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The recovery of a simplified lichen community near the Palmerton Zinc Smelter after 34 years

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Abstract: In a landmark study in 1972, Thomas H. Nash III surveyed the lichen communities in the vicinity of the Lehigh Gap, Pennsylvania immediately downwind of a large-scale operating zinc smelter in the city of Palmerton, Pennsylvania and compared them to those of a relatively unpolluted site approximately 30 miles away in the Delaware Water Gap. He found that the lichen cover and diversity were considerably lower in the highly contaminated sites of the Lehigh Gap, and concluded that lichen diversity and abundance had been severely negatively impacted by the air pollution emanating from the zinc smelter there. In 2006, we repeated Nash's study of lichens in the Lehigh Gap using the same methodology in order to see what changes had occurred in the intervening 34 years with cessation of zinc smelting in 1980. We found increased lichen cover and species diversity in comparing the data from 1972 and 2006. In total across all transects, lichen cover on rocks and soils went from 7.6 m^2 to 22 m^2 (296% increase) and in corticolous lichens, the cover went from 0.60 m^2 to 1.4 m^2 (229% increase). Species diversities (as measured by the Shannon-Wiener diversity index) increased concurrently. The average diversity of transects through rocks and soils at the Lehigh Gap increased from 0.32 to 2.7 (859%), and average corticolous lichen diversity increased from .42 to 1.5 (348%) We conclude that the lichen community is recovering on the basis of increased lichen diversity and lichen cover.

Keywords: ecology, lichen communities, Pennsylvania, zinc smelter

Introduction

NASH (1972) was the first lichenologist to report on the lichens growing in the vicinity of the Lehigh Gap, in central-eastern Pennsylvania. His study focused on the impact of a zinc smelter, in the town of Palmerton, on the surrounding lichen communities in the mountains adjacent to the smelter properties. Not surprisingly, his study showed that the lichen communities suffered significant negative impact from the operation of the smelter that contaminated the area with high levels of zinc, cadmium and lead. At the time of Nash's study there were fewer than a dozen species of lichens growing within roughly one kilometer of Lehigh Gap, and none of the species he found had extensive cover. Nash also reported a conspicuous absence of corticolous foliose or fruticose lichens. Smelting operations in Palmerton did not end until 1980, so there were eight additional years of heavy metal accumulation following his study.

We were curious how the lichen communities in Lehigh Gap had changed in the decades following the closure of the smelter so we decided to relocate the original transects and repeat Nash's study. Upon visiting the area of the Lehigh Gap for the first time we were immediately confronted by a rocky landscape nearly devoid of trees and shrubs (Fig. 1). We were daunted by what appeared, at first, to be a lack of lichens, despite a considerable amount of substrate that had been made available by the absence of nearly all vascular plants. Closer inspection however, revealed that in fact lichens were thriving in some parts of the Gap where they had previously been absent. Stimulated by the discovery of a small population of the zinc tolerant (BUCK et al., 1999) *Vezdaea leprosa* (a species that we later found to be quite common) we began our study, the results of which are reported here.

Study site

Palmerton, in Carbon County, Pennsylvania, is situated just north of Blue Mountain, the southernmost ridge in the Appalachian Ridge and Valley Province. The ridge rises 1500 ft (457 m) above sea level, and the valley sits at approximately 400 ft. (192 m). At the Lehigh Gap in Palmerton, the Lehigh River cuts almost perpendicularly through the ridge. The bedrock in these mountains is Silurian Shawangunk conglomerate (WIDMER 1964), and the ridgetop soils that overlay this material are Dekalb very stony loams. (FISHER et al. 1962). On the north side of the mountain, Laidig very stony loams overlie sandstone, shale and conglomerate glacial till (FISHER et al. 1962). Soil classified as very stony lands lie on the mountainsides facing the Lehigh River. Emissions from the east and west smelters have significantly influenced the properties of all of these soils. The pH of the upper layers in these soils is uncharacteristically high, perhaps because of deposition of zinc oxide (BUCHAUER 1973). The topmost soil (the organic horizon, or litter layer) also had high levels of Pb, Zn, Cd, and Cu several years after atmospheric deposition of these materials had ceased (STORM et al. 1994). The organic horizons in the soils close to the smelters show decreased rates of respiration compared with those farther away (STROJAN 1978b).

Blue Mountain was originally classified as part of the Oak-Chestnut forest region (BRAUN 1950). Logging, fires, and the chestnut blight have altered this community significantly, and now there is a mixed forest of chestnut oak (*Quercus prinus* L.), red oak (*Quercus rubra* L.), red maple (*Acer rubrum* L.), sweet birch (*Betula lenta* L.), sour gum (*Nyssa sylvatica* Marsh.), sassafras (*Sassafras albidum* Nees), eastern hemlock (*Tsuga canadensis* Carrière), and eastern white pine (*Pinus strobus* L.) (JORDAN 1975). At the Lehigh Gap, these communities have been significantly modified by heavy air pollution.

