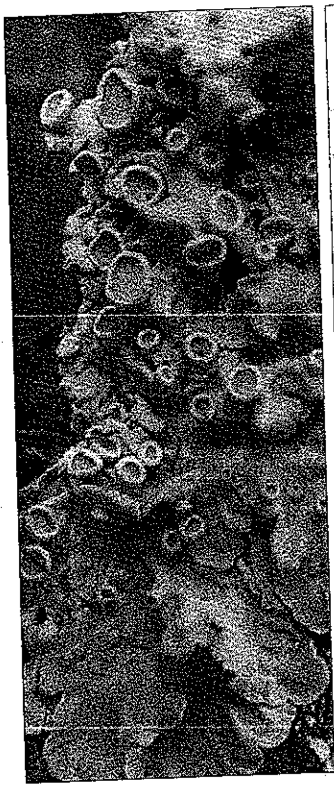
Using Epiphytic Lichens as Bio-indicators of Air Pollution



Photographs by Brian Craig (right and left), Sonia Dong (center)

by Andrew Kett, Sonia Dong, Heather Andrachuk and Brian Craig

Subject areas: science, geography, civics, mathematics, visual arts

Key concepts: lichen, biological monitoring, symbiosis, biodiversity, succession, indicator species, scientific protocol

Skills: conducting the scientific method, observation, taking scientific measurements, data synthesis and analysis, presentation skills

Location: outdoors

Time: 2-day introduction to lichen identification and monitoring; 1 day to organize equipment, go to the site, and complete sampling; 1 day data analysis; 1 or more days for extension (e.g., presentation, report, project)

Materials: air-quality monitoring equipment, guide to lichen identification, magnifying lens, tape measure, compass, data recording sheets

It can be a challenge to make environmental problems such as air pollution concrete and meaningful to students. Students learn the general concepts and the big causes and effects — greenhouse gases, acid rain, climate change — but in many cases the problems seem so huge and intangible that they have difficulty grasping how their own daily lives are linked to them. Indeed, teachers and students can both be in danger of missing the trees for the forest, of being too conceptual and overlooking the details, the "little picture." As educators, we need to make environmental problems relevant, local and concrete: that is, to show students how these problems affect the local environment in ways that can be seen and felt. When teaching about air pollution, one way to accomplish these goals is to have your class monitor air quality using lichens as biological indicators.

What exactly *are* lichens?

On first glance, lichens may appear to be a type of moss; but on closer examination they reveal themselves to be a unique life form. A lichen is composed of not one, but two organisms: a fungus and an alga, or cyanobacterium. The two organisms live in a symbiotic relationship in which the alga provides both partners with energy through photosynthesis and the fungus provides shelter and protection for the alga.

Approximately 20,000 species of lichens exist worldwide, about 3,600 of which are found in North America. Lichens cover eight percent of the Earth's terrestrial surface and they can grow just about anywhere: on soil, rocks, trees, even on human-made surfaces. They exist in some of the most extreme, inhospitable environments on the planet, including mountaintops, deserts and polar regions. While lichens often grow on trees and shrubs as epiphytes, they do not extract nutrients from the surfaces on which they grow, but instead absorb nutrients from the atmosphere. Lichens vary widely in size, color and shape. They also change color during the rain as they soak up water and produce food energy. This is one of the remarkable qualities of lichens, perhaps even the key to their survival in harsh climates: they can dry out completely, becoming very fragile and brittle, but will quickly rehydrate when moisture becomes available in their environment.

Lichens as bio-indicators

While harsh climates don't bother lichens, scientists have known for over 140 years that lichens are extremely sensitive to air pollution. They lack roots and so depend on atmospheric sources of nutrients. They also lack the protective waxy cuticle that plants have and so they are fully exposed to any pollutants present in the air. As they absorb nutrients, they also absorb air pollutants, and these accumulate in their tissues. Further, lichen morphology (unlike that of, say, a deciduous tree) does not change with the seasons, which means that lichens accumulate pollutants all year long.

