



Vegetation Composition and Structure: Baseline Monitoring in the Southwest Alaska Network

2009 Annual Summary Report

Natural Resource Technical Report NPS/SWAN/NRTR—2010/342



ON THE COVER

Dwarf shrub tundra above Hammersly Lake, Katmai National Park and Preserve, July 2009. Photograph by Amy Miller, Southwest Alaska Network.

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Natural Resource Technical Report NPS/SWAN/NRTR—2010/342

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Abstract

This report summarizes the results of baseline vegetation sampling in Katmai National Park and Preserve in 2009. The sites will be revisited every five years.

During the 2009 field season, we established thirty-three 0.25 hectare plots, sampling four vegetation types (spruce woodland; closed spruce forest (beetle kill); dwarf shrub tundra; treeline spruce) in low (0-450 m) and mid-elevation (450-900 m) bands in the interior of Katmai (GRTS plots). Three mid-elevation plots were collocated with the RAWS weather station above Lake Colville (elevation 470 m). Four closed spruce-beetle plots were established near Lake Colville, Lake Brooks, and the Bay of Isles (Naknek Lake). All beetle-affected stands had been cored in 2007 as part of a separate study examining historic spruce beetle activity. Additional tree cores were collected in 2009 to describe age and size-class structure of the stands, and to relate climate variables to growth characteristics (e.g., growth suppression) that preceded the recent beetle outbreak. Soil temperature loggers were installed at 1-2 sites in each vegetation type (eleven sites total) to monitor the timing and duration of freeze-thaw periods, snowpack development, and snowmelt.

Plot variables were summarized within and across sites for the four vegetation types (closed spruce forest, spruce woodland, treeline, dwarf shrub). Species richness was highest at higher elevations (450-900 m), particularly at upper treeline, where species from low elevation forested communities and mid- to high elevation dwarf shrub and alpine communities co-occurred. Nonvascular species richness, as measured in nested frequency plots, was up to three times greater than for vascular species at a given site.

Trees in spruce forest and spruce woodland sites ranged from less than 50 years to greater than 240 years in age. The oldest trees were found in mature forest affected by the spruce beetle, including stands on the east shore of Lake Colville (212 years) and the Valley of 10,000 Smokes Road (312 years). Treeline spruce ranged from approximately 20-60 years in age. Tree mortality ranged from 0%-45% in spruce woodland sites, and from 36%-98% in the beetle plots. Snag densities and fine fuel loads were highest in the beetle plots, but large woody debris loads did not differ between the woodland and closed forest (beetle) sites, nor did seedling densities, on average.

A globally endangered lichen, *Erioderma pedicellatum* (Hue) P.M. Jørg, known from only two populations in North America, was found at one of the beetle-affected sites. A second rare lichen, *Hypogymnia pulverata* (Nyl.) Elix, was found at several additional locations in the park.

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Introduction

Vegetation composition and structure has been targeted for monitoring in the Southwest Alaska Network (SWAN) due to its intrinsic ecological value (primary production, habitat, forage) and because vegetation is a sensitive indicator of environmental conditions. Monitoring objectives are to document trends in the structure (e.g., height, density), composition (e.g., species richness and diversity), and demography (e.g., mortality and species turnover) of selected late-successional vegetation types in the three largest parks in the SWAN (Lake Clark NPP (LACL), Katmai NPP (KATM), Kenai Fjords NP (KEFJ)). This report summarizes the results of baseline sampling in Katmai National Park and Preserve (2009) and discusses refinements to the current sampling design.

Methods

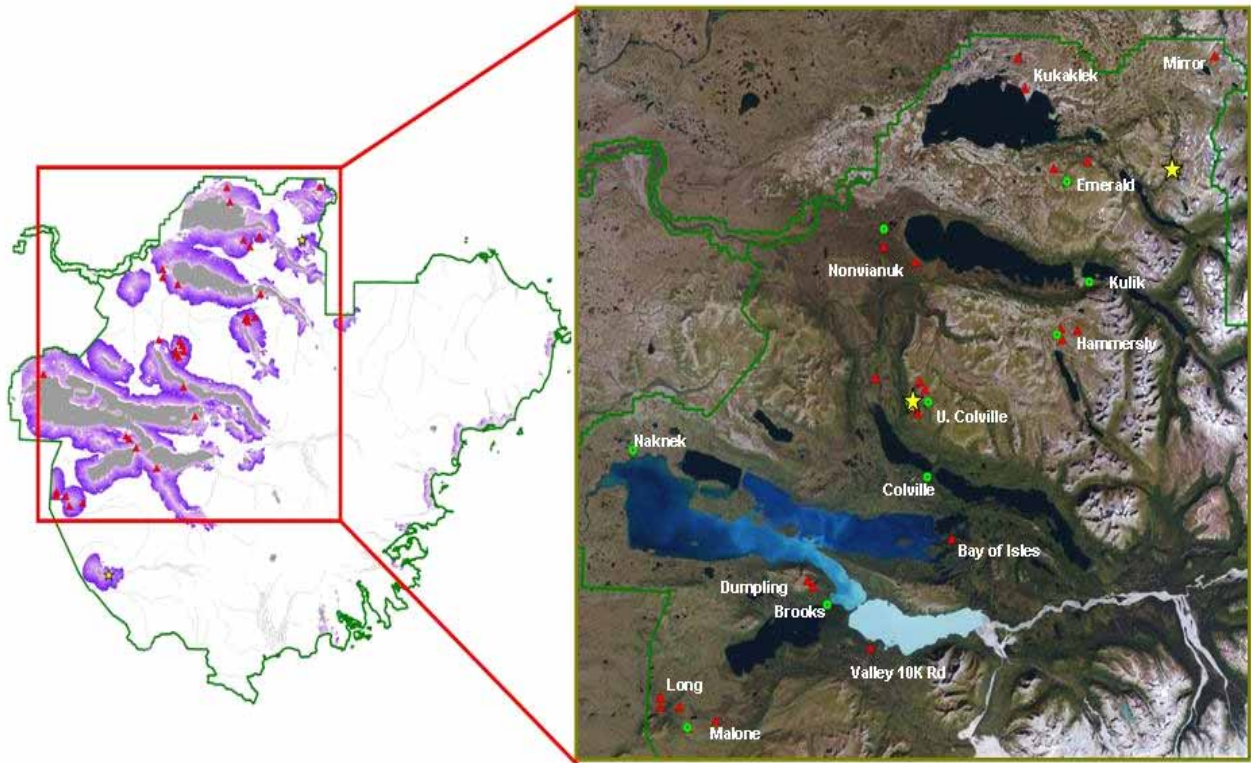
Sampling Design and Site Selection

We established monitoring plots at 16 low elevation (0-450 m) and 17 mid-elevation (450-900 m) sites in Katmai NPP in 2009 (Table 1; Figure 1). Three plots were collocated near the Coville remote area weather station (RAWS). Baseline sampling was conducted between June 21 and August 26, 2009, following methods outlined in Miller et al. (2010). This report describes preliminary results for the first four elevation $\times$ vegetation class combinations shown in Table 1 (low elevation spruce woodland; low elevation closed spruce (beetle kill); mid-elevation treeline spruce; mid-elevation dwarf shrub tundra).

Our sampling design requires that we sample a minimum of eight plots from each elevation $\times$ vegetation class combination in a given year (Miller et al. 2010). Prior to the start of the field season, we drew sites from a generalized random-tessellation stratified (GRTS, Stevens 1997; Stevens and Olsen 2004) sample established for three elevation bands (0-450 m, >450-900 m, >900 m) within an access layer (GIS) developed for Katmai (Figure 1; Mortenson and Miller 2008).

Following a field reconnaissance in early June, 2009 (Appendix 1), we selected twenty-two GRTS points for monitoring in low-elevation spruce woodland, mid-elevation treeline spruce, and mid-elevation dwarf shrub tundra community types (Viereck et al. 1992; Table 1; Figure 2). Plots that could not be accessed due to unanticipated barriers (e.g., dangerous stream crossings) were rejected (Appendix 1). The low frequency of spruce classes on the landscape necessitated that we sample from two populations: 1) a set of GRTS points including all landcover classes, and 2) a set of GRTS points including only spruce classes. Dwarf shrub sites (mid-elevation) were selected from the first set of GRTS points, and spruce sites (low- and mid-elevation spruce woodland) were selected from the latter population. Even with the constrained GRTS sample, we were unable to locate enough suitable mid-elevation treeline spruce sites to satisfy our sampling requirements. As a result, we established an additional three sites in representative areas of the upper treeline zone, independent of the GRTS sample (elevation 450-560 m; KATM-2009-02-S96, -S97, and -S99; Table 1).

Figure 1. Long-term vegetation monitoring plots established in 2009 in Katmai National Park & Preserve. Access areas developed using slope, elevation, land ownership, and hydrology layers (GIS) are indicated in purple on the park overview map (left). Sites with temperature loggers are indicated in green on the inset map (right). All other sites are indicated in red. The RAWS weather stations at Upper Colville and Pfaff (unlabeled) are shown by yellow stars. Three monitoring plots were collocated with the RAWS station at Upper Colville.



In order to monitor the long-term effects of forest disturbance, we also established four sites in representative stands of low-elevation, mature white spruce that had been impacted by recent spruce beetle (*Dendroctonus ruffipennis*) activity (Table 1; Figure 2). These sites were not part of the GRTS sample, but were randomly located in closed-canopy spruce stands that had been cored in 2007, as part of a separate project examining historic spruce beetle disturbance (Sherriff et al. 2009).

An additional four sites were sampled, but did not fall within the major elevation $\times$ vegetation class combinations analyzed in this report (Table 1); i.e., the sites were low-elevation analogues of mid-elevation spruce woodland (KATM-2009-01-S94) and mid-elevation dwarf shrub tundra (KATM-2009-01-030; KATM-2009-01-051), or they represented low elevation, closed canopy spruce unimpacted by spruce beetle (KATM-2009-01-S98) (Table 1). The sites were established for a variety of reasons, but were not adequately replicated and may be removed from the sample population in the future. Funds permitting, however, we will expand our sampling to include at least the low elevation dwarf shrub tundra sites (e.g., KATM-2009-01-030; KATM-2009-01-051) over the next 3-5 years.

Table 1. Plot locations and major vegetation types sampled in Katmai National Park and Preserve (2009). Site elevations are rounded to the nearest 5 m. Datum = NAD83. Sites at which a soil temperature logger was installed are indicated with a dagger (†).

Site ID	Location	Elevation (m)	Latitude/Longitude
Low elevation (0-450 m) white spruce woodland			
KATM-2009-01-S35†	Nonvianuk Lake	200	59.02561 N; 155.65126 W
KATM-2009-01-S38	Nonvianuk Lake	210	59.00354 N; 155.65115 W
KATM-2009-01-S41	Nonvianuk Lake	230	58.98554 N; 155.56126 W
KATM-2009-01-S02	Malone Lake	105	58.39696 N; 156.08060 W
KATM-2009-01-S08	Malone Lake	80	58.41311 N; 156.18103 W
KATM-2009-01-078†	Malone Lake	130	58.38685 N; 156.15849 W
KATM-2009-01-S12	Long Lake	75	58.42385 N; 156.23411 W
KATM-2009-01-S27	Long Lake	85	58.41150 N; 156.23391 W
KATM-2009-01-S50†	Naknek Lake	40	58.73486 N; 156.33030 W
Low elevation (0-450 m) closed white spruce forest – beetle kill			
KATM-2009-01-S99†	Lake Colville	65	58.71354 N; 155.51570 W
KATM-2009-01-S97	Bay of Islands	35	58.63577 N; 155.44461 W
KATM-2009-01-S96†	Lake Brooks	20	58.54811 N; 155.78345 W
KATM-2009-01-S95	Valley 10K Road	80	58.49552 N; 155.66191 W
Mid-elevation (450-900 m) treeline spruce			
KATM-2009-02-S04	Upper Colville	450	58.83467 N; 155.54281 W
KATM-2009-02-S08	Upper Colville	540	58.82429 N; 155.52685 W
KATM-2009-02-S99	Upper Colville	470	58.80135 N; 155.56283 W
KATM-2009-02-S97†	Upper Colville	560	58.80844 N; 155.51689 W
KATM-2009-02-S96	Upper Colville	435	58.79344 N; 155.54685 W
KATM-2009-02-S17	Dumpling Mt.	545	58.57804 N; 155.83974 W
KATM-2009-02-S14†	Dumpling Mt.	470	58.57090 N; 155.82382 W
Mid-elevation (450-900 m) dwarf shrub tundra			
KATM-2009-02-048	Mirror Lake	570	59.25351 N; 154.73283 W
KATM-2009-02-003†	Hammersly Lake	505	58.89690 N; 155.16341 W
KATM-2009-02-006	Hammersly Lake	705	58.90388 N; 155.10660 W
KATM-2009-02-008	Hammersly Lake	535	58.89082 N; 155.14918 W
KATM-2009-02-023	Hammersly Lake	550	58.90544 N; 155.15290 W
KATM-2009-02-032	Narrow Cove	500	59.11821 N; 155.08566 W
KATM-2009-02-005	Emerald Lake	510	59.10821 N; 155.17981 W
KATM-2009-02-016†	Emerald Lake	470	59.09137 N; 155.14210 W
KATM-2009-02-050†	Upper Colville	465	58.80704 N; 155.56795 W
Low elevation sites - other			
KATM-2009-01-S94†	Kulik Lake	240	58.96499 N; 155.07612 W
KATM-2009-01-S98	Lake Colville	40	58.83713 N; 155.66446 W
KATM-2009-01-051	Kukaklek Lake	260	59.20874 N; 155.26366 W
KATM-2009-01-030	Kukaklek Lake	330	59.24684 N; 155.28370 W

Study Area

Sites identified for monitoring occurred in proximity to a number of the major lakes in the interior of the park (Mirror, Kukaklek, Nonvianuk, Hammersly, Colville, Naknek, Brooks, Malone, Long). The lakes feed two major river drainages: the Alagnak, to the north, and the Naknek, to the south (Figure 1) and span six ecological subsections (Boggs et al. 2003).

Low-elevation spruce woodland sites occurred primarily on undifferentiated outwash south of Lake Brooks, and on moraines, till, and colluvial deposits west of Nonvianuk. The southern extent of treeline occurs roughly 3-5 km south of Malone Lake, near Granite Peak. Canopy cover ranges from 10-25% in woodland communities and is dominated by white spruce (*Picea glauca*). Lowbush cranberry (*Vaccinium vitis-idaea*), lowbush blueberry (*Vaccinium uliginosum*), crowberry (*Empetrum nigrum*), and mosses (e.g., *Dicranum scoparium*, *Hylocomium splendens*, *Pleurozium schreberi*) are understory dominants (Figure 2a-b).

Figure 2. Representative low and mid-elevation white spruce (*Picea glauca*) and dwarf shrub tundra communities sampled in Katmai National Park and Preserve (2009). Low elevation closed spruce forest – beetle kill: a) KATM-2009-01-S96 - Lake Brooks; b) KATM-2009-01-S99 - Lake Colville; low elevation spruce woodland: c) KATM-2009-01-S27 - Malone Lake; d) KATM-2009-01-S41 - Nonvianuk Lake; mid-elevation treeline spruce: e) KATM-2009-02-S08 - Upper Colville; f) KATM-2009-02-S99 - Upper Colville; mid-elevation dwarf shrub tundra: g) KATM-2009-02-048 - Mirror Lake; h) KATM-2009-02-003 - Hammersly Lake.



Mature closed spruce (beetle kill) sites were localized on well-drained loamy to sandy soils at the east end of Lake Colville, south side of Bay of Isles-Naknek Lake, north of Lake Brooks, and out to MP 6 on the Valley of 10,000 Smokes Road. Canopy cover was 60% or greater in these stands, and paper birch (*Betula papyrifera* var. *kenaica*) was a common associate (Figure 2c-d). Mid-elevation dwarf shrub tundra sites occurred on a range of sites extending from Kukaklek Lake to Lake Colville, primarily on well-drained rolling ridges and plateaus. Dwarf shrub cover was 25% or greater and included crowberry, alpine bearberry (*Arctostaphylos alpina*), arctic willow (*Salix arctica*) and alpine azalea (*Loiseleuria procumbens*). Lichen cover (e.g., *Cetraria islandica* ssp. *crispiformis*, *Cladonia arbuscula* ssp. *beringiana*) was frequently high (Figure 2g-h). Treeline spruce sites (Figure 2e-f) were intermediate in composition between low elevation spruce woodland sites and mid- to high elevation dwarf shrub sites, and commonly had a measurable shrub (e.g., *Salix glauca*, *Salix pulchra*) and graminoid component. The upper limit of treeline (overstory spruce cover <1%) is at approximately 575-600 m.

Sampling Methods

Field methods are described in detail in Miller et al. (2010). At each field site, we established a 50 m × 50 m (0.25 ha) monitoring plot and intensively sampled the inner 30 m × 30 m (0.09 hectare), which was divided into three 30-m transects. We measured vascular and nonvascular species occurrence using nested quadrats (0.25 m²; 1 m²; 4 m²) at 7-m intervals along each transect (n = 15 quadrats/plot), and vascular species cover by point-intercept at 0.5 m intervals along each transect. Species cover was recorded in each of four height classes (<0.5 m; 0.5-1.0 m; >1-4 m; >4 m). Vascular species present in the 30 m × 30 m plot but not recorded in the nested frequency quadrats were documented separately. Percent cover by plant growth form (tree, shrub, dwarf shrub, forb, graminoid, lichen, moss) and substrate type was recorded using ocular estimates in the 4-m² quadrats. Tree seedling counts were also recorded in 4-m² quadrats.

Where applicable, we counted saplings in the 30 m × 30 m (0.09 hectare) inner plot and measured the diameter and height of all trees ≥ 12 cm diameter at breast height (DBH), and the diameter only of saplings. We cored the four largest trees in the outer 10-m surrounding the 30 m × 30 m plot and estimated canopy cover at the center and four corners of the plot using a spherical densiometer. Trees were cored at approximately 10-30 cm above the root crown for estimation of tree age.

We calculated basal area for trees within the 0.09 hectare as follows:

$$\text{Basal area (cm)} = \pi \times (\text{DBH}/2)^2$$

We estimated aboveground live and dead biomass (trees and saplings) using allometric equations derived for *Picea glauca* (Harding and Grigal 1985):

$$\text{Dry mass (kg)} = 0.069 \times (\text{DBH (cm)})^{2.324} \times (\text{height (m)})^{0.210}$$

In 2009, we began quantifying coarse woody debris (CWD) loads using the line-intersect method (Van Wagner 1968, Brown 1974), and assuming a specific gravity of 0.34 g/cm³ for white spruce (Taylor et al. 1982):

$$\text{Volume of wood per unit area (m}^3\text{/ha)} = V = [\pi^2 \times \Sigma (\text{diameter (m)})^2] / [8 \times (\text{transect length (m)})]$$

$$\text{Weight per unit area (kg/ha)} = V \times \text{specific gravity (kg/m}^3\text{)}$$

At each site, we recorded attributes related to forest condition (insects, pathogens, mortality) and site characteristics (slope, aspect, drainage). We measured the thickness of the litter, living mat (vegetation), and organic horizons, and depth to seasonal frost, where applicable.

We collected approximately 5-7 g dry weight of stair-step moss (*Hylocomium splendens*) at each site for analysis of nitrogen (N), sulfur (S) and heavy metals. Finally, we installed soil temperature loggers (HOBO Pro v2; Onset Computer Corporation, Bourne, MA) to a depth of 10 cm at 2-3 sites per vegetation type (11 sites total; Table 1). Data for airborne contaminants in *Hylocomium* and for soil temperature profiles are pending and will be included in a future report.

Analysis

Plot variables (species occurrence in 4-m² quadrats; species cover; cover by growth form and height class) were summarized within and across sites using PROC SURVEYMEANS in SAS (SAS Institute, Cary, NC). Relationships between elevation and species richness across all vegetation types, and site productivity (standing biomass), canopy cover, and seedling densities in low-elevation forested types, were explored using regression analysis.

Nonmetric multidimensional scaling (NMS) in PC-ORD (McCune and Mefford 2009) was used to ordinate plots in species space and to describe gradients in the vegetation community based on the nested frequency data. Prior to analysis, we removed species found in fewer than 5% of plots to reduce noise from rare or inadequately sampled taxa. We used the Sørensen index (Beals 1984) to calculate the distance matrix for the ordination. The significance of the best fit was evaluated using a Monte Carlo test that compared final axes to those calculated from 250 runs of randomized data. The ordination was rigidly rotated to load the strongest environmental variable onto a single axis. An arbitrary cut-off value of $r^2 \geq 0.30$ was used when assessing correlations of environmental variables and diversity estimates with the ordination axes.

Results and Discussion

Species cover and frequency

The communities shared many of the same species but differed in overall species composition and structural characteristics. Visual estimates of cover by growth form classes (tree, shrub, dwarf shrub, graminoid, forb, lichen, moss) were used to describe broad patterns in community structure. Tree cover ranged from <1% in treeline spruce sites to >80% in closed spruce forest (beetle kill) sites (Table 2). Shrub cover was highest in low elevation spruce woodland and lowest in dwarf shrub tundra sites, whereas dwarf shrub cover was high in all vegetation types. Forb and graminoid cover was greatest at closed spruce and treeline sites. Lichen cover was greatest in mid-elevation dwarf shrub tundra (40%), and moss cover was greatest in closed spruce sites, where it approached 84%.

Species cover, recorded by point-intercept along transects, indicated variation in the abundance of major vascular species across vegetation types and height classes (Table 3; Appendix 2). In spruce woodland and closed spruce (beetle kill) plots, live white spruce (*Picea glauca*) was

recorded in all four height classes, but averaged less than 5% cover in each layer (Table 3). In treeline plots, *Picea* was recorded only in the lowest height class (<0.5 m). Shrub cover in height classes >0.5 m ranged from <1% to 8%. Alder (*Alnus viridis* ssp. *sinuata*) was the dominant species at treeline; whereas Barclay's willow (*Salix barclayi*) and tealeaf willow (*Salix pulchra*) were the dominant species in closed spruce-beetle kill sites. Lichen cover was greatest in mid-elevation dwarf shrub tundra sites, and moss cover was highest in low-elevation spruce woodland and, to a lesser extent, closed spruce-beetle kill sites (Table 3).

Species occurrence, measured in nested frequency quadrats, indicated that the majority of species occurred at low frequency within a vegetation type, but that the distribution of frequencies varied across elevation and vegetation types (Figure 3). A small number of species (e.g., *Lupinus nootkatensis*, *Trientalis europaea*, *Petasites frigidus*) occurred at low frequency across all vegetation types (Appendix 3). A second set of species, including *Empetrum nigrum*, *Vaccinium vitis-idaea*, *Vaccinium uliginosum*, *Cladonia arbuscula* ssp. *beringiana*, *Dicranum scoparium*, *Polytrichum commune* ssp. *commune*, and *Hylocomium splendens* occurred in a high proportion of plots ($\geq 10\%$) across all vegetation types (Figure 3; Appendix 4). These latter, widespread and relatively common species are expected to be good candidates for detecting changes in community composition through time, due to their high abundance and low sample variance. A total of 118 vascular and 179 nonvascular species were recorded in monitoring plots during the 2009 field season (Appendix 3).

Species richness, or number of species per plot, was estimated from the frequency data. The richness estimates are conservative and the number of species present is likely higher, particularly for the nonvascular taxa. Species richness increased with elevation and was highest in dwarf shrub (63-85 species/plot) and treeline sites (72-88 species/plot) and lowest in closed forest-beetle kill sites (32-51 species/plot; Figure 4; Appendix 3). Although this result is constrained by our selection of vegetation types for monitoring, a similar pattern has been reported by the Central Alaska Network, which samples systematically across the elevation gradient using a two-stage grid (C. Roland, *personal communication*). Ordination results, discussed in the next section, suggested that the increase in richness with elevation is likely due to greater spatial heterogeneity (e.g., greater number of microsites) at higher elevations, rather than to elevation-related variables (e.g., temperature and moisture gradients), per se.

