern U. S. A. Journal of Biogeography 13(4):293-311.

NatureServe. 2006. NatureServe Conservation Status. http://www.natureserve.org/explorer/ranking.htm (date accessed October 17, 2006).

Ogilvie, R. T. 1998. Vascular plants. IN: Smith, I. M. and G. G. E. Scudder, eds. Assessment of species diversity in the Montane Cordillera Ecozone. Ecological Monitoring and Assessment Network, Burlington, Ontario.

Pavlik, B. and E. Manning. 1993. Assessing limitations on the growth of endangered plant populations, 1. Experimental demography of *Erysimum capitatum* ssp. *angustatum* and *Oenothera deltoides* ssp. *howellii*. Biological Conservation 65:257-265.

Pimm, S. L. 1984. The complexity and stability of ecosystems. Nature 307:321-326.

Preston, F. W. 1948. The commonness, and rarity, of species. Ecology 29:254-283.

Rabinowitz, D. 1981. Seven forms of rarity. IN: The Biological Aspects of Rare Plant Conservation. (Ed. Hugh Synge). John Wiley and Sons Ltd., New York, New York. pp. 205-217.

Rabinowitz, D. and J. K. Rapp. 1981. Dispersal abilities of seven sparse and common grasses from a Missouri prairie. American Journal of Botany 68:616-624.

Rabinowitz, D., J. K. Rapp and P. M. Dixon. 1984. Competitive abilities of sparse grass species: means of persistence or cause of abundance. Ecology 65:1144-1154.

Rabinowitz, D. and J. K. Rapp. 1985. Colonization and establishment of Missouri prairie plants on artificial soil disturbances. III. Species abundance distributions, survivorship and rarity. American Journal of Botany 72:1635-1640.

Sætersdal, M. 1994. Rarity and species/area relationships of vascular plants in deciduous woods, western Norway—applications to nature reserve selection. Ecography 17:23-38.

Schemske, D. W., B. C. Husband, M. H. Ruckleshaus, C. Goodwillie, I. M. Parker and J. G. Bishop. 1994. Evaluating approaches to the conservation of rare and endangered plants. Ecology 75:584-606.

Schoener, T. W. 1987. The geographical distribution of rarity. Oecologia 74:161-173.

Schwartz, M. W. 1993. The search for pattern among rare plants: are primitive species more likely to be rare? Biological Conservation 64:121-127.

Schwartz, M. W. and D. Simberloff. 2001. Taxon size predicts rates of rarity in vascular plants. Ecology Letters 4:464-469.

Stebbins, G. L. 1942. The genetic approach to problems of rare and endemic species. Madrono 6:241-272.

Tilman, D. and J. A. Downing. 1994. Biodiversity and stability in grasslands. Nature 367:363-365.

Tilman, D., P. B. Reich and J. M. H. Knops. 2006.Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature 441:629-632.

Walck, J. L., J. M. Baskin and C. C. Baskin. 2001. Why is *Solidago shortii* narrowly endemic and *S. altissima* geographically widespread? A comprehensive comparative study of biological traits. Journal of Biogeography 28:1221-1237.

White, P. S. and R. I. Miller. 1988. Topographic models of vascular plant richness in the southern Appalachian high peaks. Journal of Ecology 76:192-199.

Wilcove, D. S. and L. L. Master. 2005. How many endangered species are there in the United States? Frontiers in Ecology and the Environment 3 (8): 414-420.

Willis, J. C. 1922. Age and Area. Cambridge University Press, Cambridge.

Willoughby, M. G. and M. J. Alexander. 2003. Range plant community types and carrying capacity for the subalpine and alpine subregions. Second Approximation. Public Lands and Forests Division, Alberta Sustainable Resource Development, Edmonton, Alberta. 200 pp..

Willoughby, M. G., M. J. Alexander and B. W. Adams. 2005. Range plant community types and carrying capacity for the montane subregion. Sixth Approximation. Public Lands and Forests Division, Alberta Sustainable Resource Development, Edmonton, Alberta. 235 pp..

Chapter 2: Classification of Vegetation Types in the Northern Rocky Mountains of Alberta in Relation to Conservation Planning

Introduction

The pace at which changes to the landscape are occurring far exceeds our ability to conduct surveys for rare species. Therefore indicators at the scale of the landscape would be useful to assist with assessing the probability of finding rare vascular plant species within an area. If a plant has a high specificity to a particular habitat, there may be an opportunity to use this to predict where rare species occur. This may be particularly appropriate for species with high habitat specificity; one of three factors important for determining type of rarity in plants (Rabinowitz 1981). Vegetation types and plant communities are two such indicators that may be useful at this scale, and the evaluation of the ability of plant communities for capturing rare species has been described as a "critical task facing conservation biologists" (Wilcove and Master 2005 p. 420). Whittaker (1975) stated that plant communities are good surrogates for species diversity. The use of plant communities as a way to identify priority sites for conservation was tested by Lesica (1993) who successfully used plant communities in combination with measures of community diversity and dissimilarity to select nature reserves in the Prairie Pothole region of Montana. Another advantage for using plant communities or vegetation types is that they can be mapped and hence used as layers of information in Geographic Information Systems (GIS).

The use of plant communities or vegetation types for determining conservation priorities in the northern Rocky Mountains of Alberta poses a challenge given the history of vegetation work in the area. Lewis (1917; 1923) provided the first description of the vegetation of the Rocky Mountains of Alberta but it was thirty or more years before additional contributions were made (Cormack 1953; Moss 1955; Porsild 1959; Ogilvie 1969). Subsequently, several ecological studies on specific areas, particularly the alpine of the Rocky Mountain National Parks, were conducted in the 1960's and 1970's, including those for Banff National Park (Beder 1967; Broad 1973; Knapik et al. 1973), Highwood Pass (Trottier 1972), Plateau Mountain (Bryant 1968; Bryant and Scheiberg 1970), Ram Mountain (Johnson 1975), Jasper National Park (Stringer 1973; Stringer and La Roi 1970; Hettinger, L. R. 1975; Kuchar 1975; Lee 1976; Crack 1977; Tande 1979; Lee and La Roi 1979a and b; See and Bliss 1980; La Roi and Hnatiuk 1980; Hrapko and La Roi 1978) and Waterton Lakes National Park (Kuchar 1973; Achuff et al. 1997).

The most comprehensive studies of the vegetation and soils of the mountain National Parks in Alberta are Corns and Achuff (1982) and Achuff et al. (1997). Classifications of the vegetation which include the northern Alberta Rockies outside of the National Parks is limited and includes Willoughby and Alexander (2003) and Willoughby et al. (2005) for range types for the montane and subalpine regions, Jacques and van Eck (1979) for Kakwa Falls, Beckingham et al. (1996) for the forested areas on the eastern slopes of the Rockies, Kembel (2000) for shrubland types and Strong (2002) for lodgepole pine/labrador tea communities. An ecological land classification, including sampling of the vegetation and environmental attributes, for Willmore Wilderness Provincial Park was initiated in the 1990's but never completed. Studies of vegetation in Willmore are restricted to range types (Bork 1994 and Lane et al. 2001). A summary of selected types for the Rocky Mountains of Alberta is provided in Timoney (1999). Even though there has been considerable effort put into describing the vegetation of the Rocky Mountains of Alberta, a comprehensive synthesis and treatment of plant community types is lacking.

While several studies in the Rocky Mountains of Alberta have examined the relationship between selected vegetation types and environmental variables (Beder 1967; Hettinger 1975; Kuchar 1975; Mortimer 1978; Stringer 1973; Stringer and La Roi 1970; La Roi and Hnatiuk 1980), there are few studies (but see Hettinger 1975) that examine the pattern of distribution of several vegetation types in Alberta along an elevational gradient in relation to environmental factors.

My interest in describing the vegetation for the study area was to see if vegetation type could be used as a framework for predicting the occurrences of rare vascular plant taxa. The objectives of this study therefore were to determine: 1) vegetation types within the study area to form a framework for assessing fidelity of rare plants and 2) the factors responsible for distribution of vegetation types across the landscape.

Study area

The study area is located in the northern Rocky Mountains of Alberta at 54° 10' to 52° 35' N latitude, 120° to 117° 10' W longitude and encompasses approximately 54 000

km^2. There are two northwest-southeast trending mountain ranges (Main and Front Ranges) within the area and these are bisected by several east-west trending valleys. Elevation ranges from 1006 m in the river valleys to 3020 m on alpine summits. A diversity of lithologies is represented with Precambrian and Early Paleozoic quartzite and limestone dominating the Main Range and Late Paleozoic limestone and Mesozoic shales in the Front (Mountjoy 1978; Gadd 1986). The Continental Divide forms the western boundary of the study area.

The climate is continental and three weather stations are located either within or in close proximity to the study area. There is considerable variation in temperature and precipitation due to topographic relief. Daily average temperature ranges from -0.3° C at Lake Louise (160 kms southeast of the southern boundary) to 3.7° C at Jasper townsite. Average yearly precipitation ranges from 398.9 mm at Jasper townsite to 620.2 mm at the eastern gate of the Park (Environment Canada http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e. html.--date accessed Oct. 3, 2004).

Fifty-four rare vascular plants species were known to occur within the study area prior to the initiation of this study (ANHIC data files 2001), many of which occur at higher elevations. The Rocky Mountain Natural Region has the largest number of rare species in Alberta (Kershaw et al. 2001), the majority of which are common outside of the province, with many reaching the southern limits of their distribution in the northern Rockies. The northern Rockies is one of two areas of concentration of rare vascular plants within the

Montane Cordilleran Ecozone of Alberta, the other being the southern Rockies south of the Crowsnest Pass (Ogilvie 1998).

Vegetation

Three Natural Subregions (montane, subalpine and alpine) are represented within the Rocky Mountain Natural Region (Natural Region Committee 2006). The montane subregion is a mosaic of forest types including Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), trembling aspen (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* (Moench) Voss) and grass and shrub dominated communities (Corns and Achuff 1982; Achuff 1989; Natural Region Committee 2006) all of which are situated between 1000 and 1350 m a.s.l. (Corns and Achuff 1982; Achuff 1989). The subalpine subregion is characterized by closed forests dominated by lodgepole pine (*Pinus contorta* Dougl. *ex* Loudon), subalpine fir (*Abies bifolia* A. Murray) and Engelmann spruce (*Picea engelmannii* Parry *ex* Engelm.). Forests at higher elevations are open and consist of stunted trees of subalpine fir and Engelmann spruce with an understory of alpine vegetation (Corns and Achuff 1982; Natural Regions Committee 2006). Altitudinal limits of the subalpine in Jasper National Park range from 1350 – 2200 m (Corns and Achuff 1982). The alpine subregion is a complex of plant associations dominated by dwarf shrub and herbaceous vegetation occurring at elevations above 2200 m in Jasper National Park (Corns and Achuff 1982).

Methods

Field protocol

Sites were selected so as to include a diversity of landform features as ascertained from analysis of airphotos, topographic maps and the literature, given the size of the area, remoteness and difficulty with access. At each site, sample locations were established in as many different plant associations as possible within the time available. Forty-eight sites were visited and data were collected from 297 sample locations (Figure 2.1). Plant associations at each sample location were described using protocols outlined in the Alberta Natural Heritage Information Centre (ANHIC 2000) using 5 x 5 m plots for herbaceous (forb, graminoid and dwarf shrub) dominated communities, 10 x 10 m plots for taller shrubs and 20 x 20 m for treed sites unless the size of the association was such that it was too small to use the standard size (i.e. some cliffs, shrub sites). Larger plots were used occasionally when the herbaceous or shrub dominated vegetation was clumped in nature. One plot was established in each association and in most cases more than one association was described at each site. Canopy cover for each vascular plant species was estimated for each plot, and cover of less than 1% was considered 0.05% for analysis. Estimates of cover were done in increments of 5% for cover >5% and were in increments of 1% for values <5%. Covers for total lichen (including cryptogamic crust), moss, litter, rock and bare soil were estimated for each plot. Species that could not be identified in the field were collected for subsequent identification in the lab or annotation by taxonomic experts. Nard sedge (*Carex nardina* E. Fries) and Pacific kobresia (*Kobresia myosuroides*

(Vill.) Fiori & Paol.) cannot be distinguished in a vegetative state and several additional taxa are difficult to tell apart in the field and are therefore treated as species complexes in the dataset. These include alpine willow-herb (*Epilobium anagallidifolium* Lam.) and clavate-fruit willow-herb *(E. clavatum* Trel.), short-leaved fescue (*Festuca brachyphylla* Schultes) and small-flowered fescue (*F. minutiflora* Rydb.) as well as prairie club-moss (*Selaginella densa* Rydb.), Rocky Mountain spike-moss (*S. scopulorum* Maxon) and Standley's spike-moss (*S. standleyi* Maxon). Plants that could not be identified to the species level or were part of a species complex were excluded from the analysis. Individuals of species alleged to form introgressive hybrid swarms (e.g. *Picea engelmannii* and *P. glauca*) were classified as one of the two parental species depending on the dominant traits shown by the hybrid.

A number of environmental parameters that were thought to operate at the scale of both the community and landscape (Urban et al. 2002) were recorded from each plot including elevation, slope angle and aspect and soil moisture and nutrient regime (assessed using protocols summarized in Luttmerding et al. (1990)). In addition, a sample of mineral soil was collected from 0-15 cm from each plot in each association, assessed for field texture and subsequently air dried and passed through a 2 mm sieve prior to analysis. Total carbon and total nitrogen were determined using an elemental analyzer, total phosphorus using perchloric acid digestion (O'Halloran 1993), exchangeable cations (K, Ca, Na, K) and CEC using the ammonium actetate method (Hendershot et al. 1993) and pH by soil paste-glass electrode. Elevation and geographic position of each plot were determined in the field using a Garmin 12XL GPS unit. Values for nutrient concentration were either log or arcsine transformed prior to analysis (see Table 2.1) (Palmer 1993; Gotelli and Ellison 2004; Quinn and Keough 2002).

A complete list of vascular taxa noted from the study area is provided in Appendix 1. Nomenclature for species follows Moss (1983) and Flora of North America (Flora of North America Editorial Committee 1993-2006). Family names are from Flora of North America, NatureServe (http://www.natureserve.org/explorer) and Stevens (2001 onwards). Common names for taxa without common names in Moss (1983) or Flora of North America are taken from NatureServe. Voucher specimens were deposited at the herbarium, University of Alberta (ALTA).

Analyses

Cover values for total lichen, moss, bare soil, litter and rock were included in the environmental matrix. Moss and lichen cover were included in the environmental rather than the species matrix since identification to the species level for mosses and lichens was not done. Inclusion of total moss and total lichen cover in the species matrix would have meant that species with very different ecological preferences were treated as the same thing thereby influencing the analyses inappropriately. Texture classes were coded as dummy variables and aspect transformed according to Beers et al. (1966) (see Table 2.1) prior to analysis.

Cluster analysis was used to partition samples into groups, and constrained ordination was used to determine the response of these groups in relation to the measured environmental variables and to confirm the results of the cluster analysis. Cluster analysis is a form of classification that results in discrete units (community types), while ordination is a form of gradient analysis which portrays sites along environmental gradients (Legendre and Legendre 1998). The combination of cluster analysis and ordination, particularly when the same distance measure is used, is a powerful tool for interpreting vegetation pattern (Legendre and Legendre 1998; Urban et al. 2002).

Three separate analyses were done in order to retain a similar plot size within groups (20 x 20 m for treed, 10 x 10m for shrub, 5 x 5 m for herbaceous) and to facilitate ease of interpretation. Consistency of plot size is important since use of different plot sizes is known to affect vegetation-environmental correlations (Reed et al. 1993) and classification of vegetation (Fekete and Szöcs 1974 cited in: Milan and Zdenka 2003). Matrices were checked for outliers using PC-Ord 4.1, and one plot was subsequently removed from the 5 x 5 m dataset prior to analysis.

Classification of Vegetation Types

Cluster analysis was conducted using a flexible beta linkage method with $\beta = -0.25$ and Sorenson's distance measure. Flexible beta is a space-conserving hierarchical agglomerative technique that is not prone to chaining (McCune and Grace 2002). Chaining is defined as the "addition of single items to existing groups" (McCune and

Grace 2002 p. 84). Indicator Species Analysis (ISA) after Dufrêne and Legendre (1997) was used to prune the dendrogram of the cluster analyses by running the analysis using different numbers of groups as cutoffs and then choosing the group cutoff level by selecting that with the lowest average *p*-value for indicator species (McCune and Grace, 2002). It was also used to determine significant indicator species for groups using Monte Carlo permutations (999 randomizations). Analyses were conducted using PC-Ord Version 4.1. The significance of these groups was further tested using Multi-response Permutation Procedures (MRPP), a non-parametric procedure that tests for significant differences between groups that are determined *a-priori* (McCune and Grace 2002).

Response of vegetation types to environmental gradients

Distance-based redundancy analysis (db-rda) (Legendre and Anderson 1999) was used to look at the plant association data in relation to measured environmental variables. The main advantages of db-rda are that it allows for the use of distance measures of choice (Anderson 1998; Legendre and Anderson 1999) and of linear models to test significance of interaction terms. This is done by conducting a redundancy analysis on the principal co-ordinates of a similarity measure of choice (Anderson 1998; Legendre and Anderson 1999). Bray-Curtis similarity coefficient (quantitative equivalent of Sorenson's distance) (Bray and Curtis 1957) was chosen as the distance measure to ensure consistency with that used in the cluster analysis. Another advantage to db-rda is the use of Monte Carlo methods to test the significance of particular terms thereby foregoing assumptions about the distribution of the data (Anderson 1998). Samples were coded according to vegetation types derived from the cluster analysis, and these types were then used to code samples on the resultant ordination plots. This facilitated the interpretation of the relationship of the vegetation types to measured environmental variables. Distance-based redundancy analysis was conducted using Canoco for Windows 4.5 (ter Braak and Šmilauer 2002), with the focus on samples, species scores divided by the standard deviations of species, no transformations of species data, centering by species and forward selection of environmental variables (with 499 permutations). Environmental variables with high variance inflation factors (>20) were removed from the analysis as they are highly correlated with other variables (ter Braak and Šmilauer 2002). Kendal's τ correlation coefficient was used to determine significance of interset correlations.

Spatial autocorrelation

Spatial autocorrelation is a common property of ecological data in which variables are not independent of each other due to geographic proximity (Legendre and Legendre 1998). If positive spatial autocorrelation is not tested and accounted for, parametric statistics can be considered to be significant when they should not be due to inflated rates of Type 1 error (Legendre and Legendre 1998; Fortin and Payette 2002; Legendre et al. 2002).

A Mantel test was used to evaluate the correlations between matrices of species cover x environmental variables, species cover x geographic position (utm) and environmental variables x geographic position (utm). Sorenson's distance was used as the distance measure for the species cover matrix and Euclidean distance for matrices of environmental variables and geographic position. A significant association between species cover data and the matrix of geographic position would indicate positive spatial autocorrelation (McCune and Grace 2002; Urban et al. 2002). The significance of the Mantel statistic was evaluated using Monte Carlo randomization techniques with 999 permutations (PC-Ord 4.1). No significant spatial autocorrelation was detected.

Indicators for vegetation types

Indicator Species Analysis (ISA) (Dufrêne and Legendre 1997) was used to determine the primary species unifying the groups resulting from the cluster analysis. ISA works by calculating separately the abundance and frequency of a species within a group relative to its abundance or frequency in other groups. Relative frequency and relative abundance are then multiplied to produce an Indicator Value (IndVal). A good indicator is a species that is restricted to one group and is well represented within that group (Dufrêne and Legendre 1997; McCune and Grace 2002). Significance of the indicator values were determined using Monte Carlo permutation procedures. PC-Ord Version 4.1 was used to conduct the analysis.

Results

Treed plots (20 x 20 m)

Classification

Eight groups resulted from the cluster analysis of the 62 plots, which was pruned using Indicator Species Analysis (Figure 2.2). Chaining for the cluster analysis was low at 2.34%.

The main division in the cluster analysis separated higher elevation (*Picea engelmannii*, *Abies bifolia* and *Pinus contorta*) from the lower elevation stands (*Picea glauca*, *Populus tremuloides*, *Elymus-Koeleria* and *Pseudotsuga menziesii)*.

Significant indicators for the groups in Figure 2.2 are shown in Table 2.2. The main indicators were often the dominant species; however, this was not the case for the *Gymnocarpium dryopteris* (L.) Newm. group. This cluster consisted of three sample locations—all forested stands in the subalpine but each dominated by different taxa (Table 2.3). These sample locations (stands) are anomalous in the dataset in that they represent single occurrences of a particular vegetation type.

Ordination (Distance-based redundancy analysis)

The results of the db-rda indicate that 93.5% of species-environment relations were accounted for by the first four axes and that there was a strong relationship between species and environment (ter Braak and Šmilauer 2002) (Table 2.4). However, the majority of the variance in the data remained unexplained, with first four axes capturing 28.2% of the variance in the species data (Table 2.4).

Significant environmental correlates ($p \leq 0.05$) for the first four axes as determined by an examination of interset and canonical correlations were elevation, log potassium, log sodium, total moss cover, total cover of bare soil and arcsine phosphorus (Table 2.4).

The importance of these variables is shown in the plots from the db-rda (Figure 2.3), where it is apparent that the subalpine forest types (*Picea engelmannii* and *Abies bifolia*) showed a positive association with elevation, moss cover and log Na, and negative association with log K, while forested vegetation types of valley bottoms (*Populus tremuloides, Pseudotsuga menziesii*) showed the opposite (Figure 2.3). Arcsine P was important in influencing the distribution of several of the *Picea glauca* sample locations and grassland sample locations were positively associated with cover of bare soil.

Description of vegetation types and relationship to measured environmental variables

<u>Picea glauca</u>

Stands of white spruce occurred throughout the valley bottoms within the study area at elevations of <1550 m. The cover of the vascular understory for these sample locations was generally sparse (<20%) with the exception of three of them; the understory of these was dominated by *Equisetum arvense* L., *Leymus innovatus* (Beal) Pilger [*Elymus* *innovatus* Beal] or *Shepherdia canadensis* (L.) Nutt.. Total bryophyte cover was $\geq$50% in four of the eight sample locations and $\leq$10% in the remaining four. Total cover of lichen and bare ground was sparse. Soil moisture regime ranged from xeric to subhygric. Age of the stands is unknown. *Picea glauca* was the only significant indicator for this vegetation type (Table 2.2).

The distribution of most white spruce dominated sample locations, as compared to other vegetation types, was positively associated with total arcsine phosphorus in the mineral soil and with high amounts of total log K for at least one of the sample locations (Figure 2.3). It was also negatively associated with elevation.

<u>*Populus tremuloides*</u>

Stands of trembling aspen were found at low elevation (<1500 m) in the study area and were found on soils with pH ranging from 5 to 8. Two sample locations (no. 114 and 116) were situated in the bottom of the Athabasca River valley in an area that had been burned in April, 1998 (Shepherd pers. comm.). The tree cover prior to the burn was lodgepole pine, but trembling aspen is now represented and the understory vegetation was similar to that of a nearby aspen stand (stand 115). *Leymus innovatus* was present in all these and dominated the ground cover in all but one sample location. Total moss cover did not exceed 5% cover in any of the stands sampled and total cover of lichen, rock and bare soil was also low. Distribution of trembling aspen sample locations was negatively associated with elevation and total moss cover and positively associated with log K. Significant indicators at $p \leq 0.05$ are shown on Table 2.2 and included *Populus* *tremuloides*, *Lathyrus ochroleucus* Hook., *Leymus innovatus* and *Taraxacum officinale* Weber.

Elymus lanceolatus (Scribn. & J. G. Sm.)-*Koeleria macrantha* (Ledeb.) J. A. Schult.

Two grassland sample locations were included in this grouping of treed 20 x 20 m plots. One of these sample locations (117) was formerly lodgepole pine but was burned in 1998 (Shepherd pers. comm.) and is now *Elymus lanceolatus-Koeleria macrantha* grassland. The second sample location (12) was located on a slope near the bottom of the Athabasca River valley. The cover of bare soil was high (60%) and the vegetation was patchy in its distribution with shrubs such as *Juniperus communis* L. being an important component. The dominant species included *Antennaria microphylla* Rydb., *Koeleria macrantha* and *Juniperus communis.* Both sample locations were associated with high total cover of bare soil, low elevation and low arcsine P (Figure 2.3). Species with significant indicator values included *Anemone multifida* Poir., *Astragalus tenellus* Pursh, *Elymus lanceolatus*, *Gaillardia aristata* Pursh, *Koeleria macrantha* and *Solidago simplex* Kunth (Table 2.2).

Pseudotsuga menziesii

All sample locations of Douglas-fir sampled were situated in the Athabasca River valley on coarse to medium textured soils of the valley floor or lower slopes. The soil pH of all seven sample locations was >6 and all were positioned at the lower end of the elevational gradient. Two sample locations were at that high end for potassium (Figure 2.3). The moisture regime of these sample locations ranged from subxeric to subhygric. The only indicator species for this group was Douglas-fir itself (Table 2.2).

Pinus contorta

Forests of lodgepole pine were extensive throughout the study area spanning an elevational gradient of 1059 m from valley bottoms to the subalpine. Seven of the sample locations had *Shepherdia canadensis* as an important component of the shrub layer and two had *Vaccinium scoparium* Leiberg. *Leymus innovatus* was represented in all but two of the sample locations and it dominated the understory in seven of these. Total bryophyte cover ranged from 10-70%, and lichen cover rarely exceeded 20%. Sample locations were scattered throughout the ordination plot suggesting that this vegetation type occurred over a wide range of measured environmental parameters (Figure 2.3). *Pinus contorta* itself was the only significant indicator for this vegetation type (Table 2.2).

Abies bifolia

High elevation forests in the study area were dominated by either *Abies bifolia*, *Picea engelmannii* or both and were either closed or open with the open forest occurring at higher elevations. The stands of *Abies bifolia* that were sampled were situated between 1494 and 2185 m and had pH ranging between 3 and 6. Total moss cover was generally high and that of bare soil, litter and lichen was low. These sample locations were distributed at the high end of the gradient for total moss cover and elevation and low end of the gradient for log K (Figure 2.3). *Abies bifolia, Cassiope tetragona* (L.) D. Don, *Empetrum nigrum*, *Phyllodoce empetriformis* (Smith) D. Don, *P. glanduliflora* (Hook.) Coville and *Vaccinium membranaceum* Dougl. were significant indicators for this type.

Picea engelmannii

Elevation of sampled stands of *Picea engelmannii* ranged from 990 to 2050 m, all were rated as mesic and subhygric for moisture regime and occurred on soils of pH between 5 and 7.5. These sample locations were similar in species composition to those of *Abies bifolia* stands as shown by the close proximity of sample locations on the dendrogram (Figure 2.2) and ordination (Figure 2.3). Sample locations of Engelmann spruce in the study area were positively associated with moss cover and elevation and negatively associated with log K. There were no significant indicators for this stand type other than *Picea engelmannii.*

Gymnocarpium dryopteris

This group consisted of three sample locations, one dominated by *Abies bifolia* and *Salix drummondiana* Barratt and a second by *Picea engelmannii*, *Pinus albicaulis* Engelm. and *Menziesia ferruginea* J. E. Smith. The third sample location in this group was dominated by *Betula papyrifera* Marsh., *Menziesia ferruginea* and *Viburnum edule* (Michx.) Raf.. The heterogeneity of this group was reflected in the db-rda ordination where it was apparent that there was no common relationship to measured environmental variables other than the positive association with elevation (Figure 2.3). The *Betula papyrifera* sample location was at the high end of the arcsine P gradient along axis 3 (Figure 2.3). *Abies bifolia* occurred in all three sample locations but *Gymnocarpium dryopteris* was the only significant indicator.

Shrub plots (10 x 10 m)

Cluster analysis in combination with Indicator Species Analysis resulted in a classification of eight groups for the 26 shrub dominated sample locations (10 x 10 m plots) (Figure 2.4). Chaining was 10.18%. Indicator species for the various groups are outlined in Table 2.2.

In the shrub dominated 10 x 10 m plots, shrubby grassland dominated by common bearberry (*Arctostaphylos uva-ursi* (L.) Spreng.) formed one group, shrublands dominated by silver-berry (*Elaeagnus commutata* Bernh.*ex* Rydb.) another, krummholtz subalpine fir stands formed another distinct group, while sample locations dominated by various species of willow (*Salix* spp.) were represented in 5 distinct groups based on dominant species.

Ordination (Distance-based redundancy analysis)

There was general concordance between the cluster analysis (Figure 2.4) and the db-rda ordination, with most groups forming distinct clusters in multivariate space (Figure 2.5).

Eighty-four percent of the species-environment relations were accounted for in the first four axes, and there was a strong relationship between species and environment (ter Braak and Šmilauer 2002) (Table 2.4). The first four axes captured 29.4% of the variance in the species data, thus a large portion remained unexplained.

Elevation, texture, total moss cover and pH were significant environmental correlates ($p \leq 0.05$) for the first four axes (Table 2.4), with elevation having the strongest influence on axes 1 and 2 and total moss cover on axis 3.

Vegetation types associated with the valley bottom (*Arctostaphylos uva-ursi*, *Elaeagnus commutata* and *Salix glauca* L.) were positioned at the low end of the elevational and high end of the pH gradients (axes 1 and 2), while higher elevation types were at the low end of the pH gradient (Figure 2.5).

Description of vegetation types and relationship to measured environmental variables

Arctostaphylos uva-ursi

Three sample locations were contained within the *Arctostaphylos uva-ursi* group and all were located at low elevation (<1100 m) with soil pH >8.0. Cover of total moss, lichen, bare soil, rock and litter varied between sample locations. *Juniperus horizontalis* Moench was co-dominant in one sample location, *Leymus innovatus* and *Koeleria macrantha* in another, and a third had more shrub cover with *Betula pumila* L. and *Pentaphylloides fruitcosa* (Pursh) A. Löve having 30% and 20% cover, respectively. These sample locations were positioned at the high end of the pH gradient and low end of the elevation gradient (Figure 2.5). *Comandra umbellata* (L.) Nutt., *Galium boreale* L., *Juniperus horizontalis* and *Pentaphylloides floribunda* were significant indicators for this type.

Elaeagnus commutata

The two sample locations dominated by *Elaeagnus commutata* were situated at low elevation (<1100 m) on the floor of the Athabasca River valley. The pH of both sample locations was high (>7.5) and the moisture regime was rated as subxeric and mesic. Total cover of bare soil was <5% in both sample locations although litter cover was higher. Graminoids dominated the understory, with *Carex eburnea* Boott and *Leymus innovatus* dominating in one sample location and *Achnatherum richardsonii* (Link) Barkw., *Koeleria macrantha* and *Poa pratensis* L. the other. Both sample locations were associated with low elevation and high pH as shown in the db-rda plot (Figure 2.5). Several species including *Antennaria microphylla*, *Cerastium arvense*, *Elaeagnus commutata*, *Gaillardia aristata*, *Oxytropis splendens* and *Taraxacum officinale* were significant indicators for this vegetation type (Table 2.2).

Salix glauca

Five sample locations were included in the *Salix glauca* group, but only three members of the group had this species. The vegetation of these three sample locations was quite different with one (21) dominated by *Salix exigua* Nutt., *S. glauca* and *Betula glandulosa* Michx. with little cover of bare soil, rock, litter, moss and lichen. This sample location was situated in a valley bottom at the base of a slope dominated by lodgepole pine. A second sample location (35) was found in the floor of the Berland River valley and was dominated by *Salix glauca* and *Deschampsia cespitosa* (L.) Beauv.. Litter covered 20% of the ground surface but moss, lichen, rock or bare soil was <1%. The third sample location of *Salix glauca* was at high elevation (2010 m) and *Abies bifolia*, *Salix* *barrattiana* Hook. and *S. vestita* Pursh were significant components of the vegetation cover. The two sample locations that lacked *Salix glauca* were dominated by either *Elymus repens* (L.) Gould or *Picea glauca* and *Juniperus communis* and occurred at low elevation (<1250 m) on soils of high pH (>7). The sample locations of *Salix glauca* were widely dispersed on the ordination with three sample locations associated with low elevation and high pH (Figure 2.5). There were no significant indicator species for this group (Table 2.2).

Salix drummondiana

Three plots that were dominated by *Salix drummondiana* were sampled and these were between 1500 and 1800 m elevation. The moisture regime was ranked xeric to mesic and the pH >5.5. Trees, *Picea glauca* at the low elevation sample location and *Abies bifolia* at the higher sample locations, were represented by low cover within the group. Other species of willow such as *Salix barclayi* Anderss. and *S. farriae* Ball were also represented within one or more sample locations of this cluster. Sample locations of *Salix drummondiana* were positively associated with coarse textured soils and negatively associated with total moss cover for at least two of them (Figure 2.5). Significant indicator species included *Epilobium latifolium* L., *Salix drummondiana*, *Saxifraga lyallii* Engler., *S. nelsoniana* D. Don and *Vaccinium caespitosum* Michx..

Salix farriae

Three sample locations dominated by *Salix farriae* were located in the floodplain of the stream between Angel Glacier and Cavell Lake in Jasper National Park. All sample locations were in the subalpine at >1700 m elevation, with subhygric to hygric moisture regimes and pH ranging from ca. 5 to 6. Total cover of moss and litter was high and amount of rock, total lichen and total bare soil was $\leq$10% for all sample locations. Sample locations were found at the higher end of the elevational and moss cover gradients (Figure 2.5). *Carex aquatilis* Wahlenb., *C. canescens* L. and *Salix farriae* were significant indicators.

Salix barrattiana

Two sample locations, both of which were dominated by *Salix barrattiana*, were found in this group. Graminoids co-dominated with *Festuca altaica* Trin. in one sample location and *Deschampsia cespitosa* in the other. Both sample locations occurred at elevations >2000 m, on medium textured soils with pH >6.0. Total moss cover was high in one sample location (20%) but otherwise cover of total lichen, rock, bare soil and litter was low. The sample locations were positioned at the higher end of the elevational gradient as shown in Figure 2.5. Significant indicators for this vegetation type included *Achillea millefolium* L. and *Salix barrattiana.*

Salix arctica Pall.

Two sample locations of *Salix arctica* were placed in this group, one of which was dominated by *Salix alaxensis* (Anderss.) Coville, *S. arctica* and *Dryas integrifolia* M. Vahl, the other by *Salix arctica*. Both sample locations were at high elevation (>1900 m) and had high soil pH (>7). Cover of total rock was 80% in the sample location dominated by *Salix arctica* alone, and total moss and lichen cover exceeded 50% in the other. The sample locations were positively associated with elevation, fine textured soil and high soil pH as shown in Figure 2.5. Eight species were listed as significant indicators and these are shown in Table 2.2.

<u>*Abies bifolia*</u>

The six stands of *Abies bifolia* that were sampled with 10 x 10 m plots were at high elevation (>1600 m) on sites with a soil pH of 4-6 and coarse to medium texture. These were not treed stands but rather high elevation stands at tree line where *Abies* and *Picea engelmannii* were represented as small trees (<2m height). Moss cover was >10% for all sample locations except one and cover of bare soil was sparse. Cover of lichen, litter and rock was variable among sample locations. *Picea engelmannii* was present in four of the six sample locations and *Phyllodoce glanduliflora* was >10% in all but one. Sample locations were positively associated with elevation and medium to coarse textured soils and negatively associated with pH (Figure 2.5). Significant indicators included *Abies bifolia* and *Picea engelmannii.*

<u>Herbaceous plots (5 x 5 m)</u>

There was a considerable amount of heterogeneity among sample locations within the dataset from the herb dominated 5 x 5 m plots, and the cluster analysis (with group level determined using Indicator Species Analysis and supported by MRPP) resulted in the 209 sample locations forming 45 groups (Figure 2.6). It was 2.75% for the cluster analysis. The majority of sample locations within a group as identified by the cluster analysis were similar in terms of dominant species (Table 2.3). Some sample locations appeared to be misclassified considering only the dominant taxa but there was usually an indicator species that unified the groups. These sample locations were retained within the classification because they may be transitional (ecotonal) or of ecological interest, including some that are rare according to the Alberta Natural Heritage Information Centre (Allen 2005).

Ordination

76.4% of the species-environment relations were accounted for in the first four axes (Table 2.4).

Elevation, aspect, moisture regime, arcsine P, log Ca and total cover of lichen, moss and rock were significant environmental correlates ($p \leq 0.05$) for the first three axes (Table 2.4). Total arcsine N was significant on the fourth; however, ordination plots are restricted to the first three axes for ease of presentation. Elevation was the strongest determinate of axis 1, log Ca of axis 2, total moss cover for axis 3 and arcsine total N for axis 4.

Given the difficulties in portraying 45 classes on one plot, groups from the cluster analysis were further grouped into like habitat/physiognomic classes. These larger groups were then portrayed on the diagrams although the analyses were done on the entire dataset.

Description of vegetation types and relationship to measured environmental variables

Grassland types

Three distinct grassland types were found within the study area, *Elymus lanceolatus-Koeleria macrantha*, *Achnatherum [Stipa] richardsonii* and *Festuca altaica*. Three additional groups, *Fragaria virginiana* Dechesne, *Antennaria microphylla* and open graminoid were included with these for presentation on the ordination diagrams.

Elymus-Koeleria

The *Elymus lanceolatus-Koeleria macrantha* grassland type of this study occurred at 1400 m in the Athabasca River valley on soils of pH>6.5. Moisture regime ranged from very xeric to mesic. *Koeleria macrantha* dominated the vascular flora in all sample locations although *Elymus lanceolatus* is a co-dominant in three. Cover of cryptogamic crust was included within the total cover of lichen and it approached 50% in some sample locations. In contrast, cover for total moss, bare soil, rock and litter was low for most sample locations. These sample locations were portrayed as a group on the db-rda plot reflecting similarities in species composition and response to environmental variables (Figure 2.7). Distribution of sample locations was negatively associated with elevation and arcsine P (Figure 2.7). *Elymus lanceolus* and *Koeleria macrantha* were the only significant indictor species for this group (Table 2.2).

Achnatherum richardsonii

A second grassland type dominated by *Achnatherum richardsonii* was found in the bottom of the Athabasca River valley. Soil pH was high (>7) and moisture regime was rated as subxeric to mesic. *Poa pratensis* co-dominated in two of the three sample locations. Total cover of litter was 50% in two of the three sample locations and total lichen cover was high in the other. These sample locations, like those of the *Elymus-Koeleria*, were distributed at the low end of the elevational gradient (Figure 2.7). Significant indicators for this grassland type included *Achnatherum richardsonii, Astragalus agrestis* Dougl. *ex* G. Don, *Poa pratensis, Sisyrinchium montanum* Greene *Vicia americana* Muhl. *ex* Willd. and *Viola adunca* J. E. Smith (Table 2.2).

Festuca altaica

A third grassland type dominated by *Festuca altaica* was recognized. These sample locations were located north of Jasper National Park near Grande Cache and in Willmore Wilderness Park, at 1647 and 1961 m, respectively, on medium and coarse textured soils with pH $\geq$6.5. Moisture regime was submesic. This type had a higher cover of vascular plants than other grassland types and grazing was not evident in either sample location. *Festuca altaica* was the only species common to both sample locations. Total litter cover exceeded 10% for both sample locations and moss cover in one was 20%. The lack of similarity in species composition was reflected in the db-rda plot (Figure 2.7). *Aconitum delphinfolium* DC, *Festuca altaica*, *Potentilla diversifolia* Lehm., *Pyrola minor* L. and *Rhinanthus minor* L. were significant indicators (Table 2.2). The relationship of the distribution of sample locations within this group to environmental variables was not apparent.

Fragaria virginiana

Several sample locations had a high cover of *Fragaria virginiana*, and these formed a separate grouping on the cluster analysis (Figure 2.6), even though co-dominant species varied as shown in Table 2.3. *Fragaria virginiana* was the only species that occurred in all sample locations. Sample locations were found across the elevational gradient in the montane and subalpine zones and soil pH was high for all sample locations (>7.0). Total lichen, moss and rock cover was variable while that of litter and bare soil was low. Sample locations were dispersed over the three axes of the constrained ordination (Figure 2.7) reflecting the heterogeneity of the response of members of the groups to environmental gradients. *Arctostaphylos uva-ursi*, *Botrychium lunaria*, *Fragaria virginiana*, *Pinus contorta* (seedlings), *Populus balsamifera* (seedlings) and *Trifolium pratense* were significant indicators of the group.

Open graminoid (Group 8)

Three sample locations were included in the open graminoid cluster, and these were presented with the grassland types in the ordination for ease of presentation. The grouping was heterogenous and included two sample locations of sparse vascular plant cover (223 and 252) that were found at high elevation (>1900 m) on dry, medium textured soils of various pH. Total vascular cover was low (<1%) but rock cover high (≥90%). A third sample location was dominated by *Carex lenticularis* Michx. var. *dolia*

(M.E. Jones) L. A. Standley and it occurred at the highest elevation and moisture regime and lowest soil pH of any of the sample locations within this group. The sample locations within this group do not cluster together on the ordination diagram reflecting the heterogenous nature (Figure 2.7). There were no significant indicators for this group (Table 2.2).

Antennaria microphylla (Group 5)

Both *Antennaria microphylla* sample locations were situated on the floor of the Athabasca River valley on medium-textured soils of high pH (>7.5). Total vascular plant cover was about 50%, and at one sample location *Antennaria microphylla* and *Calamagrostis montanensis* Scribn. were the dominant species. The second sample location was dominated by *Carex duriscula* C. A. Meyer, *Artemisia frigida, Agropyron cristatum* (L.) Gaertn. and *Antennaria microphylla.* Cover of bare ground was high. *Antennaria microphylla, Linum lewisii* Pursh and *Taraxacum officinale* were significant indicators. Both sample locations were associated with low elevation as shown in Figure 2.7.

Sparse vegetation habitats

Thirteen clusters were included within a grouping of sparse vegetation habitats for ease of presentation on the ordination diagrams. These habitats included cliff faces, trail and river edges, scree and talus slopes and rock outcrops in both the Front and Main Ranges. Total cover of bare ground was high in all sample locations. The diverse nature of the sample locations within this class was shown in the db-rda plots (Figure 2.7) although some groups, such as calcareous cliff (group 2) and calcareous cliff/outcrop (group 3), did occur as discrete clusters.

Members of the calcareous cliff group (2) were situated at low elevation (<1200 m), with a very xeric moisture regime, high soil pH (>7.5) and high total rock cover. *Koeleria macrantha* was the only species common to all members of the cluster. These sample locations clustered together in the db-rda plots (Figure 2.7) indicating a strong similarity between groups in terms of species composition and response to measured environmental gradients. This group was associated with the low end of the elevational gradient and high end of the gradient for total rock cover (Figure 2.7). *Juniperus horizontalis* was a significant indicator for this group.

Two sample locations were represented within group 3. One of these sample locations was a calcareous cliff in the valley of the Athabasca River, the other a calcareous outcrop at high elevation (2068 m). Total plant cover was <5% for each sample location and rock cover was $\geq$95%. Soil pH was high (>7.5) and the moisture regime of both sample locations rated as xeric. *Koeleria macrantha* was the only species found in both members of this cluster. The dissimilarity between sample locations in terms of species composition was evident in the plot (Figure 2.7); however, both had a positive association with the elevational gradient with the calcareous cliff sample location positioned at a lower elevation than that of the outcrop (Figure 2.7). There were no significant indicators for this group (Table 2.2).

A second group with a low elevation cliff (1050 m) and a high elevation outcrop (2073 m) comprised group 4. This group was similar to group 3, with high soil pH (>7.5), high total rock cover (95%) and a xeric moisture regime. *Telesonix heucheriformis* Rydb., a rare species in Alberta, is the only species that was found in both sample locations. Both sample locations were positively associated with bare rock and the difference between the elevations of the two sample locations was apparent as shown on Figure 2.7. *Telesonix heucheriformis* was a significant indicator for this group (Table 2.2).

Group 6 was heterogeneous, with two of the sample locations associated with edges of drainages and the third a high elevation valley. Total cover of rock or bare soil was high for the sample locations associated with drainages and low for the other. Sample locations spanned a range of elevation, moisture regimes and soil pH. The relationship of these sample locations to the measured environmental variables is shown on Figure 2.5, where the heterogenous nature of the group was apparent. *Barbarea orthoceras* Ledeb., a rare plant in Alberta, was found in two of the three sample locations and was a significant indicator for this group, as were *Deschampsia cespitosa* and *Phleum alpinum*.

The sample locations of group 7 were at high elevation on scree with on a range of soil pH. Total rock cover was high ($\geq$60%) and there was little cover of litter, although moss cover was high in one sample location and lichen in the other. The relationship of these sample locations to measured environmental variables is shown in Figure 2.7, where it appeared that the sample locations are responding to different variables. *Saxifraga lyallii* was a significant indicator, but was found at only one of the sample locations (Table 2.2).

Two sample locations, one a cliff face (65) and one a scree slope (156) made up group 9. Both sample locations occurred at high elevation (>2090 m), with high total rock cover (>60%), low pH (<5) and a xeric to subxeric moisture regime. *Carex micropoda* C. A. Meyer was a significant indicator for this group. Sample locations were associated with low log Ca (Figure 2.7).

There were five sample locations in group 10 and all were at high elevation (>1900 m). Four of the five sample locations were on scree, and one was at the end of a high elevation creek channel. Moisture regime was ranked as subxeric or submesic with soil pH >6. Total rock cover was high (70-100%), and cover of lichen, litter and moss was <5%. There appeared to be little correlation between all group members and measured environmental variables (Figure 2.7). There were no significant indicators for this group.

Group 11 had three members ranging in elevation from 1010-1649 m on coarse-textured soils with 25-50% total rock cover. Soil pH was > 6.5, and moisture regime ranged from xeric to mesic. Total lichen cover was sparse and moss cover was 10% in two of three sample locations. Sample locations were clustered together at low end of the elevational gradient (Figure 2.7). *Epilobium angustifolium* was a significant indicator (Table 2.2).

Three sample locations occurring at elevations between 1700 and 1950m were found in group 14. Soil pH varied between sample locations, total cover of bare ground and soil was high and that of litter, lichen and moss was low (<5%). These sample locations did not cluster together on the ordination (Figure 2.7) reflecting the diversity of this group, although all sample locations were negatively associated with log Ca. *Agrostis variabilis* Rydb., *Epilobium latifolium* and *Salix drummondiana* were significant indicators.

Sample locations from three high elevation scree slopes comprised group 23. Total rock cover was ≥90% and that of lichen, moss, litter and bare ground was <5% for all sample locations. Soils had coarse to medium texture and a pH >6.5. All sample locations were positioned at the high end of the total rock cover gradient and low end of that for lichen cover (Figure 2.7). *Erigeron compositus* Pursh and *Taraxacum ceratophorum* (Ledeb.) DC. were significant indicators.

Group 24 had four sample locations that all occur at high elevation (>1900 m), on rocky substrate with medium to fine textured soils of high pH (>7). Sample locations were dry with the moisture regime rated as very xeric to subxeric. Total rock cover was high (≥90%) and that for litter, lichen and moss was low (<5%). There was considerable dispersion within the group as shown in the db-rda plot (Figure 2.7). *Erigeron trifidus* Hook., a rare species in Alberta, and *Elymus alaskanus* (Scribn. & Merr.) A. Löve [*Agropyron latiglume* (Scribn. & J. G. Sm.) Rydb.] were significant indicators (Table 2.2).

There were three sample locations in group 25 and all were at high elevation (>2000 m) on coarse to medium textured soils with pH >5.5. The sample locations are dry and moisture regime was very xeric to subxeric. Total rock cover was high (>60%) and that of litter, lichen, rock and moss was low (<20%). There was no clear pattern with the distribution of members of this group to environmental variables (Figure 2.7). *Cerastium beeringianum* Cham. & Schlect., *Saxifraga cernua* L., *Silene acaulis* (L.) Jacq. and *Stellaria longipes* Goldie are significant indicators.

Group 28 had four members. Elevation of sample locations within this group was >1800 m and moisture regime was very xeric or xeric for all but one of the sample locations. Soil texture was coarse to medium and pH was variable. Total cover of rock or bare soil was high and that for moss, lichen and litter was low (<5%). There was a high degree of similarity between sample locations relative to others in the dataset as shown on Figure 2.7. Three of the four sample locations were found at the low end of the log Ca gradient (Figure 2.7). There were no significant indicators for this group.

Heath types

Five groups, all dominated by ericaceous plants, were included in this class. The *Phyllodoce*, *Cassiope tetragona* and *Empetrum* groups formed fairly discrete clusters, while there was considerable overlap between the *Cassiope* and *C. mertensiana* groups (Figure 2.7).

Cassiope mertensiana

Ten sample locations were represented within the *Cassiope mertensiana* group. All occurred at elevations of >1900 m in areas of late-lying snow on medium to coarse textured soils with soil pH <6.5. Moisture regime for all but one sample location was rated as submesic to hygric. Total vascular plant cover exceeded 50% for all but one sample location and cover of bryophytes and lichens was <50%. *Cassiope mertensiana* dominated the vegetation, but *Phyllodoce glanduliflora* or *P. empetriformis* were well represented within most sample locations often as co-dominants. *Luetkea pectinata* (Pursh) Kuntze occurred in nine of ten sample locations and *Antennaria lanata* (Hook.) Greene and *Carex spectabilis* Dewey in six. These sample locations were positioned at the high end of the moisture gradient on slopes with northern exposures and low log Ca (Figure 2.7). *Cassiope mertensiana* and *Gentiana glauca* Pall., a rare species in Alberta, were significant indicators.

Cassiope tetragona

Eight sample locations were represented in the *Cassiope tetragona* group, all of which were at elevations >1900 m on medium textured soils with a diversity of pH and moisture regimes. Total plant and lichen cover was high and that of bare soil and litter low ($\leq$5%). Rock cover varied among sample locations. *Cassiope tetragona* dominated sample locations and *Dryas*, *S. arctica* and/or *S. nivalis* co-dominated in several. The distribution of the majority of the members of this group was correlated with elevation and high lichen cover (Figure 2.7). *Cassiope tetragona* was the only significant indicator for this group (Table 2.2).

Phyllodoce glanduliflora (Group 35)

There were four sample locations in the *Phyllodoce glanduliflora* group; however, this species was not represented in the cover of one sample location. All sample locations were at high elevation (>2000 m) on medium to coarse textured soils with pH <6, and moisture regime was ranked as subxeric to mesic. Total vascular plant cover was high with *Phyllodoce* dominating in three sample locations, *Antennaria lanata* in the fourth. Distribution of sample locations was associated with aspect and high elevation and low log Ca (Figure 2.7). *Antennaria lanata*, *Diphasiastrum alpinum* and *Phyllodoce glanduliflora* were significant indicators for this group.

<u>*Cassiope*</u>

The fourth group within the class had eight sample locations in which either *Cassiope mertensiana* or *C. tetragona* were dominant. Members of this group spanned a range of elevation and soil textures. Total bare soil and litter cover was low and cover of moss and lichen cover was ≤40%.This was a heterogeneous group and this was reflected in the ordination, although all sample locations were positioned at the high end of the moisture and aspect gradients (Figure 2.7). There were no significant indicators for this group.

<u>*Empetrum nigrum*</u>

Four sample locations were included in the *Empetrum nigrum* class, three of which were dominated by *Empetrum* and one by *Loiseleuria procumbens* and *Cassiope tetragona*. All sample locations were at high elevation (>1800 m) on medium textured soils of low pH (<5), and moisture regime ranged from xeric to submesic. Total vascular plant cover was low in three of the four sample locations and total cover of litter was low in all. *Vaccinium vitis-idaea* was the only species occurring in all sample locations within the group, but *Cassiope tetragona*, *Empetrum nigrum*, *Hierochloe alpina* (Sw.) Roem. & Schult. and *Loiseleuria procumbens* occurred in three. Cover of lichen, moss, bare soil and rock was variable among sample locations. There was considerable dispersion of the plots in multivariate space (Figure 2.7), although all were negatively associated with log Ca and arcsine P (Figure 2.7). *Loiseleuria procumbens* and *Empetrum nigrum* were the only significant indicators.

Dryas-Vaccinium tundra types

There were four groups included within this class, two of which were dominated by *Dryas octopetala* (although one was co-dominated by *Vaccinium uliginosum* L.) and two dominated by *Dryas integrifolia.*

The *Dryas octopetala-Vaccinium uliginosum* group (group 40) had *Vaccinium* in three of the six sample locations and because it was a significant indicator for this group, the cluster was labelled as such. Sample locations from the *Vaccinium uliginosum* group were at high elevation (>1900 m) and pH was <6 in all but one. Soils were medium to coarse textured and the moisture regime was rated from very xeric to submesic. Total vascular cover was <55%, rock cover was variable and cover of lichen, litter and moss was ≤5%. *Dryas octopetala* dominated, although *Vaccinium uliginosum* was co-dominant in three sample locations. Sample locations were associated with low log Ca, arcsine P and moss cover (Figure 2.7).

The second group of *Dryas octopetala* (37) occurred at high elevation (>2100 m) on medium textured soils (one sample location had coarse) of various pH. Moisture regime was xeric to mesic. Total vascular plant cover was >35% and was dominated mainly by

Dryas octopetala. Cover of moss and bare soil was <20% each and that of rock varied among sample locations. *Vaccinium uliginosum* had significant cover in two sample locations and *Salix nivalis* in several. This group was positively associated with lichen cover, arcsine P and elevation (Figure 2.7). *Dryas octopetala* was the only significant indicator for this group.

Sample locations in which *Dryas integrifolia* formed a significant component of the plant cover formed two groups, and these appeared to be separated on the basis of total plant cover. The first group (22) contained four sample locations, and cover of *Dryas integrifolia* ranged from 1-5%. Total vascular cover was low for three of the four sample locations (<15%). All sample locations were at high elevation (>1900 m) primarily on medium textured soils with pH between 6 and 8. Cover of litter, moss and lichen was ≤20% and that for rock and bare soil ranged from 0-100%. The sample locations did not form a discrete cluster on the plot (Figure 2.7) but they were positively associated with high elevation and log Ca and negatively associated with moss cover. There were no significant indicators for this group (Table 2.2).

The second group of *Dryas integrifolia* (45) consisted of 13 sample locations with higher vascular plant cover than the previous group. All sample locations were at high elevation (>1900 m) primarily on medium textured soils of pH >5.5. Moisture regime was very xeric to submesic. Cover for each of bare soil, litter and moss was ≤10%, but lichen cover was higher although ≤35%. Other species that had significant cover in several of the sample locations include *Salix arctica*, *S. nivalis* and *Carex nardina/Kobresia* *myosuroides* and/or *Festuca altaica*. The sample locations were clustered together in the db-rda plot, reflecting similarities in species composition and response to environmental gradients (Figure 2.7). Distribution of sample locations was positively associated with elevation, lichen cover, arcsine P and log Ca, and negatively associated with moisture regime (Figure 2.7). *Dryas integrifolia* was the only significant indicator for this cluster.

<u>*Salix arctica-Salix nivalis* types</u>

<u>*Salix arctica*</u>

Areas dominated by *Salix arctica* occurred at high elevation (>2000 m) over a broad range of moisture regimes (very xeric to hygric) and soil pH. Two groups dominated by *Salix arctica* were recognized in the classification of the 20 x 20 m sample locations (Figure 2.7), and the separation of groups appeared to be based on degree of vacular plant cover. There was a considerable degree of overlap between the two groups in the db-rda plots, reflecting similarity in species composition and response to environmental gradients (Figure 2.7). A third group was recognized in the 10 x 10 m sample locations.

The first group (43) had 14 sample locations and total vascular plant cover >28%, with *Salix arctica* dominating. Cover of moss and lichen was variable (0-60%) and bare soil, rock and litter $\leq$30% each. Sample locations were situated at the high end of the elevational, arcsine P and log Ca gradients (Figure 2.7). *Salix arctica* was the only significant indicator for this type (Table 2.2).

The second group of *Salix arctica* sample locations (group 44) had low total vascular plant cover and high cover of bare soil and rock. Total cover of moss and lichen was similar to, but cover of *Salix arctica* cover was lower than, that of group 43. There were no significant indicators for this group. Association with environmental variables was similar to that of group 43 as shown in Figure 2.7.

The two *Salix arctica* sample locations from the 10 x 10 m plots were similar in species composition to those from the 5 x 5 m plots; however, one of the 10 x 10 m sample locations (plots) was co-dominated by *Dryas integrifolia*. This type was associated with pH >7 and elevation >1990 m.

<u>*Salix nivalis*</u>

The first cluster of *Salix nivalis* sample locations (group 41) occurred at high elevation >2100 m on medium textured soils on a range of soil pH and moisture regimes. Total vascular plant cover was high, and that of lichen and moss ranged from 5-60% and 5-25%, respectively. Cover of bare soil and litter were each low (<5%), while that of rock ranged from 0-60%. Sample locations were associated with high total lichen cover (Figure 2.7). *Salix nivalis* was the dominant species, and *Myosotis asiatica* and *Salix nivalis* were the only indicator species.

The second *Salix nivalis* cluster (42) consisted of five sample locations, all at elevations >1800 m on medium-textured soils with a range of soil pH and moisture regimes. Cover of *Salix nivalis* was low (5-10%), and that of moss and lichen ranged from 0-60% and 5-

50%, respectively. The amount of bare rock and soil was high for most sample locations. There was no clear relationship between the distribution of the sample locations of this group to measured environmental variables (Figure 2.7). There were no significant indicator species (Table 2.2).

Shrub types

Low shrub

The low shrub cluster (12) consisted of two groups, both of which were near the bottom of the Miette River valley (<1200 m elevation). These two sample locations were dominated by different taxa—one by *Rhododendron groenlandicum* (Oeder) Kron & Judd and the other by *Betula pumila*, *Carex tenuiflora* Wahl. and *Eriophorum viridicarinatum* (Engelm.) Fern.. Cover of bare soil, lichen, litter and rock was low (≤5%), and that of moss was 80% in both sample locations. The moisture regime was subhygric to hygric and soil pH was ca. 4 in one sample location and 6 in the other. The two sample locations were positioned together in the constrained ordination (Figure 2.7), indicating similarity between them both in terms of species composition and response to environmental gradients. Members of this group were associated with the high end of the gradient for moisture regime and low end for elevation and lichen cover (Figure 2.7). *Betula pumila* and *Linnaea borealis* were significant indicators for the cluster.

Salix-Betula glandulosa

Two sample locations were represented within this group both of which occurred in the bottom of the Adams River valley of Willmore Wilderness Park at approximately 1600

m. One sample location was dominated by *Betula glandulosa* with *Deschampsia cespitosa* and the other by *Salix glauca* and *S. pedicellaris* Pursh. Soils at both sample locations were organic with a pH of ca. 5 and 7, and moisture regime was ranked as subhygric. Cover of bare soil, lichen, litter and rock was ≤10% and moss was 25-30%. *Betula glandulosa* and *Polemonium acutiflorum* Willd. *ex* Roem. & Schult. were significant indicators (Table 2.2). Sample locations were positioned together in the db-rda plot (Figure 2.7) and were associated with the low end of the elevational gradient.

<u>*Salix barclayi-S. drummondiana-S. vestita*</u>

Two of the samplelocations within this group were dominated by *Salix barclayi*, *S. drummondiana* and *S. vestita*, and both were at the edge of parking lots or trails. The third member of the group was dominated by *Poa alpina* and *Equisetum arvense* and it too was at the edge of a trail. Sample locations were found at between 1700 and 2100 m on medium to coarse textured soil of pH between 6 and 7.5. Moisture regime was submesic to mesic. There was little cover of bare soil, litter or lichen and cover of moss and rock was 20% in some sample locations. Cover of vascular plants was ≥75%. *Petasites frigidus*, *Ranunculus eschscholtzii* Schlecht. and *Salix barclayi* were significant indicators for this group (Table 2.2). There was little relationship between the three sample locations and the measured environmental variables (Figure 2.7).

<u>*Alnus/Ribes/Calamagrostis*</u>

There were two sample locations within this cluster (20), one of which was dominated by *Alnus viridis* (Vill.) DC., *Ribes lacustre* (Pers.) Poir., *R. laxiflorum* Pursh (a rare species in Alberta) and *Calamagrostis canadensis* (Michx.) Beauv., and the other by *Salix drummondiana*, *R. laxiflorum* and *C. canadensis*. The sample locations were between 1600 and 1700 m on medium textured soils with pH of 5-7. The moisture regime was subxeric and mesic. Total vascular plant cover was >20%, lichen and bare soil was $\leq$5% for both sample locations, rock cover was 30%, moss was $\leq$20% and that of litter $\geq$10%. The sample locations were positioned together on the db-rda plot (Figure 2.7) and were at the low end of the elevational and arcsine P gradients. Plants that were significant indicators included *Alnus viridis*, *Calamagrostis canadensis*, *Dryopteris expansa*, *Ribes laxiflorum*, *R. lacustre* and *Rubus idaeus*.

Sedge types

Carex aquatilis

Two sample locations dominated by *Carex aquatilis* occurred in this cluster. One was found in the Berland River valley at 1543 m on coarse soils with pH of 8 and xeric moisture regime. Total vascular plant cover was 62%, with *Carex aquatilis*, *Salix maccalliana* Rowlee and *Pedicularis groenlandica* Retz. dominating the vegetation. The second sample location was on a ridge near Copton Pass in Willmore Wilderness and Kawka Wildland Provincial Parks and at higher elevation (2058 m) on medium textured soils of pH ca. 8 with a hygric moisture regime. Total vascular plant cover was 77% and was dominated by *Carex aquatilis* and *Salix arctica*. Cover of lichen, rock and bare soil was $\leq$5% in both sample locations, moss cover $\leq$30% and litter was $\leq$20%. *Carex aquatilis* and *Equisetum variegatum* Schleich. were significant indicators for this group.

The distribution of this type was positively associated with log Ca and moss cover (Figure 2.7).

<u>*Carex spectabilis*</u>

There were three sample locations represented in the *Carex spectabilis* cluster, all of which had a high cover of vascular plants (>50%). Elevation was >1700 m and sample locations were found on slight north-facing slopes of various soil pH and moisture regimes. Cover of bare ground, litter and lichen was low in all sample locations ($\leq$10%), but cover of moss and rock varied between sample locations. *Carex spectabilis* dominated the vascular cover. Two of the sample locations (those with less bare ground) were clustered together in the constrained ordination (Figure 2.5) and were associated with moisture and aspect gradients. The relationship of the third sample location to environmental gradients was less clear, although it appeared to be positively associated with high cover of rock for one of the sample locations. *Carex spectabilis* was the only plant that was a significant indicator for this group (Table 2.2).

<u>*Carex nigricans* C. A. Meyr.</u>

Sample locations dominated by *Carex nigricans* were split into two groups in the cluster analysis (Figure 2.7) based on total vascular cover. Both groups are associated with areas of late snowbeds. One group (33) had high total vascular plant cover (>65%), low litter, lichen and bare soil cover ($\leq$10%) with moss cover ranging from 0.05-40% and rock from 0-55%. Sample locations were at high elevation (>1700 m) on medium textured soils with pH of 4-6 and moisture regime of submesic to subhydric. Eight of nine sample locations were clustered together at the high end of the moisture gradient and low end of the log Ca in the db-rda (Figure 2.7). *Carex nigricans*, *Caltha leptosepala* DC and *Juncus drummondii* were significant indicators.

The second group consists of two *Carex nigricans* sample locations (32). These had lower vascular plant cover (<25%) than that of group 33. Both sample locations were at high elevation (>2200 m) on soils with pH of >6 and mesic moisture regime. Soils of one sample location were organic and the second had medium texture. Rock cover was high, lichen cover ≤30% and that of litter, moss and bare soil was ≤10% each. Cover of *Carex nigricans* was sparse in one sample location and higher in the other. These sample locations were widely separated in the db-rda plot indicating little similarity between them (Figure 2.7). There were no significant indicator species for this group (Table 2.2).

Forb types

Anemone occidentalis S. Wats.

There were two sample locations within the *Anemone occidentalis* group, both of which occurred at high elevation (>2200 m) on medium textured soils with a pH of 5 and 7 and moisture regime of xeric and submesic. *Anemone occidentalis* and *Luetkea pectinata* dominated one sample location and *Anemone* and *Selaginella densa* the other. Cover of litter and bare ground was low (≤5%), and lichen and moss cover were each ≤20%. Cover of rock varied. Sample locations were separated along the moisture gradient in the constrained ordination reflecting a difference in moisture regime between the two sample locations (Figure 2.7). Both sample locations were positively correlated with elevation and total lichen cover. Significant indicators for this group included *Anemone occidentalis*, *Arnica mollis*, *Gaultheria humifusa* (Graham) Rydb., *Luetkea pectinata* and *Saxifraga occidentalis* (Table 2.2).

Parnassia fimbriata Konig.

There were two sample locations within the *Parnassia fimbriata* cluster; one was dominated by *Aquilegia formosa* Fisch. *ex* DC (a rare species in Alberta) and *Parnassia fimbriata*, and the other dominated by *Arnica cordifolia* and *Parnassia fimbriata*. Sample locations were between 1600 and 1900 m on medium textured soils with pH between 6 and 6.5. The moisture regime of both sample locations was subhygric. Cover of rock, soil, lichen and litter was low (≤5%), and cover of moss was high (>40%). The response of sample locations along an environmental gradient was related to moisture regime and moss cover (Figure 2.7). Significant indicators for this group were *Aquilegia formosa*, *Rhododendron albiflorum* and *Parnassia fimbriata* (Table 2.2).

Trollius albiflorus (A. Gray) Rydb.

Three sample locations were dominated by *Trollius albiflorus*, all at high elevation (>2000 m) on medium textured soils. Soil pH varied between sample locations, and moisture regime was ranked as mesic to subhygric. Cover of bare ground, lichen, litter and rock was <1% each and cover of moss ≤20%. Vascular plant cover was high and was dominated by *Trollius albiflorus* and *Valeriana sitchensis* Leiberg. Two of the three sample locations were in close proximity to each other on the db-rda plot, and sample locations were positively associated with elevation (Figure 2.7). *Castilleja rhexifolia*

Rydb., *Mitella pentandra* Hook., *Pedicularis bracteosa* Benth., *Trollius albiflorus* and *Valeriana sitchensis* were significant indicators for this type.

<u>*Artemisia norvegica*</u>

There were nine sample locations within this group, all at high elevation (>1900 m) on soils with pH <6. Soil texture varied between sample locations and moisture regime was rated from xeric to mesic. Total vascular plant cover varied between sample locations with *Artemisia norvegica* dominating. Co-dominant taxa also varied between sample locations and included *Anemone occidentalis, Kobresia myosuroides, Luzula arcuata, L. spicata* and *Saxifraga bronchialis* L.. Cover of litter, lichen, moss and bare soil was ≤10%. Sample locations were dispersed on the ordination diagram (Figure 2.7), and there did not appear to be a common response to environmental variables. *Artemisia norvegica* was the only significant indicator for this group.

<u>*Artemisia michauxiana* Bess.</u>

There were three sample locations within the *Artemisia michauxiana* group. Sample locations were distributed across a range of elevations, and pH and moisture regime varied between them. Cover of rock was high in some sample locations, lichen and moss were ≤40% and litter and bare soil ≤5 each. Total vascular plant cover was ≤31% with *Artemisia michauxiana* either dominating or co-dominating sample locations. There was no common response to measured environmental variables. *Artemisia michauxiana* and *Silene hitchguirei* Bocquet were significant indicators.

Discussion

Classification

Classification of the vegetation sampled as part of this study resulted in 58 broad vegetation types within the study region, some of which consisted of several plant communities or associations (Table 2.3). There was little concordance among previous authors (Corns and Achuff 1982; Beckingham et al. 1996; Willoughby and Alexander 2003; Willoughby et al. 2005) in terms of their descriptions of plant communities of the area; thus there was no pre-existing standard taxonomy/nomenclature for types. Lack of consistency in sampling methodologies and analytical techniques between these studies makes it difficult to synthesize and subsequently classify vegetation types. This has made it difficult to compare the groups arising from this analysis with prior work; however, an attempt was made to "cross-walk" plant community and vegetation type descriptions of previous studies (Corns and Achuff 1982; Beckingham et al. 1996; Willoughby and Alexander 2003; Willoughby et al. 2005) to those of this work (see Table 2.3). A unified approach to plant community classification would further our understanding of the distribution of plant communities, as iterated by Daubenmire (1943) and Strong (2002). Damm (2001) has attempted such an approach using the European phytosociological method (Braun-Blanquet) for the alpine types of Glacier National Park.

Distribution of vegetation types in relation to environmental variables

Distribution of vegetation types in the study area was primarily along an elevational gradient for all physiognomic types as shown in the constrained ordinations. Elevation is the primary factor controlling vegetation in the Rockies of North America, although topographic moisture gradient (Lee and LaRoi 1979b; Peet 1988), aspect and slope are important correlates, at least of forested vegetation (Whittaker 1956; Barbour 1988; Peet 1988; Busing et al. 1993; Boyce 1998). Elevation also controls other variables such as temperature and precipitation (Whittaker 1956; Whittaker 1960; Austin, et al. 1984; Reed et al. 1993; Urban et al. 2002), with temperature decreasing and precipitation increasing with elevation (Daubenmire 1943). Total soil organic matter content and nitrogen increase, but temperature and length of growing season decrease with elevation and valley bottoms may experience inversions where cold air drains (Daubenmire 1943). Both precipitation (Woodward and Williams 1987; Corney et al. 2004; Darmody et al. 2004) and temperature (Wohlgemuth 1998; Corney et al. 2004; Darmody et al. 2004; Belland 2005) are known to be strong environmental variables that are correlated with distribution of vegetation. Pattern of snow distribution and duration are known to drive community pattern in the alpine (Bamberg and Major 1968; Ogilvie 1969; Kuchar 1975; Peinado et al. 2005), with chionophobous (intolerant of snow) species occurring in areas such as windswept ridges that become snow-free early in the season, and chionophilous (tolerant of snow) species that occur in depressions where snow cover is of longer duration (snowbeds and mesic slopes) (Kiener 1939; Johnson and Billings 1962; Bliss 1966; Beder 1967; Bamberg and Major 1968; Webber and May 1977; Komárková and Webber 1978; Isard 1986; Billings 1988; Walker and Halfpenny 1993; Boyce et al. 2005). This pattern has been observed in other studies of the alpine vegetation of the Rocky Mountains of Alberta (Ogilvie 1969; Hrapko and La Roi 1978; Mortimer 1978). Distribution of snow may also be an important factor in determining distribution of nitrogen and phosphorus (Bowman 1992; Walker and Halfpenny 1993).

Distribution and duration of snow cover is related to aspect in mountainous regions with snow accumulating and lasting longer on north- and east-facing slopes (Daubenmire 1943). The effect of aspect was apparent only in some of the alpine vegetation types (herb dominated 5 x 5 m plots), suggesting the importance of snow accumulation. In particular, *Cassiope mertensiana* and *Phyllodoce glanduliflora* dominated communities were associated with northerly slopes, a reflection of their dominance in areas with deeper snow accumulation. *Cassiope* in particular was also associated with higher moisture regimes. My findings are in direct contrast to the work of Hettinger (1975) who indicated that the influence of aspect and slope in determining vegetation types decreased with increased elevation in the Vine Creek basin of Jasper National Park. Kuchar (1975), however, found that aspect and slope, after snow depth and timing of snow melt, were important drivers of alpine vegetation of the Bald Hills. Aspect may also be correlated with other variables such as C:N ratios and pH (Boyce et al. 2005) although such a relationship was not apparent in this study.

The importance of moisture regime and elevation in influencing vegetation of Jasper and Banff National Parks was summarized by LaRoi and Hnatiuk (1980), where they noted that *Koeleria-Calamagrostis* grassland was at the driest end of the low elevation types, followed by Douglas-fir stands on submesic-to mesic sites, *Picea glauca* on mesic sites and black spruce forest and fens on subhygric and hygric sites. They found that Engelmann spruce-subalpine fir forest occupied a range of moisture regimes at mid-elevations, with *Kobresia* steppe on xeric sites in the alpine, *Dryas* scrub on submesic sites, *Cassiope* heath on mesic sites, *Trollius* meadows on subhygric sites and

Eriophorum fens on hygric sites at high elevation. I found that moisture regime was not an important driver for determining distribution of forested or shrub dominated vegetation types, but it was for herbaceous types with late lying snowbeds (*Cassiope mertensiana* and *Carex nigricans* types) and wet meadows (*Carex spectabilis*, *Parnassia fimbriata*, low shrub types) associated with high moisture regimes. Vegetation types associated with wind-swept ridges (*Dryas integrifolia*) were associated with low moisture.

Type of parent material (siliceous or limestone) has been shown to affect vegetation of both forested (Despain 1973) and alpine communities (Mooney et al. 1962; Whittaker and Niering 1968; Mortimer 1978; Billings 1988). Soil pH can be used as an attribute to determine the effect of type of parent material on vegetation as pH is directly affected by the geological substrate (Kiener 1939). Soil pH itself is known to be an important factor determining the distribution of vegetation (Mortimer 1978; Reed et al. 1993; Diekmann and Falkengren-Grerup 1998; Michalet et al. 2002; Corney et al. 2004; Pärtel et al. 2004), as it affects a number of soil properties including nutrient uptake and microbial activity (Brady and Weil 2004). However, in this study it was identified as an important variable for the shrub dominated (10 x 10 m) sample locations only. Lower elevation sample locations of the valley bottoms were associated with high pH, while high elevation open coniferous sample locations (krummholtz *Abies bifolia*) were at the lower end of the pH gradient. Nutrient availability is affected by microtopography, duration of snow cover (Michalet el al. 2002) and elevation (Daubenmire 1943).

