Distribution, rarity and habitats of three aquatic lichens on federal land in the U.S. Pacific Northwest

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Abstract. In this study, the occurrence of *Dermatocarpon meiophyllizum*, *Leptogium rivale* and *Peltigera hydrothyria* on federal land in western Oregon and Washington, and northern California is documented using a large-scale random sampling approach amplified by historical site data, frequency, distribution and habitat "preferences," including water quality, forest age and land use allocations. A total of 256 sites were surveyed, of which 216 were randomly selected. All three species were distributed throughout the study area in all three states, and mostly in interior mountain ranges. Only *L. rivale* was widespread, and both *D. meiophyllizum* and *P. hydrothyria* appear to be rare in the region but can become locally common in some watersheds. All three lichens probably benefit from older streamside forests, but association with forest age was inconclusive at the watershed level. Federal protective land use allocations and Aquatic Conservation Strategy components appear to play a minor role in protecting existing populations for the three aquatic lichens. Climate factors appear to be of major importance to habitat suitability for the three aquatic lichens. Results from this study suggest the following habitat summaries for the three aquatic lichens. Higher elevation, exposed streams with large rocks or bedrock appear to be important habitat for *D. meiophyllizum*. This lichen was also often found above the stream water level. *Leptogium rivale* was found most frequently in shallow, partially shaded streams and submerged or just above the water level. For *P. hydrothyria*, this study suggests that cool, partially shaded small mountain streams are important habitat; however, this only appears to be habitat characteristics for this lichen from southern Washington and southward in the study area. In Washington's North Cascades and in to British Columbia, *P. hydrothyria* is often observed in colder, higher elevation exposed sites. Upper 95% confidence interval values for stream sites suggests good water quality across the region: dissolved oxygen = 9.60 mg^{-1}, conductivity = 78 μS/cm, pH = 7.51, nitrogen = 0.07 mg^{-1} and phosphorus = 0.024 mg^{-1}. Benthic diatom-based indices suggest that these aquatic lichens are subject to siltation and high flow stream scouring. Results from this study can be used to guide management in the face of global climate change and research needs are discussed.

Keywords. *Dermatocarpon meiophyllizum*, *Leptogium rivale*, *Peltigera hydrothyria*, aquatic lichens, rarity, Pacific Northwest, nonparametric multiplicative regression.

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The Pacific Northwest is home to a diverse assemblage of lichens (Peterson & McCune 2003), and there have been many studies investigating lichens of terrestrial systems within this region (e.g., Martin et al. 2002; McCune 1993; McCune et al. 2002; Peterson & McCune 2001, 2003; Rosso 2000). The focus of most lichen research has been on terrestrial environments whereas aquatic habitats have received less attention. Although research on aquatic lichens has been conducted globally with many studies in Europe (Gilbert 1996; Gilbert & Giavarini 1997, 2000; Gregory 1976; James et al. 1977; Pentecost 1977; Thüs et al. 2004), few studies have been conducted in North America. Rosentreter (1984) investigated the zonation of lichens along the Salmon River in Idaho, and Dennis et al. (1981) studied the habitat of a *Peltigera hydrothyria* population in Tennessee. In the laboratory, Davis et al. (2000, 2003) studied the response of *Peltigera hydrothyria* to water temperature and nitrogen levels. There has also been some research on marine aquatic lichens in North America; Brodo and Sloan (2005) studied marine lichen zonation in the Queen Charlotte Islands, British Columbia, and Ryan (1988a, b) studied marine lichens on Fidalgo Island, Washington.

Three aquatic lichens are or were listed in species management programs in the U.S. Pacific Northwest. At the time of listing, these lichens were *Dermatocarpon luridum*, *Leptogium rivale* and *Peltigera hydrothyria*, and they were listed for management in the interagency Bureau of Land Management (BLM) and U.S. Forest Service (USFS) Survey & Manage (S&M) program of the Northwest Forest Plan (NWFP). The NWFP was initiated in 1994 to manage forests in western Washington and Oregon, and northern California (USDA & USDI 1994). The S&M program was developed to maintain old-growth forest associated species within the NWFP area (**Fig. 1**).

Requirements for S&M listing included being rare, association with late-seral—old-growth (LSOG) forests and not having adequate populations on protected land allocations (USDA & USDI 2006a). LSOG forests were defined as 80 years old or older, and this designation was used because 80 year-old forests in the Pacific Northwest can exhibit old-growth forest characteristics (Franklin & Spies 1991). Federal lands are divided up into several land use allocation categories. For example, "matrix" lands are USFS and BLM lands subject to logging and "adaptive management areas" are, essentially, forestry research lands. Late-successional reserves are parcels that are protected from disturbance activities, such as logging.

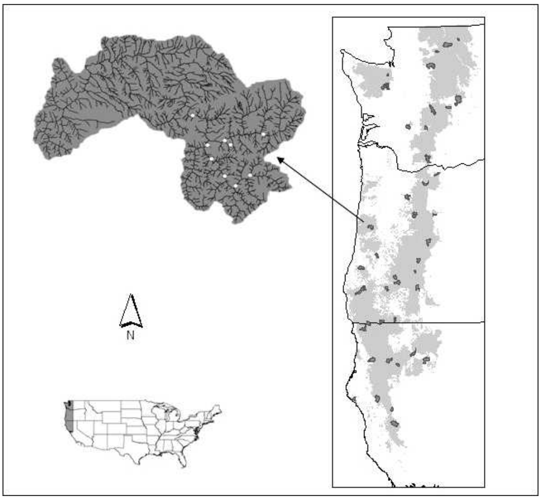

Figure 1. Study area and example of the two-stage sample. Light gray shaded area is federal land in the Northwest Forest Plan area and dark gray polygons are randomly selected USGS watershed units. The enlarged watershed provides an example of randomly selected stream reach points within a watershed.

Taxonomic and management changes have occurred over the course of this study. The USFS Sensitive Species and BLM Special Status Programs (ISSSSP) have now taken over conservation efforts for S&M listed species still in need of management. *Peltigera hydrothyria* was removed from the S&M list in 2001 (USDA & USDI 2001); at the time, *P. hydrothyria* was known as *Hydrothyria venosa*. Miadlikowska and Lutzoni (2000) reëvaluated the genus *Peltigera* and concluded that *H. venosa* belonged to the genus. *Dermatocarpon luridum* and *Leptogium rivale* were ranked from "rare" to "critically imperiled" by the Oregon Natural Heritage Program for Washington, Oregon & California (ORNHIC 2004). *Leptogium rivale* was thought to possibly be extinct in California (ORNHIC 2004), but an initial report from this study revealed extant populations in that state (Glavich & Geiser 2006). *Dermatocarpon luridum* listings in the ISSSSP and Natural Heritage programs were recently replaced with *D. meiophyllizum.* Specimens collected for this study at historical and newly suspected *D. luridum* sites were identified as *D. meiophyllizum*, a species that has been overlooked in North America; details can be found in Glavich and Geiser (2004). Of the three lichens, *Dermatocarpon meiophyllizum* is the only remaining species on management lists, which are the ISSSSP (http://www.fs.fed.us/r6/sfpnw/issssp/agency-policy/) and the Oregon Natural Heritage Program lists (http://oregonstate.edu/ornhic/plants/index.html).

