2014

Biodiversity of Corticolous Macrolichens in a Selected Northeastern Indiana Forest and Implications for Conservation

Margaret L. (Gray) Kubina

BIODIVERSITY OF CORTICOLOUS MACROLICHENS IN A SELECTED NORTHEASTERN INDIANA FOREST AND IMPLICATIONS FOR CONSERVATION

by

Margaret L. Gray

A thesis submitted in partial fulfillment
of the requirements for the degree
MASTER OF ENVIRONMENTAL SCIENCE

Taylor University
Department of Earth and Environmental Science
Upland, Indiana

August 20, 2014

Approved by:

____

Robert T. Reber, MSF
Committee Chair
Asst. Professor of Environmental Science
Taylor University

____

Paul E. Rothrock, Ph.D.
Committee Member
Professor of Biology/Environmental Science
Graduate Program Director
Taylor University

____

Ray E. Showman,
Committee Member
Lichenologist
McArthur, Ohio

____

William E. Toll, Ph.D.
Dean
School of Natural and Applied Sciences
Taylor University

ABSTRACT

The hardwood forests of Indiana are experiencing a decline in oak (*Quercus*) regeneration. Most forests are undergoing sugar maple (*Acer saccharum*) replacement in the understory. This dynamic is of concern because of the potential decline in total species diversity in these forests. Lichens can be valuable indicators of forest health; however, they are not included in Indiana's forest health monitoring program. An analysis of lichen biodiversity was conducted at Salamonie River State Forest (SRSF) in Wabash County, Indiana. The objectives of this study were to survey the current lichen biodiversity within SRSF in northeastern Indiana and to evaluate a potential shift in lichen diversity due to the maple growth in forests with an oak-dominant canopy. Additional questions related to the dependence of lichen richness and coverage on bark crevice depth, tree diameter, and a soil moisture gradient were addressed.

A total of 11 species of corticolous macrolichens were identified in the study. The shade-tolerant lichen, *Phaeophyscia rubropulchra*, was found in the highest abundance in each plot and on sugar maples. There is the potential for *P. rubropulchra* to outcompete other lichen species. Mean lichen richness and coverage were significantly higher in upland sites. A general regression analysis revealed as the mean bark crevice depth increased, the mean lichen coverage decreased. Tree diameter was not a statistically significant variable. An R^2 value of 15.5% indicated that more factors were at work determining lichen coverage and diversity than those included in this study. Overcrowding in the understory by sugar maples reduces the light intensity which may explain the decline in lichen diversity and coverage on the trunks of oak species. Silvicultural treatments such as the thinning of sugar maples and the opening of gaps in the forest canopy could help increase the biodiversity of lichens in the forest and promote overall forest health.

INTRODUCTION

Indiana forests located in the Eastern Deciduous Forest have undergone many decades of human-induced disturbance. Before Euro-American settlers arrived in the early 19th century, Native American peoples had altered the landscape (Jackson 1997). Fire was the tool used to clear trails and small-scale agricultural plots (Jackson 1997). The first settlers of Indiana employed many of the Native Americans' forest clearing practices, but eventually the increase in settlement induced large-scale clearing of land for timber, pasture, agricultural land, and more living space (Jackson 1997). By the 1900s, most of the forested land suitable for farming had been converted to agricultural land (Jackson 1997). As a result of continued human-induced disturbance, oak (*Quercus*) species dominated the canopies of regenerating, shade-intolerant forests. Forest species such as sugar maple (*Acer saccharum*) and tulip poplar (*Liriodendron tulipifera*) were unable to survive the periodic fires and the soil compaction from grazing livestock (Jackson 1997; IDNR 2008).

Currently, the oak forests are declining, which is of particular concern to Indiana foresters (IDNR 2008). For more than thirty years, there has been a decline in timber harvesting and changes in timber harvesting methods. These changes in conjunction with the suppression of wildfires for more than 150 years has led to low-light conditions not conducive to oak and hickory (*Carya*) species seedling growth and survival (IDNR 2008). This has led to a substantial increase in sugar maple in the understory which does not allow for oak regeneration. Oak species are essential to the current forest structure. Their loss in the community would "directly and indirectly affect multitudes of species, reduce native biodiversity, and generally drive community-level shifts and alterations" (IDNR 2008). Consequently, the Division of Forestry has recommended specific management techniques to encourage and promote oak-hickory regeneration (IDNR 2008). The Division of Forestry owns and operates approximately 3% of forested lands in Indiana. Of all forested land, 75% is privately owned, 49% of which is categorized as oak-hickory dominant (IDNR 2008). While 80% of the upper canopy in the oak-hickory forests is dominated by oak and hickory species, approximately 11% of the understory is experiencing oak and hickory regeneration (IDNR 2008). This uneven-aged forest structure could have a negative impact on forest composition, plant and wildlife biodiversity, and the timber industry if management practices encouraging oak reproduction in the understory are not implemented quickly (IDNR 2008).

Salamonie River State Forest (SRSF), located in Wabash County along the Salamonie River, is on land originally cleared for agricultural purposes. SRSF was converted from farm and grazing land to forest when the Civilian Conservation Corps (CCC) was commissioned in the early 1930s to undertake its planting and restoration (Mancini and Cairns 1998). The CCC planted SRSF with many types of readily-available trees such as white pine (*Pinus strobus*) and sweet gum (*Liquidambar styraciflua*), not necessarily native to northeastern Indiana (personal communication with Hank Hefner, SRSF). Since its reforestation, SRSF has been managed by the Indiana Department of Natural Resources Division of Forestry. While some areas continue to be dominated by white pine in the canopy, most of the forest consists of an oak-hickory canopy with sugar maple regeneration in the understory. This study site provides a model habitat for monitoring the potential impact of declining oak populations on the overall biodiversity of the forest, and on lichens specifically.

The Division of Forestry has begun a monitoring program of state forestland, including SRSF, for signs of decline in ecosystem health as a result of increasing density of sugar maple. The Division of Forestry's Environmental Assessment provides a lengthy list of species included on Indiana's list of Greatest Conservation Need. These species could be impacted by the coming decline in oak species (IDNR 2008). However, one organism not included on the list was lichens. Lichens have been documented as bioindicators of ecosystem health in many recent studies (McCune 2000; Brodekova et al. 2006; Thormann 2006; Jovan 2008; Moning et al. 2009; Nag et al. 2011; Paltto et al. 2011; Svoboda et al. 2011). The inclusion of lichens in the IDNR's Environmental Assessment would provide additional insight into future forest management decisions.

Approximately 18,800 lichen species have been identified worldwide (Lattman 2010), with new species being discovered every year. Lichens are found in a variety of shapes and sizes. They are principally classified into three groups according to their growth form: crustose, foliose, and fruticose. Foliose and fruticose lichens also are grouped together as macrolichens. Lichens provide several biological benefits to other organisms. Lichens often act as pioneer species, arriving first to sterile environments to assist in the breakdown of rocks and establish nutrients in the soils. This allows other early successional plant species to colonize the area (Brodo et al. 2001). Many insects use lichens as camouflage, while hummingbirds regularly use lichen fragments to construct and camouflage their nests (Brodo et al. 2001). Several microscopic invertebrates and macroscopic coleopterans use lichens as shelter and as a food source. Tardigrades (water bears) are a type of microscopic invertebrate that live within lichen microhabitats (Nichols 2005). In more northern biomes, moose, caribou, deer, reindeer, and musk oxen are common foragers of lichens, especially in the winter when other food sources are scarce (Brodo et al. 2001). Humans also have utilized lichens for thousands of years by preparing dyes from the various chemical compounds produced by these organisms (Brodo et al. 2001).

