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Canopy distribution and survey detectability of a rare old-growth forest lichen

Jesse E.D. Miller[a,*], John Villella[b], Greg Carey[b], Tom Carlberg[c], Heather T. Root[d]

[a] Department of Environmental Science and Policy, University of California Davis, 1 Shields Avenue, Davis, CA 95616, United States
[b] Siskiyou Biosurvey, LLC, Eagle Point, OR 97524, United States
[c] Six Rivers National Forest, Eureka, CA 95501, United States
[d] Botany Department, Weber State University, Ogden, UT 84403, United States

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ABSTRACT

Forest managers in many parts of the world are charged with protecting rare lichen species, including species growing near their range limits. Rare lichens may be particularly vulnerable to effects of climate change, and conserving lichen diversity necessitates understanding factors that limit species distributions. Habitat suitability envelopes for lichens are shifting as the climate changes, but it is unclear whether and how local (e.g., within-tree) lichen species distributions will shift. Conserving lichen biodiversity also requires effective field surveys to detect and monitor rare lichen populations. However, the reliability of rare lichen survey methods currently used across global forest lands is rarely tested. In this study, we quantify the canopy distribution of an epiphytic old-growth forest cyanolichen near its southern range limit and test whether ground surveys reliably detect canopy populations. Near its southern range limit, *Lobaria oregana* was most abundant in two distinct zones within tree crowns: on branches of large trees in the mid-crown, and on boles of small trees near ground level. The abundance of this species near ground level suggests that lichens may benefit from cooler, wetter microclimates near the equatorial edges of their ranges. Maintaining these microclimate habitats may be a key to long-term viability of rear edge lichen populations. Targeted ground surveys reliably detected *L. oregana* in litterfall underneath trees where it was abundant in the crowns. However, ground surveys did not reliably detect the lichen underneath trees when it occurred in the crowns in low abundance. Our results suggest that ground surveys are useful for characterizing abundant lichen species, but that canopy surveys (e.g., tree climbing) may be needed to reliably detect lichens when they occur at low abundance.

1. Introduction

Lichens, although sometimes inconspicuous, contribute significantly to forest biodiversity and play key ecological roles. Lichens are important for forest nutrient cycling, and together with other cryptogammic organisms (bryophytes, algae, cyanobacteria, and fungi), are responsible for almost 50% of terrestrial nitrogen fixation (Elbert et al., 2012). Lichens can be sensitive to disturbances and small changes in ambient conditions, in part because they respond to the environment at fine scales (Esseen and Renhorn, 1998). Environmental changes at multiple scales, including those caused by climate change and forestry practices, can threaten lichen populations (Nascimbene and Marini, 2015). Rare species, including species growing near the edge of their ranges, may be especially vulnerable (Allen and Lendemer, 2016). Maintaining lichen diversity is a goal of forest managers in many parts of the world, and management efforts often focus on conserving populations of rare species.

Planning for lichen conservation in a changing climate requires understanding factors that control lichen distributions at both local and regional scales. While it is known that biogeographic lichen habitat suitability envelopes are shifting due to climate change (Allen and Lendemer, 2016; Rubio-Salcedo et al., 2016), it is less clear whether and how local (e.g., within-tree) lichen species distributions will shift in response to an altered climate. However, understanding species microclimate affinities is crucial for understanding the effects of climate change on populations (Potter et al., 2013). Studies of lichen distributions within the forest canopy have typically been conducted where lichens are abundant in the heart of their ranges (e.g., McCune et al., 1997), but the canopy distributions of lichens growing at their range limits have

* Corresponding author.
E-mail address: kawriver@gmail.com (J.E.D. Miller).

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less commonly been quantified. If species growing near their range limits exhibit local habitat adaptations (e.g., growing in cooler microclimates at the warmer end of the range), this could inform the restoration and maintenance of habitat for lichens of conservation concern. For example, local assisted relocation to more benign microclimates could be effective, especially for dispersal-limited species, if species show signs of adaptations to these microclimates in the wild. Understanding habitat requirements of populations at the rear edge of a species' range (e.g., populations at the southern range limit of a species that is moving north) is particularly important because rear edge populations usually contain high genetic diversity and can be nuclei for future speciation (Hampe and Petit, 2005).

Locating and monitoring rare lichen populations is crucial for informing management practices that further lichen conservation, and for studying lichen distributions and global change impacts on lichen populations. Field surveys for rare lichens are often conducted over large areas, such as in timber sales covering hundreds to thousands of hectares, thus representing significant financial cost (Molina et al., 2006). Surveys for rare canopy-dwelling lichens are usually conducted entirely from the ground, and rely on finding lichen thalli in litterfall to detect populations (e.g., Derr et al., 2003), in part because tree climbing for canopy lichen surveys is labor intensive. While the survey detectability of organisms such as birds has received substantial consideration (e.g., Royle et al., 2005), there has been less work testing lichen detectability and the effectiveness of lichen survey protocols. Studies of canopy lichen survey protocols have mostly focused on comparing various ground-survey techniques (e.g., Britton et al., 2014; Frati and Brunialti, 2006). While litterfall is known to be coarsely representative of canopy lichen abundance (McCune, 1994), there has been little direct investigation of whether lichens present in the canopy in low abundance are reliably represented in litterfall (but see Rosso et al., 2000).

