Lichens as indicators of forest health in Canada

by Markus N. Thormann[1]

ABSTRACT

Canadian forests are naturally dynamic ecosystems, changing species composition and abundance as the ecosystem evolves through succession or reacts to disturbances, such as wind and insects. Pollution and climate change will be the largest stressors to Canada's forests in the future. Their future impact on the health of Canada's forests remains speculative. Lichens have been identified as valuable indicators of forest health; however, there are no comprehensive datasets on which lichens are indicative of forest health in Canada. An analysis of the existing literature reveals a large number of lichens that can be used to monitor levels of various pollutants (general pollution: 51 species; sulphur dioxide: 42 species; photochemicals: 23 species; fluoride: 18 species; heavy metals: 3 species; acid precipitation: 8 species; sulphite: 2 species; nitrate: 2 species). The use of lichens as indicators of climate change is also reported in the literature but, there are insufficient data to monitor the effects of climate change on lichen communities in North America. While various provincial and federal government departments and industries have been monitoring lichen communities across Canada for up to nearly three decades, there exists no standard monitoring protocol for lichens in Canada, which makes comparisons among studies challenging. The development of a standard monitoring protocol would allow integration of the various initiatives into a nationwide lichen monitoring program.

Key words: lichens, biomonitoring, forest health, pollution, climate change

RÉSUMÉ

Les forêts du Canada sont des écosystèmes naturellement dynamiques, changeant de composition et d'abondance d'espèces à mesure qu'ils évoluent suivant la succession naturelle ou qu'ils réagissent à des perturbations telles le vent et les insectes. Les plus grands stress auxquels seront soumises les forêts du Canada dans l'avenir sont la pollution et les changements climatiques. Leurs impacts demeurent cependant spéculatifs. Parmi les indicateurs de la santé des forêts, on a déterminé que les lichens étaient très valables ; cependant, il n'existe pas de banque de données complètes au Canada qui le démontrent. L'information sur eux révèle qu'un grand nombre de lichens peuvent être employés pour suivre la teneur de nombreux polluants (pollution générale : 51 espèces ; dioxyde de soufre : 42 espèces ; substances photochimiques : 23 espèces ; fluorure : 18 espèces ; métaux lourds : 3 espèces ; précipitations acides : 8 espèces ; sulfite : 2 espèces ; nitrate : 2 espèces). On a aussi rapporté l'emploi des lichens comme indicateur des changements climatiques, mais il n'existe pas assez de données pour suivre leurs effets sur les populations de lichens en Amérique du Nord. Malgré le fait que diverses organisations gouvernementales fédérales, provinciales et de l'industrie ont procédé à des suivis de populations de lichens au Canada pendant près de trois décennies, il n'existe toujours pas de protocole de surveillance standardisé les concernant. Cela rend hasardeux les exercices de comparaison des différentes études. La mise au point d'un protocole standardisé de surveillance permettrait d'intégrer à l'échelle nationale les diverses initiatives inscrites dans un programme de suivi global des lichens.

Mots clés : lichens, surveillance biologique, santé des forêts, pollution, changement climatique

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Lichens

Lichens are not single entities, but a mutualistic symbiotic composite of a fungus, the mycobiont, and an organism capable of producing food via photosynthesis, the photobiont (Brodo *et al.* 2001). These photobionts are predominantly members of the Chlorophyta (green algae) or Cyanophyta (blue-green algae or cyanobacteria). The mycobiont of the lichen association is most frequently a member of the division Ascomycota, or sac fungi. This association resulted in nearly 14 000 species globally, which are tremendously diverse in size, form, and colour. Because of the diversity of organisms involved in this fungal-algal association, lichens likely do not have a common evolutionary ancestor and are linked solely based on their mode of nutrient-acquisition.