Because they are so responsive to pollution and environmental change, lichens are useful as bio-indicators. Like the canary in the coal mine, they can provide us with warning signs of unhealthy environments. Studies have shown that the abundance and diversity of lichens decrease as urban development and industrial activity increase. Sulfur dioxide, in particular, has been strongly linked to declines in lichen populations. This common by-product of fossil fuel combustion apparently disrupts photosynthesis and the transfer of carbohydrates from the alga (or cyanobacterium) to

Lichen FAQs

What are lichens?

- Lichen = fungus (provides structure) + alga or cyanobacterium (provides energy through photosynthesis)
- Lichens are classified as fungi, even though they are made up of members of two different kingdoms
- Tree-dwelling types are called epiphytic lichens (*epi* = upon; *phyte* = plant)

What do lichens look like?

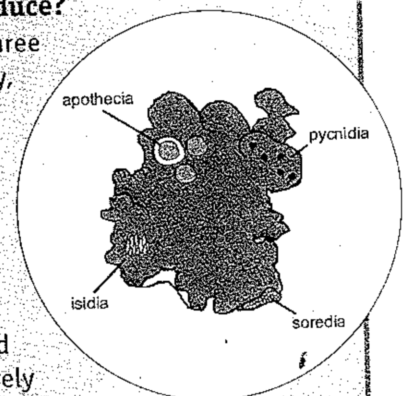
Lichens have three main forms: crustose (crust-like), foliose (leaf-like), fruticose (stem-like, shrubby). For photos and a detailed discussion of lichen biology, see <www.lichen.com/vocabulary>, a website that supports the book *Lichens of North America* by Brodo, Sharnoff and Sharnoff.

What do lichens "eat" and how/where do they grow?

- Lichens do not decompose, "eat," or otherwise harm trees; they trap nutrients directly from the air.
- Lichens grow 1–10 mm a year, and can live for up to 1,000 years.
- Lichens are opportunists: they are active when they are wet and dormant during hot, dry periods.
- Lichens can survive the harshest of conditions. There are 350 species in the Antarctic, where only two species of vascular plants are found.

How do lichens reproduce?

Lichens reproduce in three different ways: sexually, through the release of spores that form within bowl-like structures called *apothecia*; asexually through another type of spore that usually forms within tiny black "spots" on the lichen surface called *pycnidia*; and vegetatively through the fragmentation and dispersion of outgrowths such as *lobules*, *isidia* and *soredia*, each of which contains fungal and algal cells.