Aside from the NWFP area, these lichens are also known in other parts of the Pacific Northwest. *Dermatocarpon meiophyllizum* has been found east of the Cascade Mountain range in several locations in the Ochoco Mountains, Ochoco National Forest, OR (R. Dewey, pers. comm. 2008). The only known Pacific Northwest *L. rivale* location outside of the NWFP area so far is a site on Galiano Island, British Columbia (http://www.botany.ubc.ca/herbarium). *Peltigera hydrothyria* is known from several locations in British Columbia: Trophy Mountains, Tweedsmuir Provincial Park, Garibaldi area, Wells Gray Provincial Park and Hudson Bay Mountain (http://www.botany.ubc.ca/herbarium). Outside of the NWFP area, the only known U.S. Pacific Northwest site for *P. hydrothyria* is from Southeast Alaska (Geiser et al. 1998).

Whether listed or not, there is another protective mechanism in place that might contribute to the conservation of these aquatic lichens; it is the interagency BLM and USFS Aquatic Conservation Strategy (ACS), which was developed to restore and maintain watershed health on federal lands (USDA & USDI 1994). Like the S&M program, it is a component of the NWFP. However, the ACS is a habitat-based plan rather than a species-based plan. Components of this strategy include "riparian reserves," "key watersheds" and systematic watershed analyses and restoration (USDA & USDI 1994). Riparian reserves exist in federal land allocations subject to disturbances, such as logging, and are "buffer zones" around streams where disturbance activities are prohibited. The size of riparian buffer zones is dependent on stream size; disturbance activities must not occur within 100 m of a "fish bearing" stream and, at the very least, 33 m from small, intermittent streams on federal land (USDA & USDI 1994). Key watersheds are those that have or, are expected to have, high quality fish habitat, and land disturbing activities are prohibited in these watersheds without a formal watershed analysis (USDA & USDI 1994). Although key watersheds were developed to preserve anadromous fish populations and water quality, this management approach may contribute to aquatic lichen conservation as well.

With conservation strategies in place in the Pacific Northwest, aquatic habitat-focused studies that evaluate the rarity and ecology of *D. meiophyllizum*, *L. rivale* and *P. hydrothyria* are needed to effectively guide management of their populations. Prior to this study, management of these species has been based on terrestrial habitat-focused research or subjective information. Even though the S&M tenets may not be required at this time, answering questions for its guidelines could contribute to species conservation, e.g., forest age and land use associations. With the ACS in mind, whether or not these species are associated with key watersheds or riparian reserves will also help guide management of these species.

There are many questions pertaining to aquatic lichens that still remain to be answered: How widely are these species distributed across the Pacific Northwest? How rare are these species? Do they occur in streams of perturbed landscapes or are they restricted to streams within old-growth forests? Do populations of these species mostly occur in protected or unprotected land allocations? Do riparian buffer zones protect populations? What are dispersal, establishment and growth rates?

The objective of this research was to address several of the above questions for *D. meiophyllizum*, *L. rivale* and *P. hydrothyria*. New locality information from this study for *D. meiophyllizum* can be found in Glavich and Geiser (2004), and that for *L. rivale* and *P. hydrothyria* can be found in Glavich and Geiser (2006).

In this paper, results for *D. meiophyllizum*, *L. rivale* and *P. hydrothyria* are reported from sites surveyed across federal land in the Northwest Forest Plan area to identify 1) distribution within the study area, 2) rarity status based, in part, on statistical frequency, 3) forest age, federal land allocation and key watershed association and 4) environmental variables indicative of suitable habitat.

Methods

Field work was conducted by field crews on federal land within the NWFP area from June through September in 2002 and 2003 (**Fig. 1**). Field crews surveyed a total of 256 sites throughout the study area, of which 216 were randomly selected and 40 were non-randomly selected sites.

Random sample. For the primary sampling structure, the framework of the interagency BLM and USFS Aquatic Riparian Effectiveness Monitoring Program (AREMP) was used. AREMP surveys stream sites annually, which began in 2000, to monitor stream and overall watershed health across the Northwest Forest Plan area (USDA & USDI 2001). Field crews surveyed sites for this study that were sampled by AREMP from 2000 through 2002. AREMP employed the Generalized Random Tessellation Stratified (GRTS) sampling design, which is a multi-density (two-stage cluster) survey design that incorporates a hierarchical randomization process (Stevens 1997; Stevens & Olsen 1999), developed by the Environmental Protection Agency (EPA). Essentially, this is a sample within a sample which, in this case, are stream sites within a watershed. The GRTS design generated random points along streams in randomly selected USGS 5th and 6th field watershed units (USDA & USDI 2002a). A total of 216 randomly selected stream sites were surveyed across 38 randomly selected watershed units with an average of five stream sites per watershed (**Fig. 1**). Using the AREMP sampling infrastructure not only provided a sample design, but also important stream habitat data.

These 5th and 6th field watershed units are a component of the USGS hydrologic unit system. Water drainage systems in the United States are successively divided into smaller and smaller hydrologic units, from the largest 1st field "regions" to the smallest 6th field "subwatersheds." For example, the 1st field Pacific Northwest "region" essentially encompasses Oregon, Washington and Idaho, and the smallest 6th field sub-watersheds—such as those used in this study—range from 4,047 to 16,188 ha in size (Legleiter 2001). Hereafter, these watershed units are referred to as watersheds.

Non-randomly selected sites. Because the potential for a low detection rate due to rarity existed, the random sample was supplemented with data collected from non-randomly selected sites. These were historic sites revisited by field crews and "purposive" survey sites to increase the resolution of habitat information. Historical site locality information was gathered from the Interagency Species Management System (ISMS; USDA & USDI 2006b) in 2002 documented in Lesher et al. (2003) and USDA Forest Service (2005). "Purposive" survey sites were those found by searching habitats similar to those at historical sites. Data were collected from where population densities appeared highest.

Field data collection. Stream sites were found using GPS units and topographic maps to locate UTM X/Y coordinates. Once the X/Y point of each stream was located, field personnel surveyed an upstream reach length determined by multiplying the average bank-full width by 20, with a minimum length of 150 m and a maximum length of 500 m (USDA & USDI 2002a); this stream survey protocol is often followed to ensure capture of habitat diversity inherent in larger streams (Fitzpatrick et al. 1998).

Field crews were trained in identification of target aquatic lichen species, which involved differentiating them from similar aquatic species and detecting them in wet and dry stream conditions. For *L. rivale*, training topics were differentiation of their black, appressed, foliose thalli from the black, crustose thalli of *Verrucaria* species, and detecting *L. rivale* thalli when dry and camouflaged among stream rocks. Because there was potential for the presence of several *Dermatocarpon* species in the study area, detectability involved rough field differentiation and targeting *Dermatocarpon* thalli that lacked morphological features of obviously different species. For example, thalli with a granular lower cortex like *D. reticulatum* and thalli with a pruinose upper cortex like *D. miniatum* were usually avoided. *Peltigera hydrothyria* was easily differentiated in the field by its suberect, bluish gray to black, thin, veined lobes. Any thallus in doubt was assumed to be a target species, and field crews collected vouchers that were later verified.

At all sites, survey data for this component of the study included target lichen abundance and forest age. Abundance was evaluated for each of the target lichens, using population size classes: 0 = 0, 1 = 1–10, 2 = 10–100, 3 = 100–1000, 4 = >1000 individuals. Forest age data were collected by counting rings of tree cores extracted from at least two of the largest trees, outside of the riparian zone, representing the forest around the stream reach. The riparian zone was identified as the streamside region consisting of obvious riparian vegetation. For long stream reaches or heterogeneous forests, forest age sampling occurred at three midpoints on each side of the stream to capture isolated forest stand structures that might affect stream habitats. Tree cores were extracted using an increment borer, and diameters at breast heights (DBH) were measured in case age estimation was needed for very large trees.

