#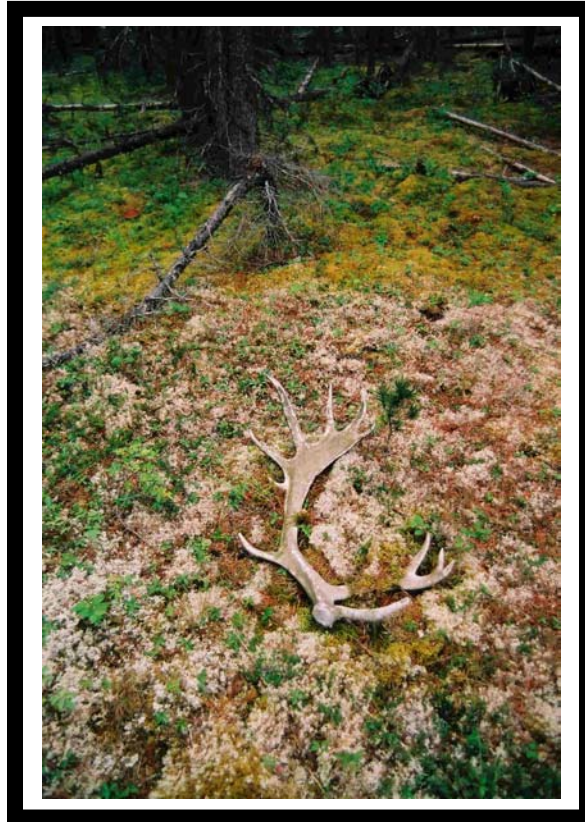 THE RESPONSE OF CARIBOU TERRESTRIAL FORAGE LICHENS TO MOUNTAIN PINE BEETLES AND FOREST HARVESTING IN THE EAST OOTSA AND ENTIAKO AREAS

ANNUAL REPORT – 2005/06 – YEAR 5

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PREFACE

This report summarizes data collected in 2005 and incorporates information from two adjacent study areas: the East Ootsa area between Tetachuck Lake and the Chelaslie River; and the Entiako area which includes Entiako Park and Entiako Protected Area.

The focus of our project was to determine the response of caribou terrestrial forage lichens to forest harvesting and mountain pine beetles under various ecological conditions in four biogeoclimatic subzones (SBSmc2, SBSdk, SBPSmc and ESSFmc). We selected sites within sites series in each subzone that supported high lichen cover, but that did not necessarily typify each site series. Therefore, the data presented in this report are representative of localities that support high lichen cover within these site series/subzones and cannot be used to characterize average conditions within site series or subzones.

In 2005, we collected additional stand structure and regeneration information at each plot to contribute to other studies lead by Dr. Dave Coates, Ministry of Forests (Forest Sciences Program Y061148), and Dr. Phil Burton, Canadian Forest Service (Forest Sciences Program Y061184). These are continuing projects so results from those studies will be published in 2007. Already, data from this project has contributed to an assessment of secondary stand structure in lodgepole pine stands affected by the mountain pine beetle epidemic (Coates *et al*. 2006).

ACKNOWLEDGEMENTS

Table of Contents

List of Tables

List of Figures

INTRODUCTION

The Tweedsmuir-Entiako caribou (*Rangifer tarandus caribou*) population summers in the North Tweedsmuir Park area, moves through the East Ootsa area during spring and fall migration, and winters in the Entiako and East Ootsa areas. During winter, caribou select mature lodgepole pine (*Pinus contorta*) forests on poor sites and forage primarily by cratering through the snow to obtain terrestrial lichens (Cichowski 1993).

The two main large-scale natural disturbance factors in the area are fire and mountain pine beetles. Fire suppression has been effective in reducing large-scale fires in the Entiako area for the last 40-50 years, resulting in a landscape of primarily older lodgepole pine forests (Cichowski *et al*. 2001). Mature lodgepole pine trees are the preferred host of the mountain pine beetle (*Dendroctonus ponderosae*). The recent mountain pine beetle outbreak has affected significant areas of mature lodgepole pine caribou winter range in the East Ootsa and Entiako areas and most of the attacked trees have lost their needles and are now in the "grey attack" phase of the epidemic.

In 2000, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated all woodland caribou in the Southern Mountains National Ecological Area (SMNEA), which includes the Tweedsmuir-Entiako population, as Threatened (Northern Caribou Technical Advisory Committee 2004). That same year, Northern Caribou in all of British Columbia were blue-listed by the BC Conservation Data Centre (CDC). A recovery strategy for Northern Caribou in the SMNEA was recently complete but is awaiting approval (Northern Caribou Technical Advisory Committee 2004). That strategy identified the impact of the extensive mountain pine beetle outbreak on winter forage (terrestrial lichens), on caribou habitat and winter range use, and on population dynamics as one of the greatest threats currently facing Northern Caribou in the SMNEA, and identified research on the effects of mountain pine beetles on Northern Caribou and their habitat as a priority. Because the Tweedsmuir-Entiako caribou population is the first population to experience the current mountain pine beetle epidemic, information collected on the Tweedsmuir-Entiako population will also benefit other caribou populations where mountain pine beetle will occur.

This study was initiated in 2001 to investigate the effects of mountain pine beetles and forest harvesting on terrestrial caribou forage lichens. Permanent plots were established in 2001 and revisited in 2003 and 2005. Although the focus was on mountain pine beetle and forest harvesting disturbance, a wildfire burned 6 study plots in 2004, providing some additional information on the initial effects of fire.

Williston and Cichowski (2002) outlined the rationale and framework for this multi-year project, and provided a discussion of caribou ecology, lichen ecology and mountain pine beetle history, and a detailed account and preliminary results of work conducted in Year 1 (2001). Cichowski and Williston (2003) summarized

information collected during Year 2 (2002) of the project, and Williston and Cichowski (2004) summarized activities conducted during the 2003 field season (Year 3) and included some preliminary results that described initial responses to mountain pine beetle and forest harvesting disturbances. This annual report summarizes activities conducted during the 2005 field season (Year 5) and provides preliminary interpretations of results in relation to earlier years. A final report will be completed that will provide final results and interpretations collected during the first 5 years of the study.

OBJECTIVE

The objective of this project is:

- to gain an understanding of how terrestrial caribou forage lichen species respond to mountain pine beetle disturbances and forest harvesting in the East Ootsa and Entiako areas.

Although our project focuses on the effects of mountain pine beetle disturbances and forest harvesting on caribou terrestrial forage lichens, it does not address whether caribou will use this disturbed habitat. Further investigation is required to assess how caribou habitat use will respond to the mountain pine beetle epidemic.

STUDY AREA

The study area is located in west-central B.C., approximately 100 km south of Burns Lake. It includes the portion of the East Ootsa caribou migration and winter range that lies south of the Chelaslie River and north of Tetachuck Lake, and the portion of the Entiako caribou winter range that lies within Entiako Park and Protected Area.

The area is characterized by low-lying, flat or gently rolling terrain on the Nechako Plateau (Holland 1976, Figure 1). The plateau landscape ranges between 850 and 1300 meters, rising gently to 1500 meters in the western part of the East Ootsa area, and rising more rapidly to over 1900 meters in the Fawnie Mountains along the eastern boundary of Entiako Protected Area. Eskers and deep glacio-fluvial deposits are common features of the plateau as the physical landscape is largely a result of glacial movement from southwest to northeast across the area (Holland 1976). Soils are predominantly Brunisolic Gray Luvisols and Dystric Brunisols on morainal and glacio-fluvial deposits (Lewis *et al*. 1986, Clement *et al*. 1987).

The East Ootsa and Entiako areas fall within 4 main biogeoclimatic subzones and variants:
- the dry cool subzone of the Sub-Boreal Spruce zone (SBSdk);
- the Babine variant of the moist cold Sub-Boreal Spruce subzone (SBSmc2);

- the moist cold subzone of the Sub-Boreal Pine-Spruce zone (SBPSmc); and,
- the moist cold subzone of the Engelmann Spruce-Subalpine Fir zone (ESSFmc).

The SBSdk subzone is located along the lakes of the Nechako Reservoir including Tetachuck Lake, Chelaslie Arm, Euchu Reach, Natalkuz Lake and Intata Reach. The SBSmc2 lies above the SBSdk in the East Ootsa area while the SBPSmc lies above the SBSdk in the Entiako area. Most of the Entiako area consists of the SBPSmc. The ESSFmc is found at higher elevations above the SBSmc2 in the East Ootsa area and is primarily restricted to the western portion of the study area where the plateau rises towards the Quanchus Mountains in Tweedsmuir Park; however, a small pocket of ESSFmc is also found between Chelaslie Arm and the Tetachuck River. Two additional biogeoclimatic subzones are found in the southeastern portion of Entiako Protected Area (the Kluskus variant of the SBSmc subzone [SBSmc3] and the moist, very cold subzone of the ESSF [ESSFmv]) but were not sampled as part of this project.

Low elevation forests consist mostly of lodgepole pine or mixed lodgepole pine/white spruce (*Picea glauca*) stands. Spruce stands occur primarily on wetter seepage sites and as bands along lakes and wetlands, and black spruce (*Picea mariana*) is generally restricted to forested wetlands. Deciduous stands of trembling aspen (*Populus tremuloides*) are found mostly in the band of SBSdk along the Nechako Reservoir. Lakes and sedge fens are common and often occur together in mosaics that include fringe forests of spruce. Subalpine fir (*Abies lasiocarpa*) occurs mostly at higher elevations in the ESSF but is also found in the SBSmc2, especially in the understory. Most of the pine and pine/spruce stands that dominate the study area have poorly developed shrub and herb layers. Common understory vascular plant species are *Shepherdia canadensis*, *Spirea betulifolia*, *Rosa acicularis*, *Arctostaphylos uva-ursi*, *Linnaea borealis*, *Cornus canadensis*, and *Vaccinium caespitosum*.

Caribou, moose (*Alces alces*), wolves (*Canis lupus*), grizzly bears (*Ursus arctos*) and black bears (*Ursus americanus*) are the most common wildlife species in the study area. Caribou use the area primarily during winter and migration. Entiako Park and Protected Area are the core of the caribou winter range; however, some caribou also use the East Ootsa area during winter (Cichowski and MacLean 2005). Caribou travel through the East Ootsa area during spring and fall migration and the area on the north and south side of Ootsa Lake are important staging areas during spring migration.

Fire and forest insects are the main large-scale natural disturbance factors in the study area. The SBPSmc, SBSmc2 and SBSdk are characterized by somewhat frequent stand destroying fires with mean fire return intervals of 125-175 years, 100-150 years, and 100-150 years respectively (Parminter 1992). The ESSFmc is characterized by infrequent stand destroying fires with a mean fire interval of 200-300 years. Mountain pine beetles are the main forest insects present in the study area; however, spruce beetles (*Dendroctonus rufipennis*) and western balsam bark beetle

(*Dryocoetes confusus*) also play an important role in the dynamics of spruce and subalpine fir stands. Mountain pine beetles preferentially attack mature trees; larger trees (>20-25 cm dbh) are especially susceptible (Safranyik *et al*. 1974).

The East Ootsa and Entiako areas lie within the rainshadow of the Coast Mountains and are characterized by a dry, continental climate, with generally cool, short and dry summers, and long, cold and dry winters. Mean monthly temperature averages 13°C in the summer and –14°C in the winter with mean annual precipitation levels of 450 mm in the SBS and the SBPS, and 580 mm in the ESSF. Annual snowfall averages 2 meters for the lower elevation SBS and SBPS, and 2.5 meters for the higher elevation ESSF. Actual snow accumulation is relatively low during winter, especially at lower elevations where snow accumulation rarely exceeds 1 meter in openings.

LICHEN ECOLOGY

The distribution of terrestrial forage lichens in the East Ootsa and Entiako areas is largely determined by interactions among four factors:
- site characteristics (moisture, nutrients, and light);
- disturbance history;
- reproduction and dispersion; and,
- competition with terrestrial plants.

Our investigation into the response of terrestrial lichens to changes in stand structure caused by mountain pine beetles and forest harvesting focuses on these four factors and their interactions.

Caribou consume several species of terrestrial lichen. The most common genera of terrestrial forage lichens are *Cladina*, *Cladonia*, *Cetraria*, and *Stereocaulon* (Cichowski 1993). *Cladina* is favoured above all others and is represented by four species in the study area: *C. arbuscula*; *C. mitis*; *C. rangiferina*; and *C. stellaris*. This study concentrates on the distributional ecology of *Cladina*; however, the patterns reported apply to most terrestrial forage lichens in the study area.

Site characteristics

Terrestrial forage lichens, particularly species in the genus *Cladina*, have a broad tolerance for moisture conditions and can be found growing on dry, rapidly draining substrates such as sand, coarse gravel and bedrock, or on (at least temporarily) wet substrates such as *Sphagnum* hummocks. Whether wet or dry, *Cladina* is most abundant on nutrient poor sites where the success of potential competitors is limited (Ahti 1961). Although these lichens are physiologically capable of inhabiting moist, rich sites (and often grow larger on those sites than on drier ones) they tend to be uncommon on rich sites due to competition from mosses and vascular plants (Ahti 1961).

Where competitors are few, terrestrial forage lichens can become the dominant component of the terrestrial vegetation and are especially prevalent in cold climates. For example, lichen dominated communities are characteristic of arctic and boreal ecosystems (Ahti and Hepburn 1967). Terrestrial forage lichens are largely absent from very wet or very dry sites. They do not generally tolerate prolonged submersion, nor are they able to establish on dry, elevated substrates such as the bark of trees (on rare occasions they colonize living trees where humidity is very high such as in coastal wetlands; Williston, pers. obs.).

Ahti and Hepburn (1967) noted that terrestrial forage lichens are photophiles, or sun lovers, which is why they are seldom found in densely shaded forests. However, Goward (2000) observed no difference in lichen abundance in dense stands as compared to open stands on the dry Chilcotin Plateau, and Miège *et al*. (2001a) reported negative effects on lichens from high light exposure in partially cut stands with 70% removal. Terrestrial forage lichens appear to be tolerant of a range of moderate to high light exposures but may be vulnerable to rapid changes in the light conditions under which they became established. They may also respond to other attributes that are affected by stand density such as the humidity at the forest floor. While terrestrial forage lichens are able to withstand desiccation, they also require humidity for transpiration and growth (Ahti and Hepburn 1967). Prolonged humid conditions, such as under the cover of dense forests in most boreal ecosystems (but not on the Chilcotin Plateau; Brulisauer *et al*. 1996), allows red-stemmed feathermoss to thrive at the expense of terrestrial lichens. In the canopy gaps where the terrestrial forage lichens are abundant, humid conditions are interrupted by periods of desiccation, which prevents competitors like mosses from becoming established and allows lichens to flourish.

Disturbance history

In many ecosystems, terrestrial forage lichens are dependent on periodic disturbance to maintain their prevalence on the landscape. However, if disturbances are too frequent, for instance constant trampling, lichen cover can be dramatically diminished (Crittenden 2000). The most common natural large-scale disturbances in the East Ootsa/Entiako area are fire and mountain pine beetles.

