University of Alberta

PLANT AND SOIL BIOPHYSICAL PROPERTIES FOR EVALUATING LAND RECLAMATION IN JASPER NATIONAL PARK, CANADA

by

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ABSTRACT

Jasper National Park has numerous disturbances in the montane and subalpine ecoregions of varying ages and causes, such as pipelines, road ways, trade waste pits and recreational activities. These disturbances are in various degrees of effective reclamation, in some cases soil conditions have promoted invasion by non-native plant species that in turn have limited self sustaining native plant communities. Of 23 research sites 4 are effectively reclaimed and another 4 are not because of the over abundance of non-native plant species. Presently, there is no standard method for use in Jasper National Park to monitor and judge effectiveness of land reclamation. This research thesis developed a biophysical monitoring and evaluation process which is simple to employ, efficient and economic. Along with plant and litter cover, species composition, and individual densities there are 8 soil physical and chemical properties which can support science-based ecosystem management of human initiated land disturbances.

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1.0 BACKGROUND AND RESEARCH RATIONALE

1.1.0 Introduction

Each year Jasper National Park hosts on average two million visitors and one million motorists pass through the park (Parks Canada 2004a, 2007, UNESCO 1984). Ecological integrity of habitats in the Canadian Rocky Mountains has been altered by human activity from inside, outside and across park boundaries. Disturbances in or near Jasper National Park are mainly associated with the tourist industry and with natural resource exploration and development. Human activity east of the park consists of private property development, industrial scale mineral and surface rights development and big game hunting (Natural Regions Committee 2006, UNESCO 1984). External pressures such as the Cheviot mining operations are believed to have decreased grizzly bear habitat (UNESCO 1984, 2005). Internal pressures from encroaching developments such as ski hills are believed to impinge on woodland caribou habitat (Parks Canada 2004b, Jasper Environmental Association 2007ab). Faunal and floral resources have been, and continue to be, impacted to various degrees by these activities.

This research thesis focused on developing a protocol for monitoring biophysical properties of terrestrial habitats impacted by land disturbances from management practices for utility transport corridors and tourism recreation facilities and their subsequent reclamation. The most difficult problems associated with these disturbances are restoring native plant communities and controlling the spread of non-native plants (AXYS Environmental Consulting Ltd. and David Walker and Associates 1998, Parks Canada 2000). Land disturbance can facilitate establishment of non-native plants which can potentially displace native plants, violating Parks Canada Agency's mandate to protect and maintain ecological integrity of biodiversity (Parks Canada 2000). Through development of an effective monitoring protocol, reclamation outcomes can be evaluated and reclamation practices improved to prevent negative alterations, such as simplification of native species composition or loss of soil through erosion. Such knowledge and activity could contribute to a general reversal in the decline of biological diversity at multiple scales in montane grasslands and subalpine forests as suggested by Rhemtulla et al. (2002)

Parks Canada (2000) lists disturbances associated with maintenance of rights of way (RoW) and recreational facilities. Activities requiring monitoring include brushing, clearing, road maintenance, grading, excavation, backfilling, soil settling, soil erosion control, stream channelization, stream works, new and existing disturbance rehabilitation and non-native species management. For each activity monitoring requirements and revegetation success criteria are presented but there are no standard methods for collecting biophysical property data relating to reclamation or restoration of the soil intended to protect and maintain ecological integrity (Naeth 2008, Westhaver 2008). Whether a site is reclaimed or restored depends largely on the probability and periodicity of re-disturbance, whereas some facilities may be upgraded indefinitely others may be decommissioned permanently; either way monitoring helps set acceptable limits on activity by evaluating progress towards end goals (Naeth 2008, Westhaver 2009). Judging a site to be reclaimed or restored depends on the status of established native species and soil profile developments after reclamation practices have been applied.

1.2.0 History And Administration

1.2.1 National Park Formation and World Heritage Site Designation

On September 14, 1907 the Jasper Forest Park of Canada (Order In Council 1907-1323) was dedicated, under the Dominion Lands Act of 1883, making it the fifth park in Canada's fledgling network of National Parks (Lothian 1987, Murphy 2007). Since the Province of Alberta was created in 1905, Jasper Forest Park was not dedicated under the Dominion Forest Reserves Act of 1906, as this would have been ultra vires (beyond the powers) of the Dominion Parliament (Lothian 1987, Murphy 2007). Establishing the park was prompted by plans for construction of a second trans-continental railway; a shared similarity with the Rocky Mountains Park at Banff. The name changed to Jasper National Park by Order In Council in 1929 (1929-158, 1929-159). Jasper National Park remained in flux, with boundaries changing for nearly 25 years after the 1907 dedication (Murphy 2007). With the National Parks Act of 1930 the present day borders were established with a total area of 10,878 km^2 (Lothian 1987, Parks Canada 1985, Murphy 2007).

Banff, Yoho and Kootenay National Parks share boundaries with southern pats of Jasper and together were recognized in 1984 as a United Nations Educational, Scientific and Cultural Organization World Heritage Site known as the Canadian Rocky Mountain Parks (UNESCO 1984, 2009). Significant developments since inscription strengthened protection of the land base and now 95 % of the site is legally protected wilderness rather than by administrative policy (Parks Canada 2004c). For example, changes to the National Parks Act in 2000 make ecological integrity the primary consideration in management decisions. The remaining 5 % of the land base is where the greatest concentration of human activity takes place and thus places significant pressures are placed on montane and subalpine ecoregions (Parks Canada 2000).

1.2.2 Parks Canada Agency and Administration

Jasper National Park is managed by Parks Canada Agency, established in 1998 with the Parks Canada Agency Act, which is part of the Department of Canadian Heritage (Government of Canada 1998, Canadian Heritage 1994). The Field Unit Superintendent (Jasper) is responsible to the Chief Executive Officer of Parks Canada Agency via the Executive Director of Mountain Parks and the Director General of Western and Northern Canada (Parks Canada 2004c).

In 1983 there were 137 full time employees, equaling 222 person years; the number of employees in 2004 was 158 full time employees or 256 person years calculated against the 1982 ratio (UNESCO 1984, Parks Canada 2004c). In 1983 the annual budget for operation was $11.9 million and in 2007 it was $13.1 million' in the late 1990s it was as high as $15.0 million (Jasper Environmental Association 2007c, UNESCO 1984).

1.2.3 Community and Visitors

Jasper National Park hosted 1,937,436 visitors in 1982-1983 and 1.6 to 2.0 million in 2002-2007 (Parks Canada 2004a, 2007; UNESCO 1984). The annual number of highway users is 1.0 million (Parks Canada 2004a). The population of Jasper in 2006 was 4,265 residents with a median income of $77,415 and approximately 534 privately owned dwellings with mean value of $395,937 (Statistics Canada 2006). The most common occupations are sales and service (1,195), management (505) and trades (420) (Statistics Canada 2006).

1.3.0 Biophysical Setting

1.3.1 Geographic Location and Ecological Characterization

Jasper National Park is located in west-central Alberta on eastern slopes of the Canadian Rocky Mountains (Figure 1.1) (Parks Canada 2004a). Highway 16 links Jasper town site to Edmonton, approximately 366 km east; Banff National Park is 286 km south along Highway 93. Jasper town site elevation is 1061 m above sea level (masl), the east gate is 985 masl; highest point in Jasper National Park is Mount Columbia at 3782 masl (Gadd 1986, Parks Canada 2004b).

The Continental Divide is the western boundary (180 km) of Jasper National Park; the northern boundary runs from Mount Lucifer to Daybreak Peak (70 km); the eastern boundary runs atop the Bosche, Boule and Nikanassin ranges (125 km); the southern boundary is set against the Brazeau River (65 km) (Parks Canada 1985). The total area of the park is 10,878 km^2 since the final boundaries were fixed in 1930 (Murphy 2007, UNESCO 1984).

The Montane Cordillera Ecozone (Figure 1.2) covers approximately 49 million ha and is the most complex Canadian ecozone due to topography and climate interactions (Scudder and Smith 1998). Longitudinally, the area extends from the eastern Rocky Mountains in Alberta to the western slopes of the Cascade Mountains in British Columbia. Latitudinal, the area extends from the Skeena Mountains in northern British Columbia to the 49th parallel.

Ecoregion 207 around Jasper (Figure 1.3) is identified as the Eastern Continental Ranges and there are five related ecodistricts, numbered 996, 997, 998, 999 and 1000 (Figure 1.4) (Ecological Stratification Working Group 1995). The Eastern Continental Ranges are dominated by alpine complexes which make up the largest proportion of the landscape, over 60 % by area (Ecological Stratification Working Group 2008). The montane and subalpine complexes, 36 % by area (Ecological Stratification Working Group 2008), are the most intensively used by humans and wildlife (Holland and Coen 1983a).

The Yellowhead Ecosystem covers approximately 68,000 km^2 and is situated in west-central Alberta and east-central British Columbia (Parks Canada 2000). Jasper National Park, Willmore Wilderness Area and Mount Robson Provincial

Park form a contiguous protected area in the center of the Yellowhead Ecosystem. The Yellowhead Ecosystem extends west to McBride, British Columbia; east to Edson, Alberta; north to the Kakwa River and south to Kootenay Plains

The Rocky Mountain Natural Region of Alberta covers approximately 49,070 km^2 and is composed of alpine, subalpine and montane natural subregions (Natural Regions Committee 2006). Several notable features are associated with the Rocky Mountains Natural Region in the Jasper area, including extremely calcareous soils, the Columbia Icefields, rare plant communities and habitat for grizzly bear and woodland caribou (Downing and Pettapiece 2006).

The primary purpose of the Ecological (Biophysical) Land classification for Jasper and Banff is to inventory, map and report on soil, vegetation and wildlife resources and landform processes in the park (Holland and Coen 1983ab). Natural resource and landform process information helps make decisions where the expectation is that active management will yield profitable returns, social benefit and reduce operating costs (Holland and Coen 1983ab, Parks Canada 2008c). The format is in two parts; a 1:50,000 scale series with integrated legend and a three volume report with descriptive details for soils, vegetation, wildlife and landforms (Holland and Coen 1983ab). Ecological and biophysical information is represented at three distinct levels of generalization: ecoregion, ecosection and ecosite where specific differences in soil, vegetation and landform at each scale determine the classification (Holland and Coen 1983ab).

1.3.2 Climate

Distance from the Pacific and Arctic oceans supports a continental climate in the Athabasca Valley (Janz and Storr 1977). The Montane Cordillera Ecozone annual temperature and water regime according to Koeppen’s classification system codes as Dfc (Gadd 1986, Holland et al. 1983a). Valleys and slopes are subject to snowy cold winters and no distinct dry season; cool short summers have periodic heat spells (Gadd 1986, Holland et al. 1983a). Within the Eastern Slopes Jasper town site at 1062 masl is within the montane natural subregion between 825 and 1850 masl (Natural Regions Committee 2006) and is associated with ecodistrict 997 because of similar elevation ranges (Figure 1.4)

(Ecological Stratification Working Group 1995). Lower elevations and mid-winter chinooks bring drier conditions. Mean annual temperature is 3.7 ^oC with a minimum mean of -2.3 ^oC and a maximum mean of 9.7 ^oC (Ecological Stratification Working Group 1995). Mean annual precipitation is 515.5 mm, with 182.3 cm of snow and 350.4 mm of rain. Winds from the south-west (Janz and Storr 1977) have a mean speed of 8.5 km h^{-1}; maximum speed in April 1954 was 61 km h^{-1} (Environment Canada 2008); and maximum mean speed is 11.3 km h^{-1} (Ecological Stratification Working Group 1995). Potential evaporation is 627.3 mm (Penman) and 515.9 mm (Thornthwaite), thus the annual water deficit is -111.8 or -0.4, respectively. The growing season is short with 1,176.6 growing degree days above 5 ^oC; the season length is 182 days with 1,909 hours mean annual sunshine (Ecological Stratification Working Group 1995) and 64 frost free days (Natural Regions Committee 2006).

Subalpine slopes reflect a shift in vegetation between 1,350 and 2,040 masl (Gadd 1986, Parks Canada 2004b) where greater water supports greater canopy closure via biomass production (Holland and Coen 1983b, Ecological Stratification Working Group 1995, Natural Regions Committee 2006). The effect is lower mean temperatures, decreased wind speeds and moderate temperature fluxes (Holland and Coen 1983a). The ecodistrict best approximating the subalpine in Jasper is 999; mean elevation is 2,140 masl, minimum 1,118 and maximum 3,416 masl (Figure 1.4) (Ecological Stratification Working Group 1995). Mean annual temperature is 2.7 ^oC with minimum -3.7 ^oC and maximum 9.1 ^oC (Ecological Stratification Working Group 1995, Natural Regions Committee 2006). Mean annual precipitation is 508.2 mm, with 205.3 cm of snow and 326.0 mm of rain. South winds (Janz and Storr 1977) have mean speed of 9.6 km h^{-1} and maximum speed of 13.7 km h^{-1} (Ecological Stratification Working Group 1995). Potential evaporation is 624.6 mm (Penman) and 488.3 mm (Thornthwaite) for an annual water deficit of -116.4 or 19.9, respectively. The growing season is short with 1,015.9 growing degree days above 5 ^oC, growing season of 170 days, 1,854 hours of bright sunshine and 55 frost free days.

1.3.3 Geology, Hydrology, Topography and Soils

Bedrock strata of the area originate from three eras; the oldest is Precambrian (>1.1 bya) followed by Paleozoic (570 to 225 mya) then Mesozoic (225 to 65 mya) (Barnes 1978, Holland and Coen 1983b). Three generalized lithologies include; non-calcareous medium and fine grained clastics; non-calcareous medium and course grained clastics; carbonate and/or calcareous clastics (Holland and Coen 1983b).

River systems and sources differ between front ranges that are trellised, relying on annual snow pack, and main ranges which are dendritic with drainage linked to perennial snow fields (Barnes 1978). Total annual runoff from the two ranges differs with eastern boundary discharge at 380 mm whereas the western boundary discharge is 1,000 mm. These correspond to annual precipitation at east and west boundaries of 380 to 500 and 1,250 mm, respectively (Holland and Coen 1983a). Discharge is linked to gradient which is dependent on topography and location of reach relative to valley bottom. Sulphur Creek is a high reach with inclines of 71 m km^{-1} that discharges into the Fiddle River with slopes of 17 m km^{-1} that flows into the Athabasca River at valley's bottom with slope of 0.13 m km^{-1} (Holland and Coen 1983a). Peak flow is in June or July and 70 % of total annual flow occurs June to August. Highest mean monthly discharge of the Athabasca River at Jasper is 242 in June and 268 m^3 sec^{-1} in July; lowest mean discharges in February and March are 10.7 and 10.1 m^3 sec^{-1}, respectively (Alberta Environment 1986).

The ecoregion 207 is 78 % mountain, 16 % hilly and 6 % plateau landforms (Figure 1.3) (Ecological Stratification Working Group 1995). Three of five ecodistricts around Jasper are all mountainous; 997, 999 and 1,000. Mountainous ecodistricts are 40 % inclined, 30 % steep and 15 % rolling topography. Mountain ranges are oriented in northwest-southeast direction parallel to geologic strike, trunk rivers tend to be perpendicular to geologic strike and streams tend to parallel geologic strike (Barnes 1978, Beswick 1984).

Genetic material in polygon 207 is predominantly alpine complex, > 60 %, the remainder is 25 % till veneer, 7 % colluvial rubble and 4 % till blanket (Ecological Stratification Working Group 1995). Eutric Brunisols develop on calcareous parent materials in lower and upper subalpine; Dystric Brunisols are associated with non-calcareous materials (Holland and Coen 1983a). Montane is dominantly Eutric Brunisols from calcareous morainal material. Luvisolic soils occur where warmer drier conditions persist on calcareous parent material under forest vegetation (Holland and Coen 1983a). Zonal soils from Podzolic, Luvisolic and Regosolic orders account for 5 % of soils, clay or sandy loams are 10 % (Ecological Stratification Working Group 1995).

1.3.4 Vegetation

Plant communities are a complex response to multiple factors with climate the primary influence (Holland and Coen 1983a, Macyk 2001). Habitat variability has led to high concentrations of rare or unique plant species and communities in the Canadian Rocky Mountain Parks (Beswick 1984, Natural Regions Committee 2006). For example, Haller's apple moss (*Bartramia halleriana* Hedw.) is listed as threatened by the Committee on the Status of Endangered Wildlife in Canada and protected under the Species at Risk Act (COSEWIC 2008a). It is found in shaded moist sites at the base of overhangs or rock slides of acidic parent material (Parks Canada 2005b, United States Department of Agriculture 2009).

Montane grasslands in the Athabasca River valley and its tributaries range from 1,000 to 1,300 masl in the northern most latitudes (Holland and Coen 1983b). Grasslands are often supported on dry south facing slopes; north faces tend to support mixed forests. Depending on available water, montane forests may include lodgepole pine (*Pinus contorta* Dougl. ex. Loud.), trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), white spruce (*Picea glauca* (Moench) Voss), black spruce (*Picea mariana* (Mill.) BSP.) and interior douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) (Holland and Coen 1983a, Moss 1994). The herbaceous understory may include hairy wild rye (*Elymus innovatus* Beal), bear berry (*Arctostaphylos* spp. Adans), buffalo berry (*Shepherdia canadensis* (L.) Nutt.), juniper (*Juniperus* spp. L.), pasture sagewort (*Artemisia frigida* Willd.), red osier dogwood (*Cornus stolonifera* Michx.), wood rose (*Rosa woodsii* Lindl.) and horsetail (*Equisetum* spp. L.).

The subalpine around Jasper has lower and upper sections with elevation ranges from 1,300 to 1,900 masl and 1,800 to 2,250 masl, respectively. Cooler, wetter conditions persist at high elevation (Holland and Coen 1983a). Closed canopy forest in the lower subalpine is seral lodgepole pine or engelmann spruce (*Picea engelmannii* Parry ex. Englem.) with subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) (Holland and Coen 1983a, Moss 1994). Open canopy forest in the upper subalpine is engelmann spruce and subalpine fir with seral lodgepole pine. Herbaceous understory of the lower zone may include buffalo berry (*Shepherdia canadensis* (L.) Nutt.), showy aster (*Aster conspicuus* Lindl.), twin flower (*Linnaea borealis* L.), grouse berry (*Vaccinium scoparium* Leib. ex Colville), false azalea (*Menziesia ferruginea* J.E. Smith) and feather moss (*Hylocomium* spp. Schimp.) (Holland and Coen 1983a, Moss 1994, United States Department of Agriculture 2009). Herbaceous understory of the upper zone may include heather (*Phyllodoce* spp. Salib.), valerian (*Valerian dioica* L.), fleabane (*Erigeron* spp. L.), tall bilberry (*Vaccinium caespitosum* Michx.), liverwort (*Scrophulariaceae* family), grouse berry (*Vaccinium scoparium* Leib. ex Colville) (Holland and Coen 1983a, Moss 1994, United States Department of Agriculture 2009). On front ranges understory species consist of rock willow (*Salix vestita* Pursh), white mountain heather (*Cassiope* spp. D. Don), heather (*Phyllodoce* spp. Salib.), feather moss (*Hylocomium* spp. Schimp.), hairy wild rye (*Elymus innovatus* Beal), june grass (*Koeleria macrantha* (Ledeb.) J.A. Schultes f.) and bear berry (*Arcotstaphylos* spp. Adans) (Holland and Coen 1983a, Moss 1994).

1.3.5 Wildlife

Seven species of ungulates are endemic to the park, of these Bison (*Bison bison athabascae* Rhoads) are locally extirpated since the 1850s (Soper 1970). Wapiti (*Cervus canadensis* V.Bailey) were locally extirpated but have since been re-introduced (Beswick 1984, Soper 1970). Mule Deer (*Odocoileus hemionus hemionus* Rafinesque), Moose (*Alces alces andersoni* Peterson), White-tailed Deer (*Odocoileus virginiana ochroura* V. Bailey), and Bighorn Sheep (*Ovis canadensis* Shaw) are present and stable (Beswick 1984, Soper 1970); these are primary grazers and can exert significant pressures on reseeded land disturbances (Westhaver 2009).

Notably woodland caribou (*Rangifer tarandus caribou* Gmelin) populations are small and declining in number; they are listed as threatened (Beswick 1984, Committee on the Status of Endangered Wildlife in Canada 2008b, Parks Canada 2004d). Wide ranging caribou prefer subalpine mature conifer forests, and are sensitive to disturbances by human activity (Beswick 1984, Jasper Environmental Association 2007ab, Parks Canada 2004d).

Grizzly bear (*Ursus arctos horribilis* Merriam) and black bear (*Ursus americanus cinnamomum* Aud. and Bach.) are present (Beswick 1984, Soper 1970). The grizzly bear is listed as a species of concern due to its large home range needs that conflict with development of areas outside the park in potential habitat (Committee on the Status of Endangered Wildlife in Canada 2008c).

Two felines, mountain lion (*Felis concolor missoulensis* Goldman) and lynx (*Lynx canadensis canadensis* Kerr.) are present (Beswick 1984, Soper 1970). Three canine species, gray wolf (*Canis lupus columbianus* Goldman), coyote (*Canus latrans incolatus* Hall) and red fox (*Vulpes vulpes abietorum* Merriam) are present (Beswick 1984, Soper 1970). Another 34 species of mammals such as shrews, voles, bats, pikas, rabbits, squirrels, muskrat and beaver also occur in the area (Holroyd and Van Tighem 1983, Beswick 1984, Parks Canada 2004d).

Over 280 species of avifauna are present or transient migrants (Beswick 1984, Holroyd and Van Tighem 1983). Local populations consist of clark's nut cracker (*Nucifraga columbiana* Wilson), black billed magpie (*Pica pica* Linnaeus), common raven (*Corvus corax* Linnaeus), osprey (*Pandlion haliaetus* Linnaeus), mountain chickadee (*Parus gambeli* Ridgeway) and gray jay (*Perisoreus canadensis* Linnaeus) (Holroyd and Van Tighem 1983).

Amphibians and reptiles are less diverse due to harsh climate. Boreal chorus frog (*Pseudacris triseriata maculate* Agassiz), wood frog (*Rana sylvatica* LeConte), columbia spotted frog (*Rana luteiventris* Thompson), western toad (*Bufo boreas* Baird and Girard), long-toed salamander (*Ambystoma macrodactyum* Baird) and wandering garter snake (*Thamnophis elegans* Kennicott) occur in wetlands (Beswick 1984, Holroyd and Van Tighem 1983, Russell 2000).

1.4.0 Issues And Responses

1.4.1 Introduction to Issues

Overlapping land uses by humans and wildlife in montane and subalpine is a valued research objective (Epp 1977, Hamilton 1981, Rhemtulla et al. 2002). The goal of land reclamation or restoration in this contested space should always be to reclaim disturbances in an ecosite with native plants representative of the wider Upper Athabasca River valley (Harrison 1984, Macyk 2000, Smrecui 2002).

Vegetation change in this area is documented at specific scales and key factors have been identified from past research, policies and practices (Harrison 1984, Holland and Coen 1983a, Rhemtulla 1984). The Best Available Methods for Common Leaseholder Activities (1998) by AXYS Environmental Consulting and David Walker and Associates represents a significant review and collection of knowledge about reclamation practices useful in mountain environments of the Eastern Continental Ranges of the Montane Cordillera. This work will be useful in understanding changes in plant communities and soil profiles due to maintenance of utility and transport corridors, tourist recreational facilities, legacy trade waste pits and other routine land disturbances. This practices manual clearly states rational for monitoring and suggests how and when when would be appropriate in Jasper National Park.

1.4.2 Vegetation Changes

Two difficult and intertwined problems in Jasper National Park are controlling aggressive non-native plant species and managing native plant species for representative communities of the Upper Athabasca River valley (AXYS Environmental Consulting Ltd. and David Walker and Associates 1998, Parks Canada 2000). Newly disturbed or ineffectively reclaimed areas may develop soil conditions that can simultaneously support aggressive non-native plant species and impose constraints on revegetation with native plant species (Erichsen Arychuk 2001, Macyk 2000). Land reclamation relies on scientifically accepted practices to minimize negative impacts on soil profiles and native plant communities, enhancing visitor experience quality and wildife habitat in protected areas (Harrison 1984, Macyk 2000, Smreciu et al. 2002). Examples of invasion pathways are contaminated vehicles and equipment, rail hopper spillage, inappropriate seed mixes, improperly prepared soil amendments and livestock offal (AXYS Environmental Consulting Ltd. and David Walker and Associates 1998, Erichesen Arychuk 2001, Hansen and Clevenger 2005, Harrison 1984, Von Der Lippe and Kowarik 2007, Westhaver 2009).

The harsh mountain climate with low soil nutrients can minimize non-native plant invasion opportunities (Harrison 1984, Macyk 2002, Takyi 1984). Alternatively, this harshness and reduced occurrences of natural disturbance such as wildfire may increase plant community susceptibility to non-native plant invasion

(Erichsen Arychuk 2001). To prevent invasion of non-native species, manage infestations and restore native plant communities, routine activities have been undertaken by the Jasper Leaseholders Working Group. These activities include minimizing excavations, minimizing brushing, seeding with locally adapted certified native seed mixes and post-reclamation monitoring for plant cover establishment (AXYS Environmental Consulting Ltd. and David Walker and Associates 1998).

Natural vegetation of the montane natural subregion is primarily grassland, which is in decline in Jasper National Park (Parks Canada 2000, Rhemtulla et al. 2002, Stringer 1969). This grassland is critical habitat for both carnivores and herbivores but ease of access has meant human development, which has all combined to change vegetation structure and composition over time (Parks Canada 2000, Rhemtulla et al. 2002). Other stressors are invasion by non-native plant species, restricted fire disturbances and habitat fragmentation (Hansen and Clevenger 2005, Parks Canada 2000, Sanchro 2005). Historic and current land uses created a complex pattern of active or abandoned linear and point disturbances of varying sizes; many are related to utility transport corridors or tourist recreation facilities (Harrison 1984, Takyi 1984).

The subalpine natural subregion, composed mainly of coniferous forest, is changing due to restriction of fire disturbance (Parks Canada 2000, Sachro et al. 2005). Limiting fire disturbance in Banff National Park for a century has increased homogeneity in vegetation composition, age and structure (Sachro et al. 2005). Such practices in Jasper create abnormal fuel build-up, increase canopy closure and decrease open space (Mitchell 2005, Parks Canada 2000). Prescribed burns have been re-implemented as a strategic tool for park management, although they are still less frequent than natural or aboriginal initiated fire regimes historically occurring in Upper Athabasca River valley (Mitchell 2005, MacLaren 2007, Tande 1977, Westhaver 2009).

1.4.3 Stakeholder Participation in Development

Development serves the needs of public and commercial parties and protecting ecological integrity increases complexity of land use management (Parks Canada 2000, 2005, 2007). Parks Canada is committed to participatory governance through timely stakeholder consultation on park management plans and policy (Parks Canada 2000, 2005, 2007). Management of human disturbances is dynamic and new approaches to communicating information and involving the public are presently being developed (Parks Canada 2005, 2007, 2008c).

The Jasper Leasholders Working Group is a unique example of collaborative effort to streamline reclamation practices and achieve a common standard among a diverse group of operators within the park (Westhaver 2009). Members are mainly representatives for the various corporate stakeholders with infrastructure passing through or delivering services to the town of Jasper. For example, Canadian National Railway, Telus Communications, and ATCO Pipelines have representation in the working group.

The mandate of maintaining and protecting ecological integrity is supported in a framework with three key ecological goals: diversity, processes and stressors (Parks Canada 2005, 2007, 2008a). Frameworks for acquiring ecological information used in ecosystem based management for tracking changes over time are being reassessed (Parks Canada 2005, 2007). The ideal framework will allow land managers to judge management plans and actions, increase awareness of changes, identify information gaps and collect baseline information for comparison (Parks Canada 2005, 2007, 2008c).

1.4.4 Response to Issues by Parks Canada Agency

To maintain ecological integrity is to support representative native plant communities where populations are declining or have become over abundant due to change in disturbance regimes (Parks Canada 2000, 2008b). Key ecosystem function related actions include grazing management of wildlife and horses, reintroducing prescribed burning, minimizing effects of human activity and utilizing native plant species in reclamation. Key reclamation related actions include an inventory of land disturbances; researching habitat with priority composition, structure and function; providing Jasper Leaseholders Working Group with high quality native seed; eliminating or controlling non-native species (Parks Canada 2000). The Best Available Methods for Common Lease Holder Activities is an example of a guiding tool (AXYS Environmental Consulting Ltd. and David Walker and Associates 1998).

To maintain biological diversity is to protect and restore populations of native and rare species across the landscape (Parks Canada 2000). Key actions include monitoring and identifying critical habitat for native vegetation, herbivores and carnivores; minimizing adverse singular and cumulative effects of human activity with standardized reclamation practices. An example is protecting and restoring rare ecosite / landscape units such as the Vermillion Lakes and Mount Edith Cavell Meadows Trails (Parks Canada 2000, 2008).

To maintain environmental processes is to protect landforms and geologic processes from degradation or inhibition due to human activity with decisive management and, where possible, reclamation (Parks Canada 2000). Key actions include long term planning, recognizing the sensitivity of ecosites and landscape units, developing and implementing site specific rehabilitation plans to a common standard; presentation of significant landscape features or processes while protecting them. An example is the simultaneous protection and presentation of Jasper Lake Dunes landscape (Parks Canada 2000, 2008).

To facilitate stakeholder participation is to openly and actively involve them, such as the public and industrial partners in protecting and maintaining ecological integrity (Parks Canada 2000). An example of multi-stakeholder collaboration, where parks objectives are discussed openly, is the Jasper Leaseholders Working Group, which has been implementing disturbance rehabilitation practices for over a decade (Parks Canada 2000, Westahaver 2009).

To monitor reclamation effectiveness is to measure erosion control, establish native plant species cover and protect ecological integrity (Parks Canada 2000). Presently inventory and monitoring programs seek to balance core indicators reportable to a wider audience and serve specific park's needs over the long term (Parks Canada 2005, 2007, 2008a). Key actions are developing biophysical and disturbance inventories, monitoring species in parks that may be at risk, and also enhancing diminishing habitat (Parks Canada 2005, 2007, 2008a). For example, in montane grasslands, achieving reclamation objectives using native seeds adapted to the ecoregion (Parks Canada 2000, 2008).

Utilizing ecosystem based management Parks Canada has categorized deleterious effects on ecological integrity such as habitat fragmentation, disturbance of soil profiles, and appearance of aggressive non-native species. The above objectives and key actions can maintain and protect the natural heritage in the park from diminishing. These goals are integrated into Jasper National Park's overall management plan to protect endemic ecological communities and enhance visitor experience by protecting biological diversity, environmental processes and ecological integrity. A fundamental component of ecosystem based management is sound ecological information of abiotic and biotic properties that help to make informed management decisions; these biophysical properties are the substance of this research thesis.

1.5.0 Disturbances

1.5.1 Historical Disturbances

Recorded history of human activity in the Upper Athabasca river valley is about 200 years and natural disturbance has been ongoing since the glacial retreat about 10,000 years ago (MacLaren 2007). Before park creation, resource extraction and agriculture, including mining, forestry and small farm holdings had an impact. Many sites pre-date active management or laws that protected the environment by setting standards for construction and reclamation.

Presently, several types of land disturbances are associated with human related land uses in the montane and subalpine such as transportation utility corridors, tourism recreation facilities, local infrastructure facilities (Jasper Leaseholders Working Group 2007, Parks Canada 2000). Three pipelines and two transportation corridors traverse the park and numerous infrastructure and tourist facilities exist, besides those listed in the disturbance database (Jasper Leaseholders Working Group 2007, Parks Canada 2000).

Reclamation can have an effect as several rail road beds and highways have been abandoned as new technology and new highways were built (Westhaver 2009). With abandonment, maintenance, installation and removal of features associated with current uses, land disturbance is unavoidable. The late 1970s and early 1980s brought better management and construction regulations such that and mitigation is now integral to any project (AXYS Environmental Consulting Ltd. and David Walker and Associates 1998, Westhaver 2009).

Though construction and reclamation tend to differ for most project types, recent advances with standard reclamation practices are used for more common human disturbances. However, measures for effectiveness are as yet undeveloped for Jasper National Park (Westhaver 2009).

1.5.2 Natural Disturbances

Besides human related disturbance impacts, fire is the dominant environmental factor altering plant establishment and succession on the landscape prior to and during recorded park history (Corns and Achuff 1983, Westhaver 2009). Fire disturbance depends on anthropogenic, climatic, organic and stochastic factors whether it is a prescribed burn or a true wildfire (Parks Canada 2008d). About 24 major wild fires, greater than 500 ha, have occurred in the Upper Athabasca River valley around Jasper town site between 1665 and 1975 (Tande 1977). Most of the present forest originated as a result of three wild fires in 1758, 1847 and 1889 (Tande 1977). Prescribed burns are presently used to re-introduce fire back into ecological processes occurring in the Upper Athabasca River valley (Parks Canada 2008d, Westhaver 2009). The intensity and breadth of fire disturbances has and will continue to dramatically impact vegetation cover composition and succession (Corns and Achuff 1983, Parks Canada 2008d).

Other land disturbances such as flooding, mass wasting, grazing or parasitism disturb vegetation cover and may degrade soil but usually these are localized phenomena (Corns and Achuff 1983). Ungulate populations affect vegetation visibly as their habitat needs vary during the year; in the montane elk, deer and mountain sheep are highly visible grazers (Parks Canada 2004c). Populations of elk are estimated at 1300 individuals, mountain sheep are estimated at 3000 individuals (Parks Canada 2004c). The impact of ungulates on vegetation, especially newly seeded mixes for revegetation, can be pronounced and poses challenges for establishing native plant communities adequately (Westhaver 2009).

1.6.0 Background Conclusion

Convergence of anthropogenic, biotic and abiotic disturbance agents is significant because of adverse effects on persistent vegetation stand types and soil catenas (Parks Canada 2008a). Surveillance methods developed in this research will account for disturbance type to evaluate successes and failures of recovery. Determining successional stage and potential rate of change for a specific site is an expected result of applying systematic surveillance methods over time (Naeth 2009, Westhaver 2009). An evaluation process to isolate success factors and level of succession will help in designing effective management practices for all vegetation types.

1.7.0 Research Rationale, Objectives And Hypotheses

1.7.1 Research Rationale

Human related disturbances in Jasper National Park are varied and numerous. For example, recreation facilities, pipeline and utility rights of way, road set backs, borrow pits and legacy trade waste pits are routinely being constructed and operated or decommissioned and reclaimed. Depending on the activity and its location, some human disturbances are likely to be repeated and ongoing, some are almost permanent ongoing, whereas others are discrete and last a short time. For instance, infrastructure upgrades to gas pipelines or buried fiber optics may repeatedly affect plant and soil cover. However, deactivated borrow pits and legacy trade waste pits are not intentionally disturbed again.

Expenditures to reclaim disturbances will continue to meet the overarching park management goal of maintaining and enhancing ecological integrity. Some historical reclamation efforts have been successful, while some barely resemble the former ecological conditions they have tried to recreate, even decades later. Reclamation effectiveness is important as budgetary resources are limiting and stakeholders cannot be expected to support indefinite reclamation or complex monitoring programs.

Construction, decommissioning and reclamation practices have changed within the park but there is scarce historical records and biophysical data on pre-disturbance conditions, factors of disturbance and effects of reclamation practices, thus understanding present levels of recovery on disturbed sites is constrained. Therefore, an assessment of what data and information are useful, what properties should be monitored to determine reclamation effectiveness and how results might be interpreted ecologically and economically needs to be addressed. This research thesis was designed to elucidate these issues.

1.7.2 Research Questions

Questions to focus this research center on the interaction between plants and soil, particulalry in the rooting zone that have developed after disturbance and reclamation practices occurred; these are as follows.

- Has land reclamation, with the standard set of practices, effectively reclaimed disturbances of various sizes and types?
- Are differences among reclaimed sites great enough to discern a gradient of effective land reclamation in terms of revegetation performance?
- What biophysical properties might appropriately evaluate effective reclamation after plant cover has established?

1.7.3 Research Strategy

The primary research objective is to assess reclaimed land disturbances in an effort to develop a biophysically based monitoring and evaluation process; specific research strategies follow.

- Select a cross section of sites having unique disturbance types, ecological settings, reclamation practices, existent plant and soil properties, and time periods since reclamation.
- Develop standard methods for plant and soil data collection that are reproducible, adaptable, accessible, inexpensive and useable for different disturbances.
- Determine which biophysical variables best represent ecological structure, function and composition on these reclaimed sites.
- Evaluate the order of varying ecological circumstances along a reclamation effectiveness gradient and establish which biophysical criteria best assess land reclamation practices.
- Make recommendations for monitoring land reclamation practices and suggest modifications towards enhancing the park's ecological integrity.

1.7.4 Reclamation Effectiveness Hypotheses

Because natural variability off-site is not likely to be similar to variability imposed on sites affected by human disturbances it is possible off-site reference conditions are not useful in satisfying the research objectives. By sampling many replicated sites, with visible differences in performance, the sites themselves should yield an order, from least to most effectively reclaimed, without need of off-site reference conditions. Criteria from other mountain reclamation sites support determination of effectiveness in the general sense as outlined below.

After three growing seasons have passed, if native plant communities establish and are sustained at a site level, then reclamation success is likely assured. Generally, where native species are established and promote soil retention, live plant cover meets or exceeds criteria in the best available methods manual. Alternatively, where plant cover is low, or composition is predominantly non-native species, it is likely ground cover of native plants in the community structure partially supports this situation and requires management.

If, during construction and reclamation, soil horizons are removed and replaced in close approximation of the original profile, then reclamation success is likely assured for excavations. Where soil profile modification techniques were applied, but not excavation, rooting zone properties will be within tolerance thresholds for primary variables. Alternatively, where soil properties exceed tolerable limits it is likely parent geologic material or landform factor into this condition and may require mitigation, where possible in the form of more tolerant native plants, soil amendments, artificial surface cover, etc. to modify rooting zone conditions.

Combining the above hypotheses for plant cover and soil profile, where reclamation is effective, live plant cover will meet criteria and soil properties will fall within known tolerance limits. Soil properties support native species and together these create sustainable relationships to a high degree of effective reclamation. Conversely, bare ground or soil properties beyond known limits of stable developing profiles indicate reclamation was not effective, likely because specific site factors such as local climate, parent geologic material, landforms or site hydrology present a greater challenge than was previously known or can be mitigated presently.

1.7.5 Thesis Structure

This thesis is structured to guide the reader through the successive stages of program evolution. Chapter 1 provided a history on park formation, background and current ecological knowledge, land use issues relating to disturbances and reclamation and research objectives for evaluating land reclamation. Chapter 2 presents selection criteria for research sites and biophysical properties, design and methods to capture plant-soil relationships and design execution. Chapter 3 reports on characteristic plant-soil relationships, ranked successes and failures in plant performance, ranked performance in selected biophysical criteria and biophysical properties to evaluate reclamation. Chapter 4 provides a synthesis of the work and presents future research challenges, achievements and implications of analysis and recommendations for monitoring of land reclamation.

Figure 1.1 Boundaries of Jasper National Park (AltaLIS 2008, Ecological Stratification Working Group 1995, QGIS 2011)

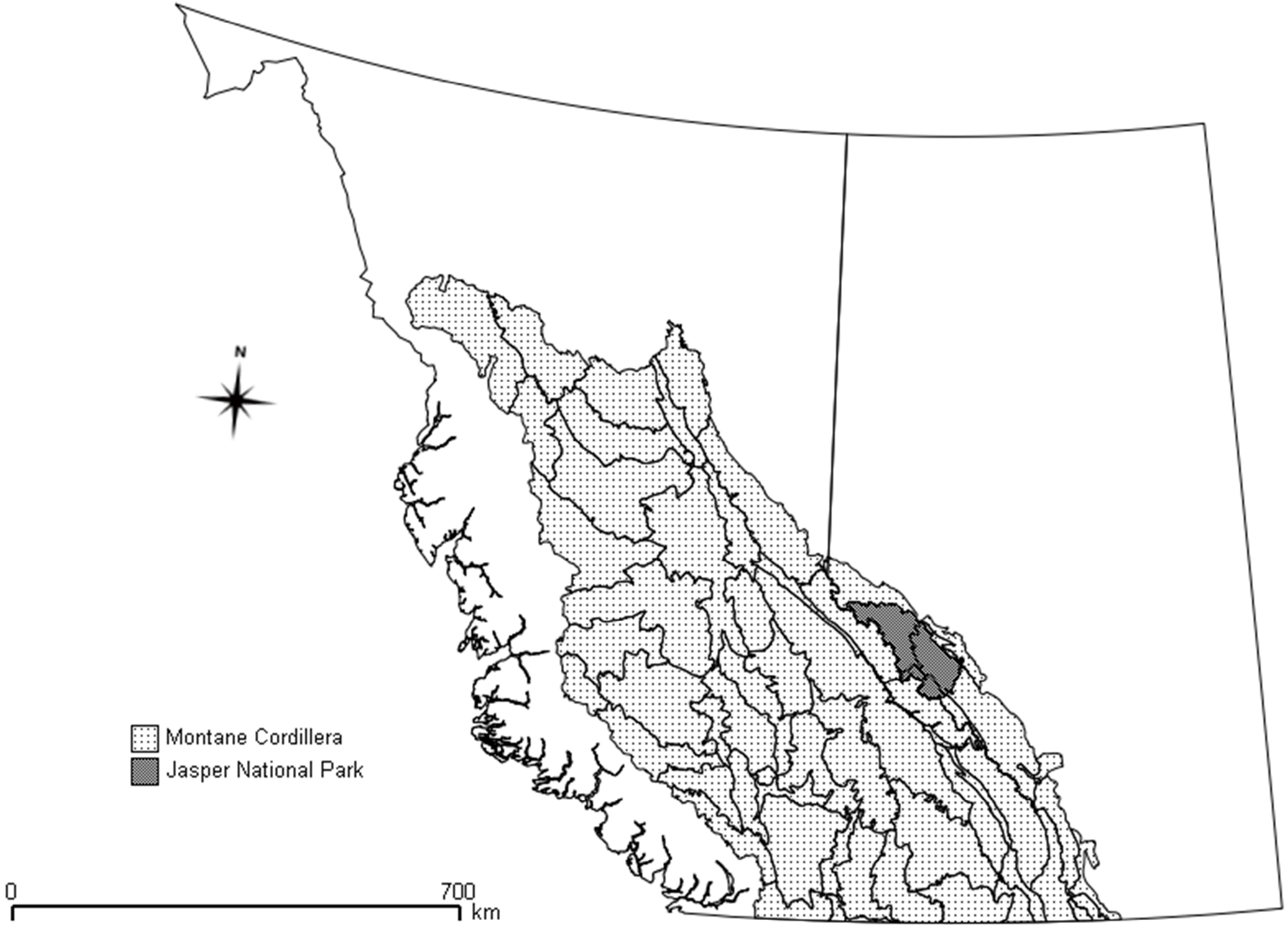

Figure 1.2 Jasper National Park in Montane Cordillera of Canadian Rocky Mountains (AltaLIS 2008, Ecological Stratification Working Group 1995, QGIS 2011)

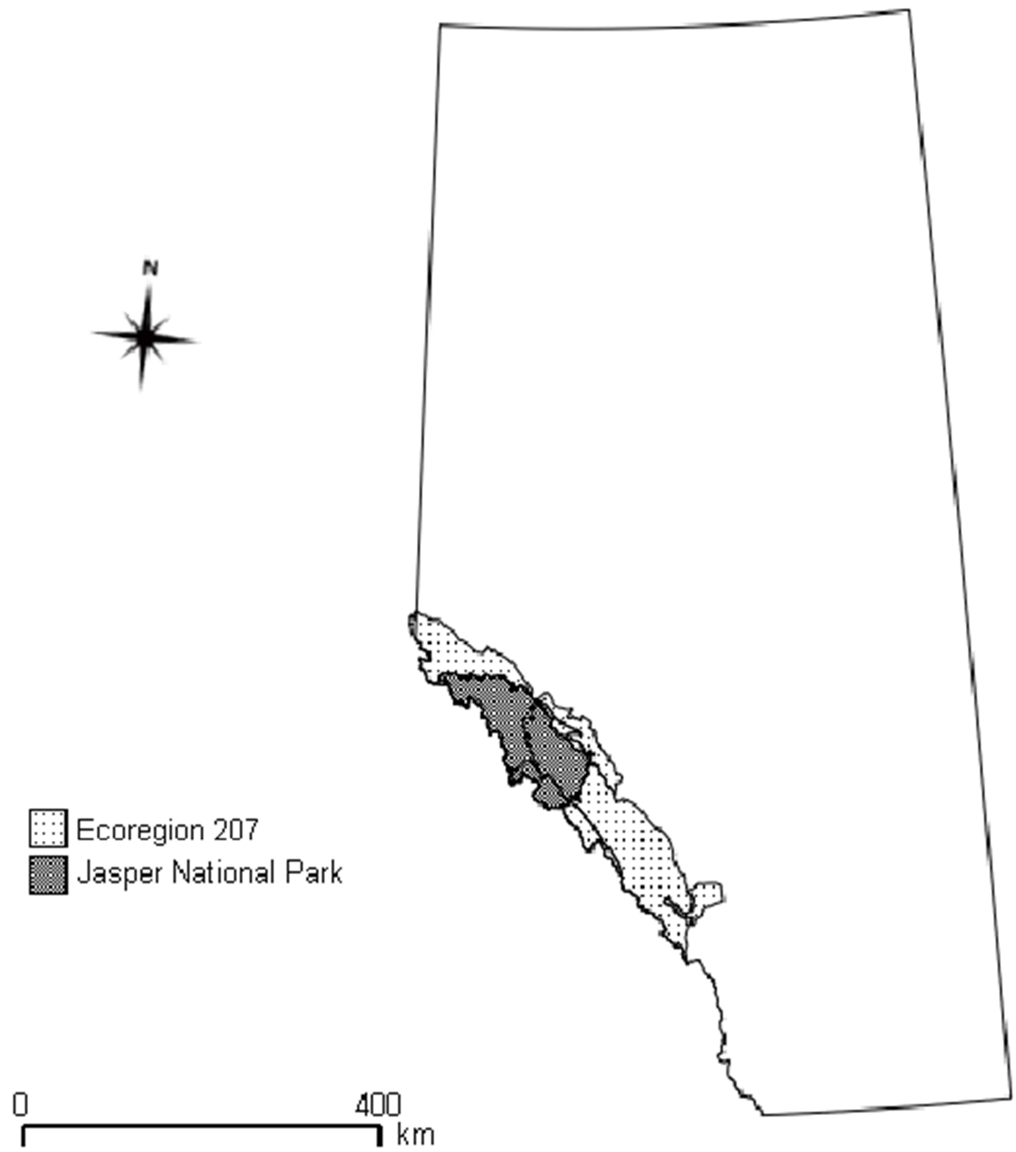

Figure 1.3 Location of Jasper National Park in ecological region 207 (AltaLIS 2008, Ecological Stratification Working Group 1995, QGIS 2011)

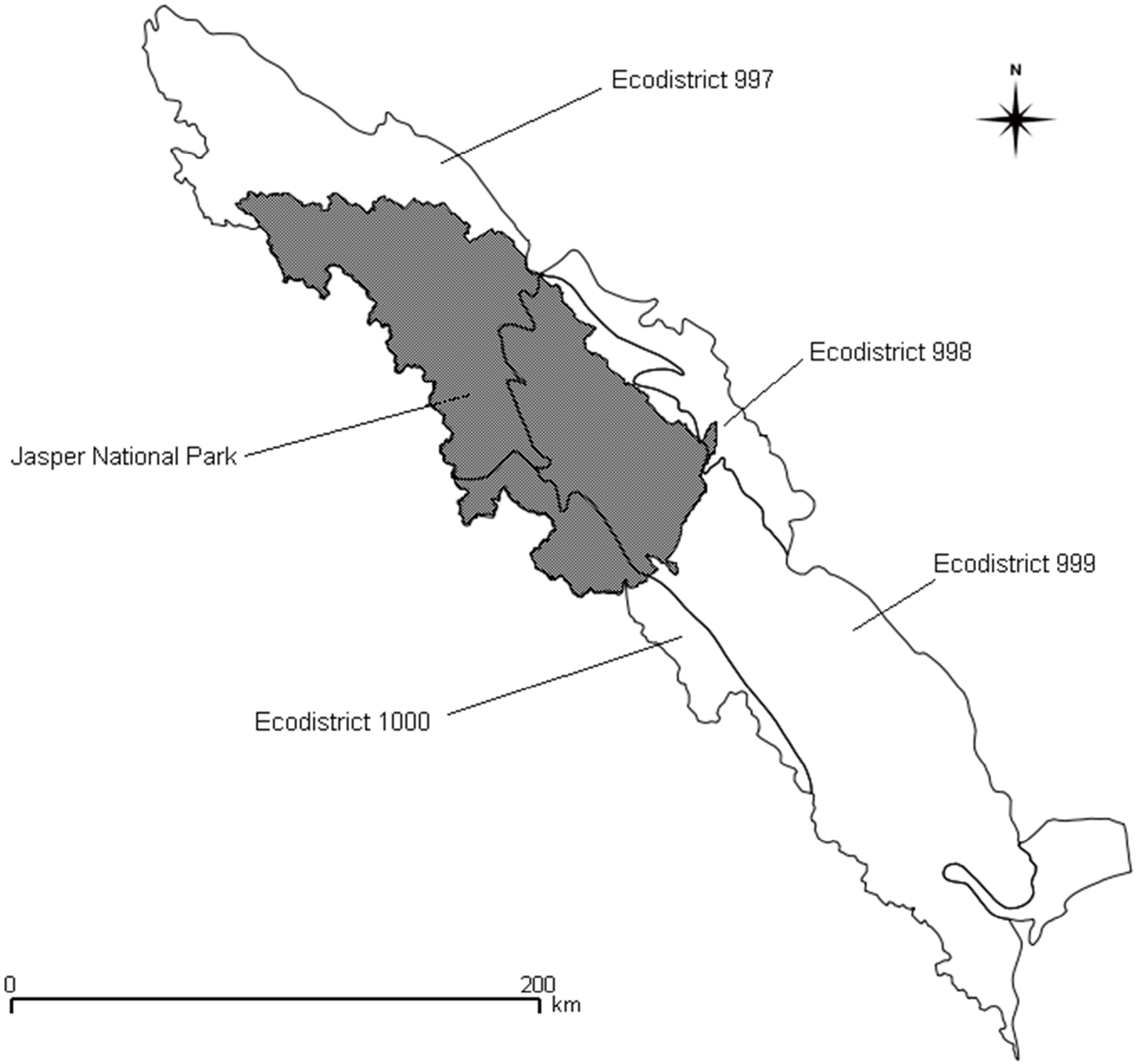

Figure 1.4 Ecological districts inside Jasper National Park boundaries (AltaLIS 2008, Ecological Stratification Working Group 1995, QGIS 2011)

2.0 STUDY SITE SELECTION, RECONNAISSANCE AND SAMPLING

2.1.0 Introduction

This chapter outlines the process of applying selection criteria for important factors in the research project are outlined. Criteria for research sites were primarily; disturbance type, ecological setting and growing seasons since reclamation. Criteria for soil properties were known influences on plant performance and ease of field collection, laboratory and statistical analyses. Criteria for plant properties were responsiveness to growing conditions and ease of field collection, laboratory and statistical analyses. The design and methods capturing plant-soil relationships on such a variable landscape are presented. A line transect design balanced the needs of stratifying heterogeneous sites and disturbances with randomized sampling ensuring minimal sampling bias. Assessment designs were implemented in the field and working methods for gathering data on biophysical properties were the end result.

2.2.0 Land Disturbance And Reclamation Database

2.2.1 Database Development

In 2007 a reclamation database was developed for Jasper National Park by Dr. M. Anne Naeth of the University of Alberta in partnership with the Jasper Leaseholders Working Group and Alan Westhaver of Parks Canada Agency staff from Jasper National Park (Naeth 2008, Westhaver 2008). Information from records relating to the Jasper Leaseholders Working Group and Parks Canada Agency operations was collected and compiled to identify areas in the park that had been disturbed and reclaimed. Hundreds of disturbances were identified, with varying levels of detail on disturbances and reclamation activities.

The large database of disturbed sites was assessed to select those sites with potential for reclamation research. Disturbed sites with large amounts of detailed information and recorded histories were selected as having the most potential for this research. Information and histories included file numbers, geographic coordinates, environmental assessment reports, project photographs, project completion dates, reclamation activities, revegetation seed mixes and proponent contacts. Project and site information was compiled as full text on MS Excel spreadsheets with single proponent pages and combined sheets for topics such as ecosite association, site identification, reclamation and revegetation monitoring. The database, which is a comprehensive record of management, reveals how evenly reclamation was practiced across disturbances and ecosites. Full text was simplified for selecting research sites for the research developed in this thesis; examples are given in Tables 2.1 to 2.4.

2.2.2 Grouping Disturbances in Reclamation Database

All documented disturbances were human related and involved activities such as demolition of facilities, pipeline installation or decommissioning, reclamation of rights of way or trails, modifications to existing installations and road cut slope engineering (Table 2.1). A comprehensive description of activities common to leaseholders operations can be found in Best Available Methods for Common Leaseholder Activities manual (AXYS Environmental Consulting Ltd. and David Walker and Associates 1998). Most common surface and subsoil disturbances were related to brushing, sod or soil salvage, excavation, contouring, stream works, erosion control, back filling, amendment application, transplanting, fertilizer application and seeding (Table 2.3). Reclamation activities such as scarification, decompaction, aeration, herbicide application, soil importation and contaminant remediation occurred less frequently often on 2 or fewer sites (Table 2.4). All sites had been treated with the intent to reclaim; thus examining the efficacy of natural recovery, an initial research idea, was not possible. The evenness of reclamation treatments on projects with multiple disturbances indicated adherence to the best available methods manual.