Soil nutrients, specifically arcsine total P, arcsine total N, log exchangeable Ca and log exchangeable K were determined to be associates of observed vegetation pattern. P and K were associates in forested types, while P, N and Ca were important in types dominated by herbaceous vegetation. High total N was correlated with several of the higher elevation vegetation types, particularly *Cassiope tetragona* and *Phyllodoce glanduliflora.* Soil organic content and amount of nitrogen are known to increase with elevation (Daubenmire 1943), and work in Colorado has shown that high elevation snowbeds accumulate nitrogen, which is then released to adjacent vegetation as the snow melts (Bowman 1992). This may explain the high levels of nitrogen in the sample locations in which it is found. High soil N was not correlated with the vegetation types where snow beds are of longer duration (i.e. *Cassiope mertensiana*, *Carex nigricans*), and this may be the result of denitrification in the saturated soils associated with these sample locations and/or redeposition of nitrogen that has accumulated in the snow bed to adjacent communities through flow of meltwater (Bowman 1992). The importance of P in influencing vegetation growth was apparent in high elevation sample locations, where high P levels were correlated with the *Salix arctica* types and low levels were associated with *Empetrum nigrum, Vaccinium uliginosum* and *Alnus-Ribes* types. Availability of P is related to soil pH (Brady and Weil 2004) and all sample locations associated with high levels of phosphorus had high pH (and vice versa).

Amounts of available N and P may also be associated with fire history, with higher nutrient levels in areas that are either unburned or in areas where there has been a longer time since fire (Hettinger 1975); fire becomes less frequent although perhaps more intense with increasing elevation in the northern Rockies (Tande 1979). High log exchangeable K was correlated with low elevation trembling aspen and Douglas-fir forests, which is in keeping with other vegetation work in Jasper National Park (Stringer and La Roi 1970; Hettinger 1975). This may be related to the effect of soil pH on uptake of potassium, which is reduced in soils with low pH (Brady and Wiel 2004), such as those associated with the high elevation *Abies* and *Picea engelmannii* stands. High amounts of calcium are, in part, a reflection of high soil pH (Patten 1963), the calcareous nature of many of the substrates of the Front Ranges and in part on the aridity of sites in the valley bottoms where leaching of nutrients, such as calcium, is less extensive than for wetter areas (Brady and Weil 2004). Calcium was found to be an important variable associated with the distribution of high elevation vegetation types on dry, high pH sample locations.

Soil texture and depth were also important variables determining the distribution of vegetation with trees developing on sites with thin or rocky soils, while grasslands were located on deep fine-textured soil (Peet 1988). However, here the influence of soil texture on vegetation was apparent only for the shrub dominated sample locations with *Salix drummondiana* associated with coarse textured soils of riparian systems. Other factors, such as elevation and soil nutrients, were more important drivers of the vegetation distribution of treed sample locations.

Elevation and total cover of moss on the ground surface were the only two of the measured environmental variables that were significant across all plot sizes (physiogonomic groups). The amount of bare soil was identified as an important associate of the first three axes of the ordinations for the forested (20 x 20 m) plots. The grassland type in the 20 x 20 m plot was positively associated with amount of bare soil, which is likely due to the aridity of the sample locations. Total rock cover was important only for sparsely vegetated habitats in the herbaceous (5 x 5 m) plots, and even then, only three of the clusters, calcareous cliff (2), calcareous outcrop (4) and calcareous ridge (23) showed a positive association. Total lichen cover was positively associated with one of the *Dryas* types, one of the *Salix nivalis* types and *Cassiope tetragona*. The majority of sample locations of each of these groups had high vascular plant cover ($\geq$50%). Total lichen cover was negatively associated with a sparsely vegetated calcareous ridge (23) and a low elevation shrub dominated wetland (12). Total moss cover was a signicant environmental variable for all plot sizes and was positively associated with *Abies bifolia* and *Picea engelmannii* forests (20 x 20 m plots) and *Parnassia fimbriata* and *Carex aquatilis* wetlands (5 x 5 m plots). The lack of relationship between the occurrence of the *Abies* vegetation type(s) and moss cover (in the analysis of the shrub-dominated 10 x 10 m plots) may be due to the higher elevation and open nature of these sample locations, where species such as *Cassiope* and *Phyllodoce* become important components of the ground cover. The *Populus tremuloides* forest type, two shrub dominated types, *Salix glauca* and *S. drummondiana* and *Vaccinium uliginosum* type were negatively associated with moss cover.

I have not factored non-environmental variables into an assessment of variables affecting distribution of vegetation on the landscape within the study area. Historical factors

(McGlone 1996; Wohlgemuth 1998; Graae et al. 2004), land-management activities (Luoto 2000; Yeo and Blackstock 2002), plant-animal (mutualism, herbivory etc.) and plant-plant interactions (i.e. competition) may be important in understanding patterns of plant community composition and distribution. I have tried to reduce the impact of land-management activities by working in protected areas, which are largely remote and where issues such as habitat loss through cultivation, forest harvesting, mining, etc. and alteration through grazing by domestic livestock are minimized when compared with the matrix in which they are found.

Disturbance history, primarily fire, has been an important determinant of vegetation in the Rocky Mountains throughout North America (Peet 1988). Most of the vegetation of Jasper National Park has been affected by fire in the past (Holland and Coen 1982). Tande (1979) showed that historically, there were frequent low to medium intensity fires in the forests around Jasper townsite with few high intensity fires. Reduced fire frequency in the last century, which may be related to fire suppression, initiated in 1913, has resulted in changes to vertical and horizontal structural diversity in coniferous forests in Jasper National Park (Tande 1979) and to increases in forest cover and canopy closure (Rhemtulla et al. 2002). Prescribed fire is being reintroduced into Jasper National Park with at least two burns located within the study area over the past 10 years (Rocky River valley and Palisades).

Climatic variables, including those for micro-climate, were not incorporated in the study, although their importance in terms of influencing vegetation is recognized (Proctor 1967;

Birks and Deacon 1973; Woodward and Williams 1987; Myklestad and Birks 1993; McLaughlin 1994; Wohlgemuth 1998; Duckworth et al. 2000; Corney et al 2004; Darmody et al. 2004; Belland 2005). Climatic data were not available at a fine-enough resolution for use given the areal extent of the the study area and large elevational gradients. Other correlates to distribution of vegetation for which I was unable to collect specific information include duration of snow pack (Weir and Wilson 1987), radiation index (Austin et al. 1984), disturbance history (Peet 1988), frost action (Billings 1988), water availability and temperature (Boyce et al. 2005). Some of these might account for a large part of the variance left unexplained.

Comparison of vegetation types to others from the Rocky Mountains of Alberta

Forests

Several forest types were recognized during the course of this study. Stands of Douglas-fir, trembling aspen and white spruce were typically found on valley bottoms and lower slopes of the montane and lower subalpine subregions. Lodgepole pine stands exhibited the greatest range in elevational gradient and forests of Engelmann spruce and subalpine fir, often in association with lodgepole pine, dominated the subalpine. Open forests were located in the upper subalpine where climate (Daubenmire 1943) and soil becomes limiting for tree growth (Billings 1988) or in the valley bottom where moisture (Daubenmire 1943), temperature inversions (Beder 1967; Ogilvie 1969), grazing and/or fire history may impeed forest development (Stringer 1973).

Picea glauca

The white spruce forests of Jasper National Park have not been studied in as much detail as lodgepole pine and Douglas-fir forest types in the area, although work by Hettinger (1975) in the Vine Creek basin of Jasper National Park included several stands of *Picea glauca*. The fire history of the *Picea glauca* stands sampled is not known, but the majority of the study area has been influenced by fire to some degree (Tande 1979; Corns and Achuff 1982).

Several types of white spruce forest were noted, three of which resemble the C2 *Picea glauca/Thuidium abietinum* type of Corns and Achuff (1982), the MN c5.3 white spruce/feather moss-wiry fern moss type of Beckingham et al. (1996) and the E12 *Picea glauca*/moss community type of Willoughby et al. (2005). These stands have low shrub cover and are associated with northerly slopes on aeolian and fluvial landforms near the east gate of Jasper (Corns and Achuff 1982) and from the Cadomin area on the Front Range east of the National Park (Allen 2005). This type is currently on the tracking list of rare community types for Alberta and is ranked S2S3 (Allen 2005).

One sample location had a high component of *Shepherdia canadensis* in the understory and resembled the C37 *Picea glauca/Shepherdia canadensis/Hylocomium splendens* type of Corns and Achuff (1982), the MN c5.1 white spruce/Canada buffalo-berry/hairy wild rye/wiry fern moss of Beckingham et al. (1996) and the E12 *Picea glauca*/moss type of Willoughby et al. (2005). This type is associated with mesic sitestands with northerly aspect in both Banff and Jasper (Corns and Achuff 1982) and is also known from Kananaskis in Alberta (Kondla 1978) and the Yukon (La Roi 1964; Douglas 1974 IN: Achuff 1989).

One sample location had *Pseudotsuga menziesii* as co-dominant and it occurred on a northeast-facing slope in the valley of the Athabasca River. It was closest to the C5 *Picea glauca-Pseudotsuga menziesii/Hylocomium splendens* type of Corns and Achuff (1982), the MN c5.3 white spruce/feather moss-wiry fern moss of Beckingham et al. (1996) and the E10 *Picea glauca-Pseudotsuga menziesii/Spirea betulifolia* type of Willoughby et al. (2005).

The C5 type of Corns and Achuff (1982) has a limited distribution outside of the Canadian Rocky Mountain National Parks. The *Picea glauca/Equisetum arvense*/moss type of my study was in the valley of the Miette River on organic soil with a subhygric moisture regime. It most closely resembled the C4 *Picea glauca/Rosa acicularis/Equisetum arvense* type of Corns and Achuff (1982), MN c5.3 white spruce/feather moss-wiry fern moss of Beckingham et al. (1996) and E12 *Picea glauca*/moss type of Willoughby et al. (2005). The C4 type of Corns and Achuff (1982) is found on subhygric to hygric sites in the Montane subregion of Banff and Jasper National Parks and similar types extend from the southern Northwest Territories to Montana (see references in Achuff 1989). The mixedwood stand of *Picea glauca-Populus tremuloides-Betula papyrifera/Bromus inermis*/moss type was found in the Athabasca River valley of Jasper National Park near an area with a long history of human habitation. It was closest to the C16 *Populus tremuloides/Elymus innovatus/Lathyrus ochroleucus* type of Corns and Achuff (1982), MN c5.3 white spruce/feather moss-wiry fern moss (Beckingham et al. 1996) and E12 *Picea glauca*/moss type of Willoughby et al. (2005). The C16 type is associated with mesic sites of southerly aspects in Banff and Jasper (Corns and Achuff 1982) and is known from elsewhere in the Canadian Rockies of Alberta, British Columbia and the Yukon (Corns and Achuff 1982). There was one more mixedwood stand described as part of this study, a *Populus balsamifera-Picea glauca/Leymus innovatus*/moss type associated with the valley of the Berland River. This type most closely resembled the C17 *Populus balsamifera/Shepherdia canadensis* type of Corns and Achuff (1982) a type associated with fluvial landforms, the MN c3.1 balsam poplar/Canada buffalo berry/hairy wild rye type of Beckingham et al. (1996) and the F7 *Populus tremuloides-P. balsamifera-Picea glauca/Calamagrostis rubescens* type of Willoughby et al. (2005). A type similar to C17 of Corns and Achuff (1982) is known from the Yukon and Kananaskis (see references in Achuff 1989). It has not been reported from Willmore Wilderness or Kakwa Wildland Parks.

Populus tremuloides

All sample locations but number 116 (the burned lodgepole pine sample location) fell into the C16 *Populus tremuloides/Elymus innovatus/Lathyrus ochroleucus* type of Corns and Achuff (1982), MN c3.2 Aw/Canada buffalo-berry/hairy wild rye type of Beckingham et al. (1996) and *Populus tremuloides/Rosa acicularis/Elymus innovatus* type of Willoughby et al. (2005), which occur on mesic montane to subalpine, generally south-facing slopes. The presence of *Taraxacum* as a significant indicator for this type suggests that many of these stands are subject to some form of disturbance such as described by Tande (1979), where he indicated that aspen forests are generally associated with naturally disturbed upland areas (scree slopes, avalanche paths, fans and till deposits). Most of the stands that were sampled were located in close proximity to human-modified habitats such as roads and trails and this may explain the high indicator value for *Taraxacum*. This type of community has also been described for Kakwa Falls (Jacques and van Eck 1979) and from many other areas throughout the mountains and foothills of Alberta (Corns and Achuff 1982).

Pseudotsuga menziesii

The Douglas-fir forests of Banff and Jasper National Parks have been described by Stringer and La Roi (1970), Corns and Achuff (1982) and Achuff (1989). Closed forests are dominated by Douglas-fir with an understory dominated by *Leymus innovatus* and are classified as a *Pseudotsuga menziesii/Elymus innovatus* association (Stringer and La Roi 1970), C1 *Pseudotsuga menziesii/Elymus innovatus* vegetation type (Corns and Achuff 1982), MN c1.2 *Pseudotsuga menziesii/Elymus innovatus/Thuidium abietinum* type (Beckingham et al. 1996) and E6 *Pseudotsuga menziesii/Elymus innovatus* type (Willoughby et al. 2005). Such forests are discontinuous in their distribution within Jasper National Park, have subxeric to mesic moisture regimes (Achuff 1989; Willoughby et al. 2005), are restricted to valley bottoms and lower slopes (Stringer and La Roi 1970; Corns and Achuff 1982) and are often associated with Brunisols or Regosols (Achuff 1989) where profile development is poor, pH neutral to acid, levels of available nitrogen and phophorus are low and potassium levels are high (Stringer and La Roi 1970).

Trembling aspen and lodgepole pine often replace these forests after fire (Stringer and La Roi 1970). The mean age of stands in Jasper National Park described by Stringer was 258 years in 1965 (Stringer and La Roi 1970). Age of the stands was not surveyed as part of this study but trees of all sample locations were large and many had obvious signs of stress (dead and/or dying trees).

Stringer and La Roi (1970) found that diversity of the understory was low in these stands but noted that *Juniperus communis*, *Rosa acicularis*, *Shepherdia canadensis* and *Elymus innovatus* had high prominence values. Composition of the stands of this study was similar with *Rosa* occurring in every sample location and *Shepherdia* and *Leymus* [*Elymus*] in all but one.

Stringer and La Roi (1970) found that the environmental factors that were found to be significantly associated with the presence of Douglas-fir forests in Banff and Jasper National Parks were maximum stand age, available potassium at 25 cm and aspect. While available potassium was not measured as part of this study, total exchangeable potassium was significantly associated with the distribution of treed sample locations as shown on the db-rda plot. La Roi and Hnatiuk (1980) indicated that available K was highest in low elevation dry stands and lowest in mesic high elevation stands.

All but one of the sample locations surveyed, a *Pseudotsuga menziesii/Juniperus communis* type, fit the C1 *Pseudotsuga menziesii/Elymus innovatus* type of Corns and Achuff (1982). This sample location was located on a SW-facing slope of the Athabasca River valley and was comparable in composition and structure to the O5 *Pseudotsuga menziesii/Juniperus communis/Arctostaphylos* vegetation type of Corns and Achuff (1982), a type restricted to xeric to subxeric, moderate to steeply sloping erosional scarps with southerly aspects (Corns and Achuff 1982; Achuff 1989).

Douglas-fir reaches its northern limit in Alberta in Jasper National Park and is not known from Willmore or Kakwa Wildland Provincial Parks.

Lodgepole pine

La Roi and Hnatiuk (1980) provided a synthesis of the ecology and classification of pine forests in Banff and Jasper National Parks and noted that most stands occurred in moderate to well-drained drainage classes with poor soil profile development. I did not find an association between presence of sample locations to either elevation or soil moisture, in spite of elevation being a significant factor affecting the distribution of forest types. Pine sample locations were distributed along the elevational gradient suggesting that for pine stands at least, elevation is not the most important variable controlling distribution. None of the other measured environmental variables, including moisture regime were significantly associated with the distribution of pine in the study area.

Much of the study area has been burned in the past (Tande 1979; La Roi and Hnatiuk 1980; Achuff and Corns 1982) although fire suppression has been evident for many years, particularly in the federal and provincial parks. Physical site factors rather than fire appear to have a greater impact on determining composition of the understory in pine stands (La Roi and Hnatiuk 1980).

La Roi and Hnatiuk (1980) recognized five different *Pinus contorta* associations in Banff and Jasper National Parks, and of the four types, only the *Pinus contorta/Shepherdia canadensis/Leymus innovatus* and *P. contorta/Ledum groenlandicum/Vaccinium scoparium* types appeared to be represented within the stands that I sampled. The *Pinus contorta/Shepherdia canadensis/Leymus[Elymus] innovatus* association is a montane type typically found on the slopes of the major river valleys (Hnatiuk and La Roi 1980), and four of the fourteen stands sampled during the course of this study fell into this association. It was closest to the C19 *Pinus contorta/Shepherdia canadensis/Linnaea borealis* association of Corns and Achuff (1982), the subalpine c1.1 *Pinus contorta/Shepherdia canadensis/Elymus innovatus* type of Beckingham et al. (1996) and E5 *Pinus contorta/Shepherdia canadensis/Calamagrostis rubescens* type of Willoughby et al. (2005). The C19 type of Corns and Achuff (1982) is known from other locations in the Canadian Rockies including Kakwa Wildland Park (Jacques and van Eck 1979).

The *P. contorta/Ledum groenlandicum/Vaccinium scoparium* type of La Roi and Hnatiuk (1980) occurs on sites with cold, poorly drained sites with a short growing season. It is closest to the C29 *Pinus contorta/Ledum groenlandicum* type of Corns and Achuff

(1982), a type found on northerly slopes in the montane and lower subalpine (Corns and Achuff 1982). It also closely resembles the SA d1.6 *Pinus contorta*/feathermoss type of Beckingham et al. (1996), the SASME3 *Pinus contorta-Picea engelmannii*/moss spp. type of Willoughby and Alexander (2003) and *Pinus contorta/Ledum groenlandicum/Vaccinium scoparium/Pleurozium schreberi* type of Strong (2002). This is a rare community type in Alberta (Allen 2005) and is known from Banff and Jasper National Parks and the northern foothills of Alberta (Corns and Achuff 1982).

The *Pinus contorta/Vaccinium caespitosum-V. scoparium, Pinus contorta/Vaccinium caespitosum*/moss and *Pinus contorta-Picea engelmannii/Vaccinium scoparium*/moss types of this study are closest to this association and occurred on mesic sites at higher elevation. The majority of the other sample locations resembled the C11 *Pinus contorta-Picea* spp./*Hylocomium splendens* type of Corns and Achuff (1982) and the SA c1.6 and d1.6 Pl/feathermoss of Beckingham et al. (1996), which are on mesic gently sloping sites with northerly aspects (Corns and Achuff 1982). This type was not described by La Roi and Hnatiuk (1980) but is known from Banff and British Columbia (Corns and Achuff 1982).

I had one representative of the C36 *P. contorta-Picea glauca/Salix glauca/Elymus innovatus* vegetation type of Corns and Achuff (1982); a type resembling the SA c3.3 Engelmann spruce/willow-hairy wild rye type of Beckingham et al. (1996) and *Pinus contorta*/moss type of Willoughby et al. (2005). This type is usually found on gentle to moderate slopes of various aspects (Corns and Achuff 1982).

Abies bifolia

Forests dominated by *Abies bifolia* are known from Kakwa (Jacques and van Eck 1979), Willmore (Lane et al. 2001) and Jasper National Park (Tande 1979; La Roi and Hnatiuk 1980; Corns and Achuff 1982). The stands described as part of this study were either open or closed (>20% tree cover) and may or may not have been associated with other tree species, particularly Engelmann spruce. They were distributed at high elevation and the low end of the log K gradient which is in keeping with the findings of LaRoi and Hnatiuk (1980).

The relationship of sample locations described as part of this study to previously described types is presented in Table 2.3. Most stands fell into the O10 *Picea engelmannii-Abies lasiocarpa/Phyllodoce glanduliflora-Cassiope mertensiana* and C14 *Picea engelmannii-Abies lasiocarpa/Menziesia glabella/Vaccinium scoparium* types of Corns and Achuff (1982). The O10 and C14 types are associated with mesic sites in the subalpine, primarily on north-facing slopes—C14 at lower elevations than O10 (Corns and Achuff 1982). Both types are known from other areas in Alberta and British Columbia (Corns and Achuff 1982). The *Abies bifolia-Picea engelmannii/Vaccinium scoparium* stands resembled the C15 *Picea engelmannii/Vaccinium scoparium* type of Corns and Achuff (1982), SA d26 Engelmann spruce/subalpine fir/feathermoss type of Beckingham et al. (1996) and E18 *Picea engelmannii/Vaccinium scoparium* type of Willoughby et al. (2005). The C15 type is typically on mesic south-facing slopes in the upper subalpine (Corns and Achuff 1982), although in this case it occurred on one with a northeast aspect. It is distributed from northern Jasper south and westward to Washington

State (Corns and Achuff 1982) and is not known from Willmore Wilderness or Kakwa Wildland Provincial Parks.

Two sample locations fell into the C21 *Picea engelmannii-Abies lasiocarpa/Vaccinium membranaceum/Barbilophozia locopodioides* vegetation type of Corns and Achuff (1982), a subalpine type of steep slopes of various aspects. The two sample locations occurred on northeast and southwest-facing slopes of 20 and 40° respectively in the Main Range of Jasper National Park. The C21 type is known from elsewhere in the foothills and Rocky Mountains of Alberta and British Columbia (Corns and Achuff 1982), but has not been described for Willmore Wilderness and Kakwa Wildland Parks.

Six additional sample locations of *Abies* were described using 10 x 10 m plots because of the open nature of the vegetation and low stature of plants (<2m). All sample locations were located at high elevation, and three of the six sample locations resembled most closely the S2 *Abies lasiocarpa-Salix* spp./*Valeriana sitchensis* type of Corns and Achuff (1982). The S2 type is associated with avalanche slopes in the subalpine and occurs in other areas in Alberta including Kakwa Wildland (Jacques and van Eck 1979) as well as in British Columbia and Montana (Corns and Achuff 1982). Equivalent types have not been described in either Beckingham et al. (1996), Kembel (2000) or Willoughby and Alexander (2003). Two of the other sample locations of this group had high cover of *Phyllodoce* and resembled either the O10 *Picea engelmannii-Abies lasiocarpa/Phyllodoce glanduliflora-Cassiope mertensiana* or the L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata* types of Corns and Achuff (1982) and ALPA3 *Cassiope* spp.-*Phyllodoce* spp. type of Willoughby and Alexander (2003) depending on the number of trees in the plot. Both types were associated with high elevation mesic areas and are widely distributed throughout Alberta and British Columbia (Corns and Achuff 1982). The fourth type represented in this group had a high cover of *Menziesia* in the understory and most closely resembled the C14 *Picea engelmannii-Abies lasiocarpa/Menziesia glabella/Vaccinium scoparium* type of Corns and Achuff (1982). This type is also known throughout the mountains of Alberta and British Columbia (Corns and Achuff 1982).

Picea engelmannii

A second group of high elevation forests that were dominated by *Picea engelmannii*, often in association with *Abies bifolia*, was described. *Abies* and *Picea* dominated stands are often considered to be one forest type by other authors (Daubenmire 1943; Moss 1955; Ogilvie 1969; Achuff 1989), and species composition of the *Abies* and *Picea* dominated sites is similar as shown by the close proximity on the dendrogram and the db-rda ordination. These two forest types also showed a similar response to measured environmental gradients of elevation, total moss cover, and log K. However, the *Picea* sample locations were, in general, at lower elevation than those of *Abies* and had species often associated with closed forests such as *Linnaea borealis* and *Ribes oxyacanthoides*. In contrast, many of the *Abies* dominated sample locations of this study had species such as *Antennaria lanata*, *Phyllodoce empetriformis* and *P. glanduliflora* that are associated with late snow snowbeds. Indicator species also differ between these two groups (Table 2.2) suggesting that they are different vegetation types. Engelmann spruce is a longerlived tree than subalpine fir and thus is more prevalent in mature stands (Ogilvie 1969). It is generally believed that fire is an important form of natural disturbance in the subalpine; wildfire results in the replacement of Engelmann spruce and subalpine fir by lodgepole pine (Daubenmire 1943; Ogilvie 1969).

Two sample locations of *Picea engelmannii* resembled the C31 *Picea engelmannii-Abies lasiocarpa/Elymus innovatus-Arnica cordifolia/Linnaea borealis/Hylocomium splendens* type of Corns and Achuff (1982), SA c3.4 Engelmann spruce/hairy wild rye type of Beckingham et al. (1996) and E8 *Picea engelmannii/Spirea betulifolia* type of Willoughby et al. (2005). The C31 type is restricted to mesic sites in the lower subalpine mainly in the Front Ranges and has been described from other areas in the mountains of Alberta (Corns and Achuff 1982). Only one of the two sample locations was in the Front Ranges (in Whitehorse Wildland Provincial Park), and the other was in the valley of the Miette River.

Two other sample locations resembled the C32 *Picea engelmannii/Equisetum arvense/Hylocomium splendens*, SA d2.7 Engelmann spruce/feather moss type of Beckingham et al. (1996) and E19 *Picea engelmannii* of Willoughby et al. (2005). These stands were situated north of Jasper National Park at low elevation and both had significant components of either *Equisetum arvense* or *E. pratense* in the understory. The C32 type is known from Jasper and Banff National Park and other areas in the mountains and foothills of Alberta (Corns and Achuff 1982). The *Picea engelmannii-Pinus contorta/Rhododendron groenlandicum*/moss stand resembled the C29 *Pinus* *contorta/Ledum groenlandicum* type of Corns and Achuff (1982) SA d1.4 Lodgepole pine/Labrador tea type of Beckingham et al. (1996), E8 *Pinus contorta/Spirea betulifolia* of Willoughby et al. (2003) and *Pinus contorta/Ledum groenlandicum/Vaccinium scoparium*/moss type of Strong (2002), a rare community type in Alberta (Allen 2005). The sample location of *Abies bifolia-Picea engelmannii/Menziesia ferruginea*/moss resembled the C14 *Picea engelmannii-Abies lasiocarpa/Menziesia glabella/Vaccinium scoparium* type of Corns and Achuff (1982), SA d2.5 Engelmann spruce/green alder/feather moss type of Beckingham et al. (1996) and E21 *Abies lasiocarpa-Picea engelmannii/Arnica cordifolia* type of Willoughby et al. (2005). The C14 type is found on mesic to subhygric sites in the lower subalpine in Banff and Jasper National Parks, and similar types are found throughout the mountains of Alberta (Corns and Achuff 1982), although not reported for Willmore Wilderness or Kakwa Wildland Parks. A second sample location resembled the *Abies bifolia-Pice engelmannii/ Menziesia ferruginea*/moss type, although it had more *Alnus viridus* in the understory.

Gymnocarpium dryopteris

There were sample locations in the *Gymnocarpium* cluster, all of which were similar to the *Abies* sample locations as shown by their proximity in the ordination plot; however, only two of these sample locations had *Abies* as a dominant or co-dominant species. One of these sample locations had a large component of *Pinus albicaulis* in the canopy, a species currently under threat from white pine blister rust (*Cronartium rubicola* J. C. Fisch.), and *Menziesia ferruginea* in the understory. This stand resembled the C12 *Picea engelmannii-Pinus albicaulis/Menziesia glabella* type of Corns and Achuff (1982) although this sample location was more open than what they described. It had a subhygric moisture regime and the highest levels of soil arcsine total N, arcsine total C, log exchangeable Ca, log exchangeable Mg and log CEC of any of the other sample locations dominated by *Abies bifolia* and/or *Picea engelmannii*. Timoney (1999) called this type W4 *Picea engelmannii-Pinus albicaulis/Menziesia ferruginea* and it is known from elsewhere in the mountains of Alberta and British Columbia (Corns and Achuff 1982).

The second *Abies* type in the *Gymnocarpium* cluster was a high elevation open forest on moraine. It was closest to the O6 *Picea engelmannii-Abies lasiocarpa/Salix spp./Aulocomnium palustre* type of Corns and Achuff (1982) and SA G1.1 Engelmann spruce/willow/horsetail type of Beckingham et al. (1996). The third sample location in the *Gymnocarpium* cluster did not have *Abies bifolia* in the canopy but was a *Betula papyrifera* stand, with *Menziesii ferruginea* and *Viburnum edule* dominating the understory. This type has not been described elsewhere in the northern Rocky Mountains of Alberta. Elevation was the only significant environmental variable for this cluster.

Shrublands

Several shrub dominated vegetation types were identified as part of this study, many of which were located in valley bottoms. Distribution of these types was associated with elevation, soil texture, pH and total moss cover. *Eleagnus commutata* types were associated with low elevations of the valley floor on calcareous materials, and the majority of the *Salix* types were at higher elevation. There was considerable overlap between the distribution of *Salix glauca* and *S. drummondiana*, with both types associated with lower elevation than the *S. barrattiana* and *S. farriae* types. *Salix farriae* and *S. drummondiana* types were associated with floodplains, with *S. farriae* occurring at higher elevation in areas with more moss cover. *Salix glauca* was also associated with floodplains, although it occurred at lower elevation than *S. farriae* and in areas with less moss cover such as would be expected with more dynamic systems.

Elaeagnus commutata

Stands dominated by *Elaeagnus commutata* were of limited distribution in the study area, and both sample locations were situated on the floor of the Athabasca River valley on subxeric to mesic sites with calcareous soils. This vegetation type is not described in Corns and Achuff (1982), Kembel (2000) or other studies of vegetation in the Rocky Mountains of Alberta. Willoughby and Alexander (2003) described an *Elaeagnus commutata-Rosa acicularis* community type from a hillside in the Castle River area of Alberta; however, associated species for this type are different that the ones described for this study. This type resembled most closely the prickly rose-silverberry grassland of Beckingham et al. (1996), a type associated with slopes having xeric to mesic moisture regimes. It may resemble the provincially rare *Elaeagnus commutata* riparian shrubland of Allen (2005), a riparian type known from several Natural Regions in Alberta.

Salix glauca

A *Salix glauca* vegetation type was recognized by Beder (1967) and Ogilvie (1969) as occurring along streams in valley bottoms where low temperatures preclude tree establishment (Ogilvie 1969) and where snow accumulation is high (Beder 1967). Crack

(1977) described a *Salix glauca* association from the lower subapine where there is high snow cover and shade in summer. *Antennaria lanata*, *Elymus innovatus*, *Phyllodoce glanduliflora* and *Aquilegia flavescens* were listed as associates.

Two of the sample locations resembled the S1 *Betula* spp.-*Potentilla fruticosa-Salix glauca/Tomenthypnum nitens* type of Corns and Achuff (1982), willow/cow parsnip-tall larkspur meadow of Beckingham et al. (1996) and *Salix glauca-Potentilla fruticosa/Elymus innovatus* type of Willoughby and Alexander (2003). Common associates include *Aster ciliolatus* [*Aster foliaceous*] (Beder 1967; Ogilvie 1969), *Betula glandulosa* (Beder 1967; Ogilvie 1969), *Carex aquatilis* (Corns and Achuff 1982), *Delphinium glaucum* (Beder 1967; Ogilvie 1969), *Deschampsia cespitosa* (Beder 1967; Ogilvie 1969; Corns and Achuff 1982), *Leymus [Elymus] innovatus* (Crack 1977), *Equisetum pratense* (Beder 1967; Ogilvie 1969), *E. scirpoides* (Beder 1967; Ogilvie 1969), *E. variegatum* (Beder 1967; Ogilvie 1969), *Pedicularis bracteosa* (Corns and Achuff 1982), *Phyllodoce glanduliflora* (Crack 1977), *Rubus acaulis* (Corns and Achuff 1982), *Salix drummondiana* [*S. subcoerulea*] (Beder 1967; Ogilvie 1969), *Salix farriae* (Beder 1967; Ogilvie 1969), *Selaginella selaginoides* (Beder 1967; Ogilvie 1969) and *Senecio indecorus* (Beder 1967; Ogilvie 1969). Associated species for the *Salix glauca* dominated sample locations of this study that were in common with other studies included *Betula glandulosa, Delphinium glaucum, Deschampsia cespitosa, Leymus innovatus, Pedicularis bracteosa, Rubus acaulis* and *Salix farriae*. Similar types have been described from other places in Alberta and in British Columbia (Corns and Achuff 1982).

A third sample location was closest to the *Abies lasiocarpa/Salix vestita-S. glauca/Artemisia norvegica* type of Kemble (2000), and there were no apparent equivalents in Corns and Achuff (1982), Beckingham et al. (1996), Willoughby and Alexander (2003) and Willoughby et al. (2005).

The open *Picea glauca/Juniperus communis* dominated sample location was closest to the O17 *Picea glauca/Juniperus communis/Arctostaphylos uva-ursi* type of Corns and Achuff (1982), the MN b5.1 white spruce/bearberry-juniper/wiry fern moss type of Beckingham et al. (1996) and the A7 *Arctostaphylos uva-ursi/Juniperus* spp. type of Willoughby et al. (2005).

Salix drummondiana

Two sample locations in which *Salix drummondiana* was the dominant species were found on the floodplain of creeks in the subalpine in Jasper National Park. The third sample location was along the Berland River in Willmore Wilderness Park, and here seedlings of *Picea glauca* were prevalent in the understory. Two members of *Salix drummondiana* group most closely resembled the S7 *Salix* spp./*Equisetum arvense* vegetation type of Corns and Achuff (1982), a type that occurs at low elevation in the montane and subalpine, often on fluvial landforms. There are no equivalents in Beckingham et al. (1996), Kemble (2000), Willoughby and Alexander (2003) or Willoughby et al. (2005). The third sample location did not resemble any of the described types. A *Salix drummondiana-Thalictrum* type has been described for Willmore

Wilderness Park (Lane et al. 2001); however, it does not appear to resemble this stand. This *Salix drummondiana* type appeared to be included within the *Salix glauca* association of Beder (1967) and Ogilvie (1969). Associated species include *Salix glauca, S. bebbiana, S. planifolia, S. myrtillifolia, S. farriae* and *Fragaria virginiana* (Corns and Achuff 1982), although in this study *S. bebbiana, S. planifolia* and *S. myrillifolia* were not represented in any of the sample locations. The herb and shrub layers are heterogenous (Corns and Achuff 1982) as a result of the successional nature of this type. The S7 type of Corns and Achuff (1982) is not known from outside of Banff and Jasper National Parks.

Salix farriae

Three sample locations dominated by *Salix farriae* were located in the floodplain of a subalpine stream in Jasper National Park. This group most closely resembled the S1 *Betula* spp.-*Potentilla fruticosa-Salix glauca/Tomenhypnum nitens* vegetation type of Corns and Achuff (1982), the willow/sedge/tufted moss-peat moss and graminoid fen types of Beckingham et al. (1996) and *Salix farriae-S. brachycarpa*-(*Salix* spp.)/herb type of Kemble (2000), although many of the forb taxa of Kemble's type were not represented in the stands sampled as part of this study. Corns and Achuff (1982) included plots dominated by *Salix farriae* and *S. glauca* in the same type (S1); however, my results suggest that these formed two distinct associations based on dominant taxa, associated species, and response to measured environmental variables. This type does not appear to be recognized by Willoughby and Alexander (2003) but may be included within the *Salix* type of Beder (1967) and Ogilvie (1969). Species associated with the S1 type of Corns and Achuff (1982) include *Carex aquatilis, Deschampsia cespitosa, Pedicularis bracteosa* and *Rubus acaulis. Carex aquatilis* was the only one of these four taxa represented in the plots sampled as part of this study, further suggesting the recognition of this as a separate type.

Salix barrattiana

Beder (1967), Ogilvie (1969), Trottier (1972) and Kuchar (1975) described *Salix barrattiana* associations as occurring along valley bottoms in areas with high water table and periodic sediment deposition (Knapik et al. 1973). Others (Corns and Achuff 1982; Timoney 1999; Willoughby and Alexander 2003) have indicated that it occurs in the subalpine on gentle slopes, particularly those with with northerly or easterly exposures (Corns and Achuff 1982) or in wet areas with deep snow cover (Crack 1977). Both sample locations of this study were at located in the subalpine of Willmore Wilderness Park and Jasper National Park.

This type resembled the S8 *Salix barrattiana/Potentilla diversifolia* type of Corns and Achuff (1982) and the SA i2.1 willow/sedged/tufted moss-peat moss type of Beckingham et al. (1996), and one stand resembled the SACFB4 *Salix glauca-Betula glandulosa/Deschampsia cespitosa* type of Willoughby and Alexander (2003). *Achillea millefolium* (Trottier 1972), *Arnica mollis* (Beder 1967; Ogilvie 1969), *Artemisia norvegica* (Corns and Achuff 1989), *Aster foliaceous* (Beder 1967; Ogilvie 1969), *Carex atrosquama* (Crack 1977), *Cardamine umbellata[um]* (Crack 1977), *Cerastium arvense* (Crack 1977), *Delphinium glaucum* (Beder 1967; Ogilvie 1969), *Deschampsia cespitosa*

(Beder 1967; Ogilvie 1969), *Draba longipes* (Crack 1977), *Epilobium alpinum* (Beder 1967; Ogilvie 1969), *Erigeron peregrinus* (Corns and Achuff 1989; Willoughby and Alexander 2003), *Pedicularis bracteosa* (Timoney 1989), *Petasites vitifolius* (Crack 1977), *Phleum commutatum* (Willoughby and Alexander 2003), *Polygonum viviparum* (Timoney 1999), *Potentilla diversifolia* (Corns and Achuff 1989; Timoney 1999), *Salix glauca* (Beder 1967; Ogilvie 1969; Corns and Achuff 1982; Willoughby and Alexander 2003), *Senecio triangularis* (Beder 1967; Ogilvie 1969), *Solidago multiradiata* (Crack 1977), *Trisetum spicatum* (Trottier, 1972) and *Trollius albiflorus* (Beder 1967; Ogilvie 1969; Corns and Achuff 1982; Willoughby and Alexander 2003) have been listed as associates of the *Salix barrattiana* community type. All associated species, with the exception of *Arnica mollis*, *Aster foliaceous*, *Erigeron peregrinus* and *Potentilla diversifolia*, were noted from the two sample locations in my study; however, *E. peregrinus* and *P. diversifolia* were present in the association but not the plot used to determine cover. This type is known from other localities in Alberta (Corns and Achuff 1982).

Grassland

Grasslands in Jasper National Park are restricted to valley bottoms, primarily the Athabasca River and low elevation slopes. The floor of the Athabasca valley is covered with till, alluvium and glaciofluvial materials that have been worked by wind and water (Stringer 1973). Many of the grasslands were subject to fire in past and grazing by native ungulates (Stringer 1973) and appear to be of two types—*Koeleria macrantha* dominated on drier, grazed sites and *Achnatherum [Stipa] richardsonii* dominated on moister sites with less grazing pressure. *Artcostaphylos uva-ursi* can also be a significant component of the vegetation. An additional grassland type, *Festuca altaica*, has been described from the area north of Jasper National Park (Bork 1994, Lane et al. 2001). Stringer (1973) noted that pH, elevation, thickness of A horizon, available K and P and fecal pellet group counts were significantly correlated with the distribution of grassland types in the Alberta Rocky Mountain National Parks. The *Elymus-Koeleria* type of this study was correlated with low elevation and arcsine total P and high cover of bare soil in the 20 x 20 m plots, low elevation and high pH in the 10 x 10 m (*Arctostaphylos uva-ursi*) and low elevation and arcsine total P in the 5 x 5 m. Levels of log exchangeable K were not determined to be significant associates at either the 20 x 20 m or 5 x 5 m plot size in this study.

The *Elymus lanceolatus-Koeleria macrantha* vegetation type resembled the *Koeleria cristata* [*macrantha*]-*Calamagrostis montanensis* type of Stringer (1973), H6 *Koeleria macrantha-Artemisia frigida-Linum lewisii* type of Corns and Achuff (1982), MN a2.1 pasture sagewort grassland of Beckingham et al. (1996) and A1. *Artemisia frigida/Koeleria macrantha* type of Willoughby et al. (2005). Dominant plants as described by Stringer (1973) include *Calamagrostis montanensis*, *Koeleria cristata*, *Antennaria nitida[microphylla]/rosea*, *Artemisia frigida* and *Astragalus striatus* (Stringer 1973). The aridity of this habitat is due to low precipitation/evapotranspiration ratios which are caused by strong winds, coarse soil, low elevation and a rain shadow and is likely maintained by grazing (Stringer 1973). The H6 type of Corns and Achuff (1982) is known from elsewhere in the Rocky Mountains of Alberta including Willmore Wilderness Park (Lane et al. 2001).

Two of the three sample locations in the shrub dominated 10 x 10 m plots that had high cover of *Arctostaphylos uva-ursi* ($\geq$30%) were otherwise similar in species composition to the *Elymus lanceolatus-Koeleria macrantha* association of this study and the A1 *Artemisia frigida/Koeleria macrantha* grassland of Willoughby et al. (2005). Both of these sample locations were located in the valley bottom of the Athabasca River and there was evidence of use by ungulates. These sample locations resembled the H6 *Koeleria cristata-Artemisia frigida-Linum lewisii* and H7 *Agropyron dasystachyum-Artemisia frigida* vegetation types of Corns and Achuff (1982) and the bearberry grassland of Beckingham et al. (1996). One sample location dominated by *Pentaphylloides fruticosa-Betula pumila/Arctostaphylos uva-ursi* had a small amount of *Koeleria*; however, it has little other resemblance to the other members of the group and to the *Elymus-Koeleria* grassland. It was similar to the L1 *Potentilla fruticosa/Arctostaphylos uva-ursi/Galium boreale* vegetation type of Corns and Achuff (1982) and the willow-sedge meadow of Beckingham et al. (1996). This association was located in a calcareous meadow (pH 8) on a floodplain of the Maligne River in Jasper National Park.

Calamagrostis montanensis was found at only one site; however, many of the grasses were not blooming at the time of survey and it is possible that it was overlooked and not differentiated from vegetative *Koeleria*. An alternative explanation relates to grazing history. Stringer (1973) indicates that when grazing pressure is reduced in *Koeleria-Calamagrostis* grasslands, species such as *Elymus lanceolatus* [*Agropyron dasystachyum*] may attain a higher cover. There was evidence of grazing at all of the sites that I visited; however, the extent of grazing in relation to levels at the time of Stringer's work is unknown.

Stringer (1973) also recognized an *Achnatherum* [*Stipa*] *richardsonii* shrub savanna with dominant species of *Agropyron dasystachyum* [*Elymus lanceolatus*] *Bromus inermis* (ssp. *pumpellianus*), *Danthonia intermedia*, *Achnatherum richardsonii*, *Poa pratensis*, *Arctostaphylos uva-ursi*, *Fragaria virginiana*, *Penstemon confertus*, *Pentaphylloides fruticosa* and *Salix glauca*. This grassland type is similar to the H13 *Stipa richardsonii-Koeleria cristata-Antennaria nitida* vegetation type of Corns and Achuff (1982) and the *Selaginella densa/Stipa richardsonii* community type of Willoughby et al. (2005). These grasslands have a limited distribution in the study area (Corns and Achuff 1982), occurring in valley bottoms and the base of slopes on moister sites in the fescue prairie-coniferous ecotone of Banff and Jasper National Parks (Stringer 1973), and Willmore Wilderness Park (Lane et al. 2001). They appear to be a type that is dissimilar to any others in western Canada or the northwestern United States (Stringer 1973) with the closest alliance to the *Agropyron-Stipa* communities of the Peace River area (Moss 1952) and the *Festuca-Stipa richardonsii* association of the northern foothills (Loomon 1969). Stringer (1973) found that the vegetation cover in this grassland type was higher than that of the *Koeleria-Calamagrostis* type and that the impact of grazing was less evident. The results of this study do not support his findings as there were similar amounts of plant cover between the two types.

A third grassland type in which *Festuca altaica* dominates occurs north of Jasper National Park near Grande Cache and in Willmore Wilderness Park, at elevations between 1600 and 2000 m. This vegetation type appears to be restricted to the Rockies north of Jasper National Park as it has not been recognized by either Stringer (1973) and Corns and Achuff (1982). This type is similar to those described from Willmore by Bork (1994) and Lane et al. (2001).

The sample locations associated with the *Fragaria virginiana* and open graminoid clusters were unique and did not appear to have equivalents in Corns and Achuff (1982). The *Fragaria virginiana* group in particular was associated with disturbance such as the edges of trails and parking lots. These sample locations had similar species composition and responded in similar ways to the measured environmental variables suggesting recognition as a type. The open graminoid cluster however was an assemblage of various plant associations and did not therefore constitute a cohesive vegetation type.

Sparsely vegetated sites

Areas of sparse vegetation at high elevation are often described as boulder field (Daubenmire 1943), fell-field (Daubenmire 1943; Moss 1955), stonefield lichen community (Ogilvie 1969), rock lichen tundra (Hettinger 1975), lichen tundra (Kuchar 1975), rock tundra (Mortimer 1978) and saxicolous lichen vegetation type (Corns and Achuff 1982). Daubenmire (1943) and Moss (1955) differentiated fell-fields from boulder fields where boulder fields are dominated by large rocks and boulders, and plants are restricted to cracks between rocks where soil and snow accumulates and some protection from wind is afforded. In contrast, fell-fields are areas in which gravels accumulate between the boulders (Daubenmire 1943; Moss 1955). Ogilvie (1969) recognized two types of sparsely vegetated terrain which he termed stonefield lichen community and "plants of rock and talus". Subsequent authors have used other terminology and have often included *Dryas* dominated sites in which there is a significant amount of lichen cover as a rock tundra type (Kuchar 1975; Hrapko and La Roi 1978; Mortimer 1978). These types may also have less rock cover than other types.

Daubenmire (1943) and Moss (1955) list species that they consider to be associated with fell-field and boulder fields. Ogilvie (1969) does the same for stone lichen tundra and "plants of rock and talus". Plants associated with fellfield include *Dryas octopetala* Daubenmire (1943), *Erigeron compositus* (Daubenmire 1943), *Erigeron* spp. (Moss 1955), *Luzula spicata* (Daubenmire 1943), *Selaginella densa* (Daubenmire 1943) and *Silene acaulis* (Daubenmire 1943). Species associated with boulder fields include *Dryas octopetala* (Moss 1955), *Silene uralensis [Lychnis apetala]* (Moss 1955), *Oxyria digyna* (Daubenmire 1943; Moss 1955), *Poa alpina* (Moss 1955), *Salix nivalis* (Moss 1955) and *Sibbaldia procumbens* (Daubenmire 1943; Moss 1955). Stone lichen communities have *Oxytropis podocarpa* (Ogilvie 1969), *Papaver radicatum* [*P. kluanensis]* (Ogilvie 1969), *Salix nivalis* (Ogilvie 1969), *Silene acaulis* (Ogilvie 1969), *Smelowskia calycina* (Ogilvie 1969) and *Taraxacum ceratophorum* (Ogilvie 1969), and rock and talus slopes include *Campanula lasiocarpa* (Ogilvie 1969), *C. uniflora* (Ogilvie 1969), *Crepis nana* (Ogilvie 1969), *Eriogonum androsaceum* (Ogilvie 1969), *Saussurea densa* (Ogilvie 1969), *Saxifraga oppositifolia* (Ogilvie 1969).

Species associated with the rock lichen tundra of Hettinger (1975) include *Dryas octopetala [D. hookeriana], Festuca brachyphylla, Saxifraga oppositifolia* and *Trisetum spicatum.*

Sparsely vegetated types are poorly represented in current vegetation classifications for the northern Rocky Mountains. Corns and Achuff (1982) recognized a saxicolous lichen vegetation type (H12) that occurs on subxeric to xeric alpine sites; however, this type is restricted to non-calcareous areas. It is characterized as being dominated by lichens (<20%) with few vascular plants represented. Willoughby and Alexander (2003) refer to a lichen stonefield; however, little information is given upon which to classify vegetation. The results of this work suggest that classification of sparsely vegetated sites may be possible if sample and plot sizes are large enough as clusters were generally reflective of landform units (cliffs, river flats) and substrate type (acidic vs. calcareous).

Other sparsely vegetated sites in the northern Rockies of Alberta include low elevation cliffs, river/creek beds, lakeshores and rock outcrops. While cover of vegetation is sparse and composition is heterogeneous making classification difficult, these areas provide habitat for several rare taxa including *Barbarea orthoceras, Heuchera glabra, Koenigia islandica, Juncus biglumis, Pellaea glabella, Rorippa truncata, Sagina nivalis* and *Telesonix heucheriformis. Pellaea glabella* and *Telesonix heucheriformis* are restricted to calcareous cliffs and outcrops. Gravelly river flats provide habitat for *Barbarea orthoceras* and *Rorippa truncate*, and siliceous talus and moraine for *Heuchera glabra* and *Sagina nivalis*. *Koenigia islandica* and *Juncus biglumis* are associated with fine textured soils that have an input of water such as the edges of ponds, lakes and creeks.

Heaths

Communities dominated by ericaceous shrubs such as *Cassiope* and/or *Phyllodoce* usually occur in areas protected from wind where snow accumulates (Timoney 1999), with *Phyllodoce empetriformis* and *Cassiope mertensiana* found in areas of higher precipitation typical of the Main Ranges, and *P. glanduliflora* and *C. tetragona* in the drier habitats of the Front Ranges (Crack 1977). There were exceptions to this pattern as *Cassiope mertensiana* was found to occur with *P. glanduliflora* on occasion. Five groups were included within the heath class all of which are dominated by *Cassiope tetragona*, *C. mertensiana*, *Phyllodoce glanduliflora* or *Empetrum nigrum*. Sample locations dominated by *Cassiope tetragona* and *Empetrum* were more closely allied to the *Dryas* groups than to *Phyllodoce* and the other *Cassiope* groups (Figure 2.7). *Cassiope tetragona* can occupy sites that are more exposed and subject to colder temperatures than those of *Cassiope mertensiana* as *C. mertensiana* requires more protected areas with snow accumulation (Harder 1983). All but the *Cassiope tetragona* group was influenced by aspect. Aspect is an important variable influencing distribution of alpine plant communities with north- and east-facing slopes generally cooler and moister and west- and south-facing slopes warmer and drier (Kiener 1939; Daubenmire 1943; Ogilvie 1969; Boyce et al. 2005).

Cassiope tetragona

Communities dominated by *Cassiope tetragona* often in association with *Dryas octopetala* and/or *Salix nivalis* typically occur at high elevation on north-facing slopes where snow accumulates (Beder 1967; Kuchar 1975; Crack 1977; Hrapko and La Roi 1978; Mortimer 1978; Corns and Achuff 1982). *Dryas integrifolia* replaces *D. octopetala* in some sites (Mortimer 1978). All sample locations were included within the L7 *Cassiope tetragona-Dryas octopetala-Salix nivalis* type of Corns and Achuff (1982). Willoughby and Alexander (2003) include communities dominated by *Cassiope* and *Phyllodoce* in the ALPA3 *Cassiope* spp.-*Phyllodoce* spp. type.

Common associates, at least in the Alberta Rocky Mountains, include *Artemisia norvegica* (Beder 1967), *Carex albo-nigra* (Crack 1977), *Carex rupestris* (Mortimer 1978), *Dryas octopetala* (Crack 1977), *Equisetum scirpoides* (Beder 1967; Crack 1977), *Festuca brachyphylla* (Crack 1977), *Gentiana glauca* (Hrapko and La Roi 1978), *Oxytropis podocarpa* (Mortimer 1978), *Polygonum viviparum* (Ogilvie 1969; Mortimer 1978; Corns and Achuff 1982), *S. arctica* (Beder 1967; Ogilvie 1969; Hrapko and La Roi 1978; Corns and Achuff 1982), *Salix nivalis* (Crack 1977), *Saxifraga oppositifolia* (Mortimer 1978), *Silene acaulis* (Mortimer 1978) and *Tofieldia pusilla* (Mortimer 1978). All of these taxa except *Saxifraga oppositifolia* were associated with at least one member of the *Cassiope tetragona* type in the study area. The *Cassiope tetragona* group of this study was similar to the described types and is known from several areas throughout the Rocky Mountains of Alberta, British Columbia and Montana (Corns and Achuff 1982;

Damm 2001). However, it had not been described from Willmore Wilderness or Kakwa Wildland Provincial Parks prior to this study.

Phyllodoce glanduliflora

Phyllodoce glandulifora is a vegetation type associated with high elevation and moderate to deep snow cover (Beder 1967; Trottier 1972; Broad 1973; Crack 1977) often in openings in high elevation spruce-fir forests on north-facing slopes (Hettinger 1975; Trottier 1972; Kuchar 1975) on well-drained stable slopes (Knapik et al. 1973). Snow cover and duration are less than other snowbed communities such as those dominated by *Carex nigricans* (Broad 1973; Crack 1977).

Types dominated by *Phyllodoce glanduliflora* included the *Phyllodoce glanduliflora* type of Broad (1973) and Crack (1977), L5 *Phyllodoce glandulfilora-Cassiope mertensiana-Antennaria lanata* type of Corns and Achuff (1982), alpine heath (*Phyllodoce glanduliflora*) type of Griffiths (1982), Timoney (1999) and ALPA3 *Cassiope* spp.-*Phyllodoce* spp. type of Willoughby and Alexander (2003).

The *Phyllodoce glanduliflora* type is often included in a *Cassiope-Phyllodoce* type; however, it can be distinguished from that of *Cassiope mertensiana* by the dominance of *Phyllodoce* and presence of *Sibbaldia procumbens* and *Potentilla diversifolia* (Timoney 1999). *Potentilla diversifolia* was found in every sample location within the *Phyllodoce* group and not within the *Cassiope* group supporting the findings of Timoney (1999). *Sibbaldia*, however, was present in members of both groups. Common associates include

Antennaria lanata (Trottier 1972; Broad 1973; Corns and Achuff 1982), *Artemisia norvegica* (Corns and Achuff 1982), *Carex nigricans* (Crack 1977), *Cassiope mertensiana* (Timoney 1999), *Equisetum scirpoides* (Crack 1977), *Erigeron aureus* (Crack 1977), *Erigeron peregrinus* (Trottier 1972), *Festuca brachyphylla* (Crack 1977), *Pedicularis bracteosa* (Trottier 1972), *Potentilla diversifolia* (Trottier 1972; Crack 1977), *Salix arctica* (Beder 1967; Broad 1973; Corns and Achuff 1982), *Salix nivalis* (Crack 1977), *Sibbaldia procumbens* (Trottier 1972; Corns and Achuff 1982), *Vaccinium scoparium* (Beder 1967; Broad 1973) and *Veronica alpina* [*wormskjoldii*] (Trottier 1972). All species but *Equisetum, Erigeron aureus, E. peregrinus* and *Vaccinium scoparium* were found in sample locations described for this, and in addition *Campanula lasiocarpa*, *Castilleja occidentalis*, *Diphasiastrum alpinum* and *Poa arctica* were in almost every sample location, with *Antennaria* and *Diphasiastrum* being significant indicators for this type. The L5 type of Corns and Achuff (1982) occurs in several places in the Rocky Mountains of Alberta and British Columbia (Corns and Achuff 1982) and in Montana (Damm 2001) but it has not been described from Willmore Wilderness or Kakwa Wildland Parks.

Crack (1977) recognized an *Antennaria lanata* association found in hollows with deep and late lying snow on Wilcox Pass in Jasper National Park. It was found in close proximity to *Phyllodoce* where patches dominated by these two species alternated on tops and sides of hummocks or next to *Carex nigricans* dominated types (Crack 1977). Kuchar (1975) in a study of the vegetation of the Bald Hills, Jasper National Park described an *Artemisia norvegica-Antennaria lanata* type from east-facing slopes at high elevation where snow pack was deep. A distinct *Antennaria lanata* type was not recognized as part of this study and this species was often found in association with heath species primarily *Cassiope mertensiana* or *Phyllodoce* spp..

Cassiope mertensiana

Sample locations dominated by *Cassiope mertensiana* occur at high elevation primarily on north, north-east and east-facing slopes (Broad 1973; Hettinger 1975). These associations are similar to the L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata* type of Corns and Achuff (1982) and *Cassiope mertensiana-Phyllodoce glanduliflora* community type of Hrapko and La Roi (1978) and the *Phyllodoce glanduliflora-Cassiope mertensiana* type of Kuchar (1975) and Mortimer (1978).

Common associates of the *Cassiope mertensiana* type as distinct from *Cassiope mertensiana-Phyllodoce* types include *Salix arctica* (Broad 1973) and *Vaccinium scoparium* (Broad 1973). Both of these species were represented in at least one sample location within this vegetation type. Timoney (1999) argued for separation of the *Phyllodoce-Cassiope* type into distinct associations based in part on cover of dominant taxa and in part on characteristic taxa. He indicated that *Luzula piperi* was more commonly associated with the *Cassiope mertensiana* type than the *Phyllodoce glanduliflora* type and the results of this study support that. The main associates of the sample locations of the *Cassiope mertensiana* type were *Antennaria lanata*, which occurred in 8 of 10 sample locations, *Luetkea pectinata* in 9 and *Carex spectabilis* in 7.

This vegetation type occurs throughout the Rocky Mountains of Alberta as well as in Montana (Timoney 1999). Recognition of different indicator species for these groups (Table 2.2) supports recognition as different types.

Cassiope spp.

Classification of vegetation resulted in the formation of a cluster in which *Cassiope tetragona* or *C. mertensiana* were dominant, often in association with *Phyllodoce glanduliflora*. Differences in composition between these types are not readily apparent, although this type shows a greater similarity to the *Phyllodoce glanduliflora* group than the *Cassiope mertensiana* group due in large part to the greater abundance of *Phyllodoce* in both types. In addition, *Sibbaldia* was quite common in the group while *Luzula piperi* is not, suggesting a closer affiliation to the *Phyllodoce glanduliflo*ra association of Timoney (1999). All sample locations were found at high elevation on north and east-facing slopes and resembled the L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata* type of Corns and Achuff (1982), ALPA3 *Cassiope* spp.-*Phyllodoce* spp. type of Willoughby and Alexander (2005) or the L4 *Cassiope tetragona-Dryas octopeta-Salix nivalis* type of Corns and Achuff (1982) and ALPA3 *Cassiope* spp.-*Phyllodoce* spp. type of Willoughby and Alexander (2005).

Empetrum nigrum

Four sample locations of *Empetrum nigrum*, three of which were co-dominated by *Loiseleuria procumbens* (a rare species in Alberta) were grouped together in a cluster which had a great degree of similarity to the *Cassiope tetragona* group (Figure 2.7). The three *Loiseleuria* sample locations were situated at high elevation on west-facing slopes in the Main Ranges of Jasper National and Willmore Wilderness Parks. The fourth sample location did not have *Loiseleuria* as a co-dominant species but rather *Cassiope tetragona*. It was found at high elevation on a north-facing slope on the Main Ranges in Jasper National Park. Moisture regime of the sample locations ranged from very xeric to submesic and pH for all was <5.

This type may be part of the *Dryas octopetala-Empetrum nigrum* type of Hrapko and La Roi (1978) and Broad (1973), although *Dryas* is present in only one of the sample locations. The other associates listed by Hrapko and La Roi (1978) include *Vaccinium vitis-idaea, Salix arctica, S. nivalis, Phyllodoce glanduliflora, P. empetriformis* and *Cassiope tetragona*. Broad (1973) lists *Cassiope mertensiana, Elymus alaskanus, Erigeron aureus, Juniperus communis, Phyllodoce glanduliflora* and *Solidago multiradiata* as associates. All associated taxa listed by Hrapko and La Roi (1978) are represented in one or more sample locations of this group, with *Vaccinium* found in all four sample locations. None of the species listed by Broad (1973), other than *Cassiope* and *Phyllodoce*, were represented in the sample locations from northern Jasper, suggesting a closer affinity to the Signal Mountain type than that from Bow Summit in Banff. Neither Hrapko and La Roi (1978) nor Broad (1973) found *Loiseleuria*. The *Dryas octopetala-Empetrum nigrum* type of Hrapko and La Roi (1978) occurs on NE-facing slopes at Signal Mountain and it may be the only representative of this type in Alberta (Timoney 1999), although a similar type is reported from Banff (Broad 1973).

Dryas types

Dryas octopetala and *D. integrifolia* are both associated with calcareous substrates (Bamberg and Major 1968), and in the Rocky Mountains of Alberta, these two species occur in similar habitats: wind-swept areas in the alpine (Bamberg and Major 1968; Trottier 1972; Knapik et al. 1973; Kuchar 1975; Crack 1977; Komarkova and Webber 1978; Mortimer 1978), where cryopedogenic processes are often evident (Bamberg and Major 1968; Trottier 1972; Mortimer 1978). However, Beder (1973) noted that *Dryas octopetala* occurs on acidic substrates at Bow Summit in Banff National Park, a finding supported by this work. Corns and Achuff (1982) included plots dominated by one or the other species of *Dryas* into one type; however, floristically types dominated by these species are often dissimilar (Mortimer 1978). This is supported by the results of this study in which the dissimilarity of the two groups is shown on all multivariate analyses. In addition, it appeared that different environmental variables affected the distribution of these communities. Both types were associated with high elevation; however, *Dryas integrifolia* dominated sample locations were also affected by moisture and levels of P, N and Ca, whereas these variables did not appear to be related to the distribution of *D. octopetala* sample locations. High levels of N were important, however, for those sample locations of *Dryas octopetala* in which there is a significant component of *Vaccinium uliginosum*.

Dryas octopetala

Two *Dryas octopetala* types were recognized during the course of this work, and separation was based primarily on total vegetation cover. Several of the sample locations in the more sparsely vegetated group were also co-dominated by *Vaccinium uliginosum*, a species which in the Rocky Mountains of Alberta occurs only as far south as Jasper National Park (Moss 1983). Sampled plots fell into the H1 *Dryas octopetala-Salix nivalis-Silene acaulis* type of Corns and Achuff (1982), ALP2 *Dryas octopetala, D. integrifolia* type of Willoughby et al. (2005) or the H4 *Dryas octopetala-Kobresia myosuroides-Arctostaphylos uva-ursi* type of Corns and Achuff (1982) and SACFA14 *Dryas integrifolia/Kobresia myosuroides* type of Willoughby et al. (2005).

Hrapko and La Roi (1978) recognized a *Dryas octopetala-Oxytropis podocarpa* community type that is associated with stabilized scree where there is little winter snow cover. A second type is a *Dryas octopetala-Festuca brachyphylla* type that is more mesic than the *D. octopetala-Oxytropis podocarpa* type. *Dryas octopetala-Salix nivalis* tundra was also described with *Carex rupestris, Kobresia myosuroides [bellardii], Selaginella densa* and *Silene acaulis* listed as associates (Hrapko and La Roi 1978). These three types are included in the H1 *Dryas octopetala-Salix nivalis-Silene acaulis* type of Corns and Achuff (1982). The *Dryas octopetala-Oxytropis podocarpa-Cetraria cucullata-C. nivalis* type of Beder (1967), *Dryas octopetala*/lichen, *D. octopetala-Arctostaphylos uva-ursi* and *D. octopetala/Polytrichum piliferum* types of Kuchar (1975), *Dryas octopetala [hookeriana]-Oxytropis podocarpa* type of Hettinger (1975), *Dryas octopetala* type of Trottier (1972) and Crack (1977) and *Dryas octopetala-Polygonum viviparum* type of (Cooper et al. 1997) are also similar to the H1 type of Corns and Achuff (1982).

Hrapko and La Roi (1980) also described a *Dryas octopetala-Kobresia myosuroides [bellardii]* type found in areas exposed to wind. This equates to the H4 *Dryas octopetala-Kobresia myosuroides-Arctostaphylos uva-ursi* type of Corns and Achuff (1982). Similar types have been described by Trottier (1972 as *Kobresia myosuroides*), Kuchar (1975 as *Kobresia bellardii* type) and Crack (1977 as *Kobresia myosuroides* type).

Species commonly associated with the H1 *Dryas octopetala-Salix nivalis-Silene acaulis* type of Corns and Achuff (1982) include *Androsace chamaejasme* (Trottier 1972), *Anemone drummondii* (Trottier 1972), *Arctostaphylos uva-ursi* (Corns and Achuff 1982), *Astragalus alpinus* (Crack 1977), *Campanula uniflora* Bamberg and Major (1968), *Carex nardina* (Bamberg and Major 1968), *Carex petrophila* (Hrapko and La Roi 1978), *Carex rupestris* (Bamberg and Major 1968; Crack 1977; Hrapko and La Roi 1978), *Elymus alaskanus* (Hrapko and La Roi 1978), *Festuca brachyphylla* (Bamberg and Major 1968; Hrapko and La Roi 1978), *Hedysarum sulphurescens* (Trottier 1972), *Kobresia myosuroides* (Bamberg and Major 1968; Trottier 1972; Hrapko and La Roi 1978; Corns and Achuff 1982), *Oxytropis podocarpa* (Corns and Achuff 1982), *Oxytropis sericea* (Bamberg and Major 1968), *Polygonum viviparum* (Bamberg and Major 1968; Trottier 1972; Corns and Achuff 1982), *Potentilla diversifolia* (Trottier 1972), *Salix nivalis* (Trottier 1972; Crack 1977), *Salix reticulata* (Bamberg and Major 1968), *Selaginella densa* (Bamberg and Major 1968; Hrapko and La Roi 1978) and *Silene acaulis* (Bamberg and Major 1968; Hrapko and La Roi 1978; Corns and Achuff 1982).

Common associates of the H4 *Dryas octopetala-Kobresia myosuroides-Arctostaphylos uva-ursi* type of Corns and Achuff (1982) include *Androsace chamaejasme* (Trottier 1972; Corns and Achuff 1982), *Antennaria alpina* (Trottier 1972), *Astragalus alpinus* (Crack 1977), *Carex drummondiana [rupestris]* (Crack 1977), *Potentilla diversifolia* (Trottier 1972), *P. nivea* (Trottier 1972), *Oxytropis podocarpa* (Corns and Achuff 1982), *Polygonum viviparum* (Trottier 1972; Crack 1977; Corns and Achuff 1982), *Salix nivalis* (Crack 1977) and *Silene acaulis* (Trottier 1972). All of the taxa listed with the exception of *Androsace chamaejasme, Arctostaphylos uva-ursi, Elymus alaskanus, Hedysarum sulphurescens* and *Oxytropis sericea* were associated with the *Dryas octopetala* or *D. octopetala-Vaccinium uliginosum* sample locations of this study.

<u>*Dryas integrifolia*</u>

The two groups dominated by *Dryas integrifolia* are very similar in species composition, at least of the common taxa, but are separated into two groups based on amount of vascular plant cover. All sample locations but one appear to fall into the H1 *Dryas octopetala-Salix nivalis-Silene acaulis* type of Corns and Achuff (1982), ALPA2 *Dryas octopetala, D. integrifolia* type of Willoughby et al. (2005) or H4 *Dryas octopetala-Kobresia myosuroides-Arctostaphylos uva-ursi* type of Corns and Achuff (1982) and SACFA14 *Dryas integrifolia/Kobresia myosuroides* type of Willoughby and Alexander (2003).

Sample locations in which *Dryas integrifolia* dominates are reported by Mortimer (1978) and See and Bliss (1980). The *Dryas integrifolia-Carex rupestris* type of Mortimer

(1978) is the most common community on Prospect Mountain in the Front Ranges of Alberta and a similar type has been described from Willmore Wilderness Park (Lane et al. 2001). *Carex rupestris* was found in several of the plots that were sampled as part of this study but it was never a dominant species. *Androsace chamaejasme*, *Oxytropis campestris [sericea]* and *Polygonum viviparum* were noted to be important associates of *Dryas integrifolia* dominated sites (Bamberg and Major 1968; Mortimer 1978); and all three of these taxa were found in at least one of the sample locations here.

Mortimer (1978) also described a *Dryas integrifolia-Salix arctica* type from scree slopes of Propsect Mountain. There was high rock cover and common associates include *Androsace septentrionalis, Castilleja occidentalis, Cerastium beeringianum* and *Erigeron lanatus*. At least one of the sample locations from this study resembled the *D. integrifolia-S. arctica* type of Mortimer (1978); however, the associated species *Androsace septentrionalis* and *Erigeron lanatus* were not present.

The H1 *Dryas octopetala-Salix nivalis-Silene acaulis* type of Corns and Achuff has been reported throughout the Rocky Mountains of Alberta, British Columbia and Montana (Corns and Achuff 1982). Types similar to the H4 *Dryas octopetala-Kobresia myosuroides-Arctostaphylos uva-ursi* type of Corns and Achuff (1982) have been described from other areas in Alberta and Montana.

<u>*Salix* types</u>

Salix arctica

Twenty-two of the twenty-four sample locations resemble the *Salix arctica-Potentilla diversifolia* vegetation type of Corns and Achuff (1982), *Salix arctica–Carex* spp. type of Beder (1967), *Salix nivalis* type of Ogilvie (1969), *Salix arctica* type of Trottier (1972) and Crack (1977), *Salix arctica-Antennaria lanata* community type of Hrapko and LaRoi (1978), *Salix arctica-Salix nivalis* of Mortimer (1978), arctic willow type of Willoughby and Alexander (2003) and *Salix arctica/Polygonum bistortoides* type of Cooper et al. (1997).

It is a deep snowcover (Ogilvie 1969; Hrapko and LaRoi 1978; Mortimer 1978), late snowmelt (Corns and Achuff 1982; Willoughby and Alexander 2003) or streamside (Trottier 1972) community type occurring at high elevation.

Common associates include *Salix nivalis* (Ogilvie 1969; Corns and Achuff 1982), *S. glauca* (Ogilvie 1969; Trottier 1972), *Achillea millifolium* (Trottier 1972), *Anemone parviflora* (Trottier 1972), *Antennaria lanata* (Beder 1967; Corns and Achuff 1982; Willoughby and Alexander 2003), *Artemisia norvegica* (Hrapko and LaRoi 1978; Corns and Achuff 1982; Willoughby and Alexander 2003), *Astragalus alpinus* (Ogilvie 1969), *Bromus pumpellianus* (Trottier 1972), *Cassiope mertensiana* (Hrapko and LaRoi 1978), *Carex microptera* (Beder 1967), *C. nigricans* (Crack 1977), *C. phaeocephala* (Beder 1967), *C. pyrenaica* (Beder 1967), *Castilleja occidentalis* (Trottier 1972; Hrapko and LaRoi 1978; Corns and Achuff 1982), *Deschampsia caespitosa* (Trottier 1972), *Erigeron* *peregrinus* (Trottier 1972; Hrapko and LaRoi 1978; Corns and Achuff 1982), *Equisetum scirpoides* (Crack 1977), *Festuca brachyphylla* (Beder 1967), *Fragaria virginiana* (Trottier 1972), *Kobresia myosuroides* (Trottier 1972), *Parnassia fimbriata* (Trottier 1972), *Pedicularis groenlandica* (Trottier 1972), *Phyllodoce glanduliflora* (Corns and Achuff 1982), *Poa alpina* (Beder 1967; Trottier 1972; Corns and Achuff 1982), *Phleum alpinum* (Trottier 1972), *Poa arctica* [*Poa longipila*] (Ogilvie 1969), *Polygonum viviparum* (Ogilvie 1969; Corns and Achuff 1982; Willoughby and Alexander 2003), *Potentilla diversifolia* (Beder 1967; Trottier 1972; Corns and Achuff 1982; Willoughby and Alexander 2003), *Ranunculus eschscholtzii* (Crack 1977), *Solidago multiradiata* (Ogilvie 1969), *Sibbaldia procumbens* (Beder 1967; Crack 1977; Hrapko and LaRoi 1978; Corns and Achuff 1982) and *Veronica alpina* [*wormskjoldii*] (Crack 1977). Common associates of the *Salix arctica* sample locations of this study included *Artemisia norvegica*, *Luzula spicata*, *Poa alpina*, *Polygonum vivaparum*, *Potentilla diversifolia*, *Sibbaldia procumbens* and *Silene acaulis*.

A second plant community dominated by *Salix arctica* with *Caltha leptosepala* co-dominating occurred in two sample locations, and it had similarities to the H9 *Caltha leptosepala-Trollius albiflorus* type of Corns and Achuff (1982). The H9 *Caltha leptosepala-Trollius albiflorus* type occurs at high elevation and the moisture regime is subhygric to hygric (Corns and Achuff 1982). Common associates for the H9 *Caltha-Trollius* type include *Antennaria lanata*, *Carex nigricans*, *Erigeron peregrinus* and *Salix arctica* (Corns and Achuff 1982). *Antennaria lanata* and *Carex nigricans* occur in both sample locations. *Trollius albiflorus* did not have high cover in the two plots sampled, although it occurred outside of the plot in one.

Salix nivalis

Fourteen sample locations dominated by *Salix nivalis* were separated into two groups in the study area. There was a great deal of similarity in species composition between the *Salix nivalis*- and *S. arctica*-dominated sample locations, although the *S. nivalis* sites had a higher cover of *Dryas integrifolia* or *D. octopetala* than those of *S. arctica* and were closely aligned with the *Dryas octopetala-Salix nivalis-Silene acaulis* vegetation type of Corns and Achuff (1982).

The species composition was similar in all sample locations, although differences in the cover of *Salix arctica* vs. *S. nivalis* separated these two main groups. In addition, separation of the groupings within these willow types appeared to be due to the presence or absence of species including *Aconitum delphiniifolium*, *Dryas integrifolia*, *Gentiana glauca*, *Pedicularis arctica*, *Poa alpina*, *Solidago multiradiata*, *Saxifraga nelsoniana* and *S. occidentalis* in the *Salix nivalis* groups, and *Pedicularis langsdorfii* ssp. *arctica*, *P. capitata* and *Ranunculus eschscholtzii* in the *Salix arctica* groups. Vascular plant species that were common associates of *Salix nivalis* included *Antennaria monocephala* DC, *Artemisia norvegica*, *Campanula lasiocarpa*, *Carex nardina*/*Kobresia myosuroides*, *Cerastium beeringianum*, *Festuca brachyphylla*, *Luzula spicata*, *Poa alpina*, *Polygonum viviparum*, *Potentilla diversifolia*, *Salix nivalis*, *Sibbaldia procumbens* and *Silene acaulis*. However, none of these taxa were significant indicators for these groups.

