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# LICHENS OF THE CALLAHAN MINE, A COPPER- AND ZINC-ENRICHED SUPERFUND SITE IN BROOKSVILLE, MAINE, U.S.A.

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ABSTRACT. Metal-enriched habitats often harbor physiologically distinct biotas able to tolerate and accumulate toxic metals. Plants and lichens that accumulate metals have served as effective indicators of ecosystem pollution. Whereas the diversity of metal-tolerant lichens has been well documented globally, the literature of metal-tolerant lichen communities for eastern North America is limited. We examined the lichen flora of the Callahan Mine, a Cu-, Pb-, and Zn-enriched superfund site in Brooksville, Hancock County, Maine, U.S.A. Through collections along transects across metal-contaminated areas of the mine, we documented 76 species of lichens and related fungi. Fifty species were saxicolous, 26 were terricolous. Forty-three species were macrolichens, 31 were microlichens. Although no globally rare or declining species were encountered at the mine, two regionally rare or declining species, *Stereocaulon tomentosum* and *Leptogium imbricatum*, were found. The species found at the Callahan Mine were mostly ecological generalists frequenting disturbed habitats. Two extensively studied Cu-tolerant lichens, *Acarospora smaragdula* and *Lecanora polytropa*, and other known Cd-, Cu-, Pb-, and Zn-tolerant taxa, were found at the site.

Key Words: biomonitoring, conservation, edaphic ecology, endemism, environmental pollution, extremophiles, lichen-metal relations, remediation, serpentine

Recently there has been much interest in edaphically extreme environments as hotspots for plant diversity (Whiting et al. 2004). Metal-enriched sites have also attracted attention as refuges for rare and/or physiologically distinct species or ecotypes (Rajakaruna and Boyd 2008). Such edaphically restricted species have served as models for testing key ecological and evolutionary theories (Harrison and Rajakaruna 2011). Metal-tolerant and hyperaccumulating plants are also potentially useful for phytoremediation, a rapidly developing green technology that employs plants to clean up metal-contaminated sites (Chaney et al. 2007; Marques et al. 2009; Pilon-Smits and Freeman 2006).

Lichens are a dominant component of the biodiversity of many metal-contaminated sites. The ability of lichens to tolerate and accumulate high levels of potentially toxic heavy metals has led to their widespread use as biomonitors of atmospheric (Conti and Cecchetti 2001) and substrate-level metal concentrations (Aznar et al. 2008), including their potential use in biogeochemical prospecting for heavy metals such as Cu, Fe, Pb, and Zn (Easton 1994; Purvis and Halls 1996) and assessing airborne Hg (Garty 2001) and radionuclides (Kirchner and Daillant 2002). Lichens lack a protective cuticle and roots; they obtain their nutrients mainly through atmospheric inputs or direct contact with mineral particles (Nash 1989; Purvis 1996; Richardson 1995). Thus, lichens are able to accumulate minerals, including toxic heavy metals, at levels exceeding their metabolic requirements (Bačkor and Loppi 2009). Lichens tolerate excessive amounts of heavy metals extracellularly via sequestration as metal oxalates, lichen acid-metal complexes, melanin pigments, and organic phosphates (Purvis and Pawlik-Skowrońska 2008) and intracellularly by chelation and detoxification via phytochelatin synthesis (Bačkor and Loppi 2009). Some lichens are able to accumulate considerable amounts of heavy metals including Cd, Cu, Cr, Fe, Hg, Ni, Pb, U, and Zn (Garty 1993; McLean et al. 1998; Purvis et al. 2004, 2011). Notable in this regard are *Acarospora rugulosa* Körb. (16% Cu on a dry mass basis; Chisholm et al. 1987), *Lecidea lactea* Flörke *ex* Schaer. (5% Cu on a dry mass basis; Purvis 1984), and *Lecanora polytropa* (Ehrh.) Rabenh. (1.3% Cu on a dry mass basis; Pawlik-Skowrońska et al.

2006). Additional species of these genera and those in *Aspicilia* A. Massal., *Porpidia* Körber, *Rhizocarpon* Ramond *ex* DC., *Stereocaulon* Hoffm., and *Tremolecia* M. Choisy dominate metal-enriched substrates worldwide (Bačkor and Loppi 2009; Nash 1989). Many metal-tolerant species exhibit a high degree of specificity for metal-enriched substrates and show disjunct distributions corresponding to the availability of such substrates worldwide (Easton 1994; Nash 1989).

Metallophytes, including lichens, and their habitats are of special conservation interest (Rajakaruna and Boyd 2008; Whiting et al. 2004). Metal-enriched sites are quickly being converted to industrial or recreational settings or being remediated via intrusive technological and chemical means to remove or immobilize the metal contaminants. Although metal-enriched sites such as mine spoils are toxic and adversely impact ecosystem health, they often support unusual life forms, including rich lichen floras harboring physiologically distinct, rare, and endangered species (Purvis 1993; Purvis and James 1985). For example, the 'copper lichen' (*Lecidea inops* Th. Fr.) is a *Red Data Book* species included in Schedule 8 of the U.K. Wildlife and Countryside Act of 1981 (Church et al. 1996).

Although lichens of metal-enriched habitats have attracted much attention globally (Purvis and Halls 1996; Purvis and Pawlik-Skowrońska 2008), there has been little recent effort to document lichen communities of metal-enriched habitats in northeastern North America (Rajakaruna et al. 2009a). A recent study by Harris et al. (2007) documented a unique lichen flora for a small, metal-enriched serpentine outcrop on Little Deer Isle, Maine. This suggests that other metal-enriched habitats in the region may also harbor rare or physiologically distinct species.

Maine has a rich history of metal mining (Lepage et al. 1991). Such activity has left a few large areas contaminated with Cu, Fe, Pb, Ag, and Zn along the coastal volcanic belt from the Blue Hill Peninsula to Lubec. Probably the most famous operation was the open-pit Harborside Mine between Brooksville and Cape Rosier (now the Callahan Mine) which produced 800,000 tons of copper and zinc ore from 1968 to 1972. The ore contained approximately 17% zinc, 7% copper, and 5% lead (Environmental Protection Agency 2003). The largest producer in the region was the Black Hawk mine (now Kerr-American Mine) in nearby Blue Hill, an underground mine that produced an estimated 1,000,000 tons of zinc-copper-lead ore between 1972 and 1977. Although heavy metals have not been mined in Maine since 1977, previous mining activity, including those at the Callahan and Kerr-American mines, has led to several vast, metal-enriched habitats along coastal Maine. The biodiversity of such habitats is largely unknown, although unpublished baseline environmental assessments have been conducted by the Environmental Protection Agency [EPA; website (http://www.epa.gov/region1/superfund/sites/callahan), EPA Regional Office, Boston, MA.] Currently there is no mining activity beyond gravel extraction, but there are additional significant deposits of metals in Maine, including the Ledge Ridge deposit in Parmachenee, a sulfide deposit with several million tons of Cu, Zn, Pb; the Bald Mountain deposit west of Portage, a Cu-Zn sulfide deposit with an estimated 36 million tons of ore; the Mount Chase Cu-Pb-Ag-Zn deposit near Patten; and the Alder Pond deposit, with an estimated 1.5–3 million tons of high grade Cu-Zn ore underground. The habitats overlying these deposits are potential sites for the discovery of unusual metallophytes, including rare and metal-indicating lichens.