Nonvascular species were an important component of each vegetation type and comprised approximately 60%-70% of the taxa recorded in 1-m² quadrats (Figure 4a). Spruce woodland sites, in particular, were characterized by low vascular species richness but a relatively high number of nonvascular species, comparable to the number of nonvascular taxa found in species-rich sites at higher elevations (Figure 4b).

Table 2. Percent cover by cover class and spruce seedling counts/quadrat for low and mid-elevation vegetation types sampled in Katmai National Park and Preserve (2009). Cover was estimated visually in 4-m² quadrats arrayed along 30-m transects (n = 15 per plot); mean percent cover ($\pm$ 1 S.E.) and coefficient of variation (CV) are shown for each cover class within the broader vegetation types. Total cover >100% is due to layering within vegetation type. Mean seedling counts in 4-m² quadrats were converted to seedling densities (stems/ha) reported in the text. Cover classes showing high constancy (CV $\leq$ 35%) are in boldface.

	Low elevation spruce woodland (n=9)		Low elevation closed spruce forest - beetle kill (n=4)		Mid-elevation treeline spruce (n=7)		Mid-elevation dwarf shrub tundra (n=9)	
Cover class	% Cover	CV	% Cover	CV	% Cover	CV	% Cover	CV
Tree	4.9 (0.7)	0.13	25.3 (4.6)	0.18	0.4 (0.3)	0.65	0.0 (0.0)	-
Shrub	15.11 (2.1)	0.14	4.6 (2.8)	0.61	10.8 (2.4)	0.22	9.5 (2.3)	0.24
Dwarf shrub	49.7 (5.8)	0.12	16.5 (5.3)	0.32	61.0 (4.4)	0.07	43.5 (3.3)	0.07
Forb	0.1 (0.0)	0.33	5.2 (3.2)	0.62	2.0 (0.5)	0.22	0.3 (0.2)	0.57
Graminoid	0.1 (0.0)	0.35	0.7 (0.4)	0.57	2.2 (0.5)	0.22	0.6 (0.2)	0.34
Lichen	15.0 (3.6)	0.24	1.7 (0.4)	0.25	26.8 (6.7)	0.25	40.1 (6.7)	0.17
Moss	55.4 (8.2)	0.15	83.8 (5.2)	0.06	37.7 (6.3)	0.17	7.4 (2.7)	0.36
Cryptobiotic crust	0.0 (0.0)	-	0.0 (0.0)	-	0.4 (0.2)	0.42	0.6 (0.3)	0.47
∞ Tree seedlings (no. stems/quadrat)	1.3 (0.24)	0.19	2.2 (1.5)	0.65	0.1 (0.0)	0.32	0.0 (0.0)	-
Gravel	0.0 (0.0)	-	0.0 (0.0)	-	<0.1 (0.0)	0.86	1.8 (1.2)	0.68
Cobble	0.0 (0.0)	-	0.0 (0.0)	-	<0.1 (0.0)	0.71	0.8 (0.3)	0.38
Bedrock	0.0 (0.0)	-	0.0 (0.0)	-	0.0 (0.0)	-	0.3 (0.1)	0.50
Bare soil	<0.1 (0.0)	0.63	<0.1 (0.0)	0.88	0.1 (0.1)	0.89	0.3 (0.2)	0.57
Litter	12.5 (3.7)	0.29	20.2 (4.4)	0.22	10.9 (1.8)	0.16	4.3 (1.4)	0.32
Downed wood	0.1 (0.0)	0.45	2.2 (1.0)	0.46	0.1 (0.0)	0.34	<0.1 (0.0)	0.94
Standing dead	1.3 (0.5)	0.34	12.8 (5.0)	0.39	0.6 (0.2)	0.34	0.1 (0.0)	0.29

Table 3. Percent cover by species and height class for low and mid-elevation vegetation types sampled in Katmai National Park and Preserve (2009). Cover was estimated by point-intercept at 0.5-m intervals along 30-m transects; mean percent cover ($\pm$ 1 S.E.) and coefficient of variation (CV) are shown for a subset of species within each vegetation type. Total cover >100% is due to layering within vegetation type. Cover by height class (<0.5 m; 0.5-1.0 m; >1.0-4.0 m; >4.0 m) is shown for tree species. Cover for all other species is shown for the ground layer (<0.5 m). Species showing high constancy (CV $\leq$ 35%) are in boldface. See Appendix 2 for plot-level summaries.

	Low elevation spruce woodland (n=9)		Low elevation closed spruce forest - beetle kill (n=4)		Mid-elevation treeline spruce (n=7)		Mid-elevation dwarf shrub tundra (n=9)	
Species	% Cover	CV	% Cover	CV	% Cover	CV	% Cover	CV
Tree								
<i>Picea glauca</i> (<0.5 m)	1.8 (0.3)	0.19	1.7 (0.4)	0.21	0.8 (0.4)	0.49	0.0 (0.0)	-
<i>P. glauca</i> (0.5-1.0 m)	2.6 (0.4)	0.15	0.4 (0.2)	0.56	0.0 (0.0)	-	0.0 (0.0)	-
<i>P. glauca</i> (>1.0-4.0 m)	5.0 (0.8)	0.15	2.5 (1.1)	0.43	0.0 (0.0)	-	0.0 (0.0)	-
<i>P. glauca</i> (>4.0 m)	0.6 (0.3)	0.57	0.0 (0.0)	-	0.0 (0.0)	-	0.0 (0.0)	-
<i>Betula papyrifera</i> var. <i>kenaica</i> (<0.5 m)	0.0 (0.0)	-	0.4 (0.3)	0.64	0.0 (0.0)	-	0.0 (0.0)	-
<i>B. papyrifera</i> var. <i>kenaica</i> (0.5-1.0 m)	0.0 (0.0)	-	0.6 (0.4)	0.71	0.0 (0.0)	-	0.0 (0.0)	-
<i>B. papyrifera</i> var. <i>kenaica</i> (>1.0-4.0 m)	0.0 (0.0)	-	21.6 (8.1)	0.37	0.0 (0.0)	-	0.0 (0.0)	-
<i>B. papyrifera</i> var. <i>kenaica</i> (>4.0 m)	0.0 (0.0)	-	5.4 (2.3)	0.43	0.0 (0.0)	-	0.0 (0.0)	-
Shrub								
<i>Alnus viridis</i> ssp. <i>sinuata</i>	0.0 (0.0)	-	0.0 (0.0)	-	1.0 (0.1)	0.83	0.0 (0.0)	-
<i>Betula glandulosa</i>	6.5 (1.2)	0.18	0.0 (0.0)	-	2.3 (0.1)	0.43	9.1 (3.3)	0.36
<i>Ledum palustre</i> ssp. <i>decumbens</i>	9.2 (1.1)	0.12	0.1 (0.1)	0.88	3.8 (1.1)	0.30	4.8 (1.8)	0.37
<i>Salix glauca</i>	0.6 (0.3)	0.50	0.0 (0.0)	-	0.2 (0.2)	0.65	0.2 (0.2)	0.96
<i>Salix pulchra</i>	1.3 (0.6)	0.51	0.1 (0.1)	0.88	0.4 (0.2)	0.47	0.0 (0.0)	-
<i>Spiraea stevensii</i>	0.6 (0.3)	0.50	0.1 (0.1)	1.00	0.0 (0.0)	-	0.0 (0.0)	-
<i>Vaccinium uliginosum</i>	5.5 (1.8)	0.32	0.0 (0.0)	-	5.1 (1.7)	0.33	8.7 (2.6)	0.30
Dwarf shrub								
<i>Arctostaphylos alpina</i>	0.2 (0.2)	0.96	0.1 (0.1)	0.88	0.0 (0.0)	-	0.2 (0.1)	0.48
<i>Empetrum nigrum</i>	41.1 (3.0)	0.07	8.8 (2.9)	0.33	54.6 (4.9)	0.09	38.2 (3.0)	0.08
<i>Louisleuria procumbens</i>	0.9 (0.6)	0.67	0.0 (0.0)	-	8.5 (3.2)	0.38	4.0 (1.6)	0.40
<i>Salix arctica</i>	0.4 (0.2)	0.50	0.0 (0.0)	-	2.7 (1.3)	0.49	1.6 (0.6)	0.35
<i>Vaccinium vitis-idaea</i>	13.7 (1.5)	0.11	20.1 (6.8)	0.34	2.6 (1.1)	0.44	1.3 (0.4)	0.30
Graminoid								
<i>Calamagrostis canadensis</i>	0.1 (0.1)	0.63	5.5 (3.2)	0.58	1.1 (0.6)	0.50	0.0 (0.0)	-
<i>Carex bigelowii</i> ssp. <i>lugens</i>	0.1 (0.1)	0.96	0.0 (0.0)	-	0.5 (0.3)	0.65	0.1 (0.1)	0.96
<i>Carex microchaeta</i>	0.0 (0.0)	-	0.0 (0.0)	-	0.6 (0.3)	0.58	3.0 (1.0)	0.34
<i>Festuca altaica</i>	0.3 (0.2)	0.66	0.0 (0.0)	-	1.0 (0.7)	0.73	0.9 (0.6)	0.70
Lichen	24.6 (3.3)	0.13	3.1 (1.4)	0.46	29.6 (6.1)	0.21	49.9 (7.3)	0.15
Moss	84.7 (2.7)	0.03	50.1 (7.7)	0.15	32.8 (6.8)	0.21	15.1 (3.9)	0.26

Figure 3. Frequency of vascular species (mean $\pm$ 1 SE) in low elevation spruce woodland and closed spruce stands (above) and mid-elevation dwarf shrub and treeline sites (below), Katmai National Park and Preserve (2009). Inset figures show the distribution of species as a function of abundance (frequency). High elevation sites have a large number of species that occur at low frequency.

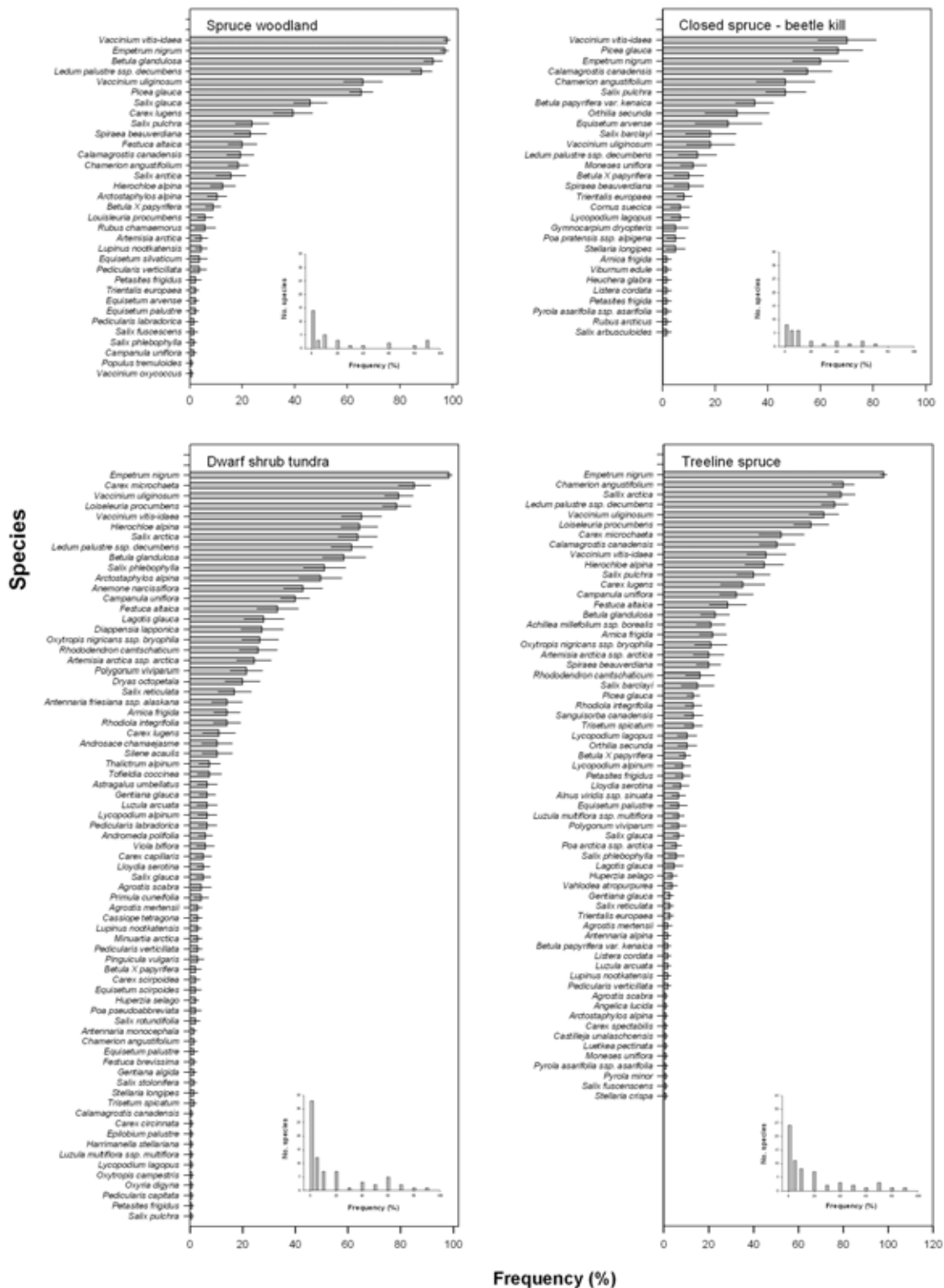
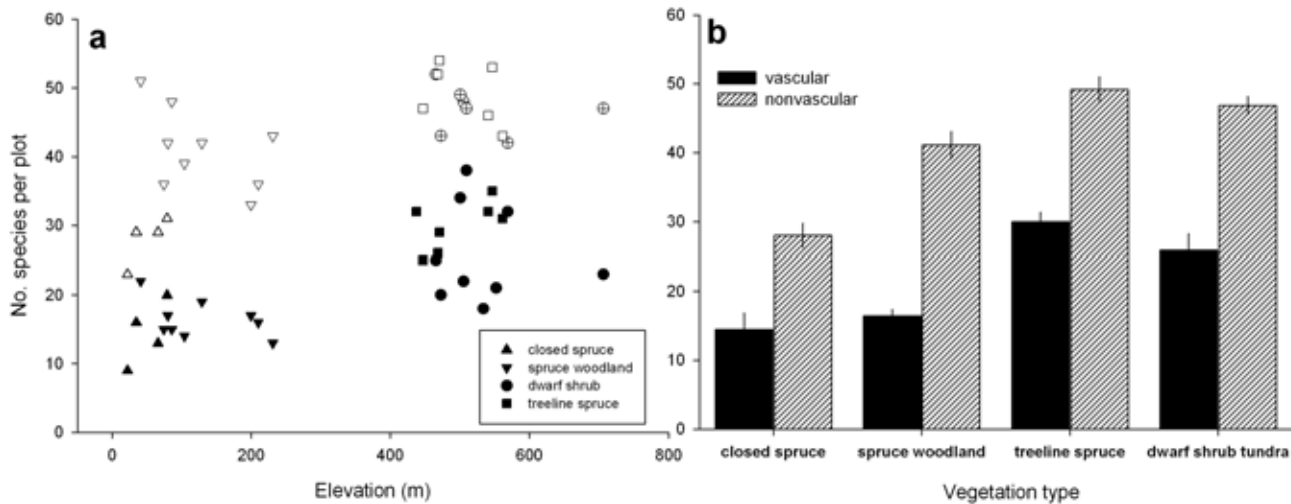


Figure 4. Vascular and nonvascular species richness as a function of elevation and vegetation type in Katmai National Park and Preserve. (a) Number of species per plot as estimated from nested frequency plots. Closed symbols denote vascular species and open symbols denote nonvascular species in a given vegetation type. (b) Mean species richness (± 1 S.E.) summarized by vegetation type. Beetle-affected closed spruce and spruce woodland were sampled at elevations between 0-450 m. Treeline spruce and dwarf shrub tundra were sampled between 450-900 m.



Ordination

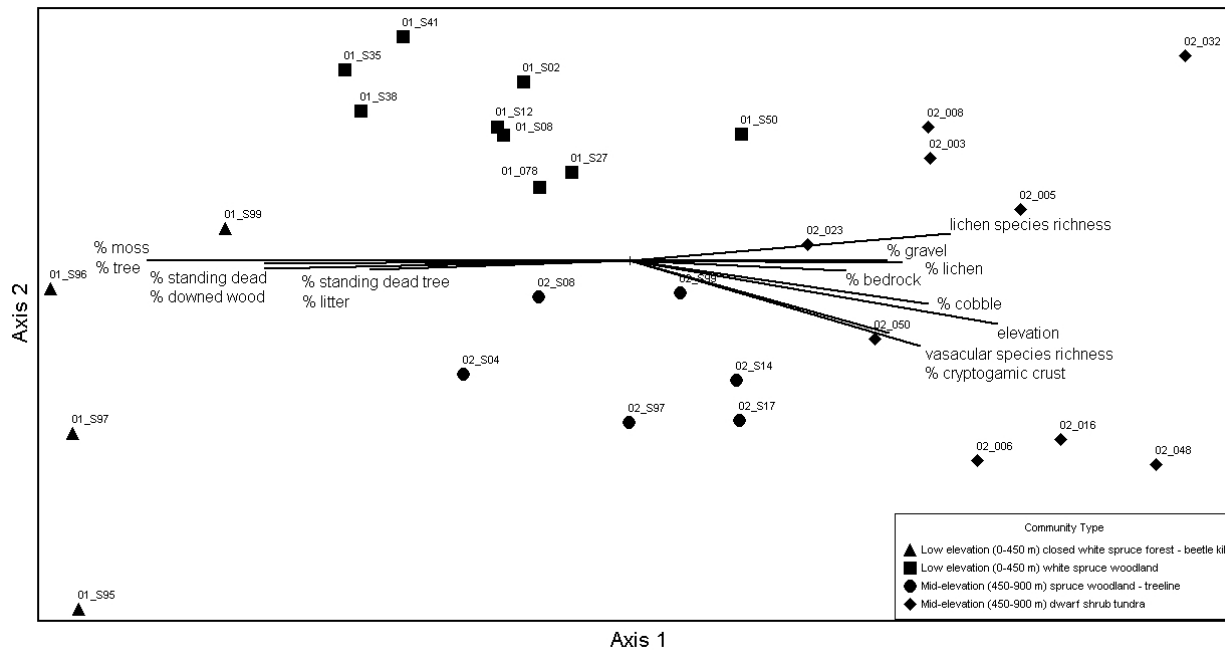
Ordination by NMS yielded two axes that explained 94.0% of the variance in the frequency data (Figure 5). The first axis represented 86.5% of the community variation. Species most strongly positively correlated with this axis were *Campanula uniflora* ($r = 0.81$), *Anemone narcissiflora* ($r = 0.80$), *Racomitrium lanuginosum* ($r = 0.78$), *Loiseleuria procumbens* ($r = 0.77$), *Psoroma hypnorum* ($r = 0.76$), *Carex microchaeta* ($r = 0.75$), and *Cetraria islandica* ssp. *crispiformis* ($r = 0.74$). Elevation, lichen species richness, vascular species richness, and percent cover of bedrock, gravel, cobble, cryptogamic crust, and lichen were also positively correlated with this axis. Species most strongly negatively correlated with Axis 1 were *Picea glauca* ($r = -0.80$), *Ptilium crista-castrensis* ($r = -0.79$), *Sanionia uncinata* ($r = -0.73$), *Polytrichum strictum* ($r = -0.70$), *Peltigera praetextata* ($r = -0.68$), *Cladonia scabriuscula* ($r = -0.67$), and *Aulacomnium palustre* ($r = -0.66$). Percent cover of tree, moss, standing dead tree, standing dead non-tree, litter, and downed wood were also negatively correlated with this axis.

Although a number of the species correlated with Axis 1 tend to be associated with high or low elevation communities (e.g., *Loiseleuria procumbens*; *Psoroma hypnorum*; *Picea glauca*), most species are relatively widespread and not necessarily strong indicators of elevation. Instead, Axis 1 reveals a gradient that appears to combine substrate and microsite heterogeneity. Plots of low, expansive moss-carpeted forest clustered at the negative end of the axis, while upland dwarf shrub tundra plots with heterogeneous soil types (e.g., well-drained gravels and soil microsites) and microtopography (e.g., due to frost pockets and solifluction) clustered at the positive end.

The second axis, representing 7.5% of the variation, had no strong correlation (i.e., $r^2 \geq 0.30$) with any environmental and vegetation community variables and was not easily interpretable. Positively correlated variables with this axis included percent cover of dwarf shrub ($r = 0.31$) and

lichen species richness ($r = 0.21$), and negatively correlated variables included percent cover of forb ($r = -0.51$), percent cover of graminoid ($r = -0.51$), and bryophyte species richness ($r = -0.41$).

Figure 5. NMS diagram for communities sampled in Katmai National Park and Preserve (2009). Axis 1 represented a gradient in site elevation. Axis 2 was not readily interpretable. Species clustered according to vegetation type, with plots separating out by elevation. The best solution yielded a model stress of 9.5 and instability of 0.00182. The extracted axes were stronger than those expected by chance, based on a Monte Carlo test ($p = 0.004$).



Stand structure and fuel loads in low elevation spruce sites

Mean tree age in closed spruce-beetle kill stands ranged from approximately 110-165 years, as estimated from cores collected in 2007 (Figure 6; Table 4; R. Sherriff, *unpublished data*). Two cohorts of spruce were evident in the stand near the Valley of 10,000 Smokes Road (KATM-2009-01-S95); i.e., one set of trees was aged approximately 95 years and another at 215 years (Figure 6; Sherriff and Berg 2009). The Valley 10K Road site had the lowest mortality and the oldest trees (Table 4), which were dated at approximately 310 years (Sherriff and Berg 2009; *data not shown*).

Tree densities in closed spruce-beetle kill stands ranged from approximately 630-1500 stems/ha (Table 4; Figure 7), and sapling densities varied by an order of magnitude (Table 4). The highest seedling densities (ca. 17,800 stems/ha) were found at a site near Lake Brooks (KATM-2009-01-S96), which also supported high tree and sapling densities. It is unclear why this site had such high seedling regeneration (Figure 9), as overstory structure did not suggest a canopy gap (Figure 7, Table 4), and understory species, including bryophytes and lichens, included no unusual indicators. Seedling densities in the remaining three closed spruce sites did not differ from those in most spruce woodland sites (Table 4; Figure 8a). Tree biomass ranged from approximately 12-22 metric tons/ha, with 36%-98% in standing dead (Figure 7; Figure 8b).

Spruce woodland sites were characterized by lower tree densities and canopy cover than closed spruce sites. Tree biomass ranged from approximately 0.3-3.2 metric tons/ha, with 0%-45% in standing dead (Table 4). Mean tree ages were generally similar to those at closed spruce sites (Table 4); however, two spruce woodland sites (KATM-2009-01-S50; KATM-2009-01-S78) appeared to have been recently established (Table 4). These latter two sites were structurally distinct from the remaining woodland sites (Table 4) and had lower moss cover (Appendix 3). If necessary, they will be treated as outliers in future analyses.

Table 4. Stand attributes for low elevation spruce woodland and closed forest (beetle kill) sites. Stand age and seedling counts are site means (± 1 SE). Biomass estimates and stem densities for trees and saplings are scaled up from plot-level inventories.

