Elemental Analysis of Pohlia nutans Growing on Coal Seeps in Pennsylvania

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Abstract

A distinctive, luxuriant development of Pohlia nutans, a moss widespread in both northern and southern hemispheres, was studied where it grew on three exposed bituminous coal seeps in Clearfield County, Pennsylvania. Elemental analyses of the Pohlia plants were compared with Polytrichum juniperinum and Brachythecium oxycladon, collected from an adjacent roadside habitat. The percent dry weights of N, P, Mg, K, and S were higher in Pohlia compared to those of the two reference species. The concentrations of Fe, Al, Mn and Zn were particularly high in the Pohlia plants. The high mineral content of the Pohlia plants was correlated with the mineral content of the seepage water which had a pH of 2.65-2.75. The extensive Pohlia turfs on the coal seeps are apparently related to the tolerance of Pohlia nutans for the low pH and mineral-rich conditions provided by the seepage sites.

Introduction:

Pohlia nutans (Hedw.) Lindb. is a widespread moss species that typically grows in disturbed habitats, which, although frequent throughout its range, is rarely abundant or luxuriant. Recently the author observed Pohlia nutans forming distinctive and luxuriant turfs, where it was closely associated with, and apparently restricted to, three different seeps that emerged from bituminous coal seams. The coal seams had been exposed as a result of highway construction, nearly twenty years earlier. A survey of the adjacent area failed to reveal Pohlia nutans plants growing away from the seepage sites, while other bryophytes were absent from the seeps. Therefore, the elemental contents of Pohlia nutans from the turfs and two non-seepage species (Brachythecium oxycladon (Brid.) Jaeq. & Sauerb. and Polytrichum juniperinum Hedw.) from an adjacent roadbank were determined and compared to the seepage water in order to ascertain if mineral factors were correlated with the development of the Pohlia turfs.

Recent reviews of the literature demonstrate that mosses effectively absorb minerals from their environment and can therefore be used as indicators of the mineral relationships in various habitats (Longton, 1980; Richardson, 1981, Brown, 1982). Correlations of the mineral content between substrates and mosses growing on those substrates have been recorded for a variety of substrates and mosses. However, these studies do not relate directly to the specific microtopographic and mineral-edaphic situation observed for Pohlia nutans growing on coal seeps. The study that most closely parallels this situation on the coal seeps is Rastorfer (1972), where his descriptions of Pohlia nutans and the mineral analyses of the plants correspond well to this study. Other reports in the literature correlate Pohlia with mineral-rich substrates and peaty situations but do not provide mineral analyses. The present study provides evidence that Pohlia nutans tolerates mineral-rich habitats and can accumulate heavy metals in acid-stressed environments.

Description of Study Sites:

Pohlia nutans was found on two coal seeps at Site 1 and on one coal seep at Site 2 in Clearfield County, Pennsylvania (Figure 1). At Site I two seams of Middle Kittanning coal were exposed as a result of construction of Interstate 80 during 1965. The two seams are separated by a terrace, thus the water flowing from the upper coal seep does not flow across the lower seep (Figure 2). The roadbank at Site 1 faces to the northeast (12^{0} NNE), rising at an angle of 26^{0} from the highway. The coal seeps originate at the interface of the coal and the adjacent sandstone overburden. Both seeps at Site 1 flow continuously throughout the year. Site I is located specifically one-half mile west of Exit 20 (Woodland Exit) of Interstate 80 in Clearfield County, Pennsylvania (78^{0}21'15"W, 41^{0} 1'15"N) at an elevation of 1450 feet.

Site 2 is approximately three-fourths of a mile east of Site 1 along Route 970, approximately 100 yards south of Interstate 80 at Exit 20 (78^{0}20'45"W, 41^{0}1'0"N) at an elevation of 1520 feet. The roadbank consists of a large, exposed rock face that is approximately 24 meters in length from the roadside ditch to the coal seep at the top of the face (Figure 3). The rock face rises at an angle of 29^{0} and is devoid of vascular vegetation and soil. The roadbank faces to the northwest (307^{0} NNW). The coal seep is similar to Site 1 in that water emerges from the ground at the overburden-coal interface and flows throughout the year. The microtopographic and hydrologic features of the sites are therefore similar; however the extent of the Pohlia turfs differ between sites. At Site I the turfs on both seeps are more extensive and thicker than the Pohlia at Site 2 (Figures 2 and 3). At Site 1 the roadcut was nearly perpendicular to the rock and coal beds while at Site 2 the roadcut was more parallel with the beds.

The regional geology is dominated by Pennsylvania Age sedimentary rocks located in the Appalachian Physiographic Province (DER, 1973). The exposed coal seams at both sites are Middle Kittanning coal, part of the Middle Kittanning formation, Allegheny Group, Pennsylvanian Series (DER, 1982) which lies on the northeastern edge of the Appalachian bituminous coal belt. The roadbank vegetation immediately adjacent to the seeps is characterized as grassy-herbaceous cover with scattered tree saplings. The three major tree species on the roadbanks are quaking aspen (Populus tremuloides Michx.), gray birch (Betula populifolia Marsh.) and fire cherry (Prunus pennsylvanica L.f.) with some bristly locust (Robinia hispida L.). Summer herbaceous plants include Aster sp., Solidago sp., Oxalis sp., and grasses (Gramineae).

Nomenclature of mosses follows Crum and Anderson (1981).