In most cases, the bulk of a lichen consists of its thallus (the vegetative body, as opposed to its reproductive or fruiting structures), which has three major growth forms: fruticose, foliose, and crustose. Foliose lichens are characterized by a more or less flattened thallus with easily distinguishable upper and lower surfaces and are attached to the substrate either directly by the hyphae of the lower cortex or medulla or by rhizines. Lichens that grow erect or are pendant and without distinguishable upper and lower surfaces on their thalli are called fruticose lichens. These lichens are attached to the substrate at one or very few points. Crustose lichens form

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crusts over their substrates. Their entire lower surface grows on and among the particles that constitute the substrate; hence, they can not be removed from the substrate in one piece (Brodo *et al.* 2001).

Most lichens thrive in high light and moisture but moderate temperature habitats, maximizing rates of photosynthesis while limiting rates of respiration. These conditions are frequently found in coastal regions, the canopies of temperate rain forests and montane tropical cloud forests, and some coastal fog forests. Within these habitats, a multitude of microhabitats exist that are colonized by lichens in an effort to outcompete faster-growing vascular plants and bryophytes. While lichens are very abundant and significantly contribute to the overall productivity in these forests, they are also very common in continental and northern forests and can be used as indicators of forest health there as well. Lichens can grow on almost every natural substrate, including tree bark, wood, rock, soil, leaves, peat, mosses, and other lichens. In contrast to their non-lichenized cousins, lichens derive very little, if any, nourishment from their substrate. Despite the variety of substrates colonized by lichens, most lichens are generally restricted to certain substrate types, i.e., tree lichens are rarely found on rocks, and limestone lichens are rarely found on granite. Lichens play significant roles almost everywhere they occur. They form the dominant vegetation over about 8% of the Earth's terrestrial surface, influencing the growth and development of other plants and animals within the same habitat. Lichens have been called "nature's pioneers" because of their ability to colonize bare rock surfaces and they are usually the first plant-like organisms to become established on exposed surfaces (Brodo *et al.* 2001). Subsequently, they are involved in the process of soil formation and soil stabilization. The ability of lichens to colonize new habitats lies in their resistance to drought, they are self-sufficient in their acquisition and synthesis of nutrients, and their propagules are very small, enabling them to become established on almost all surfaces.

This manuscript outlines the value of lichens as indicators of forest health, pollution, and climate change and then addresses some biomonitoring programs currently in use in Canada. Recommendations for future research conclude this paper.

Lichens as Indicators of Forest Health in Canada

Biomonitoring, the use of biological organisms to detect environmental changes caused by anthropogenic or natural impingements, involves three steps before a successful monitoring system is established (background data compilation on air quality and emission sources and pollutants, field work and reconnaissance surveys, establishment and maintenance of the biomonitoring system; Enns 1996). Effective biomonitoring programs require the use of appropriate bioindicators. These are preferentially lichens that have a timely, accurate, and precise tracking-history for several decades, including *Alectoria sarmentosa* (Ach.) Ach., *Platismatia glauca* (L.) Culb. & C. Culb., *Hypogymnia enteromorpha* (Ach.) Nyl., and *Hypogymnia physodes* (L.) Nyl. (Enns 1996).

It is challenging to define what constitutes a "healthy" forest. In general terms, healthy forests maintain and sustain desirable ecosystem functions and processes. A healthy forest is manifested through a spectrum of ecological indicators, including those related to biodiversity change, resilience to disturbances, wildlife habitats, aesthetic appeal, and resource sustainability. Forests are naturally dynamic ecosystems, often changing species composition and abundance as the ecosystem evolves through succession or reacts to disturbances, such as wind and insects (CFS 1999). One approach to measure forest health is to measure a set of variables in a forest. These variables may include stand age and composition, dependent plant and animal species, and/or soil physical and chemical variables. In the end though, the variables are only "indicators" of a healthy forest and do not allow us to diagnose a specific problem. These indicators can be used to pinpoint an emerging or already existing problem in the forest or indicate that an existing problem is being alleviated.

