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Vegetation Response to Prescribed Fire in the Kenai Mountains, Alaska

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Cover photographs: (top) prescribed burns at Caribou East in the foreground and Caribou West in the background (left side), photo by Michele Potkin (1995); (bottom left) Caribou West burn, Forest Service archive (1984); (bottom right) birch seedlings along the Caribou West monitoring transect, photo by Tina Boucher (1999).

Abstract

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Between 1977 and 1997, 4000 ha were burned to promote regeneration of tree and shrub species used for browse by moose (*Alces alces*) in the Kenai Mountains. Species composition was documented along burned and unburned transects at 17 prescribed burn sites. Relationships among initial vegetation composition, physical site characteristics, browse species abundance, and competitive herbaceous vegetation were examined to determine controls on browse species regeneration after prescribed burning. Browse species abundance after burning was inversely related to *Calamagrostis canadensis* Michx. Beauv. (bluejoint reedgrass) abundance prior to burning. *Calamagrostis canadensis* abundance was related to specific landscape characteristics. Depositional slopes, such as fluvial valley bottoms and toe slopes, often featured soils with deep, loamy surface horizons. Sites with these characteristics generally showed large increases in *C. canadensis* cover after prescribed burning, even when *C. canadensis* was a low percentage (3 percent) of the canopy cover prior to burning. The most important preburn variables for predicting postburn browse species abundance were preburn *C. canadensis* cover and the type of surficial deposit. Site conditions that are favorable to *C. canadensis* may be problematic for successful regeneration of browse species, especially if browse species are not present in the initial composition.

Keywords: Chugach National Forest, prescribed fire, vegetation change, *Calamagrostis canadensis*, moose habitat, nonmetric multidimensional scaling.

Summary

The Chugach National Forest has been using prescribed fire to manage wildlife habitat in the Kenai Mountains since 1977. Increasing moose (*Alces alces*) winter range was the primary goal of past burning. Winter range tree species include *Betula papyrifera* Marsh. (paper birch), *Populus balsamifera* ssp. *trichocarpa* (Torr. & Gray ex Hook.) Brayshaw (black cottonwood), *P. tremuloides* Michx. (quaking aspen), *Salix scouleriana* Barratt ex Hook. (Scouler willow), *S. barclayi* Anderss. (Barclay willow), and other tall *S.* L. species.

The purpose of this study was to assess vegetation response to burning and provide guidelines for future prescribed burn planning and execution. Relationships among preburn and postburn vegetation composition, physical site characteristics, browse species abundance, and fire severity were evaluated. With few exceptions, browse species increased in abundance after burning where they were present in the initial composition (measurements were made 15 to 20 years postburn).

Early-successional grasses and forbs such as *Epilobium angustifolium* L. (fireweed) and *Calamagrostis canadensis* (Michx.) Beauv. (bluejoint reedgrass) also increased. Browse species abundance was inversely related to *C. canadensis* abundance. Moist sites with deep loamy soil generally showed large increases in *C. canadensis* abundance after burning. These site characteristics typically were found on high-quality depositional slopes such as fluvial valley bottoms and toe slopes.

Late-successional and forest-associated species decreased after burning; these species include conifer seedlings, saplings, and trees, *Rubus pedatus* Sm. (fiveleaf bramble), *Linnaea borealis* L. (twinflower), *Dryopteris dilatata* auct. non (Hoffmann) Gray (wood fern), and *Menziesia ferruginea* Sm. (rusty menziesia). Dwarf shrubs such as *Vaccinium uliginosum* L. (bog blueberry), *V. vitis-idaea* L. (lowbush cranberry), and *Empetrum nigrum* L. (crowberry) also tended to decrease.

Contents

Introduction

The Chugach National Forest has been using prescribed fire to manage wildlife habitat in the Kenai Mountains since 1977. Between 1977 and 1997, over 4000 ha have been burned to improve winter range for moose (*Alces alces*). Winter range in the region occurs from 100 to 400 m elevation and is considered the most limiting factor for survival and vigor of moose (Weixelman et al. 1998).

Fire in Alaska tends to improve range conditions for moose by improving the quality and availability of deciduous woody plants such as *Betula papyrifera* Marsh. (paper birch), *Populus balsamifera* ssp. *trichocarpa* (Torr. & Gray ex Hook.) Brayshaw (black cottonwood), *P. tremuloides* Michx. (quaking aspen), *Salix scouleriana* Barratt ex Hook. (Scouler willow), *S. barclayi* Anderss. (Barclay willow), and other tall *Salix* L. species (Spencer and Halaka 1964). Moose on the Kenai Peninsula depend on early-seral hardwoods for winter browse (Oldemeyer 1983, Spencer and Halaka 1964).[1] There is evidence that the moose population on the Kenai has fluctuated over the past 150 years (Lutz 1960), likely as a result of fire. Several authors have reported moose population peaks on the Kenai Peninsula associated with large burns (LeResche et al. 1974, Spencer and Chatelain 1953). Widespread fires burned between 1871 and 1910 creating favorable, but transient, moose browse on the Kenai Peninsula (Spencer and Halaka 1964). The abundance and distribution of moose and wildfire on the Kenai Peninsula prior to 1900 is not well documented, though it is likely that moose populations varied with abundance and availability of high-quality habitat (Lutz 1960).

Extensive *Dendroctonus rufipennis* (Kirby) (spruce bark beetle) mortality in south-central Alaska over the past decade has increased resource managers' interest in using prescribed burning to promote forest regeneration, reduce fuel loads, and enhance wildlife habitat. Quantifying the effects of prescribed fire on vegetation composition across the landscape facilitates the use of fire as an effective management tool.

The Chugach National Forest has conducted intensive vegetation monitoring in prescribed burns since the inception of the burn program in 1977. Initial progress reports suggest that, in general, browse production has increased on the burn units. Some vegetation types, however, did not respond well to burning (Weixelman 1987). A wide range of results may be achieved depending on a number of variables including initial vegetation composition and severity of burn (Viereck and Schandelmeier 1980). Species such as *Calamagrostis canadensis* (Michx.) Beauv. (bluejoint reedgrass) may negatively affect the establishment and survival of browse species such as *Salix* species and *Betula papyrifera* through competitive interactions (Holsten et al. 1995) and microsite modification, specifically, changes in the soil thermal regime (Cater and Chapin 2000, Hogg and Lieffers 1991). Season of burn and fire severity, including lighting technique and preburn fuel treatment, are variables that can be manipulated to achieve desired fire effects on a given site. Identification of factors that limit or promote the abundance of woody regeneration will enable managers to plan for and reduce the effects of competition and soil insulation on forest regeneration and browse production.

The purpose of this analysis is to assess vegetation response to prescribed burning across the landscape in order to provide guidelines for managers regarding the use of fire for habitat enhancement and landscape-level planning. This analysis evaluates the relationships among initial vegetation composition, physical site characteristics,

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[1] See appendix 1 for a list of common and scientific names of plant species.

browse abundance, competitive herbaceous vegetation, and fire severity. It is hypothesized that postburn vegetation composition is strongly influenced by preburn vegetation composition, and vegetation response to fire is influenced by disturbance severity, abundance of *Calamagrostis canadensis*, and site characteristics such as land type, surficial deposit, and soil depth. The following review addresses fire ecology of species discussed in this study and the effects of fire on vegetation development on the Kenai Peninsula.

Autecology of Selected Species

Browse species—The major browse species under consideration for this study include *Populus tremuloides,* and *P. balsamifera* ssp. *trichocarpa*, *Betula papyrifera*, *Salix scouleriana*, *S. barclayi*, and other tall shrub *Salix* species. *Populus balsamifera* ssp. *balsamifera* (balsam poplar) also occurs in the study area, but because *P. balsamifera* ssp. *trichocarpa* (black cottonwood) is more common, and the two species are difficult to differentiate when young capsules are not present (Hulten 1968), in this study, both were considered *P. balsamifera* ssp. *trichocarpa*. The reproductive strategy of individual browse species significantly affects their responses to fire. The ability of a species to establish and persist after disturbance determines the successional development of the stand. In general, these browse species regenerate most successfully in large openings under full sunlight (Collins 1996). Each has the capacity to resprout vigorously after fire. Reproductive variables and seedbed requirements for each species are described in table 1. Additional information for each species is described below.

Betula papyrifera seed requires mineral soil for germination, but organic matter nearby enhances seedling survival and growth (Haeussler and Coates 1986, Safford et al. 1990). The ability of *B. papyrifera* to resprout from the trunk declines with age (Viereck and Schandelmeier 1980). *Betula papyrifera* occurs on a variety of site types but grows most abundantly on upland terrain (Foster and King 1986, Haeussler and Coates 1986, Safford et al. 1990).

Populus tremuloides produces large quantities of light tufted seeds, although reproduction is generally through sprouts from lateral roots (Viereck and Schandelmeier 1980). Root suckering is most successful when the entire clone is top-killed (Collins 1996) and is strongly linked to soil temperature (Zasada and Schier 1973). The growth of root suckers tends to decrease with increasing fire severity (Perala 1974). Within the study area, the distribution of *P. tremuloides* is patchy and is concentrated on warmer, south-facing slopes.

Populus balsamifera also produces large quantities of light tufted seeds and is capable of producing root suckers and sprouting from the stem. Suckering is considered the primary means of expansion but not necessarily the primary means of recovery after disturbance (Haeussler and Coates 1986, Krasny et al. 1988). Fire stimulates root suckering where *P. balsamifera* is present in a stand in any successional stage (Haeussler and Coates 1986). Zasada et al. (1981) found sucker production after logging was most common where mineral soil had been exposed. *Populus balsamifera* has high nutrient requirements and displays optimal growth on deep alluvial soils (Haeussler and Coates 1986).

Salix species produce large quantities of light-tufted seeds in early summer, and crowns sprout prolifically even when plants are mature to decadent (Viereck and Schandelmeier 1980). Seven species of willow occurred in the study sites: *S. scouleriana, S. alaxensis* (Anderss.) Coville (feltleaf willow)*, S. bebbiana* Sarg.

Table 1—Seed, seedbed, and vegetative reproduction variables for *Betula papyrifera* (paper birch), *Populus tremuloides* (aspen), *P. balsamifera* (black cottonwood), and *Salix scouleriana* (willow) in Alaska

Variable	Paper birch	Quaking aspen	Cottonwood	Scouler willow
Tree age seed production in natural stands:				
First abundant production	15 years[a]	20 years[a]	[a]	Sprouts bear in 2 to 3 years
Period of optimum production	45 to 100+ years	50 to 70 years[a]	[a]	[a]
Seed ripening	May be as early as July, but most commonly Aug.–Sept.[a]	June[a]	May or June[a]	End of May
Dispersal:				
Initial	July–Sept.[a]	June[a]	Early June[a]	As early as end of May
Duration	90% by Dec.	June–July[a]	June[a]	[a]
Seed quantity (seeds/acre)	2.2 to 300 million	Up to 200 million[a]	[a]	[a]
Seed quality (% viable seed)	1 to 42% (average 17%)	May be very high (98%) viability of short duration under natural conditions[a]	[a]	[a]
Dispersal distance	At least 2 to 3 tree heights, greater distance on snow	Long distance[a]	Long distance[a]	Long distance[a]
Periodicity of maximum seed crops	2 to 4 years	4 to 5 years[a]	Large quantities every year[a]	[a]
Viable seed: seedling ratio:				
Mineral soil	20 to 400[a]	Many thousands[a]	Many thousands[a]	[a]
Organic matter	400+[a]	Rare[a]	Rare[a]	[a]
Seedbed requirements (i.e., believed most optimal under Alaska conditions)	Mineral soil[a]	Mineral soil[a]	Mineral soil[a]	Mineral soil
Vegetative reproduction:				
Type	Sprouting of dormant buds	Root suckers	Root suckers	Sprouting of dormant buds
Capacity	Common under some conditions[a]	Very common in fire-killed aspen stands	Common[a]	Common
Duration of seed viability	[a]	Short lived	Short lived	Short lived

[a] Data not available for Alaska.

Sources: adapted from Viereck 1973, Viereck and Schandelmeier 1980, Zasada 1971, 1986.

(Bebb willow)*,* *S. commutata* Bebb (undergreen willow)*,* *S. sitchensis* Sanson ex Bong. (Sitka willow)*,* *S. barclayi,* and *S. pulchra* Cham (tea-leaf willow). Of these seven, *S. barclayi* and *S. scouleriana* were the most abundant. *Salix barclayi* occurs on a variety of habitats, but in the study area, it often can be found in continuous thickets in moist, poorly drained sites with fine-textured soils in association with *S. pulchra* (Collet 2002). The remaining willows sampled in the study occur across a range of habitats from moist riparian to upland, but in general, do not occur on sites that are poorly drained (Argus 1973, Collet 2002). Of the willows in the study area, *S. scouleriana* is most common on upland slope positions and often occurs in association with birch and aspen (Argus 1973, Collet 2002, Viereck and Little 1972).

Betula nana L. (dwarf birch) and *B. glandulosa* Michx. (bog birch) occur in the study area and are used by moose but are not preferred browse species. Because *B. nana* and *B. glandulosa* are reported to hybridize where the ranges overlap (Hulten 1968, Viereck and Little 1972), the two species were grouped together as *B. nana* for this analysis. In Alaska, both *B. nana* and *B. glandulosa* occur on poorly drained soils and sites underlain with permafrost (Moss 1953, Pojar et al. 1984) but also can occur on dry, stony slopes (Viereck and Little 1972). Both species have low nutrient requirements (Krajina et al. 1982) and commonly occur in the understory of many black and white spruce taiga communities of Alaska and Canada (Foote 1983, Viereck and Little 1972). Both *B. nana* and *B. glandulosa* produce prolific seed crops, but vegetative regeneration by layering is more common. When aboveground plant parts of *B. nana* and *B. glandulosa* are killed by fire, these plants often sprout from the base of the stem (Parminter 1983).

Dwarf ericaceous shrubs—The following dwarf and low ericaceous shrubs occurred in the study area: *Vaccinium uliginosum* L. (bog blueberry), *V. caespitosum* Michx. (dwarf blueberry), *V. vitis-idaea* L. (lowbush cranberry), and *Ledum palustre* L. (Labrador tea). *Empetrum nigrum* L. (crowberry) also occurred in the study area and will be included with the ericaceous group owing to its similar growth form and ecology. Within the study area, dwarf ericaceous shrubs consistently occurred on certain site types. Taken as a group, these shrubs can be used to indicate site quality. *Vaccinium* species thrive on acid soils and can grow on relatively infertile, nitrogen-poor sites (Korcak 1988). Subtle differences in rooting structure and depth may help explain why these shrubs did not always respond similarly to burning. For example, cover of *E. nigrum* and *V. uliginosum* generally decreased after burning, whereas cover of *V. caespitosum* generally increased.

Vaccinium uliginosum and *E. nigrum* have wide ecological amplitude and occur on well-drained to poorly drained sites. Both have low nutrient requirements and are often found on cold, nitrogen-poor sites (Henry et al. 1990, Klinka et al. 1989). Both *V. uliginosum* and *E. nigrum* root in the organic layer or near the soil surface and sprout from rhizomes or rootstocks following fire (Lutz 1956, Parminter 1983, Viereck 1983). Postfire regeneration is most successful where the organic layer is not consumed (Chapin and Van Cleve 1981). In the Wickersham Dome Fire near Fairbanks, Alaska, fire severity affected the postburn regeneration of these shrubs. Five severity classes were assigned to indicate the degree to which the organic layer was removed: (1) heavily burned—deep ash layer present, organic material in the soil consumed or nearly so to mineral soil; (2) moderately burned—organic layer partially consumed, shallow ash layer present, parts of woody twigs remaining; (3) lightly burned—plants charred but original form of mosses and twigs visible; (4) scorched—moss and other plants brown or yellow, but species usually identifiable; and (5) unburned—plant parts green and unchanged (Viereck et al. 1979). Severe fires tended to suppress postburn recovery of *V. uliginosum* and *E. nigrum.* Four years after the Wickersham Dome Fire near Fairbanks, Alaska, *V. uliginosum* recovery in *Picea mariana* (Mill.) B.S.P. (black spruce) stands was higher in lightly burned than in heavily burned stands. Percentage of cover of *E. nigrum* was slightly less in lightly burned stands than in the control for 4 years following the burn, whereas in severely burned stands, *E. nigrum* was absent for 4 years following the burn (Foote 1983, Viereck and Dyrness 1979).

Like the other dwarf huckleberries, *V. caespitosum* has low nutrient requirements (Korcak 1988). Rhizomes are relatively shallow in the soil allowing *V. caespitosum* to survive most light to moderate fires; however, severe fires may be extremely damaging to the species (Hungerford 1986).

Vaccinium vitis-idaea often grows on low-fertility sites (Holloway 1981). Rooting is shallow, although rhizomes may penetrate to mineral soil and plants may possess a taproot (Smith 1962). Like *V. caespitosum, V. vitis-idaea* often survives light to moderate fires, but underground propagules may be killed in severe fires (Viereck and Schandelmeier 1980). Four years after the Wickersham Dome Fire near Fairbanks, Alaska, *V. vitis-idaea* recovery in black spruce stands was higher in lightly burned than in heavily burned stands (Viereck and Dyrness 1979).

Competitive herbaceous vegetation—*Calamagrostis canadensis* and *Epilobium angustifolium* L. (tall fireweed) are herbaceous perennials that reproduce vegetatively from shallow underground rhizomes. Both survive in midseral spruce-hardwood forests and mature spruce forests but often increase greatly in vigor when the overstory is removed (Lieffers and Stadt 1994).

Calamagrostis canadensis is common throughout the study area. Its range in Alaska extends from the south-central region to the interior and northern regions. Throughout its range, it has been reported on a variety of sites, but within the study area, *C. canadensis* generally occurs on moist fine-textured soils (Mueller-Dombois and Sims 1966). Mitchell and Evans (1966) report that *C. canadensis* will readily recolonize logged-over areas in the boreal forest, reducing the occurrence of hardwood seed germination. A dense mat of *C. canadensis* may compete with tree seedlings for resources or change the thermal regime of the soil, thereby reducing the potential for seedling establishment and growth (Cater and Chapin 2000). Tree seedlings also may be subjected to shading and smothering effects of the grass, which often reaches heights of 1 to 2 m (Mitchell and Evans 1966). Lieffers et al. (1993) found that where *C. canadensis* occurs abundantly prior to disturbance (i.e., in every square meter), rapid postdisturbance recolonization can be expected unless the clones are killed by a deep burn or through other site treatment. According to Sims and Mueller-Dombois (1968), most of the rhizome growth occurs within 4 to 5 cm of the surface of the mineral soil.

Calamagrostis canadensis is a prolific seed producer, although regeneration via underground rhizomes is the most common form of spread except in areas of severe burning (Viereck and Schandelmeier 1980). *Calamagrostis canadensis* propagates in May or June from rhizomes or seeds, which mature in late September. Conn (1990) found that buried seeds retained 9-percent viability after nearly 5 years.

Epilobium angustifolium is an early-seral species that occurs abundantly after fire but generally becomes sparse in mature forests (Foote 1983). *Epilobium angustifolium* produces prolific, light seeds and can readily invade severely burned areas. Rhizomes are shallow (2 to 4 cm deep in the soil) and often are killed in fires of moderate to high intensity (Moss 1936). On burned sites, invasion by seed is considered more common than vegetative reproduction, although rhizomes can invade a burned area from nearby (Viereck and Schandelmeier 1980). *Epilobium angustifolium* litter is less persistent than that of *Calamagrostis canadensis* (Hogg and Lieffers 1991). In a comparison of soil thermal regimes under *C. canadensis* cover and *E. angustifolium* cover, warmer soils occurred under *E. angustifolium* (Hogg and Lieffers 1991). Eis (1981) suggested that *E. angustifolium* is not as great an inhibitor of white spruce seedlings as *C. canadensis*.

Study Area

Topography, geology, and geomorphology—The upper Kenai Peninsula can be divided into two distinct physiographic areas, the Kenai Lowlands on the western side of the peninsula and the Kenai Mountains on the eastern side (DeVelice et al. 1999). The study area is in the Chugach National Forest portion of the Kenai Mountains excluding the eastern coastal mountains bordering Prince William Sound (figs. 1 and 2). The Kenai Mountains feature rugged alpine terrain dissected by glacially carved valleys. Elevations range from sea level to 1900 m. The main geologic process involved in mountain formation is the uplifting of sedimentary rock accreted mainly during the late Cretaceous to early Paleocene time. More recently, periods of glaciation have shaped the landscape. The lithology consists of metasedimentary rock with minor occurrences of limestone (Plafker et al. 1994).

The general area of the study is the forested lower slopes and valley bottoms of the Kenai Mountains region. Six land type associations (ECOMAP 1993) have been described in the Kenai Mountains (Davidson 1998) and are listed in table 2. Land type associations are defined based on “similarities in geomorphic process, geologic rock type, soil complexes … and plant associations” (ECOMAP 1993). These slopes have been shaped by glaciation and depositional processes. Surficial deposits (the soil parent material) are derived from either glacial or nonglacial processes. Glacial deposits include ablation till deposited on the side slopes, hills, and valley bottoms, and glacial outwash; nonglacial deposits include alluvium and colluvium (material eroded from mountain side slopes by gravity and running water accumulating in concave lower slopes and toe slopes), as well as bedrock residuum. Surficial deposits have a strong influence on the hydrology, geomorphology, and soil-forming processes of the valley bottom and lower slopes, and subsequently, on vegetation development on each site. West of the Kenai Mountains, the Kenai Lowlands feature deep deposits of loess originating from flood plains of glacial streams and deposits of volcanic ash from the Alaska Peninsula volcanoes (Gallant et al. 1995). Within the Kenai Mountains, however, ash and loess deposits differ in depth and are not consistent throughout the area.

Soils developed on glacial deposits feature unsorted gravel and cobbles in the upper profile. These soils can be well drained, but compacted water-restricting layers are often present in the lower profile. Soils developed on glacial deposits generally lack a layer of deep, loamy soil in the upper horizon. Soils developed on alluvial and lower slope colluvial deposits are generally deep and have a sandy to loamy soil texture and a wide range of stoniness (Davidson 1989, Davis et al. 1980). Land type, surficial deposit, and soil variables for the 17 prescribed burns are listed in tables 3 and 4.