Fig. 1. Study site on the north-facing slopes of the west side of the Lehigh Gap (left; photo taken in 2006) compared to Nash's original control site on the north-facing slopes of Mount Minsi, west side of the Delaware Water Gap (right, photo taken in 2006).

After coal was discovered in the nearby town of Mauch Chunk (now called Jim Thorpe) in 1791, canals were built to carry the coal downriver to Philadelphia. During the Civil War, railroads were also built through the area. This increase in accessibility made the area more amenable to industry and in 1898, the New Jersey Zinc Company began its operation at the Gap and established the City of Palmerton (WALTZ 1923). The company initially only used franklinite and willemite ores, which contained no sulfur or trace heavy metals (Jordan 1975). However, after 1915, sulfide ores were also roasted, and these released cadmium, lead and copper in oxide form, as well as sulfur dioxide into the air. During this period, in the immediate vicinity of Palmerton, much vegetation was killed; a sequence of United States Department of Agriculture aerial photographs taken in 1938, 1947, 1959, and 1964 show increasing vegetation damage and erosion (JORDAN 1975). This damage is most likely attributable to the emissions from the smelters (NASH 1975; JORDAN 1975). Further, actinomycetes, bacteria, and fungi in the soil suffered severe population declines (JORDAN & LECHEVALIER 1975) to such a degree that dead tree trunks remained on the mountainside undecomposed. Since the area was placed on the National Priority List by the Environmental Protection Agency in 1983, there have been various revegetation efforts (EPA 2006, SOPPER 1989) and natural revegetation of some portions of the mountain by *Arenaria patula*, *Nyssa sylvatica*, and *Sassafras albidum* has occurred (BUCHAUER 1973).

In light of the time that has elapsed since Nash originally conducted his survey and the change in vegetation that has occurred during this period (LATHAM et al. 1997), we decided to assess whether the lichen communities in the Lehigh Gap had also undergone changes. Since lichen growth was being suppressed by operation of the smelters (NASH 1975), any recovery that did occur would have begun after 1980, when the smelting operations ceased.

Materials and methods

Our survey was conducted in the spring (May and June) of 2006. We attempted to relocate Nash's original transects however, their exact location (latitude/longitude or UTM) was not available. Using published (NASH 1972) and unpublished data (T.H. Nash, pers. comm. 2006) we established transects in approximately the same location as the original study (Fig. 2). The latitude and longitude of the starting point and ending point of each transect is included below; the location of each point on each transect is not provided here, however, it is available from the senior author (NMH).

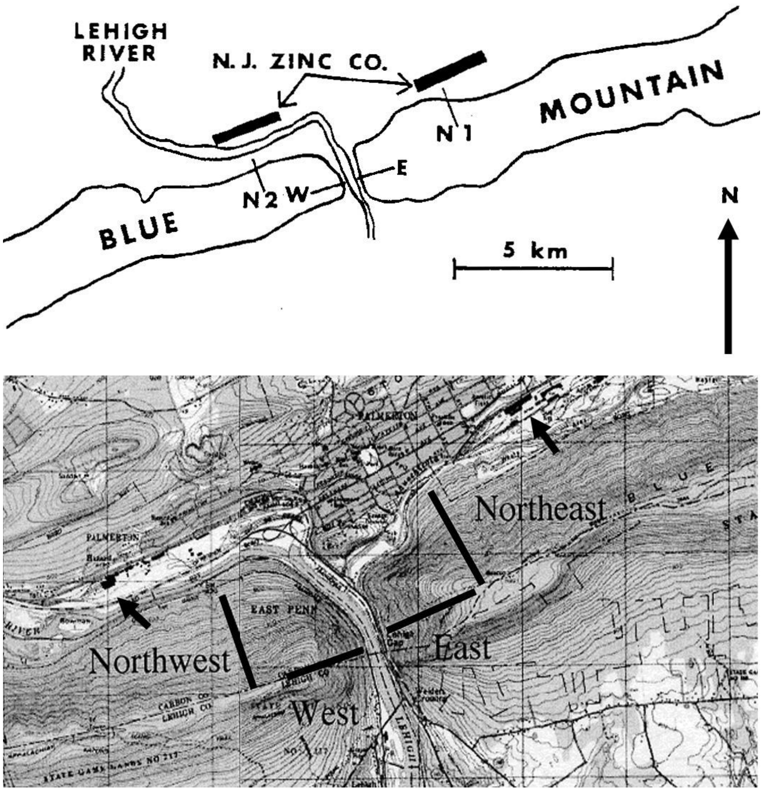

Fig. 2. Above, original map of the locations of transects at Lehigh Gap reproduced from Nash (1972). Below, locations of transects established in the present study overlain on a topographic map of the region (note arrows indicate the location of the zinc smelters and one grid square = 1 sq. kilometer).