Procedures:

Field samples of Pohlia nutans growing on the coal seeps at both sites were collected on May 22, 1983. In addition, collections of bryophytes growing on the roadbank in the vicinity of the Pohlia turfs were made in order to determine the relationship of adjacent bryoflora to the coal seeps. Two collections of Polytrichum juniperinum and one collection of Brachythecium

.oxycladon were used for elemental analyses in comparison with the Pohlia samples. Table I provides a summary of the collection data. Voucher specimens were deposited in the herbarium at The Pennsylvania State University (PAC). One liter samples of the water draining from the Pohlia turfs (coal seeps) were collected and delivered to the Institute for Research on Land and Water Resources, The Pennsylvania State University, for chemical analysis. The water samples were collected immediately below the Pohlia turfs on the upper and lower seeps at Site 1. In addition, a third water sample at Site 1 was collected from the ditch upslope from the Pohlia turf. At Site 2 water samples were collected immediately below the turf and from the ditch at the base of Site 2. The water analyses followed standard procedures for atomic absorption spectrophotometry (EPA, 1979).

The moss samples were taken to the laboratory where all visible contamination was physically removed. Then the current (green) growth was carefully cut from the old (brown) portions of each sample. If sporophytes were present, the sporophytes were severed at the surface of the gametophytic tissue and were removed. Current gametophytic tissue was used for analysis except for one sample of old tissue of Pohlia from Site 2. The old-tissue sample consisted of a 1 cm wide portion of the brown peaty growth, removed from the midsection of the 10 cm thick turf.

The samples were then washed with a mild detergent solution (approximately 2 g of sparkleen laboratory detergent dissolved in 2 1 of tap water). The moss-detergent slurry was stirred vigorously for one minute and then allowed to stand for one minute to permit heavier contaminants to separate from the floating moss samples. The moss tissue was skimmed from the surface, placed in a Buchner funnel with Whatman #41 filter paper, and then resuspended in 500 ml of tap water, stirred and filtered by vacuum. The washing was repeated with a second 500 ml distilled water. With each washing, a fresh piece of filter paper was used and any visible contamination removed. The washed samples were air-dried at 55-60 ^{0} C and ground in a Wiley Mill using a 45 mesh screen. The ground samples were placed in clean glass jars, redried and sealed.

Mineral analysis of the moss tissue was performed by the Department of Horticulture, College of Agriculture, The Pennsylvania State University. Total nitrogen was determined with a Technicon AutoAnalyzer following block digestion (Isaac and Johnson, 1976). Sulfur was determined according to procedures for high frequency combustion titration provided in Laboratory Equipment Corporation procedures #200-054. The remaining elements were determined by plasma emission spectrometry (Dahlquist and Knoll, 1978). Results:

A list of bryophytes collected in the vicinity of the coal seeps but not on the seeps themselves reveals plants typical of disturbed sites (Table 1). Aulacomnium palustre (Hedw.) Schwaegr. was found in scattered patches at the perimeter of the Pohlia turf at Site 2. The other species were not associated with the seepage sites, nor was Pohlia nutans on the roadbank proper. only Pohlia, Brachythecium and Polytrichum were used for elemental analyses.

The macroelemental analyses for N, Ca, P, Mg, and K in Pohlia nutans at Site 2 (mean of 3 samples) was greater than Pohlia nutans at Site 1 (mean of 4 samples) by a factor of approximately 2 (Table 2). The difference for sulfur was less than 2 times greater for Site 2. The old growth of Pohlia nutans on Site 2 had lower levels of the macroelements than the new growth of Pohlia nutans on Site 2. The Polytrichum juniperinum and Brachythecium oxycladon samples had lower N, P, Mg, K, and S levels than Pohlia from either site. The calcium content of Polytrichum was equal to Pohlia on Site l, but less than Pohlia on Site 2. Brachythecium had a higher Ca content than Pohlia from either site.

The microelemental analyses were more variable but Pohlia samples from Site 1 had lower Mn, Fe, Cu, B, Al, Zn, Sr and Pb values than Pohlia from Site 2 (Table 3). The silicon values exceeded 500 ug/g in all samples except for the old growth samples of Pohlia, which had lower levels of Fe, Al, Cu, Mn, and Zn, but higher levels of B than the new growth of Pohlia. Pohlia had higher levels of Fe, Al, Mn, Zn, and B than did Polytrichum and Brachythecium. The Sr content of Polytrichum was nearly equal to that of Pohlia from Site 1 but less than Pohlia from Site 2. In contrast, Brachythecium had Cu values nearly equal to the Pohlia samples while Polytrichum had lower Cu values than the Pohlia samples. Pb in both Polytrichum and Brachythecium were nearly equal to Pohlia from Site 2 but higher than Pohlia from Site 1.

In summary, the Pohlia samples had higher element values for 10 of the 15 elements analyzed, compared to Polytrichum and Brachythecium samples.

The water analyses from Site 1 showed that water collected from the ditch upslope from the Pohlia turf was lower in all minerals except K, compared to water flowing from the turfs (Table 4). At Site 2, the water collected at the top of the rock face (at the lower edge of the Pohlia turf) had lower mineral concentrations in general than water collected at the base of the 24 m rock face. The pH of the water ranged from 2.65 to 2.75.

Ratios of the mineral content of Pohlia tissue to the mineral content of the water samples were calculated in order to estimate the relationships between the Pohlia plants and the seepage water (Table 5). For all nine minerals where ratios could be calculated, the plant tissue on a per unit weight basis had a higher content of the mineral than was available in the water. These ratios demonstrate the ability of Pohlia to absorb these minerals.

Discussion:

Pohlia nutans is described as widespread in Northern and Southern Hemispheres, "common on turfy soil, decaying logs and especially tops of rotten stumps, old Sphagnum hummocks, and soil in rock crevices" (p. 152, Crum, 1973). Crum and Anderson (1981) add the parenthetical comment, "but not weedy or cosmopolitan in distribution" (p. 530).

In addition, Pohlia nutans has been associated with mineral-rich habitats. Fraser (1961) found Pohlia nutans growing on peaty soils in New Brunswick, Canada, where the copper content of the soil killed trees. Fraser referred to a mimeographed report by Beschel in which the copper content of Pohlia on these seeps was 3.8 percent. The pH of these sites ranged from 5.5 to 6.5. In these seepage areas the Pohlia plants were the dominant plants, received little competition from other plants, and grew to a height of five inches. The plants were, however, etiolated and a light green color. The correlation of Pohlia nutans with the copper-rich seepage sites in New Brunswick is analogous to the Pohlia turfs on the mineral-rich coal seeps in Pennsylvania. In contrast, Shacklette (1965a) listed Pohlia nutans as one of five bryophytes associated with lead-zinc but not copper deposits in Alaska.