Site ID	Forest type	Stand age (y)	All trees biomass (t/ha)	Snags biomass (t/ha)	CWD	Tree density (stems/ha)	Sapling density (stems/ha)	Seedling density (stems/ha)
01-S35	woodland	225.8 (8.6)	2.21	0.71	0.93	267	1367	2500 (1170)
01-S38	woodland	153.3 (16.3)	3.24	1.45	3.28	289	1100	2167 (875)
01-S41	woodland	113.3 (17.5)	1.21	0.00	0.43	189	833	2667 (861)
01-078	woodland	52.5 (1.6)	0.09	0.00	0.47	33	367	2667 (1130)
01-S02	woodland	126.8 (2.8)	2.52	0.33	2.74	356	467	8167 (2993)
01-S08	woodland	113.0 (22.8)	1.02	0.00	0.30	89	444	2500 (880)
01-S12	woodland	129.5 (34.6)	1.32	0.02	0.70	122	444	2833 (1141)
01-S50	woodland	75.3 (4.3)	0.28	0.00	0.93	33	867	3167 (928)
01-S27	woodland	160.3 (10.0)	1.50	0.06	3.37	222	500	2333 (826)
01-S95	closed	164.2 (4.3)	20.74	7.49	6.10	633	89	167 (167)
01-S96	closed	151.4 (1.8)	22.47	13.95	4.31	1500	1122	17833 (4397)
01-S97	closed	108.9 (2.3)	16.03	16.03	4.62	989	367	2833 (1579)
01-S99	closed	114.9 (2.6)	12.38	12.21	4.73	667	122	1500 (476)

Figure 6. Age structure for low elevation closed spruce (beetle kill) stands at (a) Colville, (b) Naknek-Bay of Isles, (c) Lake Brooks, (d) Valley 10K Smokes Road (from Sherriff & Berg 2009). Stands were cored in 2007 and monitoring plots established in 2009. The oldest trees dated from 1696 and were found at a site along the Valley 10K Road.

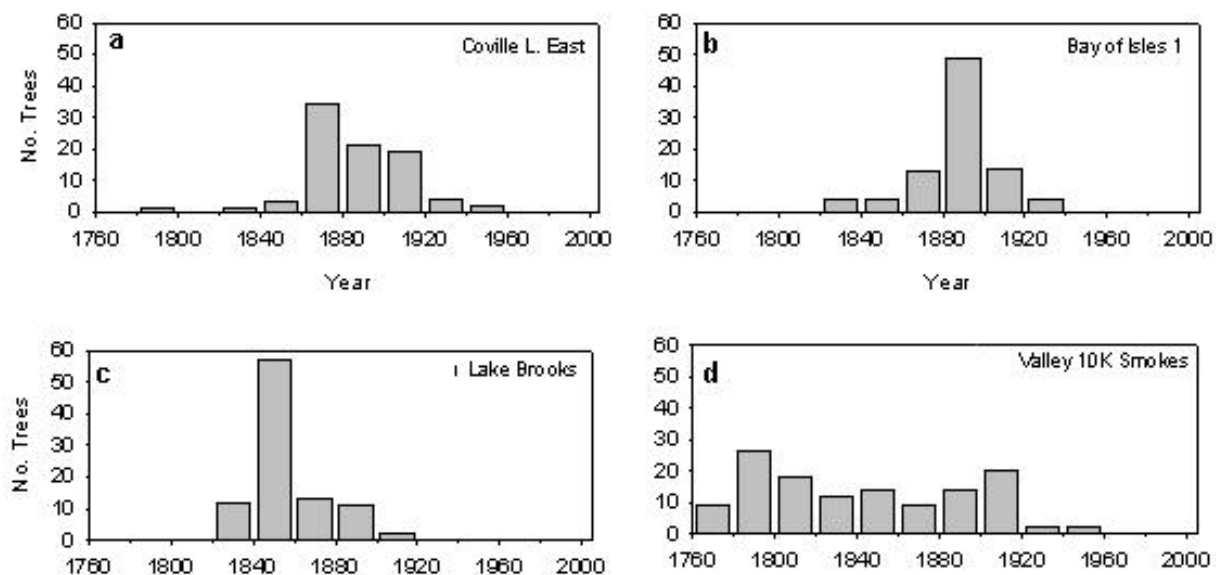
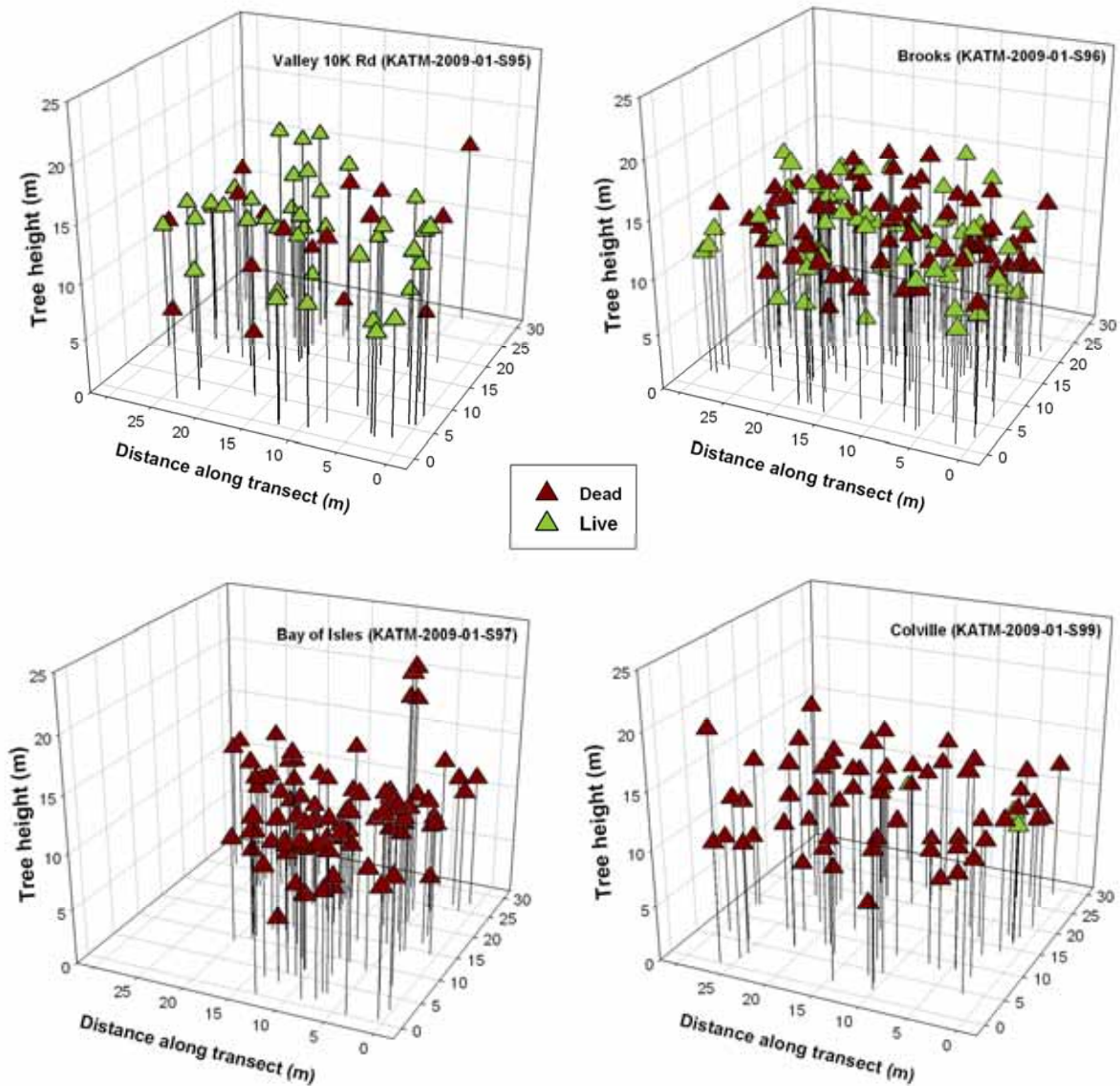


Figure 7. Three-dimensional plots of stand structure for closed spruce sites (beetle kill) sampled in 2009. Tree height is shown on the vertical axis for live and dead mature white spruce (≥ 12 cm DBH). Tree age, density and percent mortality varied among stands; trees along the Valley 10K Smokes Road showed the most recent damage and lowest mortality.



Standing biomass, including snag biomass, and coarse woody debris (CWD) loads were up to 20-fold greater in the closed forest-beetle kill stands than in spruce woodland (Figure 8b). Seedling densities were not affected by standing biomass (live and dead trees ≥ 12 cm DBH), including standing dead (snag) biomass (Figure 9a-b), and were also unaffected by stand age (Figure 9c), overstory cover (e.g., shrub cover; Figure 9d), and moss thickness (*data not shown*). In contrast, sapling densities increased linearly with shrub cover (Figure 9d; $df = 2$; $F=4.6$; $P=0.06$), perhaps as a result of increasing site productivity.

Figure 8. (a) Seedling densities (mean $\pm$ 1 SE) in low-elevation (0-450 m) white spruce stands. (b) Total standing biomass (live and dead trees; DBH $\geq$ 12 cm), standing dead biomass (snags), and coarse woody debris (CWD) loads in low-elevation spruce stands.

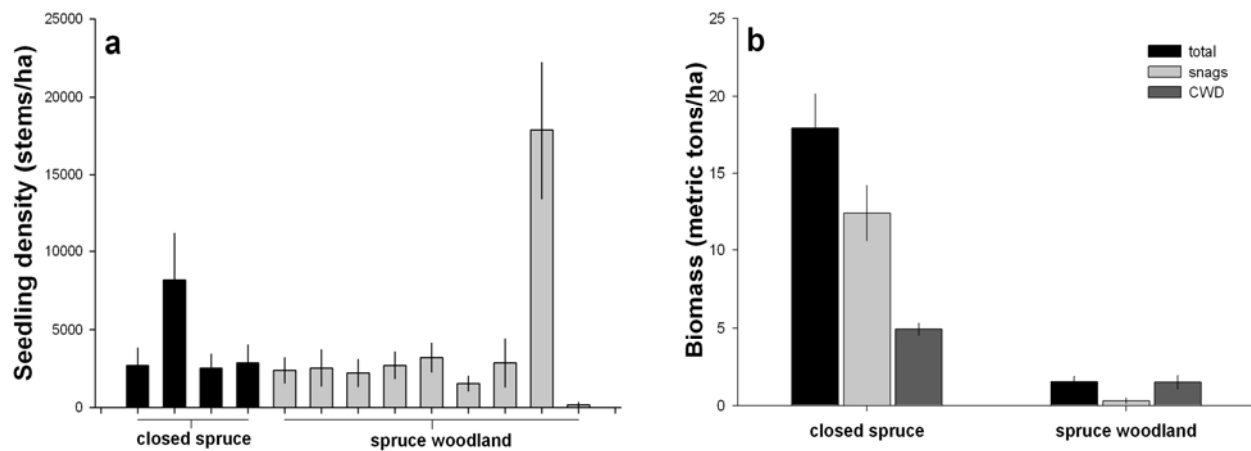
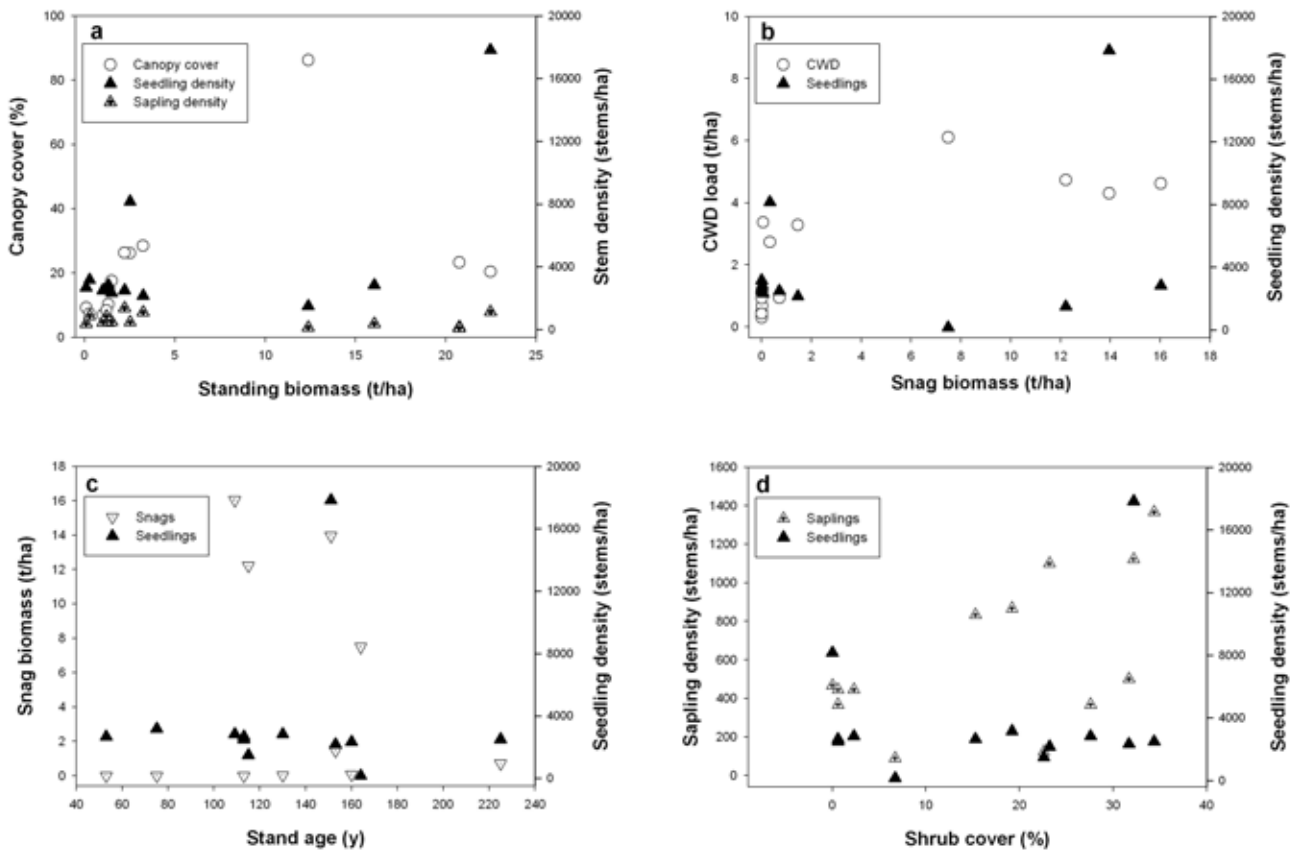


Figure 9. Relationship between seedling density and standing biomass (a, b), stand age (c), and shrub cover (d) in low elevation white spruce communities (spruce woodland and closed spruce – beetle kill) in Katmai National Park and Preserve (2009). Standing biomass (live and dead trees $\geq$ 12 cm DBH) was used as a proxy for site productivity. Seedling densities were independent of standing biomass (a), including standing dead (snag) biomass (b), and stand age (c). Shrub cover had no effect on seedling densities (d), but showed a positive relationship with sapling densities.



Fuel loads were relatively consistent within forest types, although spruce woodland sites were characterized by either very low loads (<1 t/ha) or, in areas where trees appeared stressed and/or subject to blowdown, relatively high loads (>2.5 t/ha; Table 4). Small-diameter ground fuels (1 h-100 h) comprised the majority of the fuel loads measured in low elevation forested sites, and were roughly an order of magnitude higher in closed spruce-beetle kill than in most woodland sites. One-hour fuels (< 0.625 cm diameter) include fallen needle and leaf litter, grassy fuels, lichens, and small twigs. They are the most important fuels for carrying surface fires, and their moisture content governs fire behavior. Ten-hour fuels (0.625 - 2.5 cm diameter) include small branches and woody stems that can carry hot fires and help ignite larger (100- and 1000-hour) fuels.

Large CWD (1000-h) fuel loads were comparable between woodland and closed forest stands and tended to be very low along transects at all sites. However, closed canopy-beetle kill sites had much higher standing dead (snag) biomass than spruce woodland sites (Table 4; Figure 8b), suggesting that the volume of CWD could increase measurably at these sites in the next 5-10 years. Thousand-hour fuels (> 7.6 cm diameter) include large downed branches, logs, and tree stumps, and burn only under prolonged dry conditions or when sufficiently preheated by adjacent fuels. Although they can serve as natural firebreaks under some conditions, they can also burn for days after ignition, creating air quality and re-burn hazards (Pyne et al. 1996). A full-plot inventory of 1000-h fuels for the beetle-kill sites recorded CWD volumes ranging from 2.7 to 7.1 m³/ha (*data not shown*).

At sites near Malone and Long Lake (KATM-2009-01-S08, KATM-2009-01-S12) we found evidence of what appeared to be heart rot, and a high incidence of trees that had broken tops due to wind damage. Whether these trees were old and decadent or were growing on sites that predisposed them to the fungus is uncertain. At one site (KATM-2009-01-S12), we were unable to get good ages for the largest trees due to decay in the heartwood. At most woodland sites, the trees appeared stressed, as evidenced by narrow growth rings and dead branches in the lower one-third to one-half of the canopy. Windthrow appeared to be a common source of disturbance, and was evident at a number of plots (e.g., KATM-2009-01-S02, KATM-2009-01-S38, KATM-2009-01-S41).

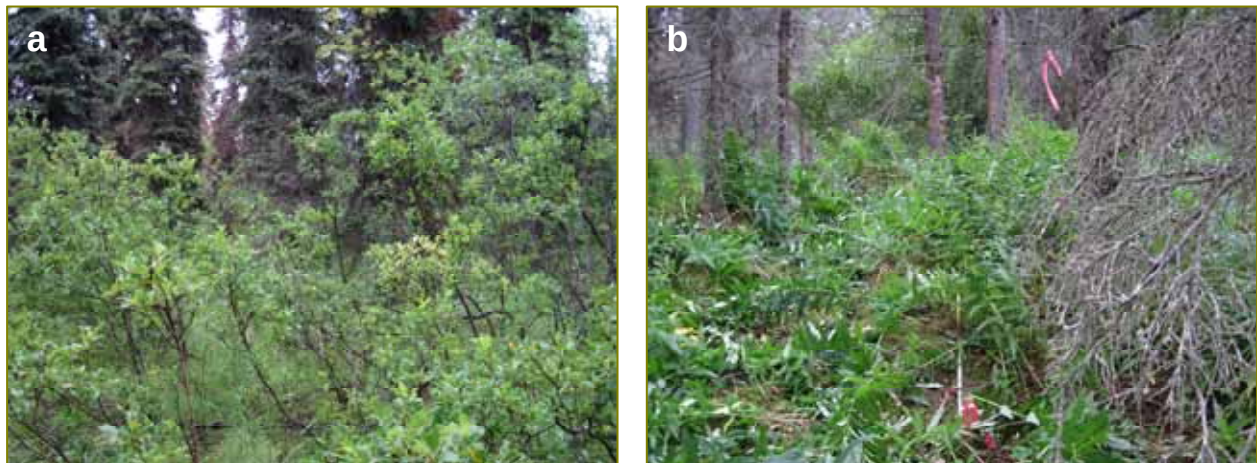
The understory in low elevation spruce woodland sites in Katmai was dominated by prostrate to low-growing (≤ 0.5 m) *Betula glandulosa* (cf. *B. nana*; 3-14%); low- to mid-stature willows, including *Salix glauca* (0-3%) and *S. pulchra* (0-6%); and spiraea (*Spiraea beauverdiana* (0-3%)). We found abundant moose sign in the spruce woodland sites near Nonvianuk, Malone and Long Lakes, and although we saw some evidence of browse (e.g., KATM-2009-01-S38), willows were in good condition across all sites.

Spruce beetle damage in low elevation closed spruce

Isolated spruce beetle damage dates from the mid-1980s at sites near Lake Brooks/Brooks Camp (ca. 5% mortality; Manski 1986, *unpublished report*). Measurable damage was recorded by airborne surveys elsewhere in the park beginning in 2003 and peaking in 2006 (USFS 2009). As of the 2008 aerial surveys, approximately 46,700 ha of spruce forest had been affected in Katmai (USFS 2009).

Of the four stands that we sampled, all but one showed >50% mortality (Table 4; Figure 7; Figure 10a). Paper birch comprised between 0-40% of the canopy at these sites, and tall shrubs (*Salix barclayi*, *S. pulchra*) were understory dominants (Table 3; Figure 3). Comparable levels of spruce beetle-related mortality on the Kenai Peninsula have resulted in increased cover of bluejoint (*Calamagrostis canadensis*) and fireweed (*Epilobium angustifolium*) in the understory, but no measurable reduction in spruce seedling regeneration over the 15-year period between 1989 and 2000 (Boucher and Mead 2006). In Katmai, much of the spruce beetle damage is much more recent (e.g., dating from ca. 2000), and only two of the four sites sampled had measurable *Calamagrostis* cover (Figure 10). One of these sites (KATM-2009-01-S95) also had anomalously low sapling and seedling densities. It appears that the limited spruce regeneration at this site could be related to seasonal flooding by Margot Creek, although light limitation due to overstory cover may be a contributing factor. Large-diameter (1000-h) CWD volumes were relatively high at both the Valley 10K Road (7.1 m³/ha) and Bay of Isles (6.9 m³/ha) sites, and it is likely that as the logs decompose they will provide nursery habitat for new seedlings.

Figure 10. Mesic understory vegetation at two closed spruce-beetle kill sites, (a) KATM-2009-01-S95, Valley of 10K Smokes Road; and (b) KATM-2009-01-S97, Naknek Lake-Bay of Isles. Spruce mortality and seedling densities were low at the Valley 10K Road site.