As in the original study, we established four transects on the slopes of the mountains surrounding the Gap. One transect starts at the east side of the river where it passes through the gap, (40°47’23.8” N, 75°36’30.6” W) and goes to the top of the mountain (40°47'37.4" N, 75°35'57.5" W). Another transect mirrors this one on the west side of the river (40°47'15.7" N, 75°36'37.1" W to 40°47'11.3" N, 75°37'04.7" W). The two other transects go up the north sides of the mountain, one to the east of the river (40°47'58.6" N, 75°36'11.9" W to 40°47'35.9" N, 75°35'57.8" W) and one to the west (40°47'28.8" N, 75°37'44.8" W to 40°47'04.0" N, 75°37'36.9" W). Both transects on the northern sides of the mountains were approximately 1 km from the gap itself. These transects are referred to as East, West, Northeast, and Northwest, respectively (Fig. 2).

Each transect includes 10 points ~35 m (100 ft) in elevation apart (~200 steps, or 140 meters along the ground). At each point, the coordinates were determined using a GPS, and 20 contiguous 1 $meter^2$ ground quadrats were established on either the right or left side (randomly chosen) of the baseline and perpendicular to it. In each quadrat, cover for each lichen was recorded. Where living trees greater than 10 cm dbh were present, eight quadrats were established on the four trees closest to the transect point. These trees were chosen using the point centered-quarter method (Cottam & Curtis 1956). On each tree eight 10 x 50 cm quadrats were established: one in each direction (N, S, E, and W), at breast height (1.3 m off the ground) and at the base of the tree (0.2 m off the ground). Within these tree quadrats, the percent cover of each lichen species was recorded. Although our sampling method was the same as that used by NASH (1972), more trees had grown in the area since his study, so our sample included more trees. In 1975, the most frequently occurring tree in the plots was *Quercus rubra*, *Sassafrass albidum*, *Nyssa sylvatica*, *Quercus prinus*, and *Betula lenta* were other common trees. These species represented the majority of the trees in our corticolous samples also, with the addition of *Acer rubrum*. Since tree age can influence the suitability of bark as lichen habitat, we took measurements of the diameter at breast height of the trees we sampled. NASH (1975) found most lichen species and cover occurred on trees between 10 and 34 cm in diameter, and our trees were also in this range. The fact that our tree community was similar to that present in 1972 suggests that changes we found in the corticolous community were more directly attributable to cessation of the smelting operations than to changes in substrate availability.

From these data, a table was constructed to show the cover and frequency for each species in each transect. The original values from NASH (1972) are reproduced in the same table for comparison. Species diversity for each transect was calculated using the Shannon-Weiner Diversity Index (MACARTHUR & MACARTHUR 1961). This index is often calculated using the formula $\sum p_i{*}{-}\log_2(p_i)$. In this equation p_i is the proportion of the i^{th} species (the total cover of that species in that transect, divided by the total cover of all lichens in that transect). The $p_i{*}{-}\log_2(p_i)$ values for each species are then all added together to get the diversity index for that transect.

In order to ascertain if the lichen diversity observed in the experimental framework of our study was representative of the overall diversity of the site the second author also conducted a survey of the lichen biota outside of the transects (this data is presented in Appendix I.). Voucher specimens from this survey have been deposited in the herbarium of The Academy of Natural Sciences of Philadelphia (PH). Lichen nomenclature throughout the present work essentially follows ESSLINGER (2006), however any deviations reflect the views of the second author.

The first author (NMH) identified the species in each quadrat after studying the voucher specimens collected by the second author as well as numerous representative specimens in the herbarium of The Academy of Natural Sciences of Philadelphia (PH). While the majority of species could be identified with confidence in the field several groups of morphologically similar taxa were lumped together for the purposes of our quantitative study as follows: 1) all *Cladonia* thalli without podetia were treated collectively as "*Cladonia* spp."; 2) *Lepraria caesioalba* (de Lesd.) J.R. Laundon and *L. neglecta* (Nyl.) Erichs. were treated as a single taxon 3) all *Placynthiella* thalli were treated a single taxon due to their frequent sterility; and 4) all *Verrucaria* with endolithic thalli were treated collectively as "*Verrucaria spp.*" while *Verrucaria* species with epilithic thalli were treated as "*V. nigrescens*".

Results and discussion

The primary conclusion of Nash's original study at the Lehigh Gap (NASH 1972) was that the lichen communities of the site had become "simplified". Nash considered a simplified community structure to be relative, and in the case of the Lehigh Gap he compared it to the lichen community of an ecologically similar unpolluted sited at the Delaware Water Gap in northeastern Pennsylvania. He characterized the simplified community at the Lehigh Gap as one where there was only one dominant species (cover greater than 50 cm^2/m^2 on at least one slope), one species of intermediate importance (cover from 5-50 cm^2/m^2) and three subordinate species (cover less than 5 cm^2/m^2). This was in marked contrast to the Delaware Water Gap where the community consisted of five dominant species, 20 species of intermediate importance, and 39 subordinate species.

