LICHEN COLONIZATION IN NATURAL GAP DISTURBANCES
AND OLD GROWTH STANDS

by

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ABSTRACT

Lichen colonization was studied in small (1-3 ha) natural gap disturbances embedded in a matrix of old growth cedar-hemlock forest in east central British Columbia, Canada. Lichen biomass, in relation to stand structural attributes, was examined to understand the role of microclimate, substrate quality, and dispersal capability in lichen colonization. Regenerating trees, approximately 100 years old and of similar structure, in the gap disturbance stands and in the old growth matrix were compared for lichen composition, abundance, and distribution. There was no difference in total lichen biomass between regenerating trees in the gap stands and the old growth stands. However, analysis of the individual functional groups (Alectoria, Bryoria, Foliose, and Cyanolichen) revealed distinct differences between the two stand types. The Bryoria functional group was more abundant in the crowns of regenerating trees in the gap disturbance stands and was distributed vertically through a larger proportion of the tree crown. The Cyanolichen functional group occurred more frequently on the regenerating trees in old growth stands. The Alectoria and Foliose functional groups did not differ significantly in biomass or in distribution between the two tree classes. Additional comparisons showed that tree size (amount of available substrate) positively affected lichen loading, while substrate type (foliated or non-foliated substrates) had no effect. Stand-level projections for arboreal lichen biomass indicated that old growth stands had 19% more biomass and contained greater species diversity than gap stands owning to the abundant cyanolichen community.
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CHAPTER 1: INTRODUCTION

Disturbances, both natural (wildfire, insects and disease, etc.) and human caused (logging), are common in forest ecosystems and result in the removal of overstory trees and open up the forest. This action initiates a new cycle of succession that begins with colonization. For vascular plants, the process of colonization and the subsequent successional stages of stand development are well understood (Collins and Pickett 1988, Platt and Strong 1989, Denslow and Spies 1990). In contrast, relatively little is known about how arboreal lichens colonize a stand. Lichen colonization is of particular interest in the realm of forest ecology considering current management objectives to preserve biodiversity and ecosystem function while continuing to extract timber from forest lands. A better understanding of lichen colonization would provide forest managers with a valuable predictive and explanatory tool to aid in management decisions.

Intuitively, one would expect that the process of lichen colonization is influenced by dispersal, lichen propagules must first arrive at the site; by substrate quality, lichen propagules must adhere to a suitable surface for establishment; and by microclimate, conditions must be adequate for lichens to grow. Many studies have shown that old growth stands support a greater diversity and biomass of arboreal lichens than second growth stands (Lesica et al. 1991, McCune 1993, Goward 1994, Esseen et al. 1996, Enns et al. 1999, Uliczka and Angelstam 1999, Rosso et al. 2000). This suggests that lichen colonization is more effective in old growth stands. Old growth stands are distinguished from second growth stands by various structural features, including large, old trees; multi-layered canopy; and abundant coarse woody debris (Franklin et al. 1981). These
features are hypothesized to be important for lichen colonization. The large branches and rough bark on the large, old trees may provide more surface area to catch and trap lichen propagules (Armstrong 1990). The multi-layered canopy creates a vertical moisture gradient in canopy emergent trees and results in a multitude of microenvironments for diverse groups of lichens (McCune 1993). The heterogeneous stand structure and the moisture retaining coarse woody debris act together to buffer the stand from environmental extremes. This environmental stability appears to be important for lichen diversity (Goward 1994).

The environment created by second growth stands is considered less optimal for lichen diversity and abundance. Esseen et al. (1996) reported that smaller trees with less total surface area provide less available substrate for lichen and limit their abundance. The dense, homogeneous stand structure of second growth stands allows little light to penetrate into the lower canopy and forest floor. Low light levels may inhibit some species from colonizing this region and/or slow the growth rate of those that do become established (Neitlich and McCune 1997). The structure of young forests provides less buffering from environmental extremes than the structure of old growth forests (Franklin et al. 1981). Thus, these young stands may experience extreme conditions in heat, wind, and moisture. Many lichen species are thought to depend on stable environmental conditions and may not be found with any considerable abundance in second growth stands (Lesica et al. 1991, Goward 1994, Rosso et al. 2000).

Limitations in dispersal capabilities are thought to have the greatest effect on lichen colonization in second growth stands (Stevenson 1988, Dettki 1998, Sillett and McCune 1998, Quesnel and Waters 1999). Lichen dispersal happens through asexual
reproduction, when bits of the lichen thallus (body) are dislodged and are carried away by wind, water, or animals; or through sexual reproduction (Barkman 1958). The asexual lichen propagules take three forms: soredia (powdery granules, 20-50 μm in diameter), isidia (minute finger like projections, 30 μm-1mm high), or fragments (broken off portions of the thallus, i.e. strands of Bryoria sp., lobules of Lobaria oregana, etc.) (Bowler and Rundel 1975, McCune and Geiser 1997). These propagules contain both the fungal and algal components of the lichen needed to regenerate a new thallus. There is still much to be learned about dispersal distances for the various propagule types and how these distances vary for different species. The mechanisms and relative importance of sexual reproduction in lichens is not well understood (McCune and Geiser 1997). The fungal partner produces fungal spores, in a structure called an apothecium, which are released to encounter free-living algae and create new lichen individuals.

The quality of surrounding forests as sources for lichen propagules is extremely important in lichen colonization. Stevenson (1988) suggested that the abundance of lichen in mature stands, the distance of mature stands from the second growth stand, and the area of the mature stand all affect lichen colonization in the second growth stand by influencing lichen dispersal capabilities. Armstrong (1994) concluded that height of the mature stand is important in determining distances propagules travel.

There are numerous other aspects of lichen ecology that are not yet understood (succession, competition, growth rates, and interactions with other organisms) despite their significant role in the functioning of forest ecosystems. Lichens contribute to forest biodiversity, nutrient cycling, and climate control (Pike 1978, Goward 1994, Rhoades 1995). Lichens have been used successfully as bio-indicators of air pollution, forest
health, and environmental continuity (Goward 1994, Loppi 1996, McCune 2000). Many forest animals, both arboreal and terrestrial, depend on lichens for food and shelter (Richardson and Young 1977, Gerson and Seaward 1977, Lawrey 1987).

This study examined lichen biomass, in relation to stand structural attributes, to understand the role of microclimate, substrate quality, and dispersal capability in lichen colonization. Regenerating trees of similar structure (approximately 100 years old) growing in small natural gap disturbances (1-3 ha) and in old growth stands were assessed for lichen composition, abundance and distribution. By controlling for tree structure (height and diameter) in the sample trees, the effects of dispersal capability and microclimate associated with canopy structure between the two stand types could be inferred. For example, if regenerating trees in gap stands had the same amount and types of lichen as regenerating trees in old growth stands, then dispersal was not limiting. If the distribution of the lichens within the trees was different in gap and old growth regenerating trees, then microclimate associated with canopy structure had an effect. The role of substrate quality was evaluated by comparing branch structural attributes (diameter, length, density) of gap and old growth sample trees.

The effect of tree size on lichen loading was analyzed using regenerating trees of similar age but different diameter. Foliated and non-foliated substrates were inspected to detect habitat differences affecting colonization. This study tested five hypotheses: 1) Regenerating trees in old growth forests will support more lichen biomass than regenerating trees in gap disturbance stands, 2) Regenerating trees in old growth stands will have a greater diversity of lichens than trees in gap disturbance stands, 3) Lichens will be distributed differently within the crowns of regenerating trees found in old growth
and gap disturbance stands 4) Larger trees will support more lichen biomass than smaller trees of the same age, 5) Foliated substrates will contain more lichen biomass than non-foliated substrates.
CHAPTER TWO: METHODS

Study Area

The study area consisted of old growth forests (250+ years old) in the Viking Ridge and Hungary Creek areas of the Interior Cedar-Hemlock (ICH) biogeoclimatic zone. Three field sites were selected in the Interior Wet-Belt (IWB) Region of the ICH, approximately 90 kilometers east of Prince George, BC, Canada (Figure 1). The interior wet-belt is loosely defined as an inland rainforest, composed of the wet and very wet subzones of the Engelmann Spruce-Subalpine Fir (ESSF) and (ICH) biogeoclimatic zones (Jull 1997). The interior, continental climate of the ICH is characterized by easterly moving air masses that produce cool wet winters and warm dry summers (Ketcheson et al. 1991). Mean annual precipitation in the ICH is 839.8 mm (374.3 mm in summer and 465.5 mm in winter) with a mean summer temperature of 14.7 °C and a mean winter temperature of -12.1 °C. Recorded mean annual snowfall is 306.8 cm, with snow persisting on the ground 9 months of the year (Reynolds 1997). The slow-melting snow pack keeps soil moisture levels high during the summer (Ketcheson et al. 1991).

Small patches of even-aged regenerating trees were sparsely scattered throughout an old growth matrix. These areas resulted from past natural disturbance processes. The most likely cause of the disturbance was western hemlock looper (Lambdina fiscellaria lugubrosa (Hulst) (Lepidoptera: Geometridae), a defoliating insect. This conclusion
Figure 1. Study area. Red areas represent the portion of the ICH zone that occur in the Interior Wet-Belt.
was based on disturbance pattern, past history of occurrence in the area (Parfett et al. 1995), and lack of evidence indicating any other disturbance agent. Figure 2 shows the disturbance pattern of the most recent looper outbreak (1991-1994) in the study area. The disturbance considered in this study occurred approximately 100 years ago based on the age of the regenerating trees. The occasional large diameter veteran tree that survived the gap-forming disturbance was interspersed within the regenerating stands.

The forests in the study area were in the very wet cool (vk2) subzone of the ICH (BC MOF, 1996). Western hemlock, *Tsuga heterophylla* (Raf.) Sarg., dominated the overstory in gap disturbance stands, whereas western hemlock and western red cedar, *Thuja plicata* L., were co-dominants in old growth stands. Gap understory was identified as the step moss series (ICH vk 2/03) (BC MOF, 1996). The shrub layer was virtually absent and *Cornus canadensis* L., *Chimaphila umbellata* (L.) Bart., and *Pyrola secunda* L. dominated the sparse herb layer. A continuous moss layer comprised three main species: *Hylocomium splendens* (Hedw.) B.S.G., *Rhytidiadelphus triquetrus* (Hedw.) Warnst., and *Pleurozium schreberi* (Brid.) Mitt. Old growth stands were classified as oak fern series (ICH vk 2/04) (BC MOF, 1996) with a sparse shrub layer dominated by *Oplopanax horridum* (Smith) Miq. The herb layer was dominated by *Gymnocarpium dryopteris* (L.) Newm., *Rubus pedatus* J.E. Smith, and *C. canadensis*. The moss layer again comprised largely *H. splendens*, *R. triquetrus*, and *P. schreberi*. As in coastal forests, the very wet subzones of the ICH house abundant epiphyte communities (Arsenault and Goward 1997). Lichens constituted the majority of the arboreal epiphyte community. Few epiphytic bryophytes and fungi were noted and when present, were found on the lowermost limbs and base of tree.
Western Hemlock Looper Base Map with Defoliation Areas Identified by Aerial Survey, Summer 1995

Reference

- Light, Old Attack
- Moderate, Old Attack
- Severe, Old Attack
- Cutblocks
- Dead

Figure 2. Western hemlock looper attacks in the vicinity of the study area. Map provided by the Ministry of Forests, Robson Valley and Prince George Forest Districts.
Arboreal macro lichen communities within the study area were represented by four functional groups. The use of functional groups is a common method for increasing the speed of assessments by grouping lichens based on ecological or functional similarities rather than taxonomic features. Functional groups are formed on the basis of the following ecological roles: nutrient cycling, response to pollutants, and use as food or shelter (McCune 1993). In most studies, the Alectorioid functional group includes all pendulose, fruticose lichens. This study divided the Alectorioid group into the Alectoria functional group and the Bryoria functional group to investigate their ecological roles separately despite their common function as forage for mountain caribou within the study area (Rominger et al. 1996). The Alectoria functional group consisted of *Alectoria sarmentosa* (Ach.) Ach. and *Usnea* spp. Dill. ex Adans. The Bryoria functional groups included *Bryoria* spp. Brodo & D. Hawksw. and *Nodobryoria oregana* (Tuck.) Common & Brodo. The Cyanolichen functional group (dominated by *Lobaria pulmonaria* (L.) Hoffm.) is well represented in the wettest subzones of the ICH. Members of this group are typically sensitive to air pollution and may play an important role in the forest’s nitrogen budget (Rhoades 1995). The Foliose functional group included all other foliose lichen species not containing a cyanobacterium as the photobiont. The major constituents of this group were *Platismatia glauca* (L.) Culb. & C. Culb., *Hypogymnia* spp. (Nyl.) Nyl., and *Parmelia* spp. Ach. The Foliose functional group provides food and shelter for a diversity of arthropods (Gerson 1973). A complete lichen species list is included in the appendix. This study did not consider crustose lichen species.