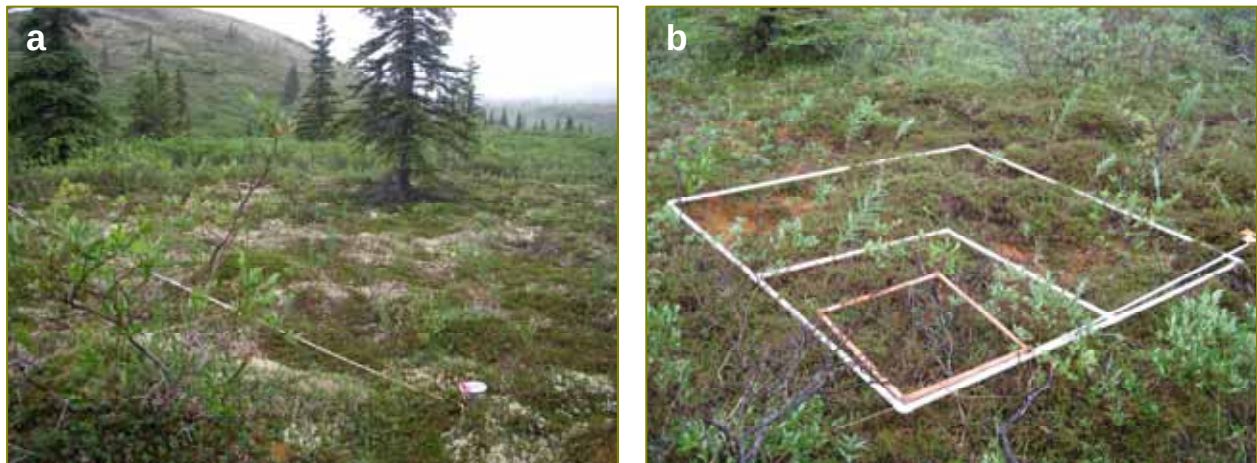


Shrub encroachment at treeline

Shrub encroachment appeared to be occurring at some treeline sites, where the persistence of shade-intolerant dwarf shrub species, even under a closed shrub canopy, suggested that the shrubs had recently established (Figure 11). We measured high species richness at these sites, as they supported species from both low elevation forested communities and mid- to high elevation dwarf shrub and alpine communities, appearing most similar in species composition to the dwarf shrub sites (Figure 5; Appendix 2). Increased shrub cover at the treeline sites has the potential to lead to greater shading of the ground layer and associated changes in species composition through time (e.g., loss of species with high light requirements; cf. Chapin et al. 1995). At some sites, the shrub component appeared to have been established for a longer period of time, and future sampling will include an estimation of shrub age to aid in describing ecotone dynamics. We will also continue to monitor changes in the structure of the understory (e.g., cover of shrub species in each height class) and in the composition of the lower stature vegetation, particularly

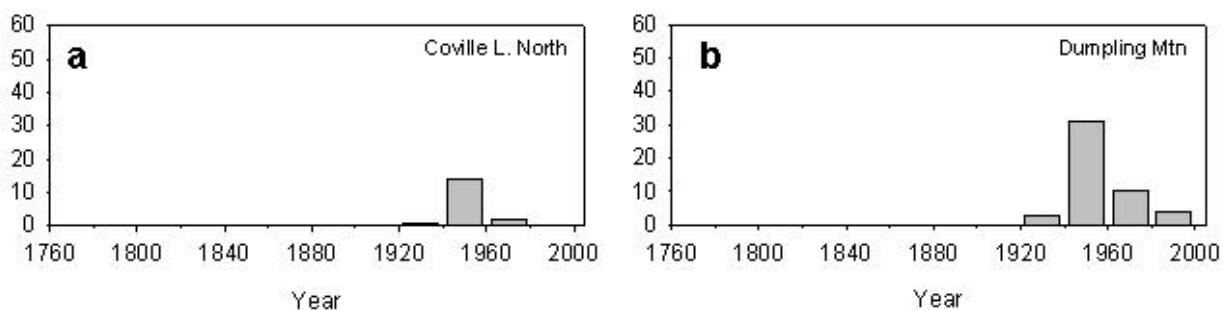
the nonvascular taxa (e.g., species frequency, cover, and overall species richness). In addition to shading effects, increased shrub cover and/or height could result in increased protection from wind and greater snow capture (snow depth) than in adjacent, low-stature vegetation (e.g., Kershaw and McCulloch 2007), potentially extending the snowmelt season and increasing early-season soil moisture. However, such changes in shrub cover and stature could likewise lead to increased albedo and greater evapotranspiration (e.g., Beringer et al. 2005), potentially resulting in reduced soil moisture during the growing season.

Figure 11. Treeline site (KATM-2009-02-S08) above the RAWS station north of Lake Colville characterized by (a) open stand structure and (b) scattered shrubs in dwarf shrub tundra.



Mean tree age at treeline sites ranged from roughly 30-50 years (Table 5), with the oldest trees (≥ 12 cm DBH) dating to roughly 60 years old at the lower margins of treeline (e.g., KATM-2009-02-S04), and the youngest saplings (< 12 cm DBH) dating to less than 10 years old at upper treeline (*data not shown*). The age structure of lower treeline sites cored in 2007 indicates a cohort of trees that established approximately 60 years ago (Figure 12), during a period of relatively mild winters that spanned the late 1940s-early 1950s (King Salmon, AK, 1947-2010; Western Regional Climate Center 2009). The young age structure suggests recent upslope encroachment of white spruce, and site chronologies show increased growth during the 1990s relative to previous decades, likely in response to regional warming (Sherriff and Berg 2009).

Figure 12. Age structure for treeline spruce sites (a) near the Colville RAWS station (elev. 435 m), and (b) on Dumping Mountain (elev. 470 m; Sherriff & Berg 2009). Stands were cored in 2007 and monitoring plots established in each area in 2009. The oldest trees dated from 1930 (76 years) and were found at a site on Dumping Mountain. Most trees sampled were ≤ 60 years old.



As of 2009, seedling establishment in treeline sites appeared to be relatively low. Seedling densities ranged from approximately 0-670 stems/ha (Table 5) and were roughly an order of magnitude lower than in low elevation spruce woodland sites. At several upper treeline sites near the Colville RAWS station (e.g., KATM-2009-02-S97; KATM-2009-02-S99), up to 50-60% of established saplings were dead, presumably due to wind exposure and desiccation. Treeline sites at Dumpling Mountain appeared to be more sheltered, perhaps due to the presence of alder (*Alnus viridis* ssp. *sinuata*), which appeared to act as a nurse plant for newly established spruce.

Table 5. Stand attributes for treeline spruce sites. Stand age and seedling counts are site means (± 1 SE). Biomass estimates and stem densities for trees and saplings are scaled up from plot-level inventories.

Site ID	Stand age (y)	Shrub cover (%)	Biomass (kg/ha)	Tree density (stems/ha)	Sapling density (stems/ha)	Seedling density (stems/ha)
02-S04	50.5 (11.7)	13.9 (6.7)	148.4	33	111	333 (227)
02-S08	48.3 (5.3)	15.0 (4.5)	8.7	0	78	167 (167)
02-S14	31.1 (12.7)	5.5 (1.3)	0.9	0	44	667 (383)
02-S17	29.1 (17.4)	22.1 (2.2)	1.1	0	89	500 (267)
02-S96	ND	3.1 (0.5)	71.1	11	67	167 (167)
02-S97	50.0 (11.0)	4.0 (1.6)	0.57	0	67	0
02-S99	29.3 (15.4)	16.6 (3.9)	9.5	0	89	167 (167)

Species of conservation concern

Three species of conservation concern, or species that are tracked as rare by the states and/or by the International Union for Conservation of Nature (IUCN), were collected in the park during the 2009 field season. The collections will be archived at the University of Alaska Fairbanks Museum of the North (ALA) through a loan agreement with the National Park Service.

Erioderma pedicellatum (Hue) P.M. Jørg, is a globally endangered (red-listed by the IUCN), foliose cyanolichen known from Scandinavia, southeastern Canada, and the upper Cook Inlet region of Alaska (Figure 13a). A small population of *Erioderma* was found in a beetle-killed mature white spruce forest near Lake Colville, representing the southern and westernmost site known in North America (*J. Walton 13503*, NPS Accession # 0492, Catalog # 47584, *J. Walton 13504*, NPS Accession # 0492, Catalog # 47585).

Hypogymnia pulverata (Nyl. ex Crombie) Elix, is an epiphytic foliose macrolichen considered common in the southern hemisphere but rare in North America (S1 in Oregon; Figure 13b). The species is known currently from three wide-ranging locations in Quebec, Oregon, and Alaska. Several collections of *Hypogymnia* were made in spruce woodland stands near Nonvianuk Lake, Naknek Lake, Lake Colville, and Malone Lake (*J. Walton 13007*, Accession # 492, Catalog # 47501; *J. Walton 13023*, Accession # 492, Catalog # 47504; *J. Walton 13039*, Accession # 492, Catalog # 47517; *J. Walton 13040*, Accession # 492, Catalog # 47518; *J. Walton 13041*, Accession # 492, Catalog # 47519; *J. Walton 13381*, Accession # 492, Catalog # 47554; *J. Walton 13406*, Accession # 492, Catalog # 47557; *J. Walton 13411*, Accession # 492, Catalog # 47558; *J. Walton 13472*, Accession # 492, Catalog # 47577; *J. Walton 13479*, Accession # 492, Catalog # 47582; *J. Walton 13507*, Accession # 492, Catalog # 47588; *J. Walton 13508*, Accession # 492, Catalog # 47589).

Schistostega pennata (Hedw.) Web. & Mohr, is a moss previously known from eight sites in southeast Alaska and one site near Fairbanks (Figure 13c). Within western North America, the species is considered rare to uncommon (S1 in Montana and Idaho, S2 in Oregon and Washington State). The new population from KATM constitutes a significant range extension to the west. A population was found on damp mineral soil in the hollows of overturned white spruce rootwads on the western end of Nonvianuk Lake (*J. Walton 13027*, NPS Accession # 492, Catalog # 47506).

Figure 13. Rare nonvascular taxa found in Katmai National Park and Preserve (2009): a) *Erioderma pedicellatum*; b) *Hypogymnia pulverata*; c) *Schistostega pennata*.



Modifications to the sampling design and sampling methods

We have used the baseline data from Katmai to examine variability in plot attributes for four representative vegetation types (low elevation spruce woodland, low elevation closed forest, mid-elevation treeline spruce, mid-elevation dwarf shrub tundra). Low sample variances (CVs) for a number of attributes, including cover by growth form, species cover, and frequency indicate that our estimated minimum sample size of eight plots per vegetation type (Thompson et al., *in review*) will be sufficient to detect long-term trends in vegetation parameters (minimum detectable total change of 25% over 31 years, for a true change of 50%; Thompson et al, *in review*). In addition, we find that the sample variances for targeted vegetation types (closed spruce-beetle kill; treeline spruce) are sufficiently low to detect change with fewer than eight replicates. In 2010, we plan to resample four to six plots in Katmai (i.e., up to two plots per vegetation type in low elevation spruce woodland, mid-elevation treeline spruce, and mid-elevation dwarf shrub tundra) to estimate interannual variability for the period 2009-2010.

In 2010, we made a number of improvements to our sampling methods. We hired a term biotech (GS-7) to lead the nonvascular monitoring and to serve as crew leader in the field, and we hired a crew consisting of one seasonal biotech (GS-5) and one SCA intern. Crew size ranged from 2-4 persons and was supplemented by intermittent help from SWAN and AKRO staff. We restricted nonvascular frequency measurements to 0.25-m² and 1-m² quadrats to compensate for the increased sampling effort, and adopted the use of a monitoring staff (cf. Roland et al. 2004) to improve point-intercept cover estimates within our four height classes. We added fuels measurements to our sampling in forested sites, following the line-intersect methods of Van Wagner (1968) and Brown (1974). We continued to use descriptors adopted in 2008 to delineate between current-year frost damage and dead branches in low-stature woody vegetation (shrubs

and dwarf shrubs), but refined the definition of ‘standing dead’ to include only dead trees and shrubs, and not dead branches on live plants.

As indicated in the Methods section, we parsed the GRTS sample into two populations (all classes and spruce classes only) based on landcover classes derived from the 2000 landcover map for Katmai. Even with the separate population of ‘spruce’ points, we were unable to locate enough GRTS sites at treeline to provide adequate replication. The problem with treeline is twofold: (1) the landcover map does not accurately capture treeline, so many ‘spruce’ GRTS points identified as high elevation spruce were in fact dwarf shrub tundra (Appendix 1); and (2) upper treeline is by definition discontinuous and patchy, reducing the probability that a GRTS point will land in a location occupied by spruce. We established several of the treeline sites (02-S96, 02-S97, 02-S99) in relatively close proximity to a GRTS point, thus maintaining spatial dispersion to the extent possible. Because a subset of the treeline sites were subjectively located, we are treating the entire sample as targeted, and thus limiting our area of inference accordingly.

Recommendations and Conclusions

Baseline sampling conducted in 2009 was limited to low (0-450 m) and mid-elevation (450-900 m) sites in interior Katmai. In 2010, our activities in Katmai will include establishing plots in high elevation sites (>900 m) above Pfaff Mine, Hammersly Lake and Mirror Lake; re-measuring four to six plots established in 2009; and downloading soil temperature loggers installed at eleven sites in the park.

Our crew (one seasonal biotech, GS-6; one student intern from UAF) led by the SWAN veg biotech (GS-7 term) will be based in Lake Clark, where we plan to establish sites in all elevation bands across a N-S gradient in the interior of the park. We will continue to sample in the mid-elevation band, due to its importance as a transitional zone for vegetation (e.g., treeline), but will also sample in the low (0-450 m) and high (>900 m) elevation bands. A subset of sites in the low elevation band will be in the headwaters of the Chulitna River, near Lake 423 (as indicated on the 1:63,000 USGS quads). This area is upstream of the proposed Pebble mine site, and may provide useful baseline data with respect to contaminant loads (e.g., as measured in *Hylocomium splendens*).

Because of the importance of snowpack and timing of snowmelt to vegetation development, we will continue to monitor soil temperature at the two sites established in 2008, and at an additional six to eight sites in Lake Clark. Soil temperature provides a good proxy for snow cover and snowmelt date, as soil temperatures stabilize once a snowpack develops and begin to increase rapidly once the sites are snow-free. We will establish at least one site in close proximity (within 0.5 km) of the RAWS at Snipe Lake. We also plan to install digital cameras (phenocams) at 1-2 sites in Lake Clark and Katmai to document the timing of snowpack development, snowmelt, and phenological metrics (leaf out, senescence). Temperature data will then be cross-referenced to known melt-out dates, thus improving interpretation. The phenocams will be co-located at weather station locations where infrastructure is already in place. Proposed sites include the Snipe RAWS and Hickerson RAWS (LACL), and the Coville RAWS (KATM).

We will continue to revisit a subset of plots in consecutive years to estimate interannual variability in species cover and frequency. An understanding of the inherent variability in the system is essential to our interpretation of longer-term, decadal-scale changes in vegetation. For example, it may enable us to distinguish between the effects of an episodic event (e.g., a mid-winter thaw period, late snowmelt, or anomalies in summer precipitation for a given year) and longer-term, directional change.

Literature Cited

- Beals, E. W. 1984. Bray-Cutis ordination: an effective strategy for analysis of multivariate ecological data. *Advances in Ecological Research* 14: 1-55.
- Beringer, J., Chapin, F.S., Thompson, C.C., and D.A. McGuire. 2005. Surface energy exchanges along a tundra-forest transition and feedbacks to climate. *Agricultural and Forest Meteorology* 131:143-161.
- Boggs, K., Klein, S.C., Grunblatt, J., and B. Koltun. 2003. Landcover classes, ecoregions and plant associations of Katmai National Park and Preserve. National Park Service, Alaska Region, Anchorage, AK. 273 pp.
- Boucher, T.V., and B.R. Mead. 2006. Vegetation change and forest regeneration on the Kenai Peninsula, Alaska following a spruce beetle outbreak, 1987-2000. *Forest Ecology and Management* 227:233-246.
- Brown, J.K. 1974. Handbook for inventorying downed woody material. USDA Forest Service Gen. Tech. Rep. No. INT-16.
- Chapin, F.S., Shaver, G.R., Giblin, A.E., Nadelhoffer, K.J., and J.A. Laundre. 1995. Responses of arctic tundra to experimental and observed changes in climate. *Ecology* 76:694-711.
- Harding, R.B., and D.F. Grigal. 1985. Individual tree biomass estimation equations for plantation-grown white spruce in northern Minnesota. *Can. J. For. Res.* 15:738-739.
- Kershaw, G.P., and J. McCulloch. 2007. Midwinter snowpack variation across the Arctic treeline, Churchill, Manitoba, Canada. *Arctic, Antarctic, and Alpine Research* 39:9-15.
- Manski, D. 1986. Spruce beetles in Katmai National Park and Preserve: A survey of baseline conditions. Unpublished report, National Park Service, Alaska Region, Anchorage, AK, 19 pp.
- McCune, B. and M. J. Mefford. 2009. PC-ORD. Multivariate Analysis of Ecological Data. Version 6.76 beta MjM Software, Gleneden Beach, Oregon, U.S.A.
- McDonald, T.L. 2003. Review of environmental monitoring methods: survey designs. *Environmental Monitoring and Assessment* 85:277-292.
- Miller A.E., Thompson, W.L., Mortenson D.C., Moore C., and C. Lindsay. 2010. Protocol for ground-based monitoring of vegetation in the Southwest Alaska Network. Natural Resource Report NPS/SWAN/NRR-2010/XXX. U.S. Dept. Interior, National Park Service, Alaska Region, Anchorage, AK, 275 pp.
- Mortenson, D.C., and A.E. Miller. 2008. Path-distance analysis to determine accessibility for long-term vegetation monitoring program, Lake Clark National Park and Preserve. Natural Resource Technical Report NPS/SWAN/NRTR—2008/126, National Park Service, Fort Collins, CO.
- Pyne, S.J., Andrews, P.L., and R.D. Laven. 1996. *Introduction to Wildland Fire*. Wiley, New York.

- Roland, C., Oakley, K., Debevec, E.M., and P. Loomis. 2004. Monitoring vegetation structure and composition at multiple spatial scales in the Central Alaska Network (Version 1.0). National Park Service, Alaska Region, 50 pp + appendices.
- Sherriff, R., and E. Berg. 2009. Annual Technical Report: Tree-ring Reconstruction of Historic Insect Outbreaks in Katmai National Park and Preserve. National Park Service, Alaska Region, Anchorage, AK. 19 pp.
- Stevens, D.L., Jr. 1997. Variable density grid-based sampling design for continuous spatial populations. *Environmetrics* 8:167-195.
- Stevens, D.L., Jr., and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. *Journal of the American Statistical Association* 99:262-278.
- Taylor, F.W., Wang, E.I.C., Yanchuk, A., and M.M. Micko. 1982. Specific gravity and tracheid length variation of white spruce in Alberta. *Canadian Journal of Forest Research* 12:561-566.
- Thompson, W.L., Miller, A.E., Mortenson, D.C., and A. Woodward. Developing effective sampling designs for monitoring natural resources in Alaskan National Parks: An example using simulations and vegetation data. *Biological Conservation* (In review).
- U.S. Forest Service. 2009. Forest health conditions in Alaska – 2008. USDA Forest Service, Alaska Region, R10-PR20, 102 pp.
- Van Wagner, C.E. 1968. The line-intersect method in forest fuel sampling. *Forest Science* 14:20-26.
- Viereck, L.A., Dyrness, C.T., Batten, A.R., and K.J. Wenzlick. 1992. The Alaska vegetation classification. U.S. Forest Service, Pacific Northwest Region, General Technical Report PNW-GTR-286, 278 pp.
- Woodward, A.E., Hutten, K.M., Boetsch, J.R., Acker, S.A., Rochefort, R.M., Bivin, M.M., and L.L. Kurth. 2009. Forest vegetation monitoring protocol for national parks in the North Coast and Cascades Network: U.S. Geological Survey Techniques and Methods 2-A8, 228 pp.

Appendix 1. Site reconnaissance for Katmai National Park and Preserve (2009). Forested and non-forested sites in elevation bands 1 and 2 were selected from separate GRTS samples due to the low frequency of spruce cover classes, as derived from the landcover map. Fifty sites were surveyed in each stratum, with the exception of spruce stratum 2, which had a total of only 46 points. Closed spruce (beetle kill) sites and a subset of treeline spruce sites (S96-S99) were subjectively chosen.

1a. GRTS – all classes, including spruce								
GRTS	SLOPE	LC	ELEV_BND	POINT_X	POINT_Y	General Location	Accept/Reject	Reason
1	1	11	2	-154.983	58.74969	Murray	reject	not target veg
2	7	2	2	-155.092	58.74397	Murray	reject	not target veg
3	5	11	2	-155.163	58.89689	Hammersly	accept	
4	4	11	2	-155.175	58.91182	Hammersly	reject	access - unsafe
5	3	11	2	-155.087	59.11148	Emerald Lake	accept	
6	10	7	2	-155.106	58.90545	Hammersly	accept	
7	7	11	2	-155.085	58.79235	Hammersly	reject	not target veg
8	4	8	2	-155.148	58.89354	Hammersly	accept	
9	10	12	2	-155.159	58.9227	Hammersly	reject	access - unsafe
10	10	15	2	-155.004	58.76456	Murray	reject	not target veg
11	3	12	2	-155.09	58.79607	Murray	reject	not target veg
12	5	11	2	-155.184	59.01293	Nonvianuk-Kukaklek	reject	access - too far
13	7	13	2	-155.129	58.9082	Hammersly	reject	see notes
14	6	9	2	-155.014	58.76341	Murray	reject	not target veg
15	2	11	2	-155.164	58.90655	Hammersly	reject	not target veg
16	9	11	2	-155.144	59.093	Nonvianuk-Kukaklek	reject	access - too far
17	9	11	2	-155.494	58.82181	Upper Colville	reject	not target veg
18	3	11	2	-155.175	58.89732	Hammersly	reject	not target veg
19	4	8	2	-155.174	58.90539	Hammersly	reject	not target veg
20	9	13	2	-154.984	59.04225	Battle	reject	not target veg
21	9	17	2	-154.98	59.03342	Battle	reject	access - too far
22	7	8	2	-155.148	58.88844	Hammersly	reject	access - too far
23	5	11	2	-155.155	58.90743	Hammersly	accept	
24	9	15	2	-154.967	58.75008	Murray	reject	not target veg
25	10	12	2	-155.531	58.83024	Upper Colville	reject	not target veg
26	10	11	2	-154.971	59.03107	Battle	reject	access - too far
27	8	12	2	-155.126	58.8991	Hammersly	reject	not target veg
28	7	12	2	-155.109	58.9014	Hammersly	reject	not target veg
29	9	12	2	-155.176	58.87987	Hammersly	reject	not target veg
30	9	11	2	-155.236	59.01835	Nonvianuk-Kukaklek	reject	access - too far
31	3	8	2	-155.087	59.11093	Narrow Cove	reject	not target veg
32	7	18	2	-155.088	59.11817	Narrow Cove	accept	
33	2	10	2	-154.828	59.2701	Mirror	accept	not sampled
34	6	14	2	-155.069	58.75839	Murray	reject	not target veg
35	5	11	2	-155.161	58.81827	Hammersly	reject	access - too far
36	3	11	2	-155.19	58.90122	Hammersly	reject	not target veg
37	3	11	2	-155.138	58.91027	Hammersly	reject	access - too far
38	7	13	2	-155.109	58.88663	Hammersly	reject	not target veg
39	7	8	2	-155.205	58.88658	Hammersly	reject	not target veg
40	4	15	2	-154.997	58.7528	Murray	reject	not target veg
41	7	12	2	-155.098	58.89075	Hammersly	reject	not target veg
42	3	11	2	-155.206	59.01729	Nonvianuk-Kukaklek	reject	access - too far
43	4	9	2	-155.086	58.79342	Murray	reject	not target veg
44	6	12	2	-155.523	58.82899	Upper Colville	reject	not target veg

1a. GRTS – all classes, including spruce

GRTS	SLOPE	LC	ELEV_BND	POINT_X	POINT_Y	General Location	Accept/Reject	Reason
45	2	11	2	-155.096	58.81078	Hammersly	reject	not target veg
46	7	11	2	-155.174	58.89035	Hammersly	reject	not target veg
47	7	12	2	-155.162	58.82255	Hammersly	reject	not target veg
48	8	13	2	-154.733	59.2535	Mirror	accept	
49	4	11	2	-155.123	58.91926	Hammersly	reject	not target veg
50	6	11	2	-155.567	58.80699	Upper Colville	accept	

