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Macrolichen Communities of *Quercus garryana* in the Puget Trough and Columbia River Gorge Areas of Washington State

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Abstract: We investigated macrolichen diversity on *Quercus garryana* at ten sites in the Puget Trough and Columbia River Gorge areas of Washington. The known ranges of some oak-associated species are expanded within Washington and occurrences of several species new to the state are reported. We identified 111 lichen taxa, 80 of which occurred at more than one site and three species, *Fuscopannaria pulveracea*, *Placidium fingens* and *Collema quadrifidum*, which are reported for the first time for Washington. We report four additional species, *Bryoria furcellata*, *Dendriscoaulon intricatulum*, *Usnea cavernosa* and *Waynea californica*, which are reported from oaks on two or fewer sites in Washington prior to this study. We compiled records from herbaria and other Washington oak lichen studies to evaluate the rarity of observed species and potentially rare species known from nearby locations. Using macrolichens we developed an Index of Ecological Continuity for oak habitats in Washington to help land managers assess the health of the lichen communities on oaks. We also recorded lichen species diversity and abundance in air quality monitoring plots at six of our sites in order to assess the threat level from

increasing air pollution to oak lichens. We discuss the effects of management practices on lichen diversity and abundance at oak sites and suggest species of interest for future conservation efforts.

Key words: *Quercus garryana*, Washington, lichens, conservation, index of ecological continuity, oak habitat

Introduction: *Quercus garryana* Dougl. ex Hook, also known as Oregon White Oak or Garry Oak, is a broadleaved deciduous hardwood with a distribution from southern California north through southern coastal British Columbia (Burns et al. 1990; Erickson, 1993). It is the only native *Quercus* in British Columbia and Washington and the most commonly occurring oak in Oregon where it attains its most robust size and abundance in the Willamette Valley and the Klamath-Siskiyou ecoregion. *Quercus garryana* communities in Washington are restricted to a limited number of habitats including grasslands, prairies, meadows, woodlands, and savannas (Dunwiddie and Bakker 2011). At the northern limits of its range, *Q. garryana* stands are among the most geographically limited ecosystems in Canada (GOERT 2011).

Historically, the Puget Sound region of western Washington contained the largest oak ecosystem north of the Willamette Valley. Most of the remaining oak habitats in Washington are highly fragmented and degraded due to increasing threat by development, agriculture, pollution, conifer encroachment and invasion by non-native species (Kessler 1990; Thysell et al. 2001; Hamman et al. 2011). Because of these factors, some of the lichen communities found in oak stands may be at risk.

Studies concerning lichen species diversity and distribution on *Quercus* have been conducted in temperate settings such as Italy (Zedda 2002), Turkey (Oran & Öztürk 2012), Sweden (Jönsson et al. 2011) and the United States in Maine (Stubbs, 1989), Oregon (Pike 1973, Stone 1989) and Wisconsin (Culberson 1955) and in tropical

areas such as India (Kumar 2010), Florida, (Kaminsky 2011), and Costa Rica (Kappelle and Sipman 1992). To our knowledge there have been no studies focusing on macrolichens found on *Quercus garryana* in Washington.

In this study, we investigated macrolichen diversity on *Quercus garryana* in ten oak stands located within the Willamette Valley-Puget Trough-Georgia Basin and Columbia River Gorge ecoregions of Washington (Figure 1). We develop an Index of Ecological Continuity based on macrolichens for oak habitats. We recorded lichen species diversity and abundance in air quality monitoring plots at six of the ten sites in order to assess the threat level from increasing air pollution to lichens. Our results will be useful as a baseline for managing the remaining oak habitat in Washington and will help to track changes in air quality in the future. We discuss the effects of management practices on lichen diversity and abundance at oak sites and suggest species of interest for future conservation efforts.

Materials and Methods

Study Sites- Between 2011 and 2012, we surveyed *Quercus garryana* at ten sites within Washington for epiphytic lichens (Figure 1). Sites visited represent the broad range of habitat types found on public land within the respective ecoregions, Columbia River Gorge and the Puget Trough. These sites were selected in an attempt to cover the eastern and western extremes as well as some north to south distribution of oaks in Washington. Land area of oak cover varies by site. At sites with extensive oak cover a survey was confined to an area of approximately 25

acres. Some sites had less than 25 acres of oak habitat present; at these sites we conducted a survey of all the acres present. All sites are on public lands (Figure 1).

Field Protocol- We conducted fieldwork as two teams of approximately four lichenologists, one team going to the Columbia River Gorge area and the other to the Puget Trough area.

