Indicating Climate in the Western Pacific Northwest with the Forest Inventory and Analysis Lichen Communities Indicator

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Fig.1-- *Bryoria fuscescens* (Horsehair lichen) is a critical winter forage species for many species in western North America. Photo by Roger Rosentreter.

I. Introduction

We demonstrate with data from the FIA Lichen Community Indicator in the western Pacific Northwest (PNW) how **lichen communities can indicate shifts in temperature regime** (Geiser and Neitlich 2007, Jovan 2007). Temperature and moisture are both of central importance to lichen distributions because they influence photosynthesis rates and basic metabolic processes. Lichens also lack a vascular system and so cannot store water like plants can.

In climate change monitoring, fast-responding **lichens are the "canaries in the coal mine" for the vegetation community.** Shifting lichen distributions provide early warning of shifting climate in a region, which helps us forecast how plant communities will respond. Moreover, tracking climate-driven changes to lichen communities is important because **wildlife and plants dependent on lichens for food**, shelter, and nutrient flux will be adversely impacted. For example:

-- "Forage" lichens provide critical winter sustenance for some wildlife species (Fig. 1).
--Cyanolichens fix nitrogen, which leaches into the soil and fertilizes plants.
--A variety of birds and rodents use lichens for nesting material and camouflage.

Fig. 4-- The west-side Pacific Northwest has worldwide importance as a refuge for *Usnea longissima* (Keon and Muir 2002), an indicator species of the "lowland" zone that is used as nesting material for birds. This species is a poor **disperser** and relies entirely on fragmentation. to reproduce: chunks of thallus break off in the wind and, if lucky, snag on a nearby tree and grow into clones. Photo by Karen Dillman.

II. Data Collection

Data for the Lichen Community Indicator are periodic surveys of epiphytic ("tree-dwelling") lichens used primarily for assessing status and trends in climate, biodiversity, and air quality. Surveys are conducted on a circular, 0.38-ha plot centered on subplot 1 in the standard FIA plot design (Fig. 2). Surveys last 30 minutes to 2 hours during which a crew member estimates each species' abundance.

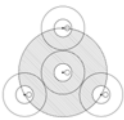

Fig. 2-- FIA plot design (graphic from U.S. Department of Agriculture, Forest Service 2005). Lichen communities are surveyed in the shaded area.

III. Climate Scoring (Fig. 3a,3b)

Lichen surveys are used to score climate at each plot with the help of a model. The western PNW model was built by Geiser and Neitlich (2007) with nonmetric multidimensional scaling ordination (NMS; McCune and Grace 2002), which analyzes which species were present and how abundant they were, to quantify how community composition differs between each and every plot in the dataset. **This quantification results in scores for each plot (i.e., "climate scores") that reflect local temperature.** Climate scores are closely correlated with minimum December temperature and continentality, both being long-term climate averages from the Parameter-elevation Regressions on Independent Slopes Model (PRISM; Daly and Taylor 2000). Forests at low-scoring plots experience, on average, higher minimum temperatures and a less continental climate than high-scoring plots

The model was applied to determine climate scores for 1,426 plots including sites on the FIA grid, the FS Region 6 Current Vegetation Survey grid, and supplementary sites in urban and remote areas (Fig. 3a). Each plot was surveyed for lichens between 1994 and 2001 using the standardized FIA field protocol. Geiser and Neitlich (2007) divided climate scores into four broad zones: maritime, lowland, montane, and high elevation. Scores were then interpolated using inverse distance weighting to map the four climate zones (Fig. 3b). **That lichens could be used to classify forests into these distinctive climate zones is itself a compelling indication that community composition will be highly responsive to climate change.**

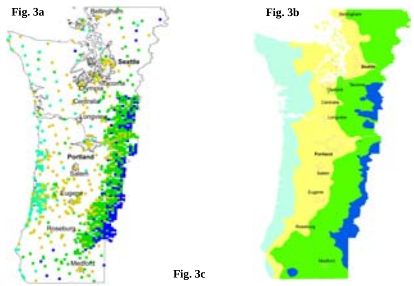

Fig. 3c

Climate zone	Year 2000 (°C) Mean	Year 2040 (°C) Predicted minimum	Predicted maximum
Maritime	10.2	11.7	13.4
Lowland	9.6	11.1	12.8
Montane	7.2	8.7	10.4
High elevation	4.9	6.4	8.1

Fig 3--a) map of climate scores estimating temperature at each plot surveyed for lichens, b) climate scores interpolated with inverse distance weighting. Plots are coded according to the broad climate zones described in c) table comparing current mean temperatures to temperatures predicted for 2040 (1.5 to 3.2° C; Mote et al. 2003.) **Warming is predicted to shift temperatures in lichen-defined climate zones to unprecedented levels**, raising concerns for local or regional extirpation of lichen species limited by habitat availability or slow dispersal rates. Rare coastal, old-growth associated and alpine lichens would face the greatest threat. Like other taxa groups, most of the biodiversity in lichens is contributed by rare species.