1b. GRTS – spruce only

GRTS	SLOPE	LC	ELEV_BND	POINT_X	POINT_Y	General Location	Accept/Reject	Reason
1	0	2	1	-155.947	58.4511	Brooks	reject	not target veg
2	3	2	1	-156.08	58.39689	Malone	accept	
3	2	2	1	-155.605	58.43115	Valley 10K Road	reject	not target veg
4	9	3	1	-155.654	58.83141	Colville	reject	not target veg
5	2	2	1	-155.58	59.06025	W Nonvianuk	reject	access - too far
6	3	3	1	-155.67	59.05939	W Nonvianuk	reject	access - too far
7	4	3	1	-155.562	58.67898	E Naknek	reject	not target veg
8	6	3	1	-156.18	58.41347	Malone	accept	
9	5	2	1	-155.742	58.99939	W Nonvianuk	reject	access - too far
10	7	3	1	-155.283	58.64771	Jojo/Grosvenor	reject	not target veg
11	2	3	1	-156.033	58.57356	S Naknek	reject	not target veg
12	4	3	1	-156.234	58.42356	Long	accept	
13	5	2	1	-155.688	58.45962	Valley 10K Road	reject	access - too far
14	3	2	1	-155.534	59.05839	W Nonvianuk	reject	access - too far
15	7	3	1	-155.813	59.00753	W Nonvianuk	reject	not target veg
16	4	2	1	-156.122	58.40693	Malone	reject	access - unsafe
17	8	2	1	-155.684	59.03291	W Nonvianuk	reject	access - too far
18	7	2	1	-155.568	58.44638	Valley 10K Road	reject	access - unsafe
19	1	2	1	-155.654	58.46007	Valley 10K Road	reject	not target veg
20	9	3	1	-155.492	59.04277	W Nonvianuk	reject	not target veg
21	4	3	1	-156.081	58.4044	Malone	reject	not target veg
22	7	3	1	-156.259	58.42607	Long	reject	not target veg
23	0	2	1	-155.612	58.82093	Colville	reject	access - too far
24	7	3	1	-155.546	59.05851	W Nonvianuk	reject	access - too far
25	3	3	1	-155.691	59.05375	W Nonvianuk	reject	access - too far
26	3	3	1	-155.58	58.68468	E Naknek	reject	not target veg
27	4	3	1	-156.233	58.41148	Long	accept	
28	6	2	1	-155.732	58.99764	W Nonvianuk	reject	access - too far
29	1	2	1	-155.381	58.55649	Illiuk Arm	reject	not target veg
30	9	2	1	-155.55	58.74599	Colville	reject	not target veg
31	1	2	1	-156.141	58.58953	S Naknek	reject	not target veg
32	6	2	1	-155.568	58.97798	W Nonvianuk	reject	access - too far
33	2	3	1	-155.472	58.97187	W Nonvianuk	reject	access - too far
34	10	3	1	-155.59	58.67193	E Naknek	reject	not target veg
35	5	2	1	-155.651	59.02554	W Nonvianuk	accept	
36	0	2	1	-155.622	58.96927	W Nonvianuk	reject	access - too far
37	2	2	1	-155.646	58.45667	Valley 10K Road	reject	not target veg
38	3	2	1	-155.651	59.00353	W Nonvianuk	accept	
39	1	3	1	-155.873	58.98172	W Nonvianuk	reject	access - too far
40	3	3	1	-155.338	58.64044	Jojo/Grosvenor	reject	access - too far
41	1	2	1	-155.563	58.98368	W Nonvianuk	accept	

1b. GRTS – spruce only

GRTS	SLOPE	LC	ELEV_BND	POINT_X	POINT_Y	General Location	Accept/Reject	Reason
42	0	2	1	-155.172	58.50944	Savonoski	reject	access - too far
43	7	2	1	-156.007	58.58526	S Naknek	reject	access - too far
44	7	2	1	-155.653	59.02336	W Nonvianuk	reject	access - too far
45	2	2	1	-155.672	58.46063	Valley 10K Road	reject	access - too far
46	10	2	1	-156.256	58.42881	Long	reject	access - too far
47	4	3	1	-155.782	59.00287	W Nonvianuk	reject	access - too far
48	7	2	1	-155.819	58.47044	Brooks	reject	access - too far
49	4	3	1	-156.195	58.40168	Malone	reject	access - too far
50	0	2	1	-156.338	58.74213	N Naknek	accept	
78	1	3	1	-156.158	58.38685	Malone	accept	
1	8	3	2	-155.962	58.80535	Idavain	reject	not target veg
2	7	3	2	-155.497	58.84031	Upper Colville	reject	not target veg
3	10	3	2	-155.193	58.92722	Hammersly	reject	access - too far
4	10	3	2	-155.542	58.83386	Upper Colville	accept	
5	9	3	2	-155.548	58.83138	Upper Colville	reject	not target veg
6	10	3	2	-155.561	58.84787	Upper Colville	reject	not target veg
7	8	3	2	-155.549	58.83084	Upper Colville	reject	not target veg
8	10	3	2	-155.523	58.82362	Upper Colville	accept	
9	9	3	2	-155.534	58.83423	Upper Colville	reject	not target veg
10	8	3	2	-155.549	58.83111	Upper Colville	reject	see notes
11	4	3	2	-155.545	58.84592	Upper Colville	reject	not target veg
12	8	3	2	-155.961	58.80509	Idavain	reject	see notes
13	9	3	2	-155.542	58.83413	Upper Colville	reject	see notes
14	9	3	2	-155.875	58.58807	Dumpling	accept	
15	7	3	2	-155.562	58.84759	Upper Colville	reject	not target veg
16	8	3	2	-155.542	58.83038	Upper Colville	accept	
17	9	3	2	-155.876	58.57999	Dumpling	accept	
18	10	3	2	-155.567	58.84833	Upper Colville	reject	not target veg
19	10	3	2	-155.517	58.82692	Upper Colville	reject	not target veg
20	3	3	2	-155.9	58.58366	Dumpling	reject	not target veg
21	5	3	2	-155.543	58.83386	Upper Colville	reject	see notes
22	6	3	2	-155.568	58.84859	Upper Colville	reject	not target veg
23	9	3	2	-155.577	58.56765	Dumpling	reject	see notes
24	10	3	2	-155.193	58.92749	Dumpling	reject	see notes
25	9	3	2	-155.548	58.83085	Upper Colville	reject	see notes
26	9	3	2	-155.562	58.84786	Upper Colville	reject	not target veg
27	9	3	2	-155.526	58.83433	Upper Colville	reject	not target veg
28	10	3	2	-155.509	58.83103	Upper Colville	reject	not target veg
29	4	3	2	-155.545	58.84565	Upper Colville	reject	not target veg
30	0	3	2	-155.509	58.83077	Upper Colville	reject	not target veg
31	5	3	2	-155.518	58.82664	Upper Colville	reject	not target veg
32	10	3	2	-155.549	58.8311	Upper Colville	reject	see notes
33	2	3	2	-155.543	58.83385	Upper Colville	reject	see notes
34	8	3	2	-155.902	58.5831	Dumpling	reject	see notes
35	7	3	2	-155.36	58.94383	S Nonvianuk	reject	access - too far
36	9	3	2	-155.542	58.8344	Upper Colville	reject	see notes
37	10	3	2	-155.877	58.58051	Dumpling	reject	see notes
38	10	3	2	-155.194	58.92722	Hammersly	reject	access - too far

1b. GRTS – spruce only

GRTS	SLOPE	LC	ELEV_BND	POINT_X	POINT_Y	General Location	Accept/Reject	Reason
39	9	3	2	-155.542	58.83065	Upper Colville	reject	see notes
40	9	3	2	-155.876	58.57972	Dumpling	reject	see notes
41	9	3	2	-155.542	58.83038	Upper Colville	reject	see notes
42	8	3	2	-155.539	58.82988	Upper Colville	reject	see notes
43	9	3	2	-155.588	58.38893	Valley 10K Road	reject	not target veg
44	10	3	2	-155.526	58.83432	Upper Colville	reject	not target veg
45	7	3	2	-155.36	58.9441	S Nonvianuk	reject	access - too far
46	10	3	2	-155.577	58.56738	Illiuk Arm	reject	not target veg

Appendix 2. Within-site variance in species cover for selected vegetation types in Katmai National Park and Preserve (2009). Means ($\pm$ 1 SE) are shown for a subset of species in each growth form. Cover is estimated by point-intercept along 30-m transects. Total cover >100% is due to layering within vegetation type. Cover by height class (<0.5 m; 0.5-1.0 m; >1.0-4.0 m; >4 m) is shown for white spruce (*Picea glauca*) only, but was recorded for all species. Species with high constancy in cover (CV $\leq$ 35%) are indicated in boldface.

2a. Low elevation (0-450 m) spruce woodland									
Vascular species	Site ID								
	01-078	01-S02	01-S08	01-S12	01-S27	01-S35	01-S38	01-S41	01-S50
Tree									
<i>Picea glauca</i> (<0.5 m)	3.4 (2.0)	1.7 (0.0)	0.6 (0.6)	2.3 (1.1)	1.1 (0.6)	0.6 (0.6)	1.1 (0.6)	2.3 (1.5)	3.4 (1.0)
<i>P. glauca</i> (0.5-1.0 m)	4.5 (3.0)	0.6 (0.6)	1.7 (1.0)	1.7 (1.7)	2.8 (1.5)	2.3 (0.6)	4.0 (0.6)	2.8 (1.1)	2.8 (2.0)
<i>P. glauca</i> (>1.0-4.0 m)	2.3 (2.3)	7.9 (3.0)	4.5 (2.3)	5.1 (1.0)	4.0 (3.1)	9.0 (3.4)	6.2 (3.7)	4.0 (1.5)	2.3 (2.3)
<i>P. glauca</i> (>4.0 m)	0.0	0.0	0.0	0.0	1.7 (1.7)	2.8 (2.0)	0.6 (0.6)	0.0	0.0
Shrub									
<i>Alnus viridis</i> ssp. <i>sinuata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Betula glandulosa</i>	13.6 (1.0)	7.9 (1.5)	5.1 (2.6)	3.4 (1.7)	3.4 (1.7)	5.1 (2.6)	6.2 (2.5)	11.3 (3.0)	2.8 (0.6)
<i>Cornus suecica</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ledum palustre</i> ssp. <i>decumbens</i>	14.7 (8.8)	9.6 (3.0)	9.0 (2.5)	10.2 (1.0)	11.9 (2.6)	5.6 (3.4)	7.9 (1.5)	11.3 (2.5)	2.8 (1.5)
<i>Rhododendron camtschaticum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Salix barclayi</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Salix bebbiana</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Salix glauca</i>	1.7 (1.7)	0.0	0.6 (0.6)	0.6 (0.6)	0.0	0.0	0.0	2.8 (2.0)	0.0
<i>Salix pulchra</i>	0.6 (0.6)	0.0	0.0	1.1 (0.6)	1.1 (1.1)	2.3 (1.5)	6.2 (3.7)	0.0	0.0
<i>Spiraea beauverdiana</i>	1.1 (1.1)	0.0	0.6 (0.6)	0.0	0.0	0.0	2.8 (1.5)	0.0	0.0
<i>Vaccinium uliginosum</i>	0.0	16.9 (1.7)	7.9 (1.1)	0.0	2.8 (1.5)	9.6 (4.4)	4.5 (0.6)	6.8 (2.6)	1.1 (0.6)
Dwarf shrub									
<i>Arctostaphylos alpina</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7 (1.1)	0.0
<i>Diapensia lapponica</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Dryas octapetala</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Empetrum nigrum</i>	40.1 (13.6)	44.6 (4.9)	42.9 (1.5)	39.5 (6.5)	49.7 (7.2)	40.7 (9.9)	18.1 (4.6)	48.0 (5.4)	46.3 (6.9)
<i>Louisleuria procumbens</i>	4.5 (4.5)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4 (1.7)
<i>Salix arctica</i>	1.1 (1.1)	0.0	0.0	0.0	1.1 (0.6)	0.0	0.0	0.0	1.1 (1.1)
<i>Salix reticulata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Vaccinium vitis-idaea</i>	22.6 (3.7)	13.0 (1.5)	15.8 (1.1)	18.6 (1.7)	11.3 (0.6)	6.2 (2.0)	13.6 (4.9)	10.7 (0.6)	11.3 (3.4)
Graminoid									
<i>Calamagrostis canadensis</i>	0.6 (0.6)	0.0	0.0	0.0	0.0	0.6 (0.6)	0.0	0.0	0.0
<i>Carex lugens</i>	1.1 (1.1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Carex microchaeta</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Festuca altaica</i>	0.0	1.1 (1.1)	0.0	0.0	0.0	0.0	0.0	0.0	1.1 (0.6)

2a. Low elevation (0-450 m) spruce woodland

Vascular species	Site ID								
	01-078	01-S02	01-S08	01-S12	01-S27	01-S35	01-S38	01-S41	01-S50
<i>Hierochloa alpina</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Trisetum spicatum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forb									
<i>Artemisia arctica</i> ssp. <i>arctica</i>	0.0	0.0	0.0	0.0	0.6 (0.6)	0.0	0.0	0.0	0.6 (0.6)
<i>Arnica frigida</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Campanula uniflora</i>	1.1 (1.1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lichen	22.6 (9.4)	32.8 (6.5)	23.2 (6.9)	29.9 (6.2)	27.8 (7.0)	11.9 (6.4)	9.0 (4.8)	21.5 (3.0)	42.4 (3.4)
Moss	28.8 (14.8)	37.9 (7.6)	56.5 (6.5)	56.5 (6.3)	63.8 (5.2)	73.4 (8.9)	84.2 (8.5)	40.7 (0.0)	9.6 (7.1)

2b. Low elevation (0-450 m) closed spruce – beetle kill

Vascular species	Site ID			
	01-S95	01-S96	01-S97	01-S99
Tree				
<i>Picea glauca</i> (<0.5 m)	1.1 (0.6)	2.8 (1.5)	1.1 (1.1)	1.7 (1.0)
<i>P. glauca</i> (0.5-1.0 m)	0.6 (0.6)	1.1 (0.6)	0.0	0.0
<i>P. glauca</i> (>1.0-4.0 m)	5.6 (1.5)	3.4 (1.7)	1.1 (1.1)	0.0
<i>P. glauca</i> (>4.0 m)	14.7 (4.8)	18.6 (5.4)	0.0	0.0
<i>Betula papyrifera</i> var. <i>kenaica</i> (<0.5 m)	0.0	0.6 (0.6)	1.1 (1.1)	0.0
<i>B. papyrifera</i> var. <i>kenaica</i> (0.5-1.0 m)	0.0	1.7 (1.0)	0.6 (0.6)	0.0
				39.1
<i>B. papyrifera</i> var. <i>kenaica</i> (>1.0-4.0 m)	0.0	24.9 (5.4)	22.6 (11.5)	(10.8)
<i>B. papyrifera</i> var. <i>kenaica</i> (>4.0 m)	0.0	5.6 (3.0)	4.5 (3.0)	11.3 (7.5)
Shrub				
<i>Alnus viridis</i> ssp. <i>sinuata</i>	0.0	0.0	0.0	0.0
<i>Betula glandulosa</i>	0.0	0.0	0.0	0.0
<i>Cornus suecica</i>	0.6 (0.6)	0.0	0.0	0.0
<i>Ledum palustre</i> ssp. <i>decumbens</i>	0.0	0.0	0.0	0.6 (0.6)
<i>Rhododendron camtschaticum</i>	0.0	0.0	0.0	0.0
<i>Salix barclayi</i>	1.1 (1.1)	0.0	0.0	0.0
<i>Salix bebbiana</i>	0.0	0.0	0.0	0.0
<i>Salix glauca</i>	0.0	0.0	0.0	0.0
<i>Salix pulchra</i>	0.0	0.6 (0.6)	0.0	0.0
<i>Spiraea beauverdiana</i>	0.6 (0.6)	0.0	0.0	0.0
<i>Vaccinium uliginosum</i>	0.0	0.0	0.0	0.0

2b. Low elevation (0-450 m) closed spruce – beetle kill

	Site ID			
Vascular species	01-S95	01-S96	01-S97	01-S99
Dwarf shrub				
<i>Arctostaphylos alpina</i>	0.0	0.0	0.0	0.6 (0.6)
<i>Diapensia lapponica</i>	0.0	0.0	0.0	0.0
<i>Dryas octapetala</i>	0.0	0.0	0.0	0.0
<i>Empetrum nigrum</i>	11.9 (5.2)	15.3 (5.2)	0.0	7.9 (2.8)
<i>Louisleuria procumbens</i>	0.0	0.0	0.0	0.0
<i>Salix arctica</i>	0.0	0.0	0.0	0.0
<i>Salix reticulata</i>	0.0	0.0	0.0	0.0
<i>Vaccinium vitis-idaea</i>	2.3 (1.1)	30.1 (0.7)	12.4 (10.8)	35.6 (2.6)
Graminoid				
<i>Calamagrostis canadensis</i>	15.3 (8.8)	0.0	6.8 (3.5)	0.0
<i>Carex lugens</i>	0.0	0.0	0.0	0.0
<i>Carex microchaeta</i>	0.0	0.0	0.0	0.0
<i>Festuca altaica</i>	0.0	0.0	0.0	0.0
<i>Hierochl�e alpina</i>	0.0	0.0	0.0	0.0
<i>Trisetum spicatum</i>	0.0	0.0	0.0	0.0
Forb				
<i>Artemisia arctica</i> ssp. <i>arctica</i>	0.0	0.0	0.0	0.0
<i>Arnica frigida</i>	0.0	0.0	0.0	0.0
<i>Campanula uniflora</i>	0.0	0.0	0.0	0.0
Lichen	1.7 (1.0)	1.1 (1.1)	1.7 (1.7)	8.0 (4.4)
Moss	87.0 (4.1)	88.7 (2.5)	76.8 (7.5)	86.3 (4.5)

2c. Mid-elevation (450-900 m) dwarf shrub tundra

[illegible]

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[illegible]

2c. Mid-elevation (450-900 m) dwarf shrub tundra

Vascular species	Site ID								
	02-003	02-005	02-006	02-008	02-016	02-023	02-032	02-048	02-050
Forb									
<i>Artemisia arctica</i> ssp. <i>arctica</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Arnica frigida</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6 (0.6)
<i>Campanula uniflora</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6 (0.6)
Lichen	59.9 (5.9)	55.4 (0.6)	58.2 (4.6)	61.0 (5.1)	70.6 (0.6)	49.2 (17.0)	0.0	26.0 (6.4)	70.1 (4.4)
Moss	10.7 (3.0)	1.7 (1.0)	31.1 (4.0)	2.8 (0.6)	0.0	15.8 (2.5)	22.0 (5.4)	27.1 (7.1)	24.9 (6.9)

2d. Mid-elevation (450-900 m) treeline spruce

Vascular species	Site ID						
	02-S04	02-S08	02-S14	02-S17	02-S96	02-S97	02-S99
Tree							
<i>Picea glauca</i> (<0.5 m)	0.0	0.0	2.8 (1.5)	0.0	0.0	1.1 (1.1)	1.7 (1.0)
<i>P. glauca</i> (0.5-1.0 m)	0.0	0.0	0.0	0.0	0.0	0.0	0.6 (0.6)
<i>P. glauca</i> (>1.0-4.0 m)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>P. glauca</i> (>4.0 m)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shrub							
<i>Alnus viridis</i> ssp. <i>sinuata</i>	0.0	0.0	1.1 (1.1)	6.2 (2.5)	0.0	0.0	0.0
<i>Betula glandulosa</i>	0.0	4.5 (2.5)	3.4 (1.7)	0.0	1.1 (1.1)	0.0	7.3 (3.4)
<i>Cornus suecica</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ledum palustre</i> ssp. <i>decumbens</i>	0.0	5.1 (1.7)	10.2 (2.6)	2.8 (1.1)	3.4 (2.0)	2.3 (1.5)	2.8 (1.1)
<i>Rhododendron camtschaticum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Salix barclayi</i>	2.3 (1.5)	0.0	0.0	0.0	0.0	0.0	0.0
<i>Salix bebbiana</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Salix glauca</i>	0.0	0.0	0.0	0.0	0.6 (0.6)	0.0	1.1 (1.1)
<i>Salix pulchra</i>	0.0	1.1 (0.6)	0.0	0.0	0.6 (0.6)	0.0	1.1 (1.1)
<i>Spiraea beauverdiana</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Vaccinium uliginosum</i>	7.3 (4.8)	2.8 (0.6)	4.5 (1.5)	14.7 (8.0)	3.4 (1.7)	2.3 (0.6)	0.6 (0.6)

2d. Mid-elevation (450-900 m) treeline spruce							
Vascular species	Site ID						
	02-S04	02-S08	02-S14	02-S17	02-S96	02-S97	02-S99
Dwarf shrub							
<i>Arctostaphylos alpina</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Diapensia lapponica</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Dryas octapetala</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Empetrum nigrum</i>	37.9 (3.7)	66.1 (2.9)	52.6 (4.6)	37.3 (8.5)	74.0 (4.5)	58.8 (4.6)	55.4 (5.4)
<i>Louiseuria procumbens</i>	2.8 (2.0)	1.1 (0.6)	6.8 (3.4)	25.4 (4.3)	1.7 (1.7)	12.4 (0.6)	9.0 (4.1)
<i>Salix arctica</i>	0.0	9.0 (2.3)	0.6 (0.6)	6.2 (2.5)	0.0	2.3 (1.1)	1.1 (1.1)
<i>Salix reticulata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Vaccinium vitis-idaea</i>	2.8 (1.1)	7.3 (1.1)	0.0	0.0	1.1 (1.1)	0.0	6.8 (1.7)
Graminoid							
<i>Calamagrostis canadensis</i>	4.0 (4.0)	0.6 (0.6)	2.8 (2.8)	0.6 (0.6)	0.0	0.0	0.0
<i>Carex lugens</i>	0.0	2.3 (0.6)	0.0	0.0	0.0	0.0	1.1 (0.6)
<i>Carex microchaeta</i>	0.0	0.0	1.1 (1.1)	2.3 (1.5)	0.0	0.6 (0.6)	0.0
<i>Festuca altaica</i>	1.1 (1.1)	0.0	0.0	0.0	5.1 (2.0)	0.0	0.6 (0.6)
<i>Hierochloë alpina</i>	0.0	0.0	0.0	0.0	0.0	0.6 (0.6)	0.0
<i>Trisetum spicatum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forb							
<i>Artemisia arctica</i> ssp. <i>arctica</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Arnica frigida</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.6 (0.6)
<i>Campanula uniflora</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lichen	21.5 (7.4)	13.0 (2.5)	55.4 (5.6)	20.9 (4.9)	22.0 (2.0)	21.5 (4.0)	53.1 (6.3)
Moss	54.2 (10.8)	52.0 (1.5)	10.7 (1.1)	17.5 (2.3)	48.0 (6.0)	24.3 (4.5)	23.2 (6.9)

Appendix 3. Within-site estimates of frequency for vascular and nonvascular species in Katmai National Park and Preserve (2009). Frequencies were measured in 4- m² quadrats (n = 15) and are expressed as percent occurrence across quadrats, within a site (e.g., 1.00 = 100% occurrence). † indicates species with ≥ 20% frequency across all elevation × vegetation class combinations (all sites). ‡ indicates species with ≤ 1% frequency across all sites.