Some indigenous tribes in North America, Russia, and Africa even use some lichen species for food (Brodo et al. 2001).

While lichens are a valuable resource for many organisms, its value to humans as a bioindicator of environmental health (McCune 2000) should not be overlooked. Lichens are highly dependent on moisture and light for their photosynthetic function, growth, and ultimate survival (McCune 2000). They are able to colonize various substrates, including "tree bark, wood, rock, soil, leaves, peat, mosses, and other lichens" (Thormann 2006). The nonvascular characteristics of these organisms enhance their sensitivity to changes in climate and ecosystem structure (i.e. air pollution, climate change, forest structure, or natural and man-made disturbances) (McCune 2000; Brodo et al. 2001). They are ideal bioindicators for environmental quality assessments. Recent studies have shown the dependent relationship select lichen species have with continuous tracts of old oak forests (Ranius et al. 2008b; Lattman 2010; Paltto et al. 2011). Habitat loss, forest fragmentation, and the increase in shade-tolerant tree species threaten the biodiversity of lichens in oak-dominant forests around the world (Esseen and Renhorn 1998; Ranius et al. 2008b; Moning et al. 2009; Lattman 2010; Paltto et al. 2011). Other correlating factors to lichen abundance on old oaks are the bark crevice depth and competition with existing bryophytes (Ranius et al. 2008b). As oaks age, their bark becomes more creviced allowing for a more suitable habitat for lichen colonization. Older oak trees provide a long-term substrate for lichen colonization, growth, and reproduction to occur (Ranius et al. 2008b). This illustrates the importance of maintaining these forests. If oak-dependent lichens are unable to colonize oak species because of unsuccessful oak regeneration, the biodiversity of the lichen community will decline (Ranius et al. 2008b). Monitoring of lichen populations is necessary to determine the lasting impacts of disturbance on the forest structure and function. Documenting current populations will allow for assessment of future forest management on lichen biodiversity and overall forest health to be assessed (Moning et al. 2009; Svoboda et al. 2010; Nag et al. 2011; Johansson et al. 2012).

Lichens have been used to evaluate the impacts of air pollution, timber harvesting, fires, industrial encroachment, and changes in canopy composition (Thormann 2006). The US Forest Service has developed a standard lichen biodiversity sampling protocol which is included in the Forest Health Monitoring Program's assessments of overall forest health (McCune 2000; Jovan 2008). There is an increasing concern over the changing forest composition in the Eastern Deciduous Forest. Lichen biodiversity studies can provide valuable insight into the relationship and dependence of these organisms on their oak substrates. They also can serve as an indicator of ecosystem disturbance.

The principal objective of this study was to survey the current lichen biodiversity within SRSF in northeastern Indiana. The results were analyzed in light of the potential increased maple recruitment in Indiana forests. Additional questions related to the dependence of lichen growth on bark crevice depth, lichen substrate specificity, and lichen abundance due to microtopography also are addressed in the analysis.

MATERIALS AND METHODS

Field Methods:

Salamonie River State Forest, a site experiencing minimal human-induced disturbances during the past 80 years, was chosen as the study site. SRSF is an 850-acre mixed hardwood forest (N 40˚48'44.5684", W 85˚41'45.9814"). The soils in the SRSF are comprised of glacial till parent material (United States Department of Agriculture 1983; Indiana Geological Survey 2011). Seven randomly-selected sampling plots were located within the state forest boundaries

(Figure 1). The center point of each sampling plot was recorded using a Garmin® GPSMAP® 62 handheld unit. Using a modified version of the US Forest Inventory and Analysis sampling method (Jovan 2008), each plot was constructed using a 20-meter radius (a total of 1,256 m^2). Photographs of each plot were taken at angles of 0, 90, 180, and 270 degrees from the center (Appendix A).

Every tree within the plot with a diameter breast height (dbh) over 13 cm was included in the lichen biodiversity survey. Thirteen centimeters was the minimum dbh required to cover all four cardinal directions when using a 10 x 10 cm sampling area for calculating percent lichen coverage. The species and location of each tree was recorded. The location of each tree relative to the center of the plot was determined by distance from the center point and angle from true north (field readings were adjusted for declination). The bark crevice depth was measured on the north side of each tree at heights of 0.5 meters, 1.0 meter, 1.5 meters, and 2.0 meters, and then the values were averaged. Lichen species were identified around the circumference of each tree from a height of 0.5 meters to 2.0 meters to avoid including terricolous lichens (Jovan 2008). Any unknown lichens were collected and later identified under a dissecting microscope. Identification of macrolichens was conducted using Brodo et al. (2001) and Showman and Flenniken (2004). Nomenclature followed the North American Lichen Checklist (Esslinger 2014).

The percent lichen coverage for each lichen species was recorded using a modified version of the method prescribed by Ranius et al. (2008b). A clear, plastic 10 x 10 cm square divided into centimeter squares was used to calculate the percent lichen coverage on each tree. The square was placed at a height of approximately 1.5 meters and then moved until lichen coverage data had been recorded for the entire circumference of the tree at that height. Lichen coverage for each species was determined by counting the number of lichens in the one centimeter squares down to the half-square level.

Data Analysis:

The estimated lichen coverage for each tree sampled was determined. Percent coverage was calculated for each lichen species per tree by using the data obtained from using the plastic square method. These values for each lichen species present on a tree were collected individually and then combined for the total percent lichen coverage per tree. Bar graphs depicting species richness of lichens were created for the moisture gradients and for sugar maples and oak species. Each sampling plot was assigned a moisture gradient classification of 'upland', 'lowland', or 'midland' depending on qualitative observations made during sampling. Increasing moisture in a site can influence lichen species richness and coverage (Harris 1972). Of the seven sampling plots, two were designated as upland (Sites 1 and 5), two were midland (Sites 3 and 6), and three were classified as lowland (Sites 2, 4, and 7).

Two separate analysis of variance tests were run to determine whether mean crevice depth and diameter breast height were influenced by tree species. The results of these tests were used to build a general regression model for lichen coverage. A general regression model was constructed to analyze the impact of mean crevice depth, diameter breast height, and moisture gradient classification on percent lichen coverage. A t-test was used to determine whether significant differences were present in lichen richness and percent coverage between sugar maples and oak species. Non-parametric Kruskal-Wallis tests were conducted to determine the effect of the moisture gradient on lichen coverage and richness. Kruskal-Wallis analyses were used after one-way analysis of variance tests failed to meet the equality of variance test.

RESULTS

Eleven species of macrolichens were recorded on 18 different tree species in the sampling plots at SRSF (Table 1). All 11 species were encountered in the lowland sites, but only 5 were found in the upland sites (Figure 4a). Six species were documented in the transitional sites (Figure 4a). The overall lichen richness was highest in the lowland sites. The upland sites averaged more lichen species per tree (expressed as mean lichen richness) than the lowland or transitional sites (Figure 4b). A comparison of lichen richness on sugar maple and oak species revealed higher overall lichen richness and mean lichen richness on sugar maple. Ten lichen species were found on sugar maple with a mean richness of 2.5. Five lichen species were recorded on oak species with a mean richness of 1.5 (Figures 6a and 6c).

In this study, *Phaeophyscia rubropulchra* was the principal lichen encountered, appearing 202 times out of 434 recorded lichen encounters (47% of the time) (Table 2 and Figure 2). This lichen occurred on 202 of 309 trees (65% of the trees) (Table 3 and Figure 3).

