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Research paper

Ten years of monitoring air quality and ecological integrity using field-identifiable lichens at Kejimkujik National Park and National Historic Site in Nova Scotia, Canada

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ABSTRACT

Arboreal lichens have a wide range of tolerance to habitat disturbance. As a result, they have been used globally as bioindicators of environmental change, particularly for monitoring atmospheric pollution. Here, we use lichens to monitor air quality and ecological integrity (EI) at Kejimkujik National Park and National Historic Site in Nova Scotia, Canada. We provide descriptions of two protocols and compare the results using data gathered in 2006, 2011, and 2016. To monitor air quality, we established 12 monitoring sites throughout the park and used a suite of lichens that are intolerant to air pollution to develop an index of air purity (IAP) that we compared every 5 years. Our protocol for monitoring EI of forest ecosystems was set up at these same 12 sites. We selected 50 regionally common field-identifiable lichen species and genera ranging in sensitivity from disturbance-tolerant to intolerant, and compare their presence in spatially constrained zones on a variety of tree species every 5 years. Our results suggest that air quality in Kejimkujik has increased slightly in the 10 years since monitoring was implemented, which is consistent with improvements in local air quality. Species richness also increased slightly, suggesting that EI has not declined. The maintenance of EI, through protection and restoration of natural resources, is a key priority in the management of national parks in Canada. Our protocols will provide early detection of changes to EI, enabling park managers to take responsive action. We are confident that our protocols can be replicated in other parts of the world with different suites of regionally common lichens.

1. Introduction

Arboreal lichens, colonizing the bark and woody tissue of trees, are recognized worldwide as useful bio-indicators (Henderson, 2000). As composite organisms comprised of a mycobiont (fungus) and a photobiont, which is an alga, a cyanobacterium, or both (McMullin and Anderson, 2014), lichens lack the protective cuticle found in vascular plants. This allows them to acquire nutrients directly from the atmosphere and from the precipitation that washes over them (Richardson, 1975; Richardson and Cameron, 2004). As a result, airborne toxins are also taken in by lichens, which have a range of tolerances to these pollutants, making it possible to correlate the presence of particular species with air quality (Richardson, 1975, 1992). Air quality monitoring protocols using lichens have been established in many regions, e.g., Europe (Asta et al., 2002), the United States (United States Department of Agriculture Forest Service. 1993, Will-Wolf et al., 2015), and Canada (Cameron et al., 2007; Ecological Monitoring and Assessment Network, 2007). In all of these methods it is the presence and frequency of occurrence of particular lichen species on defined portions of tree bark that is being monitored over time.

In addition to their usefulness as air pollution monitors, lichens have recently been employed as bioindicators of forest structure, age, and continuity, which is the length of time a stand remains undisturbed by major natural or unnatural events (Rose, 1976; Selva, 2003; McMullin et al., 2008). Many species tend to only occur at particular stages of forest development (Lesica et al., 1991; McMullin et al., 2008). As a forest matures its structural complexity increases, which increases the number of lichens able to colonize the forest (Pipp et al., 2001; Stewart et al., 2003; McMullin et al., 2010). Consequently, the presence of particular lichen species can be used as indicators of various stages of