**Study design**

Lichen composition, abundance, and distribution were compared on regenerating
trees in natural gap disturbances and in old growth forests. The regenerating trees used for sampling (hereafter referred to as regen trees) were restricted by species to decrease the variability in the results and allow for a better comparison within and between stands. All regen sample trees were western hemlock. In the gap stands, the regen trees were split into two different size classes, standard regen and large regen. Table 1 reviews the terminology and definitions of the various tree classes sampled in this study. Large regen were more similar in structure to old growth regen than standard regen. For the comparison of gap regen and old growth regen trees, only large gap regen were used. Standard and large regen were compared to evaluate the effect of tree size (amount of available substrate) on lichen colonization. The abundance and composition of lichen growing in foliated and non-foliated regions of branches were examined in regen trees to assess the effect of substrate type on lichen colonization.

Veteran trees in gap stands were assessed for lichen to evaluate their role as propagule sources for regen trees. Veteran sample trees were restricted to western hemlock to represent their dominant proportion within the gap stands. In old growth stands, western red cedar and western hemlock were co-dominant and old growth trees of both species were sampled to get a complete picture of lichen propagule sources.

Lichen biomass was visually estimated using a lichen standard of known dimensions, otherwise known as the "clump method" (Stevenson 1979, Campbell et al. 1999). Assessments were made from within the tree crown using the single rope climbing technique. Sampling from within the crown was desired for easy lichen viewing at all levels within the crown, which increased consistency of assessments (Stevenson 1979). For safety reasons, only live, structurally sound trees greater than 15
Table 1. Definitions for tree classes: old growth regen (OGR), gap regen (GR), standard regen (SR), large regen (LR), veteran (VET), old growth (OG).

<table>
<thead>
<tr>
<th>Tree Class</th>
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<tr>
<td>OGR</td>
<td>Early-seral stage western hemlock with diameter range of 20.34-44 cm, located in the understory of older trees</td>
<td>Old Growth</td>
</tr>
<tr>
<td>GR</td>
<td>SR  Early-seral stage western hemlock with diameter range of 17.31-30.89 cm</td>
<td>Gap</td>
</tr>
<tr>
<td></td>
<td>LR  Early-seral stage western hemlock with diameter range of 30.90-44 cm</td>
<td>Gap</td>
</tr>
<tr>
<td>VET</td>
<td>Large diameter western hemlock (generally greater than 55 cm); dead, broken, or forked top; large, complex branch systems in lower crown; greater than 180 years old</td>
<td>Gap</td>
</tr>
<tr>
<td>OG</td>
<td>See veteran, note: species=western hemlock and western red cedar</td>
<td>Old Growth</td>
</tr>
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cm diameter at breast height (dbh) were considered for sampling.

Plot Layout

Field sites containing desired attributes (see below) were located using a search of aerial photos and forest cover maps. Each field site comprised:

- a small (1-3 ha) natural gap disturbance
- even-aged regeneration within the gap approximately 100 years old and dominated by western hemlock
- old growth ICH forest surrounding the gap with western red cedar or western hemlock as the leading species.

Two of the study sites (Viking East and Viking West) were located off Viking Road, now managed by BC Parks and closed to motorized vehicles (Figure 3). The third site (Hungary) was adjacent to Hungary Creek Road, approximately 6 km due east of the Viking East site (Figure 4).

At each site, a 50 m transect was established in both the old growth and gap stands. The gap transect was located close to the center of the gap to minimize edge effects. The old growth transect was established at least 50 m from any edge (to minimize edge effects) and placed so that understory regeneration western hemlock within the old growth stand were included within the sampling area. At three equidistant points along the transect line (1.7 m, 25 m, and 48.3 m), an 11.3 m radius circular plot was established for measuring stand characteristics (Figure 5). The area within the three circular plots defined the sampling area of the stand. Diameter of all trees within the circular plots greater than 1 cm dbh were recorded by species, including snags. A variety
Figure 3. Viking field sites: (A) Viking East Gap, (B) Viking East Old Growth, (C) Viking West Gap, (D) Viking West Old Growth. Gap stands were identified in photos by a difference in texture.
Figure 4. Hungary field site: (A) Hungary Gap, (B) Hungary Old Growth.
Figure 5. Plot layout in a gap stand. Three 11.3 m radius circular plots were placed at equidistant points along a 50 m transect line (1.7 m, 25 m, and 48.3 m).
of diameter size classes for the early-seral stage trees, from both stand types, were selected for coring to understand diameter-age relationships and determine the disturbance history in the gaps. Slope, aspect, elevation, and site series were recorded for each stand. The ICHvk2 vegetation series guide was used to identify the site series (BC MOF, 1996).

Sample Tree Selection

Sample trees were randomly selected from a pool of representative candidates. The dbh range identifying standard regen sample trees was arrived at by calculating the mean dbh from stand characteristic data. The data set included early-seral stage tree dbh data from gap stands at four sites (the fourth site was not used for lichen assessments) (Figure 6). A minimum dbh value of 15 cm was used to ensure that the resulting mean diameter range would not include trees unsafe for climbing. The standard regen tree diameter range was defined by the mean ± one standard deviation (24.08 ± 6.79 cm or a range of 17.31-30.89 cm dbh).

The large regen tree diameter range was set at greater than 1 standard deviation above the mean (24.08 + >6.79 or >30.89 cm dbh). An upper limit of 44 cm dbh was established to denote the point above which structural features characteristic of veteran/old growth trees were noticed.

The dbh range for old growth regen trees was calculated in a similar fashion. The data set included early-seral stage tree dbh data from three old growth sites with lower and upper limits set at 15 and 44 cm dbh respectively. The mean dbh was 27.61 ± 7.27 cm or a range of 20.34-34.88 cm dbh (Figure 7). The upper end of this diameter range was extended to 44 cm dbh to include the desired number of sample trees. The crowns of
Figure 6. DBH frequency distribution of the regeneration cohort from gap stands. Diameter data from 4 gap stands was used to calculate the diameter range for standard and large regen sample trees with a minimum dbh limit of 15 cm.

Figure 7. DBH frequency distribution of the regeneration cohort from old growth stands. Diameter data from 3 old growth stands was used to calculate the diameter range for old growth regen sample trees with a minimum and maximum dbh limit of 15 and 44 cm.
many early-seral stage trees less than 25 cm dbh were spindly and rejected as sample
trees for safety reasons. Again, the upper limit of the dbh range was established to
exclude trees with old growth structure.

In each gap stand, 5 standard regen trees, 5 large regen trees, and 3 veteran trees
(if present) were identified as sample trees. In each old growth stand, 5 regen trees and 3
old growth trees (two western red cedar and one western hemlock, to represent the ratio
of species occurrence within the stand) were identified as sample trees. All selections
were randomized from a pool of eligible trees within the respective sampling areas.
When a sample tree of a specific tree class was not found within the sampling area
defined by the three 11.3 m radius circular plots, the nearest tree within the stand meeting
all specifications was selected as the sample tree. In total, 60 trees were sampled, 36
from the gap stands and 24 from old growth stands (Table 2).

Canopy Access

The single rope technique (SRT) was used to access all areas within the tree
crown for sampling (Perry 1978). The advantage of this technique over using a belt and
spurs was the reduced impact on tree surfaces, since the climber ascended a rope rather
than the tree bole (Moffett and Lowman 1995). Another advantage of the SRT is that it
enabled the climber to maneuver away from the trunk and access outer regions of
branches. Other, more permanent canopy access methods (towers, cranes, platforms,
walkways) were not well suited to this study because of their permanence, cost, and time
needed for construction. Cherry pickers or high-lifts were also not an option for this
study due to the remote location of the field sites.
Table 2. Inventory of sample trees by site. Standard regen (SR), large regen (LR), veteran (VET), old growth regen (OGR), and old growth (OG).

<table>
<thead>
<tr>
<th>Tree class</th>
<th>Hungary Gap</th>
<th>Viking East Gap</th>
<th>Viking West Gap</th>
<th>Hungary Old Growth</th>
<th>Viking East Old Growth</th>
<th>Viking West Old Growth</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>LR</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>VET</td>
<td>3</td>
<td>0*</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>OGR</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>OG</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60</td>
</tr>
</tbody>
</table>

* trees present but unsafe to climb
To set up the SRT, a line was shot over several strong branches near the top of the tree using a crossbow, sling shot, or throw bag. This line was used to hoist a climbing rope into the tree. One end was anchored around the base of the tree and the other end was used for ascending with the aid of mountaineering equipment.

Tree Assessment

Tree age was determined for each sample tree using an increment borer and tree height was recorded at the upper anchor point, above which branch diameter was <1 cm and no sampling occurred (approximately 1-2 m from the top of the tree). Branch diameter of all branches longer than 10 cm and greater than 1 cm diameter at the base of the branch was measured. Trees identified for destructive biomass sampling (see section on verifying estimates) received numbered labels for all branches assessed. Branch length was recorded using length classes (Table 3). The proportion of foliage on each branch was estimated using a foliar index (Table 4).

Lichen Assessment

All branches longer than 10 cm and greater than 1 cm diameter at the base were assessed for lichen composition and abundance. The "clump method" (Stevenson 1979, Campbell et al. 1999) was used to estimate lichen biomass for each functional group. The amount of lichen present was compared to a visual standard (the "clump") and then recorded as a multiple of that standard (i.e. 2 "clumps" or 1/2 "clump" etc.). The standards used by Campbell et al. (1999) for the Alectoria and Bryoria functional groups (approximately 2.5 grams of lichen per "clump") and the Foliose functional group (8.5 cm x 8.5 cm card, approximately equal to 1.5 grams of lichen per "card") were well
Table 3. Branch length classes.