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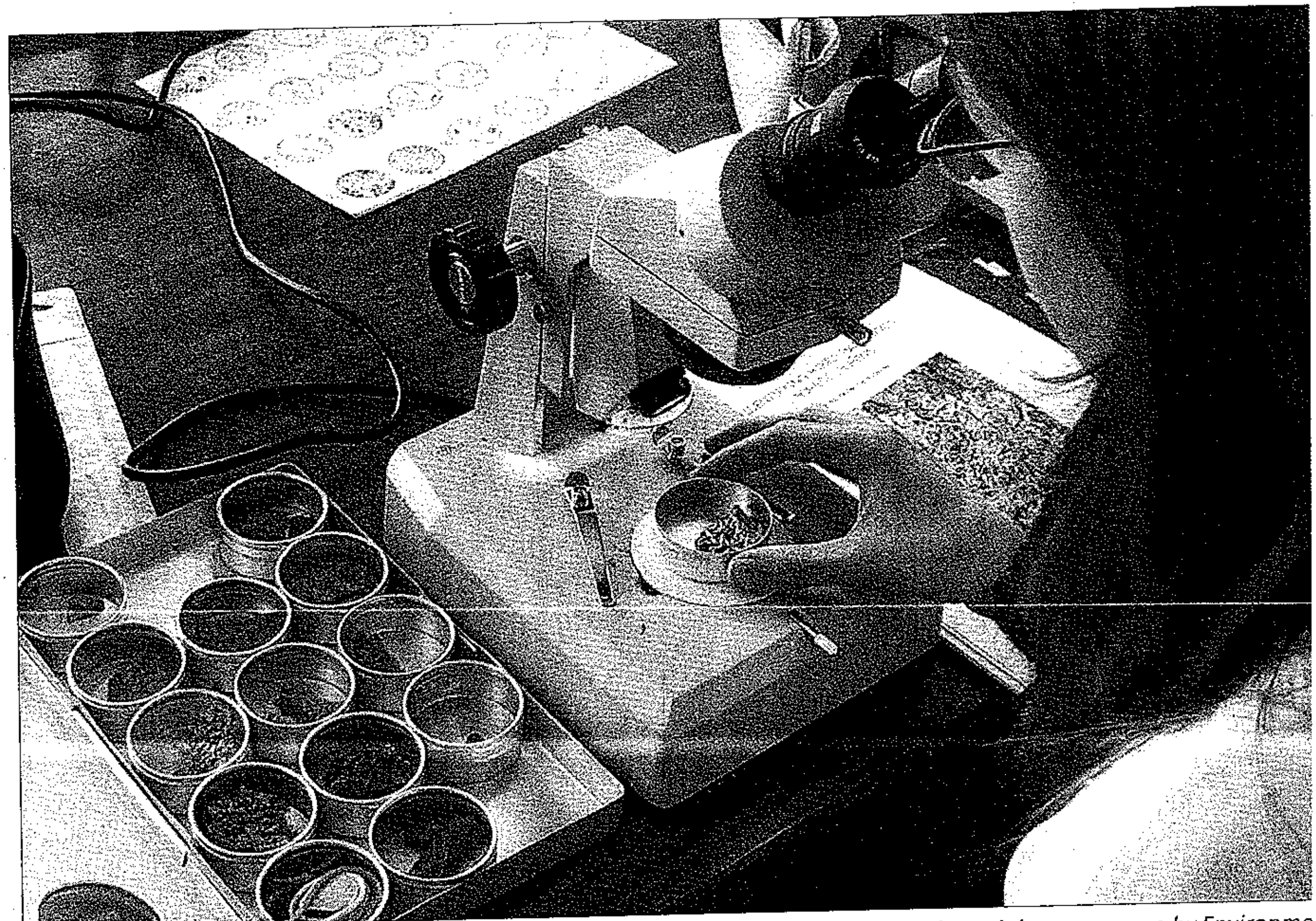

Brock University student learning to identify lichens as part of a "youth mentoring youth" training course run by Environme Canada's Ecological Monitoring and Assessment Network.

the fungus. Sulfur dioxide is also a major component of acid rain, which can make tree bark less hospitable to lichens. As the concentration of sulfur dioxide increases, lichen abundance decreases. Still, the populations do not vanish completely. Different lichens have different levels of tolerance to pollutants. Some can endure environments that are severely polluted, while others will perish in all but the most pristine conditions. Thus, through a simple study of the presence or absence of particular kinds of lichen, a class can make an accurate, scientifically valid assessment of the general air quality at a particular site.

Bio-monitoring projects

Many teachers integrate an air-quality monitoring project using lichens into their ecology units, chemistry or biology classes, or independent studies for upper year courses in high school. Related topics include ecology, pollution, climate change and biodiversity. Monitoring projects can even be linked to geography (mapping, Global Positioning System, environmental issues), math (data analysis), civics (environmental action, informing the decision-making process) or ar classes (photography, drawing, sculpture).

Because lichens have a considerable geographical range, studies can be carried out over large regions. And while lichens are slow-growing, they are extrem long-lived, so that studies can be long term. The dep and breadth of a monitoring project will depend on how involved you and your students want to become and your reason for monitoring. You may want only get your feet wet, doing little more than getting out into the field to identify lichens and do a simple surv Maybe you are interested in surveying lichens in ord to assess air quality in an area near the school. Or yo may want to answer a specific question about a pollutant source, or collect data that you can submit to government or scientific database.

