

The Response of Caribou Terrestrial Forage Lichens to Mountain Pine Beetles and Forest Harvesting in the East Ootsa and Entiako areas

Annual Report – 2012/13 – Year 11



April 15, 2013

Prepared by:

Deborah Cichowski
Caribou Ecological Consulting
Box 3652, Smithers, B.C., V0J 2N0

Sybillie Haeussler
Skeena Forestry Consultants
2041 Moncton Rd. Smithers, B.C., V0J 2N4

Prepared for:

Bulkley Valley Centre for Natural
Resources Research
and Management
Smithers, B.C.

Habitat Conservation Trust
Foundation
Victoria, B.C.

Ministry of Forests, Lands and
Natural Resource Operations
Smithers, B.C.

Preface

This report summarizes data collected in 2011 and compares it to data collected from 2001 to 2007. The focus of our project was to determine the response of caribou terrestrial forage lichens to mountain pine beetles and forest harvesting 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. 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 generalize average conditions within site series or subzones.

Acknowledgements

We would like to thank everyone who contributed to the success of this project this year and in 2011/12 through both logistical and field support. Doug Steventon (Ministry of Forests, Lands and Natural Resource Operations) helped secure funding. Mark Wong (Mark Wong Consulting), Bree Korobanik (BC Parks), Philip Clement (BC Parks), Darren Fillier (BC Parks) and Mark Parminter (BC Parks) all cheerfully and tirelessly assisted with fieldwork in 2011, despite extremely long days and often buggy conditions. We would especially like to thank Mark Parminter for contributing logistic support by providing staff time and boat support. Tracy Coombes (Ministry of Forests, Lands and Natural Resource Operations) organized the use of the BC Forest Service trailer during the vehicle-based field session in August, and Miles Fuller allowed us to use his cabin on Tetachuck Lake during the boat-based field session in early September. Pat Rooney (Highland Helicopters) safely flew us around during the helicopter session in September and Lakes District Air safely flew us into Entiako Lake during the fixed-wing session in August. Anne Macadam assisted with analyzing lichen photos and entering data.

Funding for the project was provided by the Habitat Conservation Trust Foundation, the Ministry of Forests, Lands and Natural Resource Operations, and the Canadian Wildlife Foundation.

Table of Contents

Background	1
Study Area.....	4
Terrestrial Lichen Ecology.....	5
Methods.....	8
Sampling	8
Plot Identification.....	10
Plot Characteristics.....	11
Terrestrial Lichen Photoplots.....	11
Analysis of 2001 to 2007 Trends in Ground-layer Vegetation.....	14
Coarse Woody Debris	15
Results and Discussion.....	17
Stand Structure and Regeneration.....	17
Light Transmission.....	22
Response of Caribou Forage Lichens to Forest Disturbance	25
Patterns of Ground-layer Vegetation Change from 2001 to 2011: Forests.....	26
Patterns of Ground-layer Vegetation Change from 2001 to 2011: Clearcuts	31
Predictive Models of Lichen Abundance	35
Vegetation Composition Following Fire	38
Coarse Woody Debris	40
Effects of Mountain Pine Beetles on Caribou Habitat and Caribou Habitat Use	46
References	47

List of Tables

Table 1. Number of permanent plots established by biogeoclimatic subzone, site series and disturbance type in the East Ootsa and Entiako areas.....	10
Table 2. Average density of trees >7.5 cm dbh for each species for mountain pine beetle plots in the East Ootsa and Entiako areas in 2011.....	18
Table 3. Cumulative percent of standing trees in 2005 that fell by 2007 and 2011 on plots in East Ootsa and Entiako areas.....	20

Table 4. Percent of trees fallen/year from 2005 to 2007, and 2007 to 2011 on plots in the East Ootsa and Entiako areas.	20
Table 5. Average density of seedlings (0.1-1.3 m height) and saplings (0.1-7.5 cm dbh) combined on plots in the East Ootsa and Entiako areas, 2011.	22
Table 6. Multiple regression models for lichen abundance.	36
Table 7. Regeneration and vegetation cover in 2011 for 6 permanent plots in the East Ootsa area that were burned by a wildfire in August 2004.	39

List of Figures

Figure 1. Mountain pine beetle attacked stands in the East Ootsa area on the north side of Tetachuck Lake, 2005.	2
Figure 2. Photoplot with pigtail stakes and labelled tag on the SW corner.	12
Figure 3. Photographing a photoplot.	13
Figure 4. 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 from 2001 to 2011.	19
Figure 5. Cumulative percent of tree fall since 2005 on all plots combined in 2007 and 2011 in the East Ootsa and Entiako areas.	21
Figure 6. Percent trees fallen/year on all plots combined from 2005 to 2007, and 2007 to 2011 in the East Ootsa and Entiako areas.	21
Figure 7. Changes in understory vegetation and growth of advance regeneration on plot SBSmc2/01c-C10 from 2001 (top) to 2011 (bottom).	23
Figure 8. Ten-year changes in total light transmission to the forest floor by site unit in (a) unlogged MPB-affected forest, (b) clearcuts, (c) burned MPB forest and (d) burned clearcuts.	24
Figure 9. Caribou forage lichen cover by site unit in MPB forest and clearcuts in (a) 2001, (b) 2007, and (c) 2011. Error bars are + 1 standard error, from untransformed ANOVA.	25
Figure 10. Changes in caribou forage lichen abundance by site unit from 2001 to 2011 on (a) unlogged MPB-affected forests,	

	(b) recent clearcuts, (c) MPB-affected forest that burned in 2004, and (d) clearcuts that burned in 2004.	27
Figure 11.	Changes in kinnikinnick abundance by site unit from 2001 to 2011 on (a) unlogged MPB-affected forests, (b) recent clearcuts, (c) MPB-affected forest that burned in 2004, and (d) clearcuts that burned in 2004.	28
Figure 12.	Changes in moss abundance by site unit from 2001 to 2011 on (a) unlogged MPB-affected forests, (b) recent clearcuts, (c) MPB-affected forest that burned in 2004, and (d) clearcuts that burned in 2004.	29
Figure 13.	Frequency distribution of two year changes in lichen cover on photoplots from 2011 to 2011 in unburned MPB-affected forests (left), and clearcuts (right). A distribution that is shifted to the left indicates that most photoplots experienced a decrease in lichen cover, while a right-shift indicates an increase in lichen cover.	30
Figure 14.	Frequency distribution of two year changes in kinnikinnick cover on photoplots from 2011 to 2011 in unburned MPB-affected forests (left), and clearcuts (right). A distribution that is shifted to the left indicates that most photoplots experienced a decrease in kinnikinnick cover, while a right-shift indicates an increase in kinnikinnick cover.....	32
Figure 15.	Change in terrestrial lichen and kinnikinnick abundance from 2001 to 2011, photoplot SBPSmc/02-C04-3.	33
Figure 16.	Changes in the total cover of major non-lichen ground vegetation (kinnikinnick + crowberry + twinflower + mosses) by site unit from 2001 to 2011 on (a) unlogged MPB-affected forests, (b) recent clearcuts, (c) MPB-affected forest that burned in 2004, and (d) clearcuts that burned in 2004.....	34
Figure 17.	Percent cover of caribou forage lichens in relation to the total cover of major species of non-lichen ground vegetation (mosses, kinnikinnick, twinflower, crowberry) on photoplots in unburned forests (red circles) and unburned clearcuts (blue x's) in 2011.....	37
Figure 18.	Mean volume, mass and pieces of coarse woody debris by biogeoclimatic subzone and year in the East Ootsa and Entiako areas, 2001-2011.	41
Figure 19.	Mean number of new pieces of coarse woody debris per year on MPB plots by biogeoclimatic subzone and year in the East Ootsa and Entiako areas, 2001-2011.....	42
Figure 20.	Mean number of new pieces of coarse woody debris per year on logged plots by biogeoclimatic subzone and year in the East Ootsa and Entiako areas, 2001-2011.....	42

Figure 21. Mean pieces of coarse woody debris on mountain pine beetle plots in each decay class and mobility class and year in the East Ootsa and Entiako areas, 2001-2011.43

Figure 22. Mean mobility index of coarse woody debris by year for mountain pine beetle sites in the East Ootsa and Entiako areas, 2001-2011.....45

Figure 23. Mean mobility index for mountain pine beetle (MPB) and logged sites by biogeoclimatic subzone and year in the East Ootsa and Entiako areas, 2001-2011.....45

Background

The Tweedsmuir-Entiako caribou (*Rangifer tarandus caribou*) population is the first Northern Caribou population to experience the recent mountain pine beetle (*Dendroctonus ponderosae*) epidemic. During winter, Tweedsmuir-Entiako caribou select mature lodgepole pine (*Pinus contorta*) forests and forage primarily by cratering through the snow to obtain terrestrial lichens (Cichowski 1993). Entiako Park is the core of the winter range but caribou also use the East Ootsa area during some winters, and during spring and fall migration (Steventon 1996, Cichowski and MacLean 2005).

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 (MPB).

The current mountain pine beetle epidemic was detected in the East Ootsa and North Tweedsmuir Park areas in the early 1990's (Garbutt and Stewart 1991). By the late 1990's, mountain pine beetle numbers reached epidemic levels along Eutsuk and Tetachuck lakes. The area on the south and north side of Tetachuck Lake is an important spring migration staging area and winter range for the Tweedsmuir-Entiako caribou. Low impact "snip and skid" forest harvesting operations were undertaken on the north side of Tetachuck Lake for beetle management purposes; current-attacked trees were removed and efforts were made to protect high value caribou habitat from mechanical disturbance. In some cases, extensive areas were harvested. By 2000, beetle numbers overwhelmed management efforts and beetle management harvesting on the north side of Tetachuck Lake was suspended.

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 (Figure 1). Prior to this study, there was no information available on the effects of mountain pine beetles on terrestrial forage lichens.

In 2002, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed all caribou in the Southern Mountains National Ecological Area (SMNEA) as Threatened, including the Tweedsmuir-



Figure 1. Mountain pine beetle attacked stands in the East Ootsa area on the north side of Tetachuck Lake, 2005.

Entiako population. The Recovery Strategy for Northern Caribou in the SMNEA in BC identified research on the effects of mountain pine beetles on Northern Caribou as a priority (Northern Caribou Technical Advisory Committee 2004).

This project was initiated in 2001 to assess changes to caribou habitat following the mountain pine beetle epidemic in a variety of ecological conditions in Entiako Park and in the adjacent East Ootsa area. A total of 79 permanent plots (Entiako Park: 15 plots; East Ootsa: 64 plots) were established to monitor ground vegetation changes and forest dynamics after the mountain pine beetle epidemic impacted the area in the late 1990s.

All plots were established in stands with red mountain pine beetle attack and re-measured again in 2003, 2005 and 2007. Initially, terrestrial lichen abundance declined on mountain pine beetle-attacked sites in response to an increase in kinnikinnick (*Arctostaphylos uva-ursi*; Cichowski et al. 2008). The initial decline in terrestrial lichen abundance led to additional research on assessing the effectiveness of wildfire and prescribed fire for rehabilitating terrestrial lichen habitat following mountain pine beetle attack (Cichowski and de Groot 2010, Sulyma 2009). In 2004, a wildfire burned 6 plots in this study, providing additional information on the

potential of using wildfire or prescribed burning to re-establish terrestrial lichen sites.

On mountain pine beetle-attacked sites, although terrestrial lichen abundance declined between 2001 and 2007, the decline leveled off by 2007. Patches of kinnikinnick die-off were observed in 2007 and observations during a brief site visit in 2010 suggested that kinnikinnick die-back continued.

Because the Tweedsmuir-Entiako caribou is the first Northern Caribou population to experience the mountain pine beetle epidemic, information collected in the Tweedsmuir-Entiako caribou range will also benefit other Northern Caribou populations in BC and Alberta that are experiencing, or are at risk of experiencing, the mountain pine beetle epidemic.

The overall goals of this project are:

- to assess the short term and long term response of terrestrial caribou forage lichens and competing vegetation to the mountain pine beetle epidemic;
- to assess the timing and extent of coarse woody debris accumulation, as an indicator of movement barriers for caribou, following a mountain pine beetle epidemic;
- to assess changes in stand structure and composition in caribou winter habitat following a mountain pine beetle epidemic; and,
- to assess the effects of wildfire on mountain pine beetle affected terrestrial lichen sites.

The objective for 2011/12 was:

- to re-measure terrestrial lichen abundance, competing vegetation abundance, stand structure, regeneration and coarse woody debris on 79 permanent plots in the East Ootsa and Entiako areas 10 years following mountain pine beetle attack.

The objective for 2012/13 was:

- to assess changes in forest floor vegetation dynamics, stand structure, regeneration and coarse woody debris accumulation since the last re-measurement in 2007, and since the study began in 2001.

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. The area is characterized by low-lying, flat or gently rolling terrain on the Nechako Plateau, ranging between 850 and 1300 meters.

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).

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. 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.

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. 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.

Fire and forest insects are the main large-scale natural disturbance factors in the study area. The recent mountain pine beetle outbreak was first detected in northern Tweedsmuir Park near its eastern boundary in 1994. In 2000, 36 000 ha were moderately to heavily attacked in Entiako Park, and by 2001, most of Entiako Park north of the Entiako River was under moderate or heavy attack (Cichowski 2008).

Terrestrial Lichen Ecology

Caribou primarily forage on terrestrial forage lichens in the genera *Cladina*, *Cladonia*, *Cetraria*, and *Stereocaulon*. *Cladina* is especially favoured 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.

The distribution and abundance 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.

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 and poorer ones) they tend to be uncommon on rich sites due to competition from mosses and vascular plants (Ahti 1961). 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, allows red-stemmed feathermoss (*Pleurozium schreberi*) to thrive at the expense of terrestrial lichens. In canopy gaps where 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.

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). Fire is important

for maintaining lichen-dominated plant communities on the landscape. Although lichens burn readily, they also re-establish more rapidly than many of their competitors. Undamaged colonies in areas skipped by fire 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. On very dry soils, sites may not reach the feathermoss stage.

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. Goward (2000) hypothesized that caribou may be responsible for enlarging established lichen colonies by spreading fragments while cratering. Regardless of the dispersal mechanism, *Cladina* appears to establish most effectively if a nearby source population exists.

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;
- red-stemmed feathermoss;
- crowberry (*Empetrum nigrum*); and,
- twin-flower.

However, other plant species also 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 suberic sites such as south facing slopes, eskers, or outwash plains.

Red-stemmed feathermoss is the most abundant ground cover in the study area and grows well in humid habitats often dominating 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, although on drier sites, it 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.

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. 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.

Twin-flower is another fast-growing understory species in the study area. While reasonably common, the distribution of this species can be patchy.

In the East Ootsa and Entiako areas, caribou terrestrial forage lichens are most abundant in the following ecosystems:

- SBSmc2/01c (submesic);
- SBSmc2/02 (subxeric);
- SBSdk/03 (subxeric);
- ESSFmc/03(subxeric);
- SBPSmc/02 (subxeric); and,
- SBPSmc/01b (submesic).

In the SBPSmc, mesic phase sites (01a) with open canopies also support a modest cover of terrestrial caribou forage lichens.

Methods

Methods for field sampling in 2011 followed methods used during the first 7 years (2001-2007) of the study (Cichowski et al. 2008).

Sampling

We initiated this project in 2001 as a long-term study monitoring the response of terrestrial forage lichens to epidemic mountain pine beetle numbers and forest harvesting. The effect of mountain pine beetles was considered to be a gradual loss of canopy trees, while the effect of forest harvesting was considered to be a rapid loss of canopy trees. Permanent sample plots were established in 2001 and were re-sampled in 2003, 2005, 2007 and 2011. Data collection in 2011 marked the eleventh year of the study and documents changes over ten growing seasons.

In 2001, we established 5 to 14 long-term permanent plots for each biogeoclimatic subzone/site series and disturbance type (Map 1, Table 1). We treated each site series within each biogeoclimatic zone as a separate site. All mountain pine beetle plots were established in mixed red and green 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 were harvested. We also established plots on already harvested sites; sampling occurred one or two years after harvesting so we were not able to directly compare conditions prior to harvesting to following harvesting. To avoid confounding effects of canopy loss and mechanical disturbance to terrestrial forage lichens due to forest harvesting, we only sampled in cutblocks that were harvested during the winter (when the snowpack prevents the disturbance of the forest floor) and/or where harvested sites appeared to be “machine-free” zones. We do not have any control sites that lack a disturbance type because all mature pine stands in the study area were 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, providing us with some information on the effects of fire.

We focused our efforts on submesic sites in the SBSmc2 biogeoclimatic subzone and subxeric sites in the SBSmc2, SBSdk and ESSFmc subzones in the East Ootsa area. In the SBPSmc in the Entiako area, we sampled subxeric, submesic and mesic sites. In total, we sampled 65 sites in the East Ootsa Area and 15 in the Entiako.