On the upland sites, the mean lichen coverage was 3.5% (Figure 4c). Coverage was significantly lower in the transitional and lowland sites, with mean percentages of 2.0% and 2.5%, respectively (Figure 4c). The mean lichen coverage also was significantly higher on sugar maples (6.7%) than on oak species (2.3%) (Figure 6b).

Separate background analysis of variance tests for tree species versus dbh and tree species versus mean crevice depth were conducted. There was a significant relationship between dbh ($p < 0.001$; DF = 17) and crevice depth to tree species ($p < 0.001$; DF = 17). To avoid confounding variables, the ‘tree species’ variable was not included in the general regression model.

The moisture gradient and mean crevice depth correlated with the percent lichen coverage (Table 4). The upland class had a larger constant than the other gradient classes and was separated in the general regression output. The upland class attained a p-value less than 0.001, while the lowland and transitional classes had a p-value of 0.007. Mean crevice depth had a p-value of less than 0.001. Diameter breast height was not a significant variable in this model ($p = 0.208$). The R^2 value for this model was only 15.5%.

Sugar maples attained significantly higher lichen richness than the five oak species observed ($p < 0.001$; T-value = 5.34; DF = 95). The 80 sugar maples sampled had an average richness of 2.5 while the 50 oak trees sampled had an average richness of 1.5. Sugar maple also had a significantly higher coverage ($p < 0.001$; T-value = 6.41; DF = 124). Sugar maples averaged 6.7% coverage compared to only 2.3% on oaks.

Analysis of the lichen richness and coverage along a moisture gradient required a Kruskal-Wallis non-parametric test. Results from the analysis of lichen richness had a median of 2.0 lichen species for upland sites and a median of 1.0 lichen species for the transitional and lowland sites ($p < 0.001$) (Table 6). Median values of lichen coverage were 1.4%, 0.3%, and 0.3% for the upland, transitional, and lowland sites, respectively ($p < 0.001$) (Table 5).

DISCUSSION

The lichen biodiversity recorded on tree trunks in SRSF was higher than expected given the geographic location and historic disturbances of the study site. Approximately twenty species of macrolichens are expected to be found in northeastern Indiana based on the number of species recorded in similar glacial till regions of northwestern Ohio (Showman and Flenniken 2004). The eleven corticolous macrolichen species found within this shaded forest community that has a history of disturbance reflects positively on the current forest health of SRSF. It should be noted that the tree species with the greatest lichen richness was sugar maple, with ten species of macrolichen recorded during this study.

Although the overall lichen richness was higher than expected, the dominance of *Phaeophyscia rubropulchra* should not be overlooked. This shade-tolerant macrolichen was encountered 47% of the time (recorded 202 times out of 427 total lichen data points) and occurred on 65% of trees in the study (Figures 2 and 3). These values are more than twice the coverage of the next-most-abundant lichen species, *Candelaria concolor*, which had an encounter rate of 17% (Figure 2). The average percent coverage for *P. rubropulchra* along a moisture gradient was 3.5% for upland sites, 2.6% on transitional sites, and 3.8% for lowland sites (Figure 5a). This species had high coverage on sugar maples throughout all sampling plots (Figure 6c). The dominance of *Phaeophyscia rubropulchra* in SRSF (and more specifically on shade-tolerant maples) may lower the biodiversity of lichens over time if the forest continues succession from an oak-dominant to a sugar maple-dominant canopy (Paltto et al. 2011). The current data on lichen biodiversity in SRSF only provides a snapshot of the community making it difficult to predict the future lichen biodiversity of this area. Additional studies are necessary to track the changes of the macrolichen community over time as the forest canopy structure changes.

The mean lichen richness and coverage values were significantly higher in the upland sites compared to the transitional and lowland sites. When comparing the percent coverage of different lichen species, there were statistically significant differences along the moisture gradient (Figures 5a-c). This may indicate species-specificity based on the moisture gradients and other abiotic factors not measured in this study (Schmitt and Slack 1990). From the results of the general regression model these values declined as crevice depth increased. Diameter breast height did not significantly influence lichen coverage for the general regression model used. Qualitative observations of litterfall indicate a diverse lichen community in the canopy with *Flavoparmelia caperata* (pollution-intolerant species), *Punctelia caseana*, and *Punctelia rudecta* being observed. Due to the limited scope of the sampling method these established lichen populations were not quantified. A potentially higher biodiversity could be present in the canopy, but the crowded understory may prevent vegetative propagules and sexual spores from dispersing successfully on lower branches and on the trunks (Paltto et al. 2011). This could explain the observed decline in richness as crevice depth increased; crevice depth is associated with older trees (Ranius et al. 2008b). It also is possible the older trees are not yet old enough to have allowed sufficient time for the establishment of old growth lichen populations (Ranius et al. 2008b). In the study by Ranius et al (2008b), frequency of crustose lichen occurrence was significantly higher on trees 100 years of age or older than on those under 100 years old.

The R^2 value of 15.5% obtained from the general regression model indicates that crevice depth and access to moisture only modestly predict lichen richness. Several abiotic factors not accounted for in this study design also may have contributed to the noticeable differences in richness and coverage between the upland sites and the other gradient categories. Perhaps the most important factor is light intensity. While access to moisture plays a vital role in lichen growth and development, the amount of light available to lichens impacts their ability to photosynthesize at an optimal rate (Harris 1972). While the lowland sites may have provided more moisture than the upland sites, a greater light intensity in the upland sites could explain the significantly higher mean richness and coverage values. Other potential factors include the age of the forest community, microsite conditions, and the rate of primary productivity (plant growth). As the forest community ages, the continued presence of older oak trees will provide stable habitat for crustose lichens to colonize (Ranius et al. 2008b). Given the relatively young age of SRSF, the low biodiversity of lichens on the oak species sampled has the potential to increase with time. Microsite conditions such as rain tracks on tree trunks (Ranius et al. 2008b), bark pH (Bates 1992), bark hardness (Culberson 1955), bark eutrophication as a result of agriculture (Loppi and Dominicis 1996), or the reduced light conditions as a result of high rates of plant growth also have the potential to impact the lichen richness and coverage within SRSF. Including these variables in future studies would provide a more holistic view of how lichen biodiversity is determined by the ecosystem.

The sugar maples at SRSF recorded higher lichen richness and coverage than the oak species. This result is surprising based upon the decline in lichen biodiversity on oaks recorded in other studies as a result of understory growth in oak pastures (Paltto et al. 2010; Paltto et al. 2011), historical habitat density (Ranius et al. 2008a), or tree age (Ranius et al. 2008b; Claesson 2009; Johansson et al. 2009; Svoboda et al. 2010). Most of these studies focused on endangered or threatened crustose lichen species. The results from these studies are from lichens and conditions much different from this study. It should be noted, however, that qualitative observations of the oak species in this study revealed a relatively high occurrence of the dust lichen, *Lepraria lobificans*, in the bark crevices. It is possible that as the oaks at SRSF continue to age, the biodiversity and abundance of crustose lichens will increase as well (Ranius et al. 2008a; Claesson 2009; Johansson et al. 2009; Paltto et al. 2010; Svoboda et al. 2010; Paltto et al. 2011).