IV. Climate Projections (Fig. 3c)

Geiser and Neitlich (2007) compared current mean temperature per climate zone to temperatures predicted for 2040 (Fig. 3c). Current mean temperatures for each plot were determined from the PRISM climate data (Daly and Taylor 2000). Temperatures in the PNW are expected to increase by 1.5 to 3.2˚C by 2040 (Mote et al. 2003), so these values were added to current mean temperature to calculate the predicted minimum and maximum mean temperature per zone, respectively. From this comparison it was apparent that:

"even under the most conservative scenario [+1.5 ° C] mean maritime temperatures would shift above any current climate zone range [in the study area]. The lowland mean would be shifted into the maritime range under the minimum change scenario and above any current zone under the maximum change [+3.2 ° C] scenario" (Geiser and Neitlich 2007).

V. Species and Communities at Risk

Specificity of each lichen species for a particular climate zone was investigated with Indicator Species Analysis (ISA; Dufrêne and Legendre 1997). A strong indicator determined with ISA is faithful and exclusive, meaning the species tends to occur in its zone and be absent from the others. ISA identified 17 to 23 statistically significant indicator species per zone. Being a significant indicator for a zone suggests greater sensitivity to climate change than species with wide distributions spanning multiple zones. Highlights from the ISA are summarized below along with life history traits that increase a species' risk of climate-driven extirpation:

- **poor dispersal rate**: As climate warms, sedentary organisms (like plants, bryophytes, lichens) will need to migrate to cooler habitats at higher latitudes and elevations. Species reproducing by large propagules have difficulty dispersing over long distances to colonize new habitats.
- **rarity/endemism**: Odds are that rare species are inherently at greater risk than abundant species simply for having low numbers.
- **narrow ecological amplitude**: Potential 'new' habitat is limited for species with strict habitat requirements.

Species of particular concern for the western PNW include:

- **Communities of the high elevation zone:** Warming will be especially troubling for alpine and subalpine lichens, which have limited opportunity to migrate farther upwards in elevation to find cooler habitat conditions. The other option, migration towards the north pole, will be most successful for species with good dispersal ability. According to ISA, examples of species closely associated with the high elevation zone include: forage lichens (see below), *Hypogymnia imshaugii*, *Letharia vulpina*, and *Parmeliopsis* spp.

- **Forage lichens**: Several ecologically important species of forage lichen are indicators of the high elevation zone (*Alectoria sarmentosa*, *Bryoria capillaris*, *B. fremontii* (Fig. 1), *B. fuscescens*, *B. glabra*, and *Nodobryoria oregana*). Many forage species are dispersal-challenged, relying on thallus fragmentation for reproduction and colonization of new habitats (Fig. 4). This functional group of hair-like species is critical forage for elk, caribou, deer, and flying squirrels in the western U.S. Birds, rodents, and invertebrates use these lichens for nesting materials and shelter.

- **Large stratified cyanolichens:** These species directly influence forest health by contributing to nutrient cycling in PNW forests. The cyanobacteria partner in these lichens fix atmospheric nitrogen (N_2) into a form that is useable by plants. Owing to their unique physiology, lichens in this group are renowned for their susceptibility to both thermal and moisture stress. Several large cyanolichens are indicator species of the maritime and montane zones. Examples from the ISA include: *Lobaria oregana*, *L. pulmonaria* (Fig. 5), *Peltigera collina*, *Pseudocyphellaria crocata*.

- **Rare species in the maritime zone:** there is the suite of rare and endemic lichen species restricted to a thin band of forest hugging the PNW coastline. In this special habitat we find such rarities as *Bryoria pseudocapillaris*, *Erioderma sorediatum*, *Leptogium brebissonii*, *Pseudocyphellaria perpetua*, and *Usnea hesperina* (Glavich et al. 2005a, 2005b). Habitat models forecast a high sensitivity to climate fluctuation (Glavich et al. 2005b).

VI. Conclusions

These data show that predicted warming trends have considerable potential to alter the lichen flora of the western PNW. Similar patterns were detected using the FIA Lichen Indicator data for northern and central California (Jovan 2007). Lichenologists in Europe have already documented the incursion of tropical and subtropical lichen species into higher latitudes while also witnessing a net decrease in alpine species (van Herk et al. 2002). **We expect to see similar trends in the U.S., which would be detectable with data from the FIA Lichen Community Indicator if plots are periodically re-sampled for lichens.** With change data, we can begin tracking species migrations and regional shifts in climate

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VIII. Acknowledgements

Foremost thanks to our 45 field observers. We also thank Jim Riley, Mark Boyll, Pekka Halonen, Daphne Stone, Doug Glavich, Shanti Berryman, Linda Hasselbach, Abbey Rosso, Trevor Goward, and Ted Esslinger for help with identifications; John Coulston, William Bechtoldand Anne Ingersoll for statistical and data assistance; Dottie Riley, Roger Eliason and the UMN Research Analytical Laboratory for elemental analyses; and Forest Service and University cooperators Ken Snell, Jim Russell, Deigh Bates, Nancy Diaz, Richard Helliwell, Jon Martin, Mary Zuschlag, Suzy Will-Wolf, Bruce McCune, Sally Campbell and Ken Stolte. This study was funded by the USDA-Forest Service Air Resource Management and PNW Research Station Forest Inventory & Analysis programs.