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Patterns of Epiphytic Lichen Abundance on Aspen Stands in Proximity to Roads of Varying Vehicular Traffic

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Abstract
Although present in nearly any wild space with available moisture and on a wide variety of substrates, lichen, and its importance as a bioindicator for an ecosystem, is often overlooked. As air pollution becomes a greater concern for flora, fauna, and even humans, the story told by lichen growth becomes more useful as we try to make sense of the downstream effects of anthropogenic contributions to poor air quality. One such human-driven pollutant is the level of emissions that result from vehicular travel. The Jackson Hole area has experienced a large increase in vehicular traffic in the past five to ten years in relation to the tourist industry, yet the long term effects on the sought after wild places of the region have not been thoroughly explored. By looking at lichen abundance on aspen trees near roads, the effects of varying levels of vehicular traffic can be documented. Our research supports the relationship between increased vehicular traffic and decreased overall lichen abundance, as well as suggests further use of lichens as bioindicators for understanding the negative impacts of air pollutants and the health of an ecosystem as a whole.

Introduction
As budding students of ecology, our interest and participation in this study is rooted in an expanding and developing knowledge of place. As we consider our own research, we want to acknowledge our presence on the unceded and occupied territory of the Eastern Shoshone, Shoshone-Bannock, Northern Arapaho, Cheyenne and at least 26 other tribes, who first stewarded and continue to steward these lands. Along with acknowledging the complex cultural history of this environment, we chose to consider that climate shifts and resource exploitation in Rocky Mountain forests have caused profound changes in quaking aspen structure and function since Euro-American settlement (Rogers, Bartos & Ryel, 2001). We are curious to see how/if these changes in aspen structure may be affecting lichen communities. These factors and many others have played part in the ever-evolving development of the biotic community we have chosen to study. We hope to explore the relationship between epiphytic lichen abundance on aspen stands exposed to varying levels of vehicular traffic. In this study vehicular traffic will serve as a proxy for air pollution.

<u>Research Question</u>
Is there a relationship between epiphytic lichen formation on aspen and proximity to vehicular traffic (a proxy for air pollution)?

<u>Null and alternative hypotheses</u>
H_o = there is no relationship between lichen formation on aspen stands and proximity to vehicular traffic.
H_a = change in traffic volume will cause change in lichen community abundance.

<u>Lichen as an organism</u>
Lichens are very common organisms on Earth. They are found in a vast range of environments, including the surfaces of rocks, both deciduous and coniferous trees, and man-made structures. (Armstrong 2004). Lichens are a category of fungi that rely on mutualistic symbiosis with the fixed carbon capabilities of either minute green algae or cyanobacteria cells; these are referred to as the photobiont. Lichen-forming fungi are not naturally occurring, but a heterogenous assembly of nutritional specialists like mycorrhizal or plant pathogenic fungi (Honegger 1998). There are three major types of lichen, including the fruticose type where the lichen thallus is attached to the respective substrate at a single point and forms a complex branched structure, the foliose type, comprised of a series of radially arranged leaf-like lobes, and lastly, the crustose type that is tightly pressed against the substrate (Armstrong 2004). The ability for the thalli of lichens to switch between polar and apolar growth (directional transport of auxin across membranes to stimulate growth versus inhibition of transport) and hydrophilic and hydrophobic capabilities (ability to absorb or repel water molecules to facilitate growth) makes lichen highly tolerant of drought as well as heat and cold stress, attributed to a combination of protective and repair mechanisms at the cellular level (Honegger 1998). In nature, many lichen-forming fungi produce symbiotic propagules, while others are capable of regenerating new thalli from fragments (Honegger 1995). Each lichen

species has an optimal range of moisture, temperature, light, and nutrient availability, influencing maximal growth. Climate and pollution interact, impacting lichen community composition. Temperature extremes and moisture availability (relative humidity) are the climate variables most strongly associated with lichen community composition, yet the resilience to these factors varies greatly among lichen species (McMurray et. al. 2015).

Types of Lichen

In study conducted by Rogers & Ryel (2008), they found that *Physcia adscendens*, *Xanthomendoza montana*, and *Xanthomendoza galericulata* were found on all 47 of their plots, yet were found on both conifer and aspen trees, whereas *Phaeophyscia nigricans* and *Physcia tenella* were solely found on aspen trees, but were only found on 38 and 24 of the 47 plots, respectively. Due to the similar shape and color of the lichen species that grow on aspen trees, identification and categorization can be extremely difficult. With this understanding, lichens can be grouped into groups of similar traits, as researchers in Scotland did to look at diversity as it relates to climate response. In their study, lichen epiphytes were classified into six non-reproductive functional groups, based on the photosynthetic partner and growth form: (1) green-algal fruticose, (2) cyanobacterial foliose, (3) tripartite foliose (green-algal and cyanobacterial), (4) green-algal foliose, (5) green-algal crustose and (6) leprose (Ellis & Coppins 2006).

