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# A STUDY OF EPIPHYTIC LICHEN COMMUNITIES IN URBAN AND RURAL ENVIRONMENTS IN SOUTHWESTERN PENNSYLVANIA[1]

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## ABSTRACT

**Community analyses of epiphytic lichens were used to study the controlling factors of lichen abundance and diversity in urban and rural environments of Pittsburgh in southwestern Pennsylvania. Two urban sites included Schenley and Frick Parks in metropolitan Pittsburgh and two rural sites at Mingo Creek County Park in Washington County and Roaring Runs Natural Area in Westmoreland County. Community composition of lichens was measured at six intensive monitoring plots per site and site-wide species diversity surveys. The lichen diversity value, a statistical estimator of the environmental conditions at a site, was greater at the rural sites (20.8 ± 3.0) compared to the urban sites (11.3 ± 3.5) (± standard error), suggesting a less disturbed lichen community at Mingo and Roaring Runs. In the intensive monitoring plots, species richness was greater at Mingo and Roaring Runs compared to Schenley and Frick, averaging 5.2 ± 0.3, 4.7 ± 0.4, 3.7 ± 0.8 and 2.0 ± 0.4, respectively. The dominant lichens across all sites were *Lepraria lobificans*, an unidentified sterile crustose lichen and *Cladonia ochrochlora*. The dominance of nitrophilous and sulfur dioxide–tolerant lichens at all sites suggests that the lichen community within the larger geographical region is influenced by nitrogen and sulfur dioxide air pollutants. The differences between sampling sites are most likely driven by lichens responding to changes in urbanization, which include humidity and habitat fragmentation.**
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## INTRODUCTION

The diversity of lichens and their differing levels of sensitivity allow for informative community analyses to monitor pollution gradients over large areas. In urban environments, numerous studies have shown correlations between lichen abundance and air quality (Bennett & Wetmore, 2010; Perlmutter, 2010; Washburn & Culley, 2006). Additional factors that may affect the lichen community in an urban area are habitat alteration and the influence of the "city effect" resulting in less atmospheric moisture and greater temperatures than the surrounding countryside. Brodo (1966) was one of the first studies to succinctly conclude that the "city effect" on epiphytic lichens was the primary influencing factor on lichens in a city, whereas, air pollution was the most influential factor describing lichen diversity over a larger area.

Pittsburgh, located in southwestern Pennsylvania, has a long industrial history. This began with the War of 1812, sparked by the region's rich seam of bituminous coal and three navigable rivers, and continued until the collapse of the steel industry in the 1980s. Pittsburgh's economy has shifted away from industry and significant reductions in sulfur dioxide ($SO_2$) and nitrogen oxides have occurred in the region due to implementation of the 1990 Clean Air Act Amendments and Acid Rain Program (EPA, 2010). In the past ten years, Allegheny and its neighboring counties of Washington and Westmoreland have been two to three times below the U.S. Environmental Protection Agency's National Ambient Air Quality Standards for $SO_2$ and nitrogen dioxide ($NO_2$) but continue to exceed the standards for fine particulate matter ($PM_{2.5}$) and ozone (PADEP, 2006).

Our study examines the lichen abundance and diversity between urban and rural environments to determine the extent of impact to the lichen community due to anthropogenic influences. Community analyses were conducted at two urban parks in the metropolitan area of Pittsburgh in Allegheny County and two rural parks in the neighboring counties of Washington and Westmoreland counties to the south and southeast of the city, respectively. The study is in an area that has experienced a decline from a primarily steel-based industry, with a subsequent shift to service-based industries. Additionally, urban sprawl has increased in the past several decades throughout the region, which has contributed to a population increase and greater land fragmentation providing an opportunity to investigate the role of lichens as bioindicators of urbanization.