Terrestrial forage lichens appear to respond favourably to fire disturbance. Lichens burn readily, but they also re-establish more rapidly than many of their competitors. Because the landscape is comprised of a mosaic of wetlands, gentle slopes, and eskers, fires in the study area tend to be discontinuous and patchy, leaving localized populations of terrestrial forage lichens undamaged. Those undamaged colonies are sources for re-establishment on burned substrates that lack vegetation. Successional studies in boreal forests indicate that terrestrial forage lichens are a part of a dynamic understory community in post-fire landscapes. A generalized post-fire pattern of succession in boreal ecosystems begins with a *Cladonia* dominated understory community, which is replaced by *Cladina* species after 30-80 years (depending on latitude, climate, and site conditions; Ahti 1977), and eventually by

feathermoss after 150 years or more (Coxson and Marsh 2001). This pattern is moderated by soil moisture: wetter soils progress to the feathermoss stage more rapidly than drier soils. Events that influence soil moisture, therefore, also influence the successional process.

The relationships between mountain pine beetle disturbance and terrestrial forage lichen ecology have not yet been documented and represent a significant gap in our understanding of vegetation dynamics in sub-boreal ecosystems. Furthermore, forest harvesting is now playing an increasing role in creating large-scale disturbances in the area. The implications of forest harvesting on terrestrial lichens has been examined in other regions, but has not been closely investigated in the ecosystems found in the study area.

Dispersion

The genus *Cladina* is capable of reproducing by both sexual and asexual spores; however, most species propagate by thallus fragmentation (Ahti and Hepburn 1967). During dry periods, the thallus of *Cladina* species becomes brittle and susceptible to breakage. Broken fragments are then dispersed by wind or by animal vectors. Wind is considered the dominant dispersal vector in most ecosystems (Ahti and Hepburn 1967); however, a study by Pegau (1970) in Alaska documented the fragmentation and localized dispersion of *Cladina* species by foraging caribou, and Goward (2000) hypothesized that caribou may be responsible for enlarging established lichen colonies by spreading fragments while cratering. With a complex branching system of numerous hooked or pointed branch-tips, a tendency to become brittle when dry, and the ability to reproduce by fragmentation, *Cladina* species appear to be well adapted to dispersion by fur bearing animals. Those same characteristics also give *Cladina* species a high surface area to mass ratio, which render them easily transportable by wind. Regardless of the dispersal mechanism, by wind or by animal, *Cladina* appears to establish most effectively if there is a source population nearby. If the establishment of new populations is a function of the proximity of source populations, then large areas where lichens are absent, such as cutblocks that have been broadcast burned, will recolonize more slowly than smaller or patchier disturbances.

Competition

Lichens compete poorly with vascular plants and mosses, in part because of their slow growth rates. Vascular plants and mosses grow much more rapidly and are able to overgrow adjacent lichen colonies (Ahti and Hepburn 1967). *Cladina,* however, is able to out compete many other lichen genera, including the closely related genus *Cladonia*, especially those that are shorter in stature. The main competitors of terrestrial forage lichens in the study area are:
- kinnikinnick (*Arctostaphylos uva-ursi*);
- red-stemmed feathermoss (*Pleurozium schreberi*);
- crowberry (*Empetrum nigrum*); and,
- twin-flower (*Linnaea borealis*).

There are, however, many other plant species that play a role in restricting the distribution of terrestrial lichens.

Kinnikinnick is a low-growing (less than 10 cm tall in the study area) evergreen dwarf shrub that grows by sending a radial series of horizontal shoots from a central axis. Kinnikinnick is adapted to dry habitats and is intolerant of persistent humidity; it is most commonly found growing on subxeric sites such as south facing slopes, eskers, or outwash plains. On submesic and mesic sites in the study area, kinnikinnick appears to be commonly restricted to growing in the dry zone beneath the cover of canopy trees where rain and snow is intercepted. Where conditions are suitably dry, kinnikinnick is able to out compete terrestrial forage lichens for substrate because of its spreading habit and faster growth rate.

Kinnikinnick is the fastest growing ground cover in the East Ootsa and Entiako areas. We have measured horizontal shoots growing more than 25 cm in a single growing season. By comparison, red-stemmed feathermoss grows up to 1.5 cm/yr and caribou forage lichens grow less than 1.0 cm/yr. There are at least four reasons why kinnikinnick, despite growing rapidly, does not cover the entire forest floor.

1. Kinnikinnick is intolerant of soils with prolonged moisture and does not grow well if soils are too dry. Kinnikinnick grows best on subxeric sites with moderately low soil moisture.
2. Kinnikinnick has a relatively high rate of shoot mortality. Even under favourable growing conditions, approximately 3% of shoots dieback each year. Under more stressful situations, for instance in a sub-mesic cutblock, as many as 17% of shoots dieback each year.
3. Kinnikinnick seeds and rhizomes die at temperatures greater than 80°C, which means that survival is uncommon in areas that have been burned in forest fires.
4. Kinnikinnick seeds disperse by animal vectors and require passage through the gut of an animal before germination can take place. In our study area, kinnikinnick berries are mainly consumed by grouse and bears (thus the common name 'bearberry') (McLean 1967). These vectors disperse kinnikinnick over short to medium distances, but are somewhat inefficient for colonizing large areas, for instance, burned areas measuring tens or hundreds of hectares. Organisms dispersed by wind, such as mosses and lichens, can colonize larger areas more rapidly.

The study area is dominated by morainal till, interspersed with glacio-fluvial deposits. On most till sites, kinnikinnick occurs on dry microsites, often beneath the rain shadow of the tree canopy. With the death of the canopy trees, kinnikinnick may experience increased rates of dieback, at least on till sites where a greater exposure to precipitation and an increasing water table creates conditions that are unfavourable to kinnikinnick. Mesic and submesic sites, which are the most common site types in the study area, are becoming wetter as the water table rises. In effect, kinnikinnick is moving to higher ground, which is spatially restricted. Areas that were too dry in the past, such as tops of eskers, are becoming more favourable as the water table

increases. These dry sites and drier microsites of otherwise mesic sites are the same habitats where lichens tend to grow.

Red-stemmed feathermoss is the most abundant ground cover in the study area. Red-stemmed feathermoss grows well in humid habitats and often dominates submesic to subhygric sites, primarily over till landforms, which account for much of the landscape. On mesic sites, red-stemmed feathermoss can comprise close to 100 % cover and can be up to 15 cm thick earning the nickname 'smother moss'. It grows slowly, approximately 1.5 cm/yr in boreal ecosystems (Ahti 1961), which is still more than twice as fast as most terrestrial lichens. Red-stemmed feathermoss is unable to tolerate dry moisture conditions; however, on drier sites, red-stemmed feathermoss will inhabit humid microsites, such as beneath the cover of a low bush.

Although red-stemmed feathermoss is a prominent component of fire-driven boreal ecosystems, it is not a common post-fire species. Large areas in recently burned ecosystems are relatively dry, owing to the loss of moisture-retaining litter, and provide little in the way of suitable habitat for this moisture-dependent species. Instead, red-stemmed feathermoss is dominant in late successional plant communities where it tends to out-compete species like terrestrial forage lichens that are able to establish earlier. Red-stemmed feathermoss is intolerant of temperatures greater than approximately 80°C, and will perish in most surface fires (Norberg *et al*. 1997). This species frequently inhabits cool, humid microsites and may avoid burning where fires are patchy; however, even if populations survive close to burned areas, re-establishment is dependent upon the development of suitably humid habitats, which often takes up to 100 years or longer. Red-stemmed feathermoss primarily reproduces by indeterminate branching, an inefficient mechanism for dispersing across large areas such as a large fire; however, occasionally this species produces spores through sexual reproduction. Spore production enables red-stemmed feathermoss to disperse over large distances, provided there is suitably humid habitat available for germination and growth.

Crowberry is a low growing (usually less than 25 cm tall in the study area) evergreen shrub that bears numerous short, ascending branches. This shrub is tolerant of cold, nutrient poor soils and it can occur under a broad range of moisture conditions. In several ways, its ecological niche is similar to *Cladina*, but its distribution on a given site appears to be more difficult to predict. Crowberry produces its seeds in a fruit that is consumed by birds and mammals such as grouse, thrushes, foxes, squirrels, and even caribou (Bell and Tallis 1958). The distribution and germination of crowberry seeds may be related to the location of animal droppings; however, the main mechanism for propagation is vegetative layering (Bell and Tallis 1958). Crowberry is most common in subalpine habitats where it can form a near-continuous cover. It is also infrequently found at lower elevations though rarely with the same dominance. Crowberry shoots can elongate up to 10-15 cm per year (Bell and Tallis 1958). Its ascending habit and faster growth rate give it a competitive advantage over terrestrial forage lichens where the two occur together.

Twin-flower (*Linnaea borealis*) is another fast-growing species of ground cover common in the study area. The distribution of this species is patchy; however, it is most common in submesic sites of the SBSmc2 and SBPSmc subzones and appears to be re-establishing on some of the burned plots.

Caribou forage lichen distribution in the East Ootsa and Entiako areas

In the East Ootsa and Entiako areas, terrestrial forage lichens are an important ecological component of an ecosystem largely dominated by red-stemmed feathermoss. Lichens are associated with glaciofluvial landforms: eskers, glacio-fluvial terraces and outwash plains where coarse textured soils allow for rapid drainage. Lichens also occur, though with less abundance, on till parent material, which covers much of the rolling terrain. These landforms are not uniformly distributed across the landscape and sites with high lichen cover are not common, especially in the northern (East Ootsa) part of the study area. In general, lichen dominated stands become more common in the southern (Entiako) portion of the study area.

Most of the forested ecosystems now present on the Nechako Plateau originated from stand initiating fires. After fire, wind blows spores and vegetative fragments of lichens from neighbouring unburned stands, depositing them on unoccupied substrates. Once established, lichen colonies expand slowly, possibly facilitated by localized dispersal by caribou. Competitors such as kinnikinnick, red-stemmed feathermoss, twin-flower, and crowberry gradually become established and progressively displace lichens until the next fire occurs. The establishment of competitors and the subsequent displacement of terrestrial forage lichens is accelerated on moist (submesic or wetter) sites, while on dry sites (subxeric or drier), terrestrial forage lichens may persist without succeeding to red-stemmed feathermoss because of edaphic conditions and relatively frequent surface fires (Cichowski *et al.* 2001).

To understand how terrestrial forage lichens will respond to the mountain pine beetle epidemic and forest harvesting, we examined how these disturbances affect both the lichens and their main competitors: kinnikinnick, red-stemmed feathermoss, crowberry and twin-flower. Changes in understory dynamics are predicted to be highly dependent on the modification of soil moisture conditions, which are expected to become wetter as the water table rises in response to the mountain pine beetle-mediated death of the pine canopy.

LONG-TERM MONITORING

This project was initiated in 2001 and 2005 marks the fifth year of the study, which has documented changes over four growing seasons. We initially expected a response of the forest floor vegetation to take several years and to be difficult to detect; however, dramatic changes were taking places within the first few seasons.

SAMPLING MATRIX

We established 5 to 14 long-term permanent plots for each biogeoclimatic subzone/site series and disturbance type (Table 1). Terrestrial lichen response to forest harvesting and mountain pine beetles depends on competition from other plants and on site type, and may vary between biogeoclimatic subzones due to varying overall site conditions. Therefore, we treated each site series within each biogeoclimatic zone as a separate site. All mountain pine beetle plots were established in red-attacked stands. Originally, half of the mountain pine beetle plots in the East Ootsa area were intended for forest harvesting; however none of the sites have yet been harvested. Because we did not know if and when our plots would be harvested, we also established plots on already harvested sites. We do not have any control sites that lack a disturbance type because all mature pine stands in the study area have been affected by the mountain pine beetle epidemic. In addition, a wildfire in August 2004 burned six of our permanent plots in the East Ootsa area.

Table 1. Number of permanent plots established by biogeoclimatic subzone, site series and disturbance type in the East Ootsa and Entiako areas.				
Study area	**Biogeoclimatic subzone**	**Biogeoclimatic site series**	**Disturbance type**	
			Forest Harvesting	**Mountain Pine Beetles**
East Ootsa	ESSFmc	Subxeric (03)	5[1]	10
	SBSmc2	Submesic (01c)	7 (1)[2]	14 (1)
		Subxeric (02)	5 (1)	10 (3)
	SBSdk	Subxeric (03)	7	7
Entiako	SBPSmc	Subxeric (02)	-	5
		Submesic (01b)	-	5
		Mesic (01a)	-	5

[1] One plot was disctrenched following establishment and was removed from the study since it could no longer be re-established accurately
[2] The number in parentheses indicates the number of the total number of sites that were burned in 2004

ACTIVITIES - YEARS 1 TO 3

During Year 1, we established 65 permanent sample plots in the East Ootsa area in the SBSdk, SBSmc2 and ESSFmc biogeoclimatic subzones and 14 permanent sample plots in the Entiako area in the SBPSmc subzone (Table 1, Williston and Cichowski 2002). For the forest harvesting and mountain pine beetle treatments, we established plots in recent mountain pine beetle attack so that forest harvesting sites could be chosen from all the treatment plots established. However, because forest harvesting treatments was not conducted during winter 2001/02, in 2002,we selected treatments for each permanent plot and marked them accordingly. As of 2005, none of the plots have been harvested.

Basic site information for each 200 m^2 circular plot (7.98 m radius) was collected including GPS location data (UTM coordinates), elevation, slope, aspect, stand age, dbh and a visual estimate of canopy closure; and vegetation cover for shrubs, herbs, bryophytes and lichens was estimated. An oblique photograph of the plot was taken from the south side of the plot. Stand density was recorded by tree species and size, and by status of mountain pine beetle attack for lodgepole pine trees. Coarse and fine woody debris were also measured to assess potential obstruction to caribou mobility.

Terrestrial lichen cover was documented by photographing permanently marked lichen colonies; 6 to 12 photoplots were established in each permanent plot. Since terrestrial lichen growth is affected by competing vegetation such as red-stemmed feathermoss (*Pleurozium schreberi*) and kinnikinnick (*Arctostaphylos uva-ursi*), in addition to the permanent sample plots, at one site we transplanted terrestrial forage lichens to red-stemmed feathermoss colonies, and vice versa, to document competition.

In Year 2, we collected additional information at permanent plots in the East Ootsa area including canopy openness using a fish-eye camera and additional coarse woody debris data, and we marked treatment plots for mountain pine beetle or forest harvesting treatment. Plots selected for forest harvesting were marked with "Machine-free Zone" flagging tape and plots selected for mountain pine beetle treatment were marked with "No Harvesting Zone" flagging tape. Plots established in cutblocks were also marked with "Machine-free Zone" flagging tape. In addition, we collected soil moisture data at SBSmc2/01c plots and established growth rate monitoring sites for terrestrial lichen, red-stemmed feathermoss and kinnikinnick at three SBSmc2/01c sites. For the Entiako area, we also established one more permanent plot in the SBPSmc/02 site series. In the East Ootsa area, one of our ESSFmc/03 harvested plots had been disc-trenched since 2001.