Trottier (1972) and Crack (1977) both described *Salix nivalis* associations from high elevation on gentle mesic slopes of various aspects. Associated taxa include *Astragalus alpinus* (Trottier 1972), *Erigeron aureus* (Crack 1977), *Equisetum scirpoides* (Crack 1977), *Kobresia myosuroides* (Crack 1977), *Polygonum viviparum* (Trottier 1972), *Potentilla diversifolia* (Trottier 1972; Crack 1977) and *Silene acaulis* (Trottier 1972). All of these species with the exception of *Astragalus* and *Erigeron* were represented in the *Salix nivalis* sample locations described as part of this study, and *Antennaria monocephala* (a rare species in Alberta), *Artemisia norvegica*, *Campanula lasiocarpa*, *Polygonum viviparum* and *Silene acaulis* were present in many of these sample locations.

<u>Sedge types</u>

Carex spectabilis

A *Carex spectabilis* community occurs on sites where soils are not well drained and snow duration is into the growing season (Douglas 1972). It is not recognized in Corns and Achuff (1982); however, Hrapko and La Roi (1978) included a similar type in their *Cassiope mertensiana-Phyllodoce glanduliflora* community. The three sample locations were from the Main Ranges in Jasper National and Willmore Wilderness Parks on slight north-facing slopes at high elevation. This type has not previously been reported for Willmore Wilderness or Kakwa Wildland Parks.

Carex aquatilis

Wet meadows dominated by *Carex aquatilis* have been described by Crack (1977) and Corns and Achuff (1982). These meadows have standing water throughout the growing season and are found from the montane to the upper subalpine (Corns and Achuff 1982). This type resembled the H11 *Carex aquatilis-C. rostrata* type of Corns and Achuff (1982), MN e1.1 willow/sedge meadow of Beckingham et al. (1996) and either the D10 *Betula pumila-Potentilla fruticosa/Valeriana dioica/Carex* spp. or B12 *Carex rostrata, C. aquatilis* type of Willoughby et al. (2005) depending on the amount of shrub cover. Species diversity is low as *C. aquatilis* and mosses dominate the ground cover (Crack 1977; Corns and Achuff 1982). Corns and Achuff (1982) indicate that similar types have been described from the Yukon south to Alberta.

Carex nigricans

Vegetation dominated by *Carex nigricans* occurs at high elevation in areas that are often covered with snow well into the growing season (Beder 1967; Ogilvie 1969; Douglas 1972; Trottier 1972; Broad 1973; Kuchar 1975; Crack 1977; Hrapko and La Roi 1978; Corns and Achuff 1982; Cooper et al. 1997; Willoughby and Alexander 2003), and these habitats have the shortest snow-free periods of all habitats in alpine areas (Douglas and Bliss 1977).

Sample locations dominated by *Carex nigricans* in this study were separated into two groups based on its cover ($\leq$20% vs. $\geq$ 30%). The more sparsely vegetated plots occurred at higher elevation, but both groups were usually located in depressions at the base of slopes where the moisture regime was high. Cover of *Carex nigricans* is often very high and species diversity is poor (Trottier 1972; Broad 1973; Douglas and Bliss 1977). These sample locations resembled the H2 *Carex nigricans-Antennaria lanata* type of Corns and Achuff (1982) and ALPA4 *Carex nigricans* type of Willoughby and Alexander (2003).

Common associates include *Antennaria lanata* (Broad 1973; Corns and Achuff 1982; Cooper et al. 1997), *Caltha leptosepala* (Cooper et al. 1997), *Erigeron peregrinus* (Cooper et al. 1997), *Juncus drummondii* (Broad 1973; Corns and Achuff 1982; Cooper et al. 1997), *Luzula wahlenbergii [piperi]* (Hrapko and La Roi 1978; Corns and Achuff 1982), *Phleum alpinum* (Crack 1977; Cooper et al. 1997), *Poa alpina* (Crack 1977), *Potentilla diversifolia* (Crack 1977), *Ranunculus eschscholtzii* (Broad 1973; Crack 1977, Hrapko and La Roi 1978), *Sibbalidia procumbens* (Crack 1977; Corns and Achuff 1982) and *Veronica alpina* [*wormskjoldii*] (Hrapko and La Roi 1978; Corns and Achuff 1982). *Phleum alpinum* was the only species not associated with at least one of the sample locations. Similar types have been described for the Alberta Rocky Mountains by Broad (1973), Beder (1967), Crack (1977), Hrapko and La Roi (1978), Kuchar (1975), Jacques and van Eck (1979) and for Montana by Cooper et al. (1997).

Shrub types

Low shrub

Neither of the sample locations in this cluster appear to have been described in Corns and Achuff (1982), but the *Betula pumila/Carex garberi-C. tenuiflora* sample location is similar to the shrubby fen MNg2.1 willow sedge meadow of Beckingham et al. (1996).

Both sample locations were small in size. Descriptions of similar sites in the Rocky Mountains of Alberta could not be found.

The second cluster within this group was one in which *Salix* or *Betula glandulosa* dominates the vegetation. The closest affinity to known types was the S1 *Betula* spp.-*Potentilla fruticosa-Salix glauca/Tomenthypnum nitens* type of Corns and Achuff (1982) a type associated with subhygric to hygric sites in the montane and subalpine. *Pentaphylloides [Potentilla] fruticosa*, however, was not found in either of the two sample locations. The *Betula-Deschampsia* sample location had no equivalent in Beckingham et al. (1982) but was similar in many respects to the D10 *Betula pumila-Potentilla fruticosa/Valeriana dioica/Carex* spp. type of Willoughby et al. (2005), a low elevation type with subhygric to subhydric moisture regimes. The *Salix glauca-S. pedicellaris* sample location more closely resembled the SACMB2 *Salix glauca-Betula glandulosa/Carex* spp. type, which is the result of willow encroachment into meadows. The S1 *Betula* spp.-*Potentilla fruticosa-Salix glauca/Tomenthypnum nitens* type of Corns and Achuff (1982) has been described from Kananaskis (Kondla 1978) as well as British Columbia (see Corns and Achuff 1982).

Two of the sample locations within the *Salix barclayi-S. drummondiana-S. vestita* cluster were dominated by these three willows, and *Equisetum arvense* formed a significant portion of the ground cover in one of these sample locations. The S7 *Salix* spp./*Equisetum arvense* type of Corns and Achuff (1982) had the closest affinity to these two sample locations; however, this type is associated with fluvial landscapes. The sample locations in this study were on old floodplain at the edge of an old parking lot and a trail. The third sample location within this group was dominated by *Equisetum arvense* and *Poa alpina*, and willows are poorly represented; however, the complement of species other than willow associated with this sample location resembled that of the S7 type of Corns and Achuff (1982). It too was at the edge of a trail on a drainage channel. There were no equivalents in Beckingham et al. (1982), Willougby and Alexander (2003) or Willoughby et al. (2005). Descriptions of similar types for the Alberta Rocky Mountains have not been found.

The fourth cluster in this low shrub group consisted of two sample locations, one of which was dominated by *Alnus viridis* with *Ribes lacustre, R. laxiflorum* and *Deschampsia cespitosa.* This type was situated at the base of a rock slide and had not been described for other Rocky Mountain sites. The second sample location in this group was dominated by *Salix drummondiana* and *Ribes laxiflorum*, and it too appears to be a unique association.

<u>Forb types</u>

Anemone occidentalis

The two sample locations of this group appeared to be related to the H16 *Erigeron peregrinus-Valeriana sitchensis* group of Corns and Achuff (1982) and the SACME2 forb meadow type of Willoughby and Alexander (2003). These meadows were generally situated in the subalpine, and moisture regime was mesic to subhygric (Willoughby and Alexander 2003). Broad (1973) described an *Anemone occidentalis-Thalictrum* *occidentale* type from Banff National Park; however, *Abies* had high presence and *Salix arctica* and *Vaccinium scoparium* had high cover values. *Abies* and *Vaccinium scoparium* were not noted in either of the sample locations of this study, and *Salix arctica* was present in one sample location although of low cover. The resemblance to this type does not appear to be high.

Parnassia fimbriata

The *Parnassia fimbriata* sample locations were similar in many ways to the *H16 Erigeron peregrinus-Valeriana sitchensis* type of Corns and Achuff (1982) and SACMA2 Forb meadow type of Willoughby and Alexander. The sample locations were situated in subhygric areas in the subalpine and many of the species noted were similar. However, the diagnostic taxa of the H16 type (*Erigeron peregrinus* and *Trollius albiflorus*) were either absent from at least one of the sample locations (*Trollius*) or of low cover (*Erigeron*). In addition, *Parnassia fimbriata* is absent from the H16 type of Corns and Achuff but dominated or was a subdominant in the cover of these sample locations suggesting that it may be a different type. Similar types have not been noted in the literature of the vegetation of the Rocky Mountains of Alberta.

Trollius albiflorus

Meadows dominated by *Trollius albiflorus* and other forbs are situated on mesic to subhygric sites in the upper subalpine and alpine (Daubenmire 1943; Corns and Achuff 1982), where snow accumulates and where there is input of meltwater from above (Broad 1973). All sample locations in the study area were situated at elevations >2000m on medium textured mesic to subhygric soils. Broad (1973) indicated that soils associated with this community type in Bow Summit, Banff National Park were acidic; however, this relationship was not apparent in the study area, as two of the three locations sampled had soil pH<5.5 and the third had pH >6. *Trollius albiflorus* and *Valeriana sitchensis* dominated all sample locations and were significant indicators for this type. These sample locations resembled the H16 *Erigeron peregrinus-Valeriana sitchensis* vegetation type of Corns and Achuff (1982) and SACMA2 forb meadows of Willoughby and Alexander (2003).

Common associates include *Agrostis thurburiana* (Broad 1973), *Anemone occidentalis* (Corns and Achuff 1982), *Antennaria lanata* (Corns and Achuff 1973), *Arnica mollis* (Broad 1973), *Artemisia norvegica* (Corns and Achuff 1982), *Caltha leptosepala* (Broad 1973), *Juncus drummondii* (Broad 1973), *Pedicularis bracteosa* (Corns and Achuff 1982), *Potentilla diversifolia* (Corns and Achuff 1982), *Salix arctica* (Corns and Achuff 1982) and *Senecio triangularis* (Corns and Achuff 1973). *Agrostis* and *Arnica* were the only two associates not observed in the sample locations of this study. Communities similar to this have been described from other areas in the Rocky Mountains of British Columbia, Alberta and Montana (see Corns and Achuff 1982).

Artemisia norvegica

One sample location within the *Artemisia norvegica* group had *Anemone occidentalis* as a co-dominant. It was a high elevation mesic meadow which most closely resembled the H16 *Erigeron peregrinus-Valeriana sitchensis* type of Corns and Achuff (1982) and the

SACME2 forb meadows of Willoughby and Alexander (2003), a type known from other areas in the Rocky Mountains of Alberta (Corns and Achuff 2003). Kuchar (1975) described a similar type from steep slopes of various aspects in the Bald Hills in which there was steady supply of moisture. A second high elevation sample location was co-dominated by *Kobresia myosuroides*, and the moisture regime of this sample location was xeric. It most closely resembles the *Kobresia myosuroides [bellardii]* type of Kuchar (1975) and Crack (1977) and *Dryas octopetala-Kobresia myosuroides-Arctostaphylos uva-ursi* type of Corns and Achuff (1982), which is associated with snow-free south-facing slopes.

One sample location was on a sparsely vegetated talus slope where total vegetation cover is <20% and where *Saxifraga bronchialis* and *Artemisia norvegica* were the dominant species. There were no equivalents in Corns and Achuff (1982), Beckingham et al. (1996), Willoughby and Alexander (2003) and Willoughby et al. (2005). Three of the sample locations in this group had species of *Luzula* as co-dominants, and these sample locations may resemble the *A. norvegica-Luzula parviflora* type described by Kuchar (1975) from a high elevation basin with a high water table in the Bald Hills.

Mortimer (1978) described an *Artemisia norvegica-Aquilegia flavescens* type from an area with constant water supply on Prospect Mountain, but none of those from the study area are the same as those described by Mortimer.

Artemisia michauxiana

Kuchar (1975) described an *Artemisia michauxiana-Rubus idaeus* type from a mesic west-facing slope at high elevation in the Bald Hills of Jasper National Park. *Rubus idaeus* was not found in any of the sites that were sampled as part of this study and therefore do not appear to be similar to this type. Reference to a similar type in other pertinent literature could not be found.

Conclusions

Investigations of the fidelity of rare species to habitat/vegetation types requires a good classification prior to building models of rare species distribution in relation to habitat (Luoto 2000; Rushton et al. 2004). Given that many areas of Alberta lack information on vegetation type at a large scale, a survey of and subsequent classification of vegetation was a necessary requirement in determining the degree of association of vascular plant species to types.

While there have been several attempts to classify the vegetation for the Rocky Mountains of Alberta, there is little concordance between classifications making it difficult to integrated existing vegetation classification systems into models of rare plant distribution. This lack of concordance may be due to differences in sampling technique, area surveyed and data analysis. For example, Podani (2006) indicated that the use of ordinal scores, such as with Braun-Blanquet abundance/dominance scores, requires specialized numerical classification and ordination techniques. The majority of studies on the vegetation of the Rocky Mountains have used different scales for estimating abundance, and therefore combining data from these various treatments will require ordinal procedures that can handle such datasets (Podani 2006). This lack of concordance reflects a need for standards for data collection and analysis.

There is a great deal of topographic relief in the mountainous environment of the study area resulting in steep elevational and climatic gradients. These gradients are reflected in the diversity of vegetation types and the responses of those types to measured environmental variables. A number of different vegetation types of different physiognomy were recognized in the northern Rocky Mountains of Alberta, and these were associated with different measured environmental variables, although elevation was the main factor influencing all types. Soil nutrients were important correlates of vegetation type, particularly arcsine P, log K for forested types, and arcsine P, arcsine N and log Ca for herbaceous and dwarf shrub types. Soil moisture and aspect were important only for the herbaceous types, and this is likely a reflection of the significance of pattern of snow distribution and duration in determining vegetation patterning in the alpine (Bamberg and Major 1968; Ogilvie 1969; Kuchar 1975; Peinado et al. 2005).

Recognition of distinct vegetation types in combination with an examination of their relationship to measured environmental variables has the potential for testing the fidelity of rare vascular plant species to vegetation types. Knowing how vegetation types are distributed on the landscape and the association of these types with rare species will facilitate planning for rare plant conservation.

Literature Cited

Achuff, P. L. 1989. Old-growth forests of the Canadian Rocky Mountain national parks. Natural Areas Journal 9(1):12-26.

Alberta Natural Heritage Information Centre. 2000. Draft Plant Community Sampling Guidelines. Alberta Community Development, Edmonton, Alberta.

Alberta Natural Heritage Information Centre. 2001. data files. Alberta Community Development, Edmonton, Alberta.

Allen, L. 2005. Alberta Natural Heritage Information Centre Preliminary Plant Community Tracking List. Alberta Community Development, Edmonton, Alberta.

Anderson, M. J. 1998. Effects of patch size on colonization in estuaries: revisiting the species-area relationship. Oecologia 118:87-98.

Austin, M. P., R. B. Cunningham and P. M. Fleming. 1984. New approaches to direct gradient analysis using environmental scalars and statistical curve-fitting procedures. Vegetatio 55:11-27.

Bamberg, S. A. and J. Major. 1968. Ecology of the vegetation and soils associated with calcareous parent materials in three alpine regions of Montana. Ecological Monographs 38:127-167.

Barbour, M. G. 1988. North American Terrestrial Vegetation. M. G. Barbour and W. D. Billings (editors). Cambridge University Press, Cambridge, N.Y. 434 pp..

Beckingham, J., I. G. W. Corns and J. H. Archibald. 1996. Field guide to ecosites of west central Alberta. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. Special Report No. 9.

Beder, K. 1967. Ecology of the alpine vegetation of Snow Creek Valley, Banff National Park. MSc Thesis, University of Calgary. 243 pp.

Belland, R. J. 2005. A multivariate study of moss distributions in relation to environment in the Gulf of St. Lawrence region, Canada. Canadian Journal of Botany 83:243-263.

Beers, T. W., P. E. Dress and L. C. Wensel. 1966. Aspect transformation in site productivity research. Journal of Forestry 64:691-692.

Billings, W. D. 1988. Alpine Vegetation. IN: North American Terrestrial Vegetation. M. G. Barbour and W. D. Billings (editors). Cambridge University Press, New York. pp. 392-420.

Birks, H. J. B. and J. Deacon. 1973. Numerical analysis of past and present flora of the British Isles. New Phytologist 72(4):877-902.

Bliss, L. C. 1966. Alpine community pattern in relation to environmental parameters. IN: Essays in Plant Geography and Ecology. (ed.. N. H. Greenridge). Nova Scotia Museum, Halifax N.S. pp. 167-184.

Bork, E. 1994. Ecological Range Classification of Willmore Wilderness Park. Alberta Environmental Protection. 65 pp..

Bowman, W. D. 1992. Imputs and storage of nitrogen in winter snowpack in an alpine ecosystem. Arctic and Alpine Research 24(3):211-215.

Boyce, R. L. 1998. Fuzzy set ordination along an elevation gradient on a mountain in Vermont, USA. Journal of Vegetation Science 9:191-200.

Boyce, R. L., R. Clark and C. Dawson. 2005. Factors determining alpine species distribution on Goliath Peak, Front Range, Colorado, U.S.A. Arctic, Antarctic and Alpine Research 37(1):88-96.

Brady, N. C. and R. R. Weil. 2004. Elements of the Nature and Properties of Soil. 2nd Edition. Pearson Prentice Hall, New Jersey. 606 pp..

Bray, J. R. and J. T. Curtis. 1957. An ordination of upland forest communities of southern Wisconsin. Ecological Monographs 27: 325-349.

Broad, J. 1973. Ecology of alpine vegetation at Bow Summit, Banff National Park. M.Sc. thesis, University of Calgary. 93 pp.

Bryant, J. P. 1968. Vegetation and frost activity in an alpine fellfield on the summit of Plateau Mountain, Alberta. MSc thesis, University of Calgary, Calgary, Alberta. 93 pp.

Bryant, J. P. and E. Scheinberg. 1970. Vegetation and frost activity in an alpine fellfield on the summit of Plateau Mountain, Alberta. Canadian Journal of Botany 48:751-771.

Busing, R. T., E. E. C. Clebsch, C. C. Eagar and E. F. Pauley. 1988. Decades of change in a Great Smoky Mountains spruce-fir forest. Bulletin of the Torrey Botanical Club 115(1):25-31.

Cooper, S. V., P. Lesica and D. Page-Dumroese. 1997. Plant Community Classification for Alpine Vegetation on the Beaverhead National Forest, Montana. United States Department of Agriculture, Forest Service. Intermountain Research Station General Technical Report INT-GTR-362. 61 pp..

Cormack, R. G. H. 1953. A survey of coniferous forest succession in the eastern Rockies. Forestry Chronicles 29:218-232.

Corney, P. M., M. G. Le Duc, S. M. Smart, K. J. Kirby, R. G. H. Bunce, R. H. Marrs. 2004. The effect of landscape-scale environmental drivers on the vegetation composition of British woodlands. Biological Conservation 120:491-505.

Corns, I. G. W. and P. L. Achuff. 1982. Ecological (Biophysical) Land Classification of Banff and Jasper National Parks. IN: Volume 2: Soil and Vegetation Resources. (Holland, W. D. and G. M Coen editors). Alberta Institute of Pedology Publication No. SS-82-44. pp. 71-142.

Crack, S. 1977. Flora and vegetation of Wilcox Pass, Jasper National Park, Alberta. MSc thesis, University of Calgary. 284 pp..

Damm, C. 2001. A phytosociological study of Glacier National Park, Montana, U. S. A. with notes on the syntaxonomy of alpine vegetation in western North America. Ph.D. thesis. Georg-August University, Gottingen.

Darmody, R. G., C. E. Thorn, P. Schlyter and J. C. Dixon. 2004. Relationship of vegetation distribution to soil properties in Kärkevagge, Swedish Lapland. Arctic, Antarctic and Alpine Research 36(1):21-32.

Daubenmire, R. G. 1943. Vegetation zonation in the Rocky Mountains. Botanical Review 9:325-393.

Despain, D. G. 1973. Vegetation of the Big-horn Mountains, Wyoming, in relation to substrate and climate. Ecological Monographs 43(3):329-355.

Diekmann, M. and U. Falkengren-Grerup. 1998. A new species index for forest vascular plants: development of functional indices based on mineralization rates of various forms of soil nitrogen. Journal of Ecology 86(2):269-283.

Douglas, G. W. 1972. Subalpine plant communities of the western North Cascades, Washington. Arctic and Alpine Research 4(2):147-166.

Douglas, G. W. 1974. Montane zone vegetation of Alsek River region, southwestern Yukon. Canadian Journal of Botany 52(12):2505-2532.

Douglas, G. W. and L. C. Bliss. 1977. Alpine and high subalpine plant communities of North Cascades Range, Washington and British Columbia. Ecological Monographs 47(2):113-150.

Duckworth, J. C., R. G. H. Bunce and A. J. C. Malloch. 2000. Vegetation-environment relationships in Atlantic European calcareous grasslands. Journal of Vegetation Science 11(1):15-22.

Dufrêne, M. and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetric approach. Ecological Monographs 67:345-366.

Fekete, G. and Z. Szöcs. 1974. Studies on interspecific association processes in space. Acta Botanica Hungarica 20:227-241.

Flora of North America Editorial Committee. 1993-2006. Flora of North America. Oxford University Press, New York, New York.

Fortin, M.-J. and S. Payette. 2002. How to test the significance of the relation between spatially autocorrelated data at the landscape scale: a case study using fire and forest maps. Ecoscience 9(2):213-218.

Gadd, B. 1986. Handbook of the Canadian Rockies.Corax Press, Jasper, Alberta. 878 pp..

Gotelli, N. J. and A. M. Ellison. 2004. A Primer of Ecological Statistics. Sinauer Associates, Sunderland, Massachusetts. 510 pp..

Graae, B. J., R. H. Øklund, P. M. Peterson, K. Jensen and B. Fritzbøger. 2004. Influence of historical, geographical and environmental variables on understorey composition and richness in Danish forest. Journal of Vegetation Science 15:465-474.

Harder, J. E. 1983. Comparative autecology of *Cassiope* spp. at treeline in Jasper National Park, Alberta. PhD thesis, University of Alberta. 267 pp.

Hendershot, W. H., H. Lalande and M. Duquette. 1993. Ion exchange and exchangeable cations. IN: Soil Sampling and Methods of Analysis. M. R. Carter (editor). Canadian Society of Soil Science, Lewis Publishers, Boca Raton. p. 167-176.

Hettinger, L. R. 1975. Vegetation of the Vine Creek basin, Jasper National Park. PhD thesis, University of Alberta. 276 pp..

Holland, W. D. and G. M Coen (editors). 1982. Ecological (Biophysical) Land Classification of Banff and Jasper National Parks. IN: Volume 2: Soil and Vegetation Resources. Alberta Institute of Pedology Publication No. SS-82-44. 540 pp. and maps.

Hrapko, J. O. and G. H. La Roi. 1978. The alpine tundra vegetation of Signal Mountain, Jasper National Park. Canadian Journal of Botany 56:309-332.

Isard, S. A. 1986. Factors influencing soil moisture and plant community distribution on Niwot Front Range, Colorado, USA. Arctic and AlpineResearch 18(1):83-96.

Jacques, D. and P. van Eck. 1979. Biophysical Features and Recommendations for Recreational Development in the Kakwa Falls Region, Alberta. Part I. Biophysical Features. Alberta Recreation, Parks and Wildlife. 106 pp. plus appendix.

Johnson, J. D. 1975. An Evaluation of the Summer Range of Bighorn Sheep (*Ovis canadensis canadensis* Shaw) on Ram Mountain, Alberta. MSc thesis, University of Calgary. 136 pp.

Johnson, P. L. and W. D. Billings. 1962. The alpine vegetation of the Beartooth Plateau in relation to cryopedogenic processes and patterns. Ecol. Monogr. 22(2):105-135.

Kembel, S. 2000. A Preliminary Classification of the Rocky Mountain Shrubland Community Types of Alberta. 131 pp..

Kershaw, L., J. Gould, D. Johnson and J. Lancaster. 2001. Rare Vascular Plants of Alberta. University of Alberta Press, Edmonton, Alberta and Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. 484 pp..

Kiener, W. 1939. Sociological studies of the alpine vegetation on Longs Peak. PhD thesis, University of Nebraska, Lincoln, Nebraska. 68 pp.. (Reprinted as Univ. Nebr. Stud., N. S. 34, 1967. 75 pp.)

Knapik, L. J., G. W. Scotter and W. W. Pettapiece. 1973. Alpine soil and plant community relationships of the Sunshine area, Banff National Park. Arctic and Alpine Research 5(3):A161-A170.

Komárková, V. and P. J. Webber. 1978. An alpine vegetation map of Niwot Ridge, Colorado. Arctic Alpine Res. Research 10:1-29.

Kondla, N. G. 1978. An overview vegetation survey of Kananaskis Provincial Park. Alberta Recreation, Parks and Wildlife. Edmonton, AB.123 pgs. plus maps.

Kuchar, P. 1973. Habitat types of Waterton Lakes National Park. Contract No. WR 54-72. National and Historic Parks Branch, Dept. of Indian Affairs and Northern Development. 301 pp. and maps.

Kuchar, P. 1975. Alpine tundra communities and *Dryas octopetala* ssp. *hookeriana* in the Bald Hills, Jasper National Park. PhD thesis, University of Alberta. 351 pp..

La Roi, G. H. 1964. An ecological study of the Boreal spruce-fir forests of the North American taiga. Ph.D. Thesis, Duke University, North Carolina. Unpublished. (Diss. Abstr. 25:6180).

La Roi, G. H. and R. J. Hnatiuk. 1980. The *Pinus contorta* forests of Banff and Jasper National Parks: a study in comparative synecology and syntoxonomy. Ecological Monographs 50(1):1-29.

Lane, C., J. Gould, M. Willoughby and E. Lee. 2001. Rangeland, Rare Plant and Weed Monitoring in Willmore Wilderness Park. Progress Report II. Foothills Model Forest, September 2000. Alberta Environment.

Lee, T. D. 1976. Gradient analysis, habitats, and species diversity of bryophytes in Jasper National Park, Alberta. MSc thesis, University of Alberta, Edmonton, Alberta.

Lee, T. D. and G. H. La Roi. 1979a. Bryophyte and understory vascular plant beta diversity in relation to moisture and elevation gradients. Vegetatio 40(1):29-38.

Lee, T. D. and G. H. La Roi. 1979b. Gradient analysis of bryophytes in Jasper National Park, Alberta. Canadian Journal of Botany 57:914-925.

Legendre, P. and M. Anderson. 1999. Distance-based redundancy analysis: testing multispecies response in multifactorial ecological experiments. Ecological Monographs 69(1):1-24.

Legendre, P., M. R. T. Dale, M.-J. Fortin, J. Gurevitch, M. Hohn and D. Myers. 2002. The consequences of spatial structure for the design and analysis of ecological field surveys. Ecography 25:601-615.

Legendre, P. and L. Legendre. 1998. Numerical Ecology. Elsevier Press, New York, New York. 853 pp.

Lesica, P. 1993. Using plant community diversity in reserve design for pothole prairie on the Blackfeet Indian reservation, Montana, USA. Biological Conservation 65:69-75.

Lewis, F. J. 1917. Vegetation distribution in the Rocky Mountains National Park. Canadian Alpine Journal 8:87-95.

Lewis, F. J. 1923. Forest Line. Canadian Alpine Journal 13:130-136.

Luoto, M. 2000. Modelling of rare plant species richness by landscape variables in an agriculture area in Finland. Plant Ecology 149:157-168.

Luttmerding, H. A., D. A. Demarchi, E. C. Lea, D. V. Meidinger and T. Vold. 1990. Describing Ecosystems in the Field. BC Ministry of Forests, Forest Science Program, Miscellaneous Report 074m 281 pp..

McCune, B. and J. B. Grace. 2002. Analysis of Ecological Communities. MjM Sortware Design. Gleneden Beach, Oregon. 300 pp.

McGlone, M. S. 1996. When history matters: scale, time, climate and tree diversity. Global Ecology and Biogeography Letters 5(6):309-314.

McLaughlin, S. P. 1994. Natural floristic areas of the western United States. Journal of Biogeography 16:239-249.

Michalet, R., C. Gandoy, D. Joud, J.-P. Pagès and P. Choler. 2002. Plant community composition and biomass on calcareous and siliceous substrates in the northern French Alps: comparative effects of soil and water status. Arctic, Antarctic, and Alpine Research 34(1):102-113.

Milan, C. and O. Zdenka. 2003. Plot sizes for phytosociological sampling of European vegetation. Journal of Vegetation Science 14:563-570.

Mooney, H. A., G. St. Andre and R. D. Wright. 1962. Alpine and subalpine vegetation patterns in the White Mountains of California. American Midland Naturalist 68(2):257-273.

Mortimer, P. R. 1978. The alpine vascular flora and vegetation of Prospect Mountain, Front Range, Rocky Mountains, Alberta. M.Sc. thesis, University of Albera. 238 pp..

Moss, E. H. 1952. Grassland of the Peace River region, western Canada. Canadian Journal of Botany 30:98-124.

Moss, E. H. 1955. The vegetation of Alberta. Botany Review XXI(9):493-568.

Moss, E. H. 1983. Flora of Alberta. Second edition (revised by J. G. Packer). University of Toronto Press, Toronto, Ontario. 687 pp.

Mountjoy, E. W. 1978. Geology—Mount Robson. Geological Survey of Canada. Map 1499A.

Myklestad, A. and H. J. B. Birks. 1993. A numerical analysis of the distribution of patterns of Salix L. species in Europe. Journal of Biogeography 20(1):1-32.

Natural Region Committee. 2006. Natural Subregions and Subregions of Alberta. Compiled by D. J. Downing and W. W. Pettapiece. Government of Alberta, Pub. No. I/005. 254 pages.

Ogilvie, R. T. 1969. The mountain forest and alpine zones in Alberta. IN: Vegetation, Soils and Wildlife (J. G. Nelson and M. J. Chambers editors). Methuen, Toronto, Ontario. pp. 25-44.

Ogilvie, R. T. 1998. Vascular plants. IN: Smith, I. M. and G. G. E. Scudder, eds. Assessment of species diversity in the Montane Cordillera Ecozone. Ecological Monitoring and Assessment Network, Burlington, Ontario.

O'Halloran, I. P. 1993. Ion exchange and exchangeable cations. IN: Soil Sampling and Methods of Analysis. M. R. Carter (editor). Canadian Society of Soil Science, Lewis Publishers, Boca Raton. p. 213-229.

Palmer, M. W. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. Ecology 74(8):2215-2230.

Pärtel, M., A. Helm, N. Ingerpuu, Ü. Reier and E.-L. Tuvi. 2004. Conservation of Northern European plant diversity: the correspondence with soil pH. Biological Conservation120:525-531.

Patten, D. T. 1963. Vegetational pattern in relation to environments in the Madison Range, Montana. Ecological Monographs 33(4):375-406.

Peet, R. K. 1988. Forests of the Rocky Mountains. IN: North American Terrestrial Vegetation (M. G. Barbour and W. D. Billings ed.). Cambridge University Press. pp. 63-101.

Peinado, M., J. L. Aguirre, J. Delgadillo and J. M. Martinez-Parras. 2005. A phytosociological survey of the chionphilous communities of western North America. Part I: temperate and Mediterranean associations. Plant Ecology 180:187-241.

Podani, J. 2006. Braun-Blanquet's legacy and data analysis in vegetation science. Journal of Vegetation Science 17:113-117.

Porsild, A. E. 1959. Botanical Excursion to Jasper and Banff National Parks, Alberta: alpine and subalpine flora. National Museum of Canada, Dept. of Indian and Northern Affairs and National Resources, Ottawa, Ontario. 38 pp..

Proctor, M. C. F. 1967. The distribution of British liverworts: a statistical analysis. Journal of Ecology 55:119-135.

Quinn, G. P. and M. J. Keough. 2002. Experimental Design and Data Analysis for Biologists. Cambridge University Press. Cambridge, New York. 537 pp.

Rabinowitz, D. 1981. Seven forms of rarity. IN: The Biological Aspects of Rare Plant Conservation (ed. Hugh Synge). John Wiley and Sons Ltd., New York, N.Y. pg. 205-217.

Reed, R. A., R. K. Peet, M. W. Palmer and P. S. White. 1993. Scale dependence of vegetation-environment correlations:a case study of a North Carolina piedmont woodland. Journal of Vegetation Science 4:329-340.

Rhemtulla, J. M., R. J. Hall, E. S. Higgs and S. E. Macdonald. 2002. Eighty years of change: vegetation in the montane ecoregion of Jasper National Park, Alberta, Canada. Canadian Journal of Forest Research 32:2010-2021.

Rushton, S. P., S. J. Omerod and G. Kerby. 2004. New paradigms for modeling species distributions? Journal of Applied Ecology 41(2):193-200.

See, M. G. and L. C. Bliss. 1980. Alpine lichen-dominated communities in Alberta and the Yukon. Canadian Journal of Botany 58:2148-2170.

Shepherd, B. 2005. Park ecologist-Jasper National Park. Pers. comm.. to J. Gould Nov. 8, 2005.

Stevens, P. F. 2001 onwards. Angiosperm phylogeny website-Version 6, May 2005 [and more or less continuously updated since]. hppt://www.mobot.org/MOBOT/research/APweb/.

Stringer, P. W. 1973. An ecological study of grasslands in Banff, Jasper, and Waterton Lakes National Parks. Canadian Journal of Botany 51:383-411.

Stringer, P. W. and G. H. La Roi. 1970. The Douglas-fir forests of Banff and Jasper National Parks, Canada. Canadian Journal of Botany 48:1703-1726.

Strong, W. L. 2002. Lodgepole pine/Labrador tea type communities of western Canada. Canadian Journal of Botany 80:151-165.

Tande, G. F. 1979. Fire history and vegetation pattern of coniferous forests in Jasper National Park. Canadian Journal of Botany 57:1912-1931.

ter Braak, C. J. F. and P. Šmilauer. 2002. CANOCO Reference Manual and CanoDraw for Windows User's Guide: software for Canonical Community Ordination (version 4.5). Microcomputer Power, Ithaca, New York. 500 pp.

Timoney, K. P. 1999. Limber Pine, Whitebark Pine, Alpine Heath and Terricolous Alpine Lichen Vegetation Alliances in Alberta (Compilation of Information on Selected Alberta Plant Community Types 1998-1999). Resource Data Division, Alberta Environmental Protection. 62 pp.

Trottier, G. C. 1972. Ecology of the Alpine Vegetation of Highwood Pass, Alberta. MSc thesis, University of Calgary. 229 pp.

Urban, D., S. Goslee, K. Pierce and T. Lookingbill. 2002. Extending community ecology of landscapes. Ecoscience 9(2): 200-212.

Walker, D. A. and J. C. Halfpenny. 1993. Long-term studies of snow-vegetation interactions. BioScience 43(5):287-302.

Webber, P. J. and D. E. May. 1977. Magnitude and distribution of below ground plant structures in alpine tundra of Niwot Ridge, Colorado. Arctic and Alpine Research 9(2):157-174.

Weir, D. A. and J. B. Wilson. 1987. Micro-pattern inan area of New Zealand alpine vegetation. Vegetatio 73:81-88.

Whittaker, R. H. 1956. Vegetation of the Great Smoky Mountains. Ecological Monographs 30(3):280-338.

Whittaker, R. H. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. Ecological Monographs 30(3):280-338.

Whittaker, R. H. 1975. Communities and Ecosystems (second edition). Macmillan, New York. 385 pp..

Whittaker, R. H. and W. A. Niering. 1968. Vegetation of the Santa Catalina Mountains, Arizona IV. limestone and acid Soils. Journal of Ecology 56:523-544.

Wilcove, D. S. and L. L. Master. 2005. How many endangered species are there in the United States? Frontiers in Ecology and the Environment 3(8):414-420.

Willoughby, M. G. and M. J. Alexander. 2003. Range plant community types and carrying capacity for the subalpine and alpine subregions. Second Approximation. Public Lands and Forests Division, Alberta Sustainable Resource Development, Edmonton, Alberta. 200 pp..

Willoughby, M. G., M. J. Alexander and B. W. Adams. 2005. Range plant community types and carrying capacity for the montane subregion. Sixth Approximation. Public Lands and Forests Division, Alberta Sustainable Resource Development, Edmonton, Alberta. 235 pp..

Wohlgemuth, T. 1998. Modelling floristic species richness on a regional scale: a case study in Switzerland. Biodiversity and Conservation 7:159-177.

Woodward, F. I, and B. G. Williams. 1987. Climate and plant distribution at global and local scales. Vegetatio: 69:189-197.

Yeo, M. J. M. and T. H. Blackstock. 2002. A vegetation analysis of the pastoral landscapes of upland Wales, UK. Journal of Vegetation Science 13:803-816.

Table 2.1. Measured environmental variables and transformations used in analysis

Variable	Transformation
pH	None
Total exchangeable calcium (ppm)	Log
Total exchangeable sodium (ppm)	Log
Total exchangeable potassium (ppm)	Log
Total exchangeable magnesium (ppm)	Log
Cation exchange capacity	Log
Total carbon (%)	Arcsine
Total nitrogen (%)	Arcsine
Total phosphorus (%)	Arcsine
Elevation (m)	None
Slope (degrees)	degrees
Aspect (degrees)	easting=Sin(radians(degree aspect)); northing=cos(radians(degree aspect))
Texture (classes) (categorical variable)	Coarse (Sandy Loam, Loamy Sand, Sand), medium (Silty Clay Loam, Clay Loam, Silt, Silty Loam, Loam, Sandy Clay Loam), fine (Heavy Clay, Clay, Sandy Clay, Silty Clay), organic
Moisture	None
Nutrients	None

Table 2.2. Results of Indicator Species Analysis of 297 sample locations showing only species with an Indicator Value of >25 (Dufrêne and Legendre 1997) and significant at p ≤0.05. Number in front of vegetation or habitat name represents group number referred to in Table 2.3 and on Figures 2.1-2.6. Bold indicates a rare species.

Primary vegetation or habitat type	n	Indicator Value (IndVal) Species	IndVal
20 x 20 m plots			
1. *Picea glauca*	8	*Picea glauca* (Pigl)	91.5
2. *Populus tremuloides*	10	*Arctostaphylos uva-ursi* (Aruv)	64.3
		Galium boreale (Gabo)	63.7
		Lathyrus ochroleucus (Laoc)	67.2
		Leymus innovatus (Lein)	60.4
		Populus tremuloides (Potr)	94.2
		Taraxacum officinale (Taof)	59.4
3. *Elymus lanceolatus-Koeleria macrantha*	2	*Anemone multifida* (Anmu)	48.1
		Antennaria microphylla (Anmi)	49.9
		Astragalus striatus (Asst)	50
		Astragalus tenellus (Aste)	88.9
		Carex filifolia (Cafi)	49.3
		Crepis tectorum (Crte)	50
		Elymus lanceolatus (Ella)	66.6
		Gaillardia aristata (Gaar)	90.9
		Koeleria macrantha (Koma)	96.1
		Linum lewisii (Lile)	48.3
		Solidago simplex (Sosi)	99
4. *Pseudotsuga menziesii*	7	*Pseudotsuga menziesii* (Psme)	91.1
5. *Pinus contorta*	14	*Arnica cordifolia* (Arco)	44.1
		Pinus contorta (Pico)	79.9
		Salix glauca (Sagl)	31.4
6. *Abies bifolia*	11	*Abies bifolia* (Abbi)	76.9
		Cassiope tetragona (Cate)	44.9
		Empetrum nigrum (Emni)	51.9
		Phyllodoce empetriformis (Phem)	36.4
		Phyllodoce glanduliflora (Phgl)	50.1
		Vaccinium membranaceum (Vame)	45.1
7. *Gymnocarpium*	3	*Gymnocarpium dryopteris* (Gydr)	66.7
		Menziesia ferruginea (Mefe)	49.7
8. *Picea engelmannii*	7	*Picea engelmannii* (Pien)	61.3
10 x 10 m plots			
1. *Arctostaphylos uva-ursi*	3	*Arctostaphylos uva-ursi* (Aruv)	99.9
		Carex richardsonii (Cari)	100

		Comandra umbellata (Coum)	66.7
		Galium boreale (Gabo)	66.7
		Juniperus horizontalis (Juho)	66.7
		Potentilla fruticosa (Pofr)	66.5
2. *Elaeagnus commutata*	2	*Antennaria microphylla* (Anmi)	100
		Cerastium arvense (Cear)	71.4
		Elaeagnus commutata (Elco)	100
		Gaillardia aristata (Gaar)	75.0
		Oxytropis splendens (Oxsp)	98.9
		Taraxacum officinale (Taof)	83.3
3. *Salix glauca*	5	none	
4. *Salix drummondiana*	2	*Epilobium latifolium* (Epla)	66.5
		Salix drummondiana (Sadr)	99.6
		Saxifraga lyallii (Saly)	66.7
		***Saxifraga nelsoniana* (Sane)**	**66.7**
		Vaccinium caespitosum (Vaca)	63.6
5. *Salix farriae*	3	*Carex aquatilis* (Caaq)	66.7
		Carex canescens (Cacu)	66.7
		Salix farriae (Safa)	85.7
6. *Salix barrattiana*	2	*Achillea millefolium* (Acmi)	65.1
		Salix barrattiana (Saba)	93.3
7. *Salix arctica*	3	*Carex nardina / Kobresia myosuroides* (CnKm)	100
		Cerastium beeringianum (Cebe)	100
		Polygonum viviparum (Povi)	95.2
		Potentilla diversifolia (Podi)	100
		Salix arctica (Saar)	99.2
		Salix nivalis (Sani)	100
		Silene acaulis (Saac)	100
8. *Abies*	6	*Abies bifolia* (Abbi)	82.1
		Phyllodoce glanduliflora (Phgl)	71.4
5 x 5 m plots			
1. *Elymus lanceolatus-Koeleria macrantha*	6	*Elymus lanceolatus* (Ella)	40.0
		Koeleria macrantha (Koma)	88.2
2. Cliff (calcareous)	4	*Juniperus horizontalis* (Juho)	50
3. Outcrop (calcareous)	2	none	
4. Outcrop (calcareous)	2	***Telesonix heucheriformis* (Tehe)**	**99.4**
5. *Antennaria microphylla*		*Antennaria microphylla* (Anmi)	97
		Linum lewisii (Lile)	66.7
		Taraxacum officinale (Taof)	83.9
6. Drainage channel	3	***Barbarea orthoceras* (Baor)**	**66.7**
		Deschampsia cespitosa (Dece)	60.1
		Phleum alpinum (Phal)	48.2
7. Talus	2	*Saxifraga lyallii* (Saly)	36.3

8. Open graminoid	5	none	
9. Rocky (acidic)	2	*Carex micropoda* (Camc)	72.8
10. Consolidated talus	5	none	
11. sparse	3	*Epilobium angustifolium* (Epan)	43.9
12. Low shrub	2	*Betula pumila* (Bepu)	100
		Linnaea borealis (Libo)	64.9
13. *Salix* spp.-*Betula glandulosa*	2	*Betula glandulosa* (Begl)	98.8
		Delphinium glaucum (Degl)	38.9
		Draba borealis (Drbo)	38.6
		Polemonium acutiflorum (Poac)	73.3
14. Sparse (mesic)	3	*Agrostis variabilis* (Agva)	59.4
		Epilobium latifolium (Epla)	42.9
15. *Anemone occidentalis*	2	*Anemone occidentalis* (Anoc)	59.6
		Arnica mollis (Armo)	99.6
		Gaultheria humifusa (Gahu)	46.2
		Luetkea pectinata (Lupe)	30.7
		Saxifraga occidentalis (Saoc)	60
16. *Achnatherum richardsonii*	3	*Achnatherum richardsonii* (Acri)	99.9
		Astragalus agrestis (Asag)	66.7
		Poa pratensis (Popr)	66.3
		Sisyrinchium montanum (Simo)	38.1
		Vicia americana (Viam)	66.7
		Viola adunca (Viad)	66.0
17. *Carex aquatilis*	2	*Carex aquatilis* (Caaq)	100
		Equiseum variegatum (Eqva)	80.5
		***Eriophorum callitrix* (Erca)**	**43.7**
		Gentianella prostrata (Gepr)	29.8
18. *Salix barclayi-S. drummondiana-S. vestita*	3	*Abies bifolia* (Abbi)	47.6
		Equisetum arvense (Eqar)	39.5
		Moneses uniflora (Moun)	38.1
		Petasites frigidus (Pefr)	51.5
		Ranunculus eschscholtzii (Raes)	61.2
		Salix barclayi (Saba)	66.6
		Salix vestita (Save)	54.0
19. *Parnassia fimbriata*	2	***Aquilegia formosa* (Aqfo)**	**99.7**
		Arnica cordifolia (Arco)	36.4
		Parnassia fimbriata (Pafi)	59.0
		Vaccinium scoparium (Vasc)	79.2
		Veratrum viride (Vevi)	47.8
20. *Alnus viridis* ssp. *cripsa/Ribes lacustre/ Calamagrostis canadensis*	2	*Alnus viridis* ssp. *crispa* (Alni)	100
		Calamagrostis canadensis (Caca)	49.2
		Dryopteris expansa (Drex)	93.1
		***Ribes laxiflorum* (Rilx)**	**83.3**
		Ribes lacustre (Rila)	100
		Rubus idaeus (Ruid)	99.7
21. *Trollius albiflorus*	3	*Arnica diversifolia* (Ardi)	52.5

		Castilleja rhexifolia (Carh)	66.7
		Mitella pentandra (Mipe)	58.3
		Pedicularis bracteosa (Pebr)	75.6
		Trollius albiflorus (Tral)	91.9
		Valeriana sitchensis (Vasi)	89.7
22. *Dryas integrifolia*	4	*Polygonum viviparum* (Povi)	29.8
23. Rocky (calcareous)	3	*Erigeron compositus* (Erco)	71
		Taraxacum ceratophorum (Tace)	34
24. Rocky (calcareous)	4	*Elymus alaskanus* (Elal)	69.8
		***Erigeron trifidus* (Ertr)**	**76.1**
25. Rocky (neutral)	3	*Cerastium beeringianum* (Cebe)	45.4
		Saxifraga cernua (Sace)	29.1
		Silene acaulis (Siac)	40.0
		Stellaria longipes (Stlo)	41.8
26. *Artemisia michauxiana*	3	*Artemisia michauxiana* (Armi)	93.0
		Potentilla uniflora (Poun)	33.3
		***Silene hitchguirei* (Sihi)**	**66.7**
27. *Artemisia norvegica*	6	*Artemisia norvegica* (Arno)	48.7
28. Rocky (acidic)	4	none	
29. *Festuca altaica*	2	*Aconitum delphinfolium* (Acde)	44.3
		***Festuca altaica* (Feal)**	**92.8**
		Potentilla diversifolia (Podi)	56.7
		Pyrola minor (Pymi)	43.7
		Rhiananthus minor (Rhmi)	43.7
30. *Fragaria virginiana* (with one plot *Empetrum nigrum-Vaccinium myrtillifolia*)	6	*Arctostaphylos uva-ursi* (Aruv)	63.6
		Botrychium lunaria (Bolu)	67.4
		Fragaria virginiana (Frvi)	50.5
		Pinus contorta (Pico)	45.6
		Populus balsamifera (Poba)	49.6
		Trifolium pratense (Trpr)	66.7
31. *Carex spectabilis*	3	*Carex spectabilis* (Casp)	89.1
32. *Carex nigricans*	2	none	
33. *Carex nigricans*	9	*Caltha leptosepala* (Cale)	33.7
		Carex nigricans (Cani)	79.2
		Juncus drummondii (Judr)	44.2
34. *Cassiope*	8	none	
35. *Phyllodoce glanduliflora*	4	*Antennaria lanata* (Anla)	71.9
		Diphasiastrum alpinum (Dial)	67.1
		Phyllodoce glanduliflora (Phgl)	45.1
36. *Cassiope mertensiana*	10	*Cassiope mertensiana* (Came)	74.7
		***Gentiana glauca* (Gegl)**	**34.5**
37. *Dryas octopetala*	13	*Dryas octopetala* (Droc)	59.8
38. *Cassiope tetragona*	8	*Cassiope tetragona* (Cate)	71.6
39. *Empetrum nigrum*	4	*Empetrum nigrum* (Emni)	39.1

		***Loiseleuria procumbens* (Lopr)**	**73.5**
40. *Vaccinium uliginosum*	6	***Vaccinium uliginosum* (Vaul)**	**43.0**
41. *Salix nivalis*	8	*Myosotis asiatica* (Myal)	27.6
		Salix nivalis (Sani)	54.3
42. *Salix nivalis*	5	none	
43. *Salix arctica*	14	*Salix arctica* (Saar)	45
44. *Salix arctica*	8	none	
45. *Dryas integrifolia*	14	*Dryas integrifolia* (Drin)	80

Table 2.3. Summary of vegetation types/habitats of the study area determined by cluster analysis and Indicator Species Analysis in comparison to existing classification systems. * denotes rare community type according to Allen (2005). ** indicates association which may be new type. An open forested stand is a plot with tree height ≤ 5 m and cover ≤ 20% (Corns and Achuff 1982) and a sparse habitat is one with ≤ 20% vascular plant cover.

Dominant and/or indicators species	Site number	Vegetation types (Corns and Achuff 1982)	Plant Communities (Beckingham et al. 1996)	Plant Community types (Willoughby and Alexander 2003 and Willoughby et al. 2005)
20 x 20 m plots (treed)				
Group 1—*Picea glauca*				
Picea glauca/Shepherdia canadensis/moss	2	C37 *Picea glauca/Shepherdia canadensis/Hylocomium splendens*	MN c5.1 Sw/Canada buffalo-berry/hairy wild rye/wiry fern moss (hairy wild rye Sw)	E12 *Picea glauca*/moss
Picea glauca/moss	11	C2 *Picea glauca/Thuidium abietinum*	MN c5.3 Sw/feather moss-wiry fern moss (hairy wild rye Sw)	E12 *Picea glauca*/moss
Picea glauca-Populus tremuloides-Betula papyrifera/Bromus inermis/moss*	17	Closest to C16 *Populus tremuloides/Elymus innovatus/Lathyrus ochroleucus*	Closest to MN c5.3 Sw/feather moss-wiry fern moss (hairy wild rye Sw)	E12 *Picea glauca*/moss
Populus balsamifera-Picea glauca/Leymus innovatus/moss	33	C17 *Populus balsamifera/Shepherdia canadensis*	Closest to MN c3.1 Pb/Canada buffalo berry/hairy wild rye (hairy wild rye Aw)	F7 *Populus tremuloides-Populus balsamifera-Picea glauca/Calamagrostis rubescens*
Picea glauca-Pseudotsuga	61	C5 *Picea glauca-Pseudotsuga*	MN c5.3 Sw/feather	E10 *Picea glauca-*

menziesii/moss		*menziesii/Hylocomium splendens*	moss-wiry fern moss (hairy wild rye Sw)	*Pseudotsuga menziesii/Spirea betulifolia*
Picea glauca/moss*	175	C2 *Picea glauca/Thuidium abietinum*	MN c5.3 Sw/feather moss-wiry fern moss (hairy wild rye Sw)	E12 *Picea glauca*/moss
Picea glauca/moss*	184	C2 *Picea glauca/Thuidium abietinum*	MN c5.3 Sw/feather moss-wiry fern moss (hairy wild rye Sw)	E12 *Picea glauca*/moss
Picea glauca/Equisetum arvense/moss	212	C4 *Picea glauca/Rosa acicularis/Equisetum arvense*	MN c5.3 Sw/feather moss-wiry fern moss (hairy wild rye Sw)	E12 *Picea glauca*/moss
Group 2—*Populus tremuloides*				
Populus tremuloides/Leymus innovatus	4	C16 *Populus tremuloides/Elymus innovatus/Lathyrus ochroleucus*	MN c3.1 Aw/Canada buffalo-berry/hairy wild rye (hairy wild rye Aw)	G2 *Populus tremuloides/Rosa acicularis/Elymus innovatus*
Populus tremuloides-Pinus contorta/Leymus innovatus	114	C16 *Populus tremuloides/Elymus innovatus/Lathyrus ochroleucus*	MN c3.1 Aw/Canada buffalo-berry/hairy wild rye (hairy wild rye Aw)	G2 *Populus tremuloides/Rosa acicularis/Elymus innovatus*
Populus tremuloides/Elymus lanceolatus	115	C16 *Populus tremuloides/Elymus innovatus/Lathyrus ochroleucus*	MN c3.2 Aw/prickly rose (hairy wild rye Aw)	G2 *Populus tremuloides/Rosa acicularis/Elymus innovatus*
Arctostaphylos uva-ursi/Leymus innovatus (burned *Pinus contorta* stand)	116	C3 *Pinus contorta/Juniperus communis/Arctostaphylos uva-ursi*	MN b2.1 Pl/bearberry-Canada buffalo berry/hairy wild rye	E3 *Pinus contorta/Arctostaphylos uva-ursi/Juniperus* spp.
Populus	118	C16 *Populus*	MN c3.1 Aw/Canada	G2 *Populus*

tremuloides/Leymus innovatus		*tremuloides/Elymus innovatus/Lathyrus ochroleucus*	buffalo berry/hairy wild rye (hairy wild rye Aw)	*tremuloides/Rosa acicularis/Elymus innovatus*
Populus tremuloides/Leymus innovatus	161	C16 *Populus tremuloides/Elymus innovatus/Lathyrus ochroleucus*	MN c3.1 Aw/Canada buffalo berry/hairy wild rye (hairy wild rye Aw)	G2 *Populus tremuloides/Rosa acicularis/Elymus innovatus*
Populus tremuloides /Shepherdia canadensis/Leymus innovatus	179	C16 *Populus tremuloides/Elymus innovatus/Lathyrus ochroleucus*	MN c3.1 Aw/Canada buffalo berry/hairy wild rye (hairy wild rye Aw)	G2 *Populus tremuloides/Rosa acicularis/Elymus innovatus*
Populus tremuloides /Shepherdia canadensis/Leymus innovatus	182	C16 *Populus tremuloides/Elymus innovatus/Lathyrus ochroleucus*	MN c3.1 Aw/Canada buffalo berry/hairy wild rye (hairy wild rye Aw)	G2 *Populus tremuloides/Rosa acicularis/Elymus innovatus*
Populus tremuloides/Leymus innovatus	274	C16 *Populus tremuloides/Elymus innovatus/Lathyrus ochroleucus*	MN c3.2 Aw/prickly rose/hairy wild rye (hairy wild rye Aw)	G2 *Populus tremuloides/Rosa acicularis/Elymus innovatus*
Populus tremuloides/Leymus innovatus	285	C16 *Populus tremuloides/Elymus innovatus/Lathyrus ochroleucus*	MN c3.1 Aw/Canada buffalo berry/hairy wild rye (hairy wild rye Aw)	G2 *Populus tremuloides/Rosa acicularis/Elymus innovatus*
Group 3— *Elymus lanceolatus- Koeleria macrantha*				
Elymus lanceolatus-Koeleria macrantha *	12	H6 *Koeleria cristata-Artemisia frigida-Linum lewisii*	MN a2.1 *Artemisia frigida* grassland (graminoid grassland)	A1 *Artemisia frigida/Koeleria macrantha*
Elymus lanceolatus-Koeleria macrantha *	117	H6 *Koeleria cristata-Artemisia frigida-Linum*	MN a2.1 *Artemisia frigida* grassland	A1 *Artemisia frigida/Koeleria*

		lewisii	(graminoid grassland)	*macrantha*
Group 4—*Pseudotsuga menziesii*				
Pseudotsuga menziesii/Leymus innovatus/moss	10	C1 *Pseudotsuga menziesii/Elymus innovatus*	MN c1.2 *Pseudotsuga menziesii/Elymus innovatus/Thuidium abietinum* (hairy wild rye Fd)	E6 *Pseudotsuga menziesii/Elymus innovatus*
Pseudotsuga menziesii/Leymus innovatus/moss	166	C1 *Pseudotsuga menziesii/Elymus innovatus*	MN c1.2 *Pseudotsuga menziesii/Elymus innovatus/Thuidium abietinum* (hairy wild rye Fd)	E6 *Pseudotsuga menziesii/Elymus innovatus*
Pseudotsuga menziesii/Juniperus communis	180	O5 *Pseudotsuga menziesii /Juniperus communis /Arctostaphylos uva-ursi*	MN A1.1 *Arctostaphylos uva-ursi* grassland (shrubby grassland)	E3 *Pinus contorta/Arctostaphylos uva-ursi-Juniperus* spp.
Pseudotsuga menziesii/Leymus innovatus	181	C1 *Pseudotsuga menziesii/Elymus innovatus*	MN c1.2 *Pseudotsuga menziesii/Elymus innovatus/Thuidium abietinum* (hairy wild rye Fd)	E6 *Pseudotsuga menziesii/Elymus innovatus*
Pseudotsuga menziesii/Leymus innovatus	186	C1 *Pseudotsuga menziesii/Elymus innovatus*	MN c1.2 *Pseudotsuga menziesii/Elymus innovatus/Thuidium abietinum* (hairy wild rye Fd)	E6 *Pseudotsuga menziesii/Elymus innovatus*
Pseudotsuga menziesii/Leymus innovatus	208	C1 *Pseudotsuga menziesii/Elymus innovatus*	MN c1.2 *Pseudotsuga menziesii/Elymus innovatus/Thuidium abietinum* (hairy wild rye Fd)	E6 *Pseudotsuga menziesii/Elymus innovatus*

Pseudotsuga menziesii/Linnaea borealis/Aster conspicuous /Leymus innovatus	211	C1 *Pseudotsuga menziesii/Elymus innovatus*	MN c1.2 *Pseudotsuga menziesii/Elymus innovatus/Thuidium abietinum* (hairy wild rye Fd)	E6 *Pseudotsuga menziesii/Elymus innovatus*
Group 5—*Pinus contorta*				
Pinus contorta/Shepherdia canadensis/Vaccinium vitis-idaea	3	C11 *Pinus contorta-Picea* spp./*Hylocomium splendens*	SA d1.6 Pl/feather moss (*Rhododendron* mesic Pl)	E5 *Pinus contorta/Shepherdia canadensis/Calamagrostis rubescens*
Pinus contorta-Picea glauca/moss	20	C11 *Pinus contorta-Picea* spp./*Hylocomium splendens*	SA d1.6 Pl/feather moss (*Rhododendron* mesic Pl)	E9 *Pinus contorta/Calamagrostis rubescens*
Pinus contorta-Picea engelmannii/Vaccinium scoparium/moss*	152	C11 *Pinus contorta-Picea* spp./*Hylocomium splendens*	SA d1.6 *Pinus contorta*/feather moss (*Rhododendron* mesic Pl)	E5 *Pinus contorta/Shepherdia canadensis/Calamagrostis rubescens*
Pinus contorta/Vaccinium scoparium/moss*	153	C11 *Pinus contorta-Picea* spp./*Hylocomium splendens*	SA d1.6 Pl/feather moss (*Rhododendron* mesic Pl)	E7 *Pinus contorta/Vaccinium caespitosa/Elymus innovatus*
Pinus contorta/Shepherdia canadensis/Leymus innovatus	159	C19 *Pinus contorta/Shepherdia canadensis/Linnaea borealis*	SA c1.1 *Pinus contorta/Shepherdia canadensis/Elymus innovatus* (hairy wild rye Pl)	E5 *Pinus contorta/Shepherdia canadensis/Calamagrostis rubescens*
Pinus contorta/Shepherdia canadensis/Leymus innovatus	168	C19 *Pinus contorta/Shepherdia canadensis/Linnaea borealis*	SA c1.1 *Pinus contorta/Shepherdia canadensis/Elymus innovatus* (hairy wild rye Pl)	E5 *Pinus contorta/Shepherdia canadensis/Calamagrostis rubescens*

Pinus contorta/Calamagrostis canadensis/lichen	169	C11 *Pinus contorta-Picea* spp./*Hylocomium splendens*	SA c1.6 Pl/feather moss (hairy wild rye Pl)	SASME3 *Pinus contorta-Picea engelmannii*/moss spp.
Pinus contorta/Vaccinium caespitosum	170	C35 *Pinus contorta-(Picea engelmannii)/Empetrum nigrum*/lichen	SA c1.6 Pl/ feather moss (hairy wild rye Pl)	SASME3 *Pinus contorta-Picea engelmannii*/moss spp.
*Pinus contorta/Shepherdia canadensis/Vaccinium scoparium**	171	C18 *Pinus contorta/Shepherdia canadensis/Vaccinium scoparium*	SA c1.1 *Pinus contorta/Shepherdia canadensis/Elymus innovatus* (hairy wild rye Pl)	E5 *Pinus contorta/Shepherdia canadensis/Calamagrostis rubescens*
Pinus contorta/Leymus innovatus/moss	172	C11 *Pinus contorta-Picea* spp./*Hylocomium splendens*	SA c1.4 *Pinus contorta/Elymus innovatus*/feather moss	E5 *Pinus contorta/Shepherdia canadensis/Calamagrostis rubescens*
Pinus contorta/Shepherdia canadensis/Leymus innovatus	190	C19 *Pinus contorta/Shepherdia canadensis/Linnaea borealis*	SA c1.1 *Pinus contorta/Shepherdia canadensis/Elymus innovatus* (hairy wild rye Pl)	E5 *Pinus contorta/Shepherdia canadensis/Calamagrostis rubescens*
Pinus contorta/Shepherdia canadensis/Leymus innovatus	207	C19 *Pinus contorta/Shepherdia canadensis/Linnaea borealis*	SA c1.1 *Pinus contorta/Shepherdia canadensis/Elymus innovatus* (hairy wild rye Pl)	E5 *Pinus contorta/Shepherdia canadensis/Calamagrostis rubescens*
Pinus contorta/Shepherdia canadensis/Leymus innovatus	210	C19 *Pinus contorta/Shepherdia canadensis/Linnaea borealis*	SA c1.1 *Pinus contorta/Shepherdia canadensis/Elymus innovatus* (hairy wild rye Pl)	E5 *Pinus contorta/Shepherdia canadensis/Calamagrostis rubescens*
Pinus contorta-Picea	298	C36 *Pinus contorta-Picea*	SA c3.3 Se/willow/hairy	SASME3 *Pinus contorta-*

engelmannii/Salix glauca-Cornus stolonifera-Betula glandulosa/Leymus innovatus		*glauca/Salix glauca/Elymus innovatus*	wild rye (hairy wild rye Se)	*Picea engelmannii*/moss spp.
Group 6—*Abies bifolia*				
Abies bifolia-Picea engelmannii/Empetrum nigrum	25	O10 *Picea engelmannii-Abies lasiocarpa/Phyllodoce glanduliflora-Cassiope mertensiana*	No equivalent	E21 *Abies lasiocarpa-Picea engelmannii/Arnica cordifolia*
Abies bifolia/Phyllodoce glanduliflora-Empetrum nigrum	74	O10 *Picea engelmannii-Abies lasiocarpa/Phyllodoce glanduliflora-Cassiope mertensiana*	No equivalent	E21 *Abies lasiocarpa-Picea engelmannii/Arnica cordifolia*
Abies bifolia/Phyllodoce glanduliflora-Empetrum nigrum	100	O10 *Picea engelmannii-Abies lasiocarpa/Phyllodoce glanduliflora-Cassiope mertensiana*	SA d2.6 Se/subalpine fir/feather moss (*Rhododendron* mesic Se)	E21 *Abies lasiocarpa-Picea engelmannii/Arnica cordifolia*
Abies bifolia/Menziesia ferruginea/moss	143	C14 *Picea engelmannii-Abies lasiopcarpa/Menziesia glabella/Vaccinium scoparium*	SA d3.2 Fa/false azalea/feather moss (*Rhododendron* mesic Fa)	E21 *Abies lasiocarpa-Picea engelmannii/Arnica cordifolia*
Abies bifolia-Picea engelmannii/ Vaccinium scoparium	151	C15 *Picea engelmannii-Abies lasiocarpa/Vaccinium scoparium*	SA d2.6 Se/subalpine fir/feather moss (*Rhododendron* mesic Se)	E18 *Picea engelmannii/Vaccinium scoparium*
Picea engelmannii-Abies bifolia/Vaccinium membranaceum/moss	158	C21 *Picea engelmannii-Abies lasiocarpa/Vaccinium membranaceum/Barbilophozia locopodioides*	SA d2.3 Se/tall bilberry/feather moss (*Rhododendron* mesic Se)	E21 *Abies lasiocarpa-Picea engelmannii/Arnica cordifolia*
Abies bifolia/Picea engelmannii/moss	167	C21 *Picea engelmannii-Abies lasiocarpa/Vaccinium*	SA d2.6 Se/subalpine fir/feather moss	E21 *Abies lasiocarpa-Picea engelmannii/Arnica*

		membranaceum/Barbilophozia locopodioides	(*Rhododendron* mesic Se)	*cordifolia*
Abies bifolia-Picea engelmannii/Menziesia glabella/moss	258	C14 *Picea engelmannii-Abies lasiocarpa/Menziesia glabella/Vaccinium scoparium*	SA d3.2 Fa/false azalea/feather moss (*Rhododendron* mesic Fa)	E21 *Abies lasiocarpa-Picea engelmannii/Arnica cordifolia*
Abies bifolia-Picea engelmannii/Phyllodoce glanduliflora/moss	262	O10 *Picea engelmannii-Abies lasiocarpa/Phyllodoce glanduliflora-Cassiope mertensiana*	SA D2.6 Se/subalpine fir/feather moss (*Rhododendron* mesic Se)	E21 *Abies lasiocarpa-Picea engelmannii/Arnica cordifolia*
Abies bifolia-Picea engelmannii/Menziesia ferruginea/Phyllodoce glanduliflora/moss	276	C14 *Picea engelmannii-Abies lasiocarpa/Menziesia glabella/Vaccinium scoparium*	SA d2.2 Se/false azalea/feather moss (*Rhododendron* mesic Se)	E21 *Abies lasiocarpa-Picea engelmannii/Arnica cordifolia*
Abies bifolia-Picea engelmannii/Menziesia ferruginea/moss	302	C14 *Picea engelmannii-Abies lasiocarpa/Menziesia glabella/Vaccinium scoparium*	SA d2.2 Se/false azalea/feather moss (*Rhododendron* mesic Se)	E21 *Abies lasiocarpa-Picea engelmannii/Arnica cordifolia*
Group 7—*Gymnocarpium dryopteris*				
Abies bifolia/Salix drummondiana/Equisetum arvense/moss (open)	40	O6 *Picea engelmannii-Abies lasiocarpa/Salix* spp./*Aulocomnium palustre*	SA G1.1 Se/willow/horsetail (horsetail Se)	No equivalent
*Betula papyrifera/Menziesia ferruginea-Viburnum edule***	286	No equivalent	No equivalent	No equivalent
Abies bifolia-Picea engelmannii-Pinus albicaulis/Menziesia ferruginea	303	C12 *Picea engelmannii-Pinus albicaulis/Menziesia glabella*	SA d2.2 Se/false azalea/feather moss (*Rhododendron* mesic Se)	E21 *Abies lasiocarpa-Picea engelmannii/Arnica cordifolia*

Group 8—*Picea engelmannii*				
Picea engelmannii/Equisetum pratense	34	C32 *Picea engelmannii/Equisetum arvense/Hylocomium splendens*	SA d2.7 Se/feather moss (*Rhododendron* mesic Se)	E 19 *Picea engelmannii*
Picea engelmannii-Pinus contorta/Salix glauca/Linnaea borealis/Leymus innovatus	103	C31 *Picea engelmannii-Abies lasiocarpa/Elymus innovatus-Arnica cordifolia/Linnaea borealis/Hylocomium splendens*	SA c3.4 Se/hairy wild rye/feather noss (hairy wild rye Se)	E8 *Pinus contorta/Spiraea betulifolia*
Abies bifolia-Picea engelmannii/Alnus viridus/Menziesia ferruginea/moss	209	Closest to C14 *Picea engelmannii-Abies lasiocarpa/Menziesia glabella/Vaccinium scoparium*	SA d2.5 Se/green alder/feathermoss (*Rhododendron* mesic Se)	E21 *Abies lasiocarpa-Picea engelmannii/Arnica cordifolia*
Picea engelmannii/Equisetum arvense/moss	275	C32 *Picea engelmannii/Equisetum arvense/Hylocomium splendens*	SA d2.7 Se/feather moss (*Rhododendron* mesic Se)	E19 *Picea engelmannii*
Abies bifolia-Picea engelmannii/Menziesia ferruginea/moss	278	C14 *Picea engelmannii-Abies lasiocarpa/Menziesia glabella/Vaccinium scoparium*	SA d2.5 Se/green alder/feather moss (*Rhododendron* mesic Se)	E21 *Abies lasiocarpa-Picea engelmannii/Arnica cordifolia*
Picea engelmannii-Pinus contorta/Rhododendron groenlandicum/moss*	299	C29 *Pinus contorta/Ledum groenlandicum*	SA d1.4 Pl/Labrador tea/feather moss (*Rhododendron* mesic Pl)	E8 *Pinus contorta/Spiraea betulifolia*
Picea engelmannii-Pinus contorta/moss	301	C31 *Picea engelmannii-Abies lasiocarpa/Elymus innovatus-Arnica cordifolia/Linnaea borealis/Hylocomium*	SA d2.7 Se/ feather moss (*Rhododendron* mesic Se)	E8 *Pinus contorta/Spiraea betulifolia*

		splendens		
10 x 10 m plots (shrub)				
Group 1—*Arctostaphylos uva-ursi*				
*Arctostaphylos uva-ursi-Juniperus horizontalis**	6	H7 *Agropyron dasystachum-Artemisia frigida*	MN a1.1 bearberry grassland (shrubby grassland)	A1 *Artemisia frigida/Koeleria macrantha*
Pentaphylloides fruticosa-Betula pumila/Arctostaphylos uva-ursi	185	L1 *Potentilla fruticosa/Arctostaphylos uva-ursi/Galium boreale*	MN e1.1 willow-sedge meadow meadow	D10 *Betula pumila-Potentilla fruticosa/Valeriana dioica/Carex* spp.
*Arctostaphylos uva-ursi/Leymus innovatus-Koeleria macrantha**	187	H6 *Koeleria cristata-Artemisia frigida-Linum lewisii*	MN a1.1 bearberry grassland (shrubby grassland)	A1 *Artemisia frigida/Koeleria macrantha*
Group 2—*Elaeagnus commutata*				
Eleagnus commutata/Leymus innovatus	14	No equivalent	MN a1.2 prickly rose-silverberry grassland (shrubby grassland)	No equivalent
*Eleagnus commutata/Koeleria macrantha-Stipa richardsonii**	183	H13 *Stipa richardsonii-Koeleria cristata-Antennaria nitida*	MN a1.2 prickly rose-silverberry grassland (shrubby grassland)	No equivalent
Group 3—*Salix glauca*				
Salix exigua-S. glauca-Betula glandulosa	21	S1 *Betula spp.-Potentilla fruticosa-Salix glauca/Tomenthypnum nitens*	Uf g1.1 willow/cow parsnip-tall larkspur meadow (shrubby meadow)	SACMB3 *Salix glauca-Betula glandulosa/Elymus innovatus*
Salix glauca/Deschampsia cespitosa	35	S1 *Betula spp.-Potentilla fruticosa-Salix glauca/Tomenthypnum nitens*	Uf g1.1 willow/cow parsnip-tall larkspur meadow	D10 *Betula pumila-Potentilla fruticosa/Valeriana*

			(shrubby meadow)	*dioica/Carex* spp.
Elymus repens	60	Cliff face, no equivalent	Cliff face, no equivalent	No equivalent
Abies bifolia-Picea engelmannii/Salix barrattiana-S. glauca-S. vestita	202	No equivalent	No equivalent	No equivalent
Picea glauca/Juniperus communis (open)	215	O17 *Picea glauca/Juniperus communis/Arctostaphylos uva-ursi*	Mn b5.1 Sw/bearberry-juniper/wiry fern moss (bearberry Sw)	A7 *Arctostaphylos uva-ursi/Juniperus* spp.
Group 4—*Salix drummondiana*				
Picea glauca /Salix drummondiana/Fragaria virginiana (open)	32	S7 *Salix* spp./*Equisetum arvense*	No equivalent	No equivalent
Salix drummondiana/Juncus mertensiana	39	S7 *Salix* spp./*Equisetum arvense*	No equivalent	No equivalent
Abies bifolia-Salix drummondiana/Phyllodoce glanduliflora (open)	45	S7 *Salix* spp./*Equisetum arvense*	No equivalent	No equivalent
Group 5—*Salix farriae*				
Picea engelmannii-Salix farriae/Carex aquatilis	42	S1 *Betula* spp.-*Potentilla fruticosa-Salix glauca/Tomenhypnum nitens*	No equivalent	No equivalent
Salix farriae/Carex aquatilis/moss	43	S1 *Betula* spp.-*Potentilla fruticosa-Salix glauca/Tomenhypnum nitens*	SA i2.1 willow/sedge/tufted moss-peat moss (i2 shrubby fen)	No equivalent
Salix farriae/Carex spp.-*Equisetum variegatum*/moss	44	H11 *Carex aquatilis-Carex* [*rostrata*]	SA i3.1 (i3 graminoid fen)	No equivalent