Lichen as a bioindicator

As early as 1866, lichen has been studied as a bioindicator (Nylander, 1866) and mostly studied as an indicator for air pollution (Ferry et al., 1973). Lichen communities grow slowly and depend on their environment for a variety of operational environmental factors. Most notably for our study, lichen communities obtain all of their nutrients from atmospheric deposition (McMurray et al., 2015). Due to their lack of cuticle or stomata, different contaminants are absorbed over the entire surface of the organism (Hale, 1971). Lichen with varying sensitivities react differently to air pollution. Some may formulate chemical changes, such as an increase in chlorophyll a+b concentration, meaning a reduction in photosynthesis or bleaching of the lichen (LeBlanc and Rao, 1975). According to a study conducted by James D. Lawrey, at the Natural Resource Program Center in Fort Collins, CO "pollution can also cause the death of the lichen algae, discoloration and reduced growth of the lichen fungus, or kill a lichen completely. Over time, sensitive species may be replaced by pollution-tolerant species. Hence the species of lichens present in a location and the concentration of pollutants measured in those lichens can tell us a lot about air quality." (Lawrley, 2011) We will go into greater detail in our section titled "Lichen as a Bioindicator on Aspen" explaining the effects of nitrogen as a fertilizer on lichen. We recognize that the effects of air pollution can both increase or decrease the amount and diversity of lichen in a community. We hypothesize that a relationship between air pollution and lichen can be measured through abundance. More research will need to be conducted after data collection to determine if air pollution is increasing or decreasing the amount and type of lichen present.

Nitrogen

Since the turn of the century, total inorganic reactive Nitrogen deposition (reduced + oxidized) in the northern Rocky Mountains has been estimated between 0.5 and 5 kgN per hectare per year (Burns 2003), while historic levels (prior to 1950) are estimated to be less than 1.0 kgN per hectare per year (Sverdrup et al. 2012). Eutrophication, or the absorption of Nitrogen by living organisms, has either aided or stunted the growth in a variety of plants and algae, yet has most notably reduced competition for invasive species that thrive in environments with excessive nitrogen (McMurray et. al. 2013). Epiphytic lichens get nutrients from atmospheric deposition, including canopy drip, and lichen community composition shifts when forest stand makeup changes, climate warms, and nitrogen and sulfur-containing air pollutants increase. Therefore, lichens are often used as indicators of forest health (McMurray et. al. 2015). McMurray et. al. (2013) took two common epiphytic macrolichens, *Letharia vulpina* and *Usnea lapponica*, from the Wind River Range in Wyoming and measured nitrogen concentrations in the thalli of the lichens. They found that increased NH_4 throughfall (responsible for Nitrogen deposition) correlated with increased levels of nitrogen in the thalli of both targeted macrolichen species. Upon further study, McMurray et. a. (2015) found that "sensitivity to and nutritional requirements for N differ among lichen species. The abundance and diversity of eutrophs [plants that thrive with rich nutrient and mineral levels,] typically increases in N-enriched environments, mesotrophs [plants that have an intermediate nutrient productivity,] show little change, and oligotrophs [plants that require very low levels of nutrients,] typically decline

or disappear. Lichen species were classified as eutrophic or oligotrophic based on published analyses" (p.155). Therefore, lichen can be collected to identify the percentage of Nitrogen in the atmosphere, but do not exhibit the same growing patterns due to nitrogen in the atmosphere, differing in expansion or destruction across species.

Lichen on aspen

Considering our own observations of epiphytic lichen and their formation on the knots and scars of mature aspen and prior research done in the Wasatch Mountains in Utah, lichen communities have difficulty growing on the smooth dead periderm that comprises the trunk of aspen trees (Holt et al., 2015). Rogers & Ryel found that only 0.24% of lichens on aspen were located on smooth bark based on cover estimates across their study area(Roger, Ryel, 2008). Because of this, lichens cluster on the rough surfaces of branch scars and wounds, this surface presents more surface area and water holding capacity than the straight, smooth bark (Holt et al., 2015). We will utilize this phenomena in our data collection methods. We will only measure for lichen percentages on the knots and scars.