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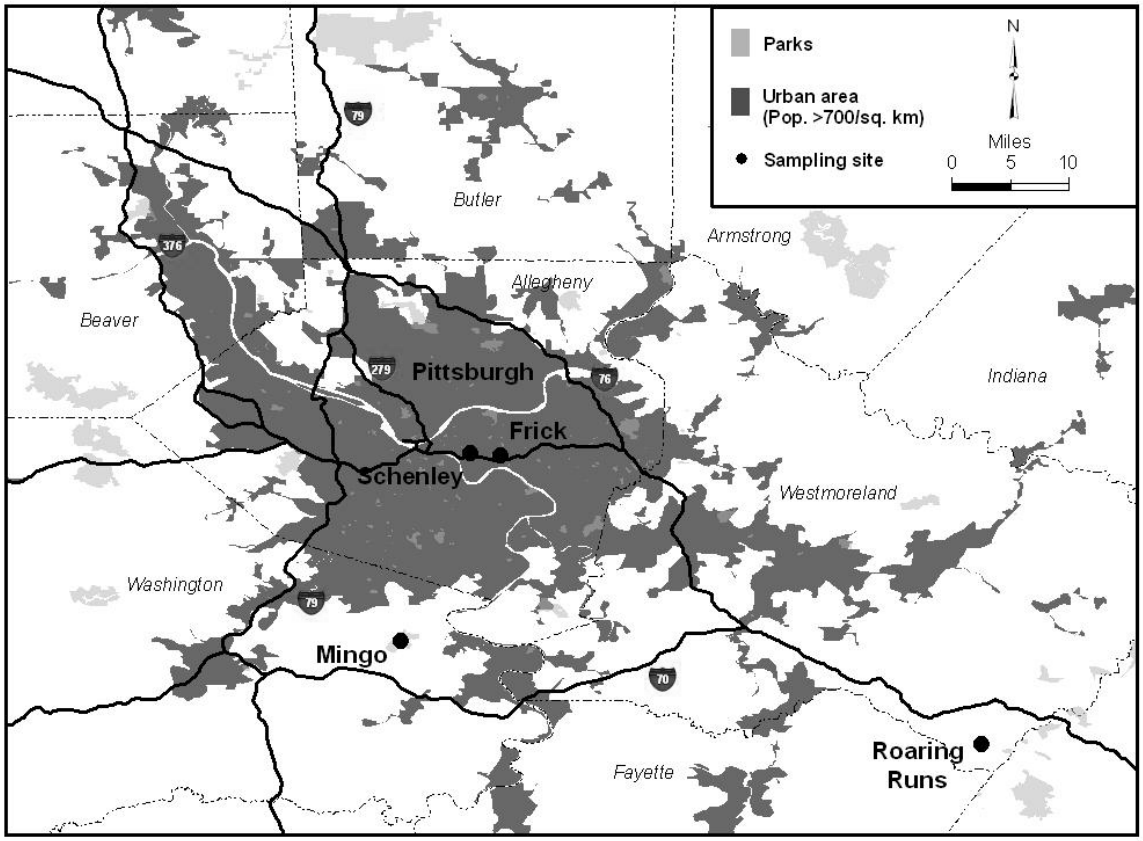


Figure 1. Site map of the locations of sampling sites that include Schenley and Frick in Allegheny County, Mingo in Washington County and Roaring Runs in Westmoreland County in southwestern Pennsylvania.

## MATERIALS AND METHODS

### *Site Description*

Lichen communities were sampled at four sites in southwestern Pennsylvania in Allegheny, Washington and Westmoreland Counties (Fig. 1). The study area lies in the Allegheny Plateaus Physiographic Province that is characterized by mixed topography on shale residuum. Winter minimum and summer maximum temperatures for Pittsburgh from 1971–2000 were –30 °C in January and 39.4 °C in July, respectively, and annual mean precipitation and snowfall was 961 and 1024 mm, respectively (NCDC, 2004).

Schenley Park (Schenley) and Frick Park (Frick) are 8 km east of downtown Pittsburgh in Allegheny County. Mingo Creek Park (Mingo) is in rural Washington County approximately 23 km south of Pittsburgh and Roaring Runs Natural Area (Roaring Runs) is part of Forbes State Forest in rural Westmoreland County approximately 61 km southeast of Pittsburgh. All sites are in mesophytic woodlands in the mid–successional stage. The four sites were chosen because of their similarities in forest type, accessibility and relative location to Pittsburgh.

Population and annual traffic densities were used as surrogate variables for urban development and mobile source emissions of $NO_2$ (Table 1). Population estimates for 2000 were determined from the U.S. Census Bureau for the zip codes in which the sites occur (USCB, 2002). The average population density was determined where multiple zip codes overlap a given site. Schenley and Frick are classified by the U.S. Census Bureau as urban areas, with >386 persons per square kilometer, with Mingo and Roaring Runs being non-urban areas.

Table 1. The surface areas, elevation ranges above sea level, population density estimates for 2000 (USCB 2002) and annual traffic estimates for 2008 (PennDOT 2009) of the sampling sites that include Schenley, Frick, Mingo and Roaring Runs.

| Site | Area (km2) | Elevation Range(m) | Population (persons/km2)* | Annual Traffic (106 km/yr.) |
|---|---|---|---|---|
| Schenley | 1.85 | 232–335 | 3,944 | 320 |
| Frick | 2.27 | 238–335 | 3,944 | 270 |
| Mingo | 10.50 | 280–378 | 80 | 14 |
| Roaring Runs | 14.50 | 561–890 | 34 | 10 |

*Sites in areas with densities >386 are urban and <386 non-urban.

Annual traffic data were obtained from the Pennsylvania Department of Transportation's annual average daily traffic maps for 2008 (PennDOT, 2009). Traffic volume data within a 3 km radius of each site were multiplied by the road lengths and by 365 days per year to determine the annual

vehicle distance traveled within a designated impact area (Washburn & Culley, 2006).