Pohlia nutans was reported from coal spoils in Iowa by Carvey et al. (1977), but their report indicated P. nutans was a minor component. Dicranella heteromalla (Hedw.) Schimp. and

Ceratodon purpureus (Hedw.) Brid. were the two most commonly sampled species while Pohlia nutans was not found in the sample quadrats (Carvey et al., 1977). Working on reclaimed mines in Illinois Rastorfer (1981) found a species of Pohlia in his sample quadrats but Barbula unguiculata Hedw., Ceratodon purpureus, and Funaria hygrometrica Hedw. were the most abundant mosses. Lawry (1978) did not report Pohlia nutans in his study of cryptogams on strip-mined areas in Ohio. The species listed by Carvey et al. (1977) and Rastorfer (1981) on coal spoils and reclaimed strip mines include many of the species found on the roadbank near the Pohlia turfs (Table 1). Apparently the coal spoil sites and reclaimed stripmines lacked seep habitats analogous to the sites in this study.

Pohlia nutans developed thick, luxuriant turfs on the three coal seeps in Clearfield County, Pennsylvania, which provide mineral-rich water throughout the year. These hydro-edaphic factors and microtopographic positions apparently control the rich development of the P. nutans at these sites. Luxuriant, extensive turfs of P. nutans are uncommon in temperate areas. J. Shaw (personal communication) commented, after verifying the identification of reference collections of P. nutans, ". . I can say that I have never seen such robust P. nutans as yours, except for a few others that have been sent to me from similar coal rich areas. . ."

The heights of the Pohlia samples used for mineral analyses were measured. The sample with the least height on Site 1 was 4.0 cm high and was from the lowest edge of the turf on the lower seep where the Pohlia turf reached the roadside ditch (Figure 2). In contrast, the other three samples from Site 1 ranged from 11.3 cm to 12.0 cm tall (Table 1). The sample of Pohlia growing as an isolated colony on the rock face at Site 2 was 8.2 cm tall in the center of the colony. The two collections from the continuous turf at Site 2 were 10.0 cm and 11.5 cm deep (Table 1). The length of green tissue at the time of collection ranged between 2 mm and 3 mm. The ratio of total length to green tissue indicate that these turfs have been growing for several years, perhaps from the time when the coal seams and seepage sites were exposed nearly twenty years earlier.

Rastorfer (1972) reported on the mineral content of Pohlia nutans collected in maritime Antarctica. The growth form that Rastorfer described for the Antarctic collections is comparable to the development of Pohlia on the coal seeps. The macroelement values are similar except for N from Site 2 which is two times greater than the N content of the Antarctic collection and for S which is three to four times higher than the Antarctic collections (Table 2). Distinct differences are noted in the microelement analyses (Table 3). The seepage collections had greater than 10^{4} higher Si values, 3.1-5.3 times more Zn, 3.6-4.0 times more Cu, 4.6-5.6 times more Fe, 1.9-2.0 times more Al, and 78-100 times more Mn than the Antarctic samples (Table 3, Rastorfer, 1972). These microelement differences are dramatic and reflect the mineral-rich conditions of the seepage water.

Pohlia nutans in Antarctica typically was associated with Polytrichum turfs in wetter habitats (Rastorfer, 1972). In this study however, Polytrichum juniperinum was not associated with Pohlia on the coal seeps, although Polytrichum juniperinum grew nearby on the dry roadbank. The overall descriptions of Pohlia habitats in Antarctica resemble the physical conditions of Pohlia on the coal seeps.

Brown (1982) notes that the extent to which analyses of mineral content reveals the overall requirements of mosses requires a consideration of the chemical source and its final location within the plant. The analysis of the seepage water and of the elemental content of Pohlia nutans, relative to that of Polytrichum juniperinum and Brachythecium oxycladon, was accomplished in this study, but the distribution of elements within the Pohlia plants warrants further investigation.

The old (brown) tissue in Pohlia nutans had lower levels of all elements except B and possibly Sr and Pb, when compared to the new (green) tissue of Pohlia at Site 2. This is contrary to patterns reported for other mosses (Bates, 1979; Ruhling & Tyler, 1970; Gorham & Tilton, 1978).

The mineral content of Polytrichum juniperinum in this study compares well with values reported for Polytrichum species from a variety of studies (Table 6). Few discrepancies occur among the macroelements. The greatest variation occurs with values of Mn, Fe, Al, N and Pb, where up to tenfold differences are found among the data for Polytrichum species. Lawry (1978) suggests low mineral availability limits the growth of bryophytes on strip mines. The level of Ca and P in P. ohioense in Ohio strip mines were higher than those for P. juniperinum in this study while Mg was lower in P. ohioense. P. juniperinum in this study grew on an exposed roadbank in shallow soil over shale bedrock. Its elemental content probably represents typical levels for this species.

The mineral relationship of Brachythecium oxycladon in this study appears to be comparable to Polytrichum juniperinum although the comparisons among pleurocarpous species are less direct. The author is unaware of other analyses of the element content of Brachythecium oxycladon. Shacklette (1965b) reported values for B. rutabulum (Hedw.) BSG and B. salebrosum (Web. & Mohr) BSG collected from soil in the United States. For twelve elements that can be compared, these two species of Brachythecium had higher levels of eleven elements than were found in B. oxycladon. The greatest differences were with B. salebrosum for Ca, Mg, Mn, Fe, Al, Zn and Pb (Table 7). Comparison of B. oxycladon with Hypnum cupressiforme Hedw. and H. curvifolium Hedw. shows good agreement for four macroelements and most microelements (Bates, 1978; Shacklette, 1965b). H. curvifolium had higher levels of Fe, Al, Sr and Pb than Brachythecium oxycladon while H. cupressiforme on sandstone rock had lower levels of Fe and Al than B. oxycladon (Bates, 1978; Shacklette, 1965b).