Ecoregion and ecosite classifications were assessed to determine the range of site conditions and reclamation end points that might need to be considered in the research (Table 2.3). There were 55 ecosections and 124 ecosites detailed in a land classification of Jasper and Banff National Parks, which indicated considerable heterogeneity of the landscape. The research area consisted of 2 ecoregions, montane and subalpine; 7 ecosections, Athabasca, Devona, Egypt, Hillsdale, Norquay, Patricia and Vermillion Lakes; and 13 associated ecosites (Holland and Coen 1983, Jasper Leaseholders Working Group 2007). Ecoregions were subdivided by differences in vegetation cover due to macroclimatic patterns; ecosections were subdivided by general differences in landform, drainage and soil character; ecosites were further subdivided by specific soil and vegetation differences (Holland and Coen 1983). The alpine ecoregion was not considered for this project as there were too few land disturbances to research.

Disturbance size, type and location were next addressed (Table 2.2). Disturbances were confined on a site, as activity beyond boundaries of a lease was prohibited. There were 10 projects and 12 sites where disturbance type was isolated spatially and temporally. Mean area of this grouping was 0.77 ha with a median of 0.45 ha and range of 0.012 to 2.78 ha. There were five projects with a total of 43 sites where disturbances were linear, with the exception of pipeline laydowns. Mean site area in this group was 0.16 ha, the median was 0.09 ha and the range was 0.012 to 0.98 ha. There were approximately 13 ecosite types with affected vegetation communities ranging from shrubby grasslands to aspen glades to spruce and fir dominated conifer forests. Site age ranged from 3 to 25 years with most sites classed as recent 3 to 4 years or aged over 25 years.

2.2.3 Candidate List of Research Sites

Criteria for choosing suitable research sites were developed; sites had to have been disturbed and subsequently reclaimed by techniques listed in the best available methods manual; project information needed to be recorded in the disturbance database; and sites needed to have a minimum of 3 years where sustained plant growth was possible. Replication of disturbance type and reclamation practice at various times and places were necessary for stratification of performance and statistical analyses of variation among plant community and soil profile responses. Worker safety, including steepness of slopes, accessibility, potential for wildlife encounters and highway traffic were important although not as analysis design components. Sites that met these criteria follow by proponent with year of reclamation in brackets.

- Jasper National Park: Miette Hot Springs Road (1983), Goat Lick Viewpoint (2001), Mount Edith Cavell Trailhead (2002), Old Rodeo Pit (2006).
- ATCO Pipelines: Mile 12 Pipeline Relocation (2004), Jasper Lake Dunes Pipeline Relocation (2005).
- Trans Mountain Pipelines: Pipeline Km 380 to 383 Cut Outs (2000),

Athabasca River Bank Armouring (2001).

- Marmot Basin Ski Area: Eagle Ridge Chairlift Development (1998), Interim Snowmaking System (2004).
- Jasper Park Lodge: Landfill and Access Road (2000), Golf Cart Path (1994), Golf Course Wildlife Fence (no date).
- Jasper Lions Club: Ski Hill Lift Decommissioning (2000).
- Allstream AT&T: Pyramid Mountain Microwave Tower (2003).
- Petro-Canada: Abandoned Service Station Highway 16 (2003).

2.3.0 Candidate Site Reconnaissance

2.3.1 Qualitative Site Reconnaissance

To select a final group of research sites, reconnaissance was conducted in summer 2008 with the aim of assessing site suitability for research. A qualitative site categorization was attempted that included plant and soil properties, which could have been used as a standard biophysical collection method. As will be discussed in Chapter 4, this method did not result in significant variation to distinguish reclamation effects and was not continued as it was not clear how thesis objectives could be satisfied.

Each site reconnaissance started with a brief walk, observing general ecological site conditions. Vegetation was then visually assessed for cover, composition, distribution, health, litter and bare ground. Soil was visually and manually assessed for texture, colour, cohesion, stoniness and drainage. For each soil and plant property a 3 point scale from low to major (or poor to excellent if that better suited the property being assessed) was assigned. A site map was drawn to record dimensions by walking pace and compass directions were given and recorded as headings. Geographic coordinates, slope angle and aspect were recorded for landform features.

Photographs were taken to record general information and provide a site overview. Photographs were taken to distinguish ground cover, plant density, non-native species and landscape. These photographs were used for further site evaluation out of the field; for example, to work out finer categorization of sites suitable for biophysical sampling. In developing soil and vegetation sampling plans their greatest value was as an aide-de-memoire. Site conditions and vantage points for photographs varied for flat and open versus sloped sites. The flat open vantage points were taken inside the potential research area looking out and from the outside looking back in. Sloped sites were panned in a series across the face with frame overlap. Regardless of the landform photographed, five photographs were taken at a standing posture for each of the sites.

2.3.2 Semi Qualitative Site Reconnaissance

In the next step, moving from qualitative to more quantitative methods, certain components trialed in the qualitative reconnaissance survey of sites were carried forward. Characterization of biophysical properties became more numerical while transect, photography and GPS coordinate protocols remained unchanged. What follows are details of the semi qualitative site assessments which were also to be used to structure a site evaluation that could be used by Parks Canada in assessing reclamation success on sites in the future.

Transects were used for semi qualitative assessments to better select representative vegetation plots in a repeatable and systematic manner (Figure A.1). From randomly walking the site the variability of vegetation or bare ground patterns on a site noticeably changed with observation vantage point making it difficult and subjective to select representative units. Transects, however, presented an alternative because a line is cut through an abundance of surface cover variation and gives a repeatable method of randomizing sample plot locations. During transect set up site variability observed and special features were noted on the site map and this variability became the basis for stratifying sites by plant performance later on. The first longitudinal axis of the transect was in a north easterly quadrant (Figure A.1). Compass bearings were used to locate three other axes at 90 degree increments and in a clockwise direction. Longitudinal axes were long, laterals were short and the first long axis could be a short lateral. Geographic coordinates were acquired with a Garmin GPS, set to NAD 83 benchmark, after a 30 second wait time for satellite acquisition.

General observations about ecological condition were recorded, such as bare cut slope, vegetated cut slope, grassy plain or shrubby glade. Plant density was noted as loose clumps or dense sod mats. Stand health may be influenced by many factors and so necrotic tissues and sexual maturity was noted, as these were easily observed. Soil was assessed by: colour to approximate organic matter and mineralogy, clod stability to provide evidence of pedogenesis, stones and pebble blankets to indicate either erosion or surface crusting. Potential drainage capacity combined amount of vegetation cover, coarseness of soil texture and slope angle, if present in the landform. Reclamation treatments were identified by decaying erosion matting, wood chips, restaurant based compost and transplanted trees.

2.4.0 Selected Research Sites

Based on 2008 reconnaissance information, sites were selected for detailed sampling and assessment because they represented a diverse set of geographical, geological, hydrological, physiological, chronological and ecological settings (Tables 2.1 and 2.2). These sites represent land disturbances with a range of plant and soil development trajectories and evidence of reclamation for investigation of successful and problematic disturbances in Jasper National Park (Tables 2.3 and 2.4). There were a sufficient number of montane and subalpine sites for replicates. However multiple treatments on a given site confound evaluation of land reclamation practices individually with traditional statistical methods of testing for differences between experimentally isolated treatments.

Study sites included a cross section of land disturbances and land reclamation with a sufficient number of sites for replication. Many sites were relatively young, ranging from 3 to 9 years since reclamation which represents critical time period for establishing revegetation to enable soil conservation, two components of effective reclamation. Other sites were over 25 years of age and may represent well developed reclamation sites. Of the 55 sites deemed suitable for assessments, 23 were selected for further analysis of plant and soil relationships (Table 2.5). Numbering of sites reflects which had soil samples taken, the longer site lists for stratification and vegetation assessments meant this listing should be kept so as not confuse what sites had been assessed (Table 2.9). The names of sites indicate the kind of disturbance that affected each site.

The research sites, managed by various proponents, selected for further assessment follow (Figure 2.1).

- Jasper National Park: Miette Hot Springs Road (1983), Goat Lick Viewpoint (2001), Old Rodeo Pit (2006).
- ATCO Pipelines: Mile 12 Pipeline Relocation (2004), Jasper Lake Dunes Pipeline Relocation (2005).
- Trans Mountain Pipelines: Athabasca River Bank Armouring (2001).
- Marmot Basin Ski Area: Interim Snowmaking System (2004).
- Jasper Park Lodge: Landfill and Access Road (2000).
- Jasper Lions Club: Ski Hill Lift Decommissioning (2000).

2.5.0 Biophysical Property Selection

2.5.1 Selection Framework

Multiple scales of observation for attributes of soil processes may be necessary to explain non-random variability of sites within the greater landscape context (Farina 2006, Ruiz-Jaen and Aide 1997). With so many available plant and soil parameters, those that best represent diversity, structure and process should reflect classification methods for comparability and relevancy (Jasper Lease Holders Working Group 2009, Naeth et al. 1985 and 1987, Ruiz-Jaen and Aide 1997, White and Walker 1997). All data collected are quantitative and continuous, or at least finely divided categories, because this level of biophysical information contains the most and best ecological information (Legendre and Legendre 1998, McCune and Grace 2002).

2.5.2 Physical and Chemical Soil Properties

Soil properties expected to be affected by reclamation included soil reaction (pH), total nitrogen, calcium carbonate equivalent, total carbon, total organic carbon, cation exchange capacity, exchangeable cations, saturation percentage, texture, electrical conductivity, sodium adsorption ratio and penetration resistance (Naeth et al. 1985 and 1987). The selection of properties was limited to those which were measurable or calculable by an analytical laboratory. Soil properties analyzed, laboratory codes for the laboratory used in this study, methods, detection limits and units are summarized in Table 2.6. The importance of these selected properties is discussed below.

Hydronium ion concentration represents potential proton activity influencing chemical constituents in aqueous solution and on soil colloid surfaces (Thomas 2006). A solution ideal for plant growth has a neutral pH between 6.5 and 7.5; above 7.5 is basic and below 6.5 is acidic (Dexter and Zoebish 2006). Calcium carbonate equivalent (Eaton et al. 2005) is a measure of hydroxyl ions, or the potential alkalinity, important because of calcareous soils on some study sites (Ming 2006). Electrical conductivity indicates salinity and as it increases may be detrimental to plant growth because osmotic pressure gradients reduce plant ability to take up water (Arp and Krause 2006, Dudas 2006). Values for optimal plant growth are from 0 to 2 dS m^{-1}; 2.0 to 4.0 is acceptable, 4.0 to 8.0 is saline and poor for plants, > 8.0 is highly saline and unsuitable for plants (Macyk 2004). Sodium adsorption ratio is an index of sodicity calculated from the concentration of sodium, calcium and magnesium (Eaton et al. 2005). Ratios greater than 4 signal conditions unacceptable for plant root growth or soil particle cohesion.

Nitrogen affects biological growth and at a plant community level its availability moderates species composition (Arp and Krause 2006, Naeth 2009). Total carbon incorporates both inorganic and organic fractions of the soil sample, the inherent carbon content due to parent material and content originating from plant and microbial biomasses (Ming 2006).

Cation exchange capacity is a measure descriptive of soil exchange complexes (Hendershot et al. 2006). The exchangeable cations calcium, magnesium, potassium and sodium that adsorb to negatively charged clay colloids are constituents of calculations for sodium adsorption ratio and cation exchange capacity (AGAT Laboratories Ltd. 2009, Bache 2006). These soluble cations that are dissolved in the aqueous phase of soil are major constituents of electrical conductivity measurements (AGAT Laboratories Ltd. 2009).

Particle size classes and texture were determined using wet and dry sieving where the sample remaining after passing through a 75 µm sieve, from a known mass, separates fine and coarse materials (Carter and Gregorich 2007). Penetration resistance is an important, easily obtainable property to approximate soil rooting quality. Values > 2 MPa are often associated with restricted root penetration (Dexter and Zoebisch 2006, Macyk 2004). Dial readings in pounds per square inch (psi) were converted to penetration resistance (Equaiton A.1)

2.5.3 Plant Properties

Vegetation properties expected to be affected by disturbance and subsequent reclamation practices are canopy, basal and litter cover; succession state; species richness and composition. There are only two cover classes mentioned in the best available methods, canopy and plant litter (mulch). During assessments other classes were assessed because hypothetically they can capture ecological function or indicate habitat usage. The properties measured are discussed in more detail below.

Plant cover has a long history in plant ecology as a fixed downward view of vertical leaf spread cast on the ground, and must practically be defined by each ecologist in what they mean and how they use the concept (Anderson 1986, Bonham 1988, Daubenmire 1953, Kent and Coker 1992). In the best available methods manual 80 % ground cover, as canopy cover and plant mulch, is the critical threshold for reclamation success; this is about 10 plants m^{-2} and balances space for pioneering with soil erosion prevention (AXYS Environmental Consulting and David Walker and Associates 1998). Not explicit in the manual are at what height canopy cover is distinguished from basal cover; whether canopy cover is estimated with or without leaf gaps; and whether plant litter is classed as rooted or loose in the quadrat.

A combined mulch (plant litter) and live plant cover of over 90 % can be 99 % effective in controlling erosion but erosion control may drop quickly when ground cover is below 70 % (AXYS Environmental Consulting and David Walker and Associates 1998). A value of 80 % ground cover was chosen as a reasonable compromise that would provide an adequate level of erosion control and yet not exclude the invasion of native species onto the site. Ground cover may be assessed by well established techniques including point quadrat, line intercept, 35 mm slide and ocular estimate methods (AXYS Environmental Consulting and David Walker and Associates 1998).

In this study, basal cover was assessed, defined as any live plant cover < 3 cm, or situated at ground surface, for any type of vascular plant rooted in the plot. Canopy then refers to foliage higher than 3 cm and rooted in the plot. From field observations and literature a height of 3 cm is acceptable for separating cover layers (Bonham 1986, Daubenmire 1953). Cover was separated into two layers to partition and quantify structure meaningfully and generate potentially testable differences in the data. Plant litter / mulch was differentiated in the field as rooted in the plot or loosely sitting on the surface, but in the analysis these two categories were combined as the distinction was too fine to be of use in terms of variability worthy of analyzing.

Describing plant community by its composition is fundamental because patterns across the landscape are typified by groups of plant species associated with site factors such as landform, hydrology, disturbance regime and soil properties (Daubenmire 1953, Kent and Coker 1992). Thus species identification plays an important role in monitoring developing plant communities after disturbance because no other quantification indicates diversity so well, and knowing if species are native or non-native has tremendous implications for evaluating site and land reclamation effects (AXYS Environmental Consulting Ltd. and David Walker and Associates 1998, Parks Canada 2000). Land reclamation relies on grasses, forbs and shrubs to achieve revegetation goals (Hardy BBT 1989, Smrecui et al. 2002). It is for these reasons species identification, especially of grasses, forbs and shrubs, is indispensible to monitoring in Jasper National Park (Naeth 2008). Mosses, lichens, sedges and willow were not identified to species level in the field due to the complexity and difficulty in doing so if the assessor is not very familiar with them. Much like the distinction in litter types, these are descriptive of the site conditions but numerically are not significantly large enough for use in statistical analysis.

To help identify plants to species level in the field several steps were taken to ensure correct identification. The following field guides proved immensely helpful: Plants of the Western Boreal Forest and Aspen Parkland (Johnson et al. 1995); Plant of the Rocky Mountains (Kershaw et al. 1998); Common Plants of the Western Rangelands (Tannas 2004), Weeds of Canada and the Northern United States (Royer and Dickinson 1999); and Flora of Alberta (Moss 1982). Two other books helpful but not essential were: Handbook of the Canadian Rockies (Gadd 1986) and Plant Identification Terminology: An Illustrated Glossary (Harris and Woolf Harris 2001). The Ecological (Biophysical) Land Classification of Banff and Jasper National Parks (Holland and Coen 1983) provided additional information on plant species in the park. Field samples of plants that were difficult to identify in the field were collected, dried and mounted for careful examination once out of the field.

2.6.0 Quantitative Sampling Design

2.6.1 Sampling Rationale

Ecosystems register the effects of disturbances, thus biophysical measurements should capture results of reclamation activities to quantitatively estimate levels of success achieved. Management or reclamation success can be defined based on character, diversity and/or process (Ruiz-Jaen and Aide 1997). This project evaluates all three in the above and below ground condition of soil and vegetation properties (Naeth 2009). Data from unsuccessfully reclaimed sites may provide insight on reclamation practices that were dependent on site specific conditions (Westhaver 2009). A broad based sampling design with a low level intensity deployed across many disturbances, as implemented in this study, should locate basic signals of ecosystem function, form and process altered by human activities (Chanasyk 2009).

Reconnaissance data and aerial photographs helped with developing designs for sampling various disturbances (Jensen and Bourgeron 2001, Jasper Leaseholders Working Group 2007). After viewing several dozen photo pairs (Table 2.7) doubts arose about the general concerns that human activity almost always has a negative impact on protected areas. This doubt reasserts the rationale to investigate human disturbances, quantify biophysical properties and evaluate reclamation for its ability to mitigate human impacts.

Due to off-site variability and the timethat was needed to make an effective sampling of undisturbed areas for a reference condition it was decided that no reference sites would be assessed for this research project (Chanasyk, Hamann, Naeth, and Westhaver 2009). By sampling many replicated sites, that have visible differences in performance, sites themselves will order from least to most effective without need of referring to external conditions (Chanasyk, Hamann, Naeth, and Westhaver 2009).

2.6.2 Sampling Scale

Determination of the effects of reclamation rests on the summation and/or comparison of small scale, fine resolution plot data from many disturbed sites. Appropriate scales depend on the variability of the disturbance and the selected ecological properties used to assess the extent of that variability (Farina 2006, Pennock et al. 2006). Examination of variability here occurs at the micro scale because areas affected are between 1 m^2 to 1 km^2 (Table 2.2) (Jasper Leaseholders Working Group 2007) and temporal lag effects may last from 1 to 500 years (Delcourt and Delcourt 1988). A unique feature of this research is the pairing of plant and soil data at the same scale in both location and time frame. Assumptions about the relationship between plant and soil data from differing years and locations have to be made with unpaired datasets, not so here.

Perception of spatial variability depends on scale, which has two components, grain and extent (White and Walker 1997). Grain is the unit measured in area or time and extent is the number of units measured making up a set of observations. To reduce sampling bias the grain should be 2 to 5 times smaller than features of interest and the extent should be 2 to 5 times larger than the disturbance (O'Neill et al. 1996). With this project, achieving a grain smaller than the disturbance was not difficult because quadrat size and total area sampled never exceeded the disturbance boundaries. Sampling larger areas was not possible so to compensate similar disturbances were sampled many times (Table 2.8). Time series sampling was not possible due to program constraints of time and budget. However, these constraints would be similar to those that Jasper National Park would be under for routine assessment of reclamation effectiveness.

2.6.3 Sampling Threshold

Scientific literature suggests number of soil samples to take regardless of site dimensions is 20 (Pennock et al. 2006). Number of samples in proportion to disturbance size for vegetation communities ranges from 0.25 to 1 % of an area; these are confirmed with species area curves (Naeth 2009). Vegetation sampling plots > 4 m^2 in communities where a single species has > 40 % cover will likely over shoot the plant community variability (Daubenmire 1953).

For the 23 sites assessed, paired plant and soil plots represented an area ranging from 0.001 to 0.78 % (Table 2.8). The extremes corresponded to the largest and smallest sites; the Old Rodeo Pit and Goat Lick Viewpoint, respectively. All sites were sampled for a total of 2.0 m^2. This selection process followed the above criteria and was finalized on budgetary constraints and statistical necessities. By stratifying the sampling at plant performance extremes, the statistical examination exposed those soil properties relevant to the potential successes or failures and maximized the effort of having 330 samples rigorously analyzed in a laboratory.

2.6.4 Stratified Random Sampling

Site location, disturbances and reclamation treatments were not directly controlled by the researcher thus the project is a comparative mensuration of disturbance recovery (Pennock et al. 2006). Stratified random sampling was considered the best strategy due to heterogeneity in vegetation, soil, topography and reclamation practices; this was supported by initial field reconnaissance data (Naeth 2009). There were few meaningful opportunities to statistically test reclamation treatments among sites due to complex sets of treatments; stratifying sites limited variability for plant response and soil property development since reclamation (Hamann 2008). Number of replicates of stratified vegetation and hence soil plots were ultimately determined by repetition of disturbance types and numbers of unique ecological sites in a given project. Once stratified on paper sites were located by map and aerial photograph reconnaissance, visual inspection and GPS verified the site location was accurate. In all 7 ecological sites were not replicated to the phase level, i.e. Devona 2 or Hillsdale 1, of the 23 sites yet other factors make for interesting similarities despite the difference in classification for sites.

Stratification had two stages. In the first, distinctive ecosite polygons were isolated, as defined in Holland and Coen (1983); then disturbance boundaries were visually determined. Transition from disturbed to undisturbed was visually based on vegetation cover; large tree cover was especially useful to delineate boundaries. In stage two, sites were stratified into distinct classes using linear transects to capture topography, soil or vegetation pattern changes (Naeth 2009).

2.6.5 Partitioning Disturbances

Soil and vegetation sampling were preceded by stratification to distinguish disturbed areas from the surrounding undisturbed landform and vegetation (Table 2.9). Stratification is a preliminary and systematic step aimed at distinguishing site variability by its own plant community development. Transects are a systematic and repeatable method of organizing sites to undertake a wide range of activities such as mapping, photography and biophysical sampling and are not difficult to apply to many kinds of disturbed sites encountered during this research project.

In disturbed areas, 4 transects were laid from central point of the disturbed area to cover length and width of the disturbance (Figure A.1). On linear disturbances, such as pipelines, length transects were given an arbitrary distance of 80 to 100 m, to make data collection feasible. Transects were evenly separated by 90 ^{o} angles. Coloured pin flags were placed along each transect to indicate zones of visibly different ground cover, plant density and distribution. Vegetation cover 0 to 15 % with sporadic individuals or clumps of plants was designated low density and sparse distribution; cover 16 to 50 % with several individuals or clumps was designated moderate density and spaced distribution; cover > 50 % with uniform spread of individuals or clumps was designated high density. The first two areas were considered to potentially represent soils not properly reclaimed and hence were in need of further attention.

Most sites were easily differentiated between disturbed and undisturbed areas. One exception was Access route 33. Difficulty finding the disturbed area should indicate reclamation success. Other exceptions were due to topography, several sites could not be transected as described above. Item 28, site 69 on Miette Hot Springs Road, is a steeply sloped site (> 35 ^{o}) so two belt transects were stacked on each other, running across the slope for approximately 40 m. One transect was along the ditch just above the slope toe with a second transect following a shallow bench between 10 and 15 m higher up slope. The bench transect was run perpendicular to the fall line at mid slope, approximately parallel with the lower transect. Item 44, a new right-of-way on the ATCO Dunes project was transected as a T with three transects in three directions. Item 56, Goat Lick View Point on Highway 93 had a reclaimed trail width < 1.5 m along its entire length so one transect was run down the middle for approximately 75 m.

Each transect was mapped; maps labeled with bearing, total distance, pin flag colour classes, individual distal measures and GPS waypoints. From site center, a photo was taken of each transect in a clockwise direction from the first longitudinal. This ensures biophysical information can be linked to measurement locations; information is useless if context is lost.

2.7.0 Field Sampling Methods

2.7.1 Vegetation Assessment

Vegetation assessments took place July 13 to 25, 2009 (Table 2.9). Number of sampling points needed to capture site variability was determined by proportions of line transects falling into one of three classes of vegetation density and distribution. Numbers of paired plant and soil plots assessed at each site were determined by presence of low and high density strata (Table 2.10). Separated segments of the same class were allotted portions of the total number of samples deemed necessary for that class. Plots classed as moderate plant density and distribution were assessed for vegetation cover, height and composition but soil was not sampled due to time, labour, budget and research focus.

A minimum of five 0.1 m^2 quadrats were randomly placed on the right hand side of transects crossing bare ground, sparse vegetation and dense vegetation cover stratifications. If more than 1 such unit for any stratification was found along a transect vegetation assessment plots were distributed among them. For example, if there were 3 units of bare ground, 5 quadrats were situated such that 2 smaller units had 1 quadrat and a larger unit had 3 quadrats. Quadrats of this size were small for mature woody vegetation, but best facilitated vegetation assessment in disturbed areas where cover was grass and forb. A method suggested in the best methods manual is an ocular estimate, the percent cover of bare ground, plant litter, live plant cover and other features such as rocks were estimated for each quadrat. Stand structure, as in the form and numbers of layers were determined visually and included as comments on the data sheet.

For sites with modified transect arrangements all 20 quadrats were placed in a line along the transect. At item 28, site 69 on Miette Hot Springs Road 20 plots were divided in two and then spaced along both transects at consistent distances of 3.5 m from a start point on the most eastern position. At item 44 there were 5 extra plots from the truncated transect split up and added to three viable lines of plots. At item 56, Goat Lick View Point all 20 plots were randomly sited alternating one plot on the right side followed by a plot on the left side.

2.7.2 Soil Assessment

Soil was sampled August 19 to 30, 2009 (Table 2.9). In quadrats where vegetation was assessed soil approximately 15 cm long x 10 cm wide x 10 cm deep was cut with a knife then extracted by hand or trowel. This provided minimum mass for analyses (650 g wet, 500 g dry) (Table 2.10). Rocks, roots, plants and litter were removed. Samples were separated, stored and transported in labeled plastic bags. Samples were later sent to the laboratory for analyses (Table 2.6).

Soil samples were drawn from the right side of a transect marked by a 100 m tape strung on a site specific bearing from site center. Sometimes there was no soil to sample but rather a mixed substrate of rock, coarse sand and possibly organic material that was weathered compost or accumulated leaf litter. In these cases, samples were drawn from this medium and extra material taken to ensure coarse sands and organic materials for adequate analysis. Location of a soil sample was recorded on the field data sheet. Observations about rooting density and rockiness in a pocket were noted on a qualitative scale of none, minor, moderate or major presence. Rooting depth was qualitatively noted as > 10 cm or < 10 cm. This qualitative information was not analyzed but is a record of rooting zone properties at time of sampling.

In one case plots were moved from the original vegetation plot location as substrate conditions were so hard sampling was not possible. For example, the Old Rodeo Pit on Highway 93 south of Jasper had weathered deposits of poured concrete yet there was vegetation present. In cases where dense sod layers formed, soil was shaken out of the matted roots before the sample was bagged. A soil sample to a depth of 10 cm beneath the sod mat was taken and mat thickness was noted on the field data sheet.

Soil penetration resistance readings were taken in late August 2009. Assessment was a penetration resistance reading at two depths using a conical tipped proving ring penetrometer (Soil Test / ELE International model CN-973 Corps of Engineers). Five readings in psi units were taken in each quadrat where vegetation assessments and soil sampling have been carried out at depths of 5 and 10 cm. Penetration resistance readings were taken even if rockiness was high, although no more than 8 test starts occurred for one reading before classifying it as rock.

2.8.0 Selection, Reconnaissance And Sampling Conclusion

This chapter outlined the process of applying selection criteria for important factors in the research project as a whole. Criteria for selecting research sites were primarily; disturbance type, ecological setting, growing seasons since reclamation and plant performance. Criteria for selecting soil properties were known influences on plant performance and ease of field collection, laboratory and statistical analyses. Criteria for selecting plant properties were responsiveness to growing conditions and ease of field collection, laboratory and statistical analyses. The design and methods captured plant-soil relationships on a variable landscape. A line transect design balanced the needs of stratifying heterogeneous sites and disturbances with randomized sampling for minimal sampling bias. Assessments were implemented in the field and working methods for gathering data on biophysical properties resulted.

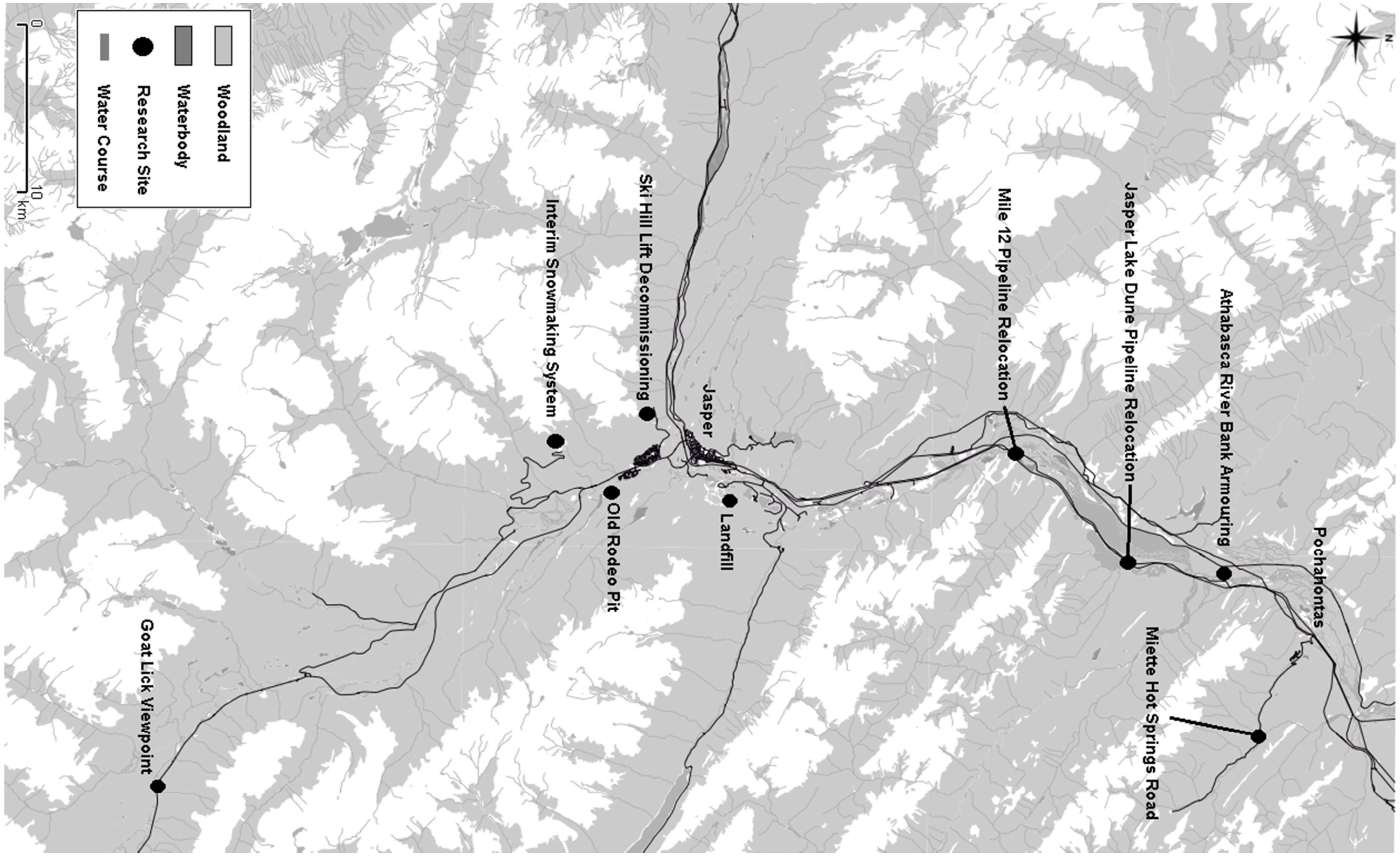

Figure 2.1 Selected research sites (Natural Resources Canada 2011, QGIS 2011)

Table 2.1 Ecological classification, geology, soil texture, drainage and available water classes for research sites

Site Name	Ecosite Class	Parent Material	Texture Class	Drainage Class	Available Water Class
Staging.area.2	Hillsdale 1	calcareous	fine	well	mesic
Ski.hill.8	Patricia 5	calcareous	coarse	well	mesic
Water.line.18	Egypt 1	non-calcareous	coarse	well	mesic
Water.line.19	Egypt 4	non-calcareous	coarse	well	mesic
Water.line.20	Egypt 4	non-calcareous	coarse	well	mesic
Water.line.22	Egypt 1	non-calcareous	fine	well	mesic
Water.line.23	Egypt 1	non-calcareous	fine	well	mesic
Water.line.25	Cavell 1	non-calcareous	fine	imperfect	subhygric
Waste.pit.28	Athabasca 1	calcareous	coarse	well	mesic
Pipe.valve.31	Vermillion Lakes 3	calcareous	fine	poor	hygric
Access.route.33	Devona 1	calcareous	coarse	rapid	subxeric
Access.route.34	Devona 1	calcareous	fine	rapid	subxeric
Pipe.pullout.35	Devona 1	calcareous	fine	rapid	subxeric
Staging.area.37	Vermillion Lakes 3	calcareous	coarse	poor	hygric
Pipe.valve.39	Vermillion Lakes 1	calcareous	coarse	very poor	subhydric
Pipe.route.40	Vermillion Lakes 1	calcareous	fine	very poor	subhydric
Staging.area.41	Vermillion Lakes 1	calcareous	coarse	very poor	subhydric
Pipe.route.42	Devona 2	calcareous	coarse	well	mesic
Pipe.valve.44	Vermillion Lakes 5	calcareous	fine	poor	hygric
Pipe.pullout.45	Vermillion Lakes 4	calcareous	fine	poor	hygric
Waste.pit.51	Athabasca 1	calcareous	coarse	well	mesic
Walking.path.56	Athabasca 1	calcareous	coarse	well	mesic
Road.cut.69	Norquay 3	calcareous	coarse	very rapid	xeric

Adapted from Holland Coen 1983b

Table 2.2 Geographical locators, landform properties and age classes for research sites

Site Name	Easting	Northing	Elevation Class	Slope Class	Aspect Class	Size Class	Time Class
Staging.area.2	433860	5890714	1000	4.9	113	1	84
Ski.hill.8	425281	5856359	1200	14.9	0	1	108
Water.line.18	426071	5850547	2000	14.9	23	0.1	36
Water.line.19	425927	5850375	2000	4.9	23	0.1	36
Water.line.20	425812	5850357	2000	14.9	23	0.1	36
Water.line.22	426023	5850758	2000	9.9	68	0.1	36
Water.line.23	426191	5850824	1800	9.9	68	0.1	36
Water.line.25	426616	5850749	1800	9.9	113	0.1	36
Waste.pit.28	429875	5860774	1000	9.9	113	3	96
Pipe.valve.31	434440	5888605	1000	4.9	0	0.1	36
Access.route.33	433241	5884117	1000	4.9	0	1	36
Access.route.34	433805	5885437	1000	9.9	68	0.1	36
Pipe.pullout.35	433809	5885609	1000	4.9	113	1	36
Staging.area.37	434519	5888178	1000	4.9	158	1	36
Pipe.valve.39	426753	5877296	1000	4.9	0	1	48
Pipe.route.40	427000	5877545	1000	4.9	0	0.1	48
Staging.area.41	427362	5877814	1000	4.9	0	1	36
Pipe.route.42	428044	5879127	1000	9.9	68	0.1	48
Pipe.valve.44	428357	5879621	1000	4.9	0	1	48
Pipe.pullout.45	428762	5880074	1000	4.9	0	1	48
Waste.pit.51	427832	5856224	1000	9.9	0	3	24
Walking.path.56	442754	5829942	1200	9.9	68	0.1	96
Road.cut.69	443380	5892376	1200	29.9	203	1	312

Note: Coordinates are Universal Transverse Mercator for zone 11 U, elevation is meters above sea level, slope is degrees, aspect is degrees with 0 indicating a flat surface, size is hectares and time is months since reclamation.

Table 2.3 Disturbance activities on research sites

Site Name	Demolition	Contamination	Brushing	Compaction	Excavation
Staging.area.2	no	no	yes	no	yes
Ski.hill.8	yes	no	no	no	yes
Water.line.18	no	no	yes	no	yes
Water.line.19	no	no	yes	no	yes
Water.line.20	no	no	yes	no	yes
Water.line.22	no	no	yes	no	yes
Water.line.23	no	no	yes	no	yes
Water.line.25	no	no	yes	no	yes
Waste.pit.28	no	yes	no	no	yes
Pipe.valve.31	yes	no	yes	no	yes
Access.route.33	yes	no	yes	no	yes
Access.route.34	yes	no	yes	no	yes
Pipe.pullout.35	yes	no	yes	no	yes
Staging.area.37	yes	no	yes	no	yes
Pipe.valve.39	yes	no	yes	no	yes
Pipe.route.40	yes	no	yes	no	yes
Staging.area.41	yes	no	yes	no	yes
Pipe.route.42	yes	no	yes	no	yes
Pipe.valve.44	yes	no	yes	no	yes
Pipe.pullout.45	yes	no	yes	no	yes
Waste.pit.51	no	yes	yes	yes	no
Walking.path.56	yes	no	no	yes	yes
Road.cut.69	no	no	yes	no	yes

Table 2.3 Disturbance activities on research sites (continued)

Site Name	Soil Mixing	Soil Salvage	Dewatering	Erosion Control	Backfilling	Contouring
Staging.area.2	no	yes	no	yes	no	yes
Ski.hill.8	no	no	no	no	no	yes
Water.line.18	yes	yes	no	yes	yes	yes
Water.line.19	yes	yes	no	yes	yes	yes
Water.line.20	yes	yes	no	yes	yes	yes
Water.line.22	yes	yes	no	yes	yes	yes
Water.line.23	yes	yes	no	yes	yes	yes
Water.line.25	yes	yes	no	yes	yes	yes
Waste.pit.28	yes	yes	no	no	yes	yes
Pipe.valve.31	yes	yes	yes	yes	yes	yes
Access.route.33	yes	yes	yes	yes	yes	yes
Access.route.34	yes	yes	yes	yes	yes	yes
Pipe.pullout.35	yes	yes	yes	yes	yes	yes
Staging.area.37	yes	yes	yes	yes	yes	yes
Pipe.valve.39	yes	yes	no	yes	yes	yes
Pipe.route.40	yes	yes	no	yes	yes	yes
Staging.area.41	yes	yes	no	yes	yes	yes
Pipe.route.42	yes	yes	no	yes	yes	yes
Pipe.valve.44	yes	no	no	yes	yes	yes
Pipe.pullout.45	yes	no	no	yes	yes	yes
Waste.pit.51	yes	no	no	no	yes	yes
Walking.path.56	no	yes	no	no	yes	no
Road.cut.69	yes	no	no	yes	no	yes

Table 2.4 Reclamation activities on research sites

Site Name	Soil Import	Scarification	Seeding	Transplanting
Staging.area.2	no	yes	yes	yes
Ski.hill.8	yes	no	no	no
Water.line.18	no	no	yes	yes
Water.line.19	no	no	yes	yes
Water.line.20	no	no	yes	yes
Water.line.22	no	no	yes	yes
Water.line.23	no	no	yes	yes
Water.line.25	no	no	yes	yes
Waste.pit.28	yes	yes	yes	yes
Pipe.valve.31	no	no	yes	no
Access.route.33	no	no	yes	no
Access.route.34	no	no	yes	no
Pipe.pullout.35	no	no	yes	no
Staging.area.37	no	no	yes	no
Pipe.valve.39	no	yes	yes	no
Pipe.route.40	no	yes	yes	no
Staging.area.41	no	yes	yes	no
Pipe.route.42	no	yes	yes	no
Pipe.valve.44	no	yes	no	no
Pipe.pullout.45	no	yes	no	no
Waste.pit.51	yes	yes	yes	no
Walking.path.56	yes	no	yes	yes
Road.cut.69	no	no	no	yes

Table 2.4 Reclamation activities on research sites (continued)

Site Name	Herbicide	Amendment	Amendment Type	Fertilizer	Mixture
Staging.area.2	no	yes	wood chip	no	-
Ski.hill.8	no	yes	topsoil	no	-
Water.line.18	no	no	-	yes	11-55-0
Water.line.19	no	no	-	yes	11-55-0
Water.line.20	no	no	-	yes	11-55-0
Water.line.22	no	no	-	yes	11-55-0
Water.line.23	no	no	-	yes	11-55-0
Water.line.25	no	no	-	yes	11-55-0
Waste.pit.28	no	yes	topsoil + woodchip	yes	unknown
Pipe.valve.31	no	yes	topsoil	no	-
Access.route.33	no	yes	topsoil + compost	no	-
Access.route.34	no	yes	topsoil + compost	no	-
Pipe.pullout.35	yes	yes	topsoil + compost	yes	32-59-7
Staging.area.37	no	yes	topsoil + compost	yes	11-52-0
Pipe.valve.39	yes	yes	topsoil	no	-
Pipe.route.40	yes	yes	topsoil	no	-
Staging.area.41	yes	yes	compost	yes	54-0-0
Pipe.route.42	yes	no	-	no	-
Pipe.valve.44	no	no	-	no	-
Pipe.pullout.45	no	no	-	no	-
Waste.pit.51	no	yes	topsoil + compost	no	-
Walking.path.56	no	yes	topsoil + compost	no	-
Road.cut.69	no	no	-	yes	80-40-10-10

Note: Fertilizer mixtures indicate percentages of nitrogen, phosphorus, potassium and sulfur, in the order presented

Table 2.5 Parks Canada Agency file name, proponent and research name designations

JNP File	Proponent	Project Title	Database Name	Site Name
J01-020	Trans Mountain Pipelines	Athabasca Bank Armouring	Laydown	Staging.area.2
J00-045	Jasper Lions Club	Removal of Built Structures	Abandoned ski hill	Ski.hill.8
J04-044	Marmot Basin	Interim Snowmaking Line	Site 6	Water.line.18
J04-044	Marmot Basin	Interim Snowmaking Line	Site 7	Water.line.19
J04-044	Marmot Basin	Interim Snowmaking Line	Site 8	Water.line.20
J04-044	Marmot Basin	Interim Snowmaking Line	Site 10	Water.line.22
J04-044	Marmot Basin	Interim Snowmaking Line	Site 11	Water.line.23
J04-044	Marmot Basin	Interim Snowmaking Line	Site 13	Water.line.25
J00-028	Jasper Park Lodge	Landfill Reclamation	Trade waste pit	Waste.pit.28
J05-028	ATCO Pipelines	Jasper Lake Dune Pipeline Relocation	New RoW start	Pipe.valve.31
J05-028	ATCO Pipelines	Jasper Lake Dune Pipeline Relocation	Access segment #2	Access.route.33
J05-028	ATCO Pipelines	Jasper Lake Dune Pipeline Relocation	Access exposed pipe	Access.route.34
J05-028	ATCO Pipelines	Jasper Lake Dune Pipeline Relocation	Pull out #4	Pipe.pullout.35
J05-028	ATCO Pipelines	Jasper Lake Dune Pipeline Relocation	Laydown	Staging.area.37
J04-020	ATCO Pipelines	Mile 12 Pipeline Relocation	New RoW start	Pipe.valve.39
J04-020	ATCO Pipelines	Mile 12 Pipeline Relocation	Abandoned RoW S	Pipe.route.40
J04-020	ATCO Pipelines	Mile 12 Pipeline Relocation	Laydown	Staging.area.41
J04-020	ATCO Pipelines	Mile 12 Pipeline Relocation	Forested RoW	Pipe.route.42
J04-020	ATCO Pipelines	Mile 12 Pipeline Relocation	New RoW end	Pipe.valve.44
J04-020	ATCO Pipelines	Mile 12 Pipeline Relocation	Pull out	Pipe.pullout.45
J06-004	Parks Canada	Old Rodeo Pit Restoration	Old rodeo pit	Waste.pit.51
J01-055	Parks Canada	Fencing and Footprint Reduction	Goatlick viewpoint	Walking.path.56
1983	Parks Canada	Slope Stabilization and Revegetation	Miette Road site 28	Road.cut.69

Table 2.6 Laboratory analysis of soil properties

Property	Method	Reference	Detection Limit	Units
Soil Reaction (pH)	saturated paste extract	Carter and Gregorich 2007	-	-
Electrical Conductivity	saturated paste extract	Carter and Gregorich 2007	0.01	$dS\ m^{-1}$
Soluble Cations	saturated paste extract	Carter and Gregorich 2007	1 to 2	$mg\ L^{-1}$
Sodium Adsorption Ratio	saturated paste extract	Carter and Gregorich 2007	-	-
Exchangeable Cations	inductively coupled plasma	Standard Methods 3120 B 2005	4 to 12	$mg\ kg^{-1}$
Cation Exchange Capacity	inductively coupled plasma	Standard Methods 3120 B 2005	-	-
Calcium Carbonate	acid titration extract	Standard Methods 2320 B 2005	5	$mg\ L^{-1}$
Total Nitrogen	Leco combustion	ASTM E1019-08 2007	0.001	%
Total Carbon	Leco combustion	ASTM E1915-07a 2007	0.01	%
Total Organic Carbon	wet combustion	Nelson and Sommers 1996	1	%
Particle Size Classification	75 µm sieve	Carter and Gregorich 2007	-	-

Table 2.7 Air photos covering research site in Jasper National Park

Project	Job	Scale	Roll	Line	Start Picture	End Picture
49-83F	49-1	1:40000	AS 140	5304	35	37
49-83F	49-1	1:40000	AS 141	5303	105	115
49-83F	49-1	1:40000	AS 142	5302	121	127
49-83F	49-1	1:40000	AS 142	5300/01	149	-
49-83F	49-1	1:40000	AS 142	5301/02	94	97
49-83D	49-1	1:40000	AS 144	5216	21	24
49-83D	49-1	1:40000	AS 145	5215	50	53
49-83D	49-1	1:40000	AS 145	5214/15	9	13
49-83D	49-1	1:40000	AS 146	5214	87	90
49-83D	49-1	1:40000	AS 147	5213	155	157
49-83D	49-1	1:40000	AS 148	5212	183	184
49-83D	49-1	1:40000	AS 148	5211	8	9
49-83D	49-1	1:40000	AS 149	5210/11	194	196
BR 74343	74-194(4-4)	1:24000	AS 1446	8	340	346
S78-196	2-9	1:25000	AS 2900	5	1	43
E-5	78-49	1:21120	AS 1723	12	54	55
E-5	78-49	1:21120	AS 1723	11 A	27	28
E-5	78-49	1:21120	AS 1723	10 A	1	-
82-089-83F	81-47	1:30000	AS 2636	29	1	5
S84-85	1-3	1:25000	AS 2937	5 sw	6	10
S84-85	1/2-3	1:25000	AS 2937	4 sw	11	23
S84-85	2-3	1:25000	AS 2937	3 se	24	32
S84-85	3-3	1:25000	AS 2937	2 sw	33	39
S84-85	3-3	1:25000	AS 2937	9 se	80	-
85-123 83F	85-123	1:60000	AS 3143	49	56	57
85-123 83F	85-123	1:60000	AS 3143	48	110	115
F88-014	1-6	1:20000	AS 3807	1 sw	194	202
F88-014	3-11	1:20000	AS 3807	6 w	153	-
F88-014	3-11	1:20000	AS 3807	5sw	154	161
F88-014	2/3-11	1:20000	AS 3807	4 ssw	162	171
F88-014	2-11	1:20000	AS 3807	3 sw	172	181
F88-014	2-11	1:20000	AS 3807	2 se	182	193
T91-077	12-13	1:20000	AS 4212	1 e	1	15
T91-077	12-13	1:20000	AS 4212	2 e	19	25
T91-077	12-13	1:20000	AS 4212	2 e	33	35
T92-031	1-3	1:20000	AS 4266	6 ese	75	77
93-131 83F	93-131	1:40000	AS 4420	48 A	139	140
93-131 83F	93-131	1:40000	AS 4420	48 B	167	169
G97062	1-4	1:40000	AS 4867	1 nw	20	-
G97062	2-4	1:40000	AS 4867	1 nw	1	7
G97062	2-4	1:40000	AS 4867	2 nw	31	36
G97062	1-4	1:40000	AS 4867	3 nw	38	51
G97062	3-4	1:40000	AS 4867	4 ne	60	63
G97062	3-4	1:40000	AS 4867	5 ne	80	83

Table 2.8 Percentage of disturbed area represented by paired plots for each site

Site Name	Disturbance Area (m^2)	Plot Area (m^2)	Percent Area Sampled
Staging.area.2	8,712	1.60	0.02
Ski.hill.8	6,666	0.80	0.01
Water.line.18	288	1.90	0.66
Water.line.19	560	2.00	0.36
Water.line.20	624	2.00	0.32
Water.line.22	689	1.80	0.26
Water.line.23	752	0.50	0.07
Water.line.25	296	0.60	0.20
Waste.pit.28	19,008	1.30	0.01
Pipe.valve.31	480	1.70	0.35
Access.route.33	2,450	0.90	0.04
Access.route.34	560	0.50	0.09
Pipe.pullout.35	1,760	2.00	0.11
Staging.area.37	9,800	1.50	0.02
Pipe.valve.39	2,324	1.60	0.07
Pipe.route.40	784	1.30	0.17
Staging.area.41	6,890	0.70	0.01
Pipe.route.42	871	0.80	0.09
Pipe.valve.44	3,300	1.90	0.06
Pipe.pullout.45	1,620	2.00	0.12
Waste.pit.51	27,800	1.20	0.00
Walking.path.56	128	1.00	0.78
Road.cut.69	5,577	2.00	0.04
Total Area	101,939	31.60	0.03

Table 2.9 Dates in 2009 for site stratification, vegetation assessment and soil sampling

Number	Proponent	Site Descriptor	Stratification	Vegetation	Soils
2	TMPL	Laydown	06-Jun	26-Jul	19-Aug
3	TMPL	Km 380.174	08-Jun	14-Jul	
4	TMPL	Km 381.220	08-Jun	14-Jul	
6	TMPL	Km 382.046	07-Jun	14-Jul	
7	TMPL	Km 383.166	07-Jun	13-Jul	
8	JLC	Abandoned Ski Hill	07-Jun	13-Jul	30-Aug
9	Petro Canada	Abandoned Station	15-Jun	18-Jul	
10	Marmot	Bottom Chair	11-Jun	25-Jul	
11	Marmot	Top Chair	11-Jun		
15	Marmot	Site 3	12-Jun		
16	Marmot	Site 4	12-Jun		
17	Marmot	Site 5	11-Jun		
18	Marmot	Site 6	11-Jun	24-Jul	20-Aug
19	Marmot	Site 7	11-Jun	27-Jul	20-Aug
20	Marmot	Site 8	11-Jun	21-Aug	21-Aug
21	Marmot	Site 9	11-Jun		
22	Marmot	Site 10	11-Jun	24-Aug	24-Aug
23	Marmot	Site 11	12-Jun	22-Aug	20-Aug
24	Marmot	Site 12	12-Jun		
25	Marmot	Site 13	12-Jun	24-Jul	20-Aug
26	Marmot	Site 14	12-Jun		
28	JPL	Landfill	09-Jun	17-Jul	24-Aug
30	JPL	Golf Cart Paths	09-Jun		
31	ATCO Pipe	New RoW Start	10-Jun	17-Jul	17-Aug
32	ATCO Pipe	Pull Out #2	10-Jun	16-Jul	
33	ATCO Pipe	Access Segment #2	10-Jun	16-Jul	18-Aug
34	ATCO Pipe	Access Exposed Pipe	10-Jun	16-Jul	18-Aug
35	ATCO Pipe	Pull Out #4	10-Jun	16-Jul	17-Aug
36	ATCO Pipe	Pull Out #6	10-Jun	16-Jul	
37	ATCO Pipe	Laydown	11-Jun	15-Jul	17-Aug
38	ATCO Pipe	New RoW End	10-Jun	15-Jul	
39	ATCO Pipe	New ROW Start	09-Jun	14-Jul	19-Aug
40	ATCO Pipe	Abandoned RoW S	09-Jun	15-Jul	19-Aug
41	ATCO Pipe	Laydown	09-Jun	14-Jul	18-Aug
42	ATCO Pipe	Forested RoW	09-Jun	15-Jul	19-Aug
43	ATCO Pipe	Abandoned RoW N	09-Jun	17-Jul	
44	ATCO Pipe	New RoW End	15-Jun	17-Jul	18-Aug
45	ATCO Pipe	Pull Out	09-Jun	15-Jul	18-Aug
47	Allstream AT&T	Lower Tram Station	15-Jun		
50	Allstream AT&T	Fire Road Access	15-Jun		
51	JNP	Old Rodeo Pit	07-Jun	13-Jul	22-Aug
55	JNP	Trailhead	12-Jun		
56	JNP	View Point	12-Jun	17-Jul	21-Aug
57	JNP	Site 1	14-Jun		

Table 2.9 Dates in 2009 for site stratification, vegetation assessment, and soil sampling (continued)

Number	Proponent	Site Descriptor	Stratification	Vegetation	Soils
58	JNP	Site 2	14-Jun		
59	JNP	Site 3	14-Jun		
60	JNP	Site 7	14-Jun		
61	JNP	Site 8	14-Jun		
62	JNP	Site 10	14-Jun		
63	JNP	Site 11	14-Jun		
64	JNP	Site 12	14-Jun		
65	JNP	Site 13	13-Jun		
66	JNP	Site 15	13-Jun		
67	JNP	Site 21	13-Jun		
68	JNP	Site 22	13-Jun		
69	JNP	Site 28	13-Jun	23-Aug	23-Aug

Table 2.10 Numbers of low and high performance plots and total paired plots for each site

Name	Low Performance	High Performance	Total Pairs
Staging.area.2	9	7	16
Ski.hill.8	8	0	8
Water.line.18	20	0	20
Water.line.19	20	0	20
Water.line.20	20	0	20
Water.line.22	0	17	17
Water.line.23	5	0	5
Water.line.25	6	0	6
Waste.pit.28	9	4	13
Pipe.valve.31	0	17	17
Access.route.33	9	0	9
Access.route.34	0	5	5
Pipe.pullout.35	0	20	20
Staging.area.37	3	12	15
Pipe.valve.39	4	13	17
Pipe.route.40	0	19	19
Staging.area.41	9	0	9
Pipe.route.42	3	6	9
Pipe.valve.44	0	20	20
Pipe.pullout.45	0	20	20
Waste.pit.51	10	3	13
Walking.path.56	9	2	11
Road.cut.69	20	0	20
Sample Size	164	165	329

3.0 BIOPHYSICAL PROPERTIES, RELATIONSHIPS, PERFORMANCE AND CRITERIA FOR EVALUATING LAND RECLAMATION

3.1.0 Introduction

After surveying many statistical analyses, methods in this chapter were chosen to best satisfy the research objectives. Relationships between plant responses and soil properties, resulting from land reclamation, are characterized by multivariate regression trees. Soil properties with high frequency and power to explain observed plant abundances are proposed for monitoring land reclamation. Plant related biophysical properties are plant abundance, litter (mulch) cover, species diversity and density scored for each site, then sites ranked from best to worst. Ranked averages of plant and soil properties on the research sites were visually compared in relation to tolerance thresholds and performance criteria suited to montane and subalpine ecoregions.

