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The Urban Heat Island Effect And Its Impact On Lichen Abundance And Diversity In Jefferson County, Kentucky

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Abstract

For the past century, it has been widely accepted that air pollution (such as SO_x and NO_x) causes lichen mortality in urban areas. In recent years, however, the Urban Heat Island Effect (UHI) has been explored as a possible cause of lichen mortality. Lichens are the result of a unique symbiotic relationship between fungi and a photosynthesizing partner. One of the benefits obtained from the fungus partner is water retention. The UHI also affects the amount of air moisture, as increased impervious surfaces are found. Areas with less impervious surface cover, and therefore more air moisture, theoretically, should have higher species richness and abundance. In this study, six sites were chosen around Jefferson County in Kentucky. Air temperature and humidity data were obtained from each site along with the abundance and diversity of lichen species. Species richness was performed by the rubber band and circle method on six trees at each of the eight sites. Abundance values were obtained by using only the rubber band method. Both the Shannon and Simpson indices were calculated and compared for each site. Our results suggest that lichen species richness increases with increasing temperature in Jefferson County, and that species richness decreases with increasing air humidity. This is the opposite of what we expected to find. Analysis of Shannon's index shows that species richness and evenness decrease with increased air temperature and increases with increased air humidity, which we expected to find. However, analysis of the Simpson index shows that diversity increases with increasing air temperature, and decreases with increasing air humidity. Our findings highlight the need for more studies investigating the impacts of UHI on local ecosystem health.

Keywords: Lichen, Urban Heat Island, Louisville

1. Introduction

Lichens are the result of a unique symbiotic relationship between a fungus and photosynthesizing partner: cyanobacteria or green algae. Due to their symbiotic nature, both the photobiont (photosynthesizing partner) and mycobiont (fungal partner) are able to provide its other species with essential survival needs. The mycobiont provides the photobiont with protection from light intensity, temperature extremes, and helps with water availability, all which allow the photobiont to live in inhospitable areas that it otherwise could not survive. The photobiont supplies the mycobiont with photosynthate and in some cases nitrogen.[1,2]

Historically, lichens have been used as bioindicators of air quality.[2] Recent studies, however, have highlighted a potential in the urban heat island effect (UHI) as playing a larger role in lichen diversity.[3] The UHI is the temperature difference between urban and rural areas, created by a lack of tree canopy. Also, associated with the UHI is an increased number of impervious surfaces, such as concrete or rooftops. Higher amounts of impervious surfaces decrease the amount of air moisture due to increased evaporation rates and reduced humidity.

Lichens are poikilohydric, meaning that they cannot regulate their water content,[4] thus air moisture is critical to lichen survival. Uptake of essential minerals occurs during photosynthesis,[5] which is reliant on water.[6] Lichens average two peaks of photosynthesis per day; the first peak occurs in the morning due to moisture from fog or dew and a second peak which occurs with the afternoon humidity.[6] Therefore it is expected that as the effects of UHI increase, the peaks in lichen photosynthesis will decrease. Only certain, more adapted, species would be able to survive under these conditions. Thus, higher temperatures are expected to have significantly negative effects on lichen survival and therefore areas where the UHI is prevalent lower diversity and abundance in lichen are expected.

Biodiversity indices are used to discuss species richness and their relative abundances. The Shannon index (H) produces values typically between 1.5 and 3.5. As the richness and evenness increase so does the index value. The Simpson index (D) produces values between 0 and 1. These values show a measure of dominance, meaning that as the index value increases, the diversity decreases.

The objective of this study is to explore the correlation between lichen diversity with the change in air temperature and moisture that are associated with the UHI.

2. Methods and Materials

2.1 Study Sites

For this study, six sites were chosen throughout Jefferson County, Kentucky (Figure 1). Air temperature and humidity data were obtained between 12/11/16 and 1/23/17 from weather stations set up at each site. Some of the sites data were obtained from Dr. David Howarth at the University of Louisville and others were obtained by manually downloading the data from the weather station.