Since lichens grow year-round, monitoring can b performed any time of the year, but in the interests of avoiding inclement weather, it is best done in the warmer months of the school season. Because of the physiological changes that occur in lichens during ra or snow (they change color and become more diffic to identify), it is best to plan "rain dates" for field tri

Species selection

Deciding which species to monitor and how to monitor them are perhaps the most important considerations when starting your project. For purposes of bio-monitoring, lichenologists have identified suites of indicator species for different forest types and developed field guides that present photos or drawings of the species accompanied by explanations of their unique features.[1] The lichens in each suite have a range of pollution tolerance, from very tolerant to very intolerant. Often, different suites of lichens are linked to particular monitoring methodologies, or protocols. Most suites have 15 to 20 species, but if surveying that many species is too complex an undertaking for your class, scientists have developed suites of as few as four species that can also be effective. And resources such as the enormous *Lichens of North America*[2] can guide teachers and students in identifying lichens not included in bio-monitoring suites.

Protocols

Teachers interested in beginning a monitoring project using lichens should take some time to read and reflect on different monitoring protocols. Generally, these are of two types, both of which focus on lichens growing on trees. The first type involves examining the entire trunk of a tree, up to about chest height, noting each species of lichen present and estimating its abundance. This method is particularly useful in areas with low lichen diversity and abundance, such as heavily polluted or urban areas. The second type of protocol considers only a portion of the tree trunk, which is usually marked off with a small grid or "ladder." This type of study is used extensively in Europe and in areas with high lichen diversity and abundance. Deciding which type of protocol to use can be difficult, as both have strengths and weaknesses. The ladder method enables students to assess abundance rapidly and easily, and has the advantage of being repeatable and more objective than the whole-trunk estimates of abundance. On the other hand, students using the ladder method may miss some of the species present at a site unless they sample many times.[3]

For classes undertaking small-scale projects, any protocol will likely be fine. Teachers interested in embarking on an extensive, multi-year project should contact local government, university or environmental groups for advice on protocol selection in their region. Using standardized protocols for collecting and reporting data is one of the biggest concerns in monitoring projects in which data is shared with others. Most government agencies have a lichen bio-monitoring protocol, and many are available on the Web (although often not in the most user-friendly language or form, particularly for students). A better bet for teachers is to contact regional environmental education or monitoring groups and organizations that have developed scientific monitoring protocols ready for classroom use (see page 62). These are usually written in comprehensible language and specifically designed for local student monitoring projects. In Canada, community monitoring groups, government agencies and post-secondary institutions are currently working in partnership to pilot a protocol that is similar to that used in Europe. This will allow students to compare their data with that of students in other schools across Canada.

Site selection

Many schools have at least a few suitable monitoring sites, such as parks, yards and cemeteries, within walking distance. Almost any treed site will do for a simple survey of lichens. If the aim of your study is to answer a specific question about a pollutant source, or if you intend to submit your data to an existing database, consider having a few different monitoring sites. All sites need to be relatively uniform because the type and density of the trees, the soil conditions and the major surrounding features can all affect lichen growth. Be sure to have students document each site well, drawing maps and, if possible, taking pictures.

Equipment and resources

The equipment for monitoring lichens is inexpensive and easily obtained. It is best to have students working in groups, and only one of each item is needed for each group. The equipment for each group should include:

- magnifying glass or lens, preferably 8–20x
- guidebook or key to lichen identification
- ruler and long tape measure
- compass
- datasheets on which to record information
- clipboard and pencil

Of course, the equipment list can be expanded if you happen to have unlimited resources or want to tailor your monitoring project. Certain protocols require defining the sampling area on the tree using chalk or a hanging grid of five 10 cm x 10 cm squares vertically aligned (students can easily make these "ladders" using paper, string, or, for more durable models, coathanger wire and lamp chain). A knife and some jars could be used to collect specimens for further study back in the classroom. A camera could be used to record site information. GPS equipment could be used to plot the sampling sites. And, most beneficial of all to the study, other air-quality monitoring equipment could be used in conjunction with lichen surveys, and the respective data compared.