This study examines the saxicolous (rock inhabiting) and terricolous (soil inhabiting) lichen flora of the Callahan Mine. We present the lichen flora with relevant ecological and geochemical data from the site, and discuss the ecological significance and distribution of regionally rare species and species with known tolerance to heavy metals such as Cd, Cu, Pb, and Zn.

## MATERIALS AND METHODS

The Callahan Mine is a former intertidal open-pit mine located near the Holbrook Island Sanctuary in Brooksville, Hancock County, Maine (44°20′N, 68°48′W; WGS 84; Figure 1). The 61 ha site underwent intermittent mining operations from 1880–1964 and was heavily mined from 1964–1972. A 98 m deep pit was excavated adjacent to and under Goose Pond, a tidal estuary dammed at both ends to permit mining. The pit was flooded in 1972, returning the estuary to its original (dammed) level. In 2002, the Callahan Mine was listed as a Superfund Site (Environmental Protection Agency 2002) due to elevated levels of inorganic and organic contaminants, and a remediation plan was put into action in September 2009.

The site consists of a flooded tidal pit, Goose Pond, an artificial wetland on sediments dredged from the pit, a tailings pond, an ore pad, and three waste rock piles in addition to several dilapidated

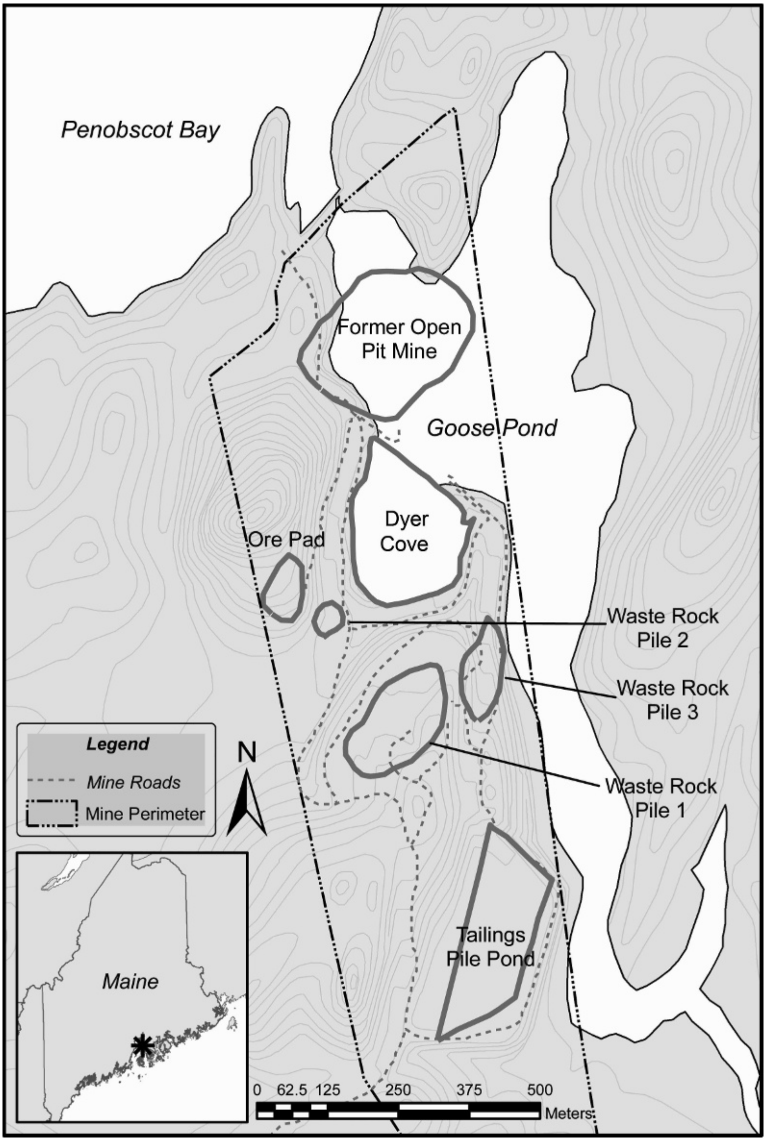

Figure 1. Map of the Callahan Mine, Brooksville, Maine, highlighting locations where lichens were sampled. Credit: Jose Perez-Orozco.

structures. Since 1972, vegetation has regenerated along the edges of Goose Pond and along roads, most commonly with *Betula populifolia* Marsh. (Betulaceae), *Comptonia peregrina* (L.) J.M. Coult. (Myricaceae), *Juniperus communis* L. (Cupressaceae), *Morella pensylvanica* (Mirb.) Kartesz (Myricaceae), *Populus balsamifera* L. (Salicaceae), and *Thuja occidentalis* L. (Cupressaceae). Substrates throughout the site range from boulders and small rocks to pebbles, coarse gravel, sand, fine silt, and wood. The underlying rock occurs as lenses of mixed sulfides of Cu, Fe, Pb, and Zn, replacing highly sheared and altered agglomerates (Environmental Protection Agency 2003). The bedrock of the Callahan Mine and the adjacent portion of the mainland is composed of a series of volcanics—rhyolitic and andesitic flows, agglomerates, and pyroclastics—folded with a northeasterly regional strike and intruded by sills and dikes of diorite. The volcanics are collectively called the Castine formation and tentatively assigned to the early or middle Paleozoic (Environmental Protection Agency 2003). At the mine itself, a large pegmatite intrusion was exploited for mineral extraction. The mined shoreline along Goose Pond is steep and rocky—ranging from coarse gravel to large boulders. Waste Rock Pile 1, the largest of the three waste rock piles, is composed of large stone, gravel, and soil and is highly exposed due to its height and central position within the mine complex (Figure 1).

Lichen samples were collected: (1) along the mined portion of Goose Pond (GP), 10 m above the low tide line, with 22 sampling points at 20 m intervals along a single transect starting at 44°21.026′N, 68°48.461′W and ending at 44°21.997′N, 68°48.429′W; and (2) at the central Waste Rock Pile 1 (WR), along three N–S transects 50 m apart, with a total of 11 sampling points at 40 m intervals along each transect. Starting and ending coordinates for the three transects were as follows: transect 1, 44°20.788′N, 68°48.463′W to 44°20.729′N, 68°48.433′W; transect 2, 44°20.794′N, 68°48.409′W to 44°20.729′N, 68°48.418′W; transect 3, 44°20.767′N, 68°48.488′W to 44°20.717′N, 68°48.481′W. Datum for all coordinates was WGS 84. At each point, lichens were collected in bulk on several dates from June–October 2006 from soil, gravel, and rock within a five-meter radius of each sampling point (sampling area 78.5 m$^2$). Collection areas are shown in Figure 1. Lichen species that had not been encountered around GP or WR were also collected from around the edges of mine roads throughout the site and Waste Rock Piles 2 and 3. Lichens were sought at the Tailings Pond but none were found.