Each site was visited for one field day during which an intensive, intuitive-controlled search (USDA Forest Service 2005) on *Q. garryana* was conducted. Surveyors spread out in the oak groves and recorded diversity within each site. We searched individual trees intensively below 6 ft. until no new species were recorded, spending ~4-6 hours at each site. Voucher specimens of each species found at a given site were collected. Global Positioning System (GPS) devices were used to document the general locations of sites and noteworthy specimens. The habitats were photographed to document the overall condition of each grove and notes on habitat type and plant communities were made. Separate Air Quality monitoring plots were conducted at six sites following Geiser (2004).

Lab Protocol- All lichen specimens collected were identified at the Evergreen State College Herbarium and one voucher collection of every species found on *Q. garryana* at each site is deposited there (EVE). Species identifications were based primarily on McCune and Geiser (2009) and nomenclature follows Esslinger (2012).

We searched and compiled records from the Consortium of North American Lichen Herbaria (CNALH, 2013) to gather databased historical lichen data from Washington. We discuss some of the historically important records of specimens that we verified but we did not include herbarium records in our table of lichen taxa found on *Quercus garryana* in Washington (Table 2).

From our air quality plots we entered species abundance data into the USDA Forest Service Region 6 Air Quality Database. The plots from west of the Cascade Mountains were assessed according to R6 Air Quality protocol, using lichen community analysis developed for the National Forest Health Monitoring Program (Geiser 2004). For the plots east of the Cascade Mountains (Badger Gulch, White Salmon Oaks and Columbia Hills), species known to be eutrophic and oligotrophic were tagged in the data table then the air quality on each east side plot was scored for air quality using the formula: $\frac{E-O}{A}$ where E is the abundance of eutrophic species, O is abundance of oligotrophs and A is all species.

East side scores were interpreted using a scale of air scores calculated by the R6 Air Quality Monitoring program. This method bases air quality scores on the presence and abundance of lichen species in the local climate and has been built by correlating actual N and S deposition rates with lichen data, then compared to other lichen-based models (Geiser et al. 2010).

Index of Ecological Continuity for

Washington Oak Stands- We developed an "Index of Ecological Continuity" (IEC) list for oak stands in Washington in order to compare the oak stands within our study and identify high quality oak lichen communities (Table 1). Rose (1974) introduced the concept of IEC using "Old Forest Indicator" species for *Quercus*-dominated woodlands in Great Britain, and it was later revised (Rose 1976) into the Revised Index of Ecological Continuity (RIEC). The formula developed was: $RIEC = \frac{N}{20,100}$ where N is the number of indicator species found at a given site from a list of 30 indicator taxa. This measure was applied in studies of *Quercus* forests in Sardinia Italy (Zedda 2002). The list of indicator species was later modified for New England by Selva (1994) to include "Old Forest Indicator" species for hardwood-dominated stands. Selva (2002)

then developed an IEC list using only calicioid lichens and fungi. McMullin et al (2008) and LaGreca (2012) have conducted RIEC analyses for locations in Nova Scotia and Massachusetts, respectively, using these lists. McMullin and co-workers (2008) suggested that in order to apply the IEC to a new location, a new indicator list that takes into account regional ecological distinctiveness would have to be developed.

In attempting to apply the RIEC list of Rose (1976) and Selva (1994) to our *Quercus* stands we observed that while many of the macrolichen taxa found on these indicator lists are not present in our lichen communities, most of these species that do occur in Washington are known to be old forest associates (McCune and Geiser 2009; USDA & USDI 2001) and as such are retained on the list.

To create an IEC list that better represents Washington's oak macrolichen communities we added species that have been identified as old growth indicators in the Northwest Forest Plan Record of Decision (USDA & USDI 2001) and oak obligates in the Pacific Northwest (McCune and Geiser 2009) or in other portions of their range (Moberg 2002).

Lichens that are intolerant to short fire return intervals may also indicate habitat continuity and many of them are also old forest indicators (Table 1). Therefore we included species that are thought to be fire intolerant (Johannson et al 2006; Bennett 2003).

Because crustose taxa make up a significant percentage of the thirty species on previous IEC lists and our study only covers macrolichens we modified the formula by reducing the number of species used on the indicator list from 30 to 21. This modification maintains the 2/3 ratio of indicator species present to possible indicator species needed to score 100 (Rose 1976). The formula used to calculate the Macrolichen Index of Ecological Continuity for Oaks in Washington

(MIEC) is: $MIEC = \frac{N}{14/100}$ where N is the number of indicator species present at a site out of a possibility of 21.

Statistical analyses were performed using Microsoft Excel Data Analysis ToolPak.