A comparison of the elemental content of Polytrichum. juniperinum and Brachythecium oxycladon, growing adjacent to but not on the coal seeps, with Pohlia nutans from the seepage sites indicates which elements were accumulated by Pohlia. As such, Pohlia nutans had higher levels of N, P, Mg, K, S, Fe, Al, Mn, Zn and B than the two reference species. All three species are exposed to similar atmospheric deposition of minerals from dust, vehicular exhaust and precipitation and to similar macroclimatic factors. The continuous availability of seepage water to the Pohlia nutans plants is a significant microclimatic and edaphic difference.

The low pH of the seep water (2.65-2.75, Table 4) is note-worthy. The low pH also increases the availability of such minerals as Fe and Al. The absence of other bryophytes from the seepage sites may be due to their lack of tolerance of the low pH and the mineral-rich seepage water, although mosses that typify disturbed sites grow nearby (Table 1). The mineral content of the Pohlia samples is generally greater than the levels found in Polytrichum juniperinum and Brachythecium oxycladon in this study, and reflect the elemental content of the seepage water (Tables 2 and 3).

A comparison of the values for Pohlia with those of mosses of different species, collected from a variety of habitats, climates, and nutrient regimes, is tenuous except to demonstrate the ability of Pohlia nutans to accumulate microelements in the coal seepage situations. Pohlia on the coal seeps had the following sequence of absorption values: Fe>Al>Mn>Zn>Cu>B=Pb>Sr. The elemental sequence for Polytrichum juniperinum and Brachythecium oxycladon in this study were the same as Pohlia nutans but the differences in concentrations were greater in Pohlia. LeBlanc et al.(1974) found a sequence of Pb>Cu>Zn>Cd>As for Hylocomnium splendens (Hedw.) BSG and Pleurozium schreberi (Brid.) Mitt. in Quebec, Canada, while Ruhling and Tyler (1970) reported an absorption sequence of Cu=Pb>Ni>Co>Cd>Zn>.Mn for Hylocomnium splendens in Sweden. The differences in the sequences probably reflect differences in the sources of minerals (seep water versus atmospheric deposition) and differences in available concentrations. Pleurozium and Hylocomnium apparently receive a significant amount of their nutrients from atmospheric sources and have been used as monitors of pollution levels (Barclay-Estrup & Rinne, 1979; Rinne & Barclay-Estrup, 1980; Ruhling & Tyler, 1969, 1970).

The absence of other bryophytes from the coal seeps may be due to toxicity of heavy metals. Circumstantial evidence supports this concept in this study. Studies of metal toxicity in mosses are limited. For example, Coombes and Lepp (1974) found copper and lead were toxic to germinating spores of Funaria hygrometrica. Their work also showed chelated forms of copper were less toxic than free copper. The relative toxicity of trace elements in higher plants is the reverse of the microelement sequence in Pohlia (Garraway, 1983). This indicates the microelements with highest levels in Pohlia are likely to be the least toxic. The concentrations of Al, Mn, Zn, and Cu in Pohlia are high compared to reports for other mosses. Consequently it is suggested that Pohlia nutans can tolerate higher levels of potentially toxic elements than other mosses.

Manganese had the third highest microelement values in Pohlia at concentrations three to four times higher than that in Pleurozium schreberi (Barclay-Estrup & Rinne, 1979; Rinne & Barclay-Estrup, 1980). None of the 29 species of bryophytes analyzed by Shacklette (1965b) had manganese levels approaching those found in Pohlia nutans . Rinne & Barclay-Estrup (1980) felt that the lower Mn levels in Pleurozium schreberi, relative to other heavy metals, reflected the presence of poor exchange sites for Mn. In this study, all three species studied have higher Mn levels than those for other microelements except for Fe and Al. These data demonstrate that Mn can be absorbed and that the Mn concentration of the mosses may be more a reflection of the available concentration of Mn than the presence of binding sites.

The aluminum content of Pohlia nutans was greater than levels reported for 32 samples of mosses from four rock types in England (Bates, 1978). The only species with higher aluminum levels was Andreaea rothii Web & Mohr growing on sandstone, basaltic, and ultrabasic rocks (Bates, 1978). Pohlia in this study had approximately 20 times more Al than Hypnum cupressiforme from mine sites in New Zealand (Ward et al., 1977) and seven times higher Al values than Arctic mosses (Rastorfer, 1974).

The zinc content in Pohlia was more than the background levels for Pleurozium schreberi but less than mean values of P. schreberi collected in the vicinity of a kraft paper mill in Ontario, Canada (Barclay-Estrup & Rinne, 1979). In contrast the zinc levels in Pohlia were higher than samples of Pleurozium schreberi and Hylocomnium splendens from both rural and urban sites in Ontario (Barclay-Estrup- & Rinne, 1978). The zinc levels of Pohlia samples, however, compare well with the zinc content of Aulacomnium palustre and Climacium dendroides collected in Poland (Czarnowska & Rejment-Grochowska, 1974).

Fraser (1961) associated the growth of Pohlia nutans with the high copper levels of peaty soils in seepage areas in New Brunswick, Canada. In contrast, Shacklette (1965b) found Pohlia rothii (Corr. ex Limpr.) Broth. on copper deposits in Alaska, but not P. nutans. Shacklette did find P. nutans growing on black slate that has been exposed during lead and zinc mining. Apparently P. nutans species absorbs and tolerates higher copper levels than species used in air pollution monitoring. Nonetheless, Hypnum cupressiforme collected from mining areas in Wales (Ward, et al., 1977) and Aulacomnium palustre and Climacium dendroides from Poland (Czarnowska & Rejment-Grochowska, 1974) had copper levels comparable to Pohlia nutans in this study.

