

Lobaria pulmonaria abundance as an indicator of macrolichen diversity in Interior Cedar Hemlock Forests

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Abstract

Orographic precipitation over interior mountains has formed the globally unique temperate, inland rainforest. It is composed of western redcedar and western hemlock dominated stands, some of which are very old and support a rich flora of epiphytic macrolichens. We documented macrolichen diversity across three age classes (5, 8 and 9) of Interior Cedar Hemlock (ICH) forests (i.e. ICHwk3 biogeoclimatic subzone) east of Prince George, British Columbia for the purposes of reporting on differences in lichen communities with stand age, and identifying potential indicators of antiquity - a condition whereby the forest is older than the oldest trees. We identified 41 taxa, including 21 foliose chlorolichens, 4 alectorioid (hair) lichens, and 16 old-growth associated chlorolichens and cyanolichens. Older forests supported more species than young or mature forests. The abundance of *Lobaria pulmonaria* was strongly correlated with this increase in diversity and may therefore be an appropriate indicator of stand age in the ICH. It is easily seen and quantified, is found in all age classes, and generally increases in abundance with stand age. The precedent for using lichens as indicators of ecosystem diversity has been previously set and we hope that by adding this to the understanding of lichen ecology across age classes, we may promote sustainable stewardship of the remaining old-growth rainforests of inland British Columbia.

Introduction

Patterns of Orographic precipitation create coastal-like forests in the interior of the province of British Columbia. These Interior Cedar Hemlock (ICH) forests are noteworthy due to both relatively low rates of disturbance and high biological diversity. Fire frequencies of more than 1000 years have been reported for stands in the wettest of the ICH subzones (Sanborn et al. 2001). This sporadic disturbance regime has resulted in a high level of ecological continuity, such that stands may be older than the age of the oldest tree (defined as antique, Goward

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1994). This has facilitated the greatest tree-level diversity of any of British Columbia's forest zones (Ketcheson et al. 1991), and the highest diversity of epiphytic lichen species of North American inland ecosystems (Goward and Arsenault 2000).

Two general groups of epiphytic macrolichens are found in ICH forests, the generalists and the old-growth associated species (Type A and B respectively; Goward 1993). Generalists (including alectorioid and foliose chlorolichen species) occur across all stand ages and conditions and are well adapted to the environmental conditions characteristic of younger, developing forests (Goward 1994). By contrast old-growth associated macrolichens are more commonly found in coastal environments where precipitation is plentiful. Inland, these species tend to become abundant only under relatively stable environmental conditions (Goward 1994) - a condition increasingly satisfied with forest age and antiquity.

With sustained or increased harvesting of our oldest and potentially antique ICH forests, there is an urgent need to understand the effect of stand-age and forest management activities on biological diversity and function of non-tree forest species. So too, the need for good biological indicators by which stands of antiquity may be identified in the ICH is required for effective conservation planning. This paper is presented in response to the need for such an indicator of stand age and macrolichen diversity in the ICH. It is intended as a general synopsis of the study. For a more detailed data presentation and analysis see Campbell and Fredeen (2004). Our specific objectives are 1) to document how epiphytic macrolichen diversity changes with stand age, and 2) to discover indicators of this biodiversity (and thus antiquity) that are both relatively easy to identify from the ground and are straightforward to use by conservationists and forest-managers in the field.

Methods

The study was located in the Robson Valley within the wet-cool variant of the Interior Cedar Hemlock biogeoclimatic zone (ICH wk3) in east-central British Columbia. Mesic to subhydric sites were identified between Clyde Creek at the south-eastern boundary to 25 km up the Morkill River at the north western boundary of the ICHwk3. Three trees were selected at each of nine sites in each of 3 stand ages; young (age classes 5/6), mature (age class 8) and old (age class 9; Table 1). A high level of epiphytic macrolichen species richness was the sole criteria for candidate trees. Selected trees were rigged, climbed and sampled vertically at various canopy heights (see Campbell et al. 1999).

A 0.1-ha circular plot was established surrounding each study tree. For candidate indicator features we recorded 1) tree species, 2) tree diameter (DBH), 3) coarse woody debris (CWD) quality and quantity (according to Meidinger 1998), 4) the height of the canopy, subcanopy, and emergent trees, 5) height of gold dust lichen (*Chrysothrix candelaris*; after Campbell and Fredeen 2004), and 6) abundance of *Lobaria pulmonaria* (assessed as the number of clumps per plot after Benson and Coxson 2003). The sample tree and 2-3 surrounding trees were cored using an increment borer to obtain tree ages. Any spruce (*Picea engelmannii* x *glauca*) in the vicinity were cored in an attempt to obtain a solid core as most western hemlock (*Tsuga heterophylla*) and redcedar (*Thuja plicata*) trees in the stands had some degree of heart rot.