Location of permanently marked lichen plots in the East Ootsa and Entiako areas.

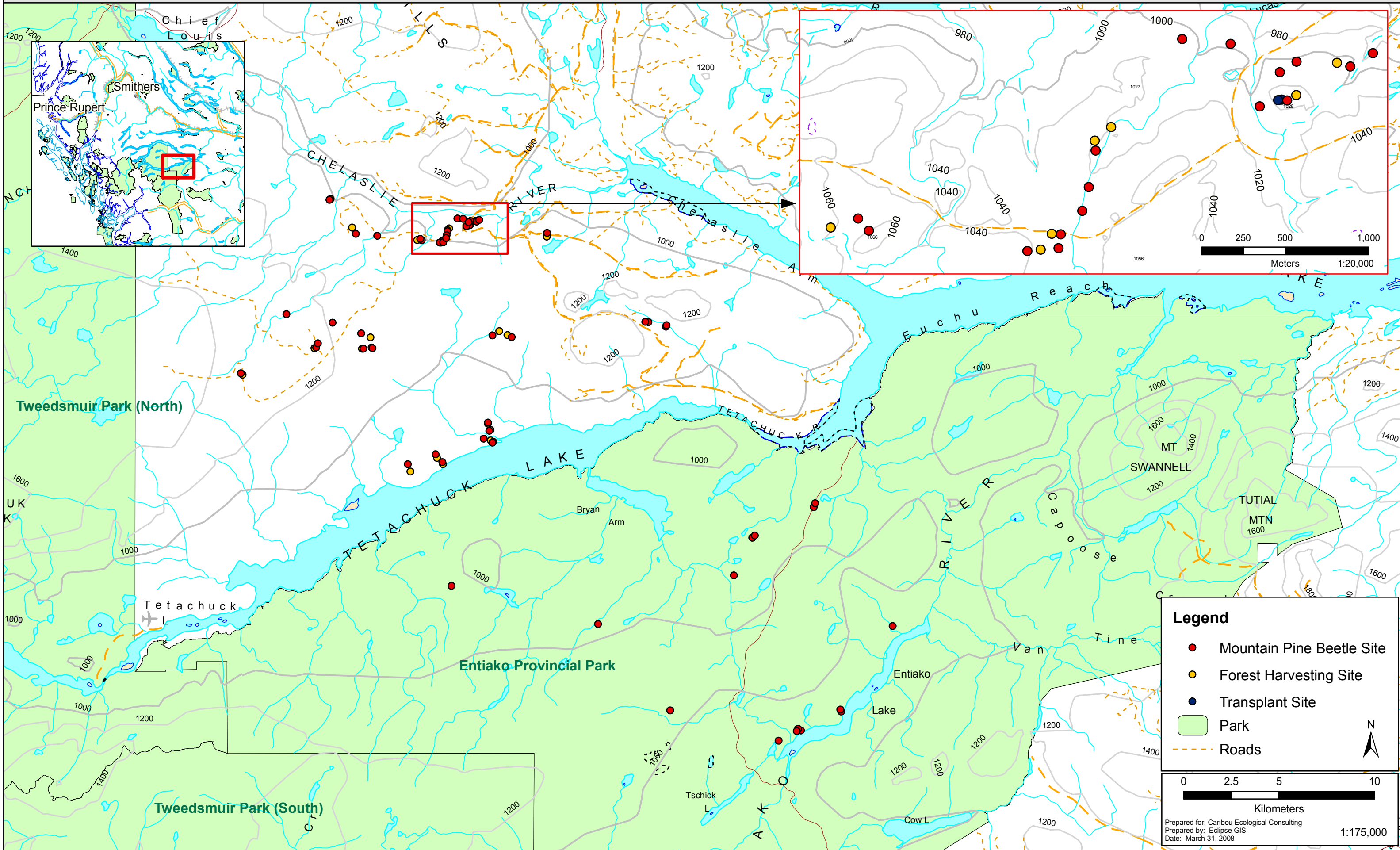


Table 1. Number of permanent plots established by biogeoclimatic subzone, site series and disturbance type in the East Ootsa and Entiako areas.				
Study area	Biogeoclimatic subzone	Biogeoclimatic site series	Disturbance type	
			Forest Harvesting	Mountain Pine Beetles
East Ootsa	ESSFmc	Subxeric (03)	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

We selected sites within sites series in each subzone that supported high lichen cover, but that did not necessarily typify each site series. 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 generalize average conditions within site series or subzones.

Plot Identification

In 2001, a 7.98 meter diameter circular plot (200 m²) was permanently established at each site. Plot centres were marked using a labeled stainless steel pigtail pin. Permanent stakes were pushed down flush to the ground in mountain pine beetle plots to minimize disturbance to stakes during potential future harvesting treatments. We established a guide tree for each plot and recorded the distance and bearing from the guide tree to the centre pin as a precaution in the event that the plot centre pin was disturbed. Guide trees were usually small (usually less than 5 m) understory spruce and were marked by three pieces of flagging and orange marker paint around the bole about 1.3 m above the ground.

Plot Characteristics

In 2001 and 2003, each tree within the plot was counted, identified to species, classified as alive or dead, and classified into the following size classes:

- > 12.5 cm dbh;
- 7.5 – 12.49 cm dbh;
- > 1.3 meters in height to 7.49 cm dbh; and,
- <1.3 meters in height.

In addition, lodgepole pine trees were classified into the following categories: alive; MPB green attack; MPB faded (yellow/orange) attack; MPB red attack; MPB red/grey attack; MPB grey; and, dead (not due to mountain pine beetle attack). In 2005, all trees >7.5 cm dbh within the 200 m² permanent plot were individually marked. Status of those trees and whether they were still standing were recorded again in 2007 and 2011. All trees >1.3 m in height to ≤7.49 cm dbh were counted, identified to species and classified as alive or dead within the 200 m² permanent plot. From 2005 to 2011, four categories of smaller regeneration (> 30 cm to 1.3 meters in height; 10 to 30 cm in height; ≤ 10 cm; Year 1 germinants) were assessed in 3.99 m² radius plots originating from plot centre.

We used fisheye photographs of the canopy to quantify the change in light availability in beetle-killed stands and in harvested sites (Canham 1988). 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 over the plot centre pin and oriented so that the top of the camera was pointed north. Initial photographs were taken in 2002 (except the SBPSmc sites), and then again in 2003 and 2005. In 2007 and 2011, canopy photographs were taken with a digital camera. The software program Gap Light Analyzer version 2 (GLA; Canham 1988) was used to determine the percent transmission of light through the canopy.

Terrestrial Lichen Photoplots

At each permanent plot, we established 6 to 12 photoplots (usually 10) based on the abundance of lichens. In total, 763 photoplots were established (excluding plot ESSFmc/03-L03, which was disctrenched and therefore abandoned). 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 2). Each southwest pigtail was labeled with an aluminium 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 2. 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 3). A small erasable board with the subzone, site series, site number, photoplot number and date written on it was placed on the west edge of the frame within the field of view. The camera was generally aligned so that north was at the top of the viewfinder. Photoplots were photographed and analyzed in 2001, 2003, 2005, 2007 and 2011. From 2001 to 2005, photographs were taken using 200 ASA film and scanned to high resolution digital jpeg files to be used for image analysis. In 2007 and 2011, a digital camera was used instead of a film camera. All digital and print format images relating to this project were catalogued and archived.



Figure 3. Photographing a photoplot.

We analyzed lichen colony percent cover within each frame using the software program Gap Light Analyzer (GLA; Canham 1988). We were unable to analyze terrestrial forage lichens to the level of species because the software could not differentiate lichens to the species level, nor could it detect differences among vascular plant species. A visual estimate of terrestrial lichen cover and the cover of the dominant competitors (kinnikinnick, feathermoss, crowberry and twin-flower) was also recorded for each photoplot for the years 2001 and 2007 by examining printed photographs of the photoplots. One observer determined all visual estimates from photographs. In 2007, % cover of all vegetation was recorded for each photoplot in the field.

Analysis of 2001 to 2007 Trends in Ground-layer Vegetation

We used ANOVA to compare 2001, 2007, and 2011 caribou forage lichen cover on unlogged MPB forest and logged clearcuts in the ESSFmc/03, SBSdk/03, SBSmc2/01c and SBSmc2/02 site units. The SBPSmc forest sites and burned SBSmc2 sites were not included in this analysis. We pooled the photoplot data for each site and transformed the visual estimates of total caribou forage lichen (hereafter “lichen”) % cover with a log transformation to improve normality and homogeneity of variances. Orthogonal contrasts were used to compare the four site unit means.

Repeated measures ANOVA was used to compare site level changes in abundance of lichen, kinnikinnick, moss and all major non-lichen ground layer species (% kinnikinnick + % crowberry + % twinberry + % moss) across site units for 2001, 2003, 2005, 2007 and 2011. For this analysis, we first compared forest to clearcut time trajectories for the four SBS/ESSF site units only to assess whether they were significantly different. Thereafter, the unlogged MPB forest sites and the logged clearcuts were analysed separately so that the SBPSmc forest sites could be included in the analysis. Burned sites were excluded.

With repeated measures, a significant linear time trend indicates that the variable of interest either increased or decreased over the time period, a significant quadratic trend allows us to conclude that the variable either accelerated or decelerated (levelled off) during the time period, and a significant cubic trend indicates that the variable oscillated (rose, then fell) over the time period. The percentage of variance explained by each of these trends indicates their relative importance.

Visual % cover estimates made from photographs from 2001 to 2007 and in the field in 2011 were used for all plant species and group comparisons, including lichens, because of difficulties in maintaining year-to-year consistency with the digital (GLA) analysis of lichen cover. The significance value was set at 0.05 for all site-level ANOVAs and t-tests. SYSTAT version 11 software (SYSTAT Software Inc. 2004) was used for all analyses.

Stepwise linear regression was used to develop predictive models at the photoplot scale for 2011 lichen abundance and the relative change in lichen abundance between 2011 and 2007 (i.e. $[2011-2007]/2007$). Lichen change was log-transformed 2011 and lichen cover was square root transformed to improve normality and homogeneity of variance.

Unlike previous years, visual % cover estimates were used for all lichen models as well as for the other plant species due to difficulties in standardizing the GLA values from year-to-year. The 2011 visual cover estimates were made in the field, whereas previous estimates were made from the photos. SYSTAT version 11 software (SYSTAT Software Inc. 2004) was used for all analyses.

Coarse Woody Debris

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, originating at plot centre, were selected randomly from a list of random bearings. 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 calipers and recorded decay class, length class, and mobility class. We also recorded distance from plot centre in 2002 (East Ootsa plots only), 2003, 2005, 2007 and 2011. Length classes included: 1 (<2 m), 2 (2-5 m), 3 (5-10 m), and, 4 (>10 m).

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.

Mobility classes included:

- 0: top side of log <10 cm above ground and log mostly part of forest floor;
- 1: top side of log 10-40 cm above ground and log mostly branch free;
- 2: top side of log or branches 40-100 cm above ground with scattered branches;
- 3: top side of log or branches 40-100 cm above ground with 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 with dense branches or 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 log 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 Coarse Woody Debris Assessment module of the CWD/Fuel Calculator Version 1.0a (B.C. Ministry of Forests 1997). 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 2003, we re-measured coarse woody debris on all plots and fine woody debris only on mountain pine beetle plots. In 2005, we re-measured coarse and fine woody debris only on mountain pine beetle plots; coarse and fine woody debris on harvested plots were re-measured only on the two harvested plots that were burned. In 2007 and 2011, we re-measured coarse and fine woody debris on all plots.

Results and Discussion

All plots were re-visited in 2011 during four field sessions:

- August 4-15;
- August 24-25;
- September 1-5; and,
- September 11-14.

The results reported here describe patterns that occur on sites with high lichen cover and do not necessarily typify the average conditions found on each site series. 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 provide insight into what may be happening at the landscape level.

Stand Structure and Regeneration

Prior to mountain pine beetle attack, the dominant canopy tree species on all site series was lodgepole pine (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 4). In 2007, some additional mortality was also observed and average pine mortality (based on stems/ha) ranged from 78% on SBSdk/03 sites to 96% on SBPSmc/01a sites. By 2011, live trees averaged between 90 and 336 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).

Overall, live stem density and basal area were lowest in the Entiako area and on SBSmc2/02 sites where lodgepole pine is the dominant species (Table 2). The SBSdk/03 and ESSFmc/03 contained the highest average densities of live trees > 7.5 cm dbh (Table 2).

Few live trees fell between 2005 and 2011 (Tables 3-4, Figures 5-6). Standing dead trees (not due to MPB) sustained the highest rate of tree fall of all tree categories. From 2005 to 2007, most of the trees that fell were standing dead. Between 2005 and 2007, on all sites combined, 2% of MPB-attacked trees had fallen and by 2011, 9.4% of MPB-attacked trees had fallen (Table 3, Figure 5). Tree fall rates for MPB-attacked trees

averaged 1%/year from 2005 to 2007 and increased to 1.9%/year from 2007 to 2011 (Table 4, Figure 6). MPB-attacked tree fall rates were highest in the SBS (SBSdk/03, SBSmc2/02, SBSmc2/01c) and on SBPSmc/01b sites. Although we did not monitor individually marked trees prior to 2005, very few fallen trees were noted on plots between 2001 and 2005 suggesting that the % MPB-attacked trees that fell between 2005 and 2011 (9.4%) provides a reasonable approximation of the % trees that fell since MPB attack in 2001.

Fall down rates of beetle-killed trees from other studies have varied from 90% fallen by 14 years post-attack (Mitchell and Priesler 1998) to 26% of trees fallen by 18 years following attack (Hawkes *et al.* 2004). Lewis and Hartley (2005) expected 25%-50% of beetle-killed trees to fall within 8 years, and 90% of trees to fall within 15 years of attack in SBSmc biogeoclimatic subzone; they anticipated that beetle-killed trees will persist slightly longer on drier sites and that smaller diameter trees will fall sooner than larger diameter trees. The sites in our study are representative of drier sites within the SBSmc.

Table 2. Average density of trees >7.5 cm dbh for each species for mountain pine beetle plots in the East Ootsa and Entiaiko areas in 2011.						
MPB Attack Plots	Average density (stems/ha)					
	N¹	Fir	Spruce	Pine Not Attacked	Pine MPB Attacked	Total Live
EAST OOTSA						
ESSFmc/03	10	95	145	75	425	315
SBSmc2/01c	13	42	146	46	558	235
SBSmc2/02	7	0	43	93	586	136
SBSdk/03	7	0	50	279	986	329
ENTIAKO						
SBPSmc/01a	5	0	60	30	680	90
SBPSmc/01b	5	0	60	130	940	190
SBPSmc/02	5	0	10	70	750	80
Average basal area (m³/ha)						
EAST OOTSA						
ESSFmc/03	10	1.3	2.7	1.5	25.0	5.5
SBSmc2/01c	13	0.5	1.8	0.9	28.5	3.1
SBSmc2/02	7	0	0.4	1.6	23.2	2.0
SBSdk/03	7	0	0.6	3.2	19.6	3.8
ENTIAKO						
SBPSmc/01a	5	0	1.2	0.2	24.2	1.4
SBPSmc/01b	5	0	0.9	1.6	24.6	2.5
SBPSmc/02	5	0	0.1	0.7	21.3	0.7