Lichen on aspen as a bioindicator

Rogers (2009), has found a relationship between forest succession and variance in lichen composition and abundance, the older the forest,the more diversity and abundance in lichen was found. More importantly, in relation to our study, atmospheric nitrogen significantly influenced the abundance of nitrophilous lichen, nitrogen loving lichen. Aspen succession, nor other environmental factors such as topography, tree damage and scarring had little influence on lichen communities in the areas studied. Clear variables affecting nitrophilous lichen was proximity to atmospheric nitrogen from local agricultural and urban sources. In particular, one specific bioindicator of nitrogen loading was found to be *Phaeophyscia nigricans.*

Ongoing research

Considering the vast amount of research that has been done to assess lichen as a bioindicator, we find it important to document the effects that rising traffic (and emission) levels in Jackson Hole, and its surrounding areas, may be having on the biotic environment. According to Seaward, the decline of lichens over the past two centuries is mainly attributable to increases in air pollution in general, specifically increasing sulfur dioxide levels. (Seaward, 1992) We have chosen to study epiphytic lichen abundance on aspen stands, as aspen are the most widely distributed native organism in North America. Taking cues from McMuarry et al, we hope to indicate the impact of traffic volume on lichen abundance in aspen stands, this can help us identify probable sensitive or impacted habitats. Lichen is one of the most sensitive terrestrial receptors, thus managing and monitoring lichen health naturally leads to managing and protecting healthy ecosystems. (McMurray et al., 2015) Stratifying our sampling across varying levels of vehicular traffic (low, medium, high) we will assess the abundance of lichen growth on aspen stands in each traffic condition.

Field Methods

Plot Sites

Our study will take place along three roads of varying traffic volume in Jackson, Wyoming. Adjacent to each road, one or more aspen stands will be sampled for lichen abundance. The low-traffic site is Coyote Canyon Road and is categorized as low traffic because it experiences less than 500 AADT. The mid-traffic site is Highway 191 next to the Elk Refuge and is categorized as mid-traffic because it experiences between 500 AADT and 1500 AADT. The high-traffic site is Highway 22 and is categorized as high-traffic because it experiences more than 1500 AADT.

Surface Area of Measurement

Our investigation will limit the measurement area to the circumference area of the tree between 0.5 meters and 1 meters from the ground (McMurray, 2015) (Rogers, 2007). The technique of measuring lichen communities in sections on aspen trees is drawn directly from Rogers' study "Factors influencing epiphytic lichen communities in aspen." In their study they measured between 0.5 and 2.5 meters on each tree. We will reduce the area measured by half due to time limitations. The Rogers' study also eliminated the boles below half a meter to exclude the possibility of ground dwelling lichen interference (Rogers, 2007) (figure 2).

Diameter at Breast Height

Lichen communities grow incredibly slowly and thus are most often found on older aspen trees upon which they have had more time to develop (Holt et al., 2015). To control for tree age, we will only be measuring lichen communities on aspen trees that have a minimum diameter at breast height of 10 cm (image 1). We will adjust and account for this measure dependent on the trees available on site. This method is consistent with the methods used by Rogers' study as a means to only include mature trees in his sample (Rogers, 2007) (figures 1 & 2).

Image 1. Diameter at DBH.

North-Facing v South-Facing Lichen Communities

Lichen communities grow more rapidly on the northern face of trees because of the reduced direct sun exposure (Case, 1977). By measuring the whole circumference we are taking into account the varying growth rates of lichen communities. However, in order to control for varying lichen growth rates at different aspects, we will only measure lichen growth on the northern side (figure 2).

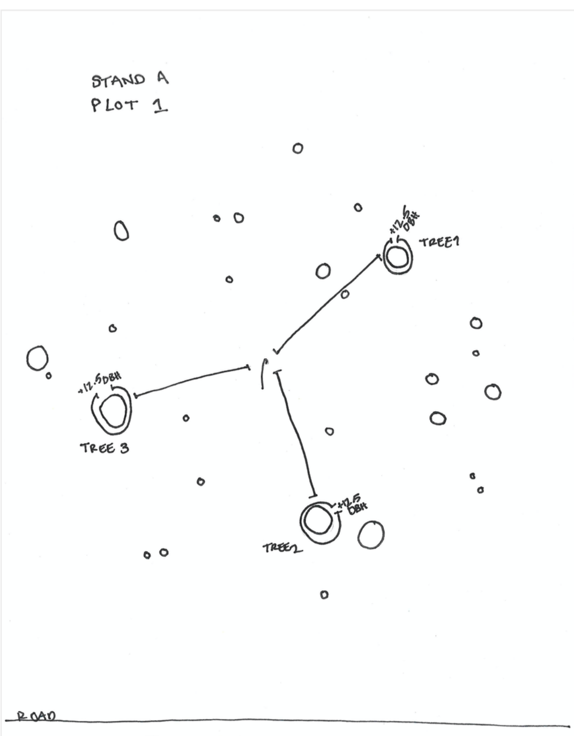

Figure 1. Tree selection within each plot.