<table>
<thead>
<tr>
<th>Class</th>
<th>Length (m)</th>
<th>Mid-points (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1-0.2</td>
<td>0.15</td>
</tr>
<tr>
<td>2</td>
<td>0.2-1</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>1-3</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>3+</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 4. Foliar index, used to estimate the proportion of foliage on a branch.

<table>
<thead>
<tr>
<th>Index</th>
<th>Definition</th>
<th>Mid-points (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>dead, no foliage</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>&lt; 1/3 of branch foliated</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>1/3-2/3 of branch foliated</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>&gt;2/3 of branch foliated</td>
<td>84</td>
</tr>
</tbody>
</table>
suited to this study. The Cyanolichen standard was a 15 cm x 20 cm "card". The Alectoria functional group "clump" estimate included all the pendulous fruticose lichens (Alectoria sarmentosa, Usnea spp., Bryoria spp. and, Nodobryoria oregana). These fruticose lichens often grow intertwined and it is difficult to visually separate them for estimating biomass. The Bryoria functional group biomass estimates were recorded as the percent of Bryoria sp. in the Alectoria functional group “clump” estimate. Biomass estimates of Foliose and Cyanolichen functional groups were straightforward multiples of their respective standard "card."

For regen trees, lichen biomass estimates were made separately in the foliar and non-foliar region to assess the effect of substrate type on colonization. The foliar region included all foliated sections of the branch. The non-foliar region was defined as any segment of branch not covered directly by foliage or any area of dead/defoliated branch among the foliar region. Separate foliar/non-foliar region estimates were not performed on old growth or veteran trees because the long, complex branch systems common in older trees made it difficult to accurately estimate lichens in the two regions.

Verifying Estimates

A subsample of branches was destructively sampled to verify the visual lichen biomass estimates for all functional groups using Probability Proportional to Prediction (3P) sampling (Cochran 1977). Biomass estimates were verified for both regen and old growth trees because of differences in tree structure and lichen loading. People may underestimate lichen biomass on long branches (lichen is difficult to see) and on branches with high lichen loading, both are unique characteristics of old growth trees. Estimates in the foliated and non-foliated regions of regen trees were verified separately. In 3P
sampling, the subsampled units (branches) are selected with a frequency proportional to their predicted (estimated) biomass. Thus, branches with greater biomass were selected with greater frequency than branches with lower biomass. The high precision of this technique allows for a smaller sample size that requires detailed measurements (Campbell et al. 1999). There are three steps in 3P sampling:

1. rapid and consistent estimates of all branches,
2. detailed measures (i.e. destructive biomass sampling) of a small subset of branches, and
3. application of a correction factor to adjust the initial estimates.

The lichen assessments for this study satisfied the requirements for step 1. The data from the lichen assessments were used to generate a subset of branches for destructive sampling in step 2. The following equation was used to identify branches for destructive biomass sampling:

\[ K+Z = \frac{\Sigma KPI}{n_o} \]

where \((K+Z)\) is the top random number, \((\Sigma KPI)\) is the sum of all estimates, and \((n_o)\) is the target sample size (Iles unp.).

The Alectoria functional group was used as the \(\Sigma KPI\) term because of its ecological significance as an indicator of winter habitat for mountain caribou within the study area. The target sample size \((n_o)\) was 7 and 13 for regen and old growth trees respectively. The \(n_o\) was set higher than what was needed to account for possible shortfall in the sample size as a result of the 3P selection process. Fewer branches were taken from each regen tree to minimize the impact of destructive sampling on the younger trees. The top random number \((K+Z)\) was calculated from the above equation.
and a list of random numbers was generated from 1 to K + Z. Branches were selected by comparing the estimated Alectoria functional group biomass for each branch to a random number from the list. If the estimated biomass was greater than or equal to the random number, the branch was used for destructive biomass sampling.

Live branches were required for destructive sampling on regen trees to verify both foliar and non-foliar region estimates. Live or dead branches could be used in destructive biomass sampling of old growth trees since lichen estimates were not split into foliar/non-foliar region. Destructive sampling occurred on 10 regen and 6 old growth trees. Two regen trees were randomly selected for destructive biomass sampling in each stand type at all three sites excluding the Hungary old growth stand. Two old growth trees, one western red cedar and one western hemlock, were randomly selected from each old growth stand for destructive sampling (Table 5). In total, 80 branches were destructively sampled from old growth trees and 48 from regen trees.

In regen trees, branches identified for destructive sampling were cut using a hand saw and lowered to the ground in a large nylon bag, taking care not to lose any lichen. Once on the ground, the branch was cut into its respective foliar and non-foliar regions and bagged separately.

On old growth branches, lichens were stripped from the branches and placed in re-closable plastic bags for lowering to the ground. Branch sections were cut only when they could not be reached for lichen removal.

All lichens were returned to the lab and stored in paper bags until they could be sorted by functional group. The sorted, air-dried lichens were then placed under a constant humidity of 60% for 48 hours to equilibrate before weighing under the same
Table 5. Inventory of destructively sampled branches. Two trees from each site were used for destructive sampling. Species codes: TSHE, *Tsuga heterophylla* and THPL, *Thuja plicata*.

<table>
<thead>
<tr>
<th>Tree Class</th>
<th>Site</th>
<th># of Branches (Tree 1)</th>
<th>Species</th>
<th># of Branches (Tree 2)</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regen</td>
<td>Viking East Gap</td>
<td>4 TSHE</td>
<td>3 TSHE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Viking East Old Growth</td>
<td>4 TSHE</td>
<td>6 TSHE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Viking West Gap</td>
<td>5 TSHE</td>
<td>5 TSHE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Viking West Old Growth</td>
<td>7 TSHE</td>
<td>6 TSHE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hungary Gap</td>
<td>5 TSHE</td>
<td>3 TSHE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total Regen Branches</strong></td>
<td></td>
<td></td>
<td><strong>48</strong></td>
<td></td>
</tr>
<tr>
<td>Old Growth</td>
<td>Viking East Old Growth</td>
<td>10 TSHE</td>
<td>9 THPL</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Viking West Old Growth</td>
<td>13 TSHE</td>
<td>28 THPL</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hungary Old Growth</td>
<td>10 TSHE</td>
<td>10 THPL</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total Old Growth Branches</strong></td>
<td></td>
<td></td>
<td><strong>80</strong></td>
<td></td>
</tr>
</tbody>
</table>
conditions. All lichen mass data reported here are based on lichen equilibrated at 60% humidity. Stevenson and Jull (1996) provide an equation to convert from mass at 60% humidity to oven-dried mass. The estimated and actual lichen biomass data were used to calculate correction factors for the lichen functional groups. Correction factors were applied to the visual estimates to convert them to biomass in grams, thus completing step 3 of 3P sampling.

**Statistical Analysis**

**Correction Factors**

For all functional groups, a linear regression analysis was run with the estimated ("clump/card") and actual (mass in grams) lichen biomass data. This analysis was run separately for regen and old growth/veteran tree classes. A separate regression analysis was performed on the foliar and non-foliar regions of regen trees. To improve the fit of the regression line, the log₁₀ transformation was used on the Foliose functional group data for old growth trees. Outliers were removed from the data sets of the Bryoria and Foliose functional groups for regen trees and the Alectoria functional group for old growth trees. For the Bryoria functional group in the foliar region, precision was low between estimated and measured biomass. This was explained by the difficulties in seeing *Bryoria* sp. in the distant, foliated regions of the branch. Unlike the bright yellow-green *Alectoria* sp., *Bryoria* sp. are brown in color and blend in with twigs and foliage. This problem was particularly evident in low biomass samples. Visual estimates that resulted in gram based measurements of <0.003 g/branch were removed and replaced by a single point representing the mean of these values. The regression equations were used as
correction factors and applied to the visual biomass estimates to convert them to grams.

**Lichen Abundance, Distribution, and Tree Structure**

The data were viewed graphically to assess linearity, normality, and equality of variance. Data from the three sites were pooled if ANOVA results showed no effect for differences within stand type. Tukey's honest significant difference test was used for post hoc comparisons of significant ANOVA results. The t-test for independent samples ($\alpha=0.05$) was used in the analysis of lichen abundance, distribution, and tree structure.

The log10 transformation was used where needed to improve the normality of skewed data and the t-test for separate variances was used when needed. For the analysis of tree structure, the canopies of each tree class were subdivided into low, mid, and upper regions to make more detailed comparisons. These regions were arbitrarily set using the maximum tree height interval (tree height marked by 4 m increments) and equally dividing the tree into thirds. An ANOVA was used to test for differences in tree structural variables across canopy strata within a given tree class. The structural variable of summed branch length was used to represent the amount of available substrate for lichen colonization. This was calculated by converting branch length classes to meters using the mid-points listed in Table 3 & 4. These lengths were then summed for a specific canopy region or for the entire tree. All statistical analyses were performed using the Statistica statistics package (1997 by StatSoft Inc.).

**Stand-Level Projections for Lichen Biomass**

A conservative approach was taken in estimating stand-level arboreal lichen loading. Projections were based only on tree classes and species restrictions described previously in the methodology. Therefore, trees present in the stand that were outside the
diameter range set for sample trees (e.g., <17.31 cm dbh and between 44 and 55 cm dbh in gap stands) were not considered in stand-level projections. Also, the projections did not include tree species other than those defined as sample trees (i.e., western hemlock for all regen class trees, western hemlock for the veteran class, and western hemlock and western red cedar for the old growth class). The mean density of each tree class was calculated, then multiplied by the mean lichen biomass for the respective tree class.
CHAPTER THREE: RESULTS

Stand Characteristics

Slope, aspect, and elevation were similar for gap and old growth stands at all sites. Slopes ranged from 7-23°, aspects were north to north-westerly, and stand elevation ranged between 900 and 1000 m.

Old growth stands were less dense than gap stands at all sites (Table 6). Stand density for the Hungary old growth stand was high in comparison to the other old growth stands because the sampling area contained a single tree opening, thick with small regenerating trees (Table 7, Figure 8). There were no large differences in basal area between gap and old growth stands (Table 6). Gap stands had a greater density of snags than old growth stands, and the diameter size class range for snags found in both stand types were similar (5-10 and 11-30 cm dbh) (Table 6 & 7, Figure 9). Diameter size class distribution of trees by stand type showed characteristic distributions: in gaps, the largest concentration of trees fell within the medium size class (11-30 cm dbh); in old growth, the trees were spread across a broad range of size classes with representatives in the large size class (Table 7, Figure 8).

Correction factors

No regression was run for the Cyanolichen functional group on regen trees because of small sample size. The 3P sampling technique used to identify samples for
Table 6. Mean composition of the tree layer for gap and old growth stands. Density, frequency, and basal area data are for all trees larger than 1 cm dbh.