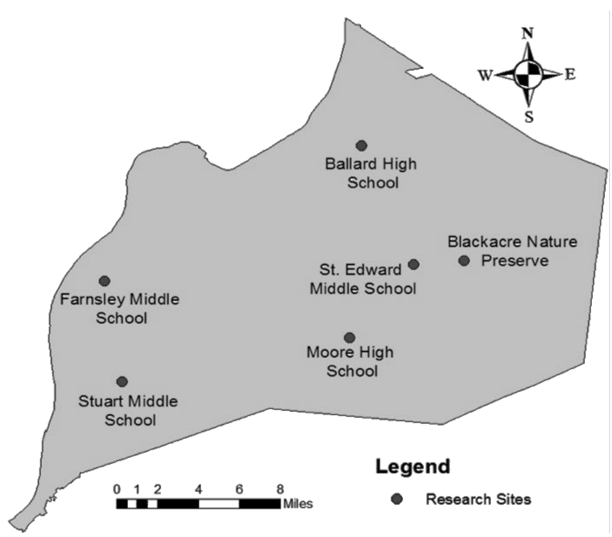

Figure 1 – Research Sites in Jefferson County, Kentucky. The shaded area above represents Jefferson County.

2.2 Field Measurements

The diversity and abundance of lichen species were found at each site using six trees and two different methods; the rubber band method and circle method (Figure 2). Both methods were used to find the species richness at all six sites. However, only the rubber band method was used to find the lichen abundance. The rubber band method involved tying a string around the tree at 100cm above the ground. Species richness is the number of species touching the string, and the abundance was found using equation (1).

$$\text{Abundance: } A = \Sigma \left(\frac{total\ \#\ of\ individual\ lichens\ touching\ the\ string}{tree\ circumference}\right) / 6 \quad (1)$$

The circle method involved draping a cloth around the tree between 50cm and 150cm above the ground. Eight-inch diameter circles were cut into the cloth with two inches between each circle. Species richness was found by counting the number of species seen in all circles.

Figure 2 – Rubber band method (left): string tied around tree 100cm above ground. Circle method (right): 8in diameter circles cut in cloth and hung between 50cm and 150cm above the ground.

2.3 Diversity Indices

Both the Shannon and Simpson indices were calculated for each site. These were used to discuss the biodiversity at each site, as well as to compare biodiversity with air temperature and air humidity. Biodiversity includes species richness, evenness, and dominance. The Shannon index is represented by equation (2) and the Simpson index is represented by equation (3). Both indices use *pi*, or the proportion of individuals found in species *i*, which is represented by equation (4).

Shannon index: $$H = -\Sigma(pi \cdot lnpi) \quad (2)$$

Simpson index: $$D = \Sigma pi^2 \quad (3)$$

Proportion of individuals: $$pi = \frac{n_i}{N} \quad (4)$$

3. Results

The results of the current study indicate that air temperature and air moisture had a non-linear relationship. Air moisture was taken as air humidity (Figure. 3).

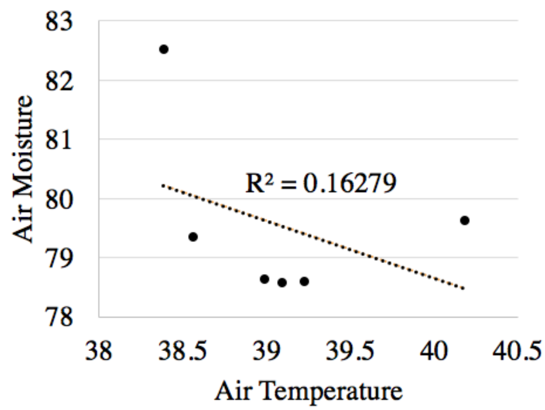

Figure 3 – Non-linear relationship between air temperature and air moisture (air moisture was taken as air humidity).

As air temperature increased so did species richness, under both the rubber band method and circle method (Figure 4). When looking at air humidity, species richness decreased under the rubber band method. Under the circle method, however, species richness was not impacted and remained relatively constant (Figure 5). Lichen abundance remained relatively constant, as both air humidity and are temperature increased (Figure 4 and 5).