Climate—The Kenai Mountains have a climate that is transitional between maritime and continental. The mean annual temperature is 3.9 °C at low elevations and –6.7 °C at high elevations (Blanchet 1983). Within the study area, annual precipitation ranges from 500 to 1500 mm, with June having the lowest average monthly precipitation (DeVelice et al. 1999). Annual precipitation increases from west to east across

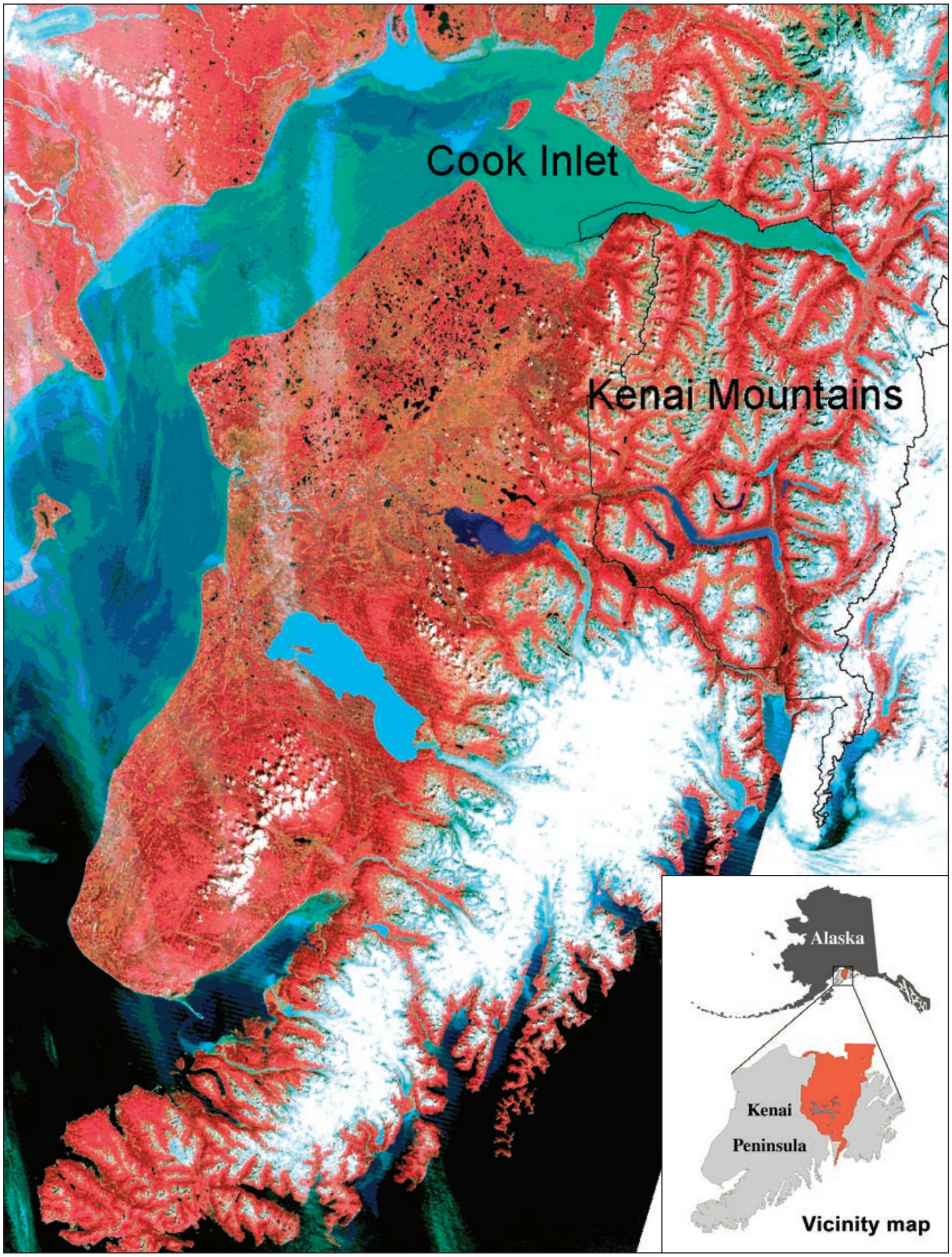

Figure 1—1989 Landsat image of the Kenai Peninsula, Alaska. The Kenai Mountains portion of the Chugach National Forest is outlined in black and highlighted in red in the inset. Coniferous (dark red) or broadleaf (red) forests occupy the valley bottoms; side slopes are generally shrub (red) or herbaceous (pink) vegetation, and alpine summits are dominated by rock (blue), and ice and snow (white).

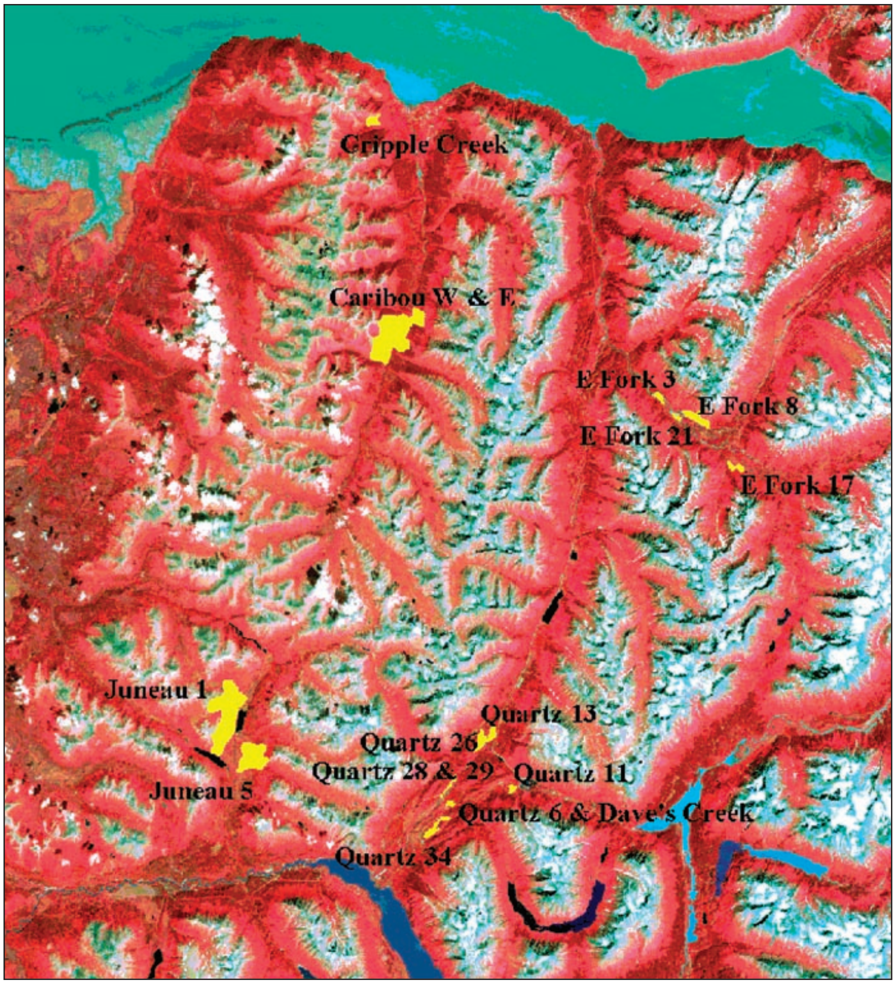

Figure 2—1989 Landsat image of the Kenai Mountains with prescribed burn study units highlighted in yellow.

the range. In the western portion of the Kenai Mountains, annual precipitation varies from 500 mm in the lowlands to 1500 mm in the mountains, whereas in the eastern mountains, the range is from 1000 mm in the lowlands to 2000 mm in the mountains. The coastal Kenai Mountains adjacent to Prince William Sound and Kenai Fjords can receive up to 5500 mm of precipitation per year (Blanchet 1983).

Vegetation—Forests of the Kenai Mountains are fragmented by mountain ranges, ravines, and avalanche slopes. Much of the area is nonvegetated (rock and ice) in alpine zones. Tree line varies, but forests generally do not occur above 600 m. Less than 20 percent of the Kenai Mountains region is forested.

Characteristic needleleaf trees in the study area include *Picea X lutzii* Little (Lutz spruce), a hybrid between *P. glauca* (Moench) Voss (white spruce) and *P. sitchensis* (Bong.) Carr (Sitka spruce). (Viereck and Little 1972), *Picea mariana* (Mill.) B.S.P. (black spruce, a minor forest component), and *Tsuga mertensiana* (Bong.) Carr. (mountain hemlock). *Betula papyrifera* (paper birch) is the dominant broadleaf tree

Table 2—Land type associations and characteristic soils of the Kenai Mountains

Land type association	Characteristic soils
Glaciers	No soil (rock and ice dominate)
Mountain summits	Shallow, coarse-textured soil with moderate amounts of coarse fragments
Depositional slopes	Deep, well-drained, medium-textured soil with variable amounts of coarse fragments
	Areas of fine-textured soil that pond water and form wetlands
Moraines	Glacial till featuring poorly- to well-drained soils with coarse fragments consisting of nonsorted gravel, cobbles, and stones in a moderate- to fine-textured matrix
	Reworked glacial till and outwash
Fluvial valley bottoms	Dominated by deep, stratified soils with rounded coarse fragments
	May pond water or form wetlands on fine-textured soil
	Commonly have high water table
Hills	Usually coarse- to medium-textured soil with 15 to 65 percent coarse fragments
	Usually organic soils in basins between hills where organic material rests on glacial till or bedrock

Source: Davidson 1998.

Table 3—Landscape variables and burn information for each study site

Unit name	Abbreviation	Burn date	Area	Slope	Aspect (true N)	Elevation	Soil depth	Fuel treatment	Type of ignition
			Hectares	*Percent*		*Meters*	*Centimeters*		
Quartz Creek 11	Q11	5/11/1984	15	6	330	200	11	Partial slash	Manual
Quartz Creek 6	Q6	5/-/1979	13	0	Flat	200	54	Full slash	Manual
Juneau 1	J1	5/13/1983	324	25	102	425	38	No slash	Helitorch
Caribou E	CE	5/15–17/1984	215	17	296	365	57	No slash	Helitorch
Caribou W	CW	5/15–17/1984	648	15	123	365	59	No slash	Escape
Cripple Creek	CC	5/9/1984	46	33	180	305	44	No slash	Helitorch
Quartz Creek 29	Q29	5/9/1981	24	2	200	180	32	Full slash	Manual
East Fork 17	EF17	8/27–28/1981	41	10	324	230	21	Partial slash	Manual
Dave's Creek Test	DC	7/14/1976	1	20	1	180	21	Partial slash	Manual
Quartz Creek 28	Q28	5/8/1981	24	8	142	245	39	Full slash	Manual
Quartz Creek 13	Q13	8/2/1978	36	5	280	305	18	Full slash	Manual
Quartz Creek 26	Q26	5/16/1981	73	19	129	305	19	Full slash	Manual
Juneau 5	J5	5/30/1982	278	3	268	395	36	No slash	Helitorch
East Fork 3	EF3	8/1/1978	11	0	Flat	165	47	Full slash	Manual
East Fork 8	EF8	8/25/1978	45	2	278	180	23	Full slash	Manual
East Fork 21	EF21	8/24/1979	24	0	Flat	180	10	Full slash	Manual
Quartz Creek 34	Q34	6/12/1981	97	17	190	260	18	Full slash	Manual

species; other common broadleaf species include *Populus balsamifera* ssp. *trichocarpa* (black cottonwood), *P. tremuloides* (quaking aspen), and *Salix scouleriana* (Scouler willow). *Alnus crispa* ssp. *sinuata* (Regel) Hulten (Sitka alder) dominates the tall scrubland of the mountain side slopes. Scrublands dominated by willow (particularly *S. barclayi* and *S. alaxensis*) are common in the valley bottoms. Undergrowth species occurring in the forest zone include *Menziesia ferruginea* Sm. (rusty menziesia),

Table 4—Plant community type (unburned), land type, surficial deposit, and source of surficial deposit (glacial or nonglacial) for each study site

Unit name	Preburn stand age (years)	Preburn plant community type	Land type	Surficial deposit	Glacial (G)/ nonglacial (NG)
Quartz Creek 11	185	Lutz spruce-black cottonwood/ Sitka alder	Depositional slope	Alluvium	NG
Quartz Creek 6	67	Lutz spruce-paper birch/ common horsetail	Fluvial valley bottom	Alluvium	NG
Juneau 1	109	Lutz spruce/barclay willow	Depositional slope	Colluvium	NG
Caribou East	154	Lutz spruce/Sitka alder	Depositional slope	Colluvium	NG
Caribou West	134	Lutz spruce-paper birch/rusty mensiezia	Depositional slope	Colluvium	NG
Cripple Creek	65	Lutz spruce-paper birch/rusty menziesia/sparse	Mountain side slope	Colluvium	NG
Quartz Creek 29	82	Quaking aspen-Lutz spruce/ lowbush cranberry	Fluvial valley bottom	Glacial outwash	G
East Fork 17	105	Lutz spruce/lowbush cranberry	Hills	Glacial till	G
Dave’s Creek Test	91	Lutz spruce-paper birch/lowbush cranberry	Hills	Glacial till	G
Quartz Creek 28	87	Lutz spruce-mountain hemlock/ lowbush cranberry	Moraine	Glacial till	G
Quartz Creek 13	73	Lutz spruce/lowbush cranberry	Moraine	Glacial till	G
Quartz Creek 26	93	Mountain hemlock-paper birch/ stiff clubmoss	Moraine	Glacial till	G
Juneau 5	67	Lutz spruce/barclay willow	Outwash plain	Reworked glacial till	G
East Fork 3	131	Lutz spruce/lowbush cranberry	Outwash plain	Reworked glacial till	G
East Fork 8	215	Lutz spruce/lowbush cranberry	Outwash plain	Reworked glacial till	G
East Fork 21	99	Lutz spruce/lowbush cranberry	Outwash plain	Reworked glacial till	G
Quartz Creek 34	75	Lutz spruce-paper birch/lowbush cranberry	Hills	Residuum and till	G

Note: Community type nomenclature follows the Chugach National Forest plant community guide (DeVelice et al. 1999).

Echinopanax horridum (Sm.) Dcne. & Planch. (devil’s club), *Calamagrostis canadensis* (bluejoint reedgrass), *Dryopteris dilatata* auct. non (Hoffmann) Gray (wood fern), *Vaccinium vitis-idaea* (lowbush cranberry), *Empetrum nigrum* (crowberry), *Pleurozium schreberi* (Brid.) Mitt. (Schreber’s big red stem moss), and *Hylocomium splendens* (Hedw.) Schimp. in B.S.G. (splendid feather moss).

Effect of Fire on Vegetation

Fire severity versus fire intensity—Vegetation succession in response to fire in Alaska is related to many factors, including severity of burn, preburn vegetation composition, fuel load, weather, and season of burn. These factors interact to create fires of different intensities and severities. Fire intensity refers to rate of energy released per unit area per unit time (Romme 1980, Van Wagner 1983, Viereck and Schandelmeier 1980), and fire severity refers to “the effect of the fire on the ecosystem, whether it affects the forest floor, tree canopy, or some other part of the ecosystem” (Viereck and Schandelmeier 1980). Fire severity can be an important factor in determining postburn successional pathways (Foote 1983). A severe burn that removes most of the organic layer is also likely to kill most of the underground reproductive parts of resprouting vegetation as well as seeds buried in the soil. The mineral soil, however, provides an ideal seedbed for most of the species that arrive by seed. A light burn that leaves the organic layer intact will favor those species that reproduce from rhizomes, crown sprouts, or root sprouts (Viereck and Schandelmeier 1980). Dyrness and Norum (1983) found that a light burn in black spruce forests favored recolonization by *Calamagrostis canadensis*, whereas a severe burn favored recolonization by *Epilobium angustifolium*.

Soil temperature—The depth of the forest floor organic layer, which includes moss, litter, and the organic soil horizons, influences soil temperature and site productivity. Fire can reduce or remove the organic layer, reducing the insulating properties of the forest floor, increasing soil temperatures, and changing the soil thermal regime (Brown 1983). Reduction in depth of the organic layer is directly related to increased soil temperatures and site productivity (Dyrness 1982, Viereck 1982, Viereck and Dyrness 1979, Viereck et al. 1979).

Vegetation succession and fire regime—In boreal forests, tree establishment generally occurs in the first few years after fire (Viereck 1973). Therefore, factors affecting tree regeneration could have a long-term effect on forest succession. Foote (1983) and Payette (1992) describe postfire forest succession in boreal forests as generally returning to the predisturbance forest cover type, thus, white spruce forests, after fire, generally return to white spruce in the absence of additional disturbance, but the rate of change and species composition can differ (Foote 1983, Payette 1992). Postfire vegetation succession depends on a number of factors including initial vegetation state, fire severity, and postfire conditions such as (1) presence of seeds and resprouting buds, (2) seedbed quality, and (3) climate and weather conditions (Foote 1983). A generalized postfire successional path to mature forest for spruce stands in interior Alaska would likely pass through the following stages: (1) the moss-herb stage with seedlings of woody species (if seeds are available and seedbed conditions are favorable for establishment) immediately following disturbance; (2) the tall shrub-sapling stage, assuming either sprouts or seeds are available and seedbed conditions are favorable; (3) the dense tree stage (either hardwoods or conifers); if hardwoods are present the stand passes into; (4) the hardwood stage; if no hardwoods are present the stand progresses to; (5) the spruce stage. In forests of interior Alaska, the age of mature spruce trees is generally less than 300 years (Foote 1983). A divergent or delayed successional pathway may be caused by several conditions: catastrophic fire events, fire events that are not sufficiently severe to create a mineral seedbed, or recurrent fire events that change the rate or pathway of forest development (Payette 1992). For example, if seedlings and shrubs are not established owing to lack of seeds or suitable seedbed, the herbaceous phase may dominate for an extended period. Herbivory is an additional factor that impacts the successional sequence and rate of vegetation composition change by selectively reducing or eliminating certain species (Foote 1983).

Although fire is considered an important disturbance force in boreal forests, few fire history studies have been completed in Alaska (De Volder 1999, Gabriel and Tande 1983, Gracz et al. 1995, Viereck and Schandelmeier 1980, Yarie 1981). Reconstructing fire history is impeded by lack of long-term historical records and lack of fire scarring on boreal tree species. The goal of many fire history studies is to produce an estimate of the fire interval (the average number of years between two successive fire events in a given area) and fire cycle (the average time required to burn an area equal to the size of the study area) (Agee 1993, Pyne et al. 1996, Romme 1980). In the Porcupine River drainage in interior Alaska, Yarie (1981) described a fire cycle and fire-return interval of 105 and 113 years, respectively, for *Picea glauca*; and 36 and 43 years, respectively, for *P. mariana*. De Volder (1999) described a fire cycle for lowland *P. mariana* on the Kenai National Wildlife Refuge (KNWR), which borders the Chugach National Forest to the west, between 42 and 56 years; an increase in fires after 1828 was coincident with European settlement of the Kenai.

Gracz et al. (1995) conducted a fire history study of *P. glauca* forests of the KNWR. In this study, one fire, with an approximate burn date of 1883, accounted for most of the area burned. The mean age of the oldest spruce trees in the remaining area was 234 years. The dominance of a single fire within the historical timeframe of the study suggests that a period of 234 years is too brief to determine a fire-return interval for *P. glauca* forests of the KNWR. Both De Volder (1999) and Gracz et al. (1995) suggest that current fire regimes on the Kenai Peninsula are influenced by human ignitions and fluctuating climatic conditions.

The Chugach National Forest portion of the Kenai Mountains is more strongly influenced by the maritime climate of Prince William Sound and Kenai Fjords than are the forests of the KNWR, which results in cooler mean summer temperatures and higher precipitation. The fragmented nature of the forests of the Kenai Mountains potentially limits the spread of fire. The combination of these factors would likely result in a fire-return interval on the Chugach National Forest portion of the Kenai Peninsula longer than that of the KNWR. Prior to European settlement, forests were predominantly in late-successional stages (Holbrook 1924, Languille 1904). Anthropogenic fires associated with mining and railroad activity burned over 30 000 ha on the national forest from 1914 to 1997 (Potkin 1997). Prior to European settlement, fires were likely less frequent. Charcoal buried in the soil profile of these forests has been dated between 500 and 3,000 years (Potkin 1997), indicating that fire played a role in forest development during this time. Charcoal found at the surface of the mineral soil, below the organic layer, was not dated, but suggests that many of these forests originated after fire. Although it is clear that forest development has been influenced by fire, there is insufficient information to propose a fire-return interval for *Picea lutzii* forests of the Kenai Mountains.

Related Studies

The response of browse species and competitive vegetation to fire on the Kenai Peninsula has not been well documented. A study addressing the effects of fire and bark beetles on vegetation was conducted within the study area (within the Caribou West prescribed burn) between 1980 and 1996 (Holsten et al. 1995, Schulz 2000). The 1984 prescribed fire burned about half of the study plots. Cover of *Calamagrostis canadensis* was high prior to burning, and the organic layer remained intact after burning with no mineral soil exposed. Seven years after the burn, *C. canadensis* and *Epilobium angustifolium* increased significantly in the beetle-affected stands in both the burned and unburned plots. By the 1996 reading, birch seedlings were more common in the burned plots than in the unburned plots; however, spruce seedlings were more common in the unburned plots. Twelve years after the burn, *C. canadensis* had decreased since the previous reading, possibly indicating a loss of vigor owing to the reported self-limiting nature of the species (Lieffers et al. 1993).

From 1974 to 1981, Oldemeyer and Regelin (1987) studied the effects of fire and management practices on browse production on the KNWR (west of the study area in the Kenai Lowlands region). They compared browse response to disturbance on different soil types and found that different browse species were associated with different soil conditions. In general, loamy soils on rolling terrain produced the greatest density of willow browse. The highest density of birch browse occurred on hilly to steep loamy soils. Aspen-dominated stands occurred on moraines on gravelly soils; however, browse density was only 57 percent of that on the loamy soils (Oldemeyer and Regelin 1987). Loamy soils were more productive than glacial moraine and glacial outwash soils. Competition from *Calamagrostis canadensis* was not reported to have interfered with woody regeneration within the lowlands study area. Topography and soil development of the Kenai Lowlands differs from that of the Kenai Mountains region. The Kenai Lowlands feature rolling to flat terrain with glacial and alluvial surficial deposits overlain by a mantle of loess (Oldemeyer and Regelin 1987), whereas the Kenai Mountains region features a wide range of land types from mountain slopes to valley bottoms and generally lacks the loess mantle found on the lowlands. Productive sites featuring deep loamy soils are restricted to land types associated with alluvial deposits and toe slopes of mountain land types.

To summarize, browse species in the study area are adapted to fire and have the ability to reproduce vegetatively by resprouting or root suckering. Regeneration after burning is influenced by preburn vegetation composition, seedbed conditions, competition, and factors affecting site quality. I hypothesize that preburn species composition and site characteristics can be used to estimate postburn species composition and browse production. Defining these relationships facilitates the development of burn planning guidelines including criteria for site selection, season of burn, and severity of burn.

Methods

Selection of Study Units

At each burn site, permanent transects (300 m long) were established by vegetation type in burned and unburned areas of similar preburn species composition and density. Preburn data from permanent transects were used where transects had been established prior to burning. Vegetation types were mapped on aerial photographs prior to burning, and transects were placed within types that represented the target winter range for moose. Transect location was random within vegetation types.

For a burn to be selected for this study, the target vegetation must have burned. A sample of 17 burns remained after several burns were eliminated from consideration owing to lack of evidence of fire in the target vegetation. All 17 sites were burned between 1979 and 1984, and the postburn surveys were conducted in 1998 and 1999.