Results

Diversity and New Records - We report a total of 111 macrolichen species on *Q. garryana* from our ten survey sites, of which 80 occurred at more than one site (Table 2). We recorded three taxa previously not reported from Washington, *Fuscopannaria pulveracea*, *Collema quadridum* and *Placidium fingsens*. Species diversity at our sites ranged from 26-53 lichen taxa with an average of 37.3 species per site (Figure 2). The site with the greatest diversity of macrolichens was Carson area oaks. The site with the least diversity was Badger Gulch.

Species Abundance -Sixteen lichens were considered common on *Q. garryana* in Washington because they occurred in at least seven out of ten of the oak stands surveyed in our study. These lichens are: *Cladonia chlorophaea* group, *Evernia prunastri*, *Hypogymnia physodes*, *Hypogymnia tubulosa*, *Leptogium lichenoides* group, *Lobaria pulmonaria*, *Melanelixia fuliginosa*, *Parmelia sulcata*, *Peltigera collina*, *Physcia adscendens*, *Physconia americana*, *Physconia perisidiosa*, *Platismatia glauca*, *Ramalina farinacea*, *Usnea wasmuthii* and *Xanthoria polycarpa*.

Four rarely reported species that are known from three or fewer sites in Washington prior to this study according to herbarium records are: *Bryoria furcellata*, *Dendroscocaulon intricatum*, *Usnea cavernosa* and *Waynea californica*.

Bryoria furcellata has one report from Washington, from Fidalgo Island collected on

bark of an unspecified species (B. Ryan #3684). It is reported here for the second time from the Puget Trough in Washington.

Dendroscopula intricatulum is reported here for the second time on oak in Washington; it has been previously been collected near Carson in 1993 (J. Davis #2803).

Usnea cavernosa was collected from Bald Hill Natural Area in 1998 (B. McCune #24069) and by our team again in our current survey of this site. E. Martin recorded the only other herbarium record of *Usnea cavernosa* from Washington in 1963 in Whatcom County growing on *Acer* sp. (E. Martin s.n. WTU-L-034942).

Waynea californica was collected in 1994 and again in 2003 in Skamania County, the former growing on an oak north of the Columbia River, east of Carson (T. Tønsberg #21048 [BG-L-64881]) and latter was also growing on oak near the south foothill of Dog Mountain, northeast of Grant Lake (T. Tønsberg 29083 [BG-L-70310]). *Waynea californica* was also collected in 2010 near Bald Hill Lake in Thurston County (R. Rosentreter, #16887). We also recorded *W. californica* growing on oaks at Bald Hill Natural Area and at the Carson area oaks site.

Esslingeriana idahoensis occurred on oaks at two of our study sites. Based on herbarium records (CNALH 2013), *E. idahoensis* has been previously reported to grow on fir, pine, alder and poplar in Washington (McCune and Geiser 2009). To our knowledge, this is the first report of *E. idahoensis* growing on oak in Washington.

Plastismatia wheeleri is a recently described species segregated from *Platismatia glauca*, with strongly sinuous marginal soralia (Lumbsch et al. 2011). *Plastismatia wheeleri* is reported from Washington in the Turnbull National Wildlife Refuge on the border of Idaho growing on *Pinus ponderosa* bark (Allen et al. 2012). We report here an additional record of *P. wheeleri* from

Bald Hill Natural Area in Thurston County, WA. To our knowledge, this is the first record of *P. wheeleri* growing on oak. We examined two additional herbarium specimens collected in 1904 on fence posts from a mounded prairie in Thurston County, likely near or within Mima Mounds Natural Area or Glacial Heritage Preserve. On the herbarium packet, the collector, T.C. Frye, noted the specimens “show remarkable mutation in foliation”. We confirmed that both of these specimens are *P. wheeleri*.

Five taxa recorded in our survey are on the current Washington Natural Heritage Program (WNHP) list of rare lichens. These taxa are *Dendroscopula intricatulum* (S1-critically imperiled), *Usnea longissima* (S2-imperiled), *Pseudocyphellaria crocata* (S3-vulnerable), and two taxa, *Leptogium teretiusculum* and *Collema nigrescens*, which are listed as unranked with a need for monitoring for rarity.

We identified four taxa that appear to be oak obligates based on our study and literature data: *Waynea californica*, *Fuscopannaria pulveracea*, *Collema quadrifidum* and *Placidium fingens* (McCune and Geiser 2009; Moberg 2002; Stone and McCune 2010).

Based on the critically imperiled status of oak habitats in Washington (Chappell 2006) combined with the limited number of reports of these taxa occurring in Washington (1 or 2 records), we suggest that they be added to the Washington Natural Heritage Program’s list of rare lichens and that future management efforts focus on monitoring their populations in order to ensure their conservation within the state.