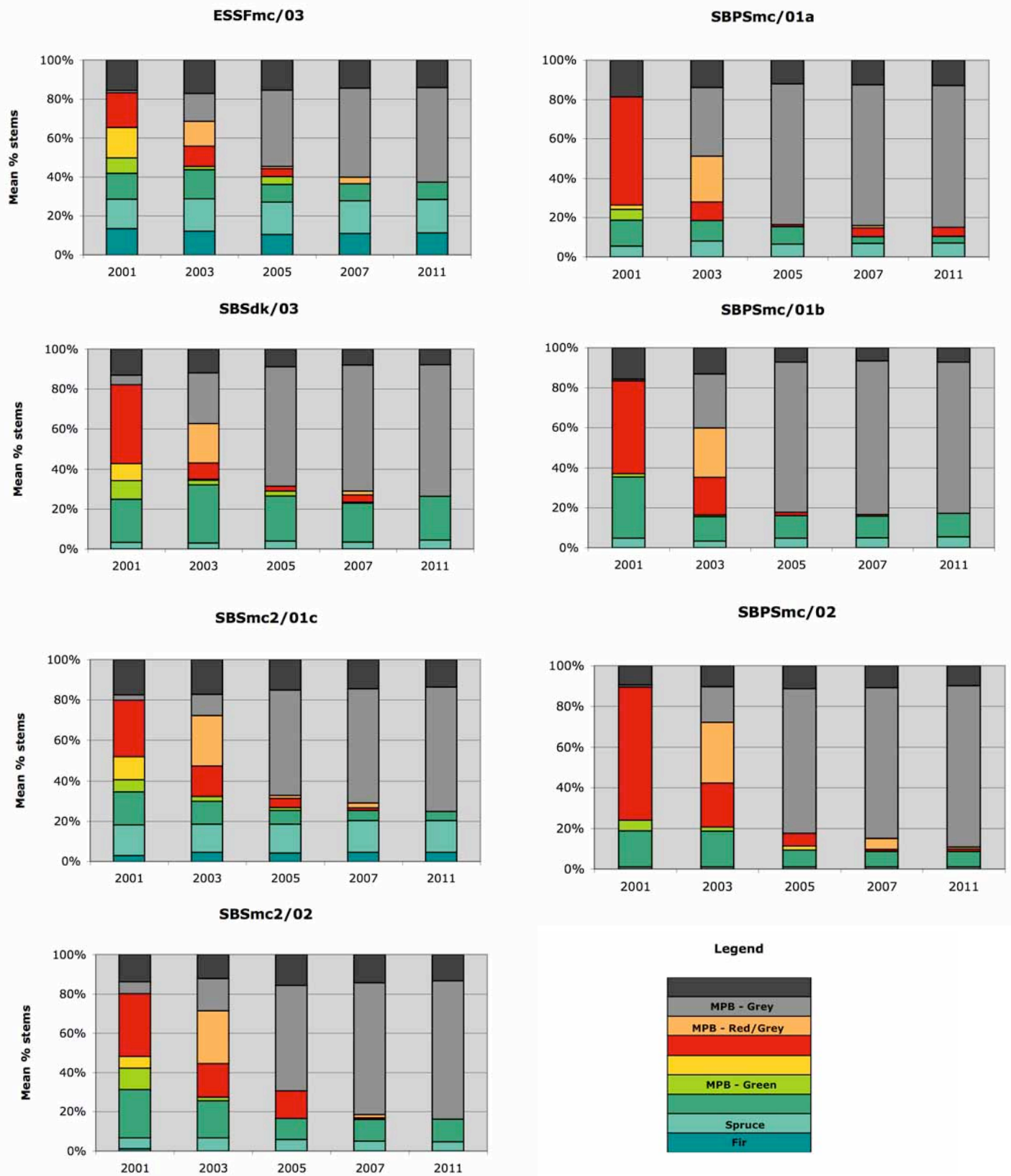


Figure 4. Average percent of trees >7.5 cm dbh in each species and mountain pine beetle attack class by biogeoclimatic subzone/site series in the East Ootsa and Entiako areas from 2001 to 2011.

	Pine (live)			Spruce (live)			Fir (live)			Dead			MPB			Total		
	N ¹	2007	2011	N	2007	2011	N	2007	2011	N	2007	2011	N	2007	2011	N	2007	2011
ESSFmc/03	15	0	0	29	0	0	19	0	0	27	7.4	11.1	85	0	3.5	175	1.1	3.4
SBSmc2/01c	12	0	8.3	37	0	0	0	-	-	53	11.3	17.0	164	4.3	9.2	266	4.9	9.4
SBSmc2/02	12	0	0	7	14.3	28.6	0	-	-	19	5.3	31.6	83	1.2	10.8	121	2.5	14.1
SBSdk/03	39	2.6	2.6	8	0	0	0	-	-	19	10.5	21.1	139	1.4	16.6	205	2.4	13.7
SBPSmc/01a	3	0	0	6	0	0	0	-	-	11	0	0	70	1.4	5.7	90	1.1	4.4
SBPSmc/01b	13	0	0	6	0	0	0	-	-	9	11.1	11.1	96	2.1	12.5	124	2.4	10.5
SBPSmc/02	7	0	0	1	0	0	0	-	-	11	0	18.2	78	1.3	1.3	97	1.0	3.1
Total	101	1.0	2.0	94	1.1	2.1	19	0	0	149	8.1	16.8	715	2.0	9.4	1078	2.6	8.9

¹ N=number of standing trees in 2005; tree status (e.g. alive, MPB, dead) based on tree status in 2011

	Pine (live)			Spruce (live)			Fir (live)			Dead			MPB			Total		
	N ¹	2005-2007	2007-2011	N	2005-2007	2007-2011	N	2005-2007	2007-2011	N	2005-2007	2007-2011	N	2005-2007	2007-2011	N	2005-2007	2007-2011
ESSFmc/03	15	0	0	29	0	0	19	0	0	27	3.7	0.9	85	0	0.9	175	0.6	0.6
SBSmc2/01c	12	0	2.1	37	0	0	0	-	-	53	5.7	1.4	164	2.1	1.2	266	2.4	1.1
SBSmc2/02	12	0	0	7	7.1	3.6	0	-	-	19	2.6	6.6	83	0.6	2.4	121	1.2	2.9
SBSdk/03	39	1.3	0	8	0	0	0	-	-	19	5.3	2.6	139	0.7	2.8	205	1.2	2.8
SBPSmc/01a	3	0	0	6	0	0	0	-	-	11	0	0	70	0.7	1.1	90	0.6	0.8
SBPSmc/01b	13	0	0	6	0	0	0	-	-	9	5.6	0	96	1.0	2.6	124	1.1	2.0
SBPSmc/02	7	0	0	1	0	0	0	-	-	11	0	4.5	78	0.6	0	97	0.5	0.5
Total	101	0.5	0.2	94	0.5	0.3	19	0	0	149	4.0	2.2	715	1.0	1.9	1078	1.3	1.6

¹ N=number of standing trees in 2005; tree status (e.g. alive, MPB, dead) based on tree status in 2011

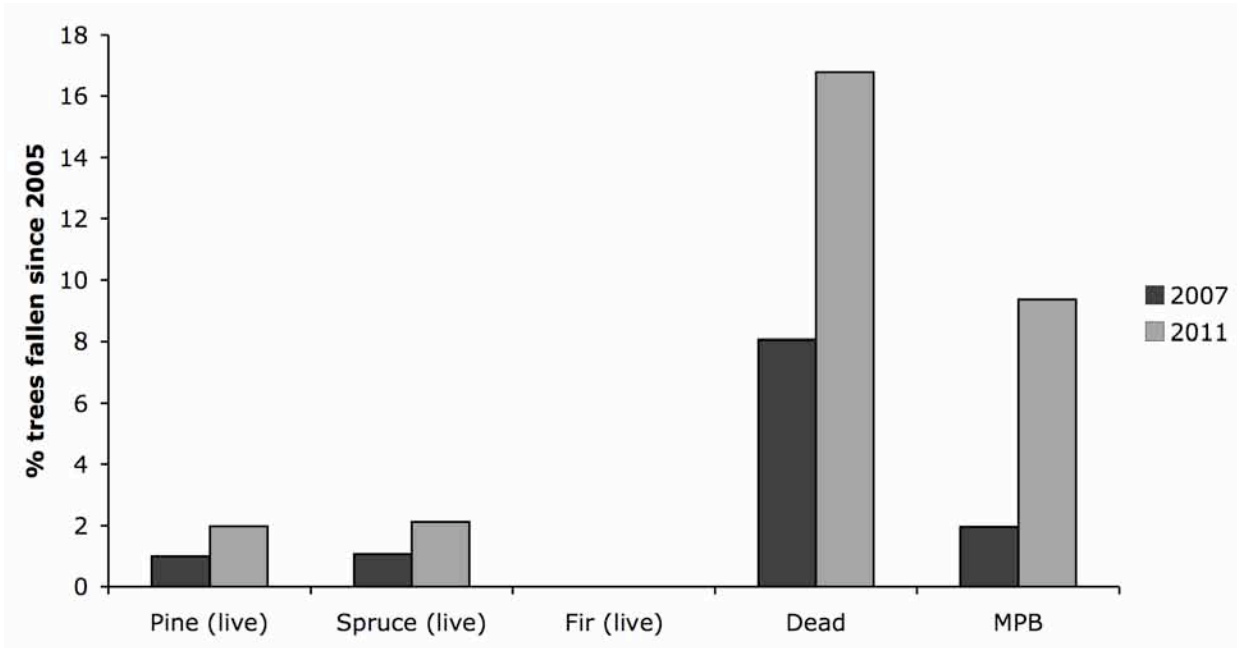


Figure 5. Cumulative percent of tree fall since 2005 on all plots combined in 2007 and 2011 in the East Ootsa and Entiako areas.

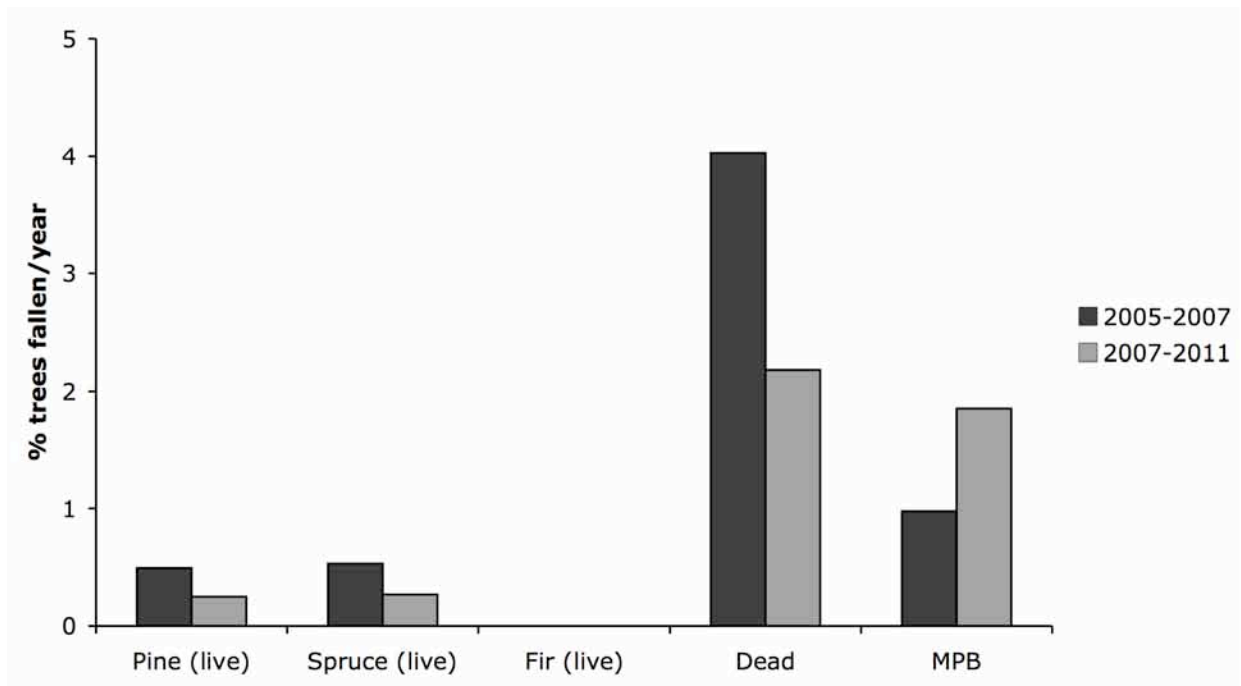


Figure 6. Percent trees fallen/year on all plots combined from 2005 to 2007, and 2007 to 2011 in the East Ootsa and Entiako areas.

Advance regeneration was highly variable within and between biogeoclimatic subzones/site series (Table 5). Average understory density on mountain pine beetle plots was highest on ESSFmc/03 plots and lowest on SBPSmc and SBSdk/03 plots. Regeneration on harvested plots, including planted trees, was similar to regeneration on mountain pine beetle 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 (Table 5). 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. Considerable growth of advance regeneration between 2001 and 2011 was observed on many plots (Figure 7).

Table 5. Average density of seedlings (0.1-1.3 m height) and saplings (0.1-7.5 cm dbh) combined on plots in the East Ootsa and Entiako areas, 2011.							
Plots	N ²	Regeneration (Stems/ha ¹)					Range
		Pine	Spruce	Fir	Aspen	Total	
MOUNTAIN PINE BEETLE PLOTS							
ESSFmc/03	10	2545	665	4355	0	7565	950-25500
SBSmc2/01c	13	2496	1054	227	35	3812	400-8000
SBSmc2/02	7	3586	743	343	0	4671	900-10450
SBSdk/03	7	1050	336	0	557	1943	550-4400
SBPSmc/01a	5	2490	730	0	40	3260	2550-4150
SBPSmc/01b	5	1440	90	40	40	1610	300-2300
SBPSmc/02	5	1850	20	0	0	1870	950-3800
HARVESTED PLOTS³							
ESSFmc/03	4	4913	400	1388	0	6700	2300-10250
SBSmc2/01c	6	2933	683	200	0	3817	2600-6600
SBSmc2/02	4	2350	238	1363	0	3950	1400-8050
SBSdk/03	7	2086	0	0	21	2107	550-5450

¹ all saplings in plot (7.98 m radius) counted; seedlings counted in a 3.99 m radius subplot; includes only "acceptable" trees

² N = number of permanent plots

³ Harvested plots include planted trees on some sites

Light Transmission

Light transmission increased slowly on MPB plots in all subzones and remained relatively constant in clearcuts (Figure 8). Following fire, light transmission increased substantially on MPB forested plots but remained relatively constant in burned clearcuts.



Figure 7. Changes in understory vegetation and growth of advance regeneration on plot SBSmc2/01c-C10 from 2001 (top) to 2011 (bottom).

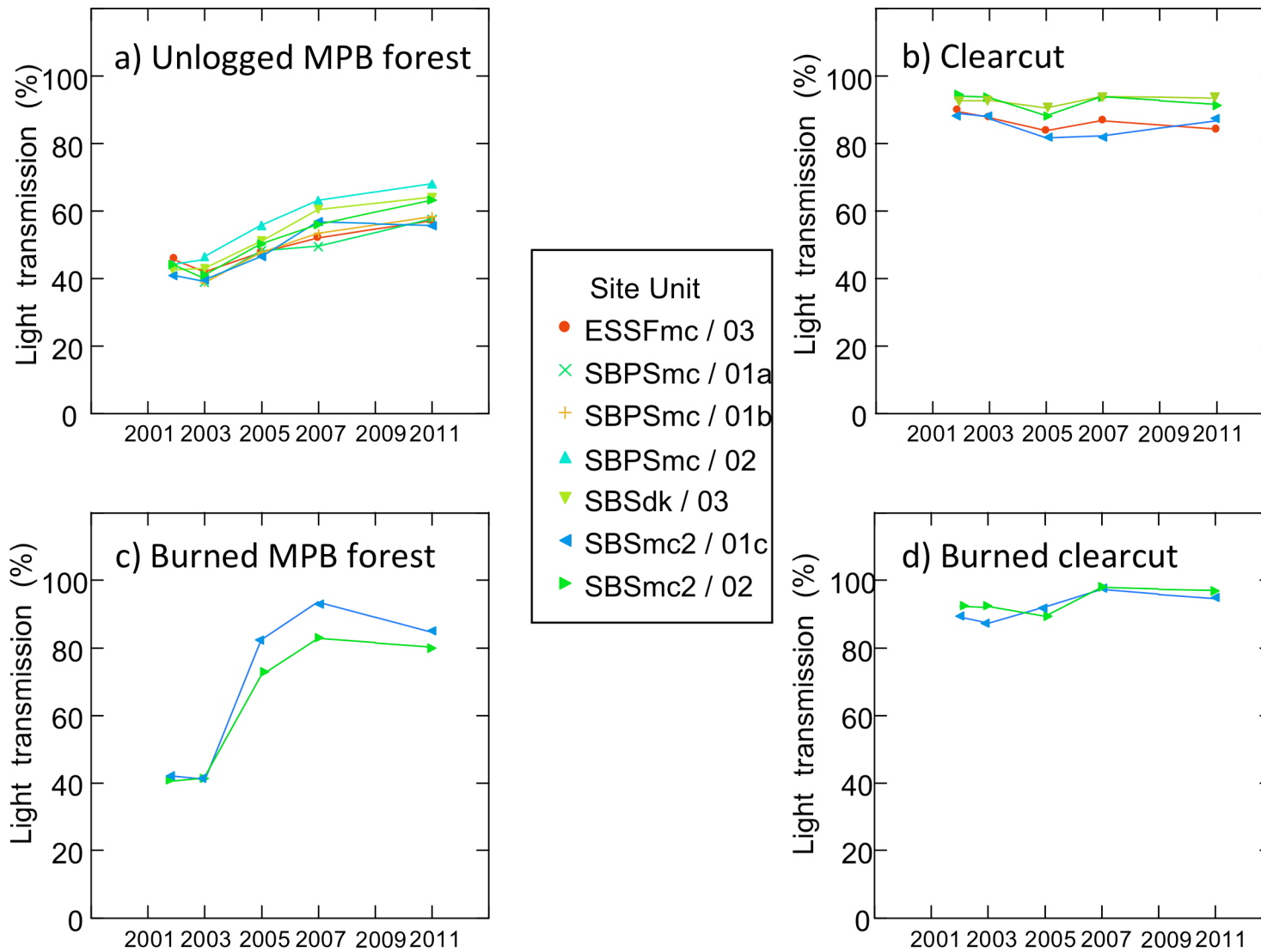


Figure 8. Ten-year changes in total light transmission to the forest floor by site unit in (a) unlogged MPB-affected forest, (b) clearcuts, (c) burned MPB forest and (d) burned clearcuts.

