The Bryologist 93(3), 1990, pp. 309–312

Effects of a Coal-fired Power Plant on the Rock Lichen *Rhizoplaca melanophthalma*: Chlorophyll Degradation and Electrolyte Leakage

JAYNE BELNAP
Canyonlands National Park, 125 West 2nd South, Moab, UT 84532

KIMBALL T. HARPER
Botany Department, Brigham Young University, Provo, UT 84602

Abstract. *Chlorophyll degradation and electrolyte leakage were measured for the umbilicate desert lichen* Rhizoplaca melanophthalma *(Ram.) Leuck. & Poelt in the vicinity of a coal-fired power plant near Page, Arizona. Patterns of lichen damage indicated by chlorophyll degradation were similar to those indicated by electrolyte leakage. Regression analyses of chlorophyll degradation as well as electrolyte leakage on distance from the power plant were significant ($p < 0.001$), suggesting that lichen damage decreased with increasing distance from the power plant. Mean values for both variables at the two sites closest to the power plant (7 and 12 km) differed significantly from values for the two sites farthest from the plant (21 and 42 km; $p < 0.001$). Mean values within each group (7 and 12 km; 21 and 42 km) do not differ significantly for either parameter. It is suggested that effluents from the power plant combine with local weather factors to produce the observed levels of damage.*

Lichens have long been used as indicators of air pollution, especially species with fruticose growth forms. In the deserts of the western United States, however, the majority of the lichen flora is crustose or foliose, forms regarded by some as more resistant to pollutants (Fenton 1964; Nash 1974). This, along with the aridity of the environment which results in shorter periods of time of metabolic activity for lichens, has led some researchers to suggest that desert species may not be useful as indicators of air pollution (Marsh & Nash 1979). Field studies with lichens have generally used patterns of species occurrence or cover values, or both, to measure pollution impacts (LeBlanc et al. 1972; Marsh & Nash 1979; Nash 1974, 1975). However, it may be that air pollution levels in the arid West are not high enough or the lichens not metabolically active often or long enough to result in mortality. Nevertheless, the impacts may be enough to impair measurably the physiological functioning of lichens.

Coal-fired power plants are potential sources of toxic levels of sulfur dioxide, nitrogen dioxide, heavy metals, or all three. All of these pollutants, when present in high enough concentrations, have been shown to affect adversely some lichen species (Gough & Erdman 1977; Hawksworth & Rose 1970; Sheridan 1979). This study examines a common foliose desert rock lichen, *Rhizoplaca melanophthalma* (Ram.) Leuck. & Poelt, for possible effects caused by effluents from a nearby coal-burning power plant.

STUDY AREA

Page, Arizona, located on the Utah–Arizona border, was a relatively pristine, sparsely populated area until construction of Glen Canyon Dam began in 1956 and the coal-fired Navajo Generating Station was built in 1974. The town of Page originated with the construction of Glen Canyon Dam, and provides support for both the dam and the power plant. However, it remains small and probably does not contribute significant amounts of pollutants relative to the Navajo Generating Station, a three unit, 2,250 megawatt plant.

Elevations in the Page basin range from 1,100 to 1,300 m. The Colorado River runs through the basin and is dammed at Page by the Glen Canyon Dam to form Lake Powell. This dam is 2.5 km northeast of Page. The Navajo Generating Station is 5 km east of Page. Surrounding plateaus rise in steep cliffs from the river basin to approximately 1,700 m. To the north is the Kaiparowitz Plateau; to the south, the Kaibito Plateau is formed by the Echo Cliffs; to the west lie the Vermillion Cliffs and the Paria Plateau. Vegetation in the Page basin is dominated by blackbrush (*Coleogyne ramosissima* Torr.).

Atmospheric stability is greatest in the Page area from September to March, with November through January exhibiting especially poor dispersive capabilities. Temperature inversions are frequent in the Page basin during the winter. Daily atmospheric conditions are most stable in the morning hours, making mornings of winter days the most likely time for ground fumigations (Anonymous 1975). Average daily temperatures range from 35.9 in August to −4.6°C in January. Average daily maximum temperatures during November through February are 12.9, 6.8, 5.8, and 10.3°C respectively, with average daily minimums for that period of 1.7, −3.4, −4.6, and −1.0°C. Precipitation averages 16 cm a year. August through De-

0007-2745/90/309–312$0.55/0

TABLE 1. Electrolyte leakage values and chlorophyll degradation ratios (expressed by the spectrophotometric optical densities of 435/415, equal to chlorophyll *a*/phaeophytin) for *Rhizoplaca melanophthalma* at different distances from the Navajo Generating Station, Page, Arizona. Differences between means were analyzed using Duncan's multiple range test. Values with the same letter in the same column are not significantly different from each other. Letters 'a' and 'b' are significantly different at $p < 0.01$.