<table>
<thead>
<tr>
<th>Species</th>
<th>Density Trees /ha</th>
<th>Frequency (%)</th>
<th>Basal Area m²/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Live</td>
<td>Dead</td>
<td>Live</td>
</tr>
<tr>
<td><strong>Hungary Gap</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tsuga heterophylla</td>
<td>857</td>
<td>494</td>
<td>100</td>
</tr>
<tr>
<td>Thuja plicata</td>
<td>115</td>
<td>107</td>
<td>67</td>
</tr>
<tr>
<td>Abies lasiocarpa</td>
<td>107</td>
<td>297</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>1079</td>
<td>898</td>
<td></td>
</tr>
<tr>
<td><strong>Hungary Old Growth</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tsuga heterophylla</td>
<td>601</td>
<td>16</td>
<td>100</td>
</tr>
<tr>
<td>Thuja plicata</td>
<td>354</td>
<td>189</td>
<td>100</td>
</tr>
<tr>
<td>Abies lasiocarpa</td>
<td>58</td>
<td>33</td>
<td>67</td>
</tr>
<tr>
<td>Picea engelmannii x glauca</td>
<td>33</td>
<td>8</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>1046</td>
<td>247</td>
<td></td>
</tr>
<tr>
<td><strong>Viking East Gap</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tsuga heterophylla</td>
<td>2158</td>
<td>1186</td>
<td>100</td>
</tr>
<tr>
<td>Abies lasiocarpa</td>
<td>49</td>
<td>165</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>2207</td>
<td>1351</td>
<td></td>
</tr>
<tr>
<td><strong>Viking East Old Growth</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thuja plicata</td>
<td>362</td>
<td>107</td>
<td>100</td>
</tr>
<tr>
<td>Tsuga heterophylla</td>
<td>239</td>
<td>91</td>
<td>100</td>
</tr>
<tr>
<td>Abies lasiocarpa</td>
<td>8</td>
<td>8</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>610</td>
<td>206</td>
<td></td>
</tr>
<tr>
<td><strong>Viking West Gap</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tsuga heterophylla</td>
<td>2430</td>
<td>1310</td>
<td>100</td>
</tr>
<tr>
<td>Abies lasiocarpa</td>
<td>74</td>
<td>222</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>2504</td>
<td>1532</td>
<td></td>
</tr>
<tr>
<td><strong>Viking West Old Growth</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tsuga heterophylla</td>
<td>371</td>
<td>156</td>
<td>100</td>
</tr>
<tr>
<td>Thuja plicata</td>
<td>247</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>Abies lasiocarpa</td>
<td>25</td>
<td>0</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>642</td>
<td>181</td>
<td></td>
</tr>
</tbody>
</table>
Table 7. Diameter size class distribution for mean number of trees/ha for gap and old growth stands. Size classes
are dbh in cm.

<table>
<thead>
<tr>
<th>Species</th>
<th>1-4</th>
<th>5-10</th>
<th>11-30</th>
<th>31-60</th>
<th>61-90</th>
<th>&gt;90</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hungary Gap</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Live</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tsuga heterophylla</em></td>
<td>16</td>
<td>8</td>
<td>486</td>
<td>546</td>
<td>857</td>
<td></td>
<td>857</td>
</tr>
<tr>
<td><em>Thuja plicata</em></td>
<td>8</td>
<td>74</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
<td>115</td>
</tr>
<tr>
<td><em>Abies lasiocarpa</em></td>
<td>66</td>
<td>41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>107</td>
</tr>
<tr>
<td><strong>Dead</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tsuga heterophylla</em></td>
<td>16</td>
<td>156</td>
<td>288</td>
<td>33</td>
<td></td>
<td></td>
<td>494</td>
</tr>
<tr>
<td><em>Thuja plicata</em></td>
<td>8</td>
<td>58</td>
<td>41</td>
<td></td>
<td></td>
<td></td>
<td>107</td>
</tr>
<tr>
<td><em>Abies lasiocarpa</em></td>
<td>41</td>
<td>255</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>297</td>
</tr>
<tr>
<td><strong>Hungary Old Growth</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Live</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tsuga heterophylla</em></td>
<td>214</td>
<td>173</td>
<td>132</td>
<td>82</td>
<td></td>
<td></td>
<td>601</td>
</tr>
<tr>
<td><em>Thuja plicata</em></td>
<td>33</td>
<td>33</td>
<td>107</td>
<td>82</td>
<td>66</td>
<td>33</td>
<td>354</td>
</tr>
<tr>
<td><em>Abies lasiocarpa</em></td>
<td>33</td>
<td>8</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td>58</td>
</tr>
<tr>
<td><em>Picea engelmannii x glauca</em></td>
<td>8</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>33</td>
</tr>
<tr>
<td><strong>Dead</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tsuga heterophylla</em></td>
<td>8</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
</tr>
<tr>
<td><em>Thuja plicata</em></td>
<td>82</td>
<td>66</td>
<td>41</td>
<td></td>
<td></td>
<td></td>
<td>189</td>
</tr>
<tr>
<td><em>Abies lasiocarpa</em></td>
<td>8</td>
<td>8</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td>33</td>
</tr>
<tr>
<td><em>Picea engelmannii x glauca</em></td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td><strong>Viking East Gap</strong></td>
<td></td>
<td></td>
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Table 7 (continued)

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</table>
Figure 8. Diameter size class distribution for mean number of live trees/ha.
Figure 9. Diameter size class distribution for mean number of snags/ha.
verifying the visual estimates was not sensitive to the Cyanolichen functional group and therefore, inclusion of branches with cyanolichen was low. In regen trees, the analysis of the Cyanolichen functional group was limited to frequency of occurrence. Regression results from the remaining functional groups were used to convert visual lichen biomass estimates ("clumps" and "cards") to gram based biomass measurements (Table 8).

**Gap Regen vs Old Growth Regen**

**Tree Structure**

Results for the structural analysis, comparing gap regen and old growth regen trees, are summarized in Table 9. There was no difference in tree height, dbh or age, however, gap regen trees had a greater number of branches than old growth regen trees. Mean branch diameter was greater in old growth regen trees throughout the canopy, while branch density was greater in gap regen at all levels except the lower canopy. Branch lengths were summed to measure total length (in meters) of available substrate for lichen. There was no difference in total summed branch length between gap regen and old growth regen trees. This was true in the mid and upper canopy however, in the lower canopy old growth regen trees had a greater summed branch length.

Within gap regen and old growth regen tree classes, branch diameter, density, and summed branch length were compared between the three canopy strata. Post hoc comparisons for significant ANOVA results are summarized in Table 10. In gap regen trees, mean branch diameter in the lower canopy was significantly smaller than mean branch diameter in the mid and upper canopy. Branch density was significant at all levels with density increasing with height. Summed branch length was significantly shorter in
Table 8. Regression results for estimated and measured lichen biomass.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>Regen Trees</th>
<th>Old Growth/Vet Trees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Foliar Region</td>
<td>Non-Foliar Region</td>
</tr>
<tr>
<td>Alectoria</td>
<td>0.73 30</td>
<td>0.82 22</td>
</tr>
<tr>
<td>Bryoria</td>
<td>0.52&lt;sup&gt;(3)&lt;/sup&gt; 28</td>
<td>0.85&lt;sup&gt;(1)&lt;/sup&gt; 21</td>
</tr>
<tr>
<td>Foliose</td>
<td>0.79&lt;sup&gt;(4)&lt;/sup&gt; 18</td>
<td>0.72&lt;sup&gt;(3)&lt;/sup&gt; 19</td>
</tr>
<tr>
<td>Cyanolichen</td>
<td>&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

<sup>(a)</sup> number of outliers removed

<sup>*</sup> log<sub>10</sub> transformed data
Table 9. Mean results for structural analysis of gap regen (GR) vs old growth regen (OGR) and standard regen (SR) vs large regen (LR). Standard deviations are in parentheses.

<table>
<thead>
<tr>
<th>Structure</th>
<th>GR</th>
<th>OGR</th>
<th>t</th>
<th>p</th>
<th>LR</th>
<th>SR</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>tree height (m)</td>
<td>20.2 (3.5)</td>
<td>19.4 (3.5)</td>
<td>0.607</td>
<td>0.548</td>
<td>20.2 (3.5)</td>
<td>17.0 (3.6)</td>
<td>2.401</td>
<td>0.023</td>
</tr>
<tr>
<td>tree dbh (cm)</td>
<td>35.3 (3.7)</td>
<td>33.1 (7.2)</td>
<td>1.044</td>
<td>0.306</td>
<td>35.3 (3.7)</td>
<td>23.4 (3.5)</td>
<td>8.979</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>age</td>
<td>90.2 (8.0)</td>
<td>83.7 (11.9)</td>
<td>-1.767</td>
<td>0.088</td>
<td>90.2 (8.0)</td>
<td>96.5 (9.7)</td>
<td>-1.928</td>
<td>0.064</td>
</tr>
<tr>
<td># of branches</td>
<td>130.9 (45.3)</td>
<td>98.0 (39.9)</td>
<td>2.111</td>
<td>0.044</td>
<td>130.9 (45.3)</td>
<td>63.2 (29.6)</td>
<td>4.843</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>branch density (branches/m)</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>low canopy</td>
<td>2.8 (1.4)</td>
<td>3.7 (2.0)</td>
<td>-1.432</td>
<td>0.163</td>
<td>2.8 (1.4)</td>
<td>1.2 (1.1)</td>
<td>3.533</td>
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</tr>
<tr>
<td>mid canopy</td>
<td>7.4 (1.7)</td>
<td>5.6 (1.8)</td>
<td>2.838</td>
<td>0.008</td>
<td>7.4 (1.7)</td>
<td>5.2 (1.8)</td>
<td>3.535</td>
<td>0.001</td>
</tr>
<tr>
<td>upper canopy*</td>
<td>13.6 (6.2)</td>
<td>7.1 (2.6)</td>
<td>3.621</td>
<td>0.001</td>
<td>13.6 (6.2)</td>
<td>9.0 (2.3)</td>
<td>2.117</td>
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<tr>
<td>total</td>
<td>6.4 (1.5)</td>
<td>5.0 (1.7)</td>
<td>2.334</td>
<td>0.027</td>
<td>6.4 (1.5)</td>
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<tr>
<td>branch diameter (cm)</td>
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<tr>
<td>low canopy</td>
<td>1.9 (.3)</td>
<td>2.8 (0.5)</td>
<td>-5.804</td>
<td>&lt;0.001</td>
<td>1.9 (.3)</td>
<td>1.9 (.4)</td>
<td>0.538</td>
<td>0.595</td>
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<tr>
<td>mid canopy</td>
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<td>2.9 (0.5)</td>
<td>-2.512</td>
<td>0.018</td>
<td>2.5 (0.4)</td>
<td>2.1 (0.3)</td>
<td>3.098</td>
<td>0.004</td>
</tr>
<tr>
<td>upper canopy*</td>
<td>2.4 (0.2)</td>
<td>3.1 (1.1)</td>
<td>-2.372</td>
<td>0.025</td>
<td>2.4 (0.2)</td>
<td>2.1 (0.6)</td>
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<td>0.216</td>
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<td>total</td>
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<td>2.9 (0.6)</td>
<td>-3.112</td>
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<td>2.4 (0.3)</td>
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<td>low canopy</td>
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<td>7.2 (8.3)</td>
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<tr>
<td>mid canopy</td>
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<td>93.1 (35.1)</td>
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<td>0.957</td>
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<td>47.5 (17.5)</td>
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<td>upper canopy*</td>
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<td>82.7 (59.1)</td>
<td>48.7 (34.5)</td>
<td>1.557</td>
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<tr>
<td>total</td>
<td>188.7 (58.7)</td>
<td>199.6 (86.9)</td>
<td>-0.403</td>
<td>0.690</td>
<td>188.7 (58.7)</td>
<td>83.9 (33.4)</td>
<td>6.011</td>
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</table>

* n=14 for GR, OGR, and LR; n=9 for SR
Table 10. Mean results from post hoc comparisons for tree structural variables compared across low, mid, and upper canopy regions within each tree class. Standard deviations are in parentheses.