Macrolichens and some microlichens were identified by T.B.H. using standard morphological and chemical methods. Verifications and additional identifications were provided by James W. Hinds (Univ. Maine, Orono), who determined macrolichens, and S.C., who determined the microlichens and some of the macrolichens. Nomenclature and naming authorities follow Index Fungorum Partnership (2010+) except where noted. Most of the macrolichens were deposited in the herbarium of College of the Atlantic (HCOA); microlichens and some macrolichens were deposited in the herbarium of the New Brunswick Museum (NBM).

To determine heavy metal concentrations in the top soils, soil/sediment samples were collected at nine locations at the Callahan Mine in June 2006. Three 100 g soil samples each were collected from GP (at beginning, mid, and end of transect), WR (one at the midpoint of each transect), and Tailings Pond (at beginning, mid, and end of one N–S transect across Pond). Soils were analyzed for bioavailable Cd, Cu, Pb, and Zn, metals known to be abundant at this site (Environmental Protection Agency 2003), by extraction with 0.005 M diethylene triamine pentaacetic acid (DTPA) buffered with triethanolamine to pH 7.3 (Lindsay and Norvell 1978) for two hours and subsequent detection by ICP-OES using matrix-matched calibration standards. The metal analyses were conducted by the Analytical Laboratory at the University of Maine at Orono.

## RESULTS

We found 74 species of lichens, a lichenicolous fungus (*Stigmidium* sp.), and one ascomycete (*Lichenothelia convexa*) with uncertain biological status (Esslinger 2009; Appendix). Although it is not lichen-forming, we have included *L. convexa* in our list, as it is commonly found among saxicolous lichens. Of the lichens collected, 43 species were macrolichens (56.6%) and 31 species were microlichens (40.8%). Saxicolous lichens were the most abundant, with 65.8% (50 species) of the total flora; terricolous lichens consisted of 34.2% (26 species) of the total flora. Of the saxicolous lichens, 44% (22 species) were macrolichens while 52% (26 species) were microlichens. Of the terricolous lichens, 80.8% (21 species) were macrolichens and 19.2% (5 species) were microlichens.

Table 1. Bioavailable Cu, Zn, Pb, and Cd content, given in ppm (µg/g dry soil), in soil samples collected along Waste Rock Pile 1 (WR), Goose Pond (GP), and Tailings Pond (TP). Means (± SE) based on three composite samples collected at beginning, mid, and end points of transects placed at the three sites. Significance (p value < 0.05) based on a one-way ANOVA.

| Site | Cu | Zn | Pb | Cd |
|---|---|---|---|---|
| WR | 145.0 (±7.9) | 385.3 (±23.7) | 5.4 (±1.2) | 2.03 (±0.17) |
| GP | 102.2 (±2.1) | 688.1 (±10.4) | 3.9 (±0.07) | 7.7 (±0.04) |
| TP | 56.8 (±2.2) | 852.3 (±3.8) | 7.0 (±0.35) | 3.5 (±0.18) |
| Degrees of freedom | 2 | 2 | 2 | 2 |
| F value | 80.06 | 246.5 | 4.4 | 405.5 |
| p value | < 0.001 | < 0.001 | > 0.05 | < 0.001 |

We found excessive concentrations of bioavailable Cd, Cu, Pb, and Zn in the DTPA-extractable metal analysis of soils collected at GP, WR, and TP (Table 1). Of the 76 lichens and fungi we documented, we recognized 19 species of lichens from the Callahan mine (25% of total flora collected) that had been documented in previous studies as tolerant of or accumulating high concentrations of Cd, Cu, Pb, and Zn worldwide (Table 2).

## DISCUSSION

Most of the lichens encountered at the Callahan Mine were ecological generalists that are not narrowly restricted to a particular substratum or habitat type. A high proportion of the species have life histories characterized by relatively precocious and abundant production of ascospores or vegetative propagules. Such traits confer an advantage in frequently disturbed habitats. Examples of such species at the Callahan Mine include: *Acarospora fuscata*, *Amandinea punctata*, *Caloplaca holocarpa*, *Candelariella vitellina*, *Cladonia cariosa*, *C. rei*, *Dibaeis baeomyces*, *Lecanora dispersa*, *L. polytropa*, *Leimonis erratica*, *Melanelixia subaurifera*, *Peltigera rufescens*, *Physcia dubia*, *Placynthiella icmalea*, *Porpidia crustulata*, *Rhizocarpon reductum*, *Scoliciosporum umbrinum*, *Stereocaulon tomentosum*, *Trapeliopsis granulosa*, and *Verrucaria muralis* (Brodo et al. 2001; Hinds and Hinds 2007; Smith et al. 2009; Appendix).

Species characteristic of nutrient-enriched substrata were also well represented, although it is unclear whether the nutrient enrichment was via organic matter, including bird and other animal

Table 2. Nineteen lichen species from the Callahan Mine previously documented to tolerate or accumulate elevated levels of Cd, Cu, Pb, and Zn.

| Species | Metal | Reference |
|---|---|---|
| *Acarospora smaragdula* | Cu | Garty 1993; Pawlik-Skowrońska et al. 2006; Purvis et al. 1985; Purvis 1996; Purvis and Halls 1996; Wedin et al. 2009 |
| | Pb | Purvis et al. 2000 |
| *Cladonia cariosa* | Pb, Zn | Purvis 1996; Purvis and Halls 1996 |
| *C. chlorophaea* | Pb | Garty 1993 |
| *C. cristatella* | Cd, Pb | Garty 1993 |
| *C. furcata* | Pb, Zn | Garty 1993; Pawlik-Skowrońska et al. 2008 |
| *C. pyxidata* | Pb | Garty 1993 |
| *C. rangiferina* | Cd, Pb | Garty 1993 |
| *C. rei* | Pb, Zn | Purvis and Halls 1996 |
| *Dibaeis baeomyces* | Pb, Zn | Purvis and Halls 1996 |
| *Hypogymnia physodes* | Cd, Pb | Conti et al. 2001; Garty 1993 |
| | Cu | Garty 1993 |
| | Zn | Garty 1993 |
| | Pb, Zn | Pawlik-Skowrońska et al. 2008 |
| *Lecanora dispersa* | Pb | Garty 1993 |
| *L. polytropa* | Cu | Alstrup & Hansen 1977; Garty 1993; Pawlik-Skowrońska et al. 2006; Purvis 1996; Purvis and Halls 1996; Purvis et al. 2008 |
| *Parmelia sulcata* | Pb, Zn | Garty 1993 |
| *Peltigera rufescens* | Cu | Baèkor et al. 2009 |
| | Pb, Zn | Garty 1993 |
| *Physcia adscendens* | Pb, Zn | Pawlik-Skowrońska et al. 2008 |
| *Rhizocarpon cinereovirens* | Pb, Zn | Purvis and Halls 1996 |
| *Stereocaulon dactylophyllum* | Pb, Zn | Purvis 1996 |
| *S. pileatum* | Pb, Zn | Purvis 1996; Purvis and Halls 1996 |
| *Xanthoria parietina* | Cd | Rossbach and Lambrecht 2006 |
| | Pb | Garty 1993; Rossbach and Lambrecht 2006; Sarret et al. 1998 |