3.2.0 Focal Plant Species

3.2.1 Introduction

Mountainous sites are diverse in plant species composition and abundances; there are about 800 species of vascular and non-vascular plants inventoried for Jasper and Banff National Park (Holland and Coen 1983). On research sites, 211 grass, forb and woody species were identified (Table 3.1). Of non-native plant species currently targeted for control in the park (Westhaver 2009) 32 species were observed on research sites (Table 3.2). On a given research site species richness varied from 1 to 35 species, thus selecting which to use in evaluating reclamation was required and where to cut was problematic. Native species with high frequency and abundance are logical choices as they make up the core of a sustainable plant community and should be conserved (Alberta Environment 2003, Naeth 2011). Plant species of low frequency and abundance may be important in community development wehre native species may reflect reclaimed soil integrity. Non-native species may indicate degrading soil which affects plant community integrity. In both cases, highlighting relative performance of plant species is needed and this method helped select plants species for analysis.

3.2.2 Methods

Scores of observed species abundance helped make selection of focal species more objective where a calculation combines total species abundance with sample frequency into relative scores. Live plant basal and canopy cover, useful and indicative biophysical properties, were added together and then multiplied by species sample frequency, the proportion of species observations to all quadrats assessed (Species Abundance * Species Site Frequency = Abundance Score). Abundance scores were computed for species in Excel 2010. Those species with abundance scores > 1 % were retained while those with < 1 % were removed. An example for Access route 34 is shown in Table 3.3. Choosing a 1 % threshold was based on cover in a quadrat where trace values were recorded as a matter of accuracy; high plant species abundance has high potential for signaling a link to soil properties and is likely to improve soil conservation. Non-native species were carried forward regardless of their abundance scores as these are considered a management priority.

Once identified, the focal species raw abundances are modified with a Hellinger distance transformation (Equation A.2). The Hellinger distance association is a Euclidean distance on row vectors where raw abundance values (Table 3.4) are divided by the total site abundance and the result is a square root transformed matrix (Table 3.5) (Borcard et al. 2011). The effect is to dampen the signal from species with larger abundances and boost the signal of species with lower abundances (Borcard et al. 2011). Compared with other measures, the Hellinger transformation is recommended for clustering and ordination of species abundance data (Rao 1995 in Legendre and Gallagher 2001) because it offers a better compromise between linearity and resolution than the chi-square metric or chi-square distance (Legendre and Gallagher 2001). The decostand function in package vegan (version 1.17-2) was used to calculate the Hellinger distance matrix prior to multivariate regression analysis (Oksanen et al. 2011).

3.2.3 Results and Discussion

Live plant basal and canopy cover were combined and multiplied by sample based frequencies to evaluate absolute species abundances for their strengths. No site is assessed in excess of 2.0 m^2 and each quadrat is a standard size, so sample intensity is similarly scaled. Random sampling ensured representative groups of individuals; thus the data was stratified by a proportion that reasonably assessed the real value of total species abundance.

The effect of distributing abundance over area means trace observations, that cannot realistically support statistical analysis, were made even more insignificant numerically and thus easily identifiable for removal (Table 3.3). Whereas, highly abundant plant species represent a greater potential for responding to soil properties and thus may signal important relationships for understanding and improving soil conservation.

Results of trimming species list are illustrated for Access route 34 where trimming data is demonstrated, reducing 13 species to 5 for analysis (Table 3.3). Abundant species retained have scores > 1 %; *Carex* 9.2, *Equisetum arvense* 3.78, *Solidago spathulata* 2.48, *Galium boreale* 2.04 and *Agropyron dasystachyum* 1.5 %. Though cover of *Bromus inermis* 0.88 and *Salsola kali* 0.04 % does not meet the first criterion of abundance, the second is satisfied; these are non-native species requiring management attention. The trimmed data set includes 7 focal plant species and although this analysis did not focus on rare plant species it could objectively identify rare species by their quantitative biological properties of live cover and presence.

Change of abundance values from raw to a transformed for each plot at Access route 34 is shown in Tables 3.4 and 3.5. Hellinger transformation is applied to absolute abundance of observed species because abundance leads to variance and too little or too much variance may draw analysis away from sensible ecological interpretations (Table 3.5) (Blanchet personal communication July 2010; Hamann personal communication July 2010). Retaining non-native species potentially brackets low plant abundances which tend to be rare and are of ecological interest. Other factors affect rarity and commonness such as; bio-geographical range, mode of dispersion, seed predation and niche competition across the landscape. Directly investigating rare native species would be a question best left until after ecosystems are characterized.

In Jasper National Park, a primary objective of revegetation is to establish abundant cover of robust and diverse native species to prevent pioneering by aggressive non-native plant species (AXYS Environmental Consulting Ltd. and David Walker and Associates 1998, Parks Canada 2009, Westhaver 2009). Results from a focal species analysis of all research sites are presented in Tables 3.6 and 3.7. There are 8 non-native species, *Agropyron repens* (113.02), *Agropyron trachycalum* (62.31), *Festuca rubra* (39.39), *Cirsium arvense* (10.23), *Taraxacum officionale* (8.40), *Sonchus arvense* (6.35), *Poa pratensis* (5.19) and *Bromus inermis* (2.66) with high scores for previously disturbed montane and subalpine sites. Alternativley, there are 20 native species with scores > 2.00 forming a core group in plant communities which developed since reclamation. Native plant species in undisturbed plant communities are present on reclaimed sites indicating reclamation can result in more than a resemblance of surroundings and is competitive with non-natives at the landscape scale, if not always at the site scale.

3.2.4 Conclusions

If a species is readily observed on a site by trained observers, it could be considered a common species; however, the crux is representing this knowledge numerically. The concept of indicator species has a history of use in community ecology, with various analytical methods. These methods were considered, however abundance scores, as described above, are a less complex means of selecting for the readily observed species on which this study focuses. The method can also be scaled up to examine a group of research sites and determined the prominence of observed species. Though, it is acknowledged that a focal species group, exclusive of rarities, likely impacts analysis and in turn impacts interpretations. However, given the challenge of how best to establish abundant, robust and diverse species, the advantage lies in selecting strong plant responses before examining relationships with soil biophysical properties.

Data sets were trimmed of native species with low abundance scores and analysis concentrated on species with high abundance scores to give stronger signals in response to soil properties; low abundance species are believed to add noise and not provide additional information. Selection of focal plant species and transformation of abundances were necessary steps prior to analysis with multivariate regression trees. Each species list retained is presented in tables from multivariate regression tree analysis and no sites have the same group of focal species. The species lists can potentially serve as a driver for management of problem species and development of reclamation seed mixes on particular sites or at the landscape level.

3.3.0 Multivariate Regression Trees

3.3.1 Introduction

Multivariate regression trees directly and hierarchically cluster dependent variables according to independent variables (Equation A.3). In this study, they determine soil properties influencing plant abundance and by how much. Multivariate regression trees serve two purposes in constructing predictors. With a new measurement vector they can predict response or trace structural relationships between response and measured variables (Breiman et al. 1984, De'ath 2002). Most pertinent to this research they can address relationships between plant response and soil properties after land reclamation. Relative, cross validated and sampling errors indicate how strong the association is between plant response and soil property. Once characterized this relationship can be used to classify and predict new biophysical properties to sample. Good predictions based cross validated errors are < 1 and approach zero (Breiman et al. 1984, De'ath 2002).

Multivariate regression trees recursively group plant response into homogeneous clusters according to an impurity criterion from a soil property that explains variance at a specific value (Brieman et al. 1984, De'ath 2002, De'ath and Fabricius 2000, Borcard et al. 2011). For this reason soil properties were not transformed prior to analysis; otherwise interpretive value would be lost due to the break in association with their units. Regression trees can handle values at different scales as standardization is carried out when minimizing sum of squares (De'ath 2002, Grace and McCune 2001). However, response variables must be numeric and in this case were continuous quantitative data (De'ath 2002). No assumptions were made about the underlying distribution characterizing the response explanatory variable relationship. This was an important factor in choosing this method of analysis as there is no certainty about how plant abundance is specifically and directly affected by soil properties in subalpine or montane ecoregions.

3.3.2 Methods

Characterizations of relationships on research sites were graphically displayed as trees with nodes splitting into leaves that split again or terminated. Plant-soil relationships ranged from simple to complex with some unbalanced and some balanced clusters of sub-systems. Plant species information relevant to the tree that cannot be displayed graphically is presented in supplementary tables. Soil properties at critical values from regression trees head table columns about variance and transformed abundances accounted for by each property. Codes for soil properties are related in Table 3.10

All computations of multivariate regression trees and graphical representations were carried out with R (version 2.13.0), a programming environment for data analysis and graphics, and package mvpart (version 1.3-1) a suite of programming functions for analysis of ecological data using multivariate partitioning algorithms (De'ath 2011). The decostand function in the R vegan package (version 1.17-2) converted plant abundance data to a Hellinger distance association matrix, (described in Section 2.2) which means distance based multivariate regression is conducted instead of Euclidean distance based regression (De'ath 2002, Legendre and Gallagher 2001, McCune and Grace 2002). Cross validations to find the best relationships between responses and explanatory variables were set to 1000 in the mvpart function, even though trees were meant to characterize relationships not predict plant occurrence.

Several diagnostic values on regression tree output require explanation to derive full meaning from deceivingly plain graphics. On the tree, the node rests in the middle of a horizontal bar and vertical bars represent either new nodes that are split again, or terminal leaves indicating the algorithm has halted. At the node of a tree informative values are the explanatory variable with impurity (splitting) criteria, variance of the group before splitting and sample size. At the terminal leaf of a tree informative values are the deviance of a homogeneous group and number of plots supporting that particular association. Deviance is a value to judge whether there is good fit of the response to explanatory variable; values > 1 are not as good a fit as deviance measures < 1. Groups of plots with deviance values > 1 may signify the algorithm setting aside data that are too noisy to be of value and in doing so isolates plots with a clear association between soil property and plant response (Blanchet personal communication July 2010).

On the x axis there are three error terms reported for each mvpart tree; the relative error is the reciprocal of the R^2 which estimates how much variance is explained by each explanatory variable. In a predictive tree this value often over estimates the predictive strength of a tree, hence a cross validated error reports ability of a tree to predict outcomes (De'ath 2002). Sampling error is a ratio of relative error in observations to relative error in expected values, based on the observations (Breiman et al. 1984).

The y axis label reports complexity (variance explained) by soil property node, also indicated by length of vertical lines representing tree leaf stems. Regression algorithms compare complexity values, minimum sums of squares, for each soil property (Borcard et al. 2011). Compared with other soil properties the property at a particular value that balances most complexity with least impurity in at least two samples per group is the best explanatory variable. Complexity for each property is a subcomponent of tree cumulative variance and reported as relative error, which when subtracted from 1 is equal to R^2 (Breiman et al. 1984, Borcard et al. 2011, De'ath 2002).

Accompanying tree figures for sites are supplementary tables summarizing explained variance and transformed plant abundance each soil property accounted for in regressions of that site. On both tables plant species occupy rows and soil properties head columns. In the first table, amount of plant variance explained, there are added column headers, tree total and species total, and an added row label, complexity total. Complexity total is R^2 (variance explained) for all species by soil properties corresponding to lengths of leaf stems in graphical trees. Tree total is summed R^2 for soil properties associated with each plant species. The cell where tree total intersects complexity total is amount of complexity (unexplained variance) captured by the regression tree (De'ath 2002). This varies and is the primary indicator of associations between plants and soils for each site. Species total is amount of variance calculated for each plant species and its complexity sums to 100 (De'ath 2002). Comparing tree and species totals indicates of how well soil properties account for plant species variability on each site. The difference between them is important; those with high proportion of unexplained variability (e.g. tree total << species total) may mean other factors affect plant species abundance. Small differences or equivalent totals (e.g. tree total ≤ species total) mean the tree, with various soil properties, explains variability in plant abundance very well (Borcard et al. 2011, De'ath 2002).

In the second table, transformed plant abundance, species are in rows with soil properties as headers; added column and row header are species total and property total. Property total specifies how much plant abundance is accounted for in every critical value of a soil property; species total specifies how much plant abundance is accounted for in every focal species. Use of the word transformed is significant; these values are the Hellinger transformation matrix. All values are a product of division of species abundance by total site abundance which is then square root transformed (Borcard et al. 2011). These are not values that would be directly observable in quadrats on the land.

Besides the mvpart regression trees the lack of graphical representations is acknowledged but as no satisfactory representative plots could be arrived at with mvpart functions tables presented the most concise summarization. The primary challenge stems from the range of information associated with any given site. Despite the focal species analysis, sites have as few as 4 to as many as 20 plant species and up to 6 soil properties. Attempts were made but the range of objects and descriptors prevented visually informative and appealing simplifications.

3.3.3 Results and Discussion

Multivariate regression trees characterize plant-soil relationships for 23 research sites. Tree performance is summarized (Table 3.8) and descriptive statistics are presented (Table 3.9). Average residual error was 0.41 (standard deviation 0.153). R^2 averaged 0.59 (standard deviation 0.15). Because these trees characterize relationships rather than predict abundance, cross validated error averaged 1.39 (standard deviation 0.15). Numbers of plot pairs varied from 5 to 20, with an average 1.37 m^2 (standard deviation 0.55) area sampled on each site. With the outputs (Table 3.8) it may be possible to determine an optimal sample size where highest R^2 is achieved while still having a low cross validated error; this was not explored but worth mentioning. Soil property codes with units and detection limits are presented in Table 3.8 to help interpret critical values of soil properties. Results for each site are presented in Appendix B which consists of a regression tree figure, a table for amount of variance explained and a table for amount of transformed abundance; these collectively quantify the relationship between focal plant species abundance and soil properties at their critical values.

Water line 20 is a worked example (Figure 3.1, Tables 3.11 and 3.12). The node sieve percent at 48.5 % had a total variance of 11.6 and the group was all 20 plots. The split sieve percent < 48.5 % separated 4 plots; with a deviance of 1.81 these are probably noisy plots with no ecological interpretation. The variance explained by the branching leaf (Table 3.11) was about 22 %, presented on the y axis under the column of that node. *Carex, Poa compressa* and *Festuca saximontana* had cumulative abundance of 115.5 %, which over four plots averaged 28.9 % cover; for each species there were totals of 25, 64.5 and 26 %, respectively (Table 3.10). These abundances were Hellinger transformed and thus a conservative representation. Working with the same figures and tables, skip to the 3 plots with mean penetration resistance ≥ 1.6 MPa. Conditions in these plots have other important soil properties such as cation exchange capacity ≥ 6.32 meq $100g^{-1}$, bicarbonate concentration < 25.5 mg L^{-1} and sieve percent ≥ 48.5 %. The deviance of these plots is 0.43, with < 1 indicating an acceptable fit of the mean square intergroup distance. The total variance explained by this branching leaf is 6.6 % (Table 3.11) with *Poa interior* the species most affected by that and preceding conditions. Average abundance of these 3 plots total 161.7 %, the highest of all plots, where *Poa interior* is one of three other graminoids found with a sedge and leafy forb (Table 3.12).

Regression trees are at their fullest size, meaning they are divided into smallest groups of plots that support association with soil properties. Regression trees graphically represent the algorithm output linking soil properties to plant responses in a dichotomous key (Brieman et al 1984, De'ath 2002). Three general forms of trees emerged. On some one node split into two groups, as with Access route 34 (Figure 3.2). Others tailed off asymmetrically either left or right, as with Water line 20 (Figure 3.1). Some split more symmetrically into as many as 5 nodes, as with Pipe pull out 45 (Figure 3.3). The simplest form was a tree with one split; this may be due to number of paired plots as most sites had a sample size between 5 and 7 pairs. As number of paired plots increased regression trees grew larger, which helped identify more linkages between soil properties and plant abundance (Figures 3.4 and 3.3 for Pipe pull out 45 and Pipe valve 39, respectively). Tree symmetry may have either statistical or ecological implications but presence of higher order interactions below ground as represented by quantitative data is clear.

Relative, cross validated and sampling errors were important indicators of association strength between plant responses and explanatory soil properties. With this association, new sample data can be classified or predicted. These error terms gauge amount and frequency of monitoring necessary to quantify ecosystem development in plant communities and soil profiles. Accumulation rates of quantitative biophysical data gathered with each successive monitoring season can be tracked because cross validated errors are high and trees that are good predictors have values < 1 and nearer zero (Breiman et al. 1984, De'ath 2002) cautious predictions are recommended; more biophysical information is needed from ecoregions or more likely a permutated data set is needed before model building can proceed with more certainty.

The two tables of values for species by soil properties represent species in a quantifiable measure and convey community composition. Zero in both tables means no relationship either in variance or abundance. Otherwise these values depict strength of association between response and property as they increase. It is important to keep in mind that abundance values are transformed so they are a score rather than an observable value. New data will need to be transformed to key out its location in a regression tree. However, scores assign importance of species in community composition. This information has immense value for land reclamation because community type most desired is directly and quantitatively linked to soil properties with critical values which support that desired native plant community. The table of transformed abundance can be used to determine which soil properties best promote a specific community. With this tool land managers can establish cover of abundant, robust and diverse species.

Water line 20 on Marmot Basin, of all habitat types associated with communities (Table 3.12) shows that physical soil properties strongly influence occurrence of non-native species such as *Poa pratensis* and *Festuca rubra*. Conversely, where sieve percent is < 48 % (fine textured soil), bicarbonate is < 25.5 mg L^{-1}, cation exchange capacity is ≥ 6.3 meq $100g^{-1}$ and penetration resistance is < 1.6 MPa, a diverse, robust community is supported but does not include non-native species. Occurrence of non-native species is more likely where sieve percent is ≥ 49 %, bicarbonate is ≥ 25.5 mg L^{-1} and soluble magnesium are around 6.5 mg L^{-1}. This is how trees and tables can be interpreted and applied to designing reclamation prescriptions. For Water line 20, importance of soil losses, surface compaction and admixing is identified and revegetation will likely be affected by soil texture, bulk density and organic matter. Future monitoring on this site should include sieve percent, penetration resistance and cation exchange capacity.

3.3.4 Conclusions

The heterogeneity of a mountain ecosystem is difficult to characterize because of many non-linear relationships that change quickly in a short time period or distance. Multivariate regression trees map the many relationships between plant abundance and soil properties without assuming anything about their distribution. The possibility of drawing the wrong conclusion from field data is averted by the regression process as it recursively and simultaneously selects best pairs of response and explanatory variables from all conceivable combinations of data pairs. Error terms associated with this selection process are meaningful not only in measuring strength of a relationship but in setting monitoring goals for collecting more biophysical data of the same types or new kinds of data but of the same quality level. For instance water related variables might be incorporated in future monitoring designs.

Land managers can use this information, linking plant responses to specific soil conditions, in design and prescription of reclamation practices with a specific native species community for soil type. The relationship between plant abundance and soil property concentrations was quantified explicitly. Non-native species in a plant community can be targeted by soil properties that support their persistence, not just spraying herbicides that may impact off target species. There is much to be learned about how these relationships change with other factors but there is knowledge of plant species and soil property links. This has theoretical and practical uses which need further study to fully appreciate implications for advancing the science of land reclamation in Jasper National Park.

3.4.0 Biophysical Properties to Monitor

3.4.1 Introduction

As a whole performance of soil properties in multivariate regressions were examined to determine which explanatory variables were likely candidate properties for monitoring because they frequently can explain the unknown. Selection criteria to find these were relative frequency per unit area and weighted average variance explained (R^2). A list of biophysical properties most likely to characterize soil rooting zone status in a meaningful way for basing management decisions about revegetation was expected when examining property performance at this scale.

Two aspects of biophysical property performance were examined to determine which soil properties influenced plant abundance on sites reclaimed four to eight years earlier in montane and subalpine ecoregions. Absolute frequency was not useful for identifying how each soil property influenced plant response because sampling intensity among sites and levels of complexity among regression trees varied. Among characterizing trees there was a common degree and an uncommon degree of complexity. With sampling intensity the area assessed made a convenient divisor and multiplier of frequency and explanatory power, respectively. The resulting lists varied in order, as if viewing the same object from different vantage points. Hence future monitoring of routine land disturbances should include some or all these biophysical properties: exchangeable sodium, sodium adsorption ratio, cation exchange capacity, soluble calcium, penetration resistance, sieve percent, electrical conductivity and bicarbonate.

3.4.2 Methods

Because there was uneven sampling intensity and varying tree complexity a difficulty arose where soil property frequency and its distribution might affect determination of representative biophysical properties. Even if sampling intensity were even on all sites these two factors, property frequency and tree complexity, were intertwined such that representation could not be determined by simple addition and ranking of absolute frequency in regression trees. Absolute frequency of each soil property (Table 3.13) does not convey the importance of tree complexity for an uneven distribution of frequencies and sampling intensity in (Table 3.14). These factors affect accuracy in determining representative soil biophysical properties.

As numbers of nodes increase so does tree complexity to a level where a common degree and an uncommon degree of complexity exist among trees. Portions of trees characterizing an uncommon degree of complexity are excluded from assessing biophysical property performance. Developing a general set of biophysical properties means examining a tree which generally characterizes plant response to soil properties.

Locations of properties in regression trees were surveyed and differences among sets of absolute frequencies (Table 3.13) means some trees may be more complex than needed. Primary, secondary and tertiary tree nodes present an even set of absolute frequencies to calculate relative frequency; column sums are even in each node at 23, 24 and 22, respectively. The fourth and fifth nodes contribute sets of 11 and 7 absolute frequencies, respectively; this added information may bias relative frequency with complex cases. To determine if this difference between third and fourth nodes was significant, single factor ANOVAs were done in MS Excel 2010 (Table 3.15). Sets of absolute frequencies differed significantly when 5 nodes were tested together, yet primary, secondary and tertiary nodes showed no significant difference within. After summing sets of absolute frequencies, with groups separated by third and fourth node breaks, there were no significant differences between the group of first, second and third nodes and the group of fourth and fifth tree nodes. A difference within sets of absolute frequencies depends on tree structure but is not evident in its summary; removing special cases ensures soil property importance is not biased.

With sampling intensity the process is less difficult as total area assessed makes a convenient divisor and multiplier to answer questions about soil property performance (Table 3.14). How frequently a property occurs per unit area was calculated by dividing absolute frequency by sampling intensity (Table 3.16). How much variance (R^2) each soil property explained was expressed as a weighted average (Equation A.4) where explained variance for each sample was multiplied by sampling intensity; then the sum of area weighted explained variances was divided by total sampling intensity (Table 3.17). Calculating standard deviation for weighted average explained variance was slightly more complex but basically was the square root of sample variance of the weighted average explained variance (Equation A.7). Sample variance had two parts multiplied; total sampling intensity divided by what remained of the sum of individually squared sampling intensities minus squared total sampling intensity (Equation A.5); sum of individual sampling intensities multiplied by squared differences of observation and weighted average (Equation A.6). These estimates are either relative or weighted to the area sampled, thus coupled with node trimming, difficulties of tree complexity and sampling intensity were mitigated and soil properties could be evaluated on regression performance accurately.

3.4.3 Results and Discussion

How frequently a property occurs per unit area was calculated by dividing absolute frequency of a soil property by sampling intensity, as in the area supporting that frequency (Table 3.16). If one hundred new quadrats were sampled for live plant cover and rooting zone soil, based on these values, 85 quadrats would show an influence by exchangeable sodium. Other properties occurred less frequently as explanatory variables for plant abundance. In this ranking there were three groups of properties with > 60 % relative frequency, Bicarbonate occurred least often at 65 %. In the 70 % range there was electrical conductivity 70%, sieve percent 73 %, penetration resistance 75 % and soluble calcium 78 % relative frequency per unit area. The top performers per unit area were cation exchange capacity 81 %, sodium adsorption 83 % and exchangeable sodium 85 %. On a per unit area basis sodium related measures most frequently were explanatory variables for plant abundance in multivariate regression trees.

How much variance each soil property explains (R^2) was expressed as a weighted average and its uncertainty was expressed as weighted standard deviation (Table 3.17). Soluble calcium was 26.4 % (standard deviation 10.8), cation exchange capacity 25.2 % (standard deviation 19.4), electrical conductivity 23.1 % (standard deviation 12.3), exchangeable sodium 19.6 % (standard deviation 11.99), penetration resistance 19.0 (standard deviation 9.53), sieve percent 18.6 % (standard deviation 14.1), sodium adsorption ratio 18.0 % (standard deviation. 20.3) and bicarbonate 11.9 % (standard deviation 5.75). With weighted standard deviation the interval about a mean indicated a range where future sample observations may occur; for example, soluble calcium may have an R^2 as low as 15.6 % or as high as 37.2 %, if similar sampling intensities result in similar tree complexities. In this ranking there were three groups of properties; on the basis of total variance explained (R^2) in the regression trees dissolved solids and ion exchange were more powerful explanatory variables of plant abundance on the ground.

Lists developed by both calculation methods validated all eight variables as effective biophysical properties to monitor. Relative frequency distributed absolute frequency of a property over sampling intensity; resulting in the property's effectiveness in spatial terms. This measure also gave an indication of what to expect in unknown quadrats. Top of the list was exchangeable sodium at 85 %, followed by sodium adsorption ratio at 83 %. A change in order came with weighted average, soluble calcium 26.4 % and cation exchange capacity 25.1 %, both playing an important role in pore water and active surfaces. Weighted average puts performance on even spatial terms and although calcium and cation exchange capacity were not as frequent they are powerful in explaining plant response. These lists suggest interactions at colloid surfaces and constituents of soil solutions are driving plant responses, especially where roots take up nutrients. Physical soil structure and buffering capacity played a role but likely in support of what ions were found in pore water, in the ion swarm near surfaces and on soil surfaces for roots to access. Interestingly, fertility related properties were not prominent, potentially because soil profiles were shallow and concentrations were barely noticeable relative to other properties. Their value in determining site dynamics should not be dismissed, although it seems their contribution was of less value than other properties.

As suggested in the introduction these lists represent two aspects of the same object where those properties dominant in one are less prominent in the other. Recall trimming the fourth and fifth nodes and uniformity present in the first three nodes (Table 3.13). In Figure 3.5 the closeness in the levels of bars in both methods signals balance between variation within and uniformity without for this structure. The way properties group into 10 and 20 % or 70 and 80 % ranges for variance and frequency by threes and fours, respectively, also shows cohesiveness from unique combinations yet orderly summed absolute frequencies. With the exception of bicarbonate, when vantage point changes the order changes and all top three properties switch over. The line in Figure 3.5 is increasing sampling intensity and bars do not show a marked influence by area. This means directly the effect of area, if present, is mitigated and just as importantly a range of areas between 5 and 12 m^2 on which to base future sampling intensities is presented. Concentration is not as dependent on space as plant abundance but for adequate statistics this is an empirically derived range of likely adequate sampling intensity for these 8 soil properties.

3.4.4 Conclusions

Determining a representative list of biophysical properties from those analyzed in regression trees was not simply achieved with absolute frequency because tree complexity and sampling intensity were not even among sites. After appropriate trimming of tree complexity and choice of methods to address possible influence by sampling area the resulting lists varied in order. As if viewing the same object from different vantage points it is clear future monitoring of routine land disturbances should include some or all these biophysical properties: exchangeable sodium, sodium adsorption ratio, cation exchange capacity, soluble calcium, penetration resistance, sieve percent, electrical conductivity and bicarbonate. In addition to complexity and intensity, independence from sampling intensity demonstrated soil properties collectively acting as a whole and hence making them all properties to monitor on future disturbed sites.

3.5.0 Scoring Plant Community Demographics

3.5.1 Introduction

An index can, if kept simple, be a very useful tool to assess and communicate revegetation status of reclaimed sites because it compiles information from several indicators into one comprehensible value (Chanasyk 2010, Parks Canada 2005). Main components of an index include a gradient, in this case plant abundance, a set of sites with varying degrees of revegetation performance, in this case sites reclaimed after routine disturbances and a method of computation to assess site performance and rank scores according to the underlying gradient of interest (Parks Canada 2005).

Site data input for the computation was taken from plant related biophysical properties of revegetated plant communities. These properties are referred to in the best available method manuals as criteria to establish revegetation for successful soil conservation and ecological protection (AXYS Environmental Consulting Ltd. and David Walker and Associates 1998). This compression of ecological information into a revegetation score provides an indicator to communicate the current state of different sites and allows for comparison of revegetation performance across space and time (Parks Canada 2005). A z-score was computed on two sets of coefficients that either excluded or included non-native plant species from the overall plant community structure. These indices can be used to address which sites were successfully revegetated based on a score of average plant community properties that represent site composition and structure. Both indices communicate a similar message about how reclaimed disturbances fit into a wider context of park ecological integrity.

3.5.2 Methods

Revegetation success scores for each site were standardized averages based on numerical input from 5 plant properties including basal, canopy and leaf litter cover, species diversity and density. The basic analysis unit was a 50 x 20 cm quadrat replicated on each site at various sample sizes; see Table 3.14 for sampling intensity of each site. Species identification helps group plant community structure according to all observed, native and non-native plant classes; see Table 3.1 and 3.2 for a list of all species observed during this research and a current list of priority non-native species to be controlled in Jasper National Park, respectively. Two indices based on plant community structure yielded similar results. One index was computed by subtracting non-native scores from all observed plant class, another index was computed from a ratio of native to non-native plant scores. Computations were completed using MS Excel 2010 with average and standard deviation functions for samples found in the Data Analysis Tool Pak.

The first index, of all observed species minus non-native species, was computed with the steps described below. In step one, sums of quadrat cover, species richness and density classes were averaged over the total number of quadrats per site. The result was a site average for a property according to species classes for all species and non-native species separately. In step two, site averages per biophysical plant property per class were standardized by subtracting sample average and dividing by sample standard deviation; resulting scores may be positively or negatively signed depending on whether the mean is larger or smaller than the original observation. In step three, the lowest score in each column were added to all values in that column. The resulting scores, labeled A and B, for all species and non-native species respectively were $\geq$ zero. In the fourth step (Tables 3.18 and 3.19) site revegetation scores for each class of vegetation were the sum of scored biophysical plant properties on each site. Leaf litter cover was not included for non-native species as litter in the field was not distinguished to that high degree of classification when measuring plant community structures. In the final computing of revegetation success scores (Table 3.20), non-native class score was subtracted from the all observed plant score; the index, dividend score was ranked and an order of success to failures was revealed.

The second index was different in that site revegetation scores represented community structure including non-native species; a quotient from dividing native species by non-native species integrated two classes into one community structure. For each property the computation of a z-score was similar to the one above with two differences. Prior to standardizing site averages the native class averages were divided by the non-native class averages and the quotient was standardized into a score then summed (Table 3.21) and finally ranked into a spectrum of successes (Table 3.22). Plant litter was not included with this site revegetation success score as an average litter class for non-native species was not possible since litter was not distinguished to such a level in the field assessments.

3.5.3 Results and Discussion

Pipe route 40, Staging area 2, and Access route 34 were considered successfully revegetated disturbances with scores of 11.02, 9.14 and 7.50 in the first index and scores of 9.79, 13.79 and 7.23 in the second index, respectively (Table 3.20 and 3.22). Pipe pull out 45, Pipe pull out 35, Waste pit 28 and Waste pit 51 were not considered successfully revegetated as plant community structure was weighted toward non-native species with scores of -2.02, -2.07, -2.95 and -2.98

in the first index and 0.91, 0.78, 1.11 and 2.77 in the second index, respectively. Road cut 69 was not successfully revegetated as there was almost no vegetation on site. Interestingly, lists arrived at by both methods (Tables 3.20 and 3.22) were similar in that Staging area 2, pipe route 40 and Access route 34 ranked highly, with values > 7.50 and 7.23, in the dividend and quotient scores, respectively. At the other end of the spectrum, Waste pit 28, Pipe pull out 35 and Pipe pull out 45 had similar low scorers with values $\leq$ zero depending on the index. These indices also revealed a large number of marginally differentiated sites; the separation was within a range of about 5 to 7 units, depending on the index.

By subtracting the narrowly defined group from the broader group this dividend score, or first index (Table 3.20) represented native species community structure without a structure created by non-native species. A negative sign on a score and magnitude showed how non-native plants out-perform native species; a positive sign and magnitude showed how well native species preformed. Where scores were negative non-native species had greater influence; where scores were increasingly positive, revegetation of a native plant community was increasingly successful. For example, the three top performing sites, pipe route 40, Staging area 2 and Access route 34, had scores ≥ 10.00; then ≥ 7.50 once influence of non-native species was discounted from whole community structure. For these sites the discount was small because native community structure was good, likely due to revegetation. The heavy discount from a weighty non-native species community was demonstrated at Pipe pull out 45 where the score of 12.80 for all observed species was dramatically reduced to -2.02 when the non-native component, with a score of 14.82, was factored into the revegetation success score. Based on field observations of all four sites this index quantitatively reflects what was present on site regarding native and non-native plant community structures.

By dividing larger native species structure by non-native species structure, this score (Table 3.22) represented native community structure with non-native species. Magnitude showed how well native species performed relative to non-native species incorporated into the structure. Quotients remaining high did so because non-native class was smaller than native; where averages were closer, quotients dropped. For example, Staging area 2 which had highly successful cover and other community aspects, scored high because non-native species in each aspect were low relative to native community structure. For this site non-native community was a fraction of native community; average basal cover was 14.04 % vs 0.07 %; average canopy cover 20.02 % vs 0.25 %; average presence 3.38 vs 0.13; average density class 4.3 vs 1.5 for native vs non-native species, respectively. Waste pit 51 was problematic because non-native community structure out-performed the native community; average basal cover was 2.49 % vs 2.08 %; average canopy cover 6.47 % vs 5.48 %; average presence 1.42 vs 2.33; average density class 3.24 vs 1.75 for native species vs non-native species.

Z-scores resulting from computation were positive and those with higher values indicated native plant community structure dominated, whereas lower scores indicated non-native species had greater influence; hence where scores were increasingly positive revegetation of the native plant community was increasingly successful (Table 3.22). With the above ratios of biophysical properties, it was clear why Staging area 2 ranked high with a score of 13.79, whereas Waste pit 51 scores were much lower with 2.77. Where non-native species dominated the score was driven even closer to zero, Pipe pullout 45 with average basal cover 0.25 % vs 1.78 %, average canopy cover 3.99 % vs 27.32 %, average presence 1.55 vs 2.75, average density class 3.26 vs 5.58 non-native species, respectively, and a final low score of 0.91, reflected field observations made in summer 2008 and 2009 as the non-native *Cirsium arvense* was dominantly established.

Two marginally negative scores of -0.01 reflected different revegetation issues. Access route 33 had no non-native species on site and road cut 69 had almost no plant cover (Table 3.22). Thus their averages are anomalies that do not follow the regular interpretation. Because Access route 33 has no observed non-native species it was the best preforming site after reclamation. Road cut 69 has steep slopes and solar loading issues making revegetation difficult.

3.5.5 Conclusions

The first index was computed by subtracting scored averages for two plant property classes; community structure was defined by what was missing and success was assigned based on quantities of native species remaining in the plant community. The second index was computed by dividing averages for two plant property classes; community structure was defined by what was contributed by both classes and success was assigned based on proportion of non-native to native species. Pipe route 40, Staging area 2 and Access route 34 were successfully revegetated disturbances. Pipe pull out 45, Pipe pull out 35, Waste pit 28 and Waste pit 51 were not successfully revegetated due to non-native species. For both lists, the same quantified properties were used, with a small exception, but what really differs are means of isolating and comparing native to non-native plant community structures.

3.6.0 Plotting Biophysical Property Thresholds

3.6.1 Introduction

Most disturbances impact the soil profile, affecting already established vegetation and revegetation efforts in reclamation. Land reclamation should always aim to reverse negative effects of human activities (Hardy BBT Limited 1989, Smrecui et al. 2002). Development of thresholds and performance criteria is generally aimed at environmental protection and enhancement for soil conservation and revegetation establishment (Alberta Environment 2001, AXYS Environmental Consulting Ltd. and David Walker and Associates 1998, Macyk et al. 2004). To that end, this exploratory method ranks and compares site average values of many soil properties against commonly accepted tolerance thresholds and performance criteria to determine site status (Chanasyk, Hamann and Naeth personal communication. 2010). Preliminary data visualization suggests physical soil properties are a key factor because variables show large ranges and often exceed thresholds, unlike chemical soil properties.

Tolerance thresholds for soil biophysical properties including electrical conductivity (Eynard et al. 2006, Macyk et al 2004), cation exchange capacity (Alberta Environment 2001, Bache 2006), sodium adsorption ratio (Alberta Environment 2001, Macyk et al. 2004), texture (Macyk et al 2004) and penetration resistance (Dexter and Zoebish 2006, Carter 2006) were derived from the literature (Table 3.23). Plant cover and performance criteria presented are aggregated measure because alone there is little to interpret about the development of revegetation on reclaimed sites (AXYS Environmental Consulting Ltd. and David Walker and Associates 1998). A minimum plant density was derived from a field classification diagram used by Parks Canada Agency (Figure A.2) (Westhaver personal communication. 2009).

Thresholds reflect plant tolerances in an agricultural setting and may be relevant in the Rocky Mountains because graminoids form the core of revegetation practices. However, there are few known thresholds for native species soil requirements in sustained native or native–like communities. Thus the use of thresholds presented here must be applied with that in mind. There are few known threshold values published for exchangeable sodium, soluble calcium and bicarbonate, nevertheless, these are included because of demonstrated association with variation in plant abundance. There are no published thresholds for plant diversity or for individual species composition, except for the presence of non-native species.

A well known factor in plant growth is tolerable conditions in which plants can root and take up water and nutrients from soil. Less understood is how native species relate and respond to soil property thresholds to the degree that agronomics or non-native species are understood. Although evaluating native species performance could have been pursued this was not within the scope of this research. This method emphasizes in an exploratory way how well sites or plant species perform in subalpine and montane ecoregions. With more advanced experimental methods that soil properties could be linked to a predominantly native plant community.

3.6.2 Methods

As an exploratory method, plotting threshold graphs was relatively simple in R. Sites were ranked based on average performance of biophysical properties. These mean values were then plotted on a transposed x axis with sites or species as labels. Along the transposed y axis tolerance thresholds were marked, if there were any, at relevant increments by vertical dashed lines or solid lines. Table 3.23 categorizes these ranges, around an optimal set of values as deficient, below optimum, above optimum and excess. Solid lines delimited excess whereas increasingly thicker dashed lines indicated transition away from optimum. Standard deviation was presented as whiskers around the mean, and shows how data were dispersed about the mean (Hamann personal communication. 2011). Sample averages and standard deviations were calculated in MS Excel 2010 then imported into R version 2.13 to develop graphical output. Graphs are depicted on traditional graphics supported in R (Murrell 2006, R Development core team 2008).

3.6.3 Results and Discussion

This exploratory method graphically helped identify potential difficulties on sites based on plant response and soil profile development relative to thresholds and criteria of performance for both. Several threshold graphs are presented as examples and those not reported or discussed are presented in Appendix C.

Sodium adsorption ratio (Figure 3.6, Table 3.24) affected both soil profile and plant community development; more negatively with higher values. Dashed lines at 4, 8, 12 and solid bar at 16 marked transition from optimal to excess. Of all 23 sites, Pipe pull out 35 had an average of 4.02 and Pipe pull out 45 had an average of 4.56 the highest values measured. Variation in SAR was low and averages were not problematic (Macyk 2004). Alone this property was acceptable, as expected for the types of soils in the area.

Cation exchange capacity (Figure 3.7, Table 3.25) for pipe route 40 exceeded the upper limit with an average 33.10 meq $100g^{-1}$. Standard deviations for three sites, walking path 56, Staging area 2 and Water line 22 are 34.82, 32.88 and 37.21 meq $100g^{-1}$, respectively. This indicated an exceedingly high value at least on parts of these sites. In salt affected soils, capacities exceeding 50 meq $100g^{-1}$ are reportedly difficult to revegetate (Alberta Environment 2001). Examining the threshold graph it is likely this limitation was not at issue for the research sites. Lowest values were for ski hill 8, Water line 20 and Water line 18 with a mean minus standard deviation equaling 0.8, 4.54 and 1.24 meq $100g^{-1}$, respectively.

Electrical conductivity (Figure 3.8, Table 3.26) shows Pipe pull out 35 with mean plus standard deviation 4.24 dS m^{-1} slightly exceeded threshold value 4 dS m^{-1}, a non-optimal level for revegetation (Macyk et al. 2004). Next highest sites, road cut 69 and Pipe route 40 had values potentially exceeding the limit for optimal plant growth at 2.43, 2.38 dS m^{-1}, respectively. Pipe pull out 45 and Walking path 56 could exceed an optimal value with mean plus standard deviations of 2.46 and 2.45 dS m^{-1}, respectively. The lowest registered values were on Water line 20, Ski hill 8 and Water line 18 with averages of 0.43, 0.4 and 0.22 dS m^{-1}, respectively.

Physical soil properties (Figures 3.9 and 3.10; Tables 3.27 and 3.28) indicate a wide range of averages with standard deviations spanning thresholds. This might indicate plant establishment and development limitations. For instance, Waste pit 51 and 28 both had high penetration resistances of 6.56 and 5.82 MPa, and sieve percent, 92.56 and 60.37 %, respectively.

With plant related biophysical properties, performance criteria highlight where and how many sites meet a priori criteria for successful revegetation after land disturbance (AXYS Environmental Consulting Ltd. and David Walker and Associates 1998). The solid line in Figure 3.11 and Table 3.29 represents the 80 % ground cover criterion, including live plant and litter (mulch) for sites to meet or exceed. Pipe pull out 45 at 130 %, Pipe route 40 at 129 % and Pipe valve 44 at 109 % are in excess. Only Pipe pull out 35 at 86 % and Access route 34 at 82 % are successfully revegetated, at least as it relates to ground cover.

A summary of average values (Tables 3.30) and graphical representation (Table 3.31) shows coarser thresholds than in the preceding graphs. Here conditions are simply defined as below optimal, optimal, and above optimal. Importantly there are relatively few sites with chemical properties on average beyond optimal conditions. However, physical properties are problematic on several sites either because texture is too coarse or fine and/or penetration resistance is too great. The link between soil property values and plant performance is not straight forward as where poor soil conditions support adequate cover and alternatively advantageous conditions do not support adequate live plant cover.

Several plant and soil biophysical properties have yet to be defined for tolerance or performance thresholds, yet they reflect important aspects of plant community and soil matrix development; the threshold graphs presented in Appendix C all fit within this classification. Individual plant species performance in Appendix C present an interesting view on plant community development.

3.6.4 Conclusions

Tolerance thresholds for the soil matrix identified soil property levels affecting revegetation (Alberta Environment 2001, Macyk 2004). Where there were thresholds chemical property averages and standard deviations tended to stay within thresholds. For example, electrical conductivity, sodium adsorption ratio, and cation exchange capacity did not give the impression of excessive conditions for more than a couple of sites. Chemical soil properties did not generally exceed known limits whereas physical properties showed sites with potential texture and soil matrix density problems. For plant community properties threshold graphs demonstrated the need to assess cumulative cover to judge success as single variables for there were sites that did not pass. Individual native and non-native plant species performance, based on average cover and an abundance score, revealed the composition and strengths or weaknesses of plant communities established after revegetation. Tolerance thresholds, aggregated live cover and species performance set against management criteria quantitatively evaluated site conditions and pointed to possible achievements or difficulties which may be due to land disturbance and or revegetation practices.

3.7.0 Biophysical Property Analysis Conclusion

Having tested many statistical analyses the preceding methods ranged in technical and statistical rigour from moderately to highly complex. The objectives outlined in Chapter 1 demanded a diverse approach if sound achievements were to be produced. Relationships between plant responses and soil properties have been characterized with multivariate regression trees. Associated error terms indicate how strongly plant species responses are associated to soil properties. Select soil properties with high frequency and explanatory power were determined and yielded a set of biophysical properties for monitoring land reclamation. Judging revegetation success in a quantified and repeatable manner has been demonstrated and future monitoring should continue, at minimum, to assess plant abundance, species identifications and litter (mulch) cover. For deeper ecological understanding, species diversity and densities have proven valuable. The value of a number of relatively unknown biophysical properties remains unexplored but could yield intriguing new direction for land reclamation research. Site performance has been assessed in a number of ways and on the whole sites that do well tend to be consistent as are sites that rank poorly in revegetation success in the montane and subalpine ecoregions.

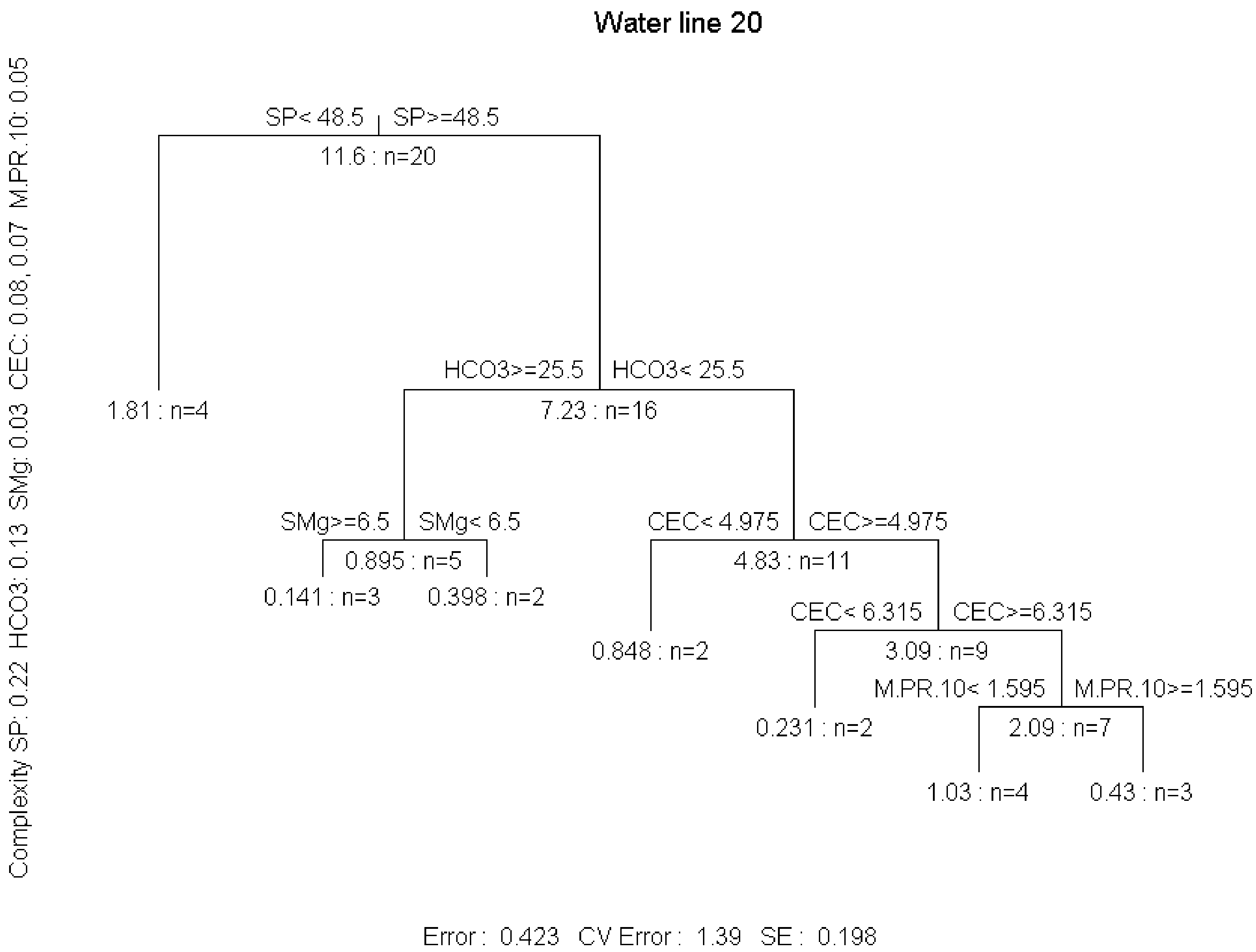

Figure 3.1 Regression tree for Water line 20 (site 8) at Marmot Basin ski area

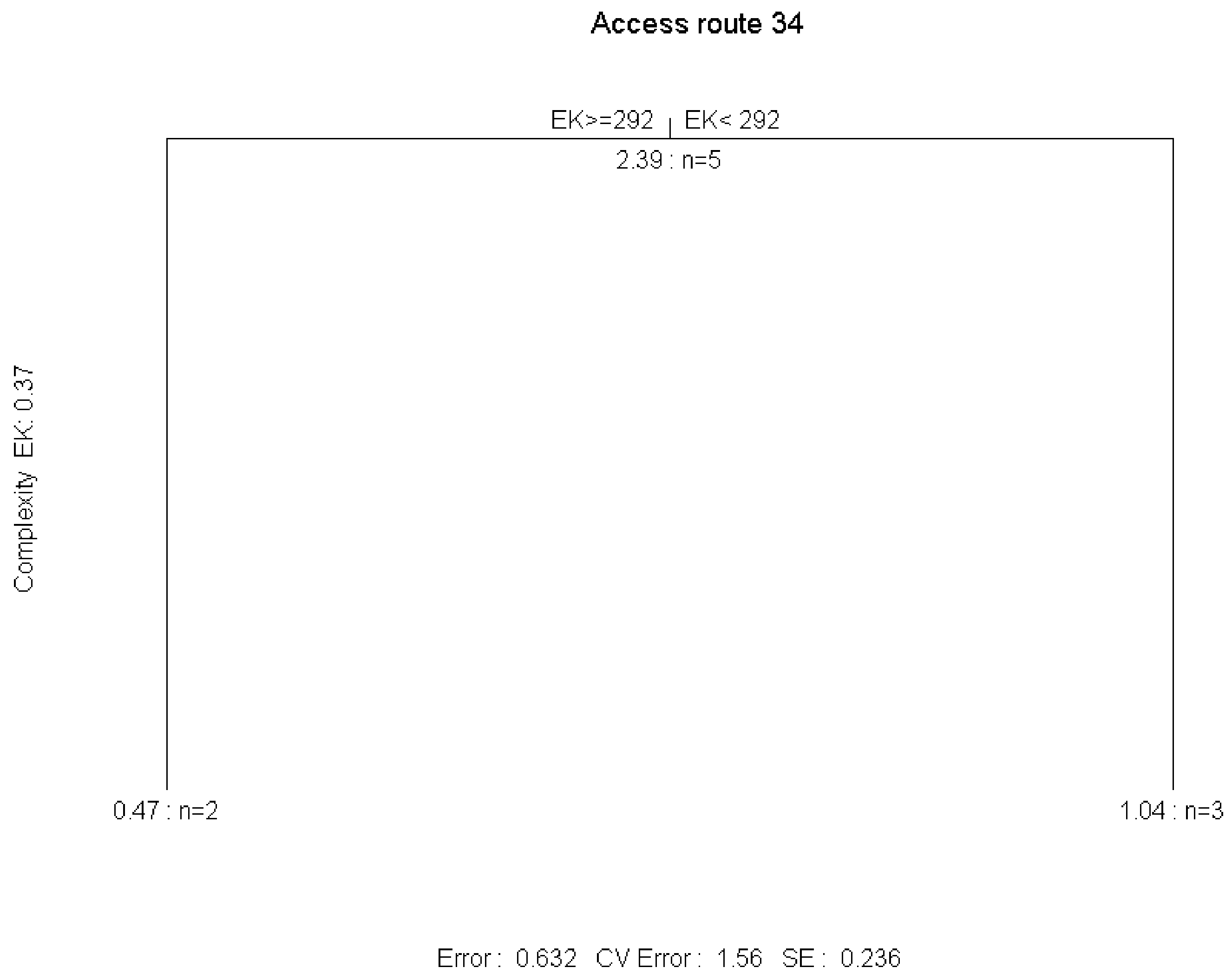

Figure 3.2 Regression tree for Access route 34 on Jasper Lake dunes pipeline relocation