3a. Low elevation (0-450 m) spruce woodland

Vascular species	Site ID								
	01-078	01-S02	01-S08	01-S12	01-S27	01-S35	01-S38	01-S41	01-S50
<i>Arctostaphylos alpina</i> (L.) Spreng.†				0.07		0.07	0.33	0.40	0.07
<i>Artemisia arctica</i> Less. ssp. <i>arctica</i>					0.07				0.33
<i>Betula glandulosa</i> Michx.†	1.00	0.93	1.00	0.93	1.00	0.67	0.80	1.00	1.00
<i>Betula</i> X <i>papyrifera</i> Marsh. var. <i>kenaica</i> (W.H. Evans) A. Henry		0.33	0.07	0.13				0.13	0.07
<i>Calamagrostis canadensis</i> (Michx.) Beauv.†	0.53	0.07			0.07	0.53	0.53		
<i>Campanula uniflora</i> L.	0.07								0.07
<i>Carex lugens</i> T. Holm†	0.93	0.13	0.87	0.27	0.27		0.20	0.07	0.80
<i>Chamerion angustifolium</i> ssp. <i>angustifolium</i> †	0.07	0.40		0.13	0.27	0.13	0.20	0.07	0.40
<i>Empetrum nigrum</i> L.†	0.93	1.00	1.00	1.00	1.00	0.93	0.93	0.93	1.00
<i>Equisetum arvense</i> L.					0.20				
<i>Equisetum palustre</i> L.		0.07	0.07	0.07					
<i>Equisetum silvaticum</i> L.‡	0.33								
<i>Festuca altaica</i> Trin.†	0.07	0.40	0.07	0.20	0.13	0.20			0.73
<i>Hierochloa alpina</i> (Sw.) R. & S.†	0.27				0.13		0.13		0.60
<i>Ledum palustre</i> ssp. <i>decumbens</i> (Ait.) Hultén†	0.93	1.00	1.00	1.00	1.00	0.60	0.67	0.73	1.00
<i>Loiseleuria procumbens</i> (L.) Desv.†	0.13								0.40
<i>Lupinus nootkatensis</i> Donn ex Sims			0.13			0.07		0.07	0.13
<i>Pedicularis labradorica</i> Wirsing									0.13
<i>Pedicularis verticillata</i> L.									0.33
<i>Petasites frigidus</i> (L.) Franch.			0.20						
<i>Picea glauca</i> (Moench) Voss†	0.40	0.53	0.87	0.60	0.73	0.80	0.53	0.67	0.73
<i>Populus tremuloides</i> Michx.‡							0.07		
<i>Rubus chamaemorus</i> L.	0.47								
<i>Salix arctica</i> Pall.†	0.27	0.07	0.13	0.13	0.07				0.73
<i>Salix fuscescens</i> Anderss.‡							0.13		
<i>Salix glauca</i> L.	0.13	0.20	0.60	0.40	0.40	0.67		0.73	1.00
<i>Salix phlebophylla</i> Andersson									0.13
<i>Salix pulchra</i> Cham.†	0.13		0.33	0.13		0.73	0.80		
<i>Spiraea beauverdiana</i> Schneid.	0.73		0.13			0.40	0.73	0.07	

3a. Low elevation (0-450 m) spruce woodland

Lichens	Site ID								
	01-078	01-S02	01-S08	01-S12	01-S27	01-S35	01-S38	01-S41	01-S50
<i>Trientalis europaea</i> L. ssp. <i>arctica</i> (Fisch. ex Hook.) Hultén									0.20
<i>Vaccinium oxycoccos</i> L.‡						0.07			
<i>Vaccinium uliginosum</i> L.†	0.07	0.87	0.80	0.07	0.87	0.93	1.00	1.00	0.33
<i>Vaccinium vitis-idaea</i> L.†	1.00	0.93	1.00	1.00	1.00	0.87	1.00	1.00	1.00
Lichens									
<i>Baeomyces rufus</i> (Hudson) Rebert.‡									0.07
<i>Cetraria islandica</i> (L.) Ach. subsp. <i>islandica</i> ‡	0.07					0.07	0.07	0.13	
<i>Cetraria islandica</i> subsp. <i>crispiformis</i> (Räsänen) Kärnefelt†	0.20		0.20	0.60	0.40				0.60
<i>Cetraria kamczatica</i> Savicz									0.07
<i>Cetraria laevigata</i> Rass.	0.60	0.20	0.80	0.27	0.40	0.13	0.13	0.33	0.07
<i>Cladonia albonigra</i> Brodo & Ahti‡									0.20
<i>Cladonia amaurocraea</i> (Flörke) Schaerer	0.27		0.13	0.07					0.07
<i>Cladonia arbuscula</i> subsp. <i>beringiana</i> Ahti†	0.60	0.93	0.87	0.73	0.80	0.53	0.27	0.53	0.67
<i>Cladonia bellidiflora</i> (Ach.) Schaerer									0.20
<i>Cladonia cenotea</i> (Ach.) Schaerer‡					0.13		0.07	0.07	
<i>Cladonia cervicornis</i> subsp. <i>verticillata</i> (Hoffm.) Ahti‡									0.13
<i>Cladonia chlorophaea</i> (Flörke ex Sommerf.) Sprengel	0.13	0.20	0.27	0.27	0.27	0.40	0.40	0.20	0.27
<i>Cladonia cornuta</i> (L.) Hoffm. ssp. <i>cornuta</i>	0.27	0.40	0.20	0.27	0.27	0.40	0.53	0.47	0.53
<i>Cladonia crispata</i> (Ach.) Flotow var. <i>crispata</i> †	0.27	0.53	0.47	0.27	0.27	0.27	0.13	0.07	0.67
<i>Cladonia cyanipes</i> (Sommerf.) Nyl.		0.07			0.13	0.07	0.27	0.20	
<i>Cladonia deformis</i> (L.) Hoffm.		0.20	0.07	0.07	0.07	0.07		0.13	
<i>Cladonia furcata</i> (Hudson) Schrader					0.07	0.13	0.07	0.07	
<i>Cladonia gracilis</i> subsp. <i>elongata</i> (Jacq.) Vainio					0.07				0.07
<i>Cladonia gracilis</i> subsp. <i>turbinata</i> (Ach.) Ahti		0.07	0.07					0.13	0.07
<i>Cladonia gracilis</i> subsp. <i>vulnerata</i> Ahti†	0.93	0.67	0.93	0.93	0.93	0.60	0.40	0.33	0.33
<i>Cladonia macrophylla</i> (Schaerer) Stenh.									0.07
<i>Cladonia metacorallifera</i> Asahina‡	0.13								
<i>Cladonia nipponica</i> Asahina.									0.40
<i>Cladonia phyllophora</i> Hoffm.	0.07				0.13				
<i>Cladonia pleurota</i> (Flörke) Schaerer					0.20				0.13
<i>Cladonia pyxidata</i> (L.) Hoffm.		0.07							0.07
<i>Cladonia rangiferina</i> (L.) F. H. Wigg.†	0.20	0.60	0.13	0.13	0.27	0.47	0.47	0.47	0.20

3a. Low elevation (0-450 m) spruce woodland

Lichens	Site ID								
	01-078	01-S02	01-S08	01-S12	01-S27	01-S35	01-S38	01-S41	01-S50
<i>Cladonia scabruscula</i> (Delise) Nyl.	0.13		0.07			0.33	0.07	0.27	0.07
<i>Cladonia squamosa</i> Hoffm.	0.20	0.07	0.07	0.13				0.07	0.53
<i>Cladonia stellaris</i> (Opiz) Pouzar & Vězda†	0.13	0.27	0.20	0.20	0.20		0.07	0.07	0.60
<i>Cladonia stygia</i> (Fr.) Ruoss†	0.73	0.60	0.93	0.93	0.93	0.47	0.40	0.87	0.67
<i>Cladonia subfurcata</i> (Nyl.) Arnold					0.07				
<i>Cladonia sulphurina</i> (Michaux) Fr.		0.07							
<i>Cladonia umbricola</i> Tønsberg & Ahti‡	0.07					0.07			
<i>Cladonia uncialis</i> (L.) F. H. Wigg.†	0.33	0.27	0.27	0.27	0.13				0.53
<i>Flavocetraria cucullata</i> (Bellardi) Kärnefelt & Thell†	0.47	0.07	0.67	0.27	0.33		0.07	0.07	0.60
<i>Flavocetraria nivalis</i> (L.) Kärnefelt & Thell									0.13
<i>Melanohalea septentrionalis</i> (Lynge) O. Blanco et al.‡			0.07						
<i>Multiclavula vernalis</i> (Schwein.) R. Petersen‡									0.07
<i>Nephroma arcticum</i> (L.) Torss.					0.07		0.07		
<i>Parmelia omphalodes</i> (L.) Ach. subsp. <i>omphalodes</i>								0.13	
<i>Parmelia sulcata</i> Taylor‡								0.07	0.07
<i>Parmeliopsis ambigua</i> (Wulfen) Nyl.‡						0.07	0.07	0.07	
<i>Parmeliopsis hyperopta</i> (Ach.) Arnold‡								0.07	
<i>Peltigera aphthosa</i> (L.) Willd.†	0.80	0.73	0.93	0.80	0.40	0.47	0.67	0.67	0.27
<i>Peltigera britannica</i> (Gyelnik) Holt.-Hartw. & Tønsberg†		0.20	0.07	0.33	0.80				0.20
<i>Peltigera canina</i> (L.) Willd.‡	0.07	0.20						0.07	
<i>Peltigera leucophlebia</i> (Nyl.) Gyelnik			0.07	0.07		0.20		0.20	
<i>Peltigera malacea</i> (Ach.) Funck†	0.27	0.73	0.73	0.47	0.73	0.20	0.13	0.53	0.27
<i>Peltigera polydactyla</i> (Necker) Hoffm.		0.13			0.53	0.40	0.33	0.40	0.07
<i>Peltigera scabrosa</i> Th. Fr.†	0.67	0.60	0.53	0.80	0.47	0.60	0.80	0.73	
<i>Psoroma hypnorum</i> (Vahl) Gray		0.13	0.13		0.13				0.13
<i>Sphaerophorus globosus</i> (Hudson) Vainio									0.40
<i>Stereocaulon alpinum</i> Laurer ex Funck‡	0.13								
<i>Stereocaulon paschale</i> (L.) Hoffm.	0.13	0.40	0.47	0.20	0.40				0.47
<i>Thamnia vermicularis</i> (Sw.) Ach. ex Schaerer									0.27
<i>Tuckermannopsis sepincola</i> (Ehrh.) Hale	0.40	0.20	0.20	0.07	0.27	0.27	0.13	0.93	0.13
<i>Vulpicida pinastri</i> (Scop.) J.-E. Mattsson & M. J. Lai					0.07	0.07	0.07	0.07	

3a. Low elevation (0-450 m) spruce woodland

Lichens	Site ID								
	01-078	01-S02	01-S08	01-S12	01-S27	01-S35	01-S38	01-S41	01-S50
<i>Anastrophyllum minutum</i> (Schreb.) R. M. Schust. var. <i>minutum</i>			0.07		0.13				
<i>Barbilophozia attenuata</i> (Mart.) Loeske†	0.07								
<i>Barbilophozia kunzeana</i> (Huebener) Gams		0.07	0.13	0.13	0.60		0.13	0.40	
<i>Ptilidium ciliare</i> (L.) Hampe†	0.20	0.73	0.60	0.27	0.40	0.20		0.53	0.67
Bryophytes (Mosses)									
<i>Aulacomnium palustre</i> (Hedwig) Schwaegr.†	0.47	0.13	0.33	0.33	0.40	0.87	0.60	0.40	
<i>Aulacomnium turgidum</i> (Wahlenb.) Schwaegr.	0.20		0.47	0.40	0.13			0.07	
<i>Brachythecium erythrorrhizon</i> Schimper in B.S.G.‡									0.07
<i>Dicranum elongatum</i> Schleich. ex Schwaegr.‡					0.20				
<i>Dicranum fuscescens</i> Turner var. <i>fuscescens</i>		0.07							
<i>Dicranum groenlandicum</i> Bridel	0.13	0.07	0.07						
<i>Dicranum polysetum</i> Sw.‡		0.07							
<i>Dicranum scoparium</i> Hedwig†	0.73	0.87	1.00	0.93	0.87	0.87	0.67	1.00	0.47
<i>Dicranum undulatum</i> Bridel	0.13	0.40	0.67	0.33	0.53	0.07	0.07	0.13	0.40
<i>Eurhynchiastrum pulchellum</i> (Hedwig) Ignatov & Huttunen var. <i>pulchellum</i>				0.07					
<i>Hylocomium splendens</i> (Hedwig) Schimper in B.S.G.†	0.20		0.67	0.47	0.47	0.80	0.87	0.67	
<i>Hypnum plicatulum</i> (Lindberg) Jaeg.					0.27		0.07		0.07
<i>Plagiothecium laetum</i> Schimper in B.S.G.‡					0.07				
<i>Pleurozium schreberi</i> (Bridel) Mitt.†	0.67	0.87	1.00	0.87	0.93	0.93	0.93	1.00	0.40
<i>Pohlia cruda</i> (Hedwig) Lindberg‡								0.07	
<i>Pohlia nutans</i> (Hedwig) Lindberg			0.20						0.27
<i>Polytrichum commune</i> Hedwig var. <i>commune</i> †	0.67	0.40	0.87	0.93	0.73	0.80	1.00	0.93	0.20
<i>Polytrichum juniperinum</i> Hedwig									0.13
<i>Polytrichum piliferum</i> Hedwig									0.07
<i>Polytrichum strictum</i> Bridel	0.33		0.07	0.07	0.47	0.73	0.53	0.27	
<i>Ptilium crista-castrensis</i> (Hedwig) De Not.†	0.27	0.27	0.33	0.67	0.73	0.67	0.67	0.60	
<i>Racomitrium lanuginosum</i> (Hedwig) Bridel	0.13	0.07			0.13				0.07
<i>Sanionia uncinata</i> (Hedwig) Loeske	0.47	0.33	0.33	0.07	0.13	0.13	0.07	0.13	0.33
<i>Sphagnum angustifolium</i> (Warnstorf) C.E.O. Jensen‡	0.27								
<i>Sphagnum girgensohnii</i> Russow	0.33		0.13	0.20	0.47	0.33	0.27		

3b. Low elevation (0-450 m) closed spruce – beetle kill

Vascular species	Site ID			
	01-S95	01-S96	01-S97	01-S99
<i>Arnica frigida</i> C.A. Mey. ex Iljin ssp. <i>frigida</i>	0.07			
<i>Betula</i> × <i>dugleana</i> Lepage		0.33		0.07
<i>Betula glandulosa</i> Michx.†				0.27
<i>Betula papyrifera</i> Marsh. var. <i>kenaica</i> (W.H. Evans) A. Henry	0.20	0.40	0.53	0.47
<i>Calamagrostis canadensis</i> (Michx.) Beauv.†	0.93	0.20	0.60	
<i>Chamerion angustifolium</i> ssp. <i>angustifolium</i> †	0.53		1.00	0.33
<i>Cornus suecica</i> L.	0.27			
<i>Empetrum nigrum</i> L.†	0.73	0.93	0.07	0.67
<i>Equisetum arvense</i> L.	1.00			
<i>Gymnocarpium dryopteris</i> (L.) Newman‡			0.20	
<i>Heuchera glabra</i> Willd. ex Roem. & Schult.‡			0.07	
<i>Ledum palustre</i> ssp. <i>decumbens</i> (Ait.) Hultén†				0.53
<i>Listera cordata</i> (L.) R. Br.‡				0.07
<i>Lycopodium lagopus</i> (Laestadius ex C. Hartman) Zinserl. ex Kuzen	0.07			0.20
<i>Moneses uniflora</i> (L.) Gray	0.13	0.33		
<i>Orthilia secunda</i> (L.) House	1.00	0.07	0.07	
<i>Petasites frigidus</i> (L.) Franch.	0.07			
<i>Picea glauca</i> (Moench) Voss†	0.33	1.00	0.93	0.47
<i>Poa</i> L.‡			0.07	
<i>Poa pratensis</i> L. subsp. <i>alpigena</i> (Fries. ex Blytt) Hiitonen‡	0.20			
<i>Pyrola asarifolia</i> Michx. ssp. <i>asarifolia</i> ‡			0.07	
<i>Rubus arcticus</i> L.‡			0.07	
<i>Salix arbusculoides</i> Anderss.‡	0.07			
<i>Salix barclayi</i> Anderss.	0.73			
<i>Salix pulchra</i> Cham.†	0.47	0.67	0.07	0.67
<i>Salix stolonifera</i> Coville‡	0.40			
<i>Stellaria longipes</i> Goldie sens strict.‡			0.20	
<i>Trientalis europaea</i> L. ssp. <i>arctica</i> (Fisch. ex Hook.) Hultén	0.13		0.20	
<i>Vaccinium uliginosum</i> L.†	0.07			0.67
<i>Vaccinium vitis-idaea</i> L.†	0.47	1.00	0.33	1.00
<i>Viburnum edule</i> (Michx.) Raf.‡			0.07	

3b. Low elevation (0-450 m) closed spruce – beetle kill

Lichens	Site ID			
	01-S95	01-S96	01-S97	01-S99
<i>Cladonia arbuscula</i> subsp. <i>beringiana</i> Ahti†		0.07	0.13	0.13
<i>Cladonia chlorophaea</i> (Flörke ex Sommerf.) Sprengel	0.13	0.13	0.20	
<i>Cladonia cornuta</i> (L.) Hoffm. ssp. <i>cornuta</i>	0.07		0.07	0.27
<i>Cladonia crispata</i> (Ach.) Flotow var. <i>crispata</i> †				0.07
<i>Cladonia furcata</i> (Hudson) Schrader	0.27			0.07
<i>Cladonia ochrochlora</i> Flörke	0.07			
<i>Cladonia rangiferina</i> (L.) F. H. Wigg.†			0.33	0.47
<i>Cladonia scabriuscula</i> (Delise) Nyl.	0.07	0.13	0.20	0.27
<i>Cladonia squamosa</i> Hoffm.			0.07	
<i>Cladonia stellaris</i> (Opiz) Pouzar & Vězda†				0.07
<i>Cladonia stygia</i> (Fr.) Ruoss†		0.07		0.07
<i>Cladonia umbricola</i> Tønsberg & Ahti‡			0.13	0.07
<i>Lobaria linita</i> (Ach.) Rabenh.	0.07			
<i>Nephroma bellum</i> (Sprengel) Tuck.‡			0.07	0.07
<i>Nephroma expallidum</i> (Nyl.) Nyl.‡		0.13		
<i>Parmelia sulcata</i> Taylor‡				0.07
<i>Peltigera aphthosa</i> (L.) Willd.†		0.07		0.20
<i>Peltigera britannica</i> (Gyelnik) Holt.-Hartw. & Tønsberg†	0.67	0.47	0.20	0.60
<i>Peltigera collina</i> (Ach.) Schrader‡		0.13	0.13	
<i>Peltigera didactyla</i> (With.) J.R. Laundon‡	0.07			
<i>Peltigera malacea</i> (Ach.) Funck†		0.33	0.13	0.20
<i>Peltigera neopolydactyla</i> (Gyel.) Gyel.	0.07			
<i>Peltigera polydactyla</i> (Necker) Hoffm.		0.13		0.20
<i>Peltigera praetextata</i> (Flörke ex Sommerf.) Zopf	0.67	0.20	0.47	0.20
<i>Peltigera scabrosa</i> Th. Fr.†		0.07		0.40
Bryophytes (Liverworts)				
<i>Barbilophozia hatcheri</i> (A. Evans) Loeske‡			0.07	
<i>Barbilophozia kunzeana</i> (Huebener) Gams				0.20
<i>Ptilidium ciliare</i> (L.) Hampe†				0.33
<i>Scapania</i> (Dumort.) Dumort., nom. cons.‡	0.07			

3b. Low elevation (0-450 m) closed spruce – beetle kill

Bryophytes (Mosses)	Site ID			
	01-S95	01-S96	01-S97	01-S99
<i>Andreaea rupestris</i> Hedwig				
<i>Aulacomnium palustre</i> (Hedwig) Schwaegr.†	0.40	0.53	0.60	0.67
<i>Aulacomnium turgidum</i> (Wahlenb.) Schwaegr.	0.07		0.07	
<i>Brachythecium erythrorhizon</i> Schimper in B.S.G.‡	0.13		0.13	
<i>Brachythecium nelsonii</i> Grout‡		0.13		
<i>Ceratodon purpureus</i> (Hedwig) Bridel subsp. <i>purpureus</i> ‡	0.07		0.07	
<i>Dicranum fuscescens</i> Turner var. <i>fuscescens</i>	0.13		0.53	
<i>Dicranum scoparium</i> Hedwig†	0.13	0.67	0.07	0.40
<i>Dicranum tauricum</i> Sappegin‡	0.07			
<i>Eurhynchiastrum pulchellum</i> (Hedwig) Ignatov & Huttunen var. <i>pulchellum</i>	0.07		0.27	
<i>Hylocomium splendens</i> (Hedwig) Schimper in B.S.G.†	1.00	0.93	1.00	1.00
<i>Hypnum plicatulum</i> (Lindberg) Jaeg.	0.07			0.07
<i>Plagiomnium medium</i> (Bruch & Schimp.) T. Kop. ‡	0.13			
<i>Pleurozium schreberi</i> (Bridel) Mitt.†	0.93	0.93	1.00	0.60
<i>Pohlia nutans</i> (Hedwig) Lindberg	0.07		0.40	0.07
<i>Polytrichum commune</i> Hedwig var. <i>commune</i> †	0.33	0.93	0.60	0.93
<i>Polytrichum juniperinum</i> Hedwig	0.07			
<i>Polytrichum strictum</i> Bridel	0.07	0.27	0.07	
<i>Ptilium crista-castrensis</i> (Hedwig) De Not.†	0.60	0.93	0.60	0.93
<i>Rhytidiadelphus loreus</i> (Hedwig) Warnst.	0.20	0.40	0.07	
<i>Rhytidiadelphus triquetrus</i> (Hedwig) Warnst.	0.73		0.40	
<i>Sanionia uncinata</i> (Hedwig) Loeske	0.33	0.40	0.40	0.07
<i>Sphagnum girgensohnii</i> Russow		0.40		

3c. Mid-elevation (450-900 m) dwarf shrub tundra

Vascular species	Site ID								
	02-003	02-005	02-006	02-008	02-016	02-023	02-032	02-048	02-050
<i>Agrostis mertensii</i> Trin.								0.27	
<i>Agrostis scabra</i> Willd.							0.40		
<i>Andromeda polifolia</i> L.		0.40					0.07		
0.07 <i>Androsace chamaejasme</i> Host							0.93		
<i>Anemone narcissiflora</i> L.	0.20	0.33	0.87	0.07	0.13	0.07	0.87	0.33	1.00
<i>Antennaria friesiana</i> (Trautv.) Ekman subsp. <i>friesiana</i> ‡		0.33					0.87		0.07
<i>Antennaria monocephala</i> DC.‡								0.13	
<i>Arctostaphylos alpina</i> (L.) Spreng.†	1.00	0.93		0.87	0.87	0.47	0.13		0.20
<i>Arnica frigida</i> C.A. Mey. ex Iljin ssp. <i>frigida</i>			0.47			0.07			0.73
<i>Artemisia arctica</i> Less. ssp. <i>arctica</i>	0.27		0.53			0.20		1.00	0.20
<i>Astragalus umbellatus</i> Bunge		0.60							
<i>Betula</i> × <i>dugleana</i> Lepage					0.20				
<i>Betula glandulosa</i> Michx.†	1.00	0.87	0.60	1.00	0.40	1.00	0.33	0.07	
<i>Betula papyrifera</i> Marsh. var. <i>kenaica</i> (W.H. Evans) A. Henry									
<i>Calamagrostis canadensis</i> (Michx.) Beauv.†		0.07							
<i>Campanula uniflora</i> L.	0.40	0.47	0.47	0.13	0.27	0.13	0.27	0.80	0.67
<i>Carex capillaris</i> L.							0.47		
<i>Carex circinata</i> C.A. Mey.‡								0.07	
<i>Carex lugens</i> T. Holm†									1.00
<i>Carex microchaeta</i> T. Holm ssp. <i>nesophila</i> (T. Holm) E. Murray	1.00						1.00	1.00	
<i>Carex microchaeta</i> T. Holm†	1.00	1.00	1.00	0.80	1.00	0.87	1.00	1.00	
<i>Carex scirpoidea</i> Michx.‡							0.20		
<i>Cassiope tetragona</i> (L.) D. Don‡								0.27	
<i>Chamerion angustifolium</i> ssp. <i>angustifolium</i> †		0.07							0.07
<i>Delphinium</i> L.‡					0.13				
<i>Diapensia lapponica</i> L.		0.93			0.60			0.93	
<i>Dryas</i> L.	0.40	0.67		0.07		0.13	1.00		
<i>Dryas octopetala</i> L. sens. lat.	0.40	0.27				0.13	1.00		
<i>Dryas octopetala</i> ssp. <i>alaskensis</i> (Porsild) Hultén		0.47							
<i>Empetrum nigrum</i> L.†	1.00	1.00	1.00	1.00	1.00	1.00	0.87	1.00	1.00
<i>Epilobium palustre</i> L.‡							0.07		
<i>Equisetum palustre</i> L.		0.13							