As a result of the sensitivity to disturbances demonstrated by lichens, they have recently been identified as useful indicators of forest health; however, there are no comprehensive datasets in which lichens are indicative of healthy forests in Canada. Canada's forests have been shaped by natural disturbances, such as wildfire, insect outbreaks, and other diseases, for centuries. Timber harvesting, resource extraction, industrial exploration and pollution, and climate change compound these impacts on forests. For example, clearcutting in uneven-aged stands, increasingly uncommon in Canada today, can create even-aged tree stands and significantly reduce the lichen diversity of these stands due to the loss of habitat heterogeneity (Rose 1992). The removal of trees results in habitat fragments, which are more prone to deleterious inbreeding effects and demographic instability, both of which can lead to population declines and possible extirpation or extinction (Freedman 1995). This was shown with the declining populations of the rare foliose lichen *Erioderma pedicellatum* (Hue) P.M. Jörg. in Newfoundland (Ringius 1997). This lichen depends on the presence of all successional stages of the forest and very specific microhabitat conditions (humidity, bark pH, light intensity) to complete its life-cycle (Ringius 1997).

Certain lichens are restricted to forests that have been anthropogenically undisturbed for long periods (e.g., 200–800 years; Brodo *et al.* 2001). These forests are characterized by trees and understory vegetation of different age classes, dead standing trees, prostrate dead and decomposing trees, and openings in the canopy. In addition, these mature forests have thick, moist soils, which contribute to a microclimate that assures a relatively homogeneous soil moisture content uncommon to younger forests (Brodo *et al.* 2001). These factors create a variety of unique habitats, which result in a greater species diversity, particularly for lichen species (Selva 1994). For example, the upper canopies of coastal rain forest trees contain virtually self-sustaining habitats, of which lichens are a vital component. Many species of *Pseudocyphellaria*, *Chaenotheca*, *Nephroma*, *Lobaria*, and *Usnea* occur exclusively in these forests and can be used as indicator species for different forest types (Brodo *et al.* 2001). These types of data are of particular interest to forest managers and natural resource departments interested in conserving forest species diversity.

Pollution

The most widespread pollution disturbances affecting forests in Canada are sulphur dioxide, nitrogen oxides, fluorides, photochemical toxins, heavy metals, and acid precipitation. Generally, two approaches are used to examine the impact of pollution on lichens: (1) analyze lichen samples for concentrations of pollutants with increasing distance from the source(s) of pollution (Richardson 1988) and (2) comparative long-term observations of lichen communities (Hawksworth and Rose 1970). The first approach lends itself well to measuring changes in concentrations of heavy metals, sulphur, fluorine, and chlorinated hydrocarbons in lichen thalli (Bacci *et al.* 1986, MacKenzie 1986). The second approach is useful in analyzing changes in lichen communities in a particular area in response to a combination of pollutants (Hawksworth and Rose 1970). This includes the decreased occurrence or disappearance of previously common lichen species or the appearance or increasing occurrence of previously less common taxa. The use of lichens as indicators of environmental pollution has received a lot of attention over the past 30 years, resulting in more than 1500 abstracted publications worldwide.

Lichens are particularly valuable as pollution bioindicators, because they are very sensitive to changes in air quality due to a lack of a protective cuticle and wax layer and the absence of stomata that facilitate the uptake of gaseous molecules (Häffner *et al.* 2001). Hence, they readily exhibit visible responses in addition to physiological responses following exposure to atmospheric pollutants. These impacts are usually exacerbated in ecosystems with elevated humidity (Goward and Schofield 1983), such as along oceanic coasts, rivers, and lakes. Non-bioindicator species may only exhibit invisible physiological responses. Previous studies have shown an increasing sensitivity from foliose to fruticose to crustose species, likely in response to an increase in the absorbing surface area. In addition, the mycobiont may play an important role in the overall tolerance of the lichen to pollutants. For example, the outer fungal layers differ among lichens in thickness, morphology, density, and detoxification capabilities (Türk *et al.* 1974, Miszalski and Niewiadomska 1993). Moreover, trace metal concentrations in lichen tissues are directly proportional to environmental concentrations of these metals (Sloof 1995, Bari *et al.* 2001). Therefore, lichens lend themselves very well to monitor spatial and/or temporal deposition patterns of trace elements (Richardson 1988). From a temporal perspective, the resolving power of lichens, i.e., their ability to distinguish between temporal gradients, is about two weeks (Boonpragob and Nash 1990).