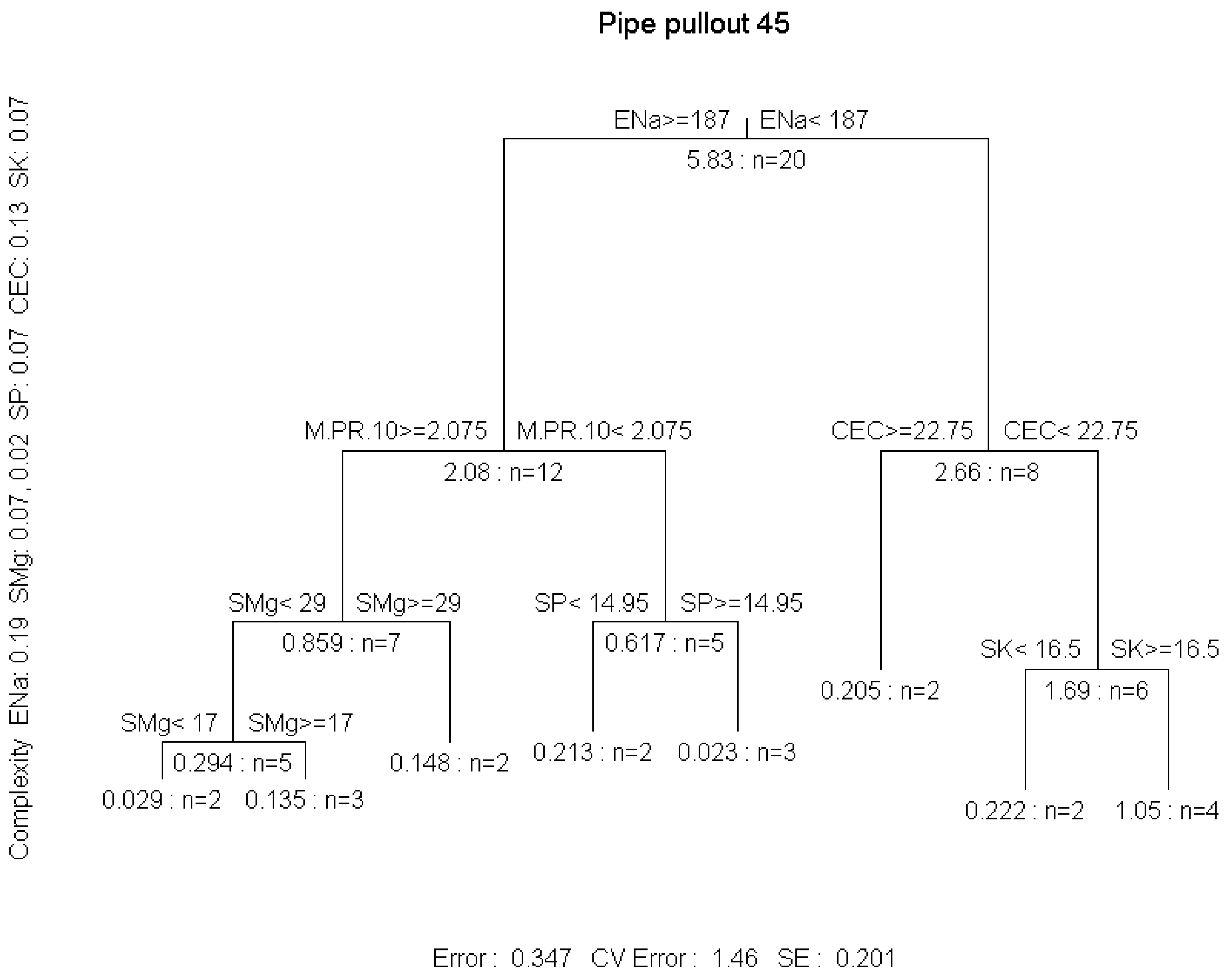

Figure 3.3 Regression tree for Pipe pull out 45 on Mile 12 pipeline relocation

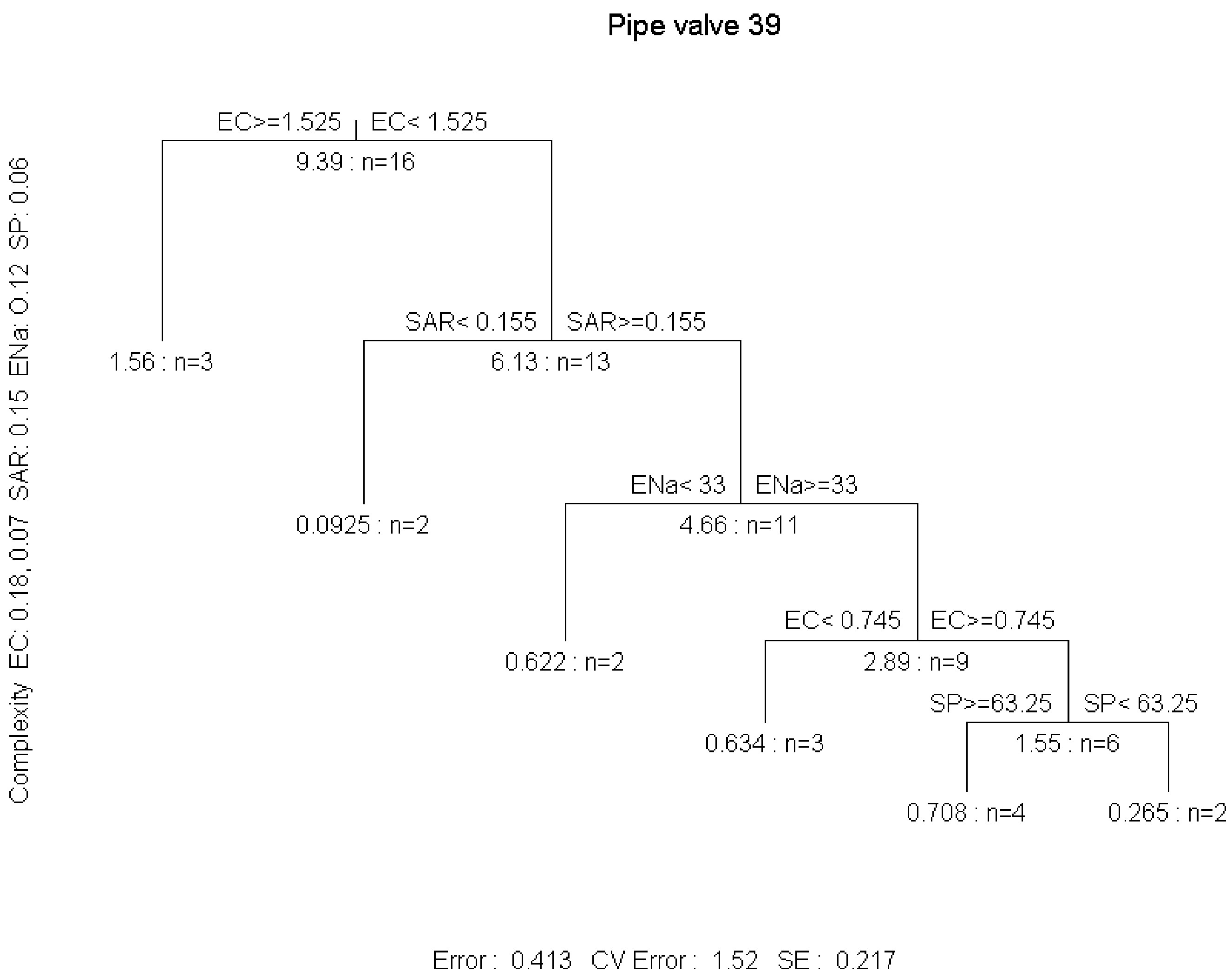

Figure 3.4 Regression tree for Pipe valve 39 on Mile 12 pipeline relocation

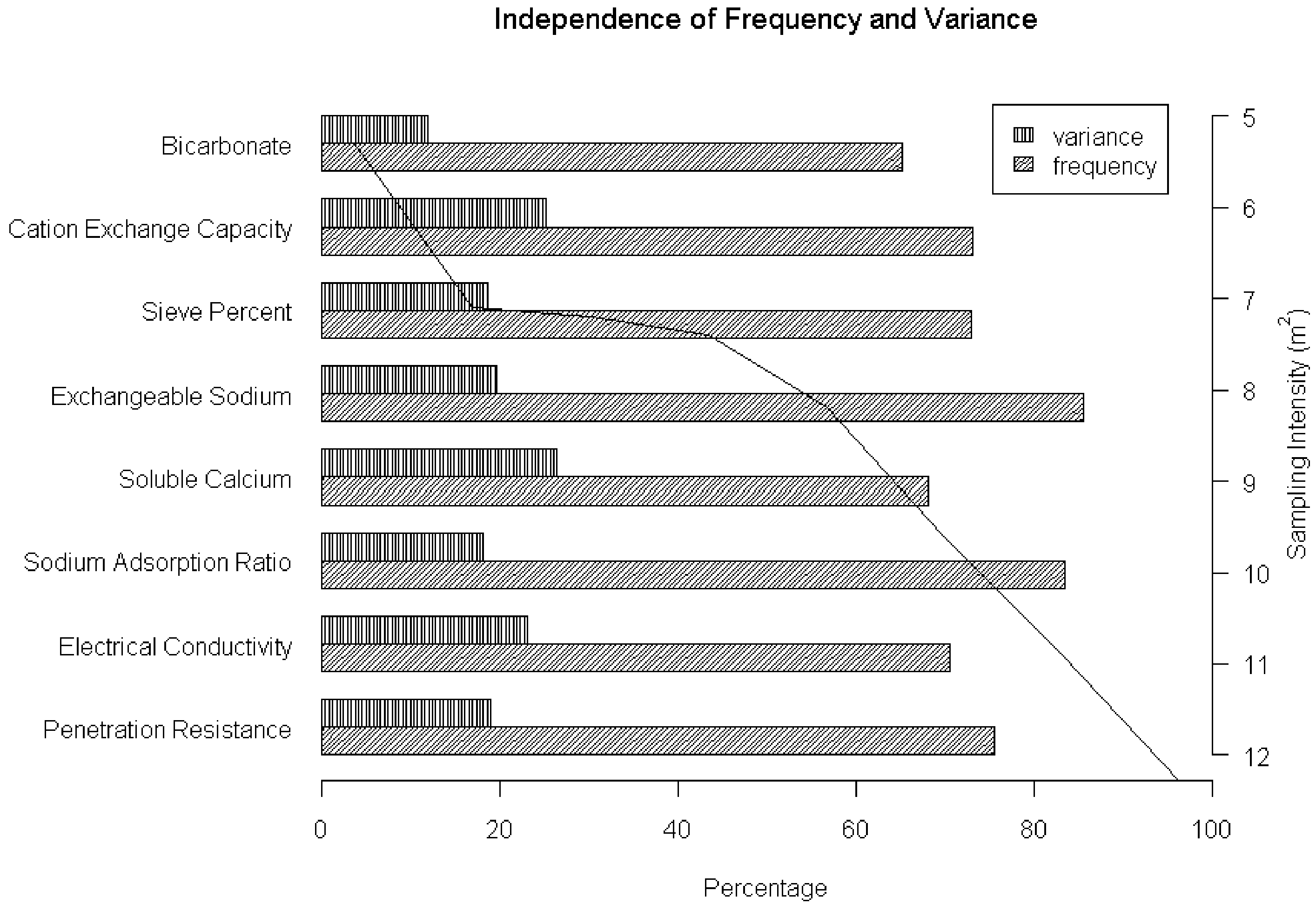

Figure 3.5 Frequency and average variance independent of sampling intensity

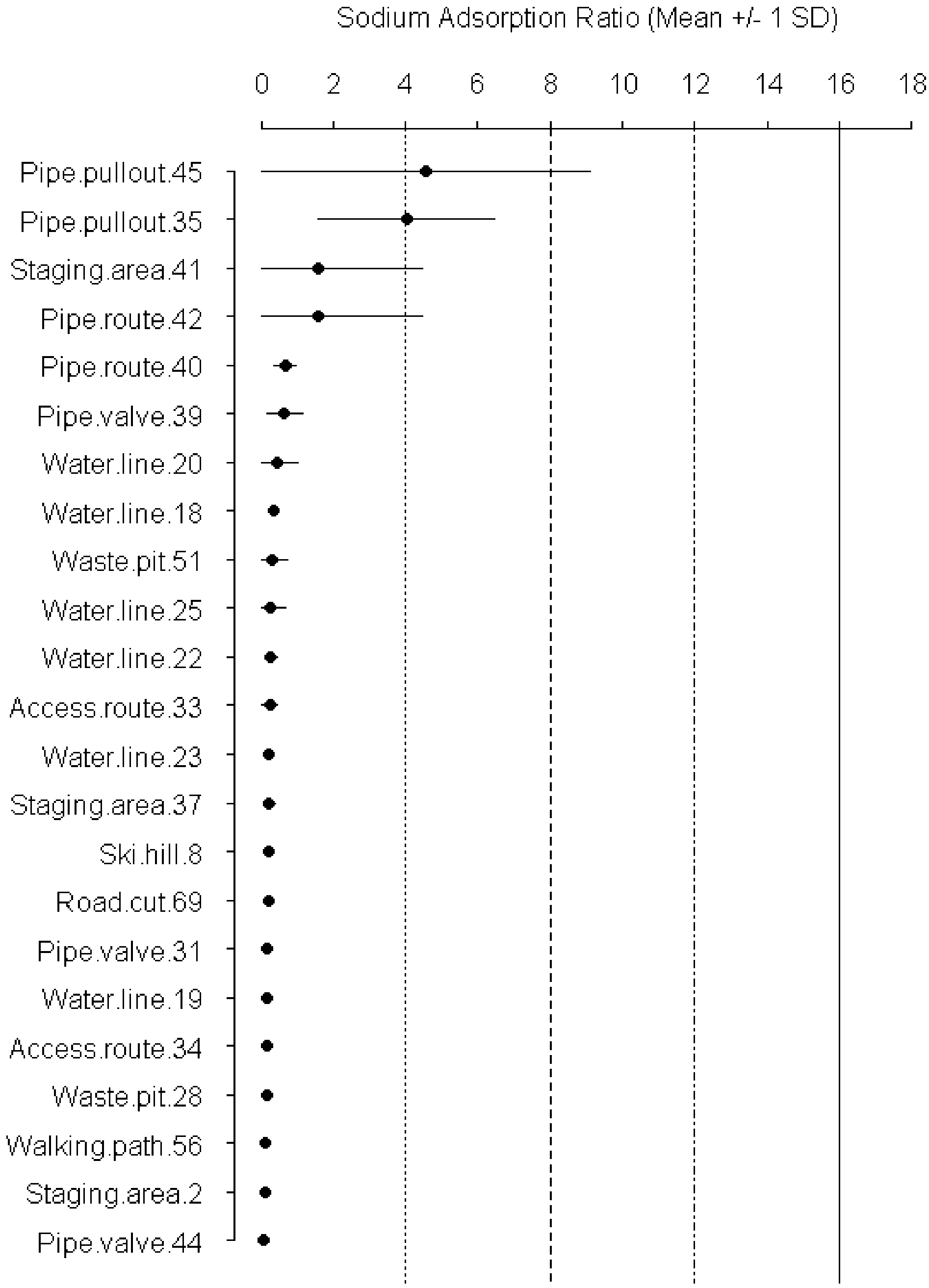

Figure 3.6 Average sodium adsorption ratios at research sites

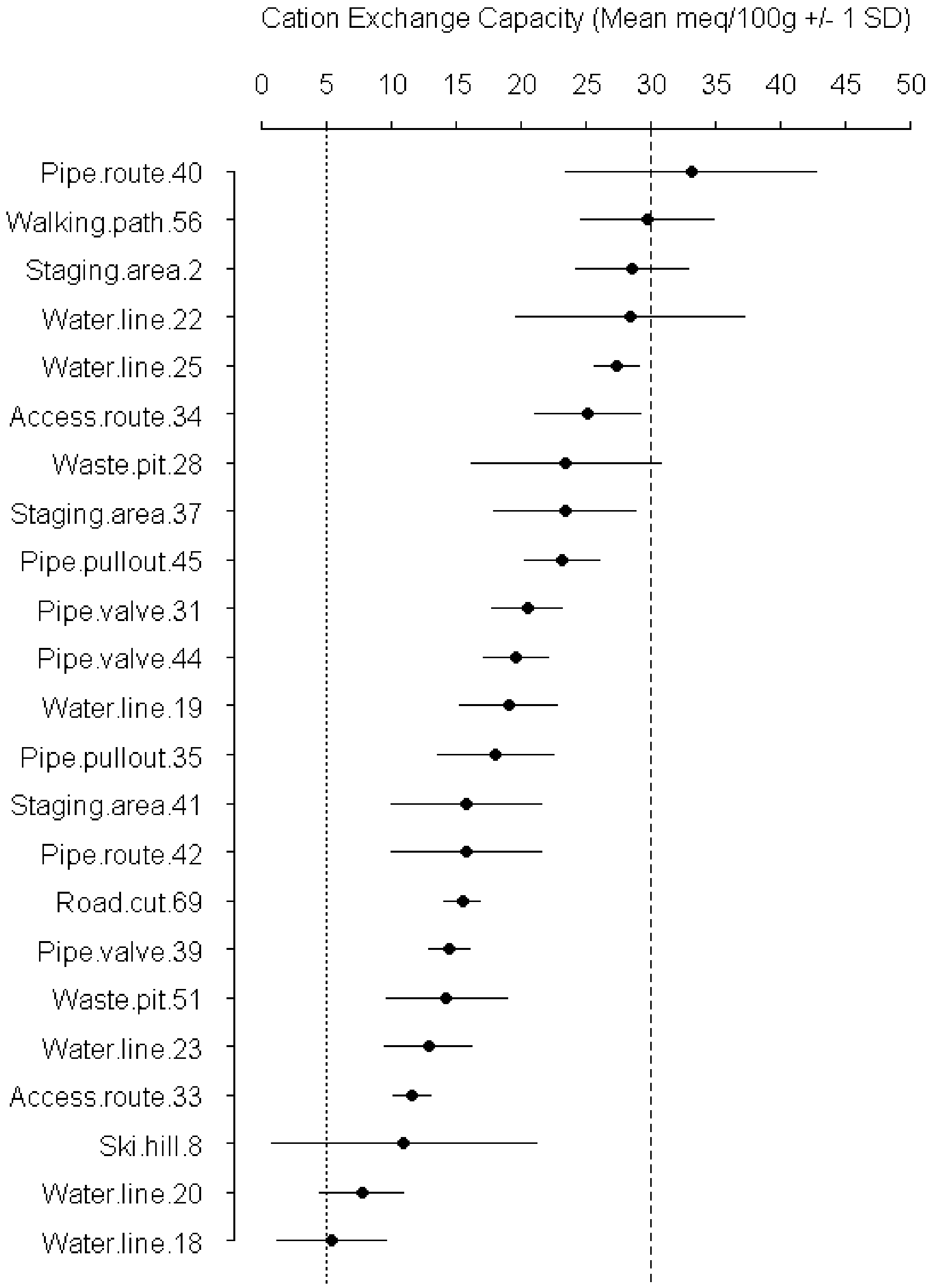

Figure 3.7 Average cation exchange capacities at research sites

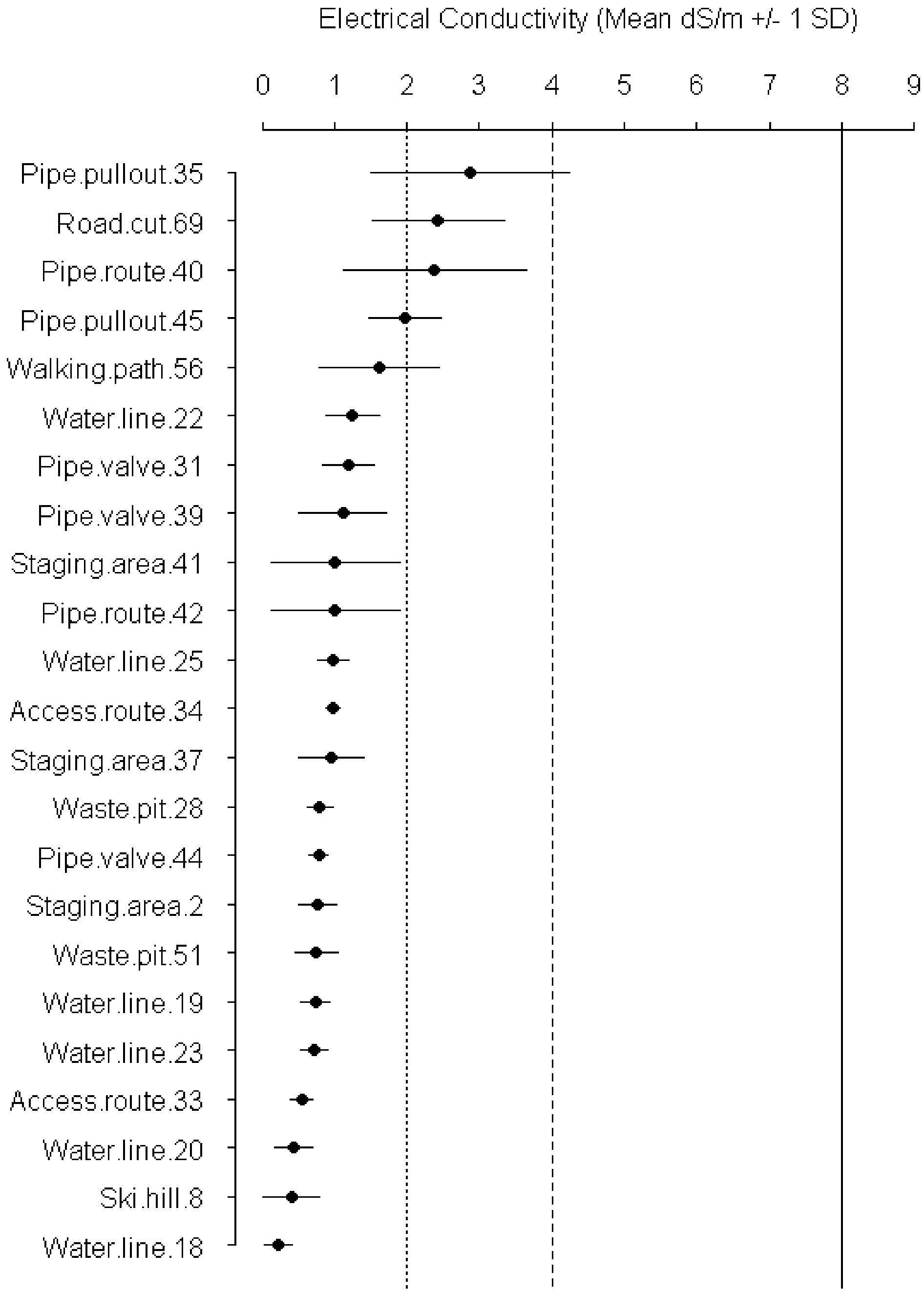

Figure 3.8 Average electrical conductivities at research sites

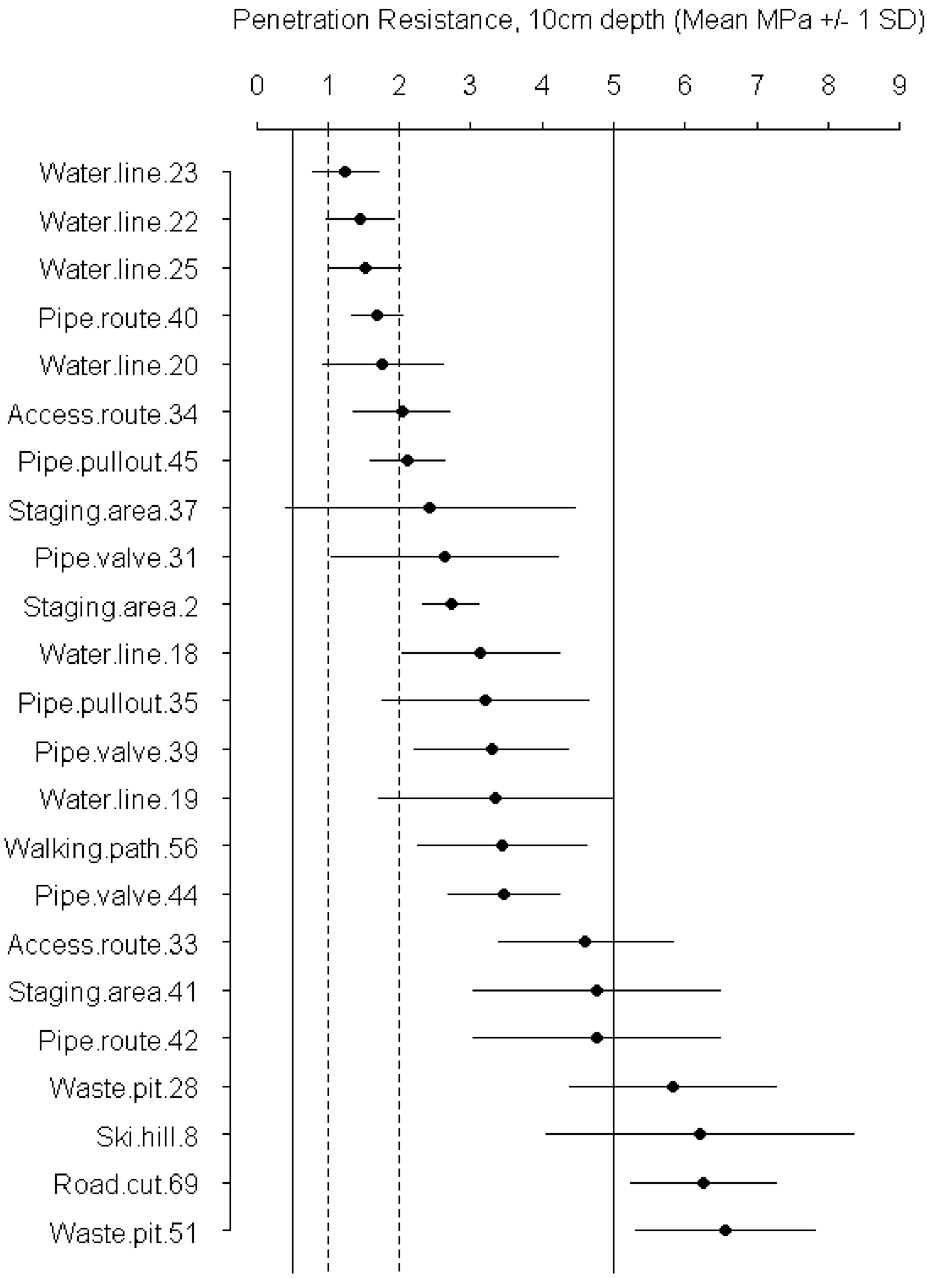

Figure 3.9 Average penetration resistances at research sites

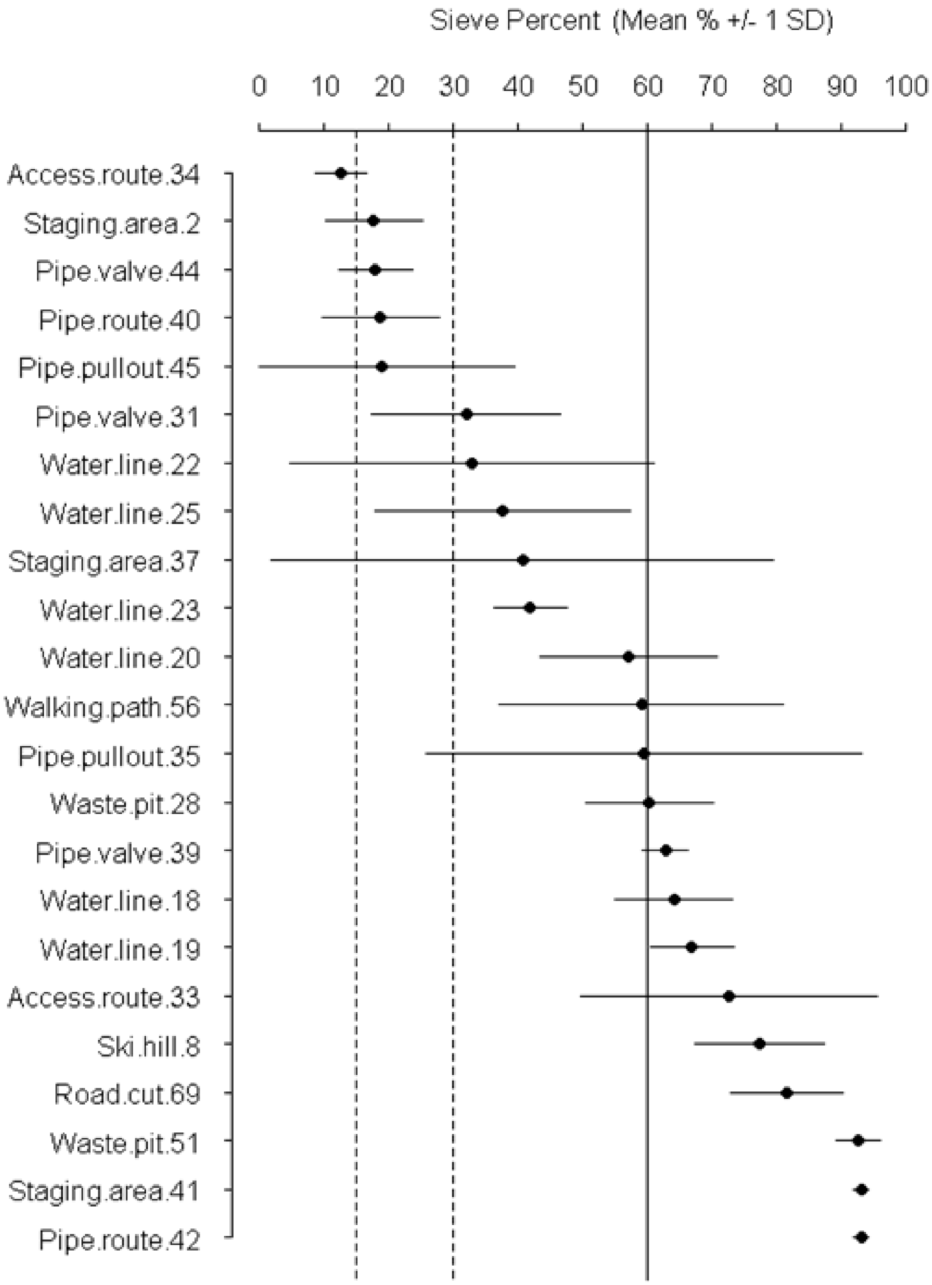

Figure 3.10 Average sieve percents at research sites

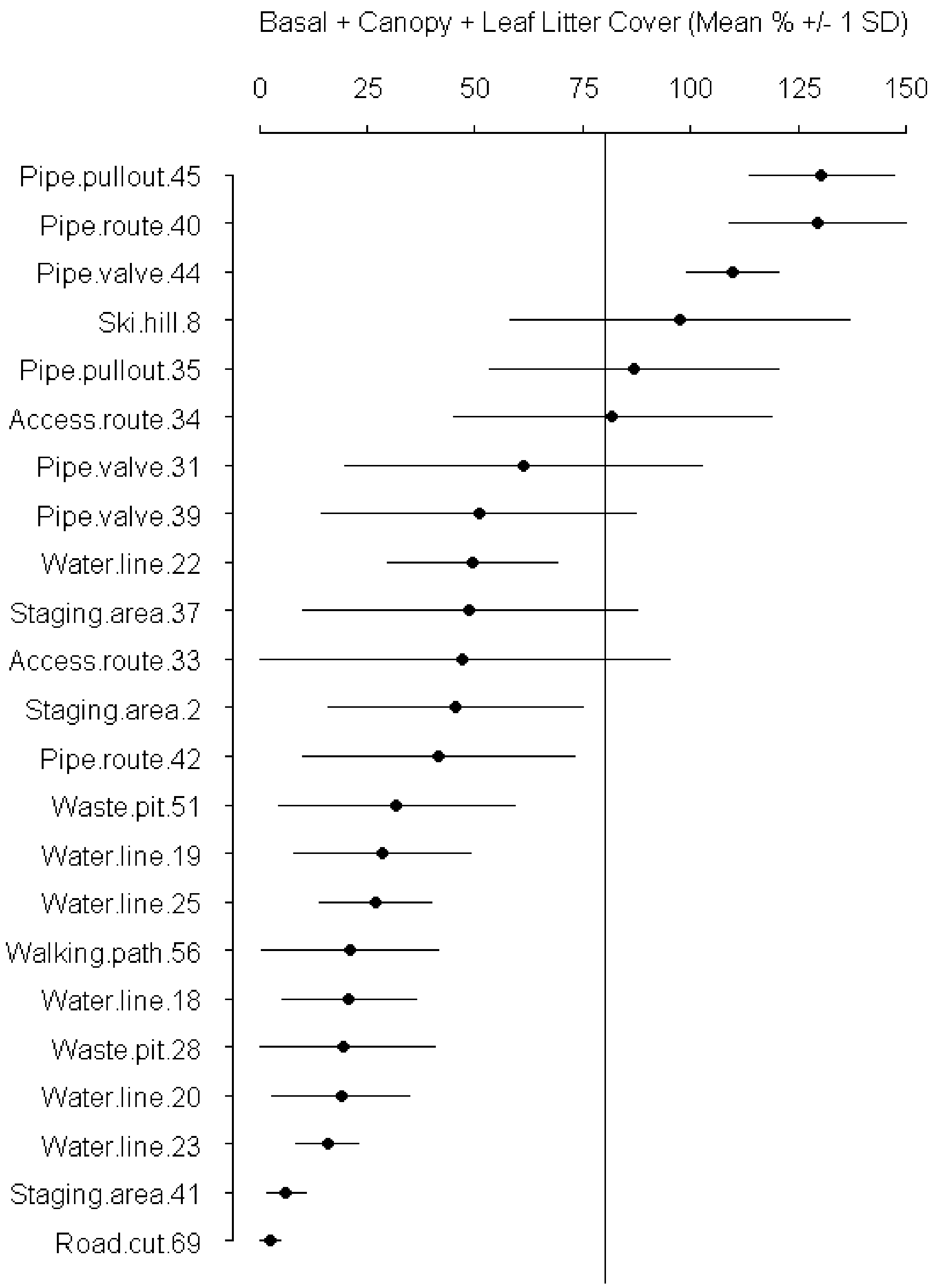

Figure 3.11 Combined average percent basal, canopy and leaf litter cover at research sites

Table 3.1 List of observed species in Jasper National Park

Scientific Name	Authority	Common Name
Abies lasiocarpa	(Hook.) Nutt	Subalpine fir
Achillea lanulosa	(Nutt.) Piper	White yarrow
Achillea millefolium	L.	Common yarrow
Agastache urticifolia/foeniculum	(Pursh) Ktze.	Giant hyssop
Agropyron dasystachyum	(Hook.) Scribn.	Northern wheat grass
Agropyron inerme	(Scribn. & Smith) Heller	Beardless wheat grass
Agropyron intermedium	(Host) Beauv.	Intermediate wheat grass
Agropyron repens	(L.) Beauv.	Quack grass
Agropyron smithii	Rydb.	Western wheat grass
Agropyron spicatum	(Pursh) Scribn. & Smith	Blue bunch wheat grass
Agropyron trachycaulum	(Link) Malte	Slender wheat grass
Alnus crispa	(Ait.) Pursh	Green alder
Amelanchier alnifolia	Nutt.	Saskatoon
Anemone multifida	Poir.	Cut leaved anemone
Anemone parviflora	Michx.	Northern anemone
Antennaria alpina	(L.) Gaertn.	Pussy toes
Antennaria microphylla	Rydb.	Pussy toes
Antennaria pulcherrima	(Hook.) Greene	Showy pussy toes
Antennaria rosea	Greene	Rosy pussy toes
Aquilegia flavescens	S. Wats.	Yellow columbine
Arabis hirsute	(L.) Scop.	Rock cress
Arctostaphylus rubra	(Rehder & Wils.) Fern.	Alpine bearberry
Arctostaphylus uva ursi	(L.) Spreng.	Bearberry
Arenaria lateriflora	L.	Blunt leaved sandwort
Arnica cordifolia	Hook.	Heart leaved arnica
Artemisia arctica	Less.	Boreal sagebrush
Artemisia biennis	Willd.	Biennial sagewort
Artemisia campestris	L.	Northern wormwood
Artemisia frigida	Willd.	Pasture sagewort
Artemisia ludoviciana	Nutt.	Prairie sagewort
Aster alpinus	L.	Alpine aster
Aster ciliolatus	Lindl.	Lindley's aster
Aster conspicuus	Lindl.	Showy aster
Aster foliaceus	Lindl.	Leafy bract aster
Aster laevis	L.	Smooth aster
Aster puniceus	L.	Purple stemmed aster
Astragalus agrestis	Dougl. ex Hook.	Purple milk vetch
Astragalus americana	(Hook.) M.E.Jones	American milk vetch
Astragalus eucosmus	Robins.	Elegant milk vetch
Astragalus tenellus	Pursh	Loose flower milk vetch
Betula glandulosa	Michx.	Bog birch
Betula papyrifera	Marsh.	Paper birch
Botrychium lunaria	(L.) Sw.	Moonwort
Bromus carinatus	Hook. & Arn.	Mountain brome
Bromus inermis	Leyss.	Smooth brome

Table 3.1 List of observed species in Jasper National Park (continued)

Scientific Name	Authority	Common Name
Bromus pumpellianus	(Scribn.) Wagnon	Awnless brome
Bromus tectorum	L.	Downy chess
Calamagrostis canadensis	(Michx.) Beauv.	Blue joint
Calamagrostis inexpansa	A. Gray	Northern reed grass
Calamagrostis montanensis	Scribn.	Plains reed grass
Calamagrostis purpurascens	R.Br.	Purple reed grass
Campanula rotundifolia	L.	Harebell
Capsella bursa pastoris	(L.) Medic	Shepherd's purse
Carex aquatilis	Wahlenb.	Water sedge
Carex disperma	Dewey	Soft leaved sedge
Castilleja miniata	Dougl. ex Hook.	Giant red indian paintbrush
Castilleja occidentalis	Torr.	Western indian paintbrush
Cassiope tetragona	(L.) D.Don	White mountain heather
Cerastium arvense	L.	Mouse ear chickweed
Chenopodium album	L.	Lamb's quarters
Chenopodium capitatum	(L.) Aschers.	Strawberry blight
Chrysanthemum leucanthemum	L.	Ox eye daisy
Cirsium arvense	(L.) Scop.	Canada thistle
Cornus canadensis	L.	Bunchberry
Cornus stolonifera	Michx.	Red osier dogwood
Crepis tectorum	L.	Annual hawks beard
Dactylis glomerata	L.	Orchard grass
Daucus carota	L.	Wild carrot
Deschampsia caespitosa	(L.) Beauv.	Tufted hair grass
Descurainia sophia	(L.) Webb	Tansy mustard
Disporum trachycarpum	(S. Wats.) B. & W.	Fairy bells
Dryas drummondii	Richards.	Yellow dryad
Elaeagnus commutata	Bernh. ex Rydb.	Silver berry
Elymus glaucus	Buckl.	Smooth wild rye
Elymus innovatus	Beal	Hairy wild rye
Epilobium angustifolium	L.	Fireweed
Equisetum arvense	L.	Common horsetail
Equisetum fluviatale	L.	Swamp horsetail
Equisetum hyemale	L.	Scouring rush
Equisetum palustre	L.	Marsh horsetail
Equisetum pratense	Ehrh.	Meadow horsetail
Equisetum variegatum	Schleich.	Variegated horsetail
Erigeron acris	L.	Bitter fleabane
Erigeron canadensis	L.	Horse weed
Erigeron glabellus	Nutt.	Smooth fleabane
Erigeron peregrinus	(Pursh) Greene	Subalpine fleabane
Erigeron philadelphicus	L.	Philadelphia fleabane
Eriophorum angustifolium	Honck.	Cotton grass
Erucastrum gallicum	(Willd.) Schulz	Dog mustard

Table 3.1 List of observed species in Jasper National Park (continued)

Scientific Name	Authority	Common Name
Festuca montana	M. Bieb.	Drymeja fescue
Festuca rubra	L.	Red fescue
Festuca saximontana	Rydb.	Rocky mountain fescue
Fragaria vesca	L.	Woodland strawberry
Fragaria virginiana	Duchesne	Wild strawberry
Gaillardia aristata	Pursh	Gaillardia
Galium aparine	L.	Cleavers
Galium boreale	L.	Northern bedstraw
Galium trifidum	L.	Small bedstraw
Gentianella amarella	(L.) Borner	Northern gentian
Gentiana calycosa	Griseb.	Mountain bog gentian
Geum macrophyllum	Willd.	Yellow avens
Haplopappus lanceolatus	(Hook.) T. & G.	Lance leaved golden weed
Hedysarum alpinum	L.	Alpine sweet vetch
Hordeum jubatum	L.	Foxtail barley
Juncus balticus	Willd.	Wire rush
Juniperis communis	L.	Ground juniper
Juniperis horizontalis	Moench	Creeping juniper
Juncus mertensianus	Bong.	Slender stemmed rush
Koeleria macrantha	(Ledeb.) J.A. Schultes f.	June grass
Lathyrus ochroleucus	Hook.	Cream pea vine
Lathyrus venosus	Muhl.	Wild pea vine
Ledum glandulosum	Nutt.	Glandular labrador tea
Ledum groenlandicum	Oeder	Common labrador tea
Lepidium densiflorum	Schrad.	Common pepper grass
Lilium philadelphicum	L.	Western wood lily
Linnaea borealis	L.	Twin flower
Linaria dalmatica	(L.) Mill.	Dalmation toadflax
Linum lewisii	Pursh	Wild blue flax
Linaria vulgaris	Hill	Toadflax
Lithospermum ruderale	Lehm.	Woolly gromwell
Lonicera involucrata	(Richards.) Banks	Bracted honeysuckle
Lophozia ventricosa	(Dicks.) Dum	Leafy liverwort
Matricaria perforata	Merat	Scentless chamomile
Medicago lupulina	L.	Black medick
Medicago sativa	L.	Alfalfa
Melilotus alba	Desr.	White sweet clover
Melilotus officinalis	(L.) Lam.	Yellow sweet clover
Mentha arvensis	L.	Wild mint
Menziesia ferruginea	J.E. Smith	False huckleberry
Mertensia paniculata	(Ait.) G. Don	Tall lungwort
Mimulus caespitosus	Greene	Mountain monkey flower
Mitella nuda	L.	Bishop's cap
Neslia paniculata	(L.) Desv.	Ball mustard
Oxytropis deflexa	(Pall.) DC.	Reflexed locoweed

Table 3.1 List of observed species in Jasper National Park (continued)

Scientific Name	Authority	Common Name
Oxytropis sericea	Nutt.	Early locoweed
Oxytropis splendens	Dougl. ex Hook.	Showy locoweed
Parnassia fimbriata	Konig	Grass of parnassus
Petasites sagittata	(A. Gray) A. Nels.	Arrow leaved coltsfoot
Phleum alpinum	L.	Mountain timothy
Phleum pratense	L.	Timothy
Phyllodoce empetriformis	(Smith) D. Don	Pink mountain heather
Phyllodoce glanduliflora	(Hook.) Colville	Yellow mountain heather
Picea engelmannii	Parry ex. Engelm.	Engelmann spruce
Picea glauca	(Moench) Voss	White spruce
Pinus contorta	Louden	Lodgepole pine
Pinguicula vulgaris	L.	Common butterwort
Plantago major	L.	Common plantain
Poa alpine	L.	Alpine blue grass
Poa compressa	L.	Canada blue grass
Poa commutata	Roem. & Schult	Turf grass
Poa epilis	Scribn.	Fendler’s blue grass
Poa glauca	Vahl.	Glaucous blue grass
Poa interior	Rydb.	Inland blue grass
Poa nervosa	(Hook.) Vasey	Wheeler blue grass
Poa palustris	L.	Fowl blue grass
Poa pratensis	L.	Kentucky blue grass
Polygonum bistortoides	Pursh	Western bistort
Polygonum viviparum	L.	Alpine bistort
Populus balsamifera	L.	Balsam poplar
Populus tremuloides	Michx.	Trembling aspen
Potentilla arguta	Pursh	White cinquefoil
Potentilla diversifolia	Lehm.	Diverse leafed cinquefoil
Potentilla fruticosa	L.	Shrubby cinquefoil
Potentilla gracilis	Dougl. ex Hook.	Graceful cinquefoil
Potentilla norvegica	L.	Rough cinquefoil
Potentilla pensylvanica	L.	Prairie cinquefoil
Puccinelia nuttalliana	(Schult.) A.S. Hitchc.	Nutall's alkali grass
Pyrola asarifolia	Michx.	Common pink wintergreen
Pyrola secunda	L.	One sided wintergreen
Ranunculus acris	L.	Tall buttercup
Raphanus raphanistrum	L.	Wild radish
Ribes lacustre	(Pers.) Poir.	Bristly black currant
Ribes oxyacanthoides	L.	Wild gooseberry
Ribes triste	Pall.	Wild red currant
Rosa acicularis	Lindl.	Prickly rose
Rosa woodsii	Lindl.	Wild rose
Rubus idaeus	L.	Wild red raspberry
Rubus parviflorus	Nutt.	Thimbleberry

Table 3.1 List of observed species in Jasper National Park (continued)

Scientific Name	Authority	Common Name
Rubus pubescens	Raf.	Dewberry
Salsola kali	L.	Russian thistle
Senecio eremophilus	Richards.	Cut leafed ragwort
Senecio pauciflorus	Pursh	Alpine groundsel
Senecio pseudaureus	Rydb.	Stream bank butterweed
Shepherdia canadensis	(L.) Nutt.	Canadian buffaloberry
Sisymbrium altissimum	L.	Tumbling mustard
Sisyrinchium montanum	L.	Blue eyed grass
Smilacina stellata	(L.) Desf.	Star flowered solomon's seal
Solidago missouriensis	Nutt.	Low goldenrod
Solidago spathulata	DC.	Western goldenrod
Sonchus arvensis	L.	Perennial sow thistle
Sonchus asper	(L.) Hill	Annual sow thistle
Spiraea betulifolia	Pallas	White meadowsweet
Stellaria media	(L.) Cyrill.	Common chickweed
Stipa comata	Trin. & Rupr.	Spear grass
Stipa viridula	Trin.	Green needle grass
Symphoricarpos albus	(L.) Blake	Snowberry
Taraxacum officinale	Weber	Common dandelion
Thalictrum venulosum	Trel.	Veiny meadow rue
Thlaspi arvense	L.	Stinkweed
Tofieldia glutinosa	(Michx.) Pers.	False asphodel
Trifolium hybridum	L.	Alsike clover
Trifolium pratense	L.	Red clover
Trifolium repens	L.	White clover
Triglochin maritima	L.	Arrow grass
Trisetum spicatum	(L.) Richt.	Spike trisetum
Vaccinium caespitosum	Michx.	Dwarf bilberry
Vaccinium membranaceum	Dougl. ex Hook.	Tall billlberry
Vaccinium vitis idaea	L.	Bog cranberry
Vicia americana	Muhl.	Wild vetch
Viola adunca	J.E. Smith	Early blue violet
Zigadenus elegans	Pursh	White camus

Table 3.2 List of Parks Canada Agency prioritized non-native species for management found on research sites

Scientific Name	Common Name	Priority
Chrysanthemum leucanthemum	Ox eye daisy	High
Circium arvense	Canada thistle	High
Linaria dalmatica	Dalmatian toadflax	High
Linaria vulgaris	Common toadflax	High
Matricaria perforata	Scentless chamomile	High
Salsola kali	Russian thistle	High
Chenopodium album	Lambs quarters	Moderate
Crepis tectorum	Annual hawk's beard	Moderate
Descurainia sophia	Flixweed	Moderate
Erucastrum gallicum	Dog mustard	Moderate
Potentilla argentea	Silvery cinquefoil	Moderate
Sisymbrium altissimum	Tumbling mustard	Moderate
Sonchus arvensis	Perennial sow thistle	Moderate
Agropyron repens	Quack grass	Low
Agropyron trachycaulum	Slender wheat grass	Low
Bromus inermis	Smooth brome	Low
Capsella bursa pastoris	Shepherd's purse	Low
Cerastium vulgatum	Mouse ear chickweed	Low
Festuca rubra	Red fescue	Low
Hordeum jubatum	Foxtail barley	Low
Lepidium densiflorum	Common peppergrass	Low
Melilotus officinalis	Yellow sweet clover	Low
Phleum pratense	Timothy	Low
Plantago major	Common plantain	Low
Poa compressa	Canada blue grass	Low
Poa pratensis	Kentucky blue grass	Low
Raphanus raphanistrum	Wild radish	Low
Stellaria media	Common chickweed	Low
Taraxacum officinale	Dandelion	Low
Thlaspi arvense	Stinkweed	Low
Trifolium hybridum	Alsike clover	Low
Trifolium repens	White clover	Low

Table 3.3 Abundance scores from input data for focal plant species on Access route 34

Species Name	Abundance	Frequency	Abundance Score	Focal Species
Carex	11.5	0.8	9.2	Yes
Equisetum arvense	6.3	0.6	3.78	Yes
Solidago spathulata	6.2	0.4	2.48	Yes
Erigeron acris	4.1	0.2	0.82	No
Galium boreale	3.4	0.6	2.04	Yes
Agropyron dasystachyum	2.5	0.6	1.5	Yes
Bromus inermis	2.2	0.4	0.88	Yes
Elymus innovatus	2.1	0.2	0.42	No
Potentilla fruticosa	2.1	0.2	0.42	No
Campanula rotundifolia	1.3	0.4	0.52	No
Festuca saximontana	0.4	0.4	0.16	No
Linum lewisii	0.2	0.2	0.04	No
Salsola kali	0.2	0.2	0.04	Yes

Table 3.4 Observed focal species abundance by quadrats on Access route 34 prior to Hellinger transformation

Species	Quadrat I	Quadrat II	Quadrat III	Quadrat IV	Quadrat V	Species Sum
Carex	0.2	2.1	1.1	8.1	0	11.5
Equisetum arvense	0	0	1.1	1.1	4.1	6.3
Agropyron dasystachyum	2.1	0.2	0	0.2	0	2.5
Galium boreale	0.2	1.1	0	0	2.1	3.4
Solidago spathulata	0	4.1	0	2.1	0	6.2
Bromus inermis	0	1.1	0	0	1.1	2.2
Salsola kali	0.2	0	0	0	0	0.2

Table 3.5 Matrix of Hellinger transformed focal species abundance by quadrats on Access route 34

Species	Quadrat I	Quadrat II	Quadrat III	Quadrat IV	Quadrat V	Species Sum
Carex	0.27	0.49	0.71	0.84	0	2.31
Equisetum arvense	0	0	0.71	0.31	0.75	1.77
Agropyron dasystachyum	0.88	0.15	0	0.13	0	1.17
Galium boreale	0.27	0.36	0	0	0.54	1.17
Solidago spathulata	0	0.69	0	0.43	0	1.12
Bromus inermis	0	0.36	0	0	0.39	0.75
Salsola kali	0.27	0	0	0	0	0.27

Table 3.6 Abundance scores for non-native species for all research sites

Species Code	Total Cover	Frequency	Abundance Score
Agropyron repens	525.2	0.215	113.02
Agropyron trachycaulum	243.1	0.256	62.31
Festuca rubra	259.3	0.152	39.39
Cirsium arvense	179.6	0.057	10.23
Taraxacum officinale	71.7	0.117	8.40
Sonchus arvensis	95.6	0.066	6.35
Poa pratensis	49.7	0.104	5.19
Bromus inermis	60.1	0.044	2.66
Phleum pratense	33.3	0.028	0.95
Hordeum jubatum	36.5	0.013	0.46
Capsella bursa pastoris	13.5	0.019	0.26
Crepis tectrorum	9.9	0.025	0.25
Comandra umbellata	6.5	0.016	0.10
Chrysanthemum leucanthemum	12.2	0.006	0.08
Descurainia sophia	5.6	0.013	0.07
Melilotus officinalis	2.2	0.006	0.01
Potentilla arguta	2.1	0.003	0.01
Linaria dalmatica	1.1	0.003	0.003
Trifolium hybridum	1.1	0.003	0.003
Linaria vulgaris	0.2	0.003	0.001
Salsola kali	0.2	0.003	0.001
Stellaria media	0.2	0.003	0.001

Table 3.7 Abundance scores for native species for all research sites

Species Code	Total Cover	Frequency	Abundance Score
Festuca saximontana	668.9	0.373	249.78
Agropyron dasystachyum	345.2	0.275	95.04
Carex spp.	297.3	0.193	57.39
Epilobium angustifolium	289.1	0.171	49.40
Poa alpina	203.3	0.206	41.82
Salix spp.	181	0.085	15.47
Poa commutata	120.1	0.095	11.40
Fragaria virginiana	114.2	0.092	10.48
Equisetum arvense	76	0.104	7.94
Anemone multifida	122.1	0.060	7.34
Poa interior	112.7	0.057	6.42
Vicia americana	59.11	0.104	6.17
Juniperis horizontalis	231.1	0.019	4.39
Koeleria macrantha	75.1	0.057	4.28
Artemisia frigida	100.2	0.032	3.17
Poa palustris	78	0.035	2.72
Antennaria pulcherima	60.2	0.041	2.48
Elymus innovatus	59.1	0.041	2.43
Poa glauca	65.4	0.035	2.28
Equisetum pratense	61.3	0.035	2.13
Smilicina stellata	31	0.054	1.67
Potentilla fruticosa	53.7	0.028	1.53
Trifolium repens	54.7	0.025	1.39
Arctostaphylus rubra	91.2	0.013	1.15
Equisetum variegatum	59.6	0.019	1.13
Festuca campestris	25.2	0.044	1.12

Table 3.8 Summary of errors and tree sizes from multivariate regressions of research sites