Field Methods

The purpose of vegetation sampling was to characterize burned and unburned vegetation composition and site characteristics in order to compare vegetation development after burning across various vegetation and site types and burn severities. Data were collected along permanent 300-m-long transects with 30 sampling points at 10-m intervals (fig. 3). At each sampling point, a nested design of a 1- by 1-m plot within a 1- by 5-m plot was used to estimate cover of herbaceous and woody vegetation. Within the 1- by 1-m plot, canopy cover was estimated by species for all herbs and dwarf shrubs. Within the 1- by 5-m plot, canopy cover was estimated for all shrubs and tree seedlings and saplings; additionally, height and number of stems were recorded for tree seedlings and saplings of browse species. Tree density, cover, and height data were collected on each species at four fixed-radius plots along the transect. In units where the transect was split to fit within the vegetation type, fixed-radius plots were positioned along the transect so that plots would not overlap (see fig. 3). Radius length was determined by tree cover and stand homogeneity; three sizes were used: small plots (8.9-m radius, 0.025 ha) were used in homogeneous stands with tree cover >40 percent, medium plots (12.6-m radius, 0.05 ha) were used where tree cover was 10 to 40 percent, and large plots (17.8-m radius, 0.1 ha) were used where tree cover was sparse (<10 percent cover). Radius length was selected based on the entire transect

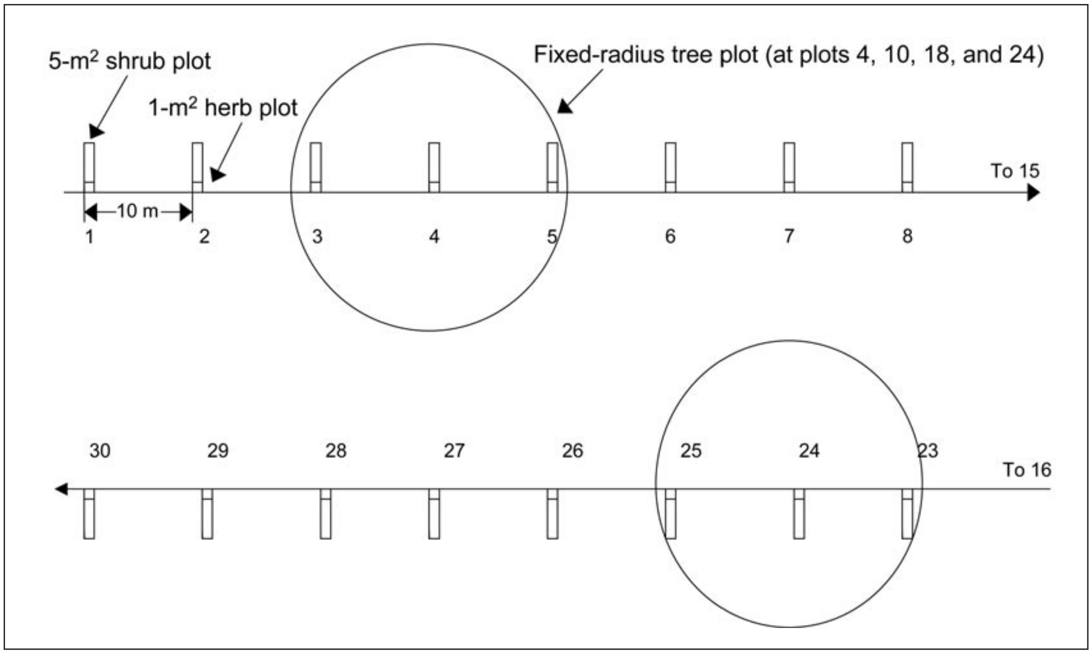

Figure 3—Burn monitoring transect diagram.

area and remained constant for each of the four plots per transect. For data analysis, canopy cover, stems, and soil depth were averaged by transect. Site characteristics, such as land type, surficial deposit, slope, aspect, and elevation, were recorded by transect.

Soil depth was measured at each of the 30 points with a 1.27-cm-diameter soil probe. The probe was able to penetrate loamy and sandy soils but not loamy-skeletal, sandy-skeletal, or fragmental soils. This measurement provided an estimate of the depth of loamy soil or sandy soil. These particle size classes are defined by the Soil Survey Staff (1992) as follows: loamy—in the fine-earth fraction, a texture of loamy very fine sand, very fine sand, or finer, including less than 35 percent (by volume) rock fragments; sandy—in the fine-earth fraction, a texture of sand or loamy sand, including less than 35 percent rock fragments; loamy skeletal—35 percent or more rock fragments with a texture of loamy very fine sand, very fine sand, or finer; sandy skeletal—35 percent or more rock fragments with a texture of sand or loamy sand; fragmental—90 percent or more rock fragments.

Fire-severity indices were developed for each transect based on fire-effects data, photographs, and narratives recorded the year of the burn. Photographs and written descriptions were available for all the burns. Preburn and postburn fuel loadings and measurements of reduction of the organic layer were available only for some of the burns. Sites that had both photographs and fuel-reduction measurements were used to calibrate photographs for those sites with less complete information. Four severity classes were developed to characterize degree of disturbance to the forest floor: (1) heavily burned—deep ash layer present, organic layer consumed or nearly so to mineral soil, mostly gray ash; (2) moderately burned—organic layer partially consumed, ash layer mostly black, parts of woody twigs remaining; (3) lightly burned—plants charred or scorched but original form of ground cover still discernable; and (4) unburned (adapted from Viereck et al. 1979).

The source of the unburned plot data was either a preburn transect within the burn unit or a control transect adjacent to the unit. Controls were selected based on similarity of vegetation, slope, aspect, and land type. Many of the preestablished controls were rejected owing to nonconformity with the selection criteria; in these cases, controls were reestablished in a type more similar to the burn transect, and control data were collected 15 to 20 years after burning. Preburn aerial photography, site visits, and preburn vegetation descriptions and photographs were used to determine whether site conditions at the control adequately represented site conditions at the burn transect site. Appendix 3 summarizes the sources of unburned transect data. Because some control data were collected 15 to 20 years after burning, a comparison was made between controls read near the date of burn and controls read 15 to 20 years after the date of burn to evaluate forest change in the 15 to 20 years after burning. On six sites, control transects were read near the date of burn; on two of these sites, controls also were read 15 to 20 years postburn. These two sites were used to evaluate change in the control stands since the date of burn. Based on an ordination of all plots, including the two control plots that were read near the time of burn and 15 to 20 years after burning, it can be concluded that the controls read 15 to 20 years after burning provide an adequate representation of the forest condition at the time of burn (Boucher 2001).

Data Preparation and Analysis

Indirect gradient analysis using ordination was selected as a means of interpreting patterns in the data since it is a useful tool when the underlying factors are thought to vary continuously (Ludwig and Reynolds 1988). Ordination allows the number of variables to be reduced to a few synthetic variables that can be represented as axes in order to assess relationships among sample units. Axes represent ordination gradients and can be related to measurable environmental variables. Indirect gradient analysis was used to position sample units according to association among species (sample units in species space). Sample unit positions in the ordination are determined by calculating the distance among them in a multidimensional space. Ordination allows the analyst to select among multiple factors and to separate strong from weak patterns.

Plant community data are generally not well suited to analytical methods that rely on assumptions of normal distributions. In a typical plant community data matrix, there are many zero values; the matrix is said to be sparse—the more heterogeneous the data, the more sparse the matrix. Abundance values along a species response curve are expressed as positive values. Once a species becomes absent, the value is zero; a zero value gives no information about how unfavorable the environment is for a given species, and many methods of assessing distance among sample units (such as correlation and chi-squared distance) recognize shared zeros as a positive relationship. This causes significant distortion in the ordination gradient. Opposite ends of a gradient appear to have a positive relationship owing to shared zeros, and the ends of the gradient are drawn toward each other, resulting in a horseshoe-shaped curve.

Nonmetric multidimensional scaling (NMS) (Kruskal 1964, Mather 1976) is a nonparametric technique that avoids assumptions of normality and linear relationships among variables. Because of its suitability for community data and its proven performance with heterogeneous samples (Minchin 1987), NMS was selected as the most appropriate ordination technique for this analysis. Because species scores are based on ranked distances, distortions associated with community heterogeneity are relieved. Nonmetric multidimensional scaling using the Sorensen similarity index as a distance measure was used to ordinate sample units in species space and to assess the dimensionality of the data set. PCORD version 4.28 (McCune and Mefford 1999) was used for all multivariate analyses.

Data were arranged in two matrices, a matrix of species abundance and a matrix of site characteristics. The matrix of species abundance contains 34 sample units (17 paired plots; rows) and 129 species (columns). As displayed in table 5, the average coefficient of variation (CV) was high in the raw species abundance data. Species data were relativized by species maxima, thereby reducing the CV to an acceptable level. Relativization by species maximum equalizes the weight given to common and uncommon species (McCune and Mefford 1999):

$$b_{ij} = x_{ij}/xmax_j \,.$$

Where rows (i) are samples and columns (j) are species, $xmax_j$ is the largest value in the matrix for species j. Rare species, those that occurred in only one sample unit, were deleted, reducing the number of species from 129 to 104, lowering both the CV and beta diversity (the amount of compositional variation in a sample).

The second matrix contains site characteristics (quantitative and categorical) for 34 sample units. Variables include slope, solar insolation (Urban 1990), elevation, treatment (burned versus unburned), land type, surficial deposit, soil depth, burn severity, season of burn, and time since burn. The following combined vegetation variables also were included in the second matrix: total browse species cover, combined seedling and sapling cover for browse trees, and combined ericaceous shrub cover.

Two methods were used to interpret the ordination axes: (1) correlation of environmental variables and species to ordination axes and (2) overlays of species and site variables on ordination points (sample units). Correlation coefficients between variables (species abundance or size of environmental variable) and sample unit position along ordination axes express the linear relationship of a variable with the ordination axis. Overlays can be used to assess whether a variable is patterned on an ordination. Each point on the ordination is replaced with a symbol whose size represents abundance of the variable (for continuous variables) or a symbol or color (for categorical variables). Overlays provide a more flexible means of examining the relationship of variables to the ordination than correlation coefficients as patterns are not limited to linear relationships.

The SAS System (version 8) was used to develop regression equations to model postburn browse species abundance. A suite of candidate models was identified prior to analysis, including a global model consisting of all variables considered influential in estimating postburn browse abundance. Akaike's Information Criterion (AIC) (Burnham and Anderson 1998) was used to evaluate candidate models and provide a measure of the discrepancy of fit between the data and the model in question. Additional factors such as overall fit of the model, variance explained, and p-values of parameters were considered in selecting the final models.

Results

Species Responses

Several species show consistent trends across all prescribed burns in the study area (fig. 4). However, the amount of increase or decrease in abundance varies widely depending on initial vegetation and site factors such as land type, hydrology, surficial deposit, soil depth, and severity of burn.

After burning, browse species such as *Salix barclayi*, *S. sitchensis*, and *Betula papyrifera* seedlings and saplings tended to increase where they were present in the initial composition. Early-successional forbs and grasses such as *Epilobium angustifolium*, *Equisetum arvense* L. (common horsetail), and *Calamagrostis canadensis* also tended to increase. Late-successional and forest-associated species tended to decrease;

Table 5—Effect of data transformations on the coefficient of variation and beta diversity for species abundance

CV and beta diversity	Raw	Relativized by species maximum[a]	Relativized and reduced[b]
Rows (sample units):			
Beta diversity	2.8	2.80	2.30
CV of sums	35.53	31.37	29.25
Columns (species):			
CV of sums	203.81	52.59	47.20

CV = coefficient of variation = 100 × standard deviation ÷ mean.

[a] Equalizes weight given to common and uncommon species.

[b] Number of species was reduced from 129 to 104 by omitting rare species.

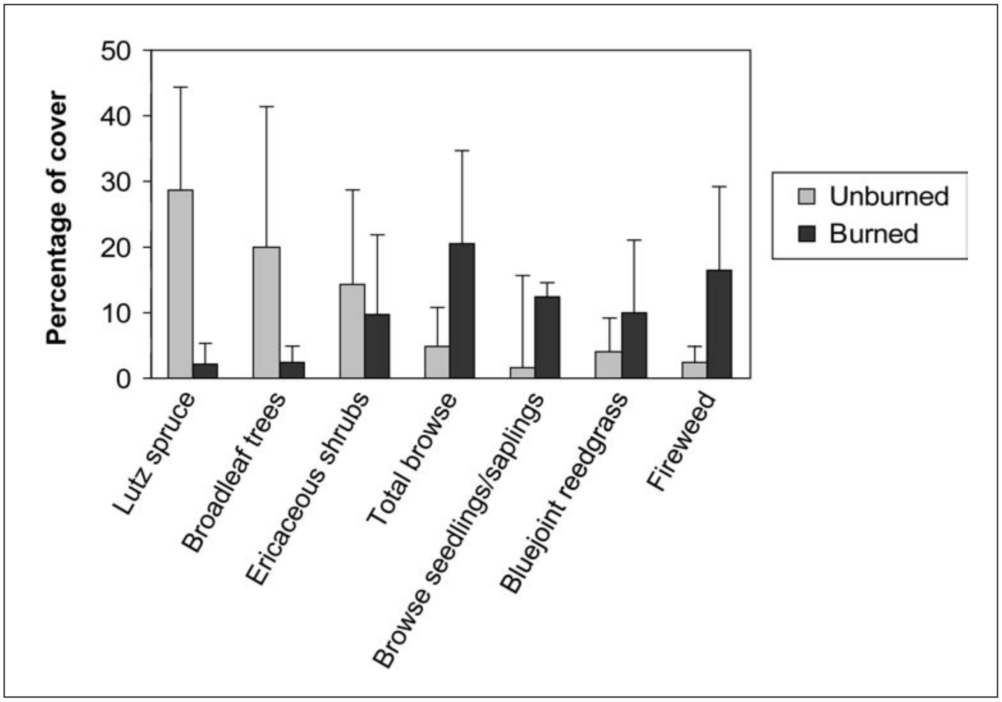

Figure 4—Average cover and standard error of selected species in burned and unburned plots across all burns (n = 17). "Ericaceous shrubs" include *Vaccinium uliginosum*, *V. caespitosum*, *V. vitis-idaea*, *Ledum palustre*, and *Empetrum nigrum*. "Total browse" includes shrub willows as well as seedlings and saplings of browse trees. Browse seedlings/saplings includes seedlings and saplings of tree species used by moose (*Betula papyrifera*, *Populus tremuloides*, *P. balsamifera*, and *Salix scouleriana*).

these species include conifer seedlings, saplings, and trees (*Tsuga mertensiana* and *Picea lutzii*), *Rubus pedatus* Sm. (fiveleaf bramble), *Linnaea borealis* L. (twinflower), *Dryopteris dilatata*, and *Menziesia ferruginea*. Dwarf shrubs such as *Vaccinium uliginosum*, *V. vitis-idaea*, and *Empetrum nigrum* tended to decrease after burning. Selected species responses by site are listed in table 6 (a complete table of species responses is given in app. 2).

Table 6—Change in percentage of cover values in burned and unburned transects (burned minus unburned) for selected species by site (column)

Species	CE	CC	Q11	CW	Q28	Q26	Q29	Q6	Q34	J1	DC	Q13	EF17	EF8	EF21	EF3	J5	Average
Trees:																		
Betula papyrifera (sapl.)	0	1	1	12	17	1	10	0	23	2	5	2	0	1	10	0	0	5
Betula papyrifera (seedl.)	0	3	0	0	6	1	12	1	8	3	16	2	0	-4	1	0	0	3
Betula papyrifera (tree)	-6	-34	-2	-12	-1	-10	-9	-42	-10	0	-23	-1	-1	0	0	0	0	-9
Picea lutzii (sapl.)	0	-1	0	-3	0	0	0	0	1	1	0	2	1	0	-2	-2	0	0
Picea lutzii (seedl.)	0	0	-2	0	0	0	-1	0	0	0	0	-3	0	-1	-1	-1	0	0
Picea lutzii (tree)	-31	-10	-50	-22	-15	-39	-7	-56	-17	-10	-25	-28	-15	-50	-34	-43	0	-27
Populus balsamifera (sapl.)	0	0	0	0	0	0	0	0	2	0	0	0	0	3	0	0	0	0
Populus balsamifera (seedl.)	0	0	-3	0	0	0	1	0	12	0	0	0	0	0	0	0	0	1
Populus balsamifera (tree)	0	0	-65	0	0	0	-2	2	-4	0	0	-2	0	2	0	0	0	-4
Populus tremuloides (sapl.)	0	0	0	0	0	0	2	0	0	0	0	0	0	0	-1	0	0	0
Populus tremuloides (seedl.)	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Populus tremuloides (tree)	0	0	0	0	1	-9	-24	0	-4	0	0	0	0	0	-1	0	0	-2
Salix scouleriana (sapl.)	0	0	0	-1	3	-1	7	0	0	0	1	6	2	4	4	0	0	2
Salix scouleriana (seedl.)	0	-1	0	0	1	0	0	0	1	0	1	1	1	-4	0	0	0	0
Salix scouleriana (tree)	0	-1	0	0	-4	-8	-16	0	-3	-3	-4	0	1	0	-1	0	0	-2
Tsuga mertensiana (sapl.)	0	-2	0	0	-3	-4	0	0	0	0	-1	0	0	0	-1	0	0	-1
Tsuga mertensiana (seedl.)	0	0	0	0	-8	-2	0	0	0	0	0	-1	0	0	0	0	0	-1
Tsuga mertensiana (tree)	0	0	0	0	-15	-24	0	0	0	0	-4	0	-2	0	0	0	0	-3
Shrubs:																		
Alnus crispa sinuata	-8	-1	-37	6	7	0	0	-1	2	7	0	0	0	0	0	0	0	-1
Betula nana	0	0	0	0	0	0	0	0	0	1	0	4	7	-4	3	10	6	2
Echinopanax horridum	-1	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Empetrum nigrum	0	0	-2	0	-14	-3	0	0	-8	1	6	-8	9	-32	-9	-11	0	-4
Ledum palustre	0	0	0	0	-8	0	0	0	0	1	1	0	0	0	-1	0	0	0
Linnaea borealis	-4	0	-3	-7	-2	-4	-1	0	-2	-1	0	-3	-1	0	-1	0	0	-2
Menziesia ferruginea	-12	-6	0	-21	5	0	0	0	0	0	-6	0	0	0	0	0	0	-2
Ribes sp.	0	0	-19	-7	0	0	0	-1	0	0	0	0	0	0	0	0	0	-2
Rosa acicularis	-1	1	-18	0	0	0	1	-4	0	8	0	0	0	0	0	0	0	-1
Rubus idaeus	-2	0	3	-1	0	0	1	4	0	2	0	0	0	0	0	0	0	0
Salix barclayi	0	0	-3	1	0	2	1	11	0	23	0	0	3	3	3	10	11	4
Salix pulchra	0	0	0	0	0	0	0	0	0	0	4	0	0	0	-1	0	2	0

Table 6—Change in percentage of cover values in burned and unburned transects (burned minus unburned) for selected species by site (column) (continued)

Species	CE	CC	Q11	CW	Q28	Q26	Q29	Q6	Q34	J1	DC	Q13	EF17	EF8	EF21	EF3	J5	Average
Salix sitchensis	0	0	0	0	0	0	4	0	5	0	0	1	0	0	0	0	1	1
Sambucus racemosa	-5	1	-2	0	0	0	0	1	0	-2	0	0	0	0	0	0	0	0
Vaccinium caespitosum	0	0	0	0	0	2	0	0	0	-5	0	7	1	1	0	0	2	0
Vaccinium uliginosum	0	0	0	0	0	0	1	0	0	0	0	-12	4	0	-6	1	-1	-1
Vaccinium vitis-idaea	0	0	-1	0	5	1	0	0	-8	2	15	3	-3	-6	-4	-5	-2	0
Forbs:																		
Cornus canadensis	-2	13	1	-3	7	-3	-8	-3	-4	-5	26	4	-13	-5	-3	-1	0	0
Epilobium angustifolium	29	22	44	25	15	23	6	31	3	11	3	12	3	8	3	6	-1	14
Geocaulon lividum	0	0	-1	0	2	-4	0	0	3	1	-6	-1	-1	-4	-6	0	0	-1
Lupinus nootkatensis	0	0	0	0	2	1	0	0	5	0	0	1	2	0	0	0	0	1
Rubus arcticus	-15	0	0	0	0	0	1	3	0	0	0	0	0	2	1	-4	-4	-1
Rubus chamaemorus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	0
Rubus pedatus	0	0	-6	-13	-1	-5	0	0	0	0	-3	0	-1	0	0	0	0	-2
Graminoids:																		
Calamagrostis canadensis	26	8	9	16	5	7	7	11	0	3	1	4	1	0	2	2	0	6
Festuca altaica	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	7	9	1
Ferns and fern allies:																		
Athyrium filix-femina	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dryopteris dilatata	-31	0	0	-35	0	0	0	0	0	-3	0	0	0	0	0	0	0	-4
Equisetum arvense	-9	11	1	34	0	9	-2	-22	0	25	0	0	0	0	0	0	-2	3
Equisetum pratense	0	0	5	1	0	1	-1	-3	0	1	0	0	0	3	0	0	0	0
Equisetum sylvaticum	18	-1	1	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	1
Gymnocarpium dryopteris	14	3	-3	7	0	13	-5	-21	0	-7	0	0	3	0	1	0	0	0
Lycopodium annotinum	-9	-5	-4	-6	-1	-14	-1	0	0	0	-3	-1	-2	0	0	0	0	-3
Lycopodium clavatum	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	-1	-1	0	0
Lycopodium complanatum	0	-1	0	0	0	0	0	0	-3	0	0	-5	-4	0	1	0	0	-1

Note: sites are listed in descending order according to site quality. Site names are cross-referenced with abbreviations in table 3. A full list of species responses, including preburn and postburn canopy cover, is given in appendix 2.

Table 7—Proportion of variance explained by each of the first three axes—NMS ordination of plots in species space

Axis	Axis descriptor	Increment	Cumulative
1	Moisture	0.21	0.21
2	Site quality	.29	.50
3	Burn signature (time)	.30	.80

NMS = nonmetric multidimensional scaling.

In general, browse species abundance after burning increased, but variation in browse species response was high among sites. Patterns of species responses can be explained by using gradient analysis to compare preburn to postburn vegetation composition and to evaluate site conditions and fire severity.

Gradient Analysis Results

The dimensionality of the data set was assessed by requesting a six-dimensional ordination using NMS. The first three axes captured 80 percent of the variance among sample units (table 7). Additional dimensions contributed little to the model. The proportion of variance explained by each of the first three axes is based on r^2 for the relation between ordination distances and distances in the original space.

The three major compositional gradients captured in the ordination can be described according to their proximity to environmental gradients. Axis 1 represents a moisture gradient related to drainage, axis 2 represents a gradient that can be described by surficial deposit and hydrology—or "site quality," and axis 3 represents a "burn signature" depicting successional status and degree of dissimilarity between burned and unburned plot pairs. Descriptions of the gradients will be presented by using correlations (species and site variables) with the three axes defined by NMS and overlays of individual species and site variables on sample units. Since a three-dimensional graphic is difficult to display, the results will be presented as two two-dimensional ordinations. Gradients illustrated in axis 2 versus axis 3 will be presented, followed by gradients illustrated in axis 1 versus axis 2.

Axis 2 versus axis 3—A projection of axis 2 (site quality) versus axis 3 (burn signature) displays 59 percent of the variance in species composition in the data set (fig. 5a). The plots ordinated vertically along axis 3 according to successional status and degree of disturbance, with unburned plots consistently occurring above their burned counterparts. Stand age was positively correlated with axis 3 ($r = 0.67$; table 8 and fig. 5b). The critical value for statistical significance of correlation coefficients at $\alpha = 0.05$ for a sample size of 34 is +/- 0.33 (Zar 1984). Vectors linking burned and unburned plots were roughly parallel, and the direction of change after burning was consistent, although vector length showed considerable variation (fig. 5a). Vectors in figure 5b represent the direction of positive correlation between a variable and the ordination axes, and vector length indicates strength of positive correlation.