droppings, or via salt spray or deposition of nitrogenous pollutants. The occurrence of a number of calciphilous species may be linked to the presence of old mortar or concrete at the site (Brodo et al. 2001; Smith et al. 2009). Among these are *Candelariella aurella*, *Cladonia* *cariosa*, *C. pocillum*, *Lecanora dispersa*, *Leptogium imbricatum*, and *Verrucaria muralis* (Appendix).

Species found at the site that are metal tolerant (Table 2; Appendix) often occur in a range of habitats in the Northeast. However, 19 lichen species encountered at the Callahan Mine (25% of total flora documented) appear to frequent mine tailings and other metal-enriched sites worldwide (Table 2). Iron-tolerant species were also frequent at the site and included *Acarospora sinopica*, *A. smaragdula*, *Candelariella vitellina*, *Lecanora polytropa*, *Porpidia macrocarpa*, *Rhizocarpon cinereovirens*, *R. infernulum*, *R. lecanorinum*, *R. reductum*, *Scoliciosporum umbrinum*, and *Stereocaulon dactylophyllum* (Brodo et al. 2001; Smith et al. 2009). Of these, only *A. sinopica* is largely restricted to iron-rich substrata (Appendix). *Acarospora smaragdula* and several other species (Table 2) tolerate elevated levels of a range of heavy metals, including Cd, Cu, Pb, and Zn (Purvis and Halls 1996). It is likely that the warm, dry weather encountered during the collection period precluded the collection of spring-time ephemeral species typical of this type of environment, such as those of the genus *Vezdaea* (Coppins 1987; Gilbert 2004). Species in this genus and other terricolous microlichens common to metal-contaminated soils are generally very inconspicuous and are fertile during specific times of year; as such, they may have been easily overlooked in our study.

No globally rare or declining macrolichen species were found at the Callahan Mine. However, two regionally rare or declining macrolichens (Hinds and Hinds 2007) were present: *Stereocaulon tomentosum* (R2; approximately 20 known sites, including 19 in Maine and one in New Hampshire) and *Leptogium imbricatum* (R1; currently known in New England from a single site in Washington County, Maine). *Stereocaulon tomentosum* was found in at least five New England states prior to 1930. However, it seems to have become restricted to Maine and New Hampshire since the 1980s (Hinds and Hinds 2007).

Remedial investigations conducted by the EPA from 2004–2008 confirmed that the Callahan Mine and the surrounding area were contaminated by elevated levels of heavy metals and other organic contaminants; the total concentrations of As, Cu, Pb, and Zn, as well as PCBs were found to be many-fold greater than levels acceptable for human contact or ecosystem health (Environmental Protection Agency 2009). Our soil analyses (Table 1) support the findings of the EPA, showing elevated concentrations of bioavailable Cd, Cu, Pb, and Zn at our sampling locations. Further, concentrations of all metals exceeded the upper limit reported for 'normal' surface soils globally (Kabata-Pendias 2001; Nash 1989), suggesting increased potential for toxicity and bioaccumulation.

Previous studies at the Callahan Mine have reported ore rocks and mine tailings containing total Zn concentrations of 17% (170,000 ppm) and 0.71% (7100 ppm), respectively (Environmental Protection Agency 2003). These concentrations are highly toxic to organisms and exceed the upper total concentrations (< 500 ppm) reported for this metal from surface soils globally (Kabata-Pendias 2001; Nash 1989). All three of our sampling locations at the Callahan Mine (Table 1) recorded high mean bioavailable Zn (383–852 ppm) at concentrations potentially toxic to the resident biota, including lichens. A recent EPA study reported that salt grass [*Distichlis spicata* (L.) Greene] at the Callahan Mine accumulated 54 times more Zn than the same taxon collected from 'unpolluted' reference locations (Environmental Protection Agency 2009).

A similar trend was documented for Cu at the Callahan Mine, a metal far exceeding the normal background total concentrations (< 120 ppm) in soil (Fernandes and Henriques 1991; Kabata-Pendias 2001; Nash 1989). Ore and tailings of the Callahan Mine contained approximately 7% (70,000 ppm) and 0.15% (1500 ppm) total Cu, respectively (Environmental Protection Agency 2003). Our soil analyses report mean bioavailable Cu concentrations (57–145 ppm; Table 1); these levels are known to cause acute toxicity in organisms, including in lichens (Fernandes and Henriques 1991). The EPA report documents salt grass at the Callahan Mine accumulating 79 times more Cu than the same taxon collected from 'unpolluted' reference locations (Environmental Protection Agency 2009).

Normal background levels of total Pb in soils from Maine range from 10–50 ppm (Bruce Hoskins, Analytical Laboratory, Univ. Maine, Orono, pers. comm.), whereas worldwide the upper limit has been reported as 70–100 ppm (Kabata-Pendias 2001; Nash 1989). The amounts of Pb extracted from chelators such as DTPA, used in our analysis (4–7 ppm; Table 1), are much less than the total content but give a better index of bioavailability (Cui et al. 2004). Given that the ore and mine tailings contained an average of 5% (50,000 ppm) and 0.06% (600 ppm) total Pb, respectively (Environmental Protection Agency 2003), the bioavailable values we report in Table 1 are much lower. However, the EPA studies document that all organisms tested in and around the Callahan Mine (benthic, aquatic, and salt grass) accumulated significantly higher concentrations of Pb than the same taxa collected from 'unpolluted' reference locations (Environmental Protection Agency 2009). For example, salt grass at the Callahan Mine accumulated 14 times more lead than the same taxon collected from the reference locations.