Group 6—*Salix barrattiana*				
Salix barrattiana/Festuca altaica	48	S8 *Salix barrattiana/Potentilla diversifolia*	SA i2.1 willow/sedge/tufted moss-peat moss (i2 shrubby fen)	No equivalent
Salix barrattiana/Deschampsia cespitosa	149	S8 *Salix barrattiana/Potentilla diversifolia*	SA i2.1 willow/sedge/tufted moss-peat moss (i2 shrubby fen)	SACFB4 *Salix glauca-Betula glandulosa/Deschampsia cespitosa*
Group 7—*Salix arctica*				
Salix arctica	71	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix alaxensis/Dryas integrifolia-Salix arctica	268	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA2 *Dryas octopetala, D. integrifolia*
Group 8—*Abies bifolia*				
Abies bifolia/Phyllodoce glanduliflora	101	S2 *Abies lasiocarpa-Salix* spp./*Valeriana sitchensis*	No equivalent	No equivalent
Abies bifolia/Phyllodoce glanduliflora	127	S2 *Abies lasiocarpa-Salix* spp./*Valeriana sitchensis*	No equivalent	No equivalent
Phyllodoce glanduliflora-Cassiope tetragona/Antennaria lanata	148	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Abies bifolia-Picea engelmannii-Alnus crispa/Phyllodoce glanduliflora	162	O10 *Picea engelmannii-Abies lasiocarpa/Phyllodoce glanduliflora-Cassiope mertensiana*	No equivalent	No equivalent
Abies bifolia-Picea engelmannii-Menziesia ferruginea	257	C14 *Picea engelmannii-Abies lasiocarpa/Menziesia glabella/Vaccinium scoparium*	No equivalent	E21 *Abies lasiocarpa-Picea engelmannii/Arnica cordifolia*

Abies bifolia-Betula glandulosa/Phyllodoce glanduliflora	284	S2 *Abies lasiocarpa-Salix* spp./*Valeriana sitchensis*	No equivalent	No equivalent
5 x 5 m plots (Herb)				
Group 1—*Elymus lanceolatus-Koeleria macrantha*				
Elymus lanceolatus-Koeleria macrantha-Plantago canescens *	1	H6 *Koeleria cristata-Artemisia frigida-Linum lewisii*	MN a2.1 pasture sagewort grassland	A1 *Artemisia frigida/Koeleria macrantha*
Elymus lanceolatus-Koeleria macrantha *	5	H6 *Koeleria cristata-Artemisia frigida-Linum lewisii*	MN a2.1 pasture sagewort grassland	A1 *Artemisia frigida/Koeleria macrantha*
*Koeleria macrantha-Artemisia frigida**	16	H6 *Koeleria cristata-Artemisia frigida-Linum lewisii*	MN a2.1 pasture sagewort grassland	A1 *Artemisia frigida/Koeleria macrantha*
*Koeleria macrantha**	165	H6 *Koeleria cristata-Artemisia frigida-Linum lewisii*	MN a2.1 pasture sagewort grassland	A1 *Artemisia frigida/Koeleria macrantha*
*Koeleria macrantha-Heterostipa curtiseta**	178	No equivalent	MN a2.1 pasture sagewort grassland	A1 *Artemisia frigida/Koeleria macrantha*
*Koeleria macrantha-Artemisia frigida**	206	H6 *Koeleria cristata-Artemisia frigida-Linum lewisii*	MN a2.1 pasture sagewort grassland	A1 *Artemisia frigida/Koeleria macrantha*
Group 2—cliff (calcareous)				
Cliff—sparse	7	No equivalent	No equivalent	No equivalent
Cliff-sparse	8	No equivalent	No equivalent	No equivalent
Cliff-sparse—*Pellaea*	9	No equivalent	No equivalent	No equivalent
Cliff-sparse—*Pellaea*	189	No equivalent	No equivalent	No equivalent

Group 3—cliff/outcrop (calcareous)				
Cliff—sparse—**Pellaea**	13	No equivalent	No equivalent	No equivalent
Ridge top—sparse—calcareous	281	No equivalent	No equivalent	No equivalent
Group 4-outcrop (calcareous)				
Cliff—limestone—*Telesonix*	188	No equivalent	No equivalent	No equivalent
Salix glauca-Telesonix, sparse vegetation	279	No equivalent	No equivalent	No equivalent
Group 5—*Antennaria microphylla*				
Antennaria microphylla-Calamagrostis montanesis	15	No equivalent	No equivalent	No equivalent
Carex duriscula-Artemisia frigida-Antennaria microphylla	177	No equivalent	No equivalent	C6 *Carex obtusata/Selaginella densa-Phlox hoodii*
Group 6—drainage channel				
Sparse drainage channel, montane	19	No equivalent	No equivalent	No equivalent
Sparse, river flat, Berland	31	No equivalent	No equivalent	No equivalent
Phleum alpinum-Trisetum spicatum	150	No equivalent	No equivalent	No equivalent
Group 7--talus				
Sparse, high elevation, talus	57	No equivalent	No equivalent	No equivalent
Sparse, high elevation, talus	134	No equivalent	No equivalent	No equivalent

Group 8—open graminoid				
Carex lenticularis var. *dolia*	138	No equivalent	No equivalent	No equivalent
sparse	223	No equivalent	No equivalent	No equivalent
sparse	252	No equivalent	No equivalent	No equivalent
Group 9—rocky (acidic)				
Sparse, cliff face	65	No equivalent	No equivalent	No equivalent
Sparse, scree	156	No equivalent	No equivalent	No equivalent
Group 10—consolidated talus				
Sparse, consolidated talus	77	No equivalent	No equivalent	No equivalent
Sparse, consolidated talus	78	No equivalent	No equivalent	No equivalent
Sparse, consolidated talus	193	No equivalent	No equivalent	No equivalent
Sparse, creek (alpine)	195	No equivalent	No equivalent	No equivalent
Sparse, consolidated talus	266	No equivalent	No equivalent	No equivalent
Group 11—sparse				
Sparse, trail side	27	No equivalent	No equivalent	No equivalent
Bromus inermis—Equisetum hyemale	105	No equivalent	No equivalent	No equivalent
Sparse, creek channel	176	No equivalent	No equivalent	No equivalent
Group 12—low shrub				
Rhododendron groenlandicum/moss	62	No equivalent	No equivalent	No equivalet
Betula pumila/Carex tenuiflora-Eriophorum viridicarinatum	63	No equivalent	MN g2.1 willow sedge meadow	No equivalent
Group 13—*Salix-Betula glandulosa*				
Betula glandulosa/Deschampsia	29	S1 *Betula* spp.-*Potentilla fruticosa-Salix*	No equivalent	D10 *Betula pumila-Potentilla*

cespitosa		*glauca/Tomenhypnum nitens*		*fruticosa/Valeriana dioica/Carex* spp.
Salix glauca-S. pedicellaris	30	S1 *Betula* spp.-*Potentilla fruticosa-Salix glauca/Tomenhypnum nitens*	No equivalent	SACMB2 *Salix glauca-Betula glandulosa/Carex* spp.
Group 14—sparse (mesic)				
Koenigia islandica	41	No equivalent	No equivalent	No equivalent
Epilobium latifolium	46	No equivalent	No equivalent	No equivalent
Sparse, *Luetkea pectinata*	163	No equivalent	No equivalent	No equivalent
Group 15—*Anemone occidentalis*				
Luetkea pectinata-Anemone occidentalis	293	H16 *Erigeron peregrinus-Valeriana sitchensis*	No equivalent	SACMA2 Forb meadows
Anemone occidentalis-Selaginella densa	294	H16 *Erigeron peregrinus-Valeriana sitchensis*	No equivalent	SACMA2 Forb meadows
Group 16—*Achnatherum richardsonii*				
Achnathurum richardsonii	160	H13 *Stipa richardsonii-Koeleria cristata-Antennaria nitida*	MN a2.1 pasture sagewort grassland	A5 *Selaginella densa/Stipa richardsonii*
Poa pratensis-Leymus innovatus-Achnathurum richardsonii	173	H13 *Stipa richardsonii-Koeleria cristata-Antennaria nitida*	MN a2.1 pasture sagewort grassland	A5 *Selaginella densa/Stipa richardsonii*
Achnatherum richardsonii-Leymus innovatus	174	H13 *Stipa richardsonii-Koeleria cristata-Antennaria nitida*	MN a2.1 pasture sagewort grassland	A5 *Selaginella densa/Stipa richardsonii*
Group 17—*Carex aquatilis*				
Salix maccalliana/Carex aquatilis-Pedicularis	36	H11 *Carex aquatilis-Carex* [*rostrata*]	MN e1.1 willow/sedge meadow	D10 *Betula pumila-Potentilla*

groenlandica				*fruticosa/Valeriana dioica/Carex* spp.
Carex aquatilis-Salix arctica	94	H11 *Carex aquatilis-Carex* [*rostrata*]	MN e1.1 willow/sedge meadow	B12 *Carex rostrata, C. aquatilis*
Group 18—*Salix barclayi-S. drummondiana-S. vestita*				
Salix spp./*Fragaria virginiana*	141	S7 *Salix* spp./*Equisetum arvense*	No equivalent	No equivalent
Salix spp./*Equisetum arvense*	142	S7 *Salix* spp./*Equisetum arvense*	No equivalent	No equivalent
Equisetum arvense-Poa alpina	204	S7 *Salix* spp./*Equisetum arvense*	No equivalent	No equivalent
Group 19—-*Parnassia fimbriata*				
Aquilegia formosa-Parnassia fimbriata	259	No equivalent	No equivalent	No equivalent
Arnica cordifolia-Parnassia fimbriata	277	No equivalent	No equivalent	No equivalent
Group 20 *Alnus viridis* ssp. *crispa/Ribes lacustre/Calamagrostis canadensis*				
Alnus viridis/Ribes spp./*Calamagrostis canadensis*	255	No equivalent	No equivalent	No equivalent
Salix drummondiana-Ribes laxiflorum	256	No equivalent	No equivalent	No equivalent
Group 21—*Trollius albiflorus*				
Valeriana sitchensis-	95	H16 *Erigeron peregrinus-*	No equivalent	SACMA2 Forb meadows

Trollius albiflorus		*Valeriana sitchensis*		
Valeriana sitchensis-Trollius albiflorus-Arnica latifolia	111	H16 *Erigeron peregrinus-Valeriana sitchensis*	No equivalent	SACMA2 Forb meadows
Valeriana sitchensis-Trollius albiflorus	112	H16 *Erigeron peregrinus-Valeriana sitchensis*	No equivalent	SACMA2 Forb meadows
Group 22—*Dryas integrifolia*				
Dryas integrifolia/moss-lichen	24	H1. *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	ALPA2 *Dryas octopetala, D. integrifolia*
(*Dryas integrifolia*)-*Saxifraga oppositifolia*	236	H1. *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	ALPA2 *Dryas octopetala, D. integrifolia*
(*Dryas integrifolia*)-*Polygonum viviparum-Trisetum spicatum-Oxytropis podocarpa-Kobresia myosuroides*	237	H4. *Dryas octopetala-Kobresia myosuroides-Arctostaphylos uva-ursi*	No equivalent	SACFA14 *Dryas integrifolia/Kobresia myosuroides*
Dryas integrifolia-Astragalus vexilliflexus	264	H1. *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	ALPA2 *Dryas octopetala, D. integrifolia*
Group 23—rocky (calcareous)				
Sparse—Caw ridge	267	No equivalent	No equivalent	No equivalent
Sparse—Hamell	269	No equivalent	No equivalent	No equivalent
Sparse—Hamell	273	H12 Saxicolous lichen	No equivalent	No equivalent
Group 24—rocky (calcareous)				
Sparse—Sulphur ridge	81	No equivalent	No equivalent	No equivalent
Sparse—Big Shovel	200	No equivalent	No equivalent	No equivalent
Sparse—Whistlers	243	No equivalent	No equivalent	No equivalent
Sparse—Hamell	270	No equivalent	No equivalent	No equivalent
Group 25—rocky				

(neutral)				
Silene acaulis/moss/lichen	84	No equivalent	No equivalent	ALPA7 Lichen stonefield
Salix nivalis-Silene acaulis/moss/lichen	205	No equivalent	No equivalent	ALPA7 Lichen stonefield
Silene acaulis-Festuca spp.-*Luzula spicata*	245	No equivalent	No equivalent	No equivalent
Group 26—*Artemisia michauxiana*				
Potentilla uniflora-Silene acaulis-Artemisia michauxiana/lichen	136	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	No equivalent
Artemisia michauxiana-Festuca brachyphylla-Trisetum spicatum	238	No equivalent	No equivalent	No equivalent
Geranium richardsonii-Artemisa michauxiana-Campanula rotundifolia	254	No equivalent	No equivalent	No equivalent
Group 27—*Artemisia norvegica*				
Anemone occidentalis-Artemisia norvegica	119	H16 *Erigeron peregrinus-Valeriana sitchensis*	No equivalent	SACMA2 Forb meadows
Kobresia myosuroides-Artemisia norvegica	144	H4 *Dryas octopetala-Kobresia myosuroides-Arctostaphylos uva-ursi*	No equivalent	No equivalent
Saxifraga bronchialis-Artemisia norvegica	203	No equivalent	No equivalent	No equivalent
Artemisia norvegica-Luzula arcuata	221	No equivalent	No equivalent	No equivalent
Artemisia norvegica-Luzula spicata	233	No equivalent	No equivalent	No equivalent
Artemisia norvegica-	234	No equivalent	No equivalent	No equivalent

Luzula arcuata				
Group 28—rocky (acidic)				
Sparse—*Saxifraga ferruginea, Poa leptocoma*	137	No equivalent	No equivalent	No equivalent
Sparse-acidic	140	H12 Saxicolous lichen	No equivalent	No equivalent
Sparse—acidic—Cavell moraine	164	H12 Saxicolous lichen	No equivalent	No equivalent
Sparse—acidic	244	No equivalent	No equivalent	No equivalent
Group 29—*Festuca altaica*				
Festuca altaica—Potentilla diversifolia	28	No equivalent	No equivalent	No equivalent
Festuca altaica-Leymus innovatus-Fragaria virginiana	271	No equivalent	No equivalent	SACFA9 *Festuca scabrella-Elymus innovatus/Carex* spp.
Group 30—*Fragaria virginiana*				
Fragaria virginiana-Trifolium repens	79	No equivalent	No equivalent	
Arctostaphylos uva-ursi-Festuca saximontana-Fragaria virginiana	213	No equivalent	No equivalent	No equivalent
Arctostaphylos uva-ursi-Fragaria virginiana	214	No equivalent	No equivalent	No equivalent
Fragaria virginiana-Antennaria rosea	240	No equivalent	No equivalent	No equivalent
Shepherida canadensis-Fragaria virginiana	295	No equivalent	No equivalent	No equivalent
Poa glauca-Fragaria virginiana	297	No equivalent	No equivalent	No equivalent

Group 31—*Carex spectabilis*				
Carex spectabilis	37	No equivalent	No equivalent	No equivalent
Carex spectabilis-Senecio triangularis	120	No equivalent	No equivalent	No equivalent
Carex spectabilis-Artemisia norvegica	157	No equivalent	No equivalent	No equivalent
Group 32—*Carex nigricans*				
Carex nigricans-lichen	56	H2 *Carex nigricans-Antennaria lanata*	No equivalent	ALPA4 *Carex nigricans*
Carex nigricans	198	H2 *Carex nigricans-Antennaria lanata*	No equivalent	ALPA4 *Carex nigricans*
Group 33—*Carex nigricans*				
Carex nigricans-moss	66	H2 *Carex nigricans-Antennaria lanata*	No equivalent	ALPA4 *Carex nigricans*
Carex nigricans-Valeriana sitchensis	91	H2 *Carex nigricans-Antennaria lanata*	No equivalent	ALPA4 *Carex nigricans*
Luetkea pectinata-Caltha leptosepala	121	H2 *Carex nigricans-Antennaria lanata*	No equivalent	ALPA4 *Carex nigricans*
Carex nigricans-Eriophorum polystachion	130	H2 *Carex nigricans-Antennaria lanata*	No equivalent	ALPA4 *Carex nigricans*
Carex nigricans	196	H2 *Carex nigricans-Antennaria lanata*	No equivalent	ALPA4 *Carex nigricans*
Carex nigricans-Caltha leptosepala	217	H2 *Carex nigricans-Antennaria lanata*	No equivalent	ALPA4 *Carex nigricans*
Carex nigricansLuetkea pectinata/moss	229	H2 *Carex nigricans-Antennaria lanata*	No equivalent	ALPA4 *Carex nigricans*
Carex nigricans-Caltha leptosepala	287	H2 *Carex nigricans-Antennaria lanata*	No equivalent	ALPA4 *Carex nigricans*

Carex nigricans-Luetkea pectinata/moss	289	H2 *Carex nigricans-Antennaria lanata*	No equivalent	ALPA4 *Carex nigricans*
Group 34—*Cassiope*				
Abies lasiocarpa-Salix drummondiana-Cassiope mertensiana-Phyllodoce glanduliflora	38	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope tetragona-Phyllodoce glanduliflora/lichen	72	L4 *Cassiope tetragona-Dryas octopetala-Salix nivalis*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope mertensiana-Phyllodoce glanduliflora/moss	128	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope tetragona-Phyllodoce glanduliflora-Epilobium latifolium	191	L4 *Cassiope tetragona-Dryas octopetala-Salix nivalis*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope mertensiana-Phyllodoce glanduliflora	218	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope mertensiana-Phyllodoce glanduliflora	226	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope mertensiana/moss	253	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Phyllodoce glanduliflora-Cassiope tetragona	288	*L4 Cassiope tetragona-Dryas octopetala-Salix nivalis*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Group 35—*Phyllodoce glanduliflora*				
Phyllodoce glanduliflora-Salix arctica	99	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.

		Antennaria lanata		
Phyllodoce glanduliflora-Cassiope mertensiana-Diphasiastrum alpinum	197	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Phyllodoce glanduliflora-Salix arctica-Antennaria lanata	225	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Antennaria lanata-Carex nigricans	248	H2 *Carex nigricans-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Group 36—*Cassiope mertensiana*				
Cassiope mertensiana-Caltha leptosepala	54	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope mertensiana-Carex spectabilis	69	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope mertensiana-Phyllodoce glanduliflora	125	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope mertensiana-Phyllodoce glanduliflora	126	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope mertensiana-Phyllodoce glanduliflora	139	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope mertensiana-Phyllodoce empetriformis-Luetkea pectinata	216	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope mertensiana-Antennaria lanata	219	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.

		Antennaria lanata		
Cassiope mertensiana-Arnica cordifolia	228	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope mertensiana-Phyllodoce glanduliflora-Phyllodoce empetriformis-Luetkea pectinata-Luzula piperi-Antennaria lanata	230	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope mertensiana-Phyllodoce empetriformis	231	L5 *Phyllodoce glanduliflora-Cassiope mertensiana-Antennaria lanata*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Group 37—*Dryas octopetala*				
Dryas octopetala-Salix nivalis	47	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	ALP2 *Dryas octopetala, D. integrifolia*
Dryas octopetala-Hierochloe alpina	55	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	ALP2 *Dryas octopetala, D. integrifolia*
Dryas octopetala/lichen*	70	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	ALP2 *Dryas octopetala, D. integrifolia*
Dryas octopetala-Kobresia myosuroides/lichen	96	H4 *Dryas octopetala-Kobresia myosuroides-Arctostaphylos uva-ursi*	No equivalent	ALP2 *Dryas octopetala, D. integrifolia*
Dryas octopetala-Cassiope tetragona-Empetrum nigrum	98	L4 *Cassiope tetragona-Dryas octopetala-Salix nivalis*	No equivalent	ALP2 *Dryas octopetala, D. integrifolia*
Dryas octopetala-Cassiope tetragona	110	L4 *Cassiope tetragona-Dryas octopetala-Salix nivalis*	No equivalent	ALP2 *Dryas octopetala, D. integrifolia*
Dryas octopetala/lichen	146	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	ALP2 *Dryas octopetala, D. integrifolia*
Dryas octopetala-Salix	222	H1 *Dryas octopetala-Salix*	No equivalent	ALP2 *Dryas octopetala,*

nivalis		*nivalis-Silene acaulis*		*D. integrifolia*
Dryas octopetala-Hierochloe alpina	224	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	ALP2 *Dryas octopetala, D. integrifolia*
Dryas octopetala-Salix nivalis	246	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	ALP2 *Dryas octopetala, D. integrifolia*
Dryas octopetala-Salix nivalis	247	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	ALP2 *Dryas octopetala, D. integrifolia*
Cassiope tetragona-Salix nivalis-Vaccinium vitis-idaea	249	L4 *Cassiope tetragona-Dryas octopetala-Salix nivalis*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Dryas octopetala-Vaccinium vitis-idaea-Salix nivalis	260	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	
Group 38—*Cassiope tetragona*				
Cassiope tetragona-Salix arctica	52	L4 *Cassiope tetragona-Dryas octopetala-Salix nivalis*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope tetragona-Salix nivalis	76	L4 *Cassiope tetragona-Dryas octopetala-Salix nivalis*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Dryas octopetala-Cassiope tetragona	106	L4 *Cassiope tetragona-Dryas octopetala-Salix nivalis*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Dryas octopetala-Cassiope tetragona	135	L4 *Cassiope tetragona-Dryas octopetala-Salix nivalis*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope tetragona-Dryas octopetala	147	L4 *Cassiope tetragona-Dryas octopetala-Salix nivalis*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope tetragona-Dryas octopetala	154	L4 *Cassiope tetragona-Dryas octopetala-Salix nivalis*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope tetragona-Salix arctica-Carex scirpoidea	201	L4 *Cassiope tetragona-Dryas octopetala-Salix nivalis*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Cassiope tetragona-Dryas octopetala	283	L4 *Cassiope tetragona-Dryas octopetala-Salix nivalis*	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.

Group 39—*Empetrum nigrum*				
Cassiope tetragona-Loiseleuria procumbens	64	No equivalent	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Empetrum nigrum-Loiseleuria procumbens	73	No equivalent	No equivalent	No equivalent
Loiseleuria procumbens-Empetrum nigrum	129	No equivalent	No equivalent	No equivalent
Cassiope tetragona-Empetrum nigrum	155	No equivalent	No equivalent	ALPA3 *Cassiope* spp.-*Phyllodoce* spp.
Group 40—*Vaccinium uliginosum*				
Dryas octopetala-Salix nivalis	75	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	SASMA14 *Dryas octopetala*
Vaccinium uliginosum-Dryas octopetala	107	No equivalent	No equivalent	SASMA14 *Dryas octopetala*
Dryas octopetala-Salix nivalis	109	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	SASMA14 *Dryas octopetala*
Empetrum nigrum-Vaccinium uliginosum	227	No equivalent	No equivalent	No equivalent
Dryas octopetala-Empetrum nigrum/moss	250	No equivalent	No equivalent	SASMA14 *Dryas octopetala*
Dryas octopetala-Empetrum nigrum-Vaccinium uliginosum/lichen	251	No equivalent	No equivalent	SASMA14 *Dryas octopetala*
Group 41—*Salix nivalis*				
Dryas integrifolia-Salix nivalis	22	No equivalent	No equivalent	No equivalent
Salix nivalis-Polygonum viviparum	59	No equivalent	No equivalent	No equivalent

Salix arctica-Salix nivalis	80	No equivalent	No equivalent	No equivalent
Salix nivalis	87	No equivalent	No equivalent	No equivalent
Salix nivalis-Antennaria monocephala	122	No equivalent	No equivalent	No equivalent
Salix nivalis-Artemisia norvegica-Potentilla diversifolia	123	No equivalent	No equivalent	No equivalent
Salix nivalis-Potentilla uniflora	145	No equivalent	No equivalent	No equivalent
Dryas integrifolia-Salix nivalis	194	No equivalent	No equivalent	No equivalent
Group 42—*Salix nivalis*				
Salix nivalis-Saxifraga oppositifolia	58	No equivalent	No equivalent	No equivalent
Salix nivalis-Silene acaulis	85	No equivalent	No equivalent	No equivalent
Salix nivalis-Carex scopulorum	113	No equivalent	No equivalent	No equivalent
Salix nivalis-Artemisia norvegica	192	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	No equivalent
Salix nivalis-Artemisia norvegica	232	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	No equivalent
Group 43—*Salix arctica*				
Salix arctica-Ranunculus occidentalis	49	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica-Salix barrattiana/Epilobium latifolium	50	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica-Caltha leptosepala	53	H9 *Caltha leptosepala-Trollius albiflorus*	No equivalent	ALPA6 *Salix arctica*
Salix arctica-Sibbaldia procumbens	67	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*

Salix arctica-Caltha leptosepala	68	H9 *Caltha leptosepala-Trollius albiflorus*	No equivalent	ALPA6 *Salix arctica*
Salix arctica-Potentilla diversifolia/moss	92	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica-Juncus spp./moss	93	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica-Sibbaldia procumbens	97	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica-S. nivalis	124	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica-Carex lachenalii/moss	133	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Dryas octopetala-Salix arctica	199	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica-Artemisia norvegica/lichen	220	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica-Salix nivalis/Sibbaldia procumbens/lichen	261	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica/moss	291	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Group 44—Salix arctica (sparse)				
Salix arctica	51	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica/Poa arctica	82	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica	89	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica/lichen	108	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*

Salix arctica/moss	132	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica	239	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica	290	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Salix arctica-Salix nivalis/lichen	292	L7 *Salix arctica-Potentilla diversifolia*	No equivalent	ALPA6 *Salix arctica*
Group 45—*Dryas integrifolia*				
Dryas integrifolia-Salix nivalis-Festuca altaica	23	No equivalent	No equivalent	ALP2 *Dryas octopetala, D. integrifolia*
Dryas integrifolia/lichen	83	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	SACFA14 *Dryas integrifolia /Kobresia myosuroides*
Dryas integrifolia-Kobresia myosuroides/lichen	86	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	SACFA14 *Dryas integrifolia /Kobresia myosuroides*
Dryas integrifolia-Salix nivalis	88	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	ALP2 *Dryas octopetala, D. integrifolia*
Dryas integrifolia-Salix arctica	90	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	SACFA14 *Dryas integrifolia /Kobresia myosuroides*
Dryas integrifolia-Kobresia myosuroides/lichen	102	H4 *Dryas octopetala-Kobresia myosuroides-Arctostaphylos uva-ursi*	No equivalent	SACFA14 *Dryas integrifolia /Kobresia myosuroides*
Dryas integrifolia/lichen	104	H4 *Dryas octopetala-Kobresia myosuroides-Arctostaphylos uva-ursi*	No equivalent	SACFA14 *Dryas integrifolia /Kobresia myosuroides*
Dryas integrifolia-Salix arctica	131	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	SACFA14 *Dryas integrifolia /Kobresia*

				myosuroides
*Dryas integrifolia-Carex rupestris**	235	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	SACFA14 *Dryas integrifolia /Kobresia myosuroides*
Dryas integrifolia-Festuca altaica-Leymus innovatus	263	No equivalent	No equivalent	SACFA14 *Dryas integrifolia /Kobresia myosuroides*
Dryas integrifolia-Salix arctica/lichen	265	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	SACFA14 *Dryas integrifolia /Kobresia myosuroides*
Dryas integrifolia-D. octopetala-Salix nivalis/lichen	272	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	ALP2 *Dryas octopetala, D. integrifolia*
Dryas integrifolia-Kobresia myosuoroides-Carex nardina-Salix nivalis	280	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	SACFA14 *Dryas integrifolia /Kobresia myosuroides*
Dryas integrifolia/moss	282	H1 *Dryas octopetala-Salix nivalis-Silene acaulis*	No equivalent	SACFA14 *Dryas integrifolia /Kobresia myosuroides*

Table 2.4. Results of constrained ordination. Asterisks indicate canonical coefficients with t-values greater than 2.1 in absolute value at a 5% significance level, ** are significant at a 1% significance level. Variables that have both significant interset correlations and canonical coefficients (t-values >2.1 in absolute value at a 5% significance level (ter Braak and Šmilauer 2002)) are in bold.

						Interset correlations			
	Axis 1	Axis 2	Axis 3	Axis 4		Axis 1	Axis 2	Axis 3	Axis 4
20 x 20 m					**20 x 20 m**				
Eigenvalue	.161	0.057	0.034	.030	Elevation	**-.7080****	**-.4215****	0.0687	.1966
Sp/env correl.	.906	.791	.767	.683	ArcsineP	-0.0978	0.2432	**-.4776****	**.4056****
Cum. % var explained	16.1	21.8	25.2	28.2	logK	**0.4745****	-0.0399	0.1233	-0.0520
Sp./env relation	53.4	72.2	83.6	93.5	logNa	**-0.3123***	-.0013	-.1691	.1225
					Bare soil	0.0452	**0.4763****	**0.5399****	0.2481
					Moss	**-.5119****	0.1550	-0.1138	**-.5115****

10 x 10 m					**10 x 10**				
					m				
Eigenvalues	.119	.072	.056	.046	Elevation	**.6301****	**.6221****	-0.2172	0.0981
Sp./env.	.922	.916	.899	.841	Texture1	0.0709	**-.3353***	-.0173*	**.7800****
Correl.									
Cum. %	11.9	19.1	25.0	29.4	Moss	0.2209	.2834	**.8259****	.0513
var.									
explained									
Sp./env.	40.7	65.1	84.2	100	pH	**-.8671****	0.0476	-0.2599	0.1458
Relation									
5 x 5 m					**5 x 5 m**				
Eigenvalues	.033	.026	.018	.014	Elevation	**-.5192****	**-.3451****	-.0480	**.3409****
Sp./Env.	.741	.778	.603	.792	n-s	-.0193	**-.2480****	.0745	-.0035
Correl.									
Cum. % of	3.3	5.9	7.7	9.1	Moisture	**.1555***	**-.3567****	**.2876***	-.3401**

Variance explained									
Sp./Env. Relation	27.7	49.7	64.6	76.4	ArcsineP	-.2705**	.0441	**.2063****	**0.0452****
					ArcsineN	-.1237	-.0030	-.0960	**-.3548****
					LogCa	**-.1804***	**.5927****	**.2300****	-.2390**
					Lichen	**-.2204****	.0261	-.1179	.0294
					Moss	-.0141	-.2131**	**.3288****	-.0994
					Rock	**.2318****	**.2333****	-.0747	**.6494****

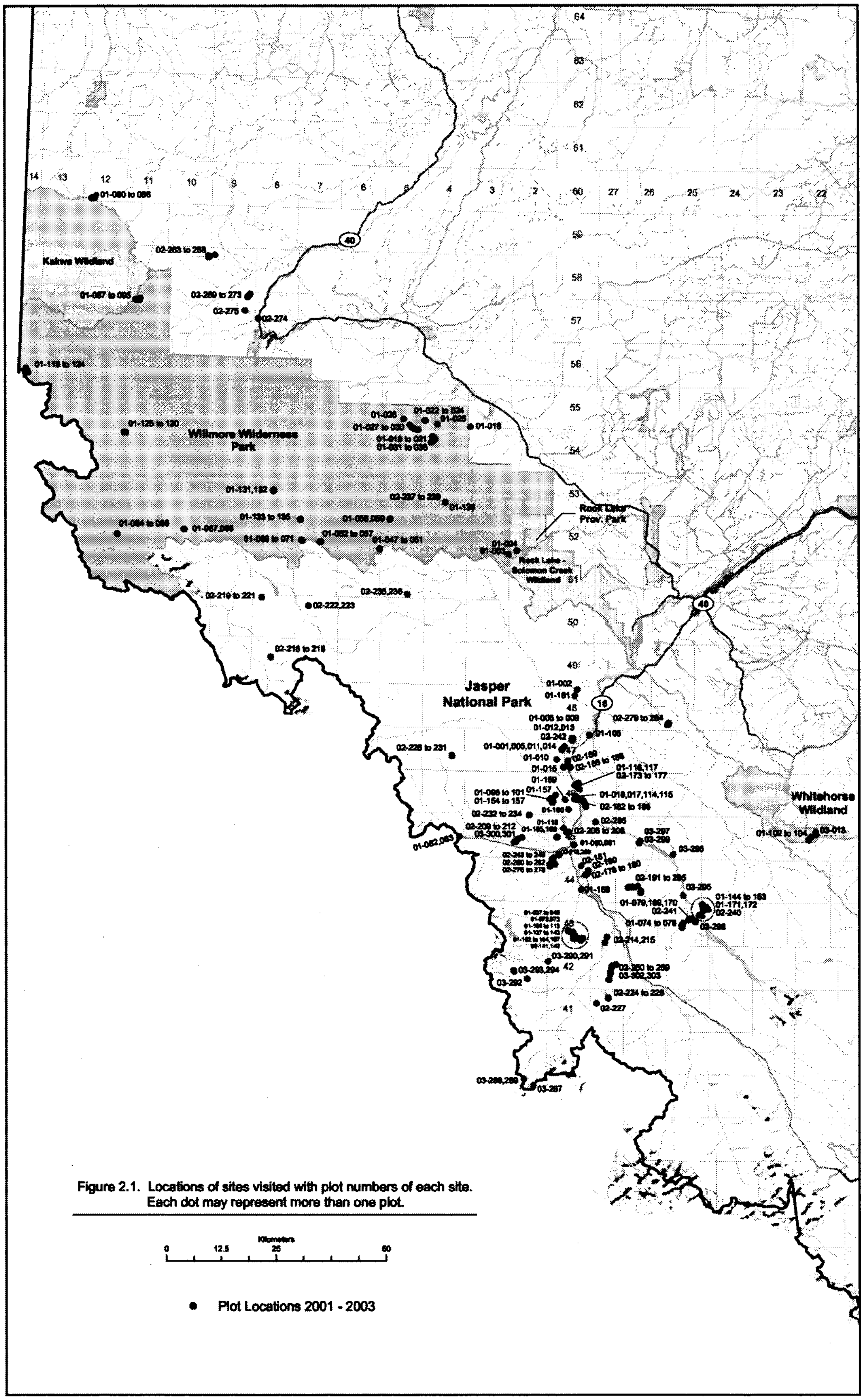


Figure 2.1. Locations of sites visited with plot numbers of each site. Each dot may represent more than one plot.

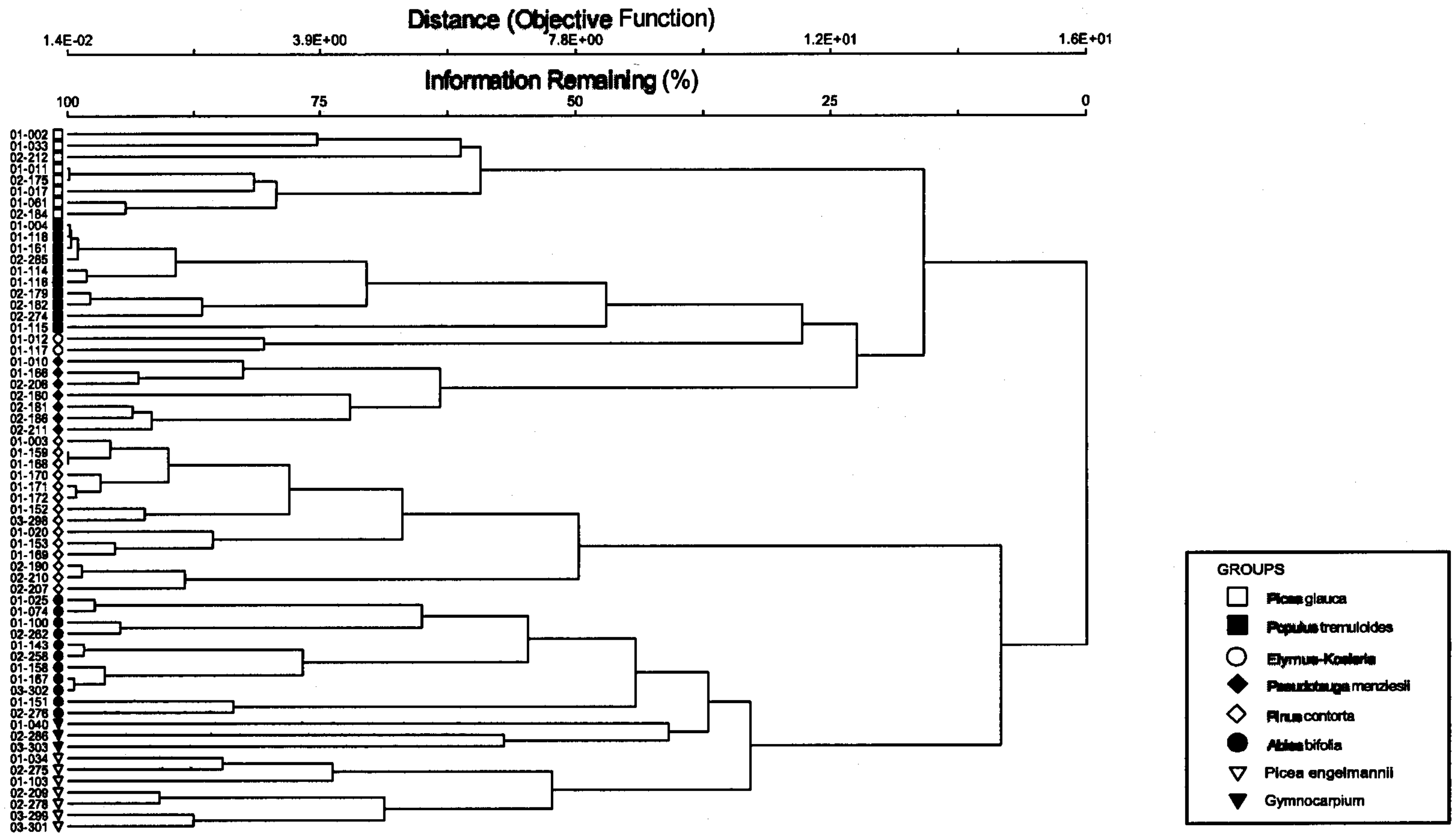


Figure 2.2. Dendrogram of hierarchical cluster analysis of 20 x 20 m plots showing eight groups of vegetation types. Chaining 2.34%.

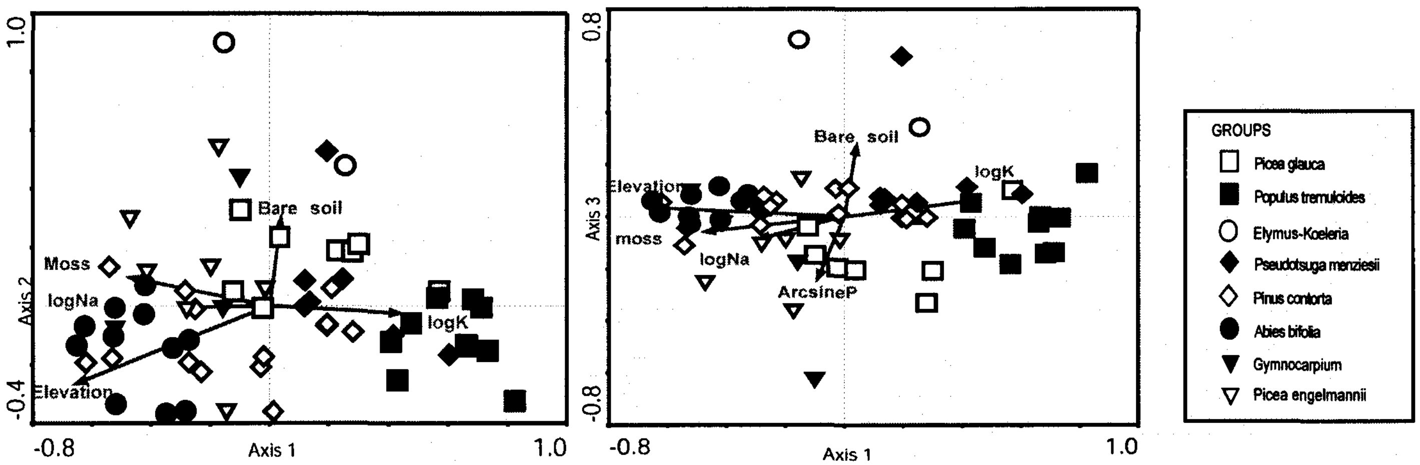


Figure 2.3. Plot of distance-based redundancy analysis for 20 x 20 m plots along axes 1, 2 and 3. Only environmental variables with p≤0.05 are shown.

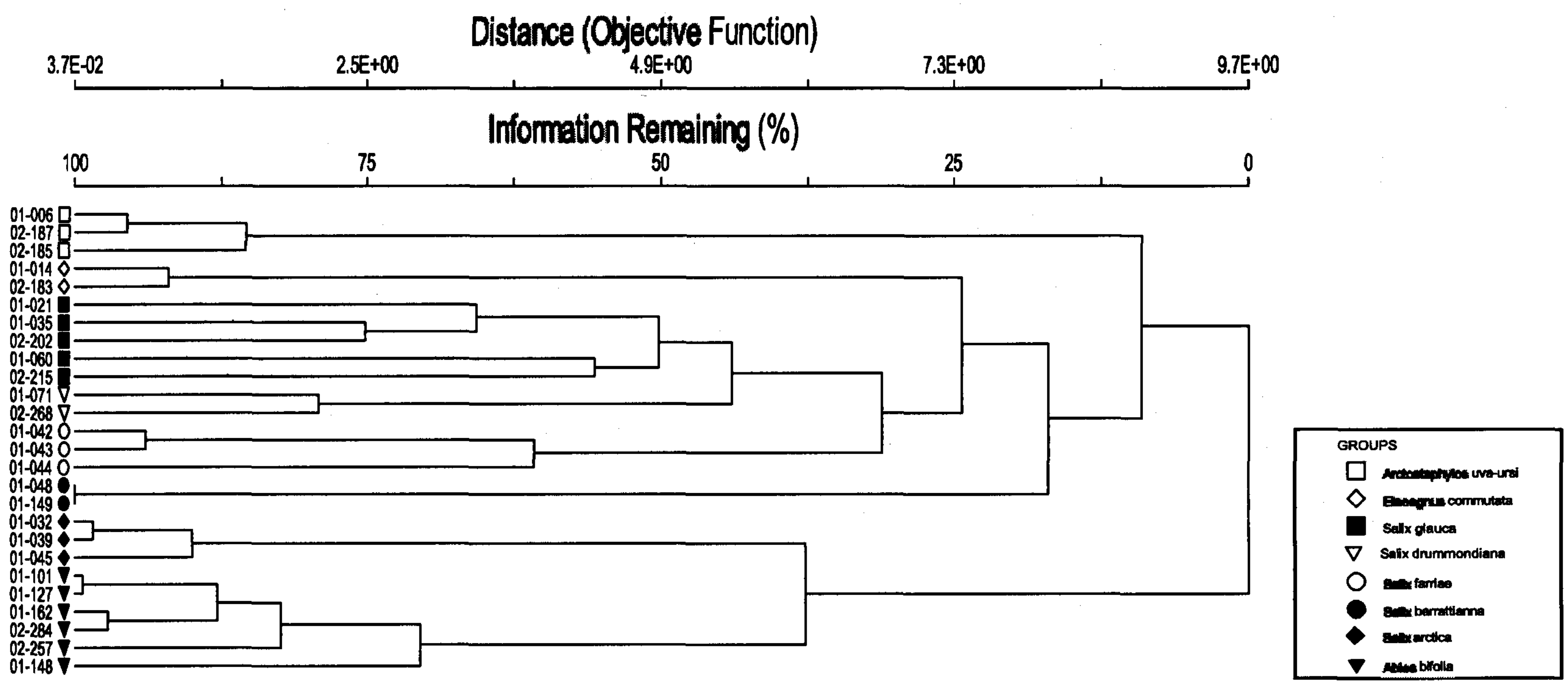


Figure 2.4. Dendrogram of hierarchical cluster analysis of 10 x 10 m plots showing eight groups of vegetation types. Chaining 10.18%.

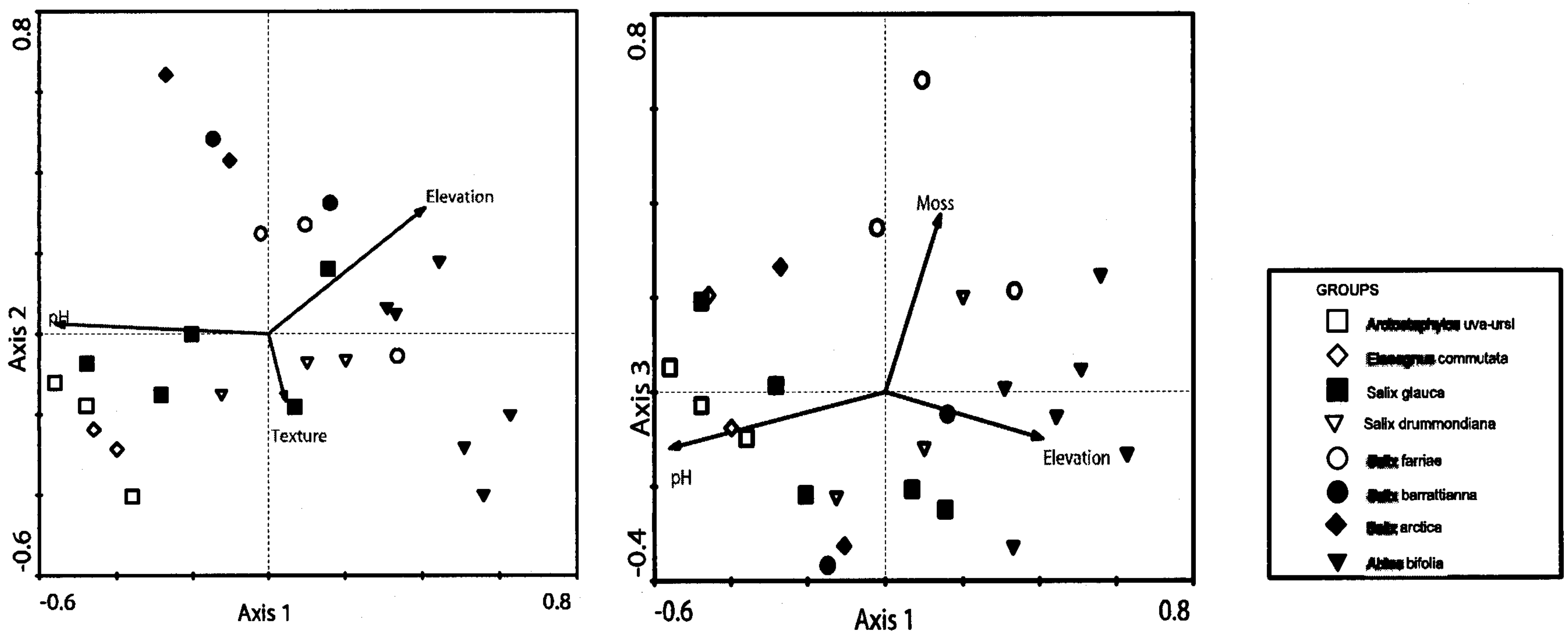
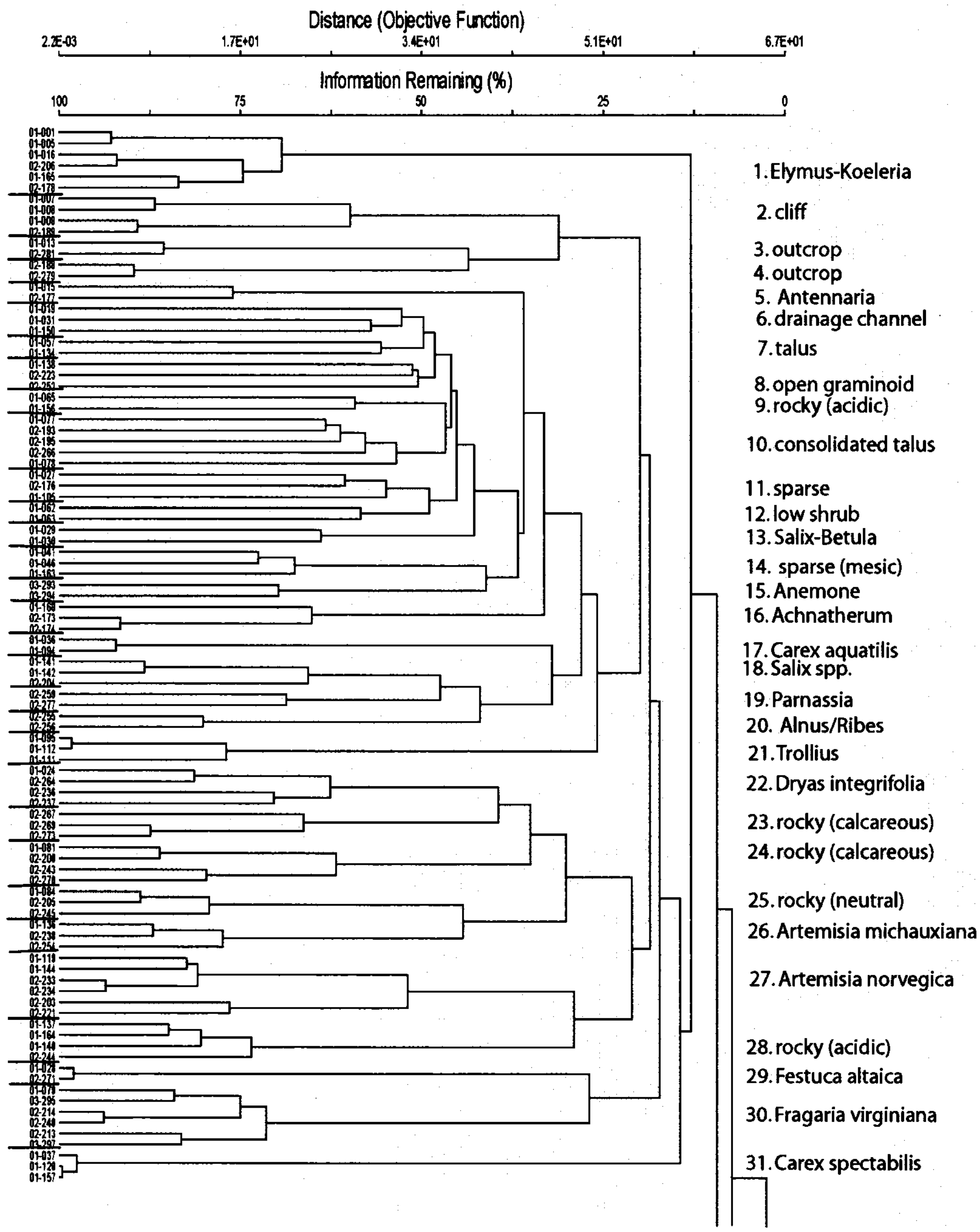


Figure 2.5. Plot of distance-based redundancy analysis of 10 x 10 m plots along axes 1 and 2. Only variables with p≤0.05 are shown.


Distance (Objective Function)
2.2E-03
1.7E+01
3.4E+01
5.1E+01
6.7E+01
Information Remaining (%)
100
75
50
25
0
1. Elymus-Koeleria
2. cliff
3. outcrop
4. outcrop
5. Antennaria
6. drainage channel
7. talus
8. open graminoid
9. rocky (acidic)
10. consolidated talus
11. sparse
12. low shrub
13. Salix-Betula
14. sparse (mesic)
15. Anemone
16. Achnatherum
17. Carex aquatilis
18. Salix spp.
19. Parnassia
20. Alnus/Ribes
21. Trollius
22. Dryas integrifolia
23. rocky (calcareous)
24. rocky (calcareous)
25. rocky (neutral)
26. Artemisia michauxiana
27. Artemisia norvegica
28. rocky (acidic)
29. Festuca altaica
30. Fragaria virginiana
31. Carex spectabilis

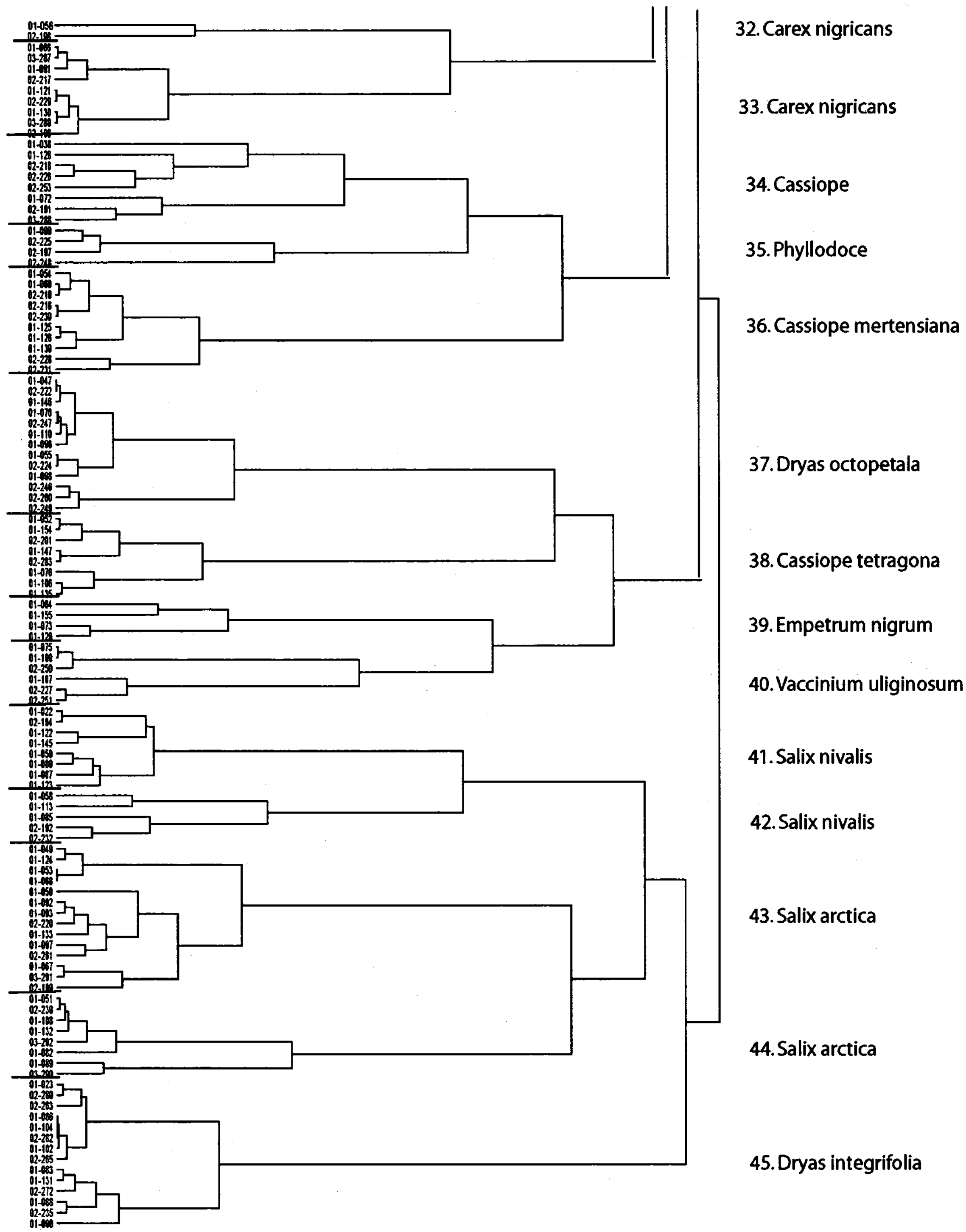
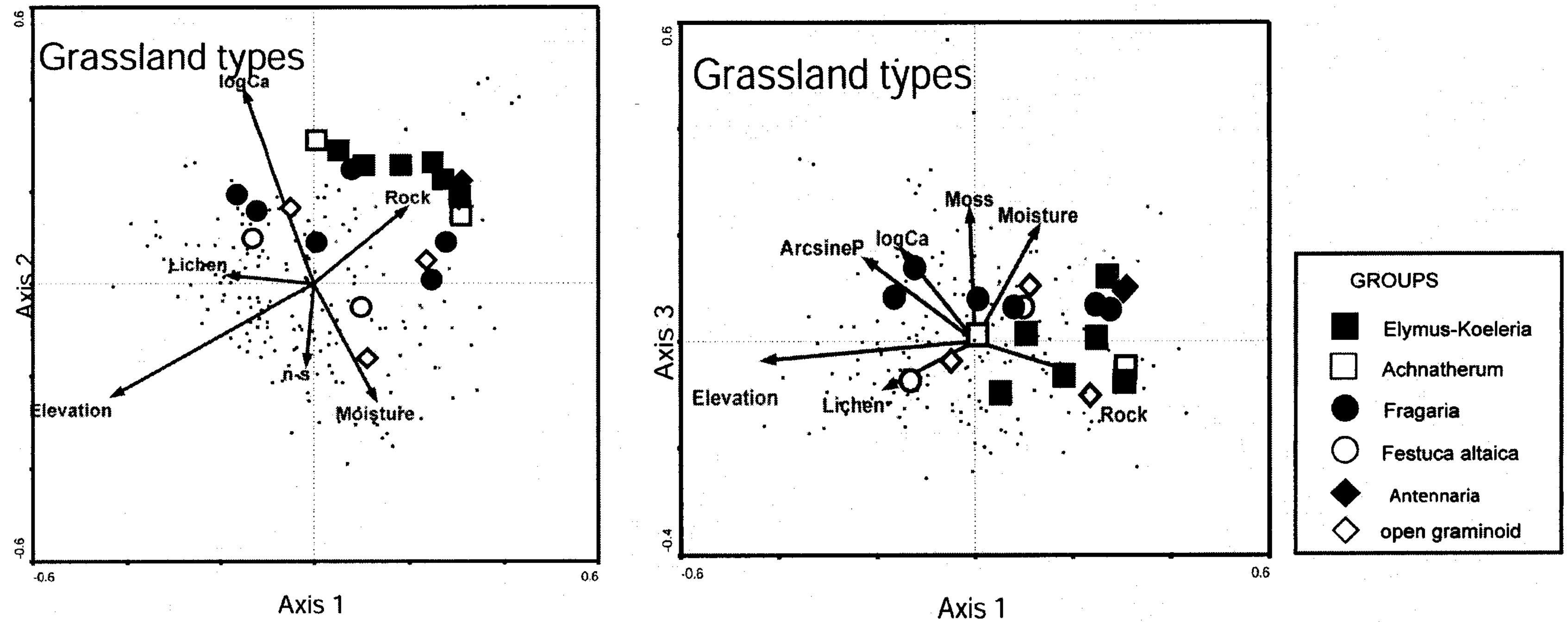
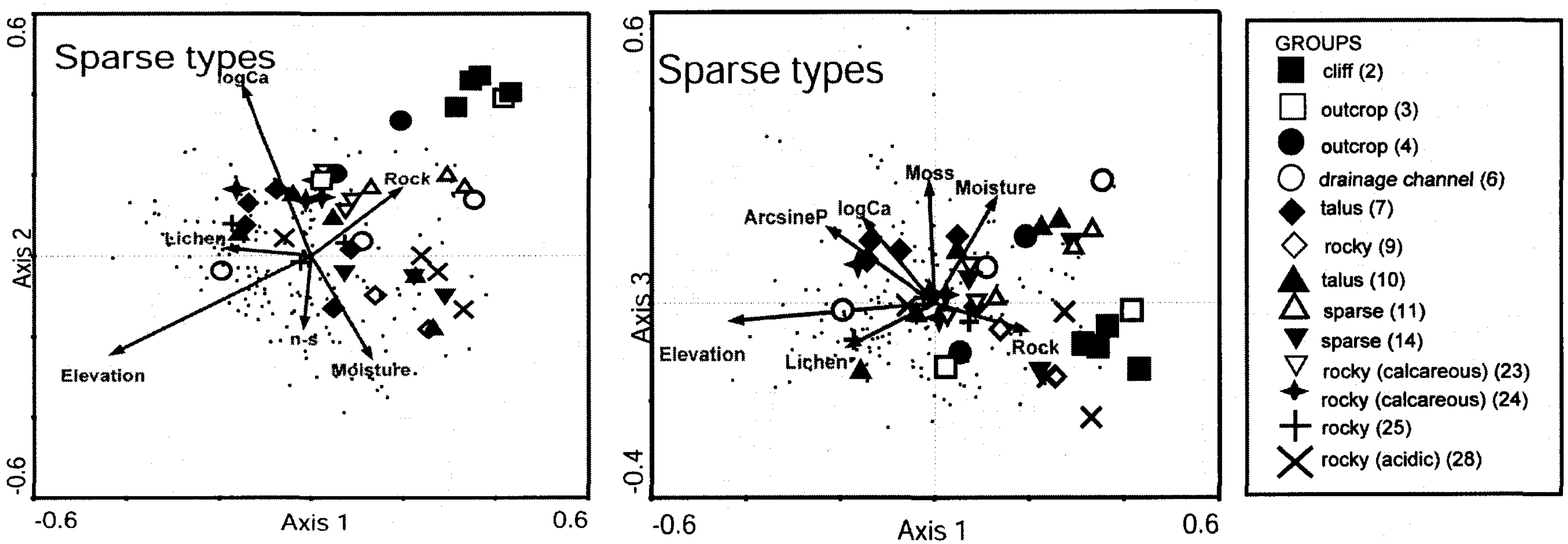
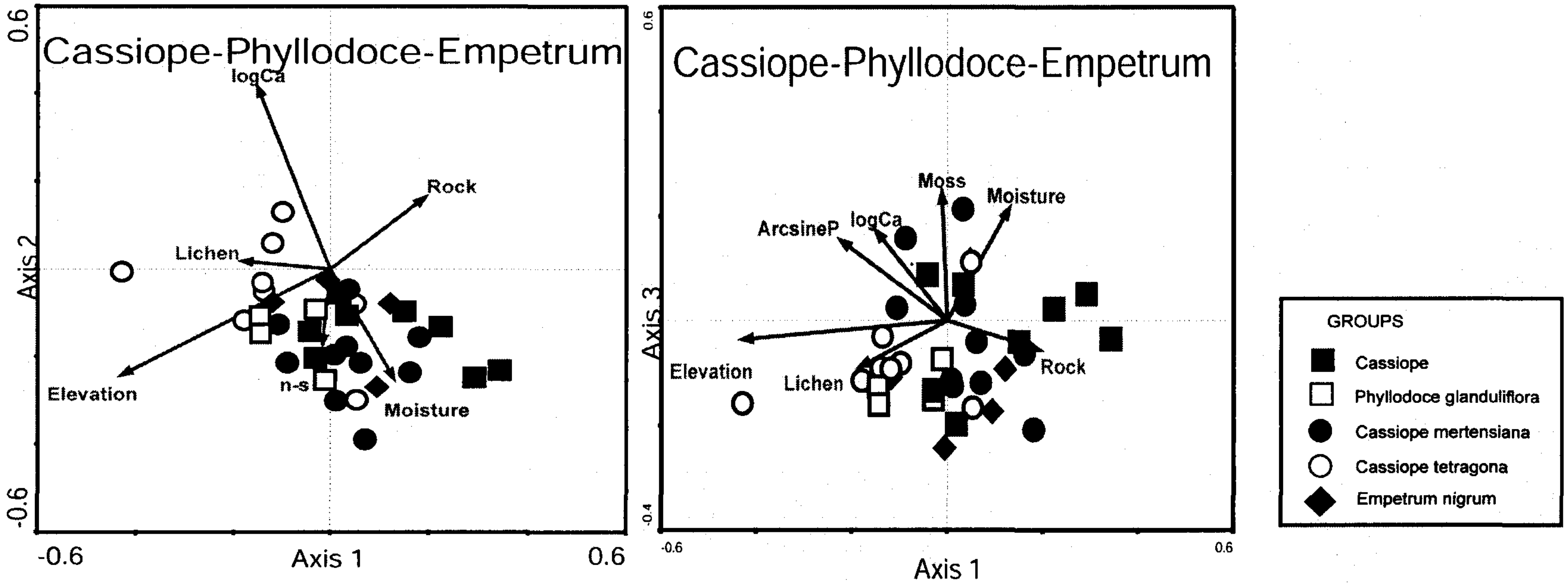
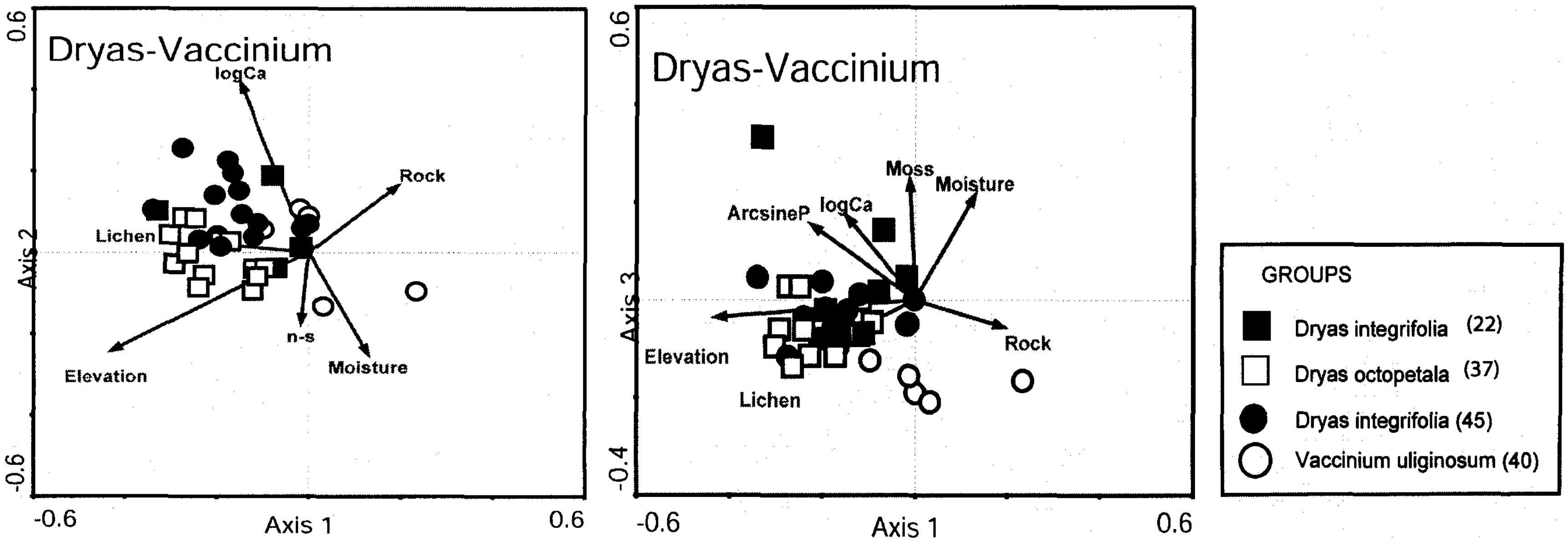


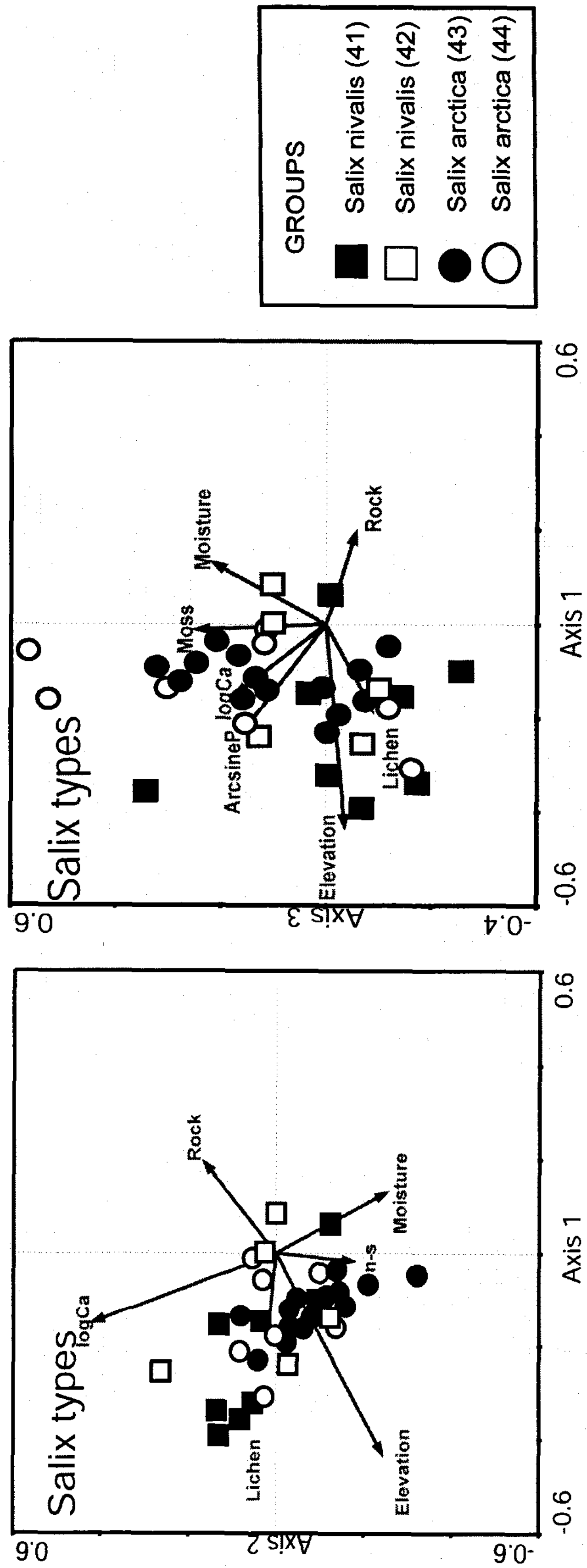
Figure 2.6. Dendrogram of hierarchical cluster analysis of 5 x 5 m plots showing forty-five groups of vegetation types (on two pages). Chaining 2.75%.