Our data (Tab. 1) indicated the present lichen community at the Lehigh Gap represents intermediate values between those found in Nash's original study. At present there are five dominant species, 11 species of intermediate importance, and 32 subordinate species. This marked increase is reflected in the species diversity values at the Lehigh Gap, in 2006 as compared to 1972 (Table 2). However, the diversity, particularly of corticolous lichens, is still far below the levels that Nash found at the control site in the Delaware Water Gap in 1972. Many of the genera from the Delaware Water Gap in 1972 are still absent from the Lehigh Gap, including *Umbilicaria, Usnocetraria* (i.e., *Allocetraria oakesiana*)*, Dimelaena, Lasallia,* and *Myelochroa*.

Of the ten genera represented in Nash's survey at the Lehigh Gap, all of them were present in our re-survey. Some species were not re-found; *Micarea peliocarpa* was Nash's most prominent lichen, but was absent from our survey. However our most common lichen was *Leimonis erratica* (= *Micarea erratica*). Comparison of the voucher specimens would clarify whether this is the same lichen.

Some lichens not present in either place, the Delaware Water Gap, or the Lehigh Gap, in 1972, appeared in our survey. *Stereocaulon saxatile* and *Vezdaea leprosa* both may have colonized the study area since the 1970s (or *V. leprosa* may have been overlooked because it is so inconspicuous).

Tab. 1. Frequency and cover data for lichens from Lehigh Gap in 1972 compared with 2006. (F) indicates frequency, the number of points out of 10 at which each species occurred on a transect. (C) is cover in cm^2 lichen / m^2 substrate. Species represented here with 0.0 cover were present in the transects, with cover of less than 0.05 cm^2 / m^2.

Species	Slope															
	East								West							
	Rocks, Soil				Trees				Rocks, Soil				Trees			
	1972		2006		1972		2006		1972		2006		1972		2006	
	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C
Acarospora fuscata	3	4.5	5	1.9					4	5.5	6	0.67				
Aspicilia cinerea									1	0.5						
Aspicilia laevata																
Candeleriella cf. *efflorescens*							1	0.0			1	0.6			3	2.9
Cladonia cristatella			2	5.2							2	1.6				
Cladonia grayi			4	20.8							3	2.2			1	1.2
Cladonia macilenta			5	21.7							4	3.6				
Cladonia ochrochlora											3	3.5			1	1.2
Cladonia polycarpoides			2	14.0							1	0.3				
Cladonia rei			1	3.0							1	0.0			1	0.2
Cladonia spp.			9	166.3			5	12.5			10	53.9	1	0.2	6	53.1
Flavoparmelia baltimorensis											1	0.0				
Flaoparmelia caperata							2	3.1			1	0.0			1	0.5
Flavopunctelia soredica							3	1.9			1	0.0				
Hypocenomyce anthracophila																
Hypocenomyce scalaris							1	0.2					2	4.0		
Lecanora sp.																
Lecanora strobilina							3	0.5								
Lecidea tessellata			2	0.5							1	0.1				
Leimonis erratica			9	69.9							7	113				
Lepraria caesiella																
Lepraria caesioalba/neglecta			2	0.0							2	0.2				
Lepraria incana													1	0.2		
Lepraria lobificans			2	3.1							2	3.8			3	10.3
Micarea peliocarpa	5	76.5							10	84.0						
Parmelia sulcata							5	9.3			2	0.6			3	1.7
Parmotrema hypotropum							1	0.2			1	0.0			2	0.5
Phaeophyscia hirsuta							1	0.0								
Physcia millegrana			3	0.6			8	75.1			3	2.1			6	124
Placynthiella spp.			2	0.8							3	5.1				
Polysporina simplex											1	1.8				
Porpidia albocaerulescens																
Porpidia crustulata			5	0.2							3	0.6				
Porpidia soredizodes																
Porpidia subsimplex																
Psilolechia lucida																
Punctelia rudecta							3	0.5			1	0.1			3	1.08
Punctelia caseana																
Rhizocarpon reductum			4	0.3							2	1.3				
Rhizocarpon rubescens																
Scoliciosporum chlorococcum					8	54.9							7	53.3		

Tab. 1 (continued)

Species	Slope															
	East								West							
	Rock, Soil				Trees				Rock, Soil				Trees			
	1972		2006		1972		2006		1972		2006		1972		2006	
	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C
Scoliciosporum umbrinum			8	9.0							8	12.2				
Stereocaulon saxatile																
sterile crust 01							2	0.6							2	1.06
sterile crust 02													2	5.8		
Trapelia glebulosa			6	8.4							7	3.4				
Trapelia placodioides																
Trapeliopsis flexuosa																
Trapeliopsis granulosa																
Verrucaria spp.			2	1.0												
Verrucaria nigrescens																
Vezdaea leprosa											1	0.1				
Xanthoparmelia plitii			1	0.0												
Species Total	**2**		**19**		**1**		**12**		**3**		**27**		**5**		**12**	
Total Cover		**81.0**		**327.0**		**109.8**		**103.9**		**90.0**		**214.4**		**127.2**		**207.0**