The lead content of the Pohlia samples was more similar to background levels in Hypnum cupressiforme (Ward et al., 1977) and Pleurozium schreberi (Barclay-Estrup & Rinne, 1979) than the lower values reported for these and other species from alleged polluted habitats. This is interesting because the Pohlia samples were collected adjacent to a major Interstate highway, downwind from prevailing winds, but in a rural location. The lead levels in Pohlia can be considered to be low and comparable to Brachythecium oxycladon and Polytrichum, juniperinum. growing in the same locality.

Pohlia: Water Relationships:

The water that emerges from the Pohlia turfs is low in P and high in SO_4 . The sequence of macroelements in the seep water is SO_4 >Mg>Ca>K>P at Site 1 and SO_4 >Ca>Mg>K>P at Site 2 (Table 4). The water that was sampled from the roadside ditch upslope and before the beginning of the Pohlia turf at Site 1 had lower levels of macroelements than the water that emerged from the seeps. it is assumed that the water emerging from the Pohlia turf is reflective of the ground water at the sites. As the water moves through the Pohlia turf, particularly the old peaty material, differential exchange of minerals could occur and alter the chemical make-up of the emerging seep water. The ability of Pohlia to remove minerals warrants further investigation.

Calculation of the ratio of each element in the Pohlia tissue relative to the concentration in the seep water resulted in positive numbers (Table 5). The ratios were smallest for S:SO_4 and greatest for P:PO_4 The source of the higher levels of minerals at Site I cannot be explained, except to assume that the seepage water differs between sites. Plant:water ratios are quite similar for Fe, but differ between sites for Cu, Mn, and Al (Table 5). However, all four ratios indicate a significant absorption of these microelements from the available water. The data on water chemistry from the study sites were compared to data obtained from a spring on the E. M. Brown stripmine and from an unnamed tributary of Abes Run (DER, 1982). The spring and tributary are part of the same watershed as Site 1 and are located approximately one-half mile west of Site 1. The spring had extremely variable conditions over three sample dates with pH ranging from 3.0 to 5.7. Total iron in the spring ranged from 0.06 mg/l to 26.32 mg/l. Mn, Al, and SO_4 showed similar fluctuations. The highest values for the spring, however, were similar to the values reported here for Site 1.

The unnamed tributary also fluctuated in its water chemistry with the highest values (pH 3.1, Fe = 23.61 mg/l, SO_4 = 2820 mg/l, Mn = 62.55 ug/l, and Al = 59.16 ug/1) being similar to the values found at Site 1. Because these two nearby water sources exhibited major fluctuations, it is possible that the seeps at Sites 1 and 2 might also vary during the year with fluctuations in surface runoff and subsurface drainage. Further work would be required to determine how the water chemistry of the sites varies during the year and if this variation influences the growth and development of the Pohlia turfs.

In summary, Pohlia nutans, growing on seepage sites on exposed bituminous coal seams, have developed luxuriant and extensive turfs. Elemental analysis of the Pohlia plants indicates they have selectively absorbed high levels of Al, Fe, Mn and Zn. The microelement content of the plants is correlated with the chemical analysis of the seep water. The ability of Pohlia nutans to grow luxuriantly on these sites is apparently related to the tolerance of Pohlia nutans to the low pH and high microelemental content of the seepage water. However, further research is needed in order to determine the rates of mineral absorption and the role of the moss in removing minerals from acid coal seeps.

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Table 1. Collection data on mosses used for mineral analysis and on bryophytes found in the vicinity of Pohlia nutans turfs.

Table 1. Collection data on mosses used for mineral analysis and on bryophytes found in the vicinity of Pohlia nutans turfs.

Collection Number	Species	Comment
80-MS-2	Pohlia nutans (Hedw.) Lindb.	Isolated dome-shaped colony on rock face near top, Site 2 (8.2 cm deep)
80-MS-2	Pohlia nutans (Hedw.) Lindb.	Downslope edge of Pohlia turf, Site 2 (10.0 cm deep)
80-MS-3	Pohlia nutans (Hedw.) Lindb.	From middle of lower turf Site 2 (12.0 cm deep)
80-MS-4	Pohlia nutans (Hedw.) Lindb.	Lower edge of turf on lower turf, Site 1 (4.0 cm deep)
80-MS-5	Pohlia nutans (Hedw.) Lindb.	Lower edge of turf on upper turf, Site 1 (11.5 cm deep)
80-MS-6	Pohlia nutans (Hedw.) Lindb.	From middle of upper turf, Site 1 (11.3 cm deep)
80-MS-7	Polytrichum juniperinum Hedw.	Growing on roadbank west and above upper turf, Site 1
80-MS-8	Polytrichum juniperinum Hedw.	Growing on roadbank to east and above upper terrace, Site 1
80-MS-10	Pohlia nutans (Hedw.) Lindb.	Back edge of turf, Site 2 (11.5 cm deep)
80-MS-11	Brachythecium oxycladon (Brid.) Jaeg. & Sauerb.	Growing above upper turf, Site 1
80-MS-12	Ceratodon purpureus (Hedw.) Brid.	On exposed, dry shale, Site 1
80-MS-13	Leucobryum glaucum (Hedw.) Angstr. ex Fries.	Above seep on roadbank, Site 2
80-MS-14	Rhynchostegium serrulatum (Hedw.) Jaeg & Sauerb.	Above seep on roadbank, Site 1
80-MS-15	Dicranum polysetum Sw.	Above seep on roadbank, Site 1
80-MS-16	Ptilidium ciliare (L.) Hampe.	In shade of sapings on roadbank, Site 1
80-MS-17	Thuidium delicatucum (Hedw.) BSG	On roadbank, Site 1
80-MS-18	Aulacomnium palustre (Hedw.) Schwaegr.	At back edge of turf, Site 2

(Continued)

Table 1 (Continued). Collection data on mosses used for mineral analysis and on bryophytes found in the vicinity of Pohlia nutans turfs.