Air Quality – The data from our air quality plots are reported in Table 3. Five out of six plots surveyed received a score between 0.21 and 2.0, indicating poor air quality. One of our plots, Oak Patch NAP, scored a 0.099, indicating fair air quality. These data are consistent with previously published reports on air pollution and climate

gradient models for western Washington. Using the same index as Geiser and Neitlich (2007) we show that air quality at the Joint Base Lewis McChord Artillery Impact Area has changed from good in the 1990's to poor in 2012 (Table 3).

The number of species present in our air quality plots ranged from 15 to 49 (Table 3). Many of these species are known to be tolerant of high levels of nitrogen (Geiser and Neitlich 2007). We observed morphological characteristics associated with poor air quality such as compaction of thalli and an increase in apothecia or asexual reproductive propagules. These observations are consistent with previous air quality plots conducted at nearby prairies in 2011 (Smith et al. 2012). The estimated average nitrogen deposition at our sites based on Community Multi-scale Air Quality Model (CMAQ) data (Byun and Schere 2006) ranged from 1.13325 - 1.99174 kg/hectare (Table 3).

Macrolichen Index of Ecological Continuity Scores for Oaks in

Washington - Table 3 reports the Macrolichen Index of Ecological Continuity scores and ecological correlates that help to explain the relative differences in MIEC scores for each of our ten study sites. MIEC scores ranged from 14-100, with Carson area oaks receiving the highest score and Glacial Heritage receiving the lowest score.

Figure 2 shows linear regressions for the three best predictors of MIEC scores: air quality, total species richness and elevation. Linear regression indicated a strong, negative correlation between air scores and MIEC scores ($r^2 = 0.87934$; $p=0.00570$) for the six sites where air quality plots were recorded (Figure 2). MIEC scores were positively correlated with overall species richness ($r^2 = 0.53400$, $p=0.01636$) and elevation ($r^2=0.45314$, $p=0.03288$) (Figure 2).

No significant correlations were observed between MIEC scores and mean annual

precipitation, distance to major metropolitan area, mean annual range temperature or time since fire.

Discussion

Diversity and new records- Only a few studies have reported oak-dwelling macrolichens from the Pacific Northwest. One hundred species were found in 38 hectares of oak woodland in the Cogswell-Foster Reserve, in the Willamette Valley of Oregon (Pike 1973). Stone (1989) conducted a study of epiphyte succession on *Q. garryana* branches and recorded 28 macrolichens. Brown-Coleman and coworkers (1956) included a survey of oak lichens in their study of the epiphytic plants of the Olympic Peninsula; they reported 12 lichens on oaks in Sequim. The results from our survey demonstrate that with careful, intense searches, a great diversity of lichens can be found in the small remnant patches of oak woodlands that remain in Washington.

Due to time constraints our current survey did not include oak stands in southwestern Washington, the northern Olympic Peninsula or the San Juan Islands. We recommend that future surveys of oak lichens in Washington focus on these areas. One taxon of special concern from the Olympic Peninsula is *Sulcaria badia*, known from one historical collection in Dungeness; this species is thought to be extirpated from Washington (Peterson et al. 1998) and it was not found during our surveys. In addition, we did not record *Ramalina menziesii* in our survey, but this lichen has been reported growing on oak from several locations on the Olympic Peninsula and in the San Juan Islands (CNALH 2013; Brown-Coleman et al. 1956). Therefore it is likely that more studies are necessary to fully catalog the diversity of oak macrolichens in Washington.

Although our current survey focused primarily on macrolichen diversity on oaks, we suspect much diversity in crustose and calicioid lichen taxa. In Pike's (1973) survey of oak stands in the

Willamette Valley of Oregon, 79% of lichen flora was composed of crustose species. Lichen communities of *Quercus rubra* in Maine were reported to contain 44% crustose species (Stubbs, 1989). One study of eight red-listed oak-dwelling crustose lichens (including three calicioid species) in Sweden found a significant, positive relationship between age-related variables (diameter, age and bark crevice depth) and occurrence of crustose species, where all eight taxa were more frequent on trees >100 years old (Ranius et al., 2008). Crustose taxa were reported to be more vulnerable to fire than foliose or fruticose taxa in the southern boreal forest of North America (Johansson et al. 2006). A survey focusing on crustose species including calicioid lichens is another logical next step in understanding oak lichen diversity in Washington.

Rarity- Thirty four of 111 taxa recorded in our survey were found at only one site. Some of these taxa appear to be rare and are currently being monitored by the Washington Natural Heritage Program (2012).