Site number	Distance from plant, km	Electrolyte leakage (μmhos/mg/ml)			OD 435/415 (nm)		
		Mean	S.E.	p	Mean	S.E.	p
1	7	1.38	0.89	a	0.794	0.100	a
2	12	1.24	0.20	a	0.715	0.061	a
3	21	0.17	0.09	b	0.957	0.144	b
4	42	0.13	0.17	b	1.07	0.039	b
5	225	0.28	0.17	b			

cember are the most moist months, averaging 1.6 cm of precipitation a month. All other months average approximately 1.2 cm with the notable exception of June, which averages 0.48 cm. Winter daytime (0900–1800) winds are predominantly from the northeast; nighttime (1800–0900) winds are from the southwest at approximately 180 m above the valley floor (Balling & Sutherland 1988).

For comparative purposes, collections of *R. melanophthalma* were also made near Moab, Utah. This area was chosen because it is located far from any point source of pollution. Collection sites were located on Navajo Sandstone with north-northeast to north exposures, at elevations of approximately 1,325 m. Average temperatures in the Moab area range from 5.4 (January) to 37.4°C (July). Precipitation averages 20 cm a year (Brough et al. 1983). Vegetation is predominantly *Coleogyne ramosissima.*

METHODS

Rhizoplaca melanophthalma was chosen for this study because it is a fairly common lichen that is easily collected without damage to the thallus. Samples of this lichen were collected along a transect running northeast from the Navajo Generating Station, with study plots located at increasing distances from the plant (7, 12, 21, and 42 km). Plots were located along Lake Powell, and were visited by boat. All plots were located on Navajo Sandstone, at approximately the same elevation (1,200 m) and the same exposures (north-northeast to north). Collections of *R. melanophthalma* were made within 150 m of the lake shore.

Electrolyte leakage (membrane permeability) of the lichen thalli was determined by methods outlined by Pearson (1985). Lichen thalli analyzed were selected for similarity of surface area. Thalli were humidified for 2 hours, rinsed for 3 seconds, and then submersed in deionized water for 5 minutes. Conductivity of the water was measured before and after immersion of the thalli with a Fisher Scientific Conductivity Meter, model 152. The thalli were dried, weighed, and pigments were extracted with DMSO (dimethyl sulfoxide). Extracts were centrifuged.

Spectrophotometric measurements were taken at 415, 435, and 750 nm. Degradation of chlorophyll *a* (435 nm) to phaeophytin (415 nm) was estimated from the optical density ratio 435/415; therefore, as damage to chlorophyll *a* increased, so did the value of OD 415. The result is that smaller numbers represent greater chlorophyll degradation. These wavelengths were determined by running spectrophotometric scans of extracts before and after acidification with 1 N HCl, following methods outlined in Ronen and Galun (1984). Turbidity levels were checked (750 nm) to make certain particulates were not interfering with the analyses. A Hewlett-Packard diode array spectrophotometer was used for the analyses. Results were analyzed with regression models, analysis of variance (ANOVA), and Duncan's multiple range test.

RESULTS

Electrolyte leakage in *R. melanophthalma* was shown to decline significantly with increasing distance from the Navajo Generating Station by regression analysis (using a log-log model, $r = -0.79$, $p < 0.001$; Fig. 1). Analysis of variance among the four sites was highly significant ($F = 16.9$, $p < 0.001$). Leakage values for the two closer sites (7 and 12 km) were significantly higher by an order of magnitude than values obtained at the two more distant sites (21 and 42 km; $p < 0.001$, Duncan's multiple range test). We could not show leakage values differing significantly between the two closer sites or between the two distant sites (Table 1).

Leakage values of lichens from the Page area were compared with those obtained from *R. melanophthalma* collected near Moab, Utah. Using ANOVA, we could not demonstrate any significant differences between the Moab values and the values at the two distant sites in the Page area (Table 1).