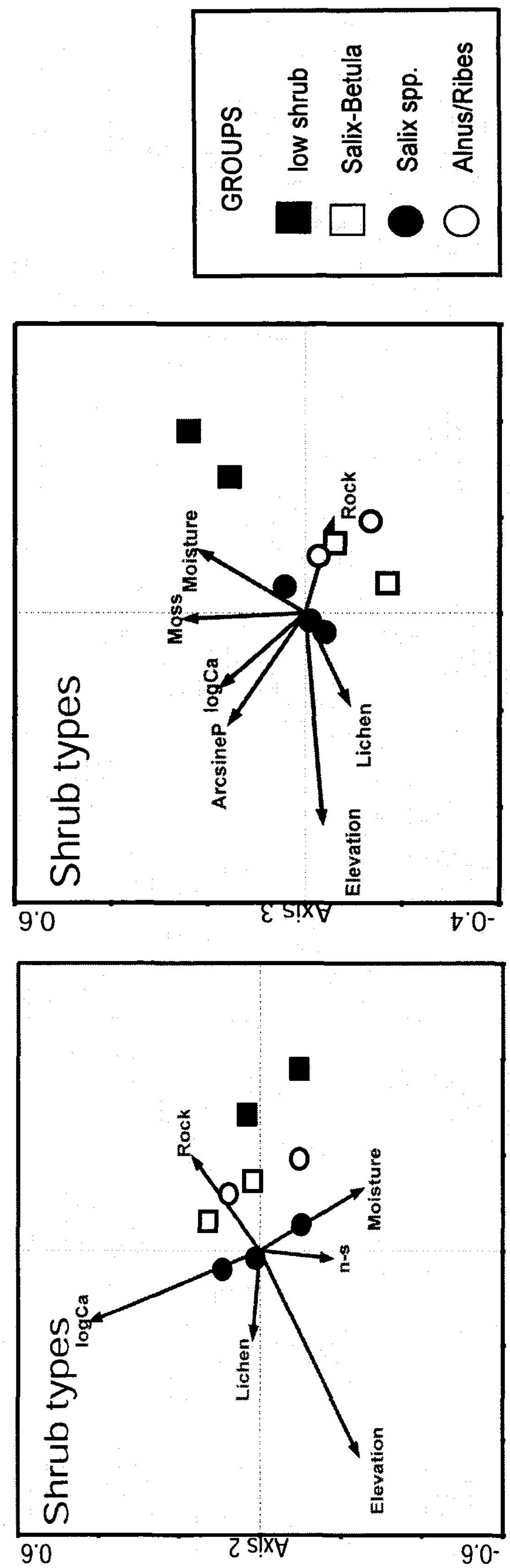

Grassland types
logCa
Rock
Lichen
n-s
Elevation
Moisture
Axis 2
Axis 1
0.6
-0.6
-0.6
0.6
Grassland types
Moss
Moisture
ArcsineP
logCa
Elevation
Lichen
Rock
Axis 3
Axis 1
0.6
-0.4
-0.6
0.6
GROUPS
Elymus-Koeleria
Achnatherum
Fragaria
Festuca altaica
Antennaria
open graminoid

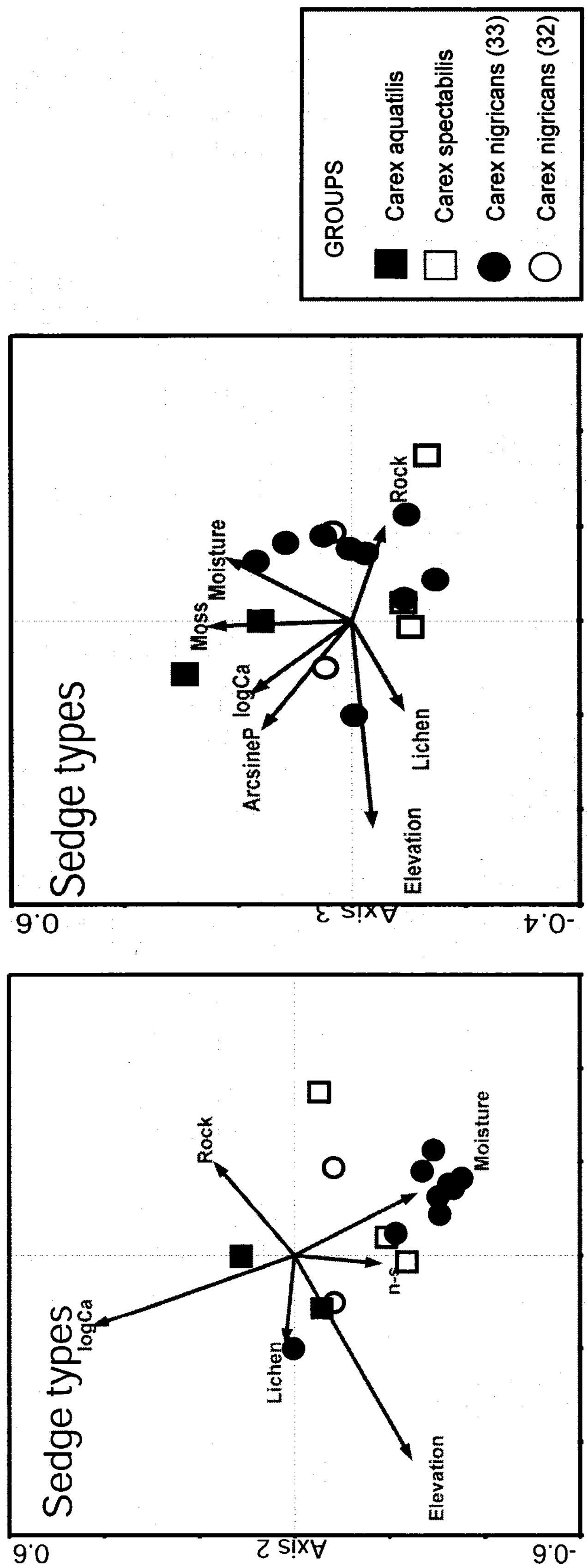

Sparse types
logCa
Rock
Lichen
n-s
Moisture
Elevation
Axis 2
Axis 1
0.6
-0.6
-0.6
0.6
Sparse types
Moss
Moisture
ArcsineP
logCa
Elevation
Lichen
Rock
Axis 3
Axis 1
0.6
-0.4
-0.6
0.6
GROUPS
cliff (2)
outcrop (3)
outcrop (4)
drainage channel (6)
talus (7)
rocky (9)
talus (10)
sparse (11)
sparse (14)
rocky (calcareous) (23)
rocky (calcareous) (24)
rocky (25)
rocky (acidic) (28)


Cassiope-Phyllodoce-Empetrum
logCa
Rock
Lichen
Elevation
n-s
Moisture
Axis 2
Axis 1
0.6
-0.6
-0.6
0.6
Cassiope-Phyllodoce-Empetrum
Moss
Moisture
ArcsineP
logCa
Elevation
Lichen
Rock
Axis 3
Axis 1
0.6
-0.4
-0.6
0.6
GROUPS
Cassiope
Phyllodoce glanduliflora
Cassiope mertensiana
Cassiope tetragona
Empetrum nigrum


Dryas-Vaccinium
logCa
Rock
Lichen
n-s
Moisture
Elevation
Axis 2
Axis 1
0.6
-0.6
Dryas-Vaccinium
Moss
Moisture
ArcsineP
logCa
Elevation
Rock
Lichen
Axis 3
Axis 1
0.6
-0.4
-0.6
GROUPS
Dryas integrifolia (22)
Dryas octopetala (37)
Dryas integrifolia (45)
Vaccinium uliginosum (40)


GROUPS
Salix nivalis (41)
Salix nivalis (42)
Salix arctica (43)
Salix arctica (44)
Salix types
Moisture
Rock
Moss
logCa
ArcsineP
Lichen
Elevation
Axis 3
Axis 1
0.6
-0.6
-0.4
Salix types
logCa
Rock
Moisture
n-s
Lichen
Elevation
Axis 2
Axis 1
0.6
-0.6


GROUPS
low shrub
Salix-Betula
Salix spp.
Alnus/Ribes
Shrub types
Moss
Moisture
logCa
ArcsineP
Elevation
Lichen
Rock
Axis 1
Axis 3
0.6
-0.6
-0.4
Shrub types
Rock
logCa
Lichen
Elevation
n-s
Moisture
Axis 1
Axis 2
0.6
-0.6


Sedge types
Axis 1
Axis 2
Axis 3
0.6
-0.6
-0.4
logCa
Rock
Moisture
Lichen
Elevation
n-s
Moss
ArcsineP
GROUPS
Carex aquatilis
Carex spectabilis
Carex nigricans (33)
Carex nigricans (32)

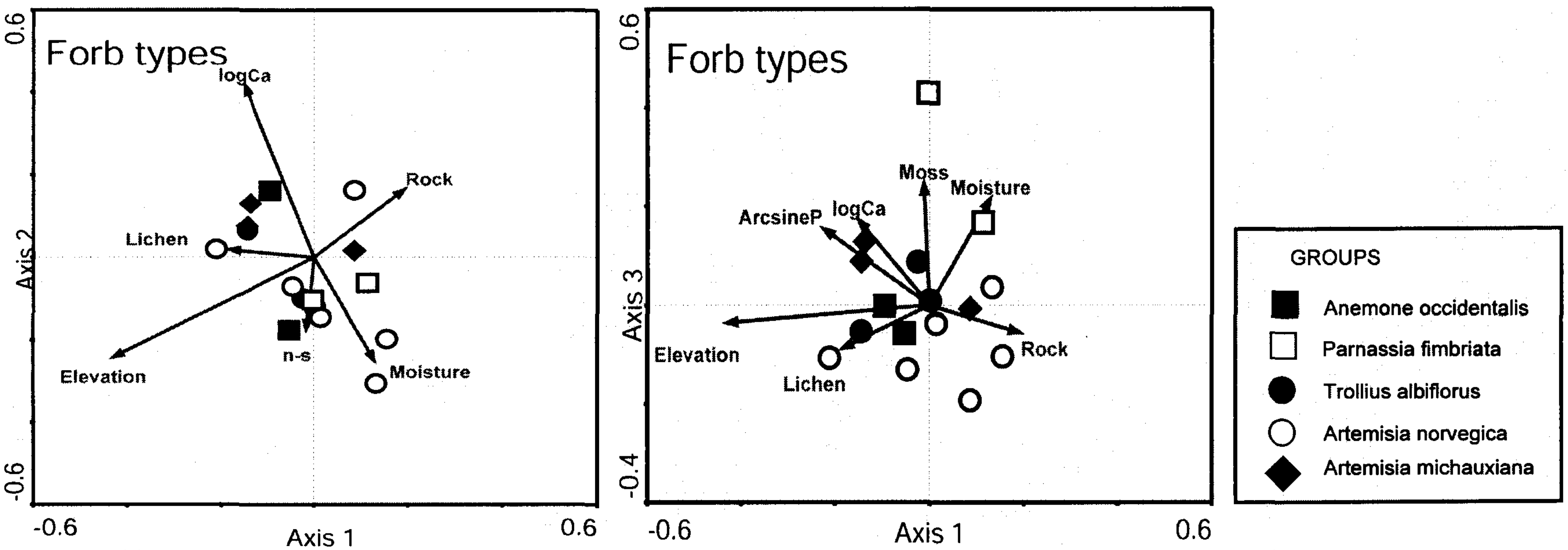


Figure 2.7. db-rda of axes 1 x 2 and 1 x 3 of habitats in 5 x 5 m plots.

Chapter 3: Habitat Fidelity of Rare Vascular Plants in the Northern Rocky Mountains of Alberta, Canada

Introduction

Currently there are 1475 species of vascular plant known for Alberta (Moss 1983; Ogilvie 1998), over 400 of which are considered to be rare according to the most recent version of the tracking list of provincially rare species when this study was conducted (Gould 2000). Rarity in Gould (2000) was determined using criteria developed by NatureServe including range, population size and threats to both habitat and population. These criteria are applied at the provincial scale; however, NatureServe also assigns a global rank to species based on the same criteria applied at the scale of North America. Inclusion of a species on a tracking list does not automatically mean that it will be designated under federal or provincial endangered species legislation, however. Criteria such as population size and threats to both population and habitat are used to identify rare species that are then subject to a status assessment process prior to listing. Limitations of funding prevent completion of more than a few status reports per year. It will take over two hundred years to complete status assessments for the species included in Gould (2000) with the existing levels of funding. Given the current lack of information on rare plants, remoteness of much of Alberta and sparse budgets available for completion of detailed assessments, information on where and how plant occurrences are patterned at the scale of the landscape would be a useful tool in directing land management activities and in setting priorities for conservation, and thereby facilitating conservation of rare plants.

There have been many attempts to model richness of rare species or distributions of individual taxa on the landscape in relation to environmental variables. Commonly used quantitative techniques include: regression (linear and additive models) (Miller 1986; Hill and Keddy 1992; Heikkinen 1998; Engler et al. 2004); ordination and classification; heuristic models such as BIOCLIM, GARP, and resource selection functions (Nielsen et al. 2003; Shepherd 2006), many of which are done in conjunction with the use of geographic information systems (GIS) (Klinkenberg 2002) and remotely sensed data (Debinski et al. 1999; Luoto 2000; Luoto et al. 2002a, b). The results of these models can be used to identify potential habitat that can then be validated using field searches. Attempts to model multiple rare species at the scale of the landscape, other than for richness, are limited (Elith and Burgman 2002; Kintsch and Urban 2002; Klinkenberg 2002; MacDougall and Loo 2002; Urban et al. 2002) as is the use of vegetation type or plant community as a predictor of rare plant species occurrence (Kintsch and Urban 2002).

One of the main assumptions with the use of models is that the predictor variables are appropriate at the spatial and temporal scales being investigated (Luoto 2000; Huston 2002; Luoto et al. 2002a, b; Vaughan and Ormerod 2003; Rushton et al. 2004). The value of models of rare species distribution, thus, depends upon prior ecological knowledge (Austin 2002); therefore, some form of initial data analysis/exploration is often necessary prior to model building (Luoto 2000; Rushton et al. 2004). While such models can be quite informative, building them can be very costly and time consuming, particularly in areas and for species for which data for predictor variables have not been previously collected (Franklin 1993; Poiani et al. 2000; Kintsch and Urban 2002; Luoto et al. 2002b) or for which the important predictor variables are unknown.

Such models may only be applicable to those rare species for which the type of rarity is based on habitat fidelity (after Rabinowitz 1981). Rabinowitz (1981) outlined three factors that are important determinants for types of rarity in plants: geographic range (wide vs. narrow), habitat specificity (wide vs. narrow) and local population size (high vs. low). Common species are those that have a wide geographic range, high abundance and occur in several habitats. All other taxa are rare. Habitat specificity can be interpreted as habitat fidelity which is "the degree of preference of a species for a given association" (Barkman 1989). Rabinowitz's scheme recognizes that plants have differing degrees of association to habitat and I can therefore expect that plant association or vegetation type as a predictor will be effective for those plants that have high habitat specificity.

Qualitative correlates of rare species to habitat found on herbarium specimens or species checklists are sometimes used to predict where species occur. Such information sources are of limited use due to variability in the data (MacDougall and Loo 2002). For example, standards for collection of information associated with these types of data do not exist, at least in Alberta, and there may be discrepancies in the amount of information collected or in the nomenclature used to categorize habitat.

Delination of ecological communities with an evaluation of their efficiency in capturing rare species has been described as "one of the most critical tasks facing conservation biologists" (Wilcove and Master 2005 p 420). In spite of this importance, few researchers have attempted to evaluate the effectiveness of vegetation type or plant association in predicting the location of rare plants (but see Kintsch and Urban 2002; MacDougall and Lou 2002). If rare species have high fidelity to habitat types, I postulate that a vegetation classification could effectively serve as the basis for models predicting the locations of occurrence of rare species. The objective of this study was to determine the fidelity of rare vascular plant species to the vegetation types described in Chapter 2.

Study area

The study area was located in the northern Rocky Mountains of Alberta at 52° 35' to 54° 10' N latitude, 117° 10' to 120° W longitude and encompasses approximately 54 000 square kilometers (Figure 2.1). There are two northwest-southeast trending mountain ranges (Main and Front Ranges) within the area and these are dissected by several east-west trending valleys. Elevation ranges from 1006 m a.s.l. in the river valleys to 3020 m on alpine summits. The area has a diversity of lithologies with Precambrian and Early Paleozoic quartzite and limestone dominating the Main Range and Late Paleozoic limestone and Mesozoic shales in the Front Range (Mountjoy 1978; Gadd 1986). The Continental Divide forms the western boundary of the study area.

The climate is continental and there is considerable variability in temperature and precipitation within the study area due to topographic relief. Daily average temperature ranges from -0.3 C to 3.7 C and average yearly precipitation ranges from 398.9 mm to 620.2 mm (Environment Canada 2004).

Several protected areas, Jasper National Park, Willmore Wilderness Park, Kakwa and Whitehorse Wildland Parks, occur within the study site. These areas have lower levels of human disturbance, particularly industrial activities, than areas outside and thus human induced causes of rarity are assumed to be low.

The northern Rockies is one of two areas of concentration of rare vascular plants within the Canadian Rockies, the other being the area south of Crowsnest Pass (Ogilvie 1998). Fifty-four rare vascular plant species were known to occur within the study area when this study started (ANHIC data files 2001). In general, these rare species were restricted to higher elevations. The Rocky Mountain Natural Region has the greatest number of rare species in Alberta (Kershaw et al. 2001); the majority of these are common outside of the province, with many reaching the southern vs. northern limits of their distribution in the northern Rockies.

Three Natural Subregions (montane, subalpine and alpine) are represented within the Rocky Mountain Natural Region of Alberta (Natural Region Review Committee 2004). The Montane Subregion is a mosaic of forest types (Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), trembling aspen (*Populus tremuloides* Michx.) and white spruce (*Picea* *glauca* (Moench) Voss)) and grass and shrub dominated communities and is generally situated between 1000 and 1350 m (Holland and Coen 1982). The subalpine is characterized by closed forests dominated by lodgepole pine (*Pinus contorta* Loudon), subalpine fir (*Abies bifolia* A. Murray) and Engelmann spruce (*Picea engelmannii* Parry *ex* Engelm.). Forests at higher elevations (within the subalpine) are open and consist of stunted trees of subalpine fir and Engelmann spruce with an understory of alpine vegetation. Vegetation of the alpine is a complex of community types dominated by dwarf shrub and herbaceous vegetation (Holland and Coen 1982).

Methods

Field protocol

Sites were selected so as to include a diversity of habitats as ascertained from examination of aerial photographs, topographic maps and the literature given the size of the area, remoteness and difficulty with access. In total I visited 48 sites and collected data at 297 sample locations. At each site, sample locations were chosen in as many plant associations within the area as possible within the time available. Each of these was sampled using protocols outlined in the Alberta Natural Heritage Information Centre (ANHIC 2000) using 5 x 5 m plots for graminoid, dwarf shrub- and forb-dominated communities, 10 x 10 m plots for shrub-dominated and 20 x 20 m for treed unless the size of the association was such that it was too small to use the standard size (i.e. some cliffs, shrub sites). A different plot size was used occasionally when the herbaceous or shrub dominated vegetation was patchy in nature such as found in some grassland types where larger mat-forming plants also occur. Canopy cover (percent) was estimated for each vascular plant species, total lichen (including cryptogamic crust), moss, litter, rock and bare soil, and cover estimated to be less than 1% was considered 0.05% for analysis. Estimates of cover were done in increments of 5% for cover >5% and were in increments of 1% for values <5%. Raw cover data were used in the dataset.

Species that could not be identified in the field were collected for subsequent identification in the lab or annotation by taxonomic experts. Nard sedge (*Carex nardina* E. Fries) and Pacific kobresia (*Kobresia myosuroides* (Vill.) Fiori & Paol.) cannot be distinguished in a vegetative state and several additional taxa, including at least three rare species, are difficult to tell apart in the field and are therefore treated as species complexes in the dataset. These include alpine willow-herb (*Epilobium anagallidifolium* Lam.) and clavate-fruit willow-herb *(E. clavatum* Trel.), short-leaved fescue (*Festuca brachyphylla* Schultes) and small-flowered fescue (*F. minutiflora* Rydb.) as well as prairie club-moss (*Selaginella densa* Rydb.), Rocky Mountain spike-moss (*S. scopulorum* Maxon) and Standley's spike-moss (*S. standleyi* Maxon). Plants that could not be identified to the species level (or species complexes as noted above) were excluded from the analysis and individuals of species thought to form introgressive hybrid swarms (eg. *Picea engelmannii* and *P. glauca*) were classified as one of the two parental species depending on the dominant traits.

Information on several environmental variables including soil pH and texture, slope angle and aspect, moisture and nutrient regime (assessed using protocols summarized in

Luttmerding et al. 1990) was collected at each sample location (plot). Elevation and geographic position of each plot were measured using a Garmin 12XL GPS unit. The data from these plots were used to determine vegetation types (see Chapter 2). Fieldwork was conducted in 2001, 2002 and 2003.

In addition to describing the association by means of the sampling within the plots, a rare plant survey was conducted outside of each plot by walking a series of parallel transects within the plant association (see Nelson 1986) for ten minutes noting all taxa encountered to capture other species (common or rare) not included with the plot. A rare species was defined as one occurring on the ANHIC tracking list, a list of rare native species ranked according to NatureServe criteria (Appendix 3) (Gould 2000). A species list for each sample location (association) was developed by combining the plot data for the community description with that of the 10 minute survey. This is referred to as the 'larger plot'.

Nomenclature for species follows Moss (1983) and Flora of North America (Flora of North America Editorial Committee 1993-2006). Common names for taxa without common names in Moss (1983) or Flora of North America are taken from NatureServe (http://www.natureserve.org/explorer). Voucher specimens were deposited at the herbarium, University of Alberta (ALTA).

Analyses

Indicator Species Analysis (ISA) (Dufrêne and Legendre 1997) was done on the matrix of species presence/absence at each sample location (sampling of the 'larger plot') to ascertain whether rare species had fidelity to any of the defined vegetation types (see Chapter 2). These defined groups were included in the second matrix. The analysis was performed for the different plot sizes separately (i.e., treed: 20 x 20, shrub: 10 x 10, herbaceous: 5 x 5). Indicator Species Analysis calculates the abundance and frequency of a species within a group relative to its abundance or frequency in other groups. An Indicator Value (IndVal) is calculated by multiplying relative frequency and relative abundance. Relative frequency is the proportion of samples of a given group, in which the species is found. For example, there were 40 samples of group Y, and rare species X was found in 20 of them; its relative frequency in group Y is then 50%. This equates to faithfulness or fidelity. Relative abundance is the proportional abundance of a species in a group relative to its abundance in all groups. For example, rare species X was found in 25 sample locations in total; and 20 of these were group Y (which had 20 sample locations) and 5 of these were in group Z (which had 10 sample locations). The relative abundance of species X in vegetation type Y is then (20/20) / (20/20 + 5/10) = 67%. This equates to exclusiveness or specificity (Dufrêne and Legendre 1997; McCune and Grace 2002). A good indicator is a species that is restricted to one group and is well represented within that group (Dufrêne and Legendre 1997; McCune and Grace 2002). Indicator Values of >25 were considered to be significant as this signifies that the relative abundance of a species is at least 50% in one group and further that it is represented in 50% of samples within the group (Dufrêne and Legendre 1997). Significance of the indicator values were determined using Monte Carlo permutation procedures (999 permutations). PC-Ord Version 4.1 was used to conduct the analysis.

I also used different cut-off levels for the number of vegetation types to explore whether fidelity of rare species changed when a broader classification of vegetation was used. Indicator Species Analysis (ISA) after Dufrêne and Legendre (1997) was used to prune the dendrogram of the cluster analyses (Chapter 2) by running the analysis using different numbers of groups as cutoffs and then choosing the group cutoff levels by selecting those with the lowest average *p*-value for indicator species (McCune and Grace, 2002). Fidelity of rare species to these new groupings was assessed using ISA in the same way that it was used to examine affinity to the vegetation types as they were defined in Chapter 2. Three additional cutoff levels, 40, 36 and 29 groups were chosen in addition to the final cutoff level of 45 groups.

In Chapter 2, I described the use of distance-based redundancy analysis (db-rda) to examine the relationships of the vegetation types to measured environmental variables. I also used db-rda to explore the relationship of rare species to the vegetation types defined in Chapter 2 and to significant environmental variables by including the species x sample matrix of the 'larger plot' as supplementary variables in the analysis done in Chapter 2. The species with significant habitat fidelity were portrayed as vectors in the ordination plot. Significant measured environmental variables are also shown as vectors. Distance-based redundancy analysis was conducted using Canoco for Windows 4.5 (ter Braak and Šmilauer 2002).

Results

Seventy-four rare vascular plant species were recorded as part of this study, twenty more than were known from the area at the commencement of the work (see Appendix 1).

In tree-dominated (20 x 20 m plot size) and shrub (10 x 10 m plots) sample locations 14 and 22 rare species were found, respectively (Table 3.1), but in the ISA of these data none of rare plants showed high fidelity to vegetation type (Table 3.2). Some tree and shrub vegetation types (white spruce, Douglas-fir, trembling aspen, wolf willow – see Chapter 2) lacked rare vascular plant taxa altogether. High elevation stands of subalpine fir and Engelmann spruce had more rare species than the other tree- or shrub-dominated vegetation types but none of these rare taxa were found to be significant indicators (Tables 3.1 and 3.2). In contrast, many of the high elevation herbaceous (including dwarf shrub) dominated vegetation types had rare species that were significant indicators (Tables 3.1 and 3.2).

Nineteen of the 74 rare species (26%) recorded from the study area were found to be significantly associated with one of fifteen vegetation types, as determined by Indicator Species Analysis (Table 3.2). The majority of these associations were with high elevation dwarf shrub vegetation or rock dominated types (Table 3.2).

Several rare species were restricted to a particular vegetation type (Table 3.1); however, only three of these were significant indicators (*Barbarea orthoceras*, *Carex capitata* and *Silene hitchguirei*) and these were represented by only two occurrences each (Table 3.2).

The relationship of these species to measured environmental variables is shown in Figure 3.1 and the relationship of these variables to vegetation types is presented in Chapter 2. None of these rare species has a strong association with a particular environmental variable as shown by the shortness of the vector. Eleven of the 19 significant species (*Antennaria monocephala*, *Aquilegia formosa*, *Botrychium minganense*, *Cardamine bellidifolia*, *Erigeron trifidus*, *Festuca altaica*, *Gentiana glauca*, *Loiseleuria procumbens*, *Pedicularis flammea*, *P. lanata* and *Vaccinium uliginosum*) were represented five or more times in the dataset. Four of these, *Antennaria monocephala*, *Gentiana glauca*, *Pedicularis flammea* and *Vaccinium uliginosum*, have a strong association with one or more measured environmental variable as shown in Figure 3.1, but of these only *Pedicularis* and *Vaccinium* have an Indicator Value of >25. *Antennaria* has a strong association with elevation and *Gentiana* with low log Ca, however, not with a particular vegetation type as shown by low Indicator Values (Table 3.2).

Relative abundance gives an indication of what proportion of the occurrences of a rare species was in a particular vegetation type while relative frequency tells us what proportion of the sampled locations of a particular vegetation type had the rare species. For the 19 rare taxa that were significant indicators, relative abundances varied from 12 to 100% while relative frequency varied from 50 to 100% (Table 3.2). Fourteen rare species showed both high relative abundance and relative frequency as shown by an indicator value of >25 (Table 3.2). A value of 25 signifies that the relative abundance of a species is at least 50% in one group and further that it is represented in 50% of samples within the group (Dufrêne and Legendre 1997). For example, *Vaccinium uliginosum* was present in four vegetation types; however, the mean abundance of this species was highest in the *Empetrum nigrum* type resulting in a relative abundance of 50% (Table 3.2). In turn, 75% of the samples of the *Empetrum nigrum* vegetation type had an occurrence of *Vaccinium uliginosum* (relative frequency), indicating the high probability of this vegetation type having this particular species. *Silene hitchgueri* is an example of a species that is restricted to one vegetation type (*Cassiope mertensiana* tundra) as shown by its relative abundance of 100% and it also occurred in 67% of the samples of that type (relative frequency) (Table 3.2). Species such as *Cardamine bellidifolia* and *Gentiana glauca* had high frequency but low relative abundance in a particular vegetation type (Table 3.2). This means that one particular vegetation type had a high probability of having that rare species but that the species was also represented in other other types. Ten of the nineteen species with significant associations to vegetation type had a relative abundance of >50% in that type, suggesting a higher fidelity for that vegetation type than for others (Table 3.2). Only three of these taxa, *Loiseleuria procumbens*, *Pedicularis flammaea* and *P. lanata* were, however, represented more than five times in the dataset. For 15 of the 19 rare species relative frequency in a vegetation type was >50% (Table 3.2); however, most of these vegetation types were represented by only a few plots. Relative frequency was 100% for seven rare species (six vegetation types) meaning that every sample of that vegetation type contained that rare species (Table 3.2)

The relationship of rare species to different cutoff levels for vegetation types is shown in Table 3.3. Several of the sparsely vegetated types were merged at higher cutoff levels (fewer groups) in the classification (Table 3.3) and as a result, some species that were significant indicators when there were 45 groups were not significant with a broader classification (e.g. *Barbarea orthoceras*, *Cardamine bellidifolia* and *Gentiana glauca*). The number of rare species that had a significant association with a vegetation type decreased as the number of vegetation types decreased (i.e. as vegetation types were more broadly defined; Table 3.3). There were thirteen rare species with fidelity to vegetation type at the 29 and 36 group level and 16 at the 40 group level as compared to the 19 I had for the 45 vegetation types described in Chapter 2. The Indicator Values of some species, however decreased as the number of vegetation types went from 29 to 45 groups (Table 3.3). For example, the Indicator Value of *Pellaea glabella*, a species with high fidelity to a cliff type, decreased from 56.2 with 29 groups to 45 with 45 groups. This pattern was reversed for other taxa such as *Aquilegia formosa* with an Indicator Value of 36.6 for 36 groups and 50 for 45 groups (Table 3.3). The Indicator Value for other species, such as *Eriophorum callitrix,* did not change as the number of groups increased (Table 3.3).

Three of 45 herbaceous vegetation types had significant associations with more than one rare species. *Cassiope mertensiana* tundra provided habitat for *Pedicularis flammea* and *Silene hitchguirei*; *Empetrum nigrum* tundra for *Carex capitata*, *Loiseleuria procumbens* and *Vaccinium uliginosum*; and rocky acidic habitat for *Cardamine bellidifolia* and *Gentiana glauca*. The relationship of rare species to each other is explored in Chapter 4.

Discussion

Approximately 26% of the rare species that were examined in the northern Rocky Mountains of Alberta exhibited a strong association with a particular vegetation type, with them being significantly more abundant in one type than another. Three species were restricted to a particular vegetation type suggesting high exclusivity to this type; seven species occurred in every sample of a particular vegetation type. This affinity for a particular vegetation type suggests that these species, at least, are not distributed randomly across the landscape. This attribute can be useful for conservation planning as we can identify potential habitat for certain species in this area and can focus conservation efforts at the habitat rather than at just the species level.

Most rare plants in the study area occurred at higher elevation and were not represented in many of the lower elevation forest types. In fact, stands of *Picea glauca*, *Populus tremuloides* and *Pseudotsuga menziesii* forest lacked rare species altogether. *Pinus contorta* was the only forest type of low to mid elevation that had one rare species (*Hierochloe alpina*). This is likely due to the relative paucity of rare plants in tree- and tall shrub-dominated sites compared to herb-dominated sites.

It is tempting to build models to predict occurrences of rare plant species given the pace at which development is occurring on the landscape and the urgent need for conservation planning. Unfortunately, our knowledge of the distribution of rare plant species in relation to environmental variables is often inadequate (Luoto 2000; Austin 2002). In addition, caution must be used when extrapolating results from one region to another, given differences in how species and vegetation respond to environmental variables in different areas (Bamberg and Major 1968; MacDougall and Loo 2002). Where species are at the edge of their range they may respond differently to habitat variables than would populations at the centre of their range (MacDougall and Loo 2002). Peripheral populations may be more strongly associated with environmental factors than populations at the centre of the distribution, such that the predictive ability of locating populations of these species may be much higher (MacDougall and Loo 2002). MacDougall and Loo (2002) found that in New Brunswick, certain rare taxa such as those associated with arctic-alpine communities were more strongly associated with particular environmental factors because the communities themselves were restricted to cool moist cliff faces, riverine spray zones, or north-facing slopes.

The use of models to predict where rare species occur can be problematic if we have not sampled adequately across the range of the species distribution. This is difficult to do in large remote areas such as the northern Rocky Mountains of Alberta, so a strategy that results in sampling across the entire range of habitats is important. Significant relationships between species distribution and habitat types defined from remotely sensed data will work if the species are specialized in their habitat utilization (Scott et al. 1993; Stoms and Estes 1993; Debinski et al. 1999; Kintsch and Urban 2002; Luoto et al. 2002a; MacDougall and Loo 2002; Boetsch et al. 2003) and/or are common within the area of interest (Scott et al. 1993; Stoms and Estes 1993). Such taxa comprise only one of the seven types of rarity defined by Rabinowitz (1981). Not all of the species found in this study can be considered habitat specialists, as shown by their relative abundance in vegetation types with only three of the eighteen species exclusive to defined types. I found that *Barbarea orthoceras*, a species thought to be associated with stream banks and moist woods (Moss 1983) was restricted to sparsely vegetated drainage channels. *Carex capitata* has been described as occurring in boggy, calcareous areas (Moss 1983) of the boreal forest (Flora of North America 2003) and primarily on calcareous substrates in the alpine (Flora of North America 2003). In this study, it was restricted to vegetation types dominated by crowberry although only two occurrences were represented in the dataset. The third species restricted to a vegetation type was *Silene hitchguirei*, an alpine tundra species (Flora of North America 2005), which in this study was associated with *Cassiope mertensiana* tundra.

Relative abundance within a vegetation type ranged from 12-87% for the other rare species and this suggests considerable variation in the strength of association to habitat (Table 3.2). The lack of specificity may be due, in part, to the scale at which vegetation types were defined (see Table 3.3). This is particularly true for those sparsely vegetated types (outcrops, talus) or rare community types (e.g. *Festuca altaica*), where few species (outcrops, talus) or few plots (rare communities) make classification more difficult. A higher level of classification did not result in a higher level of association with rare species (Table 3.3). A very broad classification of types (i.e. alpine tundra) might have resulted in a stronger association; however, such units may not be of use for conservation planning.

The lack of specificity of some rare plants to any vegetation type may be due to characteristics of the species themselves. *Antennaria monocephala*, for example, had low specificity for the vegetation type for which it was a significant indicator (*Cassiope mertensiana*). The habitat for this species has been defined as alpine slopes and ledges (Moss 1983), and in this study it was reported from 15 vegetation types including open subalpine fir krummholtz forest and rocky talus. This species clearly has low specificity to habitat although it is unclear which of its ecological characteristics, if any, can explain this.

In contrast, there are some vegetation types in which there is a high probability of finding a particular rare species as shown by relative frequency (range from 50 to 100%) (Table 3.2). A vegetation type with a high probability of having a particular rare species can be targeted for conservation action. This information can also feed into predictive models based on remotely sensed data or GIS systems. Focusing on these significant types for conservation efforts however, could result in missing several other occurrences of a particular species as the majority of the rare species in the study area were not restricted to one vegetation type.

One of the main assumptions of habitat-rare species distribution models is that sampling has been adequate to capture all rare taxa within the particular vegetation type. This is an unattainable goal unless surveys can be done several times in a season as well as over the course of several seasons to capture differences in phenology and to capture those taxa that fluctuate with changing environmental conditions. Ideally one would sample every stand in accordance with protocols for sampling biodiversity (Magurran and Henderson 2003); however, this is impractical in many cases due to lack of time allocated for such surveys or inability to return to a site more than once per year, if ever. However, even with limitations on sampling, significant patterns of the distribution of rare plants on the landscape can still be discerned, especially if predictive models incorporate such parameters (Klinkenberg 2002).

In summary, in the northern Rocky Mountains of Alberta there is a strong association of several rare species to vegetation type. This information can be used to model the distribution of rare plants on the landscape and to guide land management activities as well as aid in recovery planning such as through the identification of critical habitat. Habitat approaches to conservation may be appropriate for such species; however, there are still several species for which a single-species approach is warranted.

Literature Cited

Alberta Natural Heritage Information Centre. 2000. Draft Plant Community Sampling Guidelines. Alberta Community Development, Edmonton, Alberta.

Alberta Natural Heritage Information Centre. 2001. data files. Alberta Community Development. Edmonton, Alberta

Austin, M. P. 2002. Spatial prediction of species distribution: an interface between ecological theory and statistical modelling. Ecological Modelling 157:101-118.

Bamberg, S. A. and J. Major. 1968. Ecology of the vegetation and soils associated with calcareous parent materials in three alpine regions of Montana. Ecological Monographs 38:127-167.

Barkman, J. J. 1989. Fidelity and character-species, a critical evaluation. Vegetatio 85:105-116.

Boetsch, J. R., F. K. van Manen and J. D. Clark. 2003. Predicting rare plant occurrence in Great Smoky Mountains National Park, USA. Natural Areas Journal 23:229-237.

Debinski, D. M., K. Kindscher and M. E. Jakubauskas. 1999. A remote sensing and GIS-based model of habitats and biodiversity in the Greater Yellowstone Ecosystem. International J. of Remote Sensing 20(17):3281-3291.

Dufrêne, M. and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetric approach. Ecological Monographs 67:345-366.

Elith, J. and M. Burgman. 2002. Predictions and their validation: rare plants in the central highlands, Victoria, Highland. IN: Predicting Species Occurrences. (J. M. Scott, J. B. Haufler, M. L. Morrison eds.). Island Press, Washington, DC. pp. 303-313.

Engler, R., A. Guisan and L. Rechsteiner. 2004. An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. Journal of Applied Ecology 41:263-274.

Environment Canada. 2004. Canadian Climate Normals. http://www.climate.weatheroffice. ec.gc.ca/climate_normals/results_e.html.--date accessed Oct. 3, 2004.

Flora of North America Editorial Committee. 1993-2006. Flora of North America. Oxford University Press, New York, New York.

Franklin, J. F. 1993. Preserving biodiversity: species, ecosystems or landscapes? Ecological Applications 3:202-205.

Gadd, B. 1986. Handbook of the Canadian Rockies.Corax Press, Jasper, Alberta. 878 pp..

Gould, J. 2000. Alberta Natural Heritage Information Centre—Tracking and Watch Lists for Vascular Plants, Mosses, Liverworts and Hornworts. Alberta Environmental Protection, Edmonton, Alberta.

Hiekkinen, R. K. 1998. Can richness patterns of rarities be predicted from mesoscale atlas data? A case study of vascular plants of the Kevo reserve. Biological Conservation 83:133-143.

Hill, N. M. and P. A. Keddy. 1992. Prediction of rarities from habitat variables: coastal plain plants on Nova Scotian lakeshores. Ecology 73:1852-1859.

Holland, W. D. and G. M Coen. 1982. Ecological (Biophysical) Land Classification of Banff and Jasper National Parks. Volume 2: Soil and Vegetation Resources. Alberta Institute of Pedology Publication No. SS-82-44. 540 pp. and maps.

Huston, M. A. 2002. Critical Issues for Improving Predictions. IN: Predicting Species Occurrences. (J. M. Scott, J. B. Haufler, P. J. Heglund and M. L. Morrison eds.). Island Press. Washington, D.C., pp. 7-21.

Kershaw, L., J. Gould, D. Johnson and J. Lancaster. 2001. Rare Vascular Plants of Alberta. University of Alberta Press, Edmonton, Alberta and Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. 484 pp..

Kintsch, J. A. and D. L. Urban. 2002. Focal species, community representation, and physical proxies as conservation strategies: a case study in the Amphibolite Mountains, North Carolina, U.S.A. Conservation Biology 16(4):936-947.

Klinkenberg, B. 2002. Spatial analysis of the coincidence of rare vascular plants and landforms in the Carolinian zone of Canada: implications for protection. Canadian Geographer 46:194-203.

Lesica, P. 1993. Using plant community diversity in reserve design for pothole prairie on the Blackfeet Indian Reservation, Montana, USA. Biological Conservation 65:69-75.

Luoto, M. 2000. Modelling of rare plant species richness by landscape variables in an agriculture area in Finland. Plant Ecology 149:157-168.

Luoto, M., M. Kuussaari and Tuuli Toivonen. 2002a. Modelling butterfly distribution based on remoted sensing data. Journal of Biogeography 29:1027-1037.

Luoto, M., T. Toivonen and R. K. Heikkinen. 2002b. Prediction of total and rare plant species richness in agricultural landscapes from satellite images and topographic data. Landscape Ecology 17:195-217.

Luttmerding, H. A., D. A. Demarchi, E. C. Lea, D. V. Meidinger and T. Vold. 1990. Describing Ecosystems in the Field. BC Ministry of Forests, Forest Science Program, Miscellaneous Report 074m 281 pp..

Magurran, A. E. and P. A. Henderson. 2003. Explaining the excess of rare species in natural species abundance distributions. Nature 422:714-716.

McCune, B. and J. B. Grace. 2002. Analysis of Ecological Communities. MjM Sortware Design. Gleneden Beach, Oregon. 300 pp.

MacDougall, A. S. and J. Loo. 2002. Predicting occurrences of geographically restricted floral elements with qualitative habitat data. Environmental Reviews 10:167-190.

Miller, R. I. 1986. Predicting rare plant distribution patterns in the southern Appalachians of the south-eastern U. S. A. Journal of Biogeography 13(4):293-311.

Moss, E. H. 1983. Flora of Alberta. Second edition (revised by J. G. Packer). University of Toronto Press, Toronto, Ontario. 687 pp.

Mountjoy, E. W. 1978. Geology—Mount Robson. Geological Survey of Canada. Map 1499A.

Natural Region Review Committee (2004): Natural Subregions - Draft Version 2; Government of Alberta, 44 pages, 1 map. http://www.cd.gov.ab.ca/preserving/parks/anhic/nr_sr_2004_map.asp. (*February 17, 2005*)

Nelson, J. R. 1986. Rare plant surveys: techniques for impact assessment. Natural Areas Journal 5(3):18-30.

Nielsen, S. E., M. S. Boyce, G. B. Stenhouse and R. H. M. Munro. 2003. Development and testing of phonologically driven grizzly bear habitat models. Ecoscience 10:1-10.

Ogilvie, R. T. 1998. Vascular plants. IN: Smith, I. M. and G. G. E. Scudder, eds. Assessment of species diversity in the Montane Cordillera Ecozone. Ecological Monitoring and Assessment Network, Burlington, Ontario.

Poiani, K. A., B. D. Richter, M. G. Anderson and H. E. Richter. 2000. Biodiversity conservation at multiple scales: functional sites, landscapes, and networks. BioScience 50:133-146.

Rabinowitz, D. 1981. Seven forms of rarity. IN: The Biological Aspects of Rare Plant Conservation (Ed. Hugh Synge). John Wiley and Sones Ltd., New York, N. Y. pg. 205-217.

Rushton, S. P., S. J. Omerod and G. Kerby. 2004. New paradigms for modeling species distributions? Journal of Applied Ecology 41(2):193-200.

Scott, J. M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T. C. Edwards Jr., J. Ulliman and R. G. Wright. 1993. Gap analysis: a geographic approach to protection of biological diversity. Wildlife Monographs 57:1-41.

Shepherd, L. K. 2006. Caribou habitat selection in relation to lichen and fire in Banff and Jasper National Parks. MSc. Thesis, Department of Renewable Resources, University of Alberta, Edmonton. 131 pp.

Stoms, D. M. and J. E. Estes. 1993. A remote sensing research agenda for mapping and monitoring biodiversity. International Journal of Remote Sensing 10:1839-1860.

Urban, D., S. Goslee, K. Pierce and T. Lookingbill. 2002. Extending community ecology of landscapes. Ecoscience 9(2): 200-212.

Vaughan, I. P. and S. J. Omerod. 2003. Improving the quality of distribution models for conservation by addressing shortcomings in the field collection of training data. Conservation Biology 17(6):1601-1611.

Wilcove, D. S. and L. L. Master. 2005. How many endangered species are there in the United States? Frontiers in Ecology and the Environment 3 (8): 414-420.

Table 3.1. Rare vascular plant species and the vegetation types (described in Chapter 2) they which they were found.

Rare Species	Vegetation type
Treed	
Antennaria monocephala	Group 6 *Abies bifolia*
Aquilegia formosa	Group 8 *Picea engelmannii*
Cardamine oligosperma	Group 8 *Picea engelmannii*
Carex tonsa	Group 8 *Picea engelmannii*
Cystopteris montana	Group 7 *Gymnocarpium dryopteris*
Epilobium lactiflorum	Group 7 *Gymnocarpium dryopteris*
Festuca altaica	Group 6 *Abies bifolia*
Gentiana glauca	Group 6 *Abies bifolia*
Hierochloe alpina	Group 5 *Pinus contorta*; Group 6 *Abies bifolia*
Huperzia halaekalae	Group 6 *Abies bifolia*; Group 7 *Gymnocarpium dryopteris*
Pedicularis langsdorfii ssp. *arctica*	Group 6 *Abies bifolia*
Pedicularis capitata	Group 6 *Abies bifolia*
Ribes laxiflorum	Group 8 *Picea engelmannii*
Vaccinium ovalifolium	Group 6 *Abies bifolia*
Shrub	
Agoseris lackschewitzii	Group 6 *Salix barrattiana*
Antennaria monocephala	Group 7 *Salix arctica*
Aquilegia formosa	Group 8 *Abies bifolia*
Cardamine bellidifolia	Group 8 *Abies bifolia*
Cardamine oligosperma	Group 3 *Salix glauca*
Carex lachenalii	Group 4 *Salix drummondiana;* Group 5 *Salix farriae*
Carex lenticularis var. *dolia*	Group 4 *Salix drummondiana*; Group 5 *Salix farriae*;
Carex petricosa	Group 1 *Arctostaphylos uva-ursi*
Eriophorum callitrix	Group 4 *Salix drummondiana*

Festuca altaica	Group 6 *Salix barrattiana*; Group 7 *Salix arctica*
Gentiana glauca	Group 8 *Abies bifolia*
Heuchera glabra	Group 4 *Salix drummondiana*; Group 8 *Abies bifolia*
Hierochloe alpina	Group 8 *Abies bifolia*
Huperzia halaekalae	Group 5 *Salix farriae*; Group 8 *Abies bifolia*
Loiseleuria procumbens	Group 8 *Abies bifolia*
Pedicularis langsdorfii ssp.	
arctica	Group 7 *Salix arctica*; Group 8 *Abies bifolia*
Pedicularis capitata	Group 7 *Salix arctica*
Pedicularis flammea	Group 7 *Salix arctica*
Ribes laxiflorum	Group 8 *Abies bifolia*
Salix alaxensis	Group 7 *Salix arctica*
Saxifraga nelsoniana	Group 4 *Salix drummondiana*; Group 8 *Abies bifolia*
Vaccinium uliginosum	Group 5 *Salix farriae*
Herb	
Agoseris lackschewitzii	Group 6 drainage channel
Antennaria aromatica	Group 43 *Salix arctica*
	Group 7 talus; Group 22 *Dryas integrifolia*; Group 25 rocky (neutral); Group 27 *Artemisia*
	norvegica; Group 28 rocky (acidic); Group 34 Cassiope; Group 35 *Phyllodoce glanduliflora*;
	Group 37 *Dryas octopetala*; Group 38 *Cassiope tetragona*; Group 39 *Empetrum nigrum*; Group
	40 *Vaccinium uliginosum*;Group 41 *Salix nivalis*; Group 42 *Salix nivalis*; Group 43 *Salix*
Antennaria monocephala	*arctica*; Group 44 *Salix arctica* (sparse); Group 45 *Dryas integrifolia*
	Group 11 sparse; Group 14 (sparse mesic); Group 18 *Salix barclayi-S. drummondiana-S. vestita*;
Aquilegia formosa	Group 19 *Parnassia fimbriata*
Arnica amplexicaulis	Group 19 *Parnassia fimbriata*; Group 30 *Fragaria virginiana*
Artemisia furcata	Group 22 *Dryas integrifolia*
Barbarea orthoceras	Group 6 drainage channel
	Group 29 *Festuca altaica;* Group 30 *Fragaria virginiana*; Group 37 *Dryas octopetala*; Group 42
Botrychium ascendens	*Salix nivalis*
Botrychium lanceolatum	Group 26 *Artemisia michauxiana*

Botrychium minganense	Group 24 rocky (calcareous); Group 26 *Artemisia michauxiana*; Group 29 *Festuca altaica*; Group 30 *Fragaria virginiana*; Group 37 *Dryas octopetala*; Group 43 *Salix arctica*;
Botrychium pinnatum	Group 11 sparse; Group 26 *Artemisia michauxiana*; Group 30 *Fragaria virginiana*;
Campanula uniflora	Group 45 *Dryas integrifolia*
Cardamine bellidifolia	Group 9 rocky acidic; Group 10 consolidated talus; Group 14 sparse (mesic); Group 25 rocky (neutral); Group 27 *Artemisia norvegica*; Group 28 rocky (acidic); Group 31 *Carex spectabilis*; Group 34 *Cassiope*; Group 35 *Phyllodoce glanduliflora*; Group 38 *Cassiope tetragona*; Group 44 *Salix arctica* (sparse);
Cardamine oligosperma	Group 7 talus; Group 8 open graminoid; Group 10 consolidated talus; Group 11 sparse; Group 13 *Salix-Betula glandulosa*; Group 18 *Salix barclayi-S. drummondiana-S. vestita*; Group 20 *Alnus viridis* ssp. *crispa/Ribes lacustre/Calamagrostis canadensis*; Group 21 *Trollius albiflorus*; Group 27 *Artemisia norvegica*; Group 31 *Carex spectabilis*; Group 33 *Carex nigricans*; Group 43 *Salix arctica*
Carex capitata	Group 39 *Empetrum nigrum*
Carex lenticularis var. dolia	Group 8 open graminoid; Group 14 sparse (mesic); Group 42 *Salix nivalis*
Carex glacialis	Group 37 *Dryas octopetala*
Carex lachenalii	Group 7 talus; Group 9 rocky (acidic); Group 27 *Artemisia norvegica* Group 34 C*assiope*; Group 38 *Cassiope tetragona*; Group 41 *Salix nivalis*; Group 42 *Salix nivalis*; Group 43 *Salix arctica*; Group 44 *Salix arctica* (sparse)
Carex incurviformis	Group 22 *Dryas integrifolia*; Group 24 rocky (calcareous); Group 26 *Artemisia michauxiana*
Carex misandra	Group 45 *Dryas integrifolia*
Carex petricosa	Group 45 *Dryas integrifolia*
Draba fladnizensis	Group 37 *Dryas integrifolia*
Draba longipes	Group 37 *Dryas octopetala*; Group 41 *Salix nivalis*
Draba macounii	Group 22 *Dryas integrifolia*; Group 44 *Salix arctica* (sparse); Group 45 *Dryas integrifolia*;
Draba porsildii	Group 41 *Salix nivalis*
Draba ventosa	Group 41 *Salix nivalis*
Erigeron flagellaris	Group 1 *Elymus lanceolatus-Koeleria macrantha*
Erigeron purpuratus	Group 24 rocky (calcareous); Group 28 rocky (acidic)
Erigeron trifidus	Group 24 rocky (calcareous); Group 26 *Artemisia michauxiana*; Group 44 *Salix arctica* (sparse); Group 45 *Dryas integrifolia*

Eriophorum callitrix	Group 17 *Carex aquatilis*; Group 43 *Salix arctica*
Festuca altaica	Group 11 sparse; Group 22 *Dryas integrifolia*; Group 26 *Artemisia michauxiana*;Group 29 *Festuca altaica*; Group 37 *Dryas octopetala*; Group 41 *Salix nivalis*; Group 43 *Salix arctica*; Group 44 *Salix arctica* (sparse); Group 45 *Dryas integrifolia*
Gentiana glauca	Group 9 rocky (acidic); Group 27 *Artemisia norvegica*;Group 33 *Carex nigricans*; Group 34 *Cassiope* Group 35 *Phyllodoce glanduliflora*; Group 36 *Cassiope mertensiana*; Group 37 *Dryas octopetala*; Group 38 *Cassiope tetragona*; Group 39 *Empetrum nigrum*; Group 41 *Salix nivalis*;Group 43 *Salix arctica*
Heuchera glauca	Group 14 sparse (mesic); Group 20 *Alnus viridis* ssp. *crispa/Ribes lacustre/Calamagrostis canadensis*; Group 28 rocky (acidic); Group 31 *Carex spectabilis*
Hierochloe alpina	Group 22 *Dryas integrifolia*; Group 25 rocky (neutral); Group 35 *Phyllodoce glanduliflora*; Group 37 *Dryas octopetala*; Group 38 *Cassiope tetragona*; Group 39 *Empetrum nigrum*; Group 42 *Salix nivalis*; Group 43 *Salix arctica*; Group 40 *Vaccinium uliginosum*; Group 44 *Salix arctica* (sparse); Group 45 *Dryas integrifolia*
Huperzia halakalae	Group 7 talus; Group 8 open graminoid; Group 34 *Cassiope*; Group 35 *Phyllodoce glanduliflora*; Group 36 *Cassiope mertensiana*; Group 37 *Dryas octopetala* Group 38 *Cassiope tetragona*; Group 39 *Empetrum nigrum*; Group 43 *Salix arctica*
Juncus biglumis	Group 14 sparse (mesic); Group 27 *Artemisia norvegica*; Group 38 *Cassiope tetragona*; Group 42 *Salix nivalis*; Group 43 *Salix arctica*; Group 44 *Salix arctica* (sparse)
Koenigia islandica	Group 8 open graminoid; Group 14 sparse (mesic); Group 42 *Salix nivalis*;Group 43 *Salix arctica*; Group 44 *Salix arctica* (sparse)
Loisleuria procumbens	Group 34 *Cassiope*; Group 36 *Cassiope mertensiana*; Group 38 *Cassiope tetragona* Group 39 *Empetrum nigrum*; Group 40 *Vaccinium uliginosum*
Diphasiastrum sitchense	Group 36 *Cassiope mertensiana*
Minuartia elegans	Group 7 talus; Group 22 *Dryas integrifolia*; Group 23 rocky (calcareous)Group 24 rocky (calcareous); Group 25 rocky (neutral); Group 26 *Artemisia michauxiana*; Group 35 *Phyllodoce glanduliflora*; Group 37 *Dryas octopetala*; Group 41 *Salix nivalis*; Group 42 *Salix nivalis*; Group 45 *Dryas integrifolia*
Osmorhiza purpurea	Group 21 *Trollius albiflorus*; Group 18 *Salix barclayi-S. drummondiana-S. vestita*
Oxytropis jordallii	Group 29 *Festuca altaica*

Papaver kluanensis	Group 10 consolidated talus; Group 22 *Dryas integrifolia*; Group 24 rocky calcareous; Group 25 rocky (neutral); Group 42 *Salix nivalis*
Pedicularis capitata	Group 22 *Dryas integrifolia*; Group 29 *Festuca altaica*; Group 38 *Cassiope tetragona*; Group 41 *Salix nivalis*; Group 43 *Salix arctica*; Group 44 *Salix arctica* (sparse); Group 45 *Dryas integrifolia*
Pedicularis flammea	Group 26 *Artemisia michauxiana*; Group 45 *Dryas integrifolia*
Pedicularis lanata	Group 22 *Dryas integrifolia*; Group 41 *Salix nivalis*; Group 42 *Salix nivalis*; Group 45 *Dryas integrifolia*
Pedicularis langsdorfii ssp. arctica	Group 17 *Carex aquatilis*; Group 27 *Artemisia norvegica*; Group 35 *Phyllodoce glanduliflora*; Group 37 *Dryas octopetala*; Group 38 *Cassiope tetragona*; Group 40 *Vaccinium uliginosum*; Group 41 *Salix nivalis*; Group 43 *Salix arctica*;Group 44 *Salix arctica* (sparse); Group 45 *Dryas integrifolia*;
Pellaea glabella	Group 2 cliff-calcareous; group 3 cliff/outcrop calcareous
Plantago canescens	Group 1 *Elymus lanceolatus-Koeleria macrantha*; Group 5 *Antennaria microphylla*; Group 16 *Achnathurum richardsonii*
Poa lettermannii	Group 10 consolidated talus; Group 25 rocky (neutral)
Potentilla hookeriana	Group 1 *Elymus lanceolatus-Koeleria macrantha*; Group 4 outcrop-calcareous; Group 5 *Antennaria microphylla*
Potentilla villosa	Group 10 consolidated talus; Group 24 rocky (calcareous); Group 25 rocky (neutral); Group 37 *Dryas octopetala*
Pyrola grandiflora	Group 41 *Salix nivalis*; Group 45 *Dryas integrifolia*
Ranunculus occidentalis	Group 21 *Trollius albiflorus*; Group 27 *Artemisia norvegica*; Group 31 *Carex spectabilis*; Group 33 *Carex nigricans*; Group 43 *Salix arctica*
Ribes laxiflorum	Group 12 low shrub; Group 20 *Alnus viridis* ssp. *crispa / Ribes lacustre / Calamagrostis Canadensis*; Group 34 *Cassiope*
Romanzoffia sitchensis	Group 34 *Cassiope*
Rorippa truncata	Group 6 drainage channel
Sagina nivalis	Group 14 sparse (mesic); Group 28 rocky (acidic); Group 32 *Carex nigricans*;
Salix alaxensis	Group 3 cliff/outcrop (calcareous)
Salix commutata	Group 31 *Carex spectabilis*
Salix stolonifera	Group 38 *Cassiope tetragona*

	Group 7 talus; Group 9 rocky (acidic); Group 14 sparse (mesic); Group 27 *Artemisia norvegica*;
	Group 28 rocky (acidic); Group 31 *Carex spectabilis*; Group 33 *Carex nigricans*; Group 34
	Cassiope; Group 38 *Cassiope tetragona*; Group 39 *Empetrum nigrum*; Group 43 *Salix arctica*;
Saxifraga ferruginea	Group 44 *Salix arctica* (sparse)
Saxifraga flagellaris	Group 22 *Dryas integrifolia*; Group 26 *Artemisia michauxiana*; Group 45 *Dryas integrifolia*
	Group 7 talus; Group 9 rocky (acidic); Group 10 consolidated talus; Group 14 sparse; Group 18
	Salix barclayi-S. drummondiana-S. vestita; Group 21 *Trollius albiflorus*; Group 27 *Artemisia*
	norvegica; Group 28 rocky acidic; Group 32 *Carex nigricans*;Group 34 *Cassiope*; Group 36
	Cassiope mertensiana; Group 38 *Cassiope tetragona*; Group 41 *Salix nivalis*; Group 42 *Salix*
Saxifraga nelsoniana	*nivalis*;Group 43 *Salix arctica*; Group 44 *Salix arctica* (sparse);
	Group 23 rocky (calcareous); Group 25 rocky (neutral); Group 28 rocky (acidic); Group 41 *Salix*
Saxifraga nivalis	*nivalis*; Group 44 *Salix arctica* (sparse); Group 45 *Dryas integrifolia*
Sedum divergens	Group 22 *Dryas integrifolia*; Group 41 *Salix nivalis*; Group 43 *Salix arctica*
Silene hitchguieri	Group 26 *Artemisia michauxiana*
Silene involucrata	Group 24 rocky (calcareous)
Telesonix heucheriformis	Group 3 outcrop calcareous; Group 4 outcrop calcareous
Vaccinium uliginosum	Group 34 *Cassiope*; Group 38 *Cassiope tetragona*; Group 39 *Empetrum nigrum*; Group 40 *Vaccinium uliginosum*

Table 3.2. Results of Indicator Species Analysis showing fidelity of rare species to vegetation types (as defined in Chapter 2). Given are the: Relative abundance (% of the occurrences of the rare species that were in that vegetation type relative to other types); Relative frequency (% of samples of that vegetation type that had the rare species); Indicator value (IV; obtained by multiplying relative abundance by relative frequency) and significance. Only taxa significant at $p \leq 0.05$ are shown.

Vegetation type (# corresponding to Chapter 2)	**Rare species**	**# veg. types with rare**	**# locations with rare**	**Rel. Abun. (%)**	**Rel. Freq. (%)**	**IV**	**p**
Treed sample locations (20 x 20 m plots)	None significant						
Shrub-dominated sample locations (10 x 10 m plots)	None significant						
Herbaceous sampling locations (5 x 5 m plots)							
Alnus/Ribes/Calamagrostis (20)	*Ribes laxiflorum*	3	4	62	100	61.5	0.012
Calcareous outcrop (4)	*Antennaria aromatica*	1	3	72	50	35.9	0.045
Carex aquatilis (17)	*Eriophorum callitrix*	2	2	87	50	43.7	0.035
Cassiope mertensiana (36)	*Pedicularis flammea*	2	7	65	67	43.4	0.014
Cassiope mertensiana (36)	*Silene hitchguirei*	1	2	100	67	66.7	0.003
Cassiope tetragona (38)	*Antennaria monocephala*	16	53	12	88	10.6	0.001
Cliff (calcareous) (2)	*Pellaea glabella*	2	4	60	75	45	0.01
Drainage channel (6)	*Barbarea orthoceras*	1	2	100	67	66.7	0.006
Dryas integrifolia (22)	*Pedicularis lanata*	4	8	45	50	22.5	0.036
Empetrum nigrum (39)	*Carex capitata*	1	2	100	50	50	0.005
Empetrum nigrum (39)	*Loiseleuria procumbens*	5	7	59	75	44.4	0.014
Empetrum nigrum (39)	*Vaccinium uliginosum*	4	8	50	75	37.5	0.014
Festuca altaica (29)	*Festuca altaica*	9	13	38	100	38.5	0.003
Fragaria virginiana (30)	*Botrychium minganense*	6	9	35	67	23.4	0.029
Outcrop (calcareous) (4)	*Telesonix heucheriformis*	2	3	67	100	66.7	0.002
Parnassia fimbriata (19)	*Aquilegia formosa*	4	5	50	100	50	0.013
Rocky (acidic) (9)	*Cardamine bellidifolia*	11	19	23	100	22.7	0.042

Rocky (acidic) (9)	*Gentiana glauca*	11	45	15	100	15	0.001
Rocky (calcareous) (24)	*Erigeron trifidus*	4	11	38	100	38.4	0.011

Table 3.3. Rare species with significant Indicator Value (IV) (p<0.05) in parentheses. Numbers for Vegetation types correspond to Table 2.2. 5 x 5 m plots (herbaceous habitat types) only. Shaded boxes with borders indicate where vegetation types were grouped together for the next highest level of pruning on the cluster dendrogram (Figure 2. 5).

Vegetation type	29 groups	36 groups	40 groups	45 groups
Elymus-Koeleria				
Cliff	*Pellaea glabella* (56.2)	*Pellaea glabella* (56.2)	*Pellaea glabella* (45)	*Pellaea glabella* (45)
outcrop	*Telesonix heucheriformis* (75)			
outcrop		*Telesonix heucheriformis* (75)	*Antennaria aromatica* (35.9); *Telesonix heucheriformis*(66.7)	*Antennaria aromatica* (35.9); *Telesonix heucheriformis* (66.7)
Antennaria				
drainage channel				*Barbarea orthoceras* (66.7)
talus				
open graminoid				
rocky (acidic)				*Cardamine bellidifolia* (22.7); *Gentiana glauca* (15)
consolidated talus				
sparse				
low shrub				
Salix-Betula				
sparse (mesic)				
Anemone				
Achnatherum				
Carex aquatilis	*Eriophorum callitrix* (43.7)	*Eriophorum callitrix* (43.7)	*Eriophorum callitrix* (43.7)	*Eriophorum callitrix* (43.7)

Salix spp.				
Parnassia		*Aquilegia formosa* (36.6)	*Aquilegia formosa* (31.8)	*Aquilegia formosa* (50)
Alnus/Ribes		*Ribes laxiflorum* (85.1)	*Ribes laxiflorum* (75.5)	*Ribes laxiflorum* (61.5)
Trollius				
Dryas integrifolia		*Pedicularis lanata* (22.5)	*Pedicularis lanata* (22.5)	*Pedicularis lanata* (22.5)
rocky (calcareous)				
rocky (calcareous)	*Erigeron trifidus* (53); *Papaver radicatum* (26.8)	*Erigeron trifidus* (44.1); *Potentilla villosa* (31.5)	*Erigeron trifidus* (38.4)	*Erigeron trifidus* (38.4)
rocky (neutral)				
Artemisia michauxiana				
Artemisia norvegica	*Saxifraga ferruginea* (16.8)			
rocky (acidic)				
Festuca altaica	*Festuca altaica* (50.2); *Oxytropis jordallii* (50)	*Festuca altaica* (46.5)	*Festuca altaica* (40.5)	*Festuca altaica* (38.5)
Fragaria virginiana	*Botrychium minganense* (25.7)	*Botrychium minganense* (25.7)	*Botrychium minganense* (23.4)	*Botrychium minganense* (23.4)
Carex spectabilis				
Carex nigricans				
Carex nigricans				
Cassiope Phyllodoce				
Cassiope mertensiana			*Pedicularis flammea* (43.4); *Silene hitchguirei*	*Pedicularis flammea* (43.4); *Silene*

			(66.7)	*hitchguirei* (66.7)
Dryas octopetala				
Cassiope tetragona	*Antennaria monocephala* (13.8)		*Antennaria monocephala* (11.2)	*Antennaria monocephala* (10.6)
Empetrum nigrum	*Carex capitata* (50); *Loiseleuria procumbens* (45.9); *Vaccinium uliginosum* (38.6)	*Carex capitata* (50); *Loiseleuria procumbens* (44.4); *Vaccinium uliginosum* (37.5)	*Carex capitata* (50); *Loiseleuria procumbens* (44.4); *Vaccinium uliginosum* (37.5)	*Carex capitata* (50); *Loiseleuria procumbens* (44.4); *Vaccinium uliginosum* (37.5)
Vaccinium uliginosum				
Salix nivalis				
Salix nivalis				
Salix arctica				
Salix arctica				
Dryas integrifolia				

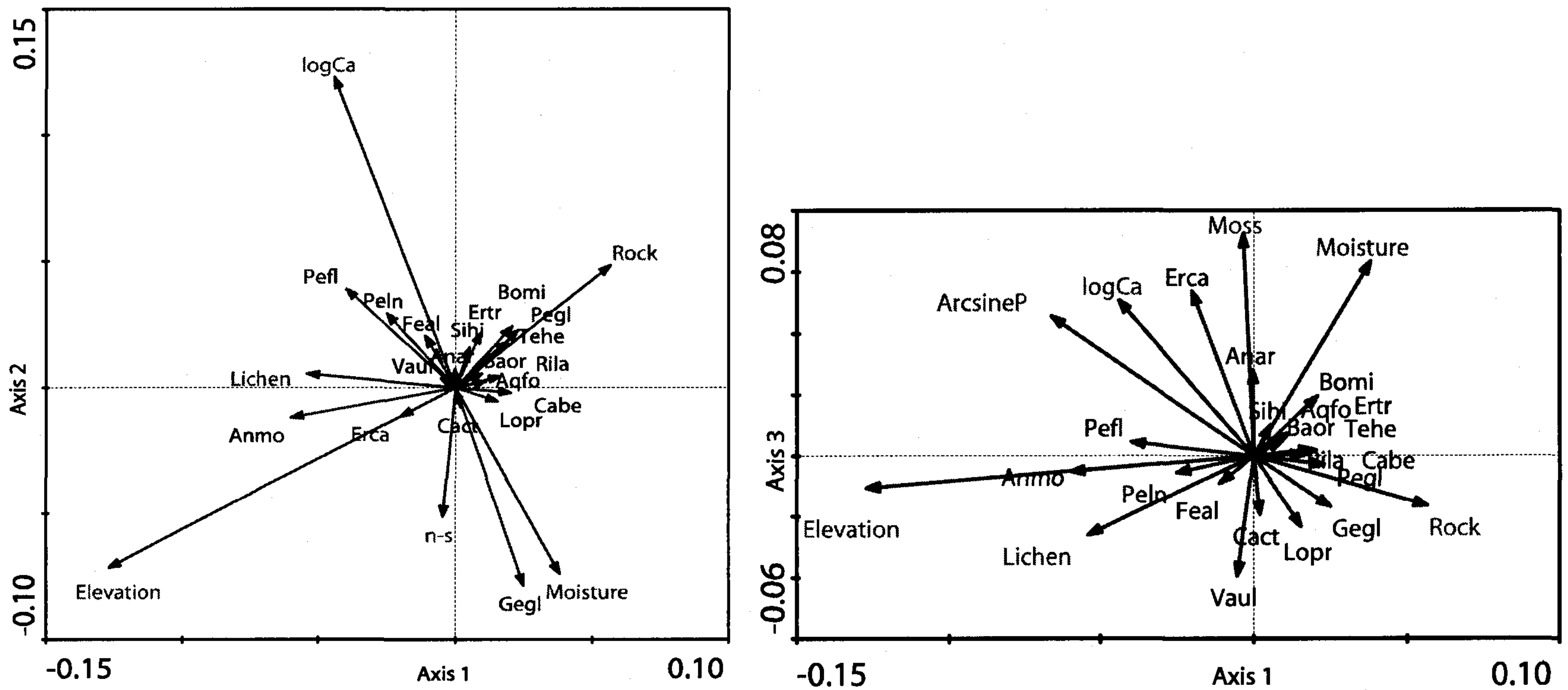


Figure 3.1. Distance-based redundancy analysis plot of rare species in relation to significant measured environmental variables. Rare species are presented as vectors. The Indicator Values of *Antennaria monocephala*, *Botrychium minganense*, *Cardamine bellidifolia*, *Gentiana glauca* and *Pedicularis lanata* are <25. Codes for names of rare species are shown in Appendix 1.

Chapter 4: Co-occurrence of rare vascular plants in the northern Rocky Mountains of Alberta, Canada

Introduction

There are currently over 450 species of rare vascular plant species in the province of Alberta (Gould 2000) and of these over 300 are considered to fall into the "May be at Risk" category (Alberta Sustainable Resource Development 2005). Species labeled "May be at Risk" are candidates for assessment and eventual consideration for designation under federal and provincial endangered species legislation. Given the current number of rare taxa and limited funds available for production of status assessments and subsequent recovery plans, both will take more time, knowledge, societal patience and resources than are currently available (Franklin 1993; Clark and Harvey 2002). In the meantime, alteration of habitat due to resource development and influx of invasive species will likely result in increases to the number of extirpated taxa or species on the rare plant list. Given the disparity between the number of rare vascular plants and funds available to provide legislative protection, there is a need to examine alternative mechanisms for assessment or recovery planning, such as multi-species or ecosystem approaches (Tear et al. 1995).

Designation of a species under the *Species at Risk Act* requires the recognition of "critical habitat" which is defined as "habitat that is necessary for the survival or recovery of a listed wildlife species" (Government of Canada 2003). Critical habitat must be defined through the recovery planning process. If species can be demonstrated to share the same habitat, this can be coupled with an understanding of their life history strategies to develop conservation or management guidelines for the group of species. This would help us move more quickly and efficiently through the long list of rare species and also avoid problems inherent in trying to integrate multiple species-specific requirements into overall conservation planning (Hill and Keddy 1992).

The presence of a species in an area is related to several things: habitat, historical factors and interactions with other species (Diamond 1975; Sfenthourakis et al. 2005). Patterns of co-occurrence, therefore, are related to one or more of these factors. That is, co-occurring rare species may occupy similar habitats, share similar history and/or have positive or neutral interactions with each other (Sfenthourakis et al. 2005). Once a species is present at a site, it occupies a niche which has been defined as "multidimensional hypervolume in which species can maintain a viable population" (Hutchinson 1957). No two species will have the same niche—there may be overlap but the overlap is not complete (Tokeshi 1999). Interactions between species such as competition may result in the species occupying a realized rather than a potential niche (van Andel 2005). Examination of distribution patterns of rare species in relation to environmental parameters and other species within a community may further our understanding of the realized niche occupied by these species. For example, a species that is distributed across a long environmental gradient other than when in the presence of another may suggest that there is competition for this resource between these two taxa.

The co-occurrence of species has been the subject of scientific interest for many years (Cole 1949; Diamond and Gilpin 1982; Gilpin and Diamond 1982; Connor and Simberloff 1983; Schluter 1984; Zobel 1997; Tokeshi 1999); however, much of this interest has been centred on trying to understand how species are assembled into communities. There has, however, been research on patterns of co-occurrence other than in the context of the community (Gotelli 2000; Auster et al. 2005; Krasnov 2005; Sfenthourakis et al. 2005; Potthoff et al 2006), but it has been sparse with respect to co-occurrence between rare taxa.

The objective of this chapter was to determine if rare species co-occur in the study area and if so whether the pattern of co-occurrence was due to sharing of habitat, as determined by rare species fidelity to vegetation types (see Chapter 3).

Study area

The study area is located in the northern Rocky Mountains of Alberta at 52° 35' to 54° 10' N latitude, 117° 10' to 120° W longitude and encompasses approximately 54 000 square kilometers. There are two northwest-southeast trending mountain ranges (Main and Front Ranges) within the area and these are dissected by several east-west trending valleys. Elevation ranges from 1006 m a.s.l. in the river valleys to 3020 m on alpine summits. The area has a diversity of lithologies with Precambrian and Early Paleozoic quartzite and limestone dominating the Main Ranges and Late Paleozoic limestone and

Mesozoic shales in the Front Ranges (Mountjoy 1978; Gadd 1986). The Continental Divide forms the western boundary of the study area.

The climate is continental and there is considerable variability in temperature and precipitation within the study area due to topographic relief. Daily average temperature ranges from -0.3 C to 3.7 C and average yearly precipitation ranges from 398.9 mm to 620.2 mm (Environment Canada 2004).

Several protected areas occur within the study area: Jasper National Park, Willmore Wilderness Park, Kakwa and Whitehorse Wildland Parks, These have lower levels of human disturbance, primarily industrial activities, than areas outside and thus human induced causes of rarity are assumed to be low.

The northern Rockies is one of two areas of concentration of rare vascular plants within the Canadian Rockies, the other being the area south of Crowsnest Pass (Ogilvie 1998) in southern Alberta. Fifty-four rare vascular plants species were known to occur within the study area at the commencement of this research (ANHIC data files 2001). In general these are species that are restricted to higher elevations. The Rocky Mountain Natural Region has the greatest number of rare species in Alberta (Kershaw et al. 2001); the majority of which are common outside of the province, with many reaching the southern limits of their distribution in the northern Rockies.

Vegetation

Three Natural Subregions (montane, subalpine and alpine) are represented within the Rocky Mountain Natural Region of Alberta (Natural Region Review Committee 2004). The Montane Subregion is a mosaic of forest types (Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), trembling aspen (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* (Moench) Voss)) and grass and shrub dominated communities and is generally situated between 1000 and 1350 m (Holland and Coen 1982). The subalpine is characterized by closed forests dominated by lodgepole pine (*Pinus contorta* Loudon), subalpine fir (*Abies bifolia* A. Murray) and Engelmann spruce (*Picea engelmannii* Parry *ex* Engelm.). Forests at higher elevations are open and consist of stunted trees of subalpine fir and Engelmann spruce with an understory of alpine vegetation. Vegetation of the alpine is a complex of community types dominated by dwarf shrub and herbaceous vegetation (Holland and Coen 1982). A diversity of vegetation types have been described for the study area (Chapter 2) and these form the framework for analysis of fidelity and species co-occurrence.

Methods

Field protocol

Sites were selected so as to include a diversity of habitats as ascertained from examination of aerial photographs, topographic maps and the literature given the size of the area, remoteness and difficulty with access. In total I visited 48 sites and collected data at 297 sample locations. At each site, sample locations were chosen in as many plant associations within the area as possible within the time available. Each plant association at a site is considered a sample location. The method used for description of the plant association is provided in Chapters 2 and 3. In addition to the sampling within the plot at each sample location, a rare plant survey was conducted outside of each plot by walking a series of parallel transects within the plant association (see Nelson 1986) for ten minutes noting all taxa encountered. This captured other species (common and rare) not found within the plot. A rare species was defined as one occurring on the ANHIC tracking list (Gould 2000). Fieldwork was conducted in 2001, 2002 and 2003. A species list for each sample location was developed by combining the plot data with that of the 10 minute survey done after the plant community description. This is henceforth referred to as the 'larger plot' and it is what is used for subsequent analyses of co-occurrence.

Species that could not be identified in the field were collected for subsequent identification in the lab or annotation by taxonomic experts. Nard sedge (*Carex nardina* E. Fries) and Pacific kobresia (*Kobresia myosuroides* (Vill.) Fiori & Paol.) cannot be distinguished in a vegetative state and several additional taxa are difficult to tell apart in the field and are therefore treated as species complexes in the dataset. These include alpine willow-herb (*Epilobium anagallidifolium* Lam.) and clavate-fruit willow-herb (*E. clavatum* Trel.), short-leaved fescue (*Festuca brachyphylla* Schultes) and small-flowered fescue (*F. minutiflora* Rydb.) as well as prairie club-moss (*Selaginella densa* Rydb.), Rocky Mountain spike-moss (*S. scopulorum* Maxon) and Standley's spike-moss (*S. standleyi* Maxon). This does not apply to any rare species. Plants that could not be identified to the species level (or species complex as noted above) were excluded from the analysis. Individuals of species thought to form introgressive hybrid swarms (eg. *Picea engelmannii* and *P. glauca*) were classified as one of the two parental species depending on the dominant traits.

Nomenclature for species follows Moss (1983) and Flora of North America (Flora of North America Editorial Committee 1993-2006). Common names for taxa without common names in Moss (1983) or Flora of North America are taken from NatureServe (http://www.natureserve.org/explorer). Voucher specimens were deposited at the herbarium, University of Alberta (ALTA).

Analyses

Association analysis (χ^2) was conducted on the matrix of species presence/absence for each sample location (data from the larger plot) to test for independence of occurrence between species. This was done for each plot size separately. Significance was determined after applying Yates' correction since there were few degrees of freedom (Townend 2002). Species that occurred fewer than five times in the dataset were removed prior to analysis in accordance with the appropriate use of chi-squared tests (Townend 2002; Zar 1999). These analyses were conducted using a program developed by R. Belland (University of Alberta).