*Sampling Design*

The epiphytic lichen community of each site was sampled by intensive monitoring plots and species diversity surveys between 2008 and 2010. The location of intensive monitoring plots were chosen based on criteria to minimize differences in lichen communities between sites caused by atmospheric moisture, sunlight exposure and substrate type. At each site, six well-distributed plots in areas of favorable lichen habitat were sampled. Sampling in favorable lichen habitat allowed for plots to be effectively compared and minimized sampling in locations where lichens were absent. Additionally, the plots were located in the interior of the parks, avoiding locations along roadways and in wet environments such as along streams or wetlands. Sampling in the park interior at all sites avoids a complication of within site variability caused by sampling a variety of interior and edge habitats. It also suggests that the intensive monitoring plots will yield more low-light tolerant lichens. A healthy *Quercus rubra* (northern red oak) tree having the most coverage of lichens was chosen as a plot after searching in an area of favorable lichen habitat. *Quercus rubra* was found to support a wide variety and abundance of lichens compared to other species of trees and is endemic to upland, mature woodlands. To further maintain consistency among plots, all plot trees had a diameter at breast height (DBH) exceeding 25 cm and a surrounding canopy cover averaging 80–90%, which was measured using hemispherical photography.

On each plot tree, the percent cover of lichens was estimated using a $20 \times 50$ cm microplot subdivided with nylon string into $2 \times 2$ cm squares. The microplot was placed on the tree at eight locations 0.5 and 1.5 m above the ground in the north, east, south and west directions. Additionally, the plot tree served as the center of a 465 $m^2$ plot in which all living trees with a DBH $\geq$ 5 cm were surveyed for lichens. The lichens found on these outlying trees were categorized into three groups: crustose, foliose and squamulose. Lichens may be a combination of fruticose and squamulose growth forms, such as *Cladonia sp.*, which have stalks of a fruticose that develop from a squamulose base. Throughout the manuscript the squamulose description will be used to identify all *Cladonia sp.* The percent cover of lichens on a tree up to 3 m above the ground was recorded for each group using the following codes: 0 for <1, 1 for 1–10, 2 for 11–25, 3 for 26–50, 4 for 51–75 and 5 for 76–100%.

At all sites, a species diversity survey was separately conducted from the intensive monitoring plots. Only those lichens attached to fallen stems, tree stumps and tree trunks were collected, with all major habitats within a site surveyed. The amount of time spent searching for lichens in a given site averaged one hour per square kilometer. Lichens were identified in the field whenever possible to avoid collection, or if collected, returned to the laboratory for identification using Lichens of North America by Brodo et al. (2001). The identification of specimens was confirmed by running thin layer chromatography of lichen thalli following methods published by Bungartz (2001) and Orange et al. (2001). Lichen specimens were run in toluene:acetic acid (170:30) and toluene:ethyl acetate:formic acid (139:83:8) solvents and retention (Rf) values were compared to those published in Orange et al. (2001) to identify lichen substances and ultimately, the species. Further confirmation of specimen identification was determined by sending a subset of samples to James C. Lendemer at the New York Botanical Gardens.

Site comparisons of the intensive monitoring plots were analyzed by species abundance, Shannon–Weiner diversity index, relative dominance and frequency and lichen diversity value (LDV). Significance testing of species abundance and percent dominance was completed using one–way Analysis of Variance (ANOVA; Statext v1.2) with a significance level of $\alpha = 0.05$. When ANOVA yielded significant F-values a post hoc Scheffe test (Scheffe test; Statext v1.2) was conducted to determine which mean is significantly different from the others. To determine the Shannon–Weiner diversity index ($H$), the proportion of species $i$ relative to the total number of species ($p_i$) is calculated, and then multiplied by the natural logarithm of this proportion ($\ln p_i$). The resulting product is summed across species and multiplied by –1.

Mean percent dominance per species is the mean percent number of grids that a species occurred within the microplots of all six plots, either separately for 0.5 and 1.5 m sampling heights or sampling heights combined. Relative dominance is the proportion of mean percent dominance of a species to the total percent dominance of all species and multiplied by 100. Frequency is the proportion of the number of occurrences of a species in a microplot to the total number of microplots per site. Relative frequency is the proportion of the frequency of a species to the total frequency of all species and multiplied by 100.