3c. Mid-elevation (450-900 m) dwarf shrub tundra

Vascular species	Site ID								
	02-003	02-005	02-006	02-008	02-016	02-023	02-032	02-048	02-050
<i>Equisetum scirpoides</i> Michx.‡		0.20							
<i>Festuca altaica</i> Trin.†	0.93	0.07	0.07	0.40		0.33	0.20		1.00
<i>Festuca brevissima</i> Jurtsev					0.13				
<i>Gentiana algida</i> Pall.‡							0.13		
<i>Gentiana glauca</i> Pall.			0.33					0.27	
<i>Harrimanella stelleriana</i> (Pall.) Coville‡	0.20	0.87	0.93	0.87	0.73	0.93		0.53	0.73
<i>Hierochloë alpina</i> (Sw.) R. & S.†									
<i>Huperzia selago</i> (L.) Bernh. ex Schrank & Mart.			0.13		0.07				
<i>Lagotis glauca</i> Gaertn.		0.80					1.00	0.07	0.67
<i>Ledum palustre</i> ssp. <i>decumbens</i> (Ait.) Hultén†	0.93	0.93	0.13	1.00	0.93	0.87	0.07		0.67
<i>Lloydia serotina</i> (L.) Rchb.		0.13							0.33
<i>Loiseleuria procumbens</i> (L.) Desv.†	0.33	1.00	0.93	0.73	1.00	1.00	0.40	0.73	0.93
<i>Lupinus nootkatensis</i> Donn ex Sims			0.20					0.07	
<i>Luzula arcuata</i> (Wahlenb.) Sw.								0.60	
<i>Luzula multiflora</i> (Ehrh.) Lej. ssp. <i>multiflora</i>									0.07
<i>Lycopodium alpinum</i> L.				0.53		0.07			
<i>Lycopodium lagopus</i> (Laestadius ex C. Hartman) Zinserl. ex Kuzen			0.07						
<i>Minuartia arctica</i> (Stev.) Aschers. & Graebn‡								0.27	
<i>Oxyria digyna</i> (L.) Hill‡		0.07							
<i>Oxytropis campestris</i> (L.) DC.‡		0.07							
<i>Oxytropis nigrescens</i> (Pall.) Fisch. ex DC. var. <i>nigrescens</i>	0.07	0.27	0.67	0.27		0.07		0.07	1.00
<i>Pedicularis capitata</i> Adams	0.20	0.73	0.20		0.13				0.13
<i>Pedicularis labradorica</i> Wirsing	0.47					0.13			
<i>Pedicularis verticillata</i> L.		0.27							
<i>Petasites frigidus</i> (L.) Franch.		0.07							
<i>Picea glauca</i> (Moench) Voss†									
<i>Pinguicula vulgaris</i> L.‡							0.27		
<i>Poa pseudoabbreviata</i> Rosh.‡		0.20							
<i>Polygonum viviparum</i> L.		0.20			0.07		0.87	0.27	0.53
<i>Populus tremuloides</i> Michx.‡									
<i>Primula cuneifolia</i> Ledeb.								0.40	
<i>Rhodiola integrifolia</i> Raf.			0.07				0.73	0.40	0.07

3c. Mid-elevation (450-900 m) dwarf shrub tundra

Vascular species	Site ID								
	02-003	02-005	02-006	02-008	02-016	02-023	02-032	02-048	02-050
<i>Rhododendron camtschaticum</i> Pall.		0.67	0.27				0.93	0.47	
<i>Salix arctica</i> Pall.†		0.87	1.00	0.47	0.27	1.00	0.40	0.73	1.00
<i>Salix glauca</i> L.	0.33			0.13					
<i>Salix phlebophylla</i> Andersson		0.80	0.93	0.27	0.73	0.07		1.00	0.80
<i>Salix pulchra</i> Cham.†	0.07								
<i>Salix reticulata</i> L.	0.20	0.33					1.00		
<i>Salix rotundifolia</i> Trautv.‡								0.20	
<i>Salix stolonifera</i> Coville‡								0.07	0.07
<i>Saussurea angustifolia</i> (Willd.) DC.							0.93		
<i>Silene acaulis</i> (L.) Jacq.							0.93		
<i>Stellaria longipes</i> Goldie sens strict.‡							0.13		
<i>Thalictrum alpinum</i> L.							0.67		
<i>Tofieldia coccinea</i> Richards.		0.67							
<i>Trisetum spicatum</i> (L.) Richter							0.13		
<i>Vaccinium uliginosum</i> L.†	0.60	1.00	1.00	0.20	1.00	0.60	1.00	1.00	0.73
<i>Vaccinium vitis-idaea</i> L.†	0.93	1.00	0.20	0.87	0.67	1.00		0.67	0.53
<i>Viola biflora</i> L.							0.53		
Lichens									
<i>Alectoria ochroleuca</i> (Hoffm.) A. Massal.				0.13			0.13		
<i>Arctocetraria andrejevii</i> (Oksner) Kärnefelt & Thell	0.47	0.67		0.20		0.13			
<i>Asahinea chrysantha</i> (Tuck.) W. L. Culb. & C. F. Culb.		0.80		0.07	0.40	0.07			
<i>Bryocaulon divergens</i> (Ach.) Kärnefelt		0.40		0.20			0.07		
<i>Cetraria aculeata</i> (Schreb.) Fr.‡									0.13
<i>Cetraria ericetorum</i> Opiz subsp. <i>ericetorum</i> ‡						0.07		0.20	
<i>Cetraria ericetorum</i> subsp. <i>reticulata</i> (Räsänen) Kärnefelt‡	0.07								
<i>Cetraria islandica</i> subsp. <i>crispiformis</i> (Räsänen) Kärnefelt‡	1.00	0.27	1.00	0.73	0.93	1.00	0.33	0.80	0.20
<i>Cetraria kamczatica</i> Savicz	0.27	0.73	0.33	0.67	0.40	0.40		0.27	
<i>Cetraria nigricans</i> Nyl.‡				0.07	0.33				
<i>Cetrariella fastigiata</i> (Delise ex Nyl.) Kärnefelt & Thell	0.07		0.93	0.07	0.60	0.07		1.00	
<i>Cladonia amaurocraea</i> (Flörke) Schaerer	0.13	0.27	0.07	0.07		0.07	0.27		0.80
<i>Cladonia arbuscula</i> subsp. <i>beringiana</i> Ahti†	0.87	1.00	1.00	1.00	1.00	1.00	0.47	1.00	1.00
<i>Cladonia bellidiflora</i> (Ach.) Schaerer	0.07	0.07	0.80		0.40	0.20		0.60	0.13

3c. Mid-elevation (450-900 m) dwarf shrub tundra

Lichens	Site ID								
	02-003	02-005	02-006	02-008	02-016	02-023	02-032	02-048	02-050
<i>Cladonia borealis</i> S. Stenroos		0.07	0.60		0.20		0.27	0.80	0.40
<i>Cladonia cervicornis</i> subsp. <i>verticillata</i> (Hoffm.) Ahti†	0.07								0.07
<i>Cladonia chlorophaea</i> (Flörke ex Sommerf.) Sprengel			0.40	0.07		0.40	0.13	0.07	
<i>Cladonia coniocraea</i> (Flörke) Sprengel				0.07		0.13			
<i>Cladonia cornuta</i> (L.) Hoffm. ssp. <i>cornuta</i>	0.07		0.20			0.13			0.13
<i>Cladonia cornuta</i> subsp. <i>groenlandica</i> (E. Dahl) Ahti†	0.07								
<i>Cladonia crispata</i> (Ach.) Flotow var. <i>crispata</i> †	0.13	0.87	0.73	0.60	0.07	0.87		0.07	0.73
<i>Cladonia cyanipes</i> (Sommerf.) Nyl.						0.13			0.07
<i>Cladonia deformis</i> (L.) Hoffm.			0.20			0.13			
<i>Cladonia gracilis</i> subsp. <i>elongata</i> (Jacq.) Vainio	0.87		0.87	0.33	0.07	1.00	0.07	0.13	0.20
<i>Cladonia gracilis</i> subsp. <i>vulnerata</i> Ahti†	0.13	0.07		0.07		0.20		0.13	0.13
<i>Cladonia kanewskii</i> Oksner			0.20					0.80	
<i>Cladonia macroceras</i> (Delise) Hav.	0.07		1.00	0.60		0.33	0.07	0.93	
<i>Cladonia macrophylla</i> (Schaerer) Stenh.			0.07						0.13
<i>Cladonia macrophyllodes</i> Nyl.							0.40		
<i>Cladonia mitis</i> Sandst.					0.33				0.40
<i>Cladonia nipponica</i> Asahina.	0.20			0.07					
<i>Cladonia phyllophora</i> Hoffm.		0.07	0.33	0.13	0.13	0.33			0.13
<i>Cladonia pleurota</i> (Flörke) Schaerer	0.07					0.07			0.07
<i>Cladonia pyxidata</i> (L.) Hoffm.			0.07		0.20		0.07		
<i>Cladonia rangiferina</i> (L.) F. H. Wigg.†	0.80		0.93	0.47	0.27	0.93	0.20	0.47	1.00
<i>Cladonia scabriuscula</i> (Delise) Nyl.						0.07			
<i>Cladonia squamosa</i> Hoffm.	0.13		0.07	0.20	0.13	0.40			0.93
<i>Cladonia stellaris</i> (Opiz) Pouzar & Vězda†	0.93			0.93	0.13	0.40			0.67
<i>Cladonia stygia</i> (Fr.) Ruoss†	0.87	0.40	0.13	0.67	0.40	0.80	0.07		0.67
<i>Cladonia subfurcata</i> (Nyl.) Arnold					0.33			0.73	0.47
<i>Cladonia sulphurina</i> (Michaux) Fr.	0.07		0.07						
<i>Cladonia uncialis</i> (L.) F. H. Wigg.†	0.53	0.27	0.87	0.87	1.00	0.87	0.13	0.27	1.00
<i>Collema ceraniscum</i> Nyl.‡							0.13		
<i>Dactylina arctica</i> (Richardson) Nyl.‡		0.07					0.07		
<i>Flavocetraria cucullata</i> (Bellardi) Kärnefelt & Thell†	0.80	1.00	0.13	1.00		0.73	0.73		0.73
<i>Flavocetraria nivalis</i> (L.) Kärnefelt & Thell	0.27	0.67		0.53	0.40	0.20	0.07		0.07

3c. Mid-elevation (450-900 m) dwarf shrub tundra

Lichens	Site ID								
	02-003	02-005	02-006	02-008	02-016	02-023	02-032	02-048	02-050
<i>Gowardia nigricans</i> (Ach.) P. Halonen, L. Myllys, S. Velmala, & H. Hyvärinen	0.13	0.13		0.20					
<i>Lobaria linita</i> (Ach.) Rabenh.	0.27	0.67	0.93	0.20	0.80	0.20	0.27	0.13	0.40
<i>Melanelia hepatizon</i> (Ach.) Thell†		0.07			0.07				
<i>Melanelia stygia</i> (L.) Essl.†		0.07							
<i>Nephroma arcticum</i> (L.) Torss.		0.07	0.33		0.27	0.20			
<i>Nephroma expallidum</i> (Nyl.) Nyl.†									0.07
<i>Parmelia omphalodes</i> (L.) Ach. subsp. <i>omphalodes</i>		0.13					0.07		
<i>Peltigera aphthosa</i> (L.) Willd.†			0.13	0.07		0.07			
<i>Peltigera britannica</i> (Gyelnik) Holt.-Hartw. & Tønsberg†		0.40		0.13		0.13	0.33		0.20
<i>Peltigera leucophlebia</i> (Nyl.) Gyelnik		0.07							0.13
<i>Peltigera malacea</i> (Ach.) Funck†				0.07		0.13			0.07
<i>Peltigera neopolydactyla</i> (Gyelnik) Gyelnik			0.73						
<i>Peltigera polydactyla</i> (Necker) Hoffm.	0.13	0.13		0.07		0.20			
<i>Peltigera scabrosa</i> Th. Fr.†	0.27	0.07	0.27	0.20		0.47		0.40	0.13
<i>Pseudephebe pubescens</i> (L.) M. Choisy†		0.07		0.07	0.07				
<i>Psoroma hypnorum</i> (Vahl) Gray	0.07	0.07	0.73	0.07	0.07	0.07	0.13	0.07	0.07
<i>Solorina saccata</i> (L.) Ach.†							0.07		
<i>Sphaerophorus globosus</i> (Hudson) Vainio	0.33	1.00		0.40	0.80	0.33	0.20		0.27
<i>Stereocaulon botryosum</i> Ach.†								0.07	
<i>Stereocaulon paschale</i> (L.) Hoffm.	0.13	0.13	1.00	0.33	0.47	0.87		0.33	0.33
<i>Stereocaulon tomentosum</i> Fr.	0.07	0.07							0.60
<i>Stereocaulon vesuvianum</i> Pers.†								0.20	
<i>Thamnia subuliformis</i> (Ehrh.) Culb.	0.53	0.33	0.93		0.87			0.80	
<i>Thamnia vermicularis</i> (Sw.) Ach. ex Schaerer	0.27	0.87			0.13		0.60		
<i>Tuckermannopsis sepincola</i> (Ehrh.) Hale	0.67			0.13					
<i>Umbilicaria cylindrica</i> (L.) Delise ex Duby†								0.07	
<i>Umbilicaria hyperborea</i> (Ach.) Hoffm. var. <i>hyperborea</i> †								0.20	
<i>Umbilicaria krascheninnikovii</i> (Savic) Zahlbr.		0.40							

3c. Mid-elevation (450-900 m) dwarf shrub tundra

Bryophytes (Liverworts)	Site ID								
	02-003	02-005	02-006	02-008	02-016	02-023	02-032	02-048	02-050
<i>Anastrophyllum minutum</i> (Schreb.) R. M. Schust. var. <i>minutum</i>		0.13	0.53	0.07	0.13	0.07			0.67
<i>Anthelia juratzkana</i> (Limpr.) Trevis.			0.07					0.60	
<i>Barbilophozia barbata</i> (Schmid. ex Schreb.) Loeske†							0.13		
<i>Barbilophozia floerkei</i> (F. Weber & D. Mohr) Loeske†							0.07		
<i>Barbilophozia kunzeana</i> (Huebener) Gams							0.07		
<i>Diplophyllum albicans</i> (L.) Dum.†								0.07	
<i>Diplophyllum taxifolium</i> (Wahlenb.) Dumort. var. <i>macrosticta</i> H. Buch					0.07				0.27
<i>Gymnomitrium concinnatum</i> (Lightf.) Corda†			0.20						
<i>Gymnomitrium corallioides</i> Nees			0.07		0.07			0.47	
<i>Lophozia wenzelii</i> (Nees) Steph. var. <i>wenzelii</i> †			0.27						
<i>Ptilidium ciliare</i> (L.) Hampe†			0.07	0.27		0.27	0.27		1.00
<i>Radula prolifera</i> S. W. Arnell†							0.07		
<i>Tetralophozia setiformis</i> (Ehrh.) Schljakov†									0.20
Bryophytes (Mosses)									
<i>Andreaea rupestris</i> Hedwig			0.07		0.13			0.60	
<i>Aulacomnium palustre</i> (Hedwig) Schwaegr.†	0.07	0.33				0.07			
<i>Aulacomnium turgidum</i> (Wahlenb.) Schwaegr.	0.20	0.13		0.07		0.20	0.93		0.60
<i>Bryum alpinum</i> Huds. ex With.†								0.07	
<i>Bryum argenteum</i> Hedwig†							0.07		
<i>Bryum</i> Hedw.							0.20		
<i>Bryum pseudotriquetrum</i> (Hedwig) Gaertn. et. al.†			0.07						
<i>Bucklandiella heterosticha</i> (Hedwig) Bednarek-Ochyra & Ochyra in R. Ochyra et al.			0.07					0.60	0.07
<i>Campylium stellatum</i> (Hedwig) C. E. O. Jensen†							0.07		
<i>Campylopus schimperi</i> Milde†							0.33		
<i>Conostomum tetragonum</i> (Hedwig) Lindberg			0.47					0.53	
<i>Dicranella</i> (Müll. Hal.) Schimp.†								0.07	
<i>Dicranum fuscescens</i> Turner var. <i>fuscescens</i>					0.07				0.20
<i>Dicranum groenlandicum</i> Bridel	0.27	0.07				0.73	0.67		0.53
<i>Dicranum scoparium</i> Hedwig†	0.67	0.27	1.00		0.27	0.73		1.00	0.40
<i>Dicranum undulatum</i> Bridel	0.07	0.13			0.47				0.07

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	Site ID								
Bryophytes (Mosses)	02-003	02-005	02-006	02-008	02-016	02-023	02-032	02-048	02-050
<i>Distichium capillaceum</i> (Hedwig) Bruch & Schimper‡							0.07		
<i>Ditrichum heteromallum</i> (Hedwig) Britt.							0.40		
<i>Fissidens osmundioides</i> Hedwig‡							0.27		
<i>Hylocomium splendens</i> (Hedwig) Schimper in B.S.G.†	0.60	0.27	0.13	0.07		0.47	0.87		0.33
<i>Hypnum cupressiforme</i> Hedw. var. <i>cupressiforme</i>							0.60		
<i>Hypnum plicatum</i> (Lindberg) Jaeg.	0.33	0.07		0.20		0.20			0.33
<i>Myurella julacea</i> (Schwaegr.) Schimper in B.S.G.‡							0.07		
<i>Oligotrichum hercynicum</i> (Hedwig) Lam. & DC.‡								0.13	
<i>Oligotrichum parallelum</i> (Mitten) Kindberg‡					0.20				
<i>Pleurozium schreberi</i> (Bridel) Mitt.†	0.53	0.07		0.07	0.07	0.40		0.07	0.27
<i>Pogonatum urnigerum</i> (Hedwig) P. Beauvois‡								0.07	
<i>Pohlia nutans</i> (Hedwig) Lindberg					0.13				0.33
<i>Pohlia prolifera</i> (Kindb. ex Breidl.) Lindb. ex Arnell						0.07			
<i>Polytrichum commune</i> Hedwig var. <i>commune</i> †	0.67	0.13	0.73	0.20	0.60	0.47		0.13	0.33
<i>Polytrichum hyperboreum</i> R. Brown	0.07		0.20	0.07		0.27	0.20	0.27	
<i>Polytrichum juniperinum</i> Hedwig		0.20			0.13	0.27	0.40	0.13	0.20
<i>Polytrichum piliferum</i> Hedwig			0.47		0.13			0.20	
<i>Polytrichum strictum</i> Bridel						0.07			0.27
<i>Ptilium crista-castrensis</i> (Hedw.) De Not.						0.07			
<i>Racomitrium lanuginosum</i> (Hedwig) Bridel	0.07	0.27	0.60	0.27	0.13	0.13	0.60	0.53	1.00
<i>Rhytidium rugosum</i> (Hedwig) Kindberg							0.60		
<i>Sanionia uncinata</i> (Hedwig) Loeske	0.20					0.07			
<i>Schistidium apocarpum</i> (Hedwig) Bruch & Schimper in B.S.G.							0.60		
<i>Tomentypnum nitens</i> (Hedwig) Loeske‡							0.13		
<i>Tortella tortuosa</i> (Hedwig) Limpricht var. <i>tortuosa</i>							0.67		

3d. Mid-elevation (450-900 m) treeline spruce							
**No nonvascular data for 02-S96							
Vascular species	02-S96**	02-S97	02-S04	Site ID			
				02-S14	02-S17	02-S99	02-S08
<i>Achillea millefolium</i> L. var. <i>borealis</i> (Bong.) Farw.	0.33	0.07	0.73			0.13	0.20
<i>Agrostis mertensii</i> Trin.						0.13	
<i>Agrostis scabra</i> Willd.	0.07						
<i>Alnus viridis</i> (Vill.) Lam. & DC ssp. <i>sinuata</i> (Regel) A.& D. Löve	0.13			0.07	0.27		
<i>Anemone narcissiflora</i> L.	0.07			0.13		0.27	
<i>Angelica lucida</i> L.‡							0.07
<i>Antennaria alpina</i> (L.) Gaertn.					0.07	0.07	
<i>Antennaria</i> Gaertn.‡		0.13					
<i>Arctostaphylos alpina</i> (L.) Spreng.†					0.07		
<i>Arnica frigida</i> C.A. Mey. ex Iljin ssp. <i>frigida</i>	0.07	0.40		0.40		0.47	0.20
<i>Artemisia arctica</i> Less. ssp. <i>arctica</i>		0.27		0.87	0.07	0.07	0.13
<i>Betula</i> × <i>dugleana</i> Lepage	0.07			0.27		0.20	0.13
<i>Betula glandulosa</i> Michx.†	0.13			0.33	0.13	0.80	0.20
<i>Betula papyrifera</i> Marsh. var. <i>kenaica</i> (W.H. Evans) A. Henry		0.07			0.07		
<i>Calamagrostis canadensis</i> (Michx.) Beauv.†	0.80	0.53	0.93	0.07	0.13	0.40	0.67
<i>Campanula uniflora</i> L.	0.40	0.60		0.73	0.13	0.40	0.07
<i>Carex lugens</i> T. Holm†			0.47			1.00	1.00
<i>Carex microchaeta</i> T. Holm ssp. <i>nesophila</i> (T. Holm) E. Murray							
<i>Carex microchaeta</i> T. Holm†	0.87	0.93		0.93	0.93		
<i>Carex spectabilis</i> Dewey					0.07		
<i>Chamerion angustifolium</i> ssp. <i>angustifolium</i> †	0.93	0.87	1.00	0.67	0.47	0.93	0.73
<i>Empetrum nigrum</i> L.†	1.00	1.00	1.00	0.93	0.93	1.00	1.00
<i>Equisetum palustre</i> L.						0.13	0.33
<i>Festuca altaica</i> Trin.†	0.60	0.07	0.47			0.87	
<i>Gentiana glauca</i> Pall.		0.13			0.07		
<i>Hierochloa alpina</i> (Sw.) R. & S.†	0.73	0.87		0.73	0.67		0.13
<i>Huperzia selago</i> (L.) Bernh. ex Schrank & Mart.							0.27
<i>Lagotis glauca</i> Gaertn.						0.33	
<i>Ledum palustre</i> ssp. <i>decumbens</i> (Ait.) Hultén†	0.73	1.00	0.27	0.93	0.80	0.93	0.67
<i>Listera cordata</i> (L.) R. Br.‡		0.07	0.07				
<i>Lloydia serotina</i> (L.) Rchb.				0.47	0.07		
<i>Loiseleuria procumbens</i> (L.) Desv.†	0.47	0.93	0.33	0.87	0.87	1.00	0.13