The responses of numerous lichens to various pollutants have been investigated, with the majority of those studies having occurred in central and northern Europe and the U.S.A., concentrating on sulphur dioxide, fluoride, and photochemical pollution. In an effort to monitor air pollution using nonvascular plants, the U.S.D.A. Forest Service of the Pacific Northwest and Alaska Regions summarized existing information on lichen sensitivities to various pollutants for the Pacific Northwest and identified numerous lichens that can be used in that region to monitor air pollution[2]. Although their lichen sensitivity ratings are specific to the Pacific Northwest, they were designed to provide a wide margin of error for variability of a species' response to pollution under variable climates, substrates, or topographic and microhabitat exposures. Table 1 provides a list of common lichen species used as indicators of pollution for maritime (NL, PE, NS, NB), central (ON, PQ), western (MB, SK, AB, B.C.), and northern (northern regions of provinces and YT, NT, NU) Canada. These lichens are described and depicted in Brodo *et al.* (2001), and their identification is generally unproblematic with minimal training. Table 1 was compiled from published information in North America about the sensitivity of lichen species to different pollutants and their commonness across the major geographical regions in Canada.

Climate Change

There is a considerable range in the prediction of regional changes in future temperatures, approaching 10 °C in some regions by 2100 (IPCC 2001). Therefore, it is desirable to develop specialized techniques to monitor the effects of climate change at the local scale. Lichens have not been used as extensively (Press *et al.* 1998, Insarov *et al.* 1999, van Herk *et al.* 2002, Parmesan and Yohe 2003) as bryophytes (see review in Gignac 2001) to monitor local climate changes; however, they may prove to be valuable organisms for such an endeavour. Lichens are poikilohydric organisms, i.e., lacking mechanisms for regulating water uptake and loss (Green and Lange 1994). Thus, even small deviations in microclimatic condition influence the abundance and diversity of the lichen community (Canters *et al.* 1991, Renhorn *et al.* 1997). Seasonal and environmental changes influence rates of various metabolic pathways in lichens, including photosynthesis, nitrogen fixation, and respiration (Galun 1988). As a result, changes in macroclimatic conditions due to natural or anthropogenic influences may result in range extensions in both latitude and elevation and increasing occurrences of thermophilic species in ecosystems from which they were previously absent (Frahm and Klaus 2001).

To date, the influence of climate change on lichen communities has mostly been studied in Europe. For example, thermophilic lichen species, e.g., *Physcia americana* G. Marr. and *Heterodermia obscurata* (Nyl.) Trevis., indigenous to tropical, subtropical, and warm-temperate regions have recently been collected with increasing frequencies in cool-temperate countries of central Europe, including Germany and The Netherlands (van Herk and Aptroot 1999, Wolfskeel and van Herk 2000, van Herk *et al.* 2002). Moreover, in a short-term field experiment on the effects of increasing temperatures on plant communities in subarctic alpine Sweden, it was determined that lichen cover and species richness increased with increasing atmospheric temperatures at the expense of bryophytes (Molau and Alatalo 1998), resulting in a complex plant community shift. These shifts in community structure were predicted to be the result of altered nutrient-cycling dynamics, moisture availability, shifts in light intensity, and different temperature and humidity optima for different vegetation strata. There are no studies that have investigated the effects of climate change on lichen communities in Canada.

Examples of Biomonitoring Using Lichens in Canada

Several Canadian industries and federal and provincial governments have established biomonitoring programs across the country. Some are recent, while others have been ongoing for decades. Since these programs were established independently, their sampling protocols differ substantially.

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[2] http://www.nacse.org/lichenair

Table 1. Lichen species used as indicators for various pollutants. Note, not all lichen species occur in all provinces of each region in Canada. "Eastern Canada" – NL, PE, NS, NB; "Central Canada" – PQ, ON; "Western Canada" – MB, SK, AB, B.C.; "Northern Canada" – northern regions of provinces, YT, NT, NU. Brackets indicate very restricted distributions within the respective region.