When a target lichen species was found and the population surveyed, field crews also recorded habitat data from the "population center"—the location on the stream where the target lichen abundance was greatest. At this site, the range of depths (−cm) or distances above (+cm) the waterline, substrate type (rock or wood), exposure (full shade, partial shade, exposed) and rock substrate size classes (sand <0.3 cm, gravel = 0.4–5.1 cm, stone = 5.2–25.4 cm, boulder > 25.4 cm, or bedrock) were recorded.

Stream data collected by AREMP and included in this study were stream physiography (bank-full depth, bank-full width, gradient, sinuosity and pool frequency), water chemistry (nitrogen, phosphate, pH, dissolved oxygen, conductivity and water temperature) and benthic diatom community structure and abundance. These sampling techniques can be found in the AREMP protocol (USDA & USDI 2002a). Bank-full depth and width equals the maximum seasonal stream channel water level (about every 1.5 years) and is measured by stream bank indicators (Wolman & Leopold 1957). Gradient was calculated by (upstream elevation minus downstream elevation)/stream reach length, and sinuosity was calculated by dividing the surveyed stream reach length by the valley channel length (Fitzpatrick et al. 1998). Gradient is an indication of the amount of energy available for the movement of water and sediment, and sinuosity is an indicator of structural complexity (Fitzpatrick et al. 1998).

Because historical and purposive sites did not have associated AREMP stream data, field crews measured some basic stream data: water chemistry (pH and conductivity) and stream channel characteristics (bank-full width and depth) following the methods of Fitzpatrick et al. (1998). Field workers were periodically checked for accuracy and consistency of all data collected.

Nomenclature. The nomenclature for all three target species follows Esslinger (2008).

Data analyses. I calculated percent frequency of these lichens at the sub-watershed level and, using the population proportion estimation equation for a two-stage cluster sample (Scheafer et al. 1990), calculated frequency at the NWFP study area level. These values were calculated in Microsoft Excel Version 2003.

To assess whether these lichens are more likely to occur in streams of older forests (maximum tree age > 80 years old) or younger forests (maximum tree age ≤ 80 years old), I used the Fisher's Exact Test for two proportions with odds ratios and 95% confidence intervals to guide statistical inference in NCSS version 2000 statistical software (NCSS 2000). The Fisher's Exact Test is the difference in sample proportions within a 2 × 2 table between actual and randomized data (Ramsey & Schafer 1997).

To assess whether these lichens are more likely to occur on protected or unprotected federal land allocations, I also used the Fisher's Exact Test as above. Land allocation GIS data were downloaded (from USDA & USDI 2002b) and extracted to the randomly selected AREMP sites using ArcGIS version 9.0 (ESRI 2004). Protected federal land allocations were defined as congressionally withdrawn USFS and BLM lands, national parks, wildernesses and late-successional reserves. All other allocations were defined as unprotected.

Basic statistics were calculated for site-specific habitat and water quality data also using NCSS statistical software. Percent frequency was calculated for substrate and exposure categories, and medians

Table 1. Explanatory variables used in the data analyses.

Category	Variable	Abbreviation	Data Type
Stand Structure	Forest age (years)	none	Continuous
	Percent of forest > 80 years old	%LSOG	Continuous
Landscape	Elevation		Continuous
Stream morphology	Average bank-full stream width	Stream width	Continuous
	Average bank-full stream depth	Stream depth	Continuous
	Gradient	none	Continuous
	Sinuosity	none	Continuous
	Pool frequency	none	Continuous
Stream water quality	pH	none	Continuous
	Total nitrogen	nitrogen	Continuous
	Phosphorus	none	Continuous
	Water temperature (average, minimum & maximum)	none	Continuous
	Diatom disturbance index	none	Categorical
	Diatom siltation index	none	Categorical
Climate	Mean minimum December temperature	MinDecTemp	Continuous
	Mean annual precipitation	Annual Precip	Continuous
	Mean annual number of days with measurable precipitation	PrecipDays	Continuous

and percentiles were calculated for vertical position (depth/height above water) in the stream channel. Median values and 95% confidence intervals were calculated for water quality data. Data from both randomly and non-randomly selected sites were used to represent these observations at all sites. Thus, probability-based interpretations of site-level habitat parameters should be made with caution.

To determine which landscape-scale habitat variables were most associated with *D. meiophyllizum*, *L. rivale* and *P. hydrothyria*, I used Nonparametric Multiplicative Regression (NMPR; McCune 2004) to build explanatory models in HyperNiche version 1.0 multiplicative habitat modeling software (McCune & Mefford 2004). NPMR assumes no particular relationship between response and predictor variables and automatically accounts for factor interactions (Bowman & Azzalini 1997; McCune 2004, 2006); therefore, it is more robust than standard regression analyses. Because rare species yield few detections, I used sites from both randomly and non-randomly selected sites to improve habitat resolution. Even though non-randomly selected data can lead to a bias in estimators (Overton et al. 1993), this analysis was essentially used to summarize the most important habitat variables for each of the target lichens and not to forecast occurrence on the landscape. To further use these models as probability-based forecasting tools, they should be tested with data from randomly selected sites (Olsen et al. 1999).

The ''Free Search'' mode in HyperNiche was used with target lichen abundance data across all plots. I used the local mean and Gaussian weighting function, and models were assessed for fit with a cross-validated R^2 ($\times R^2$). Parsimony was maintained in the final model by the following settings: minimum average neighborhood size = 12 (5% of the sample size; McCune 2004, 2006) and improvement criterion = 5%. Setting the improvement criterion to 5% in HyperNiche minimized the addition of explanatory variables by only adding variables that improved model fit by a minimum of 5%. All environmental parameters (**Table 1**) could not be used as a single data set in NPMR because all data were not collected at all sites due to technical, site access, or time constraint issues.

Because most sites had the following data, these were used in the primary model data set for habitat variable selection: stream channel (stream width and depth, gradient, sinuosity and pool frequency), climate (minimum December temperature, annual precipitation and number of precipitation days per year), forest age, percent LSOG and elevation (**Table 1**). I extracted climate values to all sites in this study from the PRISM climate GIS data (Daly & Taylor 2000) using ArcGIS software. Because tree cores were typically extracted near the stream sites, the field measurements tended to reflect forest age within the riparian buffer zones. The "percent LSOG" variable was created to assess whether or not a larger stand of older forest was important to aquatic lichen habitat. I created the "percent LSOG" variable by calculating the proportion of late-seral forest within 1000 m from each stream site X/Y coordinate using the NWFP Late Successional/Old-growth Forest boundary GIS data (USDA & USDI 2002b) in ArcGIS software.

Two diatom-based indices were developed, following Stevenson and Bahls (1999), to indicate stream disturbance by siltation and scouring. The stream siltation index was defined by the total percent frequency of motile diatom genera (*Navicula*, *Nitzschia* and *Surirella*) for each site: no siltation < 20%, minor siltation 20–39.9% and moderate siltation >40%. Because these motile diatom genera have the ability to crawl to the surface if covered by silt, their relative abundance is thought to reflect the amount of siltation (Stevenson & Bahls 1999). The disturbance index, generally indicating stream scouring, was based on the relative percent frequency of the diatom, *Achnanthes minutissima*: no disturbance < 25%, minor disturbance 25–49.9% and moderate disturbance >50%. This diatom is a highly tolerant pioneer species, and it has been found to first colonize stream beds after scouring from high flow events. The relative abundance of *A. minutissima* is thought to reflect severity of disturbance events (Stevenson & Bahls 1999). There were initially severe siltation and scouring disturbance classes (>59% and >74%, respectively), but no streams surveyed in the study area fell into those categories.