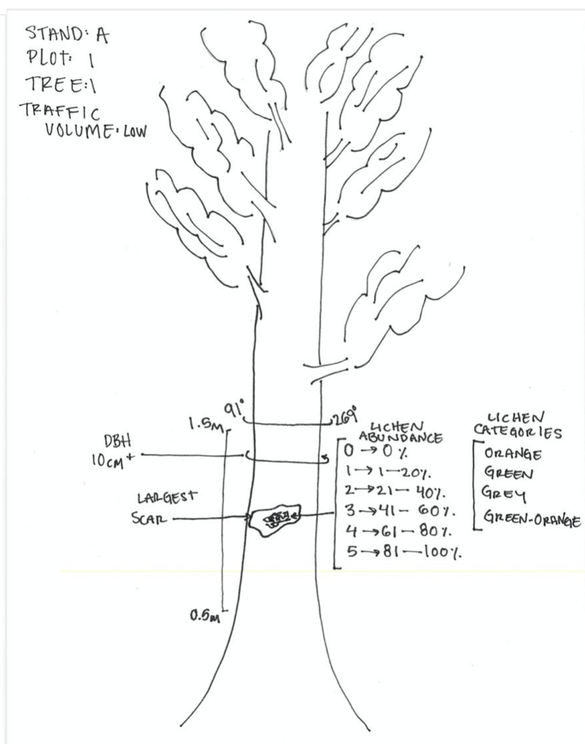

Figure 2. Controlled variables and measurement of lichen abundance.

Lichen Abundance Measurements

Lichen abundance will be measured by finding the largest scar on the northern half of the tree (within the 0.5 meter to 1.5 meter height parameters) and approximating the percentage of lichen coverage within that scar for each dominant lichen color: orange, grey, and green.. Because an exact percentage cannot be determined, the percent abundance will be grouped into six categories and determined through an ocular estimate (figure 3, image 2). To determine a percentage of lichen abundance, we will practice estimating as a group by each one of us categorizing the abundance individually and then comparing to ensure accuracy in samples. We will practice this test method until all of us consistently are coming up with the same abundance estimate.

0	1	2	3	4	5
Nill	1-20%	21-40%	41-60%	61-80%	81-100%

Table 1. Scale Percentage of Lichen Abundance.

Image 2. (A) Scar on an aspen from a medium traffic stand. **(B) Scar on an aspen from a low intensity stand.**

Slope Steepness and Slope Aspect

Solar radiation and moisture availability are both limiting factors from lichen community growth; higher solar radiation leads to decreased growth of lichen communities whereas higher moisture availability leads to increased growth (Holt et al., 2015). These factors of the operational environment are directly linked to slope steepness and slope aspect: southern facing slopes will receive more intense solar radiation (retain less moisture) and as a becomes more steep it will drain moisture more easily and face or not face the solar radiation more directly. To control for both of these factors we will plan to measure on plots that are relatively flat (between 0° and 30° slopes) minimizing the likelihood that slope steepness or slope aspect would have a major effect on our data collection. If this is not possible at the site, we will address as a confounding variable and treat it as such in our data analysis.

Categorization of Lichen Communities

Due to our underdeveloped identification abilities as a group, for this study we will categorize lichen findings by their dominant color. For example, lichen that is orange in color will be known as "orange lichen." We acknowledge that prior research has been done by Rogers et al. (2009) which shows a direct linkage between ammonia and lichen community species growth. Yet, by not being able to identify the exact species of lichen communities we may be missing key data or adding data to or sample from mixed lichen species, and we acknowledge this shortcoming and will treat this as an area for further exploration.

Data Collection Method

To collect our sample data we will be using variable radius plots that measure the three closest mature aspen trees to the center point. In the Rogers & Ryel study, the data collection method was a fixed circle plot. Because our plot sites have minimal population size, to ensure that we collect a large enough sample of mature trees we will be modifying their method from fixed to variable. We will be collecting a minimum of three variable plots per site, if

the site is conducive to additional variable plot sampling, we will extend our data collection to a maximum of five variable plots (figure 2, table 1 & 2).

Tree #	Traffic Volume	Stand #	Plot #	DBH (cm)	Aspect of Largest Scar	*Abundance of Lichen (across color)*	*Abundance by color:* Orange	*Abundance by color:* Grey	*Abundance by color:* Green - Orange	*Abundance by color:* Green	Picture #
1	*High*	*A*	*1*	*15*	*95°*	*3*	*3*	*2*	*2*	*0*	*1475*

Table 2. Sample Data Collection Sheet.