Table 1 (Continued). Collection data on mosses used for mineral analysis and on bryophytes found in the vicinity of *Pohlia nutans* turfs.

Collection Number	Species	Comment
80-MS-19	*Mnium cuspidatum* Hedw.	On roadbank, site 1
80-MS-20	*Tortella humilis* (Hedw.) Jenn.	On roadbank, Site 1
80-MS-21	*Aulacomnium palustre* (Hedw.) Schwaegr.	On roadbank, Site 1
80-MS-22	*Dicranella schreberiana* (Hedw.) Hilf. *ex* Crum & Anders.	On back edge of turf, Site 2

Table 3. Microelemental content of *Pohlia nutans* on coal seeps and of *Polytrichum juniperinum* and *Brachythecium oxycladon* on roadbank soil.

Species:Habitat:Site	Values as ug/g dry weight Fe	Al	Mn	Zn	Cu	B	Pb	Sr	Si
Pohlia nutans:Site 1									
Middle of upper turf	4300	3550	1713	137	37	15	14	7	500*
Base of upper turf	7150	3150	1383	111	35	19	14	6	500*
Middle of lower turf	6550	3850	1127	113	35	18	30	8	500*
Base of lower turf	3375	1134	166	52	21	12	11	11	500*
Average	5334	2921	1097	103	32	16	17	8	500
Pohlia nutans:Site 2									
Back of turf	8000**	4300	2111	213	52	33	30	14	500*
Edge of turf	6275	3750	2085	212	32	21	22	15	500*
Rock face	5125	967	263	98	24	16	15	15	500*
Average	6467	3006	1486	175	36	23	22	15	500
Pohlia nutans:Site 2									
Old growth	775	770	84	82	20	145	23	15	365
Polytrichum junipernium:Site 1									
Upper roadbank	566	945	111	60	25	3	23	9	500*
Lower roadbank	838	1029	101	71	24	4	26	9	500*
Average	702	987	106	66	25	4	25	9	500
Brachythecium oxycladon:Site 1									
Upper roadbank	774	983	94	65	34	13	21	27	500*

*Values over 500 ug/g dry weight are indicated as 500
**Values over 8000 ug/g dry weight are indicated as 8000

Table 4. Water analyses data as mg/l for samples flowing from exposed coal seeps with _Pohlia nutans_ turfs.

Site - Habitat	Total PO_4	Ortho P	K	Ca	Mg	SO_4	Mn	Fe	Cu	Al	pH
Site 1											
From ditch, upslope and before lower turf	0.016	0.003	2.06	66.8	45.4	494	8.73	10.8	0.02	7.1	--
From ditch, at base of lower turf	0.045	0.027	1.21	130.1	179.8	1651	66.20	28.8	0.19	34.8	2.65
From terrace, at base of upper turf	0.040	0.029	0.99	127.4	174.9	1651	62.40	22.2	0.20	35.3	2.75
Average	0.034	0.020	1.42	108.1	133.4	1265	45.78	20.6	0.14	25.7	2.70
Site 2											
Top of rock face, at seep source	0.010	0.004	2.45	112.9	44.3	630	6.24	18.9	0.01	14.4	--
Base of rock face, in roadside ditch	0.027	0.007	2.63	120.1	44.1	664	6.90	29.9	0.02	13.3	2.70
Average	0.019	0.006	2.54	116.5	44.2	647	6.57	24.4	0.02	13.9	--

Table 5. Ratio of average mineral content of *Pohlia* new growth to average mineral content of water samples at Sites 1 and 2.

Ratio of: $\frac{\text{Percent dry weight of element in } Pohlia \text{ tissue}}{\text{mg/l of mineral in seep water}} \times 10^6$

	P/Total PO_4	K	Ca	Mg	S/SO_4
Site 1	7.94×10^6	6.9×10^5	2.5×10^3	2.8×10^3	4.0×10^2
Site 2	3.16×10^7	8.3×10^5	3.9×10^3	1.5×10^4	9.9×10^2

Ratio of: $\frac{\text{ug/g dry weight of element in } Pohlia \text{ tissue}}{\text{mg/l of mineral in seep water}}$

	Mn	Fe	Cu	Al
Site 1	23.96	259.42	228.57	113.66
Site 2	226.18	265.04	1800.00	216.26

Table 6. Comparison of the elemental content of *Polytrichum* species from five studies

	Percent Dry Weight						PPM Dry Weight								
	N	Ca	P	Mg	K	S	Mn	Fe	Cu	B	Al	Zn	Sr	Pb	Si
P. juniperinum, this study	1.47	0.27	0.18	0.15	0.92	0.13	106	702	25	4	987	66	9	25	>500
P. juniperinum,[1] Poland Mean,	--	--	--	--	--	--	1143	9750	87	--	--	720	--	248	--
Low Value	--	--	--	--	--	--	850	4000	22	--	--	555	--	117	--
P. juniperinum,[2] U.S. Mean,	--	0.54	0.06	0.10	0.42	--	528	1137	9.2	5.6	2000	89	42	41	--
P. commune,[2] U.S.	--	0.24	0.12	0.16	1.20	--	1600	240	24	8	>800	160	24	80	--
P. ohioense,[2] U.S.	--	0.26	0.13	0.06	0.61	--	87	1305	13	6.1	2610	61	4.4	87	--
P. ohiosense, Ohio[3] Sample 1	--	0.32	0.29	0.07	0.88	--	--	--	--	--	--	--	--	--	--
Sample 2	--	0.68	0.30	0.10	0.62	--	--	--	--	--	--	--	--	--	--
P. commune var. *jensenii*, Alaska[4]	1.40	0.15	0.21	0.13	0.88	0.1045	0.53	537	16	10	629	45	28	--	1800

(Continued)