The LDV is a statistical estimator of the environmental conditions in a site (Asta et al. 2002). The first step in calculating the LDV of a site (j) is to sum the frequencies of all lichen species found on each tree (i) within the site. Substantial differences in lichen growth may occur on different sides of the trunks, thus, the frequencies have to be summed separately for each aspect (N, E, S, W) to obtain four Sums of Frequencies (SF) at each tree ($SF_{iN}$, $SF_{iE}$, $SF_{iS}$, $SF_{iW}$). For each aspect, the arithmetic mean of the Sums of Frequencies (MSF) for each site is calculated:

$$MSF_{Ni} = (SF_{1Nj} + SF_{2Nj} + SF_{3Nj} + \ldots + SF_{nNj})/n \quad (1)$$

The LDV of a site is the sum of the MSFs of each aspect:

$$LDV_j = MSF_{Nj} + MSF_{Ej} + MSF_{Sj} + MSF_{Wj} \quad (2)$$

The dominant trees in the plots surrounding the central plot tree of the intensive monitoring plots were determined using importance values, which is sum of relative values for dominance, frequency and density. Relative dominance is

the proportion of basal area for a species to area sampled, which is then divided by the total dominance for all species and multiplied by 100. Relative frequency is the proportion of the number of plots in which a species occurs to the total number of plots sampled which is then divided by the total frequency for all species and multiplied by 100. Relative density is the proportion of the total number of individuals of a species to the area sampled, which is then divided by the total density for all species and multiplied by 100. In the same plots, the statistical significance between sites of percent lichen cover by type (crustose, foliose and squamulose) was determined using one–way ANOVA, followed by a post hoc Scheffe test.

## RESULTS

Mean species richness of lichens was significantly greater at Mingo (Scheffe test; $F = 6.37$, $P < 0.01$) and Roaring Runs (Scheffe test; $F = 4.51$, $P = 0.01$) than Frick (Table 2). Although Schenley had a lower mean species richness compared to Mingo and Roaring Runs, it was not significant. The Shannon–Weiner species diversity index for lichens was greatest at Mingo, Roaring Runs and Schenley. Bryophytes (liverworts and mosses), sterile lichen crust, *Cladonia ochrochlora* and *Lepraria lobificans* were present at all sites. The top three dominant epiphytes at each site accounted for >70% relative dominance and >65% relative frequency. Overall, dominance of epiphytes was greater at 0.5 m compared to 1.5 m above the ground, but not significantly. Across all sites, bryophytes and *L. lobificans* were a dominant epiphyte, with relative dominance and frequency averaging 45% and 26% for bryophytes and 20% and 25% for *L. lobificans*, respectively (Table 3). Among the individual sites, sterile crustose lichen was a dominant epiphyte at Frick and Schenley, *C. ochrochlora* at Mingo and *Cladonia caespiticia* at Roaring Runs.

The lichen diversity value (LDV) was greatest at Mingo, followed by Roaring Runs, Schenley and least at Frick (Fig. 2). The average LDV at the rural sites compared to the urban sites was 20.8 ± 3.0 and 11.3 ± 3.5, respectively.

In the extended monitoring plots beyond the central plot tree, the dominant tree species at Schenley were *Q. rubra*, *Fraxinus americana* (white ash) and *Acer saccharum* (sugar maple) with importance values of 119, 31 and 29, respec-

Table 2. Ecological diversity indices by site.
Standard errors are in parenthesis.

| Site | Species Richness | Shannon-Weiner Diversity Index |
|---|---|---|
| Schenley | 3.7 (0.8) | 1.4 |
| Frick | 2.0 (0.4) | 0.3 |
| Mingo | 5.2 (0.3) | 1.0 |
| Roaring Runs | 4.7 (0.4) | 1.1 |

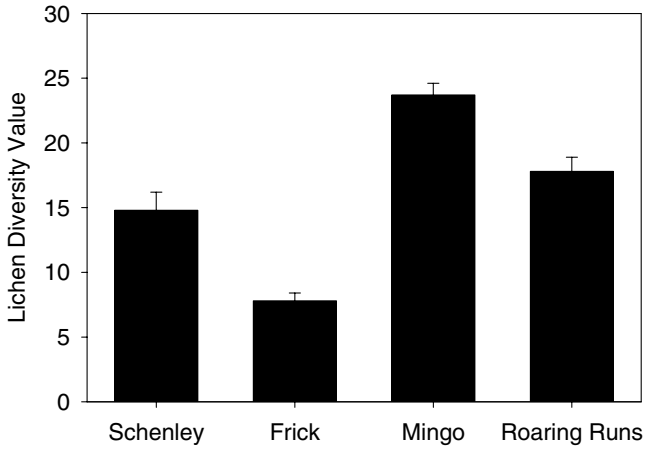


Figure 2. Lichen diversity values for the sampling sites of Schenley, Frick, Mingo and Roaring Runs determined from intensive monitoring plots. Standard error bars are shown.