<table>
<thead>
<tr>
<th></th>
<th>Low (n=15)</th>
<th>Mid (n=15)</th>
<th>Upper (n=14)</th>
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<tbody>
<tr>
<td><strong>Gap Regen</strong></td>
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<tr>
<td>Branch Diameter (cm)</td>
<td>1.9 (0.3)*</td>
<td>2.5 (0.4)</td>
<td>2.4 (0.2)</td>
</tr>
<tr>
<td>Branch Density (# branches/m)</td>
<td>2.8 (1.4)*</td>
<td>7.4 (1.7)*</td>
<td>13.6 (6.2)*</td>
</tr>
<tr>
<td>(\Sigma) Branch Length (m)</td>
<td>19.1 (11.4)*</td>
<td>92.4 (34.1)</td>
<td>82.7 (59.1)</td>
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<tr>
<td><strong>Old Growth Regen</strong></td>
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<tr>
<td>Branch Diameter (cm)</td>
<td>2.8 (0.5)</td>
<td>2.9 (0.5)</td>
<td>3.1 (1.1)</td>
</tr>
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<td>Branch Density (# branches/m)</td>
<td>3.7 (2.0)*</td>
<td>5.6 (1.8)</td>
<td>7.1 (2.6)</td>
</tr>
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<td>(\Sigma) Branch Length (m)</td>
<td>57.9 (39.0)</td>
<td>93.1 (35.1)*</td>
<td>52.1 (54.1)*</td>
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<tr>
<td><strong>Standard Regen</strong></td>
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<tr>
<td>Branch Diameter (cm)</td>
<td>1.6 (0.8)</td>
<td>2.1 (0.3)</td>
<td>2.1 (0.6)</td>
</tr>
<tr>
<td>Branch Density (# branches/m)</td>
<td>1.2 (1.1)*</td>
<td>5.2 (1.8)*</td>
<td>9.0 (2.3)*</td>
</tr>
<tr>
<td>(\Sigma) Branch Length (m)</td>
<td>7.2 (8.3)*</td>
<td>47.5 (17.5)</td>
<td>48.7 (34.5)</td>
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<td><strong>Large Regen</strong></td>
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<tr>
<td>See gap regen</td>
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</tr>
<tr>
<td><strong>Old Growth</strong></td>
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</tr>
<tr>
<td>Branch Diameter (cm)</td>
<td>5.1 (3.3)</td>
<td>4.9 (1.9)</td>
<td>3.7 (1.5)</td>
</tr>
<tr>
<td>Branch Density (# branches/m)</td>
<td>2.6 (1.8)*</td>
<td>9.1 (5.2)</td>
<td>13.2 (4.5)</td>
</tr>
<tr>
<td>(\Sigma) Branch Length (m)</td>
<td>67.4 (56.5)*</td>
<td>251.2 (143.3)*</td>
<td>205.3 (131.9)</td>
</tr>
<tr>
<td><strong>Veteran</strong></td>
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</tr>
<tr>
<td>Branch Diameter (cm)</td>
<td>4.9 (1.8)</td>
<td>5.8 (2.1)</td>
<td>4.5 (1.9)</td>
</tr>
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<td>Branch Density (# branches/m)</td>
<td>0.6 (0.6)*</td>
<td>5.1 (1.5)</td>
<td>6.9 (4.2)</td>
</tr>
<tr>
<td>(\Sigma) Branch Length (m)</td>
<td>11.4 (7.9)*</td>
<td>87.8 (10.2)</td>
<td>176.9 (108.3)*</td>
</tr>
</tbody>
</table>

*statistical significance at \(\alpha=0.05\).
the low canopy compared to the mid and upper canopy. In old growth regen trees, there was no effect between the canopy strata for branch diameter. Branch density in the lower canopy was significantly less than in the mid and upper canopy. The summed branch length in the mid canopy was significantly larger than that of the upper canopy.

**Composition**

The Alectoria, Bryoria, and Foliose functional groups were found in both gap and old growth stands at all sites. The Cyanolichen functional group was absent from both stand types at the Viking East site and from the gap stand at the Viking West site. The frequencies of occurrence for the Alectoria, Bryoria, and Foliose functional groups were 100% at all sites and in both stand types. Frequencies for the Cyanolichen functional group in old growth stands at the Viking West and Hungary sites were 60% and 100% respectively. In the Hungary gap stand, the Cyanolichen group’s frequency was 20%.

**Abundance**

Regen trees in gap and old growth stands did not differ in the total lichen biomass (Table 11). A breakdown by functional group revealed the Bryoria functional group was more abundant in gap stands. There was no difference in the Alectoria and Foliose functional group’s biomass between gap and old growth stands.

**Distribution**

A) Foliated vs Non-Foliated Region

The non-foliated portion of the tree crown contained more lichen biomass than the foliated portion (grams of lichen per region of branch) for regen trees in old growth and gap stands (Table 12). The Alectoria and Foliose functional groups contributed to the
Table 11. Lichen biomass results for old growth regen (OGR) and gap regen (GR) trees. Standard deviations are in parentheses.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>OGR</th>
<th></th>
<th>GR</th>
<th></th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=15</td>
<td>mean g lichen/tree</td>
<td>n=15</td>
<td>mean g lichen/tree</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alectoria</td>
<td>330.7 (183.9)</td>
<td>443.6 (182.7)</td>
<td>1.686</td>
<td>0.103</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bryoria</td>
<td>171.2 (242.5)</td>
<td>483.0 (309.9)</td>
<td>3.069</td>
<td><strong>0.005</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foliose</td>
<td>1130.9 (568.9)</td>
<td>983.8 (317.1)</td>
<td>-0.875</td>
<td>0.389</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Biomass</td>
<td>1632.8 (861.0)</td>
<td>1910.3 (666.9)</td>
<td>0.987</td>
<td>0.332</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 12. Lichen biomass results for foliated and non-foliated regions of the tree crown (mean g lichen/branch region) in gap regen (GR) and old growth regen (OGR) trees. Data reported by site were not pooled because of a significant effect between sites. Standard deviations are in parentheses.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>OGR (n=15)</th>
<th></th>
<th>GR (n=15)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Foliated</td>
<td>Non-Foliated</td>
<td>t</td>
<td>p</td>
</tr>
<tr>
<td>Alectoria</td>
<td>118.3 (76.3)</td>
<td>212.4 (136.7)</td>
<td>2.328</td>
<td>0.027</td>
</tr>
<tr>
<td>Hungary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viking East</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viking West</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bryoria</td>
<td>89.8 (71.6)</td>
<td>81.3 (181.8)</td>
<td>-2.33</td>
<td>0.027</td>
</tr>
<tr>
<td>Foliose</td>
<td>293.0 (140.9)</td>
<td>837.9 (456.6)</td>
<td>4.417</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total Biomass</td>
<td>501.1 (244.4)</td>
<td>1131.7 (669.9)</td>
<td>-3.425</td>
<td>0.002</td>
</tr>
</tbody>
</table>

* significant effect in the ANOVA across site, α=0.05
** n=5
* values of t and p were obtained from log10 transformed data, but means and standard deviations are from untransformed data
large biomass in the non-foliated region. The Bryoria functional group was more abundant in the foliated region of old growth stands but had no difference between foliated and non-foliated regions in gap stands.

The above data were converted to grams per meter of branch and the analysis repeated. There was no difference in total lichen loading between foliated and non-foliated regions of the tree crown for both stand types (Table 13). However, analysis by functional group revealed that Bryoria was more abundant in the foliated region in old growth stands and Alectoria was more abundant in the non-foliated region for 2 out of 3 gap stands.

B) Vertical Distribution

Lichen functional groups showed distinct vertical distributions within the canopy. The Bryoria functional group's biomass peaked in the upper canopy, while the Alectoria and Foliose functional groups peaked in the mid canopy (Figure 10). Although the Foliose functional group was most prominent in the mid canopy, its distribution was broad compared to that of the Bryoria and Alectoria functional groups for both stand types. The vertical distance between functional group peaks was smaller in gap stands (Figure 11). T-tests between gap regen and old growth regen at each height interval confirmed the apparent downward shift in the Bryoria functional group peak and the narrower distribution of the Foliose functional group in the lower canopy of gap regen trees (Figure 10).
Table 13. Lichen biomass results for foliated and non-foliated regions of the tree crown (mean g lichen/m of branch region) in gap regen (GR) and old growth regen (OGR) trees. Data reported by site were not pooled because of a significant effect between sites. Standard deviations are in parentheses.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>GR (n=15)</th>
<th>OGR (n=15)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Foliated</td>
<td>Non-Foliated</td>
<td>t</td>
<td>p</td>
<td>Foliated</td>
<td>Non-Foliated</td>
<td>t</td>
<td>p</td>
</tr>
<tr>
<td>Alectoria</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hungary**</td>
<td>1.0 (0.2)</td>
<td>2.2 (0.6)</td>
<td>-4.425</td>
<td>0.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viking East**</td>
<td>0.8 (0.2)</td>
<td>2.7 (1.1)</td>
<td>-3.692</td>
<td>0.006</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viking West**</td>
<td>4.4 (3.5)</td>
<td>3.3 (1.5)</td>
<td>0.625</td>
<td>0.549</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bryoria</td>
<td>3.3 (1.9)</td>
<td>2.2 (1.3)</td>
<td>1.701</td>
<td>0.100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foliose</td>
<td>4.8 (2.6)</td>
<td>5.5 (1.0)</td>
<td>-1.003</td>
<td>0.324</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Biomass</td>
<td>10.1 (5.3)</td>
<td>10.4 (2.7)</td>
<td>-0.232</td>
<td>0.818</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* significant effect in the ANOVA across site, α=0.05.
** n=5
Figure 10. Vertical distribution of functional groups expressed as mean lichen biomass per height interval for gap regen (GR) and old growth regen (OGR) trees. Numbers in parentheses show sample size, OG listed first followed by GR. Error bars represent the standard error of the mean, and (*) indicates a statistical significance at $\alpha=0.05$. 
Figure 11. Lichen profile of an average gap regen and old growth regen tree. Sample size and standard error of the mean is represented in Figure 10.
Large Regen vs Standard Regen

Tree Structure

Large and standard regen trees did not differ significantly in age. Large regen trees were larger than standard regen trees in height and dbh, and had more branches (Table 9). Branch density was greater in large regen trees in all regions of the crown. Large regen trees had larger overall branch diameter, however, this effect was evident only in the mid canopy. Summed branch length was greater for large regen trees than for standard regen trees, excluding the upper canopy where there was no effect.

Within large regen trees, comparison across canopy strata revealed smaller diameter branches and a shorter summed branch length in the lower canopy (Table 10). Branch density increased in each canopy region with height. In standard regen trees, a similar pattern existed for summed branch length and branch density, however, there was no difference in branch diameter across canopy strata.

Composition

The Alectoria, Bryoria, and Foliose functional groups were present on all gap regen trees sampled. The Cyanolichen functional group occurred on 13% of the standard regen trees (one tree from each of the Viking West and Hungary sites) and 7% of the large regen trees (one tree from the Hungary site).

