LICHEN INDICATORS OF ECOSYSTEM HEALTH IN NOVA SCOTIA'S PROTECTED AREAS

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SUMMARY

Air pollution and climate change are threats to maintaining ecological health of protected areas. Protected Area managers require a meaningful way to measure impacts of these threats. Lichens provide a relevant, sensitive and measurable indicator for long-term monitoring. Hundreds of studies have linked lichen communities to air quality, and several long-term lichen monitoring programs in Europe and the US are using lichens to assess climate change. Other studies have shown strong correlations of lichen abundance to ecosystem biodiversity and productivity. Analyses of existing lichen survey data suggest sensitivity of Nova Scotia lichens to air quality. The Protected Areas Branch (PAB) of the Nova Scotia Department of Environment and Labour will establish a province wide network of lichen monitoring plots within protected areas involving partners from industry, government and academia. Objectives of the project are to provide long-term monitoring in forests of: 1. air quality impacts on ecosystems; 2. climate change impacts on ecosystems; 3. elements of forest ecosystem productivity; and 4. elements of biodiversity in forest ecosystems

1. INTRODUCTION

1.1 Issue

A primary objective of most protected areas is to protect natural processes and biological diversity. Despite legal protection, threats to protected areas continue. Human activities external and internal to protected areas can affect the biota and processes occurring within the protected areas. Air quality and climate change are two significant issues affecting ecological integrity of protected areas with which managers must deal.

1.2 Air Quality and Climate Change

Despite initiatives to reduce airborne pollutants, air quality problems continue to be an issue and are anticipated to be for the next 20 to 50 years. Environment Canada (1) reports that growth in air pollution sources has the potential to outpace any gains made in recent years. Effects of acid rain continue to impact ecosystems. Recent modelling studies show that up to one quarter of lakes in eastern Canada still will be chemically damaged even after 2010 emission targets are reached (1). High levels of heavy metals are being found in ecosystems in Nova Scotia as a result of pollution (2).

Nova Scotia provides an ideal region to monitor impacts of pollutants on ecosystems. The Maritime provinces of Canada are uniquely situated within storm tracks and prevailing winds which transport industrial emissions from central and eastern North America (3). Thus, Nova Scotia receives the brunt of pollutants from industrialized areas of North America. Nova Scotia can provide an early warning system for the rest of North America on ecosystem effects of pollutants.

Climate change impacts on species and ecosystems are increasingly evident. Two recent syntheses and re-analyses of hundreds of studies on biota have shown significant changes in breeding, flowering, nesting and abundance of plants and animals consistent with expected effects of climate change (4,5). Modelling studies are predicting significant effects to biological diversity and species abundance with some of the largest effects occurring in temperate forest regions (6,7).

The relationship of lichens as early warning indicators of air pollution, particularly acidifying or fertilizing sulfur and nitrogen-based pollutants, has been documented in hundreds of scientific papers (8). Air quality monitoring studies have been done worldwide and permanent monitoring programs using lichens exist in the US, Netherlands and Switzerland. Lichens' sensitivity to air quality stems from their reliance on airborne nutrients and water, as well as lack of protective structures such as cuticles found in vascular plants. Trees and other vascular plants are affected by pollution but are much slower to show impacts than lichens (9).

More recently, lichens are being used in assessing climate in Europe and the US (8, 10). Distributions of certain species are a response to regional moisture and temperature gradients. Mapping distribution of climate sensitive species provides an indication of climatic conditions and monitoring over time reveals climate change effects.

The first challenge to managing these problems is to know when these impacts occur in ecosystems, what parts of ecosystems are most affected, and how significant the threats are. Answers to these questions can also help direct research. Because ecosystems are so complex, short-term studies are often unable to detect long-term trends such as climate change. It is most practical to answer these questions with a long-term monitoring program using ecological indicators. Indicators provide a practical way to monitor complex ecological conditions and to serve as early warning mechanisms. Thus indicators must be relevant, telling us something useful about a system, and they must be sensitive so that they indicate perturbation before significant impact occurs to the rest of the ecosystem. Further, indicators must be efficiently measurable. Lichens meet the criteria as useful indicators for assessing impacts of both air pollution and climate change.

1.3 Biodiversity and Ecosystem Productivity

The role of lichens in ecosystem processes and biodiversity also makes them a useful group to monitor. Lichens represent a significant proportion of biodiversity in many ecosystems (8). A study in boreal forests of Scandinavia showed increasing diversity of spiders with increasing lichen diversity (11). It has been suggested by researchers that forest bird diversity may be associated with lichen diversity (11). Lichens also provide food for animals and habitat for invertebrates (12, 13, 14, 15). Many lichens are habitat specific and thus a diversity of lichens at a site indicates habitat heterogeneity (16). Given the close relationship of lichens with other organisms, and their contribution to biodiversity, lichens provide an ideal group to monitor for changes in diversity in ecosystems.