Table 3. Relative percent dominance and relative frequency of bryophytes and lichens in the intensive monitoring plots at Schenley, Frick, Mingo and Roaring Runs sampling sites.

| | Relative % Dominance | | | | Relative % Frequency | | | |
|---|---|---|---|---|---|---|---|---|
| Species | Schenley | Frick | Mingo | Roaring Runs | Schenley | Frick | Mingo | Roaring Runs |
| Bryophytes | 17.9 | 44.6 | 48.3 | 69.1 | 11.5 | 25.5 | 25.1 | 30.6 |
| Sterile crusts | 35.8 | 2.5 | 3.5 | 2.4 | 27.1 | 10.6 | 8.0 | 10.2 |
| *Cladonia caespiticia* | - | - | - | 7.7 | - | - | - | 17.8 |
| *Cladonia ochrochlora* | 17.6 | 0.6 | 36.1 | 0.1 | 17.7 | 6.4 | 24.1 | 1.9 |
| *Flavoparmelia caperata* | 1.9 | - | 3.2 | 0.4 | 12.5 | - | 12.8 | 8.9 |
| *Hypogymnia physodes* | - | - | - | <0.1 | - | - | - | 1.3 |
| *Lepraria lobificans* | 19.4 | 51.9 | 7.3 | 19.1 | 14.6 | 46.8 | 16.6 | 19.7 |
| *Parmelia sulcata* | 0.3 | - | 0.1 | <0.1 | 4.2 | - | 2.7 | 1.3 |
| *Parmelinopsis minarum* | - | - | - | <0.1 | - | - | - | 0.6 |
| *Parmotrema hypotropum* | - | - | <0.1 | - | - | - | 1.1 | - |
| *Phaeophyscia rubropulchra* | - | - | 0.2 | - | - | - | 2.7 | - |
| *Physcia millegrana* | 7.0 | 0.4 | - | - | 12.5 | 10.6 | - | - |
| *Punctelia caseana* | - | - | 0.1 | 1.1 | - | - | 1.6 | 7.6 |
| *Punctelia rudecta* | - | - | 1.1 | - | - | - | 5.3 | - |

tively. The three dominant tree species at Frick and Mingo were *Q. rubra*, *Prunus serotina* (black cherry) and *A. saccharum*, with respective importance values of 68, 43 and 38 at Frick and 76, 33 and 61 at Mingo. At Roaring Runs, the three dominant trees were *Q. rubra*, *Acer rubrum* (red maple) and *A. saccharum*, with importance values of 73, 63 and 37, respectively.

Identifying *Q. rubra* as the central plot tree resulted in its dominance in all plots. Because *Q. rubra* and *A. saccharum* were abundant across all sites, these trees were chosen in this study to compare for lichen cover of crustose, foliose and squamulose lichens. *P. serotina* was abundant at Frick, Mingo and Roaring Runs within our sampling plots, thus, chosen as the third tree. However, *P. serotina* was absent from the sampling plots at Schenley. The number of individual trees of a given species surveyed for lichen cover ranged from 12 to 55 per site, excluding *P. serotina* which were not present in the plots at Schenley.

Crustose lichens, which consisted primarily of sterile crusts and *L. lobificans*, surveyed on *A. saccharum* (Scheffe test; Mingo-Schenley: $F = 3.65$, $P = 0.01$; Mingo-Frick: $F = 14.42$, $P < 0.01$; Mingo-Roaring Runs: $F = 6.33$, $P < 0.01$) and *Prunus serotina* (Scheffe test; Mingo-Frick: $F = 6.39$, $P < 0.01$; Mingo-Roaring Runs: $F = 4.40$, $P = 0.02$) had a significantly greater percent cover on trees at Mingo compared to the other sites by a magnitude of two to four (Fig. 3A). There was no significant difference between sites in crustose cover on *Q. rubra*. In regards to foliose lichen cover, which consisted primarily of *Flavoparmelia caperata*, *Parmelia sulcata*, *Physcia millegrana*, *Punctelia caseana* and *Punctelia rudecta*, there was significantly more than two times the coverage on *A. saccharum* (Scheffe test; Mingo-Schenley: $F = 12.09$, $P < 0.01$; Mingo-Frick: $F = 27.67$, $P < 0.01$; Mingo-Roaring Runs: $F = 13.88$, $P < 0.01$), *P. serotina* (Scheffe test; Mingo-Frick: $F = 26.59$, $P < 0.01$; Mingo-Roaring Runs: $F = 22.45$, $P < 0.01$) and *Q. rubra* (Scheffe test; Mingo-Schenley: $F = 11.84$, $P < 0.01$; Mingo-Frick: $F = 5.24$, $P < 0.01$; Mingo-Roaring Runs: $F = 6.41$, $P < 0.01$) at Mingo compared to the other sites (Fig. 3B). The squamulose lichen coverage, which consisted of *Cladonia sp.,* was greater on all three tree species at Mingo compared to the other sites but only significantly so on *A. saccharum* (Scheffe test; Mingo-Schenley: $F = 38.86$, $P < 0.01$; Mingo-Frick: $F = 18.53$, $P < 0.01$; Mingo-Roaring Runs: $F = 5.01$, $P < 0.01$) and *Q. rubra* (Scheffe test; Mingo-Schenley: $F = 24.79$, $P < 0.01$; Mingo-Frick: $F = 7.71$, $P < 0.01$; Mingo-Roaring Runs: $F = 7.57$, $P < 0.01$) (Fig. 3C). Mingo had significantly more squamulose lichen cover than Frick on *P. serotina* (Scheffe test; $F = 11.41$, $P < 0.01$). On *A. saccharum*, Roaring Runs had significantly more squamulose lichen cover compared to Schenley (Scheffe test; $F = 5.24$, $P < 0.01$) and Frick (Scheffe test; $F = 9.62$, $P < 0.01$). On *Q. rubra*, squamulose lichen cover was significantly greater at Roaring Runs (Scheffe test; $F = 6.80$, $P < 0.01$) and Frick (Scheffe test; $F = 3.05$, $P = 0.03$) compared to Schenley. Overall, the percent cover of squamulose lichens was greatest at the rural sites compared to the urban sites, foliose coverage was only slightly greater at the rural sites if Mingo and Roaring Runs are averaged and there is little difference in crustose coverage between rural and urban sites if Mingo and Roaring Runs are averaged.