Tab. 1 (continued)

Species	Slope															
	Northeast								Northwest							
	Rocks, Soil				Trees				Rocks, Soil				Trees			
	1972		2006		1972		2006		1972		2006		1972		2006	
	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C
Acarospora fuscata									1	0.0	5	1.8				
Aspicilia cinerea											3	1.0				
Aspicilia laevata											1	1.2				
Candeleriella cf. *efflorescens*											1	0.0				
Cladonia cristatella			1	0.5							1	0.4				
Cladonia grayi			5	51.9							8	17.1				
Cladonia macilenta			6	25.6							9	37.3				
Cladonia ochrochlora											1	0.0			2	30.9
Cladonia polycarpoides			4	23.6							2	6.9				
Cladonia rei			2	1.0							4	22.4				
Cladonia spp.			8	63.4			1	4.6			9	10.2			5	26.6
Flavoparmelia baltimorensis																
Flavoparmelia caperata							1	1.6			1	0.0			3	1.9
Flavopunctelia soredica																
Hypocenomyce anthracophila											1	0.7				
Hypocenomyce scalaris																
Lecanora sp.															2	7.5
Lecanora strobilina															2	84.4
Lecidea tessellata			3	1.7							1	1.5				
Leimonis erratica			9	90.9					7	189.5	10	62.8				
Lepraria caesiella															2	7.5

Tab. 1 (continued)

	Slope															
	Northeast								Northwest							
	Rocks, Soil				Trees				Rocks, Soil				Trees			
	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C
Lepraria caesioalba/neglecta			1	0.1			1	0.5			1	0.2				
Lepraria incana																
Lepraria lobificans									1	0.5						
Micarea peliocarpa	6	18.0														
Parmelia sulcata							2	1.6			2	0.2			6	15.3
Parmotrema hypotropum															1	1.3
Phaeophyscia hirsuta																
Physcia millegrana							4	58.9			3	0.3			8	262.4
Placynthiella spp.			8	3.1							3	1.3				
Polysporina simplex																
Porpidia albocaerulescens			3	5.6							1	1.2				
Porpidia crustulata			7	2.4							4	9.9				
Porpidia soredizodes																
Porpidia subsimplex											1	0.5				
Psilolechia lucida											2	7.75				
Punctelia rudecta							1	2.2							1	0.7
Punctelia caseana															1	2.5
Rhizocarpon reductum			2	0.6												
Rhizocarpon rubescens											2	0.91				
Scoliciosporum chlorococcum					2	18.1					2	2.7	5	45.3	1	0.1
Scoliciosporum umbrinum			10	36.2							8	50.0				
Stereocaulon saxatile											3	1.8				
sterile crust 01															2	4.4
sterile crust 02					2	5.4							1	0.4		
Trapelia glebulosa			7	8.5							5	9.3				
Trapelia placodioides											2	1				
Trapeliopsis flexuosa											1	1				
Trapeliopsis granulosa											1	1				
Verrucaria spp.	1	0.1							1	1.0	5	6.4				
Verrucaria nigrescens																
Vezdaea leprosa			4	2.5							2	0.1				
Xanthoparmelia plitii																
Species Total	**2**		**16**		**2**		**6**		**4**		**35**		**2**		**13**	
Total Cover		**18.0**		**322.3**		**47.0**		**69.3**		**191.0**		**259.9**		**91.5**		**478.7**

This increase in diversity could be due to several factors. Since zinc smelting no longer occurs at Palmerton, there is less sulfur dioxide and lower concentrations of particulate heavy metals in the air. Zinc was the contaminant that Nash (1975) concluded was severely negatively impacting the lichen community at the Lehigh Gap. In addition, as is discussed below, revegetation projects have helped in establishing grass cover on the mountains; this has provided patches of land where suitable soil is available for species of *Cladonia* to grow. Similarly, in areas where natural revegetation has occurred, roots have helped to stabilize slopes, allowing for the accumulation of organic matter, the retention of rocks, and thus for growth of more lichens.

In 1972, saxicolous lichens dominated the ground lichen communities (86.6% of the lichens in the ground quadrats were saxicolous whereas 9.2% were terricolous and 2.2% were lignicolous. Now, the distribution is somewhat more even: 50% are saxicolous, 42.5% terricolous and 6% lignicolous (the remaining 1.5% are corticolous species that were in the ground quadrat because the slab of bark or branch they had been growing on had fallen into the ground quadrats). The significant increase in terricolous lichens is due in large part to the reemergence of *Cladonia* species. Nash found them growing very thinly, at only one point on the west slope of the Lehigh Gap. However, now they constitute a conspicuous proportion of the lichen biota throughout the site.