Year 3 (2003) was our first year of resampling permanent plot data. All permanent plots were revisited in both the East Ootsa and Entiako areas. We compared data collected in Year 3 to data collected in Years 1 and 2 to document initial changes due to mountain pine beetle attack and to track changes at already harvested sites (Williston and Cichowski 2004).

In Year 3 (2003/04) we focused on:
- resampling photoplots at all plots in the East Ootsa area and at the transplant site (total - 64 sites) and in the Entiako area (15 sites);
- resampling canopy cover at all plots using a fisheye lens;
- documenting stand density by tree species and size, and by status of mountain pine beetle attack for lodgepole pine trees at plots;
- reestablishing plot centres and photoplot stakes that may have been disturbed;
- resampling coarse woody debris data on all plots and fine woody debris on mountain pine beetle plots ; and,
- remeasuring growth rates of lichens, moss and kinnikinnick at sites established in the SBSmc2/01c.

Preliminary results from Year 3 suggested that the abundance of *Cladina* spp. decreased with a corresponding increase in kinnikinnick (*Arctostaphylos uva-ursi*) and other herbaceous plants (Williston and Cichowski 2004). .

ACTIVITIES – YEAR 5

Year 5 (2005) was our second session of resampling permanent plot data. All permanent plots were revisited in both the East Ootsa and Entiako areas, and in Year 5, we focussed on:
- documenting stand density by tree species and size, and by status of mountain pine beetle attack for lodgepole pine trees at plots – in 2005 all trees >7.5 cm dbh were individually tagged with a number and tree status and dbh were recorded;
- resampling photoplots at all plots in the East Ootsa area and at the transplant site (total - 64 sites) and in the Entiako area (15 sites);
- resampling canopy cover at all plots using a fisheye lens;
- reestablishing plot centres and photoplot stakes that may have been disturbed;
- remeasuring growth rates of lichens, moss and kinnikinnick at sites established in the SBSmc2/01c; and,
- resampling coarse woody debris data on all plots and fine woody debris on mountain pine beetle plots.

We also collected additional stand structure and regeneration information at each plot to contribute to other studies lead by Dr. Dave Coates, Ministry of Forests (Forest Sciences Program Y061148), and Dr. Phil Burton, Canadian Forest Service (Forest Sciences Program Y061184). These are continuing projects so results from those studies will be published in 2007. Already, data from this project has contributed to an assessment of secondary stand structure in lodgepole pine stands affected by the mountain pine beetle epidemic (Coates *et al*. 2006). Stand structure and regeneration data presented in this report provide an overview of the stand and

regeneration characteristics of the plots. A more detailed analysis will be provided by reports published by the continuing studies.

The following sections provide a discussion of methods and results for each component of the study. A more detailed discussion of these results will be included in a final report for Years 1 to 5.

The results reported here cannot be used to describe average conditions for subzones or site series because our sampling was biased towards localities that contained high lichen cover. Although we recognize that choosing sites with high lichen cover is subjective, we feel that these sites can be used to characterize the greatest lichen potential in selected site series of each subzone, and that the patterns observed here can provide insight into what is happening at the landscape level.

STAND STRUCTURE

As the mountain pine beetle epidemic progresses, beetle-killed trees will lose their canopies and eventually blow over. Residual overstory trees will provide some canopy and vertical structure attributes until understory trees or new seedlings form the new canopy. We collected information on stand structure to document changes in overstory and understory composition and to describe residual overstory composition following the mountain pine beetle epidemic.

In 2005, each tree species >1.3 meters in height within the 400 m^2 permanent plot was counted, identified to species, and classified into the following size classes:
- \> 12.5 cm dbh;
- 7.5 – 12.49 cm dbh; and,
- \> 1.3 meters in height to 7.49 cm dbh.

We tagged all trees >7.5 cm dbh individually with a number, measured their dbh, and recorded their status as one of the following categories:
- alive;
- mountain pine beetle – green attack;
- mountain pine beetle – faded (yellow/orange) attack;
- mountain pine beetle – red attack;
- mountain pine beetle – red/grey attack;
- mountain pine beetle – grey; and,
- dead (not due to mountain pine beetle attack).

Trees <1.3 meters in height were counted and classified by species into the following size classes on a 3.99 m radius plot radiating from plot centre of the permanent plot:
- <10 cm in height;
- 10-30 cm in height; and,
- 30-130 cm in height.

Each tree was further classified as acceptable or unacceptable.

In addition, seedlings that established since mountain pine beetle attack within the 3.99 m radius plot were recorded, along with the substrate that they were growing on. Percent cover of each substrate class was then visually estimated for the 3.99 m radius plot. Rare canopy species that were not found on the plot were counted within a 10, 15 or 20 meter radius plot (depending on how close sample trees were to plot centre) and species and dbh was recorded. These data were all collected for Forest Sciences Program Project Y061148 and will be analyzed as part of that project.

The following describes average stand conditions on plots in the various subzone/site series. The intent of the discussion is to provide an overview of stand composition rather than a statistical comparison between site series.

The dominant canopy tree species on all site series was lodgepole pine prior to mountain pine beetle attack (Table 2). Most of the lodgepole pine trees > 7.5 cm dbh on each site series were attacked by mountain pine beetles in 2001; by 2005, additional trees were attacked and the majority of attacked trees were in the "grey attack" phase (Figure 1). By 2005, live trees averaged between 90 and 386 stems/ha with subalpine fir contributing to stand structure on ESSFmc/03 and SBSmc2/01c plots and spruce contributing to stand structure on all plots (Table 2).

Table 2. Average density and dbh of trees >7.5 cm dbh for each species for Mountain Pine Beetle plots in the East Ootsa and Entiako areas in 2005.								
MPB Attack Plots	**Average density (stems/ha)**						**Average dbh (cm)**	
	N^1	**Fir**	**Spruce**	**Pine Not Attacked**	**Pine MPB Attacked**	**Total Live**	N^2	**Live + MPB Attacked**
EAST OOTSA								
ESSFmc/03	10	90	145	80	420	315	147	21.4
SBSmc2/01c	13	42	146	69	607	270	224	21.5
SBSmc2/02	7	0	50	93	585	143	106	21.4
SBSdk/03	7	0	57	329	936	386	185	15.3
ENTIAKO								
SBPSmc/01a	5	0	60	80	660	140	79	20.2
SBPSmc/01b	5	0	60	140	960	200	116	17.6
SBPSmc/02	5	0	10	80	770	90	86	17.1

[1] N=number of plots
[2] N=number of trees

Attacked pine tree were larger than unattacked pine trees in all biogeoclimatic subzones (Figure 2) and the degree of mountain pine beetle attack was generally greater on plots where pine trees were larger (Figure 3). On average, both attacked and unattacked pine trees were largest in the ESSFmc, followed by the SBSmc2, SBPSmc and SBSdk (Figure 2).
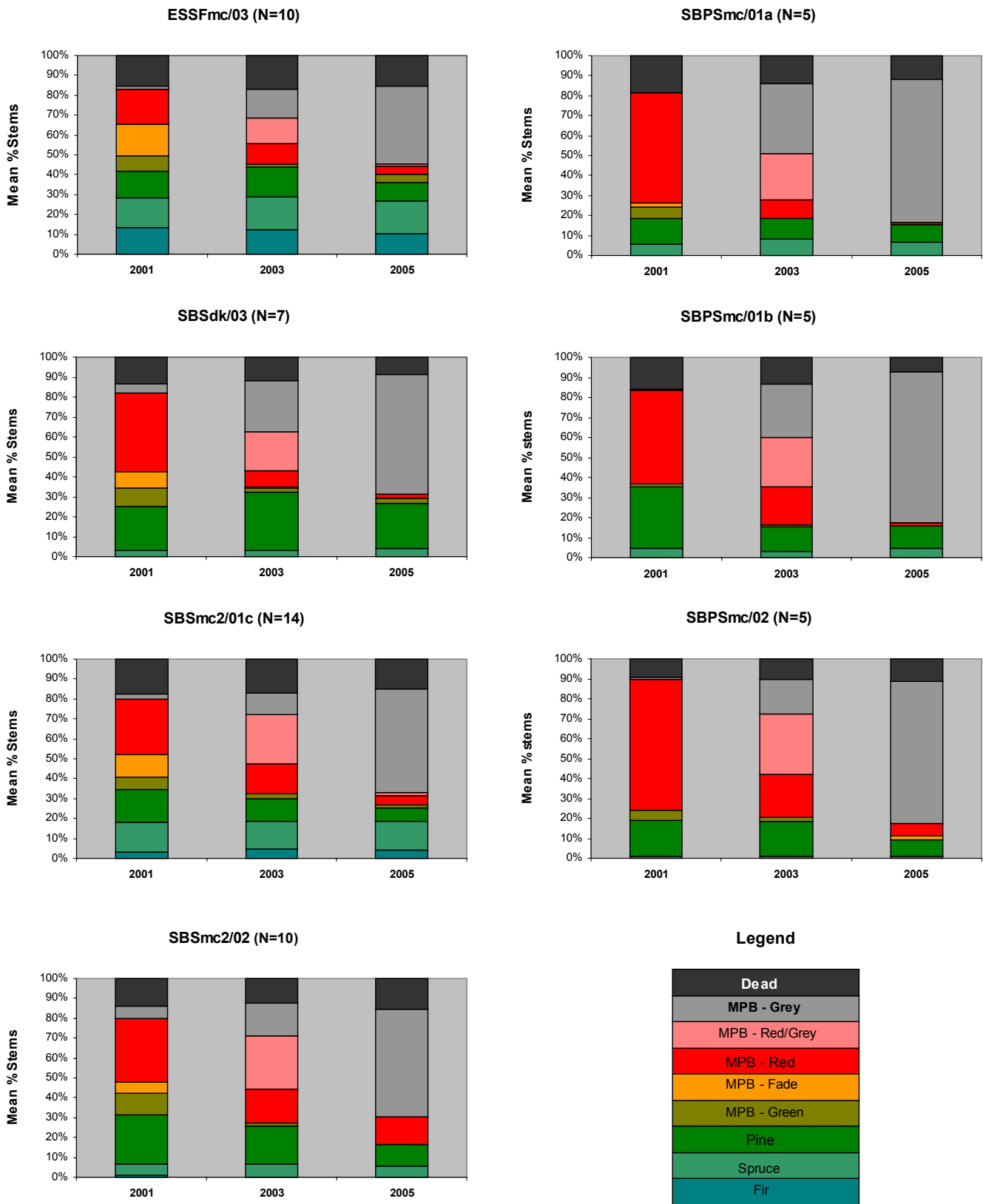
Figure 1. Average percent of trees >7.5 cm dbh in each species and mountain pine beetle attack class by biogeoclimatic subzone/site series in the East Ootsa and Entiako areas in 2001, 2003 and 2005.

Figure 2. Mean dbh (cm) of attacked and unattacked pine trees >7.5 cm dbh in each biogeoclimatic subzone/site series in the East Ootsa and Entiako areas in 2005.

Figure 3. Percent lodgepole pine trees >7.5 cm dbh attacked (based on stems/ha) in each biogeoclimatic subzone/site series in the East Ootsa and Entiako areas by 2005.

Overall, live stem density was lowest in the Entiako area and on SBSmc2/02 sites where lodgepole pine is the dominant species (Table 2). The SBSdk/03 contained the highest average density of live trees > 7.5 cm dbh and the smallest diameter trees. Mean dbh was inversely related to initial stand density (Figure 4), and overall basal area increased as stand density increased (Figure 5). Live stand density in 2005 was related to initial stand density (Figure 6), and final live stand densties in 2005 were generally greater on plots with higher initial proportions of spruce and subalpine fir (Figure 7).

Figure 4. Initial mean dbh versus initial stand density for trees >7.5 cm dbh in each biogeoclimatic subzone/site series in the East Ootsa and Entiako areas.

Natural regeneration was highly variable within and between site series (Table 3). Average understory density on mountain pine beetle plots was highest on ESSFmc/03 plots and lowest on SBPSmc/02 plots. Average understory density generally reflected overstory density with the highest average understory density on mountain pine beetle plots on ESSFmc/03 plots followed by SBSmc2 plots. Both overstorey and understory density was lowest on SBSdk/03 and SBPSmc/02 plots. Natural regeneration on harvested plots was similar or slightly lower than on mountain pine beetle plots, except for on SBSmc2/02 sites where natural regeneration was considerably lower on harvested plots.

Lodgepole pine was the dominant understory tree species on all mountain pine beetle plots except for ESSFmc/03 plots where subalpine fir was dominant and lodgepole pine was the second most prevalent. Subalpine fir was a minor component of the understory on SBSmc2/01c, SBSmc2/02 and SBPSmc/01b plots. Spruce was present on all mountain pine beetle plots and was most prevalent on SBSmc2/01c

plots. Trembling aspen was a significant component of the understory on SBSdk/03 plots and a minor component on SBSmc2/01c, SBPSmc/01a and SBPSmc/01b plots.

Figure 5. Initial live basal area versus initial live stand density for trees >7.5 cm dbh in each biogeoclimatic subzone/site series in the East Ootsa and Entiako areas.
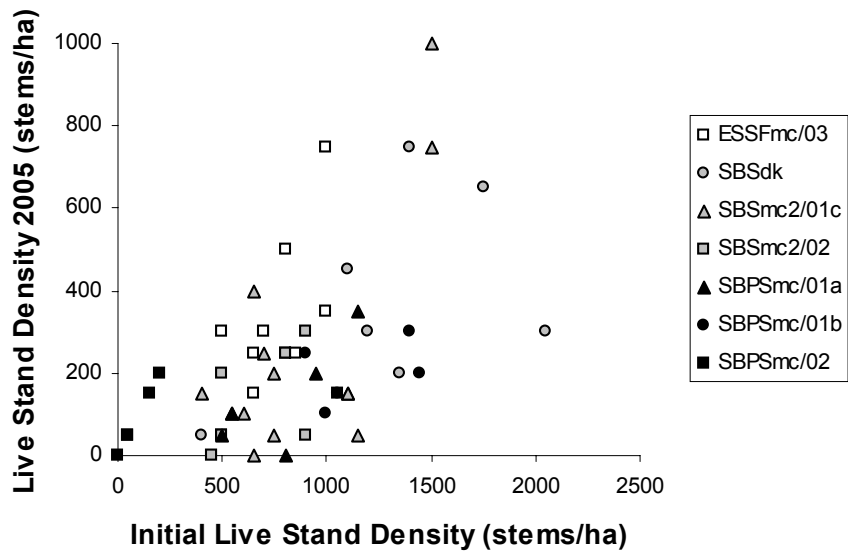
Figure 6. Live stand density in 2005 versus initial live stand density for trees >7.5 cm dbh in each biogeoclimatic subzone/site series in the East Ootsa and Entiako areas.
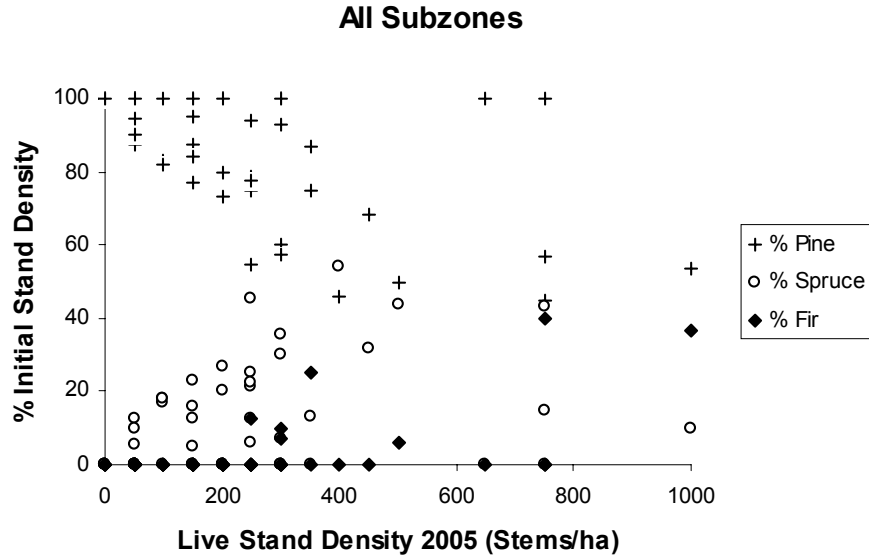
All Subzones

Figure 7. Percent of initial stand density of pine, spruce and subalpine fir versus final live stand density in 2005 for trees >7.5 cm dbh in each biogeoclimatic subzone/site series in the East Ootsa and Entiako areas.