Along axis 2 (site quality), the plots ordinated according to slope and surficial deposit. Slope percentage is positively correlated with axis 2 ($r = 0.52$) with steeper slopes generally occurring on the right side of the gradient, and flatter slopes generally occurring on the left side of the gradient. Slope percentage alone, however, does not adequately describe this gradient. The gradient appears to be strongly influenced by surficial deposit with sites featuring alluvial and colluvial deposits occupying the right

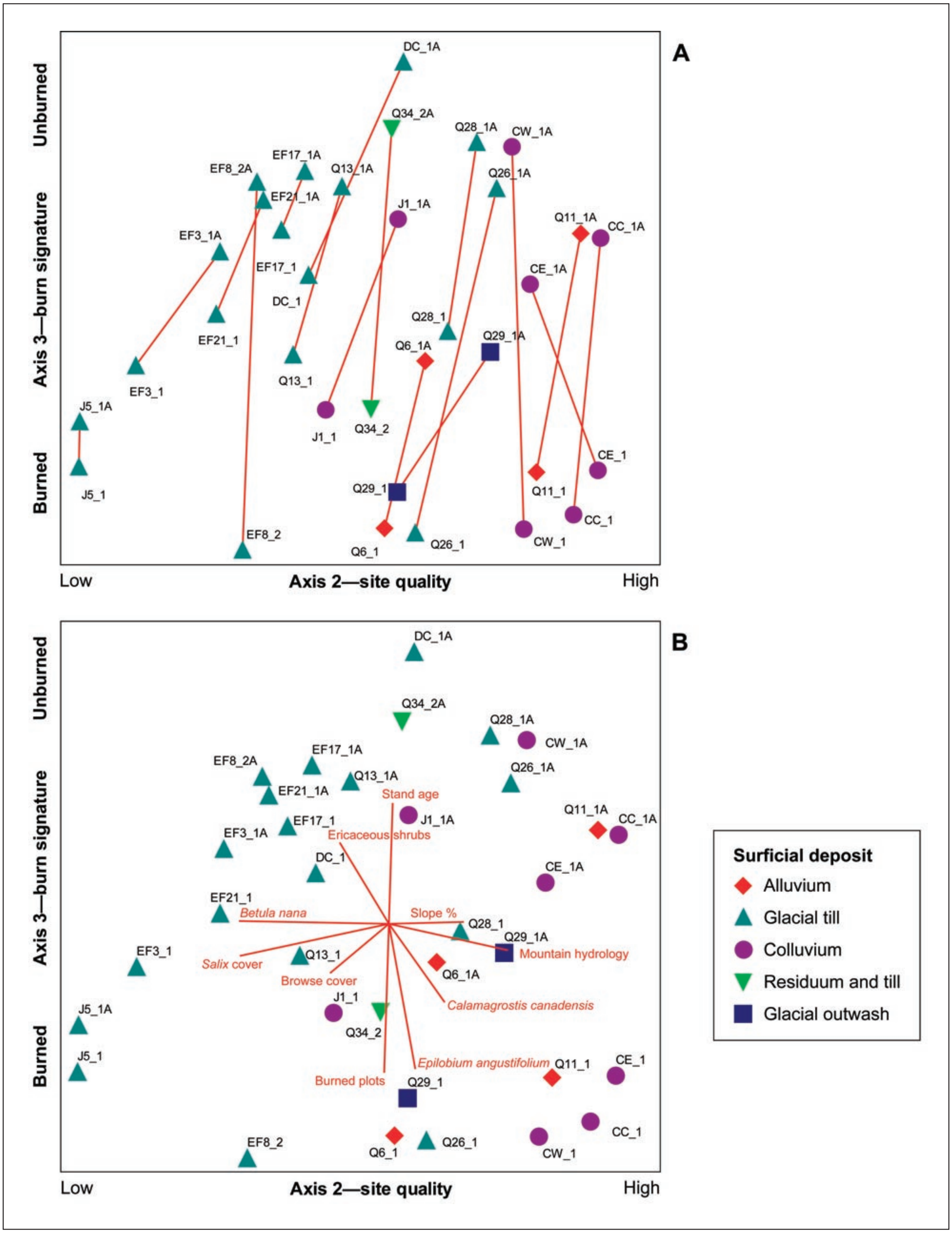

Figure 5—Nonmetric multidimensional scaling ordination of axis 2 (site quality) versus axis 3 (burn signature). Points represent plots in species space, and the same configuration is displayed in both (A) and (B). Symbols represent type of surficial deposit. (A) vectors link burned and unburned sample unit pairs. (B) vectors represent direction of positive correlation with site variables and selected species. Length of vector indicates strength of positive correlation. See table 3 for site codes. The appendage “A” to site code indicates unburned.

portion of the gradient, and glacial deposits (moraines and outwash terraces) occupying the left portion of the gradient. Sites with alluvial or colluvial deposits (nonglacial deposits) or both were positively correlated with axis 2 (r = 0.66; table 8). Colluvial and alluvial deposits occurred on depositional slopes (alluvial fans and toe slopes), fluvial valley bottoms, and mountain side slopes (lower slopes), which share a hydrologic pattern associated with runoff from alpine snow pack and thus have a continuous supply of moisture throughout the growing season. Land types associated with glacial deposits include moraines, hills, and glacial outwash terraces. The hydrology of these sites is controlled largely by onsite precipitation. These sites are not characterized by continuous runoff throughout the growing season, and the shallow soils are developed on coarse glacial till. For the purposes of this discussion, axis 2 will be referred to as a "site quality" gradient because units on the extreme right are characterized by toe slope and alluvial fans, those in the middle of the gradient occur on hills and moraines, and those on the far left occur on glacial deposits. Species correlations with axis 2 follow a pattern consistent with a gradient in site quality or productive capacity, with those species with low nutrient requirements negatively associated with axis 2 and those with high nutrient requirements positively associated with axis 2. A complete list of species correlations by axis is given in table 9.

Species correlations—Early-successional species such as *Epilobium angustifolium* and *Calamagrostis canadensis* were negatively correlated with axis 3 (burn signature), whereas species associated with mature forests, such as *Picea lutzii* (tree), *Geocaulon lividum* (Richards.) Fern. (northern comandra) (Dyrness and Grigal 1979, Reynolds 1990), and *Empetrum nigrum* (Lutz 1956, Viereck 1982), were positively correlated with axis 3. Along the horizontal gradient (axis 2), species associated with high site quality and deep soils such as *Viburnum edule* (Michx.) Raf. (highbush cranberry) (Dyrness et al. 1989, Haeussler et al. 1990), *Streptopus amplexifolius* (L.) DC. (twistedstalk) (DeMeo et al. 1992, DeVelice et al. 1999), and *C. canadensis* (Mueller-Dombois and Sims 1966) were positively correlated with axis 2, whereas those associated with lower site quality such as *Potentilla fruticosa* auct. non L. (shrubby cinquefoil), *Salix barclayi* (Argus 1973, Collet 2002), and *Betula nana* (Krajina et al. 1982) were negatively correlated with axis 2.

Both total browse abundance and *C. canadensis* abundance are negatively correlated with axis 3 (r = -0.42 and r = -0.54, respectively; table 8 and fig. 6), indicating both are more abundant in postburn plots; however, total browse is negatively correlated with axis 2, whereas *C. canadensis* abundance is positively correlated with axis 2. The occurrence of *C. canadensis* can be described by the landscape features correlated with axis 2. Figure 6 illustrates the ordination positions and relative abundance of browse species and *C. canadensis*. In general, *C. canadensis* occurs most abundantly on alluvial and colluvial deposits overlain with deep fine soil, whereas browse species occur most abundantly on glacial deposits (moraines and outwash plains) and residuum. The exception to this trend is Juneau 1; although classified as a site with colluvial surficial deposits, it also features a layer of glacial till and outwash. In figure 6, Juneau 1 appears in an intermediate position between the alluvial/colluvial deposits and the glacial deposits. *Calamagrostis canadensis* cover increased only slightly on this site after burning (from 3 to 6 percent). The dominant browse species at Juneau 1, both preburn and postburn, is *Salix barclayi*; this species often occurs with *C. canadensis,* and its ability to resprout does not appear to be severely impeded by the presence of *C. canadensis*.

Table 8—Correlations with axes 1 (moisture), 2 (site quality), and 3 (burn signature) for environmental variables and selected combined species

	r Axis 1	r Axis 2	r Axis 3
Environmental variables:			
Soil depth (cm)	0.54	0.26	-0.22
Percentage of slope	-.06	.52	.08
Stand age	.12	.12	.67
Burned/unburned	-.07	-.13	-.74
Solar insolation	-.09	.21	-.19
Mountain hydrology (nonglacial deposit)	.65	.66	-.31
Combined species canopy cover:			
Dwarf ericaceous shrubs	-.63	-.43	.55
Combined *Equisetum*	.63	.36	-.47
Combined *Salix* (excluding *S. scouleriana*)	.17	-.74	-.34
Combined *Betula papyrifera* seedlings and saplings	-.45	.02	-.27
Combined *Populus balsamifera* seedlings and saplings	-.37	.02	-.18
Combined *Populus tremuloides* seedlings and saplings	-.45	-.04	-.22
Combined *Salix scouleriana* seedlings and saplings	-.51	-.17	-.06
Combined cover of all browse species	-.35	-.46	-.42
Calamagrostis canadensis	.61	.45	-.54

Axis 1 versus axis 2—A projection of axis 1 versus axis 2 displays 50 percent of the variance in the data set. This projection shows the relationship of site quality along axis 2 to a moisture gradient along axis 1 (fig. 7). Because the vectors do not show a time-directional trend (as in the projection of axis 2 versus axis 3) and the paired burned and unburned plots are relatively close to one another, the projection illustrates the variance explained by environmental and site factors other than burn signature. In other words, it displays the variance among sites not explained by succession and burning. Land type, combined with surficial deposit and depth of loamy soil, can be viewed as indicators of potential site quality and hydrology. Along axis 2, high-quality sites (depositional slopes with colluvial and alluvial deposits) are positively correlated with axis 2, and glacial outwash plains and terraces (sites with coarse glacial deposits) are negatively correlated with axis 2. Hill slopes and glacial moraines occupy the middle range of axis 2. Along axis 1, deep deposits of loamy soil (corresponding to fluvial valley bottoms and depositional slopes) are positively correlated with axis 1 (r = 0.54; table 8 and fig. 7), whereas better drained sites, corresponding to moraine and hill land types with relatively shallow soils, are negatively correlated with axis 1 (fig. 7). The wettest sites occupy the uppermost positions on axis 1 (Quartz Creek 6 and Caribou East); and the best drained site (Quartz Creek 34) occupies the lowest position. Species correlations with axis 1 are displayed in table 9.

Figure 8 (a projection of axis 1 versus axis 2, with abundance of browse species and *C. canadensis* represented by size of symbol) depicts the relationship of total browse abundance and *C. canadensis* to a moisture gradient (axis 1) and land type (axis 2). Although the projection of axis 2 versus axis 3 illustrated the relationship of *C. canadensis* to surficial deposit and succession, the projection of axis 1 versus axis 2 better illustrates the site conditions favored by selected species because the variation related to succession is not displayed. *Calamagrostis canadensis* abundance

Table 9—Species correlations, ordered from most strongly positive to most strongly negative, with axis 1 (moisture), axis 2 (site quality), and axis 3 (burn signature)

Axis 1	r	Axis 2	r	Axis 3	r
Rubus idaeus	0.61	*Viburnum edule*	0.60	*Picea lutzii* (tree)	0.62
Calamagrostis canadensis	.61	*Streptopus amplexifolius*	.49	*Geocaulon lividum*	.59
Mertensia paniculata	.54	*Calamagrostis canadensis*	.45	*Empetrum nigrum*	.56
Equisetum arvense	.51	*Lycopodium annotinum*	.41	*Picea lutzii* (seedling)	.49
Viburnum edule	.46	*Gymnocarpium dryopteris*	.41	*Tsuga mertensiana* (sapling)	.47
Sambucus racemosa	.44	*Linnaea borealis*	.41	*Linnaea borealis*	.42
Equisetum sylvaticum	.43	*Alnus crispa sinuata*	.40	*Lycopodium annotinum*	.41
Alnus crispa sinuata	.42	*Rubus idaeus*	.40	*Rubus pedatus*	.41
Gymnocarpium dryopteris	.41	*Galium triflorum*	.40	*Picea lutzii* (sapling)	.39
Cardamine umbellata	.40	*Sambucus racemosa*	.39	*Listera cordata*	.36
Rubus arcticus	.38	*Echinopanax horridum*	.39	*Lycopodium complanatum*	.36
Epilobium angustifolium	.37	*Actaea rubra*	.37	*Tsuga mertensiana* (tree)	.35
Thalictrum sp.	.33	*Pyrola asarifolia*	.36	*Vaccinium vitis-idaea*	.34
Carex deweyana	.32	*Rosa acicularis*	.36	*Menziesia ferruginea*	.34
Rosa acicularis	.32	*Menziesia ferruginea*	.36	*Vaccinium uliginosum*	.33
Dryopteris dilatata	.31	*Ribes* sp.	.35	*Tsuga mertensiana* (seedling)	.32
Sanguisorba stipulata	.31	*Betula papyrifera* (tree)	.34	*Ledum palustre*	.31
Equisetum pratense	.30	*Epilobium angustifolium*	.31	*Betula papyrifera* (tree)	.30
Ribes sp.	.28	*Equisetum sylvaticum*	.31	*Pyrola chlorantha*	.29
Carex sp.	.27	*Dryopteris dilatata*	.29	*Lycopodium clavatum*	.29
Valeriana sitchensis	.27	*Rubus pedatus*	.29	*Corydalis sempervirens*	.23
Salix barclayi	.26	*Moneses uniflora*	.28	*Pyrola secunda*	.23
Polemonium acutiflorum	.26	*Equisetum pratense*	.28	*Sorbus sitchensis*	.22
Viola sp.	.21	*Salix scouleriana* (tree)	.26	*Vaccinium ovalifolium*	.21
Streptopus amplexifolius	.20	*Populus balsamifera*	.26	*Lycopodium alpinum*	.20
Sorbus scopulina	.20	*Athyrium filix-femina*	.26	*Dryopteris dilatata*	.19
Moehringia lateriflora	.20	*Equisetum arvense*	.25	*Salix scouleriana* (seedling)	.19
Potentilla fruticosa	.20	*Angelica lucida*	.25	*Salix scouleriana* (tree)	.19
Rumex sp.	.20	*Heracleum lanatum*	.23	*Ribes* sp.	.15
Swertia perennis	.19	*Castilleja unalaschcensis*	.23	*Spirea beauverdiana*	.13
Rubus chamaemorus	.19	*Shepherdia canadensis*	.23	*Cornus canadensis*	.12
Solidago multiradiata	.17	*Sorbus scopulina*	.20	*Populus balsamifera*	.11
Pyrola asarifolia	.16	*Tsuga mertensiana* (sapling)	.20	*Vaccinium caespitosum*	.11
Aconitum delphiniifolium	.15	*Tsuga mertensiana* (tree)	.19	*Betula nana*	.11
Picea lutzii (tree)	.15	*Listera cordata*	.19	*Shepherdia canadensis*	.10
Populus balsamifera	.15	*Pyrola chlorantha*	.18	*Moneses uniflora*	.10
Moneses uniflora	.15	*Phleum alpinum*	.17	*Trientalis europaea*	.10
Festuca altaica	.14	*Populus tremuloides* (tree)	.16	*Salix bebbiana*	.09
Spiraea beauverdiana	.13	*Tsuga mertensiana* (seedling)	.15	*Populus tremuloides* (tree)	.08
Pyrola secunda	.13	*Pyrola secunda*	.15	*Pyrola asarifolia*	.05
Anemone richardsonii	.13	*Thalictrum* sp.	.13	*Alnus crispa sinuata*	.02
Betula papyrifera (tree)	.10	*Vaccinium ovalifolium*	.12	*Sambucus racemosa*	.01
Rubus pedatus	.09	*Corydalis sempervirens*	.12	*Echinopanax horridum*	-.02
Juncus sp.	.07	*Mertensia paniculata*	.11	*Lupinus nootkatensis*	-.04
Menziesia ferruginea	.07	*Sorbus sitchensis*	.11	*Festuca saximontana*	-.04
Lycopodium annotinum	.06	*Picea lutzii* (tree)	.10	*Salix pulchra*	-.04
Achillea borealis	.06	*Valeriana sitchensis*	.08	*Trisetum spicatum*	-.07
Cinna latifolia	.05	*Ledum palustre*	.06	*Rosa acicularis*	-.07
Stellaria sp.	.04	*Populus balsamifera* (seedling)	.05	*Streptopus amplexifolius*	-.08
Shepherdia canadensis	.01	*Cardamine umbellata*	.05	*Salix scouleriana* (sapling)	-.08
Trientalis europaea	-.02	*Viola* sp.	.05	*Anemone richardsonii*	-.08
Phleum alpinum	-.04	*Cornus canadensis*	.05	*Sorbus scopulina*	-.10
Heracleum lanatum	-.04	*Betula papyrifera* (sapling)	.04	*Actaea rubra*	-.11

Table 9—Species correlations, ordered from most strongly positive to most strongly negative, with axis 1 (moisture), axis 2 (site quality), and axis 3 (burn signature) (continued)

Axis 1	r	Axis 2	r	Axis 3	r
Athyrium filix-femina	-.05	*Festuca saximontana*	.02	*Rubus chamaemorus*	-.11
Angelica lucida	-.06	*Anemone richardsonii*	.02	*Juncus* sp.	-.11
Taraxacum officinale	-.06	*Rhinanthus minor*	.02	*Salix alaxensis*	-.12
Castilleja unalaschcensis	-.06	*Populus tremuloides* (seedling)	-.01	*Populus balsamifera* (seedling)	-.12
Galium triflorum	-.07	*Betula papyrifera* (seedling)	-.03	*Rubus arcticus*	-.12
Campanula rotundifolia	-.07	*Populus tremuloides* (sapling)	-.05	*Rumex* sp.	-.13
Geranium erianthum	-.07	*Salix sitchensis*	-.05	*Solidago multiradiata*	-.14
Echinopanax horridum	-.08	*Moehringia lateriflora*	-.05	*Swertia perennis*	-.15
Populus tremuloides (tree)	-.10	*Geranium erianthum*	-.05	*Galium triflorum*	-.15
Actaea rubra	-.11	*Trientalis europaea*	-.06	*Luzula parviflora*	-.15
Vaccinium caespitosum	-.12	*Poa* sp.	-.06	*Arctostaphylos uva-ursi*	-.15
Equisetum scirpoides	-.13	*Lupinus nootkatensis*	-.07	*Mertensia paniculata*	-.16
Lycopodium alpinum	-.13	*Lycopodium complanatum*	-.08	*Betula papyrifera* (seedling)	-.16
Betula nana	-.14	*Salix alaxensis*	-.09	*Populus tremuloides* (seedling)	-.17
Poa sp.	-.14	*Arctostaphylos uva-ursi*	-.09	*Populus tremuloides* (sapling)	-.18
Salix bebbiana	-.15	*Swertia perennis*	-.10	*Festuca altaica*	-.20
Rhinanthus minor	-.15	*Salix scouleriana* (seedling)	-.10	*Potentilla fruticosa*	-.22
Salix planifolia	-.16	*Lycopodium alpinum*	-.10	*Cardamine umbellata*	-.22
Salix scouleriana (tree)	-.17	*Equisetum scirpoides*	-.11	*Cinna latifolia*	-.23
Linnaea borealis	-.18	*Populus balsamifera* (sapling)	-.11	*Viburnum edule*	-.23
Lycopodium clavatum	-.18	*Geocaulon lividum*	-.11	*Polemonium acutiflorum*	-.24
Agrostis sp.	-.19	*Stellaria* sp.	-.13	*Equisetum sylvaticum*	-.25
Salix alaxensis	-.19	*Trisetum spicatum*	-.13	*Valeriana sitchensis*	-.25
Trisetum spicatum	-.20	*Salix bebbiana*	-.14	*Carex* sp.	-.25
Populus tremuloides (sapling)	-.21	*Luzula parviflora*	-.15	*Athyrium filix-femina*	-.26
Luzula parviflora	-.21	*Picea lutzii* (seedling)	-.16	*Campanula rotundifolia*	-.26
Pyrola chlorantha	-.23	*Picea lutzii* (sapling)	-.18	*Rubus idaeus*	-.20
Vaccinium ovalifolium	-.23	*Taraxacum officinale*	-.20	*Betula papyrifera* (sapling)	-.27
Corydalis sempervirens	-.24	*Salix scouleriana* (sapling)	-.21	*Salix sitchensis*	-.27
Tsuga mertensiana (tree)	-.24	*Spirea beauverdiana*	-.21	*Viola* sp.	-.27
Sorbus sitchensis	-.26	*Agrostis* sp.	-.21	*Poa* sp.	-.29
Tsuga mertensiana (seedling)	-.28	*Campanula rotundifolia*	-.21	*Angelica lucida*	-.30
Populus balsamifera (sapling)	-.28	*Rubus arcticus*	-.23	*Agrostis* sp.	-.30
Vaccinium uliginosum	-.31	*Carex deweyana*	-.24	*Achillea borealis*	-.31
Listera cordata	-.31	*Sanguisorba stipulata*	-.25	*Gymnocarpium dryopteris*	-.32
Lycopodium complanatum	-.33	*Lycopodium clavatum*	-.26	*Salix barclayi*	-.32
Picea lutzii (seedling)	-.34	*Vaccinium vitis-idaea*	-.28	*Aconitum delphiniifolium*	-.33
Ledum palustre	-.35	*Empetrum nigrum*	-.29	*Geranium erianthum*	-.33
Tsuga mertensiana (sapling)	-.35	*Vaccinium uliginosum*	-.32	*Heracleum lanatum*	-.33
Populus balsamifera (seedling)	-.36	*Achillea borealis*	-.34	*Equisetum pratense*	-.34
Salix scouleriana (seedling)	-.36	*Cinna latifolia*	-.36	*Carex deweyana*	-.35
Picea lutzii (sapling)	-.37	*Rumex* sp.	-.38	*Sanguisorba stipulata*	-.35
Betula papyrifera (sapling)	-.39	*Rubus chamaemorus*	-.38	*Castilleja unalaschcensis*	-.35
Salix sitchensis	-.40	*Aconitum delphiniifolium*	-.40	*Phleum alpinum*	-.36
Arctostaphylos uva-ursi	-.42	*Juncus* sp.	-.41	*Populus balsamifera* (sapling)	-.36
Salix scouleriana (sapling)	-.44	*Vaccinium caespitosum*	-.44	*Equisetum scirpoides*	-.36
Cornus canadensis	-.44	*Polemonium acutifolium*	-.46	*Taraxacum officinale*	-.37
Empetrum nigrum	-.44	*Solidago multiradiata*	-.46	*Thalictrum* sp.	-.37
Festuca saximontana	-.45	*Salix pulchra*	-.49	*Equisetum arvense*	-.39
Betula papyrifera (seedling)	-.45	*Carex* sp.	-.52	*Rhinanthus minor*	-.41
Lupinus nootkatensis	-.52	*Potentilla fruticosa*	-.54	*Moehringia lateriflora*	-.51
Populus tremuloides (seedling)	-.53	*Festuca altaica*	-.60	*Calamagrostis canadensis*	-.54
Vaccinium vitis-idaea	-.59	*Salix barclayi*	-.71	*Stellaria* sp.	-.55
Geocaulon lividum	-.63	*Betula nana*	-.74	*Epilobium angustifolium*	-.73