One example of what we would consider truly rare on oak in Washington is *Dendriscocaulon intricatum*. On the other hand, some common conifer-dwelling species, such as *Esslingeriana idahoensis* and *Nodobryoria oregana* (McCune and Geiser 2009), are found on oaks at our sites where conifers surround the oak stands. We do not consider these to be rare oak species.

Usnea cavernosa was recorded growing on oak in our study and is also a conifer-dwelling taxa in the Pacific Northwest (McCune and Geiser 2009). Only three records of *U. cavernosa* and two records of *Bryoria furcellata* have been documented in Washington. Given the very limited distribution and records for these species in Washington, we recommend they be added to the Washington Natural Heritage Program's list of rare lichens.

Other uncommon taxa that were recorded in our survey may not be rare, but instead poorly known because they were recently described. This is the case for *Platismatia wheeleri* (Lumbsch et al. 2011) that can be easily mistaken at first glance for the common and widespread *Platismatia glauca*. A recent study of *P. wheeleri* (Allen et al. 2012) described the biogeographic distribution of this taxa. To further clarify the distribution and abundance of *P. wheeleri* in Washington, we recommend a detailed field study targeting this species be conducted, in addition to a re-examination of all *P. glauca* herbarium specimens from Washington. *Collema quadridum* is also a newly described species whose range is not well known (Stone and McCune 2010).

A fourth category of rarely reported species may be taxa that are difficult to identify or difficult to spot in the field. Examples include *Leptogium teretiusculum*, *Waynea californica*, *Placidium fignens*, and *Fuscopannaria pulveracea*.

MIEC scores and conservation

implications- Several factors are important to consider when managing the health of lichen communities at oak sites in Washington. Sites with the greatest number of MIEC indicator taxa should be prioritized for conservation efforts, as they are the most likely to support high quality lichen communities and propagule source populations. Species diversity in oak stands has been shown to be greatest in stands that maintain continuity of habitat, large old trees, heterogeneous light conditions, and a diverse and intact shrub and regeneration layers (Sanderson and Wolseley 2001; Gustafsson et al. 1992; Király et al. 2013). Although older trees are vital habitat, MIEC indicator species can also occur on younger understory trees. Therefore, efforts for increasing or maintaining lichen diversity at sites with low numbers of MIEC indicator species should focus on retaining the oldest trees and minimize thinning of understory trees.

The wide variation in MIEC scores for our ten

study sites can be partially explained by ecological factors that influence the overall composition of oak lichen communities in Washington (Table 3). Overall, air quality scores for lichen species abundance and presence at six of our ten study sites in Washington indicated that oak lichen communities are being negatively impacted by poor air quality (Table 3). Only one of six study sites where air quality was measured showed a “fair” score (Oak Patch Natural Area Preserve). Air quality scores showed a significant, negative correlation with MIEC scores (Figure 2). We suggest that additional data on MIEC indicator species abundance and presence/absence at oak sites in Washington may serve as an early warning tool for monitoring changes in air quality at these sites.

Regression analysis indicated a fairly strong positive relationship between overall species richness and MIEC scores where the site with the greatest number of MIEC indicator species also had the highest overall species richness and the site with the fewest number of MIEC indicator species had the lowest overall species richness (Figure 2; Table 3). However, total species richness is not always a good indicator of lichen community health. As air quality shifts at a given site, more nitrophilic species move in and replace the more air pollution sensitive species (Geiser and Neitlich 2007) resulting in very little difference in species richness or even an increase in the total number of species present. For instance, in our study White Salmon Oaks has the second highest species richness but only six MIEC indicators were recorded. At this site we observed lichens with morphological characteristics associated with poor air quality such as compaction of thalli and an increase in apothecia or asexual reproductive propagules. This was true at many of our sites, which is consistent with the poor air quality scores reported in the current study and in other studies measuring air pollution and air quality in western Washington (Geiser and Neitlich 2007; Smith et al. 2012).

Fifteen out of the 21 Washington Oak MIEC indicator species are cyanolichens, most of which are sensitive to both air pollution (Geiser and Neitlich 2007) and heat stress (Richardson and Cameron 2004). These species are especially at risk in oak communities in Washington because of poor air quality and use of prescribed fire to remove dense understory and promote habitat structure for the state-listed species, such as the western Grey Squirrel (Ryan and Carey 1995). In addition, prescribed fire is regularly employed as a restoration tool for enhancing habitat for endangered species such as Taylor’s checkerspot, Pocket Gopher and Streak-horned lark in the glacial outwash prairies bordering many of the oak woodlands in western Washington (Hamman et al. 2011).

