Parmelia sulcata as a bioindicator of air pollution in Newfoundland, Canada

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Abstract. **The global increase in air pollution has a number of consequences including damage to our environment and health. Bioindicators are living organisms which reveal certain qualities of our environment with their absence or presence. This is useful in identifying polluted areas in order to manage pollution levels. *Parmelia sulcata* is said to be a pollution-tolerant lichen and consequently a bioindicator. We wished to test *P. sulcata*'s ability as a bioindicator, indicating poor air quality with its presence. We used randomized quadrat sampling of 80 trees over four municipalities on the Avalon Peninsula of Newfoundland, Canada with increasing human populations as a proxy for pollution. Results suggest that *P. sulcata* is not an ideal bioindicator of high pollution. It was absent or diseased in areas of highest pollution and present in areas of low-medium pollution levels. We recommend further studies evaluate *P. sulcata*'s potential as a bioindicator of low-medium air pollution.**

Keywords. **Avalon Peninsula, monitoring, pollution-tolerant, urban.**

Introduction

The rapid increase in global pollution levels is having drastic and harmful consequences. Outdoor air pollution has grown 8% globally from 2008 to 2013 (World Health Organization 2016). Negative effects not only include climate change, but also health impacts such as an increase in respiratory allergy and asthma (D'Amato 2011) in areas with high air pollutants. Bioindicators are a natural way of monitoring air pollution and resulting environmental changes. This can be especially useful in indicating poor air quality so that measures can then be taken to improve air pollution. Lichens are known bioindicators of air pollution (Asta et al. 2002; McMullin et al. 2016). In most studies using lichens as a bioindicator, the absence of pollution sensitive lichens in an area is indicative of a high pollution levels (e.g., McMullin et al. 2017). Others (e.g., Munzi et al. 2007) have examined functional groups and used their presence or absence (depending on traits) as indicators of high vs. low air quality. We believe the presence of a certain lichen species is a more apparent and consequently a more effective bioindicator of pollution than a bioindicator that indicates pollution with its absence.

Here, we test the hypothesis that the presence of a single species of pollution-tolerant lichen, *Parmelia sulcata* Taylor, can indicate poor air quality. We chose *P. sulcata* for this study as it is widespread globally and it is documented to be capable of withstanding common urban pollutants (Istomina and Likhacheva 2015; McMullin et al. 2017).

Georgy Gause's competitive exclusion principle, stated as "two species competing for the same limiting resource cannot coexist" (Capitán et al. 2017), suggests that at high pollution levels, *P. sulcata* would thrive if it has a pollution-tolerant survival advantage, but in low-pollution more pollution-sensitive lichens might competitively exclude or reduce its abundance. If our results show a pattern of high *P. sulcata* abundance in areas known to have reduced air quality and lower abundance in areas away from urban centres, then this species could be an effective bioindicator of air pollution.

To examine the effectiveness of *P. sulcata* as a bioindicator for pollution, we used human population in different municipal areas on the Avalon Peninsula of Newfoundland, Canada as a proxy for pollution levels. Within these municipalities, we sub-sampled on residential streets and along busy roads to account for microclimates (which we assumed to have subtle differences in air quality). This offers another smaller scale at which air pollution could affect lichen abundance. We predicted that *P. sulcata*'s abundance would increase gradually from areas of small to large human population density for both busy roads and residential streets, although the abundance of *P. sulcata* would be higher on busy roads in each municipal area than on the associated residential streets due to motor vehicle emissions.

Materials and Methods

We sampled *Parmelia sulcata* in four municipal areas on the Avalon Peninsula of Newfoundland, Canada (Fig. 1), during the month of October 2017: Portugal Cove-St. Phillip's (population 7366), Town of Paradise (population 17 695), City of Mount Pearl (population 24 284), and the City of St. John's (population 196 966) (Statistics Canada 2015). We classified two sub-municipalities per municipality as busy roads and residential streets. We sampled *P. sulcata* along the boles of *Acer pseudoplatanus* L. with a trunk circumference between 50 and 80 cm as a proxy for tree age. We examined eighty trees (ten trees per sub-municipality) and established three quadrats on each tree. We placed a 15 cm 15 cm quadrat 50, 100, and 150 cm above ground level along a line transect on the south side of each tree to ensure sun exposure was consistent. We recorded the number of 1.5 cm^2 quadrat squares where the percent of *P. sulcata* cover was 50% or greater. We calculated the mean percent cover for the 30 samples in each sub-municipality at each location. We tested for differences in *P. sulcata* percent cover between municipal areas and between the sub-municipalities (residential streets and busy roads) using an ANOVA in the software package Stat Plus (2015, AnalystSoft Inc.).