The reason these lichens have reestablished is apparently that there is sufficient soil and organic matter available for them to grow on. It is difficult to determine if this organic matter has arisen from the decomposition of tree leaves and aeolian debris, or whether it is part of the soil substitutes (ECOLOAM or compost) that have been added to the mountainsides in efforts to promote revegetation of the slopes. On the northwest slope, compost has been applied by hand to some areas, and by helicopter to others. We assume that the grassy areas on this slope represented revegetation efforts and not natural vegetation recovery. The first four points on the northeast transect were also affected by human-assisted recovery. Remains of the roads that had been cut into the mountainside were evident in the form of leveled terraces, and a vascular plant that had escaped from test plots, thrift (*Armeria maritima* Willd.), was common in the quadrats at the second and third points on this transect. Higher up on this slope, points five and six, was a carpet of ferns between trees. Since ferns were not part of the revegetation efforts as described by SOPPER (1989), this part of the slope likely has undergone natural succession.

There are also many lichens growing on exposed rocks. *Trapelia* species were frequently found on small pebbles where the slope was stabilized enough that these smaller rocks would not slide away. Our informal observations indicated that *Leimonis erratica* tended to grow on larger rocks. In the areas that were most exposed, on the top of the western side of the mountain, and on the bottom of the northeastern face, *L. erratica* grew sparsely and was often confined to fissures in the rocks. This may be because the conditions in the exposed areas were too dry.

The corticolous lichen community experienced a large increase in diversity (Tab. 2) although the values are still below those found at the relatively unpolluted Delaware Water Gap in 1972. Nash noted a stratification of lichens on tree trunks, with Cladonias appearing mostly at the base of trees, and this pattern was still present in our surveys. The tree species we sampled represented a similar community to the one Nash found there, except that by 2006 many young sassafrass trees had sprouted at the site (the diameter requirement for our corticolous lichen surveys precluded our sampling them). NASH (1975) found that oaks harbored the most speciose lichen communities, which was true in our surveys also.

Tab. 2. Species diversities of lichens at the Lehigh Gap (LG) and the Delaware Water Gap (DG) in 1972 (NASH 1972) compared with species diversities in 2006, calculated using Shannon Wiener diversity index using the cover data by slope for corticolous and ground quadrats.

	Ground Quadrats			Corticolous Quadrats		
Slope	1972-LG	1972-DG	2006-LG	1972-LG	1972-DG	2006-LG
East	0.3089	2.873	2.325	0.0000	2.966	1.396
West	0.3802	3.491	2.104	0.8338	2.754	1.486
Northeast	0.4983	3.727	2.934	0.7806	2.010	0.9183
Northwest	0.07308	3.471	3.469	0.08039	2.136	2.104

The lignicolous lichens have not become reestablished. NASH (1975) noted their conspicuous absence in spite of the large area of available substrate (dead logs) at the Lehigh Gap. This may be because the community of decomposers has been slow to return to the area. That community might also be more sensitive to the residual heavy metals remaining on/in ligneous substrates. It is also possible that these substrates are too dry. They have been subjected mostly to physical weathering rather than the chemical decomposition that creates humus, which has a high water holding capacity.

NASH (1972) described little change in lichen species composition across the altitudinal gradient of his transects. We did not find this to be the case. At low elevations, there was less cover, fewer species were found, and thalli were more often sterile or had deformed apothecia. On some transects, in particular the northwestern and eastern ones, there was a considerable spike in number of species found towards the top of the mountain. However, at the very top, there was a considerable decrease in lichen species found. There were also drastic differences in lichen diversity due only to microhabitat that far exceeded the differences seen in elevation. For example, many plots were carpeted with an understory of vascular plants and little light was able to penetrate to the ground surface below. Consequently, points along the transect where quadrats ran through such habitats were disproportionately depauperate of lichens.

In 1972, the first identifiable fruticose lichen (*Cladonia bacillaris*) in the Palmerton area was found 3 km to the west and 9 km to the east of Lehigh Gap. Now, the same species (but a different variety) is now growing within the study area. Similarly, at that time the first foliose lichens (*Umbilicaria muhlenbergii* and *Xanthoparmelia conspersa*) were found 4.5 km to the west and 11 km to the east but now a lichen in the same foliose genus (*Xanthoparmelia*) is found in the plots. These represent a few of the several foliose and fruticose lichens now occurring within ~1 km of Lehigh Gap, well within the area covered by Nash's original transects. We found foliose and fruticose lichens now constitute 23% and 33%, respectively, of the cover in the transects (crustose lichens made up 44% of the cover). In several studies reviewed by GARTY (2001), foliose lichens accumulated more airborne heavy metals than fruticose or crustose lichens did. Garty also pointed out that most heavy metals in lichen thalli are of atmospheric origin. This may account for the suppression of foliose lichen populations while smelting still occurred, but would presumably not be impacting the communities today.