Name	Error	R^2	CV-error	Sampling Error	Sample Size	Tree Nodes	Tree Leaves
Staging.area.2	0.22	0.79	1.7	0.23	16	5	6
Ski.hill.8	0.38	0.62	1.46	0.37	8	2	3
Water.line.18	0.51	0.49	1.35	0.32	19	6	7
Water.line.19	0.33	0.67	1.21	0.18	20	6	7
Water.line.20	0.42	0.58	1.39	0.20	20	6	7
Water.line.22	0.38	0.63	1.48	0.17	18	6	7
Water.line.23	0.68	0.32	1.56	0.32	5	1	2
Water.line.25	0.64	0.36	1.55	0.25	6	1	2
Waste.pit.28	0.30	0.70	1.11	0.24	13	4	5
Pipe.valve.31	0.50	0.5	1.29	0.18	17	4	5
Access.route.33	0.04	0.96	1.18	0.35	9	3	4
Access.route.34	0.63	0.37	1.56	0.24	5	1	2
Pipe.pullout.35	0.34	0.66	1.19	0.17	20	6	7
Staging.area.37	0.29	0.71	1.41	0.27	15	4	5
Pipe.valve.39	0.41	0.59	1.52	0.22	16	5	6
Pipe.route.40	0.50	0.50	1.36	0.17	13	3	4
Staging.area.41	0.63	0.37	1.6	0.28	7	1	2
Pipe.route.42	0.36	0.64	1.42	0.32	8	2	3
Pipe.valve.44	0.37	0.63	1.2	0.16	19	6	7
Pipe.pullout.45	0.35	0.65	1.46	0.20	20	7	8
Waste.pit.51	0.26	0.75	1.36	0.19	12	4	5
Walking.path.56	0.34	0.66	1.28	0.28	10	3	4
Road.cut.69	0.53	0.47	1.32	1.04	20	1	2

Table 3.9 Statistics of errors and tree sizes from multivariate regressions of research sites

Statistic	Error	R^2	Cross Validated Error	Sampling Error	Sample Size	Tree Nodes	Tree Leaves
Minimum	0.04	0.32	1.11	0.16	5	1	2
Maximum	0.68	0.96	1.7	1.04	20	7	8
Mean	0.41	0.59	1.39	0.28	13.74	3.78	4.78
Median	0.38	0.63	1.39	0.24	15	4	5
Standard Deviation	0.15	0.13	0.15	0.188	5.46	2.02	2.02

Table 3.10 Soil property codes for column headers

Soil Property	Code	Unit
Bicarbonate	HCO3	mg L^{-1}
Cation Exchange Capacity	CEC	meq $100g^{-1}$
Electrical Conductivity	EC	dS m^{-1}
Exchangeable Calcium	ECa	mg kg^{-1}
Exchangeable Magnesium	EMg	mg kg^{-1}
Exchangeable Potassium	EK	mg kg^{-1}
Exchangeable Sodium	ENa	mg kg^{-1}
Penetration Resistance, 10 cm depth	M.PR.10	mPa
Penetration Resistance, 5 cm depth	M.PR.5	mPa
Saturation Percentage	SPa	%
Sieve Percent	SP	%
Sodium Adsorption Ratio	SAR	-
Soluble Calcium	SCa	mg L^{-1}
Soluble Magnesium	SMg	mg L^{-1}
Soluble Potassium	SK	mg L^{-1}
Soluble Sodium	SNa	mg L^{-1}
Total Carbon	TC	%
Total Inorganic Carbon	TIC	%
Total Nitrogen	TN	%
Total Organic Carbon	TOC	%

Table 3.11 Water line 20 plant variance explained (%) by soil properties at splitting criteria

Species	SP - 48.5	HCO3 - 25.5	SMg - 6.5	CEC - 4.98	CEC - 6.32	M.PR.10 - 1.6	Tree Total	Species Total
Epilobium angustifolium	9.19	5.84	2.56	0.46	2.28	0.99	21.32	26.57
Carex	0.01	0.86	0	0.91	1.75	0.32	3.84	17.50
Poa interior	2.04	4.64	0.34	0	0.83	4.41	12.27	16.05
Poa compressa	9.45	0.23	0.99	0	0.17	0.26	11.10	17.86
Festuca saximontana	0.77	0.55	1.45	0	0.39	0.61	3.77	8.87
Poa paluststris	0.25	0.08	0.11	0.22	2.28	0.03	2.98	7.49
Poa pratensis	0.07	0.52	0	1.27	0	0.02	1.88	4.01
Festuca rubra	0.02	0.24	0	0.23	0	0	0.49	1.64
Complexity Total	21.79	12.98	5.46	3.09	7.70	6.65	57.66	100.00

Table 3.12 Water line 20 average transformed plant abundance (%) for soil properties at terminal leaves

Species	SP < 48.5	SMg >= 6.5	SMg < 6.5	CEC < 4.95	CEC < 6.32	M.PR.10 < 1.6	M.PR.10 >= 1.6	Species Total
Epilobium angustifolium	0	96.48	75.50	10.94	29.92	39.28	80.86	333.0
Carex	25.00	0	29.64	57.61	10.53	25.73	26.08	174.6
Poa interior	0	0	0	19.66	88.46	37.71	22.56	168.4
Poa compressa	64.52	0	0	0	0	2.86	28.72	96.1
Festuca saximontana	26.01	0	0	0	0	34.77	3.49	64.3
Poa palustris	0	0	14.61	44.00	0	8.70	0	67.3
Poa pratensis	0	0	34.92	0	3.85	0	0	38.8
Festuca rubra	0	14.91	0	0	0	0	0	14.9
Property Total	115.5	111.4	154.7	132.2	132.8	149.0	161.7	957.3

Table 3.13 Absolute frequency and distribution of soil properties in multivariate regression trees nodes

Soil property	Primary	Secondary	Tertiary	Quaternary	Quintenary	Total
Cation Exchange Capacity	3	3	2	0	1	9
Penetration Resistance 10 cm	2	1	1	1	1	9
Electrical Conductivity	4	0	1	2	0	9
Bicarbonate	1	3	4	0	0	8
Sieve Percent	2	4	1	0	2	7
Exchangeable Sodium	3	2	2	0	2	6
Sodium Adsorption Ratio	1	3	2	0	0	6
Soluble Calcium	2	2	1	1	0	6
Soluble Magnesium	0	0	3	1	0	4
Exchangeable Potassium	1	1	0	1	0	4
Penetration Resistance 5 cm	0	2	0	2	0	3
Exchangeable Calcium	0	1	0	1	1	3
Soluble Potassium	0	1	2	0	0	3
Exchangeable Magnesium	1	0	1	0	0	2
Saturation Percentage	1	0	1	0	0	2
Total Carbon	1	0	1	0	0	2
Total Nitrogen	1	0	0	0	0	1
Total Inorganic Carbon	0	1	0	0	0	1
Soluble Sodium	0	0	0	1	0	1
Total Organic Carbon	0	0	0	1	0	1
Sum of Nodes	23	24	22	11	7	

Table 3.14 Percentage of disturbed area sampled with plot pairs on all sites

Name	Disturbance Area (m^2)	Plot Area (m^2)	Percent Area Represented
Staging.area.2	8,712	1.6	0.02
Ski.hill.8	6,666	0.8	0.01
Water.line.18	288	1.9	0.66
Water.line.19	560	2	0.36
Water.line.20	624	2	0.32
Water.line.22	689	1.8	0.26
Water.line.23	752	0.5	0.07
Water.line.25	296	0.6	0.2
Waste.pit.28	19,008	1.3	0.01
Pipe.valve.31	480	1.7	0.35
Access.route.33	2,450	0.9	0.04
Access.route.34	560	0.5	0.09
Pipe.pullout.35	1,760	2	0.11
Staging.area.37	9,800	1.5	0.02
Pipe.valve.39	2,324	1.6	0.07
Pipe.route.40	784	1.3	0.17
Staging.area.41	6,890	0.7	0.01
Pipe.route.42	871	0.8	0.09
Pipe.valve.44	3,300	1.9	0.06
Pipe.pullout.45	1,620	2	0.12
Waste.pit.51	27,800	1.2	0
Walking.path.56	128	1	0.78
Road.cut.69	5,577	2	0.04
Total Area	101,939	31.6	0.03

Table 3.15 Single factor ANOVA results for selecting general over special cases of frequency

Node Frequency Sets	F	F-critical	*p*-value	alpha	Significant
1, 2, 3, 4, 5	2.97	2.48	0.02	0.05	Yes
1, 2, 3	0.08	3.16	0.93	0.05	No
Summed 1, 2, 3 vs. 4, 5	0.99	4.1	0.33	0.05	No
1, 2, 3 x property	2.52	1.85	0.01	0.05	Yes

Table 3.16 Absolute and relative frequency of soil properties influencing plant abundance

Soil Property	Absolute Frequency	Area (m^2)	Relative Frequency (%)
Exchangeable Sodium	7	8.2	85
Sodium Adsorption Ratio	6	7.2	83
Penetration Resistance, 10 cm depth	4	5.3	75
Cation Exchange Capacity	8	10.9	73
Sieve Percent	7	9.6	73
Electrical Conductivity	5	7.1	70
Soluble Calcium	5	7.4	68
Bicarbonate	8	12.3	65

Table 3.17 Weighted average variance for soil properties explaining plant abundance

Soil Property	Variance (R^2)	Area (m^2)	Mean	Standard Deviation
Soluble Calcium	103.68	7.4	26.4	10.84
Cation Exchange Capacity	201.46	10.9	25.13	19.38
Electrical Conductivity	131.21	7.1	23.1	12.33
Exchangeable Sodium	154.6	8.2	19.63	11.99
Penetration Resistance, 10 cm depth	87.14	5.3	19.03	9.53
Sieve Percent	92.88	9.6	18.62	14.41
Sodium Adsorption Ratio	109.25	7.2	18.03	20.25
Bicarbonate	116.75	12.3	11.94	5.75

Table 3.18 Standardized scores of all observed species for site success score

Name	Basal Cover Score	Canopy Cover Score	Litter Cover Score	Species Count Score	Density Class Score	Score A
Staging.area.2	3.06	2.42	0.30	1.64	3.11	10.53
Ski.hill.8	1.83	2.14	2.06	1.64	2.13	9.80
Water.line.18	1.60	1.50	0.00	2.01	2.09	7.19
Water.line.19	1.46	1.98	0.13	1.98	0.98	6.53
Water.line.20	0.78	1.41	0.08	1.64	0.05	3.96
Water.line.22	1.53	3.14	0.45	4.24	0.61	9.96
Water.line.23	0.88	1.24	0.01	3.12	0.00	5.25
Water.line.25	1.46	2.09	0.05	3.31	0.76	7.68
Waste.pit.28	0.33	0.63	0.38	1.44	1.20	3.98
Pipe.valve.31	0.56	1.34	1.37	2.97	1.50	7.76
Access.route.33	2.13	1.07	0.82	1.41	0.54	5.98
Access.route.34	4.00	0.94	2.13	2.45	0.55	10.08
Pipe.pullout.35	0.30	1.15	2.26	1.64	2.66	8.02
Staging.area.37	0.23	1.09	1.10	1.34	1.88	5.64
Pipe.valve.39	0.93	2.10	0.86	2.63	1.02	7.53
Pipe.route.40	0.92	3.95	2.70	4.08	1.00	12.65
Staging.area.41	0.26	0.47	0.00	1.07	0.86	2.67
Pipe.route.42	0.19	1.70	0.75	3.01	0.18	5.84
Pipe.valve.44	0.25	1.44	2.84	2.26	1.29	8.07
Pipe.pullout.45	0.39	3.74	2.83	2.03	3.81	12.80
Waste.pit.51	0.96	1.42	0.43	1.76	0.70	5.27
Walking.path.56	0.08	0.29	0.50	1.07	0.36	2.31
Road.cut.69	0.00	0.00	0.04	0.00	0.31	0.35

Table 3.19 Standardized scores of nonnative species for site success score

Name	Basal Cover Score	Canopy Cover Score	Species Count Score	Density Class Score	Score B
Staging.area.2	0.11	0.05	0.15	1.09	1.39
Ski.hill.8	2.42	0.72	1.33	3.40	7.87
Water.line.18	0.52	0.14	0.87	1.72	3.24
Water.line.19	1.32	0.35	0.88	1.36	3.91
Water.line.20	0.25	0.11	0.18	1.21	1.75
Water.line.22	1.06	0.31	0.79	1.27	3.43
Water.line.23	0.32	0.14	0.47	0.73	1.65
Water.line.25	0.90	0.41	1.18	1.45	3.93
Waste.pit.28	2.05	0.61	1.99	2.28	6.94
Pipe.valve.31	0.98	0.40	1.53	2.18	5.09
Access.route.33	0	0	0	0	0
Access.route.34	0.10	0.07	0.71	1.70	2.58
Pipe.pullout.35	2.14	1.51	3.36	3.07	10.09
Staging.area.37	1.33	1.14	1.73	2.81	7.01
Pipe.valve.39	2.25	0.61	1.47	1.67	6.00
Pipe.route.40	0.10	0.07	0.72	0.73	1.62
Staging.area.41	0.95	0.27	0.84	2.04	4.10
Pipe.route.42	0.16	0.18	1.18	1.27	2.79
Pipe.valve.44	1.47	1.51	2.92	2.34	8.23
Pipe.pullout.45	2.81	4.70	3.24	4.07	14.82
Waste.pit.51	3.28	0.94	2.75	1.27	8.25
Walking.path.56	0.10	0.01	0.71	1.21	2.02
Road.cut.69	0	0	0	0	0

Table 3.20 Site revegetation scores after subtracting all species and non-native species scores

Name	Score A	Score B	Dividend Score
Pipe.route.40	12.65	1.62	11.02
Staging.area.2	10.53	1.39	9.14
Access.route.34	10.08	2.58	7.50
Water.line.22	9.96	3.43	6.53
Access.route.33	5.98	0.00	5.98
Water.line.18	7.19	3.24	3.95
Water.line.25	7.68	3.93	3.74
Water.line.23	5.25	1.65	3.60
Pipe.route.42	5.84	2.79	3.05
Pipe.valve.31	7.76	5.09	2.66
Water.line.19	6.53	3.91	2.62
Water.line.20	3.96	1.75	2.21
Ski.hill.8	9.80	7.87	1.93
Pipe.valve.39	7.53	6.00	1.53
Road.cut.69	0.35	0	0.35
Walking.path.56	2.31	2.02	0.28
Pipe.valve.44	8.07	8.23	-0.16
Staging.area.37	5.64	7.01	-1.37
Staging.area.41	2.67	4.10	-1.44
Pipe.pullout.45	12.80	14.82	-2.02
Pipe.pullout.35	8.02	10.09	-2.07
Waste.pit.28	3.98	6.94	-2.95
Waste.pit.51	5.27	8.25	-2.98

Table 3.21 Standardized scores of community structure including nonnative species

Name	Basal Cover Score	Canopy Cover Score	Species Count Score	Density Class Score	Sum
Staging.area.2	2.77	3.28	3.67	4.07	13.79
Ski.hill.8	0.07	0.13	0.29	0.86	1.34
Water.line.18	0.30	0.60	0.65	2.17	3.72
Water.line.19	0.10	0.29	0.62	2.03	3.04
Water.line.20	0.32	0.70	3.04	1.54	5.59
Water.line.22	0.13	0.55	1.69	1.84	4.22
Water.line.23	0.28	0.49	2.11	2.56	5.44
Water.line.25	0.15	0.26	0.81	1.71	2.94
Waste.pit.28	0.01	0.02	0.11	0.98	1.11
Pipe.valve.31	0.05	0.16	0.52	1.38	2.11
Access.route.33	0.00	0.00	0.00	0.00	-0.01
Access.route.34	4.13	0.73	1.04	1.32	7.23
Pipe.pullout.35	0.01	0.00	0.03	0.75	0.78
Staging.area.37	0.01	0.01	0.13	0.94	1.09
Pipe.valve.39	0.03	0.16	0.47	1.63	2.28
Pipe.route.40	0.96	3.28	1.77	3.78	9.79
Staging.area.41	0.02	0.06	0.30	1.15	1.53
Pipe.route.42	0.14	0.52	0.73	1.56	2.95
Pipe.valve.44	0.01	0.01	0.13	1.01	1.16
Pipe.pullout.45	0.01	0.00	0.07	0.82	0.91
Waste.pit.51	0.02	0.04	0.08	2.62	2.77
Walking.path.56	0.13	2.53	0.38	1.85	4.89
Road.cut.69	0.00	0.00	0.00	0.00	-0.01

Table 3.22 Site revegetation scores after dividing native species with non-native species scores

Name	Quotient Score
Staging.area.2	13.79
Pipe.route.40	9.79
Access.route.34	7.23
Water.line.20	5.59
Water.line.23	5.44
Walking.path.56	4.89
Water.line.22	4.22
Water.line.18	3.72
Water.line.19	3.04
Pipe.route.42	2.95
Water.line.25	2.94
Waste.pit.51	2.77
Pipe.valve.39	2.28
Pipe.valve.31	2.11
Staging.area.41	1.53
Ski.hill.8	1.34
Pipe.valve.44	1.16
Waste.pit.28	1.11
Staging.area.37	1.09
Pipe.pullout.45	0.91
Pipe.pullout.35	0.78
Access.route.33	-0.01
Road.cut.69	-0.01

Table 3.23 Tolerance thresholds for plant and soil biophysical properties to evaluate soil conservation and revegetation success

Variable	Units	Deficient	Below	Optimum	Above	Excess
Live Plant + Litter Cover	%	0 to 69	70 to 74	75 to 85	86 to 90	91 to > 100
Bare ground	%	-	-	0 to 20	21 to 30	31 to 100
Plant Density Class	-	0 to 2	2 to 3	3 to 4	4 to 6	6 to 9
Electrical Conductivity	dS/m	-	-	0 to 2	2.01 to 4	4.01 to 12
Sodium Adsorption Ratio	-	-	-	0 to 4	4.01 to 8	8.01 to 16
Cation Exchange Capacity	meq/L	-	0 to 5	5.01 to 30	30 to 300	-
Sieve Percent	%	-	0 to 14	15 to 30	31 to 60	61 to 100
Penetration Resistance, 10 cm	MPa	0 to 0.49	0.5 to 0.99	1 to 2	2.01 to 4.99	5 to 10

Table 3.24 Average sodium adsorption ratio at research sites

Name	Mean	Standard Deviation
Pipe.pullout.45	4.54	4.57
Pipe.pullout.35	4.02	2.45
Staging.area.41	1.58	2.87
Pipe.route.42	1.58	2.87
Pipe.route.40	0.67	0.30
Pipe.valve.39	0.64	0.49
Water.line.20	0.43	0.59
Water.line.18	0.34	0.13
Waste.pit.51	0.31	0.40
Water.line.25	0.27	0.39
Water.line.22	0.27	0.16
Access.route.33	0.25	0.21
Water.line.23	0.23	0.07
Staging.area.37	0.22	0.17
Ski.hill.8	0.22	0.06
Road.cut.69	0.19	0.10
Pipe.valve.31	0.16	0.06
Water.line.19	0.15	0.10
Access.route.34	0.15	0.03
Waste.pit.28	0.14	0.06
Walking.path.56	0.11	0.03
Staging.area.2	0.10	0.11
Pipe.valve.44	0.08	0.03

Table 3.25Average cation exchange capacity at research sites

Name	Mean	Standard Deviation
Pipe.route.40	33.10	9.60
Walking.path.56	29.74	5.08
Staging.area.2	28.58	4.30
Water.line.22	28.45	8.76
Water.line.25	27.38	1.74
Access.route.34	25.18	4.08
Waste.pit.28	23.48	7.27
Staging.area.37	23.42	5.46
Pipe.pullout.45	23.21	2.92
Pipe.valve.31	20.49	2.73
Pipe.valve.44	19.64	2.47
Water.line.19	19.08	3.75
Pipe.pullout.35	18.08	4.48
Staging.area.41	15.81	5.73
Pipe.route.42	15.81	5.73
Road.cut.69	15.53	1.37
Pipe.valve.39	14.53	1.59
Waste.pit.51	14.30	4.70
Water.line.23	12.87	3.31
Access.route.33	11.62	1.49
Ski.hill.8	10.99	10.19
Water.line.20	7.75	3.21
Water.line.18	5.43	4.19

Table 3.26 Average electrical conductivity at research sites

Name	Mean	Standard Deviation
Pipe.pullout.35	2.87	1.37
Road.cut.69	2.43	0.91
Pipe.route.40	2.38	1.26
Pipe.pullout.45	1.98	0.49
Walking.path.56	1.62	0.83
Water.line.22	1.25	0.36
Pipe.valve.31	1.19	0.36
Pipe.valve.39	1.12	0.60
Staging.area.41	1.01	0.89
Pipe.route.42	1.01	0.89
Water.line.25	0.98	0.21
Access.route.34	0.98	0.10
Staging.area.37	0.96	0.44
Waste.pit.28	0.80	0.17
Pipe.valve.44	0.79	0.13
Staging.area.2	0.76	0.27
Waste.pit.51	0.75	0.30
Water.line.19	0.73	0.19
Water.line.23	0.72	0.20
Access.route.33	0.55	0.15
Water.line.20	0.43	0.25
Ski.hill.8	0.40	0.40
Water.line.18	0.22	0.20

Table 3.27 Average penetration resistance at 10 cm depth at research sites

Name	Mean	Standard Deviation
Waste.pit.51	6.56	1.24
Road.cut.69	6.26	1.01
Ski.hill.8	6.20	2.16
Waste.pit.28	5.83	1.44
Staging.area.41	4.77	1.73
Pipe.route.42	4.77	1.73
Access.route.33	4.61	1.22
Pipe.valve.44	3.46	0.79
Walking.path.56	3.44	1.19
Water.line.19	3.34	1.64
Pipe.valve.39	3.29	1.07
Pipe.pullout.35	3.20	1.45
Water.line.18	3.13	1.10
Staging.area.2	2.72	0.39
Pipe.valve.31	2.64	1.59
Staging.area.37	2.43	2.02
Pipe.pullout.45	2.12	0.52
Access.route.34	2.03	0.66
Water.line.20	1.77	0.84
Pipe.route.40	1.68	0.36
Water.line.25	1.52	0.49
Water.line.22	1.46	0.47
Water.line.23	1.25	0.47

Table 3.28 Average sieve percent at research sites

Name	Mean	Standard Deviation
Access.route.34	12.70	4.03
Staging.area.2	17.85	7.55
Pipe.valve.44	18.06	5.57
Pipe.route.40	18.88	9.04
Pipe.pullout.45	19.07	20.38
Pipe.valve.31	32.12	14.54
Water.line.22	33.05	28.13
Water.line.25	37.58	19.69
Staging.area.37	40.70	38.82
Water.line.23	42.00	5.71
Water.line.20	57.20	13.67
Walking.path.56	59.09	21.91
Pipe.pullout.35	59.55	33.61
Waste.pit.28	60.37	9.88
Pipe.valve.39	62.78	3.51
Water.line.18	64.18	9.04
Water.line.19	66.85	6.44
Access.route.33	72.64	22.89
Ski.hill.8	77.35	9.98
Road.cut.69	81.51	8.75
Waste.pit.51	92.56	3.31
Staging.area.41	92.99	1.19
Pipe.route.42	92.99	1.19

Table 3.29 Combined average percent basal, canopy and leaf litter cover at research sites

Name	Mean	Standard Deviation
Pipe.pullout.45	130.38	16.6
Pipe.route.40	129.51	20.54
Pipe.valve.44	109.7	10.64
Ski.hill.8	97.38	39.33
Pipe.pullout.35	86.93	33.47
Access.route.34	81.9	36.93
Pipe.valve.31	61.23	41.45
Pipe.valve.39	50.88	36.52
Water.line.22	49.57	19.68
Staging.area.37	48.75	38.84
Access.route.33	46.96	48.04
Staging.area.2	45.38	29.48
Pipe.route.42	41.4	31.56
Waste.pit.51	31.87	27.41
Water.line.19	28.57	20.6
Water.line.25	26.93	12.96
Walking.path.56	21.11	20.64
Water.line.18	20.78	15.48
Waste.pit.28	19.65	21.27
Water.line.20	19.03	15.94
Water.line.23	15.88	7.25
Staging.area.41	6.23	4.57
Road.cut.69	2.46	2.39

Table 3.30 Averages for plant and soil biophysical properties at research sites

Name	Plant Cover	Electrical Conductivity	Sodium Adsorption Ratio	Cation Exchange Capacity	Penetration Resistance	Sieve Percent
Staging.area.2	45.38	0.76	0.10	28.58	2.72	17.85
Ski.hill.8	97.39	0.40	0.22	10.99	6.20	77.35
Water.line.18	20.78	0.22	0.34	5.43	3.13	64.18
Water.line.19	28.82	0.73	0.15	19.08	3.34	66.85
Water.line.20	19.03	0.43	0.43	7.75	1.77	57.20
Water.line.22	49.63	1.25	0.27	28.45	1.46	33.05
Water.line.23	15.88	0.72	0.23	12.87	1.25	42.00
Water.line.25	26.93	0.98	0.27	27.38	1.52	37.58
Waste.pit.28	20.80	0.80	0.15	23.49	5.83	60.37
Pipe.valve.31	61.71	1.19	0.16	20.49	2.64	32.12
Access.route.33	47.87	0.55	0.25	11.62	4.61	72.64
Access.route.34	81.90	0.98	0.15	25.18	2.03	12.70
Pipe.pullout.35	89.23	2.87	4.02	18.08	3.20	59.55
Staging.area.37	48.76	0.96	0.22	23.42	2.43	40.70
Pipe.valve.39	52.08	1.12	0.64	14.53	3.29	62.78
Pipe.route.40	130.28	2.38	0.67	33.10	1.68	18.88
Staging.area.41	6.23	1.01	1.58	15.81	4.77	92.99
Pipe.route.42	41.91	0.56	0.06	15.54	2.45	52.08
Pipe.valve.44	111.08	0.79	0.09	19.58	3.47	18.07
Pipe.pullout.45	130.80	1.98	4.55	23.21	2.12	19.07
Waste.pit.51	31.87	0.75	0.31	14.30	6.56	92.56
Walking.path.56	21.11	1.62	0.11	29.74	3.44	59.09
Road.cut.69	2.46	2.43	0.19	15.53	6.26	81.51

Table 3.31 Shaded biophysical property performance ranges averages at research sites

Name	Plant Cover	Electrical Conductivity	Sodium Adsorption Ratio	Cation Exchange Capacity	Penetration Resistance	Sieve Percent
Staging.area.2	Below	Optimal	Optimal	Optimal	Optimal	Optimal
Ski.hill.8	Above	Optimal	Optimal	Optimal	Above	Above
Water.line.18	Below	Optimal	Optimal	Optimal	Optimal	Above
Water.line.19	Below	Optimal	Optimal	Optimal	Optimal	Above
Water.line.20	Below	Optimal	Optimal	Optimal	Optimal	Optimal
Water.line.22	Below	Optimal	Optimal	Optimal	Optimal	Optimal
Water.line.23	Below	Optimal	Optimal	Optimal	Optimal	Optimal
Water.line.25	Below	Optimal	Optimal	Optimal	Optimal	Optimal
Waste.pit.28	Below	Optimal	Optimal	Optimal	Above	Optimal
Pipe.valve.31	Below	Optimal	Optimal	Optimal	Optimal	Optimal
Access.route.33	Below	Optimal	Optimal	Optimal	Optimal	Above
Access.route.34	Optimal	Optimal	Optimal	Optimal	Optimal	Below
Pipe.pullout.35	Optimal	Optimal	Optimal	Optimal	Optimal	Optimal
Staging.area.37	Below	Optimal	Optimal	Optimal	Optimal	Optimal
Pipe.valve.39	Below	Optimal	Optimal	Optimal	Optimal	Above
Pipe.route.40	Above	Optimal	Optimal	Optimal	Optimal	Optimal
Staging.area.41	Below	Optimal	Optimal	Optimal	Optimal	Above
Pipe.route.42	Below	Optimal	Optimal	Optimal	Optimal	Optimal
Pipe.valve.44	Above	Optimal	Optimal	Optimal	Optimal	Optimal
Pipe.pullout.45	Above	Optimal	Optimal	Optimal	Optimal	Optimal
Waste.pit.51	Below	Optimal	Optimal	Optimal	Above	Above
Walking.path.56	Below	Optimal	Optimal	Optimal	Optimal	Optimal
Road.cut.69	Below	Optimal	Optimal	Optimal	Above	Above

Legend: Above Optimal Below

4.0 RECOMMENDATIONS FOR LAND RECLAMATION IN JASPER NATIONAL PARK

4.1.0 Research Background

Jasper National Park, like many other protected areas, has numerous disturbances requiring reclamation and evaluation to improve future actions. An advantage for leaseholders in Jasper National Park is the Best Available Methods Manual for Common Leaseholder Activities because it is a set of standard practices for disturbance and reclamation planning intended to achieve a recognizable and lawful goal. These practices have been in use for about ten years and a record of activities for each project has been collected into a single accessible database.

Using scientifically based management strategies, the goal in Jasper National Park is to reclaim native habitat in montane and subalpine natural subregions. Supporting this is the requisite practice of revegetating with native species that can develop enough cover to effectively conserve what soil is put back in place after a disturbance. Alternatively, and depending on the site, there is another goal of restoration which primarily is defined by the likelihood of recurring disturbance. Restoration extends land reclamation practices with attention given to achieving sustainable plant communities which need little human intervention once established.

Determining if these goals are reached takes systematic assessments of sites to find where inappropriate plant communities are developing because of unsupportive soil conditions and/or over abundant non-native species. Site biophysical data should reveal these details so that informed management actions can be taken in a short time period to ameliorate ineffective reclamation conditions or to restrain further interventions as positive conditions are developing. Setting reclamation objectives, designing mitigation prescriptions, and determining at what point intervention or cessation of management is acceptable are a land manager’s responsibility and plant and soil biophysical data should inform each stage accurately and economically.

4.1.1 Research Scope

In Jasper National Park and other protected areas, assessment methods should be practical, reproducible, adaptable and inexpensive yet ecologically relevant for evaluating land reclamation. Although benchmarks for monitoring timing, frequency and plant cover criteria are presented in the Best Available Methods Manual there is limited guidance on how to conduct pre disturbance or post disturbance monitoring. This may explain a paucity of data collection over the last ten years relating to soil profile condition and plant community structure prior to disturbances. Following suggestions in the manual, ocular and photographic methods of data collection were adapted for use in Jasper National Park in this research project. Factors expected to influence the design of an assessment method would be assessor training and scientific skills, assessment costs, disturbance types and ecological variability.

4.1.2 Research Approach

General factors affecting plant and soil development are frequency of disturbance, type of disturbance and inherited ecological characteristics. On each reclamation site, revegetation and soil conservation needed to be assessed to determine if and how successfully sites had recovered from land disturbances. A representative group of routine land disturbances in early stages of development to evaluate leaseholder operational reclamation practices needed to be selected. A list of biophysical properties to assess and evaluate plant abundance and soil property relationships needed to be developed. Collected data needed to be analyzed and analytical methods determined. These data needed to be examined at two scales; the plot, as individual representatives, and the site, as a potentially sustainable yet variable plant community with supportive soil properties. The link between plant and soil aspects of a disturbed and then reclaimed ecosystem needed to be quantified, displayed, manipulated and interpreted.

To meet these requirements, the objective of this research was to investigate relationships between plant abundance and soil properties and in doing so attempt to develop methods for a complete cycle of reclamation evaluation. This work required numerous steps and specific objectives have been described in preceding chapters. In the end biophysical soil and vegetation data were collected from 23 research sites with a site stratification protocol and biophysical property data collection method which is flexible, repeatable and economical. Biophysical properties with ecological and reclamation relevance were selected and effectively used to illuminate the relationships between plant abundance and soil properties.

4.2.0 Reflections On Research Process

4.2.1 Site selection

Selecting a representative group of routine land disturbances to evaluate leaseholder operational reclamation practices was challenging since impacts ranged widely and number of disturbances and ecological settings were extensive. Fortunately, records of disturbances existed as did a comprehensive ecological inventory and classification. An obstacle for statistical analysis became apparent though when looking at the types of data available from these sources. Historical information was useful but the final list of research sites could not have been determined without walking the land, this proved the most helpful in deciding which sites should be selected because what was observed in plant response and soil conditions.

4.2.2 Stratification and Transects

Walking the land helped develop a site stratification protocol and biophysical property sampling method. Routine land disturbances were either linear or box like in most cases so establishing stratified transects and random plot locations was rapidly achieved by compass and measuring tape. The method developed could accommodate distances from a few meters to over 100 m but not on slopes more than 45 ^{o}. Developing this protocol proved a challenge because few sources presented methods directly applicable to evaluating land reclamation. The test, like that for any new scheme, was twofold, field testing and adoption by assessors. Some field methods for measuring variability on the ground were successful and others were not. Assistants for data collecting needed to complete their assessments under the constraints of time, hence reliance on simple tools, knowledge of principles and clear objectives were most effective for designing a site layout plan. This method can be scaled up to more than half a dozen workers or down to single worker and can focus intently down to one site or broadly capture variability on 23 sites.

4.2.3 Biophysical Property Selection

Development of a list of biophysical parameters to assess and evaluate plant abundance and soil property relationships was challenging. Plant community structures were relatively simplified since size classes greater than small shrubs did not generally occur on reclamation sites. Future assessments, once larger woody species occupy a site, can be accommodated with larger plot sizes than were used in this study. The transect and stratified random sampling methods used can accommodate such modifications. Although the plant biophysical properties selected are best suited to assessing grass, forb and shrub layers, nonvascular plants or other ground cover can be investigated. Of all properties attempted, basal cover, canopy cover, leaf litter and species identification provided necessary information to make an analysis.

Soil chemical and physical properties were obviously not as visually assessable as plant properties, this information is almost certainly only attainable by laboratory analysis. The results suggest a set of physical and chemical properties mostly related to texture and macronutrients greatly influence plant abundance. Soil fertility measures and some key properties, as identified in the literature like pH, did not influence plant abundance as might have been expected. Initially it was expected that soil properties affecting plant abundance may be narrowed down to 2 to 3 variables. This expectation was not supported by the results which clearly indicate complex relationships occurring in the rooting zone. Unlike plant properties soil properties are less influenced by the amount of area sampled though statistical analysis demonstrated a requirement of between 10 and 15 plots for clear resolution of any relationships.

4.2.4 Historical Records and Ecological Classification

Records on the disturbances show a process that is lengthy and complex, separating reclamation practices as experimental treatments in a blocked and testable design is not possible without quantitative data from prior to the disturbance and immediately afterward. This data at best can be expressed in a binary form that may be analyzable where plant and soil property data are downgraded to an equivalent level. Existing ecosite classifications were not appropriate reference conditions as these sites are often in middle to late stages of succession which should not be compared with the early successional stages of reclaimed sites. With time these sites may be comparable to those classified in previous work which would provide another avenue of determining reclamation effectiveness. Even though limitations existed, this information was useful for understanding the ecological and technical contexts differentiating candidate sites across the landscape.

4.2.5 Defining Reclamation Effectiveness

Not being able to use these historical or classification reference points to define or determine what makes reclamation effective meant reference points from a management framework of concepts about what plant and soil characteristics represent ecological integrity had to be used instead. Thresholds for soil properties influencing plant growth and identification of plant species for targeted management provided useful and relevant sets of criteria for evaluating reclamation effectiveness. At present there are no thresholds that are directly based on biophysical properties in Jasper. With this monitoring data and additional data in future years the development of reclamation criteria specific to Jasper is possible and likely a reasonable idea given the uniqueness of sites found here and how they differ from agricultural lands.

4.2.6 Plant Species Composition

Plant species composition is of major importance in identifying sites with problems from those with fewer problems. The canopy and leaf litter cover classes and criteria for success listed in the best available methods manual were integral measures and indicators of revegetation success. However, species identification was a key element for interpreting the live plant community type developing on reclaimed sites. Presence of non-native species has a large impact on ecological integrity and is important in identifying reclamation trajectories that need immediate management. Although plant communities are complex simple measures proved satisfactory in developing detailed understanding of ecosystem development a few years after reclamation.

4.2.7 Photographic Methods

A protocol was designed for photographing sites for the context and for individual plots. After field testing the protocol it was apparent the plot photos are not feasible means of recording biophysical data relating to plant cover and composition. Informally, pictures served a purpose for individual plots but the conditions for taking quality photographs were too limited to support a formal process. The capacity of human eyes to sense subtle changes in vegetation cover, colour, density, etc. exceeds a camera and can operate under a wider range of lighting conditions. The ocular method of estimation is superior means of assessing plant cover. Context photographs remain a useful tool to record site change with time and are especially effective when communicating concepts or ideas about site conditions to an audience that may not be familiar with a site except on paper. Context photos are supported by the transect method already described and requires only modest equipment to capture this information.

4.2.8 Ground Cover Classes

The field method for assessing vegetation and ground cover estimated more classes than just basal, litter and canopy but much of this information, about rock, scat, burrows, garbage and woody debris, is not influential in analysis as values did not amount to that of the three primary classes. This information can be recorded descriptively just as root density and depth is while taking soil samples, and serves to inform about conditions surrounding a sample or estimate.

Differentiation of basal from canopy cover is crucial because plant species forms vary and graminoids are not always the dominant cover, or are potentially very small at higher elevation but in both cases soil conservation is achieved by plant parts to intercept rainfall. Though not explicit in the Best Available Methods Manual, the wording is such that the definition of passable ground cover of 80 % is biased in favour of graminoids, which is maybe a more accurate reflection of the times and techniques in reclamation when this criteria was developed. Community structure analysis is possible with this level of division of data and could have important ecological implications for understanding that effective reclamation can be achieved in many ways besides the standard of grasses, forbs, and shrubs with the cover they provide. A greater benefit may be to promote the assessor to develop a pair of ecologically tuned eyes that see more facets of ground cover as cumulative and integrative where revegetation to achieve soil conservation is concerned.

Ground cover that is applied by human actions, specifically placing woody debris, erosion matting, or compost are beneficial practices for rebuilding a soil matrix keeping what salvage is replaced in situ and creating microsites to harbor initial seedlings. The two former types are relatively benign in terms of being a source for non-native propagules and the latter does pose a dilemma. Where there is not a top cover to properly be called a soil matrix some substrate is likely better than none. Longevity of all these amendments of this group of sites suggests there is positive long term effects associated with the practices as these may moderate coarse physical soil conditions. If monitoring is pursued then non-native plant species may be managed before a situation develops and sites have a proper rooting zone for native species to establish. Observation of these sites supports use of a top dressing and treatment effects could be experimentally studied with this monitoring protocol.

4.3.0 Recommendations To Jasper National Park Leaseholders

With the intent of re-writing and updating the Best Available Methods for Routine Disturbances, the Jasper Leaseholders Working Group can add information and methods regarding monitoring for biophysical information based on this research. Components could include some or all of the eight soil properties, live plant basal and canopy cover, litter (mulch) cover, species identification and density classification. Although transects establishment depends on the site, this method of locating a central point and extending four transects along major axis is crucial. While the process helps take in site variability by a repeatable order of steps it does not prevent randomization for gathering information along transects.

Land disturbance may not be the only reason for employing these practices so on some sites it may be necessary to distinguish a goal of restoration from one of reclamation. This is important as they are not the same and where frequent and recurring disturbances are expected only reclamation is feasible; restoration depends on longer intervals and perhaps smaller scales of human related disturbances. For instance, a site such as a deactivated trade waste pit is the ideal candidate for restoration whereas a buried fiber optic cable expected to be upgraded on the foreseeable future is better suited for planned reclamation. The difference is not in desired species composition or soil conservation goals but in monitoring for sustainability and planning for another disturbance, possibly in the foreseeable future.

There is a disturbance periodicity associated with different disturbances, thus monitoring vegetation establishment and development should occur at a rate relevant and specific to the frequency and level of disruption at a given location. Previous monitoring results should inform the rate of monitoring and are pivotal in determining when to stop monitoring because a site is successfully reclaimed. There is a Parks Canada Agency requirement for reporting on ecological monitoring at cycles of two and five years to communicate the state of ecological integrity within a park. As a guideline, disturbance intensity and its public visibility should govern how often a site is visited. The more intensive the disturbance, or visible the site, the more intensive monitoring should be to ensure plant establishment is occurring because of how this will affect visitor experience and because fragmentation may be more prevalent than in back country settings. These visible sites may be more accessible and see higher traffic that is linked to supporting non-native species. The total number of visits should not be set since there is no empirical base to determine where, when and how much a disturbance modifies site characteristics such that we need to monitor it so many times before feeling confident the plant community and soil condition are suitably rehabilitated.

The present state of database information should act as a guideline for prioritizing data gathering efforts. In the Best Available Methods manual there are eight ecosections described for ecology and implications for reclamation, which is an easily communicable message for land managers and the public alike. Two new ecosections entries are needed, Egypt and Cavell were investigated in the subalpine. Of the eight already described only Talbot and Fireside were not investigated during this research project. Table A.1 gives total numbers of plots sampled for each ecosite and in considering the evenness of these totals, they can guide how much emphasis is placed on projects where less information is yet to be gathered.

The cost of monitoring has been presented as an obstacle in reclamation planning, coupled with the need for effective understanding of the impacts disturbance poses, is a unique problem. This problem puts emphasis on leveraging data, especially soil property data which has a demonstrable monetary investment. Statistically the present information can be broadened where known values are taken as boundaries and by random permutation new data are generated for biophysical parameters. This new permutated data is not directly linked to points on the land but they can broaden the scientific base for better reclamation. It is not known how much soil property data are needed, hence a statistical method with error terms indicating how much closer new information advances that particular understanding empirically is used here.

Monitoring and evaluation methods from this research should be used before attempting a re-write the manual; these practices may change how they are applied and where, not whether they are applied. The lack of pre or post disturbance data cannot be underestimated in evaluating impacts of disturbances and the success of reclamation. Very little continuous data were available prior to this project; hence these practices may only change in where they are applied not in how they are applied. In a few instances the site history or local climatic regime appears to not support better performance. Waste pit 51 and Staging area 41 are instances where a history of domesticated livestock pens and a windy dry reach translocating amendment are extenuating circumstances; at least these details are convenient to those sites only.

Scientifically, next steps are testing how plant communities are developing with varying levels of these influential soil properties. Several plant community indicators are presented that easily communicate the status of sites disturbed by human activity; these should be maintained and tracked over time. Water availability should have some influence based on the results and future study of its role in the plant abundance and soil property relationship needs examination in montane and subalpine, each having very different precipitation regimes. Along with this relating climate in a given growing season might be considered.

The effect of climate on transplants was evident on some sites where small trees did not survive a period of drought, this age class was also affected in undisturbed ground so random chance may have been more than any particular practice associated with transplanting small trees on some project sites in the montane.

4.3.1 Conclusion

Evaluation of site revegetation and soil conservation to determine if and how successfully sites have recovered from land disturbances was necessary. The leaseholder activities focused on plant cover removal, soil profile disruption and revegetation conventionally classed as brushing, excavation, seeding and amendments. The selection process arrived at representative sites as the site descriptors reveal. Site status was not so easily determined, even with criteria to differentiate. Persistence in statistical analyses and graphical outlays showed numerically which sites were successful and which were not and reasons for this status. The information was presented in as clear, concise and understandable a format as possible.

Ecological monitoring builds a basis for evaluating planned disturbances, in as much as what results from reclamation resembles what existed before disturbance, or is acceptable to Parks Canada Agency where high disturbance return periods are likely. Construction, abandonment and rehabilitation practices have changed within the park. As there is scarce historical knowledge about pre disturbance conditions, factors of a disturbance and effects of reclamation practices, there is a lack of understanding and a limitation regarding present levels of recovery on disturbed sites. The extent to which reclamation can be evaluated is limited by amount, type and qualities of project specific information available.

These objectives were always under scrutiny for a better version to explain why it was important to collect specific data and how to use it analytically. In the end, there were several achievements including a monitoring protocol scalable to disturbance type and size that assesses plant community and soil development with a good degree of accuracy and precision; two concise lists of biophysical parameters for plant and soil properties with which to monitor and evaluate land disturbances and land reclamation; quantitative methods ranging from advanced to basic for evaluating and ranking a group of disparate sites according to performance of key plant community indicators. A ranking of sites by plant properties that indicates varying degrees of effective reclamation have occurred as a result of utilizing standard practices. An important practice to recommend is implementation of monitoring prior to and after planned disturbances so that biophyscial information can support greater understanding of changes due to human activities in critical areas of development in the park.

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APPENDIX A

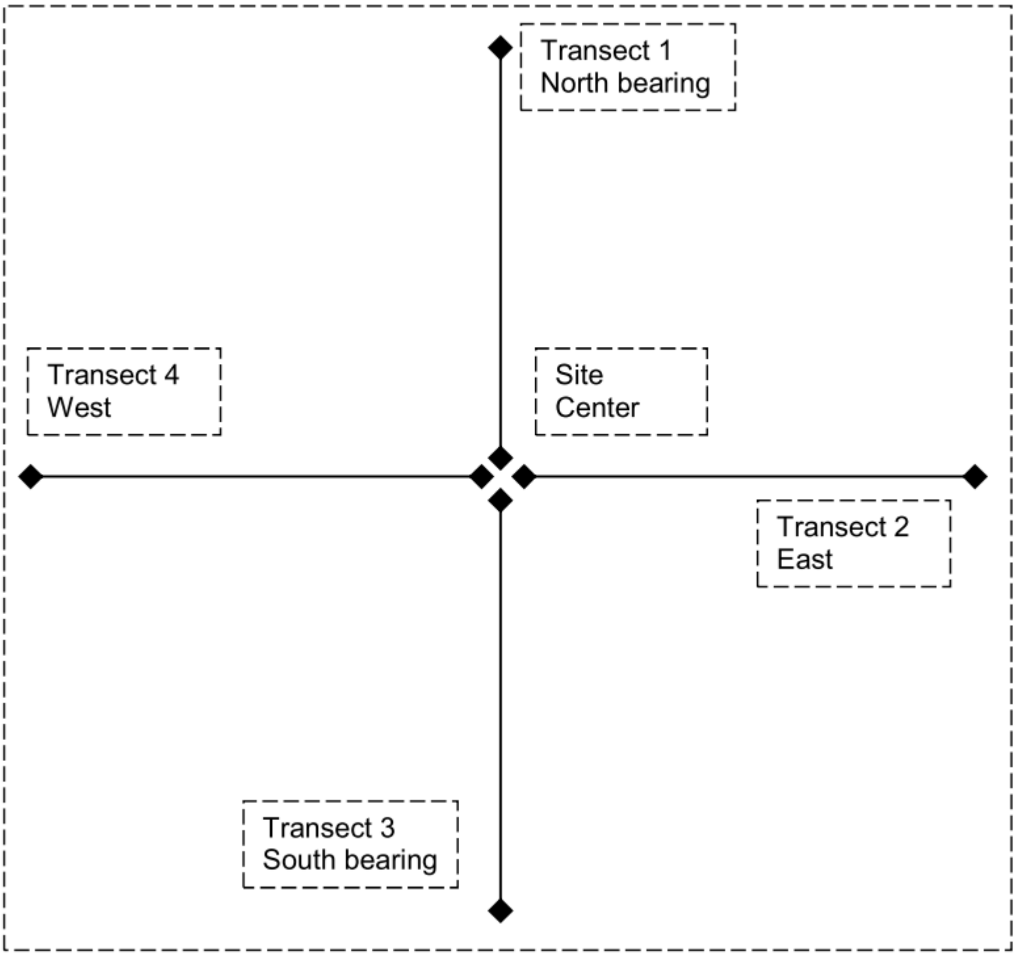


Figure A.1 Site transect set up (iron cross)

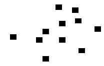
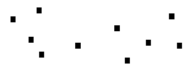
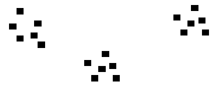
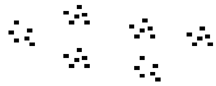
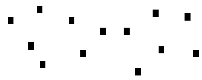
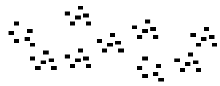
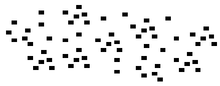
Class	Density Distribution	General Quadrat
1	Rare individual, single occurrence	
2	Few sporadically occurring individuals	
3	A single patch or clump of species	
4	Several sporadically occurring individuals	
5	A few patches or clumps of a species	
6	Several well spaced patches or clumps	
7	Continuous uniform occurrence of well spaced individuals	
8	Continuous occurrence of a species with few gaps	
9	Continuous dense occurrence of a species	

Figure A.2 Plant density classification rubric used by Parks Canada Agency (Westhaver personal communication. May 2009)

Equation A.1 Cone penetrometer conversion calculation

- Dial readings are in pound force per square inch (psi).
- Converting dial readings from psi to cone index (CI) values, reported as MPa, requires an adjustment of cone basal area if a cone used to collect field data differs in basal diameter from the calibration cone.
- Typically a smaller cone is used in uncultivated soils having a smaller diameter (11 mm).
- The adjustment accounts for how dial readings are affected when uncultivated soils resist penetration more so than cultivated soils and necessitates using a smaller cone.
- The adjustment is a ratio of large cone basal area relative to small cone basal area where large basal area is the numerator and small basal area is the denominator.
- Equation: Large cone area ÷ small cone area → (A*0.00155 in^2) ÷ (A*0.00155 in^2).
- In the above equation, cone area is given by $A = \pi r^2$ and converted to square inches when area in mm^2 is multiplied by 0.00155 in^2 / 1 mm^2, the metric units cancel.
- Radius (r) is the quotient of basal diameter divided by 2.
- Example: Large cone basal area = π(21 mm / 2)2 = 346.36 mm^2 * 0.00155 in^2 / 1 mm^2 = 0.532 in^2.
- Example: Small cone basal area = π(11 mm / 2)2 = 95.03317 mm^2 * 0.00155 in^2 / 1 mm^2 = 0.1473 $in^{2.}$
- Units cancel and the ratio (quotient) of large cone area to small cone area is 0.532 in2 ÷ 0.1473 in^2 = 3.612.
- An expanded equation to convert dial reading to cone index (CI) in MPa is as follows: dial value (psi)*((πr^2*0.00155 in^2)/(πr^2*0.00155 in^2))*6.895 kPa/psi*0.001 MPa/kPa = CI (MPa).
- For example a dial reading of 150 psi is converted to CI reported in MPa:
- 150 psi*(0.532 in^2/ 0.1432 in^2)*6.895 kPa/psi*0.001 MPa/kPa = 3.842 MPa.
- The interpretation of this value is that because it is > 2 MPa root penetration is restricted but this depends on the plant species in question.