Response of Caribou Forage Lichens to Forest Disturbance

In 2001, caribou forage lichens (*Cladina* spp., *Stereocaulon* spp., *Cladonia uncialis*, *Cetraria ericetorum*) averaged 26% cover on photoplots (visual estimate) across all site units. Differences in lichen abundance between unlogged forest sites affected by MPB and nearby clearcut-logged sites were not significant (Figure 9a, $p = 0.25$). The SBSmc2/02 photoplots had significantly higher lichen cover both in forests and on clearcuts (34% on average) than the other three site units (24% on average; $p = 0.003$ for contrast).

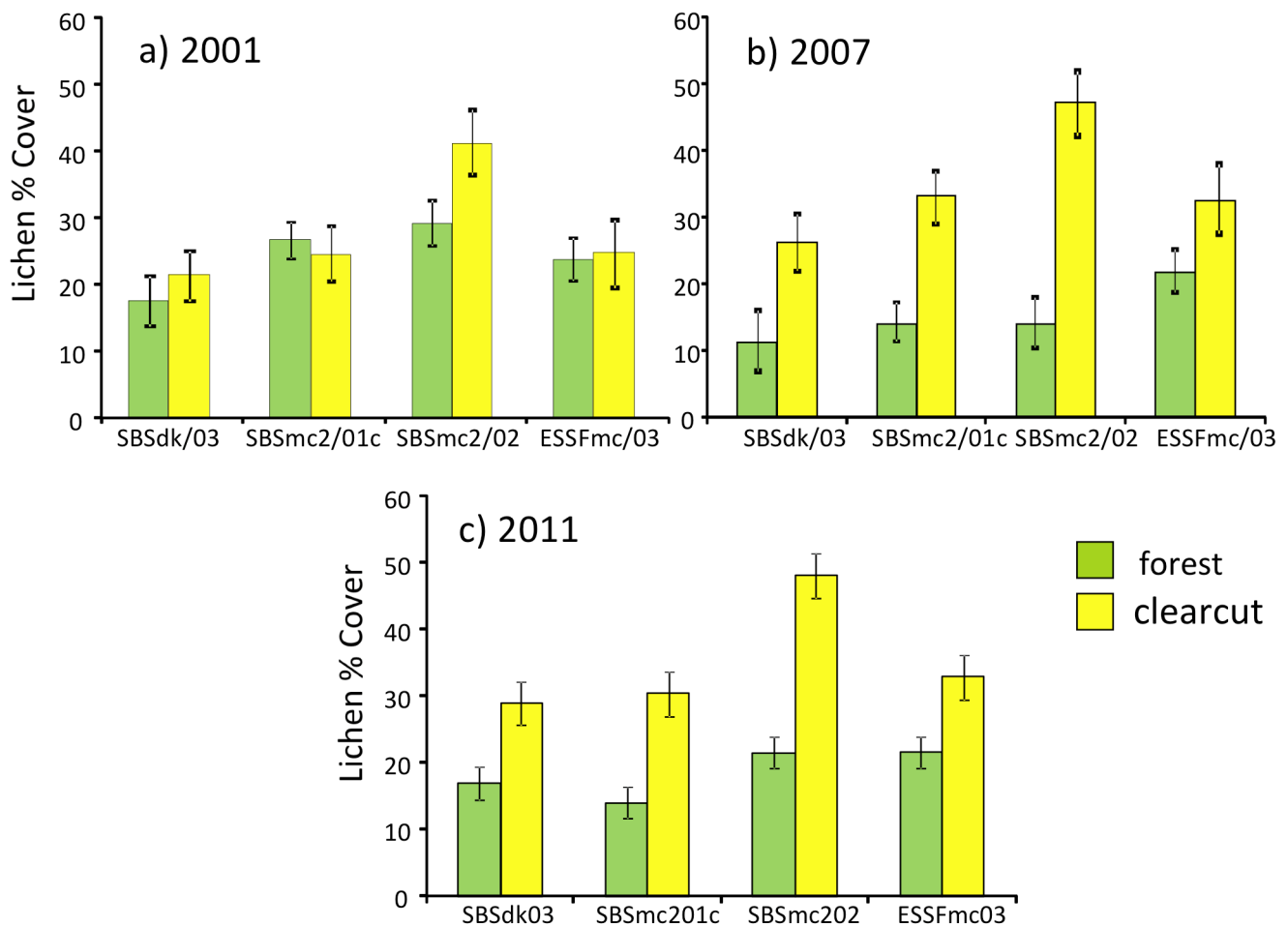


Figure 9. Caribou forage lichen cover by site unit in MPB forest and clearcuts in (a) 2001, (b) 2007, and (c) 2011. Error bars are + 1 standard error, from untransformed ANOVA.

In 2004, a wildfire in the East Ootsa area burned through several SBSmc2/01c and SBSmc2/02 forested and clearcut plots. The burned plots averaged 31% vascular plant cover and 19% moss cover by 2011, but caribou forage lichens remained near zero percent, and there was no difference in lichen recovery between forest and clearcut nor between the SBSmc2/01c and the SBSmc2/02 site units (see lower panels in Figures 10-12). The burned plots were not included in the statistical analyses that follow.

By 2007, lichen cover had decreased to 17% in forests affected by MPB, but had increased to 34% on clearcuts (Figure 9b, Figure 10a, b). The difference between MPB forests and clearcuts was highly significant ($p < 0.00001$). These results remained essentially unchanged in 2011 (18% in MPB forests, 34% on clearcuts; $p < 0.00001$). In both 2007 and 2011, the SBSmc2/02 and the ESSFmc/03 had significantly more lichen cover than the SBSdk/03 and the SBSmc1/01c site units ($p < 0.04$ for between group contrast, $p > 0.24$ for within-group contrasts). Interestingly, even though the response trajectory of lichens trended downwards in forests and upwards in clearcuts (compare Figure 10a to 10b; $p < 0.00001$ for the main effect of logging on repeated measures), the relative abundance of lichens in each site unit was not significantly different in forests than in clearcuts (site unit x stand disturbance interaction: $p > 0.33$ in 2001, 2007 and 2011).

Patterns of Ground-layer Vegetation Change from 2001 to 2011: Forests

Over the entire study, including SBPSmc sites, lichen abundance on forested ecosystems declined from 24% in 2001, to 20% in 2003, to 15% in 2005 to 13% in 2007 then increased slightly to 15% in 2011 (Figures 9a, 13). Although the dominant trend in lichen abundance was downward (linear trend = 61% of explained variability, $p < 0.0001$; compare to 89% linear for 2001-2007), there was very strong evidence of levelling off and even of a possible rebound in lichen abundance (quadratic trend = 33% of explained variability, $p < 0.00001$; compare to just 8% in 2007). Among the 6 site units, however, the shape of the trend was inconsistent (Figure 10a; $p < 0.00001$ for site unit x year interaction). To begin with, the ESSFmc/03 differed from other site units in that the decline in lichen abundance there occurred later and was less pronounced. Most notably in 2011, there was an increase in lichen abundance on the SBSdk/03 and SBSmc2/02 site units with lichen abundance recovering to levels not observed since 2003. Lichen abundance in the SBPSmc and SBSmc2/01c site units were more or less the same in 2011 as in 2007.

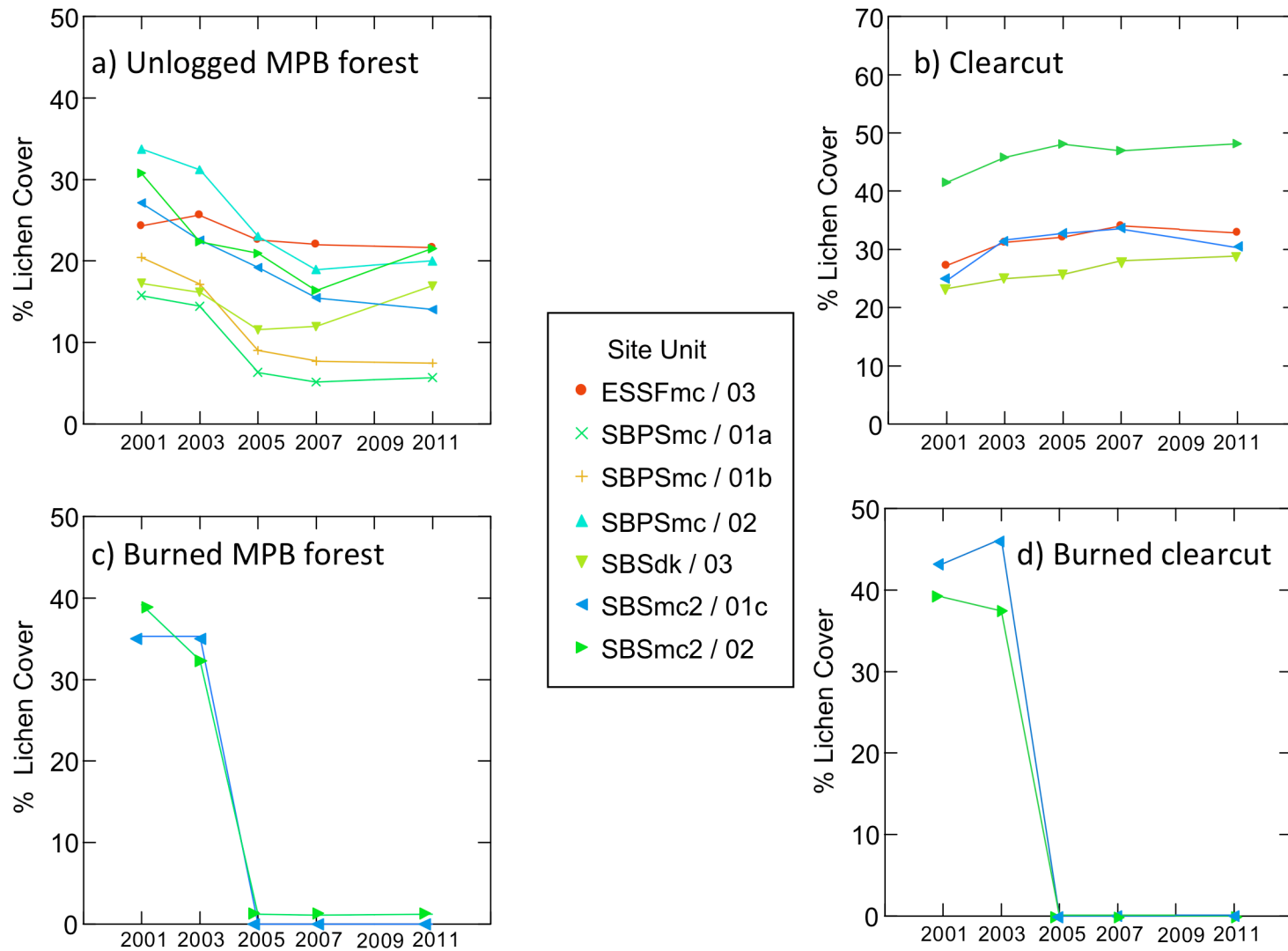


Figure 10. Changes in caribou forage lichen abundance by site unit from 2001 to 2011 on (a) unlogged MPB-affected forests, (b) recent clearcuts, (c) MPB-affected forest that burned in 2004, and (d) clearcuts that burned in 2004.

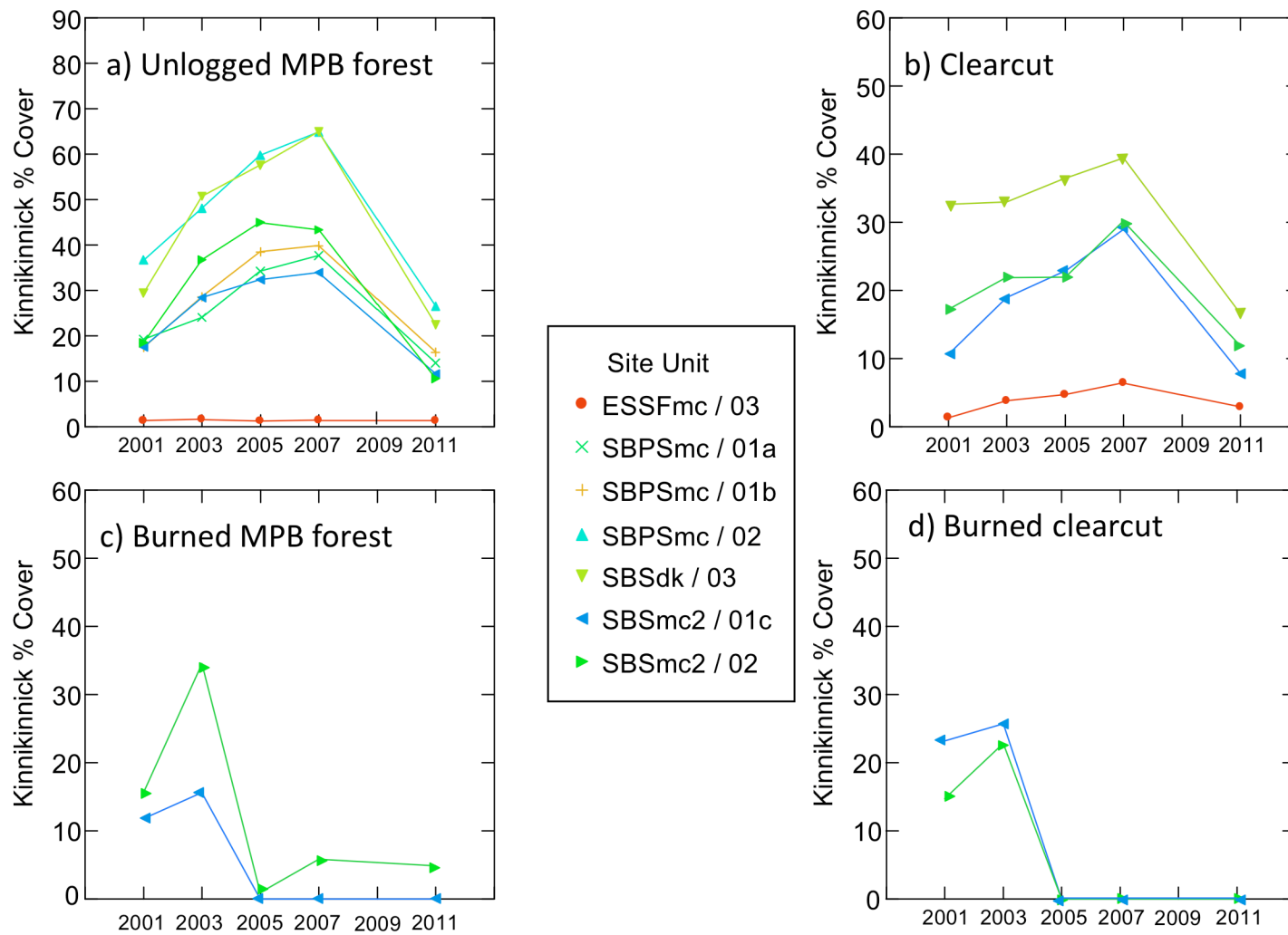


Figure 11. Changes in kinnikinnick abundance by site unit from 2001 to 2011 on (a) unlogged MPB-affected forests, (b) recent clearcuts, (c) MPB-affected forest that burned in 2004, and (d) clearcuts that burned in 2004.