Results

Frequency and distribution. *Dermatocarpon meiophyllizum* was the most rarely encountered target lichen (3.8%), followed by *Peltigera hydrothyria* (6.3%) across the NWFP study area (**Table 2**). *Leptogium rivale* was found at a high frequency (25.8%) across the NWFP area (**Table 2**). All three lichens were found in all three states, and mostly in interior mountain ranges (**Fig. 2**). Most *P. hydrothyria* sites were detected in the Oregon and southern Washington Cascade Mountain range (**Fig. 2**). *Leptogium rivale* was abundant in many of the watersheds where it occurred (**Fig. 2; Table 2**), and it was found at 76% of *P. hydrothyria* sites. The largest watershed frequency (100%) of *L. rivale* and *P. hydrothyria* was found in the Upper Quartzville Creek watershed unit in the Willamette National Forest in the Oregon Cascades (**Table 2**).

Association with forest age, land allocation and key watersheds. Although *D. meiophyllizum* was mostly detected in older forest sites within the random AREMP sample, this species was not significantly associated with either young or old forests (**Table 3**). Both *L. rivale* and *P. hydrothyria* were significantly associated with older forests (**Table 3**). Most of the *D. meiophyllizum* sites from the AREMP sample were detected in unprotected federal land allocations, but this species was not significantly associated with protected or unprotected land allocations (**Table 4**). *Leptogium rivale* was not significantly associated with either protected or unprotected federal land allocations, and *P. hydrothyria* was nearly significantly associated with protected land allocations (**Table 4**). *Dermatocarpon meiophyllizum* was not statistically associated with either key or non-key watersheds (**Table 5**). *Peltigera hydrothyria* was significantly associated with non-key watersheds, and *L. rivale* had only a marginal significant association (**Table 5**).

Site-level habitat. For exposure class, *D. meiophyllizum* was never found in full shade (**Table 6**). *Leptogium rivale* and *P. hydrothyria*, on the other hand, were found in all three exposure classes but were more frequently found in partially shaded sites (**Table 6**). For substrate types and sizes, all target lichens were dominantly found on rock. While *D. meiophyllizum* was only found on rock, it was rarely found on rock sizes smaller than stones (**Table 6**). *Leptogium rivale* was mostly found on stones and boulder-sized rocks, but it was also observed on wood (**Table 6**). *Peltigera hydrothyria* was observed on all size classes of rock, from sand to

Table 2. Frequency (%) of aquatic lichens from the Aquatic Riparian Effectiveness Monitoring Program (AREMP) sample for the entire NWFP area and per watershed. United States Geological Survey (USGS) Hydrologic Unit Codes (HUCs) are provided for watershed reference. DEME = *Dermatocarpon meiophyllizum*, LERI = *Leptogium rivale*, and PEHY = *Peltigera hydrothyria*. N is number of sites surveyed in the AREMP sample. Watersheds with an asterisk (*) are Key Watersheds where aquatic protection measures outlined in the Aquatic Conservation Strategy of the Northwest Forest Plan are required management.

Watersheds	USGS HUC	Area	State	DEME	LERI	PEHY	N
NWFP area	all sampled HUCs	NWFP Area	All	3.8	25.8	6.3	216
Beaver Creek*	1801010401	Mendocino NF	CA	0.0	37.5	0.0	8
Honey Dew Creek*	1801010703	King Range NCA, BLM	CA	0.0	0.0	0.0	6
Kosk Creek	1802000309	Shasta-Trinity NF	CA	0.0	0.0	0.0	4
Mill Creek	1801021112	Six Rivers NF	CA	0.0	33.3	0.0	3
Ney Springs Creek	1802000502	Shasta-Trinity NF	CA	0.0	0.0	0.0	9
North Fork Swift Creek	1801021104	Shasta-Trinity NF	CA	66.7	0.0	0.0	6
Shelly Creek	180101050201	Six Rivers NF	CA	0.0	0.0	0.0	1
South Fork Salmon River*	180102100102	Klamath NF	CA	0.0	50.0	0.0	4
Brush Creek	1710030303	Eugene Resource Area, BLM	OR	0.0	12.5	0.0	8
East Fork Annie Creek	180102030101	Crater Lake NP	OR	0.0	0.0	0.0	5
Elk Creek	1710031104	Siskiyou NF	OR	0.0	0.0	0.0	1
Glade Creek*	1710030903	Rogue River NF	OR	10.0	0.0	0.0	10
Lobster Creek*	1710020502	Eugene Resource Area, BLM	OR	0.0	0.0	0.0	9
Lower Jackson Creek *	1710030202	Umpqua NF	OR	66.7	0.0	0.0	6
North Coquille River *	171003050501	Roseburg Resource Area, BLM	OR	0.0	0.0	0.0	6
North Fork Mill Creek*	1707010506	Mt. Hood NF	OR	0.0	25.0	0.0	4
Six Creek	1707030103	Deschutes NF	OR	0.0	80.0	0.0	5
Sixes Creek	170900060503	Willamette NF	OR	0.0	60.0	60.0	5
Snow Creek	170703010104	Deschutes NF	OR	0.0	0.0	0.0	7
South Fork Coquille River*	171003050101	Siskiyou NF	OR	0.0	66.7	0.0	6
Steve Fork Carberry Creek	171003090105	Rogue River NF	OR	0.0	85.7	0.0	7
Still Creek	170800010201	Mt. Hood NF	OR	0.0	60.0	40.0	5
Summit Creek	170703020203	Deschutes NF	OR	0.0	57.1	28.6	7
Upper Clearwater Creek	1710030104	Umpqua NF	OR	0.0	0.0	0.0	6
Upper Mollala River	170900090503	Salem Resource Area, BLM	OR	0.0	66.7	0.0	6
Upper Quartzville Creek	170900060401	Willamette NF	OR	0.0	100.0	100.0	5
Upper West Cow Creek*	171003020801	Roseburg Resource Area, BLM	OR	0.0	85.7	0.0	7
Arrow & Illabot Creeks	1711000513	Mt. Baker-Snoqualmie NF	WA	0.0	75.0	0.0	4
Big Lava Bed Creek*	170701051002	Gifford Pinchot NF	WA	25.0	25.0	0.0	4
Copper Creek*	1711001804	Olympic NF	WA	14.3	0.0	0.0	7
Fisher Creek	171100050401	North Cascades NP	WA	0.0	0.0	0.0	3
Hamma Hamma River	171100180701	Olympic NF	WA	0.0	0.0	0.0	2
North Fork Tilton River	1708000502	Gifford Pinchot NF	WA	0.0	0.0	0.0	2
Rattle Snake Creek*	1702000806	Okanogan NF	WA	0.0	0.0	0.0	6
South Fork Taneum Creek	1703000117	Wenatchee NF	WA	14.3	28.6	0.0	7
Swauk Creek	171100140104	Wenatchee NF	WA	0.0	14.3	0.0	7
Upper South Fork Stillaguamish River *	1711000802	Mt. Baker-Snoqualmie NF	WA	0.0	0.0	0.0	6
Upper White River *	171100140104	Mt. Baker-Snoqualmie NF	WA	0.0	16.7	0.0	6
Willame Creek	170800040302	Gifford Pinchot NF	WA	0.0	0.0	0.0	6

bedrock and wood, but occurred mostly on the larger rock sizes of stones, boulders and bedrock (**Table 6**).