Most (58%) of the species found during out study are sorediate and thus reproduce primarily through lichenized diaspores. Further, sorediate lichens represent the majority (92%) of the lichen cover at the site. The success of asexually reproducing species in the heavy metal contaminated site we studied is not unique to lichens. SMITH et al. (1997) discovered that in early stages of succession of the vascular plant community, asexually reproducing trees including *Sassafras albidum* were also the most successful. It should be noted that when apothecia were present on thalli of typically sexually reproducing species at the Lehigh Gap, they were often sterile, or deformed. We suspect that the residual heavy metals in the soil may interfere with the production and development of apothecia (and functional ascospores). In England, HAWKSWORTH & MCMANUS (1989) found that when sulfur dioxide concentrations rapidly fell, pollution sensitive species often had more, or more easily dispersed, propagules than pollution tolerant species, and were able to reestablish themselves on formerly polluted sites more quickly. This trend might not be exhibited at Palmerton because the presence of heavy metals has deterred the establishment of sensitive species.

Since 35 lichen species were present in our survey of the Lehigh Gap (excluding specimens identified only to genus and sterile crusts) while Nash in 1972 found only 8 species were present, the recovery rate of 27 additional species over 26 years (since the smelter shut down in 1980) appears to be approximately one species per year. It would be interesting to be able to provide a valuable recovery rate to aid in contaminated ecosystem management, however, it is often not possible to make generalizations from site-specific information, especially with lichens, which are so micro-habitat specific. It is additionally difficult to make comparisons as so few studies are available that investigate lichen communities changes over a 34-year time scale as ours does. Just as lichen community development is highly dependent on climatic conditions, the vascular community, and the substrate, recovery rates after disturbance are also highly variable depending on site conditions as well as disturbance type and degree. So, recovery processes occurring for lichen communities in areas where the disturbance did not leave a legacy of pollution may not be operating at the Lehigh Gap, and to expect the Lehigh Gap to return to conditions similar to those of the Delaware Water Gap may be unrealistic. Other sites with similar disturbance legacies include the area around a nickel smelter in Sudbury, Ontario (FREEDMAN & HUTCHINSON 1980), a smelter near Copperhill, Tennessee, (KOZLOWSKI 1985), and an iron-sintering plant in Wawa, Ontario (RAO & LEBLANC 1967). It would be interesting to compare lichen community recoveries at these sites with our results from Palmerton to discern patterns in species distributions, dispersal types, or to see whether certain species or genera tend to recover faster.

Conclusions

When NASH (1972) studied the simplification of the lichen communities in the vicinity of Lehigh Gap he found fewer than a dozen lichen species within ~1 km of the Gap. Our re-survey of the same site just over three decades later (and twenty years after the smelters were shut down in 1980) found thirty-eight taxa, a more than three-fold increase in diversity. While the vascular flora is still compromised in areas that have not been addressed by revegetation projects (Sopper 1989), the lichen flora of the Lehigh Gap is clearly in the initial stages of succession. This is indicated by the presence of "pioneer" species such as *Lei-*

monis erratica and members of the genera *Cladonia* and *Trapelia*. These lichens are among the first lichens to colonize recently disturbed areas in eastern North America (BRODO 1969). The changes in the lichen biota were likely unnoticed by anyone previously conducting ecological studies at the Lehigh Gap following the closure of the smelter as many of the species are small and relatively inconspicuous. The increase in species level diversity coupled with a marked increase in total cover directly contradicts the notion that the area of the Lehigh Gap impacted by the activity of the smelter has remained unchanged due to persistent effects of zinc, cadmium, and lead contamination. Many of the changes in the vascular flora can be attributed to the major restoration projects undertaken at this site; trees and grasses have been planted and soil amendments have been added. Since there have been no directed efforts at re-establishing lichens at the site, it seems more straighforward to consider their recovery a 'natural' process. However, the recovery has surely been influenced by the increased availablity of soil as a growth medium for terricolous lichens and of trees as a substrate for corticolous lichens. This might help explain why the Northwest slope, the least diverse transect at the site in 1972, now exhibits higher lichen diversity than other areas at the Lehigh Gap. These changes, whether through forest succession or superfund cleanup projects, have changed the site conditions, making it more hospitable for lichens. It has been speculated that severely damaged sites, with no vegetation, and no soil, have undergone such significant changes in soil chemistry and microhabitat that recovery of the site is simply precluded (AMIRO & COURTIN 1981). Our study suggests that this is not necessarily the case, though recovery is certainly quicker and more thorough when some vegetation or soil remains.

Suggestions for Further Research: It would be very interesting to repeat this study again in the future. This would reveal whether the lichen community stalls in the present early successional stage because its progression is retarded by the presence of heavy metals or whether it proceeds through the normal stages of succession. If the latter were the case, corticolous lichen cover and diversity will likely increase as woody vegetation becomes reestablished. Additionally an increase in vascular plants would have resulted in more shade on mountainside, which would likely result in a decrease in the cover of the lichens growing on exposed rocks and soil.