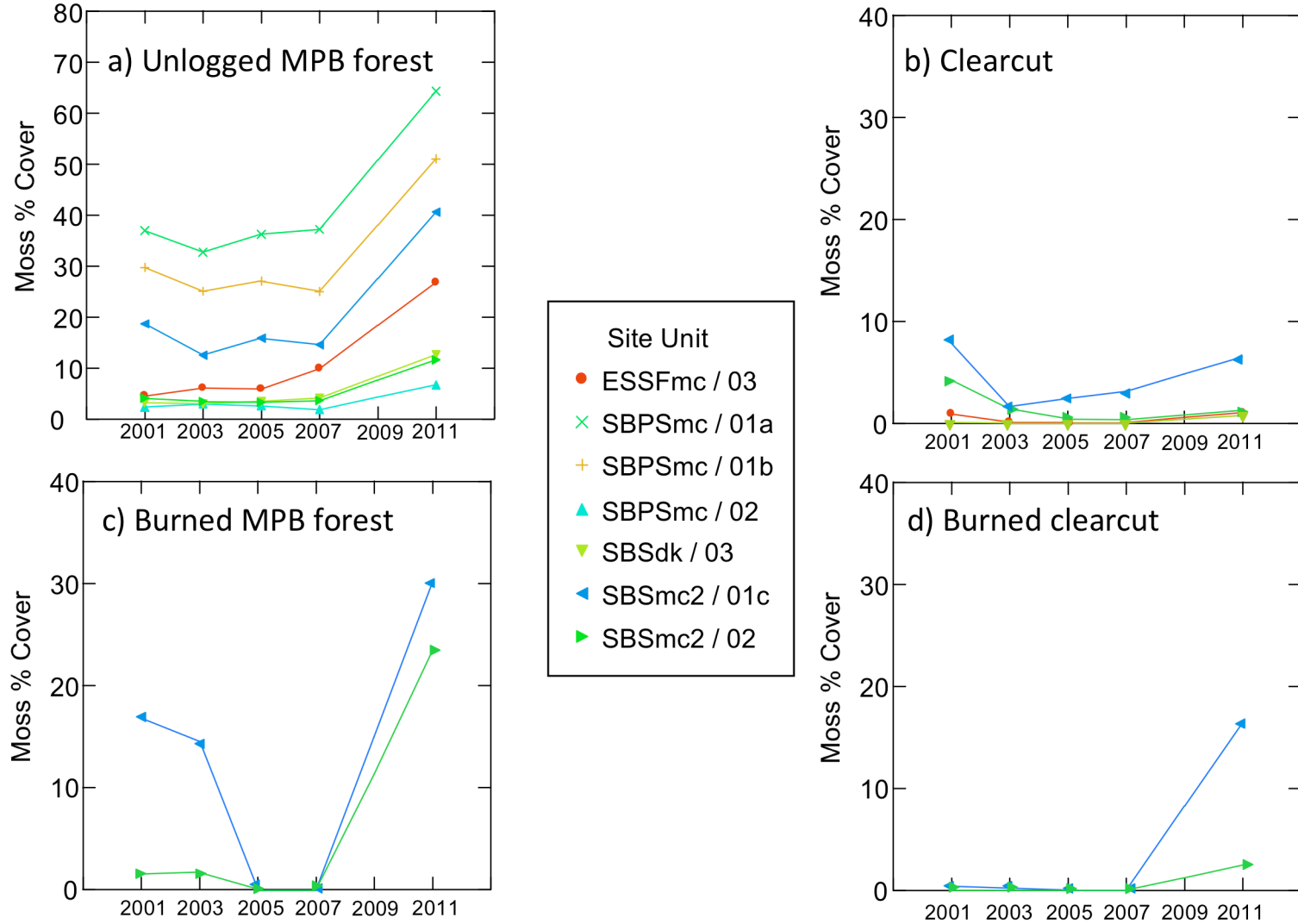


Figure 12. Changes in moss abundance by site unit from 2001 to 2011 on (a) unlogged MPB-affected forests, (b) recent clearcuts, (c) MPB-affected forest that burned in 2004, and (d) clearcuts that burned in 2004.

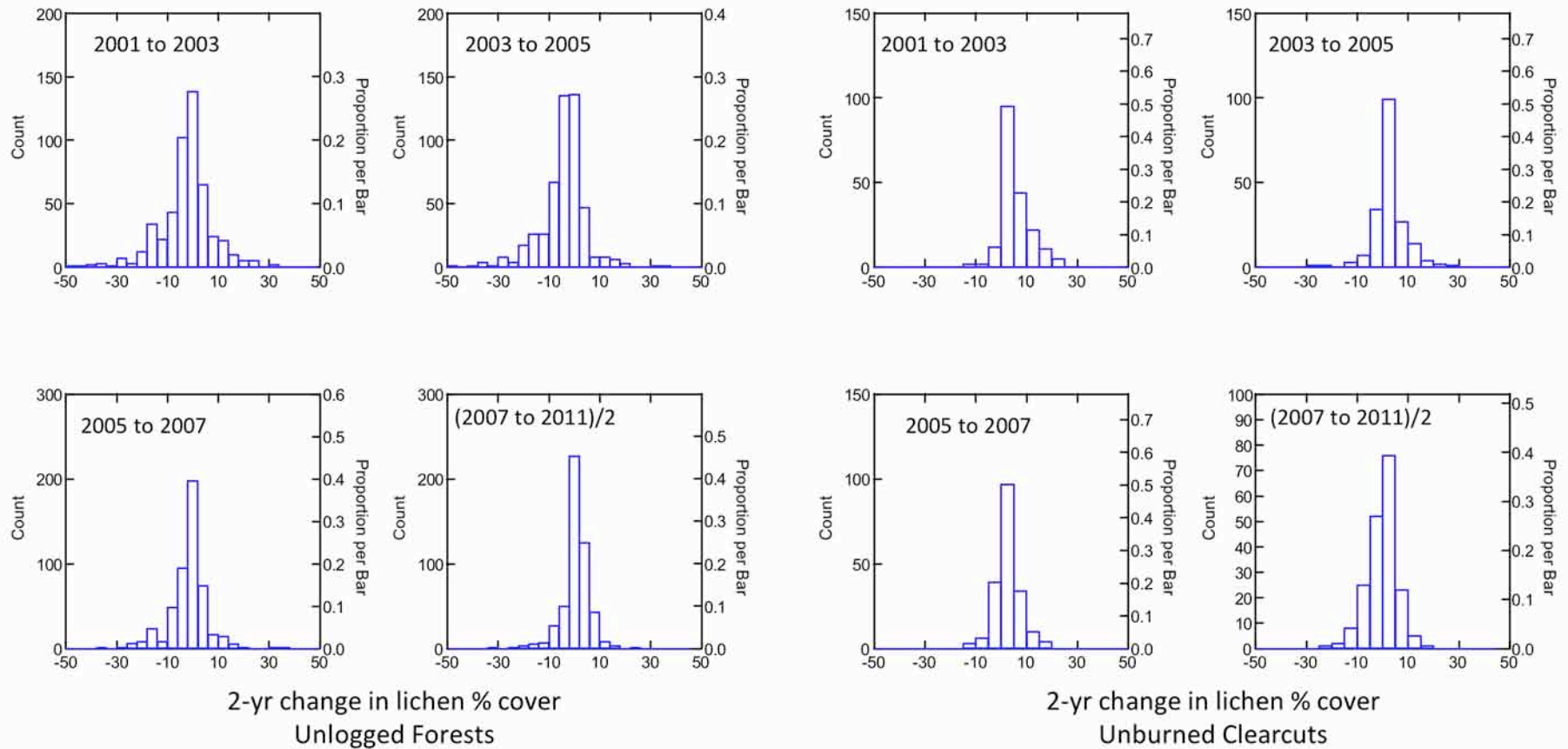


Figure 13. Frequency distribution of two year changes in lichen cover on photoplots from 2011 to 2011 in unburned MPB-affected forests (left), and clearcuts (right). A distribution that is shifted to the left indicates that most photoplots experienced a decrease in lichen cover, while a right-shift indicates an increase in lichen cover.

The behaviour of competing ground-layer vegetation species, particularly kinnikinnick, sheds light on the lichen results. The anomalous ESSFmc/03 sites had less than 2% kinnikinnick cover and there was no change in kinnikinnick abundance between 2001 and 2007 (Figures 11a, 14). All other subzones/site series averaged 20-40% kinnikinnick cover in 2001 and experienced a doubling of kinnikinnick cover (to 30 – 60+ %) by 2007, followed by a sharp dieback in 2011 to levels below those observed in 2001 (quadratic (hump-shaped) trend = 90% of explained variance, $p < 0.00001$; see Figure 15).

Across the entire study, moss levels remained relatively steady from 2001 to 2007, then increased dramatically in 2011. The dominant effect was a linear increase over the 2001 – 2011 time period (71% of explained variation, $p < 0.00001$) with also a highly significant acceleration in the later years of the study (quadratic, concave upward effect 28% of variation, $p < 0.00001$). Moss cover was consistently highest in the more productive /01 site series (SBSmc2 and SBPSmc zones) and lowest in the drier xeric – subxeric SBSdk/02, SBSmc2/02 and SBPSmc/02 site series. Part of the increase between 2007 and 2011 may have been due to the change in determining % cover in 2011. From 2001 to 2007, the % cover of moss was estimated from photographs, while in 2011, % cover of moss was visually estimated in the field so more moss was likely visible than what would have been seen in a photo. On burned sites, the increase in moss corresponded with an increase in “fire moss” (*Ceretodon purpureus*) from 2007 to 2011.

Overall, the dominant species of non-lichen ground vegetation (kinnikinnick, crowberry, twinberry and mosses) showed a consistent upward trending on the more humid site mesic and submesic site units (SBSmc2 and SBPSmc/01 and ESSFmc/03) and a rise followed by a sharp decrease between 2007 and 2011 on the drier units (Figure 16). On the drier units, the decline in kinnikinnick appears to have been accompanied by a recovery in lichens while in the moister units, lichen cover appears to have stabilized below the 2001 level while mosses and other ground vegetation have continued to increase.

Patterns of Ground-layer Vegetation Change from 2001 to 2011: Clearcuts

In clearcuts, lichen cover appears to have followed a highly significant upward trend with a stabilization by 2005 or 2007 ($p < 0.0001$; linear effect 74% of explained variation, quadratic effect 23% of explained

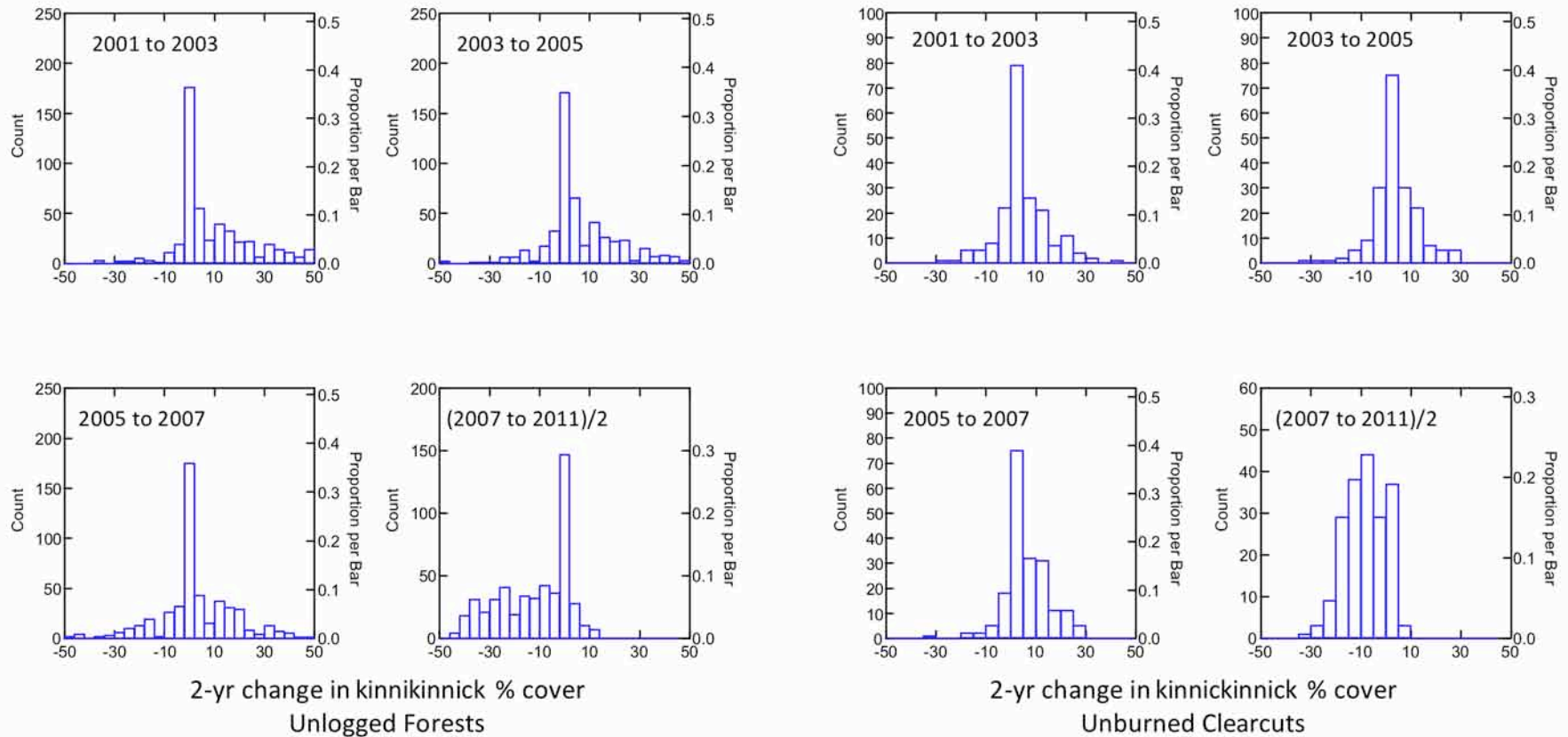


Figure 14. Frequency distribution of two year changes in kinnikinnick cover on photoplots from 2011 to 2011 in unburned MPB-affected forests (left), and clearcuts (right). A distribution that is shifted to the left indicates that most photoplots experienced a decrease in kinnikinnick cover, while a right-shift indicates an increase in kinnikinnick cover.

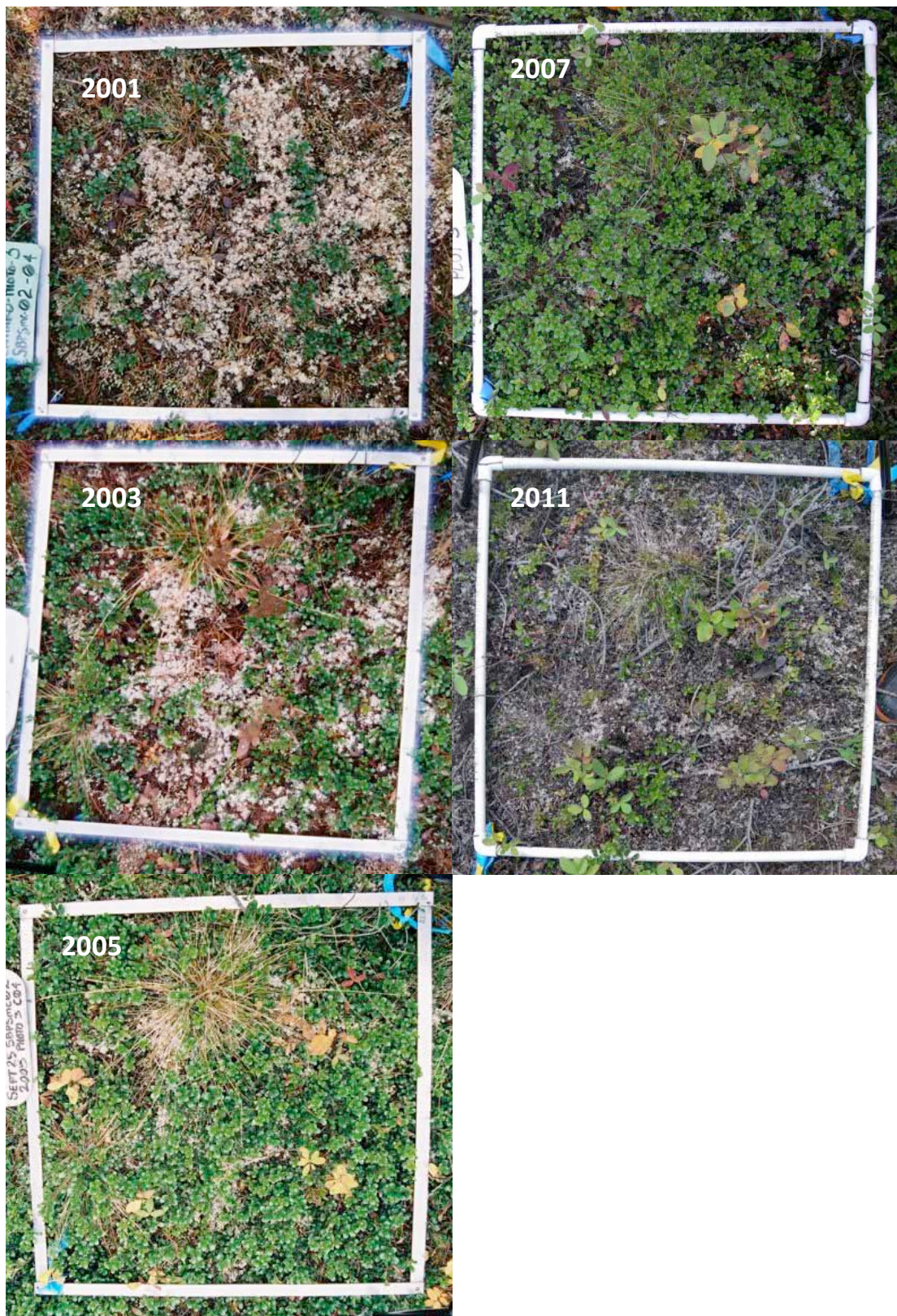


Figure 15. Change in terrestrial lichen and kinnikinnick abundance from 2001 to 2011, photoplot SBPSmc/02-C04-3.