Despite the fact that oak communities are composed of a fire-adapted group of species, various studies have shown that epiphytic lichens growing on oak are reduced in abundance and diversity after wildfire and prescribed burning (Atlas et al. 2004; Mistry 1998; Romagni and Gries 2000; Wetmore 1983; Johansson et al. 2006; Bennett 2003). Lichens are vulnerable to fire because of their slow growth and colonization rates and lack of underground parts that allow for regeneration post-fire. Many factors influence a lichen’s ability to recover or recolonize after fire including lichen growth form (i.e. crust, foliose or fruticose), photobiont partner (cyanobacterial or green algal), pre-burn population size and structure, dispersal mode and amount of live vs. dead cover post-burn.

Our study shows that the oak communities in Washington support at least seven “fire vulnerable” and six “fire indifferent” lichen species based on the available literature examining oak lichen sensitivity to fire (Table 2). Two species that were indicated as a fire-vulnerable by Johansson and co-workers (2006), *Usnea cavernosa*, and *Ramalina dilacerata* were recorded at in our current study. (*U. cavernosa*-Bald Hill NAP and *R. dilacerata*-Scatter Creek

Wildlife Refuge). These taxa should be monitored at these sites and fire should be discouraged in areas that could impact these lichens. Future studies monitoring changes in the frequency and abundance of oak lichen taxa at pre- and post-burn sites are needed to better understand the effects of prescribed fire. Results from these studies would provide a baseline for determining fire-vulnerable, fire-tolerant and fire-favorable taxa specific to Washington's remaining oak habitats and would help to assess the potential risk of extirpation for fire sensitive species.

Higher abundance of MIEC indicator species may have predictive value for overall community health. The current study did not include a direct measure of species abundance, however, we did casually observe differences in MIEC indicator species abundance at each site. For example, only a few small thalli of *Lobaria pulmonaria* were found at Glacial Heritage Preserve, whereas we found an abundance of larger, healthier *L. pulmonaria* thalli growing at Carson area oaks. Factors influencing lichen biomass and species diversity include air quality (Cleavitt et al. 2011), precipitation (Gunther 1989), and disturbance regimes (Berryman and McCune 2006). Future studies of oak lichen communities should include measures of abundance and biomass, especially for cyanolichens, which are more sensitive to air pollution (McCune and Geiser 2009).

Conclusions- The oak habitats that we surveyed were highly fragmented by human disturbance and/or encroachment by surrounding conifers, creating islands of oak stands that are vulnerable to changes in microclimate, increased eutrophication and poor air quality. Despite these challenges, the oak communities that we surveyed in Washington support many of the macrolichen species typical of oak communities

elsewhere in the Pacific Northwest (Pike 1973; Stone 1989, GOERT 2011, Ryan 1991). Our species list for each of the ten study sites, along with MIEC and air quality scores provide a starting point for conservation efforts focusing on monitoring rare taxa and overall macrolichen diversity on oaks in Washington.

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Figure 1. Map of Washington with study sites. 1. Oak Patch Natural Areas Preserve (WA DNR), 2. Black River-Mima Prairie Glacial Heritage Preserve, (Thurston County Parks and Recreation), 3. Scatter Creek Unit of the Scatter Creek Wildlife Area (WA DFW), 4. Artillery impact Zone 1, Joint Base Lewis McChord (US Military), 5. Chambers Lake, Joint Base Lewis McChord (US Military), 6. Bald Hills Natural Area Preserve (WA DNR) 7. Carson area oaks (Gifford Pinchot NF), 8. White Salmon Oaks Natural Resources Conservation Area (WA DNR), 9. Columbia Hills Natural Area Preserve (WA DNR). 10. Badger Gulch Natural Area Preserve (WA DNR).

Figure 2. Scatter plots of Macrolichen Index of Ecological Continuity scores versus A) air scores B) total species richness and C) elevation (ft.).

Table 1. Species used to calculate the Macrolichen Index of Ecological Continuity for oak habitats in Washington.

MIEC indicator species	Old forest indicator (Rose 1976)	Faithful to ancient forests (Selva 1994)	Old-growth obligate (USDA & USDI 2001)	Fire sensitive (Johansson et al. 2006)	Oak associate/obligate (Brodo & Hawksworth 1977, McCune & Geiser 2009, Moberg 2002)
<i>Collema nigrescens</i>		x	x		
<i>Collema quadridum</i>					x
<i>Dendroscopaulon intricatum</i> (oak ecotype)			x		x
<i>Fuscopannaria pacifica</i>			x		
<i>Fuscopannaria pulveracea</i>					x
<i>Leptogium saturninum</i>		x			
<i>Leptogium teretiusculum</i>	x		x		
<i>Lobaria pulmonaria</i>	x	x			
<i>Lobaria scrobiculata</i>	x				
<i>Nephroma bellum</i>			x		
<i>Nephroma laevigatum</i>	x				
<i>Nephroma parile</i>	x				
<i>Normandina pulchella</i>		x			
<i>Placidium fingens</i>					x
<i>Pseudocyphellaria crocata</i>	x				
<i>Ramalina dilacerata</i>				x	
<i>Sticta limbata</i>	x				
<i>Sulcaria badia</i>					x
<i>Unsea diplotypus</i>				x	
<i>Usnea longissima</i>			x		
<i>Waynea californica</i>					x