<u>Risk Management</u>
All aspen plots will be located on public land or land owned by Teton Science Schools. Due to proximity to heavily trafficked roads, all research members will be wearing high-visibility vests and will be making data collections during daylight hours. If aspen are extremely close to the road we will accommodate the safety hazard by having one or two members watch the road carefully for potential dangerous oncoming traffic. If traffic is heavy and of concern we will not measure the area and document the reasoning. Bear spray will be on hand for any unexpected wildlife encounters. Each member will be carrying enough hydration, nutrition, and weather (sun and precipitation) protection for the variability in the Jackson Hole area. In addition the group will be carrying a first aid kit at all times and each group member will have their cell phone on them at all times in case of emergency. Our itinerary will be shared with faculty and we will check in with Dr. Krasnow upon reaching our site and at the end of each day of data collection.

<u>Statistical Method</u>
There are two different ways for us to analyze our data depending on how we treat our independent variable. The data will be analyzed using an ANOVA test as well as a regression and the two methods for analysis will be compared in order to better understand our samples and results. In both statistical tests the dependent variable will be a numeric scale of 0-5 representing the percentage of lichen covering the scar on the bark of an aspen tree.

Regression
If the independent variable of this study is measured numerically, the traffic volume will be represented through annual average daily traffic (AADT) in which the "total volume of traffic of a highway or road for a year [is] divided by 365 days" (*Traffic Data Computation Method* 2018). Because our sites are categorized by the AADT range we have used the median traffic volume number for each classification. "High" volume sites that fall between 12,000 - 20,000 AADT, on our graphs these sites will be represented by 16,000 AADT. "Medium" volume sites fall between 6,000 - 12,000 AADT, on our graphs these sites will be represented by 8,000 AADT. "Low" volume sites fall under 2,000 AADT, on our graphs these sites will be represented by 2,000 AADT. We did not conduct any studies on roads that had a traffic volume between 2,000 and 6,000 AADT.

ANOVA
The independent variable of this study can also be measured categorically--the traffic volume of each road will be classified by "high," "medium," and "low" numbers of cars per day, relative to traffic volume in the town of Jackson, Wyoming. The dependent variable is continuous numerical in this statistical analysis as well. In order to decide any statistical significance between the amount of traffic (three different categories) and the percentage of lichen coverage of scars on aspen tree bark (grouped into numerical buckets), a single-factor ANOVA was used. If any significance was detected, the ANOVA was followed by a Tukey HSD test to determine which comparisons between traffic volumes were significant. The analyses were then visually represented with boxplots (see figure 6).