Chlorophyll degradation ratios paralleled results for electrolyte leakage. Linear regression of chlorophyll degradation ratios on distance from the power plant showed a regression coefficient of $r = 0.58$ ($F = 30.8$, $p < 0.001$; Fig. 2). Again, analysis of variance among all sites was highly significant ($F = 11.4$, $p < 0.001$). As with the electrolyte leakage results, chlorophyll degradation values were significantly higher for lichens from the two closer sites than those from the two more distant sites ($p < 0.01$). We could not demonstrate a significant difference in chlorophyll degradation between the two sites closest to the plant, or between the two more distant sites. As would be expected, the correlation

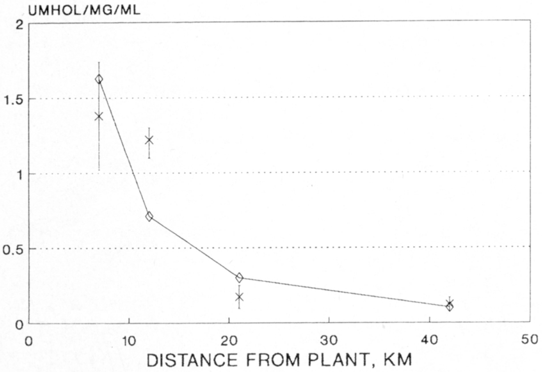

FIGURE 1. Regression of electrolyte leakage in *Rhizoplaca melanophthalma* on distance from the Navajo Generating Station near Page, Arizona (~~R = 0.92~~; $p < 0.001$).

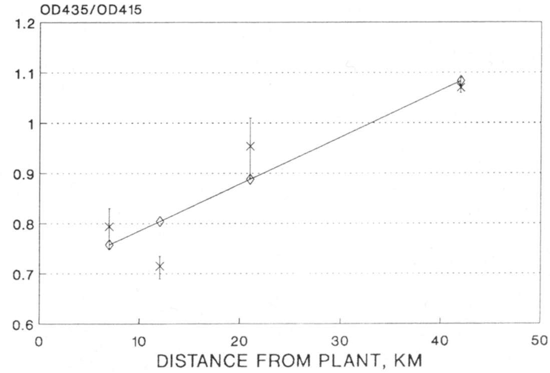

FIGURE 2. Regression of chlorophyll degradation ratios in *Rhizoplaca melanophthalma* (expressed by the spectrophotometric optical densities of 435/415, equal to chlorophyll *a*/phaeophytin) on distance from Navajo Generating Station at Page, Arizona (~~R = 0.79;~~ $p < 0.001$).

between chlorophyll degradation and electrolyte leakage was highly significant ($r = -0.76$, $F = 28.7$, $p < 0.001$).

DISCUSSION

Both chlorophyll degradation ratios and electrolyte leakage data indicate that there has been significant injury to membranes and chlorophyll of *R. melanophthalma* in the immediate vicinity of the Navajo Generating Station. Highly significant correlations, between both electrolyte leakage and chlorophyll degradation with distance from the plant, strongly suggest that the effluents from the Navajo Generating Station have a major causal role in the observed differences. This conclusion is strengthened by the fact that lichen samples at different sites were obtained from the same geologic formation, the same exposures, comparable elevations, and a comparable distance from Lake Powell.

It is apparent from our results that, where there were differences between sites, they were much greater for the conductivity results than for chlorophyll degradation. This suggests that electrolyte leakage may be a more sensitive indicator of injury to lichens than chlorophyll degradation. Fields and St. Clair (1984) reached the same conclusion when comparing electrolyte leakage, photosynthesis, and respiration as methods for evaluating sulfur dioxide damage in three species of lichens (one fruticose, one foliose, and one crustose). Values for electrolyte leakage and chlorophyll degradation reported in our study are similar in magnitude to those in other studies (Fields & St. Clair 1984; Garty et al. 1985; Pearson 1985; Ronen & Galun 1984).

Weather factors may be a major influence on injury levels of lichens in the Page basin. November through April are months with increased moisture and decreased temperatures, providing for longer periods of metabolic activity in the lichens; these are also the months when ground fumigations are most likely from the power plant. Humidity from Lake Powell may increase lichen activity periods in the Page basin, compared to surrounding areas, and may result in the lichens experiencing greater impacts from power plant effluents.

Exposure of lichens to sulfur dioxide and nitrogen dioxide has been previously implicated in degradation of chlorophyll (Garty et al. 1985; LeBlanc & Rao 1973; Nash 1973, 1976) and electrolyte leakage (Fields & St. Clair 1984; Henriksson & Pearson 1981; Pearson & Rodgers 1982). High concentrations of some trace metals have been shown to cause chlorophyll degradation as well (Garty et al. 1985; Nash 1971, 1975). There have been no studies directly correlating elemental concentrations with electrolyte leakage. The distances at which injury was demonstrated in this study are in close agreement with other studies of lichen damage by sulfur dioxide, nitrogen dioxide, and metals (Nash 1972; Newberry 1974; Sheridan 1979).

Ever-increasing pressures to locate pollution sources—such as coal-fired power plants and toxic waste incinerators—in arid regions of the West make it critical that suitable biological monitoring systems be found and utilized to evaluate effects of such industries on desert ecosystems. This study is presented as a contribution towards identification of desert lichens that can serve this purpose.