A second analysis, Indicator Species Analysis (ISA) (Dufrêne and Legendre 1997), was conducted on the same matrices to assess the ability of one rare species to predict the occurrence of another. Each rare species formed a grouping variable and the analysis was performed for the different plot sizes separately. Indicator Species Analysis calculates the abundance and frequency of a species within a group relative to its abundance or frequency in other groups. An Indicator Value (IndVal) is calculated by multiplying relative frequency and relative abundance. Relative frequency is the proportion of samples of a given group in which the species is found. For example, there were 40 samples of group (rare species) Y and rare species X was found in 20 of them; its relative frequency in group Y is then 50%. This equates to faithfulness or fidelity. Relative abundance is the proportional abundance of a species in a group relative to its abundance in all groups. For example rare species X was found in 25 sample locations in total and 20 of these were group Y (which had 20 sample locations), 5 of these in group Z (which had 10 sample locations; its relative abundance is then (20/20) / (20/20 + 5/10) = 67%. This equates to exclusiveness or specificity (Dufrêne and Legendre 1997; McCune and Grace 2002). A good indicator is a species that is restricted to one group and is well represented within that group (Dufrêne and Legendre 1997; McCune and Grace 2002). Indicator Values of >25 were considered to be significant as this signifies that the relative abundance of a species is at least 50% in one group and further that it is represented in 50% of samples within the group (Dufrêne and Legendre 1997). Significances of the indicator values were determined using Monte Carlo permutation procedures (999 permutations). PC-Ord Version 4.1 was used to conduct the analysis.

Non-metric multidimensional scaling (NMDS) using Sorenson's distance measure was done on the species presence/absence x sample matrices (focus on species) to project species in multidimensional species and to compare the results of the Association

Analysis and Indicator Species Analysis. Non-metric multidimensional scaling is an indirect ordination technique robust to noise that is appropriate for community data (Prentice 1977; Clarke 1993) including those with high beta diversity (Fasham 1977; Minchin 1987) as it does not require the assumption of a linear relationship among variables and allows one to use a distance measure that is appropriate to the dataset (Clarke 1993; McCune and Grace 2002). It preserves the order of relationships among sites/species by ranking similarity of species in relation to distance in ordination space (Prentice 1980; Clarke 1993; Legendre and Legendre 1998). An initial ordination (no transformation of data, 6 dimensions with step down to 1, instability criterion of 0.0005, 200 iterations, 10 runs of real data, 20 runs with random data) was done on the dataset to determine the appropriate number of dimensions as determined from an examination of lowest stress. This resulted in a 4-dimensional solution. The coordinates resulting from the solutions with the lowest stress were used as starting coordinates for the final solutions and axes were subject to varimax rotation to ease interpretation (McCune and Grace 2000). All non-metric multidimensional scaling analyses were conducted using PC-Ord 4.1.

In Chapter 2, I described the use of distance-based redundancy analysis (db-rda) to examine the relationships of the vegetation types to measured environmental variables. I also used db-rda to explore the relationship of rare species to the vegetation types defined in Chapter 2. I also examined the relationship of rare species to significant environmental variables by including the species in the 'larger plot' as supplementary variables in the ordination of vegetation types with environmental variables. Attribute plots were then generated to portray rare species in environmental space. Distance-based redundancy analysis was conducted using Canoco for Windows 4.5 (ter Braak and Šmilauer 2002).

Cluster analysis using a flexible beta linkage method with β= -0.25 and Sorenson's distance measure was used to partition the rare species into groups. Flexible beta is a space-conserving hierarchical agglomerative technique that is not prone to chaining (McCune and Grace 2002). Analyses were conducted using PC-Ord Version 4.1.

Results

Removal of species that occurred fewer than five times in the dataset left me with 29 of 74 taxa for subsequent analysis (Table 4.1). None of the rare plants noted from the treed (20 x 20 m) and shrub- (10 x 10 m) dominated plant associations were represented by five or more occurrences, hence all subsequent analyses were done on the herb- (5 x 5 m) dominated locations. The majority of the rare plant species retained in the dataset are common globally but rare provincially (Table 4.1); many of these occur at the edge of their range. All but *Koenigia islandica* are perennials. The families that are most commonly represented in the dataset include *Brassiceae*, *Orobanchaceae* and *Saxifragaceae*. Congeneric species pairs include *Botrychium ascendens* and *B. minganense*, *Pedicularis capitata* and *P. flammea* and *P. capitata* and *P. langsdorfii*.

All but one of the 29 rare species analyzed had at least one significant association with another rare species, as determined by the Association Analysis, the ISA, or both (Tables 4.2, 4.3). *Aquilegia formosa* was the only rare species of the 29 in the dataset that did not have a significant association with another rare species in either Indicator Species or Association Analysis (Tables 4.2 and 4.3). The relationship of *Aquilegia formosa* to other rare species is shown in Figure 4.2 where it is apparent that there was little similarity between occurrences of it and other rare species. There were three species pairs (*Cardamine bellidifolia-Carex lachenalii*, *Antennaria monocephala-Carex lachenalii* and *Hierochloe alpina-Vaccinium uliginosum*) that were significant with Indicator Species Analysis but not Association Analysis. Conversely, all species pairs that were identified as significant with Association Analysis were determined to be significant by Indicator Species Analysis.

The association of these species pairs was further explored using NMDS, db-rda and cluster analysis. In general, species with the highest χ^2 or Indicator Value were positioned in close proximity to each other in the NMDS plot (Figure 4.1) and the dendrogram produced by the cluster analysis (Figure 4.2). In addition, these species appear to have similar responses to measured environmental variables as shown by their positions in the db-rda attribute plots (Figure 4.3).

Not all of the rare species were able to predict the occurrence of the other associated rare species in spite of there being significant associations as shown by the Association Analysis. There were twenty-two such species pairs (Table 4.3). For example, *Botrychium ascendens* was a significant predictor of the occurrence of *B. minganense* but *B. minganense* was not of *B. ascendens*. This is also evident in the db-rda attribute plots where it is apparent that while there is some overlap in the distribution of these two species, one of them has a broader distribution across the environmental gradients and thus cannot accurately predict the occurrence of the other (Figure 4.3). *Botrychium ascendens* is restricted to the upper left quadrant of the attribute plot while *B. minganense* is scattered throughout (Figure 4.3). For species pairs in which one rare species predicted the occurrence of the other and vice versa, the species are represented in close proximity to each other on the NMDS plots, on the db-rda attribute plots and on the dendrogram. For example, *Erigeron trifidus* and *Minuartia elegans* are close together in the NMDS plot and dendrogram and appear in the same position on the attribute plots.

Examination of Table 4.3 shows the presence of rare species in relation to vegetation types. Several vegetation types had one or more of the 29 species that were represented in this dataset, many of which had a significant association with a particular type (fidelity) (Chapter 3). Some types such as talus, consolidated talus, rocky acidic habitat and *Dryas integrifolia* tundra had more than 5 rare species (Table 4.4). It is also apparent that there may be "multi-species" associations, that is, more than one significant association between groups of taxa (Table 4.4). For example, *Antennaria monocephala*, *Hierochloe alpina*, *Gentiana glauca* and *Pedicularis langsdorfii* occur in many of the same vegetation types (Table 4.4). *Antennaria monocephala* is significantly associated with the three other species; however, the three other species are not necessarily associated with each other. *Pedicularis langsdorfii*, for example, is not significantly associated with *Gentiana glauca* (Tables 4.2 and 4.3).

There was only one pair of co-occurring rare species for which both species showed a significant fidelity to the same habitat (*Loiseleuria procumbens* and *Vaccinium uliginosum* with fidelity to the *Empetrum nigrum* vegetation type) (Table 4.3).

Discussion

Twenty-eight of 74 rare vascular plant species observed in the northern Rocky Mountains of Alberta exhibit some degree of association with each other. *Aquilegia formosa*, a species found in several tree, shrub and herbaceous dominated habitats within the study area, was the only species that is found more than five times in the dataset that did not co-occur with another species. The high percentage of rare species exhibiting a pattern of co-occurrence may be due to several factors including similar habitat preferences, distribution patterns and/or species interactions (i.e. commensalism). The factors responsible for the patterns exhibited by the rare vascular flora of the northern Rocky Mountains are not known; however, many of the species pairs have similar responses to environmental gradients as shown by the attribute plots, suggesting that these taxa have similar habitat requirements. The majority of these rare species have similar distribution patterns as they are circumpolar species which approach the southern limits of their range in the northern Rocky Mountains of Alberta. In addition, the flora in the area is likely of the same age, as the Laurentide and Cordilleran ice sheets were thought to have coalesced in the northern Rocky Mountains of Alberta during the last glacial event (Dyke et al. 2002). Many of the species that exhibit these patterns are rare provincially but locally common.

Rare species associated with treed and shrub-dominated sites were poorly represented in the dataset and thus patterns of co-occurrence could not be detected. This is because there were few rare species in the shrub-dominated and treed sites and also because I found few occurrences of the rare species that were in these habitats (see Chapter 3). All but two of the co-occurring rare species groups in the herbaceous dataset were found only in the alpine or upper subalpine, but this is likely a reflection of the higher number of rare species at higher elevations. The two exceptions, *Botrychium minganense-B. ascendens* and *Festuca altaica-B. ascendens* were found at lower elevation in either *Fragaria virginiana* or *Festuca altaica* dominated vegetation types, respectively.

There were three species pairs that showed significant association by Indicator Species Analysis but not Association Analysis. Association Analysis was used to determine if occurrences of rare species are independent with respect to other species, while Indicator Species Analysis was used to determine if one rare species could predict the occurrence of another. The lack of complete concordance between the two types of analysis is likely due to differences in how significance is determined in the two tests.

There was no strong evidence that congeners co-occurred even though closely related species may have a large degree of overlap in their respective niches (Tokeshi 1999). There were four genera (*Botrychium, Cardamine, Pedicularis, Saxifraga*) with two or more rare species represented in the dataset. However, only three congeneric species pairs had significant associations: *Botrychium minganense* and *B. ascendens*, *Pedicularis capitata* and *P. flammea* and *P. capitata* and *P. langsdorfii*. *Botrychium ascendens* and *B.*

minganense are known to occur together (Wagner and Wagner 1993) so their demonstrated association is not surprising. Members of the genus *Pedicularis* are known to be hemiparasitic (Judd et al. 2002) and while there was a significant association between three members of this genus (*P. capitata* and *P. flammea* and *P. capitata* and *P. langsdorfii*), whether these species are hemiparasitic on the same species is unknown. All of the congeneric species pairs for which there was a significant association appear to have similar responses to measured environmental variables. The lack of strong association between other congeneric taxa (i.e. *Cardamine* and *Saxifraga*) may be explained by competition for resources, as intra-generic competition may be higher than competition between non-related taxa (see Sfenthourakis et al. 2005). Evidence, however, is either weak (Gotelli and McCabe 2002) or does not support this pattern (Sfenthouraskis et al. 2005). Sfenthouraskis et al. (2005) found no evidence of stronger competitive exclusion between closely related species of isopod relative to non-related species pairs and observed patterns of co-occurrence were attributed to similarities in habitat requirements or history. This lack of association may also be due to differences in habitat preferences as shown in the attribute plots and their presence in particular vegetation types as described in Chapter 3.

While associated species pairs may respond to measured environmental gradients in a similar way, the co-occurrence of congeners does not appear to be attributable to shared preferences for a particular vegetation type. *Botrychium ascendens*, for example, occurred in three of the six vegetation types that had *B. minganense* and was found in only one where *B. minganense* did not occur (Chapter 3). In contrast, *B. minganense* occurred in several vegetation types that did not have *B. ascendens* (Chapter 3). *Pedicularis capitata* occurred with *P. flammea* in one of the two vegetation types with *P. flammea* but was represented in several types that did not have *P. flammea* (Chapter 3). *Pedicularis langsdorfii* and *P. capitata* shared three vegetation types but there were several types in which one or the other species was present without the other. Likewise, there was little evidence that any of the instances of non-congeneric rare species co-occurrence were due to shared affinity for vegetation type, despite the fact that eleven of these rare species had been shown to have significant fidelity to such (Chapter 3). Only one species pair, *Vaccinium uliginosum* and *Loiseleuria procumbens*, had a shared fidelity to a particular vegetation type: high elevation tundra dominated by *Empetrum nigrum*. This vegetation type is generally restricted to the Main Range of the study area on siliceous materials of low pH. Both rare species form large mats on the ground surface and bare ground is often evident.

For several species pairs the ISA showed that one could predict the presence of the other but the converse was not true. This discrepancy can be explained by differences in breadth of habitat. In general, one species occurs over a narrower range of measured environmental variables and vegetation types than the other. The "narrower" species can predict the occurrence of the "wider" but the "wider" species cannot predict the "narrower". For example, *Ranunculus occidentalis*, a species of subalpine mesic meadows, can predict the occurrence of *Cardamine oligosperma* which also occurs in similar habitats. However, *Cardamine oligosperma* is found in a wider range of conditions than *R. occidentalis* and thus cannot predict its occurrence.

An association between one species and two others does not mean that the other two will have a significant association with one another (Sfenthourakis et al. 2005). For example *Erigeron trifidus* was significantly associated with both *Pedicularis flammea* and *Minuartia elegans*; however, the association between *Pedicularis flammea* and *Minuartia elegans* was not significant. This may be related to several factors including species interactions, distribution of habitats and historical factors (Sfenthourakis et al. 2005). I was not able to determine whether there are interactions between these taxa or if historical factors might affect patterns of co-occurrence. Examination of occurrences in relation to habitat shows differences between the species with *Minuartia elegans* being found in several vegetation types compared to *E. trifidus* and *P. flammea*. It also appears to have broader ecological amplitude where we see that the sample locations containing this species had a wider dispersion along axis 2. Axis 2 is associated with elevation, log Ca, moisture, total rock cover and aspect (n-s) (see Chapter 2).

Several vegetation types in the study area were found to have many rare vascular plant species, suggesting that conservation of these types will facilitate the conservation of a suite of species in spite of there being a lack of significant association between such taxa. In addition, several species exhibited patterns of co-occurrence and this information is useful for determining which species might lend themselves to multi-species assessments or recovery plans. This, in association with an assessment of fidelity to habitat, can assist with defining critical habitat as required under the current recovery planning process. Multi-species or ecosystem approaches to recovery planning will be effective only if the species that are grouped together have similar habitats and face similar threats (Clark and

Harvey 2002) or if problems identified through a single-species approach are addressed first (Tear et al. 1995). For example, multi-species plans may address broad threats but not provide enough direction to address species specific threats (Tear et al. 1995). Forty-five species did not exhibit patterns of co-occurrence and therefore will require single-species approaches to conservation.

Literature Cited

Alberta Natural Heritage Information Centre. 2000. Draft Plant Community Sampling Guidelines. Alberta Community Development, Edmonton, Alberta.

Alberta Natural Heritage Information Centre. 2001. data files. Alberta Community Development. Edmonton, Alberta

Alberta Sustainable Resource Development. 2005. General status of wildlife in Canada.

Auster, P. J., B. X. Semmens and K. Barber. 2005. Pattern in the co-occurrence of fishes inhabiting the coral reefs of Bonaire, Netherlands Antilles. Environmental Biology of Fishes 74:187-194.

Clark, J. A. and E. Harvey. 2002. Assessing multi-species recovery plans under the Endangered Species Act. Ecological Applications 12:655-662.

Clarke, K. R. 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology 18:117-143.

Cole, L. C. 1949. The measurement of interspecific association. Ecology 30:411-424.

Connor, E. F. and D. Simberloff. 1983. Interspecific competition and species co-occurrence patterns on islands: null models and the evaluation of evidence. Oikos 41:455-465.

Diamond, J. M. 1975. Assembly of species communities. IN: M. L. Cody and J. M. Diamond (eds.). Ecology and evolution of communities. Harvard University Press, Cambridge, Mass. P. 342-444.

Diamond, J. M. and M. E. Gilpin. 1982. Examination of the "null" model of Connor and Simberloff for species co-occurrences on islands. Oecologia 52:64-74.

Dufrêne, M. and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetric approach. Ecological Monographs 67:345-366.

Dyke, A. S., J. T. Andrews, P. U. Clark, J. H. England, G. H. Miller, J. Shaw and J. J. Veillete. 2002. The Laurentide and Innuitian ice sheets during the last glacial maximum. Quaternary Science Reviews 21:9-31.

Environment Canada. 2004. Canadian Climate Normals. http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html. --date accessed Oct. 3, 2004.

Fasham, M. J. R. 1977. A comparison of nonmetric multidimensional scaling, principal components and reciprocal averaging for the ordination of simulated coenoclines, and coenoplanes. Ecology 58:551-561.

Flora of North America Editorial Committee. 1993-2006. Flora of North America. Oxford University Press, New York, New York.

Franklin, J. F. 1993. Preserving biodiversity: species, ecosystems, or landscapes. Ecological Applications 3:202-205.

Gadd, B. 1986. Handbook of the Canadian Rockies. Corax Press, Jasper, Alberta. 878 pp..

Gilpin, M. E. and J. M. Diamond. 1982. Factors contributing to non-randomness in species co-occurrences in islands. Oecologia 52:75-84.

Gotelli, N. J. 2000. Null model analysis of specie co-occurrence patterns. Ecology 81:2606-2621.

Gotelli, N. J. and D. J. McCabe. 2002. Species co-occurrence: a meta-analysis of J. M. Diamond's assembly rules model. Ecology 83:2091-2096.

Gould, J. 2000. Alberta Natural Heritage Information Centre—Tracking and Watch Lists for Vascular Plants, Mosses, Liverworts and Hornworts. Alberta Environmental Protection, Edmonton, Alberta.

Government of Canada. 2003. Species at Risk Act. Canada Gazette Vol . 25, Number 3. 104 pp.

Hill, N. M. and P. A. Keddy. 1992. Prediction of rarities from habitat variables: coastal plain plants on Nova Scotian lakeshores. Ecology 73:1852-1859.

Holland, W. D. and G. M Coen. 1982. Ecological (Biophysical) Land Classification of Banff and Jasper National Parks. Volume 2: Soil and Vegetation Resources. Alberta Institute of Pedology Publication No. SS-82-44. 540 pp. and maps.

Hutchinson, G. E. 1957. Concluding remarks. Cold Spring Harbor Symposia on Quantiative Biology 22:415-427.

Judd, W. S., C. S. Campbell, E. A. Kellogg, P. F. Stevens and M. J. Donoghue. 2002. Plant Systematics: a Phylogenetic Approach. Sinauer Associates, Inc., Sunderland, Massachusetts. 576 pp.

Kershaw, L., J. Gould, D. Johnson and J. Lancaster. 2001. Rare Vascular Plants of Alberta. University of Alberta Press, Edmonton, Alberta and Natural Resources

Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. 484 pp..

Krasnov, B. R., M. Stanko, I. S. Khokhlova, L. Mošanšky, G. I. Shenbrot, H. Hawlena and S. Morand. 2005. Aggregation and species coexistence in fleas parasitic on small mammals. Ecography 28:1-10.

Legendre, P. and L. Legendre. 1983. Numerical Ecology. Elsevier. New York. 853 pp.

McCune, B. and J. B. Grace. 2002. Analysis of Ecological Communities. MjM Software Design. Gleneden Beach, Oregon. 300 pp.

Minchin, P. R. 1987. An evaluation of the relative robustness of techniques for ecological ordination. Vegetatio 69:89-107.

Moss, E. H. 1983. Flora of Alberta. Second edition (revised by J. G. Packer). University of Toronto Press, Toronto, Ontario. 687 pp.

Mountjoy, E. W. 1978. Geology—Mount Robson. Geological Survey of Canada. Map 1499A.

Natural Region Committee. 2006. Natural Subregions and Subregions of Alberta. Compiled by D. J. Downing and W. W. Pettapiece. Government of Alberta, Pub. No. I/005. 254 pages.

Ogilvie, R. T. 1998. Vascular plants. IN: Smith, I. M. and G. G. E. Scudder, eds. Assessment of species diversity in the Montane Cordillera Ecozone. Ecological Monitoring and Assessment Network, Burlington, Ontario.

Potthoff, M., K. Johst, J. Gutt and C. Wissel. 2006. Clumped dispersal and species coexistence. Ecological Modelling 198:247-254.

Prentice, I. C. 1977. Non-metric ordination methods in ecology. Journal of Ecology 65:85-94.

Prentice, I. C. 1980. Vegetation analysis and order invariant gradient models. Vegetatio 42:27-34.

Schulter, D. 1984. A variance test for detecting species associations with some example applications. Ecology 65:998-1005.

Sfenthourakis, S., E. Tzanatos and S. Giokas. 2005. Species co-occurrence: the case of congeneric species and a causal approach to patterns of species association. Global Ecology and Biogeography 15:39-49.

Tear, T. H., J. M. Scott, P. H. Hayward and B. Griffith. 1995. Recovery plans and the Endangered Species Act: are criticisms supported by data. Conservation Biology 9:182-195.

ter Braak, C. J. F. and P. Šmilauer. 2002. CANOCO Reference Manual and CanoDraw for Windows User's Guide: software for Canonical Community Ordination (version 4.5). Microcomputer Power, Ithaca, New York. 500 pp.

Tokeshi, M. 1999. Species Coexistence: Ecological and Evolutionary Perspective. Blackwell Science

Townend, J. 2002. Practical Statistics for Environmental and Biological Scientists. John Wiley and Sons Ltd., Sussex England. 276 pp..

Van Andel, J. 2005. Species interactions structuring plant communities. IN: Vegetation Ecology (E. van der Maarel ed.). Blackwell Publishing, Oxford. pp. 238-264.

Wagner, W. H. Jr. and F. S. Wagner. 1993. Ophioglossaceae C. Agardh. IN: Flora of North America, Volume 2, Pteridophytes and Gymnosperms, Oxford University Press, New York, New York. p. 85-106.

Zar,J. H. 1999. Biostatistical Analysis. Fourth edition. Prentice Hall, New Jersey. 663 pp plus appendices.

Zobel, M. 1997. The relative role of species pools in determining plant species richness: an alternative explanation of species coexistence? Trends in Ecology and Evolution 12:266-269.

Table 4.1. The 29 rare vascular plant taxa observed during sampling within the northern Rocky Mountains of Alberta, which were utilized for the examination of rare species co-occurrence. Only those species represented by five or more occurrences in the dataset are shown. Rank according to NatureServe (www.natureserve.org/explorer).

Scientific Name	Common Name	Rank*	Family	Global distribution
Antennaria monocephala	one-headed everlasting	G4G5, S2	*Asteraceae*	Northern North America
Aquilegia formosa	Sitka columbine	G5, S2	*Ranunculaceae*	western North America
Botrychium ascendens	ascending grape fern	G2G3, S1	*Ophioglossaceae*	central North America
Botrychium minganense	Mingan grape fern	G4, S2S3	*Ophioglossaceae*	western and central North America
Cardamine bellidifolia	alpine bitter cress	G5, S2	*Brassicaceae*	Circumpolar
Cardamine oligosperma	mountain cress	G5T?, S2	*Brassicaceae*	western North America
Carex lachenalii	two parted sedge	G5, S2	*Cyperaceae*	Arctic-alpine
Draba longipes	whitlow grass	G4, S1S2	*Brassicaceae*	Arctic-alpine
Erigeron trifidus	trifid-leaved fleabane	G2G3Q, S1S2	*Asteraceae*	western North America
Festuca altaica	northern rough fescue	G5, S2	*Poaceae*	Arctic-alpine
Gentiana glauca	alpine gentian	G4G5, S2	*Gentianaceae*	circumpolar
Heuchera glabra	alpine alumroot	G5, S1	*Saxifragaceae*	western North America
Hierochloe alpina	alpine sweetgrass	G5, S2	*Poaceae*	Circumpolar
Huperzia haleakalae	alpine fir-moss	G4?, S2	*Lycopodiaceae*	Alpine
Juncus biglumis	two-glumed rush	G5, S2	*Juncaceae*	Circumpolar
Koenigia islandica	koenigia	G4, S1	*Polygonaceae*	Circumpolar
Loiseleuria procumbens	alpine azalea	G5, S1S2	*Ericaceae*	Circumpolar
Minuartia elegans	purple alpine sandwort	G4G5, S1	*Caryophyllaceae*	Amphi-beringian
Papaver radicatum	arctic poppy	G5, S2	*Papaveraceae*	Circumpolar
Pedicularis capitata	large-flowered lousewort	G4, S2	*Orobanchaceae*	circumpolar
Pedicularis flammea	flame-coloured	G3G5, S2	*Orobanchaceae*	Eastern Arctic

	lousewort			
Pedicularis langsdorfii	arctic lousewort	G4T4, S2	*Orobanchaceae*	circumpolar
Pedicularis lanata	woolly lousewort	G4G5, S2	*Orobanchaceae*	circumpolar
Potentilla villosa	hairy cinquefoil	G4, S2	*Rosaceae*	western North America
Ranunculus occidentalis	western buttercup	G5, S2	*Ranunculaceae*	western North America
Saxifraga ferruginea	saxifrage	G5, S2	*Saxifragaceae*	western North America
Saxifraga nelsoniana	Nelson's saxifrage	G5T3T5, S2	*Saxifragaceae*	Circumpolar
Saxifraga nivalis	alpine saxifrage	G4G5, S2	*Saxifragaceae*	Circumpolar
Vaccinium uliginosum	bog bilberry	G5, S2	*Ericaceae*	Circumpolar

* see Appendix 3 for summary of ranks

Table 4.2. Co-occurrence of rare vascular plant species as determined by association analysis (with Yates' correction). Species are ordered alphabetically by first rare species. Only associations significant at $p \leq 0.05$ are shown.

Rare species	Associated rare species	X^2 value
Botrychium minganense	*Botrychium ascendens*	15.838
Draba longipes	*Botrychium ascendens*	6.801
Festuca altaica	*Botrychium ascendens*	10.021
Festuca altaica	*Botrychium minganense*	4.129
Gentiana glauca	*Antennaria monocephala*	11.036
Gentiana glauca	*Carex lachenalii*	8.568
Heuchera glabra	*Cardamine bellidifolia*	16.064
Hierochloe alpina	*Antennaria monocephala*	36.879
Hierochloe alpina	*Gentiana glauca*	20.968
Huperzia haleakalae	*Gentiana glauca*	5.063
Juncus biglumis	*Carex lachenalii*	16.666
Juncus biglumis	*Draba longipes*	4.387
Koenigia islandica	*Carex lachenalii*	10.021
Koenigia islandica	*Draba longipes*	6.801
Koenigia islandica	*Juncus biglumis*	92.974
Loiseleuria procumbens	*Gentiana glauca*	10.673
Loiseleuria procumbens	*Huperzia haleakalae*	4.482
Minuartia elegans	*Erigeron trifidus*	27.905
Papaver radicatum	*Erigeron trifidus*	9.762
Papaver radicatum	*Minuartia elegans*	35.544
Pedicularis capitata	*Antennaria monocephala*	7.888
Pedicularis capitata	*Festuca altaica*	38.301
Pedicularis capitata	*Pedicularis langsdorfii*	6.031
Pedicularis flammea	*Draba longipes*	4.387
Pedicularis flammea	*Erigeron trifidus*	20.529
Pedicularis flammea	*Festuca altaica*	16.666
Pedicularis flammea	*Minuartia elegans*	15.151
Pedicularis flammea	*Pedicularis capitata*	8.038
Pedicularis langsdorfii	*Antennaria monocephala*	19.76
Pedicularis langsdorfii	*Draba longipes*	11.863
Pedicularis lanata	*Minuartia elegans*	4.458
Potentilla villosa	*Erigeron trifidus*	12.397
Potentilla villosa	*Papaver radicatum*	25.326
Ranunculus occidentalis	*Cardamine oligosperma*	27.865
Saxifraga ferruginea	*Cardamine bellidifolia*	36.978
Saxifraga ferruginea	*Carex lachenalii*	17.487
Saxifraga ferruginea	*Gentiana glauca*	14.363
Saxifraga ferruginea	*Heuchera glabra*	24.899
Saxifraga ferruginea	*Loiseleuria procumbens*	7.503
Saxifraga nelsoniana	*Cardamine bellidifolia*	19.281
Saxifraga nelsoniana	*Cardamine oligosperma*	5.98

Saxifraga nelsoniana	*Carex lachenalii*	9.926
Saxifraga nelsoniana	*Pedicularis capitata*	6.031
Saxifraga nivalis	*Erigeron trifidus*	6.499
Saxifraga nivalis	*Minuartia elegans*	24.956
Vaccinium uliginosum	*Antennaria monocephala*	6.062
Vaccinium uliginosum	*Gentiana glauca*	8.264
Vaccinium uliginosum	*Loiseleuria procumbens*	29.97
Vaccinium uliginosum	*Saxifraga ferruginea*	5.962

Table 4.3. Results of Indicator Species Analysis examining co-occurrence of 29 rare vascular plant species with vegetation type for which the rare species is an indicator as well as vegetation type for which the associated rare species is an indicator. Vegetation types and group number (indicated by brackets) are defined in Chapter 2. Only significant associations ($p \leq 0.05$) with an Indicator Value (IV) >25 are presented. Given are the Indicator Value, Relative abundance and Relative frequency (see Methods for definitions) of the first rare species in the group defined by the presence of the second rare species. Also given is significance (p) of the IV. # indicates species for which the associated rare species did not predict the occurrence of the rare.

Rare species	Associated rare species	Ind. value	Rel. ab.	Rel. freq.	p	Vegetation type	Vegetation type of associated rare
Antennaria monocephala	*Gentiana glauca*	26.5	38	70	0.001	*Cassiope tetragona* (38)	Rocky acidic (9)
Antennaria monocephala	*Hierochloe alpina*	34.6	40	87	0.001	*Cassiope tetragona* (38)	none
#Botrychuim ascendens	*Botrychium minganense*	36.8	92	40	0.014	none	*Fragaria virginiana*
#Botrychium ascendens	*Festuca altaica*	35.2	88	40	0.026	none	*Festuca altaica*
Cardamine bellidifolia	*Carex lachenalii*	28.3	90	32	0.001	Rocky acidic (9)	none
Cardamine bellidifolia	*Saxifraga ferruginea*	46.6	88	53	0.001	Rocky acidic (9)	none
Cardamine bellidifolia	*Saxifraga nelsoniana*	35.1	83	42	0.001	Rocky acidic (9)	none
#Cardamine oligosperma	*Saxifraga nelsoniana*	25.6	77	33	0.034	none	none
#Carex lachenalii	*Antennaria monocephala*	44.8	73	62	0.007	none	*Cassiope tetragona* (38)
Carex lachenalii	*Cardamine bellidifolia*	40.4	87	46	0.001	none	Rocky acidic (9)
#Carex lachenalii	*Gentiana glauca*	39.6	74	54	0.012	none	Rocky acidic (9)
#Carex lachenalii	*Saxifraga ferruginea*	38.9	84	46	0.003	none	none
#Carex lachenalii	*Saxifraga nelsoniana*	30.7	80	38	0.011	none	none
#Draba longipes	*Pedicularis langsdorfii*	51.2	85	60	0.009	none	none
Erigeron trifidus	*Minuartia elegans*	41.3	91	45	0.001	*Rocky (calcareous)* (24)	none
Erigeron trifidus	*Pedicularis flammea*	25.4	93	27	0.003	*Rocky (calcareous)* (24)	*Cassiope mertensiana* (36)
Festuca altaica	*Pedicularis capitata*	55.1	90	62	0.001	*Festuca altaica*	none
Gentiana glauca	*Antennaria monocephala*	30.6	69	44	0.002	Rocky acidic (9)	*Cassiope tetragona* (38)

#Gentiana glauca	*Hierochloe alpina*	28.7	81	36	0.001	*Festuca altaica*	none
#Heuchera glabra	*Cardamine bellidifolia*	53.1	88	60	0.004	none	Rocky acidic (9)
#Heuchera glabra	*Saxifraga ferruginea*	71.7	90	80	0.003	none	Rocky acidic (9)
Hierochloe alpina	*Antennaria monocephala*	55.8	80	70	0.001	none	*Cassiope tetragona* (38)
Hierochloe alpina	*Gentiana glauca*	40.9	77	53	0.001	none	Rocky acidic (9)
#Huperzia haleakalae	*Gentiana glauca*	30.2	69	44	0.026	none	Rocky acidic (9)
#Juncus biglumis	*Carex lachenallii*	38.4	90	43	0.009	none	none
Juncus biglumis	*Koenigia islandica*	56.7	99	57	0.001	none	none
#Koenigia islandica	*Carex lachenallii*	35.2	88	49	0.03	none	none
Koenigia islandica	*Juncus biglumis*	78.6	98	80	0.001	none	none
#Loiseleuria procumbens	*Gentiana glauca*	55.9	78	71	0.011	*Empetrum nigrum*	Rocky acidic (9)
#Loiseleuria procumbens	*Saxifraga ferruginea*	34.8	81	43	0.033	*Emptetrum nigrum*	none
Loiseleuria procumbens	*Vaccinium uliginosum*	40.5	95	43	0.002	*Empetrum nigrum*	*Empetrum nigrum*
Minuartia elegans	*Erigeron trifidus*	32.9	92	36	0.001	none	rocky calcareous (24)
Minuartia elegans	*Papaver radicatum*	27.6	97	29	0.001	none	none
Minuartia elegans	*Saxifraga nivalis*	26.7	93	29	0.001	none	none
#Papaver radicatum	*Erigeron trifidus*	29.4	88	33	0.037	none	Rocky calcareous (24)
Papaver radicatum	*Minuartia elegans*	62.1	93	67	0.001	none	none
Papaver radicatum	*Potentilla villosa*	31.9	96	33	0.005	none	none
#Pedicularis capitata	*Antennaria monocephala*	47	75	63	0.002	none	*Cassiope tetragona* (38)
Pedicularis capitata	*Festuca altaica*	33.9	93	36	0.001	none	*Festuca altaica*
Pedicularis flammea	*Erigeron trifidus*	25.4	93	43	0.006	*Cassiope mertensiana* (36)	rocky calcareous (24)
#Pedicularis flammea	*Festuca altaica*	38.4	90	43	0.007	*Cassiope mertensiana* (26)	*Festuca altaica*
#Pedicularis flammea	*Minuartia elegans*	38	89	43	0.006	*Cassiope mertensiana* (26)	none
#Pedicularis flammea	*Pedicularis capitata*	35.1	82	43	0.02	*Cassiope mertensiana*	none

						(26)	
#Pedicularis langsdorfii	*Antennaria monocephala*	47	75	63	0.002	none	*Cassiope mertensiana* (38)
#Potentilla villosa	*Erigeron trifidus*	36	90	40	0.025	none	Rocky calcareous (24)
Potentilla villosa	*Papaver radicatum*	38.1	95	40	0.004	none	none
#Ranunculus occidentalis	*Cardamine oligosperma*	55.9	93	60	0.003	none	none
Saxifraga ferruginea	*Cardamine bellidifolia*	39.1	90	43	0.001	None	Rocky acidic (9)
#Saxifraga ferruginea	*Gentiana glauca*	38.9	75	52	0.001	none	Rocky acidic (9)
Saxifraga nelsoniana	*Cardamine bellidifolia*	28.3	85	33	0.001	none	Rocky acidic (9)
Saxifraga nivalis	*Minuartia elegans*	45.5	79	50	0.002	none	none
#Vaccinium uliginosum	*Antennaria monocephala*	45.2	72	63	0.025	*Empetrum nigrum*	*Cassiope mertensiana* (38)
#Vaccinium uliginosum	*Gentiana glauca*	47.4	76	63	0.008	*Empetrum nigrum*	Rocky acidic *(9)*
#Vaccinium uliginosum	*Hierochloe alpina*	38.7	79	50	0.02	*Empetrum nigrum*	none
Vaccinium uliginosum	*Loiseleuria procumbens*	35.6	85	38	0.001	*Empetrum nigrum*	*Empetrum nigrum*

Table 4.4. Presence of rare species by vegetation types as defined in Chapter 2. Vegetation types are arranged along an elevational gradient and species are arranged according to similarities off distribution in these types. Abbreviations for species names are in Appendix 1.

Vegetation type	*Anmo*	*Hial*	*Gegl*	*Pelg*	*Huha*	*Lopr*	*Vaul*	*Cabe*	*Sxfe*	*Calc*	*Sxne*	*Drlg*	*Jubi*	*Kois*
Elymus-Koeleria														
Cliff														
outcrop														
outcrop														
Antennaria														
drainage channel														
talus	X				X				X	X	X			
open graminoid					X									X
rocky (acidic)			X					X	X	X	X			
consolidated talus								X			X			
sparse														
low shrub														
Salix-Betula														
sparse (mesic)								X	X		X		X	X
Anemone														
Achnatherum														
Carex aquatilis				X										
Salix spp.											X			
Parnassia														

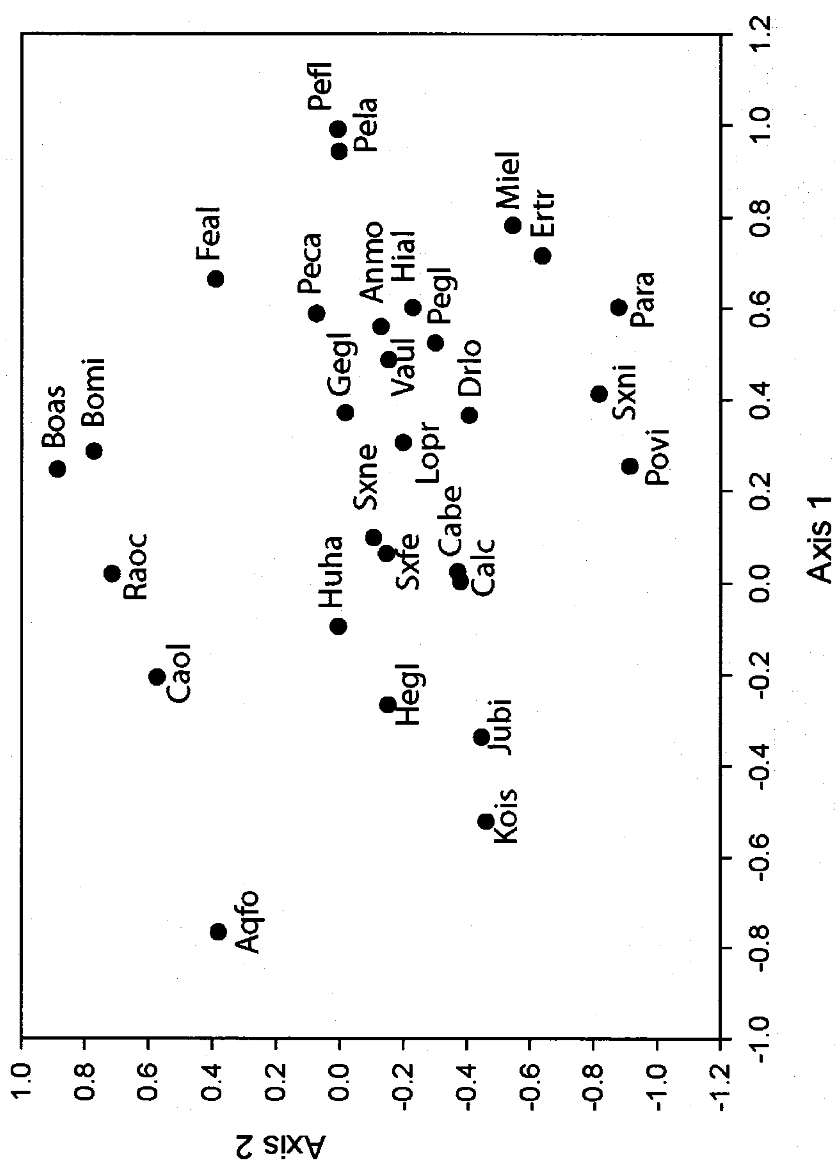
Vegetation type	*Anmo*	*Hial*	*Gegl*	*Pelg*	*Huha*	*Lopr*	*Vaul*	*Cabe*	*Sxfe*	*Calc*	*Sxne*	*Drlg*	*Jubi*	*Kois*
Alnus/Ribes														
Trollius											X			
Dryas integrifolia	X	X												
rocky (calcareous)														
rocky (calcareous)														
rocky (neutral)	X	X						X						
Artemisia michauxiana														
Artemisia norvegica	X		X	X				X	X	X	X		X	
rocky (acidic)	X							X	X					
Festuca altaica														
Fragaria virginiana														
Carex spectabilis								X	X					
Carex nigricans											X			
Carex nigricans			X						X					
Cassiope	X		X		X	X	X	X	X	X	X			
Phyllodoce	X	X	X	X	X			X						
Cassiope mertensiana			X		X	X					X			
Dryas octopetala	X	X	X	X	X							X		
Cassiope tetragona	X	X	X	X	X	X	X	X	X	X	X		X	

Vegetation type	*Anmo*	*Hial*	*Gegl*	*Pelg*	*Huha*	*Lopr*	*Vaul*	*Cabe*	*Sxfe*	*Calc*	*Sxne*	*Drlg*	*Jubi*	*Kois*
Empetrum nigrum	X	X	X		X	X	X		X					
Vaccinium uliginosum	X	X		X		X	X							
Salix nivalis	X		X	X						X	X	X		
Salix nivalis	X	X								X	X	X	X	X
Salix arctica	X	X	X	X	X				X	X	X		X	X
Salix arctica	X	X		X				X	X	X	X	X	X	X
Dryas integrifolia	X	X		X								X		

Vegetation type	*Aqfo*	*Caol*	*Raoc*	*Hegl*	*Sxni*	*Pela*	*Para*	*Povi*	*Boas*	*Bomi*	*Ertr*	*Miel*	*Pefl*	*Feal*	*Peca*
Elymus-Koeleria															
Cliff															
outcrop															
outcrop															
Antennaria															
drainage channel															
talus		X										X			
open graminoid		X													
rocky (acidic)															
consolidated talus	X	X					X	X							
sparse														X	
low shrub															
Salix-Betula		X													
sparse (mesic)	X			X											
Anemone															
Achnatherum															
Carex aquatilis															X
Salix spp.	X	X													
Parnassia	X														

Vegetation type	*Aqfo*	*Caol*	*Raoc*	*Hegl*	*Sxni*	*Pela*	*Para*	*Povi*	*Boas*	*Bomi*	*Ertr*	*Miel*	*Pefl*	*Feal*	*Peca*
Alnus/Ribes		X		X											
Trollius		X	X												
Dryas integrifolia						X	X					X		X	X
rocky (calcareous)					X						X	X			
rocky (calcareous)							X	X		X	X	X			
rocky (neutral)					X		X	X				X			
Artemisia michauxiana										X	X	X	X	X	
Artemisia norvegica		X	X												
rocky (acidic)				X	X										
Festuca altaica									X	X				X	X
Fragaria virginiana									X	X					
Carex spectabilis		X	X	X											
Carex nigricans															
Carex nigricans		X													
Cassiope			X												
Phyllodoce												X			
Cassiope mertensiana															
Dryas octopetala								X	X	X		X		X	
Cassiope tetragona															X

Vegetation type	*Aqfo*	*Caol*	*Raoc*	*Hegl*	*Sxni*	*Pela*	*Para*	*Povi*	*Boas*	*Bomi*	*Ertr*	*Miel*	*Pefl*	*Feal*	*Peca*
Vaccinium uliginosum															
Salix nivalis					X							X		X	X
Salix nivalis						X	X		X	X		X			
Salix arctica		X	X											X	X
Salix arctica					X						X			X	X
Dryas integrifolia					X	X					X	X	X	X	X


Axis 1
Axis 2
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
-1.2
Boas
Bomi
Raoc
Caol
Aqfo
Feal
Peca
Gegl
Huha
Hegl
Sxne
Sxfe
Lopr
Vaul
Anmo
Hial
Pegl
Cabe
Calc
Drlo
Jubi
Kois
Pefl
Pela
Miel
Ertr
Para
Sxni
Povi

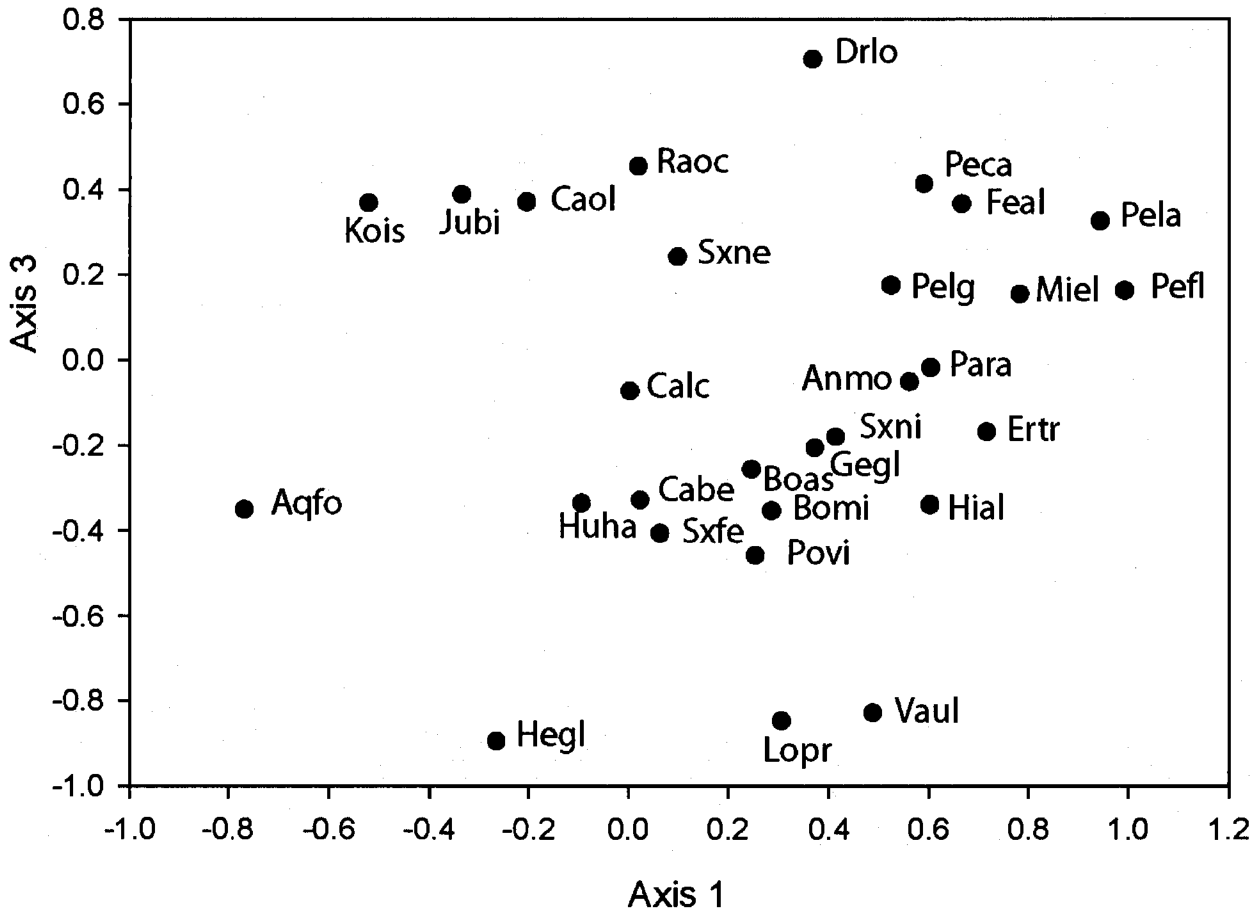


Figure 4.1. Non-metric multidimensional scaling (NMDS) focus on species showing relationships between species. Abbreviations for species names are shown in Appendix 1.

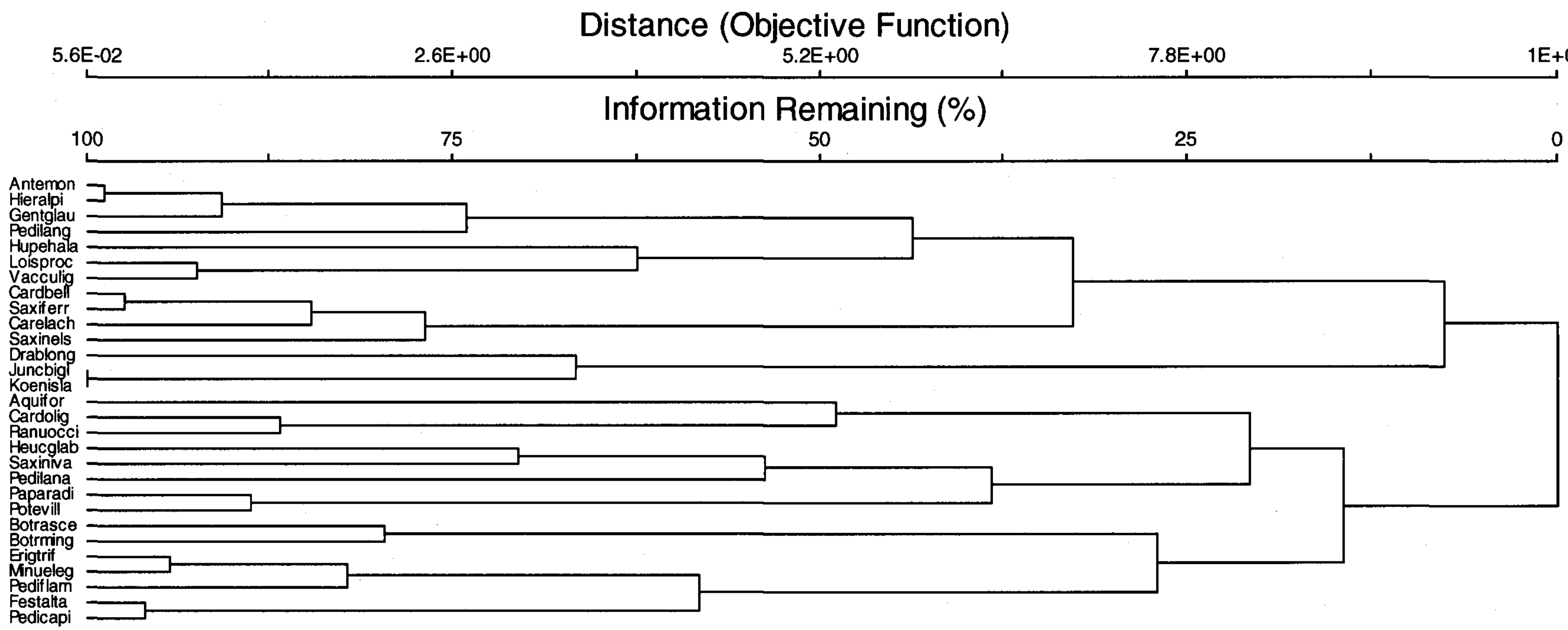
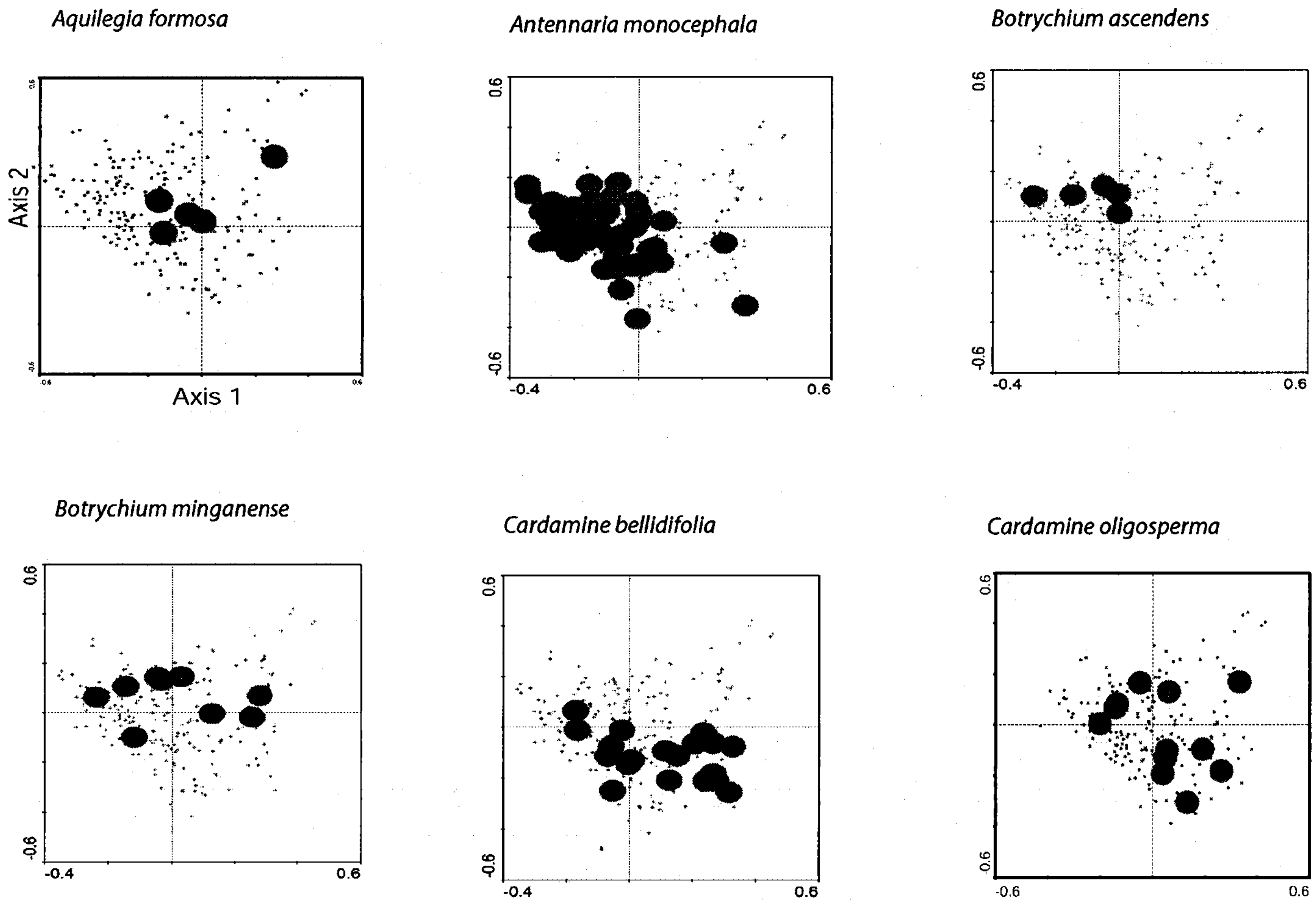


Figure 4.2.Dendrogram of hierarchical cluster analysis (flexible beta) of rare species. Chaining is 2.74%.



Aquilegia formosa
Axis 2
Axis 1
Antennaria monocephala
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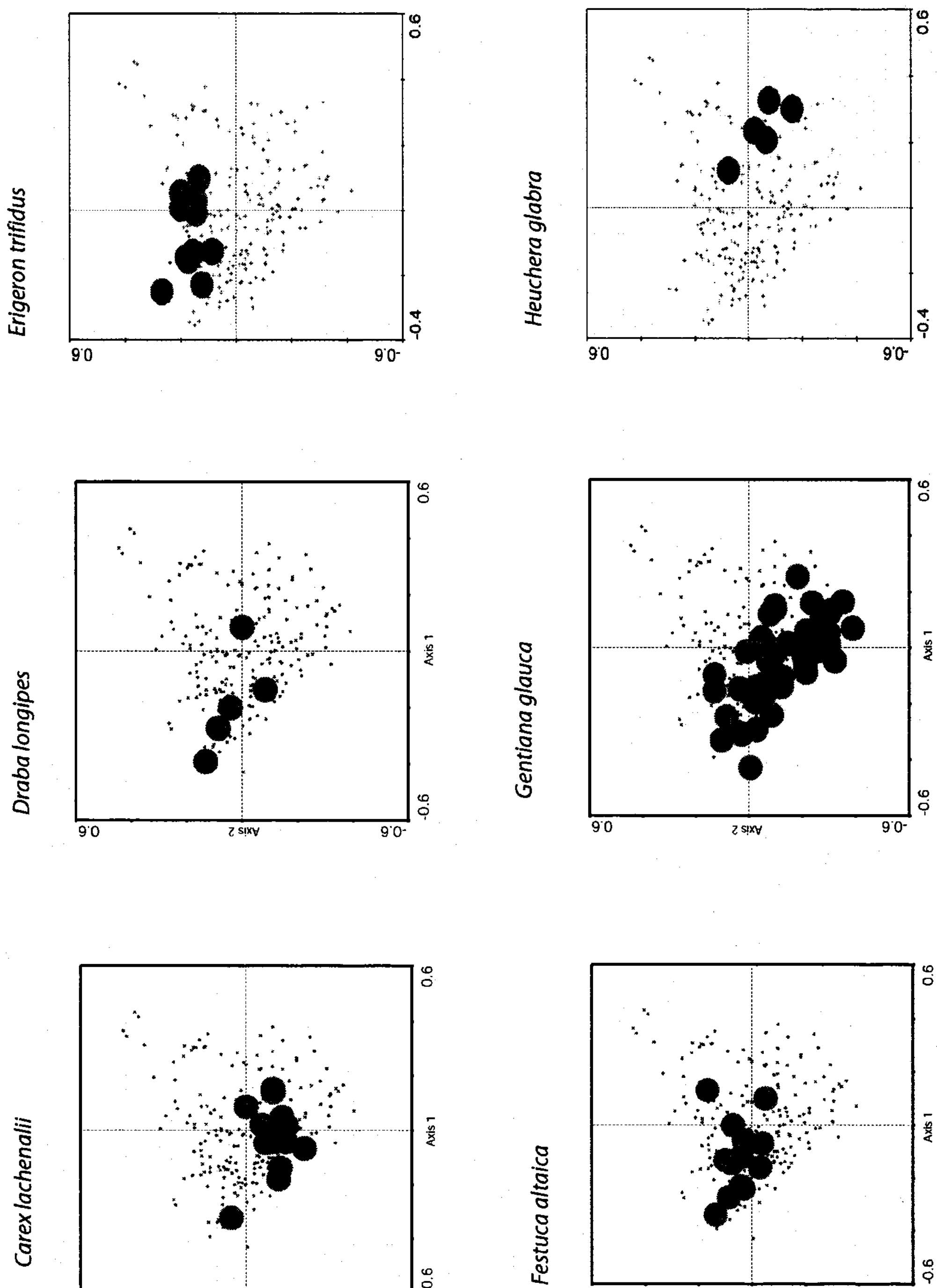
-0.6
-0.4
0.6
Botrychium ascendens
0.6
-0.6
-0.4
0.6
Botrychium minganense
0.6
-0.6
-0.4
0.6
Cardamine bellidifolia
0.6
-0.6
-0.4
0.6
Cardamine oligosperma
0.6
-0.6
-0.6
0.6


Erigeron trifidus
Heuchera glabra
Draba longipes
Gentiana glauca
Carex lachenalii
Festuca altaica
Axis 1
Axis 2
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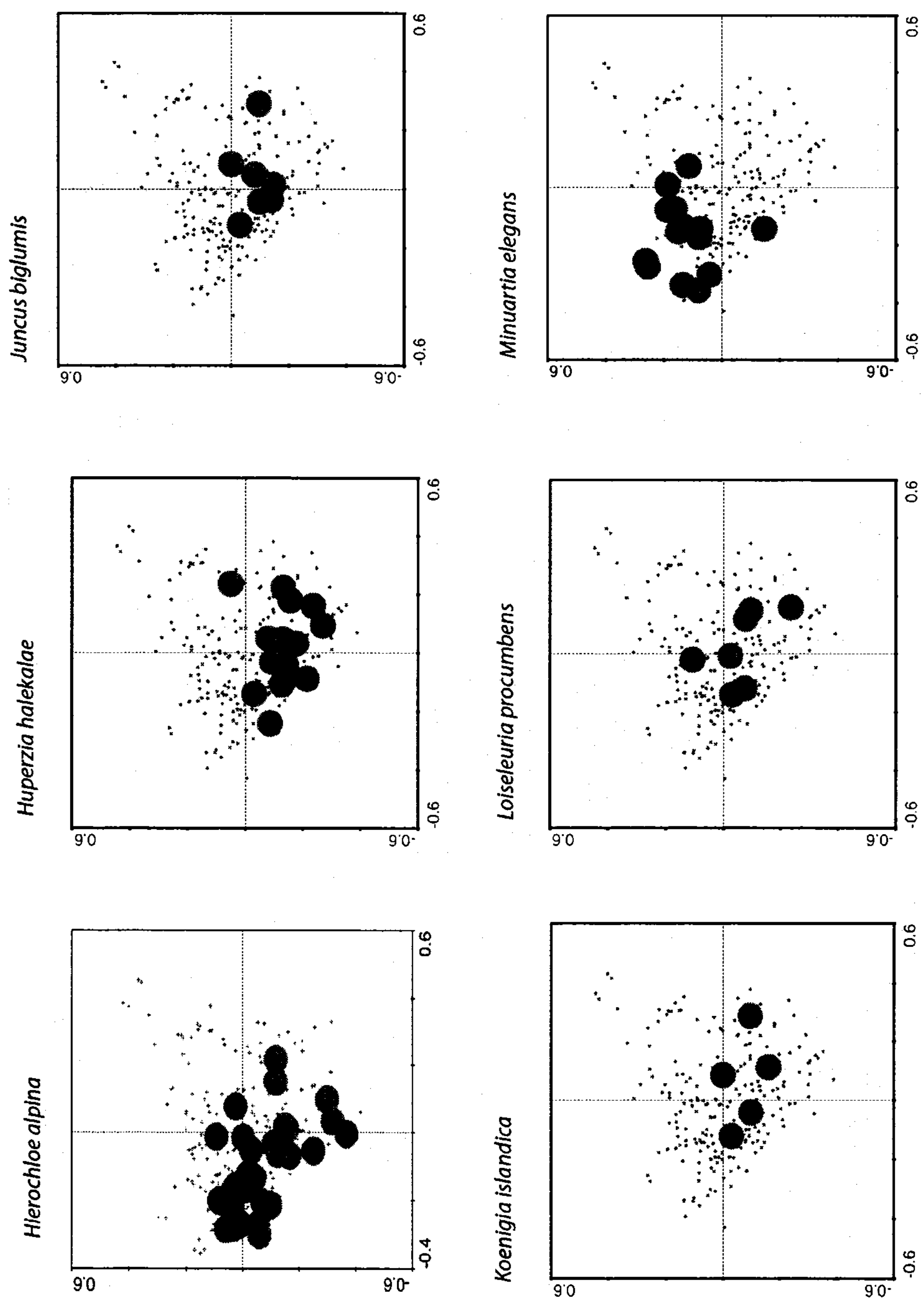
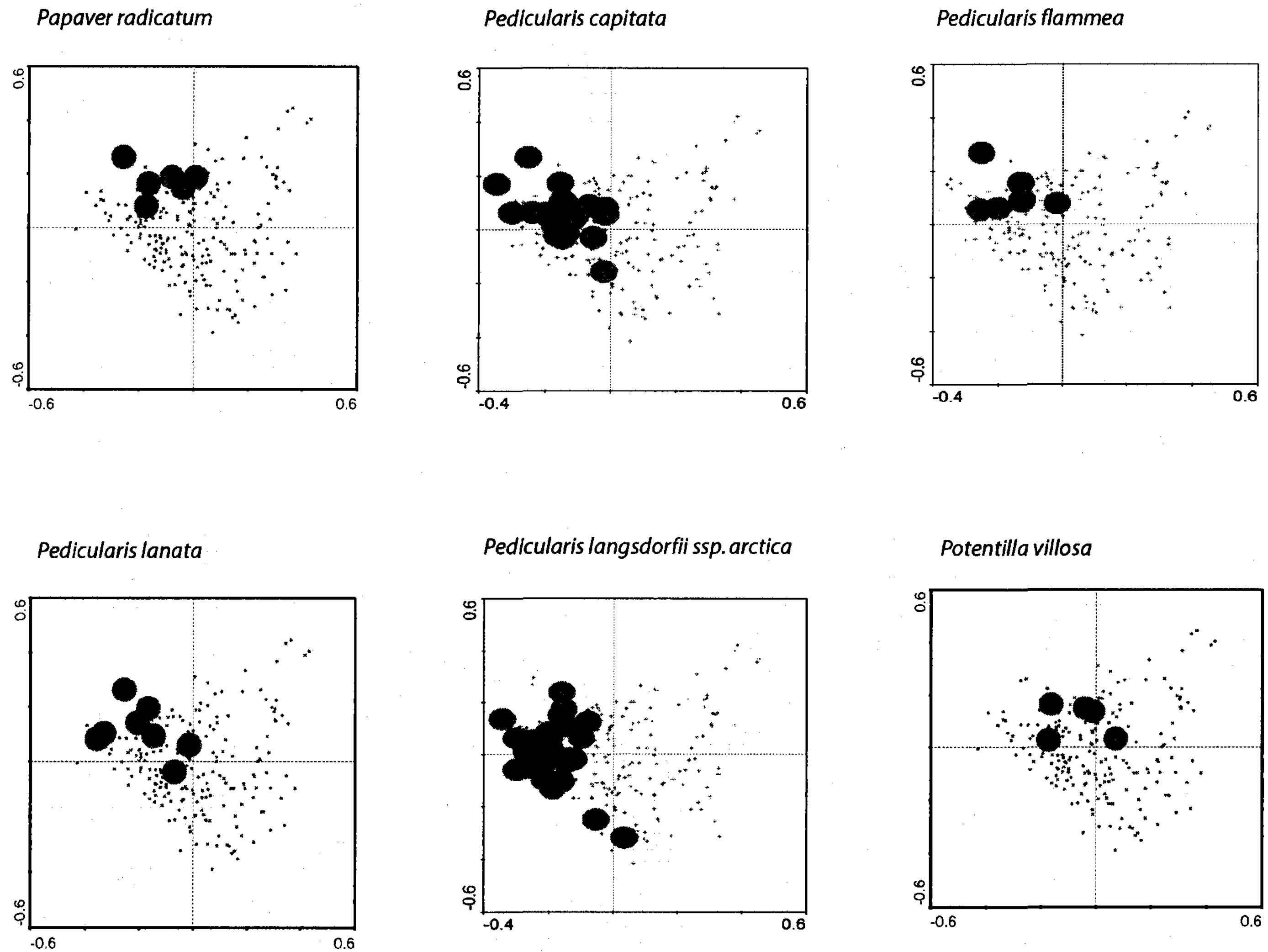
-0.6
-0.4


Juncus biglumis
Minuartia elegans
Huperzia haleakalae
Loiseleuria procumbens
Hierochloe alpina
Koenigia islandica


Papaver radicatum
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-0.6
-0.6
0.6
Pedicularis capitata
0.6
-0.6
-0.4
0.6
Pedicularis flammea
0.6
-0.6
-0.4
0.6
Pedicularis lanata
0.6
-0.6
-0.6
0.6
Pedicularis langsdorfii ssp. arctica
0.6
-0.6
-0.4
0.6
Potentilla villosa
0.6
-0.6
-0.6
0.6

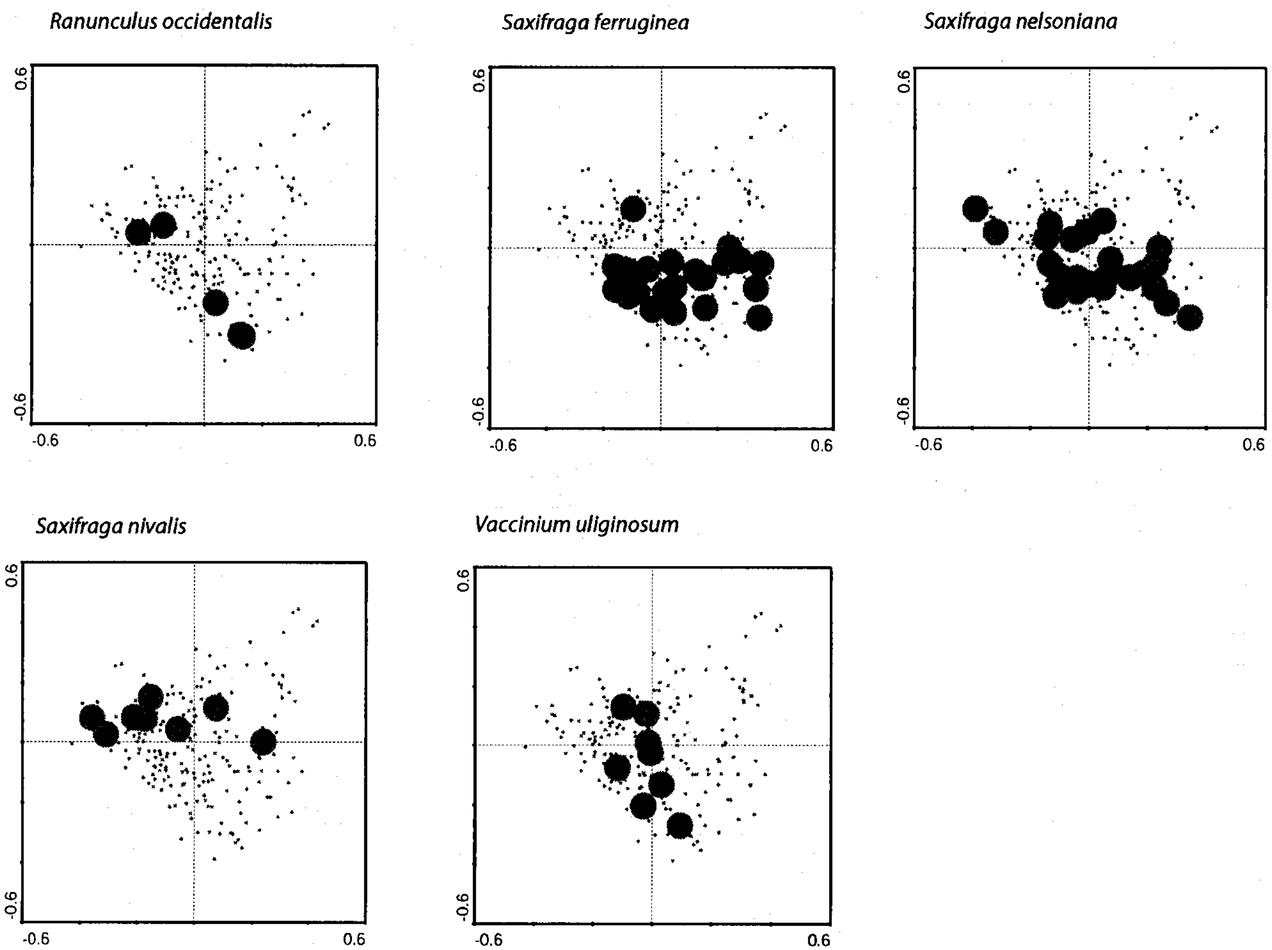

Figure 4.3 Attribute plots for those rare species showing fidelity to a vegetation type as defined in Chapter 2. Species are arranged alphabetically.

Chapter 5: Thesis Conclusions

Determining the effectiveness of ecological communities for capture of rare species is one of the most pressing tasks facing conservation biologists (Wilcove and Master 2005), and yet there has been remarkably little research on this subject as it relates to multiple rare species (but see Kintsch and Urban 2002; MacDougall and Loo 2002).

My thesis research represents a comprehensive assessment of the factors predicting occurrence for a large number of rare vascular plant species. I determined that for the northern Rocky Mountains of Alberta, most rare species occur in the alpine, some rare species show strong fidelity to vegetation type, some have significant associations with another rare species and at least one of these co-occurring species pairs has a strong fidelity to vegetation type. Few rare species are exclusive to a particular vegetation type but a rare species may have an affinity for a particular type such that this type can then be used to predict the occurrence of one or more rare species.

The results of this thesis provide insight into how rare plants are distributed across the landscape in relation to vegetation types and each other. This information will be useful for conservation planning and management such as for building predictive GIS models for rare species distribution that can then be field validated and for defining 'critical habitat'. In addition, I produced a vegetation classification for the northern Rocky Mountains of Alberta.

Finally, I developed a methodological approach to examining the patterns of distribution of suites of rare vascular plant species on the landscape using a series of modern multivariate analytical techniques. Indicator Species Analysis (ISA) (Dufrêne and Legendre 1997) was particularly effective in showing the relationship between rare species and vegetation type and rare species themselves. I am aware of only one other study (Kintsch and Urban 2002) that has used this technique to analyze the relationship of rare species to vegetation type and between species (rare to common). My work appears to be the first to use ISA to examine the ability of one rare species to predict the occurrence of another.

The vegetation types I defined through my classification analysis were compared to existing schemes for the area (Corns and Achuff 1982; Beckingham et al. 1997, Willoughby and Alexander 2003 and Willoughby et al. 2005). There was, however, limited concordance between previously described types and this research, particularly for those from the northern portion of the study area and from higher elevations. This lack of similarity is due to differences in area surveyed and methodologies for both data collection and analysis and highlights the need for standards of data collection and analysis (Daubenmire 1943; Strong 2002).

I was also interested in what factors influenced the distribution of vegetation types in order to facilitate my understanding of the distribution of rare species. Elevation was identified as the main factor influencing vegetation types for all physiogonomic groups although it is a surrogate for other environmental variables such as temperature and precipitation (Whittaker 1956; Whittaker 1960; Austin, et al. 1984; Reed et al. 1993; Urban et al. 2002). Soil nutrients were found to be important correlates of vegetation type particularly P and K for treed sites and Ca, N and P for herbaceous types. Soil moisture and aspect were determined to be important for some herbaceous community types in the alpine, and this likely reflects differences in patterns of snow duration and accumulation (Bamberg and Major 1968; Ogilvie 1969; Kuchar 1975; Peinado et al. 2005).

The vegetation classification was then used as a framework to test the fidelity of rare vascular plant species to these defined types. While a few rare species were restricted to one vegetation type, most occurred over a range of types. In addition, a few vegetation types were found to have a high probability of capturing a rare species, thereby facilitating the use of habitat approaches to rare plant conservation. If a vegetation type is known to have a high probability of having one or more rare species, conservation strategies that focus on the habitat rather than the species can be undertaken. Such information can also be of use in building predictive models to target areas for additional surveys.