Lichens play an important role in nutrient cycling (17). Lichens intercept air and rain-borne nutrients, absorbing nutrients for their use and contributing to cycling in ecosystems. Some studies have shown these aerosol and water-borne nutrients would be largely leached away without interception by lichens or other epiphytes (18, 19, 20, 21, 22). Some lichen species fix nitrogen through a symbiotic relationship with cyanobacteria. Studies from a variety of areas reveal cyanolichens can contribute significant quantities of nitrogen to forest ecosystems (22, 23, 24, 25).

Lichens are sensitive to air quality and climate change, are relevant indicators of components of ecosystem productivity and biodiversity, and are measurable. In this respect, lichens are unique in their ability to be used as indicators for such a broad range of issues. A lichen monitoring program has the potential to attract interest from a number of scientific disciplines and multiple stakeholders. A network of long-term lichen monitoring plots in protected areas is proposed for Nova Scotia. The USDA Forest Service has developed a rapid lichen assessment process that we propose to adapt. The method determines presence and abundance of macro-lichens on all standing woody plants within a plot. A number of plots across the province are required to capture and account for regional variability. Plots will be re-surveyed every five years. Partners will be solicited from industry, government and academia.

2. A PRELIMINARY LOOK AT LICHEN SURVEY DATA AND AIR POLLUTION IN NOVA SCOTIA

Boreal felt lichen (*Erioderma pedicellatum*), a globally rare species, has had more than a 90% decline in the last two decades in Nova Scotia (26). This decline is largely attributable to acid rain, although habitat loss and climate change may also be a factor (27). Nova Scotia has one of the few remaining populations of this species. It is believed to be extirpated from New Brunswick and on the brink of extinction in Europe. Newfoundland has the last population of significant size (28). The Committee on the Status of Endangered Wildlife in Canada designated the Atlantic population (Nova Scotia and New Brunswick) as Endangered and the boreal population (Newfoundland) as a species of Special Concern in 2002.

Evidence of sensitivity to air quality can be seen in other lichen species in Nova Scotia. Epiphytic lichens can be used as an indicator of environmental stress (29). I compared species richness of epiphytic lichens between two areas of Nova Scotia. Data from Cape Breton Island were from Selva (30). Data from southwestern Nova Scotia were from 1998 Tuckerman Workshop.

Since 1990, northern Cape Breton Island has consistently received less than 12 kg/ha/yr of wet non-marine sulphate deposition. Southwestern Nova Scotia, however, has consistently received more than 12 kg/ha/yr during that time period (3). Species of epiphytic lichens were counted for five sites on Cape Breton Island and five sites in southwestern Nova Scotia. Mean species richness for Cape Breton Island is higher than southwestern Nova Scotia. The difference is statistically significant at the $\underline{P} = 0.10$ level (Table 1).

Table 1. Species richness values and regional means (± standard errors) of epiphytic lichens for Cape Breton Island and southwestern Nova Scotia.

Site Location	Species Richness of Pollution Sensitive Lichens
Southwestern Nova Scotia	91
Southwestern Nova Scotia	65
Southwestern Nova Scotia	56
Southwestern Nova Scotia	39
Southwestern Nova Scotia	68
Mean for southwestern Nova Scotia	**64 (± 8)**
Cape Breton Island	124
Cape Breton Island	100
Cape Breton Island	97
Cape Breton Island	90
Cape Breton Island	60
Mean for Cape Breton Island	**94 (± 10)**

Lichen species presence can be affected by numerous factors including forest growth stage, tree species composition and local climate. The Cape Breton and southwestern sites are comparable in growth stages with both areas having sites of mature to old growth forest. However, the southwestern sites include coniferous as well as deciduous forest while the Cape Breton sites include only deciduous forest. Some of the differences may also be attributable to regional climatic differences.

Although there are no repeated surveys within regions, there is a single survey for Halifax City as well as for Kejimkujik National Park in Annapolis County. Halifax metropolitan area has a population density of 65.4 people per square km while Annapolis County has a population density of only 6.8 people per square km (31). Along with the high population density in Halifax are associated local sources of pollution including vehicular traffic, a power generation station and an oil refinery. The number of epiphytic lichen species from the Halifax survey was 38, while for Kejimkujik it was 97.

2.1 Conclusions for Nova Scotia

Limited evidence from past studies suggests potential impacts of air pollution on lichens in Nova Scotia. However, comparisons using past studies are not statistically valid. Questions of validity can be addressed with a well designed monitoring project.

3. PROPOSED METHODS

A province-wide network of long-term lichen monitoring plots will be established in Nova Scotia's protected areas. The objectives of the program are to provide long-term monitoring in forests of:

1. air quality impacts on ecosystems;
2. climate change impacts on ecosystems;
3. elements of forest ecosystem productivity; and
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3.1 Plot Size

A 0.4 ha circular plot with a 36-meter radius will be used. This plot size is comparable to USDA Forest Service national lichen monitoring program plot size of 0.378 ha. Cameron (16) reported that sampling a minimum of 16 trees is required to include most lichen species in a coniferous forest in Nova Scotia. Stewart (32) reports an average density of 509 trees per ha for old growth coniferous forest and 414 trees per ha for old growth deciduous forest in Nova Scotia. In order to sample the minimum 16 trees, 0.031 and 0.039 ha plots are needed in coniferous and deciduous old growth forests, respectively. The larger plot suggested for this study exceeds the required minimum, allows for a more rapid assessment method (see collection method below), reduces 'noise' from micro-habitat variation and increases the probability of capturing rarer species (33). A difficulty associated with a large single plot, rather than several intensively measured subplots, is that accuracy of abundance measures may be lower for the single large plot. However, a larger plot increases the number of species captured (34). Further, smaller plots result in lower counts, which then require more plots to obtain desired statistical power (35).