Lichen composition and abundance were recorded for all branches in the study tree that could safely be accessed using the single rope technique (Perry 1978). The clump method (Campbell et al. 1999, and Benson and Coxson 2003) was used to estimate biomass for four

dominant genus groups; *Alectoria* (including *A. sarmentosa*, *Ramalina thrausta* and *Usnea* spp.), *Bryoria* (including *Bryoria* spp. and *Nodobryoria* spp.), *Platismatia glauca* and *Lobaria pulmonaria*

The canopy was then divided into three distinct height zones based on significant changes in lichen species composition observed within the tree. The upper canopy was dominated by *Bryoria* spp., the middle canopy by *Alectoria sarmentosa*, and the lower canopy by the presence of cyanolichens. One sample branch was removed from each zone. The number of discrete thalli (disconnected from other thalli of the same species) greater than 3mm in length was counted for each species encountered.

Table 1: Location and site descriptions of nine field sites within the ICHwk3. Forest cover abbreviations are: C - cedar (*Thuja plicata*), S - spruce (*Picea engelmannii x glauca*), H - hemlock (*Tsuga heterophylla*), B - subalpine fir (*Abies lasiocarpa*), F - Douglas-fir (*Pseudotsuga menziesii*), At - trembling aspen (*Populus tremuloides*).

| Site | Age class | Location | Avg. Age (yrs) | Avg. DBH (cm) | Density (stems/ha) | Forest cover |
|------|----------------|-------------------------------|----------------|---------------|--------------------|--------------|
| 5-1 | 5 | Clyde Cr. | 96 | 24.3 | 580 | CS(HB) |
| 5-2 | 6 ¹ | Lamco Rd. (W. Twin Cr.) | 75 | 25.0 | 740 | SH (FB) |
| 5-3 | 4 ² | Confluence of Milk & Goat R's | 113 | 28.8 | 557 | SHB (At) |
| 8-1 | 8 | W. Twin Cr. | 220 | 40.5 | 373 | H (CS) |
| 8-2 | 8 | Morkill R. | 210 | 36.8 | 407 | HC (SB) |
| 8-3 | 8 | Btw W. Twin Cr. & Clyde Cr. | 256 | 45.0 | 300 | HC(S) |
| 9-1 | 9 | Lower Goat R. | 300 | 55.7 | 247 | CH(S) |
| 9-2 | 9 | Morkill R. | 421 | 44.7 | 427 | CSH (B) |
| 9-3 | 9 | W. Twin Cr. | 380 | 51.6 | 255 | HC |

^{1,2} Due to the relative scarcity of age class 5 stands containing *Thuja plicata* or *Tsuga heterophylla* in the ICH wk3, older age class 4 and younger age class 6 stands were used to complete the age class 5 groups. These are hereafter collectively referred to as age class 5 or young stands.

Results

Forty-one epiphytic macrolichen species were observed across all 26 trees in the study. Of these 41 taxa, 4 were hair lichens, 21 were generalist foliose chlorolichens, 6 were old-growth associated chlorolichens and 10 were old-growth associated foliose cyanolichens. The hair lichens (*Alectoria sarmentosa*, *Bryoria* spp., and *Usnea* spp.) were ubiquitous throughout canopies of all age classes, as were some members of the foliose chlorolichens. Despite the ubiquitous nature of many generalist species, the total number of species observed in each tree increased significantly with stand age. Of the 41 possible taxa, 25 were found in young forests, 33 in mature and 35 in old (Figure 1). This trend was particularly pronounced with cyanolichens and old-growth associated chlorolichens. Of 16 possible old-growth associated taxa, only 2 were found in young stands, while 12 were found in mature and 15 in old. Only *Hypogymnia oceanica* (a species identified only once across the entire study) was absent from old stands.

While a fairly diverse flora of generalist and old-growth associated species were found in young and mature stands respectively, significant increases in the abundance of all species were observed with increasing age class. For example, mean branch loadings for the generalist species *Platismatia glauca* were 73.17 ± 22.04 , 132.89 ± 22.66 and 252.59 ± 48.61 thalli per branch in young, mature and old stands respectively. The same phenomenon was observed with cyanolichens. The two most common cyanolichens, *Nephroma helveticum* and *Lobaria pulmonaria*, were entirely absent from young trees, and were found with significantly higher abundances on old branches (with 33.6 ± 22.8 and 83.2 ± 34.6 thalli per branch respectively) than on mature branches (with 2.1 ± 1.2 and 22.4 ± 7.8 thalli per branch respectively) (Figure 2). All other cyanolichen species observed in old stands were absent from young stands and found only rarely in mature stands (1 -2 thalli across the study).