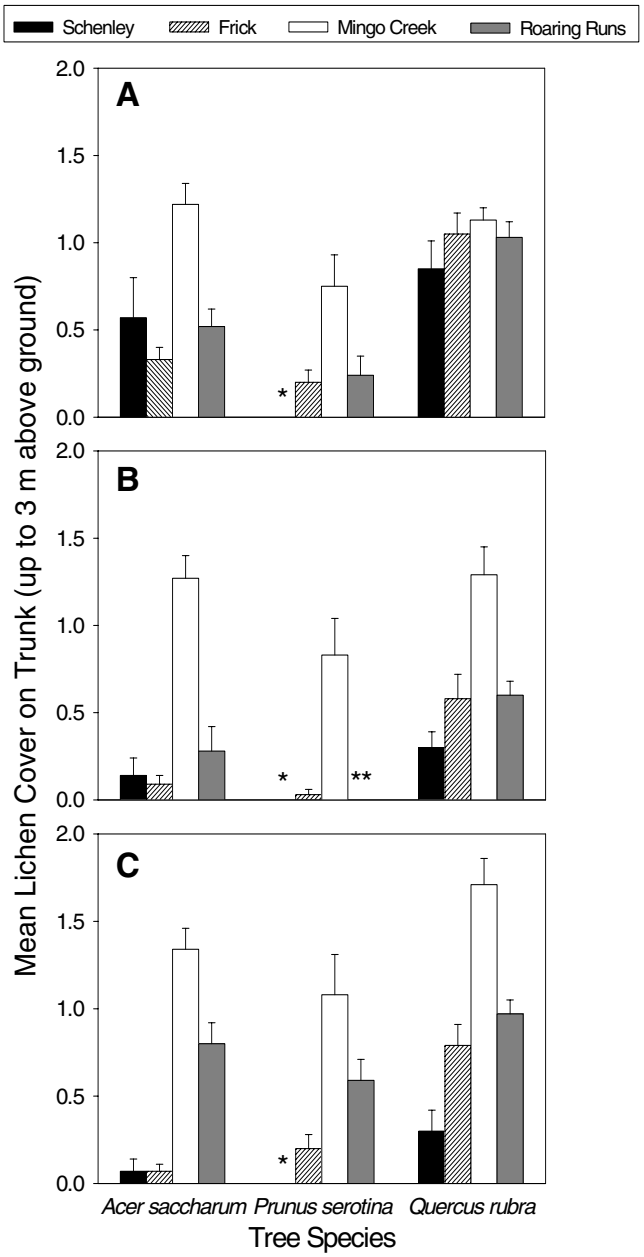


Figure 3. Mean percent lichen cover (0 for <1%, 1 for 1–10% and 2 for 11–25%) of crustose (A), foliose (B) and squamulose (C) lichen forms on *Acer saccharum*, *Prunus serotina* and *Quercus rubra* for the sampling sites of Schenley, Frick, Mingo and Roaring Runs determined from the intensive monitoring plots. Standard error bars are shown. (* no data; ** <1% lichen cover)

In the species diversity survey 46 epiphytic lichens were found throughout all of the sampling sites. The rural sites had more species, with 33 species found at Roaring Runs and 32 at Mingo compared to the urban sites, with 20 species found at Schenley and 19 at Frick (Table 4).