Table 6 (Continued). Comparison of the elemental content of *Polytrichum* species from five studies

	Percent Dry Weight							PPM Dry Weight							
	N	Ca	P	Mg	K	S	Mn	Fe	Cu	B	Al	Zn	Sr	Pb	Si
P. hyperboreum[4] Alaska															
Sample 1	0.80	0.31	0.18	0.18	0.68	0.089	0.62	399	14	17	667	55	27	--	5700
Sample 2	--	0.28	0.17	0.17	0.64	--	0.67	369	14	17	628	53	28	--	4400
P. juniperinum var. *affinae* (reported as *P. strictum*[5] Antarctica	1.50	0.23	0.44	0.11	0.50	0.075	--	--	--	--	--	--	--	--	1000

[1]
[2] Rejment-Grochowska 1976.
[3] Shacklette 1965b (recalculated)
[4] Lawrey 1978
[5] Rastorfer 1974
Rastorfer 1972

Table 7. Comparison of the elemental content of *Brachythecium oxycladon* with the element content of other pleurocarpous species.

	Percent Dry Weight						PPM Dry Weight							
	N	Ca	P	Mg	K	S	Mn	Fe	Cu	B	Al	Zn	Sr	Pb
Brachytheceum oxycladon, this study	1.79	0.63	0.09	0.15	0.34	0.14	94	774	34	13	983	65	27	21
B. rutabulum[1] on soil	--	1.08	0.14	0.18	0.57	--	118	2360	12	12	3540	94	83	59
B. salebrosum[1] on soil	--	3.08	0.12	1.03	0.74	--	308	4510	31	21	6150	4100	62	144
Hypnum curvifolium[1] on lithosol	--	0.87	0.04	0.17	0.23	--	261	2610	13	9	6090	87	87	61
H. cupressiforme[2] on sandstone	--	0.16	--	0.13	0.39	--	--	160	--	--	40	--	--	--
H. cupressiforme[2] on sandstone	--	0.12	--	0.12	0.47	--	--	40	--	--	10	--	--	--
H. cupressiforme[3] on soil	--	--	--	--	--	--	--	--	13.9	--	--	109	--	104.2

[1] Shacklette 1965b
[2] Bates 1978
[3] Ruhling & Tyler 1969

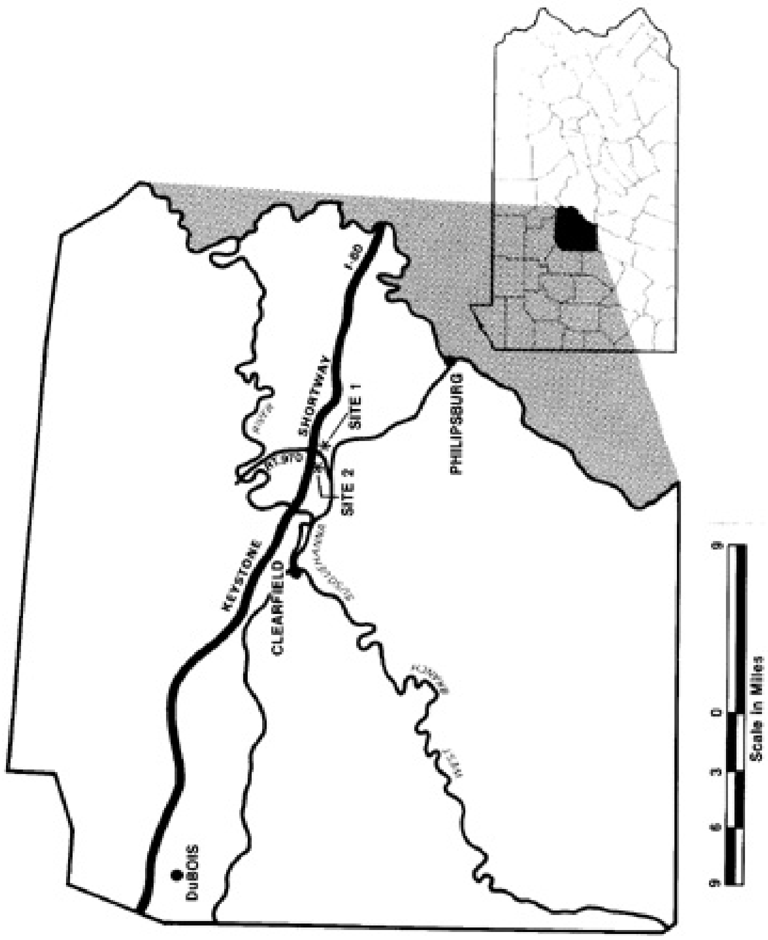

Figure 1. Location of Sites I and 2 along Interstate 80 (Keystone Shortway) in Clearfield County, Pennsylvania.