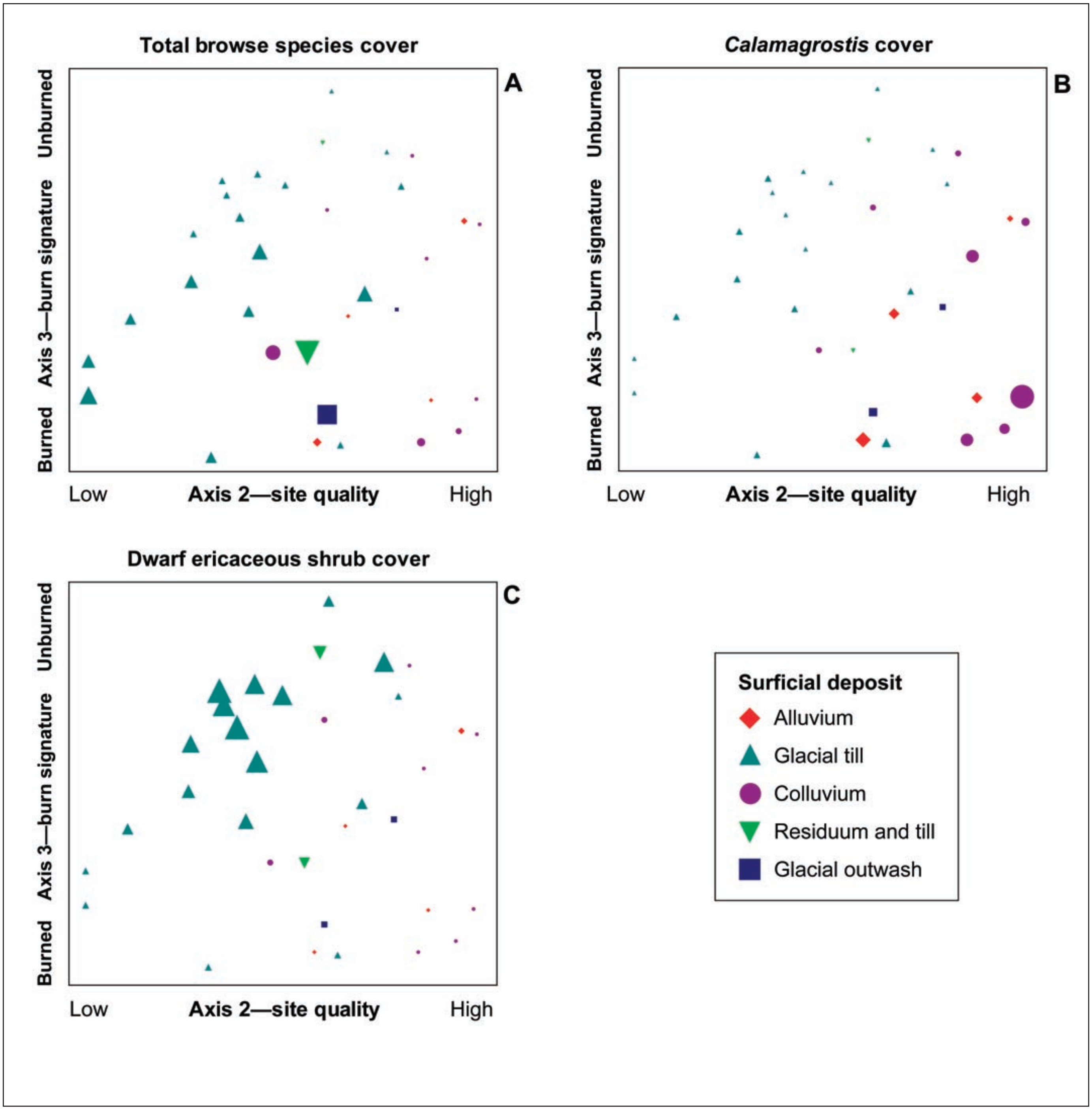

Figure 6—Nonmetric multidimensional scaling ordination of axis 2 (site quality) versus axis 3 (burn signature). Points represent plots in species space; symbols represent surficial deposit, and size of symbol reflects (A) abundance of browse species (percentage of cover), (B) abundance of *Calamagrostis canadensis*, and (C) combined abundance of ericaceous shrubs.

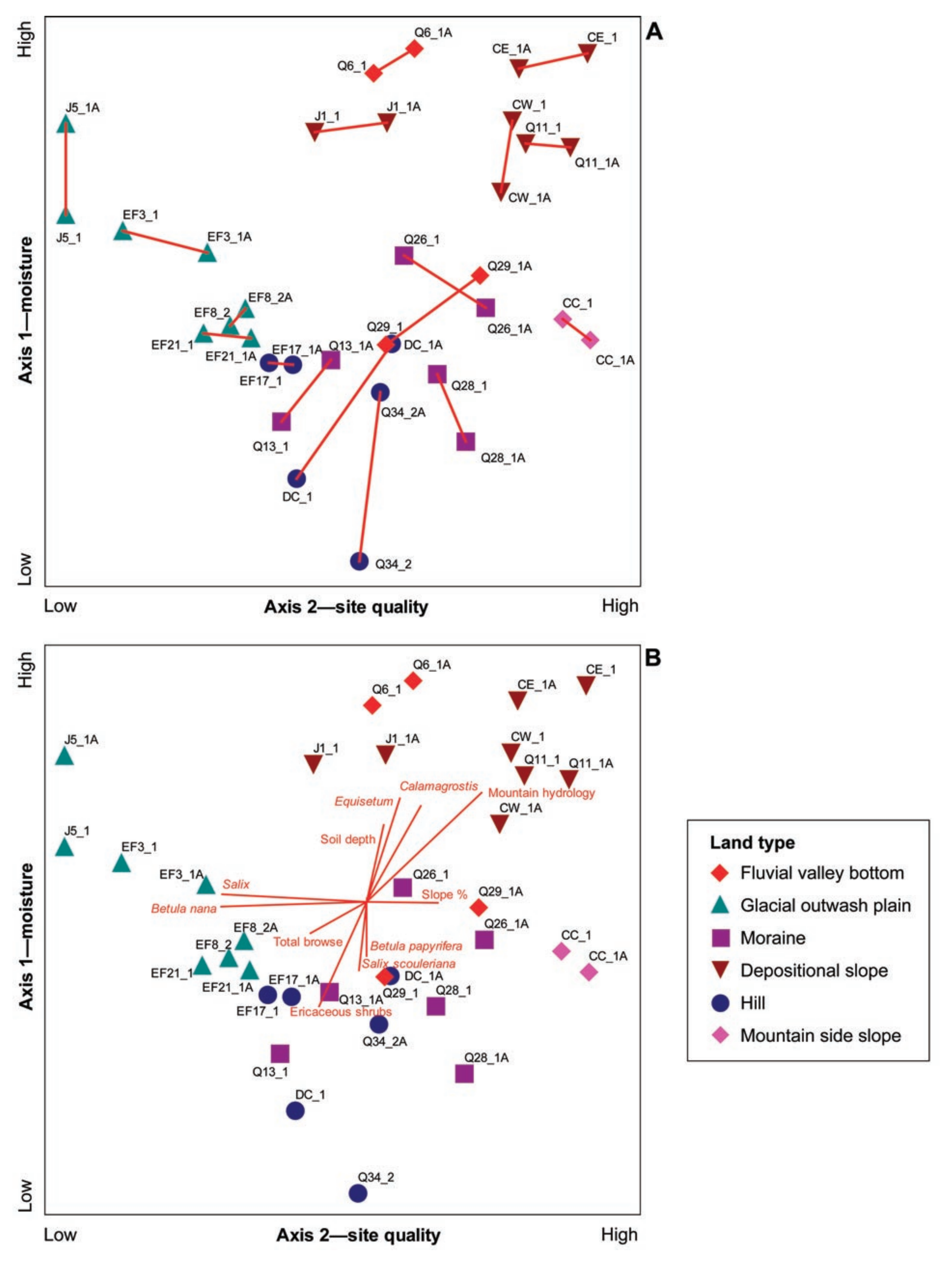

Figure 7—Nonmetric multidimensional scaling ordination of axis 1 (moisture) versus axis 2 (site quality). Points represent plots in species space; symbols represent land type. (A) vectors link burned and unburned sample unit pairs. (B) vectors represent correlations with site variables and selected species. Direction of vector indicates direction of positive correlation, and length indicates strength of correlation. See table 3 for site codes. The appendage "A" to site code indicates unburned plot.

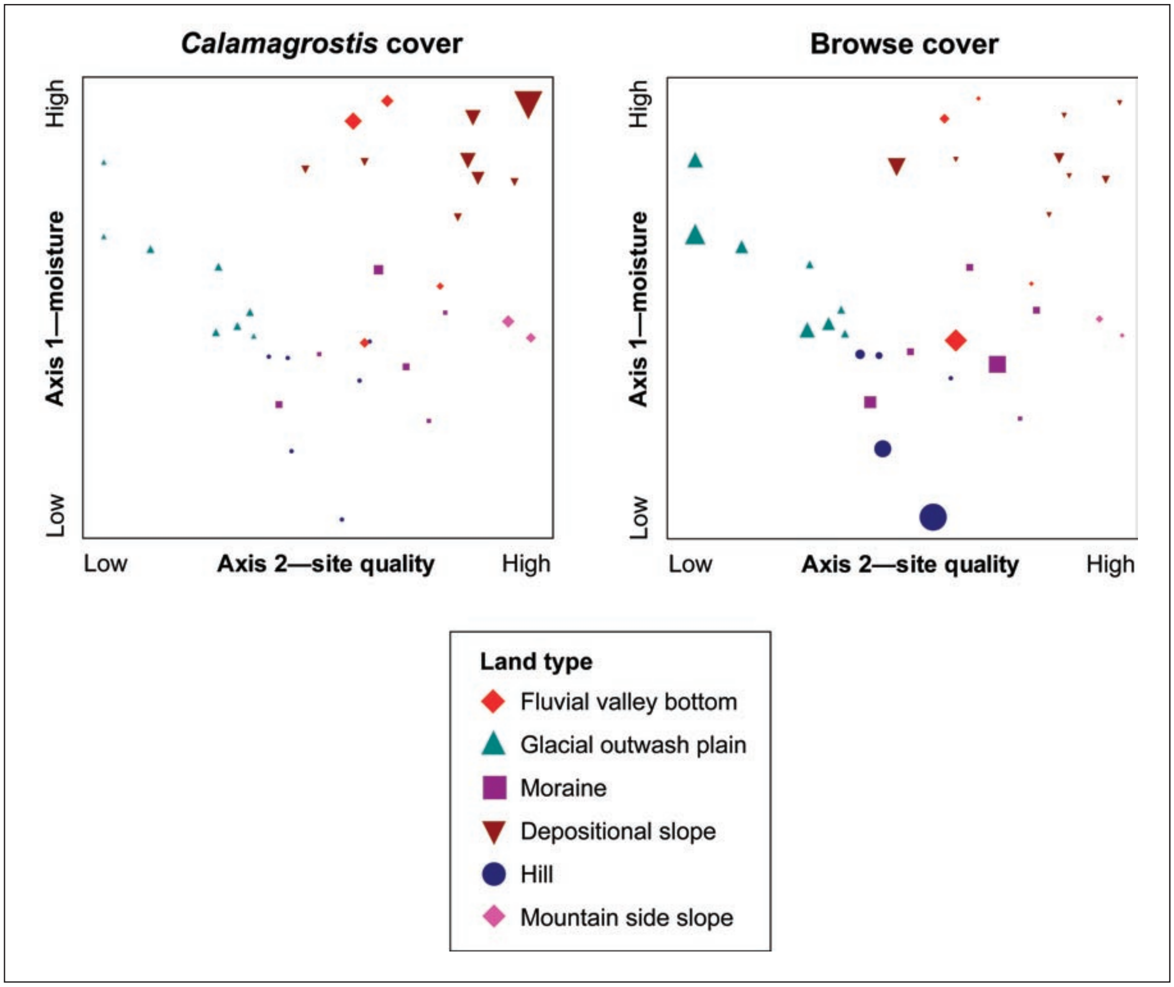

Figure 8—Nonmetric multidimensional scaling ordination of axis 1 (moisture) versus axis 2 (site quality). Symbols represent land type. Size of symbol represents abundance (percentage of cover) of *Calamagrostis canadensis* or total browse.

increases with increasingly deeper soils and increasing moisture. Deeper soils tended to occur on fluvial valley bottoms and depositional slopes, such as toe slopes. Browse species abundance is inversely related to *C. canadensis* abundance. Total browse cover is negatively correlated with both axis 1 and axis 2 (fig. 8 and table 8), whereas *C. canadensis* cover is positively correlated with both axes (fig. 8 and table 8). Total cover of browse species is generally highest on the hill and moraine land types on sites with shallow or stony soils. *Salix barclayi* is the exception to this trend, occurring most abundantly on poorly drained glacial deposits and depositional slopes (fig. 9).

Of the sites with over 3-percent cover *C. canadensis* in the preburn or control plots, only those with specific land type and soil conditions resulted in a high cover of *C. canadensis* after burning. Burn sites with deep nonstony soils (over 38 cm deep) on depositional slopes and fluvial valley bottoms produced abundant cover of *C. canadensis* (20 to 44 percent) after prescribed burning. Surficial deposits on these sites were alluvial and colluvial; *C. canadensis* did not occur abundantly on glacial till deposits before or after burning.

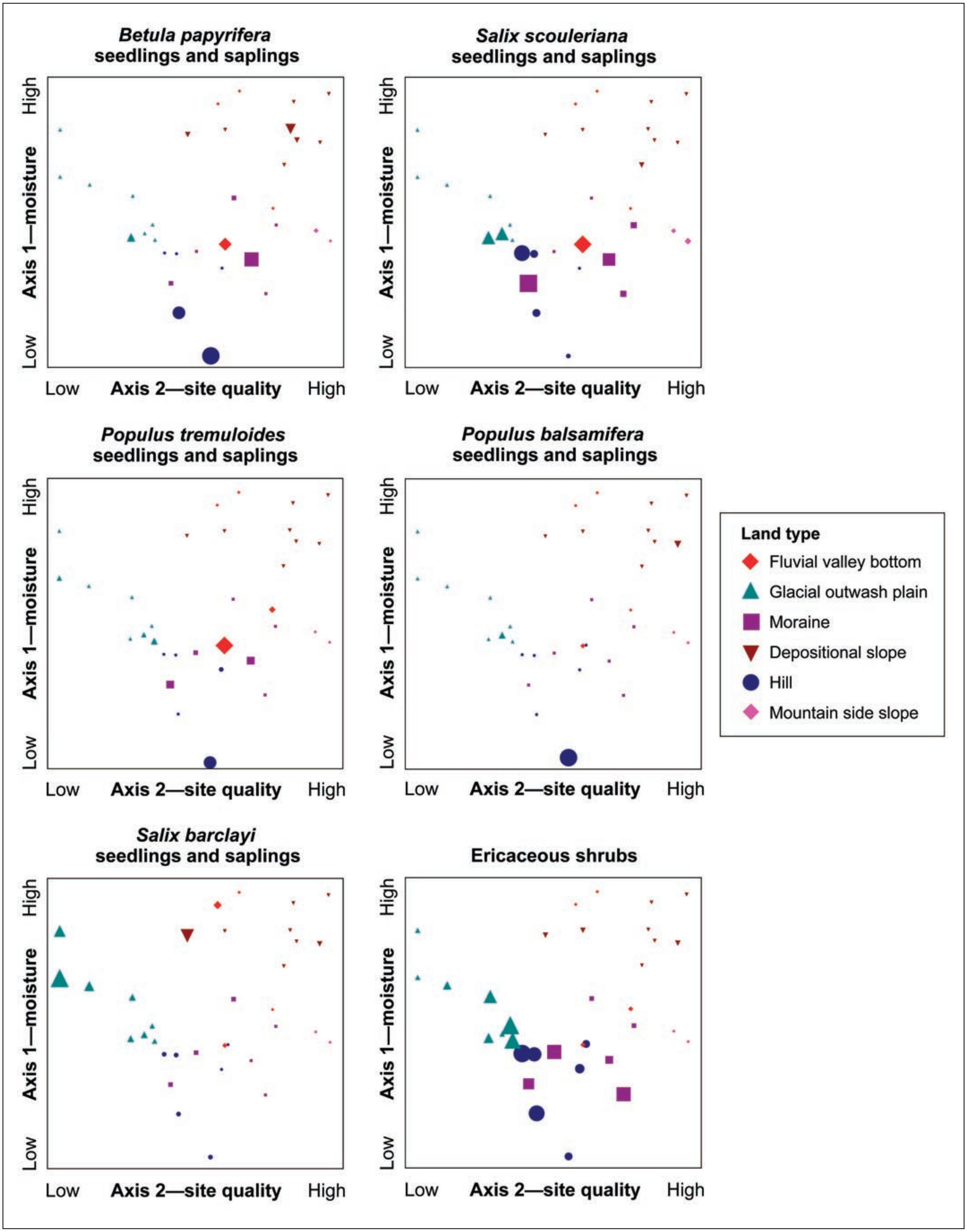

Figure 9—Nonmetric multidimensional scaling ordination axis 1 (moisture) versus axis 2 (site quality). Symbols represent land type. Size of symbol represents abundance (percentage of cover) of indicated species.

Salix scouleriana seedlings and saplings and *Betula papyrifera* seedlings and saplings occupy adjacent and overlapping regions of the ordination space (fig. 9). High cover values of *B. papyrifera* and *S. scouleriana* correspond to hill slope and glacial moraine land types. Study sites on these land types tended to be well drained with coarse-textured soils.

Salix barclayi has a wide ecological amplitude but tends to occur most abundantly on poorly drained soils, on both colluvial and glacial deposits (fig. 9). *Salix barclayi* is negatively correlated with axis 2, indicating a tendency to occur on lower productivity sites, whereas *S. scouleriana* is negatively correlated with axis 1, indicating a tendency toward better drained sites.

The occurrence of *Populus tremuloides* roughly coincides with the occurrence of *B. papyrifera*. The pattern of occurrence of *P. balsamifera* was less clear, with low percentages occurring across the ordination. Quartz Creek 34, one of the most severe burns on a well-drained site, had the highest abundance of *P. balsamifera* (fig. 9).

Browse Abundance Models

I hypothesized that postburn browse abundance is a function of preburn browse abundance, *C. canadensis* abundance, fire severity, surficial deposit, and interactions between surficial deposit and *C. canadensis*, and surficial deposit and preburn browse abundance. Subsets of this global model were tested to determine which model(s) best explained the variation in the data without overfitting the model. Akaike's Information Criterion for small data sets (AIC_c) (Burnham and Anderson 1998) was calculated for each equation and rescaled as a simple difference,

$$\Delta AIC_{ci} = AIC_{ci} - \min AIC_c ,$$

where the lowest AIC_c value of all the models ($\min AIC_c$) is subtracted from the AIC_c value for each model (AIC_{ci}). The "best" model has the lowest ΔAIC_{ci} value. ΔAIC_{ci} values within 1 to 2 of the lowest value have considerable support, models with ΔAIC_c values from 3 to 7 have less support, and those with values greater than 10 have little support (Burnham and Anderson 1998). Regression variables were defined as follows:

LCALCAN = log-transformed preburn *C. canadensis* cover.

SEVERITY = burn severity, categorical variable with three levels: lightly burned, moderately burned, and severely burned.

LPREBROWSE = log-transformed preburn browse species abundance, includes browse species trees, seedlings, and saplings and shrub willows. (Preburn data include data from control plots on sites where preburn data were not available.)

MTHYDR = categorical landscape variable defining surficial deposit with two levels: M = alluvial/colluvial deposits (hydrology associated with mountain runoff); G = glacial deposits (hydrology not associated with mountain runoff). Because of the small size of the data set, surficial deposits were grouped into these two categories based on their dominant process.

LPOSTBROWSE = log-transformed postburn browse species abundance, includes browse species seedlings, saplings, and shrubs (response variable).

Global model:

$$\text{LPOSTBROWSE} = \text{LPREBROWSE} + \text{LCALCAN} + \text{SEVERITY} + \text{MTHYDR} + \text{LCALCAN} \times \text{MTHYDR} + \text{LPREBROWSE} \times \text{MTHYDR}.$$

Owing to the high number of parameters in the global model, the ΔAIC_c value was 30.6, indicating it was not a useful model for describing variation in the data. Models with greater than three parameters had ΔAIC_c values of 8.5 or higher, indicating they have little support according to this criterion (Burnham and Anderson 1998).

Based on the overall fit of the model, variance explained, p-value of parameters, and ΔAIC_c (Burnham and Anderson 1998), the following two models were selected to explain postburn browse species abundance (standard errors are given in parentheses beneath the parameter estimates):

1. LPOSTBROWSE = intercept + LCALCAN, $\Delta AIC_c = 0$
2. LPOSTBROWSE = intercept + LCALCAN + MTHYDR + MTHYDR × LCALCAN, $\Delta AIC_c = 3.6$

Model 1

LPOSTBROWSE = intercept +LCALCAN, $r^2 = 0.36$

LPOSTBROWSE = 2.87 - 0.45(LCALCAN).

(0.24) (0.16)

The first model described the underlying relationship of *C. canadensis* prior to burning to postburn browse abundance (fig. 10), indicating a significant inverse relationship between postburn browse abundance and preburn *C. canadensis* cover (fig. 10 and table 10); however, the model could be enhanced without overfitting by allowing an interaction between *C. canadensis* and surficial deposit, as in the second model:

Model 2

LPOSTBROWSE = intercept + LCALCAN + MTHYDR + MTHYDR × LCALCAN, $r^2 = 0.49$

For MTHYDR = M (alluvial and colluvial deposits),

LPOSTBROWSE = 4.21 - 1.23(LCALCAN).

(0.94) (0.49)

For MTHYDR = G (glacial deposits),

LPOSTBROWSE = 2.97 - 1.23(LCALCAN) + 1.00(LCALCAN).

(1.8) (0.49) (0.54)

Allowing the slopes and intercepts to differ illustrates that browse species response to burning depends on both the type of surficial deposit and the abundance of *C. canadensis* prior to burning (fig. 11 and table 11). On alluvial and colluvial deposits, as preburn *C. canadensis* cover increased, the effect on postburn browse abundance was more strongly inverse. For example, at Caribou East (a burn on colluvial deposits with the highest preburn *C. canadensis* cover of all the burn sites), *C. canadensis* increased from 18 to 44 percent after burning, and cover of browse species changed very little, from 0.1 to 0.5 percent (table 12, CE). On glacial deposits, however, the effect of preburn *C. canadensis* cover on postburn browse production was less negative. For example, at Quartz Creek 29 (a burn on alluvial deposits with relatively low preburn *C. canadensis* cover), *C. canadensis* increased from 3 to 11 percent after burning, and cover of browse species increased from 3 to 40 percent (table 12, Q29).

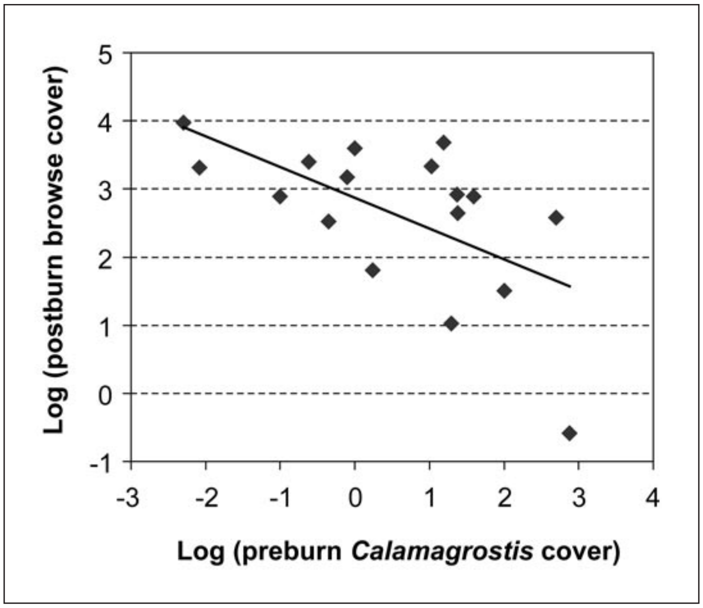

Figure 10—Regression of preburn *Calamagrostis canadensis* cover on postburn browse species cover (model 1).