Plots	N	Stems/ha[1]							
		Natural Regeneration						Planted	
		Pine	Spruce	Fir	Aspen	Total	Range	Pine	Spruce
MOUNTAIN PINE BEETLE PLOTS									
ESSFmc/03	10	610	270	2145	0	3025	500-8500		
SBSmc2/01c	13	1442	700	200	88	2431	350-4800		
SBSmc2/02	7	1807	321	236	0	2364	50-5250		
SBSdk/03	7	707	186	0	300	1193	450-2550		
SBPSmc/01a	5	1190	470	0	20	1680	1100-2550		
SBPSmc/01b	5	1070	120	40	40	1270	500-2050		
SBPSmc/02	5	540	10	0	10	560	100-1300		
HARVESTED									
ESSFmc/03	4	2275	0	488	0	2763	1150-6200	800	600
SBSmc2/01c	6	1783	267	100	0	2150	350-7400	333	67
SBSmc2/02	4	513	0	213	0	725	200-1000	550	100
SBSdk/03	7	1200	0	0	14	1214	0-3400		

Table 3. Average density of seedlings (0.1-1.3 m height) and saplings (.1-7.5 cm dbh) combined on plots in the East Ootsa and Entiako areas, 2005.

[1] all saplings in plot counted; seedlings counted in a 3.99 m radius subplot

LICHEN PHOTOPLOTS

Light and nutrient availability and soil moisture are important variables that influence the development of understory vegetation, including terrestrial forage lichens and their competitors. These variables are modified by the condition and composition of the forest canopy. Mountain pine beetle infestations and forest harvesting are two disturbances that dramatically change overstory conditions and therefore initiate changes in the rest of the ecosystem. In 2001, we established permanent photoplots to document the response of the understory plant community to these canopy disturbances, particularly changes in the abundance of the terrestrial lichens.

At each permanent plot, we established 6 to 12 photoplots based on the abundance of lichens. Generally, fewer photoplots were established on plots with lower lichen abundance and more plots were established on plots with greater lichen abundance, with an average of 10 photoplots per site. In total, 771 photoplots were established. For each photoplot, a 75 cm x 75 cm frame was placed around a lichen colony with its sides aligned in the cardinal directions. The frame defined the boundary of the photoplot and provided a scale reference for analysis. The position of the frame was permanently marked with two stainless steel pigtail stakes (marked with flagging tape) in the southwest and northeast corners (Figure 8). Each southwest pigtail was labelled with an aluminum tag that contained the site and photoplot numbers. For each photoplot, we recorded the distance and bearing from the plot centre (of the 7.98 m radius plot) to the southwest corner pigtail stake of the photoplot.

Figure 8. Photoplot with pigtail stakes and labelled tag on the SW corner.

A 35 mm camera with a 28 mm lens was mounted on a tripod and boom and positioned approximately 1.2 m directly over the frame (Figure 9). A small board containing the subzone, site series, site number, photoplot number and date was

placed on the west edge of the frame within the field of view. The camera was consistently aligned so that north was at the top of the viewfinder. If the photoplot was situated beneath a tree, the influence of the tree's canopy and the state of that tree (live; green attack; red attack) was recorded. A visual estimate of terrestrial lichen cover and the cover of the dominant competitors was also recorded for each photoplot in the first year of the study in order to evaluate the quality of the digitally analyzed cover estimates. Photoplots were photographed in 2001, 2003 and 2005.

Figure 9. Photographing a photoplot.

All photographs were taken using 200 ASA film and scanned to high resolution digital jpeg files to be used for image analysis. We analyzed lichen colony percent cover within each frame using the software program Gap Light Analyzer (GLA; Canham 1988). This program was originally designed to determine canopy closure and the amount of light that canopies transmit; however, it could also be used to determine percent cover of objects within photographs. We were not able to analyze terrestrial forage lichens to the level of species because the software could not differentiate lichens to the species level. This technology may improve in the future.

The terrestrial plant communities of the sub-boreal forests are constantly changing. At any one time, species and individual plants and lichens are either

growing and expanding, or dying back. The mountain pine beetle attack has caused a large shift in the growing conditions at the forest floor and this has resulted in a corresponding shift in the dominance of terrestrial species. Plant composition is strongly influenced by site, and we expected (and our data supports the assertion) that responses across site types would vary.

Overall, lichen cover generally decreased on mountain pine beetle plots in the East Ootsa and Entiako areas from 2001 to 2005 (Table 4, Figure 10). The greatest detectible changes in lichen cover documented in the study area were found in the SBPSmc subzone on the 01a and 01b site series. In the SBSmc2 subzone, we documented a significant decrease in lichen cover from 2001 to 2005 on the submesic (01c) site series; in contrast, changes in lichen cover were not significant in the subxeric (02) site series where the variation in response was much greater. There was no detectible change in lichen cover in the SBSdk on the subxeric (03) site series and, although the change in lichen cover in the ESSFmc on the subxeric (03) site series was not significant, a possible positive response is implied in the data. There was no detectible change in lichen cover on harvested plots from 2001 to 2005; however, overall changes were less pronounced than on mountain pine beetle plots (Table 5, Figure 11). On many plots, lichen cover decreased with a corresponding increase in kinnikinnick cover (Figure 12). There did not appear to be a relationship between stand characteristics and change in lichen cover (Figure 13).

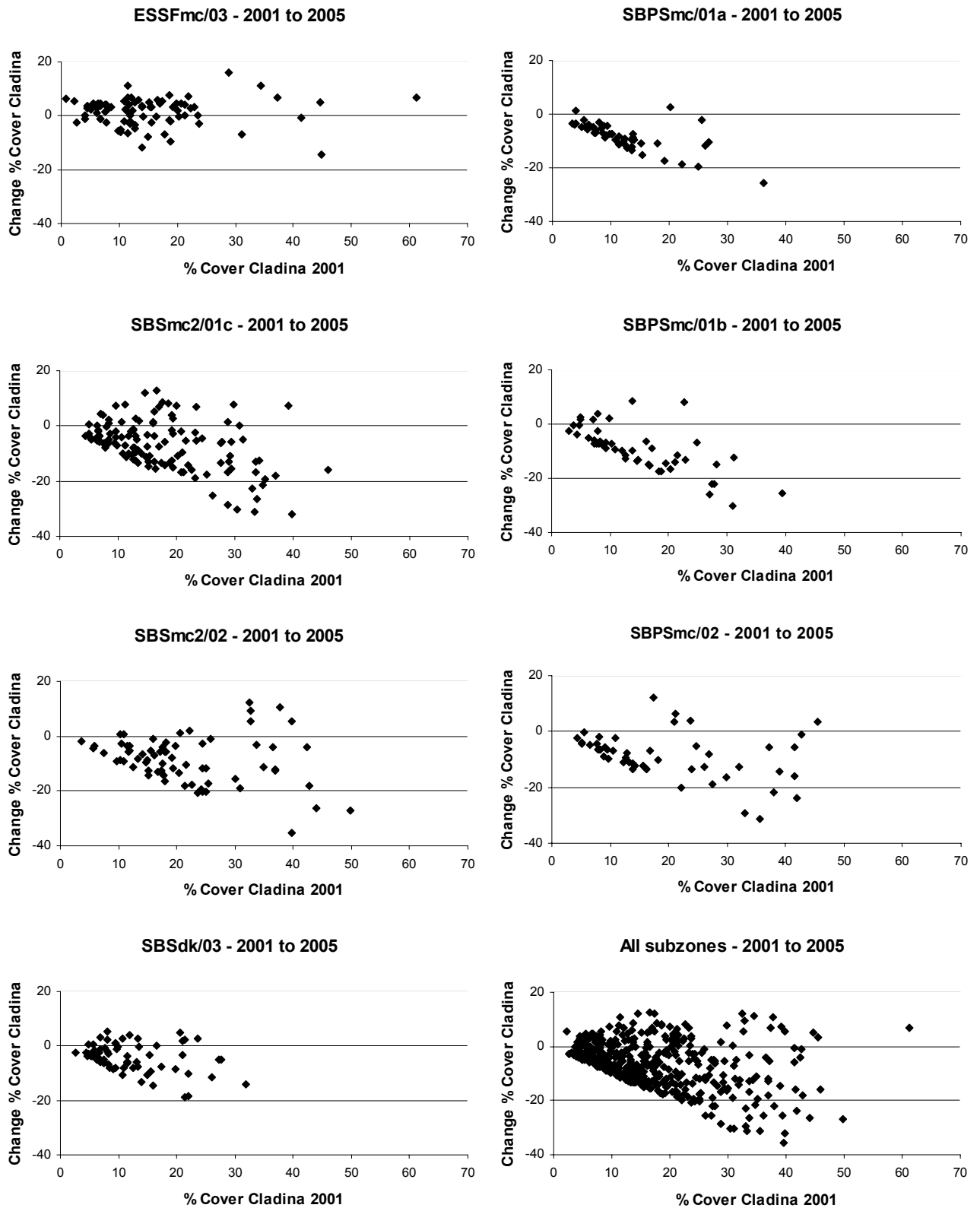| **Table 4. Average lichen cover of mountain pine beetle plots in 2001 and change in lichen cover until 2003 and 2005 plots by biogeoclimatic subzone/site series in the East Ootsa and Entiako areas.**							
Site	**Year**	**Value**	**% Cover Cladina**	**SE**	**t value**	**Pr(>|t|)**	**Significance**
ESSFmc-03	2001	average	15.61	1.67			
	2003	change	1.10	2.37	0.46	0.65	
	2005	change	1.38	2.37	0.58	0.56	
SBSdk-03	2001	average	11.83	1.65			
	2003	change	-3.04	2.33	-1.30	0.21	
	2005	change	-4.20	2.33	-1.80	0.09	
SBSmc2-01c	2001	average	17.65	1.36			
	2003	change	-4.73	1.92	-2.46	0.02	*
	2005	change	-7.03	1.92	-3.66	<0.01	***
SBSmc2-02	2001	average	21.28	2.29			
	2003	change	-6.03	3.24	-1.86	0.08	
	2005	change	-10.18	3.24	-3.14	<0.01	**
SBPSmc-01a	2001	average	12.43	1.04			
	2003	change	-5.34	1.48	-3.62	<0.01	**
	2005	change	-8.59	1.48	-5.82	<0.01	***
SBPSmc-01b	2001	average	14.60	1.86			
	2003	change	-5.81	2.64	-2.21	0.05	*
	2005	change	-9.09	2.64	-3.45	<0.01	**
SBPSmc-02	2001	average	19.85	3.40			
	2003	change	-5.58	4.81	-1.16	0.27	
	2005	change	-8.83	4.81	-1.84	0.09	

Figure 10. Change in % cover *Cladina* from 2001 to 2005 on mountain pine beetle plots in the East Ootsa and Entiako areas.

Table 5. Average lichen cover of logged plots in 2001 and change in lichen cover until 2003 and 2005 plots by biogeoclimatic subzone/site series in the East Ootsa area.							
Site	**Year**	**Value**	**% Cover Cladina**	**SE**	**t value**	**Pr(>|t|)**	**Significance**
ESSFmc-03	2001	average	14.256	2.13			
	2005	change	5.33	3.19	1.67	0.14	
SBSdk-03	2001	average	14.33	2.61			
	2005	change	-1.94	3.70	-0.52	0.61	
SBSmc2-01c	2001	average	13.70	1.84			
	2005	change	-0.07	2.61	-0.03	0.98	
SBSmc2-02	2001	average	22.03	4.56			
	2005	change	1.44	6.45	0.22	0.83	

LIGHT AVAILABILITY

Canopy trees regulate the light available to understory plant communities. In the study area, mountain pine beetles have killed a high proportion of the canopy trees. Canopy tree mortality will result in changing light conditions in the understory, especially once the dead canopy trees defoliate and eventually fall to the ground. We used fisheye photographs of the canopy, a standard approach that has been well-documented in the literature (Canham 1988), to quantify the change in light availability in beetle-killed stands and in harvested sites.

A canopy photograph was taken at each 7.98 m radius permanent plot centre using a fisheye lens on a 35 mm camera with 400 ASA film. The camera was mounted on a tripod 1.2 m above the ground and oriented so that the top of the camera was pointed north. Photographs were taken in 2002 (except the SBPSmc sites), 2003 and 2005. The software program Gap Light Analyzer version 2 (GLA; Canham 1988) was used to determine the percent transmission of light through the canopy.

Although canopy openness and light availability have increased on most plots, there doesn't seem to be any significant relationship between these two variables and change in lichen cover (Figure 14). More dramatic differences will become apparent once the dead canopy trees begin to fall over, since snags alone have been shown to cast substantial shade in the understory.