In this study, we quantify canopy distributions of an old-growth forest lichen species near its southern (equatorial) range limit and test whether ground surveys that examine lichen litterfall can effectively detect canopy populations. *Lobaria oregana* is a lichen that is endemic to the Pacific Northwest of North America, where it occurs as an epiphyte in old-growth rainforest trees (Brodo et al., 2001) and often becomes the most abundant cyanolichen (McCune, 1994). *Lobaria oregana* plays important ecological roles in northwest rainforests, particularly by providing a major source of available nitrogen for plants (Holub and Lajtha, 2004; Pike, 1978). It is also a major nutrient source for canopy-dwelling heterotrophic organisms (Cooper and Carroll, 1978), and it is rapidly consumed by ground dwelling arthropods once it accumulates as litterfall on the forest floor (McCune and Daly, 1994). Despite the fact that *L. oregana* can occur in all forest age classes when transplanted, poor dispersal and/or establishment functionally limit its occurrence to primarily old-growth stands (Sillett et al., 2000; Werth et al., 2006).

In Oregon and Washington—near the heart of its range—*L. oregana* is most abundant in the "light transition zone" of the mid-canopy at around 20 m above the ground (McCune, 1993; McCune et al., 1997). The light transition zone is a vertical portion of the canopy characterized by intermediate levels of light and moisture, between the drier, brighter upper canopy and wetter, darker lower canopy (McCune et al., 1997). There has been little work testing whether this distribution remains constant near range edges, but it has been suggested that lichens may take refuge in buffered microsites lower in the forest profile near their range limits (McCune, 1993). Understanding where such habitat shifts occur is crucial for planning management activities that are compatible with lichen population persistence. For example, small trees are frequently thinned in forests where *L. oregana* occurs, but the effects of thinning on lichen populations growing near their range limits has been little studied. Because large cyanolichens are often sensitive to anthropogenic influences and are among the lichens most threatened by climate change, survey detectability and canopy distributions of *L. oregana* have implications for other rare lichens as well (Nascimbene et al., 2016; Rubio-Salcedo et al., 2016).

Here, we examine the distribution of *L. oregana* within trees in northwest California, USA, with two specific objectives. First, we ask where on trees *L. oregana* is most likely to be found in these southern habitats and compare these microhabitat associations to other parts of the species' range. Second, we ask whether ground-based surveys consistently detect the species, even when it is found in low abundance using canopy surveys.

2. Material and methods

2.1. Site selection

Lobaria oregana reaches the southern edge of its range in northwest California (McCune and Geiser, 2009) where it occurs only sporadically and is listed as a Survey and Manage Category A species (USDA & USDI, 2001). This designation requires the U. S. Forest Service to conduct surveys for *L. oregana* to protect sites where it occurs from disturbance caused by management activities such as logging. Ground-based pre-disturbance surveys for *L. oregana* have been conducted in Six Rivers National Forest since 2001. Surveys generally follow "intuitive-controlled" methods, in which a surveyor searches for the lichen in litterfall, focusing on areas that seem likely to have the species based on the species' ecology and the surveyor's experience (Derr et al., 2003). These surveys have documented 55 occurrences of *L. oregana* populations within the Forest.

To select study sites, we grouped the 55 known sites on the forest by their distributions across 14 sub-watersheds of the Smith River. Within each sub-watershed, we selected a single site for study. We attempted to capture the greatest possible variation in vegetation type, seral stage, size class, canopy cover, and stand composition. We also attempted to maximize variation in elevation, aspect, and soil. To explore vegetation types and environmental variables, we used California's Wildlife Habitat Relationships information system (California Interagency Wildlife Task Group, 2008) and the USDA Existing Vegetation Classification Framework (Tart et al., 2005). Of the fourteen sites chosen, ten were prioritized for study and the remaining four were reserved as alternate sites if any of the first ten could not be accessed (Fig. 1). Our sites were well-dispersed among the three main branches of the Smith River watershed (North, Middle, and South Forks). The minimum distance between study sites was 1.3 km.

2.2. Field surveys

During the winter of 2014 we conducted fieldwork to quantify *Lobaria oregana* canopy distributions and ground survey detection. At each of the ten sites, we selected 10–15 trees for crown surveys. Because *Pseudotsuga menziesii* was the dominant tree species at all sites—making up an average of 86% of site-level tree occurrences—and other trees species were not abundant enough to draw reliable inference, we studied only *P. menziesii* trees. We climbed using the doubled rope technique (Adams, 2007). We assessed the abundance of *L. oregana* on tree boles and branches within vertical divisions of 6.1 m for each tree. Height in the tree was measured using marked ropes or tape measures lowered to the ground. For each 6.1 m division, we envisioned a cylinder with the bole of the tree as its axis and a radius equal to the length of the longest branch