Results and Discussion

Abundance of *Parmelia sulcata* varied across the study areas (Table 1; Fig. 2). The ANOVA test indicates that there is a statistically significant difference in *P. sulcata* abundance across the sampling areas ($F = 2.89$, $p = 0.0052$). In general, as the human population increased so did the abundance of *P. sulcata,* supporting our hypothesis. This indicates *P. sulcata* is generally more abundant in areas of higher pollution levels and can perhaps indicate pollution with its presence. However, there are significant discrepancies when examining the trends on busy roads and residential streets instead of the greater municipal area.

Trends between trees sampled along residential vs. busy streets only fit the expected pattern in the largest (St. John's) and smallest (Portugal Cove-St. Phillip's) municipal areas. These two municipal areas have a higher abundance of *P. sulcata* on busy roads than on residential streets, as predicted, indicating *P. sulcata* is more abundant in areas of higher pollution. However, in the two municipal areas of intermediate human populations the abundance of *P. sulcata* was highest on residential streets, contrary to the hypothesized relationship.

The trend on residential streets alone is consistent with our hypothesized relationship. *Parmelia sulcata* abundance increased with human population. The lowest abundance of *P. sulcata* was in the municipality with the lowest human population (Portugal Cove-St. Philips). We observed more diversity and higher abundance of other lichens and mosses in Portugal Cove-St. Philips and did not in St. John's, the municipality of highest human population. This observation supports the hypothesis that *P. sulcata* was being outcompeted by more pollution-sensitive lichens in clean air but thrived in polluted air due to its pollution-tolerant survival advantage.

However, the pattern on busy roads did not follow the same hypothesized trend. *Parmelia sulcata* was absent in two of the four municipal areas, both with intermediate human population,