Based upon the results of this study, no direct implications on forest management can be made. However, continuing the oak regeneration forest management efforts as proposed by the IDNR Division of Forestry cannot be understated. Thinning of sugar maples and opening up gaps in the canopy will allow sunlight to reach the forest floor and promote lichen biodiversity and indirectly promote the overall health of SRSF. Additional forest management practices recommended by other studies that could be incorporated into the Division of Forestry's management plan include: protecting old oaks in the canopy (Neitlich and McCune 1997), promoting stand continuity (Boch et al. 2013), and promoting the presence and success of native deciduous tree species (Root et al. 2010). Allowing old oaks to thrive in the canopy will provide a long-living, stable substrate on which more lichen species can colonize over time (Ranius et al. 2008b). Preventing fragmentation of the forest also will provide continuous tracts of forest required by some lichen species (Boch et al. 2013). Active replacement of white pine (*Pinus strobus*) trees after death with native hardwoods also would encourage the development of a native and biodiverse lichen community within SRSF. Combined use of each of these forest management methods will enhance the lichen biodiversity at SRSF and indirectly promote a healthier forest ecosystem.

CONCLUSION

The overall, relatively high lichen biodiversity of Salamonie River State Forest and its implications for the health of the forest community were overshadowed by the dominance of *Phaeophyscia rubropulchra* throughout the entire sampling area. The significantly higher coverage of this species has the potential to lower the biodiversity of the lichen community when the presence of sugar maples in the understory shifts to a maple-dominant canopy. Low biodiversity on oak species may be due to the young age of the forest (approximately 80 years) and the limited sampling parameters of this study. High richness and coverage in the upland sites may be better explained by an expanded model which could include more abiotic factors. Light intensity, forest age, microsite conditions, and the abundance of other vegetation are variables that should be considered. Further studies incorporating these factors would allow for better monitoring of changes in the lichen community.

Based on the results of this study, no direct implications on forest management can be made. However, given the current shift in canopy structure, foresters at SRSF should continue their management efforts involving sugar maple thinning and opening of gaps in the forest canopy. It also is recommended that practices such as maintaining stand continuity, keeping old oaks in the canopy, and replacing white pine with native hardwoods be incorporated into the management plan for SRSF. These silvicultural techniques can help enhance the lichen richness and coverage in the forest and indirectly boost the health of the forest community.

ACKNOWLEDGEMENTS

Many thanks are due to my thesis committee, Professor Robert Reber, Dr. Paul Rothrock, and Ray Showman, for their significant input on the development, analysis, and revision of this research project. A huge thank you also is due to Ray Showman who was willing to teach me the lichen identification skills that made this research possible. Thank you to the Indiana Department of Natural Resources Division of Forestry for providing sampling permits and access to Salamonie River State Forest. Many thanks go out to Dr. Ken Constantine for his guidance and input on the statistical analysis. I also would like to extend my sincere appreciation to Brandon Gray and Katharine Hogan for their substantial assistance with data collection.

LITERATURE CITED

Bates JW. 1992. Influence of chemical and physical factors on *Quercus* and *Fraxinus* epiphytes at Loch Sunart, Western Scotland: a multivariate analysis. Journal of Ecology 80(1):163-179.

Boch S, Prati D, Hessenmoller D, Schulze E-D, and Fischer M. 2013. Richness of lichen species, especially of threatened ones, is promoted by management methods furthering stand continuity. PLoS One 8(1):1-10.

Brodekova L, Gilmer A, Dowding P, Fox H, and Guttova A. 2006. An assessment of epiphytic lichen diversity and environmental quality in Knocksink Wood Nature Reserve, Ireland. Biology and Environment: Proceedings of the Royal Irish Academy 106(3):215-223.

Brodo I, Sharnoff SD, and Sharnoff S. 2001. Lichens of North America. New Haven (CT): Yale University Press. 828 p.

Claesson C. 2009. Epiphytes on oaks: lichens in oak-dominated forest are favoured by partial cutting. Master's Thesis, University of Gothenburg, Gothenburg, Sweden.

Culberson WL. 1955. The corticolous communities of lichens and bryophytes in the upland forests of northern Wisconsin. Ecological Monographs 25(2): 215-231.

Esseen PA and Renhorn KE. 1998. Edge effects on an epiphytic lichen in fragmented forests. Conservation Biology 12(6):1307-1317.

Esslinger TL. 2014. A cumulative checklist for the lichen-forming, lichenicolous and allied fungi of the continental United States and Canada. North Dakota State University, Fargo, North Dakota.

Harris GP. 1972. The ecology of corticolous lichens: III - a simulation model of productivity as a function of light intensity and water availability. The Journal of Ecology 60(1):19-40.

Indiana Department of Natural Resources Division of Forestry (IDNR). 2008. Indiana State Forests: Environmental Assessment 2008-2027. 147 p.

Indiana Geological Survey. 2011. Indiana University, Bloomington, Indiana. www.igs.indiana.edu.

Jackson, MT. 1997. The Natural Heritage of Indiana, Quarry Books. 512 p.

Johansson V. 2012. Distribution and persistence of epiphyte metapopulations in dynamic landscapes. Doctoral Thesis, Department of Ecology, Swedish University of Agricultural Sciences, Uppsala, Sweden.

Johansson V, Ranius T, and Snall T. 2012. Epiphyte metapopulation dynamics are explained by species traits, connectivity, and patch dynamics. Ecology 93(2):235-241.

Johansson V, Bergman K O, Lattman H, and Milberg P. 2009. Tree and site quality preferences of six epiphytic lichens growing on oaks in southeastern Sweden. Annales Botanici Fennici 46:496-506.

Jovan S. 2008. Lichen bioindication of biodiversity, air quality, and climate: baseline results from monitoring in Washington, Oregon, and California. United States Department of Agriculture, Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-737.

Lattman H. 2010. Studies on spatial and temporal distributions of epiphytic lichens. Linkoping Studies in Science and Technology Dissertation thesis number 1310, Linkoping University, Linkoping, Sweden.

Loppi S and Dominicis VD. 1996. Effects of agriculture on epiphytic lichen vegetation in central Italy. Israel Journal of Plant Sciences 44(4): 297-307.

Mancini R and Cairns M. 1998. Conserving the corps: a conditions assessment of civilian conservation corps resources in SRSF Wabash County, Indiana. Master's Thesis, Department of Architecture, Ball State University, Muncie, Indiana.

McCune B. 2000. Lichen communities as indicators of forest health. The Bryologist 103(2):353-356.

Moning C, Werth S, Dziock F, Bassler C, Bradtka J, Hothorn T, and Muller J. 2009. Lichen diversity in temperate montane forests is influenced by structure more than climate. Forest Ecology and Management 258:745-751.

Nag P, Rai H, Upreti D K, Nayaka S, and Gupta R K. 2011. Epiphytic lichens as indicator of land-use pattern and forest harvesting in a community forest in west Nepal. Botanic Orientalis-Journal of Plant Science 8:24-32.

Neitlich PN and McCune B. 1997. Hotspots of epiphytic lichen diversity in two young managed forests. Conservation Biology 11(1):172-182.

Nichols PB. 2005. Tardigrade evolution and ecology. Theses and Dissertations, Paper 794. Doctoral Thesis, Department of Biology, University of South Florida, Tampa, Florida.

Paltto H, Nordberg A, Norden B, and Snall T. 2011. Development of secondary woodland in oak wood pastures reduces the richness of rare epiphytic lichens. PLoS ONE 6(9).

Paltto H, Thomasson I, and Norden B. 2010. Multispecies and multiscale conservation planning: setting quantitative targets for red-listed lichens on ancient oaks. Conservation Biology 24(3):758-768.

Ranius T, Eliasson P, and Johansson P. 2008a. Large-scale occurrence patterns of red-listed lichens and fungi on old oaks are influenced by both current and historical habitat density. Biodiversity and Conservation 17:2371-2381.

Ranius T, Johansson P, Berg N, and Niklasson M. 2008b. The influence of tree age and microhabitat quality on the occurrence of crustose lichens associated with old oaks. Journal of Vegetation Science 19:653-662.