Results

Regression Analysis

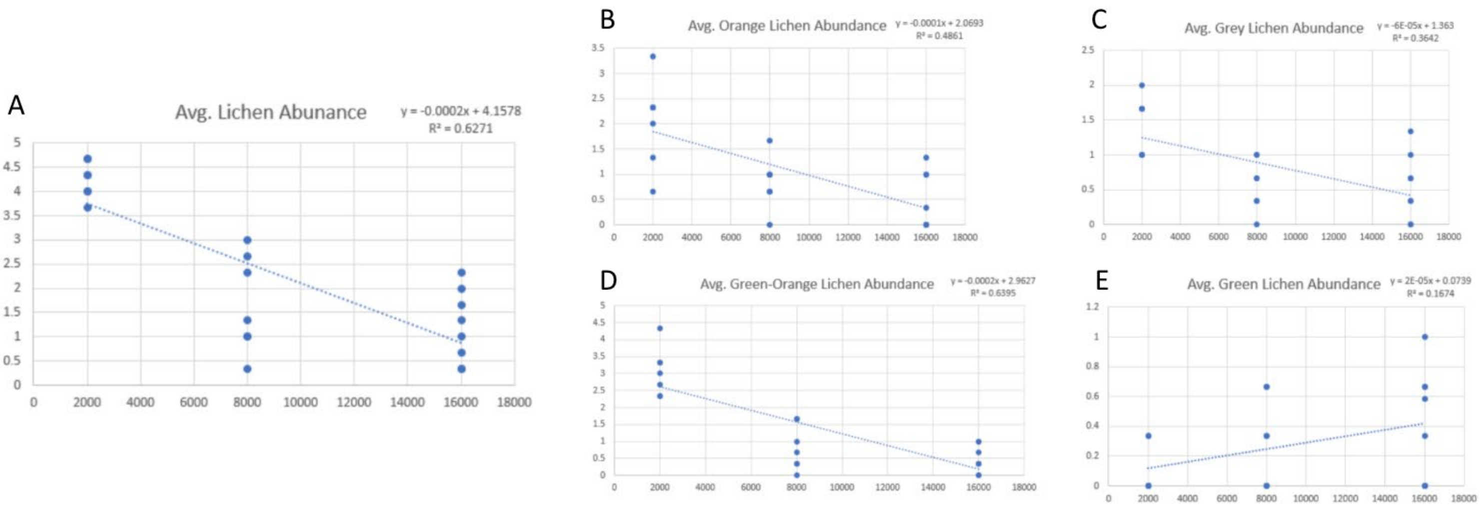

Figure 3. Scatter plots of regression analysis. Lichen abundance as the dependent variable, measured in categories for lichen coverage percentages. AADT is the independent variable on the x-axis ranging from 0 AADT to 20,000 AADT. Each point on the charts represents one sampled plot in which the three trees sampled were averaged to find a mean for the plot. **(A)** Average Lichen Abundance across color groupings by AADT. **(B)** Orange Lichen Abundance by AADT **(C)** Gray Lichen Abundance by AADT **(D)** Orange-Green Lichen Abundance by AADT **(E)** Green Lichen Abundance by AADT.

The trendline suggests that overall lichen abundance decreases as traffic volume increases ($p=0.000011$) (figure 3). This trend is consistent across three of the four color groupings (figures 3A-D): orange ($p=0.00031$), grey ($p=0.0029$), and green-orange $p=0.0000080$). The regression analysis for green lichen (figure 3E) shows an inverse relationship to that of the other lichen colors, in which green lichen abundance increases as traffic volume also increases. This did not end up fulfilling the 95% certainty ($p<0.05$) to qualify as significant, yet nearly showed significance ($p=0.059$).

The R^2 values differ between lichen groupings. For overall average lichen abundance the adjusted R^2 is 0.61, indicating that the overall variance in lichen abundance is 61% explainable by traffic volume. R^2 values were 0.46, 0.33, 0.62, and 0.13 for orange, grey, green-orange, and green lichen, respectively.