Pollutant	Lichen indicator species	Eastern Canada	Central Canada	Western Canada	Northern Canada
General	*Alectoria imshaugii*	–	–	(X)	–
	Alectoria vancouverensis	–	–	(X)	–
	Bryoria capillaris	X	X	X	X
	Bryoria friabilis	–	–	X	–
	Bryoria fuscescens	X	X	X	X
	Bryoria glabra	(X)	–	(X)	–
	Bryoria trichodes	(X)	X	–	–
	Cavernularia hultenii	–	–	(X)	–
	Cavernularia lophyrea	–	–	(X)	–
	Cladonia bellidiflora	X	X	(X)	X
	Collema nigrescens	X	(X)	(X)	–
	Fuscopannaria leucostictoides	–	–	X	–
	Fuscopannaria mediterranea	–	–	X	–
	Leptogium cyanescens	X	(X)	–	–
	Leptogium saturninum	X	X	X	X
	Lobaria oregana	–	–	(X)	–
	Lobaria pulmonaria	X	X	X	–
	Lobaria scrobiculata	X	–	X	–
	Melanelia fuliginosa	X	(X)	(X)	–
	Menegazzia terebrata	X	(X)	(X)	–
	Nephroma bellum	X	X	X	–
	Nephroma helveticum	X	X	(X)	–
	Nephroma laevigatum	X	–	(X)	–
	Nephroma parile	X	(X)	X	–
	Nephroma resupinatum	–	X	X	–
	Nodobryoria abbreviata	–	–	(X)	–
	Nodobryoria oregana	–	–	(X)	–
	Normandina pulchella	X	(X)	(X)	–
	Pannaria rubiginosa	X	–	(X)	–
	Parmeliopsis hyperopta	X	X	X	X
	Peltigera canina	X	X	X	X
	Peltigera collina	–	–	X	–
	Peltigera rufescens	X	X	X	X
	Physcia aipolia	X	X	X	X
	Physconia enteroxantha	–	–	X	–
	Physconia perisidiosa	–	–	X	–
	Pseudocyphellaria anomala	–	–	(X)	–
	Pseudocyphellaria anthraspis	–	–	(X)	–
	Pseudocyphellaria crocata	X	(X)	(X)	–
	Ramalina menziesii	–	–	(X)	–
	Ramalina pollinaria	(X)	(X)	X	–
	Ramalina roesleri	X	(X)	(X)	–
	Ramalina thrausta	(X)	(X)	X	–
	Sticta fuliginosa	(X)	(X)	(X)	–
	Sticta limbata	–	–	(X)	–
	Sticta weigelii	–	–	(X)	–
	Usnea hirta	(X)	X	X	–
	Usnea longissima	X	(X)	(X)	–
	Vulpicida canadensis	–	–	X	–
	Xanthoparmelia cumberlandia	X	(X)	X	–
	Xanthoria candelaria	–	–	X	X

Table 1 (continued)