Ordination analyses revealed these differences in macrolichen species richness and abundance to be positively correlated with increasing stand age (as determined by the tree ring analysis), decreasing stand density, increasing average tree diameter and increasing *L. pulmonaria* abundance. By contrast, *Chrysothrix candelaris* (gold dust lichen) abundance was poorly correlated with macrolichen diversity.

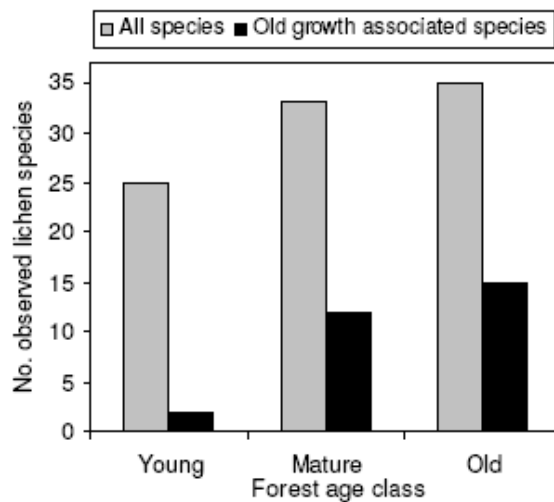


Figure 1. The total number of epiphytic macrolichen species observed over all trees in young (age class 5), mature (age class 8) and old (age class 9) forests.

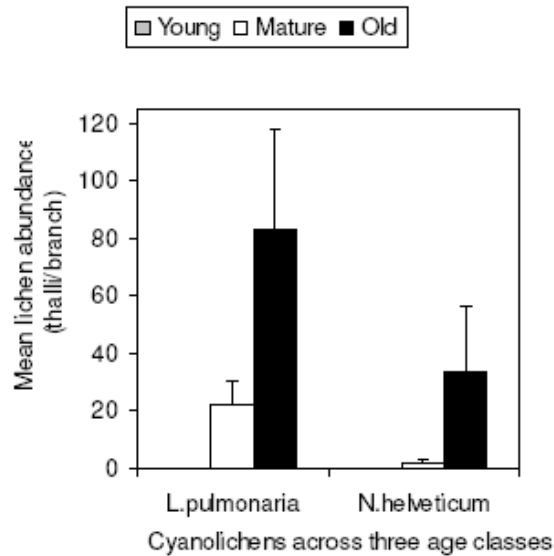


Figure 2. The mean abundance (lichen thalli per branch) for *Lobaria pulmonaria* and *Nephroma helveticum*, the two most common cyanolichens found in the ICHwk3. Means values are shown \pm SEM.

Discussion

Our data show that old ICH forests have a higher diversity of epiphytic macrolichens than do young or even mature forests (120-240 yrs). Macrolichen epiphytes found in young forests were, with two exceptions, generalists and made up less than 2/3 of the total flora. The remaining species were old-growth associated and were found prolifically in old forests and with sparse abundance in mature forests.

There are two possible explanations for the limited occurrences of old-growth associated macrolichen species in younger stands. The first hypothesis considers microclimatic requirements. Sillett and Antoine (2004) theorized that higher levels of atmospheric moisture (humidity) allow for more prolific accumulation of some macrolichen species in maritime forests, conditions that generally do not occur in younger stands. They demonstrated a higher diversity of old-growth associated, epiphytic cyanolichens in more humid forests. Eco-physiological studies explain this disparity by demonstrating that cyanolichens require liquid water for photosynthetic activity and growth (Büdel and Lange 1991).

While it appears that the absence and/or reduced biomass in younger inland forests is due, at least in part, to insufficient moisture, it is doubtful that moisture deficits are solely responsible for the limited ecological range of cyanolichens. Cyanolichens have been shown to survive when artificially transplanted into young forest stands (Sillett and McCune 1998). These data support the theory that the dearth of cyanolichens in young forests is due, not to unsuitable climate, but to ineffective dispersal into new locales (Peck and McCune 1997; Sillett and Goslin 1999; Sillett et al. 2000; Dettki et al. 2000). Lichen dispersal mechanisms are relatively ineffective over long ranges. This limitation is expected to be worsened in cyanolichen species, where the low vertical position in canopy would preclude effective wind dispersal. Absence of other old-growth associated biological dispersal agents, e.g. flying squirrels, could

also limit dispersal of certain species, especially those in lower canopy positions, delaying the onset of lichen colonization into young forests.

Our results, indicating impoverishment in old-growth associated species richness in younger stands, appear to support a combination of these two hypotheses. While it is possible that microclimatic unsuitability may preclude abundant development of old-growth associated macrolichen communities, the total absence of propagules in young forests indicates some limitation in dispersal. We therefore suggest that dispersal may be the limiting factor in young ICH forests, but that the disparity in diversity and abundance of macrolichens (particularly cyanolichens) between mature and old ICH forests is attributable to increasing microclimatic suitability with age. Three observations support this position.