Table 10—Regression model coefficients and standard errors for model 1 (n = 17)

Parameter	Estimate	Standard error	t value	p value
Intercept	2.87	0.24	11.74	<0.0001
LCALCAN	-.45	.16	-2.87	.0116

Discussion

Succession Pattern

Figure 5a shows vectors linking unburned and burned plots aligning in a unidirectional and roughly parallel fashion. Axis 3 represents the degree of dissimilarity between burned and unburned plots. The direction of vegetation change after burning is consistent in the burn units in the study area, although the lengths of the vectors differ. If prescribed burning had influenced the direction of vegetation change, it is likely that the vectors would not be consistently parallel. This finding is consistent with previous studies on boreal forest dynamics, in which the direction of forest succession was altered only in cases of severe disturbance (Foote 1983, Payette 1992). The relatively parallel alignment of the plot-pair vectors in figure 5a shows that preburn species composition is a more important factor in predicting postburn vegetation composition than burn severity.

It is possible that burn units in the study area did not encompass a sufficiently wide range of burn severities or vegetation types to display divergent successional pathways, or possibly the sample size (17 burns) was not large enough to show this range of responses. Length of vector represents the degree of dissimilarity between unburned and burned plot pairs, and there is considerable variation in vector lengths (fig. 12). Vectors between the severely burned sites and their unburned counterparts were

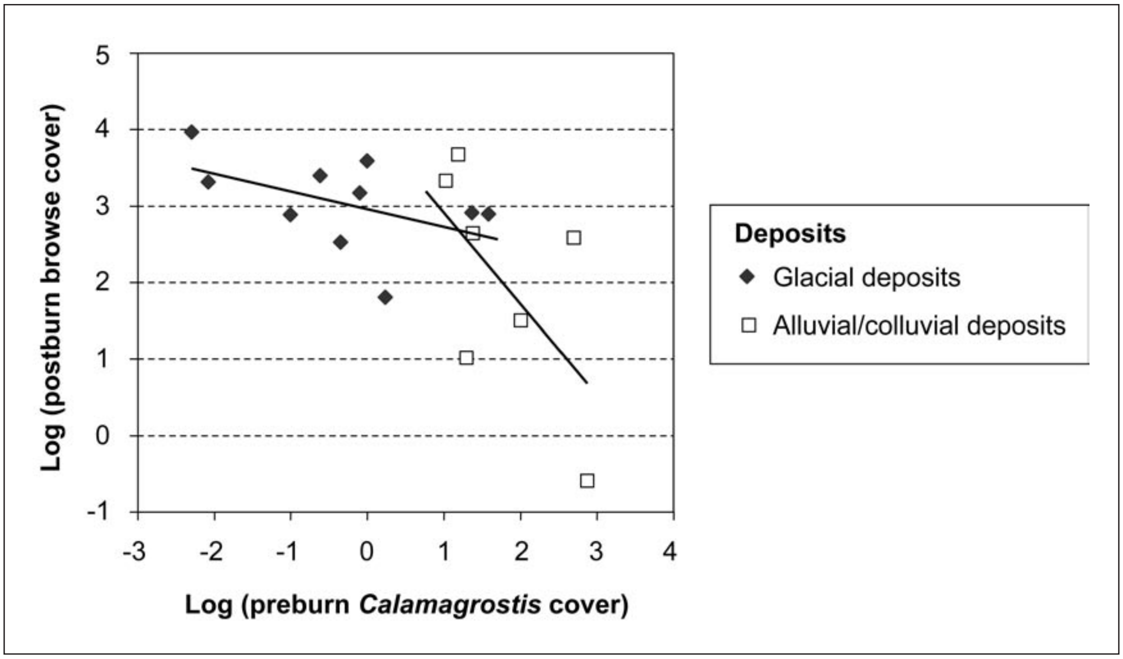

Figure 11—Regression of preburn *Calamagrostis canadensis* cover on postburn browse species cover showing an interaction between *C. canadensis* and surficial deposit (model 2).

Table 11—Regression model coefficients and standard errors for model 2 (n = 17)

Parameter	Estimate	Standard error	t value	p value
Intercept	4.21	0.94	4.50	0.0006
MTHYDR G	-1.24	.98	-1.26	.2303
MTHYDR M	0			
LCALCAN	-1.23	.49	-2.51	.0262
LCALCAN × MTHYDR G	1.00	.54	1.84	.0886
LCALCAN × MTHYDR M	0			

relatively long (fig. 12), suggesting that severe burning caused a more pronounced change in plant composition than light burning, but the direction of change was consistent with that of the other burns.

Sites dominated by *C. canadensis* after burning, such as Caribou East, Caribou West, and Quartz 6, show the same general trend in direction of vector as the remaining burns (fig. 5), indicating that the successional direction of these sites was not altered by abundant *C. canadensis,* although it is likely that the rate of succession has been slowed on these sites, caused by a delay in the recruitment of woody species. This explanation is supported by Schulz (2000); in a study within the Caribou West prescribed burn site, cover of *C. canadensis* increased significantly 7 years after the burn, but 12 years after burning, *C. canadensis* cover had decreased to preburn levels.

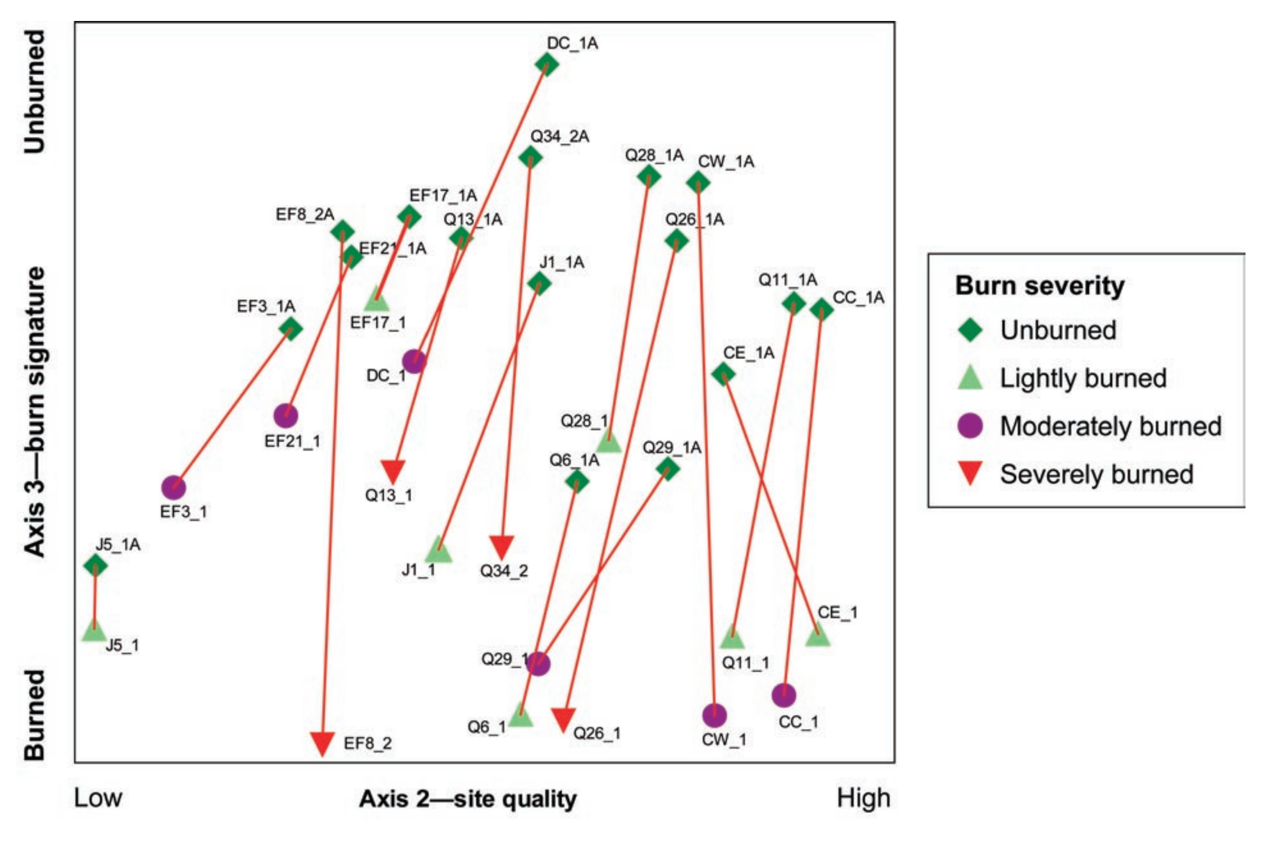

Figure 12—Nonmetric multidimensional scaling ordination of axis 2 (site quality) versus axis 3 (burn signature). Points represent sample units in species space. Symbol represents category of burn severity. Vectors link burned and unburned sample unit pairs, and the length of vector indicates degree of dissimilarity between pairs. See table 3 for site codes. The appendage "A" to site code indicates unburned plot.

Relationship of Preburn Seral Stage and Postburn Browse Production

Forest seral stage may be more important than fire severity in predicting postburn browse production in mid-seral forests where broadleaf trees (all of which propagate vegetatively) are the dominant browse species. In other words, creating abundant postburn browse from a forest dominated by birch is more likely than converting a mature conifer site to birch. The existing birch and spruce-birch forests of the Kenai Mountains were established after wildfire and, in general, have shallower organic mats than mature conifer forests. This allows the litter and duff layers to dry earlier in spring, and mineral seedbed may be more readily created after burning.

Fire Severity

These data do not provide conclusive evidence of the role that fire severity played on postburn vegetation composition of these plots. The highest frequency burn severity was "lightly burned" for seven plots (fig. 12), followed by "moderately burned" for six plots, and "severely burned" for four plots. Because most of the plots were lightly to moderately burned, trends across burn severities may be difficult to detect owing to a lack of samples in the "severely burned" category. Based on what is known of individual species traits, such as rooting habit, type of reproduction, and seedbed needs, assumptions can be made that are supported by trends observed in the data. Some of these trends are described below.

Effect of fire severity on dwarf ericaceous shrubs and browse species—Severe fires shift species composition and abundance by exposing mineral soil, thereby allowing recruitment of new species and by removing species that, under less severe burn conditions, would resprout. For example, cover of *Vaccinium uliginosum*, *Ledum palustre*, and *Empetrum nigrum* tended to decrease after severe burns (table 6), and browse species abundance tended to increase on the same sites (figs. 6 and 12). This trend of decreasing ericaceous shrub cover and increasing browse species cover is illustrated in three of the four most severe burns: East Fork 8, Quartz Creek 34, and Quartz Creek 13 (table 12, EF8, Q34, Q13). In the fourth burn, Quartz Creek 26, ericaceous shrubs were not abundant in either the control or postburn plots. The trend in ericaceous shrub cover on sites with light burns is less clear; of the two lightly burned sites with ericaceous cover, ericaceous shrubs increased after burning at East Fork 17 (30 to 41 percent) and decreased after burning at Quartz Creek 28 (33 to 16 percent), while browse species cover increased at Quartz Creek 28 (2 percent to 30 percent) and increased slightly at East Fork 17 (6 to 13 percent) (table 12, Q26, EF17, Q28).

Ericaceous shrubs as a group did not respond consistently to fire. *Vaccinium caespitosum* increased after burning on six of eight sites where it occurred, and *V. vitis-idaea* showed a mixed response, decreasing on 9 of 14 sites where it occurred. The variable response of the dwarf ericaceous shrubs could be related to their differences in rooting habit. All are shallowly rooted, but *V. caespitosum* and *V. vitis-idaea* rhizomes can penetrate mineral soil (Hungerford 1986, Smith 1962), and *V. vitis-idaea* may possess a taproot (Smith 1962). Rhizomes of *V. uliginosum*, and *Empetrum nigrum* root in the organic layer or near the mineral soil surface, rendering these species more susceptible to damage from fire (Chapin and VanCleve 1981).

***Calamagrostis canadensis* and browse species—**Four burn units developed an abundant cover (16 to 44 percent) of *C. canadensis* after burning: Caribou East, Caribou West, Cripple Creek, and Quartz Creek 6; two of these burns were classified as moderately burned and two were classified as lightly burned (table 12, CE, CW, CC, Q6). On sites with abundant *C. canadensis*, there appears to be a slight trend of increasing browse cover with increasing fire severity; however, postburn browse cover changed only slightly on these four sites. The two moderately burned sites showed increased browse abundance (Cripple Creek and Caribou West), whereas browse decreased in the remaining two sites (Caribou East and Quartz Creek 6), which were lightly burned (table 12). Unfortunately, there were no burns classified as severely burned on sites with high cover of *C. canadensis*. Presumably, more severe fires would kill *C. canadensis* rhizomes and expose mineral soil providing seedbed for recruitment of browse species. Rootstocks of resprouting species likely persist after all but the most severe fires with little change to the postburn population.

Browse species response to burn severity—*Populus balsamifera* seedlings and saplings had the greatest postburn increase in cover (from 0 to 14 percent) on the site with the highest severity burn (Quartz Creek 34) and presumably the highest exposure of mineral soil. *Betula papyrifera* seedlings and saplings also had the greatest increase in cover in the Quartz Creek 34 burn (0 to 23 percent); however, *B. papyrifera* also increased dramatically in lightly to moderately burned sites: Quartz Creek 28 (0 to 23 percent), Quartz Creek 29 (0 to 22 percent), and Dave's Creek (0 to 21 percent). This suggests that the response of *B. papyrifera* is responsive to factors beyond burn severity, such as competition for seedbed space or preburn cover of *B. papyrifera* (trees). Of the four burns described above, none had abundant preburn or postburn

Table 12—Unburned and burned average canopy cover values for selected species and groups of species by site

	CE	CC	Q11	CW	Q28	Q26	Q29	Q6	Q34	J1	DC	Q13	EF17	EF8	EF21	EF3	J5
Soil depth (cm)	57	44	11	59	39	19	32	54	18	38	21	18	21	23	10	47	36
G = glacial; M = alluvial or colluvial deposit	M	M	M	M	G	G	M	M	G	M	G	G	G	G	G	G	G
Burn severity	2	3	2	3	2	4	3	2	4	2	3	4	2	4	3	3	2
Calamagrostis canadensis	18	7	4	4	1	1	3	15	0	3	0	0	1	4	1	5	1
Burned *C. canadensis*	44	16	13	20	5	8	11	26	0	6	1	5	1	4	3	7	1
Total browse cover	0	1	7	2	2	3	3	1	0	0	1	5	6	6	6	8	22
Burned total browse cover	1	5	3	14	30	6	40	13	53	28	28	18	13	18	24	18	36
Empetrum nigrum	0	0	2	0	20	4	0	0	9	0	5	11	17	32	16	12	0
Burned *E. nigrum*	0	0	0	0	6	0	0	0	0	1	12	4	25	0	7	1	0
Vaccinium caespitosum	0	0	0	0	0	0	0	0	0	5	0	3	5	0	0	8	0
Burned *V. caespitosum*	0	0	0	0	0	2	0	0	0	0	0	9	6	1	0	7	2
Vaccinium uliginosum	0	0	0	0	0	0	0	0	0	0	2	16	5	0	10	2	1
Burned *V. uliginosum*	0	0	0	0	0	0	1	0	0	0	2	4	8	0	4	3	0
Vaccinium vitis-idaea	0	0	1	1	5	2	5	0	11	0	4	2	4	8	9	7	3
Burned *V. vitis-idaea*	0	0	0	0	10	3	4	0	3	2	19	5	1	1	5	2	1
Ericaceous combined	0	0	2	1	33	6	5	0	20	5	13	33	30	41	36	28	4
Burned ericaceous combined	0	0	0	0	16	6	5	0	14	4	35	23	41	5	18	13	3
Betula nana	0	0	0	0	0	0	0	0	0	0	0	4	14	11	19	16	9
Burned *B. nana*	0	0	0	0	0	0	0	0	0	1	0	7	21	7	22	26	15
Broadleaf tree cover	6	40	68	13	7	35	57	43	22	4	29	8	6	0	2	0	0

Note: Cover values are for unburned transects unless preceded by “burned.” Burn severity classes are as follows: 2 = light, 3 = moderate, 4 = severe. “Total browse cover” includes shrub willows and seedlings and saplings of broadleaf trees. Sites are listed in descending order according to site quality. Site abbreviations: CE = Caribou E, CC = Cripple Creek, Q11 = Quartz Creek 11, CW = Caribou W, Q28 = Quartz Creek 28, Q26 = Quartz Creek 26, Q29 = Quartz Creek 29, Q6 = Quartz Creek 6, Q34 = Quartz Creek 34, J1 = Juneau 1, DC = Dave’s Creek Test, Q13 = Quartz Creek 13, EF17 = East Fork 17, EF8 = East Fork 8, EF21 = East Fork 21, EF3 = East Fork 3, J5 = Juneau 5.

cover of *C. canadensis* (table 12). Preburn cover of *B. papyrifera* was greater than or equal to 10 percent on three of the four sites; Quartz Creek 28 had a preburn *B. papyrifera* cover of 3 percent.

Influence of Site Quality on Vegetation Response

As described earlier, the terms high-quality and low-quality site have been used in this discussion to describe a suite of site characteristics that influences species composition and species response to disturbance. High-quality sites include those found on depositional slope and valley bottom land types with alluvial or colluvial surficial deposits and deep loamy soils. Low-quality sites include those found on hill and glacial moraine land types with glacial till surficial deposits and soils with a high percentage of coarse fragments in the surface layers. Competition for space is intense on high-quality sites (e.g., Caribou East, Caribou West, and Quartz Creek 6), and as a result, there is high occupancy by competitive herbaceous species such as *C. canadensis*, and less occupancy and recruitment by browse species and ericaceous shrubs (figs. 6 and 8). The influence of surficial deposit on the inverse relationship of *C. canadensis* to browse species abundance also was supported by regression equations in figure 11. Browse species abundance after burning is more negatively affected by *C. canadensis* on high-quality sites (alluvial and colluvial deposits) than it is on sites with glacial deposits. A relatively small data set precluded further refinement of the model. It is likely that preburn browse species abundance would explain additional variance not explained by *C. canadensis* and surficial deposit; however, additional explanatory variables in the model caused unacceptably high AIC_c values indicating overfitting of the data.

It is likely that high-quality sites also would be optimal for production of certain browse species in the absence of competition from herbaceous species. Woody perennials that resprout after fire will, in general, persist after disturbance, eventually shading the competitive herbaceous species. However, 15 to 20 years after burning the sites listed above, woody species have not yet emerged sufficiently from the herbaceous layer (*C. canadensis* can grow to 2 m) to shade the competition. This may be due to two factors: herbivory by moose prevents broadleaf tree species from escape, and the resprouting capacity of birch (the most common broadleaf tree species on these sites) declines as trees mature.

In figure 9, a projection of axis 1 (moisture) versus axis 2 (site quality), the location of browse species corresponds roughly to the location of ericaceous shrubs. Land types that support browse species and dwarf ericaceous shrubs include hill slopes, glacial moraines, and glacial outwash plains. Surficial deposits on these sites include glacial till and residuum (fig. 6), and soils are generally stony. This pattern shows that browse species in the study area occurred more abundantly on low-productivity sites than on high-productivity sites where competition from herbaceous species for space may be high. The understory composition on these sites generally features a combination of several of the following species: *Vaccinium vitis-idaea*, *V. caespitosum*, *V. uliginosum*, *Empetrum nigrum*, *Ledum palustre*, and *Betula nana*, all of which are capable of growing abundantly on sites with low nutrient availability (Henry et al. 1990, Holloway 1981, Klinka et al. 1989, Korcak 1988). The vegetation composition of sites such as Juneau 5, East Fork 3, 8, 21, and 17 suggests that these sites are lower quality than depositional sites such as Caribou East, Caribou West, and Quartz Creek 6. East Fork and Juneau sites occupy the far left positions of axis 2, whereas Caribou East, Caribou West and Quartz Creek 6 occupy the far right of axis 2. Because site conditions on low-quality sites can limit the abundance of highly competitive species, browse species abundance is inversely related to *C. canadensis* abundance.

Management Considerations

Overview of unit selection—Selecting areas to burn across the forest is a decision-making process that logically begins at the landscape level and works down to the unit level. To use fire successfully as a management tool across the landscape, decisions must be made regarding where to burn, how much and how frequently to burn, and finally how to burn a selected unit. Considerations for burn unit selection can be broken down into three general categories:

1. Management goals at the landscape level, considering habitat needs and present versus desired future condition. Questions about where to burn and how much to burn are addressed at this level.
2. Operational limitations such as proximity to natural fire breaks, development, highway, or power lines.
3. Burn planning guidelines for specific site types based on existing vegetation and site characteristics. Site-specific burn prescriptions, including information on fuels (moisture and abundance) and weather limitations, are developed at this level.

The following guidelines and burn planning flowchart (fig. 13) address the third component of burn unit selection. In forested lowlands, the primary goal of prescribed burning will likely be one or more of the following: regeneration of beetle-killed spruce forests, moose range enhancement (generally winter range), and fuel reduction. Burn planning will depend on the primary objective(s) of the burn. If moose range enhancement is the primary objective, then a burn plan designed to create optimal conditions for recruitment and resprouting of desired browse species will be required, considering the availability of seed source for browse species. If forest regeneration is the primary objective, then a burn plan designed to create the most favorable seedbed conditions for the desired conifer or broadleaf tree species will be needed, also considering availability of seed for targeted tree species. These two objectives can be accomplished together; however, the potential for successful restocking of tree species will be a higher priority if the main objective is forest regeneration. For all objectives, burn timing must be planned with seed dispersal for the target species for successful regeneration by seed (see table 1 for duration of seed viability after dispersal for each browse species).