<u>ANOVA Analysis</u>

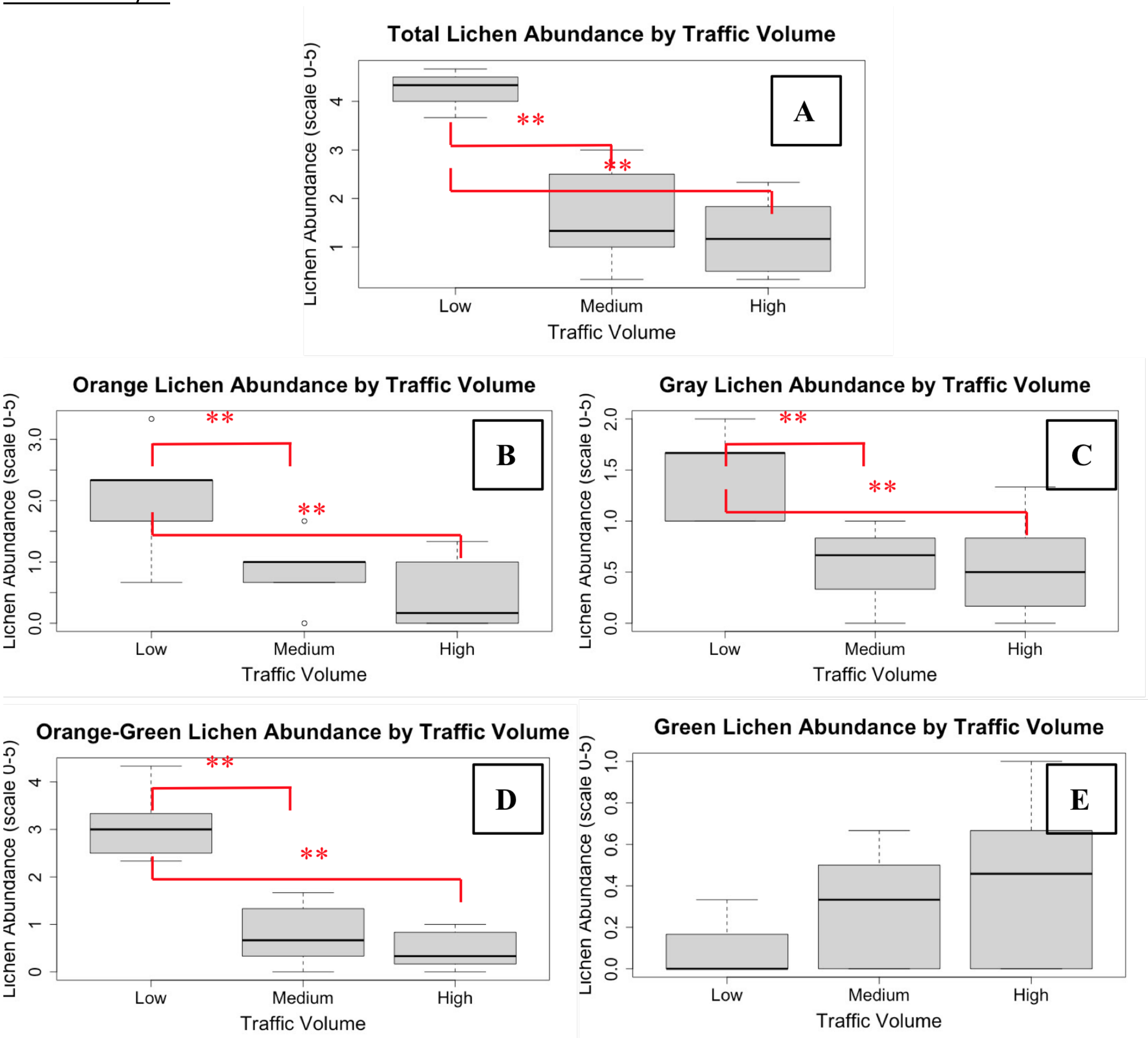

Figure 4. Boxplots of Single Factor ANOVA with Tukey HSD. Lichen abundance as it depends on low, medium, and high traffic volumes. * p<0.05 ** p<0.01 **(A)** Total Lichen Abundance by Traffic Volume. **(B)** Orange Lichen Abundance by Traffic Volume **(C)** Gray Lichen Abundance by Traffic Volume **(D)** Orange-Green Lichen Abundance by Traffic Volume **(E)** Green Lichen Abundance by Traffic Volume.

The ANOVA test revealed significance ($p<0.05$) in total lichen abundance (figure 4A), orange lichen abundance (figure 4B), grey lichen abundance (figure 4C), and orange-green lichen abundance (figure 4D), with the Tukey HSD post-hoc test revealing statistically significant differences between low and medium traffic volumes and low and high traffic volumes for total, orange, grey, and orange-green lichen abundance (low-medium: $p=0.000012$, $p=0.0077$, $p=0.0034$, $p=0.0000030$, respectively; low-high: $p=0.00000080$, $p=0.00042$, $p=0.0019$, $p=0.0000002$, respectively). Low traffic volume yielded greater lichen growth for total lichen abundance, as well as orange, gray, and green-orange lichen abundance.

There was no definitive significance ($p>0.05$) for green lichen abundance as it related to traffic volumes (figure 4E), but it was not far off being significant, so a Tukey HSD was run anyways to further understand the relationship of lichen growth to traffic volume. Neither low-medium or medium-high traffic volume differences showed any relationship to change in lichen abundance, but low-high traffic volume was nearly significant with a p-value of 0.14. Although not significant, the lichen abundance appeared to increase with high traffic volume when compared to low traffic volume.

Discussion

Our findings indicated that there is a relationship between epiphytic lichen formation on aspen and volume of nearby vehicular traffic (a proxy for air pollution). Thus, we reject our null hypothesis, H_o = there is no relationship between lichen formation on aspen stands and proximity to vehicular traffic, and accept our alternative hypothesis, H_a = change in traffic volume will cause change in lichen community abundance.

The data analyzed through both the regression and ANOVA test supports the conclusion that lichen abundance is inversely related to level of vehicular traffic when measuring total lichen abundance, as well as orange, grey, and orange-green lichen abundance. With traffic volume as a proxy for air pollution, the conclusion can be drawn that the emissions and/or the particulates from vehicles, nitrogen being the most likely pollutant, have a negative impact on lichen growth on aspen trees within a certain proximity to the road.

Because the green lichen abundance increased as vehicular traffic increased, it may be one of the species that prior research noted as a lichen species that accepts excess nitrogen in the surrounding air. However, because our statistical findings were not significant for the green lichen, and because we were not able to identify the species of this color, we cannot definitively make this statement. It is also important to note that green lichen may be more tolerant of nitrogen pollutants, but may also be benefitting from the lack of competition as the other color groupings decline in abundance.

The green-orange lichen was most common across sites and had a P-value closest to that of lichen abundance across color groupings. The green lichen was the least common across sites, and the regression and ANOVA both indicated a statistical insignificance for green lichen abundance. In order to further understand the opposite growth trends of these lichens, more samples of aspen stands close to higher traffic roads would need to be taken.

Overall, our findings are consistent with prior research conducted by Rogers et. al. (2009) and Seaward (1992) that lichen communities are extremely sensitive to air pollutants. Using vehicular traffic as a proxy for air pollution, however, was a novel relationship and could be important in future policy and considerations for construction and management of transportation in Wyoming and beyond. Due to its pollutant sensitivity, lichen communities may act as an important bioindicator of an ecosystem's health. Using visual abundance, as was done in this study, as well as biochemical and molecular lenses on nitrogen-derived compounds in the lichen itself (McMurray et. a. 2013), a more holistic picture can be drawn as to what the health of an ecosystem may actually be as its affected by roadside emissions.