Table 4. Epiphytic lichen species identified during sampling at the intensive monitoring plots and species diversity surveys at Schenley, Frick, Mingo and Roaring Runs sampling sites.

| Species | Schenley | Frick | Mingo | Roaring Runs |
|---|---|---|---|---|
| *Allocetraria oakesiana* (Tuck.) Randlane & Thell | | | | x |
| *Amandinea polyspora* (Willey) Lay & May | | x | x | |
| *Amandinea punctata* (Hoffm.) Coppins & Scheid. | x | | | x |
| *Arthonia caesia* (Flot.) Korb. | | x | x | |
| *Buellia dialyta* (Nyl.) Tuck. | | | | x |
| *Candelaria concolor* (Dicks.) Stein | x | x | x | |
| *Candelariella efflorescens* Harris & Buck | x | x | x | |
| *Cladonia caespiticia* (Pers.) Florke | | x | x | x |
| *Cladonia cristatella* Tuck. | x | | x | x |
| *Cladonia macilenta var. bacillaris* Hoffm. | | | x | x |
| *Cladonia ochrochlora* Florke | x | x | x | x |
| *Cladonia parasitica* (Hoffm.) Hoffm. | x | | x | x |
| *Flavoparmelia caperata* (L.) Hale | x | x | x | x |
| *Graphis scripta* (L.) Ach. | | | | x |
| *Hypogymnia physodes* (L.) Nyl. | | | x | x |
| *Lecania croatica* (Zahlbr.) Kotlov | x | | | |
| *Lecanora saligna* (Schaerer) Zahlbr. | x | | | |
| *Lecanora strobilina* (Spreng.) Kieffer | | x | x | x |
| *Lecanora symmicta* (Ach.) Ach. | | | x | x |
| *Lecanora thysanophora* Harris | | | x | |
| *Lepraria lobificans* Nyl. | x | x | x | x |
| *Lepraria neglecta* (Nyl.) Erichsen | | | | x |
| *Lepraria caesioalba* (de Lesd.) Laundon | | | | x |
| *Melanelia subaurifera* (Nyl.) Essl. | | x | x | |
| *Micarea peliocarpa* (Anzi) Coppins & Sant. | | | x | x |
| *Micarea prasina* Fr. | | | | x |
| *Myelochroa aurulenta* (Tuck.) Elix & Hale | | x | | |
| *Ochrolechia arborea* (Kreyer) Almb. | | | x | |
| *Parmelia squarrosa* Hale | | | x | x |
| *Parmelia sulcata* Taylor | x | x | x | x |
| *Parmelinopsis minarum* (Vainio) Elix & Hale | x | | x | x |
| *Parmotrema hypotropum* (Nyl.) Hale | x | x | x | x |
| *Phaeophyscia adiastola* (Essl.) Essl. | | | x | |
| *Phaeophyscia pusilloides* (Zahlbr.) Essl. | x | x | x | x |
| *Phaeophyscia rubropulchra* (Degel.) Essl. | x | x | x | x |
| *Physcia millegrana* Degel. | x | x | x | x |
| *Physcia stellaris* (L.) Nyl. | x | | | x |
| *Physcia subtilis* Degel. | | x | x | |
| *Placynthiella dasaea* (Stirton) Tonsberg | | | | x |
| *Placynthiella icmalea* (Ach.) Coppins & James | | | | x |
| *Punctelia caseana* Lendemer & Hodkinson | x | x | x | x |
| *Punctelia rudecta* (Ach.) Krog | x | x | x | x |
| *Pyrrhospora varians* (Ach.) Harris | | | x | |
| *Ropalospora chlorantha* (Tuck.) Ekman | | | x | x |
| *Scoliciosporum chlorococcum* (Stenh.) Vezda | x | | | x |
| *Trapeliopsis flexuosa* (Fr.) Coppins & James | | | x | x |

## DISCUSSION

In the intensive monitoring plots, lichen richness and percent cover of crustose, foliose and squamulose forms were greatest at Mingo and least at Frick. Overall, the percent cover of foliose and squamulose lichens was greatest at the rural sites. Although Schenley had the greatest Shannon-Weiner diversity value from the intensive plots, the species diversity surveys showed an average species count of 33 at the rural sites compared to 20 at the urban sites. During the intensive plot sampling it was also observed that foliose and squamulose lichens had both larger and thicker thalli, suggesting healthier specimens at the rural sites. Additionally, a greater number of *Cladonia sp.* had podetia at the rural sites.