Classroom and field resource materials enhance the learning experience for students, as well as the scientific validity of the data they collect. Species identification charts, data collection sheets and a detailed monitoring methodology will ensure that the data your students collect will be accurate and useful in comparison with data collected by academic and government monitoring programs. In addition, specialized teacher manuals can be used to plan lessons, conduct curriculum-linked activities, obtain background information and develop ideas for student action projects to improve their local environment.[4]

In order to ensure data quality, it is a good idea for teachers to obtain training in lichen identification. Many community groups provide training workshops for teachers, complete with classroom and field sessions and resources such as teacher manuals. Alternatively, some government agencies and community organizations provide teachers with trained post-secondary student volunteers who lead high school students through both in-class and outdoor field sessions. This "youth-mentoring-youth" model inspires and motivates youth with the possibilities of scientific endeavor and careers, and engages volunteers in valuable career-related work experiences while they are still in school.[5]

Sample project timeline

The following is a suggested timeline for a lichen bio-monitoring project.

1. *Project preparation:* Teachers and partners (e.g., local community or naturalist groups, academic institutions, government agencies) choose monitoring sites, schedule classroom and field sessions, gather background resources and equipment, and arrange for volunteers to assist with the project.

2. *Introduction to lichens:* Two in-class sessions of about 75 minutes each in which students learn about lichen biology and identification, and how to collect data in the field.

3. *Field work:* Two to four field sessions of two to three hours each. A typical data collection session would include:

a) site set-up. Choose five to ten trees of the same species. Record data about the trees (such as species and size) and the site (sketch a map, note the location, the date and time, weather and so on).

b) lichen identification. Identify the lichens present and record the data on a uniform data sheet. The abundance of each species may also be noted, depending on the protocol.

4. *Data analysis tutorial:* One session of about 75 minutes in which students learn how to analyze and interpret data using calculations such as the Index of Atmospheric Purity.[6]

Lichen Bio-monitoring Protocols

Citizens' Environment Watch, see "Air Quality Monitoring with Epiphytic Lichens" for a protocol, data sheets and a data analysis guide designed for school and community lichen bio-monitoring projects. <www.citizensenvironmentwatch.org/cew/resourceCentre/protocols&manuals.html>

Ecological Monitoring and Assessment Network (Environment Canada) provides protocols for a variety of lichen-monitoring studies. These include lichen surveys using a small grid or "ladder" to determine diversity; mapping of lichen diversity and regional air quality using an Index of Atmospheric Purity; a photometric method of photographing lichens and looking at them digitally; and standardized collection procedures that allow for the analysis of metals and contaminants through the use of mass spectrometry, among other techniques. <www.eman-rese.ca/eman/ecotools/protocols/terrestrial/lichens/intro.html>

The British Lichen Society, "The European Guideline for Mapping Lichen Diversity as an Indicator of Environmental Stress." Standardized European methods for monitoring air quality using lichens on tree bark. <www.thebls.org.uk/eumap.pdf>

USDA Forest Service, "Air Quality and Lichens: A Literature Review Emphasizing the Pacific Northwest of the United States. An excellent summary of lichen research and monitoring methods. <www.fs.fed.us/r6/aq/lichen/almanac>

5. *Action plan development and implementation and community dissemination of results:* This part of the project will vary, depending on students' and teachers' interests and time. (See "Taking action" below.)

This timeline is for a fairly comprehensive project. If you just want to introduce your students to lichens and take them outside to experience nature, community groups often provide half-day workshops for classes, along with preparation exercises and follow-up activities that teachers can incorporate into the classroom.

Taking action

After students have learned about lichens, and collected and analyzed their data, they often ask: "What do we do with all this data?" Within the classroom, making presentations and creating displays, information packages and brochures are just a few of the possible culminating activities. If students' analysis of the data shows that the local air quality needs improvement, they can take action by sharing their findings at a community meeting or by preparing a special display and presentation for a parents' night. Students may choose to make changes in their behavior that will reduce their impact on local air quality, or use their data to raise a red flag to governments to make changes in policies, or get involved in a large-scale monitoring study. They can invite the rest of the school community, and students from other schools, to become involved in monitoring or in actions such as planting trees or holding car-free days.