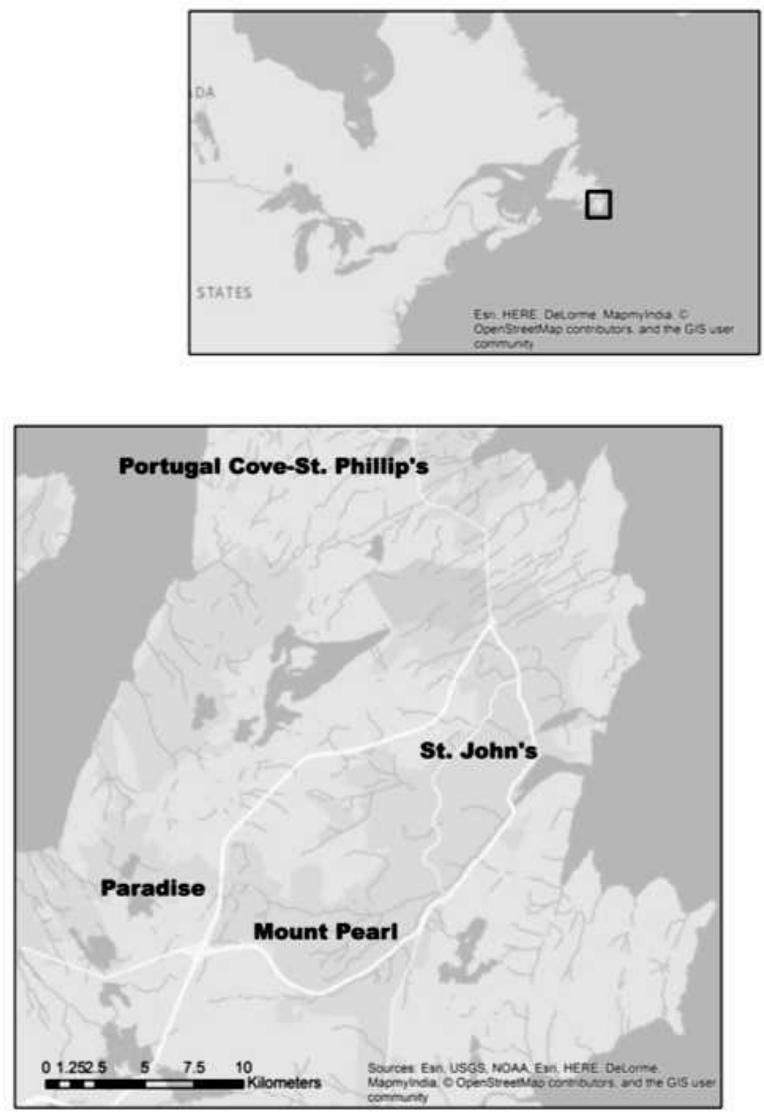

Figure 1. Map of the study area showing the four municipal areas on the Avalon Peninsula, Newfoundland and Labrador, Canada. Inset map shows location of the Avalon Peninsula.

where we predicted its abundance would be increasing. This might be due to our assumption that human population is a suitable proxy for pollution levels. We observed that these two areas with intermediate human population without *P. sulcata* were potentially more polluted than the area of highest human population. For example, there were virtually no lichens present on the trees along these two areas of busy roads whereas they were abundant in the City of St. John's, the area of highest human population. Despite two municipalities having lower human population, it is highly likely that vehicular traffic levels are higher, given that public transit is limited and building density is lower, limiting the ability for people to travel by foot or bicycle. In the future, we could deploy traffic counters to determine levels of vehicular traffic more precisely, instead of using human population as a proxy.

Notably, we observed bleaching on *P. sulcata* (Fig. 3) found on busy roads in the City of St. John's, the municipality of highest human population. This bleaching, called necro spots, is a change of colour to the thalli related to high pollution levels (Istomina and Likhacheva 2015). One study observed a change in photosynthetic rate in bleached *P. sulcata* found in a polluted area

Table 1. Percent cover of *Parmelia sulcata* along ten samples each of *Acer pseudoplantanus* along residential streets and busy roads in four municipal areas. Data shown are mean (± s.e.).

Municipal Area	**Population**	**Percent Cover (± s.e.)**	
		Residential Street	**Busy Road**
Town of Portugal Cove-St. Phillips	7 366	0.1 (0.0)%	2.0 (1.9)%
Town of Paradise	17 695	3.1 (1.4)%	0.0 (0.0)%
City of Mount Pearl	24 284	7.2 (3.4)%	0.0 (0.0)%
City of St. John's	196 966	9.8 (3.0)%	12.0 (3.8)%

compared to normal *P. sulcata* from clean air (Pearson and Skye 1965). This implies that bleaching indicates *P. sulcata* has damaged health. Our observation of bleaching on *P. sulcata*'s in the City of St. John's indicates the high pollution is compromising *P. sulcata*'s health although not affecting its abundance. However, one can extrapolate that in an area of even higher pollution the air pollution would start to compromise *P. sulcata*'s health to the extent of inhibiting survival. This could be why *P. sulcata* was absent on busy roads in the two areas with intermediate human populations if pollution levels are actually higher than in the City of St. John's.