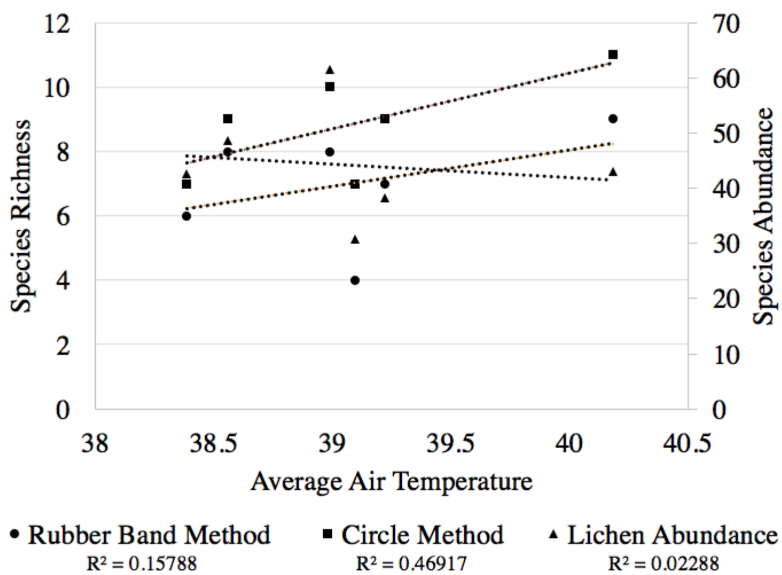

Figure 4 – Species richness, calculated using the rubber band method and circle method, and abundance compared to air temperature.

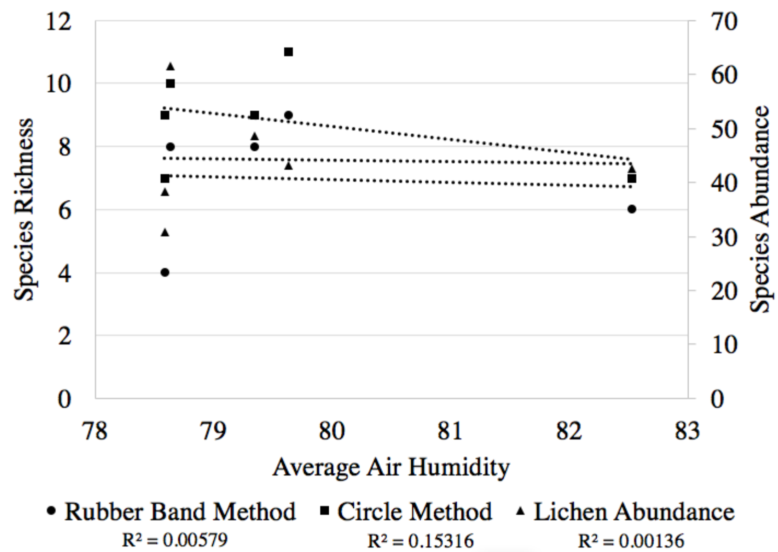

Figure 5 – Species richness, calculated using the rubber band method and circle method, and abundance compared to air humidity.

Based on the Simpson indices calculated, lichen diversity and evenness increased as temperature increased (Figure 6). Also, centered on these values, lichen diversity and evened decreased as air humidity increased (Figure 7). Whereas, lichen diversity and evenness decreased as temperature increased based on the Shannon indices calculated (Figure 6). In addition, centered on these values, lichen diversity and evenness increased as humidity increased (Figure 7).