Our ongoing studies of lichens of metal-enriched substrates in Maine point to an interesting trend. The Callahan Mine (this study) and the Ni-enriched serpentine outcrop at Pine Hill shared in common 22 species (29% of the total flora documented), including *Buellia ocellata*, a species that we reported for the first time in New England (Harris et al. 2007). Ecologically, the lichen flora at the Callahan Mine showed a similar species composition to that of Pine Hill, with a greater percentage of saxicolous species compared to terricolous species, and a relatively higher percentage of microlichens among the saxicolous species compared to a significantly greater percentage of macrolichens among the terricolous species. Favero-Longo et al. (2004), in a review of lichens of serpentine substrates worldwide, suggested that many species occupying Cr- and Ni-enriched serpentine substrates can also be found on other calcareous and siliceous substrates. Six of the 76 species we documented (ca. 8%) were also collected from a calcium-rich spring seep isolated on the granitic terrain of Mt. Katahdin, Maine's tallest mountain (Miller et al. 2005), whereas 35 species (ca. 46%) were shared in common with the subalpine and alpine lichen floras of Katahdin (Dibble et al. 2009; Hinds et al. 2009). Several species known to occur on nutrient-enriched bird nesting rocks were also found at the Callahan Mine. They include *Physcia dubia* and *P. phaea* (Hinds and Hinds 2007), *Acarospora fuscata* and *Amandinea punctata* (Smith et al. 2009), and *Xanthoria parietina* (Rajakaruna et al. 2009b). These observations suggest that chemically and physically harsh substrates, or alpine climates, that prevent the formation of dense vascular vegetation in exposed sites can provide a competition-free refuge for various lichen species in the region. We hope that this and other studies we have conducted in the recent past (Rajakaruna et al. 2009a) will generate additional field exploratory work documenting the biodiversity of unusual habitats—especially rock outcrops—across New England.

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## APPENDIX

## LICHENS AND RELATED FUNGI AT THE CALLAHAN MINE, BROOKSVILLE, MAINE

Seventy-six lichens and related fungi collected from rock/gravel and soil at the Callahan Mine, Brooksville, Maine (Site: GP = Goose Pond, WR = Waste Rock Pile 1). Collection numbers for each voucher specimen deposited at the herbaria at College of the Atlantic (HCOA) and New Brunswick Museum (NBM) are listed in parenthesis (vouchers had yet to be assigned accession numbers for either herbarium at the time of publication). Nomenclature and naming authorities follow Index Fungorum Partnership (http://indexfungorum.org) except for *Lecanora dispersa* which follows Esslinger (2009). The nature of each taxon, [macro (MA), micro (MI), lichenicolous fungus (+), and related fungus of uncertain status (*)], and substrate [Rock (= Rock/Gravel); Soil] are also listed. Range/Frequency/Substrate Ecology for macrolichens are from Hinds and Hinds (2007); for microlichens from Brodo et al. (2001); for all lichens from Smith et al. (2009); AF = Africa, AN = Antarctica, AS = Asia, AU = Australia, CA = Central America, EU = Europe, MN = Macronesia, NA = North America, NE = New England, NZ = New Zealand, SA = South America. N, S, E, W, NW = compass directions (i.e., N NA); C = Central.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Acarospora fuscata* (Schrader) Arnold<br>(NBM: *TH 222-4*, *TH 365-X-4*, *TH 371-Y-1*, *TH 375-Y-1*, *TH 391-1*, *LB CM 17 025-1*) | GP | MI | Rock | Broad global distribution and substrate tolerance; widespread across NA; on siliceous rocks and bird nesting rocks |
| *Acarospora sinopica* (Wahlenb.) Körb.<br>(NBM: *TH 422*) | WR | MI | Rock | Probably cosmopolitan; known from EU, NA, AS, AU; on iron-rich rocks, mine-spoil heaps |
| *Acarospora smaragdula* (Wahlenb.) A. Massal.<br>(NBM: *TH 22-3*, *TH 260*, *TH 288*, *TH 289-2*, *TH 320-X-1*, *TH 375-Y-2*, *TH 391-2*, *TH 399-2*) | GP | MI | Rock | Cosmopolitan; known from EU, NA, SA, AS, AF, AU; widespread across NA; on siliceous rocks and rocks slightly base-rich or high in heavy metals |

Appendix. Continued.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Amandinea punctata* (Hoffm.) Coppins & Scheid.<br>(NBM: *TH 259-1*, *TH 283-3*, *TH 292-3*, *TH 367*, *TH 398-6*, *TH 447-4*, *LB CM 21 035-2*) | WR GP | MI | Rock | Cosmopolitan; widespread across NA; on bark, wood, siliceous rocks, and bird nesting rocks; tolerant of $SO_2$ pollution |
| *Aspicilia cinerea* (L.) Körb.<br>(NBM: *TH 373-X*) | GP | MI | Rock | Cosmopolitan; known from EU, MN, NA, SA, AS, AF, NZ; widespread across NA; on siliceous rocks |
| *Aspicilia verrucigera* Hue<br>(NBM: *TH 424-1*) | WR | MI | Rock | Widespread across NA, especially eastern NA; on siliceous rocks |
| *Baeomyces rufus* (Huds.)<br>(NBM: *TH 365-Y*, *TH 371-X*, *TH 376*, *TH 396*, *LB CM 16 017*, *LB CM 16 021*) | GP | MI | Soil | Cosmopolitan but mostly in temperate and boreal regions; widespread across N NA; on shaded and damp rocks, wood, peaty and acid soils, and bark of roots |
| *Buellia ocellata* (Flot.) Körb.<br>(NBM: *TH 421*) | WR | MI | Rock | In EU, MN, NA, AS, AF, and AU; Rare in NE; on siliceous rocks, pebbles, and stonework |
| *Caloplaca holocarpa* (Ach.) A.E. Wade<br>(NBM: *TH 220-2*, *TH 292-5*, *TH 309-2*, *TH 323-X-2*, *TH 365-X-1*, *TH 398-3*, *TH 399-3*, *TH 420-1*, *TH 424-2*, *TH 435-2*, *TH 447-1*) | WR GP | MI | Rock | Widespread in NA, EU, and western AS; mainly on siliceous rocks subject to nutrient enrichment; also on tree bark, wood, and calcareous rock, including concrete and mortar |

Appendix. Continued.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Candelariella aurella* (Hoffm.) Zahlbr.<br>(NBM: *TH 222-2*, *TH 355*, *TH 398-1*, *TH 435-1*, *TH 447-3*) | WR GP | MI | Rock | Cosmopolitan; in NA, mostly in western regions and NE; on dust impregnated wood and bark, concrete and man-made basic substrata |
| *Candelariella vitellina* (Ehrh.) Müll. Arg.<br>(NBM: *TH 365-X-2*, *TH 447-2*, *LB CM 17 029-1*) | WR GP | MI | Rock | Cosmopolitan; widespread across NA; on siliceous and calcareous rocks, rusting iron, stained glass, wood, and rarely on bark and soil |
| *Cladonia cariosa* (Ach.) Spreng.<br>(NBM: *TH 238-2*, *TH 402-1*) | GP | MA | Soil | Circumpolar, arctic to temperate; EU, S SA, NA, N AF, AS; common in NE; on weakly to strongly calcareous soil in open habitats; less common on organic substrata or on rock; in EU also on mine spoil-heaps |
| *Cladonia cervicornis* subsp. *verticillata* (Hoffm.) Ahti<br>(HCOA: *TH 403*) | GP | MA | Soil | Broad global distribution including EU, NA, AS, AU, NZ; common in NE; on soil in open habitats; less common on wood or mossy rock; in EU, frequent on mine spoil-heaps |
| *Cladonia chlorophaea* (Flörke *ex* Sommerf.) Spreng.<br>(NBM: *TH 239-1*, *TH 323-Y*, *TH 326*, *TH 383*, *TH 430-2*) | WR GP | MA | Soil | Cosmopolitan, but most frequent in temperate and boreal regions; common in NE; on humus, peat, logs, tree bases, rocks with thin soil |