Root HT, McCune B, and Neitlich P. 2010. Lichen habitat may be enhanced by thinning treatments in young *Tsuga heterophylla-Pseudotsuga menzeisii* forests. The Bryologist 113(2):292-307.

Schmitt CK and Slack NG. 1990. Host specificity of epiphytic lichens and bryophytes: a comparison of the Adirondack Mountains (New York) and the Southern Blue Ridge Mountains (North Carolina). The Bryologist 93(3):257-274.

Showman RE and Flenniken DG. 2004. Macrolichens of Ohio. Ohio Biological Survey.

Svoboda D, Peksa O, and Vesela J. 2010. Epiphytic lichen diversity in central European oak forests: assessment of the effects of natural environmental factors and human influences. Environmental Pollution 158:812-819.

Thormann M. 2006. Lichens as indicators of forest health in Canada. The Forestry Chronicle 82(3):335-343.

United States Department of Agriculture, 1983. Soil Conservation Service. Soil Survey of Wabash County, Indiana.

TABLES AND FIGURES

Table 1. List of recorded tree species and lichen species at Salamonie River State Forest. Species of statistical and ecological significance are bolded.

Tree Species (18)	Lichen Species (11)
Red Maple (*Acer rubrum*)	*Candelaria concolor*
Sugar Maple (*Acer saccharum*)	***Flavoparmelia caperata***
Northern Hackberry (*Celtis occidentalis*)	*Parmelia sulcata*
American Beech (*Fagus grandifolia*)	*Parmotrema hypotropum*
Black Walnut (*Juglans nigra*)	*Phaeophyscia pusilloides*
Tulip Poplar (*Liriodendron tulipifera*)	***Phaeophyscia rubropulchra***
Osage Orange (*Maclura pomifera*)	*Physcia millegrana*
Eastern White Pine (*Pinus strobus*)	*Physcia stellaris*
American Sycamore (*Platanus occidentalis*)	*Physconia detersa*
Wild Black Cherry (*Prunus serotina*)	*Punctelia caseana*
White Oak (*Quercus alba*)	*Punctelia rudecta*
Swamp White Oak (*Quercus bicolor)*	
Rock Chestnut Oak (*Quercus prinus*)	
Red Oak (*Quercus rubra*)	
Black Oak (*Querus velutina*)	
Basswood (*Tilia americana*)	
American Elm (*Ulmus americana*)	
Slippery Elm (*Ulmus rubra*)	

Table 2. List of overall lichen species occurrences as percents.

Lichen Species	Name	Percent	N
CACO64	Candelaria concolor	17	72
FLCA2	Flavoparmelia caperata	<1	2
PAHY7	Parmotrema hypotropum	<1	1
PASU63	Parmelia sulcata	3	12
PHDE61	Physconia detersa	<1	1
PHMI15	Physcia millegrana	9	40
PHPU18	Phaeophyscia pusilloides	13	55
PHRU4	Phaeophyscia rubropulchra	47	202
PHST60	Physcia stellaris	<1	1
PURU2	Punctelia caseana	9	40
PUSU5	Punctelia rudecta	<1	1
	Total		427

Table 3. List of lichen species occurrences along the moisture gradient with total occurrences.

	Moisture Gradients			
Lichen Species	Lowland	Intermediate	Upland	Total
CACO4	39	4	29	72
FLCA2	0	1	2	3
PASU63	0	0	12	12
PAHY7	0	0	1	1
PHPU18	35	0	20	55
PHRU4	83	55	64	202
PHMI15	22	13	5	40
PHST60	0	1	0	1
PHDE61	0	1	0	1
PUSU5	9	24	7	40
PURU2	0	0	1	1
Total	189	101	144	

Table 4. Statistical output of general regression for square root of lichen coverage (percent) versus diameter breast height, mean crevice depth, and moisture gradient.

General Regression Analysis: sqrt Percent Lichen Coverage versus dbh, Mean Crevice Depth, Gradient

Regression Equation

Gradient

1 sqrtLC = 2.29372 - 0.00761724 dbh - 0.608964 MeanCD

2 sqrtLC = 1.61252 - 0.00761724 dbh - 0.608964 MeanCD

3 sqrtLC = 1.69577 - 0.00761724 dbh - 0.608964 MeanCD

Coefficients

Term	Coef	SE Coef	T	P
Constant	1.86734	0.167478	11.1497	0.000
Gradient				
1	0.42639	0.091934	4.6380	0.000
2	-0.25482	0.093015	-2.7395	0.007
dbh	-0.00762	0.006033	-1.2626	0.208
MeanCD	-0.60896	0.127261	-4.7852	0.000

Summary of Model

S = 1.07361 R-Sq = 15.52% R-Sq(adj) = 14.41%

PRESS = 361.156 R-Sq(pred) = 12.93%

Table 5. Statistical output from Kruskal-Wallis nonparametric test for mean lichen coverage (percent) versus moisture gradient.

Kruskal-Wallis Test: LC% versus Gradient

Kruskal-Wallis Test on LC%

Gradient	N	Median	Ave Rank	Z
1	101	1.3846	182.7	3.80
2	94	0.2636	134.9	-2.61
3	114	0.3091	147.0	-1.21
Overall	309		155.0	

H = 15.40 DF = 2 P = 0.000
H = 15.86 DF = 2 P = 0.000 (adjusted for ties)

Table 6. Statistical output from Kruskal-Wallis nonparametric test for mean lichen richness versus moisture gradient.

Kruskal-Wallis Test: No. Lichen versus Gradient

Kruskal-Wallis Test on No. Lichen

Gradient	N	Median	Ave Rank	Z
1	101	2.000	189.8	4.77
2	94	1.000	139.3	-2.04
3	114	1.000	137.1	-2.69
Overall	309		155.0	

H = 22.76 DF = 2 P = 0.000

H = 24.29 DF = 2 P = 0.000 (adjusted for ties)

Figure 1.