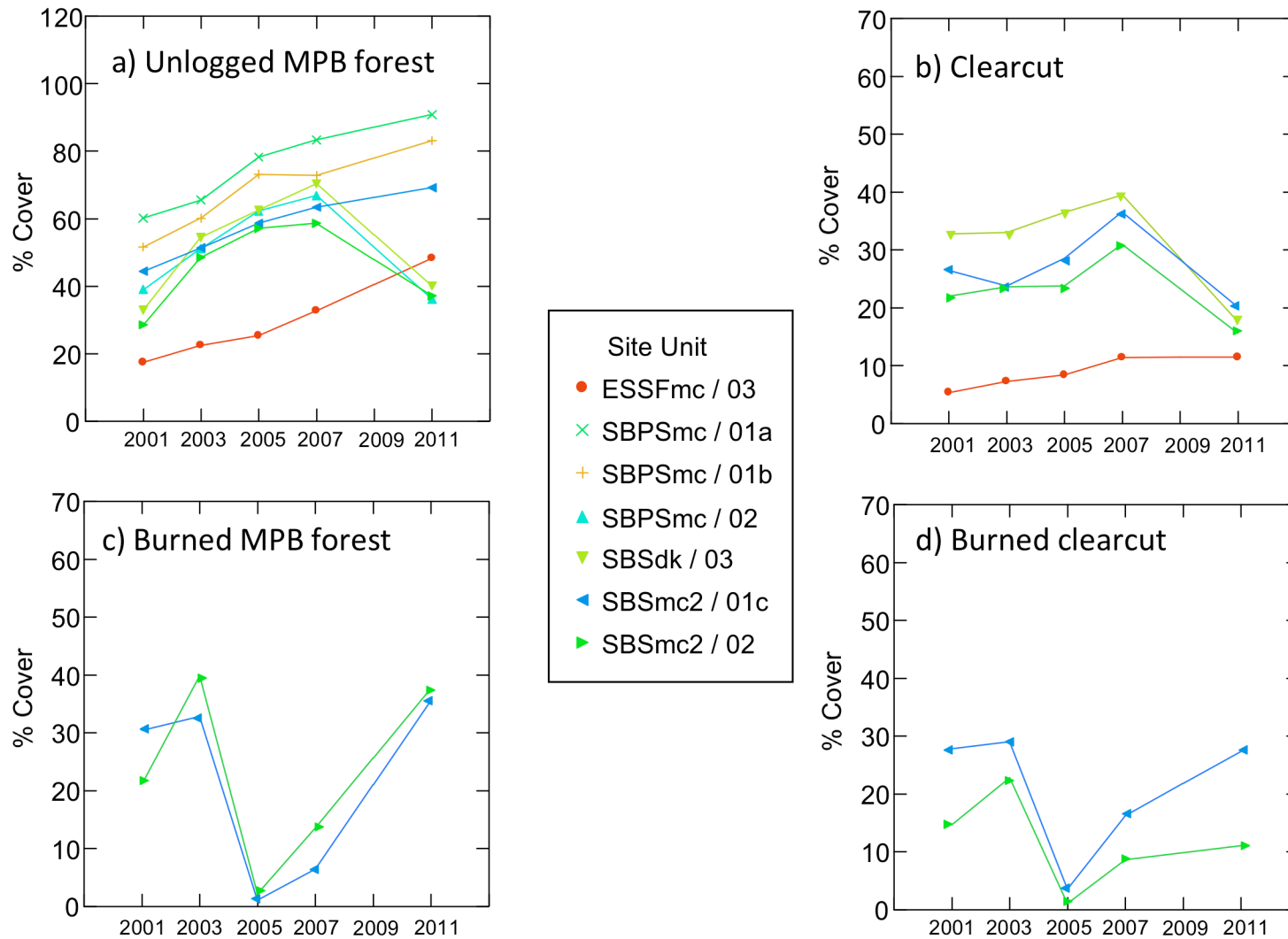


Figure 16. Changes in the total cover of major non-lichen ground vegetation (kinnikinnick + crowberry + twinflower + mosses) by site unit from 2001 to 2011 on (a) unlogged MPB-affected forests, (b) recent clearcuts, (c) MPB-affected forest that burned in 2004, and (d) clearcuts that burned in 2004.

variation). The visual lichen cover data show rather less year-to-year oscillation than was observed using the GLA data up to 2007 (Cichowski et al. 2008). All four site units followed the same general increasing trend ($p = 0.81$ for the site unit x year interaction) and due to high levels of variability there was no significant difference in lichen abundance among the four site units over the 10-year time period ($p = 0.08$).

Kinnikinnick experienced the same trend in clearcuts as in forests, rising steadily from 2001 to 2007, then falling sharply in 2011 (quadratic effect 90% of explained variation; $p = 0.00003$). Kinnikinnick abundance varied significantly across site units ($p < 0.00001$); the ESSFmc/03 clearcuts had slightly more kinnikinnick than the ESSFmc/03 forests, but again it was significantly less abundant than at lower elevations.

Moss cover fell initially between 2001 to 2003 than rose again until 2011 (quadratic time trend = 96%), but remained below 10% on all site units. In general, non-lichen ground vegetation abundance oscillated somewhat but rose overall between 2001 and 2007, but then fell sharply in 2011, except in the ESSFmc where it continued to rise ($p = 0.0007$ for difference among site units; $p = 0.0003$ for site unit x year interaction).

Predictive Models of Lichen Abundance

Despite changes in lichen abundance between 2007 and 2011, the 2011 predictive lichen model was very similar to that in 2007. Eight variables together explained 67% of the total variability in percent cover of lichens on photoplots in 2007 ($n = 752$, $p < 0.00001$, Table 6). Six of the 8 factors were negatively correlated with lichen abundance; the burned plots, which still had virtually no lichen cover, accounted for 28% of total variance. With those plots taken into account, the abundance of major species of non-lichen ground vegetation (kinnikinnick, mosses, twinflower and crowberry) in 2011 was the single best predictor of lichen abundance, accounting for 26% of total variance. Non-lichen ground vegetation in 2005 accounted for additional 8% of variance and twinberry cover in 2007 provided an extra 1% of explanatory cover ($p = 0.00001$), indicating that the effect of competing vegetation was non-linear (Figure 17). Blowdown on photoplots accounted for 4% percent of variance in lichen abundance, up from 2% in 2007, while MPB severity accounted for just 1%. Two factors had a positive influence on lichen abundance in 2011: whether a plot was in the SBSmc2 variant versus other subzones, and whether a site had a subxeric moisture regime (each accounting for 1% additional variance). In this model, as in 2007, logged versus forested sites were differentiated indirectly by means of the non-

lichen vegetation cover and the MPB basal area variables, both of which were much higher in forests than in clearcuts (Figure 17).

Table 6. Multiple regression models for lichen abundance.					
Response Variable	Explanatory Variables				
	Variable	Correlation¹	p-value	% variance explained	
				extra fit(r²)	total fit (R²)
a) 2011 lichen percent cover (square root transformed) n = 752	Burned = 1 Unburned = 0	-0.50	< 0.00001	--	25.1
	% non-lichen ground cover 2011	-0.59	< 0.00001	26.2	51.3
	% non-lichen ground cover 2005	-0.39	< 0.00001	7.6	58.9
	Blowdown =1 no blowdown = 0 in 2011	-0.30	< 0.00001	3.6	62.5
	SBSmc2 = 1 other subzones = 0	0.17	< 0.00001	1.2	63.7
	Subxeric = 1 Submesic = 0	0.18	< 0.00001	1.1	64.8
	Relative severity of MPB BA 2007	-0.15	0.0003	0.9	65.7
	% Twinflower cover 2007	-0.16	0.00001	0.9	66.6
Equation: $Y^{\sqrt{}} = 5.63 - 5.86(\text{burned}) - 0.015(\text{Veg11}) - 0.019(\text{Veg05}) - 0.05(\text{Blw11}) + 6.79(\text{SBSmc2}) + 0.6(\text{Subxeric}) - 0.65(\text{MPB07}) - 0.02(\text{Twinfl07})$					
b) Relative change in lichen cover <u>(2011- 2007)</u> 2007 (log-transformed) n = 752	Kinnikinnick Cover 2005	0.43	<0.00001	--	18.9
	Lichen Cover 2003	-0.20	<0.00001	3.3	22.2
	Blowdown 2011	-0.21	<0.00001	2.5	25.7
	Moss Cover 2001	-0.20	<0.00001	3.1	28.8
	Annual Rate of Change in Lichen Cover 2001 – 2005	-0.13	<0.00001	1.2	30.0
	Annual Rate of Change in Non-Lichen Ground Veg 2005-2011	-0.13	0.0001	1.2	31.2
	Longitude	-0.11	0.003	0.9	32.1
	Blowdown 2007	0.11	0.003	0.8	32.9
Equation: $\text{Log}_{10}Y = 0.33 + 0.00058(\text{Kinn05}) - 0.0013(\text{Lichen03}) - 0.00024(\text{Blw11}) - 0.0008(\text{Moss01}) - 0.003(\text{Lichen Chg 2001-2005}) - 0.0024(\text{Veg Chg 2005-2011}) - 0.00026(\text{Longitude}) + 0.036(\text{Blw7})$					

¹ Correlation after accounting for factors previously added to the model..

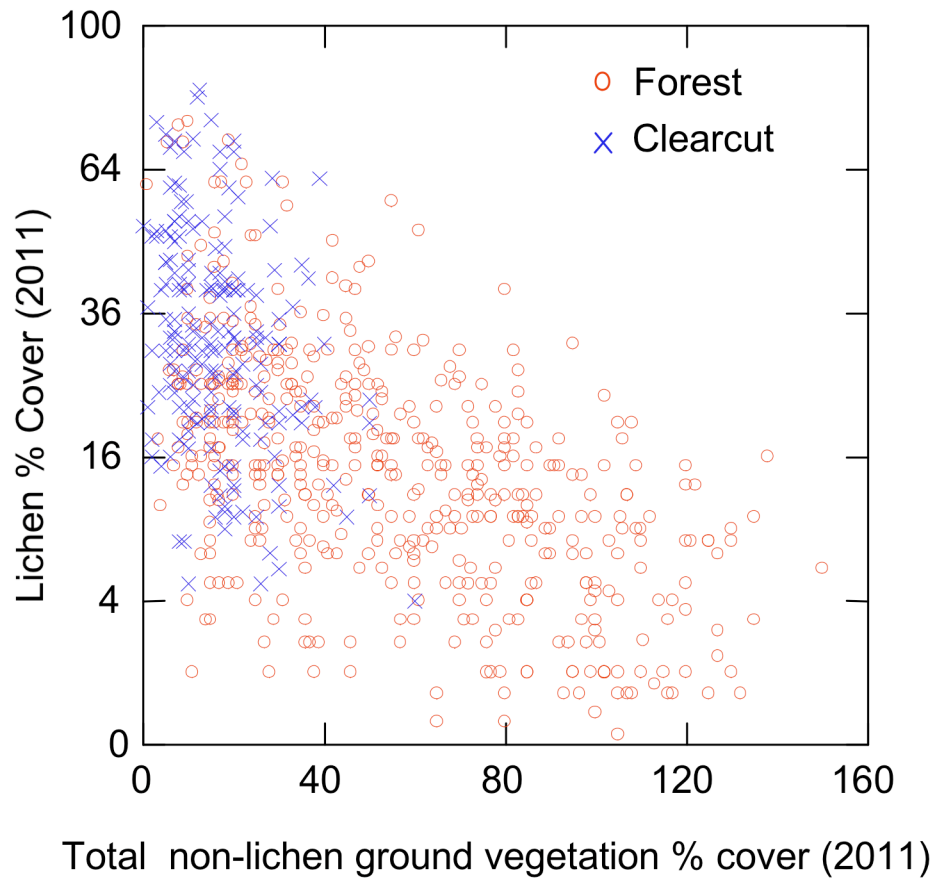


Figure 17. Percent cover of caribou forage lichens in relation to the total cover of major species of non-lichen ground vegetation (mosses, kinnikinnick, twinflower, crowberry) on photoplots in unburned forests (red circles) and unburned clearcuts (blue x's) in 2011. Note that the Y axis has a square-root scale while the X axis is linear, indicating that each unit of increase in non-lichen vegetation produces a squared negative response in lichen abundance.

The regression model for changes in lichen abundance between 2007 and 2011 also included 8 variables that together explained 33% of the total variance ($n = 752$, $p < 0.00001$, Table 6b). Note that, unlike previous years, this model indicates the relative amount of change rather than the absolute amount of change in lichen cover; thus, a loss of 1% cover from a photoplot with 2% lichen in 2007 and a loss of 30% cover from a photoplot with 60% lichen in 2007 would both amount to a -50% relative change. A negative correlation in Table 6b indicates a larger relative

decline in lichen cover. The variable that had by far the highest explanatory power (19%) was the cover of kinnikinnick in 2005 and the correlation was strongly positive. In other words, plots in which kinnikinnick cover exploded --and subsequently collapsed (Figures 11, 14)-- experienced the greatest increase in lichen cover between 2007 and 2011, while those with the least kinnikinnick in 2005 (i.e., ESSFmc and SBSmc2/01c plots) were most likely to experience a decline in lichens. With this kinnikinnick effect accounted for, a variety of other vegetation cover and vegetation change indices accounted together for an additional 9% of the variance. Plots that had a high cover of lichens early in the study (2003) and those that experienced an increase in lichens in the first half of the study (e.g., clearcuts) tended to lose more lichens between 2007 and 2011 than plots with relatively low lichen cover early on, or those that experienced an early decline in lichen abundance. Moreover, plots with high moss cover at the start of the study (moist forests) tended to lose more lichens than plots with low moss cover (clearcuts and drier forests).

In general, these results support our earlier conclusions that ongoing fluctuations in lichen dynamics reflect what is happening in the remainder of the understory vegetation community and that these dynamics are not synchronized across the study area. Some of these dynamics are clearly ongoing responses to the mountain pine beetle effect, while others are less closely tied. While direct effects of MPB are generally less evident than at earlier stages of the study (2005, 2007), blowdown is now playing a greater role. Cumulative blowdown onto the photoplots up to 2011 had a significant negative impact on lichen cover changes between 2007 and 2011 (3% of variance explained). But interestingly, blowdown observed in 2007 had a positive effect (1% of variance explained). This result suggests that the effects of blowdown may be mostly short-lived and that there has been some recovery from earlier blowdown (e.g., fine branches relative to large woody material). Finally, plots located further west tended to have a greater loss of lichen cover between 2007 and 2011 than plots located further east.

Vegetation Composition Following 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 7 summarizes regeneration and vegetation cover on those plots, 7 years following the fire.

Table 7. Regeneration and vegetation cover in 2011 for 6 permanent plots in the East Ootsa area that were burned by a wildfire in August 2004.