Equation A.2 Hellinger distance transformation (Legendre and Gallager 2001)

$$D_{Hellinger}(x_1, x_2) = \sqrt{\sum_{j=1}^{p}\left[\sqrt{\frac{y_{1j}}{y_{1+}}} - \sqrt{\frac{y_{2j}}{y_{2+}}}\right]^2}$$

Equation A.3 Sum of squares about the group means (Blanchet 2009)

$$\sum_{k=1}^{\text{group}}\sum_{i=1}^{n_k}\left(y_i - \bar{y}_k\right)^2$$

Equation A.4 Area weighted average

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i},$$

Equation A.5 Sum of area weights for sample variance

$$V_1 = \sum_{i=1}^{n} w_i$$

Equation A.6 Sum of squared area weights for sample variance

$$V_2 = \sum_{i=1}^{n} w_i^2$$

Equation A.7 Sample variance of area weighted average

$$s^2 = \frac{V_1}{V_1^2 - V_2}\sum_{i=1}^{N} w_i \left(x_i - \mu^*\right)^2,$$

Source: Wikimedia Foundation, Inc. 2011.
http://en.wikipedia.org/wiki/Weighted_mean Last accessed June 15, 2011

Table A.1Sampling intensity for ecosites in Jasper National Park

Ecosite	Number of plots
Egypt 1	42
Egypt 4	40
Athabasca 1	37
Vermillion Lakes 1	37
Vermillion Lakes 3	37
Norquay 3	20
Vermillion Lakes 4	20
Vermillion Lakes 5	20
Hillsdale 1	16
Devona 2	9
Patricia 5	8
Cavell 1	6

APPENDIX B

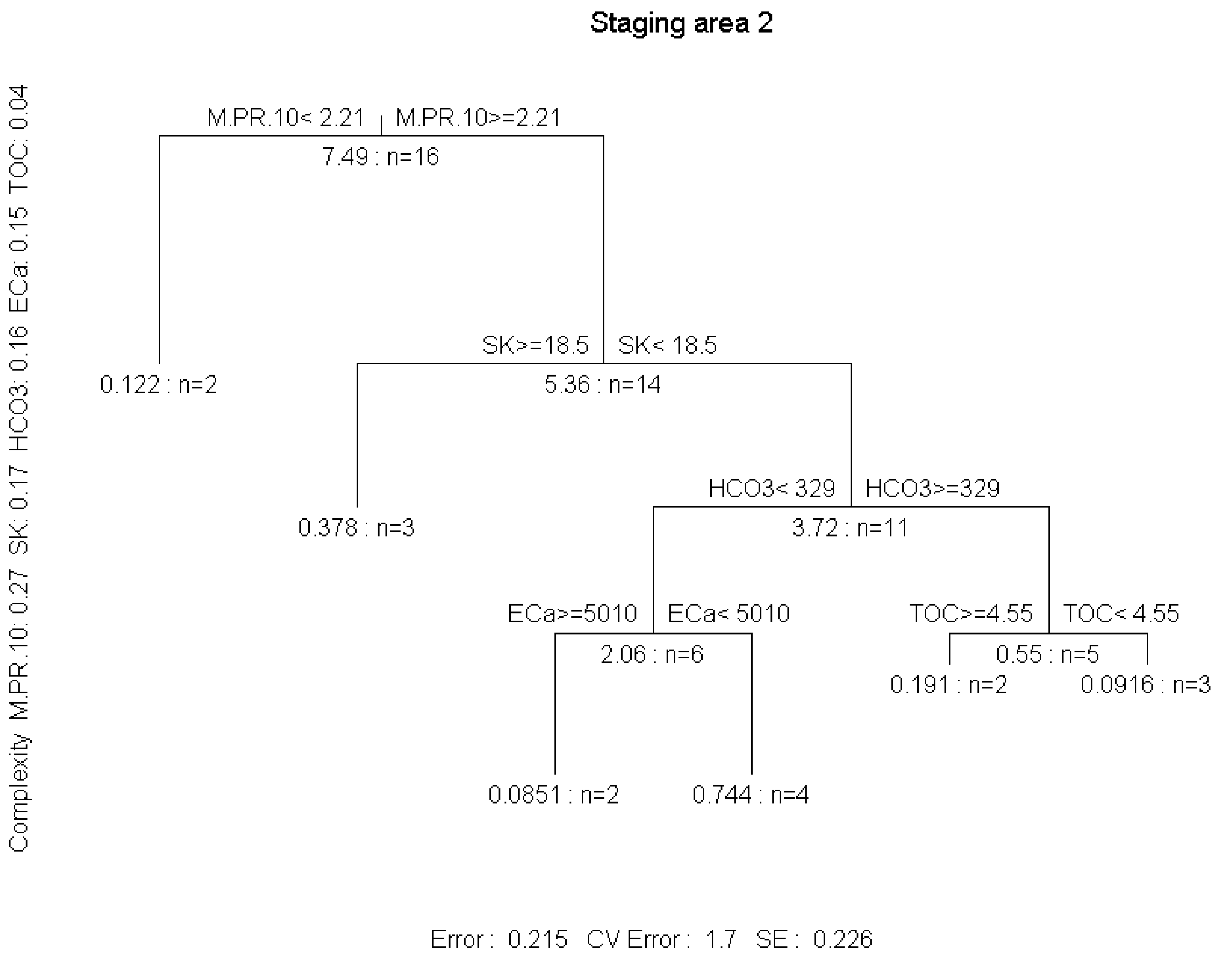


Figure B.1 Regression tree for Staging area 2 on Athabasca River bank armouring project

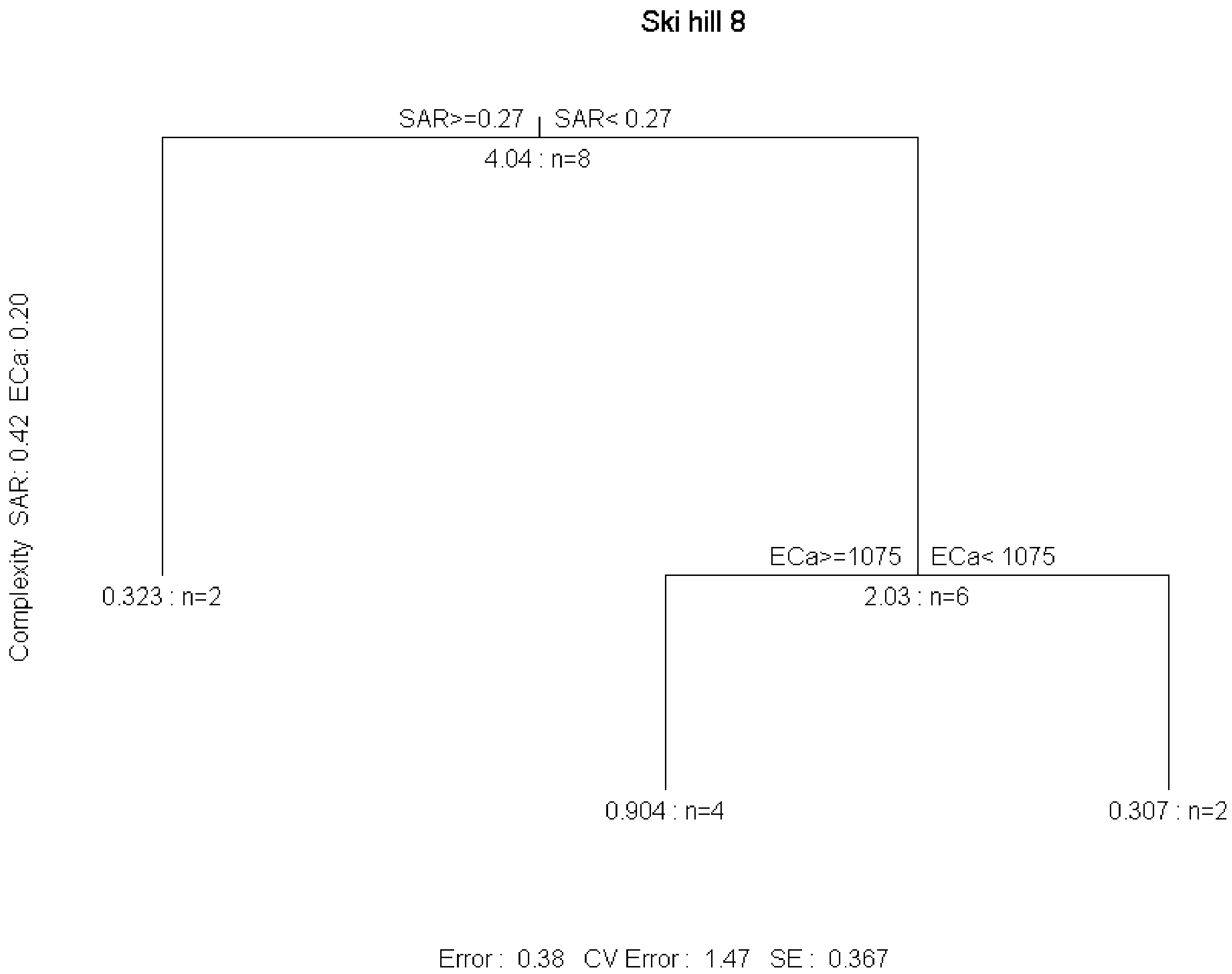


Figure B.2 Regression tree for Ski hill 8 removal of built structures

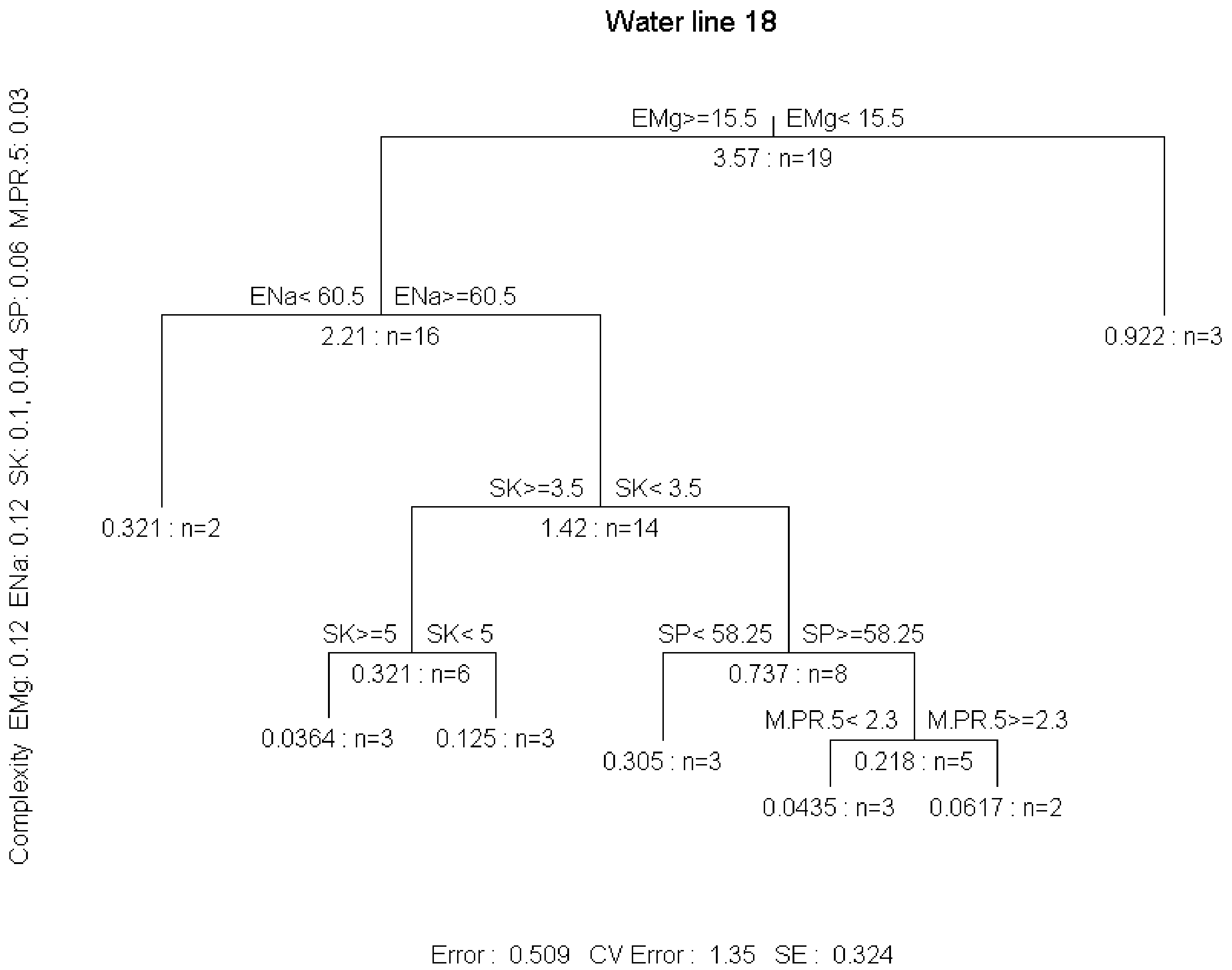


Figure B.3 Regression tree for Water line 18 (site 6) at Marmot Basin ski area

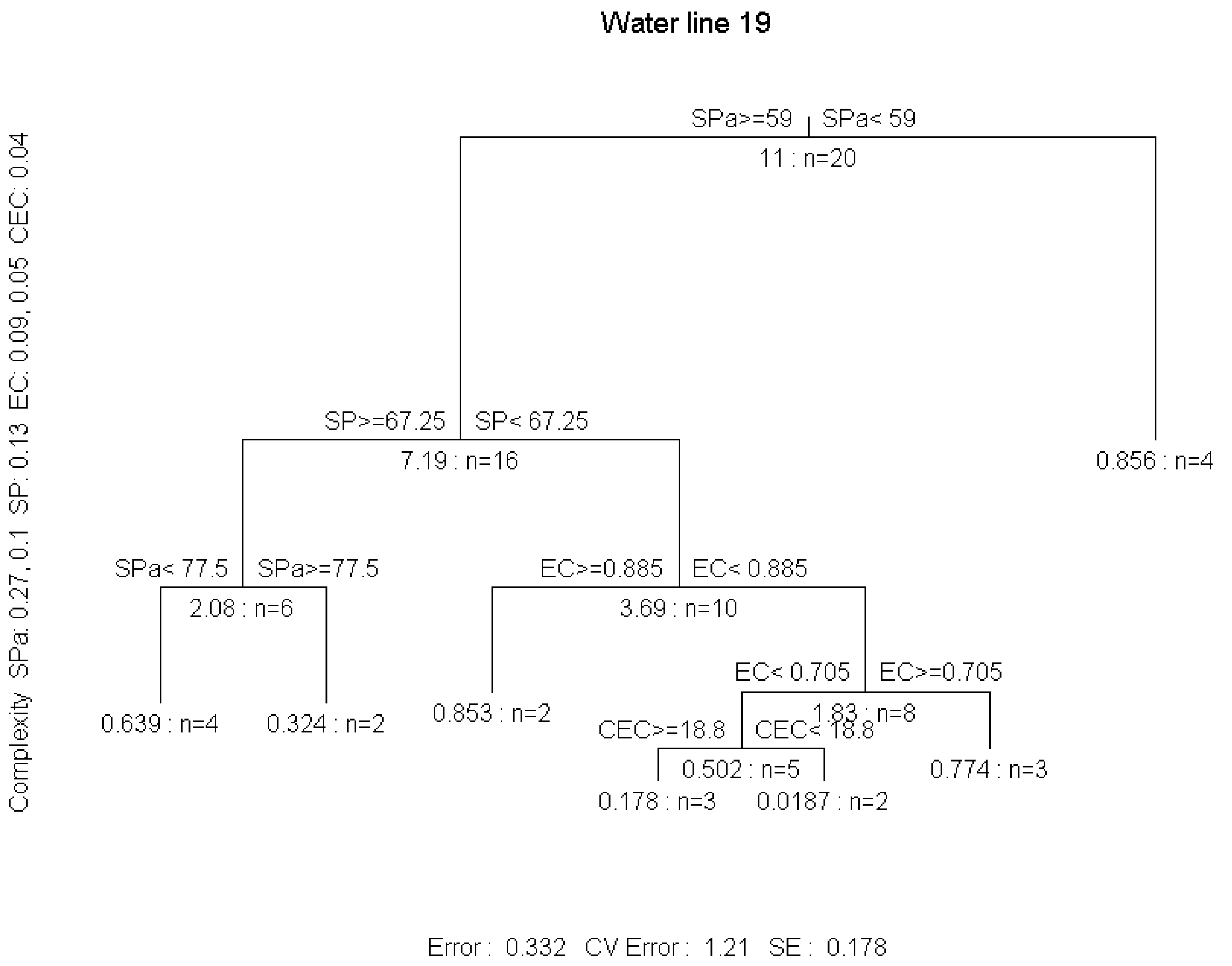


Figure B.4 Regression tree for Water line 19 (site 7) at Marmot Basin ski area

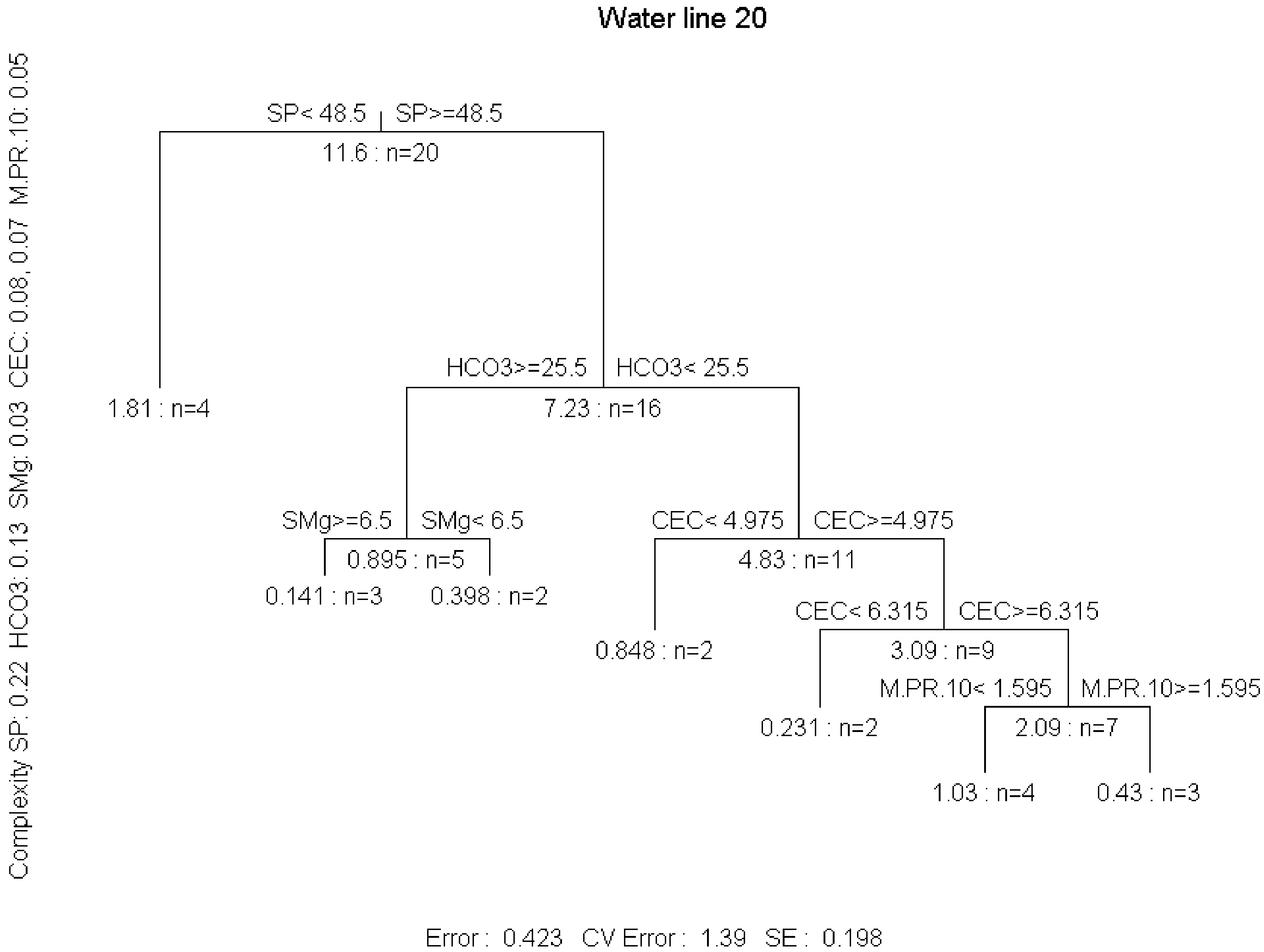


Figure B.5 Regression tree for Water line 20 (site 8) at Marmot Basin ski area

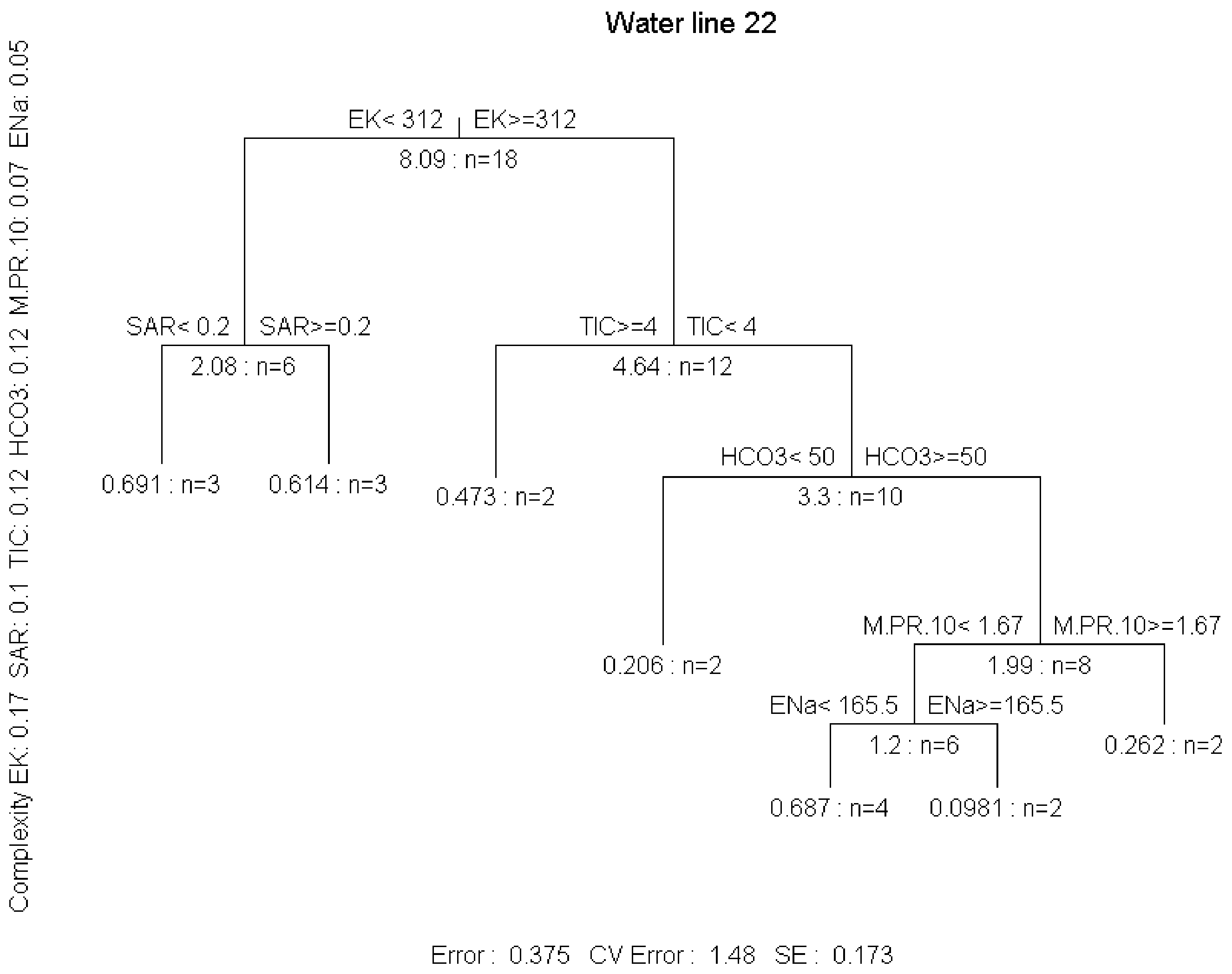


Figure B.6 Regression tree for Water line 22 (site 10) at Marmot Basin ski area

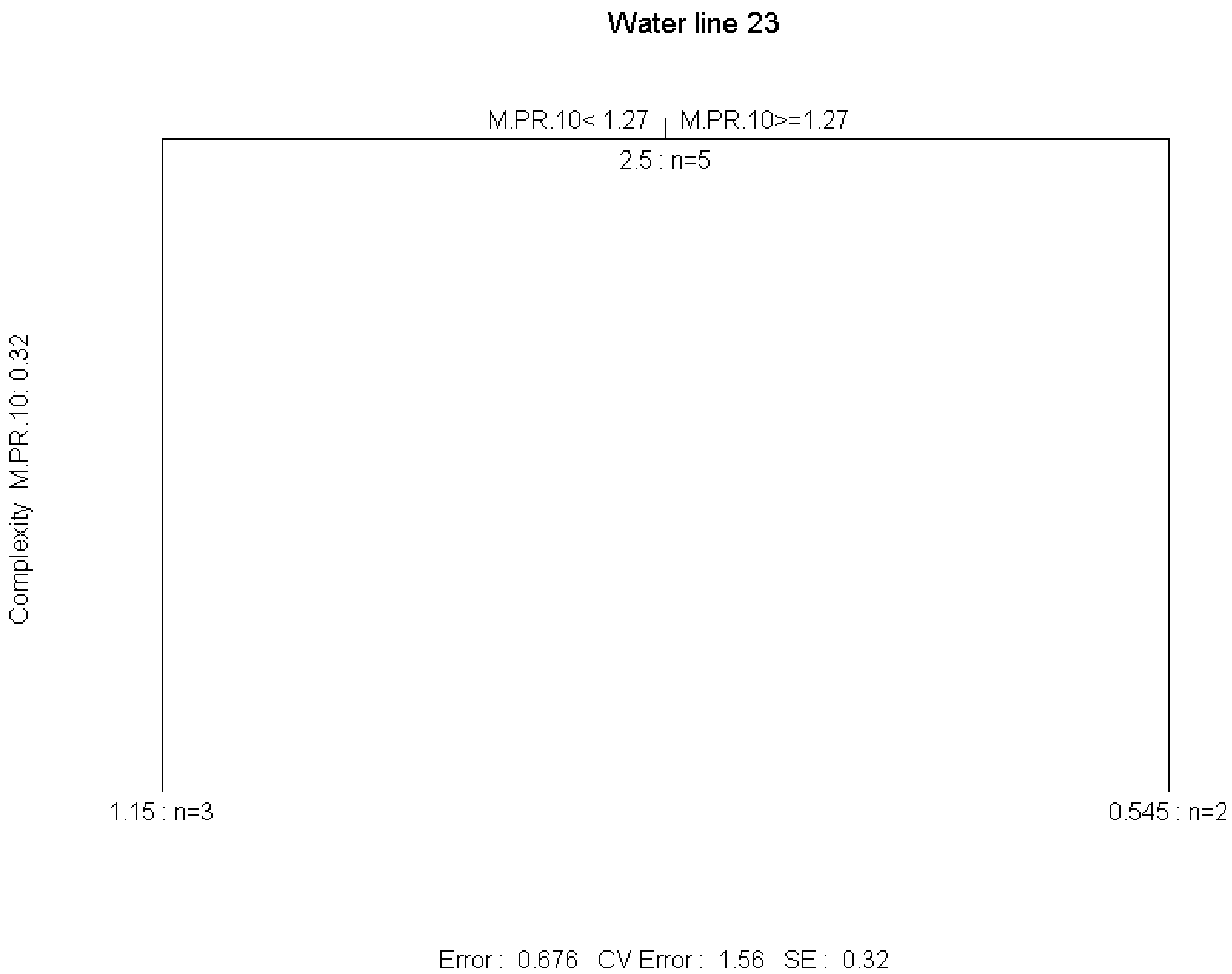


Figure B.7 Regression tree for Water line 23 (site 11) at Marmot Basin ski area

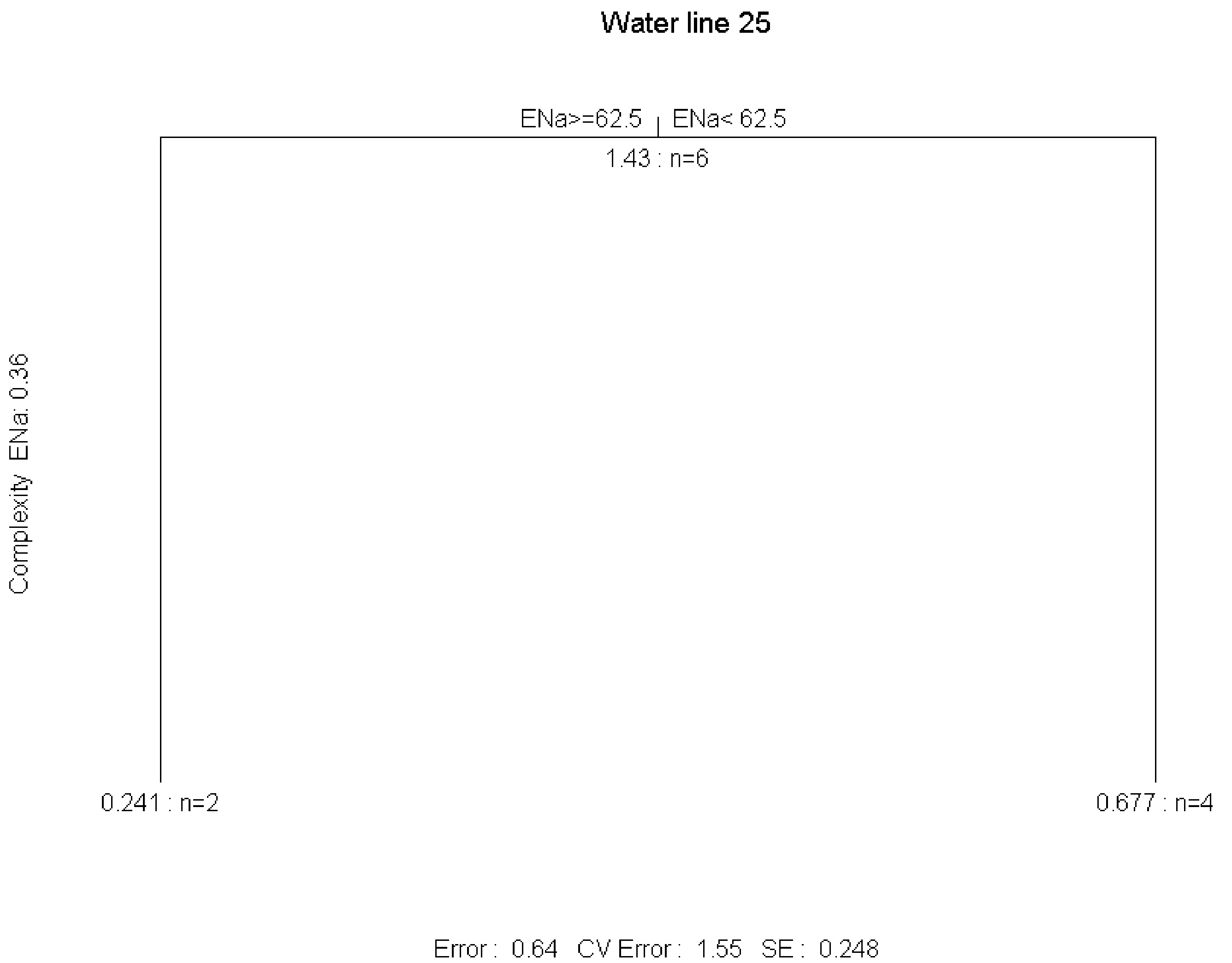


Figure B.8 Regression trees for Water line 25 (site 13) at Marmot Basin ski area

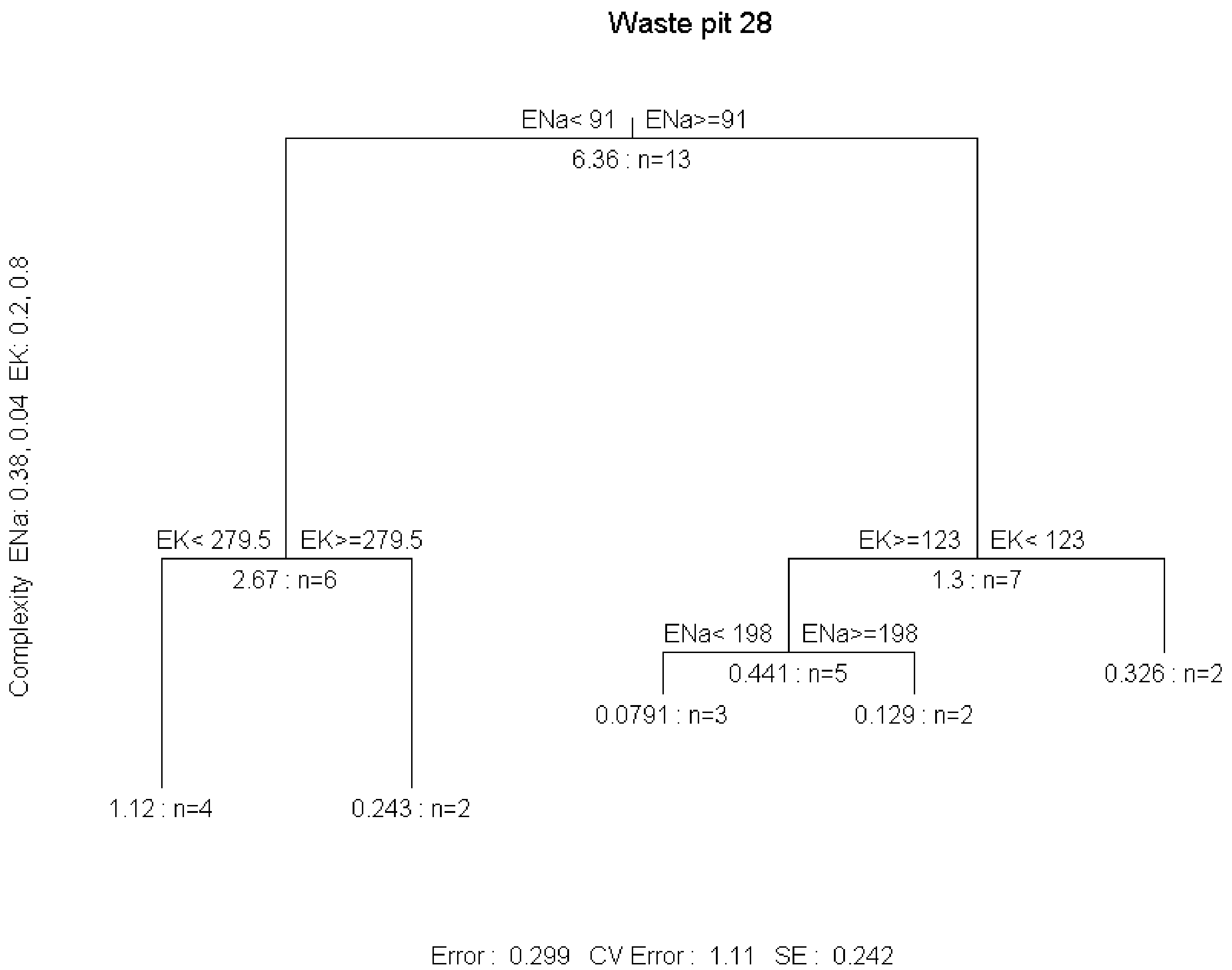


Figure B.9 Regression tree for Waste pit 28 at Jasper Park Lodge landfill

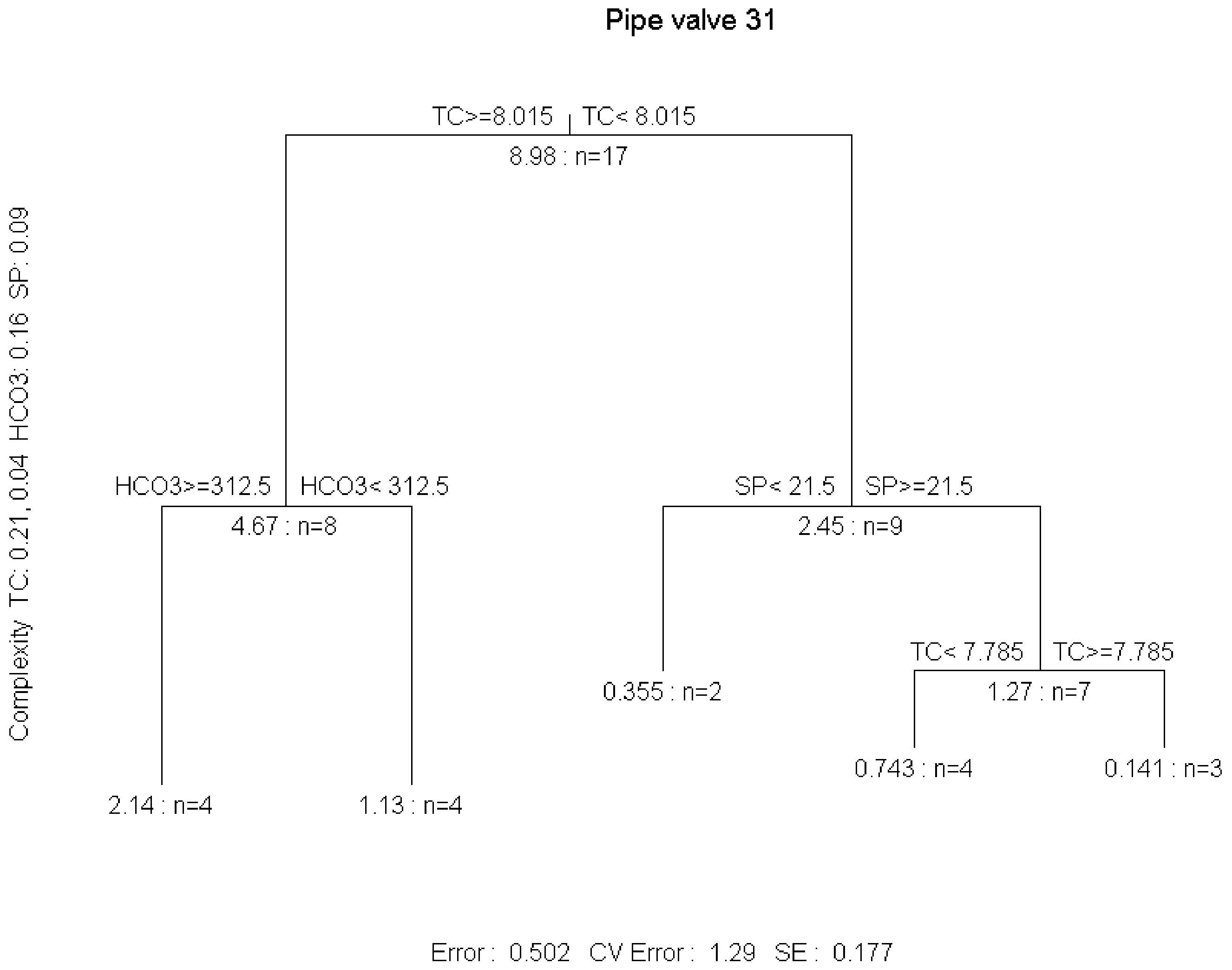


Figure B.10 Regression tree for Pipe valve 31 on Jasper Lake dunes pipeline relocation

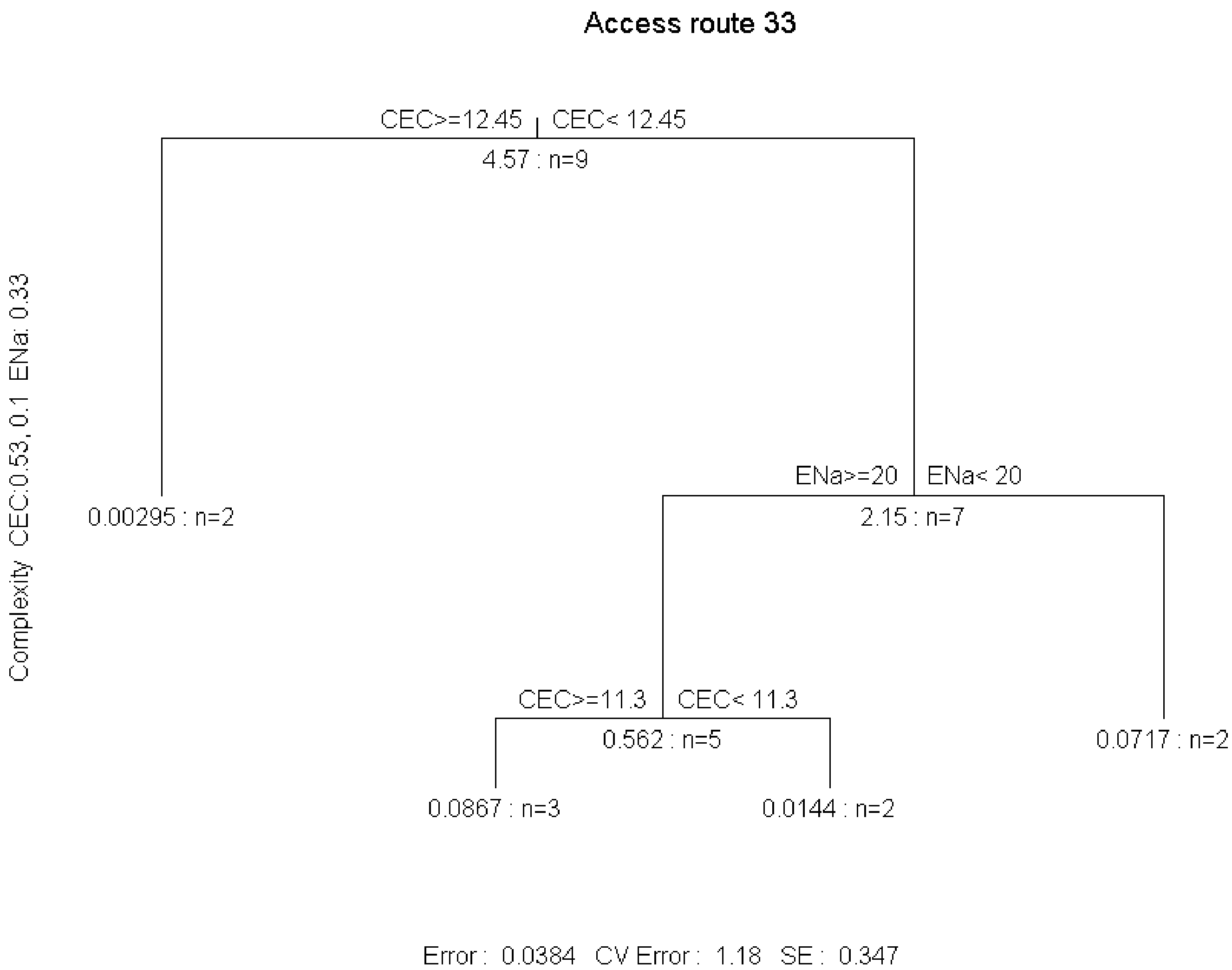


Figure B.11 Regression tree for Access route 33 on Jasper Lake dunes pipeline relocation

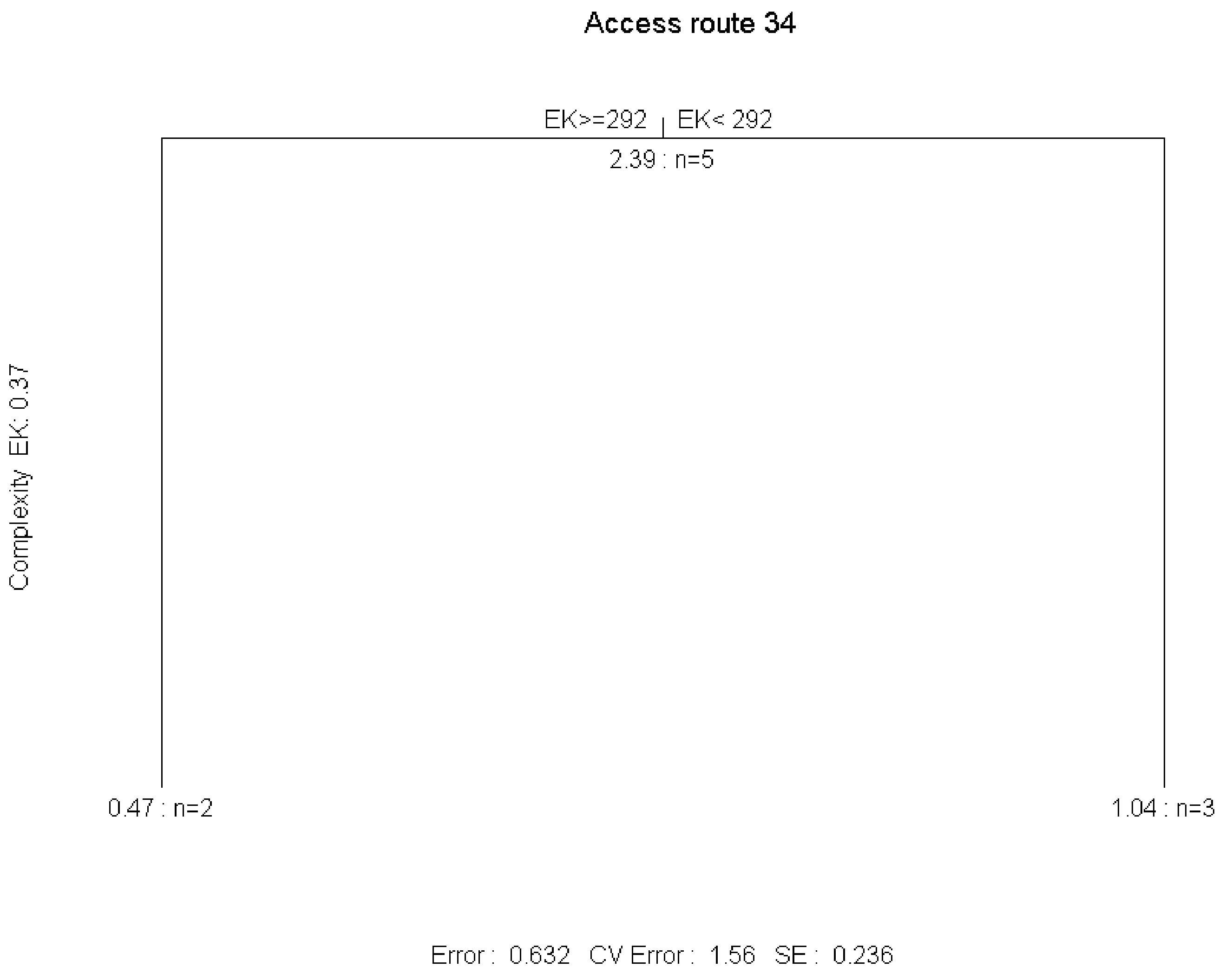


Figure B.12 Regression tree for Access route 34 on Jasper Lake dunes pipeline relocation

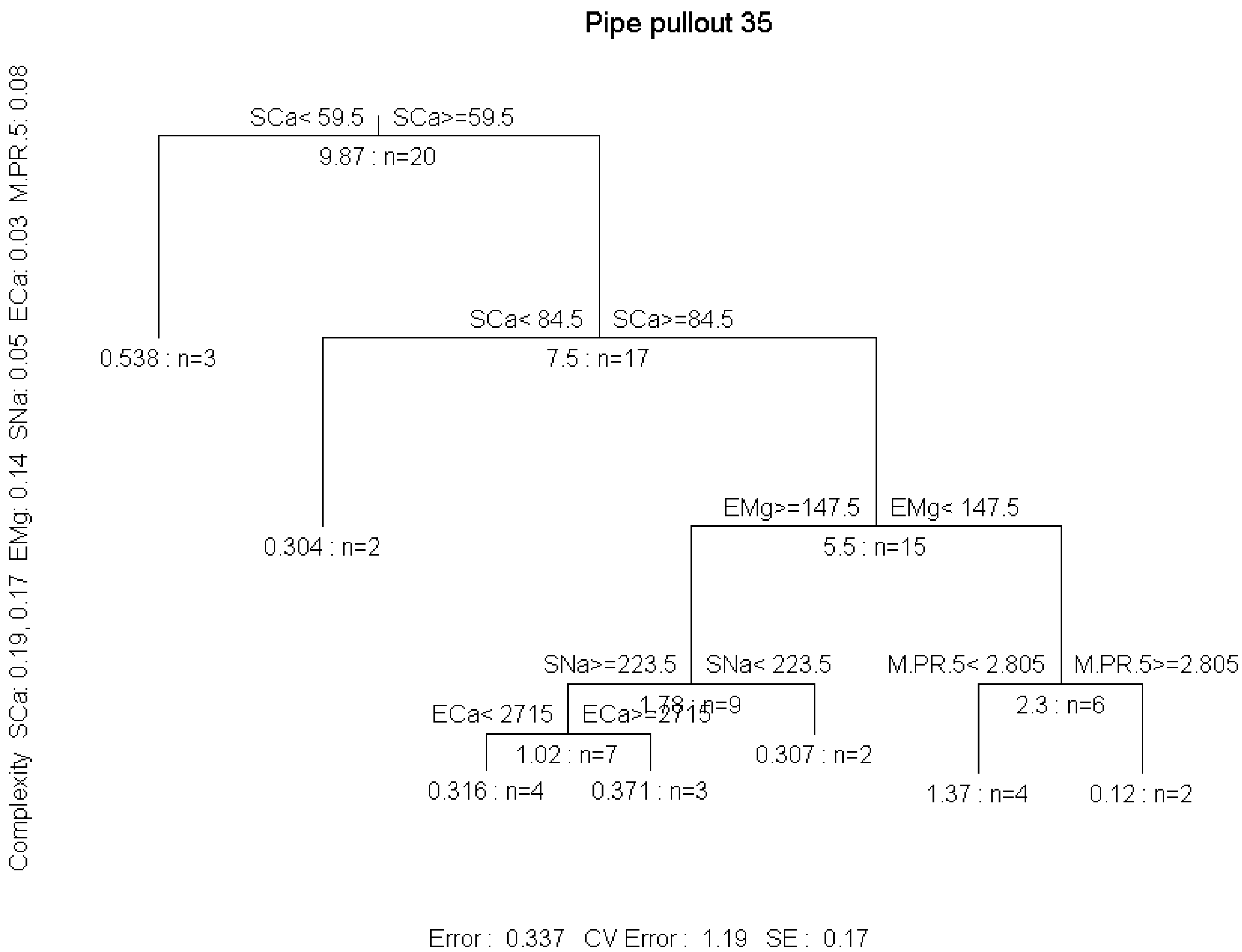


Figure B.13 Regression tree for Pipe pull out 35 on Jasper Lake dunes pipeline relocation

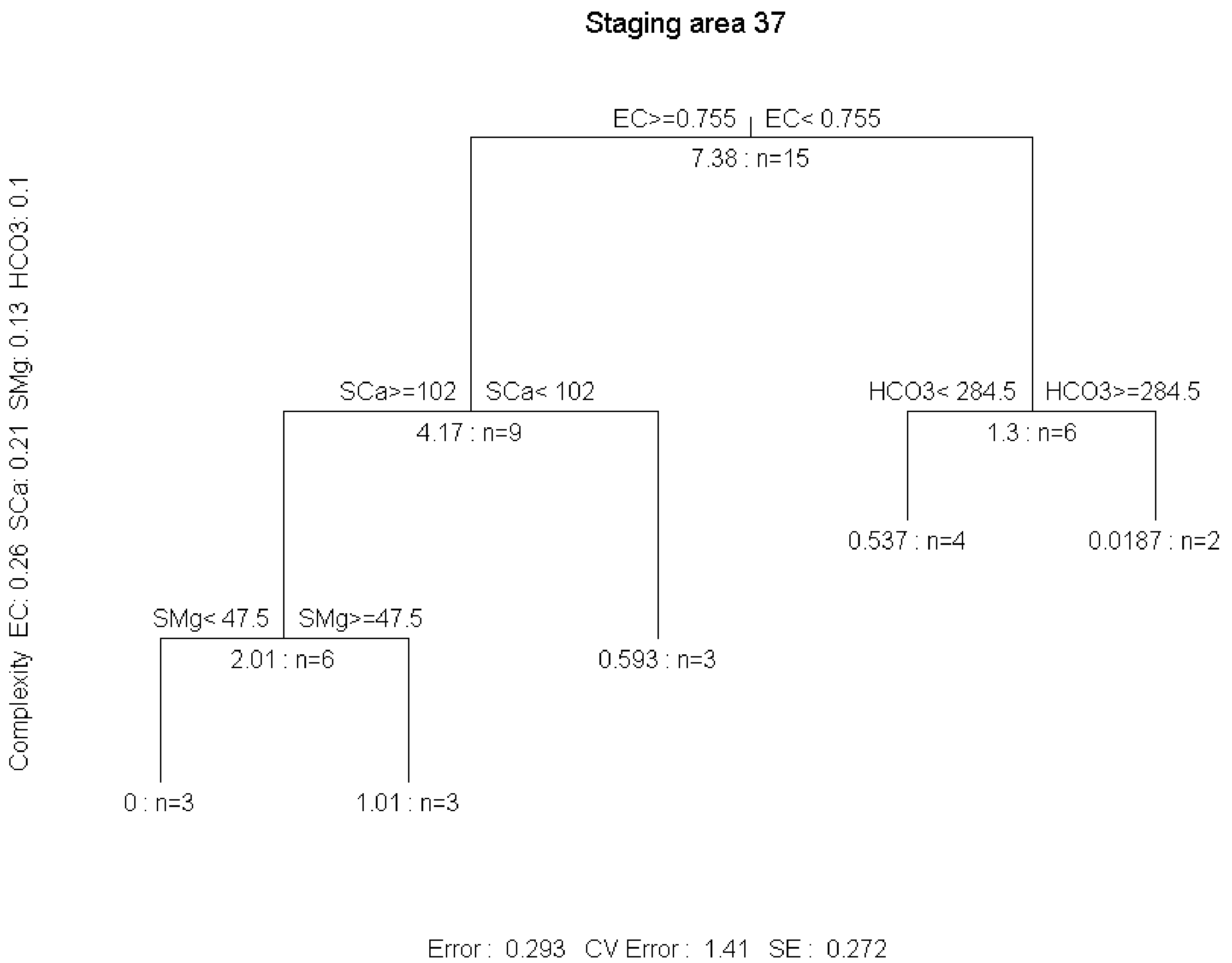


Figure B.14 Regression tree for Staging area 37 on Jasper Lake dunes pipeline relocation