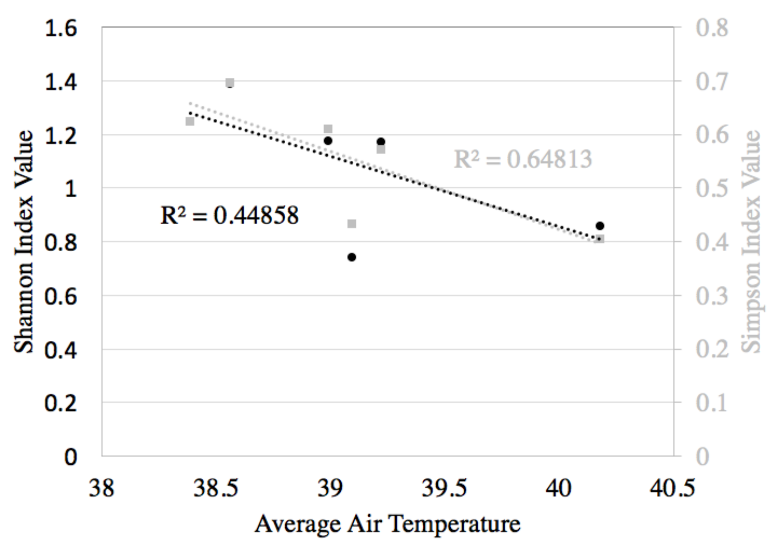

Figure 6 – Shannon index (left axis) and Simpson index (right axis) compared to air temperature.

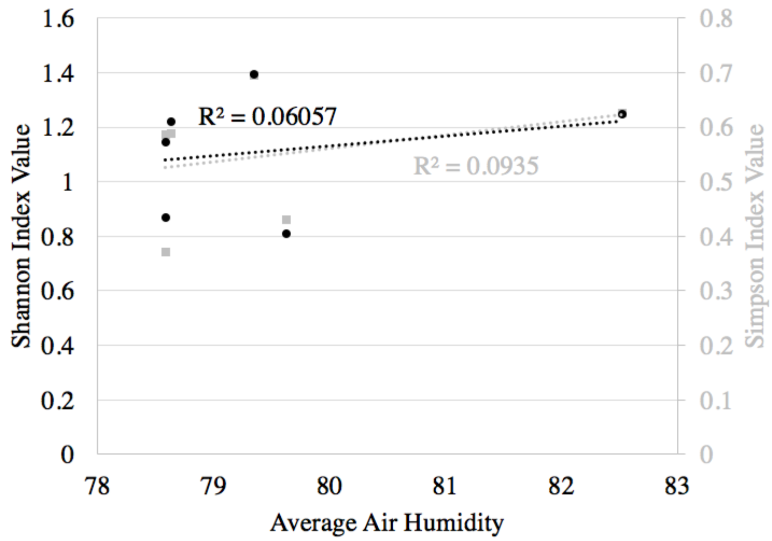

Figure 7 – Shannon index (left axis) and Simpson index (right axis) compared to air humidity.

4. Discussion

Contrary to previous research, the results of the current study indicated that the urban heat island effect (UHI) does not negativity impact lichen like initially thought. Rather, areas that experience greater impacts from the UHI have higher temperatures and lower air humidity. The findings correlated with species richness indicate that the UHI may benefit lichen diversity, but that it does not affect lichen abundance. This benefit could come in the amount of lichen species that are able to grow in one particular area because the number of species increased with increasing air temperature and decreased with increasing air humidity. These findings were contrary to previous research that indicated that increasing air temperatures are detrimental to lichen diversity.[3]

The indices calculated in this study indicate that the UHI does not affect lichens as the UHI affected each index differently. Diversity and evenness under the Shannon index decreased with increased temperature and increased with increased humidity. This result is what we expected to find. However, when calculating biodiversity using the Simpson index, diversity and evenness increased with increased temperature and decreased with increased humidity. This result is the opposite of what we expected to find and indicates that the UHI may be beneficial to lichens.

Much of the results in this study seem to suggest that the UHI is favorable to lichen diversity. An alternative is that rather than a benefit, the UHI may not a major contributor to decreased amounts of lichen diversity in urban areas. While lichens are reliant on air moisture for growth, it is possible that this is not a driving factor in lichen abundance and diversity in the Louisville area due to lichens drought resistant nature. Lichens are capable of withstanding long durations without water. During these periods, there is no growth is experienced by a lichen. Once rehydrated, however, the lichen will once again begin to grow. If the UHI is to have any impact on lichens, it is likely a decrease in growth rate, rather a decrease in abundance or diversity. However, there were a low number of replicates in this study. For us to be certain on these findings this study should be repeated with more replicates and over a duration of a few years.

From the results of this study, we can conclude that air pollution is likely the major factor in lichen abundance and diversity yet further research is needed to fully understand the driving factors in lichen abundance and diversity. The results of the current study highlight the importance of employing large-scale studies to further examine the urban heat island effect's role among lichens and furthermore in urban ecology.

5. Acknowledgments

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