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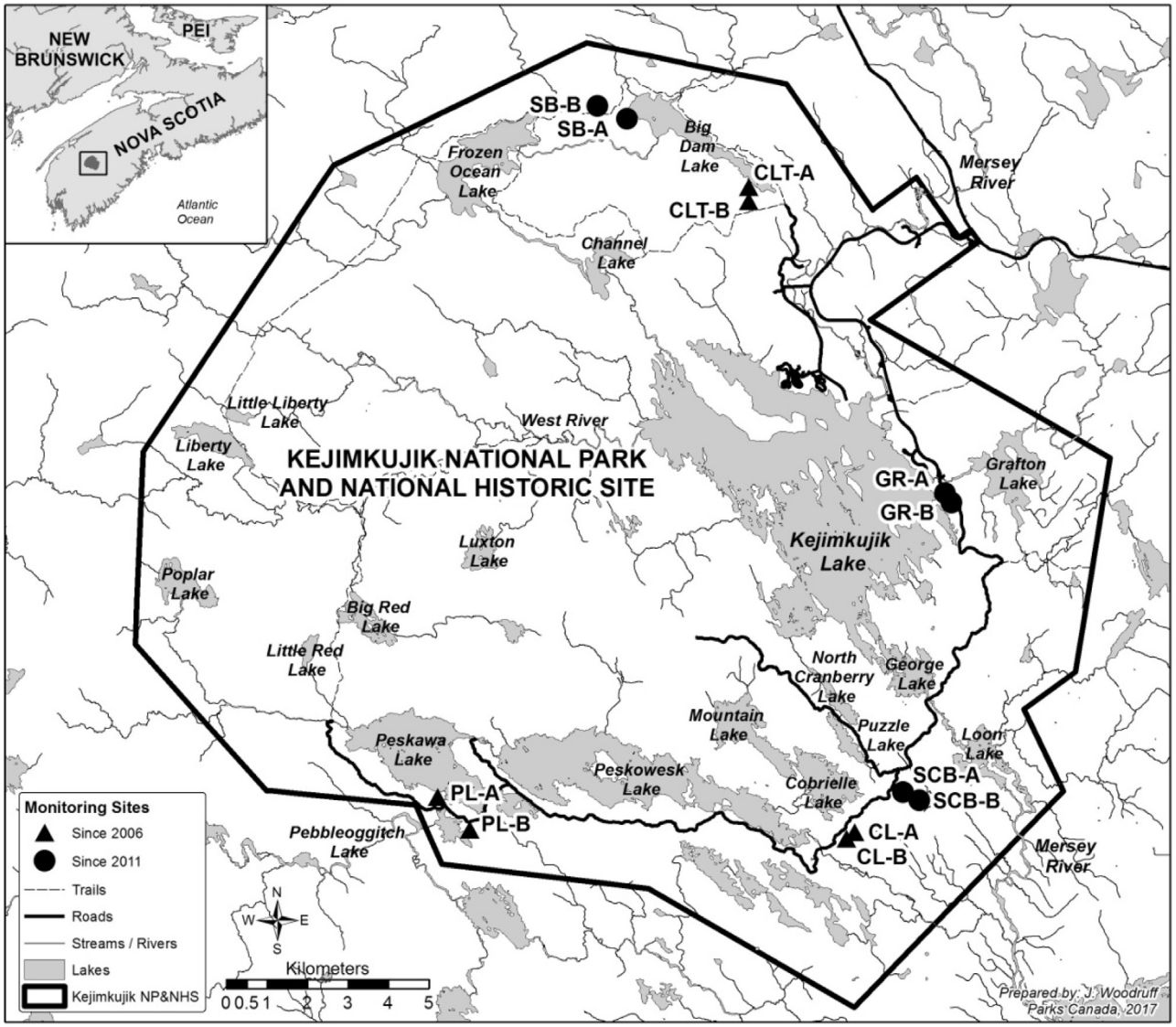

Fig. 1. Location of the 12 monitoring sites within Kejimkujik.

forest development and their absence may indicate disturbance (Tibell, 1992; Selva, 1994, 1999; Cameron, 2002; Coppins and Coppinss, 2002). These narrow habitat requirements can also be used to detect changes to their habitat (McMullin et al., 2016).

Although we understand the physiological mechanisms of lichen response to environmental stressors, developing robust monitoring protocols to track changes across space and time is more challenging. One challenge is identifying which species can usefully serve as indicators. Conti and Cecchetti (2001) provide a review of the use of lichens as bioindicators/biomonitors in general and suggest key criteria for good indicators. These include being sensitive to pollutants, geographically widespread, easy to sample (ideally abundant and sedentary), available year-round, easy to collect and analyze, and directly correlated to the quantity of the contaminant(s) of interest (Conti and Cecchetti, 2001). They propose that lichens possess many of these qualities, which make them suitable bioindicators, but they caution that researchers should select target species carefully to ensure they understand the response of the individual species to different pollutants.

Not only does a monitoring protocol have to be carefully designed to match indicators to stressors, there are practical considerations as well. Lichen identification can be difficult, so the use of species that are easily identified in the field is essential. If monitoring protocols are not consistent, then signals may be lost in statistical noise, or results may not be comparable across time and/or space. A recent paper comparing epiphytic lichen data gathered from specialists from six different European countries found discrepancies in methods, and in identification of taxa, which made it difficult to compare findings across space (Cristofolini et al., 2014). A similar assessment of the same region by five teams of investigators found that, despite being given identical standard operating procedures (SOPs), each of the teams interpreted procedures differently, with the result that sampling strategies and resultant data were not consistent (Brunialti et al., 2012).

Monitoring for ecological integrity (EI) is an important component of the management of national parks in Canada. The need to maintain EI is a key priority within the Canada National Parks Act (2000). Parks Canada's definition of EI includes the criteria that park ecosystems should be in "… a condition that is determined to be characteristic of its natural region and likely to persist…", including "composition and abundance of native species and biological communities" (Canada National Parks Act, 2000). The EI of forest ecosystems can be monitored with lichens because their relatively high sensitivity to environmental changes allows them to be used as the proverbial 'canaries in the coal mine'. By selecting a regional suite of lichen species with a range of tolerances, they can be used to monitor changes in EI, both positive, with an increase in pollution sensitive species, and negative, shown by a decrease in pollution sensitive species, and possibly an increase in