Lichen as Bioindicator of Air Quality at Penn Park
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Abstract

The student Eco-Reps lichen audit team collaborated with Samuel Royer, Penn Park Supervisor within Facilities and Real Estate Services (FRES), to identify and analyze the variety of lichen species found in Penn Park as bioindicators of the surrounding air quality. Plot sampling was conducted in both areas and photos of lichen species were taken and analyzed during the 2019-2020 academic year. Self-classification of the photos indicated that crustose lichen, specifically the *Lepraria incana* species, was most commonly found; however nearly one-third of all photos were unidentifiable. Recommendations, such as in-lab analysis and biodiversity calculations, are presented for future projects related to studying lichen as a bioindicator of air quality on or around Penn’s campus, based on the compilation of data in this report. These recommendations include using air quality monitors to evaluate the presence of specific compounds in the air around the areas in which plots were created, as the lichen audit team were unable to collect this data due to the spread of the novel coronavirus (COVID-19) in the spring of 2020.

Introduction

Lichen are hardy symbiotic organisms consisting of a fungus and bacteria that can survive in various climates. Due to their sensitivity, they are highly valued ecological indicators of many ambient factors, including air quality and climate change. Previous studies on air pollution have recognized lichen as a quick and cost-effective tool for assessing air toxins since they derive essential nutrients from the atmosphere and react to gaseous pollutants, such as those caused by factories or other anthropogenic sources. The ability to identify specific toxins is linked to the unique biology of different lichen species and their capacity to exist on different surfaces, such as trees. Lichen can be separated into three varieties: Crustose, foliose, and fruticose. Crustose lichen, or crust-like lichen that are tightly embedded in their substrate, are the most popular type of lichen found on Earth. Foliose lichen are leaf-like in appearance and adhere loosely to substrate. On the other hand, fruticose are categorized by their bushy appearance.

Penn Park is a twenty-four acre park located on the east side of Penn’s campus near the Schuylkill River waterfront. The park consists of a multipurpose stadium, various athletic fields, and multiple pedestrian pathways, and serves as a large public green space. However, the train running directly above a portion of the green space combined with the natural urban environment of the park offers many potential air pollutant sources that may impact human health. Thus,
study the air quality of Penn Park, the species richness of lichen present at Penn Park was sought through quadrat sampling (a tool for biodiversity measurement by which a quadrat, or square frame of a set size, is placed in a chosen habitat and the species within that quadrat are identified and recorded). The main goal of this project was to assess the air quality of the Penn Park area by collecting data on lichen species and conducting a comparison to the air quality at the Geology Garden near Hayden Hall, a green space located near various academic buildings on a walkway commonly used by students.

**Key Stakeholders**

**For lichen identification:**

*Facilities and Real Estate Services*

Samuel Royer | Penn Park Supervisor | sroyer@upenn.edu

*Penn Earth and Environmental Science Department*

Natalie Howe | Penn Master’s of Environmental Studies Program

**For air quality monitors:**

*Engineers Without Borders*

Christopher Lin | Penn Chapter President | cjlin@wharton.upenn.edu

*Penn Earth and Environmental Science Department*

Maria Andrews | Associate Director and Major Advisor | mandrew2@sas.upenn.edu

**Methodology**

*Literature Review:* Before outlining a methodology to assess the lichen in Penn Park, preliminary literature reviews of several lichen studies, particularly in urban environments, were conducted. From these studies, the following factors were outlined to model for the Penn Park lichen study:

- The ratio of surface area to mass of lichen is very high and assimilatory capacity is relatively low. They are therefore highly susceptible to changes in atmospheric chemistry and deposition, and thus are good indicators of such changes.
- Sensitive lichen species develop structural changes in response to pollution.
- Lichens absorb pollutants such as SO, F₂, and NO₂ extremely well.