General guidelines for burn planning for moose range enhancement are outlined in a burn-planning flowchart (fig. 13). Site characteristics such as geomorphology and soil depth influence initial vegetation as well as potential postburn vegetation development. Site conditions that favor competitive herbaceous vegetation, such as *C. canadensis*, may be problematic for successful regeneration of woody species. A proposed burn site on a valley bottom or toe slope with alluvial or colluvial deposits and deep (>30 cm), loamy soil would be likely to support *C. canadensis* and will require stringent guidelines for planning prescribed burns. Under these conditions, low preburn cover values of *C. canadensis* can increase substantially after burning. For example, within the study area, a preburn *C. canadensis* cover of 4 percent was remeasured at 20 percent 15 years after burning; at another site, a preburn value of 18 percent increased to 44 percent after burning. Given a proposed burn unit with the conditions described above, there still may be options for successful burning and regeneration of woody species. If the desired browse species are present and fuel load is high (i.e., dead spruce on the ground), the burn plan should be designed to control grass by burning the rhizomes in the organic layer and expose mineral soil to promote recruitment of woody species. These requirements result in a narrow window for burning. The organic layer (not just the thatch on the surface) must be sufficiently dry to carry

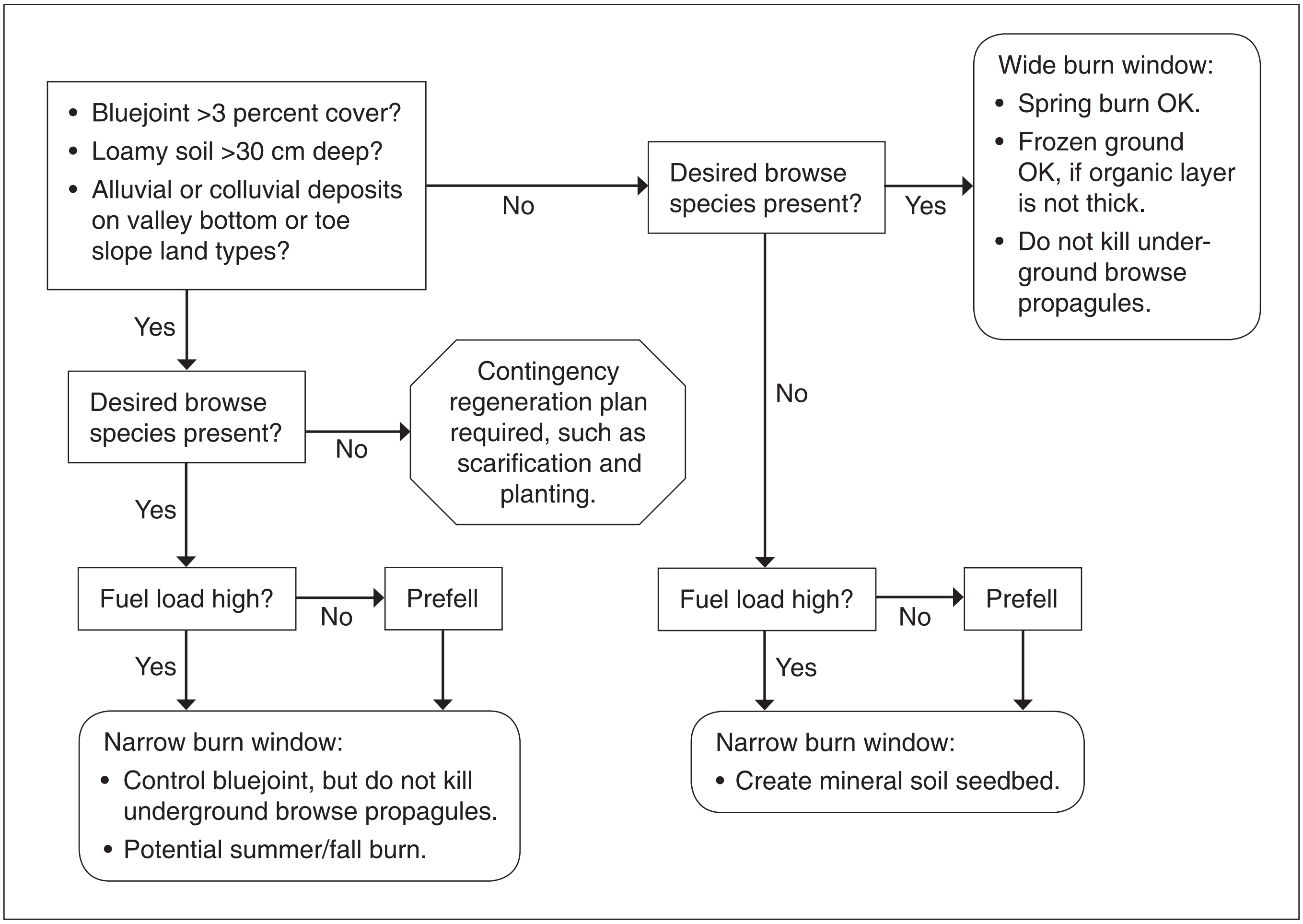

Figure 13—Prescribed burn planning flowchart, generalized for all browse species.

a fire; generally, the organic layer will not be sufficiently dry during the droughty period (May through June) to ensure removal of the organic layer. A burn on this type of site would be most likely to be successful in late summer or fall if the weather allowed sufficient drying of the organic layer; however, such weather conditions typically do not occur every year. If desired browse species are present but the fuel load is low, prefelling of standing fuels may be required. If desired browse species are not present prior to burning on a site with the above characteristics, site treatments such as scarification, seeding, or planting may be necessary for regeneration of woody species. A prescribed burn on such a site that does not result in duff removal and exposure of mineral soil will incur ongoing costs associated with alternative methods of regeneration of woody species.

If a proposed burn unit is not on a valley bottom or toe slope with alluvial or colluvial deposits and deep (>30 cm) loamy soil, and desired browse species are present, then the potential window for burning is wide. These sites will often occur on glacial moraines, hill, and mid-mountain slope land types. If resprouting stems from existing browse species are expected to result in sufficient stocking, then burning can take place across a wide range of conditions, including a spring burn on frozen ground.

However, if new recruitment of woody species is required to meet desired stocking, then exposure of mineral soil will be necessary to provide a favorable seedbed. The burn should be severe enough to expose mineral soil, but not so severe as to kill underground propagules of desired browse species. Prefelling should be considered if the fuel load is not sufficient to create the desired burn severity.

Where feasible, prefelling can be used as a tool to widen the burn window, not only by increasing the fuel load but also through opening the canopy allowing earlier drying of the fuel bed. A burn unit that has been prefelled will dry more rapidly and be more flammable than the surrounding forest.

The allocation of resources required to successfully regenerate a burn unit to the target species will be different depending on site quality and objective of burn. Regenerating a high-quality site with deep, fine soils on alluvial or colluvial deposits may require more resources than regenerating a site of lesser quality (i.e., glacial moraine with coarse-textured soils) because of competition from *C. canadensis.* If moose browse production is the primary objective, then concentrating on lower quality sites will be more cost effective. Given the extensive spruce mortality owing to the spruce bark beetle epidemic, regenerating forests on high-quality sites likely also will be a priority in a prescribed fire program. Careful burn planning along with contingency plans for restocking will be needed to ensure successful forest regeneration.

As postburn browse production is positively correlated with the abundance of browse species in the preburn condition, targeting early- to mid-seral forests where browse species (such as mature *Betula papyrifera* and *Salix scouleriana*) are abundant before burning will maximize postburn browse production. Selection and execution of prescribed burns will vary depending on the motivation for burning. Where browse production, particularly birch or aspen, is the highest priority, mid-seral stands with a birch or aspen component should be targeted. Where regenerating beetle-killed spruce forests is the highest priority, available burn units likely will be in later seral stages dominated by spruce or mountain hemlock-spruce. A viable seed source of target regeneration species and creation of favorable seedbed conditions are important if relying on natural regeneration.

Preparing multiple units with different requirements for burning will increase chances of completing burns given average seasons with often short and unpredictable windows of favorable burn weather.

Future direction—Continuing fire effects monitoring will increase knowledge regarding the influence of fire across a wider range of fire severities and vegetation types. Information is sparse on the effects of severe fires on vegetation development and the effect of fire on later successional Lutz spruce-mountain hemlock stands. To conduct successful fire effects monitoring, the burn monitoring protocol must be strictly followed. It is essential to have permanent, well-monumented transects for preburn vegetation and fuel load monitoring in the vegetation types of interest at each burn. Documentation of fire severity, including reduction of organic layer and amount of mineral soil exposed, is particularly important. A monitoring schedule including readings the year prior to burning, the first 3 years following the burn, and at 5-year intervals thereafter would be ideal. Fire effects data should be collected as soon as practical after the burn.

In this study, guidelines for burn planning at the level of the individual burn unit were developed. Additional guidelines are needed for landscape-level planning, addressing scale and frequency of burning. The historical range of variation (not yet defined for the area) could be used as a guide.

Conclusions

Preburn vegetation composition explained most of the variance in vegetation response to fire in the Kenai Mountains (fig. 5). Vegetation composition was influenced by physical site characteristics such as land type, surficial deposit, and soil depth (fig. 7). These site characteristics, combined with initial vegetation, can be used to predict the effect of prescribed burning on a given site. In addition to initial vegetation composition, specific species indicators, such as dwarf ericaceous shrubs, *C. canadensis*, and *B. nana*, can be used as indicators of site quality and provide information regarding potential postburn browse production and vegetation development. Severity of burn can be manipulated to influence postburn vegetation development by affecting seedbed conditions and allowing new species recruitment, as well as reducing underground propagules of species such as *C. canadensis* that compete with new seedlings for seedbed space and site resources. Burn severity is a higher concern on certain site types, for example, those that might support abundant *C. canadensis* after burning and those sites with a deep organic layer. Failure to execute a sufficiently severe prescribed burn on a site that supports abundant *C. canadensis* likely will result in low woody plant regeneration.

Calamagrostis canadensis occurred on each of the 17 sites on both unburned and burned plots, and abundance increased after burning on every site; however, percentage of cover varied greatly across site types after burning (from 0.1 to 48 percent). *Calamagrostis canadensis* occurs most abundantly on moist sites with deep, loamy soil, on land types including lower mountain slopes (toe slopes) and alluvial valley bottoms. Sites with these features generally show large increases in *C. canadensis* cover after prescribed burning, even when *C. canadensis* cover is low (3 percent) prior to burning. *Calamagrostis canadensis* is generally not abundant on hill and glacial moraine land types, which often feature shallow, stony soils. On these site types, *C. canadensis* cover generally does not increase dramatically after burning.

Browse abundance was inversely related to *C. canadensis* abundance after burning. Total browse abundance was generally higher after burning on sites where browse species were present prior to burning and competition from *C. canadensis* was not a factor. Land types that support these conditions include glacial moraines, hills, and mid-mountain slopes.

Within the prescribed burns of the study area, vegetation succession followed predictable pathways indicated by the direction of change on the ordination gradient representing time. Although factors such as severity, preburn vegetation composition, and landscape position varied across the 17 burns, the direction of succession after burning was relatively consistent. The rate of succession, however, may have been affected by large increases in *C. canadensis* after burning on certain sites, which impeded recruitment of woody species.

Timing and severity of burn can be manipulated to increase the probability of achieving desired burn results. Burn planning guidelines developed in this study based on site type and existing vegetation composition will assist managers in successfully meeting habitat enhancement and forest regeneration objectives.

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English Equivalents

When you know:	Multiply by:	To get:
Centimeters (cm)	0.394	Inches
Millimeters (mm)	.039	Inches
Meters (m)	3.281	Feet
Hectares (ha)	2.471	Acres
Degrees Celsius (°C)	1.8 and add 32	Fahrenheit

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Appendix 1: Species Codes, Scientific and Common Names

Code	Scientific name	Common name
Trees:		
BETPAP	*Betula papyrifera* Marsh.	Paper birch
BETPAPSA	*Betula papyrifera* Marsh. (sapling)	
BETPAPSE	*Betula papyrifera* Marsh. (seedling)	
	Picea glauca (Moench) Voss	White spruce
PICLUT	*Picea* X *lutzii* Little	Lutz spruce
PICLUTSA	*Picea* X *lutzii* Little (sapling)	
PICLUTSE	*Picea* X *lutzii* Little (seedling)	
	Picea mariana (Mill.) B.S.P.	Black spruce
	Picea sitchensis (Bong.) Carr.	Sitka spruce
POPBALT	*Populus balsamifera* ssp. *trichocarpa* (Torr. & Gray ex Hook.) Brayshaw	Black cottonwood
POPBALTSA	*Populus balsamifera* ssp. *trichocarpa* (Torr. & Gray ex Hook.) Brayshaw (sapling)	
POPBALTSE	*Populus balsamifera* ssp. *trichocarpa* (Torr. & Gray ex Hook.) Brayshaw (seedling)	
	Populus balsamifera ssp. *balsamifera*	Balsam poplar
POPTRE	*Populus tremuloides* Michx.	Quaking aspen
POPTRESA	*Populus tremuloides* Michx. (sapling)	
POPTRESE	*Populus tremuloides* Michx. (seedling)	
SALSCO	*Salix scouleriana* Barratt ex Hook.	Scouler willow
SALSCOSA	*Salix scouleriana* Barratt ex Hook. (sapling)	
SALSCOSE	*Salix scouleriana* Barratt ex Hook. (seedling)	
TSUMER	*Tsuga mertensiana* (Bong.) Carr.	Mountain hemlock
TSUMERSA	*Tsuga mertensiana* (Bong.) Carr. (sapling)	
TSUMERSE	*Tsuga mertensiana* (Bong.) Carr. (seedling)	
Tall shrubs:		
ALNCRIS	*Alnus crispa* ssp. *sinuata* (Regel) Hulten	Sitka alder
BETNAN	*Betula nana* L.	Dwarf birch
BETGLA	*Betula glandulosa* Michx.	Bog birch
ECHHOR	*Echinopanax horridum* (Sm.) Dcne. & Planch.	Devil’s club
MENFER	*Menziesia ferruginea* Sm.	Rusty menziesia
POTFRU	*Potentilla fruticosa* auct. non L.	Shrubby cinquefoil
RIBES	*Ribes* L.	
RIBBRA	*Ribes bracteosum* Dougl. ex Hook.	Stink currant
RIBGLA	*Ribes glandulosum* Grauer	Skunk currant
RIBHUD	*Ribes hudsonianum* Richards.	Northern black currant
RIBLAC	*Ribes lacustre* (Pers.) Poir.	Swamp gooseberry
RIBLAX	*Ribes laxiflorum* Pursh	Trailing black currant
RIBTRI	*Ribes triste* Pallas	American red currant
ROSACI	*Rosa acicularis* Lindl.	Prickly rose
RUBIDA	*Rubus idaeus* L.	Red raspberry
SALIX	*Salix* L.	Willow
SALALA	*Salix alaxensis* (Anderss.) Coville	Feltleaf willow
SALBAR	*Salix barclayi* Anderss.	Barclay willow
SALBEB	*Salix bebbiana* Sarg.	Bebb willow

Code	Scientific name	Common name
SALCOM	*Salix commutata* Bebb	Undergreen willow
SALPLA	Salix planifolia Pursh	Tea-leaf willow
SALPUL	*Salix pulchra* Cham.	Diamond-leaf willow
SALSIT	*Salix sitchensis* Sanson ex Bong.	Sitka willow
SAMRAC	*Sambucus racemosa* L.	Red elderberry
SHECAN	*Shepherdia canadensis* (L.) Nutt.	Soapberry
SORSCO	*Sorbus scopulina* Greene	Greene mountain ash
SORSIT	*Sorbus sitchensis* M. Roemer	Sitka mountain ash
VACOVA	*Vaccinium ovalifolium* Sm.	Early blueberry
VIBEDU	*Viburnum edule* (Michx.) Raf.	Highbush cranberry
Low and subshrubs:		
ANDPOL	*Andromeda polifolia* L.	Bog rosemary
ARCALP	*Arctostaphylos alpina* (L.) Spreng.	Alpine bearberry
ARCRUB	*Arctostaphylos rubra* (Rehd. & Wilson) Fern.	Red bearberry
ARCUVA	*Arctostaphylos uva-ursi* (L.) Spreng.	Kinnikinnick
EMPNIG	*Empetrum nigrum* L.	Crowberry
JUNCOM	*Juniperus communis* L.	Common juniper
LEDPAL	*Ledum palustre* L.	Labrador tea
LINBOR	*Linnaea borealis* L.	Twinflower
LOIPRO	*Loiseleuria procumbens* (L.) Desv.	Alpine azalea
OXYMIC	*Oxycoccus microcarpus* Turcz. ex Rupr	Bog cranberry
SPIBEA	*Spiraea beauverdiana* auct. non Schneid.	Beauverd spirea
VACCAE	*Vaccinium caespitosum* Michx.	Dwarf blueberry
VACULI	*Vaccinium uliginosum* L.	Bog blueberry
VACVIT	*Vaccinium vitis-idaea* L.	Lowbush cranberry
Forbs:		
ACHBOR	*Achillea borealis* Bong.	Yarrow
ACODEL	*Aconitum delphiniifolium* DC.	Monkshood
ACTRUB	*Actaea rubra* (Ait.) Willd.	Baneberry
ANERIC	*Anemone richardsonii* Hook.	Yellow anemone
ANGLUC	*Angelica lucida* L.	Seacoast angelica
ARABIS	*Arabis* L.	
ARNICA	*Arnica* L.	
ARNLAT	*Arnica latifolia* Bong.	Mountain arnica
ARTTIL	*Artemisia tilesii* Ledeb.	Tilesius wormwood
BOSROS	*Boschniakia rossica* (Cham. & Schlecht.) Fedtsch.	Broomrape
CAMROT	*Campanula rotundifolia* L.	Common harebell
CARUMB	*Cardamine umbellata* Greene	Siberian bittercress
CASUNA	*Castilleja unalaschcensis* (Cham. & Schlecht.) Malte	Alaska Indian paintbrush
CERBEE	*Cerastium beeringianum* Cham. & Schlecht.	Bering chickweed
CHRTET	*Chrysosplenium tetrandrum* (Lund ex Malmgr.) Th. Fries	Northern water carpet
CORCAN	*Cornus canadensis* L.	Bunchberry dogwood
CORSEM	*Corydalis sempervirens* (L.) Pers.	Pale corydalis
DELGLA	*Delphinium glaucum* S. Wats.	Larkspur
EPIANG	*Epilobium angustifolium* L.	Tall fireweed
GALIUM	*Galium* L.	Bedstraw
GALBOR	*Galium boreale* L.	Northern bedstraw
GALTRIL	*Galium triflorum* Michx.	Fragrant bedstraw

Code	Scientific name	Common name
GEOLIV	*Geocaulon lividum* (Richards.) Fern.	Northern comandra
GERERI	*Geranium erianthum* DC.	Northern geranium
GEUMAC	*Geum macrophyllum* Willd.	Large avens
HERLAN	*Heracleum lanatum* Michx.	Cow parsnip
LISCOR	*Listera cordata* (L.) R. Br. ex Ait. f.	Heartleaf tway blade
LUPNOO	*Lupinus nootkatensis* Donn ex Sims	Nootka lupine
MERPAN	*Mertensia paniculata* (Ait.) G. Don	Tall bluebells
MIMGUT	*Mimulus guttatus* DC.	Yellow monkeyflower
MITELL	*Mitella* L.	Mitrewort
MOELAT	*Moehringia lateriflora* (L.) Fenzl	Blunt-leaved sandwort
MONUNI	*Moneses uniflora* (L.) Gray	Single delight
OSMORH	*Osmorhiza* Raf.	Sweet cicely
PARPAL	*Parnassia palustris* L.	Grass of Parnassus
PEDICU	*Pedicularis* L.	Lousewort
PETASI	*Petasites* P. Mill.	Coltsfoot
PETHYP	*Petasites hyperboreus* Rydb.	Sweet coltsfoot
PLADIL	*Platanthera dilatata* (Pursh) Lindl. ex Beck	White bog orchid
POLACU	*Polemonium acutiflorum* Willd. ex Roemer & J.A. Schultes	Jacob's ladder
POLBIS	*Polygonum bistorta* ssp. *plumosum* (Small) Hult.	American bistort
POLVIV	*Polygonum viviparum* L.	Alpine bistort
PYROLA	*Pyrola* L.	Wintergreen
PYRASA	*Pyrola asarifolia* Michx.	Pink wintergreen
PYRCHL	*Pyrola chlorantha* Sw.	Green wintergreen
PYRGRA	*Pyrola grandiflora* Radius	Arctic wintergreen
PYRMIN	*Pyrola minor* L.	Lesser wintergreen
PYRSEC	*Pyrola secunda* L.	One-sided wintergreen
RANUNC	*Ranunculus* L.	
RHIMIN	*Rhinanthus minor* L.	Yellow rattle
RUBARC	*Rubus arcticus* L.	Nagoonberry
RUBCHA	*Rubus chamaemorus* L.	Cloudberry
RUBPED	*Rubus pedatus* Sm.	Fiveleaf bramble
RUMEX	*Rumex* L.	
SANSTI	*Sanguisorba stipulata* Raf.	Sitka burnet
SENECI	*Senecio* L.	
SOLMUL	*Solidago multiradiata* Ait.	Northern goldenrod
STELLA	*Stellaria* L.	
STRAMP	*Streptopus amplexifolius* (L.) DC.	Twistedstalk
SWEPER	*Swertia perennis* L.	Alpine bog swertia
TARAXA	*Taraxacum* G.H. Weber ex Wiggers	
TAXOFF	*Taraxacum officinale* G.H. Weber ex Wiggers	Common dandelion
THALIC	*Thalictrum* L.	Meadowrue
TRIEUR	*Trientalis europaea* L.	Starflower
VALSIT	*Valeriana sitchensis* Bong.	Sitka valerian
VERVIR	*Veratrum viride* Ait.	False hellebore
VIOLA	*Viola* L.	Violet
Graminoids:		
AGRSPI	*Agropyron spicatum* Scribn. & Merr.	Bluebunch wheatgrass
AGROST	*Agrostis* L.	

Code	Scientific name	Common name
CALCAN	*Calamagrostis canadensis* (Michx.) Beauv.	Bluejoint reedgrass
CAREX	*Carex* L.	Sedge
CARDEW	*Carex deweyana* Schwein.	Dewey sedge
CARINT	*Carex interior* Bailey	
CARLAE	*Carex laeviculmis* Meinsh.	Smooth stem sedge
CARMACH	*Carex macrochaeta* C.A. Mey.	Longawned sedge
CARPHY	*Carex phyllomanica* W. Boott	Stellate sedge
CARPYR	*Carex pyrenaica* Wahlenb.	
CARRHY	*Carex rhynchosphysa* Fisch., C.A. Mey. & Ave-Lall.	Bladder beaked sedge
CINLAT	*Cinna latifolia* (Trev. ex Goepp.) Griseb.	Woodreed grass
DANINT	*Danthonia intermedia* Vasey	Timber oatgrass
FESTUC	*Festuca* L.	Fescue
FESALT	*Festuca altaica* Trin.	Rough fescue
FESRUB	*Festuca rubra* L.	Red fescue
FESSAX	*Festuca saximontana* Rydb.	
HIEALP	*Hierochloe alpina* (Sw. ex Willd.) Roemer & J.A. Schultes	Alpine holygrass
JUNCUS	*Juncus* L.	Rush
LUZPAR	*Luzula parviflora* (Ehrh.) Desv.	Small-flowered woodrush
PHLEUM	*Phleum* L.	Timothy
PHLALP	*Phleum alpinum* L.	Mountain timothy
POA	*Poa* L.	Bluegrass
TRISPI	*Trisetum spicatum* (L.) Richter	Spike trisetum
Ferns and allies:		
ATHFIL	*Athyrium filix-femina* (L.) Roth	Lady fern
CYSMON	*Cystopteris montana* (Lam.) Bernh. ex Desv.	Mountain fragile fern
DRYDIL	*Dryopteris dilatata* auct. non (Hoffmann) Gray	Wood fern
EQUISE	*Equisetum* L.	Horsetail
EQUARV	*Equisetum arvense* L.	Common horsetail
EQUPRA	*Equisetum pratense* Ehrh.	Meadow horsetail
EQUSCI	*Equisetum scirpoides* Michx.	Dwarf scouring rush
EQUSIL	*Equisetum sylvaticum* L.	Woodland horsetail
EQUVAR	*Equisetum variegatum* Schleich. ex F. Weber & D.M.H. Mohr	Northern horsetail
GYMDRY	*Gymnocarpium dryopteris* (L.) Newman	Oak fern
LYCOPO	*Lycopodium* L.	Clubmoss
LYCALP	*Lycopodium alpinum* L.	Alpine clubmoss
LYCANN	*Lycopodium annotinum* L.	Stiff clubmoss
LYCCLA	*Lycopodium clavatum* L.	Running clubmoss
LYCCOM	*Lycopodium complanatum* L.	Ground cedar
Mosses:		
HYLSPL	*Hylocomium splendens* (Hedw.) B.S.G	Splendid feather moss
PLESCH	*Pleurozium schreberi* (Brid.) Mitt.	Schrebers's big red stem moss

Scientific names follow Hulten (1968).