High levels of heavy metals remained in the soil, leaf litter, amphibians, and mammals at the Palmerton site six years after the smelters had shut down (STORM et al. 1994) and high concentrations of metal contaminants are likely to remain in the soil for many centuries (STROJAN 1978a) to come. In assessing the impacts of the residual contaminants on the ecosystem, it might be useful to determine whether contaminant levels in the flora and fauna of the Lehigh Gap have changed since these studies were undertaken. It would also be valuable to investigate the lichen community on an east-west transect across the north face of the mountain; previous studies have found that the diversity of arthropods (STROJAN 1978a), vertebrates (BEYER et al. 1985) and survival of woodlice (*Porcellio scaber* Latreille) in the soil (BEYER et al. 1985) all increase with increasing distance from the smelters. Other smelter-affected sites have been studied by aerial photographs and chemical testing of the soil to more thoroughly study the gradient of impact, from the area just downwind of the smelter to the intact forest several miles away (GORDON & GORHAM 1963). If such studies were performed at the Lehigh Gap and repeated, the extent and rates of recovery could be more thoroughly quantified.

To investigate the continuing effect of heavy metals on lichens, it would be interesting to evaluate the heavy metal content in thalli of lichens and their substrates sampled from various sites in the study area. BUCHAEUR (1973) reported concentrations of 135,000 ppm zinc and 1,750 ppm cadmium in the O horizon of soils at Palmerton; in these most contaminated sites, Nash found no lichens growing. The presence of lichens in these areas from which they were previously excluded by high heavy metal concentrations suggests that the amount of zinc and cadmium present in the soils has decreased to tolerable levels for lichens. Where lichens were present NASH (1975) found concentrations of up to 25,000 ppm zinc and 334 ppm cadmium in their thalli, which represented concentrations equal or up to four times greater than the concentrations in the soil at the same site. It would be interesting to follow up this work with measurements of current heavy metal content of lichens and the bark and soil substrates on which they are growing. It might also be valuable to find out how far from the gap lichen heavy metal content returns to background levels, and to compare lichen community structure to residual presence of heavy metals. This work might further support Nash's conclusion that the main factor influencing the lichen community structure at the Lehigh Gap was the heavy metals, and not the high sulfur dioxide concentrations.

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Appendix I: A checklist of the lichens occurring in the Lehigh Gap is provided below, arranged alphabetically by genus and species with unidentified sterile crusts at the end of the list. The collection numbers are those of the first author (JCL) and voucher specimens of all collections are deposited in the herbarium of the first author which is presently housed at the Academy of Natural Sciences of Philadelphia (PH).

Acarospora fuscata (Ach.) Arnold – *6785.*
Candelaria concolor (Dicks.) Stein – *6780.*
Candelariella cf. *efflorescens* R.C. Harris & Buck – *6776* (sterile).
Cladonia macilenta Hoffm. var. *macilenta – 6760.*
Cladonia ochrochlora. Flörke – *6775.*
Cladonia polycarpoides G. Merr. – *6759.*
Dibaeis baeomyces (L.) Rambold & Hertel – *6777.*
Flavoparmelia caperata (L.) Hale – *6786.*
Flavopunctelia soredica (Nyl.) Hale – *6787.*
Hypocenomyce scalaris (Ach.) M. Choisy – *6788.*
Lecanora sp. – *6766, 6772.*
Lecanora polytropa (Hoffm.) Rabenh. – *6765.*
Lecidela tessellata Flörke – *6790*.
Leimonis erratica (Körb.) R.C. Harris & Lendemer – *5920.*
Lepraria caesiella R.C. Harris – *6764* (corticolous), *6761* (saxicolous).
Parmelia sulcata Taylor – *6767.*
Parmotrema hypotropum (Nyl.) Hale – *6755.*
Phaeocalicium polyporaeum (Nyl.) Tibell – *6791.*
Physcia adscendens (Th. Fr.) H. Olivier – *6778.*
Physcia millegrana Degel. – 6768.
Physcia stellaris (L.) Nyl. – 6779.
Porpidia albocaerulescens (Wulfen) Hertel & Knoph – 6789.
Porpidia crustulata (Ach.) Hertel & Knoph – 6774.
Porpidia soredizodes (Lamy ex Nyl.) J.R. Laundon - *6758.*
Porpidia subsimplex (J. Lowe) Fryday – 6783.
Psilolechia lucida (Ach.) M. Choisy – 6784.
Punctelia caseana Lendemer & Hodkinson ined. – 6771.
Rhizocarpon rubescens Th. Fr. – *6763.*
Sarcogyne similis H. Magn. – *6770.*
Scoliciosporum chlorococcum (Graewe ex Stenh.) Vězda – *6773.*
Scoliciosporum umbrinum (Ach.) Arnold – *5921.*
Stereocaulon saxatile H. Magn. – *6757.*
Trapelia involuta (Taylor) Hertel et al. – *6782.*
Trapelia placodioides Coppins & P. James – *6781.*
Trapeliopsis granulosa (Hoffm.) Lumbsch – *6769.*
Vezdaea leprosa (P. James) Vězda – *5918.*
Sterile sorediate crust 1 (atranorin, fatty acid, psoromic acid) – *6762.*
Sterile sorediate crust 3 (no lichen substances) – *6756.*