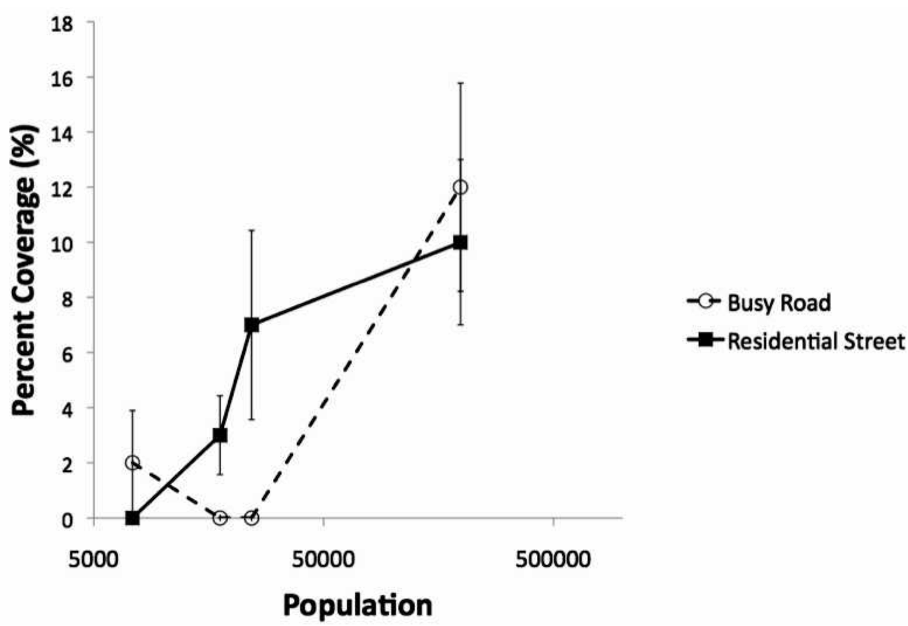

Figure 2. Mean percent cover of *Parmelia sulcata* on *Acer pseudoplatanus* sampled along busy roads (solid line, filled symbols) and residential streets (dashed line, open symbols) in the four municipal areas shown in Figure 1. Population of each municipal area is on the x-axis, from smallest to largest they are Portugal Cove-St. Phillips, Town of Paradise, City of Mount Pearl, and the City of St. John's. Values shown are mean and standard deviation from 10 trees samples for each combination of sub-municipality (busy vs. residential roads) and municipal area. Note that the x-axis is log-scaled.

Differences in *P. sulcata* abundance among trees has also been shown to be influenced by tree age, bark texture, and location (i.e., environmental conditions other than air pollution) (Istomina and Likhacheva 2015), variables which we did not quantify and could have consequently be the cause for discrepancies in our data. A study in an industrial area of Sweden classifies *P. sulcata* as sensitive to air pollution (Pearson and Skye 1965), contradicting our classification of *P. sulcata* as pollution tolerant. This is likely because they are determining *P. sulcata*'s pollution-sensitivity by a set of physiological and morphological criteria. These criteria include photosynthetic rate, photosynthetic patterns and appearance such as the discolouration in *P. sulcata* mentioned above. Although these properties vary in areas of different pollution levels causing the study to classify *P. sulcata* as sensitive to air pollutants, we are only concerned with *P. sulcata's* abundance, which is not as sensitive to air pollutants.

Overall we conclude that presence of *P. sulcata* is not a highly reliable bioindicator for high pollution levels as it is absent along roads where pollution is likely highest, and it is present in many low-human population areas where we assume pollution levels are lower. For example, *P. sulcata*'s abundance was lower on busier streets compared to residential streets in two of the four municipal areas and it displayed bleaching, a sign of reduced health, in the area of highest human population. This is consistent with recent work on lichen bioindicators by Will-Wolf et al. (2017a,b) who found that *P. sulcata* was not the most reliable bioindicator of a suite of common lichens and had confounding problems due to misidentification and lower sample size. However, *P. sulcata* may be a reliable bioindicator of areas with low-medium air-pollutant levels. *Parmelia sulcata* was outcompeted and consequently low in abundance in areas of clean air and then gradually increased its abundance with increasing air pollution until air pollution reached a certain level. This suggests a high abundance of *P. sulcata* indicates a low-medium air pollution level. Another bioindication of medium air pollution levels is bleached *P. sulcata* as observed in the City of St. John's. Further work to refine monitoring programs, perhaps in conjunction with direct measures of air quality and using a suite of lichens, can help refine our understanding of lichen bioindicators in and around urban centres.

Figure 3. *Parmelia sulcata* on a typical *Acer pseudoplatanus* trunk sampled on a busy road in the City of St. John's. There is visible bleaching, or necro spots, on the thallus of *P. sulcata* due to high pollution levels. This indicates compromised health of *P. sulcata*.

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