Table 2. Macrolichens found on *Quercus garryana* at ten sites in our study. For old forest indicator column O= old forest indicator, C=common (Rose 1976). For fire tolerance column I=indifferent to fire, V=vulnerable to fire (Johannson et al. 2006; Bennet 2003).

Lichen Species	Old forest indicator value (Rose 1976)	Old growth indicator (USDA & USDI 2001)	Fire tolerance (Johannson et al. 2006; Bennett 2003)	OR occurrence (Stone 1989; Pike 1971)	BC occurrence (Ryan 1991, Stone and McCune 2010)	Oak obligate (McCune and Geiser, 2009)	Recommended WA Oak MIEC indicator species	Frequency (# of sites)	Comments
<i>Alectoria imshaugii</i>								1	
<i>Alectoria sarmentosa</i>								4	
<i>Alectoria vancouverensis</i>								1	
<i>Bryoria capillaris</i>				1				4	
<i>Bryoria furcellata</i>								1	fewer than 3 sites in Washington
<i>Bryoria fuscescens</i>								1	
<i>Bryoria tortuosa</i>								1	
<i>Candelaria pacifica</i>								3	
<i>Cetraria chlorophylla</i>	C			1				5	
<i>Cetraria orbata</i>				1				2	
<i>Cladonia carneola</i>								1	
<i>Cladonia chlorophaea</i>			I	1				7	
<i>Cladonia coniocraea</i>								1	
<i>Cladonia fimbriata</i>					1			4	
<i>Cladonia furcata</i>				1	1			4	
<i>Cladonia multiformis</i>								1	
<i>Cladonia ocrochlora</i>								3	
<i>Cladonia pyxidata</i>								3	
<i>Collema curtisporum</i>								4	
<i>Collema furfuraceum</i>				1				3	
<i>Collema nigrescens</i>		1		1	1		1	5	WNHP recommended monitoring of rarity
<i>Collema quadrifidum</i>					1	1	1	3	new record for Washington
<i>Dendroscocaulon intricatulum</i>		1					1	1	S1-critically imperiled in Washington
<i>Esslingeriana idahoensis</i>								2	
<i>Evernia prunastri</i>				1				9	
<i>Fuscopannaria aurita</i>								1	
<i>Fuscopannaria pacifica</i>		1					1	1	

Lichen Species	Old forest indicator value (Rose 1976)	Old growth indicator (USDA & USDI 2001)	Fire tolerance (Johannson et al. 2006; Bennett 2003)	OR occurrence (Stone 1989; Pike 1971)	BC occurrence (Ryan 1991, Stone and McCune 2010)	Oak obligate (McCune and Geiser, 2009)	Recommended WA Oak MIEC indicator species	Frequency (# of sites)	Comments
<i>Nephroma bellum</i>		1					1	1	
<i>Nephroma helveticum</i>								4	
<i>Nephroma laevigatum</i>	O		V	1			1	2	
<i>Nephroma parile</i>	O						1	1	
<i>Nephroma resupinatum</i>				1				4	
<i>Nodobryoria abbreviata</i>								1	
<i>Nodobryoria oregana</i>								1	
<i>Normandina pulchella</i>			V	1	1		1	6	
<i>Parmelia barronoae</i>								2	
<i>Parmelia hygrophila</i>								3	
<i>Parmelia sulcata</i>	C		I	1				10	
<i>Parmeliopsis ambigua</i>			I					1	
<i>Peltigera aphthosa</i>								1	
<i>Peltigera collina</i>	O			1			1	10	
<i>Peltigera membranacea</i>								3	
<i>Peltigera ponojensis</i>								1	
<i>Physcia adscendens</i>			I	1				7	
<i>Physcia aipolia</i>			I	1				4	
<i>Physcia caesia</i>								1	
<i>Physcia tenella</i>				1				6	
<i>Physconia americana</i>								7	
<i>Physconia enteroxantha</i>								6	
<i>Physconia perisidiosa</i>								8	
<i>Placidium fingens</i>						1	1	2	new record for Washington
<i>Platismatia glauca</i>	C			1				9	
<i>Platismatia herrei</i>				1				2	
<i>Platismatia wheeleri</i>								1	
<i>Pseudocyphellaria anomala</i>				1				4	
<i>Pseudocyphellaria anthraspis</i>				1				2	
<i>Pseudocyphellaria crocata</i>	O			1				1	state-ranked S3 (vulnerable)
<i>Ramalina dilacerata</i>			V					2	
<i>Ramalina farinacea</i>	C			1				10	