*Data collection:* Several dozen photos of lichen species were taken in two areas on Penn’s campus: Penn Park and the Hayden Geology Garden. A quadrat sampling method, as a classic study tool for ecology and biodiversity that allows for comparable samples, was employed. Generally, this method entails placing a series of squares of a set size in an area of interest and
recording the species within the quadrants. To standardize the process, 25 feet x 25 feet plots, each containing at approximately 3-4 trees with visible lichen on their bark, were measured with a tape measure and marked with yellow spray chalk. Specifically, two plots were set in Penn Park and one plot was set in the Hayden Geology Garden as shown in Figure 1. Once the plots were set, wide angle and macro phone camera lenses were used to take magnified photos of visible lichen present on the trees using iPhones.

**Figure 1. Map of Penn campus with referenced ovals.**

*Photo Analysis:* To identify the species of trees, photo observations were posted on the website iNaturalist. iNaturalist is an online network of naturalists and citizen scientists who share observations of biodiversity and receive potential species identifications from other site members. Project partners from FRES provided a book on lichen identification and additional lichen identification guides were sought as references. Group members thus self-identified lichen into three main categorical groups: crustose, foliose, and fruticose lichen. Afterwards, the images were classified based on species type. In addition to documenting the lichen species, the tree species on which the lichen were present were identified using Penn Plant Explorer, an interactive website showcasing Penn’s extensive plant and tree inventory.
Figure II. Graphic of the three lichen classifications: Crustose (crusty), Foliose (leafy), and Fruticose (bushy).

Research Findings

Figure III. Bar chart showing appearance frequencies of the different lichen types (fruticose, crustose, and foliose).
Figure IV. Bar chart showing the frequency of the different lichen species. Bars colored in red represent fruticose lichen, bars in blue represent crustose lichen, and the bar in green represents foliose lichen.

A total of 87 photos were taken in the three plots. While the photos were uploaded on iNaturalist, no lichen species were successfully identified and common responses included “vascular plants” and “fungi.” Once self-identification of the photos was conducted, crustose lichen was the lichen type most identified and the *Lepraria incana*, a type of crustose lichen, was the species most
identified. Specifically, of the photos taken crustose lichen comprised 65.5%, foliose comprised 26.4%, and fruticose comprised 8.1%. *Lepraria incana* was identified in 31 photos, or 35.6% of all photos; however 27 photos, or nearly 31% of the photos taken, were unidentifiable.

![Frequency Index of Tree Species in Plots](image)

**Figure V.** *Bar chart showing the frequency of the different tree species lichen were found on. For reference, common names of the trees (from left to right) are as follows: American Sweetgum, Pin Oak, Northern Catalpa, American hornbeam, Sawtooth Oak, and Crabapple.*

Additionally, lichen data were collected exclusively from the trees planted in each of the three plots. The species of the trees in the plots were recorded and counted as shown in Figure V. In Penn Park, the most common species were the *Liquidambar styraciflua*, *American sweetgum*, and *Catalpa northern*, whereas the most common species in the Geology Garden were the *Malus sp. Crabapple* and the *Carpinus caroliniana musclewood*.

**Recommendations and Future Directions**

Considering the large portion of photos that were unidentifiable using lichen classification guides, this work can be improved by additional connection with and/or support from lichen researchers and networks, such as the Pennsylvania Bryophyte and Lichen Association and the Pennsylvania National Heritage Program. This study can be supplemented by biodiversity calculations, which consider species richness, or the measure of the number of species found in a sample, and species evenness, or how close in numbers each species in the environment of interest are to each other. The microbiology of lichen using laboratory analysis can also be explored to validate the species composition that was primarily classified using the natural eye. Lastly, the use of a machine learning algorithm, such as can be created through Teachable Machine, a web tool that creates machine learning models, can be used to streamline the process of identifying the types of lichen by recognizing and categorizing similar images.
In order to examine the impacts of the results and gauge how the air quality at Penn Park may negatively impact members of the Penn and West Philadelphia communities, the concentration of air pollutants should be quantified using air quality monitors. For assistance in collecting air quality measurements, the lichen audit team consulted the Penn chapter of Engineers Without Borders (EWB). EWB had recently developed a group of air quality monitors and were in the process of testing their sensitivity through statistical analysis in collecting air quality measurements around Penn’s campus. At the time of this project, their monitors were unable to detect air pollutants most heavily related to lichen development, including sulphur dioxide, and were unsure whether or not nitrogen could be assessed as well. However, as the monitors are able to measure carbon dioxide, they provide a useful resource for future projects regarding air quality at Penn, especially as they become increasingly accurate in identifying the amount of air pollutants in a collected sample.