For vertical position in the stream channel, in relation to summer season water levels, *D. meiophyllizum* was found to be the most variable. At most sites, this species was found at depths of 35 cm and to as much as 100 cm above the water surface with a median of 22 cm above the water level

(**Fig. 3**). *Leptogium rivale* and *P. hydrothyria* both had a median of 2 cm above the water surface and both were found occurring at a nearly identical range of shallow depths and heights above water (**Fig. 3**).

Landscape-level habitat parameters. Nonparametric multiplicative regression selected elevation, stream width and stream depth as the most important variables for *D. meiophyllizum* (**Table 7**); the regression curves suggested that suitable habitat is more likely found in higher elevation sites and in small shallow streams (**Fig. 4**). Although *D. meiophyllizum* was often observed at higher elevation sites, it was also found at the lowest elevation in the study (**Table 8**). NPMR selected minimum December temperature and number of precipitation days per year as the most suitable habitat variables for *L. rivale* (**Table 7**), and NPMR response curves identified climate optima (**Fig. 5**). NPMR selected stream depth and minimum December temperature as the most important variables for *P. hydrothyria* (**Table 7**). NPMR regression curves suggested that small stream size was the most suitable habitat variable and a winter temperature optimum for *P. hydrothyria.* (**Fig. 6**); the median minimum winter temperature range in the data set was $-2.1^{\circ}C$ (**Table 8**).

Water quality. Median nitrogen, phosphorus and conductivity values for *D. meiophyllizum* were high relative to median parameter values for the other two species; this lichen also occurred in stream channels with a wide range of water temperatures, including the warmest (19.6°C) stream sites in the study (**Table 9**). Median water quality values for *L. rivale* were less than or equal to the median values representing the study area (**Table 9**). Median water quality values for *P. hydrothyria*, on the other hand, had the narrowest confidence intervals for water temperature, pH and nitrogen (**Table 9**).

Disturbance indices. Benthic diatom-based indices indicated that disturbance impacted all aquatic lichen populations. *Dermatocarpon meiophyllizum*, *L. rivale* and *P. hydrothyria* were mostly observed in sites with no scouring disturbance (**Table 10**). The three target species were also found most often in stream sites with no or only minor siltation (**Table 10**).

Discussion

Rarity. There is no consistent agreement among ecologists on the definition of rarity, but definitions based on frequency of occurrence and geographic distribution within a given area have been used with lichens in the Pacific Northwest (Edwards et al. 2004). Wheeler (1988) defined "rare" as less than 5% occurrence in the sample area while Rabinowitz (1981) suggested a non-numerical approach, defining a rare species as one with a restricted geographic range, a narrow habitat specificity or a low local population abundance. Edwards et al. (2004) cautioned against assigning "rarity" rankings to species that have not been systematically sampled within the geographic area of interest. The sampling approach for this study sufficiently covered the Northwest Forest Plan area, providing both statistical frequency and geographic distribution. Five percent occurrence was used as a guideline for rarity in this study along with geographic distribution.

Dermatocarpon meiophyllizum at less than 4% occurrence in the study area and a distribution of scattered, mostly low population sites suggests that it is rare across the NWFP area. Although *P. hydrothyria* was found at a frequency of $>$ 6% for the study area, its limited range (mostly Oregon Cascades) suggests that it deserves some level of rarity designation at the NWFP level. On a smaller scale, the high watershed frequency of *P. hydrothyria* in some watersheds suggests that it can become locally common in areas, such as the Upper Quartz Creek sub-watershed, with the right conditions. This study suggests that *Leptogium rivale*, however, cannot be considered rare across the NWFP area. Both the wide geographic range and high frequency of *L. rivale* (nearly 26%) across the study area suggests it is common; this lichen was probably overlooked because it is camouflaged among stream rocks when dry and, when wet, is easily confused for the ubiquitous *Verrucaria* spp. Of the three target lichens, based on definitions of rarity described above, only *D. meiophyllizum* and *P. hydrothyria* should be considered rare at the NWFP area-scale.

Caveats of habitat data collection. When collecting habitat data over a large area, an adequate detection rate in a random sample for rare species can be a difficult endeavor—especially with rough terrain impeding access to survey sites. This certainly holds true for the mountainous Pacific Northwest and, although data were collected at historic sites in this study to increase the resolution of habitat information, populations holding important information could have gone undetected. For example, the data from this study suggest that *P. hydrothyria* prefers shaded streams at cold mid-elevation sites. However, it has been often observed at colder, subalpine sites in exposed streams in British Columbia (Trevor Goward, pers. comm.) and in the North Cascades, Washington (my observation). The discrepancy left by the absence of data from the northern Pacific Northwest area will be discussed further in the habitat section below.

Aquatic lichen habitats. This study summarized habitat characteristics that can aid field surveyors in their search for *D. meiophyllizum*, *L. rivale* and *P. hydrothyria*. Results suggest that *D. meiophyllizum* prefers some level of exposure, larger rocks and often occurs above summer season water levels in smaller, high elevation streams: characteristics consistent with results found in Europe (Gilbert & Giavarini 1997). The median stream channel "depth" of 22 cm above the water level and its occurrence in a wide range of "depths" suggests that this lichen is tolerant to desiccation. Perhaps this lichen would be better categorized as semi-aquatic. The only two species of *Dermatocarpon* that are thought to be obligately submergent are *D. luridum* and *D. rivulorum* (Heiðmarsson 2001). The NPMR analyses also suggested that suitable habitat may be found in larger streams; there were several large stream sites in this study where *D. meiophyllizum* thalli were observed on the stream edge, above the water level.

This study suggests that *L. rivale* and *P. hydrothyria* share some habitat characteristics and often coöccur. Field surveyors found both *L. rivale* and *P. hydrothyria* on rock and wood substrates, mostly at shallow depths and near the water surface in semi-shady, mid-elevation streams. While *L. rivale* appears to be adaptable to a wide range of stream sizes, the study results suggest that *P. hydrothyria* mostly occurs in small, 1st and 2nd order mountain streams, which is consistent with other observations (Dennis et al. 1981). The capability of *L. rivale* to exist in large streams is likely due to its morphology; the low profile, appressed nature of *L. rivale* thalli should be able to endure the seasonal high velocity flows in large streams. The ability of *L. rivale* to exist in larger streams also probably contributes to its more widespread distribution.

Because this study did not capture habitat parameters common to *P. hydrothyria* in the northern region of the Pacific Northwest (i.e., British Columbia and Washington's North Cascade Mountains) it leads to a major question. What does the *P. hydrothyria* habitat information from this study represent? The habitat analyses from this work do suggest that cool, mid-elevation semi-shaded streams are important for *P. hydrothyria*, but only for the southern region of the Pacific Northwest (Oregon and southern Washington Cascade Mountains and northern California). There may be undetected sites, similar to the colder more exposed *P. hydrothyria* habitats in British Columbia and northern Washington, in the southern portion of the study area; however, based on the random sample, these sites would be rare. This result raises another question; are there two Pacific Northwest populations of this species divided by some latitudinal line?