Monitoring air quality using lichens is a perfect way for students to participate in original, never-been-done-before research and to get better acquainted with their neighborhood. Students also learn about real issues that professional scientists face when conducting scientific studies: that there are possible sources of error, that one indicator doesn't tell you everything you need to know, that there is always the possibility for further study. Best of all, students get outside of the classroom and have the opportunity to get reacquainted with the particulars, the real nuts-and-bolts, of biological science: the trees and the sunlight and the air. The scientific theories, abstract concepts and the "big picture" have their place, but let's not forget that every theory was once just an observation. Every forest is really just a collection of trees. And before those trees existed, the ground was probably covered with lichens.

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Notes

1. For examples of lichen suites, see lichen identification field guides for mixed hardwood and boreal forests at the website of the Ecological Monitoring and Assessment Network of Environment Canada, <www.eman-rese.ca/eman/ecotools/protocols/terrestrial/> (follow links under "Lichen Diversity and Abundance"); and "Indicator Lichen Species and their Characteristics" at the website of Citizens' Environment Watch, <www.citizensenvironmentwatch.org/cew/resourceCentre/protocols&manuals.html> (follow "Guide to Indicator Species" link under "Air Quality Monitoring with Epiphytic Lichens").

2. Irwin M. Brodo, Sylvia Duran Sharnoff and Stephen Sharnoff. *Lichens of North America.* Yale University Press, 2001.

3. Robert Cameron, ecologist with the Protected Areas Branch of Nova Scotia Environment and Labour, personal correspondence, August 17, 2005.

4. See, for example, Margaret Peterson, "Lichens as Air Quality Indicators: A beginning lichen identification study" for Grades 6–8, Cooperative Institute for Research in Environmental Sciences, 2003, online September 27, 2005 at <http://cires.colorado.edu/education/k12/earthworks/teachers/petersonM.html>; and William C. Denison, "A Guide to Air Quality Monitoring with Lichens," Lichen Technology, Inc, 1973, online September 27, 2005 at <http://ocid.nacse.org/classroom/lichens/denison/>.

5. For example, Citizens' Environment Watch in Ontario matches trained volunteers (Monitoring Mentors) with classes to assist teachers in implementing monitoring projects. CEW also offers programs for youth outside of the school system and for community members/groups. See <www.citizensenvironmentwatch.org>.

6. A good resource for lichen data analysis is "Epiphytic Lichen Data Analysis," by Citizens' Environment Watch, 2002. It can be downloaded as a pdf file at <www.citizensenvironmentwatch.org/cew/resourceCentre/protocols&manuals.html>; click on "Data Analysis" under "Air Quality Monitoring with Epiphytic Lichens."

Resources

Brodo, I.M., S. Sharnoff and S. Sharnoff. *Lichens of North America.* Yale University Press, 2001.

Huckaby, L.S., ed. *Lichens as Bioindicators of Air Quality.* USDA Forest Service General Technical Report RM-224, Rocky Mountain Forest and Range Experimental Station, 1993.

Manning, W.J. and W.A. Feder. *Biomonitoring of Air Pollutants with Plants.* Applied Science Publishers, 1980.

Nash, T.H. *Lichen Biology.* Cambridge University Press, 1996.

Nash, T.H. and V. Wirth. "Lichens, Bryophytes and Air Quality." *Bibliotheca Lichenologica*, 30. J. Cramer, 1988.

Richardson, D.H.S. *Pollution Monitoring with Lichens.* Richmond Publishing. 1992.

United States Environmental Protection Agency, "Biological Indicators of Watershed Health." The focus of this report is watersheds rather than terrestrial systems, but it provides a good explanation of the use of bio-indicators in monitoring environmental quality. Online at <www.epa.gov/bioindicators/>.