**Evaluation**

Overall, this project was successful in achieving its primary goal of identifying various types of lichen both in Penn Park and on Penn’s main campus. The majority (69%) of photos taken of lichen species in the plots were identifiable, and pertinent information, including the prevalence of the lichen species *Lepraria incana* in particular, was expressed by the lichen inventory. Interestingly, *Lepraria incana* can tolerate poor air quality, specifically poor air quality of sulfur dioxide as compared to other species, which may be more sensitive (see Larsen et al., 2007). Common challenges to this project included seasonal restrictions on data collection, specificity in identifying relevant lichen species from the three sub-groups, and the collection of air quality data near the plots. With the timeline of this project and weather patterns in Philadelphia, the lichen audit team collected initial data (photo-taking) in the fall before there was a heavy chance of snow that would possibly cover certain lichen species on the trees. Even though iNaturalist has been successfully used for plant species identification in past Eco-Reps projects (see Penn Park Meadows Project, 2019), the platform did not prove to be particularly fruitful in regards to our project, as lichen photos were commonly misidentified or unidentified at all. Because of this, classification of lichen types became our main methodology of assessing our photo inventory, and only certain specific species of lichen were able to be identified, with the assistance of additional guides and resources from FRES. The timeline of the second phase of this project, the collection of air quality measurements, was cut short several weeks due to the university’s response to the rampant spread of COVID-19. Due to the restrictions of being on campus, we were unable to conduct our planned air quality measurements, and thus this action is recommended for future projects regarding air quality at Penn. Ultimately, the data collected on lichen categories and certain species can prove useful in subsequent environmental initiatives at Penn regarding air quality, and the knowledge developed along the way of this project provides a base for additional research.
Because there often can be dozens of hundreds of different lichen species on just a single tree, additional photo inventories of each tree in our plots would be useful. As more data are collected on other trees in Penn Park, the lichen inventory created in this project will become more precise, and increase the significance of the lichen species with the highest presence at Penn. Future data collection can focus on providing detailed identification of lichen species, and this data, in combination with air quality measurements, can provide increasingly accurate depictions of the air quality at Penn.

**Conclusion**

Ultimately, this project collected several pieces of data relevant to lichen species in Penn Park and Penn’s main campus. Though lichen were successfully classified into the three sub-groups, identifying exact species proved to be a more tedious undertaking with a large margin for error. However, using lichen classifications provided several implications as to the surrounding air quality of the plots, and these implications will only become more concrete as data measures of air pollutants, including sulfur dioxide, carbon dioxide, and nitrogen, are conducted. Results from the project’s main initiatives can be used in future projects regarding air quality at Penn, especially when considering what types of lichen species are indicative of better air quality.

**Appendix**

**Print Resources**


**Online Resources**


[http://www.naturalheritage.state.pa.us/docs/2014%20Q1%20PNHP%20newsletter.pdf](http://www.naturalheritage.state.pa.us/docs/2014%20Q1%20PNHP%20newsletter.pdf)

[https://www.opalexplorenature.org/sites/default/files/7/image/AIR%204pp%20chart.pdf](https://www.opalexplorenature.org/sites/default/files/7/image/AIR%204pp%20chart.pdf)