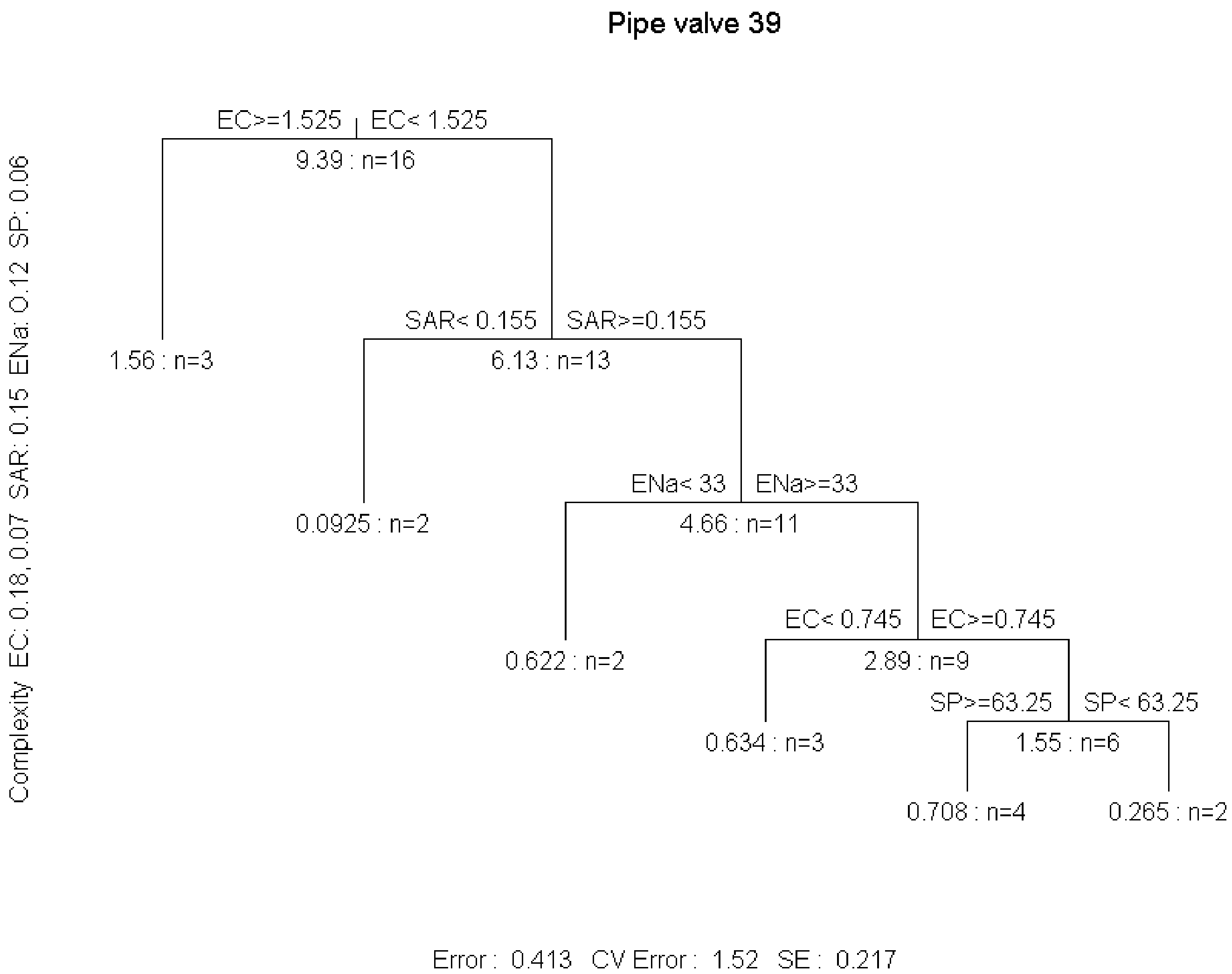


Figure B.15 Regression tree for Pipe valve 39 on Mile 12 pipeline relocation

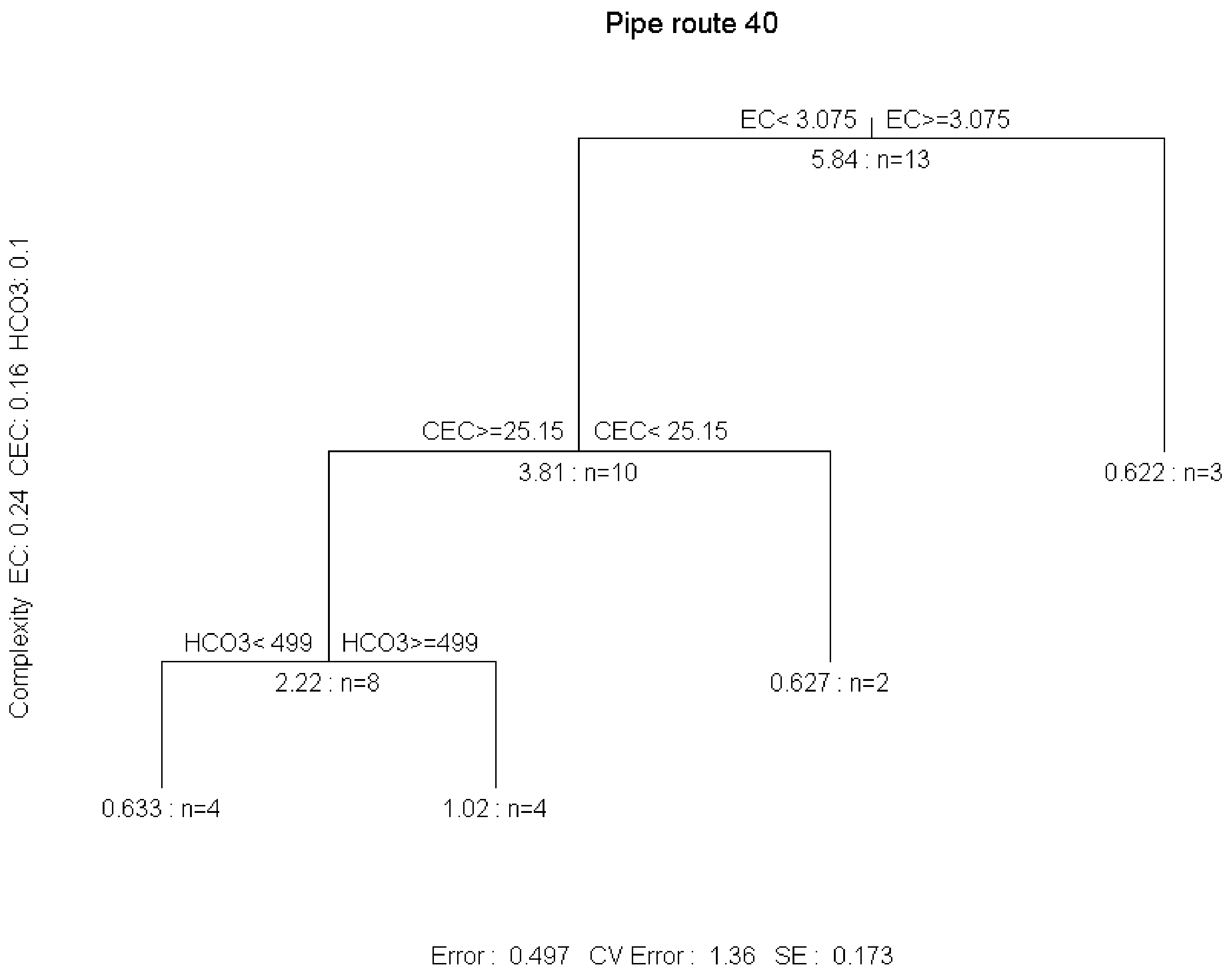


Figure B.16 Regression tree for Pipe route for Mile 12 pipeline relocation

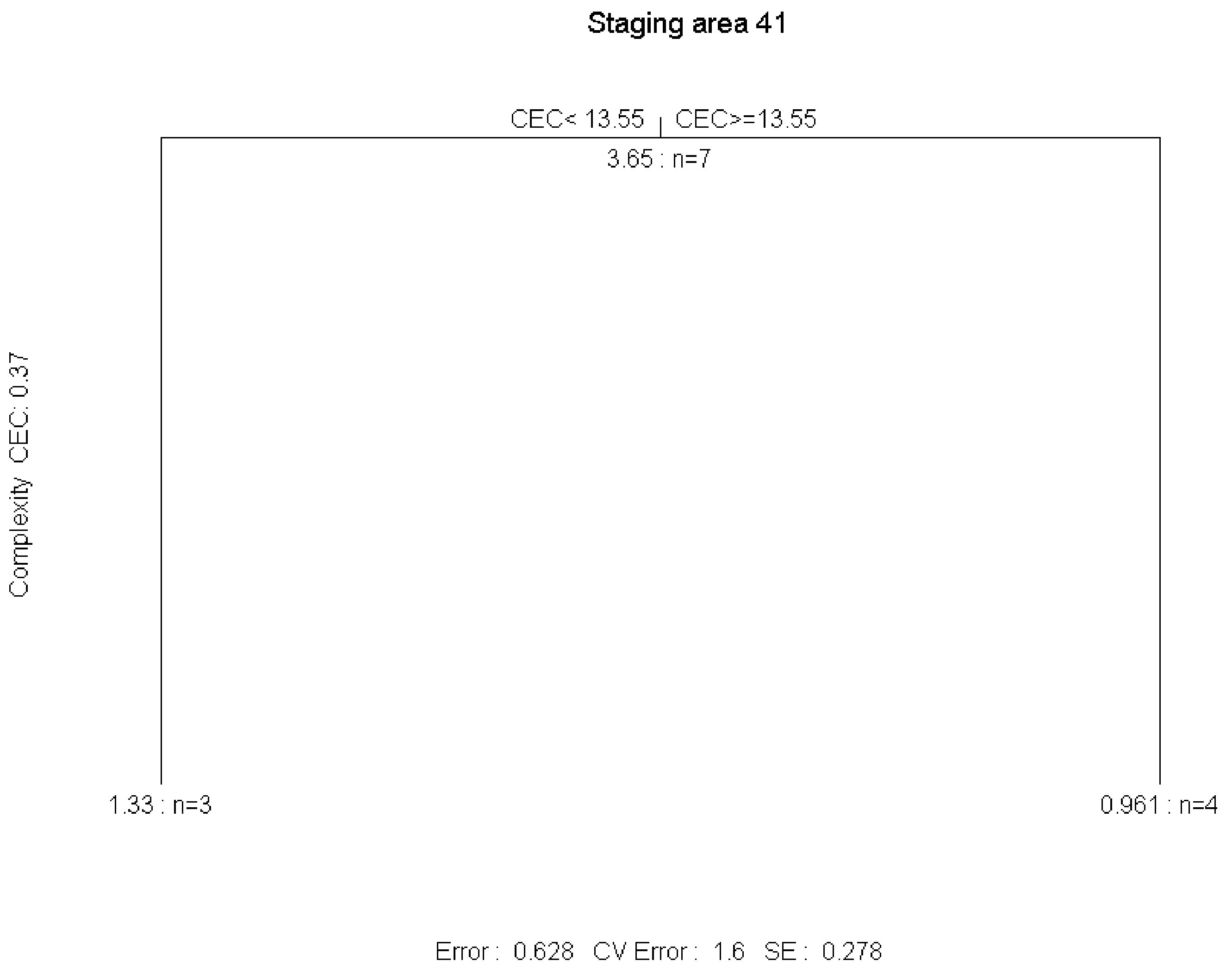


Figure B.17 Regression tree for Staging area 41 for Mile 12 pipeline relocation

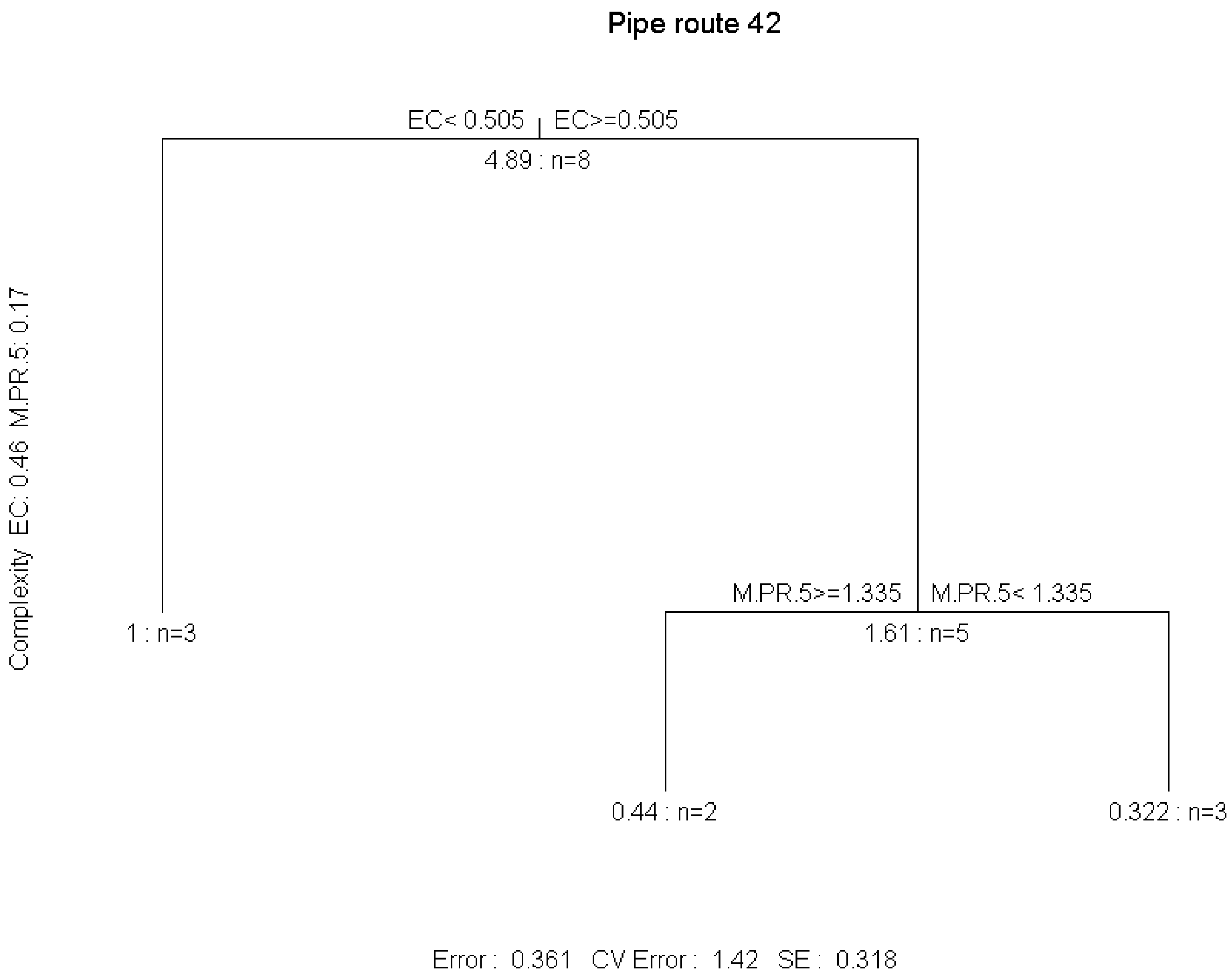


Figure B.18 Regression tree for Pipe route 42 for Mile 12 pipeline relocation

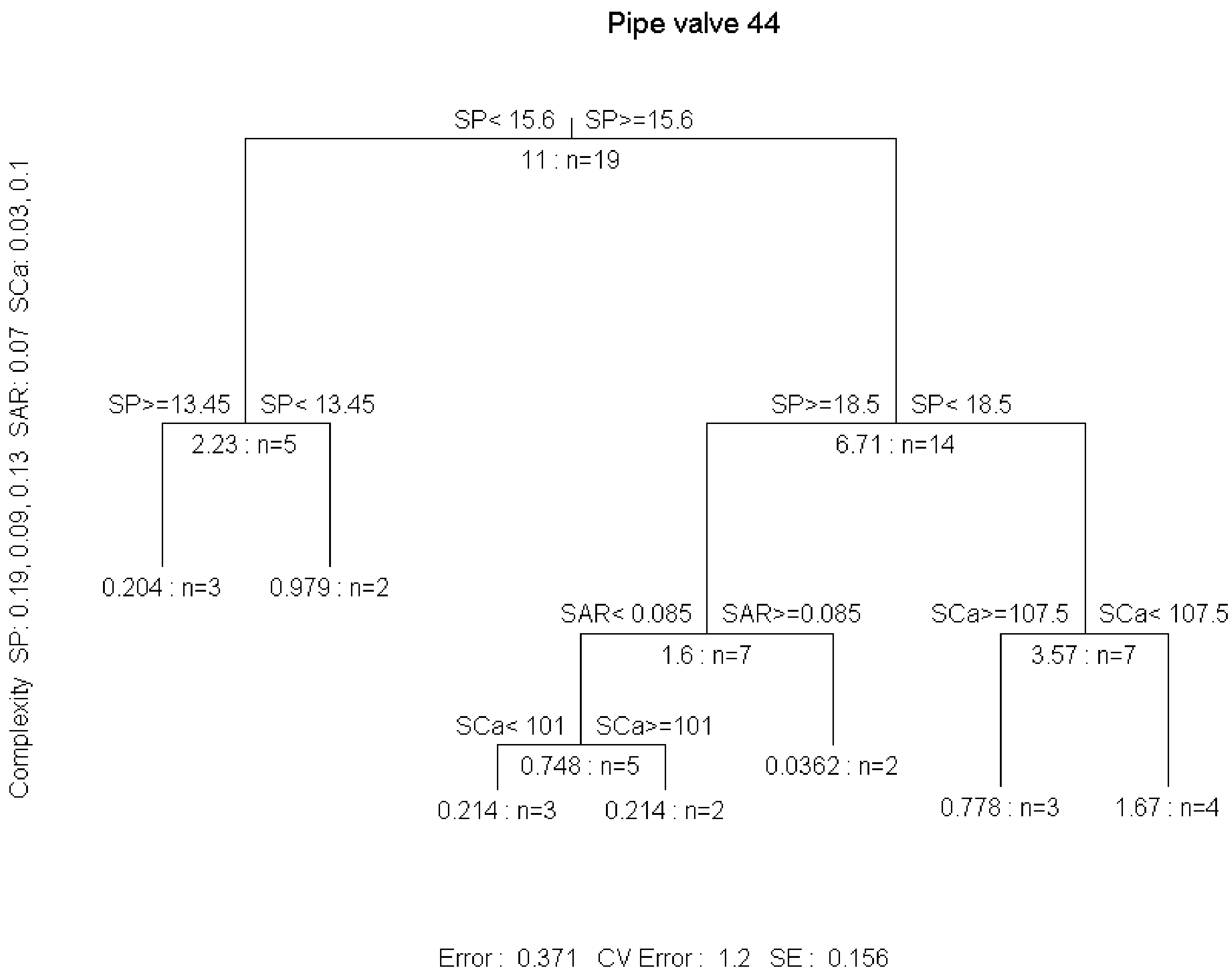


Figure B.19 Regression tree for Pipe valve 44 for Mile 12 pipeline relocation

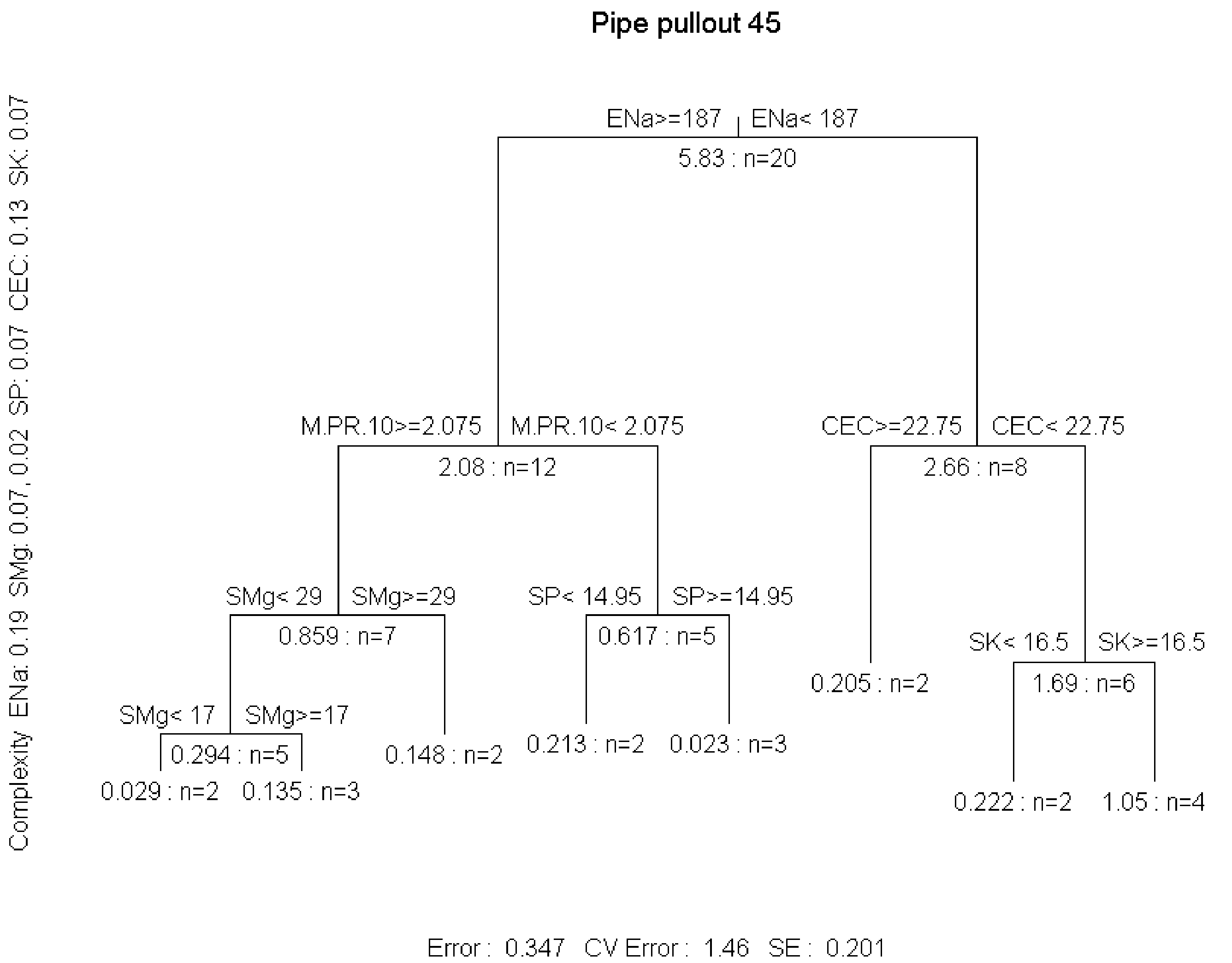


Figure B.20 Regression tree for Pipe pull out 45 for Mile 12 pipeline relocation

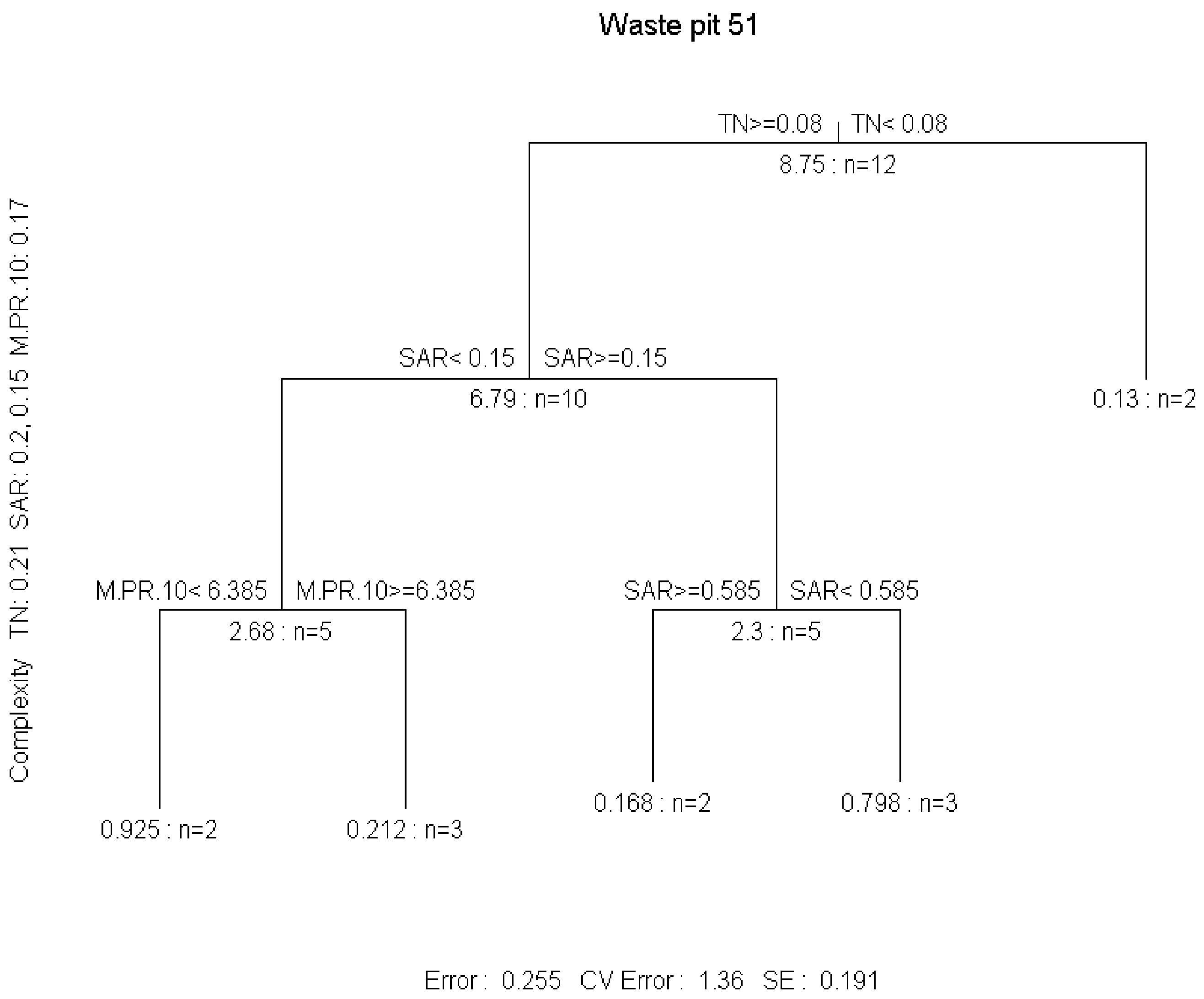


Figure B.21 Regression tree for Waste pit 51 for highway 93

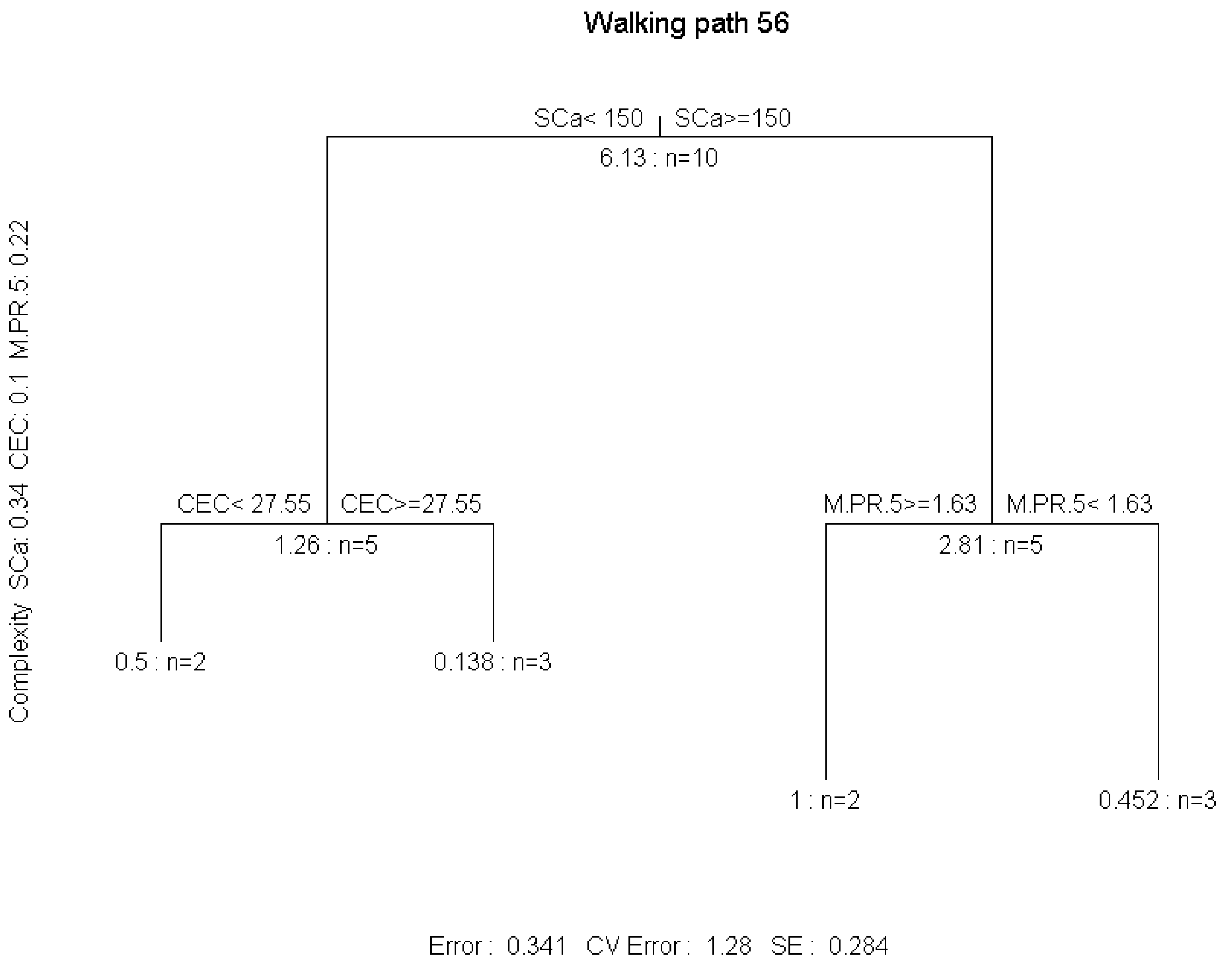


Figure B.22 Regression tree for Walking path 56 for highway 93

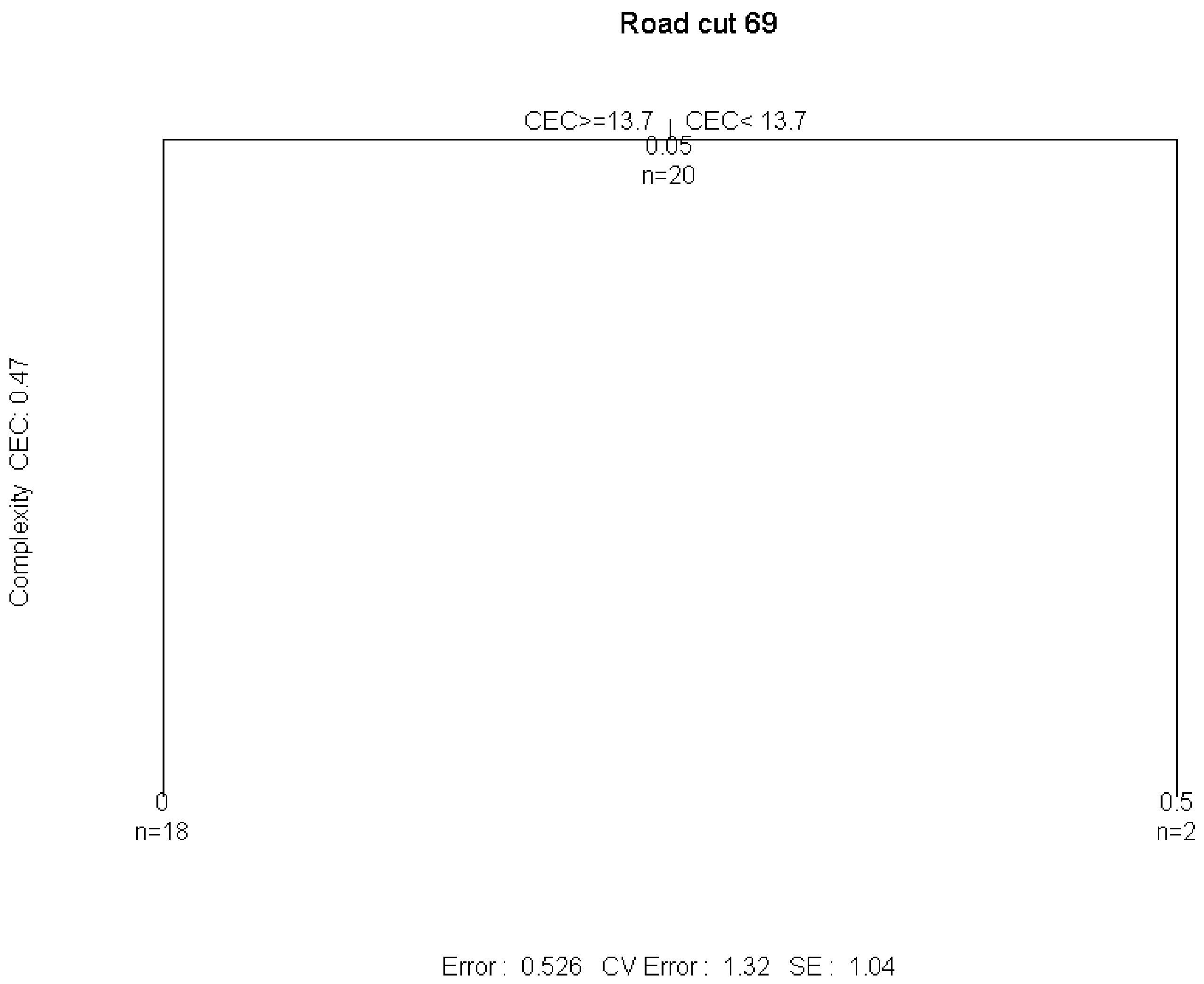


Figure B.23 Regression tree for Road cut 69 for Miette Hot Springs road

Table B.1 Staging area 2 plant variance explained (%) by soil properties at splitting criteria

Species	M.PR.10 2.21	SK 18.5	HCO3 329	ECa 5010	TOC 4.55	Tree Total	Species Total
Festuca saximontana	2.9	4.5	0	1.7	0.6	9.8	14.1
Artemisia frigida	0.1	4.9	10.1	1.0	0.7	16.9	21.9
Koeleria macrantha	2.1	4.5	0.0	3.9	1.7	12.2	16.7
Elymus innovatus	2.2	0.7	4.6	9.9	0.4	17.9	24.0
Juniperis horizontalis	19.4	0	0	0	0	19.4	19.5
Taraxacum officinale	0.1	2.2	0	0	0	2.3	3.7
Complexity Total	26.8	16.9	14.8	16.5	3.6	78.5	100.0

Table B.2 Staging area 2 plant average transformed plant abundance (%) for soil properties at terminal leaves

Species	M.PR.10 < 2.21	SK ≥ 18.5	ECa ≥ 5010	ECa < 5010	TOC ≥ 4.55	TOC < 4.55	Species total
Festuca saximontana	*0.23*	*0.58*	*0.69*	*0.39*	*0.39*	*0.59*	*2.87*
Artemisia frigida	0.24	0.31	0	0.24	0.81	0.60	2.20
Koeleria macrantha	0	0.30	0.69	0.23	0.18	0.51	1.90
Elymus innovatus	0	0.30	0	0.75	0.24	0.07	1.37
Juniperis horizontalis	0.91	0	0	0	0	0	0.91
Taraxacum officinale	0	0.06	0	0	0	0	0.06
Property Total	1.38	1.55	1.38	1.60	1.62	1.77	9.30

Table B.3 Ski hill 8 plant variance explained (%) by soil properties at splitting criteria

Species	SAR 0.27	ECa 1075	Tree Total	Species Total
Fragaria virginiana	1.21	0.07	1.28	17.61
Festuca rubra	10.08	5.31	15.39	21.42
Trifolium repens	25.72	0	25.72	26.49
Antennaria pulcherrima	1.82	14.55	16.37	18.32
Salix	1.99	0.31	2.30	13.08
Bromus inermis	0.73	0	0.73	1.70
Potentilla arguta	0.06	0.12	0.18	1.26
Stellaria media	0.05	0	0.05	0.11
Complexity Total	41.66	20.36	62.02	100.00

Table B.4. Ski hill 8 average transformed plant abundance (%) for soil properties at terminal leaves

Species	SAR ≥ 0.27	ECa ≥ 1075	ECa < 1075	Species Total
Fragaria virginiana	0.35	0.55	0.50	1.41
Festuca rubra	0	0.65	0.25	0.91
Trifolium repens	0.83	0	0	0.83
Antennaria pulcherrima	0	0	0.66	0.66
Salix	0	0.20	0.30	0.50
Bromus inermis	0.14	0	0	0.14
Potentilla arguta	0	0.06	0	0.06
Stellaria media	0.04	0	0	0.04
Property Total	1.36	1.46	1.72	4.54

Table B.5 Water line 18 plant variance explained (%) by soil properties at splitting criteria

Species	EMg 15.5	ENa 60.5	SK 3.5	SP 58.25	SK 5	M.PR.5 2.3	Tree Total	Species Total
Festuca saximontana	6.48	0.23	0.38	0.77	0.20	0.74	8.79	22.81
Poa alpina	1.43	6.95	0.12	2.37	1.86	2.07	14.79	18.57
Agropyron trachycaulum	0.36	0.02	7.88	0.00	1.72	0.36	10.34	18.25
Abies lasiocarpa	1.44	4.59	0.66	0.16	0.94	0	7.79	22.23
Poa compressa	2.43	0.06	0.33	0	1.29	0	4.11	10.22
Festuca rubra	0.13	1.25	0.26	0.45	0	0	2.09	5.75
Phleum pratense	0.04	0.04	0.41	0.72	0	0	1.21	2.16
Complexity Total	12.32	13.13	10.04	4.47	6.00	3.17	49.12	100.00

Table B.6 Water line 18 average transformed plant abundance (%) for soil properties at terminal leaves

Species	EMg < 15.5	ENa < 60.5	SK ≥ 5	SK < 5	SP < 58.25	M.PR.5 < 2.3	M.PR.5 ≥ 2.3	Species total
Festuca saximontana	0.54	0.78	0.95	0.82	0.78	0.90	0.75	5.52
Poa alpina	0.47	0	0.28	0.51	0.48	0.19	0.44	2.37
Agropyron trachycaulum	0.24	0.18	0	0	0.17	0.31	0.42	1.32
Abies lasiocarpa	0.28	0.41	0.09	0.02	0.05	0.19	0.18	1.23
Poa compressa	0.21	0	0	0	0.16	0	0	0.37
Festuca rubra	0	0.18	0	0.10	0	0	0	0.29
Phleum pratense	0	0	0	0.13	0	0	0	0.13
Property Total	1.74	1.55	1.31	1.59	1.65	1.60	1.79	11.24

Table B.7 Water line 19 plant variance explained (%) by soil properties at splitting criteria

Species	SPa 59	SP 67.25	SPa 77.5	EC 0.89	EC 0.71	CEC 18.8	Tree Total	Species Total
Epilobium angustifolium	9.18	0.46	0.29	0.02	0.08	0.14	10.18	18.49
Equisetum pratense	0.93	4.48	1.11	4.88	1.20	0.52	13.12	17.87
Poa glauca	0.32	6.61	5.50	0.36	0.03	2.03	14.84	20.40
Festuca saximontana	8.05	0	0.49	1.79	0.01	0.03	10.36	14.49
Agropyron trachycaulum	0.04	1.16	2.62	0.15	0.84	0.03	4.83	8.70
Poa aplina	7.91	0.15	0	1.58	0	0	9.64	12.00
Festuca rubra	0.31	0.07	0.15	0.33	2.78	0	3.65	7.23
Taraxacum officinale	0	0.06	0	0.04	0.08	0.04	0.23	0.81
Complexity Total	26.74	12.98	10.16	9.16	5.02	2.78	66.84	100.00

Table B.8 Water line 19 average transformed plant abundance (%) for soil properties at terminal leaves

Species	SPa < 59	SPa < 77.5	SPa ≥ 77.5	EC ≥ 0.89	EC ≥ 0.71	CEC ≥ 18.8	CEC < 18.8	Species Total
Epilobium angustifolium	0	0.44	0.59	0.57	0.64	0.57	0.59	3.41
Equisetum pratense	0.15	0	0.30	0	0.68	0.41	0.77	2.31
Poa glauca	0.19	0.79	0.12	0	0.17	0.13	0	1.40
Festuca saximontana	0.61	0.02	0.22	0.37	0.03	0	0.05	1.31
Agropyron trachycaulum	0.19	0.11	0.58	0	0.02	0.24	0	1.14
Poa aplina	0.56	0	0	0.33	0	0	0	0.89
Festuca rubra	0	0.11	0	0	0	0.40	0	0.51
Taraxacum officinale	0.01	0	0	0	0.02	0.10	0	0.13
Property Total	1.71	1.47	1.81	1.27	1.56	1.85	1.41	11.10

Table B.9 Water line 20 plant variance explained (%) by soil properties at splitting criteria

Species	SP 48.5	HCO3 25.5	SMg 6.5	CEC 4.98	CEC 6.32	M.PR.10 1.6	Tree Total	Species Total
Epilobium angustifolium	9.19	5.84	2.56	0.46	2.28	0.99	21.32	26.57
Carex	0.01	0.86	0	0.91	1.75	0.32	3.84	17.50
Poa interior	2.04	4.64	0.34	0	0.83	4.41	12.27	16.05
Poa compressa	9.45	0.23	0.99	0	0.17	0.26	11.10	17.86
Festuca saximontana	0.77	0.55	1.45	0	0.39	0.61	3.77	8.87
Poa paluststris	0.25	0.08	0.11	0.22	2.28	0.03	2.98	7.49
Poa pratensis	0.07	0.52	0	1.27	0	0.02	1.88	4.01
Festuca rubra	0.02	0.24	0	0.23	0	0	0.49	1.64
Complexity Total	21.79	12.98	5.46	3.09	7.70	6.65	57.66	100.00

Table B.10 Water line 20 average transformed plant abundance (%) for soil properties at terminal leaves

Species	SP < 48.5	SMg ≥ 6.5	SMg < 6.5	CEC < 4.95	CEC < 6.32	M.PR.10 < 1.6	M.PR.10 ≥ 1.6	Species Total
Epilobium angustifolium	0	96.48	75.50	10.94	29.92	39.28	80.86	333.0
Carex	25.00	0	29.64	57.61	10.53	25.73	26.08	174.6
Poa interior	0	0	0	19.66	88.46	37.71	22.56	168.4
Poa compressa	64.52	0	0	0	0	2.86	28.72	96.1
Festuca saximontana	26.01	0	0	0	0	34.77	3.49	64.3
Poa palustris	0	0	14.61	44.00	0	8.70	0	67.3
Poa pratensis	0	0	34.92	0	3.85	0	0	38.8
Festuca rubra	0	14.91	0	0	0	0	0	14.9
Property Total	115.5	111.4	154.7	132.2	132.8	149.0	161.7	957.3

Table B.11 Water line 22 plant variance explained (%) by soil properties at splitting criteria

Species	EK 312	TIC 4	HCO3 50	SAR 0.2	M.PR.10 1.7	ENa 165.5	Tree Total	Species Total
Anemone multifida	1.35	0	0.95	0.60	1.09	0.46	4.45	9.68
Epilobium angustifolium	1.04	1.60	0.79	2.29	0.72	0.03	6.48	10.11
Poa alpina	2.67	0.46	2.88	0	0.05	0.03	6.10	9.27
Poa compressa	1.99	0.01	3.27	0.23	0	0.86	6.37	9.54
Equisetum arvense	3.81	0.03	0.32	0.03	0.02	0.05	4.25	7.96
Festuca saximontana	1.21	0.28	1.04	0.12	1.49	3.17	7.31	8.96
Salix	0.14	0.01	0.05	9.00	0	0	9.21	13.95
Fragaria virginiana	0	0.01	0.52	0.11	0.41	0.02	1.08	5.89
Polygonum bistortoides	0	0.15	0.37	0.12	0.74	0.14	1.53	2.83
Phleum pratense	3.71	6.22	0.01	0.01	0.02	0.04	10.00	10.40
Erigeron canadensis	0.64	0	0.39	0.39	1.86	0.02	3.30	4.18
Festuca rubra	0.26	0.81	0.03	0.75	0	0	1.84	6.01
Sonchus arvensis	0.09	0	0.05	0.01	0.07	0.13	0.35	0.89
Taraxacum officinale	0.01	0	0.01	0.01	0.02	0.16	0.21	0.26
Agropyron trachycaulum	0	0	0	0	0.03	0	0.04	0.08
Complexity Total	16.93	9.58	10.69	13.69	6.51	5.11	62.52	100.00

Table B.12 Water line 22 average transformed plant abundance (%) for soil properties at terminal leaves

Species	SAR < 0.2	SAR ≥ 0.2	TIC ≥ 4	HCO3 < 50	M.PR.10 ≥ 1.7	ENa < 165.5	ENa ≥ 165.5	Species Total
Anemone multifida	0.27	0.29	0.27	0.34	0.33	0.63	0.46	2.59
Epilobium angustifolium	0.60	0.30	0.47	0	0.19	0.40	0.36	2.32
Poa alpina	0	0.16	0	0.36	0.41	0.35	0.39	1.68
Poa compressa	0.07	0.09	0.61	0.13	0.23	0.16	0.39	1.66
Equisetum arvense	0.45	0.41	0.25	0.10	0.16	0.15	0.10	1.61
Festuca saximontana	0	0.12	0.03	0.32	0.45	0.02	0.46	1.41
Salix	0.19	0.21	0.19	0.67	0	0	0	1.25
Fragaria virginiana	0.18	0.15	0.04	0.14	0.33	0.16	0.20	1.19
Polygonum bistortoides	0.16	0.07	0	0.07	0	0.23	0.14	0.68
Phleum pratense	0	0.58	0	0	0	0.05	0	0.63
Erigeron canadensis	0	0	0	0.03	0.40	0.07	0.11	0.61
Festuca rubra	0.21	0	0	0.19	0	0	0	0.40
Sonchus arvensis	0	0	0	0.07	0	0.09	0	0.16
Taraxacum officinale	0	0	0	0	0	0	0.10	0.10
Agropyron trachycaulum	0	0	0	0	0.04	0	0	0.04
Property Total	2.12	2.38	1.85	2.42	2.54	2.32	2.71	16.34

Table B.13 Water line 23 plant variance explained (%) by soil properties at splitting criteria

Species	M.PR.10 1.27	Tree Total	Species Total
Epilobium angustifolium	3.32	3.32	20.36
Festuca rubra	18.99	18.99	19.92
Phyllodoce empetriformis	3.20	3.20	13.89
Carex	0.01	0.01	4.61
Antennaria pulcherima	4.02	4.02	24.13
Trisetum spicatum	2.85	2.85	17.09
Complexity Total	32.39	32.39	100.00

Table B.14 Water line 23 average transformed plant abundance (%) for soil properties at terminal leaves

Species	M.PR.10 < 1.27	M.PR.10 ≥ 1.27	Species Total
Epilobium angustifolium	0.65	0.39	1.04
Festuca rubra	0	0.63	0.63
Phyllodoce empetriformis	0.13	0.39	0.52
Carex	0.19	0.17	0.36
Antennaria pulcherima	0.29	0	0.29
Trisetum spicatum	0.24	0	0.24
Property Total	1.50	1.58	3.08

Table B.15 Water line 25 plant variance explained (%) by soil properties at splitting criteria

Species	ENa 62.5	Tree Total	Species Total
Festuca saximontana	0.85	0.85	5.62
Agropyron trachycaulum	17.31	17.31	26.55
Poa alpina	6.20	6.20	16.04
Agropyron dasystachyum	1.95	1.95	15.90
Fragaria virginiana	3.86	3.86	12.27
Salix	5.86	5.86	23.63
Complexity Total	36.04	36.04	100.00

Table B.16 Water line 25 average transformed plant abundance (%) for soil properties at terminal leaves

Species	ENa ≥ 62.5	ENS < 62.5	Species Total
Festuca saximontana	0.45	0.54	0.99
Agropyron trachycaulum	0.66	0.23	0.90
Poa alpina	0.27	0.53	0.80
Agropyron dasystachyum	0.20	0.34	0.54
Fragaria virginiana	0.36	0.15	0.51
Salix	0	0.25	0.25
Property Total	1.94	2.05	3.99

Table B.17 Waste pit 28 plant variance explained (%) by soil properties at splitting criteria

Species	ENa 91	EK 279.5	EK 123	ENa 198	Tree Total	Species Total
Agropyron repens	21.92	0.04	0.69	0.44	23.08	27.67
Koeleria macrantha	9.89	6.44	0.10	1.15	17.56	20.07
Festuca saximontana	1.89	2.92	0.38	1.99	7.18	14.67
Sonchus arvensis	2.74	10.19	0	0	12.93	14.23
Poa pratensis	0	0.86	0.81	0.10	1.77	11.83
Taraxacum officinale	0.89	0	4.84	0	5.73	7.51
Linaria dalmatica	0.18	0	0.98	0	1.16	2.54
Capsella bursa pastoris	0.05	0	0.29	0	0.34	0.74
Descurainia sophia	0.05	0	0.29	0	0.34	0.74
Complexity Total	37.62	20.44	8.37	3.67	70.10	100.00

Table B.18 Waste pit 28 average transformed plant abundance (%) for soil properties at terminal leaves

Species	EK < 279.5	EK ≥ 279.5	ENa < 198	ENa ≥ 198	EK < 123	Species Total
Agropyron repens	0.19	0.23	0.73	0.97	0.82	2.94
Koeleria macrantha	0.79	0.23	0.11	0.08	0.33	1.54
Festuca saximontana	0.16	0.53	0	0	0.32	1.02
Sonchus arvensis	0	0.70	0	0	0	0.70
Poa pratensis	0.20	0	0	0.16	0.23	0.60
Taraxacum officinale	0	0	0.46	0	0	0.46
Linaria dalmatica	0	0	0.21	0	0	0.21
Capsella bursa pastoris	0	0	0.11	0	0	0.11
Descurainia sophia	0	0	0.11	0	0	0.11
Property Total	1.34	1.69	1.75	1.21	1.70	7.69

Table B.19 Pipe valve 31 plant variance explained (%) by soil properties at splitting criteria

Species	TC 8.02	HCO3 312.5	SP 21.5	TC 7.79	Tree Total	Species Total
Agropyron trachycaulum	9.05	0.90	0.05	0.20	10.20	12.35
Festuca saximontana	0.12	5.24	5.26	0.04	10.67	14.14
Agropyron dasystachyum	1.03	2.32	0.89	2.42	6.66	9.95
Carex	3.00	0.74	0.09	0.53	4.35	11.57
Picea glauca	2.67	0	0.18	0.04	2.90	4.40
Rosa acicularis	0.23	0.01	1.62	0	1.86	9.03
Arctostaphylos uva ursi	2.44	4.61	0	0	7.05	16.33
Smilicina stellata	0.96	0.48	0.02	0.12	1.59	4.49
Festuca rubra	0.11	0	0.85	0	0.97	2.06
Chrysanthemum leucanthemum	0.40	0.75	0	0	1.15	5.65
Sonchus arvensis	0.23	0	0.14	0.48	0.85	4.19
Taraxacum officinale	0.22	0	0.13	0.45	0.80	3.93
Agropyron repens	0.21	0.40	0	0	0.62	1.34
Bromus inermis	0.04	0.08	0	0	0.12	0.57
Complexity Total	20.71	15.54	9.24	4.28	49.77	100.00

Table B.20 Waste pit 28 average transformed plant abundance (%) for soil properties at terminal leaves

Species	HCO3 ≥ 312.5	HCO3 < 312.5	SP < 21.5	TC < 7.785	TC ≥ 7.785	Species Total
Agropyron trachycaulum	0.04	0.24	0.54	0.64	0.53	1.99
Festuca saximontana	0.14	0.62	0	0.53	0.58	1.87
Agropyron dasystachyum	0.05	0.38	0.54	0.16	0.52	1.64
Carex	0.40	0.22	0	0	0.17	0.78
Picea glauca	0	0	0.32	0.24	0.19	0.74
Rosa acicularis	0.13	0.15	0.31	0	0	0.58
Arctostaphylos uva ursi	0.45	0	0	0	0	0.45
Smilicina stellata	0.10	0.24	0	0	0.08	0.42
Festuca rubra	0	0	0.22	0	0	0.22
Chrysanthemum leucanthemum	0.18	0	0	0	0	0.18
Sonchus arvensis	0	0	0	0.16	0	0.16
Taraxacum officinale	0	0	0	0.15	0	0.15
Agropyron repens	0.13	0	0	0	0	0.13
Bromus inermis	0	0.06	0	0	0	0.06
Property Total	1.62	1.91	1.92	1.87	2.06	9.38

Table B.21 Access route 33 plant variance explained (%) by soil properties at nodes with splitting criteria

Species	CEC 12.45	ENa 20	CEC 11.3	Tree Total	Species Total
Agropyron dasystachyum	7.08	6.40	7.45	20.93	23.20
Stipa comata	12.02	21.64	2.63	36.28	36.54
Juniperis horizontalis	33.52	0	0	33.52	33.52
Dryas drummondi	0.30	5.12	0	5.42	6.75
Complexity Total	52.92	33.16	10.08	96.16	100.00

Table B.22 Access route 33 average transformed plant abundance (%) for soil properties at terminal leaves

Species	CEC ≥ 12.45	ENa < 20	CEC ≥ 11.3	CEC < 11.3	Species Total
Agropyron dasystachyum	12	89	23	76	200
Stipa comata	0	0	96	64	160
Juniperis horizontalis	99	0	0	0	99
Dryas drummondi	2	40	0	0	42
Property Total	113	129	119	140	501

Table B.23 Access route 34 plant variance explained (%) by soil properties at splitting criteria

Species	EK 292	Tree Total	Species Total
Agropyron dasystachyum	7.6	7.6	22.89
Bromus inermis	0.28	0.28	7.01
Carex	1.66	1.66	18.98
Equisetum arvense	19.65	19.65	22.36
Galium boreale	0.17	0.17	9.12
Salsola kali	0.41	0.41	2.48
Solidago spathulata	6.98	6.98	17.16
Complexity Total	36.76	36.76	100

Table B.24 Access route 34 average transformed plant abundance (%) for soil properties at terminal leaves

Species	EK ≥ 292	EK < 292	Species Total
Agropyron dasystachyum	0	39	39
Bromus inermis	19	12	31
Carex	35	54	89
Equisetum arvense	73	10	83
Galium boreale	27	21	48
Salsola kali	0	9	9
Solidago spathulata	0	37	37
Property Total	154	182	336

Table B.25 Pipe pull out 35 plant variance explained (%) by soil properties at splitting criteria