Co-occurring species pairs showed a similar response to environmental gradients suggesting overlap in habitat requirements even though there is not complete concordance in the types of vegetation in which they are found. I was also able to show that the presence of one rare species did not necessarily predict the occurrence of the other in spite of a significant association between the pair. The species that could effectively predict the occurrence of the other had a smaller ecological amplitude as reflected in both the response to measured environmental gradients and vegetation types in which it was found.

Management Implications

There is more work to be done on the high number of rare vascular plant species in the province than limited funds and resources allow (Franklin 1993; Clark and Harvey 2002). As a result, multi-species conservation strategies are viewed as an alternative to species specific recovery plans (Tear et al. 1995; Barrows et al. 2005). The strength of the association of a rare species to vegetation type can be used to help delineate 'critical habitat' through the recovery planning process. It can also be used to build predictive models of rare species occurrence that can then be validated by fieldwork. Some of the environmental variables that were measured as part of this research are more suitable to predictive modeling than others. Elevation and aspect, for example, are readily available in digital elevation models whereas data on nutrient levels, moisture regime and soil texture are not. The strength of the association of rare plants to vegetation type can also be used to guide habitat based conservation approaches.

Vegetation types and/or plant communities are used in many provincial planning initiatives such as range health assessments (Adams et al. 2005) and protected areas planning (Alberta Tourism, Parks, Recreation and Culture 2006). An understanding of how rare plants relate to defined vegetation types can therefore be useful for these types of planning.

While the use of multi-species assessments and recovery plans is a useful concept it is not applicable to all taxa. Over 45 species recorded from the study area occurred less than five times in the dataset thereby limiting the ability to test associations between them. In summary, multi-species conservation plans may be effective for some rare taxa but single-species approaches will still be required for the rarest of the rare and those for which there is no demonstrated association with other taxa.

Future Research

This research resulted in a better understanding of patterns of vegetation and rare plant distribution in the northern Rocky Mountains of Alberta but has also lead to a number of questions. Species co-occur for a number of reasons: shared habitat, history or interactions with other species (Diamond 1975; Sfenthourakis et al. 2005). I was able to demonstrate that co-occurring rare species share similarly linked to environmental gradients but questions remain related to the strength and types of interactions between vascular plants species and between them and other taxonomic groups. Even though I was able to demonstrate the relationship of rare species to environmental gradients and vegetation types, transplantation experiments in which rare species are grown under other conditions would help to determine whether distribution of species is limited by habitat preferences or lack of dispersal into an area.

This study was focused in a particular geographic area and the question exists of whether similar patterns exist in other ecosystems. Alteration of habitat through development was minimized by working in a number of protected areas. It would be interesting to examine patterns of rare plant distribution in areas in which habitat alteration through anthropogenic activities are prevalent.

The relationship of the distribution of rare plant species to species represented in the seed bank is an area of interest. Rare plant surveys for large remote areas are often done only once during the course of a season and often only once in several years. However, many species are represented in seed banks or are ephemeral and therefore may not be evident at the time of the survey. Information on which species bank seed and how this is related to vegetation type and environmental parameters would be useful to help build models of rare species distribution.

One of the next steps resulting from this research is to build predictive models based on vegetation type and significant environmental parameters and then test the suitability of these models by field validation.

We have limited information on many aspects of our rare vascular plant species. Knowledge of associations with other species, population dynamics and demography and metapopulation dynamics is poor. Species-specific research that focuses on the autoecology and demography of these taxa would greatly enhance our abilities to affect suitable conservation strategies. Compilation of such information could lead to the development of values similar to Ellenberg values used in Europe which could then be used in conservation planning.

Rabinowitz (1981) used three criteria, habitat specificity, local abundance and range, to categorize rare species into types. Further work on the relationship of type of rarity to distribution of rare species in the context of regional and provincial scales would help refine information on the patterns of distribution of rare species.

Literature Cited

Adams, B. W., G. Ehlert, C. Stone, D. Lawrence, M. Alexander, M. Willoughby, C. Hincz, D. Moisey, A. Burkinshaw and J. Carlson. 2003. Rangeland Health Assessment for Grassland, Forest and Tame Pastures. (revised 2005). Alberta Sustainable Resource Development, Public Lands and Forests Division, Rangeland Management Branch. Publication T/044. Edmonton, AB. 117 pp.

Alberta Tourism, Parks, Recreation and Culture. 2006. http://www.cd.gov.ab.ca/preserving/parks/managing/scientificframework.asp#naturalhistory. (date accessed Dec. 19, 2006).

Alberta Sustainable Resource Development. 2005. General status of wildlife in Canada.

Austin, M. P., R. B. Cunningham and P. M. Fleming. 1984. New approaches to direct gradient analysis using environmental scalars and statistical curve-fitting procedures. Vegetatio 55:11-27.

Bamberg, S. A. and J. Major. 1968. Ecology of the vegetation and soils associated with calcareous parent materials in three alpine regions of Montana. Ecological Monographs 38:127-167.

Barrows, C. W., M. B. Swartz, W. L. Hodges, M. F. Allen, J. T. Rotenberry, B.-L. Li, T. A. Scott and X. Chen. 2005. A framework for monitoring multiple-species conservation plans. Journal of Wildlife Management 69:1333-1345.

Beckingham, J., I. G. W. Corns and J. H. Archibald. 1996. Field guide to ecosites of west central Alberta. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. Special Report No. 9.

Clark, J. A. and E. Harvey. 2002. Assessing multi-species recovery plans under the Endangered Species Act. Ecological Applications 12:655-662.

Corns, I. G. W. and P. L. Achuff. 1982. Ecological (Biophysical) Land Classification of Banff and Jasper National Parks. IN: Volume 2: Soil and Vegetation Resources. (Holland, W. D. and G. M Coen editors). Alberta Institute of Pedology Publication No. SS-82-44. pp. 71-142.

Daubenmire, R. G. 1943. Vegetation zonation in the Rocky Mountains. Botanical Review 9:325-393.

Diamond, J. M. 1975. Assembly of species communities. IN: M. L. Cody and J. M. Diamond (eds.). Ecology and evolution of communities. Harvard University Press, Cambridge, Mass. P. 342-444.

Dufrêne, M. and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetric approach. Ecological Monographs 67:345-366.

Franklin, J. F. 1993. Preserving biodiversity: species, ecosystems or landscapes? Ecological Applications 3:202-205.

Gould, J. 2000. Alberta Natural Heritage Information Centre—Tracking and Watch Lists for Vascular Plants, Mosses, Liverworts and Hornworts. Alberta Environmental Protection, Edmonton, Alberta.

Kintsch, J. A. and D. L. Urban. 2002. Focal species, community representation, and physical proxies as conservation strategies: a case study in the Amphibolite Mountains, North Carolina, U.S.A. Conservation Biology 16(4):936-947.

Kuchar, P. 1975. Alpine tundra communities and *Dryas octopetala* ssp. *hookeriana* in the Bald Hills, Jasper National Park. PhD thesis, University of Alberta. 351 pp..

MacDougall, A. S. and J. Loo. 2002. Predicting occurrences of geographically restricted floral elements with qualitative habitat data. Environmental Reviews 10:167-190.

Ogilvie, R. T. 1998. Vascular plants. IN: Smith, I. M. and G. G. E. Scudder, eds. Assessment of species diversity in the Montane Cordillera Ecozone. Ecological Monitoring and Assessment Network, Burlington, Ontario.

Peinado, M., J. L. Aguirre, J. Delgadillo and J. M. Martinez-Parras. 2005. A phytosociological survey of the chionphilous communities of western North America. Part I: temperate and Mediterranean associations. Plant Ecology 180:187-241.

Reed, R. A., R. K. Peet, M. W. Palmer and P. S. White. 1993. Scale dependence of vegetation-environment correlations:a case study of a North Carolina piedmont woodland. Journal of Vegetation Science 4:329-340.

Sfenthourakis, S., E. Tzanatos and S. Giokas. 2005. Species co-occurrence: the case of congeneric species and a causal approach to patterns of species association. Global Ecology and Biogeography 15:39-49.

Strong, W. L. 2002. Lodgepole pine/Labrador tea type communities of western Canada. Canadian Journal of Botany 80:151-165.

Tear, T. H., J. M. Scott, P. H. Hayward and B. Griffith. 1995. Recovery plans and the Endangered Species Act: are criticisms supported by data. Conservation Biology 9:182-195.

Urban, D., S. Goslee, K. Pierce and T. Lookingbill. 2002. Extending community ecology of landscapes. Ecoscience 9(2): 200-212.

Whittaker, R. H. 1956. Vegetation of the Great Smoky Mountains. Ecological Monographs 30(3):280-338.

Whittaker, R. H. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. Ecological Monographs 30(3):280-338.

Wilcove, D. S. and L. L. Master. 2005. How many endangered species are there in the United States? Frontiers in Ecology and the Environment 3 (8): 414-420.

Willoughby, M. G. and M. J. Alexander. 2003. Range plant community types and carrying capacity for the subalpine and alpine subregions. Second Approximation. Public Lands and Forests Division, Alberta Sustainable Resource Development, Edmonton, Alberta. 200 pp..

Willoughby, M. G., M. J. Alexander and B. W. Adams. 2005. Range plant community types and carrying capacity for the montane subregion. Sixth Approximation. Public Lands and Forests Division, Alberta Sustainable Resource Development, Edmonton, Alberta. 235 pp..

Appendix 1. List of vascular plant species observed within the study area, 2001-2003. * from Stevens 2001 onwards, † from Moss 1983 and Flora of North America Editorial Committee 1993 onwards. Bold type indicates rare species (Gould 2000).

Scientific Name	Family Name (APG/KEW)*	Family (Moss/FNA)†	Species Code
Abies bifolia A. Murray	Pinaceae	Pinaceae	Abbi
Acer glabrum Torr.	Sapindaceae	Aceraceae	Acgl
Achillea millifolium L.	Asteraceae	Asteraceae	Acmi
Achnatherum nelsonii (Scribn.) Barkw. ssp. *dorei* (Barkw. & Maze) Barkw.	Poaceae	Poaceae	Acne
Achnatherum richardsonii (Link) Barkw.	Poaceae	Poaceae	Acri
Aconitum delphinifolium DC.	Ranunculaceae	Ranunculaceae	Acde
Actaea rubra (Ait.) Willd.	Ranunculaceae	Ranunculaceae	Acru
Adoxa moschatallina L.	Adoxaceae	Adoxaceae	Admo
Agoseris aurantiaca (Hook.) Greene	Asteraceae	Asteraceae	Agau
Agoseris glauca (Pursh) Raf.	Asteraceae	Asteraceae	Aggl
***Agoseris lackschewitzii* Henderson & Mosely**	Asteraceae	Asteraceae	**Agla**
Agropyron cristatum (L.) Gaertn.	Poaceae	Poaceae	Agcr
Agrostis scabra Willd.	Poaceae	Poaceae	Agsc
Agrostis variabilis Rydb.	Poaceae	Poaceae	Agva
Allium cernuum Roth	Alliaceae	Liliaceae	Alce
Alnus incana (L.) Moench ssp. *tenuifolia* (Nutt.) Breit.	Betulaceae	Betulaceae	Alin
Alnus viridis (Vill.) DC.	Betulaceae	Betulaceae	Alvi
Amelanchier alnifolia Nutt.	Rosaceae	Rosaceae	Amal
Amerorchis rotundifolia (Banks ex Pursh) Hult.	Orchidaceae	Orchidaceae	Amro
Anaphalis margaritacea (L.) Benth. & Hook.	Asteraceae	Asteraceae	Anma
Androsace chamaejasme Host	Primulaceae	Primulaceae	Anch
Androsace septentrionalis L.	Primulaceae	Primulaceae	Anse
Anemone drummondii S. Wats.	Ranunculaceae	Ranunculaceae	Andr

Anemone multifida Poir.	Ranunculaceae	Ranunculaceae	Anmu
Anemone occidentalis S. Wats.	Ranunculaceae	Ranunculaceae	Anoc
Anemone parviflora Michx.	Ranunculaceae	Ranunculaceae	Anpa
Anemone patens L.	Ranunculaceae	Ranunculaceae	Anpt
Anemone richardsonii Hook.	Ranunculaceae	Ranunculaceae	Anri
Antennaria alpina (L.) Gaertn	Asteraceae	Asteraceae	Anal
***Antennaria aromatica* Evert**	Asteraceae	Asteraceae	**Anar**
Antennaria lanata (Hook.) Greene	Asteraceae	Asteraceae	Anla
Antennaria media Greene	Asteraceae	Asteraceae	Anme
Antennaria microphylla Rydb.	Asteraceae	Asteraceae	Anmi
***Antennaria monocephala* DC**	Asteraceae	Asteraceae	**Anmo**
Antennaria neglecta Greene	Asteraceae	Asteraceae	Anne
Antennaria parviflora Nutt.	Asteraceae	Asteraceae	Anpr
Antennaria pulcherrima (Hook.) Greene	Asteraceae	Asteraceae	Anpu
Antennaria racemosa Hook.	Asteraceae	Asteraceae	Anra
Antennaria rosea Greene	Asteraceae	Asteraceae	Anro
Aquilegia flavescens S. Wats.	Ranunculaceae	Ranunculaceae	Aqfl
***Aquilegia formosa* Fisch. *ex* DC.**	Ranunculaceae	Ranunculaceae	**Aqfo**
Aquilegia formosa x *A. flavescens*	Ranunculaceae	Ranunculaceae	
Arabis drummondii A. Gray	Brassicaceae	Brassicaceae	Ardr
Arabis glabra (L.) Bernh.	Brassicaceae	Brassicaceae	Argl
Arabis holboellii Hornem.	Brassicaceae	Brassicaceae	Arho
Arabis lyallii S. Wats.	Brassicaceae	Brassicaceae	Arly
Arabis lyrata L.	Brassicaceae	Brassicaceae	Arlr
Aralia nudicaulis L.	Araliaceae	Brassicaceae	Arnu
Arctostaphylos alpina (L.) Spreng.	Ericaceae	Ericaceae	Aral
Arctostaphylos uva-ursi (L.) Spreng.	Ericaceae	Ericaceae	Arua
***Arnica amplexicaulis* Nutt.**	**Asteraceae**	**Asteraceae**	**Aram**
Arnica angustifolia Vahl *in* Hornem.	Asteraceae	Asteraceae	Aran
Arnica cordifolia Hook.	Asteraceae	Asteraceae	Arco
Arnica diversifolia Greene	Asteraceae	Asteraceae	Ardi

Arnica gracilis Rydb.	Asteraceae	Asteraceae	Argr
Arnica latifolia Bong.	Asteraceae	Asteraceae	Arla
Arnica louiseana Farr	Asteraceae	Asteraceae	Arlo
Arnica mollis Hook.	Asteraceae	Asteraceae	Armo
Artemisia campestris L.	Asteraceae	Asteraceae	Arca
Artemisia frigida Willd.	Asteraceae	Asteraceae	Arfr
***Artemisia furcata* Bieb.**	Asteraceae	**Asteraceae**	**Arfu**
Artemisia michauxiana Bess.	Asteraceae	Asteraceae	Armi
Artemisia norvegica Fries	Asteraceae	Asteraceae	Arno
Aster alpinus L.	Asteraceae	Asteraceae	Asal
Astragalus agrestis Dougl. *ex* G. Don	Fabaceae	Fabaceae	Asag
Astragalus alpinus L.	Fabaceae	Fabaceae	Asap
Astragalus americanus (Hook.) M. E. Jones	Fabaceae	Fabaceae	Asam
Astragalus australis (L.) Lam.	Fabaceae	Fabaceae	Asau
Astragalus eucosmus Robins.	Fabaceae	Fabaceae	Aseu
Astragalus laxmannii Jacq. var. *robustior* (Hook.) Barneby & Welsh	Fabaceae	Fabaceae	Asla
Astragalus miser Dougl. ex Hook.	Fabaceae	Fabaceae	Asmi
Astragalus tenellus Pursh	Fabaceae	Fabaceae	Aste
Astragalus vexilliflexus Sheldon	Fabaceae	Fabaceae	Asve
***Barbarea orthoceras* Ledeb.**	**Brassicaceae**	**Brassicaceae**	**Baor**
Betula glandulosa Michx.	Betulaceae	Betulaceae	Begl
Betula occidentalis Hook.	Betulaceae	Betulaceae	Beoc
Betula papyrifera Marsh.	Betulaceae	Betulaceae	Bepa
Betula pumila L.	Betulaceae	Betulaceae	Bepu
***Botrychium ascendens* W. H. Wagner**	**Ophioglossaceae**	**Ophioglossaceae**	**Boas**
***Botrychium lanceolatum* (S. G. Gmelin) Angs.**	**Ophioglossaceae**	**Ophioglossaceae**	**Bola**
Botrychium lunaria (L.) Swartz	Ophioglossaceae	Ophioglossaceae	Bolu
***Botrychium minganense* Vict.**	**Ophioglossaceae**	**Ophioglossaceae**	**Bomi**
***Botrychium pinnatum* H. S. John**	**Ophioglossaceae**	**Ophioglossaceae**	**Bopi**
Braya humilis (C. A. Mey.) Robins.	Brassicaceae	Brassicaceae	Brhu

Bromus ciliatus L.	Poaceae	Poaceae	Brci
Bromus inermis Leys.	Poaceae	Poaceae	Brin
Calamagrostis canadensis (Michx.) Beauv.	Poaceae	Poaceae	Caca
Calamagrostis montanensis Scribn.	Poaceae	Poaceae	Camo
Caltha leptosepala DC.	Ranunculaceae	Ranunculaceae	Cale
Calypso bulbosa (L.) Oakes	Orchidaceae	Orchidaceae	Cabu
Campanula lasiocarpa Cham.	Campanulaceae	Campanulaceae	Cala
Campanula rotundifolia L.	Campanulaceae	Campanulaceae	Caro
***Campanula uniflora* L.**	Campanulaceae	Campanulaceae	**Caun**
Canadanthus modestus (Lindl.) Nesom	Asteraceae	Asteraceae	Camd
***Cardamine bellidifolia* L.**	**Brassicaceae**	**Brassicaceae**	**Cabe**
***Cardamine oligosperma* Nutt. var. *kamtschatica* (Regel) Dett.**	**Brassicaceae**	**Brassicaceae**	**Caol**
Carex albonigra Mack.	Cyperaceae	Cyperaceae	Caal
Carex aquatilis Wahlenb.	Cyperaceae	Cyperaceae	Caaq
Carex atratiformis Britt.	Cyperaceae	Cyperaceae	Caat
Carex aurea Nutt.	Cyperaceae	Cyperaceae	Caau
Carex brunnescens (Pers.) Poir.	Cyperaceae	Cyperaceae	Cabr
Carex canescens L.	Cyperaceae	Cyperaceae	Cacn
Carex capillaris L.	Cyperaceae	Cyperaceae	Cacp
***Carex capitata* L.**	Cyperaceae	Cyperaceae	**Cact**
Carex concinna R. Br.	Cyperaceae	Cyperaceae	Caco
Carex deflexa Hornem.	Cyperaceae	Cyperaceae	Cade
Carex diandra Schrank	Cyperaceae	Cyperaceae	Cadi
Carex disperma Dewey	Cyperaceae	Cyperaceae	Cads
Carex duriuscula C. A. Meyer	Cyperaceae	Cyperaceae	Cadu
Carex eburnea Boott	Cyperaceae	Cyperaceae	Caeb
Carex filifolia Nutt.	Cyperaceae	Cyperaceae	Cafi
***Carex fuliginosa* Schkuhr**	Cyperaceae	Cyperaceae	**Cafu**
Carex garberi Fern.	Cyperaceae	Cyperaceae	Caga
***Carex glacialis* Mack.**	Cyperaceae	Cyperaceae	**Cagl**

Carex gynocrates Wormsk. *ex* Drejer	Cyperaceae	Cyperaceae	Cagy
***Carex incurviformis* Mack.**	Cyperaceae	Cyperaceae	**Cain**
***Carex lachenalii* Schkuhr**	Cyperaceae	Cyperaceae	**Calc**
***Carex lenticularis* Michx. var. *dolia* (M. E. Jones) L. A. Standley**	Cyperaceae	Cyperaceae	**Caln**
Carex leptalea Wahlenb.	Cyperaceae	Cyperaceae	Calp
Carex macloviana D'Urv.	Cyperaceae	Cyperaceae	Cama
Carex magellanica Lamarck ssp. *irrigua* (Wahlb.) Hiit.	Cyperaceae	Cyperaceae	Camg
Carex micropoda C. A. Meyer	Cyperaceae	Cyperaceae	Camc
Carex microptera Mack.	Cyperaceae	Cyperaceae	Cami
Carex nardina E. Fries	Cyperaceae	Cyperaceae	Cana
Carex nigricans C. A. Meyr	Cyperaceae	Cyperaceae	Cani
Carex norvegica Retz.	Cyperaceae	Cyperaceae	Cano
Carex obtusata Lilj.	Cyperaceae	Cyperaceae	Caob
***Carex petricosa* Dewey**	Cyperaceae	Cyperaceae	**Cape**
Carex phaeocephala Piper	Cyperaceae	Cyperaceae	Caph
Carex praticola Ryd.	Cyperaceae	Cyperaceae	Capr
Carex richardsonii R. Br.	Cyperaceae	Cyperaceae	Cari
Carex rossii Boott	Cyperaceae	Cyperaceae	Cars
Carex rupestris Allioni	Cyperaceae	Cyperaceae	Caru
Carex scirpoidea Michx.	Cyperaceae	Cyperaceae	Casr
Carex scopulorum T. Holm	Cyperaceae	Cyperaceae	Casc
Carex spectabilis Dewey	Cyperaceae	Cyperaceae	Casp
Carex tenuiflora Wahlb.	Cyperaceae	Cyperaceae	Cate
***Carex tonsa* (Fern.) E. P. Bick.**	Cyperaceae	Cyperaceae	**Cato**
Carex vaginata Tausch	Cyperaceae	Cyperaceae	Cava
Cassiope mertensiana (Bong.) D. Don	Ericaceae	Ericaceae	Came
Cassiope tetragona (L.) D. Don	Ericaceae	Ericaceae	Cate
Castilleja miniata Lindl.	Orobanchaceae	Scrophulariaceae	Camn
Castilleja occidentalis Torr.	Orobanchaceae	Scrophulariaceae	Caoc
Castilleja rhexifolia Rydb.	Orobanchaceae	Scrophulariaceae	Carh

Cerastium arvense L.	Caryophyllaceae	Caryophyllaceae	Cear
Cerastium beeringianum Cham. & Schlect.	Caryophyllaceae	Caryophyllaceae	Cebe
Cerastium fontanum Baumg. ssp. *triviale* (Link) Jalas	Caryophyllaceae	Caryophyllaceae	Cefo
Chamaerhodos erecta (L.) Bunge	Rosaceae	Rosaceae	Chfo
Chimaphila umbellata (L.) Bart.	Ericaceae	Ericaceae	Chum
Chrysosplenium iowense Rydb.	Saxifragaceae	Saxifragaceae	Chio
Cirsium hookerianum Nutt.	Asteraceae	Asteraceae	Ciho
Claytonia lanceolata Pursh	Portulaceae	Portulaceae	Clla
Clematis occidentalis (Hornem.) DC.	Ranunculaceae	Ranunculaceae	Cloc
Comandra umbellata (L.) Nutt.	Santalaceae	Santalaceae	Coum
Comarum palustre L.	Rosaceae	Rosaceae	Copa
Corallorhiza trifida Chatelain	Orchidaceae	Orchidaceae	Cotr
Corispermum americanum Nutt.	Amaranthaceae	Chenopodiaceae	Coam
Cornus canadensis L.	Cornaceae	Cornaceae	Coca
Cornus stolonifera Michx.	Cornaceae	Cornaceae	Cost
Cotoneaster acutifolius Turcz.	Rosaceae	Rosaceae	Coac
Crepis nana Richards.	Asteraceae	Asteraceae	Crna
Crepis tectorum L.	Asteraceae	Asteraceae	Crte
Cryptantha celosioides (Eastw.) Payson	Boraginaceae	Boraginaceae	Crce
Cryptogramma acrostichoides R. Brown	Adiantaceae	Pteridaceae	Crac
Cypripedium parviflorum Salisb.	Orchidaceae	Orchidaceae	Cypa
Cystopteris fragilis (L.) Bernh.	Woodsiaceae	Dryopteridaceae	Cyfr
***Cystopteris montana* (Lam.) Bernh. *ex* Desv.**	Woodsiaceae	Dryopteridaceae	**Cymo**
Danthonia intermedia Vasey	Poaceae	Poaceae	Dain
Delphinium glaucum S. Wats.	Ranunculaceae	Ranunculaceae	Degl
Deschampsia cespitosa (L.) Beauv.	Poaceae	Poaceae	Dece
Descurania incana (Bernh. *ex* Fisch. & C. A. Mey.) Dorn	Brassicaceae	Brassicaceae	Dein
Diphasiastrum alpinum (L.) Holub	Lycopodiaceae	Lycopodiaceae	Dial
Diphasiastrum complanatum (L.) Holub	Lycopodiaceae	Lycopodiaceae	Dico
***Diphasiatrum sitchense* (Rupr.) Holub**	Lycopodiaceae	Lycopodiaceae	**Disi**
Dodecatheon pulchellum (Raf.) Merr.	Primulaceae	Primulaceae	Dopu

Draba aurea Vahl	Brassicaceae	Brassicaceae	Drau
Draba borealis DC.	Brassicaceae	Brassicaceae	Drbo
Draba cana Rydb.	Brassicaceae	Brassicaceae	Drca
Draba crassifolia R. Grah.	Brassicaceae	Brassicaceae	Drcr
***Draba fladnizensis* Wulfen**	Brassicaceae	Brassicaceae	**Drfl**
Draba incerta Payson	Brassicaceae	Brassicaceae	Dric
Draba lonchocarpa Rydb.	Brassicaceae	Brassicaceae	Drlo
***Draba longipes* Raup**	Brassicaceae	Brassicaceae	Drlg
***Draba macounii* O.E. Schulz**	Brassicaceae	Brassicaceae	**Drma**
Draba nivalis Liljebl.	Brassicaceae	Brassicaceae	Drni
Draba oligosperma Hook.	Brassicaceae	Brassicaceae	Drol
Draba paysonii Macbr.	Brassicaceae	Brassicaceae	Drpa
***Draba porsildii* G. B. Mulligan**	Brassicaceae	Brassicaceae	**Drpo**
Draba praealta Greene	Brassicaceae	Brassicaceae	Drpr
Draba stenoloba Ledeb.	Brassicaceae	Brassicaceae	Drst
***Draba ventosa* A. Gray**	Brassicaceae	Brassicaceae	**Drve**
Dryas drummondii Richards.	Rosaceae	Rosaceae	Drdr
Dryas integrifolia M. Vahl	Rosaceae	Rosaceae	Drin
Dryas octopetala L.	Rosaceae	Rosaceae	Droc
Dryopteris expansa (C. Presl) Fraser-Jenkins & Jermy	Dryopteridaceae	Dryopteridaceae	Drex
Elaeagnus commutata Bernh. *ex* Rydb.	Elaeagnaceae	Elaeagnaceae	Elco
Elymus alaskanus (Scribn. & Merr.) A. Love	Poaceae	Poaceae	Elal
Elymus glaucus Buckl.	Poaceae	Poaceae	Elgl
Elymus lanceolatus (Scribn. & J.G. Sm.) Gould	Poaceae	Poaceae	Ella
Elymus repens (L.) Gould	Poaceae	Poaceae	Elre
Elymus trachycaulus (Link) Gould *ex* Shinners	Poaceae	Poaceae	Eltr
Empetrum nigrum L.	Ericaceae	Ericaceae	Emni
Epilobium anagallidifolium Lam.	Onagraceae	Onagraceae	Eacl
Epilobium angustifolium L.	Onagraceae	Onagraceae	Epan
Epilobium ciliatum Raf.	Onagraceae	Onagraceae	Epci
Epilobium clavatum Trelease	Onagraceae	Onagraceae	Epcl

Epilobium hornemannii Reichenb.	Onagraceae	Onagraceae	Epho
***Epilobium lactiflorum* Hausskn.**	Onagraceae	Onagraceae	**Epla**
Epilobium latifolium L.	Onagraceae	Onagraceae	Eplt
Equisetum arvense L.	Equisetaceae	Equisetaceae	Eqar
Equisetum hyemale L.	Equisetaceae	Equisetaceae	Eqhy
Equisetum pratense L.	Equisetaceae	Equisetaceae	Eqpr
Equisetum scirpoides Michx.	Equisetaceae	Equisetaceae	Eqsc
Equisetum sylvaticum L.	Equisetaceae	Equisetaceae	Eqsy
Equisetum variegatum Schleich.	Equisetaceae	Equisetaceae	Eqva
Erigeron aureus Greene	Asteraceae	Asteraceae	Erau
Erigeron caespitosus Nutt.	Asteraceae	Asteraceae	Erca
Erigeron compositus Pursh	Asteraceae	Asteraceae	Erco
***Erigeron flagellaris* A. Gray**	Asteraceae	Asteraceae	**Erfl**
Erigeron glabellus Nutt.	Asteraceae	Asteraceae	Ergl
Erigeron grandiflorus Hook.	Asteraceae	Asteraceae	Ergr
Erigeron humilus Grah.	Asteraceae	Asteraceae	Erhu
Erigeron lanatus Hook.	Asteraceae	Asteraceae	Erla
***Erigeron pallens* Cronq.**	Asteraceae	Asteraceae	**Erpa**
Erigeron peregrinus (Pursh) Greene	Asteraceae	Asteraceae	Erpe
***Erigeron trifidus* Hook.**	Asteraceae	Asteraceae	**Erti**
Eriogonum androsaceum Benth.	Polygonaceae	Polygonaceae	Eran
Eriophorum angustifolium Honck.	Cyperaceae	Cyperaceae	Erag
***Eriophorum callitrix* Cham.**	Cyperaceae	Cyperaceae	**Ercl**
Eriophorum scheuchzeri Hoppe	Cyperaceae	Cyperaceae	Ersc
Eriophorum vaginatum L.	Cyperaceae	Cyperaceae	Erva
Eriophorum viridicarinatum (Engelm.) Fern.	Cyperaceae	Cyperaceae	Ervi
Erysimum inconspicuum (S. Wats.) MacM.	Brassicaceae	Brassicaceae	Erin
Erysimum pallasii (Pursh) Fern.	Brassicaceae	Brassicaceae	Erpa
Eurybia conspicua (Lindl.) Nesom	Asteraceae	Asteraceae	Euco
Eurybia sibirica (L.) Nesom	Asteraceae	Asteraceae	Eusi
***Festuca altaica* Trin.**	**Poaceae**	**Poaceae**	**Feal**

Festuca baffinensis Polunin	Poaceae	Poaceae	Feba
Festuca brachyphylla Schultes	Poaceae	Poaceae	Febr
***Festuca minutiflora* Rydb.**	Poaceae	Poaceae	**Femi**
Festuca ovina L.	Poaceae	Poaceae	Feov
Festuca rubra L.	Poaceae	Poaceae	Feru
Festuca saximontana Rydb.	Poaceae	Poaceae	Fesa
Fragaria vesca L.	Rosaceae	Rosaceae	Frve
Fragaria virginiana Duchesne	Rosaceae	Rosaceae	Frvi
Gaillardia aristata Pursh	Asteraceae	Asteraceae	Gaar
Galium boreale L.	Rubiaceae	Rubiaceae	Gabo
Galium trifidum L.	Rubiaceae	Rubiaceae	Gatr
Galium triflorum Michx.	Rubiaceae	Rubiaceae	Gatf
Gaultheria humifusa (Graham) Rydb.	Ericaceae	Ericaceae	Gahu
***Gentiana glauca* Pall.**	**Gentianaceae**	**Gentianaceae**	**Gegl**
Gentiana prostrata Haenke	Gentianaceae	Gentianaceae	Gepr
Gentianella amarella (L.) Borner	Gentianaceae	Gentianaceae	Geam
Gentianella propinqua (Richards.) Gillett	Gentianaceae	Gentianaceae	Geps
Geocaulon lividum (Richards.) Fern	Santalaceae	Santalaceae	Geli
Geranium richardsonii Fisch. & Trautv.	Geraniaceae	Geraniaceae	Geri
Geum macrophyllum Willd.	Rosaceae	Rosaceae	Gema
Geum rivale L.	Rosaceae	Rosaceae	Gerv
Geum triflorum Pursh	Rosaceae	Rosaceae	Getr
Goodyera oblongifolia Raf.	Orchidaceae	Orchidaceae	Goob
Goodyera repens (L.) R. Br.	Orchidaceae	Orchidaceae	Gore
Gymnocarpium dryopteris (L.) Newm.	Woodsiaceae	Dryopteridaceae	Gydr
Hedysarum alpinum L.	Fabaceae	Fabaceae	Heal
Hedysarum boreale Nutt.	Fabaceae	Fabaceae	Hebo
Heracleum maximum Bartr.	Asteraceae	Apiaceae	Hema
Heterostipa comata (Trin. & Rupr.) Barkw.	Poaceae	Poaceae	Heco
Heterostipa curtiseta (A. S. Hitchc.) Barkw.	Poaceae	Poaceae	Hecu
***Heuchera glabra* Willd.**	**Saxifragaceae**	**Saxifragaceae**	**Hegl**

Hieracium aurantiacum L.	Asteraceae	Asteraceae	Hiau
Hieracium gracile Hook.	Asteraceae	Asteraceae	Higr
***Hierochloe alpina* (Sw.) Roem. & Schult.**	**Poaceae**	**Poaceae**	**Hial**
Hierochloe hirta (Schrank) Borbas	Poaceae	Poaceae	Hihi
***Huperzia halakalae* (Bracken.) Holub**	**Lycopodiaceae**	**Lycopodiaceae**	**Huha**
Juncus arcticus Willd. *var*. balticus (Willd.) Trautv.	Juncaceae	Juncaceae	Juar
***Juncus biglumis* L.**	Juncaceae	Juncaceae	**Jubi**
Juncus castaneus J. E. Smith	Juncaceae	Juncaceae	Juca
Juncus drummondii E. Meyer	Juncaceae	Juncaceae	Judr
Juncus mertensianus Bong.	Juncaceae	Juncaceae	Jumer
Juncus triglumis L. var. *albescens* Lange	Juncaceae	Juncaceae	Jutr
Juniperus communis L.	Cupressaceae	Cupressaceae	Juco
Juniperus horizontalis Moench	Cupressaceae	Cupressaceae	Juho
Kalmia microphylla (Hook.) Keller	Ericaceae	Ericaceae	Kami
Kobresia myosuroides (Vill.) Fiori & Paol.	Cyperaceae	Cyperaceae	Komy
Kobresia simpliciuscula (Wahlenb.) Mack.	Cyperaceae	Cyperaceae	Koim
Koeleria macrantha (ledeb.) J. A. Schult.	Poaceae	Poaceae	Koma
***Koenigia islandica* L.**	**Polygonaceae**	**Polygonaceae**	**Kois**
Lathyrus ochroleucus Hook.	Fabaceae	Fabaceae	Laoc
Lathyrus venosus Muhl.	Fabaceae	Fabaceae	Lave
Leptarrhena pyrolifolia (D. Don) R. Br.	Saxifragaceae	Saxifragaceae	Lepy
Leucanthemum vulgare Lam.	Asteraceae	Asteraceae	Levu
Leymus innovatus (Beal) Pilger	Poaceae	Poaceae	Lein
Lilium philadelphicum L.	Liliaceae	Liliaceae	Liph
Linnaea borealis L.	Linnaceae	Caprifoliaceae	Libo
Linum lewisii Pursh	Linaceae	Linaceae	Lile
Listera borealis Morong	Orchidaceae	Orchidaceae	Lsbo
Listera cordata (L.) R. Br.	Orchidaceae	Orchidaceae	Lico
Lithospermum incisum Lehm.	Boraginaceae	Boraginaceae	Liin
***Loiseleuria procumbens* (L.) Desv.**	**Ericaceae**	**Ericaceae**	**Lopr**
Lonicera dioica L.	Caprifoliaceae	Caprifoliaceae	Lodi

Lonicera involucrata (Richards.) Banks *ex* Spreng.	Caprifoliaceae	Caprifoliaceae	Loin
Lonicera villosa (Michx.) J. A. Schultes	Caprifoliaceae	Caprifoliaceae	Lovi
Luetkia pectinata (Pursh) Kuntze	Rosaceae	Rosaceae	Lupe
Lupinus nootkatensis Donn *ex* Sims	Fabaceae	Fabaceae	Luno
Luzula arcuata (Wahlenb.) Swartz ssp. *unalaschkensis* (Buchenau) Hulten	Juncaceae	Juncaceae	Luzr
Luzula multiflora (Ehrhart) Lejeune	Juncaceae	Juncaceae	Lumu
Luzula parviflora (Ehrh.) Desv.	Juncaceae	Juncaceae	Lupa
Luzula piperi (Cov.) M. E. Jones	Juncaceae	Juncaceae	Lupi
Luzula spicata (L.) DC	Juncaceae	Juncaceae	Lusp
Lycopodium annotinum L.	Lycopodiaceae	Lycopodiaceae	Lyan
Maianthemum canadense Desf.	Rusaceae	Liliaceae	Maca
Maianthemum stellatum (L.) Link	Rusaceae	Liliaceae	Mast
Menyanthes trifoliata L.	Menyanthaceae	Menyanthaceae	Metr
Menziesia ferruginea J. E. Smith	Ericaceae	Ericaceae	Mefe
Mertensia paniculata (Ait.) G. Don	Boraginaceae	Boraginaceae	Mepa
Minuartia austromontana Wolf & Packer	Caryophyllaceae	Caryophyllaceae	Miau
Minuartia biflora (L.) Schinz & Thell.	Caryophyllaceae	Caryophyllaceae	Mibi
***Minuartia elegans* (Cham & Schlecht.) Schischk.**	Caryophyllaceae	Caryophyllaceae	**Miel**
Minuartia rubella (wahl.) Graebn.	Caryophyllaceae	Caryophyllaceae	Miru
Mitella nuda L.	Saxifragaceae	Saxifragaceae	Minu
Mitella pentandra Hook.	Saxifragaceae	Saxifragaceae	Mipe
Moehringia latifolia (L.) Fenzl.	Caryophyllaceae	Caryophyllaceae	Mola
Moneses uniflora (L.) A. Gray	Ericaceae	Monotropaceae	Moun
Muhlenbergia richardsonis (Trin.) Rydb.	Poaceae	Poaceae	Muri
Myosotis asiatica (Vesterg.) Schischkin & Sergievskaja	Boraginaceae	Boraginaceae	Myas
Orthilia secunda (L.) House	Ericaceae	Pyrolaceae	Orse
Orthocarpus luteus Nutt.	Orobanchaceae	Scrophulariaceae	Orlu
Osmorhiza depauperata Phil.	Apiaceae	Apiaceae	Osde
***Osmorhiza purpurea* (Coult. & Rose) Suksd.**	**Apiaceae**	Apiaceae	**Ospu**
Oxycoccus oxycoccos (L.) MacM.	Ericaceae	Ericaceae	Oxox

Oxyria digyna (L.) Hill	Polygonaceae	Polygonaceae	Oxdi
Oxytropis campestris (L.) DC.	Fabaceae	Fabaceae	Oxca
Oxytropis deflexa (Pall.) DC.	Fabaceae	Fabaceae	Oxde
***Oxytropis jordalii* Pors.**	Fabaceae	Fabaceae	**Oxjo**
Oxytropis podocarpa A. Gray	Fabaceae	Fabaceae	Oxpo
Oxytropis sericea Nutt.	Fabaceae	Fabaceae	Oxse
Oxytropis splendens Dougl. *ex* Hook.	Fabaceae	Fabaceae	Oxsp
***Papaver radicatum* Rott. ssp. *Kluanensis* (D. Love) D. F. Murray**	**Papaveraceae**	**Papaveraceae**	**Para**
Parnassia fimbriata Konig.	Parnassiaceae	Parnassiaceae	Pafi
Parnassia kotzebuei Cham. & Schl.	Parnassiaceae	Parnassiaceae	Pako
Parnassia palustris L.	Parnassiaceae	Parnassiaceae	Papa
Pedicularis bracteosa Benth.	Orobanchaceae	Scrophulariaceae	Pebr
***Pedicularis capitata* Adams**	Orobanchaceae	Scrophulariaceae	**Peca**
***Pedicularis flammea* L.**	Orobanchaceae	Scrophulariaceae	**Pefl**
Pedicularis groenlandica Retz.	Orobanchaceae	Scrophulariaceae	Pegr
Pedicularis labradorica Wirsing	Orobanchaceae	Scrophulariaceae	Pelb
***Pedicularis lanata* Cham. & Schlect.**	Orobanchaceae	Scrophulariaceae	**Pela**
***Pedicularis langsdorfii* Fisch. ssp. *arctica* (R. Br.) Pennell**	Orobanchaceae	Scrophulariaceae	**Pelg**
***Pellaea glabella* Mett. *ex* Kuhn**	**Adiantaceae**	**Polypodiaceae**	**Pegl**
Penstemon ellipticus Coult. & Fisher	Plantaginaceae	Scrophulariaceae	Peel
Penstemon procerus Dougl.	Plantaginaceae	Scrophulariaceae	Pepr
Pentaphylloides floribunda (Pursh) A. Love	Rosaceae	Rosaceae	Pefb
Petasites frigidus (L.) Fries	Asteraceae	Asteraceae	Pefr
Phacelia franklinii (R. Br.) A. Gray	Hydrophyllaceae	Hydrophyllaceae	Phfr
Phacelia sericea (Graham) A. Gray	Hydrophyllaceae	Hydrophyllaceae	Phse
Phleum alpinum L.	Poaceae	Poaceae	Phal
Phleum pratense L.	Poaceae	Poaceae	Phpr
Phyllodoce empetriformis (Smith) D. Don	Ericaceae	Ericaceae	Phem
Phyllodoce glanduliflora (Hook.) Coville	Ericaceae	Ericaceae	Phgl

Phyllodoce x *intermedia* (Hook.) Camp	Ericaceae	Ericaceae	Phin
Physaria didymocarpa (Hook.) A. Gray	Brassicaceae	Brassicaceae	Phdi
Picea engelmannii Parry *ex* Engelmann	Pinaceae	Pinaceae	Pien
Picea glauca (Moench) Voss	Pinaceae	Pinaceae	Pigl
Pinguicula vulgaris L.	Lentibulariaceae	Lentibulariaceae	Pivu
Pinus albicaulis Engelm.	Pinaceae	Pinaceae	Pial
Pinus contorta Doug. *ex* Loud.	Pinaceae	Pinaceae	Pico
***Plantago canescens* Adams**	**Plantaginaceae**	**Plantaginaceae**	**Plca**
Platanthera dilitata (Pursh) Lindl.	Orchidaceae	Orchidaceae	Pldi
Platanthera huronensis (Nutt.) Lindl.	Orchidaceae	Orchidaceae	Plhu
Platanthera obtusata (Banks *ex* Pursh) Lindl.	Orchidaceae	Orchidaceae	Plob
Platanthera orbiculata (Pursh) Lind.	Orchidaceae	Orchidaceae	Plor
Poa abbreviata R. Br. ssp. *pattersonii* (Vasey) A. Love, D. Love & Kapoor	Poaceae	Poaceae	Poab
Poa alpina L.	Poaceae	Poaceae	Poal
Poa arctica R. Br.	Poaceae	Poaceae	Poar
Poa cusickii Vasey	Poaceae	Poaceae	Pocu
Poa glauca Vahl	Poaceae	Poaceae	Pogl
Poa leptocoma Trin.	Poaceae	Poaceae	Pole
***Poa lettermanii* Vasey**	Poaceae	Poaceae	**Polt**
Poa nemoralis L	Poaceae	Poaceae	Pone
Poa nervosa (Hook.) Vasey	Poaceae	Poaceae	Ponr
Poa palustris L.	Poaceae	Poaceae	Popa
Poa pratensis L.	Poaceae	Poaceae	Popr
Polemonium acutiflorum Willd. *ex* Roem. & Schult.	Polemoniaceae	Polemoniaceae	Poac
Polygonum douglasii Greene	Polygonaceae	Polygonaceae	Podo
Polygonum viviparum L.	Polygonaceae	Polygonaceae	Povi
Polystichum lonchitis (L.) Roth	Dryopteridaceae	Dryopteridaceae	Polo
Populus balsamifera L.	Salicaceae	Salicaceae	Poba
Populus tremuloides Michx.	Salicaceae	Salicaceae	Potr
Potentilla argentea L.	Rosaceae	Rosaceae	Poag

Potentilla diversifolia Lehm.	Rosaceae	Rosaceae	Podi
Potentilla gracilis Dougl.	Rosaceae	Rosaceae	Pogr
Potentilla hippiana Lehm.	Rosaceae	Rosaceae	Pohi
***Potentilla hookeriana* Lehm.**	Rosaceae	Rosaceae	**Poho**
Potentilla nana Willd. *ex* Schlecht.	Rosaceae	Rosaceae	Pona
Potentilla nivea L.	Rosaceae	Rosaceae	Poni
Potentilla ovina Macoun.	Rosaceae	Rosaceae	Poov
Potentilla pensylvanica L.	Rosaceae	Rosaceae	Pope
Potentilla recta L.	Rosaceae	Rosaceae	Pore
Potentilla uniflora Ledeb.	Rosaceae	Rosaceae	Poun
***Potentilla villosa* Pall. *ex* Pursh**	Rosaceae	Rosaceae	**Povl**
Primula mistassinica Michx.	Primulaceae	Primulaceae	Prmi
Prosartes trachycarpa S. Wats.	Colchicaeae	Liliaceae	Prtr
Pseudotsuga menziesii (Mirb.) Franco	Pinaceae	Pinaceae	Psme
Pyrola asarifolia Michx.	Ericaceae	Pyrolaceae	Pyas
Pyrola asarifolia Michx. *ssp*. bracteata (Hook.) Haber	Ericaceae	Pyrolaceae	Pyab
Pyrola chlorantha Sw.	Ericaceae	Pyrolaceae	Pych
***Pyrola grandiflora* Radius**	Ericaceae	Pyrolaceae	**Pygr**
Pyrola minor L.	Ericaceae	Pyrolaceae	Pymi
Ranunculus acris L.	Ranunculaceae	Ranunculaceae	Raac
Ranunculus eschscholtzii Schlecht.	Ranunculaceae	Ranunculaceae	Raes
Ranunculus gelidus Kar. & Kir.	Ranunculaceae	Ranunculaceae	Rage
Ranunculus inamoenus Greene var. *inamoenus*	Ranunculaceae	Ranunculaceae	Rain
***Ranunculus occidentalis* Nutt.**	Ranunculaceae	Ranunculaceae	**Raoc**
Ranunculus pedatifidus J. E. Smith var. *affinis* (R. Brown) L. D. Benson	Ranunculaceae	Ranunculaceae	Repe
Ranunculus pygmaeus Wahlenb.	Ranunculaceae	Ranunculaceae	Rapy
Rhinanthus minor L.	Orobanchaceae	Scrophulariaceae	Rhmi
Rhododendron albiflorum Hook.	Ericaceae	Ericaceae	Rhal
Rhodendron groenlandicum (Oeder) Kron & Judd	Ericaceae		
Ribes hudsonianum Richards.	Grossulariaceae	Grossulariaceae	Rihu

Ribes lacustre (Pers.) Poir.	Grossulariaceae	Grossulariaceae	Rila
***Ribes laxiflorum* Pursh**	Grossulariaceae	Grossulariaceae	**Rilx**
Ribes oxyacanthoides L.	Grossulariaceae	Grossulariaceae	Riox
Ribes triste Pall.	Grossulariaceae	Grossulariaceae	Ritr
***Romanzoffia sitchensis* Bong.**	**Hydrophyllaceae**	**Hydrophyllaceae**	**Rosi**
***Rorippa curvipes* Greene var. *truncata* (Jeps.) Rollins**	**Brassicaceae**	**Brassicaceae**	**Rocu**
Rosa acicularis Lindl.	Rosaceae	Rosaceae	Roac
Rubus arcticus L.	Rosaceae	Rosaceae	Ruar
Rubus chamaemorus L.	Rosaceae	Rosaceae	Ruch
Rubus idaeus L.	Rosaceae	Rosaceae	Ruid
Rubus pedatus J. E. Smith	Rosaceae	Rosaceae	Rupe
Rubus pubescens Raf.	Rosaceae	Rosaceae	Rupu
Rumex acetosa L.	Polygonaceae	Polygonaceae	Ruac
Rumex aquaticus L. var. *fenestratus* (Greene) Dorn	Polygonaceae	Polygonaceae	Ruaq
***Sagina nivalis* (Lindbl.) Fries**	**Caryophyllaceae**	**Caryophyllaceae**	**Sanv**
***Salix alaxensis* (Anderss.) Coville**	**Salicaceae**	**Salicaceae**	**Saal**
Salix arbusculoides Anderss.	Salicaceae	Salicaceae	Saar
Salix arctica Pall.	Salicaceae	Salicaceae	Saac
***Salix arctica* Pall. x *stolonifera* Cov.**	Salicaceae	**Salicaceae**	**Sast**
Salix athabascensis Raup	Salicaceae	Salicaceae	Saat
Salix barclayi Anderss.	Salicaceae	Salicaceae	Saba
Salix barrattiana Hook.	Salicaceae	Salicaceae	Sabr
Salix bebbiana Sarg.	Salicaceae	Salicaceae	Sabe
Salix boothii Dorn	Salicaceae	Salicaceae	Sabo
Salix brachycarpa Nutt.	Salicaceae	Salicaceae	Sabc
Salix candida Fluegge	Salicaceae	Salicaceae	Saca
***Salix commutata* Bebb.**	Salicaceae	**Salicaceae**	**Saco**
Salix drummmondiana Barratt	Salicaceae	Salicaceae	Sadr
Salix eriocephala Michx. var. *familica* (C. R. Ball) Dorn	Salicaceae	Salicaceae	Saer
Salix exigua Nutt.	Salicaceae	Salicaceae	Saex
Salix farriae Ball	Salicaceae	Salicaceae	Safa

Salix glauca L.	Salicaceae	Salicaceae	Sagl
Salix maccalliana Rowlee	Salicaceae	Salicaceae	Sama
Salix melanopsis Nutt.	Salicaceae	Salicaceae	Same
Salix myrtillifolia Anderss.	Salicaceae	Salicaceae	Samy
Salix nivalis Hook.	Salicaceae	Salicaceae	Sani
Salix pedicellaris Pursh	Salicaceae	Salicaceae	Sape
Salix planifolia Pursh	Salicaceae	Salicaceae	Sapl
Salix pseudomonticola C. R. Ball	Salicaceae	Salicaceae	Sapm
Salix pseudomyrsinites Anderss.	Salicaceae	Salicaceae	Saps
Salix reticulata L.	Salicaceae	Salicaceae	Sare
Salix scouleriana Barratt	Salicaceae	Salicaceae	Sasc
Salix vestita Pursh	Salicaceae	Salicaceae	Save
Sambucus racemosa L.	Adoxaceae	Rosaceae	Sara
Saussurea nuda Ledeb. ssp. *densa* (Hook.) G. W. Dougl.	Asteraceae	Asteraceae	Sanu
Saxifraga adscendens L.	Saxifragaceae	Saxifragaceae	Sxad
Saxifraga aizoides L.	Saxifragaceae	Saxifragaceae	Sxai
Saxifraga bronchialis L.	Saxifragaceae	Saxifragaceae	Sxbr
Saxifraga caespitosa L.	Saxifragaceae	Saxifragaceae	Sxca
Saxifraga cernua L.	Saxifragaceae	Saxifragaceae	Sxce
***Saxifraga ferruginea* Graham**	Saxifragaceae	**Saxifragaceae**	**Sxfe**
***Saxifraga flagellaris* Willd.**	Saxifragaceae	**Saxifragaceae**	**Sxfl**
Saxifraga lyallii Engler.	Saxifragaceae	Saxifragaceae	Sxly
***Saxifraga nelsoniana* D. Don**	Saxifragaceae	**Saxifragaceae**	**Sxne**
***Saxifraga nivalis* L.**	Saxifragaceae	**Saxifragaceae**	**Sxni**
Saxifraga occidentalis S. Wats.	Saxifragaceae	Saxifragaceae	Sxoc
Saxifraga oppositifolia S. Wats.	Saxifragaceae	Saxifragaceae	Sxop
Saxifraga rivularis L.	Saxifragaceae	Saxifragaceae	Sxri
Saxifraga tricuspidata Rottb.	Saxifragaceae	Saxifragaceae	Sxtr
***Sedum divergens* Wats.**	**Crassulaceae**	**Crassulaceae**	**Sedi**
Sedum lanceolatum Torr.	Crassulaceae	Crassulaceae	Sela
Selaginella densa Rydb.	Selaginellaceae	Selaginellaceae	Sede

Selaginella scopulorum Maxon	Selaginellaceae	Selaginellaceae	Sesc
Selaginella standleyi Maxon	Selaginellaceae	Selaginellaceae	Sest
Senecio fremontii Torr. & A. Gray	Asteraceae	Asteraceae	Sefr
Senecio lugens Richards.	Asteraceae	Asteraceae	Selu
Senecio pauciflorus Pursh	Asteraceae	Asteraceae	Sepa
Senecio pauperculus Michx.	Asteraceae	Asteraceae	Sepp
Senecio streptanthifolius Greene	Asteraceae	Asteraceae	Sest
Senecio triangularis Hook.	Asteraceae	Asteraceae	Setr
Shepherdia canadensis (L.) Nutt.	Elaeagnaceae	Elaeagnaceae	Shca
Sibbaldia procumbens L.	Rosaceae	Rosaceae	Sipr
Silene acaulis (L.) Jacq.	Caryophyllaceae	Caryophyllaceae	Siac
***Silene hitchguirei* Bocquet**	Caryophyllaceae	Caryophyllaceae	**Sihi**
***Silene involucrata* (Cham.) & Schlecht.) Bocquet**	Caryophyllaceae	Caryophyllaceae	**Siin**
Silene uralensis (Rupr.) Bocquet	Caryophyllaceae	Caryophyllaceae	Siur
Sisyrinchium montanum Greene	Iridaceae	Iridaceae	Simo
Solidago multiradiata Ait.	Asteraceae	Asteraceae	Somu
Solidago simplex Kunth	Asteraceae	Asteraceae	Sosi
Sonchus arvensis L.	Asteraceae	Asteraceae	Soar
Sorbus scopulina Greene	Rosaceae	Rosaceae	Sosc
Spirea betulifolia Pallas	Rosaceae	Rosaceae	Spbe
Stellaria calycantha (Ledeb.) Bong.	Caryophyllaceae	Caryophyllaceae	Stca
Stellaria longifolia Muhl. *ex* Willd.	Caryophyllaceae	Caryophyllaceae	Stlo
Stellaria longipes Goldie	Caryophyllaceae	Caryophyllaceae	Stlg
Streptopus amplexifolius (L.) DC	Liliaceae	Liliaceae	Stam
Symphoricarpos albus (L.) Blake	Caprifoliaceae	Caprifoliaceae	Syal
Symphoricarpos occidentalis Hook.	Caprifoliaceae	Caprifoliaceae	Syoc
Symphotrichum ciliolatum (Lindl.) A. & D. Love	Asteraceae	Asteraceae	Syci
Symphotrichum laeve (L.) Love	Asteraceae	Asteraceae	Syla
Taraxacum ceratophorum (Ledeb.) DC.	Asteraceae	Asteraceae	Tace
Taraxacum officinale Weber	Asteraceae	Asteraceae	Taof
Telesonix heucherifomis Rybd.	Saxifragaceae	Saxifragaceae	Tehe

Thalictrum occidentale A. Gray	Ranunculaceae	Ranunculaceae	Thoc
Thalictrum venulosum Trel.	Ranunculaceae	Ranunculaceae	Thve
Tofieldia pusilla (Michx.) Pers.	Melanthiaceae	Liliaceae	Topu
Townsendia hookeri Beaman	Asteraceae	Asteraceae	Toho
Townsendia parryii D. C. Eat.	Asteraceae	Asteraceae	Topa
Tragopogon dubius Scop.	Asteraceae	Asteraceae	Trdu
Triantha glutinosa (Michx.) Baker	Melanthiaceae	Liliaceae	Trgl
Trifolium hybridum L.	Fabaceae	Fabaceae	Trfo
Trifolium pratense L.	Fabaceae	Fabaceae	Trpr
Trifolium repens L.	Fabaceae	Fabaceae	Trre
Trimorpha acris (L.) Newsom	Asteraceae	Asteraceae	Trac
Trisetum spicatum (L.) Richt.	Poaceae	Poaceae	Trsp
Trollius albiflorus (A. Gray) Rydb.	Ranunculaceae	Ranunculaceae	Tral
Vaccinium caespitosum Michx.	Ericaceae	Ericaceae	Vaca
Vaccinium membranaceum Dougl.	Ericaceae	Ericaceae	Vame
Vaccinium myrtilloides Michx.	Ericaceae	Ericaceae	Vamy
***Vaccinium ovalifolium* J. E. Smith**	Ericaceae	Ericaceae	**Vaov**
Vaccinium scoparium Leiberg	Ericaceae	Ericaceae	Vaso
***Vaccinium uliginosum* L.**	Ericaceae	Ericaceae	**Vaul**
Vaccinium vitis-idaea L.	Ericaceae	Ericaceae	Vavi
Vahlodea atropurpurea (Wahlenb.) Fries	Poaceae	Poaceae	Vaat
Valeriana dioica L.	Valerianaceae	Valerianaceae	Vadi
Valeriana sitchensis Bong.	Valerianaceae	Valerianaceae	Vasi
Veratrum viride Ait. var. *eschscholzianum* (Roem. & Schult.) Breit.	Melanthiaceae	Liliaceae	Vevi
Veronica serpyllifolia L.	Plantaginaceae	Scrophulariaceae	Vese
Veronica wormskjoldii Roemer & Schultes var. *wormskjoldii*	Plantaginaceae	Scrophulariaceae	Vewo
Viburnum edule (Michx.) Raf.	Adoxaceae	Caprifoliaceae	Vied
Vicia americana Muhl. ex Willd.	Fabaceae	Fabaceae	Viam
Viola adunca J. E. Smith	Violaceae	Violaceae	Viad

Viola canadensis L.	Violaceae	Violaceae	Vica
Viola nephrophylla Greene	Violaceae	Violaceae	Vine
Viola palustris L.	Violaceae	Violaceae	Vipa
Viola renifolia A. Gray	Violaceae	Violaceae	Vire
Zigadenus elegans Pursh	Melanthiaceae	Liliaceae	Ziel

Appendix 2. Environmental variables measured at ech sample location. Sites are grouped first by physiognomic type and then by habitat type for each of presentation.

SITE	Elevation (m)	aspect(w-e)	aspect (n-s)	Slope (degrees)	Texture	Moisture	Nutrient
Tree							
Picea glauca							
01-002	1294	-0.5224986	0.85264016	7	Medium	subhygric	eutrophic
01-011	1042	0.78260816	0.62251464	5	Medium	mesic	hypereutrophic
01-017	1030	-0.5075384	0.86162916	7	Medium	mesic	permesotriphic
01-033	1552	-0.3826834	0.92387953	0	Coarse	xeric	permesotriphic
01-061	1066	-0.8788171	0.47715876	22	Medium	submesic	submesotrophic
02-175	1016	-0.953717	0.3007058	1	Medium	mesic	permesotriphic
02-184	1022	-0.0436194	0.99904822	2	Medium	mesic	permesotriphic
02-212	1200	0.91706007	0.39874907	4	Organic	subhydric	permesotriphic
Populus tremuloides							
01-004	1475	0.70090926	0.71325045	31	Medium	submesic	mesotrophic
01-114	1029	-0.3826834	0.92387953	0	Medium	submesic	permesotriphic
01-115	1028	-0.3826834	0.92387953	0	Medium	submesic	permesotriphic
01-116	1027	-0.3826834	0.92387953	0	Medium	submesic	permesotriphic
01-118	1033	0.93041757	0.36650123	12	Medium	submesic	mesotrophic
01-161	1211	0.52249856	0.85264016	3	Medium	subxeric	mesotrophic
02-179	1146	0.38268343	0.92387953	3	Medium	mesic	mesotrophic
02-182	1037	-0.9099613	0.41469324	3	Medium	mesic	permesotriphic
02-274	981	-0.6225146	0.78260816	3	Medium	mesic	eutrophic
02-285	1190	-0.2334454	0.97236992	6	Medium	mesic	permesotriphic

Elymus lanceolatus-Koeleria macrantha							
01-012	1063	0.35020738	0.93667219	19	Medium	submesic	permesotriphic
01-117	1033	-0.1650476	-0.9862856	4	Medium	submesic	permesotriphic
Pseudotsuga menziesii							
01-010	1097	0.66262005	0.74895572	5	Medium	subhygric	hypereutrophic
01-166	1294	0.25038	0.96814764	19	Medium	subxeric	submesotrophic
02-180	1130	-0.4924236	-0.8703557	31	Coarse	subxeric	mesotrophic
02-181	1138	0.46174861	0.88701083	13	Medium	mesic	mesotrophic
02-186	1056	-0.953717	-0.3007058	7	Medium	submesic	permesotriphic
02-208	1144	0.98901586	0.14780941	19	Coarse	submesic	mesotrophic
02-211	1213	-0.4146932	0.90996127	12	Medium	submesic	mesotrophic
Pinus contorta							
01-003	1515	-0.0087265	0.99996192	10	Medium	mesic	eutrophic
01-020	1568	0.44619781	0.89493436	1	Medium	submesic	submesotrophic
01-152	2163	-0.0261769	0.99965732	29	Medium	subxeric	permesotrophic
01-153	2163	-0.3338069	0.94264149	10	Medium	subxeric	mesotrophic
01-159	1519	0.59482279	0.80385686	13	Coarse	submesic	submesotrophic
01-168	1254	0.59482279	0.80385686	13	Medium	subxeric	submesotrophic
01-169	1798	-0.9170601	0.39874907	10	Medium	subxeric	oligotrophic
01-170	1807	-0.1650476	-0.9862856	5	Medium	subxeric	oligotrophic
01-171	1731	0.14780941	0.98901586	16	Medium	subxeric	oligotrophic
01-172	1743	-0.1305262	0.99144486	0	Medium	submesic	oligotrophic
02-190	1104	-0.1822355	0.98325491	3	Medium	mesic	mesotrophic
02-207	1150	-0.9170601	0.39874907	1	Coarse	mesic	submesotrophic
02-210	1212	-0.4146932	0.90996127	9	Medium	submesic	mesotrophic
03-298	1742	0.55193699	0.83388582	4	Medium	subhygric	mesotrophic

Abies bifolia							
01-025	1996	0.95881973	0.28401534	14	Medium	submesic	mesotrophic
01-074	2185	0.63607822	0.77162458	4	Medium	xeric	mesotrophic
01-100	2134	0.96814764	0.25038	3	Medium	xeric	permesotriphic
01-143	1728	-0.9681476	0.25038	24	Organic	subxeric	mesotrophic
01-151	2167	-0.3338069	0.94264149	22	Medium	subxeric	permesotriphic
01-158	1903	0.26723838	0.96363045	11	Medium	mesic	mesotrophic
01-167	1805	-0.1305262	0.99144486	22	Medium	subxeric	mesotrophic
02-258	1642	-0.8616292	0.50753836	19	Medium	submesic	mesotrophic
02-262	2058	-0.9304176	0.36650123	29	Medium	subxeric	submesotrophic
02-276	1980	-0.6883546	0.72537437	17	Medium	mesic	mesotrophic
03-302	1494	0.72537437	0.68835458	12	Medium	submesic	mesotrophic
Gymnocarpium dryopteris							
01-040	1781	-0.6087614	0.79335334	17	Coarse	submesic	oligotrophic
02-286	1306	-0.1822355	0.98325491	17	Medium	subhygric	permesotriphic
03-303	1609	0.60876143	0.79335334	21	Medium	subhygric	permesotriphic
Picea engelmannii							
01-034	1556	-0.3826834	0.92387953	0	Medium	mesic	submesotrophic
01-103	2050	0.98901586	0.14780941	11	Medium	mesic	submesotrophic
02-209	1227	-0.66262	0.74895572	12	Medium	subhygric	mesotrophic
02-275	990	0.13052619	0.99144486	11	Medium	mesic	eutrophic
02-278	1739	-0.0261769	0.99965732	10	Medium	mesic	mesotrophic
03-299	1489	0.21643961	0.97629601	9	Coarse	mesic	permesotriphic
03-301	1273	-0.7716246	0.63607822	11	Medium	mesic	permesotriphic
Shrub							
Arctostaphylos uva-ursi							
01-006	1065	-0.4617486	0.88701083	19	Medium	mesic	eutrophic

02-185	1032	0	1	0	Fine	subhygric	permesotrophic
02-187	1050	-0.4305111	0.90258528	30	Coarse	subxeric	mesotrophic
Elaeagnus commutata							
01-014	1031	0.19936793	0.9799247	4	Coarse	subxeric	mesotrophic
02-183	1030	-0.3826834	0.92387953	3	Medium	mesic	permesotrophic
Salix glauca							
01-021	1556	0.80385686	0.59482279	14	Medium	hygric	mesotrophic
01-035	1545	-0.3826834	0.92387953	0	Medium	submesic	submesotrophic
01-060	1090	-0.580703	0.81411552	50	Medium	submesic	submesotrophic
02-202	2010	0.35020738	0.93667219	6	Organic	subhygric	permesotrophic
02-215	1228	0.99144486	0.13052619	30	Organic	submesic	mesotrophic
Salix drummondiana							
01-032	1556	-0.3502074	0.93667219	0	Coarse	xeric	permesotrophic
01-039	1775	-0.9799247	0.19936793	3	Coarse	xeric	submesotrophic
01-045	1731	-0.3826834	0.92387953	0	Coarse	mesic	submesotrophic
Salix farriae							
01-042	1729	-0.3826834	0.92387953	0	Medium	subhygric	mesotrophic
01-043	1719	-0.3826834	0.92387953	0	Medium	hygric	permesotrophic
01-044	1731	-0.3826834	0.92387953	0	Medium	hygric	permesotrophic
Salix barrattiana							
01-048	2111	-0.1132032	0.99357186	7	Medium	submesic	submesotrophic
01-149	2171	-0.3826834	0.92387953	0	Medium	submesic	permesotrophic
Salix arctica							
01-071	2239	-0.9799247	0.19936793	6	Coarse	xeric	mesotrophic
02-268	1994	-0.9681476	-0.25038	8	Medium	subhygric	eutrophic
Abies bifolia							
01-101	2059	0.41469324	0.90996127	28	Medium	mesic	permesotrophic

01-127	1941	0.99904822	0.04361939	4	Medium	mesic	permesotrophic
01-148	2176	-0.9636305	0.26723838	14	Medium	submesic	permesotrophic
01-162	1797	-0.3826834	0.92387953	13	Coarse	xeric	submesotrophic
02-257	1628	0.92387953	0.38268343	22	Coarse	subhygric	permesotrophic
02-284	1923	-0.0087265	0.99996192	23	Medium	submesic	mesotrophic
Herb							
Elymus lanceolatus-Koeleria macrantha							
01-001	1027	0.47715876	0.87881711	5	Fine	mesic	eutrophic
01-005	1027	0.81411552	0.58070296	3	Medium	mesic	eutrophic
01-016	1030	-0.3173047	0.94832366	2	Coarse	subxeric	eutrophic
01-165	1305	0.25038	0.96814764	16	Medium	very xeric	submesotrophic
02-178	1101	-0.7372773	0.67559021	22	Medium	submesic	mesotrophic
02-206	1140	0.55193699	0.83388582	23	Medium	subxeric	mesotrophic
Achnatherum richardsonii							
01-160	1340	-0.3007058	0.95371695	11	Medium	subxeric	mesotrophic
02-173	1017	-0.953717	0.3007058	1	Medium	mesic	permesotrophic
02-174	1017	-0.953717	0.3007058	0	Medium	mesic	permesotrophic
Festuca altaica							
01-028	1647	0.71325045	0.70090926	2	Medium	submesic	submesotrophic
02-271	1961	0.98901586	0.14780941	27	Coarse	submesic	permesotrophic
Fragaria virginiana							
01-079	1874	-0.3987491	0.91706007	9	Medium	submesic	mesotrophic
02-213	1254	0.66262005	0.74895572	5	Medium	mesic	permesotrophic
02-214	1218	0.96363045	0.26723838	12	Coarse	mesic	mesotrophic
02-240	1699	0.99965732	0.02617695	3	Coarse	submesic	mesotrophic
03-295	1600	-0.3826834	0.92387953	1	Coarse	subxeric	submesotrophic
03-297	1430	0.91706007	0.39874907	1	Medium	subxeric	submesotrophic

open graminoid							
01-015	1018	0.3007058	0.95371695	1	Medium	mesic	eutrophic
01-138	1852	-0.3826834	0.92387953	0	Organic	hygric	submesotrophic
02-177	1043	-0.7716246	0.63607822	1	Medium	mesic	mesotrophic
02-223	2169	0.99144486	0.13052619	2	Medium	very xeric	permesotrophic
02-252	1913	-0.8703557	0.49242356	20	Medium	subxeric	submesotrophic
cliff (2)							
01-007	1071	0.99904822	0.04361939	45	Medium	very xeric	permesotrophic
01-008	1117	0.14780941	0.98901586	52	Coarse	very xeric	hypereutrophic
01-009	1118	0.06104854	0.9981348	63	Medium	very xeric	eutrophic
02-189	1055	-0.0261769	0.99965732	0	Medium	very xeric	permesotrophic
outcrop (3)							
01-013	1086	-0.3987491	0.91706007	45	Medium	xeric	permesotrophic
02-281	2068	-0.9996573	0.02617695	22	Medium	xeric	mesotrophic
outcrop (4)							
02-188	1050	-0.7132504	0.70090926	0	Medium	xeric	permesotrophic
02-279	2073	-0.3338069	0.94264149	11	Fine	xeric	mesotrophic
drainage channel (6)							
01-019	1550	-0.9025853	0.4305111	1	Medium	subhygric	permesotrophic
01-031	1551	-0.1305262	0.99144486	3	Fine	hygric	permesotrophic
01-150	2168	-0.3826834	0.92387953	0	Medium	submesic	permesotrophic
rocky (9)							
01-065	2091	-0.9681476	-0.25038	39	Medium	submesic	mesotrophic
01-156	2146	-0.9636305	0.26723838	15	Medium	subxeric	mesotrophic
talus (7)							
01-057	2211	-0.9426415	0.33380686	23	Medium	submesic	mesotrophic
01-134	2184	-0.3826834	0.92387953	0	Fine	subhygric	mesotrophic

talus (10)							
01-077	2357	0.28401534	0.95881973	28	Fine	very xeric	submesotrophic
01-078	2331	-0.551937	0.83388582	14	Medium	very xeric	submesotrophic
02-193	2036	-0.9862856	0.16504761	13	Medium	mesic	mesotrophic
02-195	2228	0.9981348	0.06104854	1	Coarse	subhydric	mesotrophic
02-266	1967	-0.25038	0.96814764	24	Coarse	subxeric	mesotrophic
sparse (11)							
01-027	1649	-0.9366722	0.35020738	4	Coarse	xeric	submesotrophic
01-105	1010	-0.9996573	0.02617695	10	Coarse	mesic	submesotrophic
02-176	1048	-0.8788171	0.47715876	2	Coarse	submesic	submesotrophic
sparse (14)							
01-041	1730	-0.3826834	0.92387953	0	Medium	hygric	permesotrophic
01-046	1743	-0.3826834	0.92387953	0	Coarse	mesic	mesotrophic
01-163	1913	-0.2840153	0.95881973	24	Coarse	xeric	submesotrophic
rocky (28)							
01-137	1875	-0.7253744	0.68835458	34	Coarse	mesic	mesotrophic
01-140	1833	-0.4771588	0.87881711	31	Coarse	very xeric	submesotrophic
01-164	1919	-0.9636305	0.26723838	44	Coarse	xeric	submesotrophic
02-244	2348	-0.6755902	0.73727734	24	Medium	xeric	mesotrophic
rocky (23)							
02-267	1971	0.87881711	0.47715876	6	Medium	subxeric	permesotrophic
02-269	1975	0.99904822	0.04361939	2	Coarse	subxeric	permesotrophic
02-273	2127	0.21643961	0.97629601	22	Coarse	subxeric	mesotrophic
rocky (24)							
01-081	2161	0.14780941	0.98901586	9	Medium	very xeric	mesotrophic
02-200	2304	-0.3007058	0.95371695	28	Fine	subxeric	mesotrophic
02-243	2343	-0.6087614	0.79335334	13	Medium	subxeric	mesotrophic

02-270	1968	0.99357186	0.11320321	3	Medium	subxeric	permesotrophic
rocky (25)							
01-084	2259	-0.3826834	0.92387953	0	Medium	very xeric	mesotrophic
02-205	2106	-0.9969173	-0.0784591	37	Coarse	subxeric	mesotrophic
02-245	2406	-0.8433914	0.53729961	21	Coarse	subxeric	mesotrophic
Cassiope							
01-038	1774	-0.5948228	0.80385686	5	Coarse	hygric	submesotrophic
01-072	1876	-0.7489557	0.66262005	39	Organic	hygric	submesotrophic
01-128	1974	0.89493436	0.44619781	5	Medium	submesic	mesotrophic
02-191	2264	-0.1822355	0.98325491	24	Coarse	mesic	mesotrophic
02-218	2183	0.0784591	0.99691733	2	Organic	submesic	mesotrophic
02-226	2283	0.99357186	0.11320321	9	Medium	mesic	mesotrophic
02-253	1855	-0.6755902	0.73727734	32	Medium	mesic	submesotrophic
03-288	2114	0.96814764	0.25038	17	Medium	subxeric	mesotrophic
Phyllodoce glanduliflora							
01-099	2126	-0.3826834	0.92387953	0	Medium	mesic	submesotrophic
02-197	2272	0.95371695	-0.3007058	12	Coarse	mesic	mesotrophic
02-225	2277	0.96363045	0.26723838	5	Medium	submesic	mesotrophic
02-248	2403	0.50753836	0.86162916	0	Medium	subxeric	mesotrophic
Cassiope mertensiana							
01-054	2213	-0.9304176	0.36650123	5	Medium	subhygric	permesotrophic
01-069	2238	-0.3826834	0.92387953	0	Medium	subhygric	submesotrophic
01-125	1949	-0.3826834	0.92387953	0	Coarse	mesic	mesotrophic
01-126	1951	-0.2334454	0.97236992	4	Coarse	mesic	mesotrophic
01-139	1858	-0.5372996	0.84339145	38	Coarse	very xeric	submesotrophic
02-216	2178	0.26723838	0.96363045	12	Medium	submesic	mesotrophic
02-219	2173	0.94832366	0.31730466	5	Medium	submesic	mesotrophic