Appendix. Continued.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Cladonia cristatella* Tuck.<br>(NBM: *TH 321-2*; HCOA: *TH 251*, *TH 267*, *TH 376*, *TH 405*) | GP | MA | Soil | Endemic to E NA; common in NE; on logs, stumps, tree bases |
| *Cladonia floerkeana* (Fr.) Flörke<br>(HCOA: *TH 321*) | GP | MA | Soil | Broad global distribution including EU, MN, NA, SA, AS, S AF, AU, NZ; common in NE; on tree stumps, logs, mossy scree, fence posts, peat, and humus |
| *Cladonia furcata* (Huds.) Schrad.<br>(NBM: *LB CM 14 003*; HCOA: *TH 231*, *LB CM 007*) | GP | MA | Soil | Broad global distribution including EU, MN, NA, SA, AS, AF, AU, NZ, subantarctic islands; common in NE; on rocks with thin soil or mosses, heathlands, grasslands and lawns, and litter over rocks |
| *Cladonia gracilis* (L.) Willd. subsp. *gracilis*<br>(HCOA: *TH 348*) | GP | MA | Soil | Widespread in boreal regions; in NA, mainly in eastern half of continent; in NE, largely restricted to northeasternmost areas; on thin soil over rock in heathlands or open forests |
| *Cladonia gracilis* subsp. *turbinata* (Ach.) Ahti<br>(HCOA: *TH 349*) | GP | MA | Soil | Broad global distribution; common in NE; on rotting wood and humus in open woods, clearings, heathlands, or on rock outcrops |

Appendix. Continued.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Cladonia grayi* G. Merr. *ex* Sandst. (NBM: *TH 303-2*, *LB CM 17 028-1*) | GP | MA | Soil | In E NA, EU, Japan; uncommon in NE; on logs, stumps, tree bases |
| *Cladonia macilenta* Hoffm. (NBM: *TH 321-1*) | GP | MA | Soil | Broad temperate-boreal distribution including EU, MN, NA, SA, AS, AF, AU, NZ, and subantarctic islands; common in NE; on logs, tree bases, humus, rocks with thin soil, and among mosses in acidic woodlands and heathlands |
| *Cladonia maxima* (Asahina) Ahti (NBM: *LB CM 14 010*; HCOA: *TH 348*) | GP | MA | Soil | Incompletely circumboreal in oceanic regions including EU, NA, and AS; in coastal and montane areas in NE; on humus and peat in coniferous forests and bogs |
| *Cladonia phyllophora* Hoffm. (HCOA: *TH 450*) | WR GP | MA | Soil | Circumpolar in Arctic, boreal, north-temperate regions, including EU, NA, SA, AS, subantarctic islands; fairly common in NE; on mossy rocks and in heathlands |
| *Cladonia pocillum* (Ach.) Grognot (NBM: *TH 200-C*) | GP | MA | Soil | Broad global distribution including EU, NA, SA, AS, AF, NZ, subantarctic islands, and AN; common in NE, especially Maine, Vt., Conn.; on calcareous soils |

Appendix. Continued.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Cladonia polycarpoides* Nyl.<br>(NBM: *TH 238-1*) | GP | MA | Soil | Broad global distribution, including E NA; fairly common in NE; on thin soil over rock |
| *Cladonia pyxidata* (L.) Hoffm.<br>(NBM: *TH 303-1*, *TH 439-2*; HCOA: *TH 350*, *TH 390*, *TH 404*) | WR GP | MA | Soil | Cosmopolitan; common in NE; on thin soil over rock, less commonly on wood or tree trunks; often in rather dry habitats |
| *Cladonia rangiferina* (L.) F.H. Wigg.<br>(NBM: *TH 406*; HCOA: *TH 246*) | GP | MA | Soil | Circumpolar in N Hemisphere including EU, NA as far south as Fla., and in S SA; common in NE; on rocks with thin soil, moss-lichen heaths, bogs, acidic open woodlands |
| *Cladonia rei* Schaer.<br>(NBM: *TH 235*, *TH 265*, *TH 330-Y*, *TH 342*, *TH 347*, *TH 426*, *TH 430-1*) | WR GP | MA | Soil | Circumpolar boreal to temperate, including EU, MN, NA, E AF, AS, AU, NZ; fairly common in NE; on logs and rocks with thin soil; especially on mineral soil in not very acidic woodlands, heaths, and wastelands |
| *Cladonia scabriuscula* (Delise) Nyl.<br>(NBM: *TH 224*, *TH 346*, *TH 350*, *TH 430-3*) | WR GP | MA | Soil | Broad global distribution including EU, NA, SA, AS, N AF, AU, NZ, and subantarctic islands; common in NE; on thin soil over rock, on mossy substrata in forests and forest openings; also on heavy metal mine spoil |

Appendix. Continued.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Cladonia stygia* (Fr.) Ruoss<br>(HCOA: *TH 231-2*) | GP | MA | Soil | Boreal and Arctic regions of N Hemisphere including EU, NA, and AS; known from Maine, N.H., Vt., and Mass.; mainly in wet bogs |
| *Dibaeis baeomyces* (L. f.) Rambold & Hertel<br>(NBM: *TH 214*, *TH 229*, *TH 255*, *TH 413*) | GP | MI | Soil | In EU, NA, Greenland, AS, AF; widespread in E NA and NW NA; on clayey or sandy acidic mineral soil along roadsides, in heathlands, and over rock outcrops |
| *Diploschistes muscorum* (Scop.) R. Sant.<br>(NBM: *TH 200*-B, *TH 373-Y*, *TH 377*, *TH 416*, *TH 439-1*, *TH 461*, *LB CM 14-001-2*) | WR GP | MI | Soil | Cosmopolitan; widespread across NA; overgrowing other lichens, mosses, and organic detritus on the ground |
| *Evernia mesomorpha* Nyl.<br>(HCOA: *TH 316*, *TH 362*) | GP | MA | Rock | Circumboreal; common in NE, especially in N and mountainous regions; mainly on branches and trunks of coniferous trees |
| *Fuscidea pusilla* Tønsberg<br>(NBM: *TH 389*) | GP | MI | Rock | Probably cosmopolitan; mainly on bark or wood of conifers and other acid-barked trees |