3.2 Number of Plots

Local variability will be reduced by stratified sampling in tolerant hardwood stands within protected areas. Lichens are very sensitive to microclimate changes. Activities such as adjacent tree harvesting, local vehicular traffic, adjacent use of fertilizers or pesticides can affect presence and/or abundance of lichens. Protected areas are less likely to be affected by these human activities. The protected area can be an area with formal protection or under a stewardship agreement. Old growth forests provide a relatively stable environment with a high abundance of lichens. Deciduous forests tend to have a higher diversity of lichens. Thus, analytical problems associated with low abundance values are reduced.

Data from the Netherlands were used to perform statistical power analysis because Europe is the only area with long-term lichen abundance data (10). Methods for power analysis followed Gibbs *et al.* (35). Five species of lichen from the Netherlands data and also known to commonly occur in Nova Scotia (*Hypogymnia physodes, H. tubulosa, Parmelia sulcata, P. caperata, P. saxatilis*) were used in the analyses. Statistical power is the ability of a statistical test to detect a change when it is actually occurring. As statistical significance level of a test is increased, power is decreased and the tradeoff between significance and power must be considered. For long-term monitoring, detecting a real change is of greater interest than falsely detecting a change when none has occurred (35, 36). Therefore, a relatively high statistical power (90%) and a relatively low significance value (20%) were chosen for planning this project. The power analysis was used to determine the minimum number of plots needed to detect a 10% change in abundance over 5 years given a power of 90% and significance value of 20%.

Number of plots needed ranged from 15 for *Parmelia sulcata* to 60 for *Parmelia caperata*. We plan to initially establish 30 plots. Once multi-year data is collected for Nova Scotia, power analysis can be calculated to determine if the sample size is large enough to detect a given amount of change.

3.3 Sampling Method

At each plot, field staff will search for all species of macrolichens. All tree and shrub boles between 0.5 m and 2.0 m from the ground will be searched. Fallen branches and lichens will be examined and recorded, as these provide a good sample of canopy lichen species and their relative abundances (37). Field staff will estimate the abundance of each species using the following scale: 1 = rare (<3 individuals in the plot), 2 = uncommon (4-10 individuals in the plot), 3 = common (>10 individuals in a plot but less than half the boles and branches have the species present), 4 = abundant (more than half of the boles and branches have the species present). Any species which cannot be identified in the field will be assigned a number code and abundance value. A sample of the unknown species will be collected for later identification. Re-sampling using the same methods will be done every five years.

3.4 Analyses

3.4.1 Air Quality

Lichen species sensitivity to air quality needs to be calibrated for the region. This will be done by gradient analyses as described by McCune *et al.* (33) or through development of lichen diversity classes as described by Asta *et al*.(29). The result will be an air quality lichen index for each plot which can be used to map air quality regions for the province and allow monitoring over time.

3.4.2 Climate Change

Climate change analyses will follow methods similar to van Herk *et al.* (10). Historical latitudinal distribution of species will be derived from published lichen checklists and studies and divided into five categories: 1.tropical; 2. warm-temperate to (sub) tropical; 3. cool temperate species; 4. boreal/arctic; 5. unknown distribution (these species will be excluded from analyses).

Abundances of species in each category will be monitored over time to detect climate change effects.

3.4.3 Biological Diversity

Species presence and abundance can be used to determine species richness and various diversity measures and compared over time.

3.4.4 Ecosystem Productivity

Changes in lichen abundance can indicate corresponding changes in ecosystem productivity. Nitrogen fixing cyano-lichens are of particular concern when assessing ecosystem productivity.

3.4.5 Interpretation

Data from the monitoring program can be used to identify long-term trends regionally and locally. Other scientific studies and monitoring programs can be tied into the project to help explain trends. For example, Nova Scotia Department of Environment and Labour has air quality monitoring stations across the province which measure levels of particulates, sulphur dioxides, nitrous oxides and ozone. Data for these measured pollutants can be correlated with changes in lichen presence and abundance over time to provide a better understanding of how certain pollutants may affect ecosystems. Because lichens are closely tied to overall biodiversity of ecosystems, a change in diversity of lichens over time may signify impending impacts to other groups of organisms.

4. CONCLUSION

Lichens are particularly useful for monitoring programs because they can be used as indicators for multiple objectives. Multi-element monitoring provides opportunities to bring together scientists of many disciplines. A system of bio-monitoring plots with lichens provides protected areas managers and other resource managers with measurable effects that can aid in informed decision making. Protected areas provide the ideal location for monitoring as local variation is minimized.

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