Water quality. Water quality may perhaps be the most important factor for the health of aquatic lichens. Gilbert and Giavarini (1997) found that the biodiversity of aquatic lichen communities rapidly deteriorates with increasing nitrogen ($>$ 0.6 mg/l) and phosphorus ($>$ 0.02 mg/l). Exposure to elevated NO_3 concentrations and water temperatures for extended periods of time were found to be detrimental to the growth of *P. hydrothyria* (Davis et al. 2000, 2003). Good water quality is likely necessary for *L. rivale* and *P. hydrothyria*, although apparently more so for the latter (Dennis et al. 1981), as much of their time appears to be spent below or near the water surface. Curiously, *D. meiophyllizum* occurred in a wide range of water quality levels, including streams sites with the lowest water quality. However, the lowest water quality sites in this study were within parameter values acceptable by the Oregon Department of Enviromental Quality (ODEQ). Field sites in the Lower Jackson Creek watershed in Oregon, for example, had nitrogen concentrations of 0.33 mg/l, and the acceptable maximum nitrogen

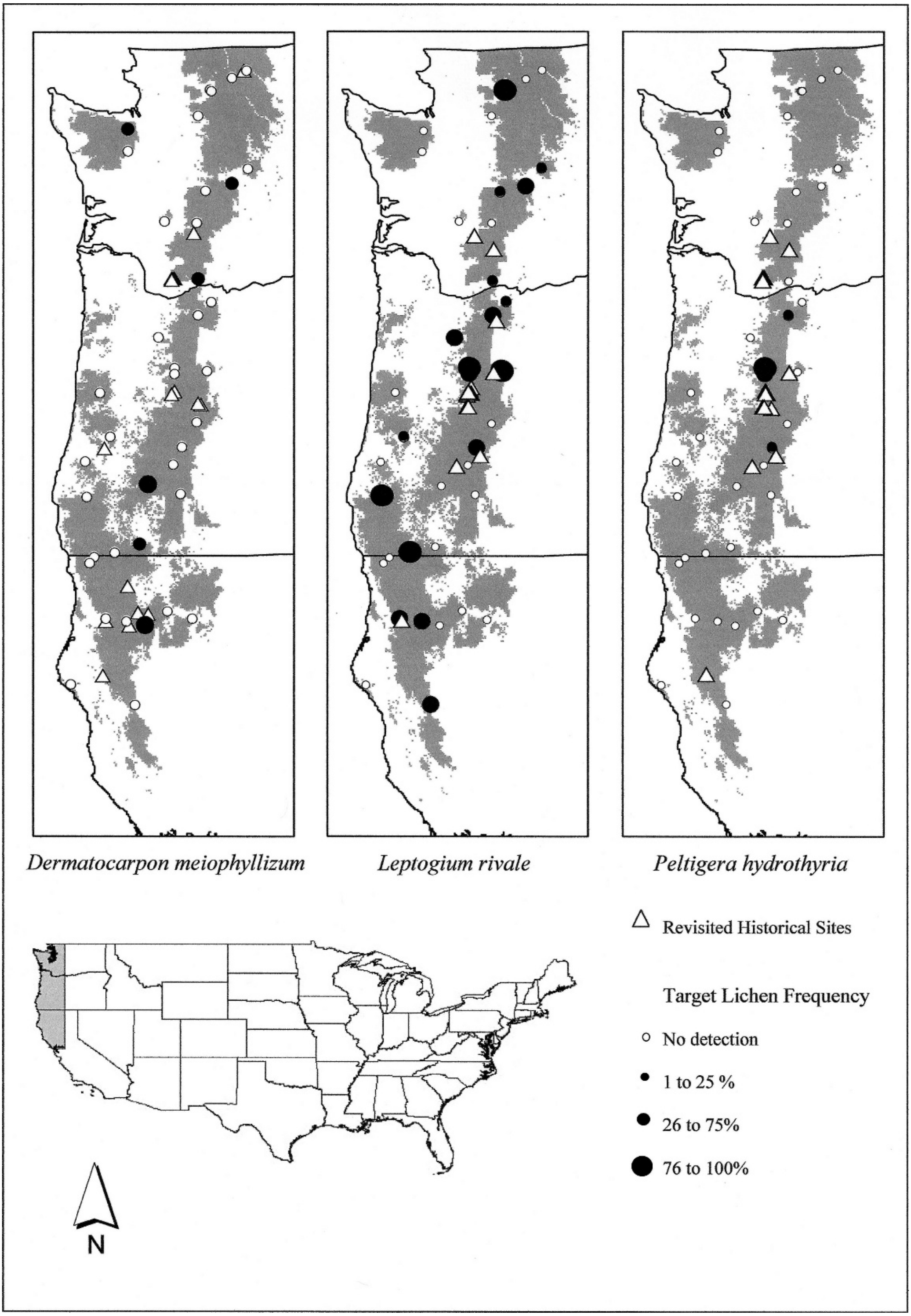
Dermatocarpon meiophyllizum
Leptogium rivale
Peltigera hydrothyria
Revisited Historical Sites
Target Lichen Frequency
No detection
1 to 25 %
26 to 75%
76 to 100%
N

Table 3. Fisher's Exact Test results for aquatic lichen association with forest age. Old Forests are those with a tree age > 80, and Young Forests are those with a tree age ≤ 80 years. Odds Ratio values in parentheses are 95% confidence intervals.

Target Lichen		Old Forests	Young Forests	p-value	Odds Ratio
D. meiophyllizum	detected	11	3		
	not detected	133	63	0.55	1.6 (0.5–5.4)
L. rivale	detected	44	8		
	not detected	100	58	0.01	3.0 (1.4–6.8)
P. hydrothyria	detected	10	0		
	not detected	134	66	0.03	10.4 (0.6–179.9)

Table 4. Fisher's Exact Test results for aquatic lichen association with federal Land Use Allocations. Odds Ratio values in parentheses are 95% confidence intervals.

Target Lichen		Protected LUA	Unprotected LUA	p-value	Odds Ratio
D. meiophyllizum	detected	3	7		
	not detected	113	93	0.06	0.4 (0.1–1.4)
L. rivale	detected	28	26		
	not detected	88	74	0.75	0.9 (0.5–1.7)
P. hydrothyria	detected	10	3		
	not detected	106	97	0.08	2.7 (0.8–9.5)

Table 5. Fisher's Exact Test results for aquatic lichen association with key watersheds. The Odds ratio values in parentheses are the 95% confidence intervals.

Target Lichen		Key Watersheds	Non-Key Watersheds	p-value	Odds Ratio
D. meiophyllizum	detected	8	6		
	not detected	86	114	0.40	1.8 (0.6–5.1)
L. rivale	detected	18	36		
	not detected	76	84	0.08	0.6 (0.3–1.1)
P. hydrothyria	detected	0	13		
	not detected	94	109	0.001	0.04 (0.01–0.73)

Table 6. Percent values for proportion of aquatic lichens in each substrate and shading class. N is the number of observations.

		Shading			Substrate					
Species	N	Full Shade	Partial Shade	No Shade	Sand	Gravel	Stone	Boulder	Bedrock	Wood
D. meiophyllizum	30	0.0	43.3	56.7	0.0	3.3	10.0	56.7	30.0	0.0
L. rivale	70	21.5	57.2	21.4	0.0	0.0	41.4	41.4	14.3	2.9
P. hydrothyria	30	33.3	60.0	6.7	3.2	6.5	32.3	22.6	29.0	6.4

←

Figure 2. Distribution of the three aquatic lichens in the Northwest Forest Plan study area. Dots represent AREMP watersheds and dot size is proportional to frequency of occurrence in each watershed. Triangles represent purposively surveyed and revisited historic sites.