3d. Mid-elevation (450-900 m) treeline spruce

**No nonvascular data for 02-S96

Vascular species	Site ID						
	02-S96**	02-S97	02-S04	02-S14	02-S17	02-S99	02-S08
<i>Luetkea pectinata</i> (Pursh) Kuntze‡		0.07					
<i>Lupinus nootkatensis</i> Donn ex Sims	0.07						0.07
<i>Luzula arcuata</i> (Wahlenb.) Sw.					0.13		
<i>Luzula multiflora</i> (Ehrh.) Lej. ssp. <i>multiflora</i>	0.13		0.07				0.27
<i>Lycopodium alpinum</i> L.	0.13	0.40	0.07				
<i>Lycopodium lagopus</i> (Laestadius ex C. Hartman) Zinserl. ex Kuzen	0.07	0.40	0.07		0.20		
<i>Moneses uniflora</i> (L.) Gray			0.07				
<i>Orthilia secunda</i> (L.) House			0.47		0.07		0.20
<i>Oxytropis nigrescens</i> (Pall.) Fisch. ex DC. var. <i>nigrescens</i>		0.07		0.73	0.67		
<i>Pedicularis verticillata</i> L.				0.13			
<i>Petasites frigidus</i> (L.) Franch.		0.13	0.33				0.13
<i>Picea glauca</i> (Moench) Voss†	0.13	0.07	0.13	0.20	0.27	0.07	0.07
<i>Poa arctica</i> R. Br. ssp. <i>arctica</i>			0.13	0.13	0.13		
<i>Polygonum viviparum</i> L.						0.40	0.07
<i>Pyrola asarifolia</i> Michx. ssp. <i>asarifolia</i> ‡		0.07					
<i>Pyrola minor</i> L.‡					0.07		
<i>Rhodiola integrifolia</i> Raf.				0.33	0.07	0.27	0.27
<i>Rhododendron camtschaticum</i> Pall.		0.33		0.07	0.73		
<i>Salix arctica</i> Pall.†	0.60	1.00	0.27	0.93	0.93	0.87	0.93
<i>Salix barclayi</i> Anderss.	0.07	0.07	0.93		0.07		
<i>Salix fuscescens</i> Anderss.‡	0.07						
<i>Salix glauca</i> L.	0.07	0.07	0.20			0.07	0.07
<i>Salix phlebophylla</i> Andersson					0.40		
<i>Salix pulchra</i> Cham.†	0.60	0.73		0.13	0.13	0.53	0.67
<i>Salix reticulata</i> L.		0.07					0.13
<i>Sanguisorba canadensis</i> L.		0.07	0.33			0.33	0.20
<i>Spiraea stevenii</i> (C.K. Schneid.) Rydb.	0.27		0.47		0.13	0.53	
<i>Stellaria crispa</i> Cham. & Schldl.‡					0.07		
<i>Trientalis europaea</i> L. ssp. <i>arctica</i> (Fisch. ex Hook.) Hultén			0.07				0.13
<i>Trisetum spicatum</i> (L.) Richter	0.33	0.07		0.27	0.07	0.20	
<i>Vaccinium oxycoccos</i> L.‡							
<i>Vaccinium uliginosum</i> L.†	0.60	0.67	0.93	0.93	1.00	0.20	0.67
<i>Vaccinium vitis-idaea</i> L.†	0.33	0.07	0.67	0.07	0.13	0.93	1.00

3d. Mid-elevation (450-900 m) treeline spruce

**No nonvascular data for 02-S96

**No nonvascular data for 02-S96				Site ID			
Vascular species	02-S96**	02-S97	02-S04	02-S14	02-S17	02-S99	02-S08
<i>Vahlodea atropurpurea</i> (Wahlenb.) Fr. ex Hartm.‡							0.27
Lichens							
<i>Cetraria aculeata</i> (Schreb.) Fr.‡		0.07					
<i>Cetraria islandica</i> subsp. <i>crispiformis</i> (Räsänen) Kärnefelt†		0.27		0.27	0.33		
<i>Cetraria kamczatica</i> Savicz					0.13		
<i>Cetraria laevigata</i> Rass.				0.27	0.40		
<i>Cetrariella fastigiata</i> (Delise ex Nyl.) Kärnefelt & Thell					0.13		
<i>Cladonia amaurocraea</i> (Flörke) Schaerer			0.07		0.07	0.13	0.13
<i>Cladonia arbuscula</i> subsp. <i>beringiana</i> Ahti†		0.80	0.87	0.93	0.80	1.00	0.53
<i>Cladonia bellidiflora</i> (Ach.) Schaerer		0.07	0.20	0.47	0.33	0.07	0.07
<i>Cladonia borealis</i> S. Stenroos		0.13	0.07	0.33	0.47	0.67	
<i>Cladonia carneola</i> (Fr.) Fr.		0.07	0.07	0.47		0.13	
<i>Cladonia cervicornis</i> subsp. <i>verticillata</i> (Hoffm.) Ahti‡				0.07			
<i>Cladonia chlorophaea</i> (Flörke ex Sommerf.) Sprengel			0.27	0.27	0.47	0.20	0.20
<i>Cladonia coniocraea</i> (Flörke) Sprengel‡				0.27			
<i>Cladonia cornuta</i> (L.) Hoffm. ssp. <i>cornuta</i>			0.40	0.40	0.53	0.27	0.60
<i>Cladonia crispata</i> (Ach.) Flotow var. <i>crispata</i> †		0.47	0.20	0.80	0.73	0.53	0.27
<i>Cladonia cyanipes</i> (Sommerf.) Nyl.			0.27	0.40	0.47		0.20
<i>Cladonia deformis</i> (L.) Hoffm.						0.07	0.07
<i>Cladonia furcata</i> (Hudson) Schrader							0.27
<i>Cladonia gracilis</i> subsp. <i>elongata</i> (Jacq.) Vainio			0.07	0.67		0.40	
<i>Cladonia gracilis</i> subsp. <i>turbinata</i> (Ach.) Ahti			0.07	0.13			0.40
<i>Cladonia gracilis</i> subsp. <i>vulnerata</i> Ahti†		0.27	0.27		0.40	0.27	0.07
<i>Cladonia macroceras</i> (Delise) Hav.				0.33	0.47		
<i>Cladonia macrophylla</i> (Schaerer) Stenh.				0.27			
<i>Cladonia mitis</i> Sandst.			0.07			0.07	
<i>Cladonia multiformis</i> G. Merr.‡							0.13
<i>Cladonia phyllophora</i> Hoffm.		0.07	0.20	0.60	0.27	0.20	
<i>Cladonia pleurota</i> (Flörke) Schaerer					0.40		
<i>Cladonia pyxidata</i> (L.) Hoffm.			0.07	0.13	0.07	0.07	
<i>Cladonia rangiferina</i> (L.) F. H. Wigg.†		0.40	0.60	0.60	0.73	0.93	0.33
<i>Cladonia scabriuscula</i> (Delise) Nyl.		0.07	0.07		0.13	0.13	0.13

3d. Mid-elevation (450-900 m) treeline spruce

**No nonvascular data for 02-S96

**No nonvascular data for 02-S96	Site ID						
Lichens	02-S96**	02-S97	02-S04	02-S14	02-S17	02-S99	02-S08
<i>Cladonia squamosa</i> Hoffm.		0.07		0.60	0.33	0.33	
<i>Cladonia stellaris</i> (Opiz) Pouzar & Vězda†		0.33	0.20	0.53	0.07	0.73	0.07
<i>Cladonia stygia</i> (Fr.) Ruoss†		0.40	0.33	0.67	0.13	0.80	0.13
<i>Cladonia subfurcata</i> (Nyl.) Arnold			0.07			0.07	
<i>Cladonia sulphurina</i> (Michaux) Fr.		0.07	0.20			0.33	0.20
<i>Cladonia uncialis</i> (L.) F. H. Wigg.†		0.07		0.07		0.40	0.13
<i>Dactylina arctica</i> (Richardson) Nyl.‡							
<i>Flavocetraria cucullata</i> (Bellardi) Kärnefelt & Thell†		0.20		0.13	0.47	0.60	0.07
<i>Flavocetraria nivalis</i> (L.) Kärnefelt & Thell		0.20			0.13	0.07	
<i>Lobaria linita</i> (Ach.) Rabenh.		0.13	0.07			0.40	
<i>Nephroma arcticum</i> (L.) Torss.		0.07	0.07	0.07		0.07	0.07
<i>Nephroma parile</i> (Ach.) Ach.‡						0.07	
<i>Peltigera aphthosa</i> (L.) Willd.†		0.07	0.27				0.07
<i>Peltigera britannica</i> (Gyelnik) Holt.-Hartw. & Tønsberg†		0.13	0.47	0.87	0.47	0.93	0.47
<i>Peltigera didactyla</i> (With.) J. R. Laundon‡				0.27			
<i>Peltigera extenuata</i> (Vainio) Lojka‡			0.07	0.07			
<i>Peltigera kristinssonii</i> Vitik.‡			0.07				
<i>Peltigera lepidophora</i> (Nyl. ex Vainio) Bitter‡				0.07			
<i>Peltigera leucophlebia</i> (Nyl.) Gyelnik		0.20	0.07				0.20
<i>Peltigera malacea</i> (Ach.) Funck†		0.20	0.33	0.27	0.20	0.80	0.33
<i>Peltigera polydactyla</i> (Necker) Hoffm.			0.07	0.40	0.07	0.13	0.47
<i>Peltigera rufescens</i> (Weiss) Humb.‡					0.07	0.07	
<i>Peltigera scabrosa</i> Th. Fr.†		0.60	0.20	0.20	0.47	0.60	0.93
<i>Pseudephebe pubescens</i> (L.) M. Choisy‡					0.07		
<i>Psoroma hypnorum</i> (Vahl) Gray				0.73	0.53	0.07	0.07
<i>Stereocaulon alpinum</i> Laurer ex Funck‡					0.20		
<i>Stereocaulon paschale</i> (L.) Hoffm.		0.20	0.07			0.07	0.07
<i>Stereocaulon tomentosum</i> Fr.				0.80		0.73	
<i>Tuckermannopsis sepincola</i> (Ehrh.) Hale				0.07			
<i>Vulpicida pinastri</i> (Scop.) J.-E. Mattsson & M. J. Lai				0.07	0.07		

3d. Mid-elevation (450-900 m) treeline spruce
****No nonvascular data for 02-S96**

	Site ID						
	02-S96**	02-S97	02-S04	02-S14	02-S17	02-S99	02-S08
Bryophytes (Liverworts)							
<i>Anastrophyllum minutum</i> (Schreb.) R. M. Schust. var. <i>minutum</i>		0.20		0.53	0.47	0.80	0.13
<i>Anthelia juratzkana</i> (Limpr.) Trevis.					0.07		
<i>Barbilophozia kunzeana</i> (Huebener) Gams		0.33			0.27		
<i>Diplophyllum taxifolium</i> (Wahlenb.) Dumort. var. <i>macrosticta</i> H. Buch				0.07	0.47		
<i>Gymnomitrium corallioides</i> Nees					0.13		
<i>Lophozia ventricosa</i> (Dicks.) Dumort. var. <i>ventricosa</i> ‡						0.07	
<i>Lophozia wenzelii</i> (Nees) Steph. var. <i>wenzelii</i> ‡		0.07					
<i>Ptilidium ciliare</i> (L.) Hampe†		0.87	0.47	0.73	0.27	1.00	0.40
<i>Andreaea rupestris</i> Hedwig					0.07		
Bryophytes (Mosses)							
<i>Aulacomnium palustre</i> (Hedwig) Schwaegr.†		0.07	0.47			0.07	0.27
<i>Aulacomnium turgidum</i> (Wahlenb.) Schwaegr.		0.07		0.27	0.33	0.07	0.40
<i>Brachythecium calcareum</i> Kindberg‡				0.07			
<i>Brachythecium erythrorrhizon</i> Schimper in B.S.G.‡				0.07			
<i>Brachythecium frigidum</i> (C. Müll.) Besch.‡					0.20		
<i>Brachythecium oedipodium</i> (Mitt.) Jaeg.‡			0.07				
<i>Bryum arcticum</i> (R. Br.) Bruch & Schimper in B.S.G.‡						0.13	
<i>Bryum</i> Hedw.					0.20		
<i>Ceratodon purpureus</i> (Hedwig) Bridel subsp. <i>purpureus</i> ‡				0.13			
<i>Dicranum fuscescens</i> Turner var. <i>fuscescens</i>		0.13	0.13			0.20	0.47
<i>Dicranum groenlandicum</i> Bridel		0.93	0.07			0.40	0.07
<i>Dicranum scoparium</i> Hedwig†		0.13	0.93	0.93	0.87	0.60	0.67
<i>Dicranum undulatum</i> Bridel			0.07		0.07	0.20	
<i>Hylocomium splendens</i> (Hedwig) Schimper in B.S.G.†		0.40	0.40	0.40	0.07	0.33	0.93
<i>Hypnum plicatulum</i> (Lindberg) Jaeg.				0.33	0.33	0.13	0.13
<i>Pleurozium schreberi</i> (Bridel) Mitt.†		0.67	1.00	0.53	0.27	0.73	1.00
<i>Pohlia nutans</i> (Hedwig) Lindberg		0.07				0.13	
<i>Polytrichum commune</i> Hedwig var. <i>commune</i> †		0.67	0.73	0.40	0.60	0.93	0.67
<i>Polytrichum hyperboreum</i> R. Brown							0.07
<i>Polytrichum juniperinum</i> Hedwig			0.07				0.07

3d. Mid-elevation (450-900 m) treeline spruce

**No nonvascular data for 02-S96

Bryophytes (Mosses)	Site ID						
	02-S96**	02-S97	02-S04	02-S14	02-S17	02-S99	02-S08
<i>Polytrichum piliferum</i> Hedwig					0.07	0.07	
<i>Polytrichum strictum</i> Bridel		0.07	0.07	0.07		0.07	0.47
<i>Ptilium crista-castrensis</i> (Hedwig) De Not.†			0.20				0.40
<i>Racomitrium lanuginosum</i> (Hedwig) Bridel		0.47		0.73	0.67	0.13	0.20
<i>Rhytidium rugosum</i> (Hedwig) Kindberg				0.07			
<i>Sanionia uncinata</i> (Hedwig) Loeske		0.27	0.07	0.07	0.07	0.33	0.07
<i>Sphagnum girgensohnii</i> Russow			0.07				0.20

Appendix 4. Mean frequencies (± 1 SE) for vascular and nonvascular species showing high constancy (CVs $\leq 35\%$) in each vegetation type. Dashes (-) indicate that the species was either not present in that vegetation type, or that it was present but variable (CV $> 35\%$) in occurrence.

4a. Vascular species	Low elevation (0-450 m)				Mid-elevation (450-900 m)			
	Spruce woodland		Closed spruce - beetle		Treeline spruce		Dwarf shrub	
	mean	CV	mean	CV	mean	CV	mean	CV
Growth form & species								
Tree								
<i>Picea glauca</i>	65.2 (4.4)	0.068	66.7 (9.3)	0.139	13.3 (2.8)	0.211	-	-
<i>Betula papyrifera</i> var. <i>kenaica</i>	-	-	35.0 (7.2)	0.204	-	-	-	-
Shrub								
<i>Arctostaphylos alpina</i>	-	-	-	-	-	-	49.6 (8.1)	0.163
<i>Betula glandulosa</i>	92.6 (3.4)	0.036	-	-	22.9 (6.4)	0.280	58.5 (8.2)	0.140
<i>Ledum palustre</i> ssp. <i>decumbens</i>	88.1 (4.1)	0.047	-	-	76.2 (6.0)	0.079	61.5 (7.9)	0.129
<i>Rhododendron camtschaticum</i>	-	-	-	-	-	-	25.9 (7.2)	0.278
<i>Salix arctica</i>	63.7 (7.4)	0.116	-	-	79.0 (6.1)	0.078	63.7 (7.4)	0.116
<i>Salix glauca</i>	45.9 (6.3)	0.137	-	-	-	-	-	-
<i>Salix phlebophylla</i>	-	-	-	-	-	-	51.1 (8.0)	0.157
<i>Salix pulchra</i>	23.7 (6.4)	0.270	46.7 (7.6)	0.163	40.0 (7.4)	0.185	-	-
<i>Spiraea beauverdiana</i>	23.0 (6.2)	0.270	-	-	20.0 (5.4)	0.271	-	-
<i>Vaccinium uliginosum</i>	65.9 (7.4)	0.112	-	-	71.4 (6.6)	0.092	79.3 (5.4)	0.068
Dwarf shrub								
<i>Empetrum nigrum</i>	97.0 (1.4)	0.014	60.0 (10.6)	0.177	98.1 (1.3)	0.013	98.5 (1.0)	0.010
<i>Diapenisa lapponica</i>	-	-	-	-	-	-	27.4 (8.0)	0.290
<i>Loiseleuria procumbens</i>	-	-	-	-	65.7 (7.7)	0.117	78.5 (5.4)	0.068
<i>Vaccinium vitis-idaea</i>	97.8 (1.2)	0.012	70.0 (11.0)	0.157	45.7 (8.7)	0.190	65.2 (7.5)	0.115
Graminoid								
<i>Carex lugens</i>	39.3 (7.4)	0.189	-	-	35.2 (9.8)	0.279	-	-
<i>Carex microchaeta</i>	-	-	-	-	52.4 (10.1)	0.193	85.2 (6.1)	0.072
<i>Calamagrostis canadensis</i>	19.3 (5.1)	0.265	55.0 (9.2)	0.168	50.5 (8.0)	0.158	-	-
<i>Festuca altaica</i>	20.0 (5.5)	0.274	-	-	28.6 (8.1)	0.283	33.3 (7.9)	0.236
<i>Hierochloe alpina</i>	-	-	-	-	44.8 (8.6)	0.191	64.4 (6.9)	0.106
<i>Trisetum spicatum</i>	-	-	-	-	13.3 (3.9)	0.293	-	-
Forb								
<i>Achillea millefolium</i> ssp. <i>borealis</i>	-	-	-	-	21.0 (6.4)	0.306	-	-
<i>Anemnone narcissiflora</i>	-	-	-	-	-	-	43.0 (7.3)	0.171
<i>Arnica frigida</i>	-	-	-	-	21.9 (6.0)	0.276	-	-
<i>Artemisia arctica</i> ssp. <i>arctica</i>	24.4 (6.5)	0.267	-	-	20.0 (6.9)	0.345	-	-
<i>Campanula uniflora</i>	-	-	-	-	32.4 (7.5)	0.231	40.0 (5.5)	0.137
<i>Chamerion angustifolium</i>	18.5 (3.8)	0.204	46.7 (11.2)	0.240	80.0 (4.9)	0.061	-	-
<i>Dryas octopetala</i>	-	-	-	-	-	-	20.0 (6.6)	0.329
<i>Lagotis glauca</i>	-	-	-	-	-	-	28.1 (7.6)	0.270
<i>Oxytropis nigricans</i> ssp. <i>bryophila</i>	-	-	-	-	21.0 (7.1)	0.339	26.7 (6.9)	0.259
<i>Polygonum viviparum</i>	-	-	-	-	-	-	21.5 (6.0)	0.277
<i>Rhodiola integrifolia</i>	-	-	-	-	13.3 (3.7)	0.275	-	-
<i>Sanguisorba canadensis</i>	-	-	-	-	13.3 (4.1)	0.310	-	-
<i>Trientalis europaea</i>	-	-	8.3 (2.9)	0.343	-	-	-	-

4b. Nonvascular species - Lichens		Low elevation (0-450 m)				Mid-elevation (450-900 m)			
		Spruce woodland		Closed spruce - beetle		Treeline spruce		Dwarf shrub	
Growth form & species		mean	CV	mean	CV	mean	CV	mean	CV
<i>Cetraria islandica</i> ssp. <i>crispiformis</i>		22.2 (5.1)	0.229	-	-	12.4 (3.9)	0.318	50.4 (8.2)	0.162
<i>Cetraria kamczatica</i>		-	-	-	-	-	-	22.2 (5.7)	0.257
<i>Cetraria laevigata</i>		32.6 (5.9)	0.180	-	-	-	-	-	-
<i>Cetrariella fastigiata</i>		-	-	-	-	-	-	28.9 (8.2)	0.283
<i>Cladonia amaurocraea</i>		-	-	-	-	-	-	17.0 (5.6)	0.331
<i>Cladonia arbuscula</i> ssp. <i>beringiana</i>		65.9 (5.7)	0.086	8.3 (2.9)	0.343	70.5 (7.4)	0.105	70.4 (8.0)	0.114
<i>Cladonia bellidiflora</i>		-	-	-	-	17.1 (4.9)	0.288	23.0 (5.7)	0.250
<i>Cladonia borealis</i>		-	-	-	-	23.8 (6.3)	0.264	25.9 (6.2)	0.240
<i>Cladonia chlorophaea</i>		26.7 (4.3)	0.163	11.7 (3.7)	0.318	20.0 (4.5)	0.225	-	-
<i>Cladonia cornuta</i> ssp. <i>cornuta</i>		37.0 (5.2)	0.141	-	-	31.4 (6.1)	0.195	-	-
<i>Cladonia crispata</i> ssp. <i>crispata</i>		32.6 (5.1)	0.155	-	-	42.9 (6.7)	0.156	-	-
<i>Cladonia cyanipes</i>		8.1 (2.4)	0.296	-	-	19.0 (5.7)	0.297	-	-
<i>Cladonia gracilis</i> ssp. <i>elongata</i>		-	-	-	-	-	-	24.4 (6.9)	0.280
<i>Cladonia gracilis</i> ssp. <i>vulnerata</i>		67.4 (6.1)	0.090	-	-	18.1 (5.4)	0.298	-	-
<i>Cladonia macroceras</i>		-	-	-	-	-	-	23.0 (7.7)	0.336
<i>Cladonia phyllophora</i>		-	-	-	-	19.0 (5.0)	0.261	-	-
<i>Cladonia rangiferina</i>		32.6 (4.6)	0.141	-	-	51.4 (8.1)	0.157	40.7 (8.3)	0.204
<i>Cladonia scabriuscula</i>		10.4 (3.2)	0.311	-	-	7.6 (2.5)	0.331	-	-
<i>Cladonia squamosa</i>		11.9 (3.7)	0.311	-	-	19.0 (6.3)	0.329	-	-
<i>Cladonia stygia</i>		72.6 (5.9)	0.081	-	-	35.2 (7.4)	0.210	28.1 (6.5)	0.231
<i>Cladonia stellaris</i>		19.3 (4.0)	0.208	-	-	27.6 (6.4)	0.232	19.3 (6.7)	0.348
<i>Cladonia subfurcata</i>		-	-	-	-	-	-	17.0 (5.3)	0.313
<i>Cladonia sulphurina</i>		-	-	-	-	11.4 (3.2)	0.280	-	-
<i>Cladonia uncialis</i>		20.0 (5.1)	0.253	-	-	-	-	45.2 (8.0)	0.177
<i>Flavocetraria cucullata</i>		28.1 (6.0)	0.212	-	-	21.0 (5.5)	0.262	-	-
<i>Lobaria linita</i>		-	-	-	-	-	-	38.5 (7.1)	0.185
<i>Peltigera aphthosa</i>		63.7 (4.9)	0.078	-	-	-	-	-	-
<i>Peltigera britannica</i>		17.8 (5.2)	0.292	48.3 (8.4)	0.173	47.6 (7.9)	0.167	-	-
<i>Peltigera leucophlebia</i>		5.9 (1.8)	0.298	-	-	-	-	-	-
<i>Peltigera malacea</i>		45.2 (5.4)	0.120	16.7 (5.2)	0.313	30.5 (6.9)	0.225	-	-
<i>Peltigera polydactyla</i>		20.7 (4.6)	0.224	-	-	16.2 (4.2)	0.259	-	-
<i>Peltigera praetextata</i>		-	-	38.3 (8.7)	0.227	-	-	-	-
<i>Peltigera scabrosa</i>		57.8 (5.0)	0.086	-	-	42.9 (7.7)	0.180	12.6 (4.2)	0.336
<i>Psoroma hypnorum</i>		-	-	-	-	20.0 (6.6)	0.332	13.3 (4.5)	0.335
<i>Stereocaulon paschale</i>		23.0 (5.7)	0.250	-	-	-	-	26.7 (6.8)	0.256
<i>Thamnolia subuliformis</i>		-	-	-	-	-	-	38.5 (8.2)	0.212
<i>Thamnolia vermicularis</i>		-	-	-	-	-	-	20.7 (6.6)	0.319
<i>Tuckermannopsis sepincola</i>		28.9 (5.5)	0.191	-	-	-	-	-	-

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