Lichen Species	Old forest indicator value (Rose 1976)	Old growth indicator (USDA & USDI 2001)	Fire tolerance (Johannson et al. 2006; Bennett 2003)	OR occurrence (Stone 1989; Pike 1971)	BC occurrence (Ryan 1991, Stone and McCune 2010)	Oak obligate (McCune and Geiser, 2009)	Recommended WA Oak MIEC indicator species	Frequency (# of sites)	Comments
<i>Sphaerophorus venerabilis</i>								1	
<i>Sticta fuliginosa</i>				1				3	
<i>Sticta limbata</i>	O		V	1				4	
<i>Usnea cavernosa</i>			V					1	fewer than 3 sites in Washington
<i>Usnea cf. diplotypus</i>			I					1	
<i>Usnea filipendula</i>				1				4	
<i>Usnea flavocardia</i>								5	
<i>Usnea fulvovirens/glabrescens</i>								3	
<i>Usnea glabrata</i>								5	
<i>Usnea lapponica</i>								2	
<i>Usnea longissima</i>		1		1				2	state-ranked S2 (imperiled)
<i>Usnea scabrata</i>								6	
<i>Usnea subfloridana</i>	C			1				1	
<i>Usnea wasmuthii</i>								7	
<i>Waynea californica</i>						1		2	third record for Washington
<i>Xanthomendoza fulva</i>								3	
<i>Xanthomendoza galericulata</i>								1	
<i>Xanthomendoza hasseana</i>			I					1	
<i>Xanthomendoza montana</i>								3	
<i>Xanthoria polycarpa</i>				1				8	

Table 3. Macrolichen Index of Ecological Continuity (MIEC) scores and ecological correlates for our ten study sites. For the fire history column t.s.f. = time since fire. Sources for data on fire history were provided by the following land managers or in the literature: David Wilderman (Badger Gulch, Bald Hills), David Hayes (Scatter Creek), Rod Gilbert and Jeffery Foster (JBLM Impact Zone and Chambers Lake), Sarah Hamman (Glacial Heritage), Kertis, 1986 (Oak Patch NAP); Dunagan, 1999 (Oak Patch NAP).

Site	MIEC Score	Total No of MIEC indicator species	Total Species Number	Cyanolichen species richness	Proportion of cyanolichens (%)	CMAQ (n_kgha) scores	Air Quality scores	Annual Precipitation (cm)	Min/Max August temp °F average 1971-2000	Distance to major metropolitan city (miles)	Fire history	Oak stand structure
Glacial Heritage NAP	14	2	30	3	10	6.543	N/A	1313.6	34/ 77	62	prescribed fire, t.s.f. ~7 years	riparian oak woodland/prairie
Scatter Creek	21	3	30	4	13	9.001	0.59 (poor)	1249.7	33/ 78	62	prescribed fire, t.s.f. ~2 years	oak woodland/prairie
Badger Gulch	21	3	26	4	15	2.323	0.46 (poor)	399.4	27/ 79	104	t.s.f. >50 years	oak woodland/bald
JBLM Impact Zone	29	4	36	5	14	6.609	0.37 (poor)	1090	33/ 75	41	prescribed fire, t.s.f. ~5 years	oak woodland/prairie
White Salmon Oaks	43	6	49	13	27	4.343	0.11 (poor)	817.6	28/ 80	62	fire history unknown	oak woodland/bald
JBLM Chambers Lake	43	6	31	11	35	7.004	N/A	1071.8	33/ 75	40	t.s.f. >20 years	oak woodland/prairie bordering lake
Oak Patch NAP	50	7	40	15	38	4.604	0.099 (fair)	1847.8	34/ 76	29	t.s.f. >13 years	oak/conifer mosaic
Bald Hills NAP	57	8	30	8	27	12.606	N/A	1028.5	33/ 78	52	t.s.f. >100 years	oak woodland/bald
Columbia Hills	57	8	48	15	31	3.451	0.1 (poor)	635.8	24/ 78	80	fire history unknown	oak woodland
Carson Oaks GPNF	100	15	53	24	45	5.722	N/A	2412.7	29/ 81	47	fire history unknown	oak/conifer mosaic