Abundance

Large regen trees supported more lichen biomass than standard regen trees (Table 14). This was true for all functional groups considered.
Table 14. Lichen biomass results for large regen (LR) and standard regen (SR). Standard deviations are in parentheses.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>LR n=15</th>
<th>SR n=15</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean g lichen/tree</td>
<td>mean g lichen/tree</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alectoria</td>
<td>443.6 (182.7)</td>
<td>199.3 (136.9)</td>
<td>4.144</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Bryoria</td>
<td>483.0 (309.9)</td>
<td>140.0 (78.9)</td>
<td>4.153</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Foliose</td>
<td>983.8 (317.1)</td>
<td>378.4 (117.3)</td>
<td>5.540</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total Biomass</td>
<td>1910.3 (666.9)</td>
<td>717.7 (287.5)</td>
<td>5.858</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
**Distribution**

A) Foliated vs Non-Foliated

The pattern of lichen distribution in foliated and non-foliated regions was similar in large and standard regen, excluding the Viking West gap stand which had a significant between site effect in the foliated region (Table 15 and 16). Overall, both tree classes had more total lichen biomass in the non-foliated region of the tree crown for analysis based on grams of lichen per region of branch. The Bryoria functional group was the only group showing no difference in distribution between foliated and non-foliated regions.

When the analysis was repeated using units of grams of lichen per meter of branch region, the results showed no difference in total lichen biomass between foliated and non-foliated regions. However, the Alectoria functional group remained more abundant in non-foliated regions of the tree crown for both tree classes. In standard regen trees, the Foliose functional group at one of the sites was more dominant in the non-foliated region, while the other two sites showed no difference. Again, there was no difference in distribution of the Bryoria functional group between foliated and non-foliated regions.

B) Vertical Distribution

The Alectoria and Foliose functional groups showed similar patterns of vertical distribution in large and standard regen trees (Figure 12). Both groups had peak biomass in the mid canopy. The Bryoria functional group peaked in the upper canopy for large and standard regen but their distributions were slightly different. In standard regen trees, the Bryoria functional group increased with height reaching maximum biomass in the last few meters of the tree. In large regen trees, Bryoria biomass increased with height to
Table 15. Lichen biomass results for foliated and non-foliated regions of the tree crown (mean g lichen/branch region) in large regen (LR) and standard regen (SR) trees. Data reported by site were not pooled because of a significant effect between sites. Standard deviations are in parentheses.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>LR (n=15)</th>
<th>SR (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Foliated</td>
<td>Non-Foliated</td>
</tr>
<tr>
<td>Alectoria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hungary**</td>
<td>58.5 (15.6)</td>
<td>365.0 (135.9)</td>
</tr>
<tr>
<td>Viking East**</td>
<td>41.4 (18.6)</td>
<td>320.8 (128.6)</td>
</tr>
<tr>
<td>Viking West**</td>
<td>224.7 (124.1)</td>
<td>320.3 (120.4)</td>
</tr>
<tr>
<td>Bryoria</td>
<td>189.9 (120.3)</td>
<td>293.1 (223.9)</td>
</tr>
<tr>
<td>Foliore</td>
<td>280.2 (144.2)</td>
<td>703.6 (244.5)</td>
</tr>
<tr>
<td>Hungary**</td>
<td>94.0 (41.7)</td>
<td>340.5 (110.6)</td>
</tr>
<tr>
<td>Viking East**</td>
<td>74.4 (28.8)</td>
<td>208.4 (73.3)</td>
</tr>
<tr>
<td>Viking West**</td>
<td>164.5 (48.8)</td>
<td>253.5 (88.0)</td>
</tr>
<tr>
<td>Total Biomass</td>
<td>578.3 (277.3)</td>
<td>1332.0 (517.4)</td>
</tr>
<tr>
<td>Hungary**</td>
<td>195.5 (34.6)</td>
<td>531.8 (226.5)</td>
</tr>
<tr>
<td>Viking East**</td>
<td>149.8 (30.3)</td>
<td>407.4 (151.0)</td>
</tr>
<tr>
<td>Viking West**</td>
<td>384.7 (186.8)</td>
<td>484.0 (211.9)</td>
</tr>
</tbody>
</table>

* significant effect in the ANOVA across site, α=0.05
** n=5
Table 16. Lichen biomass results for foliated and non-foliated regions of the tree crown (mean g lichen/m of branch region) in large regen (LR) and standard regen (SR) trees. Data reported by site were not pooled because of a significant effect between sites. Standard deviations are in parentheses.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>LR (n=15)</th>
<th>SR (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Foliated</td>
<td>Non-Foliated</td>
</tr>
<tr>
<td>Alectoria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hungary</td>
<td>1.0 (0.2)</td>
<td>2.2 (0.6)</td>
</tr>
<tr>
<td>Viking East</td>
<td>0.8 (0.2)</td>
<td>2.7 (1.1)</td>
</tr>
<tr>
<td>Viking West</td>
<td>4.4 (3.5)*</td>
<td>3.3 (1.5)</td>
</tr>
<tr>
<td>Bryoria</td>
<td>3.3 (1.9)</td>
<td>2.2 (1.3)</td>
</tr>
<tr>
<td>Foliose</td>
<td>4.8 (2.6)</td>
<td>5.5 (1.0)</td>
</tr>
<tr>
<td>Hungary</td>
<td>2.6 (0.9)*</td>
<td>4.1 (0.5)*</td>
</tr>
<tr>
<td>Viking East</td>
<td>3.4 (1.9)</td>
<td>5.0 (2.3)</td>
</tr>
<tr>
<td>Viking West</td>
<td>5.8 (1.9)*</td>
<td>8.0 (1.8)*</td>
</tr>
<tr>
<td>Total Biomass</td>
<td>10.1 (5.3)</td>
<td>10.4 (2.7)</td>
</tr>
<tr>
<td>Hungary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viking East</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* significant effect in the ANOVA across site, \( \alpha = 0.05 \).

** n=5
Figure 12. Vertical distribution of functional groups expressed as mean lichen biomass per height interval for large regen (LR) and standard regen (SR) trees. Numbers in parentheses show sample size, LR listed first followed by SR. Error bars represent the standard error of the mean, (*) indicates a statistical significance at α=0.05.
Old Growth vs Veteran

Tree Structure

All old growth trees assessed had interior rot and an accurate estimate of the age was not obtained. The mean age for veteran trees was 269 (± 30) years. It was assumed that the mean age for veteran trees was a conservative estimate of old growth tree age. Old growth trees were taller than veteran trees, but there was no difference in dbh. Old growth trees had more branches, greater branch density, and a longer summed branch length than veteran trees. Branch diameter did not differ between the two tree classes (Table 17).

Branch density was compared across canopy strata for veteran trees and the lower canopy was less dense than the mid and upper regions. For summed branch length, the lower canopy had less branch length than the upper canopy. There was no difference in branch diameter across canopy strata (Table 9). A similar pattern was seen in old growth trees with the exception of summed branch length; the lower canopy had less branch length than the mid canopy region.

Composition

The Alectoria, Bryoria, and Foliose functional groups were present on all veteran and old growth sample trees. The frequency of the Cyanolichen functional group in the veteran trees was 100% in the Hungary gap stand and 67% in the Viking West gap stand.
Table 17. Mean results for structural analysis of old growth (OG) and veteran (VET) trees. Standard deviations are in parentheses.

<table>
<thead>
<tr>
<th>Structure</th>
<th>VET</th>
<th>OG</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>tree height (m)</td>
<td>22.5 (3.4)</td>
<td>32.2 (4.3)</td>
<td>-4.672</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>tree dbh (cm)*</td>
<td>61.2 (13.2)</td>
<td>80.5 (14.0)</td>
<td>-2.175</td>
<td>0.061</td>
</tr>
<tr>
<td># of branches</td>
<td>98.5 (54.8)</td>
<td>246.6 (74.4)</td>
<td>-4.16</td>
<td>0.001</td>
</tr>
<tr>
<td>branch density (branches/m)</td>
<td>4.2 (1.8)</td>
<td>7.8 (2.7)</td>
<td>-2.887</td>
<td>0.013</td>
</tr>
<tr>
<td>branch diameter (cm)</td>
<td>5.2 (1.4)</td>
<td>4.3 (1.6)</td>
<td>1.077</td>
<td>0.301</td>
</tr>
<tr>
<td>Σ branch length (m)**</td>
<td>276.1 (110.0)</td>
<td>523.8 (118.8)</td>
<td>-3.010</td>
<td>0.020</td>
</tr>
</tbody>
</table>

* n=4 for Veteran trees, n=6 for old growth trees
** n=3 for Veteran trees, n=6 for old growth trees
No veteran trees were assessed in the Viking East gap stand for safety reasons. In old
growth stands, the Cyanolichen functional group had a frequency of 100% in the
Hungary and Viking West stands and 67% in the Viking East stand.

Abundance

Old growth trees supported significantly more lichen biomass than veteran trees,
with the Cyanolichen functional group being the main factor contributing to this result
(Table 18). There was no difference in lichen biomass between old growth and veteran
trees for the Alectoria, Bryoria, and Foliose functional groups.

Distribution

Old growth and veteran trees were less stratified than regen trees in the vertical
distribution of lichen functional groups. Peak biomass for all functional groups occurred
in the mid canopy (Figure 13).

Veteran vs Gap Regen

Tree Structure

Veteran trees were older \( t(5.28)=14.20, p<0.001 \) and larger in dbh
\( t(3.12)=3.89, p=0.028 \) than gap regen trees, however, there was no difference in tree
height \( t(19)=1.40, p=0.176 \). Veteran and gap regen trees did not differ in total number
of branches \( t(19)=-1.40, p=0.179 \) or summed branch length \( t(16)=2.05, p=0.057 \).
Branch density was greater in gap regen trees \( t(19)=-2.89, p=0.009 \) and branch diameter
was greater in veteran trees \( t(5.20)=4.61, p=0.005 \).
Table 18. Lichen biomass results for old growth (OG) and veteran (VET) trees. Standard deviations are in parentheses.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>OG n=9 mean g lichen/tree</th>
<th>VET n=6 mean g lichen/tree</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alectoria</td>
<td>3376.0 (1305.4)</td>
<td>2100.1 (1355.9)</td>
<td>-1.827</td>
<td>0.091</td>
</tr>
<tr>
<td>Bryoria</td>
<td>565.1 (161.0)</td>
<td>496.9 (268.1)</td>
<td>-0.534</td>
<td>0.605</td>
</tr>
<tr>
<td>Foliose</td>
<td>2909.5 (1421.5)</td>
<td>2795.7 (2237.0)</td>
<td>-0.121</td>
<td>0.905</td>
</tr>
<tr>
<td>Cyanolichen</td>
<td>2898.0 (4867.2)</td>
<td>20.0 (22.6)</td>
<td>-2.623*</td>
<td>0.021</td>
</tr>
<tr>
<td>Total Biomass</td>
<td>9961.6 (4756.9)</td>
<td>5412.7 (2113.2)</td>
<td>-2.182</td>
<td>0.048</td>
</tr>
</tbody>
</table>

* Values of t and p were obtained from log10 transformed data, but means and standard deviations are from untransformed data.

* n=6
Vertical Distribution of Lichen Functional Groups for OG and VET trees

Figure 13. Vertical distribution of lichen functional groups expressed as mean lichen biomass per height interval for old growth (OG) and veteran (VET) trees. Numbers in parentheses show sample size, OG listed first followed by VET. Error bars represent the standard error of the mean, (*) indicates a statistical significance at $\alpha=0.05$. 
Abundance

Total lichen loading was three times greater in veteran trees (Cyanolichen functional group excluded) compared to gap regen trees (Table 19). The Alectoria and Foliose functional groups were more abundant in veteran trees, while there was no difference in the Bryoria functional group between the two tree classes.