Species	SCa 59.5	SCa 84.5	EMg 147.5	M.PR.5 2.8	SNa 223.5	ECa 2715	Tree Total	Species Total
Agropyron repens	3.2	3.15	4.98	0.46	0.17	0	11.96	17.17
Sonchus arvensis	13.32	0.2	0.02	0.15	0.52	0.45	14.68	18.82
Agropyron dasystachyum	0.57	11.23	0.31	0.06	0.33	0	12.49	13.45
Festuca rubra	0.09	0.66	0.83	0.46	1.71	0.68	4.43	13.21
Poa pratense	0.67	0.6	0.78	2.53	0.12	0.13	4.82	8.47
Equisetum arvense	0	0.24	1.49	0.03	0.2	6.89	8.86	10.37
Bromis inermis	0.49	0.44	5.59	0	0	0.02	6.53	10.82
Agrpyron trachycaulum	0.08	0.56	0.03	0	0.1	0.01	0.78	2.48
Melilotus officinalis	0.07	0.06	0.36	0.85	0.12	0	1.47	3.94
Taraxacum officinale	0.01	0.01	0.05	0.04	0.12	0	0.23	1.1
Hordeum jubatum	0.05	0	0	0	0	0	0.05	0.17
Complexity Total	18.56	17.16	14.44	4.58	3.4	8.17	66.3	100

Table B.26 Pipe pull out 35 average transformed plant abundance (%) for soil properties at terminal leaves

Species	SCa < 59.5	SCa < 84.5	ECa < 2715	ECa ≥ 2715	SNa < 223.5	M.PR.5 < 2.81	M.PR.5 ≥ 2.81	Species Total
Agropyron repens	0.31	0.29	0.73	0.94	0.84	0.49	0.48	4.08
Sonchus arvensis	0.81	0	0.17	0	0.17	0.18	0	1.34
Agropyron dasystachyum	0	0.85	0.14	0.14	0	0	0	1.12
Festuca rubra	0.23	0	0	0.04	0.35	0.36	0.13	1.11
Poa pratense	0	0	0.44	0	0.08	0.30	0.21	1.03
Equisetum arvense	0.10	0	0	0	0.11	0	0.71	0.93
Bromis inermis	0	0	0	0	0	0.40	0.37	0.77
Agrpyron trachycaulum	0	0.21	0.05	0.07	0	0.02	0	0.36
Melilotus officinalis	0	0	0.28	0.08	0	0	0	0.36
Taraxacum officinale	0	0	0	0.08	0	0	0	0.08
Hordeum jubatum	0.04	0	0	0	0	0	0	0.04
Property total	1.50	1.35	1.81	1.36	1.55	1.76	1.91	11.23

Table B.27 Staging area 37 plant variance explained (%) by soil properties at splitting criteria

Species	EC 0.755	SCa 102	SMg 47.5	HCO3 284.5	Tree Total	Column Total
Agropyron Trachycalum	12.75	1.65	6.02	2.34	22.76	27.57
Agropyron dasystachyum	1.10	0.20	6.03	0.05	7.38	15.44
Festuca saximontana	6.63	0	0	7.69	14.32	18.04
Sonchus arvensis	2.68	13.39	0	0	16.07	16.80
Festuca rubra	1.36	4.86	0.05	0	6.27	7.85
Taraxacum officinale	0.97	0.03	1.36	0	2.36	9.07
Agropyron repens	0.24	1.20	0	0	1.44	5.04
Crepis tectorum	0.02	0	0	0.07	0.09	0.20
Complexity Total	25.74	21.33	13.46	10.15	70.68	100.00

Table B.28 Staging area 37 average transformed plant abundance (%) for soil properties at terminal leaves

Species	SCa < 102	SMg < 47.5	SMg ≥ 47.5	HCO3 < 284.5	HCO3 ≥ 284.5	Species Total
Agropyron Trachycalum	0.03	0	0.54	0.82	0.46	1.85
Agropyron dasystachyum	0.19	0	0.54	0.41	0.36	1.50
Festuca saximontana	0	0	0	0.15	0.80	0.95
Sonchus arvensis	0.70	0	0	0	0	0.70
Festuca rubra	0.45	0	0.05	0	0	0.50
Taraxacum officinale	0.16	0	0.26	0	0	0.42
Agropyron repens	0.21	0	0	0	0	0.21
Crepis tectorum	0	0	0	0	0.06	0.06
Property Total	1.74	0.00	1.40	1.38	1.69	6.21

Table B.29 Pipe valve 39 plant variance explained (%) by soil properties at splitting criteria

Species	EC 1.525	SAR 0.16	ENa 33	EC 0.75	SP 63.3	Tree Total	Species Total
Agropyron dasystachyum	7.42	4.84	2.51	0.66	0.81	16.23	21.96
Festuca saximontana	0.03	1.36	4.34	0.61	0.17	6.51	18.67
Smilicina stellata	0.60	7.56	0.61	0.12	0.29	9.18	11.93
Agropyron trachycaulum	1.60	0.59	1.98	4.40	0.23	8.80	11.18
Carex	3.59	0.07	2.07	0	0	5.73	9.34
Solidago spathulata	0.30	0	0.08	0.72	0.53	1.64	3.87
Potentilla fruticosa	0.15	0.15	0.22	0.59	3.56	4.68	4.76
Poa alpina	0.20	0	0.33	0.08	0.03	0.64	1.61
Comandra umbellata	2.36	0.01	0.02	0.04	0.06	2.49	6.66
Arctostaphylos uva ursi	1.51	0	0	0	0	1.51	5.24
Taraxacum officinale	0.28	0.01	0.01	0	0.07	0.37	0.81
Crepis tectorum	0.06	0.03	0.05	0.13	0.20	0.46	2.67
Sonchus arvensis	0.03	0.03	0.05	0.13	0.19	0.44	1.29
Complexity Total	18.13	14.66	12.26	7.48	6.15	58.68	100.00

Table B.30 Pipe valve 39 average transformed plant abundance (%) for soil properties at terminal leaves

Spcecies	EC ≥ 1.525	SAR < 0.155	ENa < 33	EC < 0.745	SP ≥ 63.25	SP < 63.25	Species Total
Agropyron dasystachyum	0	0.10	0.30	0.68	0.74	0.82	2.65
Festuca saximontana	0.33	0.53	0.66	0.16	0.22	0.18	2.07
Smilicina stellata	0.10	0.80	0	0.19	0.16	0.11	1.36
Agropyron trachycaulum	0	0.09	0	0.34	0.19	0.23	0.85
Carex	0.42	0	0.35	0	0	0	0.77
Solidago spathulata	0	0.10	0.05	0.12	0.18	0.12	0.58
Potentilla fruticosa	0	0	0	0.11	0.17	0	0.28
Poa alpina	0	0.09	0.20	0.06	0.08	0.07	0.50
Comandra umbellata	0.32	0	0	0.03	0.04	0.07	0.46
Arctostaphylos uva ursi	0.24	0	0	0	0	0	0.24
Taraxacum officinale	0.12	0	0	0.02	0.02	0	0.17
Crepis tectorum	0.08	0	0	0.05	0.08	0.12	0.33
Sonchus arvensis	0	0	0	0.05	0.08	0.12	0.25
Property Total	1.62	1.71	1.56	1.82	1.96	1.83	10.50

Table B.31 Pipe route 40 plant variance explained (%) by soil properties at splitting criteria

Species	EC 3.075	CEC 25.15	HCO3 499	Tree Total	Species Total
Carex	3.22	8.17	0.69	12.08	15.96
Salix	1.10	2.24	3.82	7.16	12.59
Arctostaphylus rubra	12.85	0.19	0.96	14.00	20.27
Aster ciliolatus	0.10	0.28	0.23	0.61	5.93
Betula glandulosa	1.90	1.88	0	3.78	8.16
Antennaria pulcherrima	0.33	0	0.09	0.41	5.34
Polygonum viviparum	0.87	0.86	0.52	2.24	3.50
Potentilla fruticosa	1.43	0.18	0.89	2.50	6.25
Carex disperma	0.33	0.88	0.42	1.63	4.36
Equisetum variegatum	0.16	0.90	0.10	1.16	3.22
Antennaria alpina	0.17	0.09	0.44	0.70	3.66
Comandra umbellata	0.10	0.36	0.11	0.57	1.92
Vaccinium caespitosum	1.36	0	0	1.36	2.25
Juncus mertensianus	0.20	0.21	1.07	1.47	3.61
Smilicina stellata	0.02	0.02	0.11	0.15	0.81
Crepis tectorum	0.02	0.02	0.09	0.13	0.67
Sonchus arvensis	0.02	0.02	0.09	0.13	0.67
Chrysanthemum leucanthemum	0.02	0.02	0.08	0.12	0.61
Linaria vulgaris	0.03	0	0	0.03	0.12
Taraxacum officinale	0	0	0.02	0.02	0.12
Complexity Total	24.23	16.33	9.71	50.26	100.00

Table B.32 Pipe route 40 average transformed plant abundance (%) for soil properties at terminal leaves

Species	EC ≥ 3.075	CEC < 25.15	HCO3 < 499	HCO3 ≥ 499	Species Total
Carex	0.36	0.21	0.83	0.68	2.08
Salix	0.08	0.48	0.02	0.36	0.94
Arctostaphylus rubra	0.64	0	0	0.17	0.80
Aster ciliolatus	0.14	0.27	0.13	0.21	0.76
Betula glandulosa	0.33	0.32	0.06	0.05	0.75
Antennaria pulcherrima	0.11	0.20	0.17	0.22	0.70
Polygonum viviparum	0	0.29	0.17	0.05	0.52
Potentilla fruticosa	0.25	0	0.16	0	0.42
Carex disperma	0	0.23	0.11	0	0.35
Equisetum variegatum	0	0.21	0.05	0	0.26
Antennaria alpina	0.11	0	0	0.11	0.23
Comandra umbellata	0	0.14	0.06	0	0.20
Vaccinium cespitosum	0.19	0	0	0	0.19
Juncus mertensianus	0	0	0.18	0	0.18
Smilicina stellata	0	0	0.06	0	0.06
Crepis tectorum	0	0	0	0.05	0.05
Sonchus arvensis	0	0	0	0.05	0.05
Chrysanthemum leucanthemum	0	0	0	0.05	0.05
Linaria vulgaris	0.03	0	0	0	0.03
Taraxacum officinale	0	0	0	0.02	0.02
Property Total	2.23	2.35	2.00	2.04	8.61

Table B.33 Staging area 41 plant variance explained (%) by soil properties at splitting criteria

Species	CEC 13.55	Tree Total	Species Total
Festuca saximontana	22.99	22.99	29.83
Agropyron dasystachyum	0.11	0.11	28.78
Agropyron trachycaulum	8.84	8.84	17.91
Capsella bursa pastoris	2.94	2.94	13.23
Crepis tectorum	2.28	2.28	10.25
Complexity Total	37.15	37.15	100.00

Table B.34 Staging area 41 average transformed plant abundance (%) for soil properties at terminal leaves

Species	CEC < 13.55	CEC ≥ 13.55	Species Total
Festuca saximontana	0	0.70	0.70
Agropyron dasystachyum	0.33	0.29	0.62
Agropyron trachycaulum	0	0.43	0.43
Capsella bursa pastoris	0.25	0	0.25
Crepis tectorum	0.22	0	0.22
Property Total	0.80	1.42	2.22

Table B.35 Pipe route 42 plant variance explained (%) by soil properties at splitting criteria

Species	EC 0.51	M.PR.5 1.34	Tree Total	Species Total
Agropyron trachycaulum	7.03	6.26	13.29	15.96
Equisetum variegatum	11.39	2.86	14.25	20.00
Agropyron dasystachyum	7.92	0.07	7.99	15.38
Carex	15.11	0	15.11	27.26
Symphoricarpos albus	4.37	7.77	12.14	13.62
Poa alpina	0.09	0.24	0.32	3.78
Disporum trachycarpum	0.47	0.04	0.50	2.76
Phleum pratense	0.09	0.16	0.25	1.06
Taraxacum officinale	0.02	0.03	0.04	0.18
Complexity Total	46.47	17.43	63.90	100.00

Table B.36 Pipe route 42 average transformed plant abundance (%) for soil properties at terminal leaves

Species	EC < 0.505	M.PR.5 ≥1.335	M.PR.5 < 1.335	Species Total
Agropyron trachycaulum	0.05	0.78	0.27	1.10
Equisetum variegatum	0	0.34	0.68	1.02
Agropyron dasystachyum	0.51	0.09	0.03	0.63
Carex	0.63	0	0	0.63
Symphoricarpos albus	0	0	0.56	0.56
Poa alpina	0.10	0.20	0.10	0.40
Disporum trachycarpum	0	0.09	0.13	0.21
Phleum pratense	0	0	0.08	0.08
Taraxacum officinale	0	0	0.03	0.03
Property Total	1.28	1.50	1.90	4.68

Table B.37 Pipe valve 44 plant variance explained (%) by soil properties at splitting criteria

Species	SP 15.6	SP 18.5	SCa 107.5	SP 13.45	SAR 0.09	SCa 101	Tree Total	Species Total
Agropyron repens	3.47	0.03	9.38	0.77	0.50	0.44	14.58	19.24
Vicia americana	0.89	0.02	0.46	0.36	1.23	3.79	6.74	10.03
Taraxacum officinale	0.08	1.53	0.15	4.25	0	0.82	6.82	12.62
Agropyron inerme	0.57	0.21	0.01	0.80	0.02	2.41	4.01	9.33
Agropyron dasystachyum	0.69	0.35	2.19	0.36	0.79	0.13	4.50	6.74
Cirsium arvense	12.15	5.58	0.08	0.07	0.34	0	18.21	19.55
Poa pratensis	0.26	0.12	0.11	0.83	0	0.17	1.49	3.55
Bromus inermis	0.75	1.61	1.42	0	0	2.12	5.90	15.84
Agropyron trachycaulum	0.09	0	0.14	0.01	0.02	0.34	0.59	3.02
Phleum pratense	0.01	0.03	0	0	0	0	0.04	0.09
Complexity Total	18.94	9.46	13.93	7.44	2.90	10.21	62.89	100.00

Table B.38 Pipe valve 44 average transformed plant abundance (%) for soil properties at terminal leaves

Species	SP ≥ 13.5	SP < 13.5	SAR ≥ 0.09	SCa < 101	SCa ≥ 101	SCa ≥ 107.5	SCa < 107.5	Species Total
Agropyron repens	0.21	0.16	0.61	0.94	0.73	0.15	0.32	3.12
Vicia americana	0.06	0.11	0.06	0.09	0.43	0.58	0.09	1.43
Taraxacum officinale	0	0.37	0.57	0	0	0.10	0.33	1.38
Agropyron inerme	0.03	0.16	0.40	0.13	0.18	0.43	0.03	1.35
Agropyron dasystachyum	0.18	0	0	0.06	0.33	0.33	0.42	1.32
Cirsium arvense	0.91	0.20	0	0	0.18	0	0	1.29
Poa pratensis	0.06	0.16	0.34	0.10	0.08	0.28	0.17	1.19
Bromus inermis	0.10	0.49	0	0	0	0	0.37	0.96
Agropyron trachycaulum	0	0	0	0.04	0	0	0.15	0.19
Phleum pratense	0	0.05	0	0	0	0	0	0.05
Property Total	1.55	1.71	1.99	1.36	1.92	1.87	1.88	12.28

Table B.39 Pipe pull out 45 plant variance explained (%) by soil properties at splitting criteria

Species	ENa 187	CEC 22.75	M.PR.10 2.08	SK 16.5	SMg 29	SP 14.95	SMg 17	Tree Total	Species Total
Agropyron repens	12.22	1.40	1.71	0.20	0.64	0.06	0.25	16.47	22.89
Festuca rubra	3.38	0.03	2.99	1.16	3.26	4.67	1.06	16.54	20.70
Cirsium arvense	2.66	8.15	0.30	0	1.03	6.42	4.71	23.29	26.54
Vicia americanum	0	0	0.85	0.68	0	0.14	0.10	1.77	4.99
Festuca saximontana	0.02	0.55	0	0	1.41	1.36	0	3.34	7.52
Equisetum arvense	0	0	0.07	0.10	0.08	0.02	0.19	0.47	3.53
Petasites sagittatus	0.17	0.20	1.20	0	0	0.31	0.61	2.49	9.71
Poa pratensis	0.04	0	0.04	0.09	0.12	0.02	0	0.31	0.99
Bromus inermis	0.19	0	0	0	0	0.10	0.21	0.50	2.38
Taraxacum officinale	0.06	0	0	0	0	0.03	0.07	0.16	0.76
Complexity Total	18.73	10.34	7.16	2.23	6.54	13.14	7.21	65.34	100.00

Table B.40 Pipe pull out 45 average transformed plant abundance (%) for soil properties at terminal leaves

Species	SMg ≥ 29	SMg < 17	SMg ≥ 17	SP < 14.9	SP ≥ 14.9	CEC ≥ 22.75	SK < 16.5	SK ≥ 16.5	Species Total
Agropyron repens	92.3	98.2	88.4	78.6	61.0	35.8	47.5	37.0	538.9
Festuca rubra	19.1	4.8	28.6	7.7	47.5	18.4	75.4	53.8	255.2
Cirsium arvense	11.1	10.9	11.3	34.9	57.3	80.2	0	45.4	251.2
Vicia americana	19.1	8.2	26.4	25.0	25.4	19.3	30.9	24.3	178.6
Festuca saximontana	0	0	0	26.2	0	23.0	0	0	49.2
Equisetum arvense	4.1	0	6.9	10.4	4.0	3.0	0	9.1	37.5
Petasites sagitta	0	0	0	0	0	0	0	16.4	16.4
Poa pratensis	3.9	0	6.6	7.7	0	3.0	0	0	21.2
Bromus inermis	0	0	0	0	0	0	0	9.5	9.5
Taraxacum officinale	0	0	0	0	0	0	0	5.4	5.4
Property Total	149.7	122.1	168.1	190.5	195.2	182.7	153.8	200.9	1363.1

Table B.41 Waste pit 51 plant variance explained (%) by soil properties at splitting criteria

Species	TN 0.08	SAR 0.15	M.PR.10 6.39	SAR 0.59	Tree Total	Species Total
Taraxacum officinale	0.90	5.81	0.13	2.76	9.60	11.86
Poa interior	2.43	4.77	12.02	0.38	19.60	21.06
Agropyron trachycaulum	3.56	0.94	0.01	3.40	7.91	8.42
Festuca saximontana	11.23	0	0	0	11.23	11.23
Hordeum jubatum	0.38	2.25	1.75	0	4.38	10.36
Poa compressa	0.31	1.28	3.53	0.04	5.15	10.17
Capsella bursa pastoris	0.59	2.94	0.02	4.30	7.85	8.78
Potentilla norvegica	0.44	2.67	0	3.56	6.67	11.76
Descurainia sophia	0.19	0	0.16	0.78	1.13	3.89
Phleum pratense	0.46	0	0	0	0.46	1.00
Trifolium pratense	0.46	0	0	0	0.46	1.00
Crepis tectorum	0.02	0	0	0.06	0.08	0.47
Complexity Total	20.96	20.65	17.61	15.27	74.49	100.00

Table B.42 Waste pit 51 average transformed plant abundance (%) for soil properties at terminal leaves

Species	TN < 0.08	M.PR.10 < 6.39	M.PR.10 ≥ 6.39	SAR ≥ 0.59	SAR < 0.59	Species Total
Taraxacum officinale	0.07	0	0.10	0.78	0.33	1.27
Poa interior	0	0	0.94	0.05	0.22	1.21
Agropyron trachycaulum	0.54	0	0.03	0.50	0	1.07
Festuca saximontana	0.77	0	0	0	0	0.77
Hordeum jubatum	0	0.50	0.14	0	0	0.63
Poa compressa	0	0.54	0.03	0.05	0	0.62
Capsella bursa pastoris	0	0.04	0	0	0.56	0.60
Potentilla norvegica	0	0	0	0	0.51	0.51
Descurainia sophia	0	0.04	0.14	0.24	0	0.42
Phleum pratense	0.15	0	0	0	0	0.15
Trifolium pratense	0.15	0	0	0	0	0.15
Crepis tectorum	0	0.03	0.04	0	0.06	0.13
Property Total	1.68	1.13	1.41	1.62	1.68	7.54

Table B.43 Walking path 56 plant variance explained (%) by soil properties at splitting criteria

Species	SCa 150	M.PR.5 1.63	CEC 27.55	Tree Total	Species Total
Poa alpina	17.92	7.33	0.18	25.43	30.47
Trifolium pratense	11.53	0	15.37	26.89	27.96
Festuca saximontana	2.56	0.33	1.31	4.20	18.51
Sonchus arvensis	1.00	0.10	4.90	6.00	14.67
Agropyron trachycaulum	0.43	2.45	0.08	2.96	7.46
Poa pratense	0.05	0	0.15	0.20	0.46
Taraxacum officinale	0.05	0	0.15	0.20	0.46
Complexity Total	33.54	10.21	22.14	65.89	100.00

Table B.44 Walking path 56 average transformed plant abundance (%) for soil properties at terminal leaves

Species	CEC < 27.6	CEC ≥ 27.6	M.PR.5 ≥ 1.6	M.PR.5 < 1.6	Species Total
Poa alpina	0.35	0.97	0	0.10	1.42
Trifolium pratense	0	0	0	0.89	0.89
Festuca saximontana	0	0.13	0.48	0.23	0.84
Sonchus arvensis	0	0.07	0.5	0	0.57
Agropyron trachycaulum	0.35	0	0	0.07	0.42
Poa pratense	0	0	0.09	0	0.09
Taraxacum officinale	0	0	0.09	0	0.09
Property Total	0.71	1.17	1.16	1.27	4.31

APPENDIX C

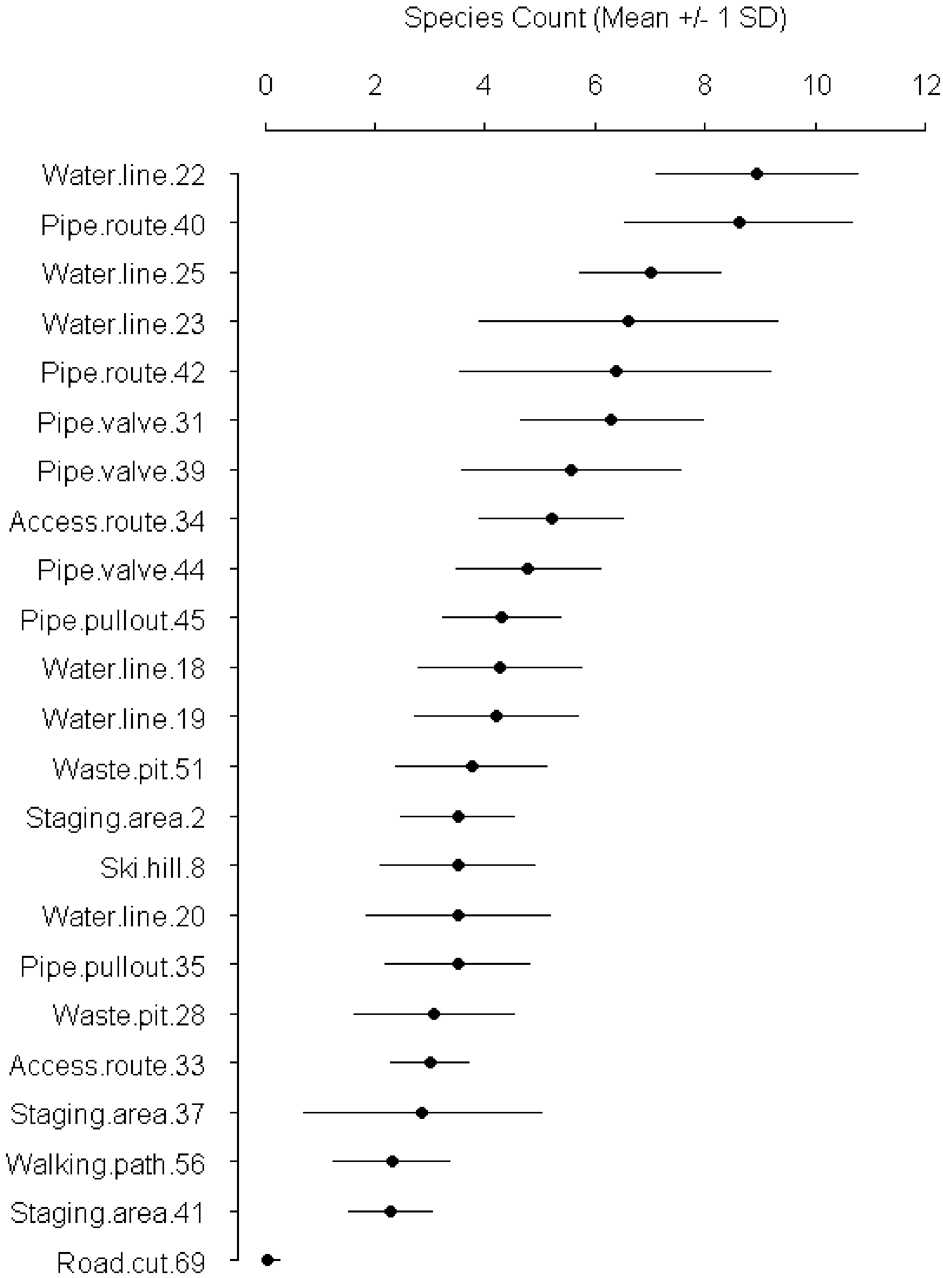


Figure C.1 Average number of species per plot for all research sites

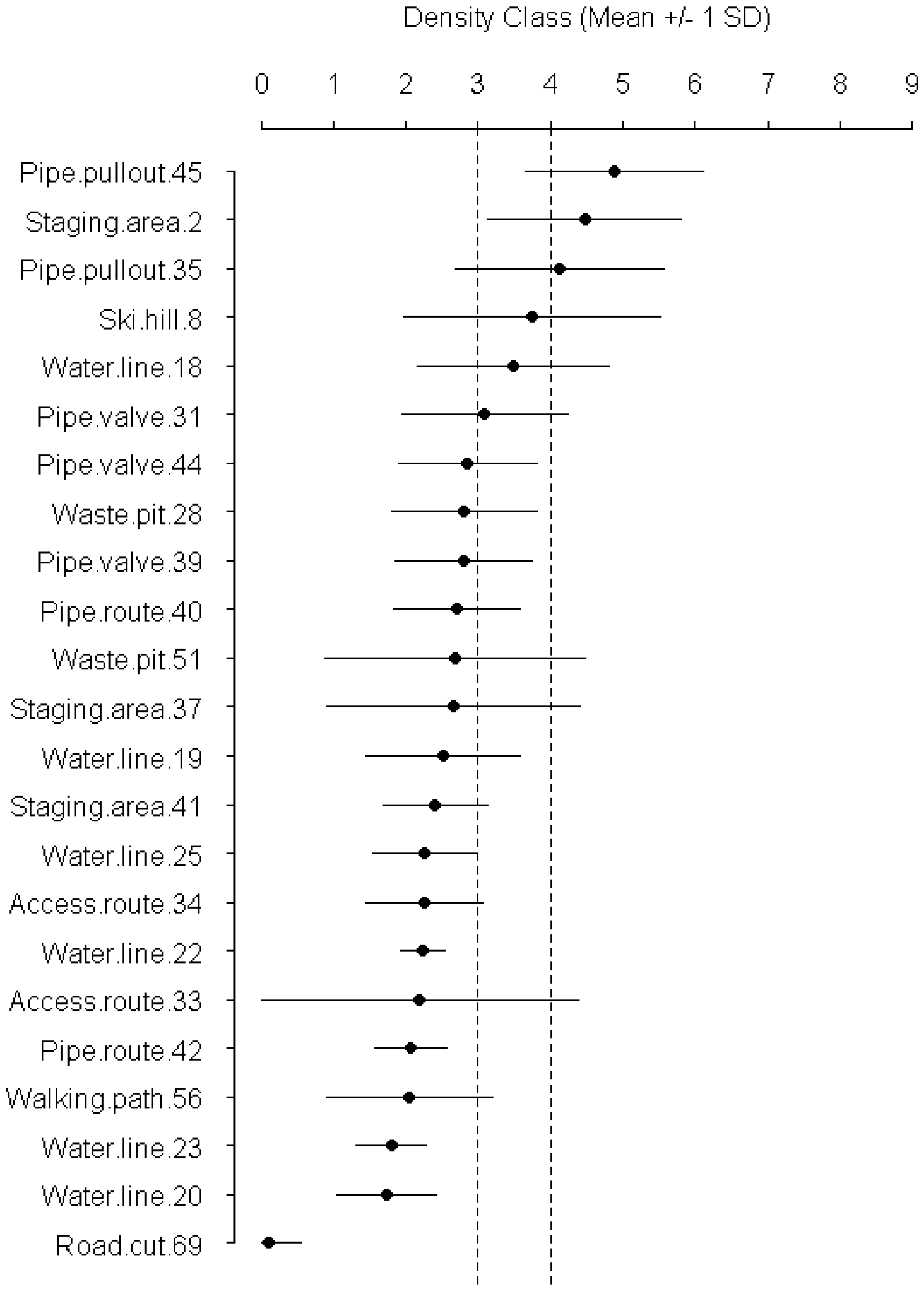


Figure C.2 Average species density class per plot for all research sites

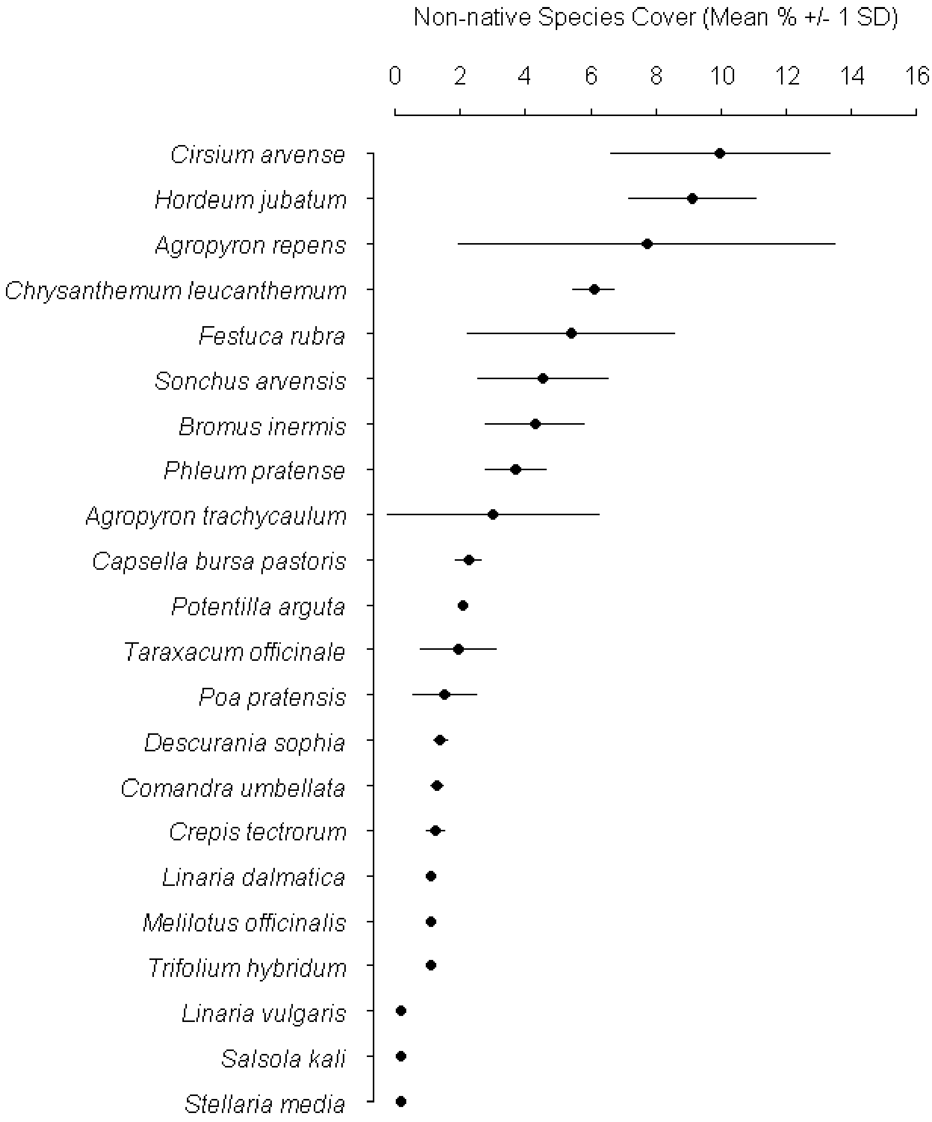


Figure C.3 Average non-native species percent cover for all research sites

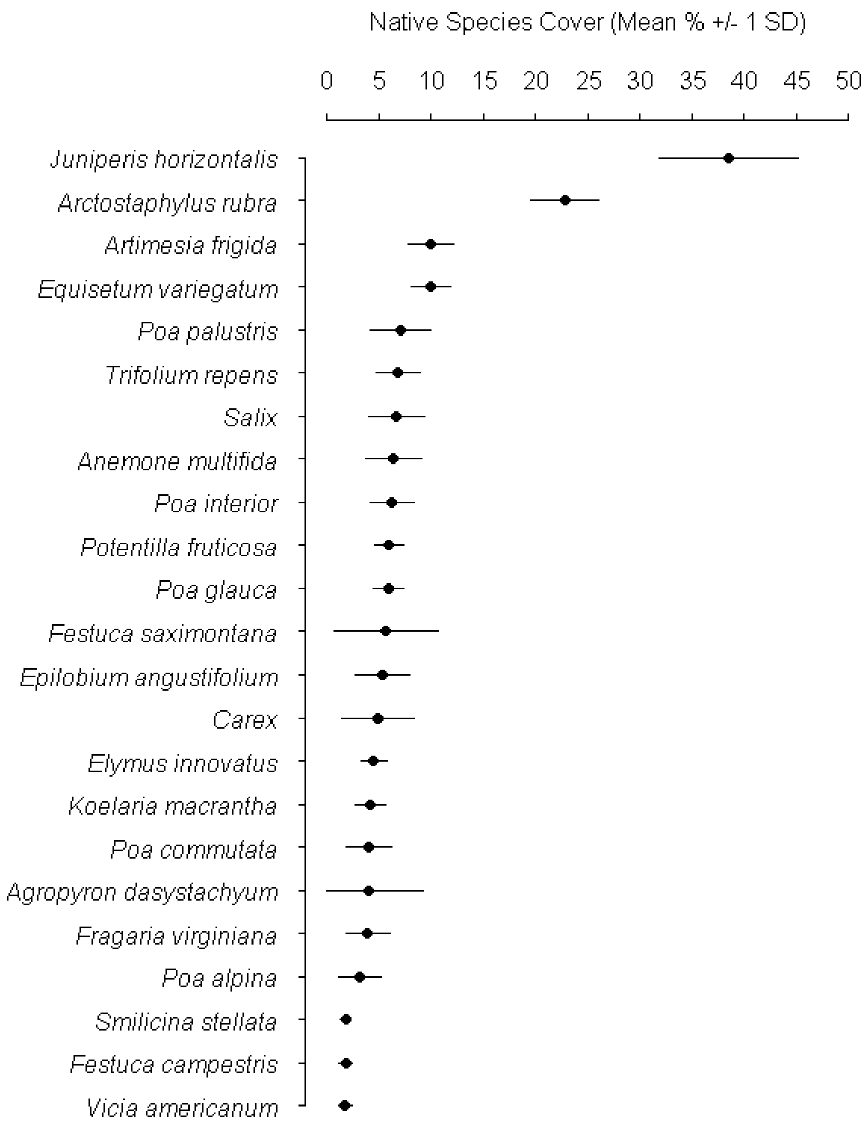


Figure C.4 Average native species percent cover for all research sites

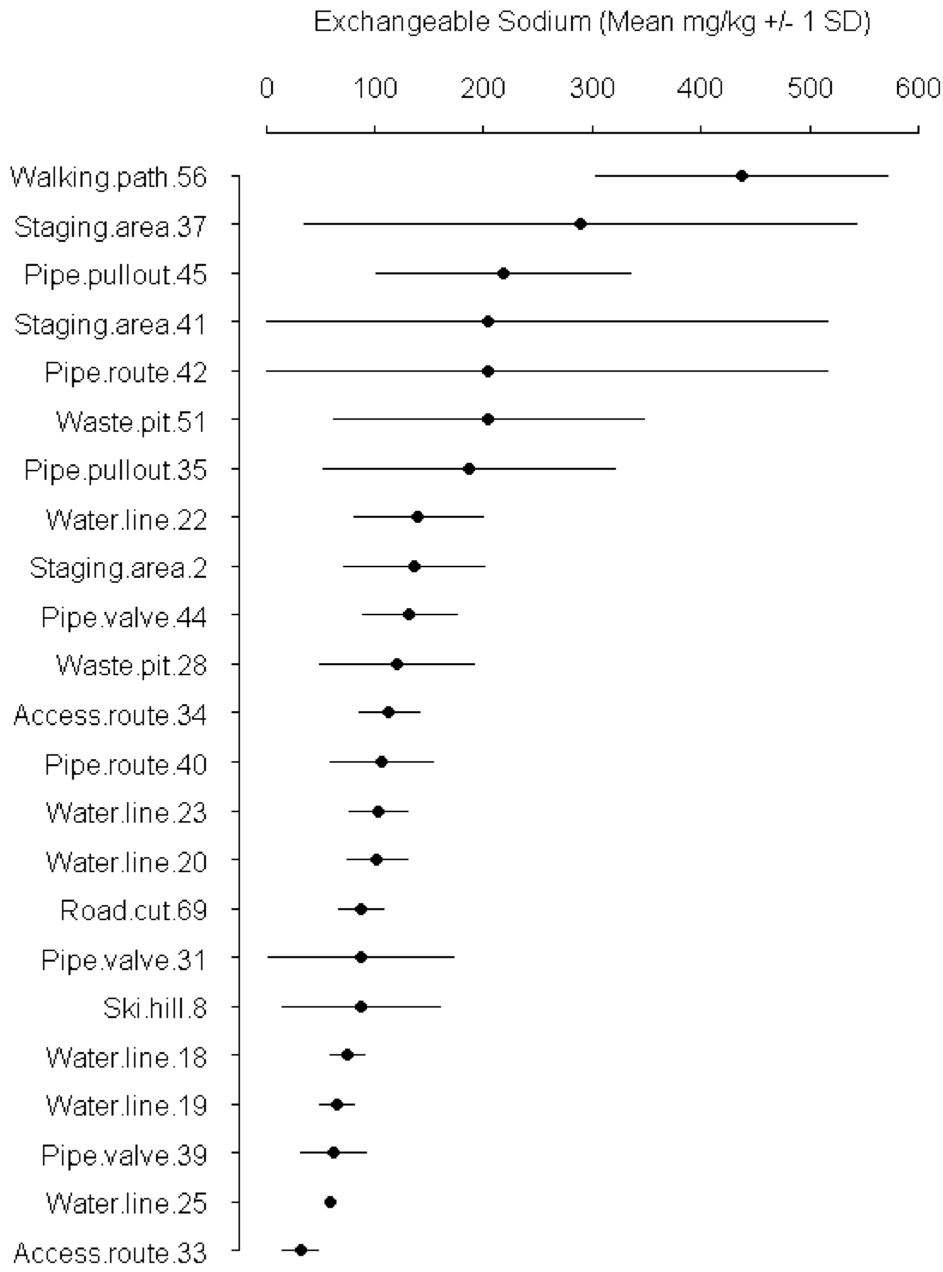


Figure C.5 Average exchangeable sodium for all research sites

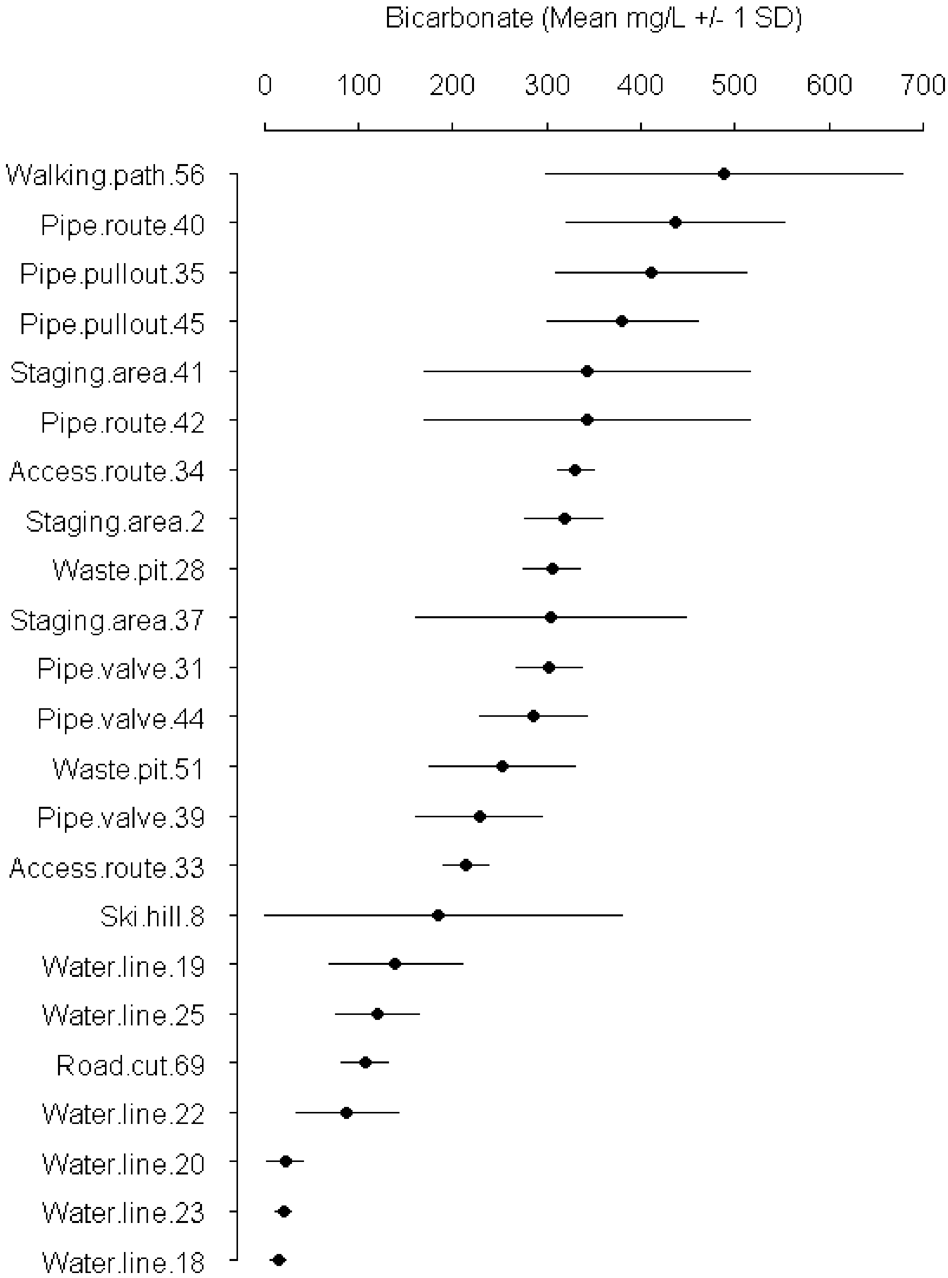


Figure C.6 Average bicarbonate for all research sites

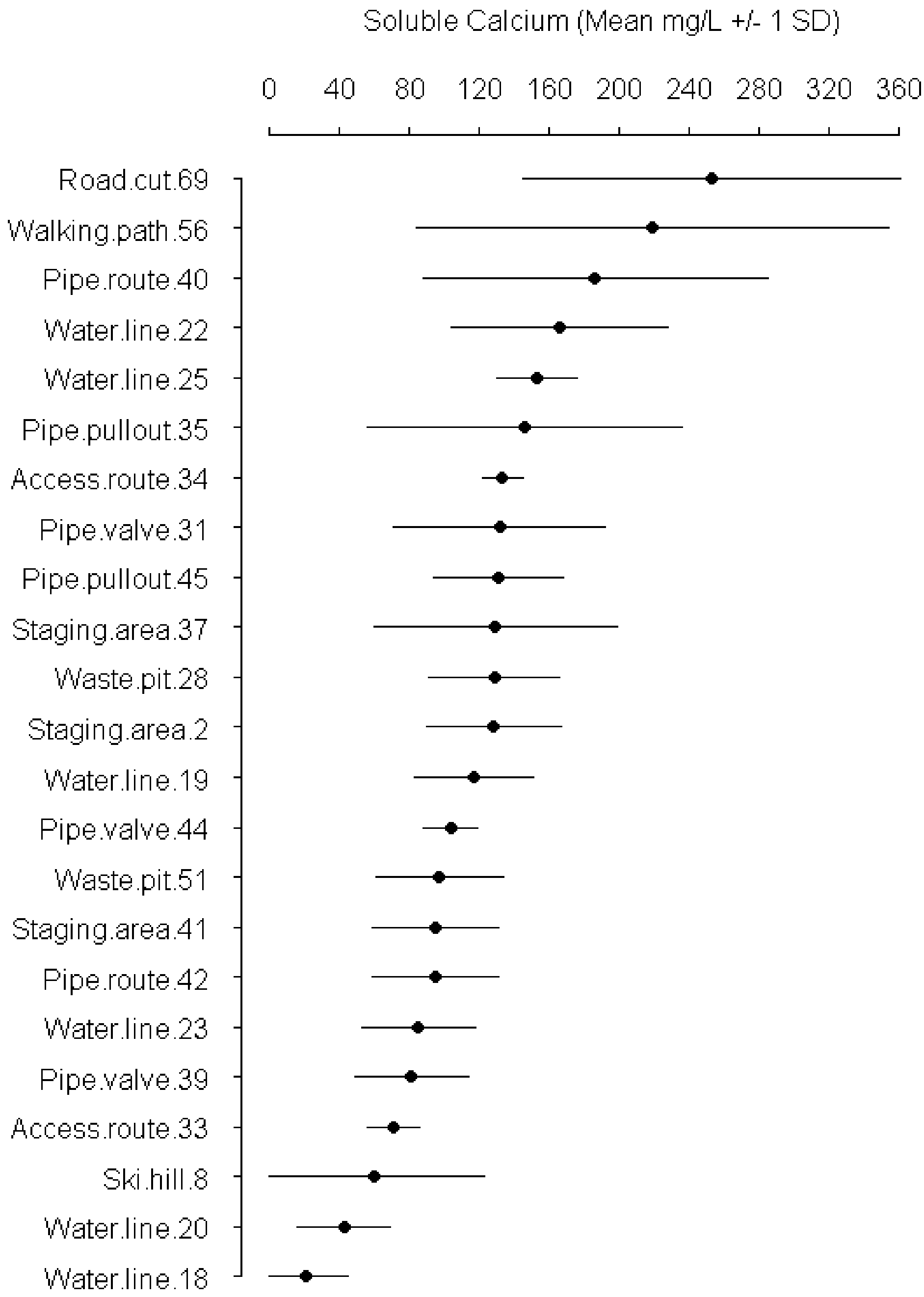


Figure C.7 Average soluble calcium for all research sites

Table C.1 Average number of species per plot for all research sites

Name	Mean	Standard Deviation
Water.line.22	8.94	1.83
Pipe.route.40	8.62	2.06
Water.line.25	7.00	1.26
Water.line.23	6.60	2.70
Pipe.route.42	6.38	2.83
Pipe.valve.31	6.29	1.65
Pipe.valve.39	5.56	2.00
Access.route.34	5.20	1.30
Pipe.valve.44	4.79	1.32
Pipe.pullout.45	4.30	1.08
Water.line.18	4.26	1.48
Water.line.19	4.20	1.47
Waste.pit.51	3.75	1.36
Staging.area.2	3.50	1.03
Ski.hill.8	3.50	1.41
Water.line.20	3.50	1.67
Pipe.pullout.35	3.50	1.32
Waste.pit.28	3.08	1.44
Access.route.33	3.00	0.71
Staging.area.37	2.87	2.17
Walking.path.56	2.30	1.06
Staging.area.41	2.29	0.76
Road.cut.69	0.05	0.22

Table C.2 Average species density class per plot for all research sites

Name	Mean	Standard Deviation
Pipe.pullout.45	4.88	1.22
Staging.area.2	4.47	1.33
Pipe.pullout.35	4.13	1.44
Ski.hill.8	3.75	1.77
Water.line.18	3.49	1.33
Pipe.valve.31	3.09	1.15
Pipe.valve.44	2.86	0.95
Waste.pit.28	2.81	1.00
Pipe.valve.39	2.80	0.93
Pipe.route.40	2.71	0.87
Waste.pit.51	2.68	1.80
Staging.area.37	2.65	1.75
Water.line.19	2.51	1.06
Staging.area.41	2.40	0.72
Water.line.25	2.26	0.71
Access.route.34	2.26	0.81
Water.line.22	2.24	0.31
Access.route.33	2.19	2.19
Pipe.route.42	2.07	0.49
Walking.path.56	2.05	1.15
Water.line.23	1.80	0.49
Water.line.20	1.73	0.68
Road.cut.69	0.10	0.45

Table C.3 Average percent non-native species cover for all research sites

Species Code	Mean	Standard Deviation
Cirsium arvense	9.978	3.357
Hordeum jubatum	9.125	1.967
Agropyron repens	7.724	5.767
Chrysanthemum leucanthemum	6.100	0.626
Festuca rubra	5.402	3.177
Sonchus arvensis	4.552	1.990
Bromus inermis	4.293	1.498
Phleum pratense	3.700	0.931
Agropyron trachycaulum	3.001	3.260
Capsella bursa pastoris	2.250	0.401
Potentilla arguta	2.100	0.118
Taraxacum officinale	1.938	1.172
Poa pratensis	1.506	0.970
Descurainia sophia	1.400	0.210
Comandra umbellata	1.300	0.170
Crepis tectrorum	1.238	0.276
Linaria dalmatica	1.100	0.062
Melilotus officinalis	1.100	0.087
Trifolium hybridum	1.100	0.062
Linaria vulgaris	0.200	0.011
Salsola kali	0.200	0.011
Stellaria media	0.200	0.011

Table C.4 Average percent native species cover for all research sites

Species Code	Mean	Standard Deviation
Juniperis horizontalis	38.517	6.641
Arctostaphylus rubra	22.800	3.308
Artemisia frigida	10.020	2.202
Equisetum variegatum	9.933	1.882
Poa palustris	7.091	2.874
Trifolium repens	6.838	2.065
Salix	6.704	2.729
Anemone multifida	6.426	2.675
Poa interior	6.261	2.099
Potentilla fruticosa	5.967	1.338
Poa glauca	5.945	1.439
Festuca saximontana	5.669	4.982
Epilobium angustifolium	5.354	2.566
Carex	4.874	3.499
Elymus innovatus	4.546	1.280
Koelaria macrantha	4.172	1.412
Poa commutata	4.003	2.188
Agropyron dasystachyum	3.968	5.230
Fragaria virginiana	3.938	2.127
Poa alpina	3.128	2.051
Smilicina stellata	1.824	0.550
Festuca campestris	1.800	0.590
Vicia americana	1.791	0.715

Table C.5 Average bicarbonate for all research sites

Name	Mean	Standard Deviation
Walking.path.56	488.40	189.17
Pipe.route.40	436.54	115.26
Pipe.pullout.35	410.15	101.01
Pipe.pullout.45	380.35	80.69
Staging.area.41	342.29	172.89
Pipe.route.42	342.29	172.89
Access.route.34	330.20	19.07
Staging.area.2	318.75	41.19
Waste.pit.28	305.15	30.14
Staging.area.37	304.13	142.78
Pipe.valve.31	302.35	34.34
Pipe.valve.44	285.56	56.50
Waste.pit.51	252.50	76.66
Pipe.valve.39	228.19	66.77
Access.route.33	214.89	23.90
Ski.hill.8	183.88	195.70
Water.line.19	138.85	70.80
Water.line.25	121.00	44.33
Road.cut.69	107.00	24.80
Water.line.22	88.00	53.95
Water.line.20	22.16	19.87
Water.line.23	20.20	8.56
Water.line.18	15.37	8.09

Table C.6 Average exchangeable sodium for all research sites

Name	Mean	Standard Deviation
Walking.path.56	436.70	134.10
Staging.area.37	289.27	253.69
Pipe.pullout.45	217.85	116.23
Staging.area.41	204.71	311.03
Pipe.route.42	204.71	311.03
Waste.pit.51	204.58	142.14
Pipe.pullout.35	186.40	133.74
Water.line.22	139.89	58.92
Staging.area.2	136.13	64.82
Pipe.valve.44	132.28	43.26
Waste.pit.28	120.46	71.20
Access.route.34	113.20	27.84
Pipe.route.40	106.38	47.17
Water.line.23	103.40	26.79
Water.line.20	102.35	27.04
Road.cut.69	87.90	20.73
Pipe.valve.31	87.82	85.40
Ski.hill.8	87.63	72.66
Water.line.18	74.37	15.44
Water.line.19	65.15	15.57
Pipe.valve.39	62.25	29.77
Water.line.25	59.33	5.13
Access.route.33	31.67	16.19

Table C.7 Average soluble calcium for all research sites

Name	Mean	Standard Deviation
Road.cut.69	252.85	107.85
Walking.path.56	218.90	134.48
Pipe.route.40	186.54	97.99
Water.line.22	166.22	61.60
Water.line.25	153.17	23.39
Pipe.pullout.35	146.30	89.90
Access.route.34	133.60	11.19
Pipe.valve.31	131.76	60.35
Pipe.pullout.45	131.30	36.77
Staging.area.37	129.27	69.33
Waste.pit.28	128.77	37.63
Staging.area.2	128.69	38.45
Water.line.19	117.10	34.12
Pipe.valve.44	103.83	15.88
Waste.pit.51	97.67	36.49
Staging.area.41	95.29	35.96
Pipe.route.42	95.29	35.96
Water.line.23	85.80	32.46
Pipe.valve.39	81.75	32.48
Access.route.33	71.56	15.08
Ski.hill.8	60.75	61.99
Water.line.20	42.95	26.79
Water.line.18	21.05	24.38