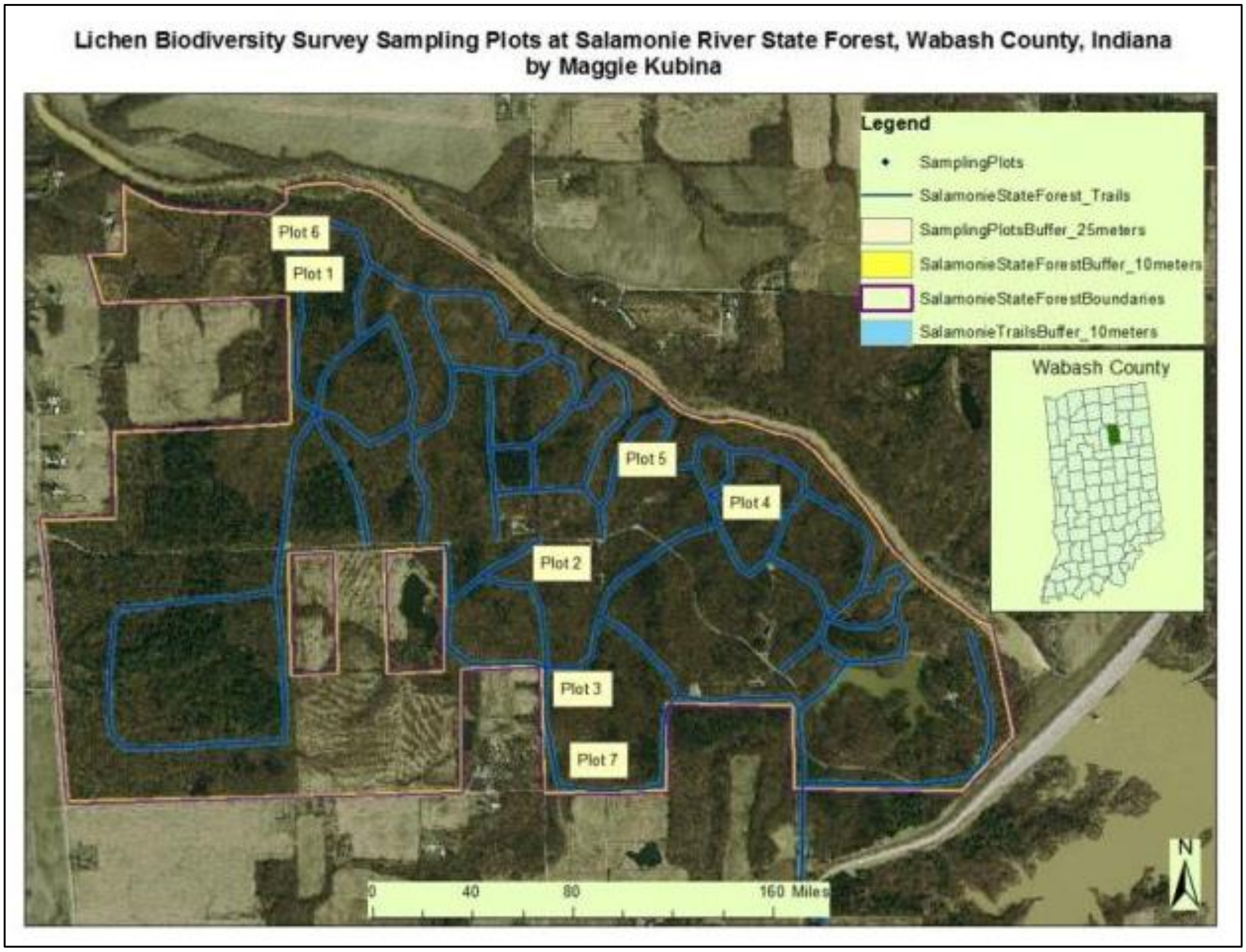

Lichen Biodiversity Survey Sampling Plots at Salamonie River State Forest, Wabash County, Indiana
by Maggie Kubina
Legend
SamplingPlots
SalamonieStateForest_Trails
SamplingPlotsBuffer_25meters
SalamonieStateForestBuffer_10meters
SalamonieStateForestBoundaries
SalamonieTrailsBuffer_10meters
Wabash County
Plot 6
Plot 1
Plot 5
Plot 4
Plot 2
Plot 3
Plot 7
0
40
80
160 Miles
N

Figure 2.

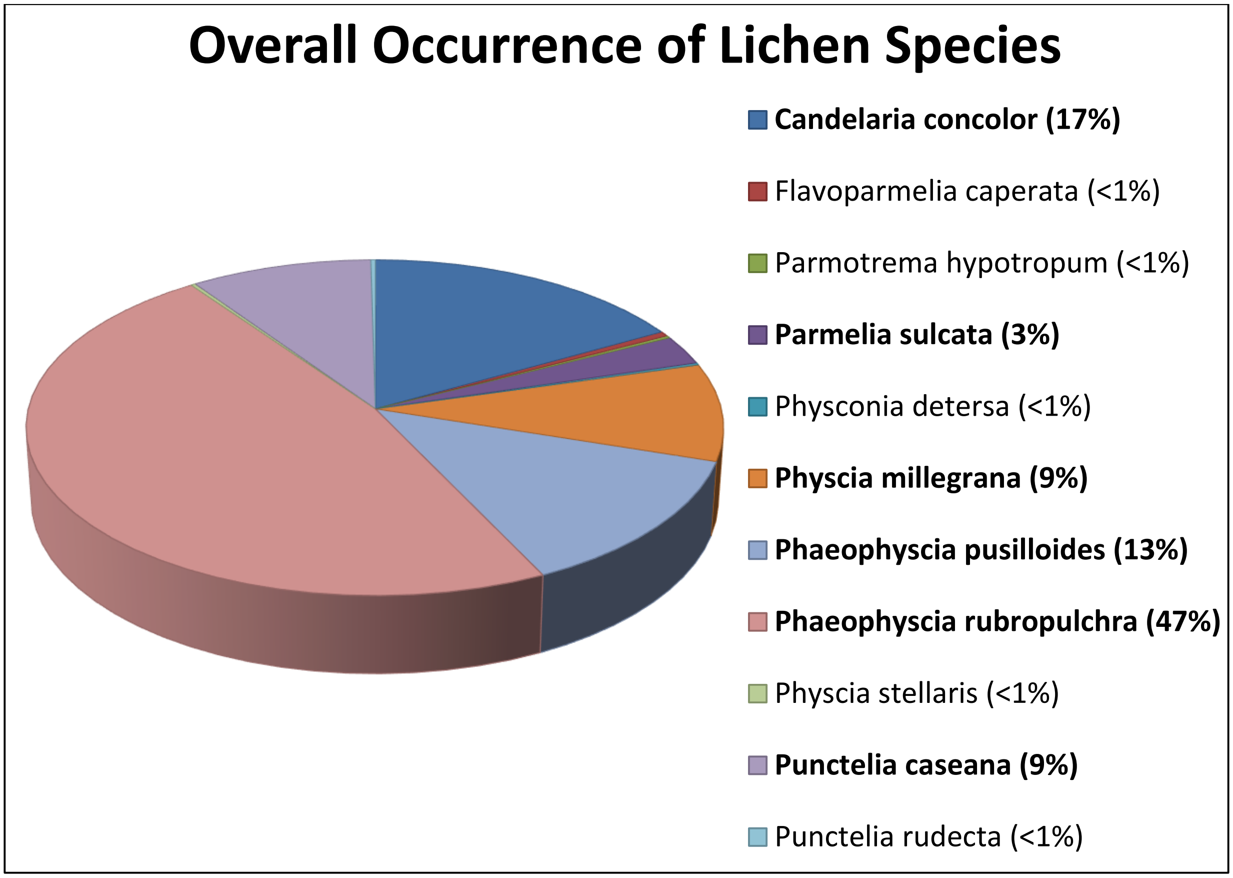

Overall Occurrence of Lichen Species
Candelaria concolor (17%)
Flavoparmelia caperata (<1%)
Parmotrema hypotropum (<1%)
Parmelia sulcata (3%)
Physconia detersa (<1%)
Physcia millegrana (9%)
Phaeophyscia pusilloides (13%)
Phaeophyscia rubropulchra (47%)
Physcia stellaris (<1%)
Punctelia caseana (9%)
Punctelia rudecta (<1%)

Figure 3.