Appendix 2: Difference in Canopy Cover Between Burned and Unburned Transects

Appendix 2 summarizes the difference in percentage of canopy cover for individual species between burned and unburned transects by site. The “A” appended to site abbreviation indicates unburned (preburn or control). Uncommon species (i.e., those occurring on only one transect with a low percentage of canopy cover) are not listed.

Species	**CW_1A**	**CW_1**	**CW change**	**CE_1A**	**CE_1**	**CE change**	**Q11_1A**	**Q11_1**	**Q11 change**	**J1_1A**	**J1_1**	**J1 change**	**Q6_1A**	**Q6_1**	**Q6 change**	**Q29_1A**	**Q29_1**	**Q29 change**	**Q28_1A**	**Q28_1**	**Q28 change**	**Q26_1A**	**Q26_1**	**Q26 change**	**Q13_1A**	**Q13_1**	**Q13 change**
Trees:																											
Betula papyrifera (seedl.)	0	1	**0**	0	0	**0**	1	1	**0**	0	3	**3**	0	1	**1**	0	12	**12**	0	6	**6**	0	1	**1**	0	2	**2**
Betula papyrifera (sapl.)	1	13	**12**	0	0	**0**	0	1	**1**	0	2	**2**	0	0	**0**	0	10	**10**	0	17	**17**	0	1	**1**	0	2	**2**
Betula papyrifera (tree)	13	2	**-12**	6	0	**-6**	3	1	**-2**	0	0	**0**	43	0	**-42**	10	1	**-9**	3	2	**-1**	10	0	**-10**	1	0	**-1**
Picea lutzii (sapl.)	3	0	**-3**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	1	0	**0**	0	0	**0**	0	0	**0**	1	3	**2**
Picea lutzii (seedl.)	0	0	**0**	0	0	**0**	2	0	**-2**	0	0	**0**	0	0	**0**	1	0	**-1**	0	1	**0**	0	0	**0**	3	1	**-3**
Picea lutzii (tree)	22	0	**-22**	31	0	**-31**	50	0	**-50**	21	11	**-10**	56	1	**-56**	8	1	**-7**	19	4	**-15**	39	0	**-39**	28	1	**-28**
Populus balsamifera (sapl.)	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Populus balsamifera (seedl.)	0	0	**0**	0	0	**0**	3	0	**-3**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**	0	0	**0**
Populus balsamifera (tree)	0	0	**0**	0	0	**0**	66	1	**-65**	0	0	**0**	0	2	**2**	5	3	**-2**	0	0	**0**	0	0	**0**	3	0	**-2**
Populus tremuloides (sapl.)	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	2	**2**	0	0	**0**	0	0	**0**	0	1	**0**
Populus tremuloides (seedl.)	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**
Populus tremuloides (tree)	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	25	0	**-24**	0	1	**1**	9	0	**-9**	3	3	**0**
Salix scouleriana (sapl.)	1	0	**-1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	7	**7**	1	4	**3**	1	1	**-1**	0	6	**6**
Salix scouleriana (seedl.)	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	1	**1**	0	0	**0**	0	1	**1**
Salix scouleriana (tree)	0	0	**0**	0	0	**0**	0	0	**0**	4	1	**-3**	0	0	**0**	17	1	**-16**	4	0	**-4**	16	9	**-8**	1	1	**0**
Tsuga mertensiana (sapl.)	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	4	1	**-3**	4	0	**-4**	0	0	**0**
Tsuga mertensiana (seedl.)	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	8	0	**-8**	2	0	**-2**	1	0	**-1**
Tsuga mertensiana (tree)	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	18	3	**-15**	24	0	**-24**	0	0	**0**
Tall and low shrubs:																											
Alnus crispa ssp. *sinuata*	0	6	**6**	21	14	**-8**	37	0	**-37**	8	15	**7**	1	0	**-1**	0	0	**0**	2	10	**7**	0	0	**0**	0	0	**0**
Betula nana	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	4	7	**4**
Echinopanax horridum	0	0	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Menziesia ferruginea	22	2	**-21**	12	0	**-12**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	5	9	**5**	1	1	**0**	0	0	**0**
Potentilla fruticosa	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Ribes sp.	9	2	**-7**	1	1	**0**	22	3	**-19**	1	1	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Rosa acicularis	3	3	**0**	1	0	**-1**	22	4	**-18**	1	9	**8**	5	1	**-4**	6	7	**1**	0	0	**0**	1	1	**0**	0	0	**0**
Rubus idaeus	3	1	**-1**	7	6	**-2**	0	3	**3**	0	2	**2**	0	5	**4**	0	1	**1**	0	0	**0**	0	0	**0**	0	0	**0**
Salix barclayi	0	1	**1**	0	0	**0**	3	0	**-3**	0	23	**23**	1	12	**11**	0	1	**1**	0	0	**0**	2	4	**2**	4	4	**0**
Salix pulchra	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Salix sitchensis	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	4	**4**	0	0	**0**	0	0	**0**	0	1	**1**
Sambucus racemosa	0	0	**0**	7	2	**-5**	2	0	**-2**	2	0	**-2**	0	1	**1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Shepherdia canadensis	0	0	**0**	0	0	**0**	2	0	**-2**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Spirea beauverdiana	0	1	**0**	3	1	**-2**	3	2	**-1**	0	4	**4**	0	2	**2**	0	0	**0**	0	2	**1**	0	1	**0**	0	0	**0**
Viburnum edule	0	1	**1**	1	2	**0**	2	1	**-1**	0	0	**0**	1	0	**0**	1	1	**0**	0	1	**1**	0	0	**0**	0	0	**0**
Dwarf shrubs:																											
Arctostaphylos rubra	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Arctostaphylos uva-ursi	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Empetrum nigrum	0	0	**0**	0	0	**0**	2	0	**-2**	0	1	**1**	0	0	**0**	0	0	**0**	20	6	**-14**	4	0	**-3**	11	4	**-8**
Ledum palustre	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**	8	0	**-8**	0	0	**0**	0	0	**0**

Species	CW_1A	CW_1	CW change	CE_1A	CE_1	CE change	Q11_1A	Q11_1	Q11 change	J1_1A	J1_1	J1 change	Q6_1A	Q6_1	Q6 change	Q29_1A	Q29_1	Q29 change	Q28_1A	Q28_1	Q28 change	Q26_1A	Q26_1	Q26 change	Q13_1A	Q13_1	Q13 change
Linnaea borealis	7	0	**-7**	4	0	**-4**	3	0	**-3**	1	1	**-1**	0	0	**0**	4	3	**-1**	6	4	**-2**	5	2	**-4**	6	3	**-3**
Vaccinium caespitosum	0	0	**0**	0	0	**0**	0	0	**0**	5	0	**-5**	0	0	**0**	0	0	**0**	0	0	**0**	0	2	**2**	3	9	**7**
Vaccinium uliginosum	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**	16	4	**-12**
Vaccinium vitis-idaea	1	0	**0**	0	0	**0**	1	0	**-1**	0	2	**2**	0	0	**0**	5	4	**0**	5	10	**5**	2	3	**1**	2	5	**3**
Forbs:																											
Achillea borealis	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	0	0	**0**
Aconitum delphiniifolium	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	0	0	**0**
Actaea rubra	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Anemone richardsonii	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Artemisia tilesii	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Cardamine umbellata	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Castilleja unalaschensis	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**
Cornus canadensis	4	1	**-3**	2	0	**-2**	1	2	**1**	9	4	**-5**	4	0	**-3**	15	7	**-8**	4	11	**7**	9	6	**-3**	3	7	**4**
Epilobium angustifolium	1	26	**25**	5	34	**29**	0	44	**44**	1	13	**11**	1	32	**31**	8	15	**6**	4	18	**15**	3	26	**23**	3	15	**12**
Galium boreale	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Galium triflorum	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Geocaulon lividum	0	0	**0**	0	0	**0**	1	0	**-1**	0	1	**1**	0	0	**0**	0	0	**0**	5	7	**2**	4	0	**-4**	4	3	**-1**
Geranium erianthum	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**
Heracleum lanatum	0	1	**1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Lupinus nootkatensis	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	3	**2**	0	1	**1**	2	2	**1**
Mertensia paniculata	0	1	**1**	4	0	**-4**	0	0	**0**	3	5	**2**	1	2	**1**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**
Moneses uniflora	0	0	**0**	0	0	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	0	0	**0**
Osmorhiza sp.	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Polemonium acutiflorum	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	1	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Pyrola secunda	0	0	**0**	0	0	**0**	4	0	**-4**	1	0	**-1**	0	0	**0**	0	0	**0**	1	0	**0**	1	0	**-1**	0	0	**0**
Pyrola sp.	0	0	**0**	0	0	**0**	11	1	**-10**	0	0	**0**	0	0	**0**	2	0	**-2**	0	0	**0**	0	0	**0**	0	0	**0**
Rhinanthus minor	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**
Rubus arcticus	0	0	**0**	15	0	**-15**	0	0	**0**	1	1	**0**	1	4	**3**	1	2	**1**	0	0	**0**	0	0	**0**	0	0	**0**
Rubus chamaemorus	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Rubus pedatus	13	0	**-13**	0	0	**0**	6	0	**-6**	0	0	**0**	0	0	**0**	0	0	**0**	1	0	**-1**	5	0	**-5**	0	0	**0**
Rumex sp.	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Sanguisorba stipulata	0	4	**4**	0	0	**0**	0	0	**0**	1	14	**13**	1	1	**0**	0	0	**0**	0	0	**0**	0	3	**3**	0	0	**0**
Solidago multiradiata	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**
Streptopus amplexifolius	0	0	**0**	0	0	**0**	1	1	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	0	**0**	0	0	**0**
Trientalis europaea	1	0	**-1**	0	0	**0**	1	1	**0**	0	0	**0**	1	1	**0**	3	0	**-3**	0	0	**0**	1	0	**0**	1	1	**0**
Viola sp.	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	2	**1**	2	0	**-2**	0	0	**0**	0	0	**0**	0	0	**0**
Graminoids:																											
Calamagrostis canadensis	4	20	**16**	18	44	**26**	4	13	**9**	3	6	**3**	15	26	**11**	3	11	**7**	1	5	**5**	1	8	**7**	0	5	**4**
Carex deweyana	0	0	**0**	0	0	**0**	0	0	**0**	0	2	**2**	0	3	**3**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Festuca altaica	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	2	0	**-1**

Species	CW_ 1A	CW_ 1	CW change	CE_ 1A	CE_ 1	CE change	Q11_ 1A	Q11_ 1	Q11 change	J1_ 1A	J1_ 1	J1 change	Q6_ 1A	Q6_ 1	Q6 change	Q29_ 1A	Q29_ 1	Q29 change	Q28_ 1A	Q28_ 1	Q28 change	Q26_ 1A	Q26_ 1	Q26 change	Q13_ 1A	Q13_ 1	Q13 change
Luzula parviflora	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	3	**3**
Poa sp.	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	1	**1**	0	0	**0**	0	3	**3**	0	4	**4**
Trisetum spicatum	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	2	**2**
Ferns and allies:																											
Athyrium filix-femina	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Dryopteris dilatata	35	0	**-35**	35	4	**-31**	1	0	**0**	3	0	**-3**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Equisetum arvense	6	40	**34**	10	1	**-9**	0	1	**1**	0	25	**25**	32	10	**-22**	4	2	**-2**	0	0	**0**	0	9	**9**	0	0	**0**
Equisetum pratense	0	1	**1**	0	0	**0**	3	8	**5**	0	1	**1**	4	0	**-3**	3	2	**-1**	0	0	**0**	0	1	**1**	0	0	**0**
Equisetum sylvaticum	0	0	**0**	1	19	**18**	0	1	**1**	0	0	**0**	5	4	**-1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Gymnocarpium dryopteris	0	7	**7**	0	14	**14**	6	2	**-3**	7	0	**-7**	25	4	**-21**	7	2	**-5**	0	1	**0**	10	23	**13**	0	0	**0**
Lycopodium alpinum	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Lycopodium annotinum	6	0	**-6**	9	0	**-9**	4	0	**-4**	0	0	**0**	0	0	**0**	1	0	**-1**	2	1	**-1**	14	0	**-14**	1	0	**-1**
Lycopodium clavatum	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Lycopodium complanatum	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	6	2	**-5**

Species	Q34_ 2A	Q34_ 2	Q34 change	EF17_ 1A	EF17_ 1	EF17 change	DC_ 1A	DC_ 1	DC change	EF8_ 2A	EF8_ 2	EF8 change	EF21_ 1A	EF21_ 1	EF21 change	EF3_ 1A	EF3_ 1	EF3 change	J5_ 1A	J5_ 1	J5 change	CC_ 1A	CC_ 1	CC change
Trees:																								
Betula papyrifera (seedl.)	0	8	**8**	0	0	**0**	0	16	**16**	4	0	**-4**	0	2	**1**	0	0	**0**	0	0	**0**	0	3	**3**
Betula papyrifera (sapl.)	0	23	**23**	1	1	**0**	0	5	**5**	0	1	**1**	0	10	**10**	0	0	**0**	0	0	**0**	0	1	**1**
Betula papyrifera (tree)	11	1	**-10**	1	0	**-1**	25	2	**-23**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	35	1	**-34**
Picea lutzii (sapl.)	0	1	**1**	1	2	**1**	1	1	**0**	0	0	**0**	2	0	**-2**	2	0	**-2**	0	0	**0**	1	0	**-1**
Picea lutzii (seedl.)	1	1	**0**	2	2	**0**	0	1	**0**	2	0	**-1**	1	0	**-1**	1	0	**-1**	0	0	**0**	0	0	**0**
Picea lutzii (tree)	17	0	**-17**	18	3	**-15**	30	5	**-25**	50	0	**-50**	39	5	**-34**	43	0	**-43**	4	4	**0**	13	3	**-10**
Populus balsamifera (sapl.)	0	2	**2**	0	0	**0**	0	0	**0**	0	3	**3**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Populus balsamifera (seedl.)	0	12	**12**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Populus balsamifera (tree)	4	0	**-4**	0	0	**0**	0	0	**0**	0	2	**2**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Populus tremuloides (sapl.)	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	0	0	**0**
Populus tremuloides (seedl.)	0	2	**1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Populus tremuloides (tree)	4	0	**-4**	0	0	**0**	0	0	**0**	0	0	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	0	0	**0**
Salix scouleriana (sapl.)	0	0	**0**	3	5	**2**	1	2	**1**	0	4	**4**	0	5	**4**	0	0	**0**	0	0	**0**	0	0	**0**
Salix scouleriana (seedl.)	0	1	**1**	0	1	**1**	0	1	**1**	5	0	**-4**	0	0	**0**	0	0	**0**	0	0	**0**	1	1	**-1**
Salix scouleriana (tree)	3	0	**-3**	5	6	**1**	4	0	**-4**	0	0	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	4	4	**-1**
Tsuga mertensiana (sapl.)	0	0	**0**	2	2	**0**	1	0	**-1**	0	0	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	2	0	**-2**
Tsuga mertensiana (seedl.)	0	0	**0**	1	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Tsuga mertensiana (tree)	0	0	**0**	3	1	**-2**	5	1	**-4**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**

Species	Q34_ 2A	Q34_ 2	Q34 change	EF17_ 1A	EF17_ 1	EF17 change	DC_ 1A	DC_ 1	DC change	EF8_ 2A	EF8_ 2	EF8 change	EF21_ 1A	EF21_ 1	EF21 change	EF3_ 1A	EF3_ 1	EF3 change	J5_ 1A	J5_ 1	J5 change	CC_ 1A	CC_ 1	CC change
Tall and low shrubs:																								
Alnus crispa ssp. *sinuata*	0	2	**2**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	0	**-1**
Betula nana	0	0	**0**	14	21	**7**	0	0	**0**	11	7	**-4**	19	22	**3**	16	26	**10**	9	15	**6**	0	0	**0**
Echinopanax horridum	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	9	5	**-4**
Menziesia ferruginea	0	0	**0**	0	0	**0**	7	0	**-6**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	6	0	**-6**
Potentilla fruticosa	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	2	2	**0**	0	0	**0**
Ribes sp.	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Rosa acicularis	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	2	**1**
Rubus idaeus	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**0**
Salix barclayi	0	0	**0**	3	6	**3**	0	0	**0**	6	9	**3**	3	6	**3**	8	18	**10**	21	32	**11**	0	0	**0**
Salix pulchra	0	0	**0**	0	0	**0**	0	4	**4**	0	0	**0**	2	2	**-1**	0	0	**0**	1	3	**2**	0	0	**0**
Salix sitchensis	0	5	**5**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**
Sambucus racemosa	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	1	**1**
Shepherdia canadensis	0	1	**1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Spirea beauverdiana	0	0	**0**	3	5	**1**	0	1	**1**	0	0	**0**	5	4	**-1**	10	1	**-9**	0	0	**0**	0	0	**0**
Viburnum edule	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Dwarf shrubs:																								
Arctostaphylos rubra	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Arctostaphylos uva-ursi	1	11	**10**	0	0	**0**	0	0	**0**	1	3	**2**	0	1	**1**	0	0	**0**	0	0	**0**	0	0	**0**
Empetrum nigrum	9	0	**-8**	17	25	**9**	5	12	**6**	32	0	**-32**	16	7	**-9**	12	1	**-11**	0	0	**0**	0	0	**0**
Ledum palustre	0	0	**0**	0	0	**0**	2	3	**1**	0	0	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	0	0	**0**
Linnaea borealis	4	1	**-2**	1	1	**-1**	0	0	**0**	0	0	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	0	1	**0**
Vaccinium caespitosum	0	0	**0**	5	6	**1**	0	0	**0**	0	1	**1**	0	0	**0**	8	7	**0**	0	2	**2**	0	0	**0**
Vaccinium uliginosum	0	0	**0**	5	8	**4**	2	2	**0**	0	0	**0**	10	4	**-6**	2	3	**1**	1	0	**-1**	0	0	**0**
Vaccinium vitis-idaea	11	3	**-8**	4	1	**-3**	4	19	**15**	8	1	**-6**	9	5	**-4**	7	2	**-5**	3	1	**-2**	0	0	**0**
Forbs:																								
Achillea borealis	0	2	**2**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**	5	1	**-4**	0	2	**2**
Aconitum delphiniifolium	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**	2	0	**-1**	0	0	**0**
Actaea rubra	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	4	5	**1**
Anemone richarsonii	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Artemisia tilesii	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Cardamine umbellata	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Castilleja unalaschensis	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	2	**2**
Cornus canadensis	7	2	**-4**	18	5	**-13**	0	26	**26**	10	5	**-5**	7	4	**-3**	4	3	**-1**	1	1	**0**	6	19	**13**
Epilobium angustifolium	0	3	**3**	1	3	**3**	0	3	**3**	1	9	**8**	1	4	**3**	1	7	**6**	8	7	**-1**	1	23	**22**
Galium boreale	0	0	**0**	0	0	**0**	0	0	**0**	0	3	**3**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Galium triflorum	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	1	**0**
Geocaulon lividum	3	6	**3**	7	6	**-1**	10	4	**-6**	4	0	**-4**	7	1	**-6**	0	0	**0**	0	0	**0**	0	0	**0**
Geranium erianthum	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Heracleum lanatum	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**	0	0	**0**	0	3	**3**

Species	**Q34_ 2A**	**Q34_ 2**	**Q34 change**	**EF17_ 1A**	**EF17_ 1**	**EF17 change**	**DC_ 1A**	**DC_ 1**	**DC change**	**EF8_ 2A**	**EF8_ 2**	**EF8 change**	**EF21_ 1A**	**EF21_ 1**	**EF21 change**	**EF3_ 1A**	**EF3_ 1**	**EF3 change**	**J5_ 1A**	**J5_ 1**	**J5 change**	**CC_ 1A**	**CC_ 1**	**CC change**
Lupinus nootkatensis	0	5	**5**	0	3	**2**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Mertensia paniculata	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Moneses uniflora	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Osmorhiza sp.	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	0	**-1**
Polemnium acutiflorum	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	5	1	**-4**	0	0	**0**
Pyrola secunda	1	0	**-1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	2	0	**-2**	0	0	**0**
Pyrola sp.	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	2	**1**
Rhinanthus minor	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Rubus arcticus	0	0	**0**	0	0	**0**	0	0	**0**	3	5	**2**	0	1	**1**	7	3	**-4**	6	3	**-4**	0	0	**0**
Rubus chamaemorus	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	2	0	**-2**	0	0	**0**
Rubus pedatus	0	0	**0**	1	1	**-1**	3	0	**-3**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Rumex sp.	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	2	0	**-2**	0	0	**0**
Sanguisorba stipulata	0	0	**0**	0	0	**0**	0	0	**0**	0	5	**5**	0	0	**0**	3	0	**-3**	5	1	**-4**	0	0	**0**
Solidago multiradiata	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	4	0	**-4**	0	0	**0**
Streptopus amplexifolius	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Trientalis europa	0	0	**0**	1	1	**0**	0	0	**0**	1	0	**-1**	1	2	**1**	2	1	**-1**	0	0	**0**	1	1	**0**
Viola sp.	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	0	**-1**	0	0	**0**	0	1	**1**
Graminoids:																								
Calamagrostis canadensis	0	0	**0**	1	1	**1**	0	1	**1**	4	4	**0**	1	3	**2**	5	7	**2**	1	1	**0**	7	16	**8**
Carex deweyana	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	1	0	**0**	0	0	**0**	0	0	**0**
Festuca altaica	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	8	**7**	6	16	**9**	0	0	**0**
Luzula parviflora	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Poa sp.	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Trisetum spicatum	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Ferns and allies:																								
Atherium filix-femina	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	4	**4**
Dryopteris dilatata	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	1	**0**
Equisetum arvense	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	2	0	**-2**	0	11	**11**
Equisetum pratense	0	0	**0**	0	0	**0**	0	0	**0**	0	3	**3**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Equisetum sylvaticum	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	1	0	**-1**
Gymnocarpium dryopteris	0	0	**0**	0	3	**3**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**	5	8	**3**
Lycopodium alpinum	0	0	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Lycopodium annotinum	0	0	**0**	2	1	**-2**	3	0	**-3**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	5	0	**-5**
Lycopodium clavatum	0	0	**0**	1	0	**-1**	0	0	**0**	0	0	**0**	1	0	**-1**	1	0	**-1**	0	0	**0**	0	0	**0**
Lycopodium complanatum	3	0	**-3**	4	0	**-4**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**	1	0	**-1**

Appendix 3: Comparison of Control and Preburn Data

Unburned transects were either established in the burn unit prior to prescribed burning or established in an area similar to the target vegetation adjacent to the burn. Several of the control transects were read more than once. Appendix 3 summarizes the source of control and preburn data for all burn units.

Unit name	Preburn transect in burn	Control transect adjacent to burn read within 5 years of burn	Control transect adjacent to burn read 15 to 25 years after burn
Quartz Creek 11	X		
Quartz Creek 6		X	X
Juneau 1	X		
Caribou E	X		
Caribou W		X	
Cripple Creek			X
Quartz Creek 29	X		
East Fork 17			X
Dave's Creek Test			X
Quartz Creek 28			X
Quartz Creek 13			X
Quartz Creek 26			X
Juneau 5		X	
East Fork 3			X
East Fork 8		X	
East Fork 21		X	X
Quartz Creek 34		X	X

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