Appendix. Continued.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Hypogymnia physodes* (L.) Nyl.<br>(HCOA: *TH 215*, *TH 233*, *TH 293*, *TH 307*, *TH 315*, *TH 328*, *TH 368*, *TH 429*, *TH 460*) | WR GP | MA | Rock | Arctic, boreal, and N temperate NA and EU, E AF, AS including in Himalayas, MN; common in NE; on trees and wood, less often on rock |
| *Lecanora dispersa* (Pers.) Sommerf.<br>(NBM: *TH 22-1*, *TH 317*, *TH 320-Y-1*, *TH 324*, *TH 335*, *TH 337-1*, *TH 365-X-5*, *TH 398-2*, *TH 447-5*, *LB CM 17 026*) | WR GP | MI | Rock | Cosmopolitan; widespread in E and C NA; on calcareous rocks, also on mortar and concrete |
| *Lecanora polytropa* (Hoffm.) Rabenh.<br>(NBM: *TH 259-2*, *TH 283-1*, *292-4*, *TH 327*, *TH 371-Y-2*, *TH 391-4*, *TH 423-1*, *TH 438-4*, *TH 448*, *TH 453*, *TH 467-2*, *TH 468*, *LB CM 17 024*, *LB CM 17 025-2*) | WR GP | MI | Rock | Cosmopolitan; widespread in N and W NA; mainly on siliceous rocks |
| *Leimonis erratica* (Körb.) R.C. Harris & Lendemer<br>(NBM: *TH 259-4*) | GP | MI | Rock | Widespread in E temperate regions in C EU, NA, AU, NZ; on pebbles and small stones in open areas |
| *Leptogium imbricatum* P.M. Jørg.<br>(NBM: *TH 401*) | GP | MA | Soil | Probably circumarctic in NA and EU, but distribution poorly known; in NE, known from one site in Washington, Co., Maine; on calcareous soil and cliff ledges, often among moss |

Appendix. Continued.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Lichenothelia convexa* Henssen<br>(NBM: *TH 259-5*, *TH 391-6*) | GP | * | R | Probably cosmopolitan; on exposed siliceous rocks |
| *Melanelixia subaurifera* (Nyl.) O. Blanco, A. Crespo, Divakar, Essl., D. Hawksw. & Lumbsch<br>(HCOA: *TH 247*, *TH 338*, *TH 351*, *TH 379*, *LB CM 005*) | GP | MA | Rock | Temperate and boreal NA and EU, Iceland, MN, CA, N and C AF, and AS; common in NE; on bark of branches and twigs, especially acid-barked trees |
| *Parmelia squarrosa* Hale<br>(HCOA: *TH 362-2*) | GP | MA | Rock | Common in E NA and E Asia, rare in W Europe and W NA; common in NE; on trees |
| *Parmelia sulcata* Taylor<br>(NBM: *LB CM 17 028-2*; HCOA: *TH 234*, *TH 248*, *TH 276*, *TH 308*, *TH 318*, *TH 331B*, *TH 332*, *LB CM 006*) | GP | MA | Rock | Cosmopolitan; common in NE; on trees and siliceous rocks |
| *Peltigera rufescens* (Weiss) Humb.<br>(HCOA: *TH 382*, *TH 455*) | WR GP | MA | Rock | Cosmopolitan; fairly common in NE; on soil in open areas |
| *Physcia adscendens* (Fr.) H. Olivier<br>(NBM: *TH 380*; HCOA: *TH 313*, *TH 331A*) | GP | MA | Rock | Cosmopolitan except AN; common in NE; on base-rich tree bark, stone, and other nutrient-rich substrata including marble gravestones |
| *Physcia aipolia* (Ehrh. *ex* Humb.) Fürnr.<br>(HCOA: *TH 331A-2*) | GP | MA | Rock | Cosmopolitan except AN; common in NE; on base-rich tree bark |

Appendix. Continued.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Physcia dubia* (Hoffm.) Lettau<br>(HCOA: *TH 393*, *TH 425*) | WR | MA | Rock | Cosmopolitan except AN; common in NE; on rocks enriched with bird guano, tree bases, and dust-impregnated bark |
| *Physcia phaea* (Tuck.) J.W. Thomson<br>(HCOA: *TH 336*) | GP | MA | Rock | Temperate and boreal NA and EU; fairly common in NE; on acid rocks, especially those enriched with bird guano |
| *Physcia subtilis* Degel.<br>(NBM: *TH 281-B*) | GP | MA | Rock | Endemic to temperate NA; fairly common in NE; on acidic rock in shaded or open, moist or dry sites |
| *Placynthiella icmalea* (Ach.) Coppins & P. James<br>(NBM: *TH 402-3*) | GP | MI | Soil | In EU, MN, NA, AS, AF, and Tasmania; in E NA, on wood, rotting bark, woody debris, and humus |
| *Porpidia crustulata* (Ach.) Hertel & Knoph<br>(NBM: *TH 241-1*, *TH 438-1*) | WR | MI | Rock | In temperate areas of EU, MN, AF, NA, SA, AS, AU, and NZ; on siliceous rocks |
| *Porpidia macrocarpa* (DC.) Hertel & A.J. Schwab<br>(NBM: *TH 372-Y*) | GP | MI | Rock | In EU, MN, NA, CA, SA, AS, AF, AU, and NZ; on siliceous rocks |
| *Punctelia rudecta* (Ach.) Krog<br>(HCOA: *TH 360*) | GP | MA | Rock | Widespread in temperate regions, including E NA, Mexico, Argentina, eastern AS, S AF; common in NE; on trees, wood, and rock |

Appendix. Continued.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Ramalina intermedia* (Delise *ex* Nyl.) Nyl.<br>(HCOA: *TH 250-2*, *TH 310-2*) | GP | MA | Rock | Boreal and temperate NA, Russia; fairly common in NE; mainly on siliceous cliffs and boulders, less often on bark |
| *Rhizocarpon cinereovirens* (Müll. Arg.) Vain.<br>(NBM: *LB CM 14 009-1*) | GP | MI | Rock | Common in E and S boreal regions including N and C EU and NA; on siliceous rocks and metal-rich mine spoil |
| *Rhizocarpon grande* (Flörke *ex* Flot.) Arnold<br>(NBM: *TH 292-1*, *TH 467-1*) | GP | MI | Rock | Widespread in boreal, temperate regions; on siliceous rock in open habitats |
| *Rhizocarpon infernulum* (Nyl.) Lynge<br>(NBM: *LB CM 14 009-2*) | GP | MI | Rock | Known from EU, Russia, Greenland, NA, and Falkland Islands; on siliceous and metal-rich rocks |
| *Rhizocarpon lecanorinum* Anders<br>(NBM: *TH 428*, *TH 466*) | WR GP | MI | Rock | Pan-temperate in N Hemisphere; on siliceous rocks in open habitats |
| *Rhizocarpon reductum* Th. Fr.<br>(NBM: *TH 226-X*, *TH 241-X*, *TH 259-3*, *TH 290*, *TH 292-2*, *TH 309-3*, *TH 320-X-2*, *TH 323-X-3*, *TH 340*, *TH 357-1*, *TH 372-X*, *TH 391-3*, *TH 398-5*, *TH 399-1*, *TH 433*, *TH 438-3*, *LB CM 14 013*, *LB CM 14 014-2*, *LB CM 16 019*, *LB CM 21 035-1*) | WR GP | MI | Rock | Cosmopolitan; common in NE; on siliceous rock |