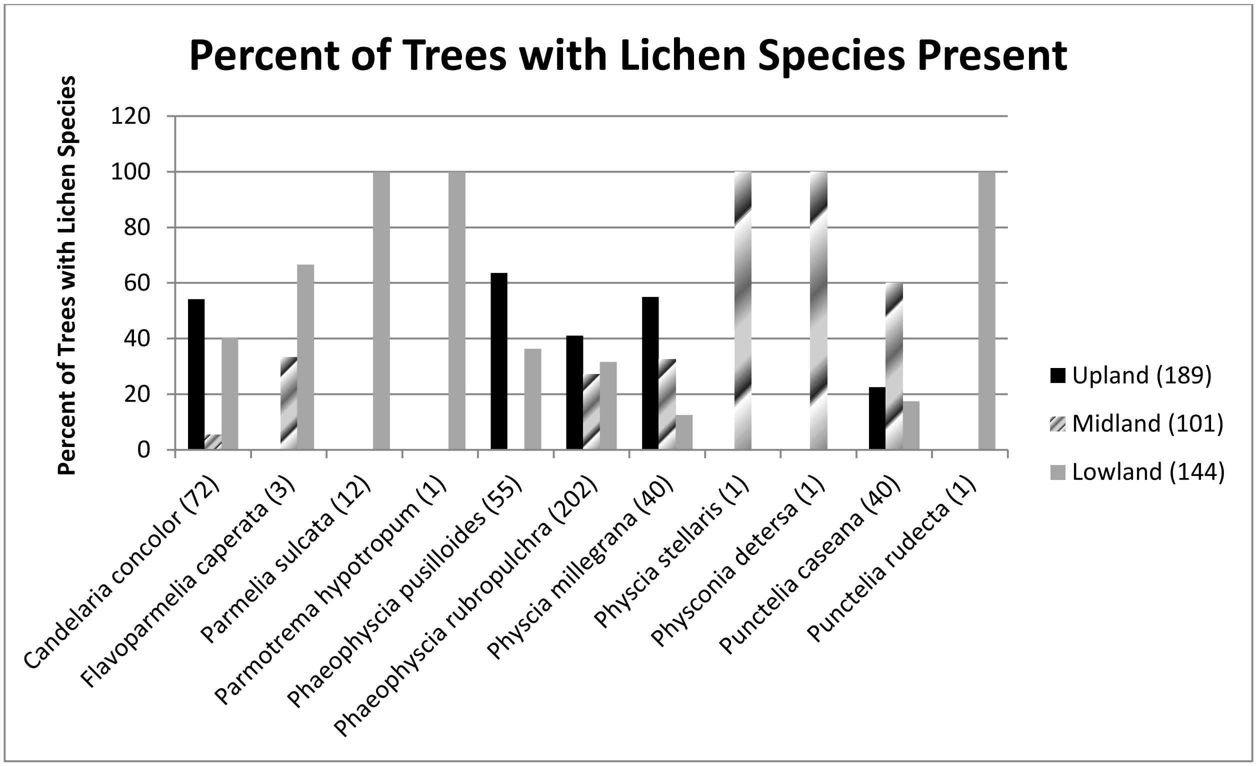
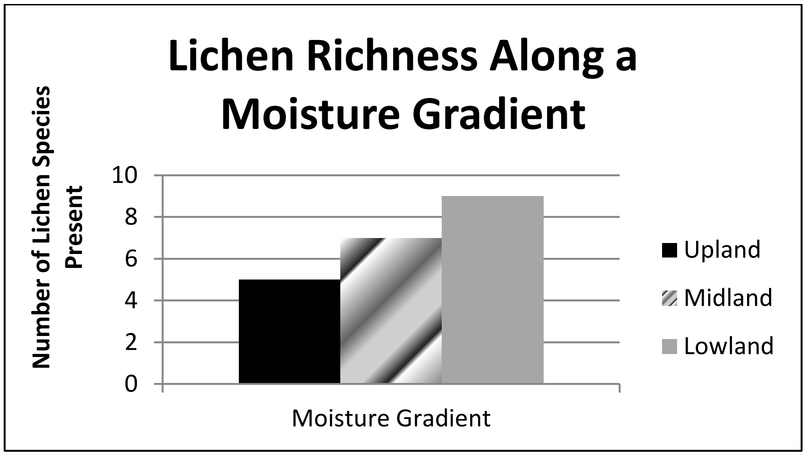
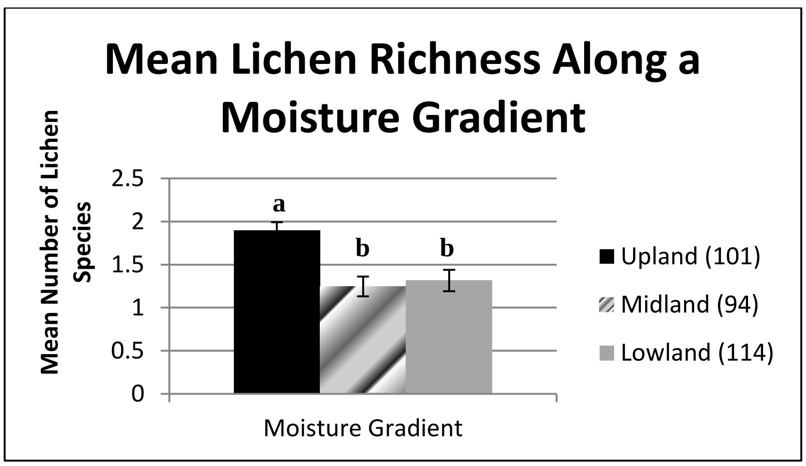

Percent of Trees with Lichen Species Present
Percent of Trees with Lichen Species
120
100
80
60
40
20
0
Candelaria concolor (72)
Flavoparmelia caperata (3)
Parmelia sulcata (12)
Parmotrema hypotropum (1)
Phaeophyscia pusilloides (55)
Phaeophyscia rubropulchra (202)
Physcia millegrana (40)
Physcia stellaris (1)
Physconia detersa (1)
Punctelia caseana (40)
Punctelia rudecta (1)
Upland (189)
Midland (101)
Lowland (144)

Figure 4 a-c.

4a)



4b)



4c)

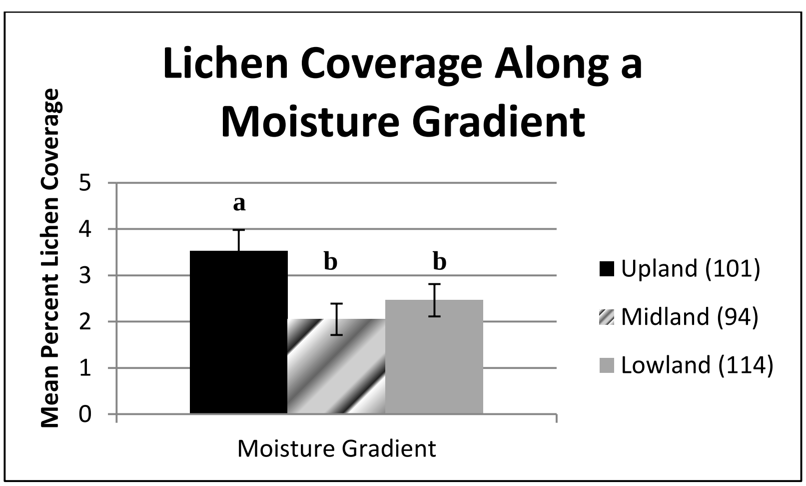
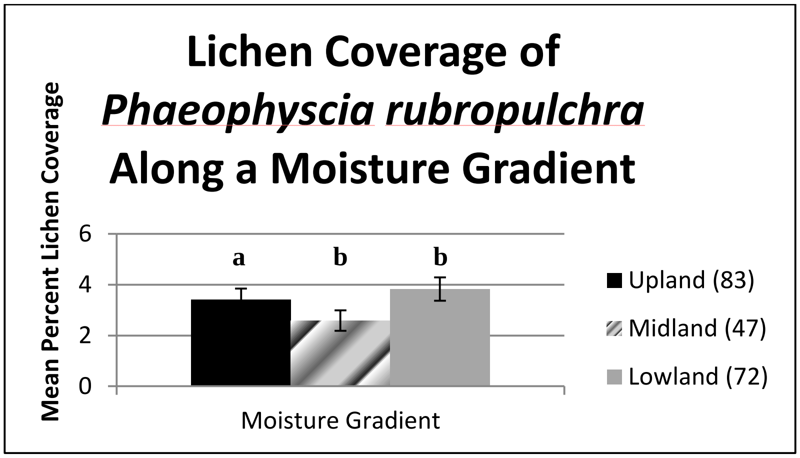
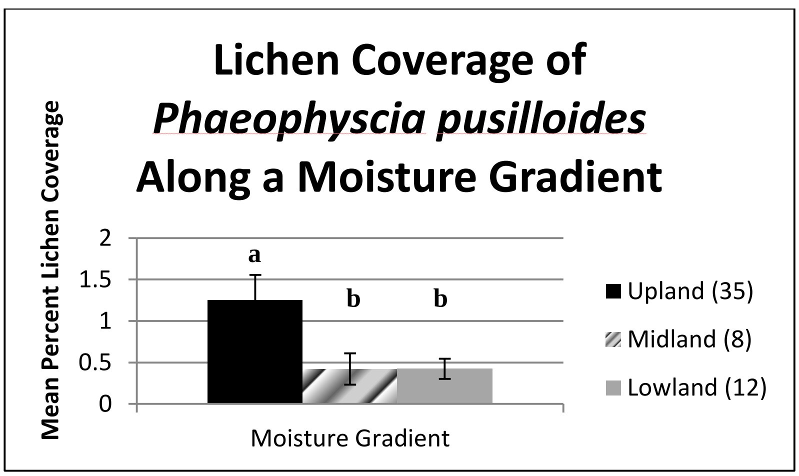