First, mature stands in our study area had relatively low abundance of old-growth associated species, compared to old stands. Mature stands were between 140 and 240 years, an age range at which forests begin to accumulate a substantial assemblage of epiphytes (McCune 1993). This implies that the forests have been in existence for a sufficiently long period to allow successful dispersal. Yet only two of these species were observed with more than very sparse abundance. Second, we observed an upper vertical limit of old-growth associated species colonization that increased with stand age (Campbell and Fredeen 2004). It is conceivable that this height is a physical representation of the upper limit of appropriate moisture or other environmental conditions permissive to growth of these cyanolichens. Third, a comparison of lichen species diversity between the ICH wk3 and the ICH vk1 (the two wettest subzones) reveals a significantly higher abundance of the rare cyanolichens in the ICHvk1 (Radies and Coxson 2004) than in the ICHwk3. The ICHvk1, being of a similar latitude, tree species composition and geography, differs from the ICHwk3 primarily with respect to a greater annual precipitation (Reynolds 1997). Thus, microclimate and particularly those aspects of microclimate affecting lichen thallus moisture, appear to be prerequisite for cyanolichen presence in our inland cedar-hemlock forests. More specifically, the maintenance of rare chlorolichens and cyanolichens within the globally unique temperate and conifer-dominated inland forests is highly dependant on locally high atmospheric humidity (e.g. toe slopes) and on long periods of time between stand level disturbances (i.e. ecological continuity). Areas that satisfy these criteria would appear to have an increased probability of supporting old-growth associated and potentially scarce lichens.

Towards an indicator of forest antiquity and species diversity

The greatest challenge in managing these biodiverse old-growth ICH stands in a sustainable manner is the absence of a reliable method for distinguishing between stands which are mature versus those that contain the highest species diversity and may be considered antique. The dominant tree species in the ICH biogeoclimatic zone are western redcedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*). Dendrochronological techniques are ineffective as these trees are highly susceptible to heart rot (Peterson et al. 1998). Even with accurate and intact cores, these techniques would only be able to provide the age of living trees, and not on the age of the stand which can be considerably older. Sanborn et al. (2001) suggested carbon dating charcoal layers in the soil as a method of determining absolute stand age. Unfortunately this method is prohibitively expensive and geographically limited to toe slope locations where the probability of landslides removing the charcoal layers is low. In any case, this approach would not identify disturbances resulting from other agents such as insect outbreaks.

The alternative to discerning the chronological age of a stand is to use an ecosystem feature to indicate relative age. International studies have shown that the diversity of arboreal lichens is an ideal indicator of diversity in other taxa (Negi and Gadgil 2002) and habitat features (Johansson and Gustafsson 2001). In the ICH, Goward and Arsenault (2000) observed that the presence of certain cyanolichens might highlight possible stands of antiquity. Unfortunately, the use of many epiphytic lichen species as indicators of stand age is operationally impractical as there are few managers who can identify lichens to species in the field. Thus a more convenient indicator is required.

Harrison and Delong (2000) suggested that gold dust lichen (*Chrysothrix candelaris*) might be an indicator due to a potentially positive correlation between gold dust lichen abundance and calicioid lichen biodiversity (Goward, pers. comm.). However, we found no relationship between gold dust lichen and macrolichen biodiversity ($r^2=0.004$). By contrast, *L. pulmonaria* abundance was strongly and positively correlated with biodiversity ($r^2=0.687$; Campbell and Fredeen 2004). Moreover, it is found in a diverse range of habitats (even at low but detectable levels within young stands), its abundance increases markedly with stand age, and is easily identified and readily quantified from the ground level due to its lower-canopy position (Benson and Coxson, 2003). In addition, the precedent for using arboreal lichens has already been set in interior forests. Armleder et al. (1998) developed a handbook for estimating the abundance of lichens for use as indicators of habitat quality. These methods could easily be expanded to include *L. pulmonaria* in appraising stands of potential biodiversity.

As a cautionary note, although *L. pulmonaria* abundance seems to be an ideal indicator for biodiversity and stand antiquity, it is only the relative abundance of this lichen that is indicative of stand conditions, not its mere presence nor its absence. There are many potential factors that could account for its absence and so stands without *L. pulmonaria* cannot be automatically classified as taxonomically poor in other taxa. Also, the abundance of *L. pulmonaria* should only be used as a preliminary feature to highlight stands of potential antiquity where further research should be conducted. Finally, we must stress that currently, *L. pulmonaria* can only be used as an indicator in sites with similar stand and geographic conditions as those in this study. The concept of a single indicator of a taxonomically difficult group is, however, broadly applicable and should be explored in other ecosystems where financial or temporal constraints prevent a full exploration of epiphytic communities.

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