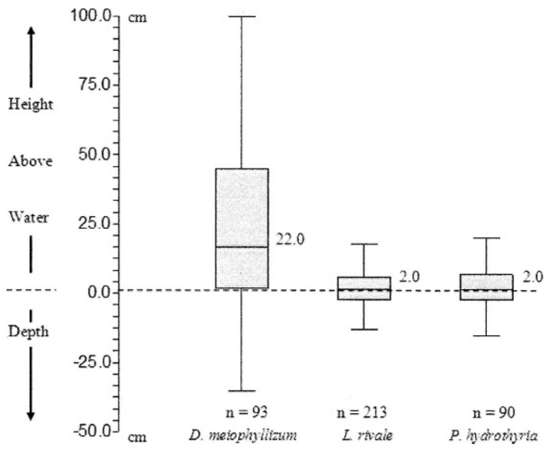

Figure 3. Aquatic lichen depth/height in the stream channel. Negative axis values are below the water surface (depths), and positive axis values are above the water surface (heights) in the stream channel. The dotted line represents stream water surface. Boxes represent 50% of the data (25–75 percentiles), and the line bisecting each box, and accompanying number, represents the median value. The "T" bars display the range of depth/height values minus the outliers. All values are in centimeters (cm). n = number of observations, of which there were as many as five per field site.

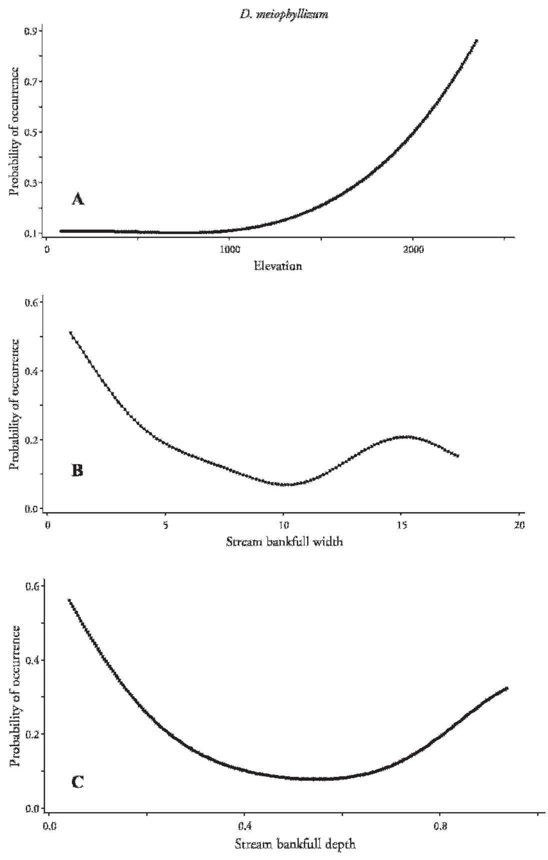

Figure 4. Nonparametric regression curves of *Dermatocarpon meiophyllizum* occurrence in relation to model selected variables. **A.** Elevation. **B.** Average stream bankfull width. **C.** Average stream bankfull depth. Units for elevation and stream measurements are in meters.

concentration in ground water is 10.0 mg/l (ODEQ 2006). Although this ODEQ maximum level could be too high for aquatic lichens, the highest levels in our sample are still lower than deleterious levels found by Gilbert and Giavarini (1997). At this time, it is unknown as to whether *D. meiophyllizum* exists in PNW streams with higher nutrient concentrations because it is tolerant or that it often occurs high enough above the water surface.

Table 7. Non-parametric Multiplicative Regression (NPMR) model results for the three aquatic lichen species. Tolerance is the standard deviation of the Gaussian function; $\times R^2$ is the cross-validated R^2; n* is the average neighborhood size. Stream BF width and depth are stream width and depth at bankfull. DecMinTemp is average minimum December temperature and Precip Days is the average number of days per year with measurable precipitation. Tolerance values for elevation and stream measurements are in meters and temperature is in °C.

Species	Environmental Variables	Tolerance	$\times R^2$	n*
D. meiophyllizum	Elevation	456.8	0.21	38.3
	Stream BF width	6.11		
	Stream BF depth	0.10		
L. rivale	DecMinTemp	1.4	0.25	12.1
	Precip Days	6.5		
P. hydrothyria	Stream BF depth	0.10	0.39	15.2
	DecMinTemp	0.7		

Table 8. Summary statistics of the three main climate variables and elevation for the aquatic lichens . MinDecTemp is average annual minimum December temperature, AnnPrecip is average annual precipitation and PrecipDays is average annual number of days with measurable precipitation.

	MinDecTemp (°C)			AnnPrecip (cm)			PrecipDays			Elev. (m)		
Species	**Min**	**Max**	**Median**	**Min**	**Max**	**Median**	**Min**	**Max**	**Median**	**Min**	**Max**	**Median**
D. meiophyllizum (n=31)	−10.5	−1.8	−2.2	107.4	312.8	189.6	99	206	139	61	2363	1138
L.rivale (n=70)	−8.1	−1.9	−2.1	73.5	351.2	196.5	88	219	139	121	1696	846
P. hydrothyria (n=30)	−8.1	−0.7	−2.1	91.7	305.6	229.7	95	206	179	363	1696	968

Stream disturbance. As indicated by the diatom-based indices, the target lichens mostly occurred in streams with no recent disturbance by siltation or extreme high flows. It is reasonable to assume that the scouring of extreme high flows would strip stream channels of aquatic lichens. In the study area, there have been several extreme flood events that likely effected aquatic lichen populations; there were extreme flow volumes in some streams that were upward of ten times the average annual high; two of the largest events occurred in 1968 and more recently in 1996 (Herrett et al. 2002). These events would probably affect each of the target lichen species differently. For example, because of its more delicate nature, it is reasonable to assume that *P. hydrothyria* could be more easily scoured from the stream channel during high flows. At this time, there is no information that links these aquatic lichens with PNW extreme flood events. There also needs to be an understanding of actual resistance to high flow scouring and establishment and growth rates for these species.

Conservation of aquatic lichens on Pacific Northwest federal lands. Old forests are important to many lichens in the Pacific Northwest as they provide long-term habitat continuity and a diverse array of habitat niches. Together, federally protected land allocations, containing old forests and other unique habitats, and ACS components may provide the niches and water quality maintenance necessary

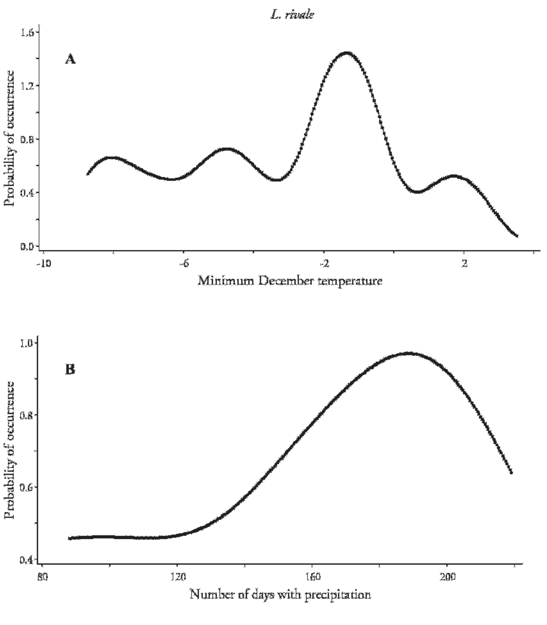

Figure 5. Nonparametric regression curves of *Leptogium rivale* occurrence in relation to model selected variables. **A.** Average minimum December temperature (°C). **B.** Average number of days per year with measurable precipitation.