Appendix. Continued.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Rhizocarpon rubescens* Th. Fr. (NBM: *TH 339-2*, *TH 357-2*, *TH 438-2*, *TH 458*, *LB CM 14 009-3*, *LB 14 014-1*, *LB CM 16 020-1*, *LB CM 19 030*) | WR GP | MI | Rock | Temperate to southern boreal in E NA and NW EU; on siliceous rock in open or shaded habitats |
| *Rinodina gennarii* Bagl. (NBM: *TH 220-1*) | GP | MI | Rock | Widespread in N and S Hemispheres, especially in coastal regions; on nutrient-enriched siliceous rocks, mortar, concrete, etc., particularly in disturbed sites; sometimes on rusting iron |
| *Scoliciosporum umbrinum* (Ach.) Arnold (NBM: *TH 289-1*, *TH 309-1*, *TH 323-X-1*, *TH 337-2*, *TH 339-1*, *TH 352*, *TH 365-X-3*, *TH 378*, *TH 391-5*, *TH 420-2*, *TH 423-2*, *LB CM 16 023*, *LB CM 17 029-2*) | WR GP | MI | Rock | Cosmopolitan; on siliceous rocks, memorials, metal-rich rocks; uncommon on other substrata |
| *Stereocaulon dactylophyllum* Flörke (NBM: *TH 228*, *TH 375-X*, *TH 436*, *TH 444*) | WR GP | MA | Rock | Discontinuously circumpolar in temperate and boreal regions; fairly common in Maine, N.H., Vt., and Mass.; on siliceous and metal-rich rocks |

Appendix. Continued.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Stereocaulon pileatum* Ach.<br>(NBM: *TH 253*, *TH 306*, *TH 397*, *TH 409*, *TH 412*, *TH 419*, *TH 442*, *TH 456*, *TH 459*) | WR GP | MA | Rock | Discontinuously circumpolar in temperate and boreal regions, also in montane subtropics; fairly common in Maine, N.H., Vt., Mass., and NW Conn.; on siliceous rocks, basalt, mine spoil heaps |
| *Stereocaulon saxatile* H. Magn.<br>(NBM: *TH 298*, *TH 374*) | GP | MA | Rock | Arctic to N temperate in N Hemisphere; common in NE except R.I.; on siliceous rock and gravelly soil |
| *Stereocaulon tomentosum* Fr.<br>(NBM: *TH 230*, *LB CM 14 011*) | GP | MA | Soil | Circumpolar arctic, boreal, and N temperate in N Hemisphere; common in N NE, uncommon in S NE; on gravelly soil or soil over rock in open habitats |
| *Stigmidium* sp.<br>(NBM: *TH 283-2*) | GP | + | Rock | Distribution unknown; lichenicolous on *Lecanora polytropa* |
| *Trapelia placodioides* Coppins & P. James<br>(NBM: *TH 394*) | GP | MI | Rock | In EU, Azores, NA, and AS; common in NE NA, rare elsewhere; on siliceous rocks and mine spoil heaps |
| *Trapeliopsis granulosa* (Hoffm.) Lumbsch<br>(NBM: *TH 432*, *TH 437*) | WR GP | MI | Soil | Cosmopolitan; widespread across NA; on peaty soil and compact organic detritus, rotting wood, recently charred wood |

Appendix. Continued.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Verrucaria muralis* Ach.<br>(NBM: *TH 287*, *TH 301*, *TH 320-Y-2*, *LB CM 16 016*, *LB CM 17 027*) | GP | MI | Rock | Widespread in EU, MN, NA–SA, AS, AF, AU, and NZ; on limestone, mortar, brick, pebbles, limestone soil, and sometimes on siliceous rocks, mostly in disturbed habitats |
| *Xanthoparmelia conspersa* (Ehrh. *ex* Ach.) Hale<br>(HCOA: *TH 257*, *TH 271*, *TH 366*) | GP | MA | Rock | Temperate NA, SA, EU, Japan, and montane tropical areas; common in NE; on siliceous, sometimes slightly nutrient-enriched rocks |
| *Xanthoparmelia cumberlandia* (Gyeln.) Hale<br>(HCOA: *TH 225*, *TH 252*, *TH 256*, *TH 264*, *TH 270*, *TH 299*, *TH 314*, *TH 319*, *TH 354*, *TH 344*, *TH 449*) | WR GP | MA | Rock | Temperate NA, SA, S AF; common in NE; on siliceous rock |
| *Xanthoparmelia plittii* (Gyeln.) Hale<br>(HCOA: *TH 327*, *TH 369*) | GP | MA | Rock | Temperate NA, SA, S AF; fairly common in NE; on siliceous rock |
| *Xanthoparmelia viriduloumbrina* (Gyeln.) Lendemer<br>(HCOA: *TH 264-2*, *TH 344-2*) | GP | MA | Rock | Temperate E NA; common in NE; on siliceous rock |
| *Xanthoria elegans* (Link) Th. Fr.<br>(HCOA: *TH 454*, *TH 302*, *TH 353*, *LB CM 031*) | WR GP | MA | Rock | Widespread in N Hemisphere and parts of S Hemisphere, extending far into Arctic and Antarctic; common in NE except R.I.; on inland calcareous rocks and coastal siliceous rocks, including bird nesting rocks; also on man-made substrates like concrete |

Appendix. Continued.

| Species | Site | Nature | Substrate | Range/Frequency/Substrate Ecology |
|---|---|---|---|---|
| *Xanthoria parietina* (L.) Th. Fr. (HCOA: *TH 236*, *TH 237*, *TH 243*, *TH 274*, *TH 280*, *TH 294*, *TH 329*, *LB CM 032*) | GP | MA | Rock | Cosmopolitan; in NA mainly along Atlantic and Pacific coasts and Gulf of Mexico, but also extending inland; common in coastal Maine, N.H., Mass., R.I., and Conn.; on siliceous and calcareous rocks, nutrient-enriched tree trunks and branches and other substrata such as fence posts, roof tiles, and old bones |