As vehicular traffic has consistently increased over the past five years it may be important to look at how lichen respond to the increased air pollution moving forward as a means to understand how other plant and animal species may respond in turn. To the naked eye, an ecosystem may not be suffering, yet the lichen communities in the community may tell a different story.

Conclusion

Through this study we have gained and provided a better understanding of the significant relationship that exists between lichen and air pollution. As many studies have concluded before us, the sensitivity of lichen and the way it is affected by environmental factors can help us to better understand the way other organisms might react in the face of the global climate crisis. Lichen serves as a major indicator of the vast ecological changes taking place within our dynamic earth.

<u>Broader Findings and New Questions</u>

Lichen is a viable bioindicator that can help us understand and potentially predict environmental problems. Our research re-affirms conclusions drawn from prior studies stating that there is a relationship between lichen abundance and proximity to vehicular traffic. The significance at which we came to understand the relationship between lichen and pollution was astounding and significant. Working on this small scale study, we found it eye-opening to see just how sensitive lichen can be to environmental factors. This conclusion has led to the development of many new questions and an increased awareness of the impact development can have on species

diversity and abundance, not just for lichen but for many other organisms. More research is needed and we are curious to explore the following questions: Why is some lichen more resilient to the effects of pollution? Will continued development lead to an overall decrease in species diversity? Will decrease in lichen diversity lead to a decrease in overall species biodiversity? Can the decline of lichen abundance predict the loss of biodiversity for other organisms?

Limitations and Revisions

Unfortunately, our study did not take into account the specific species we were observing due to our limited tools and knowledge for identification. By looking more closely at lichen community species it may be possible to understand how exactly lichen is adapting and what physiological components enable lichen to survive with the changing volume of air pollution.

Furthermore, while we did control for the aspect, by only measuring north facing scars on which lichen growth was occurring and the maturity of the tree, by only sampling trees over 10cm DBH, we did not control for slope. Most of our stands were located on flat ground as they were growing on the sides of major roads, but for one of our lower traffic density sites the stand was located on a western facing slope. This may have had an unknown effect on the lichen abundance which would be important to control for in future studies.

Additionally, while we practiced the ocular estimation technique in detail prior to collecting samples, there was room for error within these observations. Future studies would benefit from having tools to calculate exact lichen coverage of a scar as a means to minimize human error and bias.

Implications

Prior to beginning this research we had easily overlooked and dismissed lichen communities due to their size and appearance to the naked eye. Yet, by spending devoted time observing their intricacies we have grown a new found appreciation for their sensitivity and structure. Because lichen can be a viable indicator of air pollution and ecosystem health, close observations of these communities may be an important tool to track trends of biodiversity, invasive species, and overall ecosystem health as human disturbances and climate change continue to have major effects on the environment.

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Team Research Manuscript Rubric DUE: Monday, October

<table>
<tr><th>Assessment Criteria</th><th>Grad. St.</th><th>Faculty</th></tr>
<tr><td>Content: Introduction and Methods sections
Introduction provides relevant background, discusses previous research, clearly articulates your research question(s), and makes the case for the importance of the study
Field methods are described in detail including sample size, control of confounding variables, diagram of sampling design, and strategies employed to get an unbiased sample
Methods section clearly describes and defends the analysis methods employed.</td><td>A</td><td></td></tr>
<tr><td>Content / Product: Results and Discussion
Results section presents all relevant data with intuitive graphics, including error bars (or other display of uncertainty), and P-values (and r^2 values, t-values) when appropriate.
Research question(s) is answered with appropriate data display
Results are interpreted and discussed in detail in the Discussion section, especially to make sense of unexpected findings and/or to relate the ecological story to the data collected.</td><td>E</td><td></td></tr>
<tr><td>Content: Conclusion
Conclusion includes a summary statement and relates how this study might be improved in the future, recommended actions resulting from your findings, new questions, and ways this study can inform future field teaching.</td><td>A</td><td></td></tr>
<tr><td>Process:
Professional writing skills displayed (concise, appropriate vocabulary, logical flow, and solid transitions and organization)
APA citations are included where appropriate and a consistent and accurate format is used throughout (both in text and in the references section)
The manuscript is of an appropriate length and detail.
Due dates and other logistics were properly adhered to</td><td>A</td><td></td></tr>
</table>

Additional Comments:

Due to our thorough analysis of samples using both the ANOVA and regression forms we believe we exceeded expectations.