ESSFmc/03 - Logged - 2001 to 2005

SBSmc2/01c - Logged - 2001 to 2005

SBSmc2/02 - Logged - 2001 to 2005

SBSdk/03 - Logged - 2001 to 2005
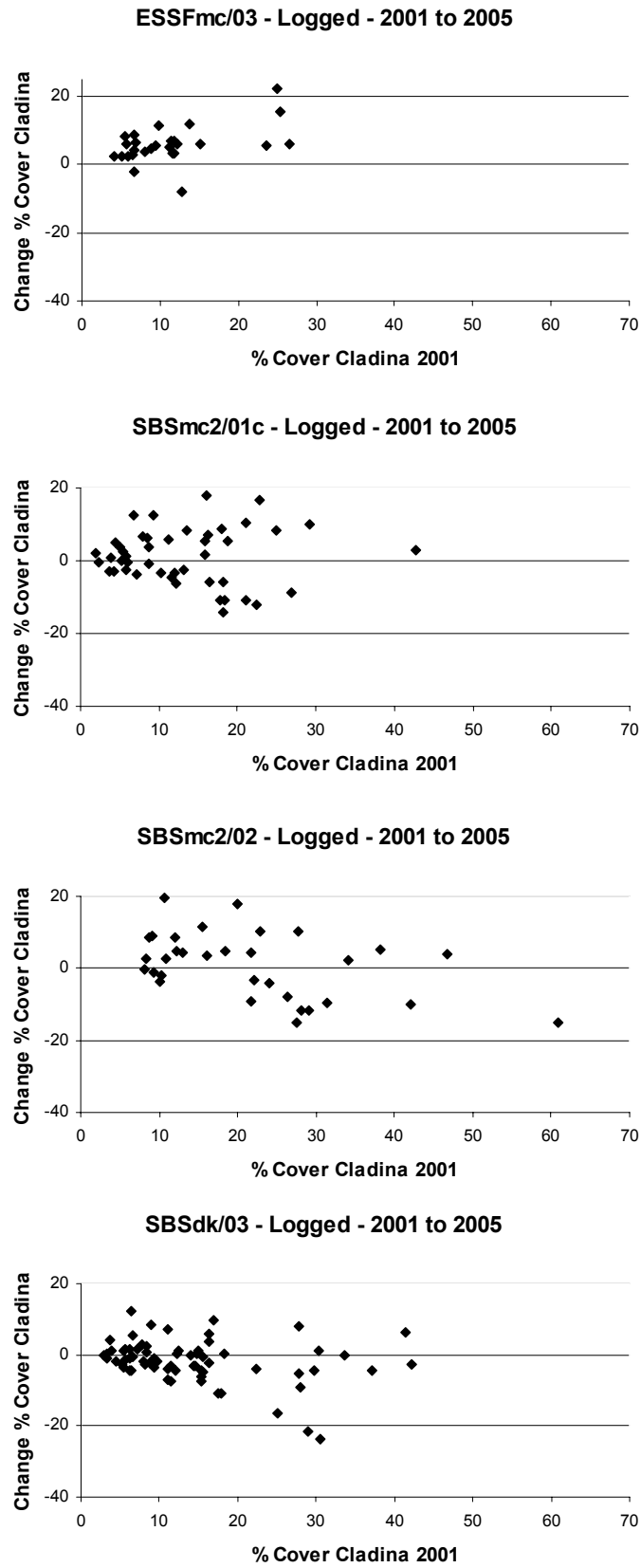
Figure 11. Change in % cover *Cladina* from 2001 to 2005 on logged plots in the East Ootsa area.

Figure 12. Change in *Cladina* and kinnikinnick cover from 2001 (top) to 2003 (middle) to 2005 (bottom) for Photoplot 5 of mountain pine beetle plot SBPSmc/01b-C05 in the Entiako area.

All subzones

All subzones

All subzones

Figure 13. Change in % cover *Cladina* from 2001 to 2005 in relation to changes in stand structure on mountain pine beetle plots in the East Ootsa and Entiako areas.

All subzones

All subzones

Figure 14. Change in % cover *Cladina* from 2001 to 2005 in relation to change in canopy openness and light availability on mountain pine beetle plots in the East Ootsa and Entiako areas.
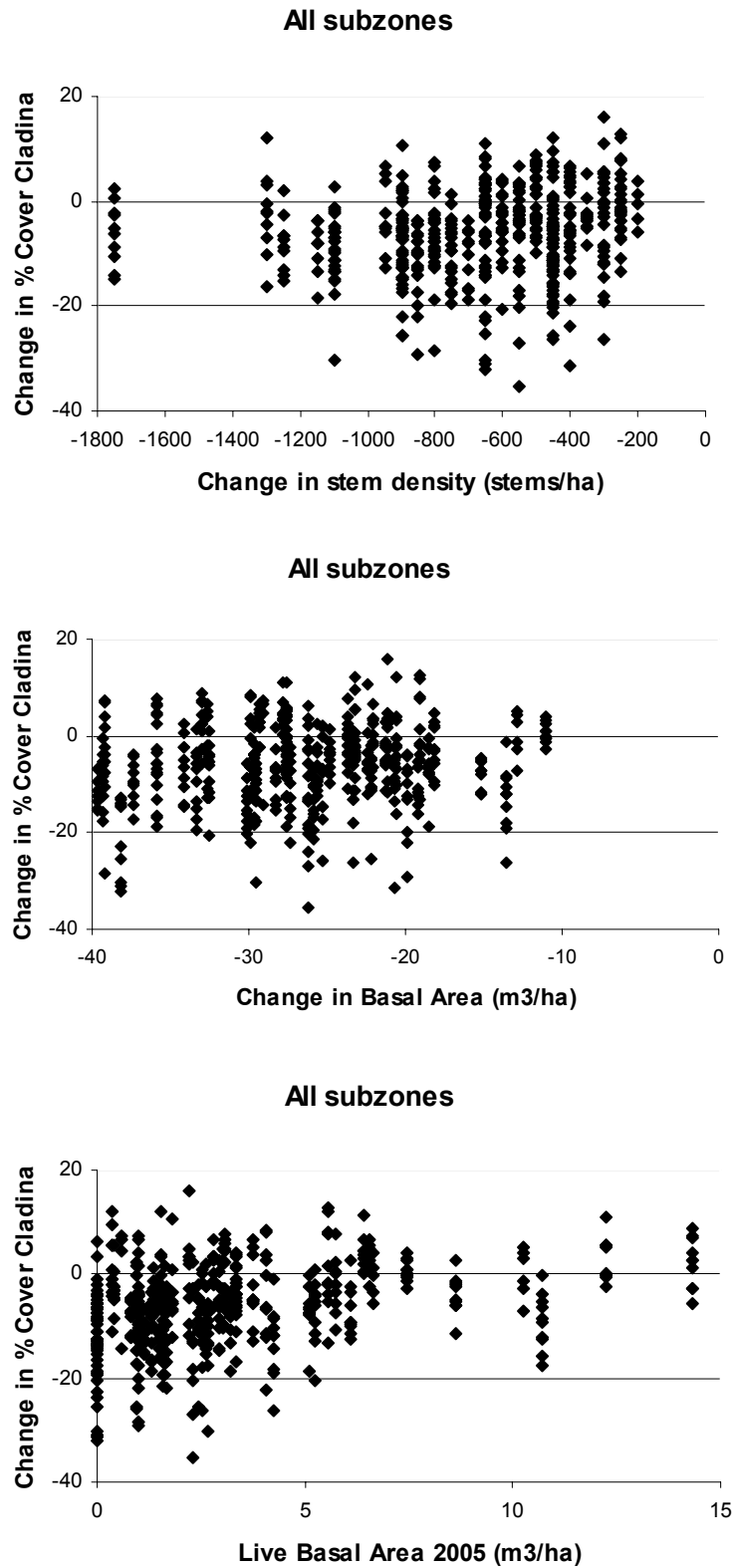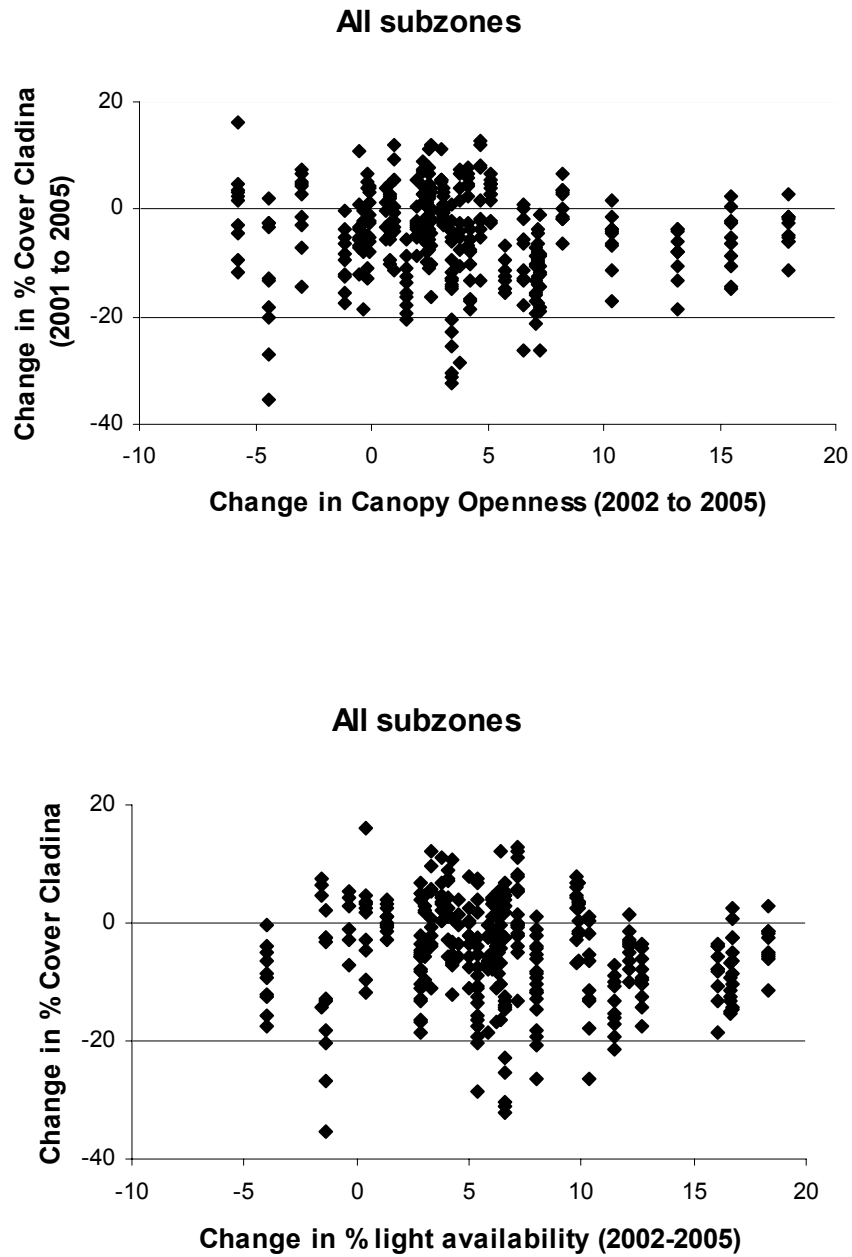
TRANSPLANT EXPERIMENT

Several studies suggest that red-stemmed feathermoss replaces terrestrial forage lichens in the successional progression of North American boreal and sub-boreal forests; however, most studies are based on chronosequence plots that replace space for time (Harris 1996; Coxson and Marsh 2001). To our knowledge, there have been few studies that have documented this pattern using repeated observations. As part of our study, we transplanted terrestrial forage lichens into red-stemmed feathermoss colonies, and red-stemmed feathermoss into lichen colonies to document competitive interactions over time and to observe the replacement of lichens by feathermosses.

We established five replicates of lichen/moss transplants at a single SBSmc2/01c site that supported large colonies of both terrestrial forage lichens and red-stemmed feathermoss. The transplant site was situated on a glacio-fluvial bench with well-drained soils and a relatively open lodgepole pine canopy (15% closure) with about an initial 35% mortality due to mountain pine beetles. Transplants were removed from single species colonies using a 19.5 cm diameter cylinder and were placed into a hole of the same dimension surrounded by either the competing species or by the original transplanted species (Figure 15). Each replicate included the following:

- a lichen transplant to a lichen colony;
- a lichen transplant to a red-stemmed feathermoss colony;
- a red-stemmed feathermoss transplant to a lichen colony; and,
- a red-stemmed feathermoss transplant to a red-stemmed feathermoss colony.

Figure 15. A transplant of *Cladina* to a red-stemmed feathermoss colony.

We conducted 20 transplants in total with four transplants per replicate and five replicates. Transplants were removed and re-placed into their parent colony to test if there was a transplanting effect.

Each transplant was photographed within a 50 cm x 50 cm frame, which was used as a reference for scale. Stainless steel pigtail pins were used to mark the centre of each transplanted colony to facilitate the re-establishment of photo-centres in future years. Photographs were analyzed for percent cover using the image analysis Gap Light Analyzer version 2 software. Comparisons were made of the percent cover for controls and treatments for the years 2001 to 2005.

In 2001 we predicted that without a transplant effect (the effect of removing and replacing transplants of mosses and lichens), red-stemmed feathermoss would respond favourably to the change in conditions brought upon by the mountain pine beetle epidemic, and would out compete terrestrial forage lichens. The opposite pattern, lichens out competing red-stemmed feathermoss, would imply that the successional sequence described in the literature (from lichen to moss) may not be as straightforward as previously believed and may include cycles of retrogression when microclimatic conditions change to favour lichens. An absence of changes among the transplants would suggest that the process of initial establishment may be more important than later competitive interactions, or that microsite differences possibly over-ride competition in determining plant community composition.

The cover of the transplanted mosses and lichens over four growing seasons are presented in Figure 16. While not significant, the data indicates that a transplant effect may have influenced the cover of mosses and lichens in the first year (2001). The cover of moss appeared to be greater than lichen as a result of transferring transplants from one colony to the other (moss 2001=lichen 2001 p= 0.07). This may reflect differences in morphology among red-stemmed feathermoss and *Cladina* (spreading versus upright) in addition to structural differences (moss remains spreading and pliable when dry, while lichens become somewhat compact and brittle).