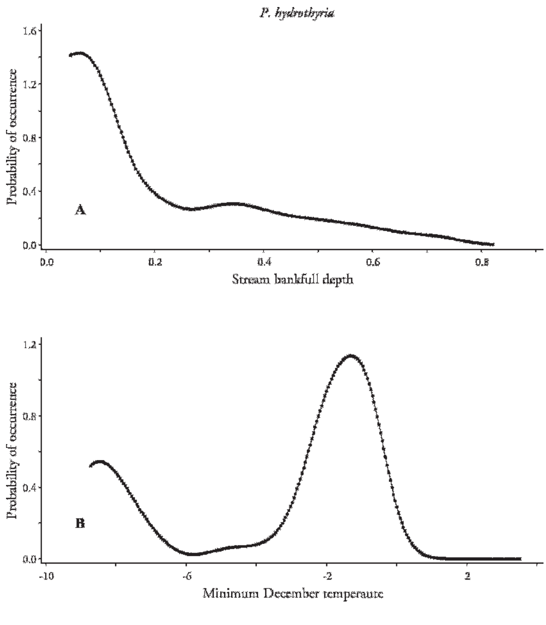

Figure 6. Nonparametric regression curves of *Peltigera hydrothyria* occurrence in relation to model selected variables. **A.** Stream bankfull depth (m). **B.** Average minimum December temperature (°C).

Table 9. Water quality parameter statistic summary for the three aquatic lichens and all sites with measurements. D.O. = dissolved oxygen, Seasonal H_2O T = average summer water temperature, 7 Day Max H_2O = 7 day average maximum summer temperature, and µS/cm = micro-siemans/cm.

Species	D.O. (mg/l)	Conductivity (µS/cm)	pH	Seasonal H_2O T (°C)	7 Day Max H_2O T (°C)	Nitrogen (mg/l)	Phosphorus (mg/l)
D. meiophyllizum							
Median	9.97	31	7.5	11.44	17.2	0.33	0.028
95% C.I.	8.18–10.45	10–110	6.69–7.80	6.06–19.59	8.4–23.9	0.06–0.33	0.007–0.087
Range	8.18–10.81	6–181	5.75–8.30	2.33–19.59	7.4–23.9	0.06–0.33	0.007–0.087
N	8	13	13	12	12	7	7
L. rivale							
Median	9.31	40	7.23	12.14	16.5	0.04	0.013
95% C.I.	8.54–9.60	31–83	7.00–7.48	11.32–13.64	16.1–18.7	0.03–0.08	0.009–0.017
Range	7.15–13.92	6–160	5.61–8.14	6.06–15.83	7.4–19.4	0.02–0.26	0.007–0.087
N	49	54	54	34	34	41	41
P. hydrothyria							
Median	8.22	26	7.02	10.61	14.6	0.03	0.013
95% C.I.	7.34–9.14	18–32	6.72–7.24	none	none	0.03–0.04	0.007–0.030
Range	7.15–11.83	10–104	5.75–7.71	8.99–10.61	14.1–14.6	0.03–0.04	0.007–0.030
N	12	15	14	5	5	12	12
All Plots							
Median	9.39	64	7.48	12.33	16.5	0.06	0.017
95% C.I.	9.14–9.60	45–78	7.35–7.51	11.70–13.55	15.9–17.2	0.05–0.07	0.013–0.024
Range	5.5–13.92	2–248	5.61–8.50	5.9–19.59	7.4–23.9	0.02–0.33	0.007–0.105
N	182	205	197	143	143	123	123

for conserving aquatic lichen populations. ACS riparian reserves should maintain older forests around streams on disturbed lands, and old-growth forests are highly retentive of nutrients and reduce soil erosion, thus maintaining water quality (Franklin & Spies 1991). Although old-growth forest and land allocation associations are not criteria for a species to be managed by the ISSSSP, the association information should help guide management. ACS key watersheds are designated for the protection of aquatic resources on federal lands; thus, habitats protected within these watersheds may contribute to aquatic lichen conservation.

This study suggests that ACS components, on their own, may only play a minor role in aquatic lichen conservation in the PNW. The Fisher's exact results suggest that *Leptogium rivale* and *P. hydrothyria* would benefit most from older forests maintained by riparian reserves. Although not statistically significant, *D. meiophyllizum* would likely benefit as well. ACS key watersheds may likely offer only limited protection for aquatic lichens. In order

Table 10. Percent values for proportion of target lichens in each diatom-based disturbance index class. The siltation index classes represent stream siltation, and the scour-disturbance classes represent degrees of recent stream scouring by high flow. N is the number of sites with diatom data.

		Siltation			Scour Disturbance		
Species	N	No Siltation	Minor Siltation	Moderate Siltation	No disturbance	Minor disturbance	Moderate disturbance
D. meiophyllizum	10	40.0	60.0	0.0	78.0	22.0	0.0
L. rivale	50	84.0	12.0	4.0	70.0	16.0	14.0
P. hydrothyria	12	83.0	17.0	0.0	92.0	8.0	0.0

for ACS key watersheds to protect aquatic lichens, aquatic lichens have to exist in these watersheds. This study suggests that a majority of *L. rivale* and *P. hydrothyria* sites do not occur in key watersheds. A concern would be, with *P. hydrothyria* populations not currently being monitored, whether or not riparian reserves can provide for its future persistence. Even though the ACS protective measures should contribute at least some aquatic lichen habitat that is safe from disturbance for these lichens, future monitoring efforts should continue in light of environmental changes, e.g., climate change, declining air quality, etc.

Large-scale habitat parameters and climate. Its not surprising that climate variables were found to be important environmental parameters for the aquatic lichens in this study. Environmental models from several studies have found climate variables to be major parameters controlling the distribution of lichens (e.g., Geiser & Neitlich 2007; Glavich et al. 2005). NPMR suggests that minimum winter temperature is a major controlling factor for all three of these lichens. This variable was directly selected for *L. rivale* and *P. hydrothyria*, but only elevation was selected for *D. meiophyllizum*. Elevation, which is often a surrogate for climate variables (Will-Wolf et al. 2006), can be interpreted as an indirect measure of temperature. Small climatic tolerances have important implications for these species' survival in terms of forecasted Pacific Northwest climatic temperature increases upwards of 2.5°C within this century (Mote et al. 2003). The potential for some of the current aquatic lichen habitat to become inhospitable due to climate change warrants consideration in current management decisions.

Future research and management. Some habitat characteristics for the three target aquatic lichens could be better defined long-term monitoring at known sites. For example, stream channel position (height above water and depth) results in this study reflect summer seasonal tendencies for these lichens. Permanent aquatic lichen monitoring sites, where water levels in relation to lichens could be measured over seasons and time, should improve submergence duration and depth information. An experimental approach would better define water quality tolerances for *D. meiophyllizum* and *L. rivale*, as was done with *P. hydrothyria* for nitrogen and temperature (Davis et al. 2000, 2003). Permanent monitoring locations could also be established at aquatic lichen sites near stream gauges, which could provide information on the effects of scouring high flow events on aquatic lichens. Other questions might be answered at permanent monitoring sites as well. What are vectors of between-stream dispersal, growth rates and establishment requirements? Additional sampling should occur in the northern Washington Cascade mountains, and even into British Columbia, to improve the habitat model for *P. hydrothyria*.

Conserving aquatic lichen populations would primarily result from the maintenance of stream health and shading regimes. For water concerns, management should not only focus on the alterative effects of siltation and elevated nutrient loading, but also consider the potential effects climate change might bring. The increasingly changing climate is expected to result in drought conditions in the western U.S. (Adams & Peck 2002) that could cause stream water quality decline and the lengthening of dry exposure periods aquatic lichens are not likely to endure. Activities that would alter shading regimes at current aquatic lichen sites are likely to affect their populations. Findings in this study suggest that *D. meiophyllizum* might not persist in fully shaded conditions, and *L. rivale* and *P. hydrothyria* (at least in the southern part of their range) may not persist in fully exposed conditions. Management can also now be prioritized by using frequency values and distribution maps from this study to conceptualize rarity for these species.

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