ACKNOWLEDGMENTS

Many thanks to the Washington Air Quality Office/National Park Service, and National Science Foundation for funding; Retsik Belnap for field and lab assistance; Lorentz

Pearson, Tim Graham, and Ken Stolte for helpful comments; John Mangum for equipment use; and Roger Rosentreter and Larry St. Clair for lichen identifications.

Literature Cited

ANONYMOUS. 1975. Navajo Generating Station Sulfur Dioxide Field Monitoring Program, Final Program Report, Vol. 1. Air Monitoring Center, Rockwell International (Thousand Oaks, Ca.)/Meteorology Research, Inc./Systems Applications, Inc. Unpublished report, on file at WASO-AQ, National Park Service Rocky Mt. Regional Offices, Denver.

BALLING, R. C. & J. L. SUTHERLAND. 1988. Diurnal and seasonal wind direction patterns within the mountain-valley terrain near Glen Canyon Dam, Arizona. Journal of Applied Meteorology 27: 594–598.

BROUGH, R. C., R. D. GRIFFIN, E. A. RICHARDSON & D. J. STEVENS. 1983. Utah Weather Guide. Society for Applied Climatology, West Jordan, Utah.

FENTON, A. F. 1964. Atmospheric pollution of Belfast and its relationship to the lichen flora. Irish Naturalist's Journal 14: 237–245.

FIELDS, R. D. & L. ST. CLAIR. 1984. A comparison of methods for evaluating SO_2 impact on selected lichen species: *Parmelia chlorochroa, Collema polycarpon,* and *Lecanora muralis.* THE BRYOLOGIST 87: 297–301.

GARTY, J., R. RONEN & M. GALUN. 1985. Correlation between chlorophyll degradation and the amount of some elements in the lichen *Ramalina duriaei* (De Not.) Jatta. Environmental and Experimental Botany 25: 67–74.

GOUGH, L. P. & J. A. ERDMAN. 1977. Influence of a coal-fired powerplant on the element content of *Parmelia chlorochroa.* THE BRYOLOGIST 80: 492–501.

HAWKSWORTH, D. L. & F. ROSE. 1970. Qualitative scale for estimating SO_2 air pollution in England and Wales. Nature (London) 227: 145–148.

HENRIKSSON, E. & L. C. PEARSON. 1981. Nitrogen fixation rate and chlorophyll content of the lichen *Peltigera canina* exposed to sulfur dioxide. American Journal of Botany 68: 680–684.

LEBLANC, F. & D. N. RAO. 1973. Effects of sulphur dioxide on lichen and moss transplants. Ecology 54: 612–617.

———, ——— & G. COMEAU. 1972. Indices of atmospheric purity and fluoride pollution pattern in Arvida, Quebec. Canadian Journal of Botany 50: 991–998.

MARSH, J. E. & T. H. NASH III. 1979. Lichens in relation to the Four Corners power plant in New Mexico. THE BRYOLOGIST 82: 20–28.

NASH III, T. H. 1971. Lichen sensitivity to hydrogen fluoride. Bulletin of the Torrey Botanical Club 98: 103–106.

———. 1972. Simplification of the Blue Mountain lichen communities near a zinc factory. THE BRYOLOGIST 75: 315–324.

———. 1973. Sensitivity of lichens to sulfur dioxide. THE BRYOLOGIST 76: 333–339.

———. 1974. Lichens of the Page environs as potential indicators of air pollution. Journal of the Arizona Academy of Sciences 9: 97–101.

———. 1975. Influence of effluents from a zinc factory on lichens. Ecological Monographs 45: 183–198.

———. 1976. Sensitivity of lichens to nitrogen dioxide fumigations. THE BRYOLOGIST 79: 103–106.

NEWBERRY, G. 1974. The influence of a sulfate-process paper mill on corticolous lichens. THE BRYOLOGIST 77: 561–576.

PEARSON, L. C. 1985. Air pollution damage to cell membranes in lichens: I. Development of a simple monitoring test. Atmospheric Environment 19: 209–212.

——— & G. A. RODGERS. 1982. Air pollution damage to cell membranes in lichens III. Field experiments. Phyton (Austria) 22: 329–337.

RONEN, R. & M. GALUN. 1984. Pigment extractions from lichens with dimethyl sulfoxide (DMSO) and estimation of chlorophyll degradation. Environmental and Experimental Botany 24(3): 239–245.

SHERIDAN, R. P. 1979. Impact of emissions from coal-fired electricity generating facilities on N_2-fixing lichens. THE BRYOLOGIST 82: 54–58.