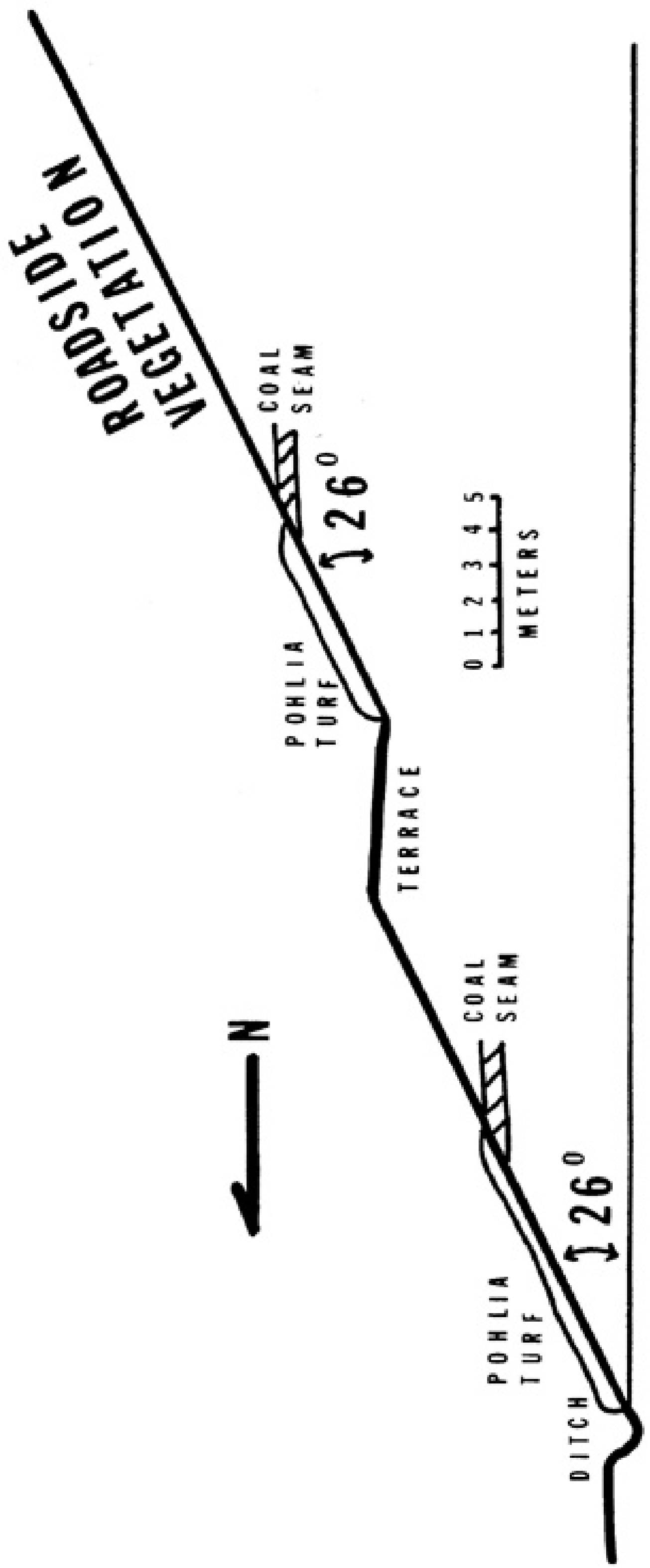

Figure 2. Schematic profile of Site I along Interstate 80, showing slope, positions of the coal seams and locations of the Pohlia nutans turfs. Vertical height of the Pohlia turfs is exaggerated.

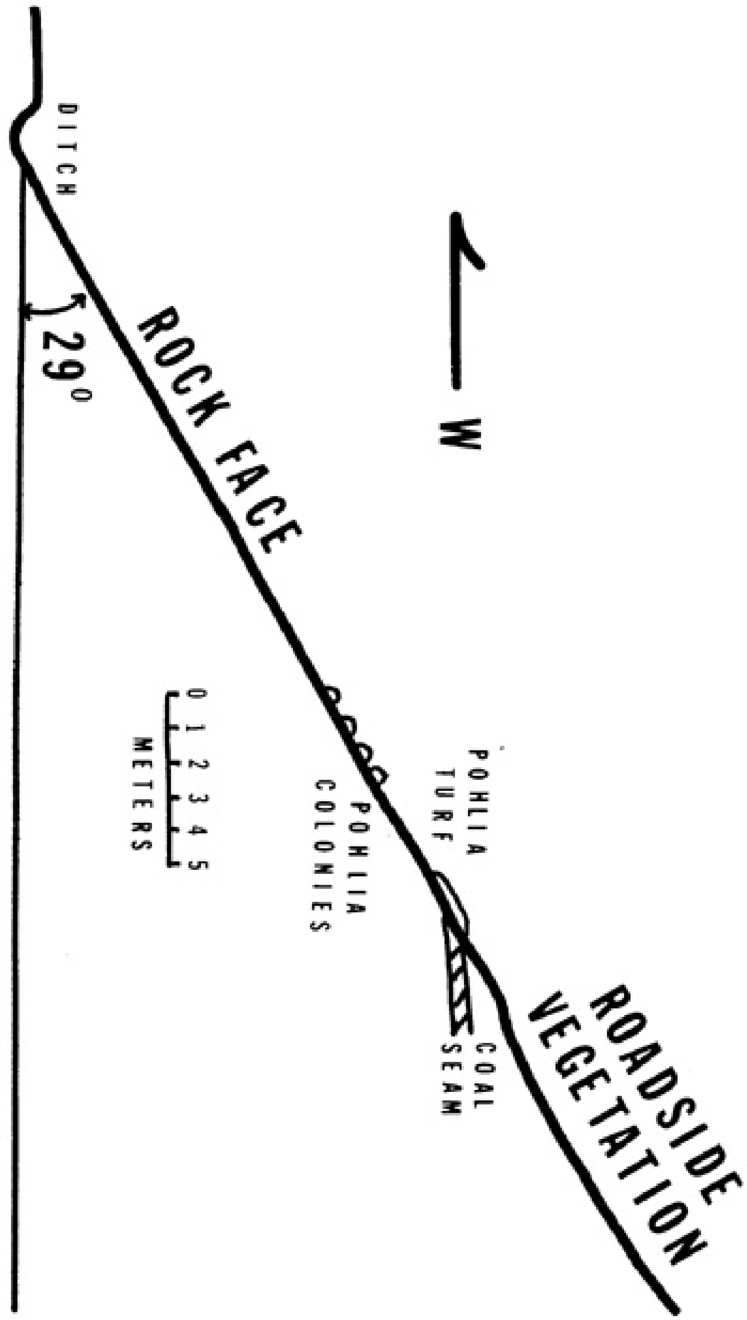

Figure 3. Schematic profile of Site 2 along Route 970, showing slope, location of the coal seam, and the positions of the Pohlia turf and the isolated Pohlia colonies. Vertical height of the Pohlia turf and colonies is exaggerated.