	Mountain pine beetle plots				Harvested plots	
	SBSmc2/01c C04	SBSmc2/02			SBSmc2/01c L03	SBSmc2/02 L01
		C01	C02	C05		
Extent of burn	All	All	All	Partial	All	All
REGENERATION (stems/ha based on 5 m² plot)						
Pine 0-10 cm tall		200	200	200		200
Pine 10-30 cm tall		2600	600	4000		1400
Pine 30-130 cm tall	600	4600	2200	1600	1600	2000
Pine 1.3 m tall to 7.49 cm dbh	50	100			800	150
Spruce 0-10 cm tall				3200		
Spruce 10-30 cm tall				800		
Spruce 30-130 cm tall				200		
Spruce 1.3 m tall to 7.49 cm dbh				100		
PERCENT COVER VEGETATION						
<i>Salix</i> sp.	1			0.5		
<i>Shepherdia canadensis</i>	6	1.5		2	15	1
<i>Rosa acicularis</i>	0.5					0.2
<i>Spirea betulifolia</i>	5					
<i>Amelanchier alnifolia</i>		0.5				
<i>Actostaphylos uva-ursi</i>	0.5	1	3	20	0.4	0.1
<i>Vaccinium membranaceum</i>	4		0.5		2	1
<i>Vaccinium caespitosum</i>	25	2	5	5	8	2
<i>Linnaea borealis</i>	7	15	12	35	25	25
<i>Empetrum nigrum</i>				2		
<i>Cornus canadensis</i>	1	2	1	1.5	2	2
<i>Arnica cordifolia</i>	<0.1				<0.1	0.1
<i>Lupinus arcticus</i>	1		0.5		2	
<i>Epilobium angustifolium</i>	1	3	1	5	1.5	<0.1
<i>Achillea millefolium</i>			0.1		1	<0.1
<i>Erigeron peregrinus</i>					1	<0.1
<i>Fragaria virginiana</i>					<0.1	
<i>Pyrola chlorantha</i>				<0.1		
<i>Hieracium</i> sp.		0.1				<0.1
<i>Taraxacum officinale</i>		<0.1	<0.1	<0.1	<0.1	<0.1
<i>Calamagrostis canadensis</i>		0.2			1	
<i>Oryzopsis pungens</i>			1			
<i>Agrostis scabra</i>						
Grass sp.	2	3		1	2	3
<i>Carex</i> sp.		2				
<i>Ceratodon purpureus</i>	20	8	5	10	10	2
<i>Pleurozium schreberi</i>				1		
<i>Polytrichum juniperinum</i>	2	1	15		2	
<i>Lycopodium complanatum</i>						
<i>Cladina mitis</i>				0.5		
<i>Cladina rangiferina</i>				1		
<i>Peltigera</i> sp.				0.5		

New pine seedlings have established on all burned plots. On 4 of the 6 plots, pine >1.3 m high were recorded. Pine was the most abundant species on all plots; spruce was present only on the partially burned plot. Regeneration was generally more abundant on burned MPB plots than on burned logged plots.

The dominant vegetation species on fully burned sites were *Linnaea borealis* (twin-flower), *Vaccinium caespitosum*, *Vaccinium membranaceum*, *Shepherdia canadensis*, *Epilobium angustifolium*, *Cornus Canadensis* and fire moss (*Ceratodon purpureus*). Although kinnikinnick was largely absent from burned plots in 2005, some resprouting was observed in 2007 and by 2011, up to 3% cover of kinnikinnick was recorded on fully burned sites. Kinnikinnick cover on the partially burned plot was 20% in 2011, down from 30% in 2007. Kinnikinnick die-back was observed on all three SBSmc2/02 burned forested plots. Originally, we expected that kinnikinnick would be consumed during fire disturbance and that it would have to re-establish through seed dispersal. Twin-flower was the most abundant forest floor plant on all sites except for the SBSmc2/01c-C04, where *Vaccinium caespitosum* was the most abundant. Lichens present on SBSmc2/02-C05 were remnants in unburned patches.

Coarse Woody Debris

We measured coarse woody debris on plots to assess whether mountain pine beetle and forest harvesting disturbances could impact caribou habitat use by impeding caribou movement (mobility). Coarse woody debris volume and mass was generally greatest on ESSFmc plots, followed by SBSmc2 and SBSdk plots (Figure 18). Overall, coarse woody debris volume, mass and density for mountain pine beetle plots were similar for all 5 years sampled in ESSFmc/03 and SBPSmc/02 plots, and increased in SBSdk/03, SBSmc2/01c, SBSmc2/02, SBPSmc/01a and SBPSmc/01b plots (Figure 18). This was reflected in the relatively constant rate of accumulation of new coarse woody debris in the ESSFmc/03 and SBPSmc/02, and the increase in new pieces of coarse woody debris in the other site series (Figure 19). The rate of accumulation of new pieces of coarse woody debris was also relatively constant on harvested sites (Figure 20).

Decay Class and Mobility Class of coarse woody debris pieces indicate that coarse woody debris pieces are distributed relatively evenly across the 5 decay classes and that most pieces are in Mobility Class 1 or 0 (Figure 21). Between 2001 and 2011, there was an increasing trend in

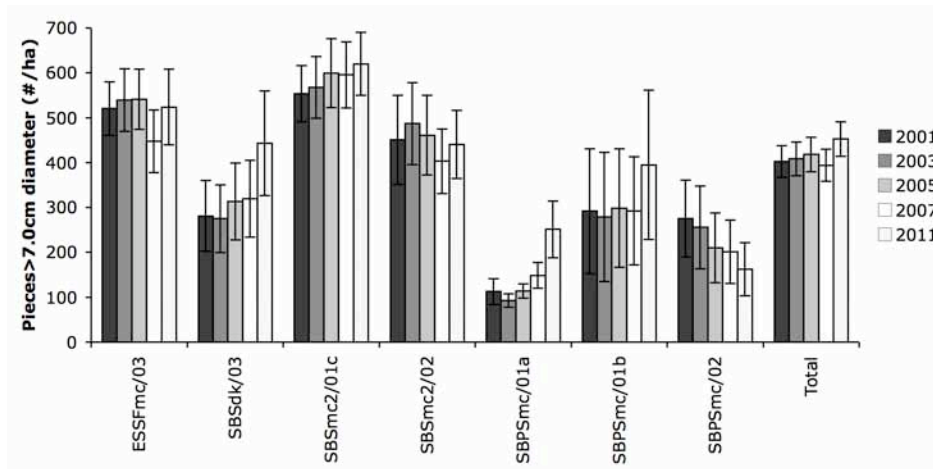
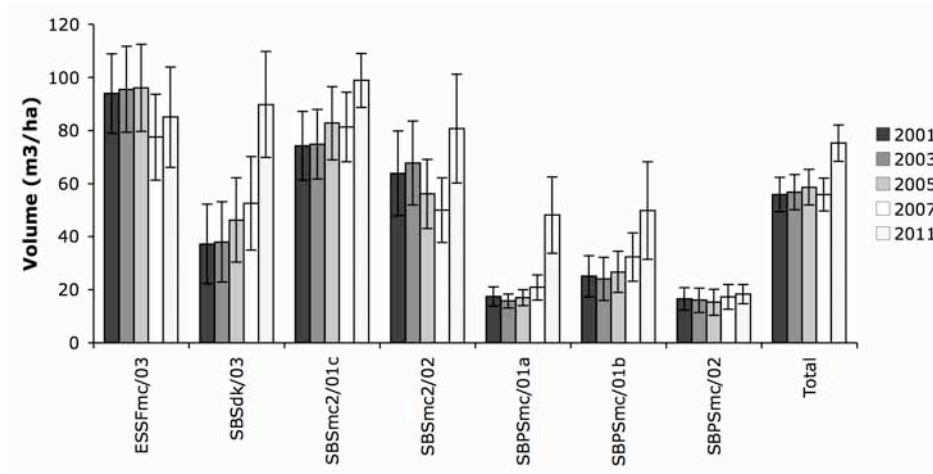
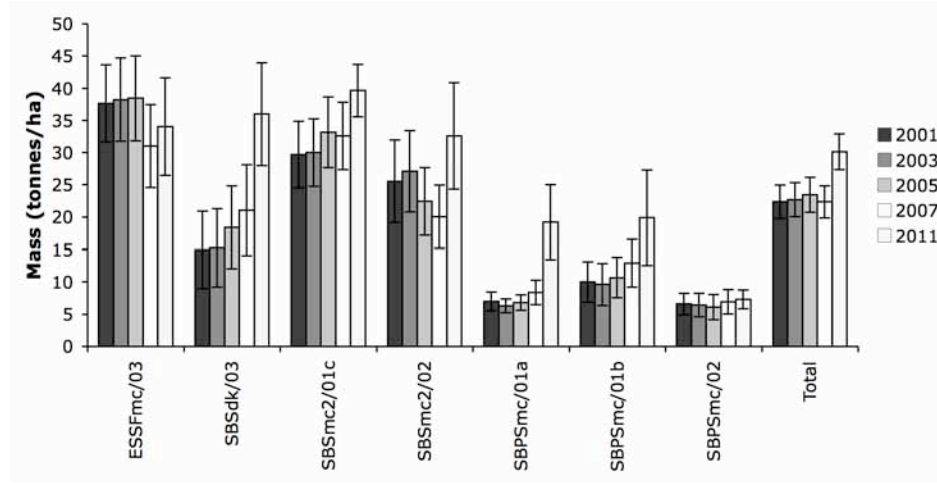


Figure 18. Mean volume, mass and pieces of coarse woody debris by biogeoclimatic subzone and year in the East Ootsa and Entiako areas, 2001-2011. Error bars are ± 1 standard error.

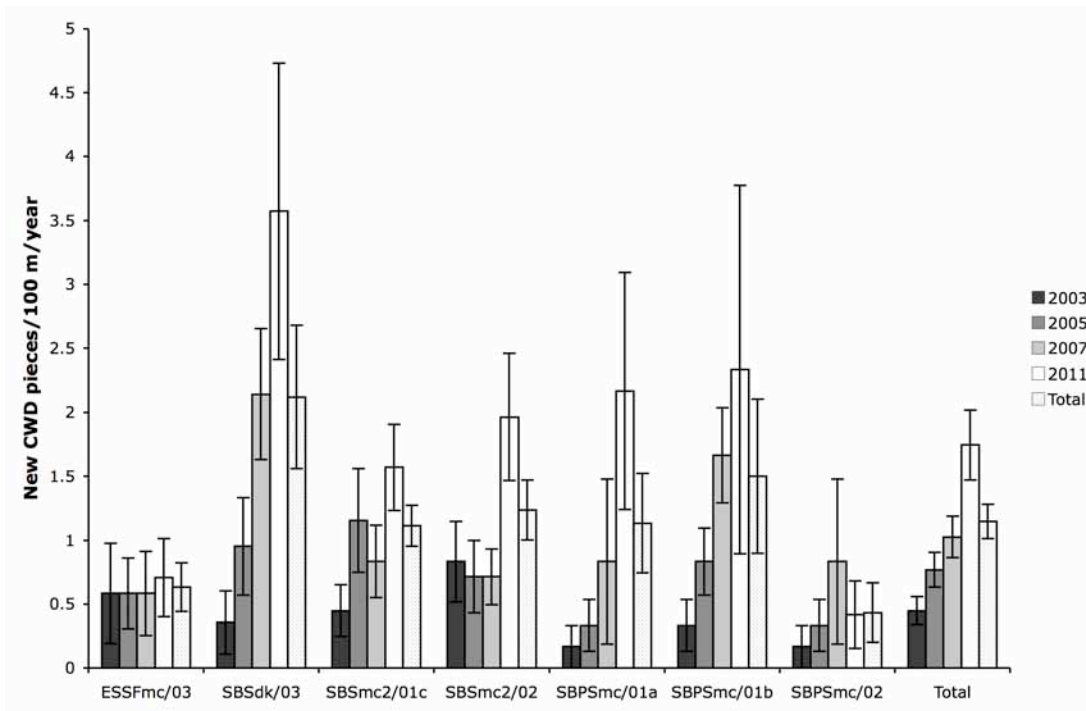


Figure 19. Mean number of new pieces of coarse woody debris per year on MPB plots by biogeoclimatic subzone and year in the East Ootsa and Entiako areas, 2001-2011. Error bars are ± 1 standard error.

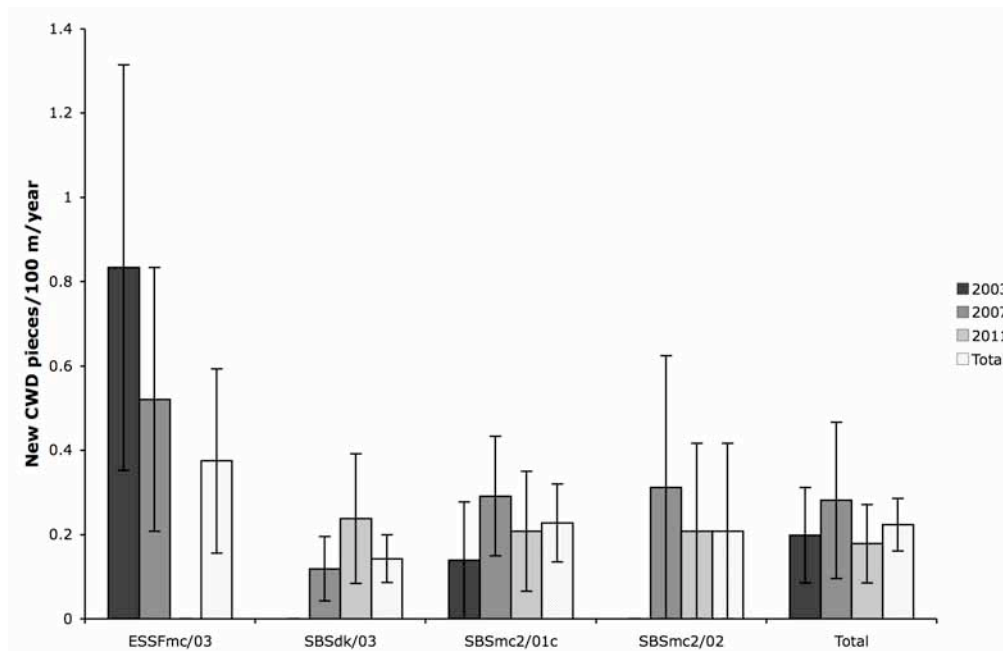


Figure 20. Mean number of new pieces of coarse woody debris per year on logged plots by biogeoclimatic subzone and year in the East Ootsa and Entiako areas, 2001-2011. Error bars are ± 1 standard error.

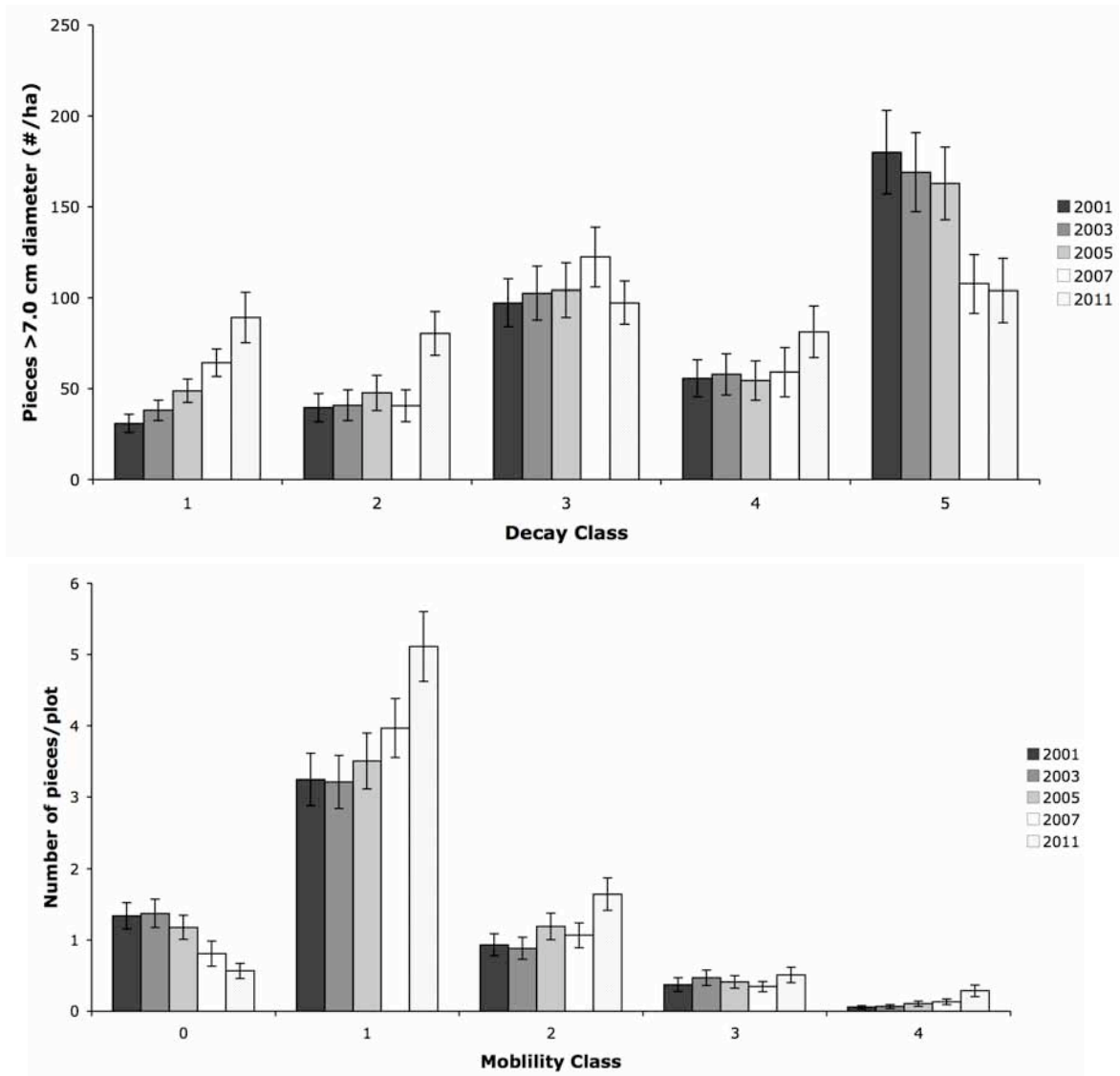


Figure 21. Mean pieces of coarse woody debris on mountain pine beetle plots in each decay class and mobility class and year in the East Ootsa and Entiako areas, 2001-2011. Error bars are ± 1 standard error.