Recognizing the possibility of a transplant effect, the cover of moss has changed little (moss 2003=moss 2005 p= 0.15), while the cover of lichen has diminished, especially in the last two years (lichen 2003=lichen 2005 p= 0.04). The period between 2003 and 2005 corresponds to needle loss in the canopy and a suspected rise in the water table. If we are able to continue following these plots, we expect the cover of red-stemmed feathermoss to continue to expand, and the cover of lichen to continue to diminish. Following these plots would provide further support for the patterns that we have observed in the submesic photoplots throughout the study area; i.e. the replacement of caribou forage lichens by red-stemmed feathermoss.
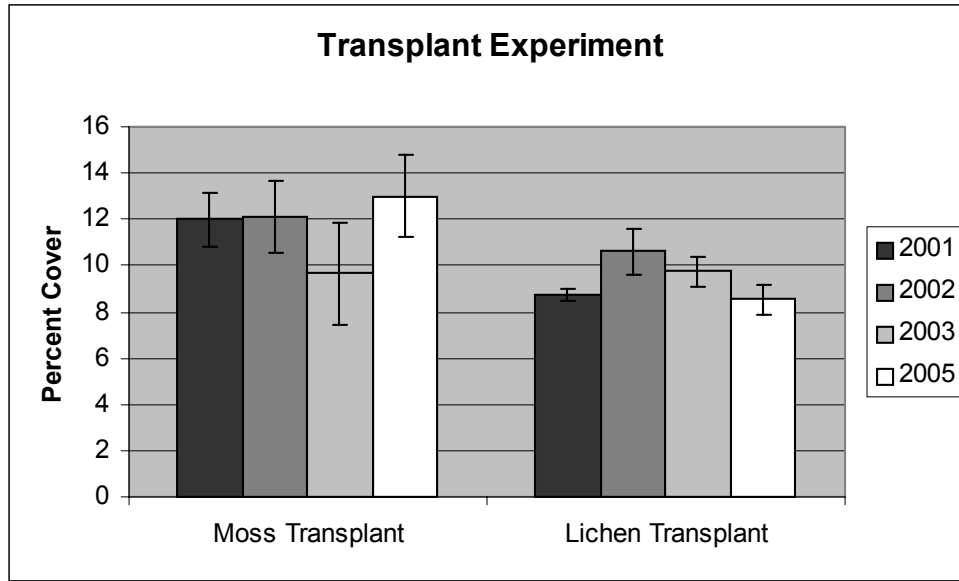
Figure 16. Percent cover of red-stemmed feathermoss and caribou forage lichens in transplanted photoplots on an SBSmc2/01c site in the East Ootsa area from 2001 to 2005.

In 2003, there was an apparent dip in the cover of red-stemmed feathermoss, a reflection of the influence in the needle cast on the cover of feathermoss. At this time, several moss transplants were covered in needles; however, by 2005, the mosses grew over the needle litter and even expanded into the surrounding lichen colonies, indicating a trend of increasing cover over time.

KINNIKINNICK PHOTOPLOTS

Kinnikinnick is a dominant terrestrial species in the East Ootsa and Entiako areas and is a significant component on drier sites throughout the boreal and sub-boreal northern hemisphere. Kinnikinnick competes with terrestrial lichens for forest floor substrate; therefore, factors determining its distribution are of particular interest for managing caribou habitat. During our field studies in the submesic forests of the East Ootsa and Entiako areas we noticed that kinnikinnick was primarily distributed beneath the cover of canopy trees and was sparse or absent from the surrounding forest floor matrix. We hypothesized that kinnikinnick is restricted to the rain-shadow of trees in the submesic SBSmc2 forests because it is intolerant of prolonged wet soils. This may be a function of the edaphic limitations of kinnikinnick's associated mycorrhizal fungi (i.e. a sensitivity to soil moisture).

In Year 2 (2002) we established 5 photoplots on a morainal till, submesic (SBSmc2-01c) site where kinnikinnick was confined to growing under the rainshadow of the canopy trees. Kinnikinnick was growing well on these dry

microsites, forming more than 50% cover in each photoplot. Each photoplot was situated beneath a lodgepole pine tree killed by mountain pine beetles. We established these photoplots as a way to monitor the fate of kinnikinnick colonies living in submesic sites beneath dying canopy trees, and to better understand the factors influencing the distribution of kinnikinnick in the study area. Photoplots were photographed in 2002, 2003 and 2005. Canopy photographs were taken in 2003 and 2005 above each photoplot to document canopy openness and to determine if changes in kinnikinnick cover was linked to changes in canopy openness.

Repeated measurements of kinnikinnick photoplots beneath beetle-killed canopy trees revealed a significant (p=0.03) decrease in kinnikinnick cover between 2003 and 2005 (Figure 17). During this time, the average canopy openness increased from 25% to 28% but the change was not significant (p=0.15). The cause of the change in kinnikinnick cover remains inconclusive and is probably not attributable to the relatively small change in canopy openness. The cause of the kinnikinnick decline in these photoplots is more likely linked to the landscape level increase in the water table, which is particularly noticeable over morainal till landforms, and includes the site where these photoplots were established. On many till sites, ponded water appeared in 2005 in places that did not have water in previous years. Our study did not measure water table depth; therefore, we cannot confirm this cause for the observed decline in kinnikinnick cover. However, we suspect that an increase in water table is the key environmental factor driving observed changes in the understory vegetation.
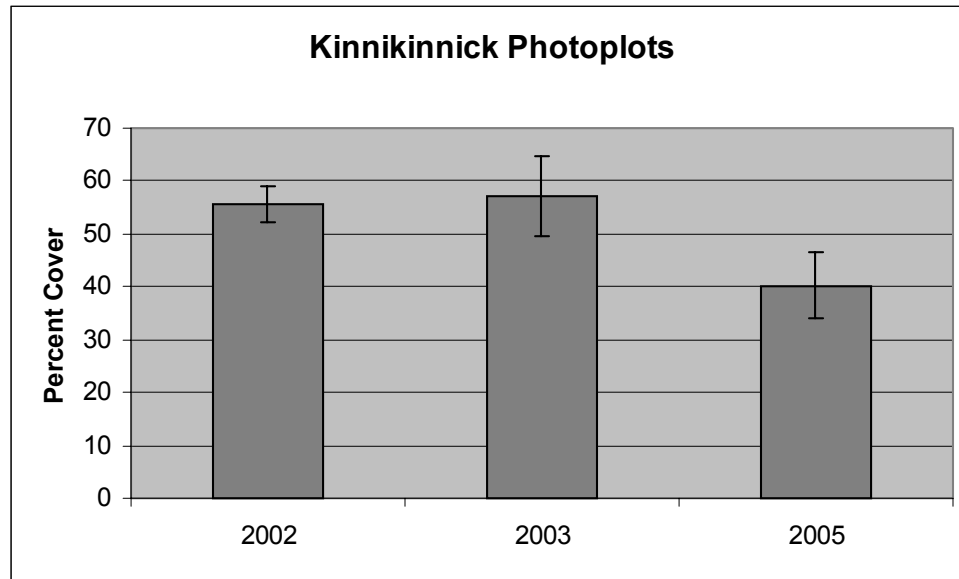

Figure 17. Percent cover of kinnikinnick under mountain pine beetle-killed canopy trees on an SBSmc2/01c site in the East Ootsa area from 2002 to 2005.
N=5 for each year.

GROWTH RATES

Competition is one of the most important determinants in the distribution of terrestrial forage lichens in the study area. Competition among forest floor species is closely linked to their differential growth rates, which change when microsite conditions are altered, such as changes imposed mountain pine beetle infestation or forest harvesting. To gain a better understanding of this competitive process, we initiated a monitoring project to determine the growth rates of *Cladina,* red-stemmed feathermoss and kinnikinnick in harvested areas, under the tree canopy and in canopy gaps.

In 2002 we selected three sites within the SBSmc2 submesic (01c) site series to conduct the growth rate experiment. At each site we tagged 5 red-stemmed feathermoss and 5 *Cladina* stems, as well as 5 kinnikinnick shoots under three microsite conditions: a canopy gap, under a canopy tree, and in a harvested area. In total, there were 15 tagged shoots per species per microsite type. Each moss and lichen was marked 10 mm from the tip with a black nylon thread and individually numbered with flagging tape attached to the free end of the thread. Growth was measured by measuring the length from the thread to the tip of the longest shoot and subtracting 10 mm. In a few instances, tagged mosses and lichens were broken or otherwise lost, and new plants were tagged. Shoots that had died were not replaced. For kinnikinnick, we marked 5 of the longest shoots in each microsite (under the canopy, in a gap and in a cutblock). Each shoot was measured from the branch-tip to the last bud-scar to quantify only the present year's growth. In subsequent years we continued to choose the longest shoot of each plant, however, several plants died over the span of the study and were not replaced with new plants.

Growth was re-measured in 2003 and 2005. The annual growth of Cladina and red-stemmed feathermoss between 2002 and 2003 was simply the length from the thread to the tip minus one. Average annual growth for 2004 and 2005 was calculated using the following formula:

$$\frac{(\text{Shoot Length 2005}) - (\text{Shoot Length 2003})}{2}$$

A comparison of growth rates of red-stemmed feathermoss and *Cladina* is provided in Figure 18 and kinnikinnick growth is shown in Figure 19. The only significant difference between 2003 and 2004/05 was the growth of red-stemmed feathermoss under the mountain pine beetle-killed canopy. The growth rate for moss on this microsite increased from 4.6 mm/yr in 2003 to 8.9 mm/yr in 2004 and 2005 ($p= 0.0002$), the same rate of growth as found under a canopy gap (8.9 mm/yr for both 2003 and 2004-5). This suggests that growing conditions under a dead canopy tree have shifted to approximate conditions found in a canopy gap, at least for red-stemmed feathermoss.

Growth of *Cladina* beneath dead canopy trees suggests a decrease in growth rate from 2003 to 2004/05 ($p=0.08$). Though the relationships are weak, it is possible that

kinnikinnick may also be experiencing a reduced growth rate under mountain pine beetle-killed canopy trees (p=0.19), while red-stemmed feathermoss may be increasing in growth in cutblocks (p=0.17). On most sites, red-stemmed feathermoss experiences die-back or reduced growth after forest harvesting, a result of the sudden exposure to high light levels and a reduction in forest floor humidity. Our study shows a possible increase in moss growth in a recently opened cutblock, which suggests that the effects from exposure may be ameliorated by a potential landscape level increase in water table.
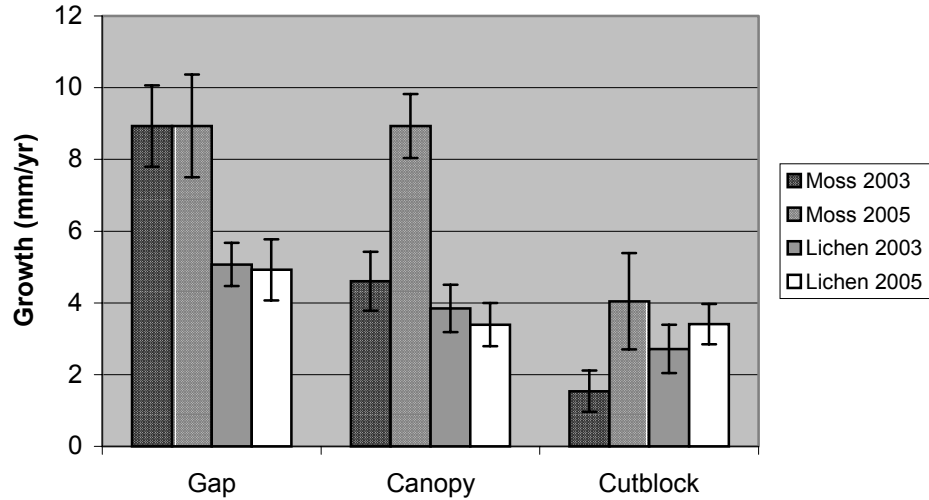

Figure 18. Growth rates for red-stemmed feathermoss and Cladina in a gap, under a canopy tree and in a cutblock from 2002 to 2005 on an SBSmc2/01c site in the East Ootsa area.
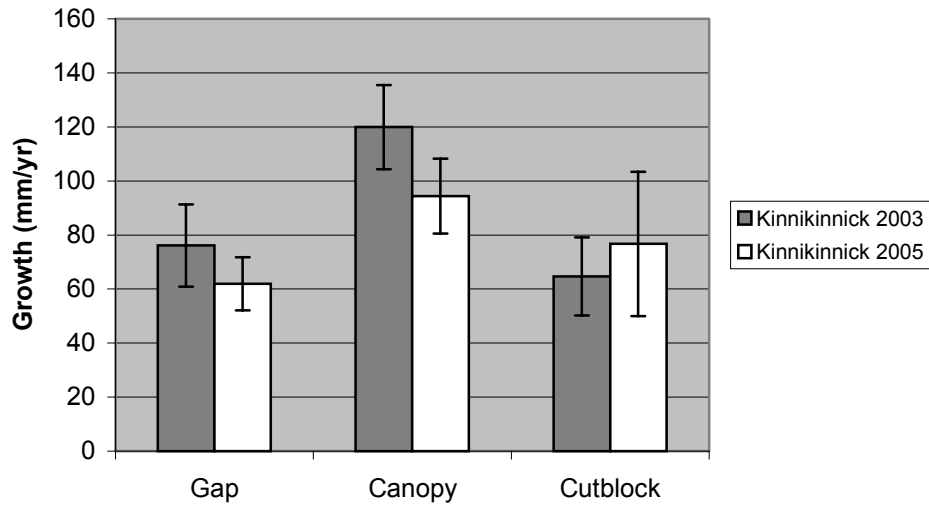

Figure 19. Growth rate of kinnikinnick in a gap, under a canopy tree and in a cutblock from 2002 to 2005 on an SBSmc2/01c site in the East Ootsa area.

The growth rate of kinnikinnick is an order of magnitude greater than rates for mosses or lichens (approximately 80 mm/yr versus 8 mm/yr); however, kinnikinnick also has a high rate of mortality, which may explain why it does not completely displace its diminutive forest floor competitors. In cutblocks, 53% of tagged kinnikinnick plants died between 2002 and 2005. In canopy gaps and beneath beetle-killed trees, 13% of plants died over the same time period. In comparison, lichen mortality was not found on any sites (though some lichens experienced broken branches), and red-stemmed feathermoss death was only observed on cutblocks (33% mortality over 3 years).

COARSE WOODY DEBRIS

In addition to changes in caribou terrestrial forage lichen abundance, disturbances such as forest harvesting and mountain pine beetles could impact caribou habitat use by making it difficult for caribou to travel through the area. Movement could be restricted either because of potential increased snow depths and/or changes in snow conditions due to reduced canopy interception, or because of increased accumulation of coarse woody debris on the ground. At harvested sites, increased accumulation of coarse woody debris is the result of slash left on the site. At mountain pine beetle attack sites, increased accumulation of coarse woody debris is the result of eventual blowdown of beetle-killed trees. In our study, we measured coarse woody debris to document potential obstructions to caribou movement (mobility) on each site.

Coarse and fine woody debris measurements were adapted from Trowbridge *et al*. (1986) and from the Field Manual for Describing Terrestrial Ecosystems (B.C. Ministry of Environment, Lands and Parks and B.C. Ministry of Forests 1998). In 2001, bearings for two transects 30 meters in length were selected randomly and transects originated at the plot centre. The bearing for the second transect was located at least 80° from the first bearing to avoid encountering the same pieces on the second transect. Occasionally, on sites of limited size, several random bearings had to be tested to determine whether a transect still represented the site along its full length. On some sites, transects were terminated at distances less than 30 meters and in 2 cases, only one transect was established. For each transect, the number of pieces were recorded for the following diameter classes and transect distances:
- 0-0.5 cm diameter from 0-5 meters;
- 0.6-1.0 cm diameter from 0-10 meters;
- 1.1-3.0 cm diameter from 0-15 meters;
- 3.1-5.0 cm diameter from 0-20 meters;
- 5.1-7.0 cm diameter from 0-25 meters; and,
- >7.0 cm for all 30 meters.