The population and traffic densities surrounding the urban sites are a magnitude of 69 and 25 times greater than at the rural sites, respectively. The greater traffic density in the Pittsburgh area influences local concentrations of $NO_2$, with an annual average concentration of $2.1 \times 10^4$ µg $m^{-3}$ compared to an annual average of $1.4 \times 10^4$ µg $m^{-3}$ at air monitoring stations within 33 km of Mingo and Roaring Runs between 1997 and 2006 (PADEP, 2006). Nitrogen

dioxide emitted by road traffic can be an influential pollutant affecting lichen communities in urban environments (Gombert et al., 2003). However, this study cannot distinguish differences in lichen communities between the urban and rural sites due to nitrogen pollution because of the overwhelming dominance of nitrophilous macrolichen species across all sampling sites. The dominant nitrophilous macrolichen species in this study include *Flavoparmelia caperata*, *Parmelia sulcata* and species in the genera *Phaeophyscia* and *Physcia*. Furthermore, most of the dominant macrolichens identified in the study, such as *P. sulcata* and *Phaeophyscia sp.* and *Physcia sp.* are considered to have an intermediate to tolerant sensitivity to $SO_2$ pollution. The lichens most sensitive to air pollution, such as those with cyanobacteria as their algal component and the noncladoniform fruticose lichens were not found at any sampling sites. However, a historical survey conducted around 1922 in Western Pennsylvania (Mozingo, 1948) and more recent surveys in central and eastern Pennsylvania have yielded these types of lichens (Harris & Lendemer, 2005; Lendemer & Macklin, 2006). The absence of a pollution gradient in our study is presumed the result of a long-term exposure to air pollutants from a steel-based industry. Although air quality has improved in recent years, lichens are slow to colonize and grow.

Brodo's (1966) "city effect" is likely a major factor in describing the differences in the lichen communities between the urban and rural sites. Lichens are indicators of air pollution as well as moisture and temperature. Temperatures between the urban, Pittsburgh area and rural countryside are likely not significant enough to explain the differences in lichen communities. However, we compared the density of streams between sites as a surrogate to humidity and found that stream density was 0.6 km per $km^2$ and 1.0 km per $km^2$ at the urban and rural sites, respectively. At Mingo, the mean distance between sampling plots and a body of water was 0.2 km, compared to Schenley, Frick and Roaring Runs which were 0.2, 0.7 and 0.3 km, respectively. The intensive monitoring plots showed that lichen coverage was greatest at Mingo compared to any other site, and we noted throughout our study that the density of lichens was greatest in the bottomlands along streams. If humidity is a factor influencing the lichen community, then the presence of bryophytes should also be more pronounced at the rural sites than the urban sites. Both bryophytes and lichens have relatively similar moisture requirements for metabolic processes. The mean relative dominance and frequency of bryophytes in the rural sites is 59% and 28%, respectively, compared to 32% and 19% in the urban sites, respectively. In a study by Perlmutter (2010), which complements our own study but was conducted around Raleigh, North Carolina, humidity was also found to play a role in lichen community structure. Thus, it appears that humidity may be a factor that influences the abundance and diversity of lichen communities between the urban and rural sites.

An additional factor to consider in its effect on lichen communities in this study is habitat quality. A study by Johansson & Ehrlen (2003) studied the influence of habitat quality on two epiphytic lichens and found that the abundance of the lichens was positively correlated with tree size and that the presence of the lichens was negatively correlated with the isolation of woodlands. The larger and older trees are exposed to colonization for a longer time and may provide more suitable substrate with rough bark to capture dispersing propagules as well as have different bark chemistry than younger trees (Armstrong, 1990; Gustafsson & Eriksson, 1995). The isolated woodlands would imply dispersal constraints, inhibiting genetic diversity among lichens in urban areas and preventing recolonization should the isolated patch become further fragmented through recreational management or environmental degradation (Johansson & Ehrlen, 2003). So while the study shows that urban sites are less suitable for lichens, it is important to recognize that the rural sites are not intact undisturbed habitats. However, Mingo and Roaring Runs consist of older growth forests that would be more suitable for lichen dispersion and propagation than the urban sites. Additionally, the overall park area of the rural sites, as depicted in Table 1, is a magnitude of ten times the urban sites. There is also a greater degree of isolation at the urban sites, being completely surrounded by development, whereas, Mingo and Roaring Runs is surrounded by woodlands or dispersed residential and agricultural lands. Therefore, habitat quality is likely a second factor in defining the differences in the lichen communities between the urban and rural sites.

In conclusion, air pollution defines the lichen community in the larger geographical region of this study as demonstrated by the dominance of nitrophilous and $SO^2$-tolerant species throughout the sampling sites and the general lack of pollutant-sensitive species. The differences in species richness and diversity between the sites are best defined by Brodo's (1966) "city effect" and habitat quality. Although our study did not directly measure humidity levels at the urban and rural sites, if humidity is lower in urban sites lichens may succumb to increased dessication, resulting in reduced metabolic activity compared to those sites that have greater humidity levels. The more isolated urban parks may inhibit the dispersion and genetic diversity of lichens resulting in a lower diversity, as observed in the species diversity survey.

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