Decay Class 1 logs (fresh blowdown) and a decreasing trend in Mobility Class 0 and Decay Class 5 logs (on the ground and decaying), which were likely overgrown by vegetation or otherwise incorporated into the forest floor. Although the amount of new blowdown has increased in most subzones, the majority of blowdown is Mobility Class 1.

Overall Mobility Index has increased from 2001 to 2011 (Figure 22). Mobility Index on ESSFmc/03 plots is lower than on SBSmc2/01c plots, whereas volume and mass are higher, suggesting that elevation of coarse woody debris (off the ground) on ESSFmc plots is generally low. Mobility Index was generally lower on harvested plots than on mountain pine beetle plots in 2001 and 2011 except for ESSFmc/03 plots where Mobility Index was similar on mountain pine beetle and logged plots (Figure 23).

Increased levels of coarse woody debris in 2011 reflect increased rates of tree fall down (see Stand Structure and Regeneration). Currently, the amount of coarse woody debris is still relatively low on most sites.

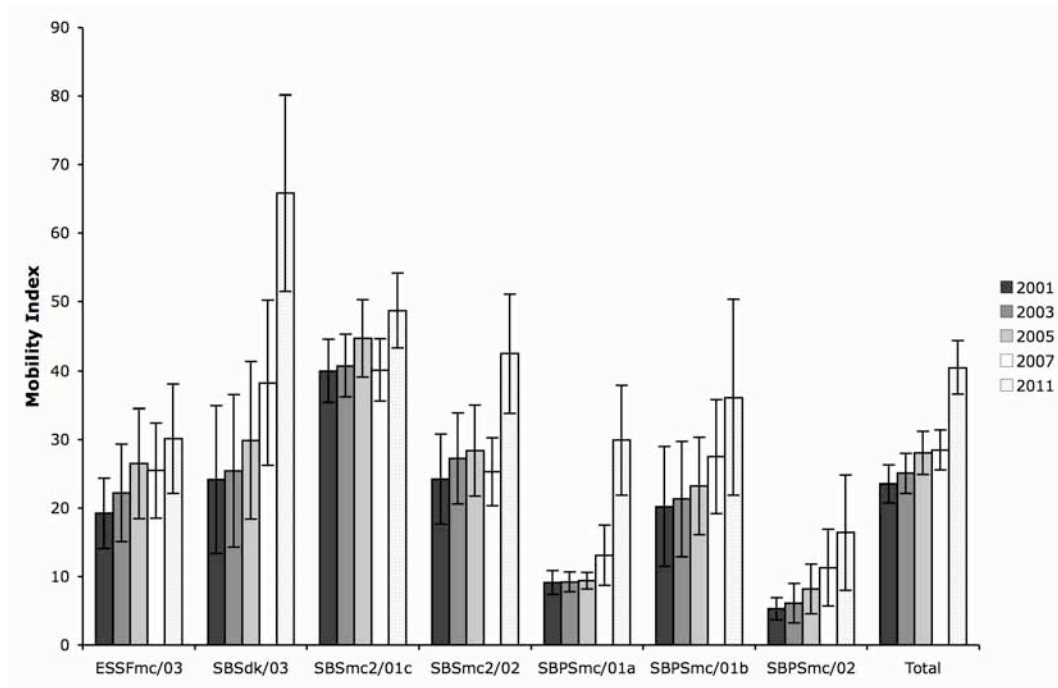


Figure 22. Mean mobility index of coarse woody debris by year for mountain pine beetle sites in the East Ootsa and Entiako areas, 2001-2011. Error bars are ± 1 standard error.

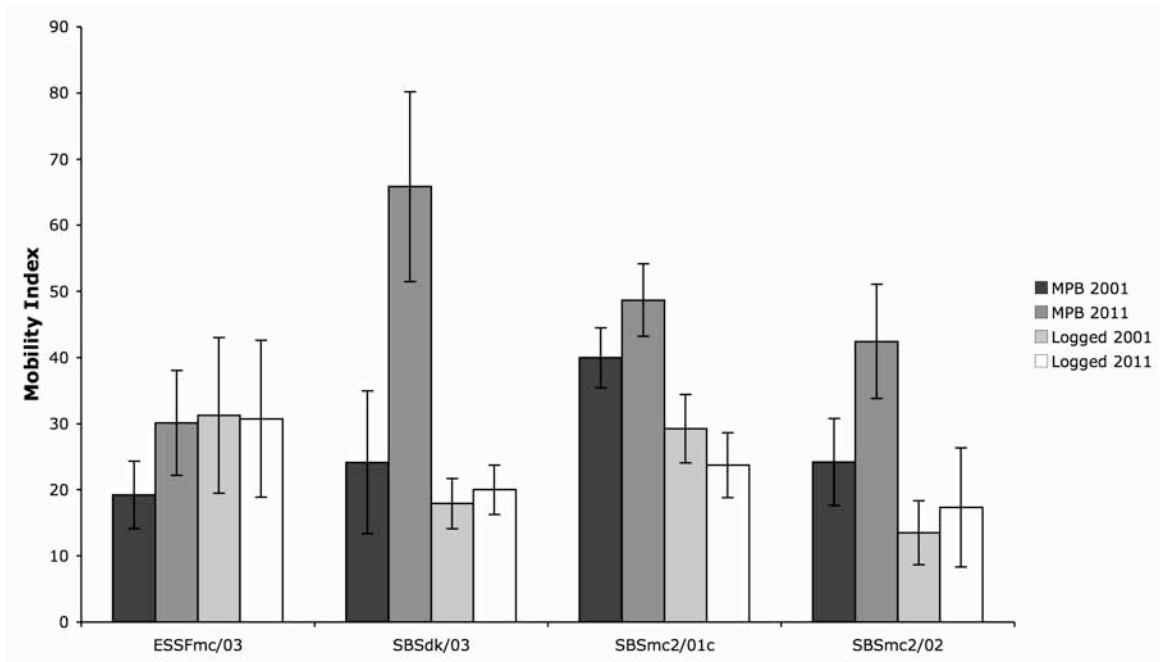


Figure 23. Mean mobility index for mountain pine beetle (MPB) and logged sites by biogeoclimatic subzone and year in the East Ootsa and Entiako areas, 2001-2011. Error bars are ± 1 standard error

Effects of Mountain Pine Beetles on Caribou Habitat and Caribou Habitat Use

The decline in caribou terrestrial forage lichens following the mountain pine beetle epidemic and increase in dwarf shrubs documented here on the Tweedsmuir-Entiako caribou winter range, has also been observed on the Kennedy-Siding and Itcha-Ilgachuz caribou winter ranges (Cichowski et al. 2009, Seip and Jones 2010, Waterhouse 2011). The primary difference between the caribou ranges is the species of dwarf shrubs that have increased. On the Kennedy-Siding caribou winter range, *Vaccinium myrtilloides* and to a lesser extent kinnikinnick, were the primary species of dwarf shrubs that increased (Seip and Jones 2010). In the western (Williams Lake TSA) portion of the Itcha-Ilgachuz caribou winter range, the primary dwarf shrubs that increased were kinnikinnick in the SPPSxc, and twinflower, crowberry and *Vaccinium scoparium* in the MSxv (M. Waterhouse, pers. comm.). In the northeastern (Quesnel TSA) portion of the Itcha-Ilgachuz caribou winter range, twin-flower, kinnikinnick and *Vaccinium* sp. (*V. scoparium*, *V. caespitosum*) all contributed to the increase in dwarf shrubs (Cichowski et al. 2009).

The pattern of a rapid increase in kinnikinnick following mountain pine beetle attack and then a rapid decrease as observed on drier sites on the Tweedsmuir-Entiako caribou winter range has not yet been observed on the other caribou ranges, partly because the Tweedsmuir-Entiako caribou range is the first to experience the mountain pine beetle epidemic so the forest floor dynamics following mountain pine beetle attack on other ranges are not as advanced as they are on the Tweedsmuir-Entiako range. It is also unclear whether the die-back is specific to kinnikinnick, or whether other dwarf shrubs on other ranges will also die-back. On the Tweedsmuir-Entiako caribou winter range, twinflower has continued to increase while kinnikinnick has declined.

Despite the decrease in terrestrial lichen abundance and potential changes in snow conditions due to needle loss in pine forests following mountain pine beetle attack, caribou still continue to crater for terrestrial lichens in mature (but MPB-killed) pine stands (Cichowski 2010, Seip and Jones 2010). At the time of those studies, tree fall of dead mountain pine beetle-killed trees on the winter ranges was low and likely had little influence on caribou movements. The effect of tree fall on caribou movements on their winter range will depend on the pattern of mountain pine beetle mortality across the winter range and on the pattern of coarse woody debris deposition over time.

References

- Ahti, T. 1961. Taxonomic studies on reindeer lichens (*Cladonia*, subgenus *Cladina*). *Ann. Bot. Soc. 'Vanamo'* 32: 1-160 + 12pl.
- Ahti, T. 1977. Lichens of the Boreal Coniferous Zone. Pp. 146-181 in: Seaward, M.R.D. (ed.), *Lichen Ecology*. Academic Press, London.
- Ahti, T. and R.L. Hepburn. 1967. Preliminary studies on woodland caribou range, especially on lichen stands, in Ontario. Ontario Department of Lands and Forests, Research Report (Wildlife) No. 74. 134p.
- Bell, J.N.B. and J.H. Tallis. 1958. Biological flora of the British Isles: *Empetrum nigrum* L. *Journal of Ecology* 61:289-305.
- BC MOELP and BC MOF. 1998. Field Manual for Describing Terrestrial Ecosystems. B.C. Min. For., Victoria, B.C. Land Manage. Handb. No. 25.
- British Columbia Ministry of Forests. 1997. CWD/Fuel Calculator – Version 1.0a. Computer program developed by Ember Research Services Ltd., Victoria, B.C. for Ministry of Forests Research Branch, Victoria, B.C.
- Canham, C.D. 1988. An index for understory light levels in and around canopy gaps. *Ecology* 69: 1634-1638.
- Cichowski, D.B. 1993. Seasonal movements, habitat use, and winter feeding ecology of woodland caribou in west-central British Columbia. B.C. Min. For., Victoria, B.C., Land Manage. Handb. No. 79. 54p. (www.for.gov.bc.ca/hfd/pubs/docs/mr/lmr079.htm)
- Cichowski, D. 2008. Tweedsmuir (North) Provincial Park and Entiako Park and Protected Area: Managing natural and cultural values in a post-mountain pine beetle landscape. Prepared for Ministry of Environment, Prince George, B.C. 64p.
- Cichowski, D. 2010. Tweedsmuir-Entiako Caribou Project: Effects of a Mountain Pine Beetle Epidemic on Northern Caribou Habitat Use – Final Report. Prepared for the Bulkley Valley Centre for Natural Resources Research and Management, Smithers, B.C. 66p.
- Cichowski, D. and A. de Groot. 2010. The Response of Caribou Terrestrial Forage Lichens to Fire in Entiako Provincial Park: Annual Report – 2009/10 – Year 3. Prepared for Ministry of Environment, Prince George, B.C.

- Cichowski, D., and N. MacLean. 2005. Tweedsmuir-Entiako Caribou Population – Technical Background Information Summary (1983-2003). Prepared for Ministry of Environment, Smithers, B.C. 199 p.
- Cichowski, D., A. Macadam, and S. Haeussler. 2009. Mountain Pine Beetle/Lichen Project Quesnel TSA – Year 4 – 2008/09. Prepared for Ministry of Environment, Williams Lake, B.C. 79p.
- Cichowski, D., P. Williston, and S. Haeussler. 2008. The Response of Caribou Terrestrial Forage Lichens to Mountain Pine Beetles and Forest Harvesting in the East Ootsa and Entiako Areas: Annual Report – 2007/08 – Year 7. A report to Morice-Lakes Innovative Forest Practices Agreement, Prince George, B.C., the Bulkley Valley Centre for Natural Resources Research and Management, Smithers, B.C., and Ministry of Environment, Prince George, B.C. 46p.
<http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=16381>
- Cichowski, D., B. Lawson, D. McLennan, P. Williston, J. Spears, T. White, C. Schell, B. Armitage, J. Carlson and N. Guy. 2001. Entiako Park and Protected Area – Ecological Background Information Summary. BC Parks, Smithers, B.C. 194p.
- Coxson, D. and J. Marsh. 2001. Lichen chronosequence (postfire and postharvest) in lodgepole pine (*Pinus contorta*) forests of northern interior British Columbia. *Canadian Journal of Botany* 79: 1449-1464.
- Crittenden, P.D. 2000. Aspects of the ecology of mat-forming lichens. *Rangifer* 20: 127-139.
- Garbutt, R. and A. Stewart. 1991. Forest Insect and Disease Conditions: Prince Rupert Forest Region - 1990. Forestry Canada FIDS Report 91-5, 42p.
- Goward, T. 2000. Fire, terrestrial lichens, and the Itcha-Ilgachuz caribou. Pp 665-669 in L.M. Darling, ed. Proc. Conf. Biology and Management of Species and Habitats at Risk, Kamloops, BC, 15-19 Feb. 1999. Vol. Two. B.C. Min. Env., Lands and Parks, Victoria, BC, and Univ. College of the Cariboo, Kamloops BC. 520p.
- Hawkes, B.; Taylor, S.; Stockdale, C.; Shore, T.; Alfaro, R.I.; Campbell, R.; Vera, P. 2004. Impact of mountain pine beetle on stand dynamics in BC. Pages 175-195 in T.L. Shore, J.E. Brooks, and J.E. Stone, editors. Proceedings of the Mountain Pine Beetle Symposium: Challenges and Solutions. Kelowna, British Columbia October 30-31, 2003, Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Information Report BCX- 399, 298 p.

- Lewis, K.J. and I.D. Hartley. 2006. Rate of deterioration, degrade and fall of trees killed by mountain pine beetle. *BC Journal of Ecosystems and Management* 7(2):11-19.
- Mitchell, R.G. and H.K. Preisler. 1998. Fall rate of lodgepole pine killed by the mountain pine beetle in central Oregon. *West. J. Appl. For.* 13(1): 23-26.
- Northern Caribou Technical Advisory Committee. 2004. A Strategy for the Recovery of Northern Caribou (*Rangifer tarandus caribou*) in the Southern Mountains National Ecological Area in British Columbia – Version 1.0. Ministry of Environment, Victoria, B.C.
<http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=15954>)
- Seip, D., and E. Jones. 2010. Response of woodland caribou to partial retention logging of winter ranges attacked by mountain pine beetle. Annual Report. FSP Project #Y102010. B.C. Ministry of Forests, Prince George, B.C., 27p.
- Steventon, J.D. 1996. Caribou habitat use in the Chelaslie River migration corridor and recommendations for management. B.C. Min. For. Research Prog. Land Management Handbook No. 37. 17p.
- Sulyma, R. 2009. Rehabilitation of caribou winter range following attack by mountain pine beetle: Pre-treatment site monitoring UWR U-7-012. Wildlife Infometrics Inc. Report No. 312. Wildlife Infometrics Inc., Mackenzie, British Columbia, Canada.
- SYSTAT Software Inc. 2004. SYSTAT 11. Richmond, CA.
- Trowbridge, R., B. Hawkes, A. Macadam, and J. Parminter. 1986. Field handbook for prescribed fire assessments in British Columbia: Logging slash fuels. B.C. Min. For. Land Manage. Handb. No. 11, Victoria, B.C. 63p. (<http://www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh11.htm>)
- Waterhouse, M. 2011. Lichen and vegetation response to mountain pine beetle damage in partial cuts and mature forests in the West Chilcotin in 2008. EP1208 File Report. Unpublished draft on file at Ministry of Forests, Lands and Natural Resource Operations, Williams Lake, B.C. 23p.