Distribution

Lichen functional groups in veteran and gap regen trees had similar vertical distributions (Figure 14). The Alectoria and Foliose functional groups peaked in the mid canopy. The Bryoria functional group peaked in the upper canopy for gap regen and the mid-upper canopy for veteran trees.

Old Growth vs Old Growth Regen

Tree Structure

Old growth trees differed significantly from old growth regen trees in all structural variables considered: height \( t(22)=8.00, p<0.001 \), dbh \( t(6.10)=7.86, p<0.001 \), total number of branches \( t(22)=6.41, p<0.001 \), branch density \( t(22)=3.15, p=0.006 \), summed branch length \( t(19)=6.97, p<0.001 \), and branch diameter \( t(22)=3.08, p=0.005 \).

Abundance

Old growth trees supported four times more total lichen biomass (Cyanolichen functional group excluded) than old growth regen trees (Table 20). All functional groups
Table 19. Lichen biomass results for veteran (VET) and gap regen (GR) trees. Standard deviations are in parentheses.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>VET mean g lichen/tree</th>
<th>GR mean g lichen/tree</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alectoria</td>
<td>2100.1 (1355.9)</td>
<td>443.6 (182.7)</td>
<td>2.982</td>
<td>0.030</td>
</tr>
<tr>
<td>Bryoria</td>
<td>496.9 (268.1)</td>
<td>483.0 (309.9)</td>
<td>0.096</td>
<td>0.924</td>
</tr>
<tr>
<td>Foliose</td>
<td>2795.7 (2237.0)</td>
<td>983.8 (317.1)</td>
<td>4.396*</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total Biomass</td>
<td>5392.7 (2108.8)*</td>
<td>1910.3 (666.9)</td>
<td>3.966</td>
<td>0.009</td>
</tr>
</tbody>
</table>

* Values of t and p were obtained from log_{10} transformed data, but means and standard deviations are from untransformed data.

* Cyanolichen group excluded from this calculation.
Vertical Distribution of Lichen Functional Groups for VET & GR

Figure 14. Vertical distribution of functional groups expressed as mean lichen biomass per height interval for veteran (VET) and gap regen (GR) trees. Numbers in parentheses indicate sample size, VET is listed first followed by GR. Error bars represent the standard error of the mean, (*) indicates a statistical significance at $\alpha=0.05$. 
Table 20. Lichen biomass results for old growth (OG) and old growth regen (OGR) trees. Standard deviations are in parentheses.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>OG</th>
<th>OGR</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=9</td>
<td>n=15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alectoria</td>
<td>3376.0 (1305.4)</td>
<td>330.7 (183.9)</td>
<td>9.020</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Bryoria</td>
<td>565.1 (161.0)*</td>
<td>171.2 (242.5)</td>
<td>3.641</td>
<td>0.002</td>
</tr>
<tr>
<td>Foliose</td>
<td>2909.5 (1421.5)</td>
<td>1130.9 (568.9)</td>
<td>4.349</td>
<td>0.005</td>
</tr>
<tr>
<td>Total Biomass</td>
<td>7063.5 (1969.1)**</td>
<td>1632.8 (861.0)</td>
<td>9.389</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

* n=6

** Cyanolichen group excluded from this calculation
considered were more abundant in old growth trees, up to ten times more for the Alectoria functional group.

Distribution

The Bryoria and Foliose functional groups had different vertical distributions in old growth and old growth regen trees (Figure 15). The Foliose functional group peaked in the mid canopy for both tree classes, however, the distribution was skewed towards the upper canopy in old growth trees and towards the lower canopy in old growth regen trees. The Bryoria functional group peaked in the upper canopy of old growth regen trees and the mid canopy for old growth trees. The vertical distribution of the Alectoria functional group was similar for both tree classes, with peak biomass in the mid canopy.

Stand-level Projections

Table 21 shows stand-level projections for standing crop of arboreal lichen. The projected total lichen biomass in old growth stands was marginally higher than in gap stands. The Cyanolichen functional group was the main contributor to this results. While old growth stands supported more Alectoria functional group biomass, gap stands contained more Bryoria and Foliose functional group biomass.
Vertical Distribution of Lichen Functional Groups for OG and OGR

Figure 15. Vertical distribution of functional groups expressed as mean lichen biomass per height interval for old growth (OG) and old growth regen (OGR) trees. Numbers in parentheses show sample size, OG is listed first followed by OGR. Error bars represent the standard error of the mean, (*) indicates a statistical significance at $\alpha=0.05$. 63
Table 21. Stand-level projections for arboreal lichen biomass.
Projections based on tree classes and species restrictions defined in methodology.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>Gap (kg/ha)</th>
<th>Old Growth (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alectoria</td>
<td>310</td>
<td>431</td>
</tr>
<tr>
<td>Bryoria</td>
<td>205</td>
<td>87</td>
</tr>
<tr>
<td>Foliose</td>
<td>564</td>
<td>481</td>
</tr>
<tr>
<td>Cyanolichen</td>
<td>1</td>
<td>333</td>
</tr>
<tr>
<td>Total Biomass</td>
<td>1080</td>
<td>1332</td>
</tr>
</tbody>
</table>
CHAPTER FOUR: DISCUSSION

Gap Regen vs Old Growth Regen

The results for total lichen biomass on gap regen and old growth regen trees seem to contradict the current literature. Most studies report that trees in old growth stands support more lichen than trees in second growth stands (Lesica et al. 1991, McCune 1993, Esseen et al. 1996). This study differs from the others in that sampling occurred on comparable units in both stand types, trees of similar structure and age. McCune (1993) and Uliczka and Angelstam (1999) showed that tree structure and age affect lichen loading. Therefore, many studies seek to prove the inevitable, that large, old trees in old growth stands have more lichen than smaller, younger trees in second growth stands. In this study, biomass of the Cyanolichen functional group was not included in the comparison of total lichen biomass on regen trees and may have affected the results.

It is valuable to recognize the differences observed in the individual lichen functional groups to understand the process of lichen colonization. The composition, abundance, and distribution of lichen functional groups appear to be differentially affected by dispersal capability, tree structure, and microclimate.

Dispersal

The availability of lichen propagules may explain the poor representation of the Cyanolichen functional group in gap stands. In old growth stands, regen trees were typically in the shadow of lichen propagule “source” trees, heavily loaded with lichen
(with the exception of the Viking East old growth stand which had a lower frequency of cyanolichens). Greater biomass of the Cyanolichen functional group on old growth “source” trees coupled with the greater density of “source” trees in old growth stands provided more cyanolichen propagules to old growth regen trees. Therefore, the higher frequency of the Cyanolichen functional group in old growth regen trees suggests that colonization by this group was limited by dispersal capabilities. Peck and McCune (1997) noted similar results for the Cyanolichen functional group in comparing lichen litter from rotation-aged stands with and without remnant old growth trees. They reported 233% more cyanolichen litter in stands with remnant trees and that cyanolichen litter biomass was positively related to the number of remnant trees present. Sillett and McCune (1998) demonstrated, through a 1 year transplant study, that 2 old growth associated cyanolichen species grew equally well and experienced the same percent mortality in second growth stands as in old growth stands. Their results point to limitations in dispersal capability, rather than microclimate factors, for explaining the poor representation of the Cyanolichen functional group in second growth stands. However, many researchers (Lesica et al. 1991, Goward 1994, Rosso et al. 2000) conclude that the diverse and abundant cyanolichen communities in old growth stands are dependent on the unique environmental conditions (light and moisture regimes) produced by old growth stand structure. Over a longer time frame than was observed in Sillett and McCune’s (1998) study, light may play a role in excluding the Cyanolichen functional group from second growth stands. When present, the Cyanolichen functional group was located in the low to mid canopy region. In the dense gap stands, light in the form of
sun-flecks may be less frequent than in the more open old growth stands. Reduced light levels in gap stands may physiologically inhibit prosperous cyanolichen communities.

The Alectoria, Bryoria and Foliose functional groups were not limited by dispersal in gap stands as evident in biomass results. These findings are supported by a litterfall study which showed uniform distribution of *Alectoria* sp. and *Bryoria* sp. fragments throughout patch cuts 1-2 ha in size (Quesnel and Waters 1999). Dettki (1998) reported thallus fragments of *Bryoria* sp. disperse efficiently up to 100 m, and Stevenson (1988) found dispersal distances of 400 m. Other studies have shown the Foliose functional group to be a primary colonizer and therefore, not limited by dispersal (McCune 1993, Esseen et al. 1996, Peck and McCune 1997).

*Microclimate*

It is helpful to consider the vertical distribution of the Bryoria functional group to understand the factors causing biomass differences between gap regen and old growth regen trees. The Bryoria functional group penetrated deeper into the canopy of gap stands. The canopy structure of gap stands was less complex than old growth stands, providing less of a buffering effect from environmental variables (i.e. wind and solar radiation) (Franklin et al. 1981). The Bryoria functional group thrives in more exposed habitats with microclimatic conditions characterized by frequent wetting and drying events (Lesica et al. 1991, Rominger et al. 1994, Sillett 1995, Esseen et al. 1996). Therefore, the microhabitat for which the Bryoria functional group is best suited occupies a larger portion of the canopy in gap stands, thus creating the potential for greater biomass loading. Bryoria functional group biomass on old growth regen trees declined sharply at the division between the upper and mid canopy regions (Figure 10).
Presumably this division marks a change in microclimate, where prolonged wetting occurs below this point (Campbell and Coxson, 2001).

Tree Structure

The Foliose functional group can be described as ubiquitous due to its sizable presence at any height within the forest canopy. This quality indicates that the Foliose functional group is not limited by changes in microenvironment. The narrower distribution of the Foliose functional group observed in the lower canopy of gap regen trees is likely the result of tree structure. The lower crowns of gap regen trees were more susceptible to self-pruning than old growth regen due to low light levels. This was evident in the data for summed branch length in the lower canopy. With less substrate available for lichen colonization, there was less lichen biomass in this region of the tree (Esseen et al. 1996, Lyons 1998).

Other studies have concluded that the distribution of the Alectoria functional group is dependent on the moist, equable climate of old growth stands (Lesica et al. 1991, Rominger et al. 1994, Esseen et al. 1996). Results from this study indicate that tree structure was also important in explaining the Alectoria functional group distribution. The vertical distribution of the Alectoria functional group was virtually identical for regen trees in both stand types. With peak biomass occurring in the mid canopy, gap and old growth regen trees must have been similar, at least in terms of the variables important for optimum Alectoria functional group habitat. Both tree classes had equal amounts of available substrate for lichen colonization based on summed branch length.
Foliar vs Non-Foliar Region

The bulk of the arboreal lichen biomass was located in the non-foliated region of the canopy of regenerating trees. However, the non-foliated portion of the tree crown comprised twice the length of the foliated region, thus explaining biomass differences between the two regions. Expressing lichen distribution using the units of grams of lichen/region of branch is useful for a stand-level view of lichen loading. Clement and Shaw (1999), Lyons (1998), and Goward (1998) indicated that lichen functional groups have different distributions in foliated vs. non-foliated regions.