For all coarse woody debris pieces >7.0 cm in diameter, we measured the diameter using callipers and recorded distance from plot centre, decay class, length class, and mobility class.

Decay classes included:
- 1: log hard; bark, branches, and twigs <3cm still present;
- 2: log hard to partly decaying; bark and some branches still present;
- 3: log hard to partly decaying and round; trace of bark still present;
- 4: all of log on ground and sinking; bark absent;
- 5: all of log on ground and partly sunken; oval; and,
- 5+: all of log mostly sunken; overgrown by moss; part of forest floor.

Length classes included:
- 1: <2 meters;
- 2: 2-5 meters;
- 3: 5-10 meters; and,
- 4: >10 meters.

Mobility classes included:
- 0: top side of log <10 cm above ground; log mostly part of forest floor;
- 1: top side of log 10-40 cm above ground; log mostly branch free;
- 2: top side of log or branches 40-100 cm above ground; scattered branches;
- 3: top side of log or branches 40-100 cm above ground; dense branches, or top side of log >100 cm above ground (log mostly branch free); and,
- 4: top side of log or branches >100 cm above ground; dense branches with branches reaching down to the ground if log is raised off the ground.

Mobility classes were determined for the condition of the log at the point of intersection with the transect. A mobility index was calculated for each log as the length class multiplied by the mobility class.

$$\text{Mobility index (MI)} = \text{Length class} \times \text{Mobility class}$$

The mobility index provides the relative contribution of each piece of coarse woody debris to mobility obstructions on the plot. The mobility index for the plot was calculated as the sum of mobility indices for all logs on the plot.

Volume, mass and density (pieces/ha) of coarse woody debris were calculated using the CWD/Fuel Calculator Version 1.0a (Ministry of Forests 1997). Volume and mass were calculated using the Fuel Loading Assessment module, and density (pieces/ha) was calculated using the Coarse Woody Debris Assessment module. The Coarse Woody Debris Assessment required piece lengths so the midpoints of the first 3 length classes were used (Class 1 [0-2 m]: 1 m; Class 2 [2-5 m]: 3.5 m; and, Class 3 [5-10 m]: 7.5 m). For Class 4 (> 10 m), an average tree height of 15 m was estimated and used.

In Year 5, we re-measured coarse and fine woody debris only along transects at mountain pine beetle attack plots. Coarse and fine woody debris on harvested plots were re-measured only the two harvested plots that were burned.

Coarse woody debris volume, mass and density for mountain pine beetle plots were similar for all 3 years sampled on all biogeoclimatic subzones/site series (Figure 20). Overall, coarse woody debris volume and mass increased slightly and number of pieces decreased slightly; however, these difference were not significant, indicating that blowdown of mountain pine beetle attacked trees is not yet occurring on a large scale. Coarse woody debris volume and mass was generally greatest on ESSFmc plots, followed by SBSmc2 and SBSdk plots. There does not appear to be any relationship between coarse woody debris density and initial stand density; however, coarse woody debris volume appears to generally increase as initial stand basal area increases (Figure 21).

Decay Class and Mobility Class of coarse woody debris pieces indicate that most coarse woody debris pieces are presently in the later stages of decay and have little effect on mobility with most pieces in Decay Class 5 and Mobility Class 1 or 0 (Figure 22). There appears to be a slight increase in Decay Class 1 (fresh blowdown) and a slight decrease in Decay Class 5 (later stage of decay) from 2001 to 2005, suggesting that a limited amount of blowdown is occurring, and that pieces in late stages of decay are being incorporated into the forest floor.

The Mobility Index pattern appears to be similar to the pattern of volume and mass of coarse woody debris, except on ESSFmc plots (Figure 23). Mobility Index on ESSFmc plots is lower than on SBSmc2/01c plots, whereas volume and mass are higher, suggesting that elevation of coarse woody debris on ESSFmc plots is generally low. Mobility Index has also increased slightly from 2001 to 2005 on all biogeoclimatic subzones/site series and was generally lower on logged plots than on mountain pine beetle plots in 2001 (Figure 24).

Coarse woody debris volume, mass and density was generally greater on logged plots than on mountain pine beetle plots in 2001 (Figure 25). This was in contrast to Mobility Index, which was greater on mountain pine beetle plots. The difference is likely due to shorter piece lengths on logged plots, which results in a lower Mobility Index.

Currently, the amount of coarse woody debris is generally low on all sites and is not enough to impede animal movements. On mountain pine beetle-killed sites, coarse woody debris is expected to increase as mountain pine beetle-killed trees blow over. Although we do not have predetermined mobility index thresholds, we will develop those thresholds as blowdown increases.
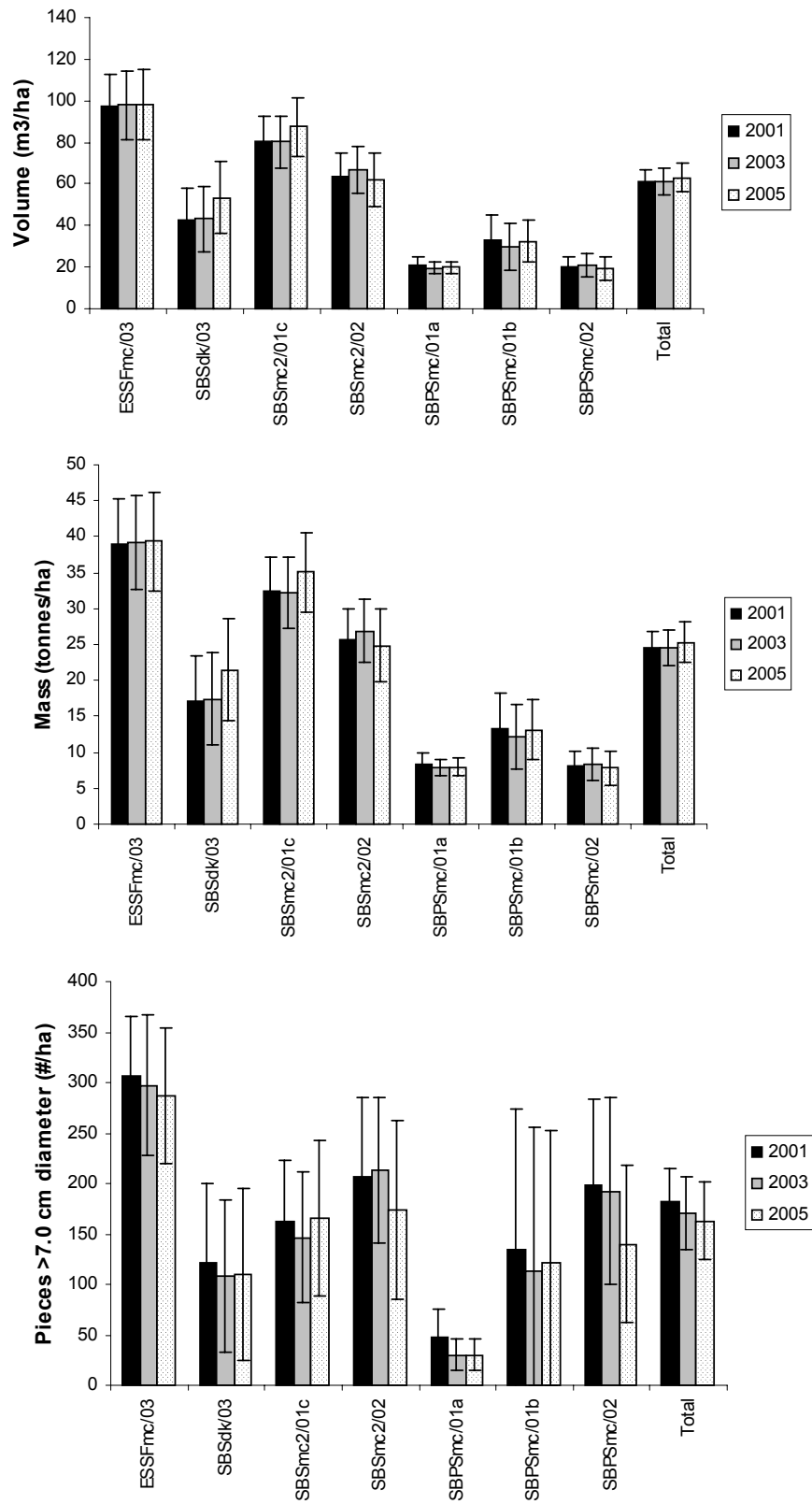
Figure 20. Mean volume, mass and pieces of Coarse Woody Debris by biogeoclimatic zone and year in the East Ootsa and Entiako areas.
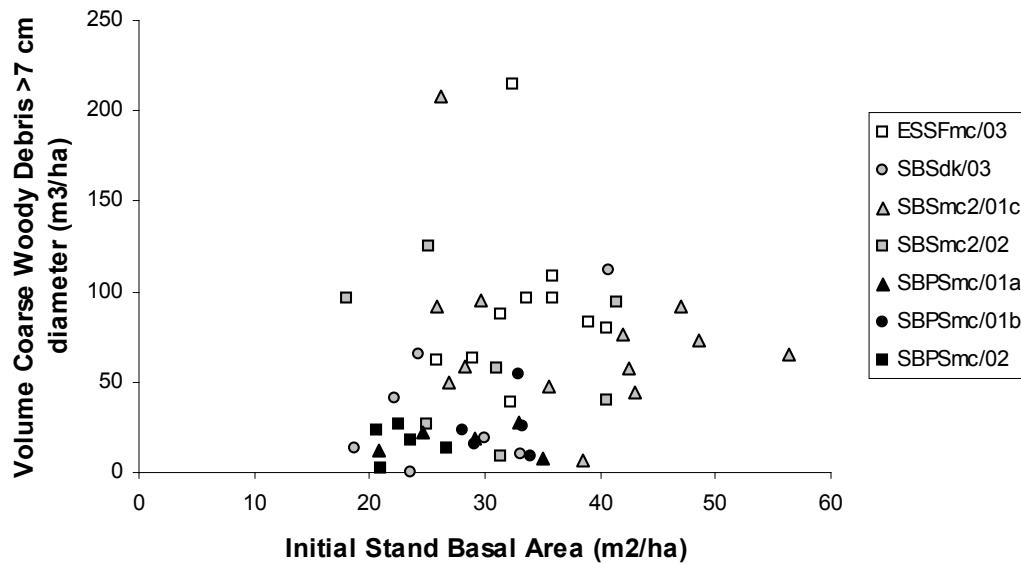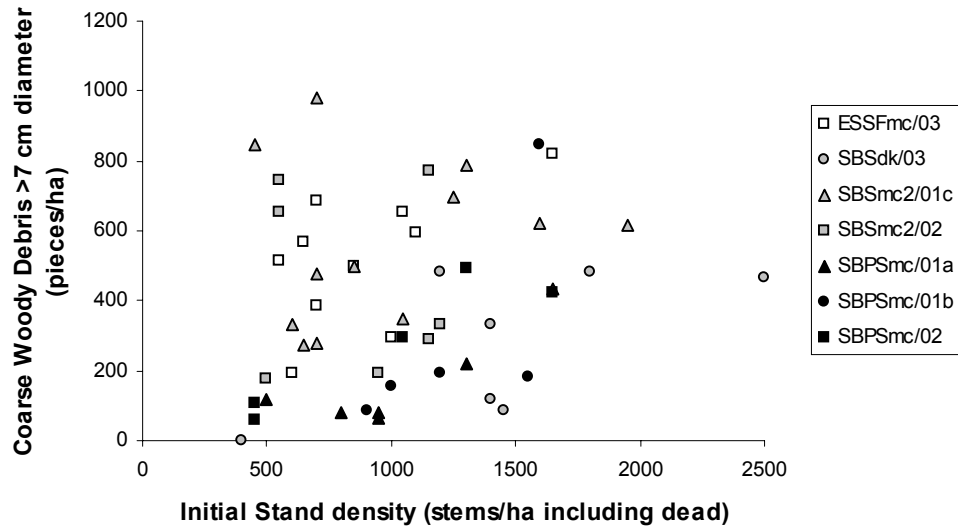Error bars = ±1 standard error.

Figure 21. Coarse woody debris and initial stand density and basal area relationships on mountain pine beetle plots in the East Ootsa and Entiako areas.
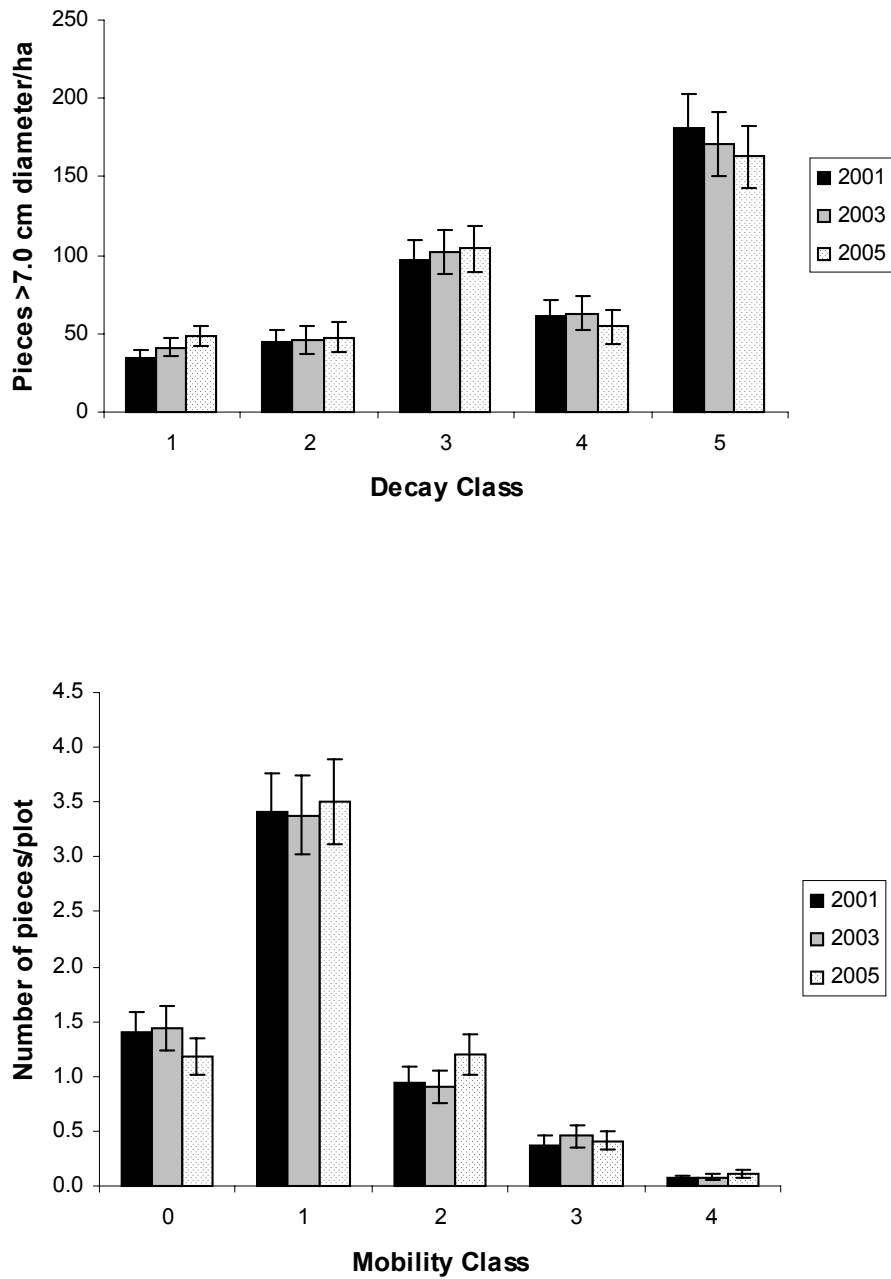
Figure 22. Mean pieces of Coarse Woody Debris on mountain pine beetle plots in each Decay Class and Mobility Class by biogeoclimatic zone and year in the East Ootsa and Entiako areas. Error bars = ±1 standard error.
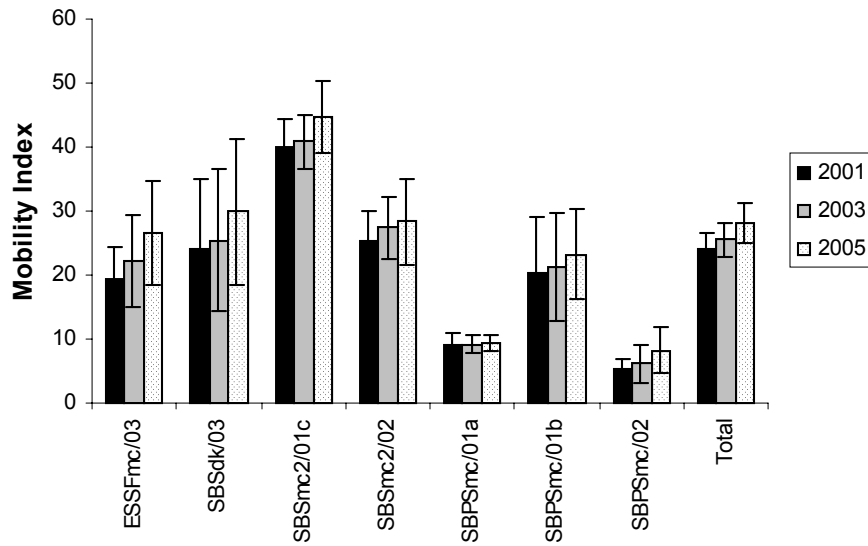
Figure 23. Mean Mobility Index of Coarse Woody Debris by year for Mountain pine beetle sites
in the East Ootsa and Entiako areas.
Error bars = ±1 standard error.