Pollutant	Lichen indicator species	Eastern Canada	Central Canada	Western Canada	Northern Canada
Sulphur dioxide	*Alectoria sarmentosa*	X	–	X	–
	Bryoria capillaris	X	X	X	X
	Bryoria fuscenscens	X	X	X	X
	Bryoria glabra	(X)	–	(X)	–
	Bryoria trichodes	(X)	X	–	–
	Candelaria concolor	–	(X)	X	–
	Cladina mitis	X	X	X	X
	Cladina rangiferina	X	X	X	X
	Cladonia bellidiflora	X	X	(X)	X
	Coccocarpia palmicola	X	–	–	–
	Erioderma pedicellatum	X	–	–	–
	Hypogymnia enteromorpha	–	–	X	–
	Hypogymnia physodes	X	X	X	X
	Hypogymnia tubulosa	X	(X)	X	–
	Lobaria linita	–	–	X	X
	Lobaria oregana	–	–	(X)	–
	Lobaria pulmonaria	X	X	X	–
	Lobaria scrobiculata	X	–	X	–
	Melanelia subaurifera	X	X	X	–
	Nephroma bellum	X	X	X	–
	Nephroma helveticum	X	X	(X)	–
	Nephroma laevigatum	X	–	(X)	–
	Nephroma parile	X	(X)	X	–
	Nodobryoria oregana	–	–	X	–
	Normandina pulchella	X	(X)	(X)	–
	Parmelia squarrosa	X	(X)	(X)	–
	Parmelia sulcata	X	X	X	X
	Parmeliopsis hyperopta	X	X	X	X
	Parmotrema chinense	–	(X)	(X)	–
	Physcia caesia	X	X	X	X
	Physconia enteroxantha	–	–	X	–
	Platismatia glauca	X	X	X	X
	Ramalina farinacea	X	(X)	(X)	–
	Ramalina pollinaria	(X)	(X)	X	–
	Rhizoplaca chrysoleuca	–	–	X	–
	Sticta fuliginosa	(X)	(X)	(X)	–
	Sticta limbata	–	–	(X)	–
	Sticta weigelii	–	–	(X)	–
	Tuckermannopsis chlorophylla	–	–	X	–
	Usnea hirta	(X)	X	X	–
	Xanthoria fallax	–	(X)	X	–
	Xanthoria polycarpa	X	(X)	X	–
Photo-chemicals	*Alectoria sarmentosa*	X	–	X	–
	Bryoria friabilis	–	–	X	–
	Collema nigrescens	X	(X)	(X)	–
	Evernia prunastri	(X)	(X)	X	–
	Lobaria linita	–	–	X	(X)
	Melanelia subaurifera	X	X	X	–
	Nodobryoria abbreviata	–	–	(X)	–
	Parmelia hygrophila	–	–	X	–
	Parmelia sulcata	X	X	X	X
	Peltigera canina	X	X	X	X
	Peltigera collina	–	–	X	–
	Peltigera didactyla	X	X	X	X
	Peltigera rufescens	X	X	X	X
	Phaeophyscia sciastra	(X)	X	X	X

Table 1 (continued)

Pollutant	Lichen indicator species	Eastern Canada	Central Canada	Western Canada	Northern Canada
	Physcia aipolia	X	X	X	X
	Platismatia glauca	X	X	X	X
	Pseudocyphellaria anthraspis	–	–	(X)	–
	Ramalina farinacea	X	(X)	X	–
	Rhizoplaca chrysoleuca	–	–	X	–
	Solorina crocea	–	–	X	X
	Usnea longissima	X	(X)	(X)	–
	Vulpicida canadensis	–	–	X	–
	Xanthoria candelaria	–	–	X	X
Fluoride	*Bryoria capillaris*	X	X	X	X
	Candelaria concolor	–	(X)	X	–
	Hypogymnia physodes	X	X	X	X
	Hypogymnia tubulosa	X	(X)	X	–
	Melanelia subaurifera	X	X	X	–
	Parmelia saxatilis	X	X	X	X
	Parmelia sulcata	X	X	X	X
	Peltigera canina	X	X	X	X
	Phaeophyscia orbicularis	(X)	(X)	X	–
	Physcia adscendens	X	X	X	X
	Physcia aipolia	X	X	X	X
	Physcia caesia	X	X	X	X
	Physcia tenella	X	X	X	X
	Punctelia subrudecta	(X)	X	(X)	–
	Ramalina farinacea	X	(X)	X	–
	Vulpicida pinastri	X	X	X	X
	Xanthoria fallax	–	(X)	X	–
	Xanthoria polycarpa	X	(X)	X	–
Metals	*Cladina arbuscula*	X	X	X	X
	Cladina rangiferina	X	X	X	X
	Flavoparmelia caperata	X	X	(X)	–
Acid rain	*Cladina mitis*	X	X	X	X
	Cladina stellaris	X	X	X	X
	Flavoparmelia caperata	X	X	(X)	–
	Lobaria pulmonaria	X	X	X	–
	Lobaria scrobiculata	X	–	X	–
	Peltigera membranacea	X	(X)	X	–
	Sticta limbata	–	–	(X)	–
	Umbilicaria mammulata	X	X	–	–
Sulphite	*Ramalina pollinaria*	(X)	(X)	X	–
	Xanthoria fallax	–	(X)	X	–
Nitrate	*Ramalina pollinaria*	(X)	(X)	X	–
	Xanthoria fallax	–	(X)	X	–