Figure 5 a-c.

5a)



5b)



5c)

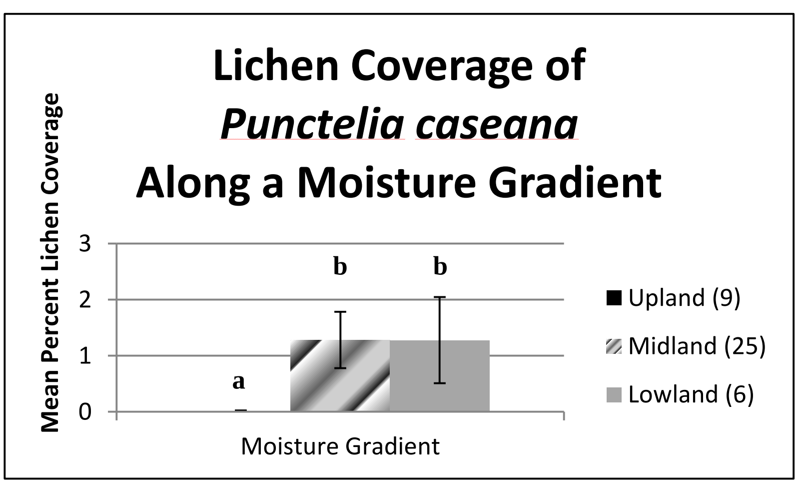
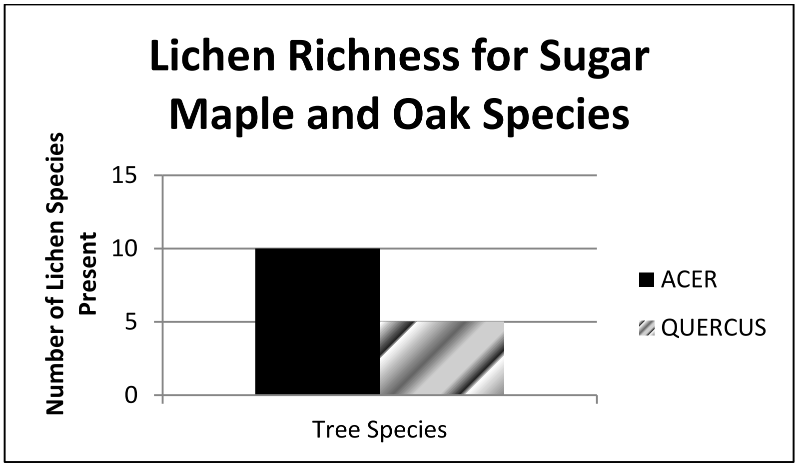
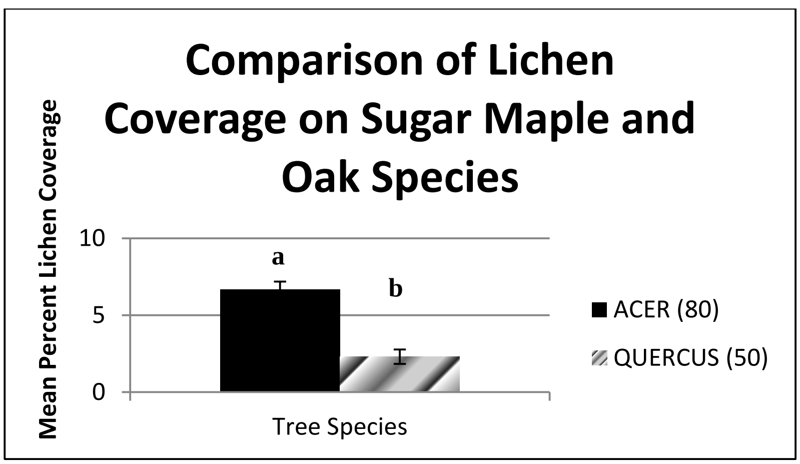


Figure 6 a-c.

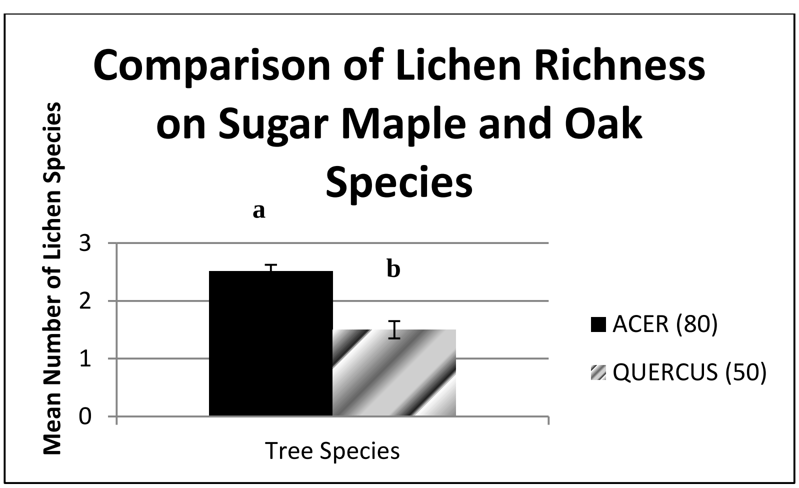
6a)



6b)



6c)



Appendix A

Figure 1 a-d. Photographs of Plot 2 at 0, 90, 180, and 270 degrees, respectively.

1a)

1b)

1c)

1d)

Figure 2 a-c. Photographs of Plot 3 at 0, 90, and 180 degrees, respectively.

2a)

2b)

2c)

Figure 3 a-d. Photographs of Plot 4 at 0, 90, 180, and 270 degrees, respectively.

3a)

3b)

3c)

3d)

Figure 4 a-d. Photographs of Plot 5 at 0, 90, 180, and 270 degrees, respectively.

4a)

4b)

4c)

4d)

Figure 5 a-c. Photographs of Plot 7 at 90, 180, and 270 degrees, respectively.

5a)

5b)

5c)