02-228	2152	0.0784591	0.99691733	26	Medium	submesic	mesotrophic
02-230	2167	0.44619781	0.89493436	2	Medium	submesic	mesotrophic
02-231	2153	0.90996127	0.41469324	6	Medium	hygric	mesotrophic
Cassiope tetragona							
01-052	2214	-0.9862856	0.16504761	17	Medium	xeric	submesotrophic
01-076	2324	0.26723838	-0.96363045	6	Medium	very xeric	submesotrophic
01-106	2134	-0.3338069	0.94264149	11	Medium	submesic	mesotrophic
01-135	2179	-0.7489557	0.66262005	5	Medium	subxeric	permesotrophic
01-147	2301	-0.9636305	0.26723838	17	Medium	subxeric	permesotrophic
01-154	2083	-0.1478094	0.98901586	11	Medium	subxeric	mesotrophic
02-201	2055	-0.976296	0.21643961	9	Medium	subhygric	permesotrophic
02-283	1971	-0.0087265	0.99996192	18	Medium	submesic	permesotrophic
Empetrum nigrum							
01-064	2091	-0.1993679	-0.9799247	1	Medium	submesic	submesotrophic
01-073	1866	-0.976296	0.21643961	39	Medium	very xeric	mesotrophic
01-129	1983	0.38268343	0.92387953	5	Medium	submesic	mesotrophic
01-155	2117	-0.4771588	0.87881711	6	Medium	xeric	mesotrophic
Dryas integrifolia							
01-024	2126	0.99357186	0.11320321	7	Coarse	mesic	mesotrophic
02-236	2366	-0.7372773	0.67559021	3	Medium	submesic	permesotrophic
02-237	2364	-0.5664062	0.82412619	1	Medium	submesic	permesotrophic
02-264	1944	0.38268343	0.92387953	7	Medium	submesic	permesotrophic
Dryas octopetala							
01-047	2111	-0.4461978	0.89493436	6	Medium	submesic	submesotrophic
01-055	2221	0.59482279	0.80385686	9	Medium	submesic	permesotrophic
01-070	2236	-0.3826834	0.92387953	0	Medium	mesic	submesotrophic
01-096	2195	0.9862856	0.16504761	22	Medium	mesic	mesotrophic

01-098	2179	0.73727734	0.67559021	9	Medium	submesic	mesotrophic
01-110	2205	-0.6087614	0.79335334	12	Medium	submesic	mesotrophic
01-146	2298	-0.9890159	-0.14780941	17	Medium	subxeric	permesotrophic
02-222	2176	0.9862856	-0.16504761	11	Medium	submesic	mesotrophic
02-224	2282	0.74895572	-0.66262005	5	Medium	submesic	mesotrophic
02-246	2394	0.97629601	0.21643961	19	Medium	subxeric	mesotrophic
02-247	2438	-0.7933533	0.60876143	2	Medium	subxeric	mesotrophic
02-249	2347	0.89493436	0.44619781	24	Medium	subxeric	mesotrophic
02-260	2240	-0.9969173	-0.0784591	22	Coarse	xeric	mesotrophic
Vaccinium uliginosum							
01-075	2312	0.79335334	0.60876143	3	Medium	very xeric	mesotrophic
01-107	2162	-0.3338069	0.94264149	11	Coarse	submesic	mesotrophic
01-109	2277	-0.3338069	0.94264149	22	Medium	very xeric	mesotrophic
02-227	2248	0.92387953	0.38268343	5	Medium	subxeric	mesotrophic
02-250	1903	-0.8433914	0.53729961	25	Medium	xeric	submesotrophic
02-251	1915	-0.9366722	0.35020738	28	Medium	xeric	submesotrophic
Dryas integrifolia							
01-023	2140	0.63607822	0.77162458	17	Medium	subxeric	mesotrophic
01-083	2223	0.23344536	0.97236992	3	Medium	very xeric	mesotrophic
01-086	2101	-0.5664062	0.82412619	7	Medium	very xeric	mesotrophic
01-088	2211	0.85264016	0.52249856	12	Medium	xeric	submesotrophic
01-090	2189	0.9953962	0.09584575	12	Medium	submesic	mesotrophic
01-102	2064	-0.8038569	0.59482279	3	Medium	submesic	permesotrophic
01-104	2040	0.85264016	0.52249856	3	Medium	submesic	permesotrophic
01-131	2259	0.86162916	0.50753836	5	Medium	subxeric	mesotrophic

02-235	2362	0.90996127	0.41469324	7	Coarse	subxeric	permesotrophic
02-263	1941	0.38268343	0.92387953	11	Medium	submesic	permesotrophic
02-265	1945	0.31730466	0.94832366	15	Coarse	submesic	mesotrophic
02-272	2131	0.0784591	0.99691733	14	Coarse	subxeric	mesotrophic
02-280	2057	-0.7253744	0.68835458	18	Medium	submesic	permesotrophic
02-282	2014	-0.7716246	0.63607822	27	Medium	submesic	mesotrophic
Salix nivalis							
01-022	2145	-0.7489557	0.66262005	22	Medium	very xeric	submesotrophic
01-059	2388	-0.25038	0.96814764	3	Medium	xeric	submesotrophic
01-080	2154	-0.1132032	0.99357186	15	Medium	very xeric	submesotrophic
01-087	2209	0.25038	0.96814764	17	Medium	subxeric	submesotrophic
01-122	2020	0.99904822	0.04361939	6	Medium	subxeric	permesotrophic
01-123	2097	0.98325491	0.18223553	15	Medium	subxeric	mesotrophic
01-145	2339	0.46174861	0.88701083	21	Medium	very xeric	mesotrophic
02-194	2035	-0.8241262	0.56640624	10	Medium	mesic	mesotrophic
Salix nivalis							
01-058	2399	-0.25038	0.96814764	6	Medium	very xeric	mesotrophic
01-085	2261	-0.760406	0.64944805	11	Medium	very xeric	mesotrophic
01-113	1852	-0.3826834	0.92387953	0	Medium	subhygric	submesotrophic
02-192	2039	-0.9366722	0.35020738	11	Fine	submesic	mesotrophic
02-232	2418	-0.4617486	0.88701083	10	Medium	submesic	mesotrophic
Salix arctica							
01-049	2115	-0.3502074	0.93667219	9	Medium	mesic	submesotrophic
01-050	2117	-0.0436194	0.99904822	7	Medium	hygric	permesotrophic
01-053	2216	-0.3826834	0.92387953	3	Coarse	mesic	mesotrophic
01-067	2134	-0.9990482	0.04361939	6	Medium	submesic	submesotrophic
01-068	2127	-0.3826834	0.92387953	0	Medium	hygric	permesotrophic

01-092	2121	0.96814764	0.25038	10	Medium	mesic	mesotrophic
01-093	2063	-0.3826834	0.92387953	4	Medium	hygric	permesotrophic
01-097	2188	0.73727734	0.67559021	16	Medium	subhygric	submesotrophic
01-124	2101	0.72537437	0.68835458	5	Medium	xeric	permesotrophic
01-133	2184	-0.3826834	0.92387953	0	Fine	subhygric	mesotrophic
02-199	2309	-0.2672384	0.96363045	22	Fine	submesic	mesotrophic
02-220	2186	-0.1132032	0.99357186	24	Medium	subxeric	mesotrophic
02-261	2126	-0.953717	0.3007058	29	Medium	subxeric	submesotrophic
03-291	2264	0.99691733	0.0784591	4	Medium	hygric	submesotrophic
Salix arctica							
01-051	2147	-0.0436194	0.99904822	56	Medium	very xeric	mesotrophic
01-082	2177	-0.9999619	0.00872654	7	Medium	mesic	mesotrophic
01-089	2226	0.53729961	0.84339145	19	Medium	subxeric	mesotrophic
01-108	2309	-0.3826834	0.92387953	0	Medium	hygric	mesotrophic
01-132	2244	0.78260816	0.62251464	2	Fine	subhygric	mesotrophic
02-239	2346	-0.4617486	0.88701083	24	Medium	subxeric	permesotrophic
03-290	2297	0.63607822	0.77162458	0	Medium	xeric	submesotrophic
03-292	2280	-0.2840153	0.95881973	1	Medium	xeric	submesotrophic
low shrub							
01-062	1142	-0.25038	0.96814764	19	Medium	subhygric	submesotrophic
01-063	1155	-0.3826834	0.92387953	0	Organic	hygric	submesotrophic
Salix-Betula							
01-029	1627	0.31730466	0.94832366	1	Organic	subhygric	oligotrophic
01-030	1617	0.72537437	0.68835458	0	Organic	subhygric	oligotrophic
Salix spp.							
01-141	1740	-0.0087265	0.99996192	5	Medium	submesic	mesotrophic
01-142	1833	-0.9723699	0.23344536	6	Medium	submesic	mesotrophic

02-204	2037	-0.9588197	0.28401534	1	Coarse	mesic	permesotrophic
Alnus-Ribes							
02-255	1701	0.21643961	0.97629601	27	Medium	subxeric	submesotrophic
02-256	1652	0.95881973	0.28401534	6	Medium	mesic	mesotrophic
Carex aquatilis							
01-036	1543	-0.3826834	-0.92387953	0	Coarse	xeric	permesotrophic
01-094	2058	-0.3826834	0.92387953	0	Medium	hygric	permesotrophic
Carex spectabilis							
01-037	1762	-0.9890159	0.14780941	2	Coarse	xeric	submesotrophic
01-120	1972	-0.3826834	0.92387953	0	Medium	mesic	submesotrophic
01-157	2126	-0.4461978	0.89493436	3	Medium	mesic	mesotrophic
Carex nigricans							
01-066	2083	-0.9366722	0.35020738	3	Medium	hygric	submesotrophic
01-091	2175	0.96814764	0.25038	10	Medium	submesic	mesotrophic
01-121	1981	-0.8141155	0.58070296	3	Medium	mesic	submesotrophic
01-130	1983	-0.3826834	0.92387953	0	Medium	mesic	permesotrophic
02-196	2234	-0.6883546	0.72537437	12	Medium	mesic	mesotrophic
02-217	2177	0.26723838	0.96363045	6	Medium	subhydric	mesotrophic
02-229	2167	0.53729961	0.84339145	7	Medium	mesic	mesotrophic
03-287	1759	-0.5224986	0.85264016	1	Medium	mesic	mesotrophic
03-289	2102	0.47715876	0.87881711	8	Medium	submesic	mesotrophic
Carex nigricans							
01-056	2226	-0.25038	0.96814764	4	Medium	mesic	permesotrophic
02-198	2256	0.8703557	0.49242356	11	Organic	mesic	mesotrophic
Anemone occidentalis							
03-293	2268	-0.0610485	-0.9981348	20	Medium	submesic	mesotrophic
03-294	2230	-0.2164396	0.97629601	32	Medium	xeric	submesotrophic

Parnassia fimbriata							
02-259	1635	0.52249856	0.85264016	3	Medium	subhygric	permesotrophic
02-277	1887	-0.6755902	0.73727734	18	Medium	subhygric	mesotrophic
Trollius albiflorus							
01-095	2049	-0.9799247	0.19936793	6	Medium	mesic	submesotrophic
01-111	2096	-0.8141155	0.58070296	11	Medium	subhygric	submesotrophic
01-112	2099	-0.8338858	0.55193699	25	Medium	subhygric	submesotrophic
Artemisia norvegica							
01-119	1978	0.84339145	0.53729961	7	Medium	mesic	permesotrophic
01-144	2279	-0.6360782	0.77162458	17	Medium	subxeric	permesotrophic
02-203	2046	0.53729961	0.84339145	20	Organic	submesic	submesotrophic
02-221	2190	0.35020738	0.93667219	35	Coarse	xeric	mesotrophic
02-233	2420	-0.3007058	0.95371695	6	Fine	mesic	mesotrophic
02-234	2413	-0.3007058	0.95371695	5	Medium	submesic	mesotrophic
Artemisia michauxiana							
01-136	2377	0.14780941	0.98901586	6	Medium	submesic	mesotrophic
02-238	2356	-0.5664062	0.82412619	19	Medium	subxeric	permesotrophic
02-254	1652	0.95371695	-0.3007058	26	Coarse	subxeric	submesotrophic

SITE	ArcsineP	ArcsineN	ArcsineC	logCa	logMg	logK	logNa+min	logCEC	pH
Tree									
Picea glauca									
01-002	0.015493	0.024497	0.117144	1.730298	0.100371	-1.01773	-1.243125	0.857152	5.1
01-011	0.023024	0.10912	0.580632	2.005266	1.110253	0.080987	-1.507638	2.15591	6.6
01-017	0.021215	0.055796	0.249313	1.458487	0.49276	-0.20204	-1.39694	1.376139	8.29
01-033	0.035221	0.029837	0.177193	1.327155	0.217484	-0.73049	-1.016729	0.652053	7.93
01-061	0.022805	0.060036	0.315668	1.693375	0.780317	-0.34775	-0.784156	1.625672	6.44
02-175	0.028111	0.069338	0.324242	1.547298	1.319453	-0.46154	0.017452	1.536453	8.03
02-184	0.035079	0.022363	0.249355	1.302087	-0.27812	-1.0997	-1.771896	0.33047	8.6
02-212	0.031469	0.129981	0.624959	1.685171	1.439036	-0.21221	-0.701477	1.945619	8.01
Populus tremuloides									
01-004	0.025301	0.040136	0.172434	0.959518	0.462398	-0.22915	-1.480486	1.100508	6.23
01-114	0.015493	0.040631	0.191804	1.693375	0.559907	-0.15181	-0.961574	1.412864	7.84
01-115	0.029159	0.069986	0.330971	1.58816	0.659916	-0.33536	-0.977811	1.399535	7.86
01-116	0.016734	0.04496	0.215175	1.485863	0.49276	-0.27901	-1.007774	1.432905	7.7
01-118	0.017321	0.041605	0.167089	0.95376	0.206826	-0.01682	-0.919819	0.980458	6.85
01-161	0.019237	0.033622	0.151777	1.040602	0.356026	-0.51428	-1.035212	1.080699	5.71
02-179	0.012649	0.037425	0.164137	0.943185	0.286774	0.120743	-1.437484	0.92147	7.12
02-182	0.034503	0.091231	0.400353	1.497603	0.812496	-0.1545	-1.555907	1.554355	8.1
02-274	0.031469	0.044736	0.18155	1.109283	0.244586	-0.20457	-1.412315	1.067412	6.43
02-285	0.030005	0.051012	0.291877	1.579526	0.282547	-0.59215	-1.523139	1.139966	7.56
Elymus lanceolatus-Koeleria macrantha									
01-012	0.025693	0.045623	0.233036	1.615319	0.462398	-0.40121	-1.375751	1.12772	8.22
01-117	0.016432	0.039507	0.182477	1.51175	0.478566	-0.66154	-0.91264	1.094785	7.98

Pseudotsuga menziesii									
01-010	0.011402	0.030827	0.175281	1.65906	0.659916	-0.20204	-0.994679	1.273973	7.74
01-166	0.017889	0.029159	0.138829	1.196729	0.498311	-0.17263	-0.88841	1.191647	6.35
02-180	0.019237	0.030005	0.116453	0.946268	0.115333	-0.28303	-1.523139	0.893484	7.82
02-181	0.010955	0.026461	0.122783	0.818638	0.019462	-0.55066	-1.424717	0.957048	7.12
02-186	0.016125	0.042439	0.257391	1.450615	0.391009	-0.12198	-1.437484	1.419772	7.93
02-208	0.019237	0.036063	0.152245	0.871354	0.079935	-0.24325	-1.831811	1.003365	7.12
02-211	0.014143	0.037425	0.164137	0.654297	0.040569	-0.49415	-1.555907	1.111384	6.15
Pinus contorta									
01-003	0.021449	0.025102	0.136734	0.965672	0.206826	-0.73049	-1.166491	0.946059	5.97
01-020	0.012248	0.030005	0.143283	0.607455	-0.0655	-0.70115	-1.166491	1.211601	5.03
01-152	0.033172	0.043946	0.226886	-0.14874	-0.27572	-0.57187	-0.868666	1.528081	4.58
01-153	0.024292	0.045513	0.237579	0.599883	0.170262	-0.43063	-0.715699	1.511255	4.38
01-159	0.014143	0.01975	0.085779	0.828015	0.117271	-0.78252	-0.852872	0.746323	5.12
01-168	0.012649	0.035363	0.215606	1.719994	0.622214	-0.28067	-0.509042	1.519644	7.89
01-169	0.016432	0.039507	0.168093	0.613842	-0.20066	-0.57187	-0.763472	1.181815	5.05
01-170	0.015812	0.031628	0.165312	0.859138	0.170262	-0.33724	-0.768551	1.274065	5.36
01-171	0.026836	0.068683	0.454839	1.096215	0.485721	0.186674	-0.868666	1.92285	3.74
01-172	0.013784	0.028814	0.123562	0.082785	-0.22915	-0.69037	-0.905578	1.0086	4.27
02-190	0.019237	0.036063	0.162266	0.735299	-0.18018	-0.64167	-1.672308	1.094102	6.46
02-207	0.013784	0.030005	0.132676	0.713805	-0.0549	-0.97302	-1.478203	1.003125	6.4
02-210	0.014143	0.028288	0.140822	0.354349	-0.37589	-0.71456	-1.555907	0.780257	5.37
03-298	0.031628	0.04972	0.243394	0.756636	-0.03152	-0.55284	-0.953677	1.31597	5.01
Abies bifolia									
01-025	0.03115	0.028288	0.107398	0.895423	-0.02228	-0.90309	-1.507638	1.233352	6.07
01-074	0.02025	0.03377	0.132333	0.103804	-0.40894	-0.89279	-0.895196	1.069779	4.87

01-100	0.022363	0.05294	0.24365	-1.22185	-0.79588	-0.68825	-0.834647	1.160439	4.67
01-143	0.017608	0.074433	0.579323	0.841985	-0.16749	-0.31515	-0.67062	2.076924	3.3
01-151	0.02864	0.057825	0.255966	0.718502	-0.08619	-0.47108	-0.840638	1.650453	4.88
01-158	0.018975	0.034792	0.147194	0.557507	0.075547	-0.78252	-0.758451	1.241322	4.4
01-167	0.023024	0.055886	0.256903	0.40824	-0.39794	-0.64016	-0.797603	1.619584	4.36
02-258	0.016125	0.022363	0.13532	0.074176	-0.94088	-0.92595	-1.831811	0.864972	4.66
02-262	0.023667	0.05294	0.205902	0.160993	-0.70352	-0.82577	-1.295148	0.921759	5.04
02-276	0.027572	0.044736	0.211087	0.740264	0.026329	-0.71456	-1.180889	1.221052	4.96
03-302	0.014143	0.035079	0.198222	0.421604	-0.4437	-0.88606	-0.916215	1.221675	4.84
Gymnocarpium dryopteris									
01-040	0.013417	0.032717	0.157203	0.738781	0.206826	-1.07058	-1.059481	0.779308	6.24
02-286	0.064075	0.053878	0.26022	1.415245	0.628389	-1.15173	-1.218338	1.439508	6.58
03-303	0.031628	0.113513	0.59023	2.021231	0.955688	-0.72125	-0.820023	1.885813	6.6
Picea engelmannii									
01-034	0.040011	0.060369	0.275673	1.397245	0.919601	-0.59176	-1.007774	1.515476	7.23
01-103	0.022138	0.057651	0.25482	1.226858	0.650308	-0.26922	-0.8031	1.564323	6.47
02-209	0.019237	0.034648	0.163204	0.192776	-0.49655	-1.08253	-1.388525	0.862496	4.81
02-275	0.035363	0.111134	0.561933	1.907324	1.438905	-0.24667	-0.358	1.920109	6.8
02-278	0.032099	0.089562	0.504327	1.425106	0.654618	-0.46477	-0.935357	1.867034	5.17
03-299	0.017321	0.042674	0.251998	0.999565	-0.07058	-0.58503	-0.849781	1.302764	5.24
03-301	0.017321	0.042321	0.205327	1.414806	0.419956	-0.85387	-0.953677	1.32695	7.62
Shrub									
Arctostaphylos uva-ursi									
01-006	0.02025	0.043373	0.330922	1.682235	0.264818	-0.52143	-1.419216	0.950267	8.1
02-185	0.022363	0.051985	0.305565	1.344368	0.708279	-1.04391	-1.259324	0.895254	8.31
02-187	0.02025	0.110223	0.53712	1.437334	-0.10605	-0.81473	-1.695147	0.845356	8.18

Elaeagnus commutata									
01-014	0.023667	0.037559	0.27636	1.634578	0.535294	-0.83268	-1.317759	1.023088	8.16
02-183	0.034503	0.063288	0.312126	1.403742	0.243555	-0.92595	-1.464202	1.068134	7.81
Salix glauca									
01-021	0.03848	0.121293	0.448063	1.874888	1.221153	-0.07263	-0.50207	2.013128	6.33
01-035	0.037824	0.051501	0.204876	1.210586	0.829947	-0.73049	-0.969616	1.19992	7.49
01-060	0.026461	0.064698	0.276797	1.909663	0.93044	-0.25885	-0.695804	1.434217	7.8
02-202	0.042908	0.139375	0.566028	1.652718	0.777548	-0.71025	-1.355118	1.908515	6.28
02-215	0.032563	0.139011	0.70718	1.740155	1.208844	0.132801	-1.507638	1.870867	7.31
Salix drummondiana									
01-032	0.036202	0.041364	0.220576	1.397766	0.264818	-0.55909	-0.927118	1.153083	7.66
01-039	0.008944	0.014833	0.054891	-0.12494	-0.50864	-1.29243	-1.090515	-0.13549	6.68
01-045	0.013784	0.025102	0.120122	0.586587	0.045323	-0.76195	-0.969616	0.67532	5.78
Salix farriae									
01-042	0.011832	0.01703	0.061357	-0.04576	-0.27572	-1.18709	-1.069581	0.196453	6.02
01-043	0.011402	0.01703	0.06225	-0.13077	-0.60206	-1.25181	-0.868666	0.304059	5.08
01-044	0.013417	0.017321	0.059785	0.075547	-0.16749	-1.22915	-0.961574	0.297761	4.71
Salix barrattiana									
01-048	0.041485	0.120541	0.487372	1.96009	1.300595	-0.15989	-0.706744	1.941178	6.03
01-149	0.03848	0.045513	0.198584	1.193403	0.772322	-1.08092	-0.91264	1.19493	7.82
Salix arctica									
01-071	0.019495	0.02324	0.139412	1.418964	0.559907	0.016197	-0.678854	0.979821	8.11
02-268	0.03377	0.059195	0.251646	1.443028	0.590136	-0.63803	-1.719254	1.406777	7.34
Abies bifolia									
01-101	0.030989	0.084718	0.337426	1.375481	0.868056	0.011147	-0.994679	1.65055	5.68
01-127	0.021215	0.039253	0.141933	-0.48149	-0.49485	-0.71897	-0.820023	1.09489	4.08
01-148	0.035504	0.06233	0.253958	0.082785	-0.55284	-0.69037	-0.751027	1.49195	4.88

01-162	0.01	0.02025	0.092272	0.526339	-1.39794	-0.7986	-0.934542	0.392169	4.74
02-257	0.015166	0.044736	0.165374	0.448899	0.063052	-0.89646	-2.416245	0.997156	4.15
02-284	0.03938	0.06861	0.314344	1.285248	0.583104	-0.47545	-1.173772	1.605933	5.22
Herb									
Elymus lanceolatus-Koeleria macrantha									
01-001	0.026271	0.063918	0.309189	1.687886	0.650308	-0.55909	-1.153902	1.264676	8.01
01-005	0.025301	0.042908	0.267352	1.621799	0.290035	-0.57025	-1.19282	1.054958	8.03
01-016	0.013784	0.023024	0.092815	1.327155	0.037426	-0.79588	-1.153902	0.792672	8.32
01-165	0.01975	0.040508	0.143035	1.069298	0.356026	-0.47108	-0.91264	1.135578	6.57
02-178	0.023667	0.060865	0.205152	1.206117	0.204685	-0.33761	-1.388525	1.133849	7.38
02-206	0.024497	0.053878	0.198274	1.305324	0.126294	-0.40566	-1.865183	0.998671	7.89
Achnatherum richardsonii									
01-160	0.035785	0.076626	0.244269	1.693375	0.414973	-0.39469	-0.808668	1.411687	7.35
02-173	0.026461	0.077537	0.30012	1.478909	0.464266	-0.27878	-1.800821	1.428944	7.75
02-174	0.032869	0.087863	0.368268	1.531303	0.320492	-0.29058	-3.246784	1.430917	7.7
Festuca altaica									
01-028	0.02608	0.040999	0.139666	0.748188	0.060698	-0.92812	-1.243125	1.194958	4.97
02-271	0.034065	0.076887	0.345821	1.545013	0.630301	-0.57508	-1.355118	1.563019	6.12
Fragaria virginiana									
01-079	0.019237	0.026461	0.12563	1.04917	-0.20848	-0.67593	-1.719254	0.921397	7.46
02-213	0.019495	0.033172	0.134945	0.787903	-0.22336	-0.86271	-1.365971	0.862413	7.6
02-214	0.024086	0.045842	0.207892	1.064879	-0.12133	-0.42449	-1.771896	1.023081	7.82
02-240	0.027752	0.031628	0.200847	1.381002	0.313955	-0.71168	-2.561387	0.779055	7.9
03-295	0.031628	0.040508	0.20685	1.473633	0.130334	-0.48149	-1.039959	1.075182	7.56
03-297	0.020001	0.049315	0.335436	1.659916	-0.04096	-0.42022	-1.039959	1.209247	7.82
open graminoid									
01-015	0.02025	0.052081	0.270222	1.640879	0.462398	-0.63639	-1.29143	1.211894	7.99

01-138	0.02608	0.074298	0.291404	0.895423	0.212188	-1.11919	-0.711198	1.68401	5.12
02-177	0.032717	0.050021	0.297097	1.445585	0.022909	-0.94027	-2.307649	0.988509	8.15
02-223	0.028814	0.031628	0.102158	1.051104	0.428	-0.78658	-1.555907	0.770033	7.79
02-252	0.014833	0.028288	0.118173	0.334705	-0.33685	-0.93067	-2.032348	0.779957	4.56
cliff (2)									
01-007	0.023877	0.057912	0.327818	1.759592	0.447158	-0.39362	-1.507638	1.231903	8.15
01-008	0.014833	0.021215	0.330206	1.503246	0.012837	-0.74715	-1.19282	0.357172	8.6
01-009	0.023024	0.05704	0.304413	1.634578	0.706718	-0.54975	-1.454932	0.968483	8.17
02-189	0.023024	0.060865	0.297454	1.424861	0.231512	-0.70457	-1.314233	1.063156	7.93
outcrop (3)									
01-013	0.033323	0.064853	0.272815	1.655006	0.40262	-0.32921	-2.032348	1.176413	7.81
02-281	0.02933	0.070057	0.387944	1.285529	0.897169	-0.59984	-1.365971	1.354135	8.03
outcrop (4)									
02-188	0.02933	0.043603	0.213515	1.751173	1.434901	-0.28949	-1.355118	1.925233	8.12
02-279	0.026461	0.051012	0.337586	1.133898	0.592686	-1.00279	-1.464202	0.977342	7.81
drainage channel (6)									
01-019	0.03634	0.068244	0.255373	1.439175	0.925828	-0.45223	-1.179456	1.524798	7.3
01-031	0.035363	0.040011	0.21443	1.448861	0.596597	-0.54061	-0.741321	0.967314	7.77
01-150	0.036887	0.068683	0.218365	1.210319	0.669317	-0.78252	-0.88841	1.569374	5.84
rocky (9)									
01-065	0.030005	0.071755	0.283366	0.40654	-0.1549	-0.36754	-0.846712	1.466512	4.57
01-156	0.017889	0.031943	0.112397	-0.5376	-1.30103	-0.78252	-0.934542	1.009706	4.9
talus (7)									
01-057	0.02324	0.020738	0.202757	1.458487	0.264818	-0.74715	-0.881729	0.548881	8.18
01-134	0.020001	0.046385	0.166967	0.697229	0.318063	-0.47886	-1.016729	1.273719	5.17
talus (10)									
01-077	0.01703	0.025693	0.081021	0.686636	0.184691	-0.52143	-1.007774	0.793301	6.3

01-078	0.027572	0.01703	0.043946	0.786041	0.639486	-0.54975	-0.986163	0.821448	7.3
02-193	0.023877	0.01	0.08071	0.429146	-0.20267	-1.08591	-1.831811	0.66472	7.44
02-195	0.022805	0.024497	0.072866	0.303466	0.276845	-1.12124	-1.719254	0.771363	6.89
02-266	0.032409	0.026461	0.191698	1.110127	0.324797	-0.86069	-2.307649	1.047275	6.73
sparse (11)									
01-027	0.025693	0.031469	0.113469	1.040998	0.584331	-0.57025	-1.21367	0.964919	6.5
01-105	0.015493	0.011832	0.263579	1.40841	0.060698	-1.25181	-0.881729	-0.41341	8.73
02-176	0.024902	0.024497	0.304693	1.285529	-0.2747	-1.40073	-2.780944	0.471862	8.64
sparse (14)									
01-041	0.017608	0.021681	0.059195	0.586587	0.10721	-0.60206	-1.044757	0.517592	7.66
01-046	0.018167	0.01975	0.052845	0.795185	0.133539	-1.13077	-0.919819	0.629206	7.8
01-163	0.010955	0.019237	0.067727	-0.04096	-0.5376	-0.74958	-0.942095	0.111263	5.89
rocky (28)									
01-137	0.02324	0.039634	0.148327	0.372912	-0.25181	-0.76447	-0.986163	0.909449	5.9
01-140	0.011832	0.021911	0.07656	-0.69897	-0.82391	-0.74958	-0.994679	-0.22475	5.36
01-164	0.01	0.015166	0.049921	-0.09151	-1.30103	-1.23657	-1.069581	-0.56067	5.68
02-244	0.024701	0.020001	0.0548	0.714853	-0.20412	-1.08591	-2.307649	0.440647	7.12
rocky (23)									
02-267	0.030664	0.064075	0.233858	1.622732	0.451978	0.894515	-1.800821	0.371837	7.85
02-269	0.026271	0.037425	0.200591	1.108861	0.153815	-0.80219	-1.555907	1.039524	7.24
02-273	0.043025	0.044736	0.177279	1.046251	0.48902	-0.77482	-1.629946	1.11185	6.59
rocky (24)									
01-081	0.036477	0.040877	0.162046	1.020775	0.68842	-0.64975	-0.977811	0.881898	7.5
02-200	0.02324	0.020001	0.065621	0.991171	-0.63202	-1.1557	-1.865183	0.912488	7.92
02-243	0.024292	0.022363	0.137178	1.5205	-0.56067	-1.15173	-1.984151	0.531124	8.34
02-270	0.028987	0.040011	0.186553	1.254034	0.397578	-0.73981	-1.365971	1.159617	7.39
rocky (25)									

01-084	0.032255	0.056776	0.211209	0.977266	0.572872	-0.53018	-1.101373	1.200248	5.91
02-205	0.028464	0.047977	0.160056	0.687863	0.336626	-0.68527	-1.719254	1.009722	6.59
02-245	0.025887	0.024497	0.070057	0.583907	-0.18293	-1.10676	-2.14854	0.546988	6.17
Cassiope									
01-038	0.010955	0.013039	0.046277	-0.33724	-0.58503	-1.42022	-0.961574	-0.33068	6.53
01-072	0.024902	0.07314	0.380316	0.556303	0.056905	0.815578	-0.604548	1.572744	4.58
01-128	0.027752	0.063209	0.231339	0.359835	-0.23657	-0.57187	-1.044757	1.464922	4.4
02-191	0.024902	0.053878	0.203137	0.727236	0.325225	-0.80396	-1.412315	0.910936	6.25
02-218	0.041243	0.127625	0.558378	0.954182	0.434702	0.341028	-1.555907	1.885864	4.42
02-226	0.023667	0.030005	0.09341	0.498138	-0.37805	-1.00843	-1.940772	0.681492	6
02-253	0.01844	0.037425	0.14819	-0.31314	-1.24988	-0.96782	-1.771896	0.570964	5.24
03-288	0.028288	0.056154	0.223486	-0.284	-0.92082	-1	-0.994679	1.41302	5.01
Phyllodoce glanduliflora									
01-099	0.026461	0.090512	0.403603	0.859739	0.521138	-0.07935	-0.953677	1.707775	4.25
02-197	0.024292	0.041243	0.167211	-0.1093	-0.7222	-1.19749	-1.672308	0.908708	5.75
02-225	0.032255	0.072866	0.260422	0.595083	-0.27641	-0.46315	-1.377102	0.907889	5.64
02-248	0.026271	0.041243	0.144727	0.069576	-0.55091	-0.72774	-1.555907	0.973256	4.78
Cassiope mertensiana									
01-054	0.024292	0.058171	0.218175	0.909021	0.478566	-0.58004	-0.88841	1.352607	5.6
01-069	0.032255	0.080897	0.39317	0.866878	0.49276	-0.33536	-0.642974	1.822351	4.45
01-125	0.014492	0.030336	0.124742	0.029384	-0.79588	-1.3279	-0.994679	0.597805	4.61
01-126	0.014833	0.034503	0.159324	-0.42022	-0.58503	-0.87615	-0.969616	0.736476	4.2
01-139	0.010955	0.018975	0.080211	-0.55284	-0.74473	-1.11919	-1.035212	0.144885	5.14
02-216	0.027752	0.059195	0.23408	-0.08223	-0.49372	-0.66292	-1.507638	1.859205	4.81
02-219	0.027572	0.045842	0.175543	-0.9537	-0.71745	-1.01703	-1.523139	1.908344	4.73
02-228	0.023024	0.026461	0.088999	0.628261	0.26961	-0.72923	-1.744778	0.803438	6.4
02-230	0.026649	0.050021	0.19488	-0.29886	-0.44825	-0.81838	-1.695147	1.12062	4.74

02-231	0.024292	0.044736	0.168123	0.714853	0.170628	-0.57091	-2.220849	1.028029	5.47
Cassiope tetragona									
01-052	0.025102	0.04724	0.18365	0.557507	0.08636	-0.97469	-0.953677	1.057894	5.6
01-076	0.025498	0.050021	0.193798	0.416641	-0.42022	-0.77728	-0.758451	1.182671	5.37
01-106	0.032717	0.082617	0.319695	1.448861	0.971276	-0.31785	-0.840638	1.436274	6.77
01-135	0.015493	0.031628	0.10721	0.474216	0.158362	-0.56225	-0.881729	1.195983	5.22
01-147	0.032717	0.066381	0.262384	0.549003	-0.09151	-0.99568	-0.814309	1.471042	5.43
01-154	0.023454	0.048907	0.203945	-0.60206	-1.39794	-1.02687	-0.895196	1.2714	5.17
02-201	0.021449	0.026461	0.080086	0.655499	0.444565	-0.99722	-1.400257	1.01313	7.15
02-283	0.044399	0.115583	0.475911	1.656505	1.165096	-0.34679	-1.259324	1.893484	7.04
Empetrum nigrum									
01-064	0.023667	0.047872	0.1742	-0.01773	-0.45593	-0.77728	-0.834647	1.307025	4.88
01-073	0.01703	0.045182	0.242237	0.075547	-0.38722	-0.59176	-0.88841	1.064046	4.57
01-129	0.019237	0.037956	0.138244	-0.01323	-0.46852	-0.97881	-1.025872	0.857152	4.75
01-155	0.012649	0.018709	0.066381	-0.95861	-1.69897	-1.25181	-1.035212	0.680517	4.78
Dryas integrifolia									
01-024	0.033473	0.048702	0.175397	0.95376	0.447158	-0.40121	-1.375751	1.23945	6.53
02-236	0.022363	0.040011	0.305391	1.500116	0.374137	-0.92595	-2.780944	0.718778	8.25
02-237	0.05111	0.033172	0.434232	1.713931	1.00789	-0.31691	-0.919347	1.288175	6.91
02-264	0.032255	0.030005	0.112487	0.851946	0.28396	-0.66037	-1.591351	0.622243	6.49
Dryas octopetala									
01-047	0.049619	0.09721	0.388971	1.954098	1.242541	-0.44491	-0.715699	1.834224	6.53
01-055	0.032869	0.069338	0.24318	0.935003	0.547775	-0.39362	-0.994679	1.489846	5.52
01-070	0.046707	0.12575	0.485254	1.935608	1.335257	-0.53018	-0.618789	2.080063	6.84
01-096	0.022805	0.041243	0.165096	0.874482	0.303196	-0.63639	-0.994679	1.135546	5.96
01-098	0.039125	0.081453	0.311664	1.40841	0.829947	-0.34199	-0.961574	1.595783	6.05
01-110	0.020738	0.036887	0.129044	0.639486	0.285557	-0.59176	-0.942095	1.06989	5.78

01-146	0.039253	0.084421	0.321667	0.803457	0.181844	-0.92445	-0.942095	1.516628	5.07
02-222	0.026836	0.050021	0.1871	0.482338	0.025477	-0.84288	-1.573267	1.200181	4.83
02-224	0.031943	0.057477	0.201613	1.305056	0.511326	-0.96524	-1.555907	1.10721	7.35
02-246	0.033021	0.063288	0.252474	0.693397	-0.00546	-0.71168	-1.672308	1.225453	5.28
02-247	0.030827	0.076887	0.312981	1.115569	0.14158	-0.3931	-2.220849	1.161493	5.51
02-249	0.026461	0.050021	0.172612	0.696684	-0.06048	-0.79588	-1.676781	0.926571	5.21
02-260	0.027752	0.047977	0.189277	0.692296	-0.18293	-0.47629	-1.831811	0.729929	5.47
Vaccinium uliginosum									
01-075	0.021681	0.03377	0.114487	0.627366	0.235528	-0.48545	-0.618789	1.195291	5.88
01-107	0.018709	0.037425	0.13666	1.03583	0.706718	-0.76195	-0.986163	1.076495	7.4
01-109	0.023024	0.041965	0.134532	0.49276	-0.05552	-0.74715	-0.961574	1.138713	5.8
02-227	0.024292	0.062491	0.252474	0.078729	-0.41173	-0.84482	-1.34453	1.232467	5.85
02-250	0.014492	0.026461	0.103139	-0.28088	-1.21884	-1.13243	-2.307649	0.281601	5.28
02-251	0.017321	0.03874	0.166906	0.440909	-0.67778	-0.82391	-1.676781	0.432479	5.56
Dryas integrifolia									
01-023	0.035645	0.070129	0.282583	1.350829	0.918555	-0.13727	-1.243125	1.472625	6.31
01-083	0.042084	0.061521	0.250669	1.439175	0.748963	-0.54975	-1.016729	1.466022	7.01
01-086	0.025887	0.049518	0.243244	1.519959	0.607455	-0.59176	-0.986163	1.217484	7.86
01-088	0.032409	0.060036	0.237164	1.327155	0.724276	-0.64975	-1.025872	1.324365	6.05
01-090	0.035645	0.060783	0.22074	1.33965	0.741152	-0.48545	-1.054517	1.344824	6.41
01-102	0.028814	0.069698	0.238082	1.536053	0.985875	-0.58004	-0.934542	1.250249	7.33
01-104	0.021681	0.048185	0.224156	1.226858	0.886491	-0.66154	-0.355547	1.243385	7.75
01-131	0.044736	0.063129	0.229834	1.439017	0.808886	-1.03621	-0.814309	1.145445	7.56
02-235	0.023454	0.059195	0.37094	1.530328	0.44163	-0.90087	-3.246784	0.938548	7.79
02-263	0.029837	0.047977	0.160374	1.070915	0.367977	-0.58674	-1.523139	0.910565	6.48
02-265	0.0295	0.0548	0.238256	1.286007	0.475308	-0.76337	-2.220849	1.325766	6.64
02-272	0.034065	0.058343	0.230284	1.072755	0.514382	-0.55264	-1.523139	1.221088	5.81

02-280	0.051888	0.114266	0.449368	1.587444	0.92846	-0.22417	-1.188125	1.890273	6
02-282	0.023024	0.057477	0.375505	1.191346	0.710047	-0.88137	-1.355118	1.067154	8.07
Salix nivalis									
01-022	0.036477	0.108239	0.442506	1.683767	1.202761	-0.17783	-0.961574	1.77315	6.06
01-059	0.073209	0.048702	0.291241	1.551572	0.920123	-0.77728	-0.622423	1.100095	8.08
01-080	0.036887	0.067949	0.308636	1.439175	0.914872	-0.68825	-1.007774	1.342679	6.63
01-087	0.035645	0.060618	0.240816	1.40841	0.68842	-0.64975	-1.035212	1.414388	6.26
01-122	0.01	0.05739	0.22221	-0.0655	-0.55284	-0.69037	-0.859121	1.437243	4.98
01-123	0.035221	0.046277	0.16364	1.045714	0.247973	-1.06048	-0.88841	1.127461	6.74
01-145	0.026836	0.04724	0.1573	0.909021	0.571709	-0.79317	-0.986163	1.041985	6.88
02-194	0.027572	0.050021	0.177854	0.284149	0.004501	-0.69481	-1.744778	0.991472	5.63
Salix nivalis									
01-058	0.021215	0.035645	0.313748	1.51175	0.255273	-0.77728	-0.91264	0.704151	7.85
01-085	0.032255	0.051792	0.182701	0.915927	0.25042	-0.79588	-1.069581	1.050766	5.25
01-113	0.019495	0.0295	0.101466	0.95376	0.478566	-0.67366	-0.852872	0.99348	6.75
02-192	0.024086	0.017321	0.053878	0.889932	-0.12615	-1.00279	-1.719254	0.609831	8.42
02-232	0.0295	0.059195	0.196192	0.083234	-0.5673	-0.52567	-2.307649	0.880575	4.94
Salix arctica									
01-049	0.044624	0.121376	0.459862	2.005266	1.296007	-0.34775	-0.618789	2.001011	6.89
01-050	0.030336	0.045292	0.29973	1.573915	0.802089	-0.59176	-0.875148	1.016866	7.7
01-053	0.015166	0.02933	0.114442	0.686636	0.113943	-0.68825	-0.927118	0.730621	6.53
01-067	0.033622	0.066833	0.254081	0.475671	-0.03152	-0.60206	-0.797603	1.384694	4.81
01-068	0.02739	0.054617	0.180109	1.210586	0.618048	-0.79588	-0.720246	1.220474	6.36
01-092	0.039634	0.058257	0.212789	1.157154	0.584331	-0.76195	-1.025872	1.150664	5.95
01-093	0.028987	0.048907	0.324491	1.682235	0.724276	-0.46092	-0.846712	1.152472	7.87
01-097	0.035363	0.07252	0.247909	1.33965	0.909021	-0.35458	-1.069581	1.504865	6.37
01-124	0.039634	0.051012	0.177538	1.03583	0.243038	-0.64016	-0.927118	1.170144	6.78

01-133	0.020001	0.040011	0.144797	0.613842	0.274158	-0.6038	-0.875148	1.078058	5.38
02-199	0.024701	0.037425	0.125227	0.56952	0.081437	-0.60429	-1.831811	1.021935	5.88
02-220	0.034065	0.059195	0.221114	-0.6752	-0.63985	-0.57091	-1.464202	1.367123	4.63
02-261	0.025693	0.033172	0.148532	0.642093	-0.14468	-0.61563	-1.555907	1.04814	4.8
03-291	0.022363	0.026649	0.074095	0.729974	-0.26761	-1.52288	-0.994679	0.699838	6.37
Salix arctica									
01-051	0.107398	0.045842	0.273605	1.397766	0.836324	-0.19723	-0.942095	1.102056	7.92
01-082	0.03874	0.087	0.321384	1.467756	0.897627	-0.55909	-0.778892	1.512471	6.73
01-089	0.038869	0.035363	0.131605	1.055378	0.584331	-0.37986	-0.895196	0.972758	7.29
01-108	0.019237	0.03115	0.086711	0.820201	0.62941	-0.86967	-0.969616	0.769525	6.47
01-132	0.029159	0.028288	0.294155	1.33965	0.117271	-1.19382	-0.88841	0.512951	8.43
02-239	0.056065	0.049009	0.245777	1.417098	0.806886	-0.91897	-2.561387	0.904295	7.96
03-290	0.020001	0.022805	0.050618	0.532754	0.262451	-1.22185	-0.820023	0.642465	5.94
03-292	0.028288	0.060203	0.223671	0.378398	-0.5376	-1.09691	-0.953677	0.903633	5.68
low shrub									
01-062	0.027206	0.096012	0.659296	1.078094	0.480007	-0.06601	-0.539608	2.119365	3.7
01-063	0.024086	0.135357	0.748655	1.935608	1.300595	-0.33536	-0.105238	2.080897	6.12
Salix-Betula									
01-029	0.050914	0.159451	0.658314	1.622939	1.073718	-0.27901	-0.61161	2.001375	5.12
01-030	0.035363	0.159738	0.714794	2.040405	1.487845	-0.14448	-0.715699	2.195822	6.74
Salix spp.									
01-141	0.021911	0.056065	0.246539	1.439017	0.238046	-0.31336	-0.927118	1.427486	7.06
01-142	0.02025	0.037425	0.150703	0.953276	0.332438	-0.56225	-0.942095	1.077622	6.17
02-204	0.025887	0.049009	0.190894	0.600565	0.20918	-0.50828	-1.610219	1.094539	6.02
Alnus-Ribes									
02-255	0.013417	0.031628	0.099157	0.074176	-0.32141	-1.28464	-2.14854	0.533073	5.24
02-256	0.021911	0.079456	0.273393	1.384197	0.662758	-0.90982	-1.865183	1.22753	6.56

Carex aquatilis									
01-036	0.03634	0.02933	0.180732	1.322012	0.161368	-0.84164	-0.846712	0.955062	8.14
01-094	0.028464	0.041121	0.307252	1.543944	0.559907	-0.53018	-0.953677	1.061867	7.87
Carex spectabilis									
01-037	0.012248	0.011402	0.037692	-0.31876	-0.4318	-1.5376	-1.090515	-1.52288	7.61
01-120	0.034212	0.077989	0.315159	0.447158	0.029384	-0.02273	-0.942095	1.556423	4.21
01-157	0.038869	0.107866	0.38617	0.509203	0.0086	-0.33068	-0.731828	1.829902	4.54
Carex nigricans									
01-066	0.044286	0.086885	0.286092	0.372912	0.021189	-0.37986	-0.828738	1.539177	4.79
01-091	0.033473	0.058257	0.207818	1.210586	0.670246	-0.73049	-0.927118	1.192818	6.1
01-121	0.031786	0.036614	0.13666	-0.36653	-0.82391	-1.03621	-0.834647	1.099888	5.35
01-130	0.026461	0.074635	0.362484	0.33646	0.025306	-0.4023	-0.834647	1.719547	4.4
02-196	0.032563	0.063288	0.240643	-0.36527	-1.06846	-1.14005	-0.915435	1.018134	5.15
02-217	0.02608	0.05294	0.188192	-0.08818	-0.65186	-0.61449	-1.424717	1.901829	4.66
02-229	0.03377	0.055706	0.222047	-0.4513	-0.4994	-0.48555	-1.695147	1.109841	5
03-287	0.046921	0.105409	0.403644	0.033424	-0.25181	-0.25964	-0.766004	0.786712	4.87
03-289	0.041243	0.073551	0.295755	-0.05061	-0.67778	-0.69897	-0.741321	1.12512	5.22
Carex nigricans									
01-056	0.01844	0.027206	0.098444	0.586587	0.25042	-0.49349	-0.953677	0.763653	6.57
02-198	0.023667	0.028288	0.097106	0.260965	-0.01943	-1.07918	-1.629946	0.62454	6.32
Anemone occidentalis									
03-293	0.034648	0.068244	0.275635	0.130334	-0.5376	-0.79588	-0.916215	1.115943	5.4
03-294	0.03874	0.053598	0.168698	1.20871	-0.31876	-1.04576	-1.039959	1.022016	7.22
Parnassia fimbriata									
02-259	0.019237	0.051012	0.146122	1.104188	0.220762	-1.15173	-1.695147	0.980256	6.51
02-277	0.028111	0.060865	0.291695	1.413907	0.694605	-0.54282	-1.10233	1.805133	6.01

Trollius albiflorus									
01-095	0.032409	0.07786	0.352925	1.559188	0.849419	-0.34199	-0.977811	1.610128	6.72
01-111	0.040999	0.080211	0.279298	1.040998	0.639486	-0.25337	-0.751027	1.55484	5.44
01-112	0.029159	0.054341	0.228092	0.686636	0.285557	-0.51145	-0.840638	1.154789	5.19
Artemisia norvegica									
01-119	0.043832	0.074095	0.291604	-0.00436	-0.63827	-0.64975	-0.846712	1.507411	4.46
01-144	0.0295	0.06297	0.219779	1.025715	0.628389	-0.69897	-0.934542	1.270493	5.7
02-203	0.02608	0.096587	0.456231	1.323484	0.283018	-0.75222	-1.771896	1.885675	5.7
02-221	0.033473	0.041243	0.147504	-0.37161	-0.53202	-0.93067	-2.220849	0.841898	5.51
02-233	0.024497	0.041243	0.128808	0.182914	-0.58087	-0.64167	-2.307649	0.754921	5.45
02-234	0.038219	0.083162	0.271464	0.601924	-0.20848	-0.27984	-1.771896	0.923633	4.91
Artemisia michauxiana									
01-136	0.047768	0.067505	0.272198	1.351796	0.68842	-0.5817	-0.828738	1.584546	7.83
02-238	0.051888	0.060036	0.267175	1.489783	0.603866	-0.45993	-2.780944	1.194823	7.56
02-254	0.013784	0.028288	0.09448	0.351941	-0.4664	-0.96268	-1.984151	0.580418	5.72

SITE	Bare soil	Lichen	Litter	Moss	Rock	utm easting	utm northing
Tree							
Picea glauca							
01-002	0.05	0.05	5	50	0	429400.9525	5893448
01-011	0.05	1	0.05	80	0	426414.8518	5880454
01-017	12	0.05	30	10	0	428860.5037	5868670
01-033	0	0	20	10	0	396479.2835	5949597
01-061	0.05	1	5	80	3	428701.9011	5858382
02-175	0	0	60	5	0	429649.528	5872258
02-184	5	1	75	10	0	431294.3434	5867472
02-212	0.05	0.05	20	50	0	414943.4548	5858929
Populus tremuloides							
01-004	1	1	33	1	0.05	415665.0382	5924971
01-114	0.05	0.05	20	5	0	429618.4514	5868453
01-115	0.05	0.05	10	0.05	0	429648.6308	5868644
01-116	0.05	0.05	20	0.05	0	428924.3388	5871677
01-118	0.05	0.05	15	0.05	0	426335.9904	5862124
01-161	0	5	25	5	0	428909.5816	5892109
02-179	0	0	50	3	0	431783.4321	5852014
02-182	0.05	0	50	1	0	430811.2616	5868347
02-274	0.05	0	30	5	0	357002.8476	5977264
02-285	0	0	0	0	0	433575.6073	5863459
Elymus lanceolatus-Koeleria macrantha							
01-012	45	0.05	0.05	0.05	1	428189.0263	5881946
01-117	80	0	5	0	0	428820.1967	5871844

Pseudotsuga menziesii							
01-010	0	1	11	70	0	424810.8532	5877590
01-166	10	20	20	0.05	20	424769.117	5860040
02-180	60	0	5	1	15	431982.7879	5852563
02-181	0.05	5	20	60	0.05	430289.6836	5853603
02-186	0.05	5	10	70	0	427820.7083	5875702
02-208	0.05	0.05	30	20	5	427504.9024	5861189
02-211	0.05	0.05	20	60	0.05	415106.587	5858984
Pinus contorta							
01-003	0.05	0.05	2	60	0.05	413822.0718	5924072
01-020	1	10	40	30	0	396919.6925	5950624
01-152	0.05	5	10	30	0.05	458043.1279	5844372
01-153	0.05	10	20	50	0	458093.193	5843417
01-159	0.05	5	30	20	0	426684.1353	5868550
01-168	0.05	3	30	30	0.05	430258.2862	5848326
01-169	0.05	20	15	30	5	455070.3257	5841580
01-170	0.05	30	15	10	5	455280.5078	5841661
01-171	0	10	7	70	10	457530.577	5842781
01-172	0	15	15	40	1	457828.5204	5842342
02-190	0	0.05	10	50	0.05	431258.1934	5851619
02-207	0.05	0.05	30	20	0.05	426995.5134	5861182
02-210	0.05	0.05	30	40	0.05	415234.7854	5858943
03-298	0	5	10	70	0	456277.5742	5840968
Abies bifolia							
01-025	10	20	1	10	5	397665.9484	5953515
01-074	1	30	1	20	0	453545.8785	5840812

01-100	0.05	5	5	10	0.05	423833.9501	5868038
01-143	0.05	0.05	5	50	0.05	427351.6385	5839174
01-151	0.05	10	10	5	0.05	457907.5144	5844979
01-158	0	5	5	60	0	424510.3262	5869569
01-167	0.05	5	10	60	5	428946.9022	5837851
02-258	0	1	10	80	0	437209.4343	5830689
02-262	0	3	0.05	60	3	423712.8871	5854575
02-276	0	5	5	50	0	423584.574	5854781
03-302	0	1	20	70	0	438181.5425	5831366
Gymnocarpium dryopteris							
01-040	5	1	5	50	5	428857.8295	5837588
02-286	0	0.05	40	5	0	425350.8886	5856001
03-303	0.05	0.05	45	20	0.05	437558.7721	5831168
Picea engelmannii							
01-034	0	0	5	70	0	396704.8512	5949846
01-103	5	5	10	5	0.05	483740.9898	5860564
02-209	0	0.05	20	40	0	415279.4923	5859165
02-275	0	0.05	5	80	0	354030.2592	5979039
02-278	0	0.05	40	40	0	424133.5781	5855472
03-299	0	5	6	80	0	443553.0909	5858708
03-301	0.05	1	30	60	0	415798.1207	5859624
Shrub							
Arctostaphylos uva-ursi							
01-006	20	10	0.05	5	5	428557.2761	5882180
02-185	1	0.05	20	10	0	431370.8115	5866918
02-187	10	0.05	5	0.05	30	427793.5555	5875835

Elaeagnus commutata							
01-014	0.05	0.05	10	20	0	426536.079	5880506
02-183	5	0	30	1	0.05	431002.4149	5867803
Salix glauca							
01-021	0	0	0	0.05	0	396470.729	5950687
01-035	0	0	20	0	0	396904.9479	5949952
01-060	0.05	5	0.05	20	70	428726.6364	5858344
02-202	0.05	0.05	5	5	0.05	441040.7357	5.85E+08
02-215	0.05	5	10	10	80	436094.4422	5837610
Salix drummondiana							
01-032	0	0	30	0	0	396278.3772	5949390
01-039	0.05	1	5	10	20	428806.5296	5837602
01-045	5	0	5	30	5	428459.3314	5838409
Salix farriae							
01-042	0.05	10	20	40	0	428390.8471	5838783
01-043	0	0.05	10	60	0	428333.7062	5838719
01-044	10	0	10	30	0	428379.5421	5838828
Salix barrattiana							
01-048	0	1	5	20	0	384463.8833	5925396
01-149	1	0.05	5	1	0	458736.5164	5844363
Salix arctica							
01-071	5	0.05	0	5	80	366921.6859	5927332
02-268	0	12	0.05	40	0	345714.3992	5991035
Abies bifolia							
01-101	0.05	0.05	0.05	0.05	0.05	423566.8475	5868764
01-127	0.05	10	3	10	10	326540.8719	5951770
01-148	0.05	5	5	20	0.05	458627.9725	5844076

01-162	0.05	0.05	0.05	20	25	428545.6277	5837865
02-257	0	3	40	30	0	436939.3043	5829740
02-284	0.05	20	5	20	1	450308.0999	5885812
Herb							
Elymus lanceolatus-Koeleria macrantha							
01-001	20	20	5	0.05	0.05	425966.382	5879744
01-005	1	10	10	10	0.05	425949.1088	5879743
01-016	5	50	5	0	0	429005.4253	5869310
01-165	5	50	1	10	10	424872.3294	5860037
02-178	5	10	5	0.05	13	431735.8695	5851846
02-206	30	30	5	1	5	427210.9677	5861132
Achnatherum richardsonii							
01-160	0.05	60	1	10	10	427511.5525	5866269
02-173	5	0	50	0.05	0	429688.7017	5872253
02-174	0	0	50	0	0	429658.7023	5872196
Festuca altaica							
01-028	0	0.05	30	20	0	391791.9204	5952883
02-271	5	0	10	0.05	0	354641.0448	5982071
Fragaria virginiana							
01-079	5	10	10	20	20	454700.3237	5841457
02-213	0	15	10	10	0.05	425273.0624	5856226
02-214	10	10	10	10	5	435700.7927	5836335
02-240	0.05	50	1	10	0	457124.7571	5842522
03-295	1	60	5	1	1	453541.5854	5847031
03-297	0.05	10	5	30	20	443741.919	5859172
open graminoid							
01-015	20	0	5	25	0	426308.0739	5875833

01-138	30	0	0.05	30	10	429190.6058	5837526
02-177	40	7	5	1	0	430021.4927	5870893
02-223	10	0	0.05	1	90	368314.5672	5912457
02-252	0.05	5	1	0.05	95	436559.5824	5828081
cliff (2)							
01-007	3	1	0	1	95	428507.9608	5882198
01-008	3	1	0.05	0.05	95	428510.3365	5882285
01-009	0.05	3	0.05	2	95	428187.298	5882287
02-189	0	1	0	3	96	427332.7669	5877251
outcrop (3)							
01-013	0	2	0.05	3	95	428204.751	5881988
02-281	0.05	0.05	0.05	0.05	97	450101.5151	5885419
outcrop (4)							
02-188	0	30	0	20	45	427760.5623	5875890
02-279	0.05	0	0.05	0.05	95	450148.9441	5885388
drainage channel (6)							
01-019	85	0	0	0	0	396912.3486	5950515
01-031	20	0	0	1	80	396245.6532	5949385
01-150	0.05	0.05	5	5	0	458726.7042	5844359
rocky (9)							
01-065	0.05	0	0	20	60	324735.9462	5928781
01-156	0.05	5	0.05	1	95	423888.2551	5867893
talus (7)							
01-057	20	0	0.05	3	75	371195.2869	5927095
01-134	0.05	10	0.05	30	60	366508.2688	5932141
talus (10)							
01-077	30	0.05	0	0.05	70	453236.9907	5839706

01-078	0	0	0.05	0	100	453206.9114	5839782
02-193	0	0.05	0.05	5	95	441583.9815	5848838
02-195	0.05	0.05	0	0.05	99	443806.2747	5847587
02-266	15	0	0	0	80	346030.2029	5991176
sparse (11)							
01-027	0	0	10	10	50	391376.7652	5953386
01-105	80	0	1	0	0	432237.6951	5883108
02-176	0	0	35	10	25	429710.2859	5871240
sparse (14)							
01-041	30	0	0	0	60	428350.3052	5838788
01-046	80	0	1	1	10	428509.5342	5838396
01-163	1	0.05	0.05	3	90	428588.0138	5837318
rocky (28)							
01-137	30	0.05	0.05	0.05	70	429389.1277	5837334
01-140	10	1	0.05	1	90	429045.3085	5837635
01-164	2	7	0.05	1	90	428623.8335	5837435
02-244	0.05	0.05	0.05	0.05	95	424136.7599	5854107
rocky (23)							
02-267	3	0	0.05	0	95	345638.6322	5991388
02-269	5	0.05	0.05	0.05	90	354622.7552	5982094
02-273	0.05	0.05	0	0.05	90	355227.7766	5982704
rocky (24)							
01-081	1	0.05	0.05	1	95	319140.0815	6004521
02-200	5	0	0	0	95	443179.3306	5849030
02-243	1	0	0	0.05	90	424161.0564	5854134
02-270	20	0	0.05	0.05	70	354633.3447	5982084
rocky (25)							

01-084	5	15	0.05	10	65	319794.7621	6004563
02-205	5	5	0.05	5	80	442371.7408	5848783
02-245	0.05	0	0.05	0.05	96	424099.6382	5853906
Cassiope							
01-038	0.05	30	0.05	0.05	40	428741.0038	5837734
01-072	0	20	1	10	60	427387.7192	5838894
01-128	0.05	10	0.05	15	60	326336.9093	5951846
02-191	0.05	0.05	0	30	40	442075.9358	5848797
02-218	0.05	5	1	5	70	359717.986	5900918
02-226	0.05	0.05	1	10	60	436491.5533	5823934
02-253	5	0.05	3	10	65	436636.8553	5828155
03-288	5	40	5	10	10	417114.5227	5805538
Phyllodoce glanduliflora							
01-099	1	3	1	5	30	423682.5799	5868107
02-197	1	5	0.05	5	0.05	443885.0799	5847704
02-225	5	10	3	5	0.05	436445.5235	5823806
02-248	0.05	5	1	0.05	0	423244.0844	5853548
Cassiope mertensiana							
01-054	0.05	0.05	3	15	0.05	371002.0718	5926999
01-069	0.05	5	5	50	5	366756.0401	5927370
01-125	0.05	10	3	10	1	326712.1727	5951799
01-126	0.05	20	3	20	1	326694.5967	5951803
01-139	5	1	0.05	10	40	429079.1225	5837591
02-216	0.05	15	15	15	1	359766.1275	5900861
02-219	0.05	30	1	10	0	357709.4502	5914450
02-228	10	0.05	0.05	1	70	400843.6533	5878455
02-230	0.05	5	10	5	0.05	400782.9744	5878513

02-231	5	0.05	5	40	10	400851.2416	5878456
Cassiope tetragona							
01-052	1	10	5	30	20	371041.7238	5926950
01-076	1	80	1	5	0.05	453193.841	5840307
01-106	5	10	0.05	5	40	430205.9224	5836851
01-135	5	30	0.05	5	30	366480.0289	5932098
01-147	0.05	5	3	10	0.05	459083.7877	5843932
01-154	10	20	1	10	10	423884.6911	5868329
02-201	5	10	0.05	10	30	441767.7529	5848866
02-283	0	5	0.05	5	20	450171.8036	5885652
Empetrum nigrum							
01-064	0	80	1	1	4	324735.1983	5928741
01-073	5	20	1	10	5	427410.8583	5838890
01-129	0.05	30	0.05	5	40	326332.4207	5951792
01-155	0.05	30	0.05	10	40	424066.4633	5868154
Dryas integrifolia							
01-024	1	20	1	20	25	394872.3386	5954355
02-236	0.05	1	0.05	0.05	100	390738.5153	5915130
02-237	0.05	20	0.05	20	10	399360.7759	5935945
02-264	90	0.05	0.05	1	0	347173.088	5991581
Dryas octopetala							
01-047	5	5	10	5	0	384463.121	5925409
01-055	5	50	0	0.05	0	370932.5492	5927036
01-070	20	10	10	0	0	366790.337	5927411
01-096	1	10	0.05	5	11	423231.3786	5868632
01-098	0.05	10	0.05	5	20	423328.7277	5868634
01-110	5	5	0.05	10	10	430382.5028	5837277

01-146	0.05	20	1	10	0	459064.4239	5843912
02-222	0	20	5	5	0	368308.319	5912554
02-224	5	30	1	10	20	436405.9421	5823839
02-246	5	0.05	1	10	50	424249.4958	5853942
02-247	0.05	5	0.05	5	30	423103.4977	5853824
02-249	0.05	7	0.05	15	0.05	424385.6347	5853956
02-260	1	20	0.05	3	30	424006.4461	5854395
Vaccinium uliginosum							
01-075	0	5	0.05	3	80	453290.8921	5840261
01-107	1	5	0.05	0.05	60	430241.3527	5837020
01-109	0.05	1	0.05	0.05	85	430584.5255	5837327
02-227	0.05	5	1	0.05	55	433757.1208	5822658
02-250	5	5	0.05	3	75	436612.4112	5828091
02-251	10	15	0.05	5	25	436642.0173	5828049
Dryas integrifolia							
01-023	0	5	0	10	0	394739.5072	5954321
01-083	1	10	1	1	60	319572.9814	6004416
01-086	1	20	1	5	20	320079.8932	6005084
01-088	5	5	0.05	10	50	329075.8694	5981601
01-090	3	10	1	10	10	329126.313	5981478
01-102	1	20	5	0.05	5	482039.3146	5859375
01-104	0.05	20	5	10	10	483652.9848	5861113
01-131	0.05	35	0	5	0	360569.4818	5938747
02-235	0.05	5	0.05	0.05	80	390766.4727	5915089
02-263	5	3	5	5	20	347185.3151	5991568
02-265	0.05	10	0.05	5	10	347219.4922	5991634
02-272	0.05	20	0.05	5	20	355158.299	5982768

02-280	0.05	0.05	0.05	5	10	450020.2363	5885407
02-282	0.05	0.05	0.05	5	50	450067.1282	5885565
Salix nivalis							
01-022	0.05	10	5	25	0	394939.6104	5954339
01-059	0.05	20	1	20	5	386726.4324	5932072
01-080	0.05	35	0.05	10	0.05	319163.5704	6004556
01-087	1	20	0	5	1	329108.0012	5981622
01-122	5	60	0.05	10	1	304220.7981	5965764
01-123	5	10	1	10	10	304051.2418	5966141
01-145	0.05	5	0.05	5	60	459250.1997	5843867
02-194	0.05	20	0.05	10	20	441585.2747	5848796
Salix nivalis							
01-058	5	5	0.05	10	70	386869.1909	5932195
01-085	16	10	3	60	15	319784.7217	6004602
01-113	20	20	0.05	0.05	50	429329.8055	5837420
02-192	20	5	0.05	5	50	441626.7872	5848848
02-232	10	50	0.05	5	30	418465.3495	5865068
Salix arctica							
01-049	0.05	0.05	3	20	0.05	384466.1865	5925388
01-050	0	0	0	0	0	384446.9435	5925388
01-053	0.05	0.05	1	40	3	371009.706	5926978
01-067	15	60	1	0	10	340004.9042	5929879
01-068	0	0	0	40	0	339951.5582	5929913
01-092	0.05	0.05	1	60	0	329409.3351	5981374
01-093	10	0	1	30	5	329910.6924	5981457
01-097	5	0.05	0.05	20	4	423259.9289	5868659
01-124	0	10	0.05	10	20	303937.3075	5966173

01-133	0.05	5	5	40	1	366508.2351	5932139
02-199	20	3	5	1	20	443988.3237	5847963
02-220	0.05	50	0.05	10	5	357660.3189	5914468
02-261	5	30	0.05	5	1	423751.1593	5854343
03-291	10	15	0.05	20	30	422828.7193	5832187
Salix arctica							
01-051	10	0	0	5	80	384465.7769	5925342
01-082	0.05	0.05	1	80	0	319357.6839	6004444
01-089	1	0.05	0	0.05	95	329024.2292	5981567
01-108	5	20	0.05	1	60	430704.1908	5837274
01-132	0.05	0.05	1	85	0	360421.4987	5938575
02-239	60	0.05	0.05	0.05	30	399386.1853	5935870
03-290	80	1	0.05	3	10	422742.085	832081.5
03-292	0.05	80	0.05	5	5	417942.9193	5828255
low shrub							
01-062	0	0.05	1	80	0	392402.2147	5952483
01-063	0	0	5	80	0	393325.1509	5952289
Salix-Betula							
01-029	0	0	1	30	0	402424.0126	5860244
01-030	0	0	10	25	0	402460.2763	5860270
Salix spp.							
01-141	0.05	0.05	5	5	10	428650.945	5838048
01-142	0.05	0.05	10	10	0	428694.0406	5838192
02-204	20	0.05	0.05	20	20	441992.267	5848911
Alnus-Ribes							
02-255	5	0.05	60	5	30	436875.7039	5829147
02-256	0.05	1	10	20	30	436963.3127	5829573

Carex aquatilis							
01-036	5	0	20	20	1	397144.579	5950198
01-094	5	0.05	1	30	0	329989.3711	5981604
Carex spectabilis							
01-037	10	0.05	0	0.05	90	428695.9531	5837828
01-120	0	0	1	3	0	304485.3611	5965272
01-157	0.05	0	1	20	0	423907.5934	5868045
Carex nigricans							
01-066	0	0	3	40	0	324689.1842	5928808
01-091	3	5	3	5	0.05	329185.4381	5981447
01-121	0.05	0.05	1	5	0.05	304380.1855	5965405
01-130	0.05	1	5	15	0.05	326620.4582	5951707
02-196	0	0	0.05	0.05	3	443819.7397	5847593
02-217	1	0.05	5	30	0	359676.9374	5900874
02-229	0.05	0.05	10	20	3	400776.1131	5878546
03-287	0.05	0.05	5	10	0	419270.966	5804053
03-289	0.05	1	5	30	55	417130.1241	5805489
Carex nigricans							
01-056	10	30	1	5	40	370897.3126	5927063
02-198	1	0.05	0.05	1	100	443922.2502	5847788
Anemone occidentalis							
03-293	1	20	0	20	5	414853.0146	5830129
03-294	5	10	0.05	5	70	414885.8148	5829884
Parnassia fimbriata							
02-259	0	0.05	5	40	0	437279.1942	5831002
02-277	0	0.05	1	90	0	423563.2013	5855075
Trollius albiflorus							

01-095	1	0.05	0.05	0.05	0	330112.1812	5981841
01-111	0	0	0.05	20	0	430039.4268	5837205
01-112	1	0	0.05	5	1	429588.5172	5837377
Artemisia norvegica							
01-119	0.05	0.05	1	20	0.05	304507.1374	5965260
01-144	0.05	0.05	1	10	0	458967.965	843853.6
02-203	0.05	5	5	0.05	90	441225.777	5848869
02-221	10	0.05	0.05	0.05	80	357641.8843	5914485
02-233	10	5	1	5	50	418461.7539	5865068
02-234	5	3	10	1	50	418404.4828	5865073
Artemisia michauxiana							
01-136	5	10	0.05	5	55	399400.3592	5935985
02-238	5	3	0.05	5	70	399348.7818	5935900
02-254	0.05	40	0.05	25	15	436894.2256	5829568

Appendix 3. Global and Subnational Ranks as defined by NatureServe

The following summarizes the ranks used by NatureServe members (including ANHIC) to assess conservation status of species and ecological communities. The following text is taken directly from the NatureServe website (http://www.natureserve.org/explorer/ranking.htm#interpret) (October 29, 2006).

Global Conservation Status Definitions

Listed below are definitions for interpreting NatureServe global conservation status ranks (G-ranks). These ranks reflect an assessment of the condition of the species or ecological community across its entire range.

NatureServe Global Conservation Status Ranks

G1	**Critically Imperiled**—At very high risk of extinction due to extreme rarity (often 5 or fewer populations), very steep declines, or other factors.
G2	**Imperiled**—At high risk of extinction due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors.
G3	**Vulnerable**—At moderate risk of extinction due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors.
G4	**Apparently Secure**—Uncommon but not rare; some cause for long-term concern due to declines or other factors.
G5	**Secure**—Common; widespread and abundant.

Rank Qualifiers

Rank	**Definition**
?	**Inexact Numeric Rank**—Denotes some uncertainty about the numeric rank (e.g. G3? - Believed most likely a G3, but some chance of either G2 or G4).
Q	**Questionable taxonomy**—Taxonomic distinctiveness of this entity at the current level is questionable; resolution of this uncertainty may result in change from a species to a subspecies or hybrid, or the inclusion of this taxon

in another taxon, with the resulting taxon having a lower-priority conservation priority.

National and Subnational Conservation Status Definitions

Listed below are definitions for interpreting NatureServe conservation status ranks at the national (N-rank) and subnational (S-rank) levels. The term "subnational" refers to state or province-level jurisdictions (e.g., California, Ontario).

Assigning national and subnational conservation status ranks for species and ecological communities follows the same general principles as used in assigning global status ranks. A subnational rank, however, cannot imply that the species or community is more secure at the state/province level than it is nationally or globally (i.e., a rank of G1S3 cannot occur), and similarly, a national rank cannot exceed the global rank. Subnational ranks are assigned and maintained by state or provincial natural heritage programs and conservation data centers.

National (N) and Subnational (S) Conservation Status Ranks

Status	Definition
N1 **S1**	**Critically Imperiled**—Critically imperiled in the nation or state/province because of extreme rarity (often 5 or fewer occurrences) or because of some factor(s) such as very steep declines making it especially vulnerable to extirpation from the state/province.
N2 **S2**	**Imperiled**—Imperiled in the nation or state/province because of rarity due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors making it very vulnerable to extirpation from the nation or state/province.
N3 **S3**	**Vulnerable**—Vulnerable in the nation or state/province due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors making it vulnerable to extirpation.
N4 **S4**	**Apparently Secure**—Uncommon but not rare; some cause for long-term concern due to declines or other factors.
N5 **S5**	**Secure**—Common, widespread, and abundant in the nation or state/province.