The Ecological Monitoring and Assessment Network (EMAN) consists of linked organizations and individuals involved in ecological monitoring in Canada to detect, describe, and report on ecosystem changes. EMAN is a cooperative partnership of federal, provincial and municipal governments, academic institutions, aboriginal communities and organizations, industry, environmental non-government organizations, volunteer community groups, elementary and secondary schools, and other groups/individuals involved in ecological monitoring. Its objectives are to (1) provide a national perspective on how Canadian ecosystems are being affected by a multitude of stresses on the environment, (2) provide scientifically defensible rationales for pollution control and resource management policies, (3) evaluate and report to Canadians the effectiveness of resource management policies, and (4) identify new environmental issues at the earliest possible stage (Environment Canada 2005). EMAN has developed freshwater, marine, and terrestrial monitoring protocols, the latter covering lichens. Specific lichen indicator species, or all lichens, as indicators of sulphur dioxide pollution are monitored in five 10 × 10 cm quadrats hung 1.5 m above ground on all cardinal points of different tree species (Asta *et al.* 2002). EMAN recognized that this approach is efficient in some parts of Canada, such as Nova Scotia. In other regions, such as southern Ontario, alternative monitoring protocols are currently being developed and tested by EMAN, Parks Canada, and several conservation authorities. Recently, EMAN partially sponsored an arboreal lichen survey in the city of Hamilton, Ontario, to assess relative local air quality. The survey showed that air quality generally improved with increasing distance from the city core, as indicated by an increase in lichen biodiversity. While this was not entirely unexpected, the study also found an uncommon maritime lichen species on the Lake Ontario waterfront (McCarthy 2004). This study was one of only three done to date in Canada and employed Brock University undergraduate students. Hence, useful scientific data can be collected by a few highly motivated amateurs with minimal training, indicating the vast potential to use lichens as indicators of air quality in communities across Canada.

Canada's Forest Inventory (CanFI)[3] is based on a periodic compilation of existing inventory material from across the country. In the past, inventory data were not collected simultaneously. Hence, these data could not reflect the current state of Canada's forests and could not be used to monitor changes or rates of change imposed by abiotic and biotic stressors on forest ecosystems. A new protocol for Canada's National Forest Inventory (NFI) based on permanent plots across the country is being implemented. The objective of the new inventory design is to assess and monitor the extent, state, and sustainability of Canada's forests in a timely and accurate manner (Gillis 2001). The NFI ground plot network is based on a series of ecological plots with a 10-m radius, accompanied by four micro plots with a radius of 0.56 m (an area of 0.004 ha). The micro plots will be used to destructively measure gross total biomass of shrubs and trees less than 1.3 m in height, herbs, grasses, mosses, and lichens. Once all vegetation has been removed from each of the micro plots, it will be dried, weighed, and identified to species. This method is designed solely to assess species richness and the biomass of each species in each plot. Lichens are being considered in the next re-measurement phase, but have not been inventoried to date (M. Gillis, Canadian Forestry Service, Pacific Forestry Centre, personal communication).