Figure 24. Mean Mobility Index for Mountain Pine Beetle (MPB) and logged sites by biogeoclimatic
zone and year in the East Ootsa and Entiako areas.
Error bars = ±1 standard error.

Figure 25. Mean volume, mass and pieces of Coarse Woody Debris for Mountain Pine Beetle (MPB)
and logged plots in 2001 in the East Ootsa and Entiako areas.
Error bars = ±1 standard error.

BLANCHET FIRE

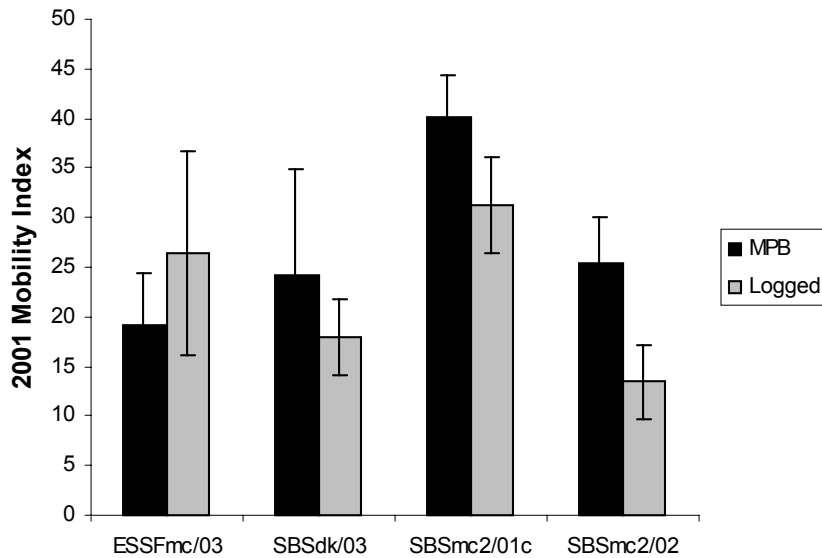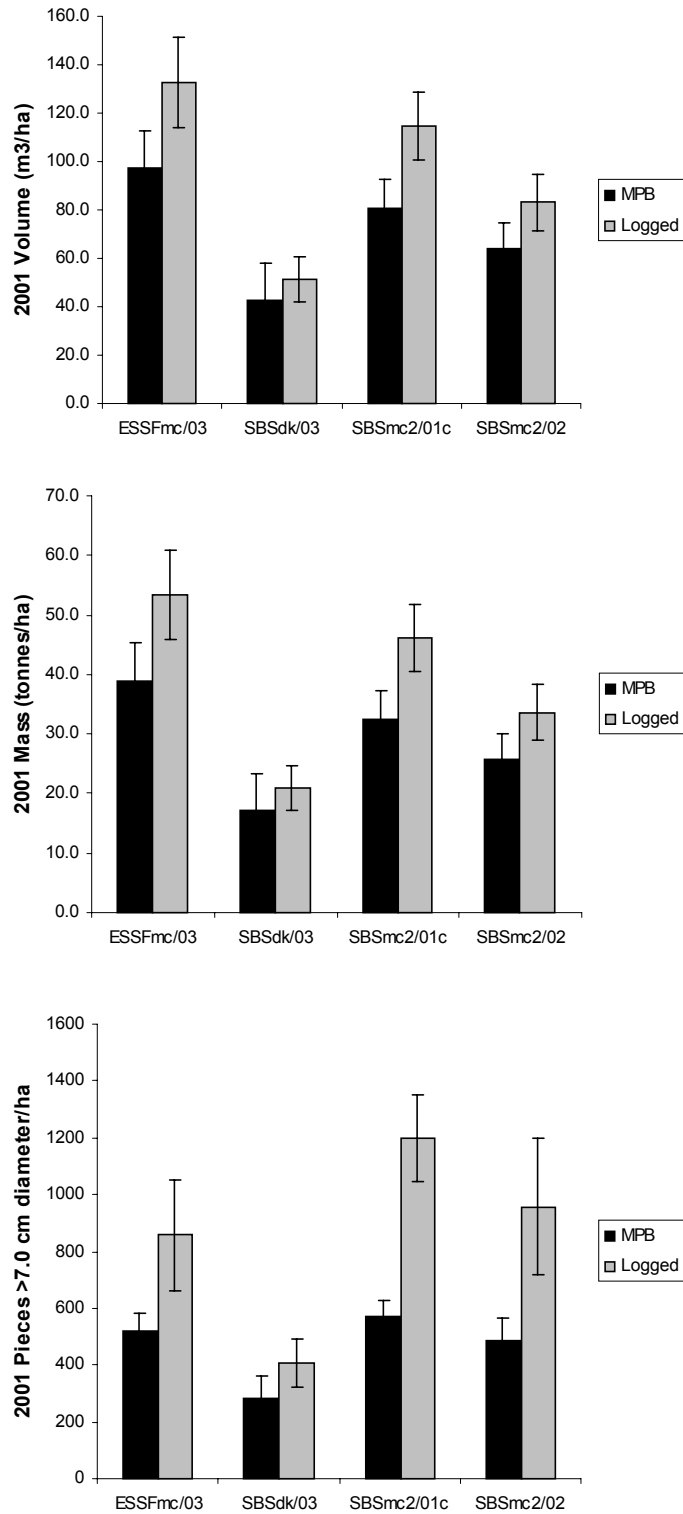In August 2004, a wildfire burned several hundred hectares on the south side of the Blanchet Main Road, just south of the Chelaslie River. In the process, 4 of our mountain pine beetle plots and 2 of our logged plots were burned. Table 6 summarizes basic characteristics of the burn on those 6 plots.

All lichens and ground vegetation, including kinnikinnick, was consumed by the fire on all plots except for in the partially burned plot where some photoplots were either partially burned or not burned. By 2005, pine germinants were already establishing on the burned sites and some shrubby early seral species were appearing; however, kinnikinnick was not present on any of the plots. At least 30% of coarse woody debris and fine fuel volume and mass were consumed on each site. The greatest consumption was on mountain pine beetle plot SBSmc2/02-C02 and logged plot SBSmc2/02-L01. Mobility Index was also reduced substantially on all sites. Canopy openness and % light availability increased substantially on all burned mountain pine beetle plots except the partially burned plot (SBSmc2/02-C05). The partially burned plot was at the northern edge of the fire; the fire on this plot appeared to be patchy and primarily restricted to the surface.

Table 6. Pre and post-burn data for 6 permanent plots in the East Ootsa area that were burned by a wildfire in August 2004.						
Plot	**Mountain pine beetle plots**				**Logged plots**	
	SBSmc2/01c C04	**SBSmc2/02 C01**	**SBSmc2/02 C02**	**SBSmc2/02 C05**	**SBSmc2/01c L03**	**SBSmc2/02 L01**
Extent of burn	All	All	All	Partial	All	All
# pine germinants	2	26	9	0	3	2
COARSE WOODY DEBRIS AND FINE FUEL VOLUME (M³/HA)						
Pre-burn	81.6	45.5	36.7	75.4	108.4	52.3
Post-burn	54.3	30.4	11.9	49.9	75.1	10.8
Change	-27.3	-15.1	-24.8	-25.5	-33.3	-41.5
% Consumed	-33.5%	-33.2%	-67.6%	-33.8%	-30.7%	-79.4%
COARSE WOODY DEBRIS AND FINE FUEL MASS (TONNES/HA)						
Pre-burn	32.8	18.3	14.9	30.3	43.6	21.3
Post-burn	21.8	12.2	4.8	20.1	30.1	4.3
Change	-11.0	-6.1	-11.1	-10.2	-13.5	-17.0
% Consumed	-33.5%	-33.3%	-74.5%	-33.7%	-31.0%	-79.8%
MOBILITY INDEX						
Pre-burn	42.5	27.3	17.2	39.0	43.5	12.5
Post-burn	24.0	7.5	9.0	28.5	26.0	6.0
CANOPY OPENNESS (%)						
Pre-burn	29.9	43.0	27.6	35.6		
Post-burn	66.5	69.7	57.6	44.7		
Change	36.6	26.7	30.0	9.1		
% LIGHT AVAILABILITY						
Pre-burn	41.7	43.5	35.3	46.2		
Post-burn	82.5	81.4	74.0	55.7		
Change	40.8	37.9	38.7	9.5		

DISCUSSION

In areas with heavy mountain pine beetle attack, more than 50% of the canopy trees have died. This has had a number of effects on the ecosystem including:
- a reduction of canopy tree evapotranspiration;
- a loss of precipitation interception by the canopy;
- a large deposition of needle litter over the forest floor;
- an increase in light availability at the forest floor; and,
- an increase in the water table.

Our study has documented the amount of canopy tree mortality and the associated changes in canopy cover. We did not directly measure needle deposition, changes to evapotranspiration levels, changes in canopy interception of precipitation, or changes to the water table.

Canopy tree death resulted in a needle pulse 2 to 3 years after mountain pine beetle attack. Needles were dispersed throughout affected stands during periods of high winds. A study in Finland (Kauppi 1990) showed that *C. stellaris*-dominated lichen mats covered in needle litter and bark fragments recovered in 3-8 years. In our study area, lichens appeared to recover in 1 to 2 years. The quicker response of lichens in our study may reflect differences in the amount of needle litter; our study may have had less litter than the manipulative study mentioned above.

No previous studies have investigated how lichen competitors respond to heavy needle litter; however, observations in the field suggest that kinnikinnick is not hampered by this phenomenon, and in fact, often flourishes where needles accumulate. The response of red-stemmed feathermoss or crowberry to large depositions of needles is also unknown. These latter two species regularly occur beneath canopy trees and so we assume that they are able to cope with at least moderate levels of needle litter. The concentrated needle pulse resulting from the mountain pine beetle epidemic likely caused a short temporal reduction in the cover of all low growing species. By 2005, signs of the needle pulse were scarcely discernable.

While canopy openness and light availability have increased with time in response to the mountain pine beetle attack, these canopy do not appear to be tied to the observed decrease in lichen cover. It is possible that lichens and understory plants may take more than 5 years to response to changes in light availability, and that we will be able to detect a relationship in future years.

As canopy trees die, they cease to evapotranspire; soil water is no longer absorbed by tree roots and pumped into the atmosphere, which results in higher soil moisture. Mountain pine beetle-killed trees lose their needles within 2-5 years, leading to less canopy interception and evaporation of rain and snow. With less interception, more rain reaches the soil surface, further contributing to wetter soils and a higher water

table. Canopy trees remain standing as snags and continue to provide at least some thermal and solar protection until fungi and windstorms cause most of them to fall, probably within the next 10 to 15 years. Surface evaporation, therefore, does not significantly change. Landscape level effects mentioned here may exert a cumulative influence on water availability–a key environmental parameter determining the distribution of terrestrial lichens and their competitors–causing the water table to increase to the detriment of terrestrial forage lichens.

Ecosystem responses to the mountain pine beetle attack discussed above represent changes to growing conditions for terrestrial forage lichens and their competitors. Our study shows that some of these responses, such as changes in light availability and living basal area, have relatively little influence on the cover of lichens, at least in first few years after the beetle attack. The needle pulse produced short-term changes that were negligible after five years. And yet, we know that the cover of lichens have diminished, more so in some sites than in others. As mentioned earlier, we strongly suspect that the reduction in lichen abundance is strongly linked to a landscape level increase in the water table. We do not, however, have the necessary hydrological data to confirm this relationship.

FUTURE WORK

This report marks the fifth year of this multi-year study that has documented changes in the forest floor vegetation following beetle attack and forest harvesting over four growing seasons. Many insights have been gained over this time period resulting in new understanding about the ecology of sub-boreal forests of British Columbia. The mountain pine beetle epidemic has caused a landscape level shift in the understory plant communities of pine forests in the East Ootsa and Entiako areas, and our research has documented these changes. As changes to the forest floor composition continue to progress, we plan to resample our permanent sample plots every two years to document the impacts of the mountain pine beetle epidemic on caribou forage lichens and the role of coarse woody debris as a mobility barrier. In addition, we are in the process of initiating a study to record up-to-date movement patterns of the Tweedsmuir-Entiako caribou population using GPS and VHF radio collars. Caribou location research will compliment vegetation data in determining the impact of the mountain pine beetle epidemic on caribou and the vegetation of their winter range.

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