For details about lichen colonization in relation to a tree’s individual structure and microhabitats, it is useful to look at this relationship in terms of grams of lichen/meter of branch. The structural, textural, and chemical quality of the foliated or non-foliated region of a branch did not appear to determine lichen distribution. This conclusion was based on evidence from all functional groups showing no difference between lichen loading in foliated and non-foliated regions, and contradicting reports from other studies. Goward (1998) and Lyons (1998) reported greater lichen loading in non-foliated regions close to the tree bole, while Clement and Shaw (1999) reported greater loading in the foliated, distal regions of branches. Therefore, measured differences in lichen loading in one region of branch over the other were the result of that region occupying a different microsite, likely governed by microclimate. For example, in old growth regen trees, the foliated portion of the branch is at the edge of the tree crown where it is presumably exposed to more frequent wetting and drying events than the inner non-foliated regions of the crown. Growth of the Bryoria functional group is best suited for the microclimatic conditions surrounding the foliated region of old growth regen branches. As a result, the
Bryoria functional group had a greater biomass in the foliated region of old growth regen trees.

The homogenous stand structure of gap stands provided less protection from environmental fluctuations. Both the foliated and non-foliated portion of the branch in gap regen trees may experience the frequent wetting and drying events required for optimum growth of the Bryoria functional group. This may explain why gap stands showed no difference in Bryoria functional group biomass between foliated and non-foliated regions. These findings lend support to Goward's (1998) hypothesis that Bryoria sp. distribution can be predicted based on exposure to prolonged wetting.

Environmental extremes in the foliated region of gap regen trees may explain the apparent restriction of the Alectoria functional group to the more protected non-foliated region of the crown. Another possibility is the difference in age between foliated and non-foliated regions of the branch. Esseen et al. (1996) reported branch age was related to lichen mass. The oldest portion of branch is the non-foliated region near the bole of the tree, and may contain more lichen because of longer exposure to colonization. The young foliated branch tips provide an environment that is constantly changing with outward crown growth. It is thought that lichens need a relatively stable environment for establishment to occur. Studies have shown that fast-growing trees have fewer lichens, presumably due to the unstable environment (Uliczka and Angelstam 1999, Stevenson 1988).

**Standard vs Large Regen**

The comparison of standard regen to large regen trees confirms findings that tree size, rather than age, is the better predictor of arboreal lichen biomass (Lyons 1998) and
that lichen colonization is limited on smaller trees because of less available substrate (Esseen et al. 1996). While lichen biomass was affected by tree size, the distribution pattern of lichen functional groups remained the same. Conclusions reached for lichen distribution in foliated and non-foliated regions discussed previously for gap regen/large regen hold true for standard regen trees. Amount of available substrate seemed the most likely factor dictating distribution of the Alectoria and Foliose functional groups. Peak biomass occurred where mean branch length (calculated from mean branch density and summed branch length from Table 10) was the longest, the mid canopy. This observation supports the findings of Lyons (1998) and Esseen et al. (1996). The environmental fluctuations (frequent wetting and drying) in the upper canopy favor the growth of the Bryoria functional group and may explain the biomass peak in that region. In standard regen trees, the increase of the Bryoria functional group towards the top of the tree may reflect a boundary layer effect caused by the large regen trees. Large regen trees overtopped standard regen trees, possibly sheltering them from the most extreme environmental effects, allowing Bryoria biomass to accumulate in the last couple meters of the tree crown.

**Veteran vs Gap Regen**

Veteran and gap regen trees were different in age and structure but shared similar microclimatic conditions due to their relatively equal canopy position. The physical differences between veteran and gap regen trees did not affect biomass of the Bryoria functional group. This suggests there was an equal amount of suitable habitat for the Bryoria functional group in both tree classes. The abundance and distribution of the
Bryoria functional group appeared to be dependent on microclimatic conditions rather than on substrate quality.

In contrast, the abundance and distribution of the Alectoria and Foliose functional groups seemed to depend on amount of available substrate. Biomass peaks occurred in the mid canopy region, where the largest branches of the tree crown were found, for both tree classes. Branches on veteran trees were also larger than branches on gap regen trees and lichen loading reflected the amount of available substrate.

Old Growth vs Old Growth Regen

The vertical distribution pattern of the Bryoria functional group in old growth regen trees was unique in that it appeared to be influenced by stand-level canopy stratification rather than the individual tree height. The stand-level canopy stratification was defined by the boundary layer climate imposed by old growth trees, the dominant, canopy emergent trees of the stand. Peak biomass for the Bryoria functional group occurred in the upper canopy of old growth regen trees, which corresponded with the stand-level peak for the Bryoria functional group at the mid canopy (Figure 15). Therefore, this location within the stand must possess ideal microclimatic conditions for growth of the Bryoria functional group. These findings support the idea that vertical distribution of the Bryoria functional group is dependent on microclimatic conditions.

This stand-level influence on vertical stratification was not seen for the Alectoria and Foliose functional groups of old growth regen trees. The Alectoria and Foliose functional groups had peak mean biomass at distinct locations within the crown of old growth regen trees irrespective of where the stand-level peak was located (Figure 15). This suggests that the Alectoria and Foliose functional groups are less dependent on
microclimatic conditions for determining their vertical position within the canopy.
Structural factors may be more important in influencing the location of peak biomass for these functional groups in old growth and old growth regen trees.

**Stand-Level Projections**

The difference in standing crop of arboreal lichen in gap and old growth stands was small, differing by 252 kg/ha or 19%. McCune's 1993 study was one of the few that used sampling methodologies appropriate for extrapolation to the stand-level. He reported that old growth stands supported 2.6 times more lichen biomass than managed stands. In this study, as in McCune's, it was the large representation of the Cyanolichen functional group that accounted for most of the biomass difference between the old growth and gap stands. Results for the relative abundance of the other functional groups in this study complement findings in the literature. McCune (1993) reported that the Foliose functional group reached the greatest abundance in managed stands. Lesica et al. (1991), Rominger et al. (1994), Esseen et al. (1996) found more Bryoria functional group lichens in second growth stands while the Alectoria functional group was more abundant in old growth stands.

Despite the similarities in relative abundance of lichen functional groups, most studies report that old growth stands have a much greater abundance of lichen (ranging from 2-6 times more) than mature second growth stands (Neitlich 1993, Esseen et al. 1996, Enns et al. 1999). The main difference between this study and many others is the size of the second growth blocks. The second growth stands used in most studies originated from clearcuts larger than 50 ha. In contrast, this study examined 1-3 ha natural gap disturbances embedded in a matrix of old growth forest. Lichens in managed
stands may have been limited by dispersal capability, contributing to the differences in results (Stevenson 1988). Another difference between this and other studies is that trees were not removed from the sites after the disturbance event, unlike in timber harvesting operations. This may have affected the availability of nutrients, moisture, and lichen propagules in the second growth stands examined in this study.

Most lichen biomass studies that compare old growth and managed stands do not provide an analysis of stand-level lichen loading. Evaluating the lichen productivity of stands differing in age, without considering their contributions at the stand-level, may introduce bias. Stand-level projections from this study show that biomass in gap stands rivaled that in old growth stands largely because of the greater density of regenerating trees in gap stands. Furthermore, a large percent of lichen biomass studies are ground-based, only sampling the lower canopy. This study and others (Campbell 1998, Clement and Shaw 1999, Liu et al. 2000) have shown that peak biomass of lichen communities occur in the mid-upper canopy regions. Therefore, an accurate description of lichen communities within a stand requires sampling the full range of the canopy.

Projections for old growth stands more likely underestimated lichen biomass than projections made for gap stands because of tree species restrictions outlined in the definitions for the tree classes. In old growth stands, the proportion of regen-size western red cedar trees not considered in the stand-level projection was greater than 50% of the species restricted regen sample. Applying lichen loading results obtained from western hemlock to other tree species for stand-level projections may introduce a bias. Enns et al. (1999) and Quesnel and Waters (1999) found that young western red cedar trees supported less lichen biomass than other conifers. In both gap and old growth stands
there was a large proportion of trees smaller than 17 cm dbh that were not included in
stand-level projections. Lichen biomass contribution from these trees was considered
negligible based on findings that lichen loading greatly decreased on trees of smaller
diameter.
CHAPTER FIVE: CONCLUSION

Lichens truly are unique and diverse organisms that respond to environmental gradients in their habitats. Many factors act in concert to affect lichen colonization and their role of importance may change under different environmental conditions. These factors also affect lichen functional groups differently. The Bryoria functional group appeared most strongly affected by microclimate conditions, the Cyanolichen group by dispersal capabilities, and the Foliose and Alectoria functional groups by substrate availability. The results of this work provide direction for future studies to take a more detailed approach at measuring these factors, such as microclimate changes through the levels of the canopy and pairing them with Bryoria functional group abundance.

The main limitation of this study is its view of a single stand type at a single point in time. The inferences made are valid only for regenerating stands of approximately 100 years old in the wet subzones of the ICH. This study tells nothing of the lichen colonization in the successional history before this point, nor of the lichen colonization in the successional future beyond this point. None-the-less, the time frame examined is important to land managers because it approaches rotation age and gives valuable insight into lichen communities at a critical point in forest management.

Forest managers in the Prince George and Robson Valley forest districts may be able to use these results to help predict the effect of small-scale patch cuts on winter habitat for mountain caribou. Assuming that arboreal lichen communities respond similarly to small patch cuts and small-scale western hemlock looper outbreaks, then this
study leads to the following predictions: 1) Bryoria functional group biomass will increase in patch cuts ranging from 1-3 ha in size, and 2) Species biodiversity will be lost in patch cuts due to the decreased presence of the Cyanolichen functional group. Therefore, managers must clearly state their goal for land management (maintained levels of winter forage for mountain caribou, OR maintained lichen biodiversity) before prescribing patch cuts.

A problem that may exist with using small patch cuts to maintain winter forage for mountain caribou is access to arboreal lichen. In old growth ICH stands, caribou feed primarily on the lichen loaded branches of large rotten hemlock trees that fall in winter storms, and secondarily on lichen litterfall on the surface of the snow pack (Edwards et al. 1960, Rominger and Evans 2000). Trees in gap stands may not be as susceptible to falling because of their earlier stage of decay. The thalli of pendulose lichens are younger in gap stands and have not had time to grow to the length of those in old growth stands. This may have a significant effect on the amount of litterfall produced in gap stands. To address this issue, litterfall studies should be conducted in gap and old growth stands. Studies should also be conducted to determine the density of patch cuts on the landscape, range of sizes/shapes of patches, and stand types for which this silvicultural design may be used effectively.
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APPENDIX

Species list of lichens found on regen trees. Lichens were identified on the regen tree branches used for biomass verification. Note, no new species were observed on the branches collected from old growth trees. Voucher specimens are housed at the UNBC herbarium.

Alectoria sarmentosa
Bryoria capillaris
B. fremontii
B. fuscescens
B. lanestris
B. pseudofuscescens
Cavernularia hultenii
Cetraria chlorophylla
C. orbata
Hypogymnia metaphysodes
H. occidentalis
H. physodes
H. tubulosa
H. vittata
H. spp. nov. (Goward)
Lobaria pulmonaria
L. scrobiculata
Nephroma helveticum
Nodobryoria oregana
Parmelia hygrophila
P. sulcata
Parmeliopsis ambigua
P. hyperopta
Platismatia glauca
P. norvegica
Sticta fuliginosa
Usnea filipendula
U. scabrata