The Alberta Biodiversity Monitoring Program (ABMP), designed to provide relevant, objective information to policy experts, managers, scientists, and the general public, is anticipated to become operational in 2007. The ABMP will monitor long-term, broad-scale changes in biodiversity and provide current and future program users with a broad range of program features. These features include (1) systematic collection of long-term data across the entire province, (2) a single, consistent repository for ABMP biodiversity data, (3) a public delivery mechanism for ABMP biodiversity data, (4) scientifically validated and cost-effective protocols, (5) scientifically rigorous and objective data, (6) standard provincial/regional information products, and (7) scientifically valid biodiversity indices (Alberta Biodiversity Monitoring Program 2005). The program collects information on a broad range of land and aquatic biodiversity in a variety of habitat elements in 50 × 50 m large sites systematically spaced on a 20-km grid across Alberta, consistent with that of the National Forest Inventory. Microhabitats will be identified in each plot before systematic surveys for mammals, birds, fish, insects, plants, fungi, and lichens are conducted for a maximum of 4.0 person-hours per plot. If microhabitats are less than 1 m^2 in size, the entire microhabitat will be surveyed; otherwise a 1 m^2 area within the microhabitat will be surveyed. Lichens (and other plants and bryophytes) will be destructively sampled, not permitting examination of changes in community composition over time within each plot (Alberta Biodiversity Monitoring Program 2005).

The Nova Scotia Protected Areas Program, part of the Department of Environment and Labour, is proposing to establish a province-wide network of long-term lichen monitoring plots to assess impacts of air quality and climate change on forest communities as well as forest productivity and biodiversity (Cameron 2003). Each circular plot will be 0.4 ha in size and all macrolichens on tree and shrub boles between 0.5 and 2.0 m above ground and fallen branches will be examined and recorded. Each lichen species will also have an abundance index assigned to it. Plots will be re-visited regularly to detect community changes in response to environmental stressors over time.

In the early 1980s, Husky Energy, one of Canada's largest petroleum companies, established a lichen community monitoring program to assess the impacts of sulphur dioxide and particulate sulphur emissions on forest ecosystems from their Ram River natural gas processing plant in west-central Alberta. Ten permanent 10 × 40 cm quadrats were attached to lodgepole pine trees at each of 12 locations at various distances from the processing plant. These quadrats are monitored every three to four years for the occurrence and abundance of all lichen species, which are concurrently examined for signs of stress (based on morphological characters). In addition, bark pH, total sulphur, and sulphate concentrations are measured as factors influencing lichen colonization of the trees. This monitoring program is ongoing and has shown that earlier predictions of severe impacts to the lichen community

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[3] http://nfi.cfs.nrcan.gc.ca/canfi/index_e.html

in the vicinity of the processing plant were unfounded (D. McCoy, Husky Energy, personal communication).

Other industries monitoring lichen communities to detect impacts from pollutants include Celgar Pulp Co. Ltd. in Celgar and Westcoast Energy in Chetwyn, B.C., and Suncor and Syncrude in Fort McMurray, Alberta. In addition, numerous non-governmental organizations, such as the Wood Buffalo Environmental Organization in Fort McMurray, Alberta, and the Long Point World Biosphere Reserve at Long Point, Ontario, survey lichen communities in an effort to monitor impacts from pollutants on forest communities.

Conclusions and Recommendations

Clearly, there is an increasing effort to use lichen communities as biomonitoring tools for a variety of forest disturbances in Canada. Many lichens are sensitive to changes in their environment, and their use as bioindicators of anthropogenic and natural disturbances and overall forest health is well documented in the literature. In Canada, numerous industries and provincial and federal government offices have implemented lichen biomonitoring programs over the past nearly three decades, each with its own monitoring protocol. These protocols employ varying sizes and shapes of sampling quadrats, sampling periods, sample substrata, and target lichen species, all in response to a specific point-source pollutant or ecophysiological region. There are efforts, most notably from EMAN, to standardize lichen monitoring protocols. Currently, there are no lichen biomonitoring programs to assess the impacts of climate change in Canada. The development of (1) a standard national lichen biomonitoring protocol so that monitoring efforts from various industries and government offices in the future can be compared and analyzed and (2) a lichen biomonitoring program to investigate the effects of climate change on lichen communities across Canada would provide data as a basis for the development of policies on biodiversity maintenance, management practices, and environmental impact in Canada's forests. Similar biomonitoring programs using lichens need to be developed for other forest disturbances, including wildfire, diseases, and timber harvesting. Nonetheless, existing biomonitoring programs, such as the NFI, have the potential to serve as mechanisms to collect and use lichen information as a means to monitor forest health.

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