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Sensitivity of Desert Cryptogams to Air Pollutants: Soil Crusts and Rock Lichens

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Abstract. Parks throughout the West are being faced with increasing air pollution threats from current or proposed industries near their boundaries. For this reason, it is important to understand the effects these industries may have on desert ecosystems. Rock lichens can be excellent biomonitors, acting as early warning systems of impending damage to other components of the desert ecosystem. Cryptogamic crusts, consisting mostly of cyanobacteria and lichens, may not only be excellent bioindicators, but also are an essential part of the desert ecosystem. Their presence is critical for soil stability as well as for the contribution of nitrogen to the ecosystem in a form available to higher plants. Air pollutants, such as emissions from coal-fired power plants, may threaten the healthy functioning of these non-vascular plants. The purpose of this study is to determine if, in fact, air pollutants do have an impact on the physiological functioning of cryptogamic crusts or rock lichens in desert systems and, if so, to what extent.

Some results have already been obtained. Both rock lichens and cryptogamic crusts exhibit physiological damage in the vicinity of the Navajo Generating Station in Page, Arizona. Increased electrolyte leakage and chlorophyll degradation, along with reduced nitrogen fixation, have been found. Preliminary studies comparing sensitivity between substrates indicate that crusts on limestone and sandstone substrates may be more sensitive than those on gypsum.

Introduction

Parks throughout the West are being threatened by ever-increasing pressures to locate polluting types of industries, such as coal-fired power plants, smelters and toxic waste incinerators, near their boundaries. For example, Zion and Bryce are located near the Intermountain Power Project, soon to be the largest coal-fired plant in the world, and the Allen Warner plant near Las Vegas. Glen Canyon National Recreation Area is adjacent to the Navajo Generating Station in Page, Arizona. Mesa Verde and Hovenweep are close to the Four Corners area, home of two very large, coal-fired plants. Parks in southern Arizona and California are threatened by urban

pollution and smelter activity. This situation makes it critical that the biological effects of such industries on desert ecosystems be evaluated, and that long-term monitoring efforts be initiated.

Non-vascular plants, most notably lichens, have long been used as indicators of air pollution (Ferry et al., 1973), especially those with fruticose growth forms. In the deserts of the Southwest, however, the majority of the non-vascular flora is crustose or foliose, forms generally regarded as more resistant to pollutants (Fenton, 1964; Nash, 1974). This, along with the aridity of the environment which results in less metabolically active time for the soil crusts and rock lichens, has led some researchers to conclude that desert species may not be as useful as indicators of air pollution (Marsh and Nash, 1979).

Field studies using non-vascular plants as indicators of pollutants have generally utilized species composition and/or cover values of lichens to measure pollution impacts (LeBlanc, et al., 1972; Marsh and Nash, 1979; Nash, 1974; Nash, 1975; Nash and Sommerfeld, 1981). No known studies have examined the effects of pollutants on soil crusts. If crustose and foliose species are more resistant to pollutants, it may be that in the arid West air pollution levels are not high enough or that the non-vascular plants are not metabolically active often or long enough to result in mortality. Nevertheless, the impacts may be enough to measurably impair physiological functioning of these crusts or rock lichens.

Cryptogamic soil crusts are found throughout the deserts of the world. They are especially well-developed in the deserts of the southwestern United States. These crusts are a very diverse microcosm, consisting of bacteria, green algae, cyanobacteria, microfungi and lichens, with cyanobacteria being the most prevalent component. These crusts play a vital role in the health of the desert ecosystem. Not only do they act to stabilize topsoil in an environment that combines otherwise loose sand with torrential rains, but they also contribute fixed nitrogen to a fairly nitrogen-poor system (MacGregor and Johnson, 1971; Snyder and Wullstein, 1973; Terry and Burns, 1986; Lynn and Vogelsberg, 1974). Rock lichens can be very sensitive biomonitors, acting as early indicators of impending damage to other components of the desert ecosystem. The purpose of this study is to determine the physiological sensitivity of desert soil crusts and some rock lichens found on the Colorado Plateau to air pollutants, as well as to assess their potential as biomonitors for these desert ecosystems.

There are three major areas of focus in this study: field transects, controlled fumigation studies, and documentation of some physiological baseline values in parks throughout the Colorado Plateau. Physiological measurements being used are chlorophyll degradation ratios (chlorophyll a to phaeophytin a), electrolyte leakage, and levels of nitrogenase activity (acetylene reduction). Elemental content of the lichens and crusts will be obtained as well. Three major crustal substrates found in parks on the Colorado Plateau will be examined: limestone from Bryce NP, sandstone from Canyonlands NP, and gypsum from Arches NP.

Field Transects

Field transects are located in the area surrounding the 2250 megawatt, coal-burning Navajo Generating Station near Page, Arizona. This power plant was chosen because of its proximity to Glen Canyon National Recreation Area. Transects run northeast of the plant, with sites located at increasing distances from the plant. Physiological measurements of rock lichens and soil crusts are being made at each site. Also, crusts will be transplanted from less polluted areas

(Canyonlands, Bryce and Arches NP) to these sites to be monitored for any long-term, physiological effects of being placed in the Page basin.

Some results from field transects have already been obtained. Rhizoplaca melanopthalma, a fairly common desert rock lichen, has been shown to exhibit significantly higher chlorophyll damage at sites near the Navajo Generating Station (7 and 12 km) when compared to sites further away (21 and 42 km). Degradation is calculated by the ratio of chlorophyll a (435 nm) to the degraded product phaeophytin a (415 nm). Consequently, a lower value for 435/415 indicates greater damage. Parallel results have been obtained for electrolyte leakage in this same lichen, with significantly higher leakage ($p < .001$) occurring at the closer stations than the two further out. Regression of chlorophyll degradation ratios and electrolyte leakage on distance from the plant is also highly significant ($r = .79$ and .92, respectively; $p < .001$: Fig.1 and 2). Electrolyte leakage values showed a much greater difference between sites near and those further removed from the Navajo plant than chlorophyll degradation, suggesting that electrolyte leakage may be a more sensitive measure of damage (Belnap and Harper, 1990). A similar conclusion was drawn by Fields and St. Clair (1984) when they compared methods of measuring SO_2 damage in lichens.

Nitrogenase activity in crusts and the lichen Collema tenax has also been measured at varying distances from the plant at three different times of year: mid-spring (March), early winter (November), and mid-winter (January). In March, nitrogenase activity in the Page basin was compared with values from Canyonlands NP and Grand Canyon NP. Activity within the Page area was an order of magnitude lower than that measured in Canyonlands and Grand Canyon ($F = 25.1$, $p < .001$, using analysis of variance and Duncan's multiple range test). In November and January, linear regression of site means on distance from the plant showed that increases in nitrogenase activity are significantly correlated with increases in distance from the plant ($p < .001$, Fig. 3; Belnap and Terry, in prep).

Weather factors may play an important role in influencing damage to the lichens. November through April are months with greater precipitation and lower temperatures than average (Sellers and Hill, 1986), generally resulting in longer periods available for photosynthetic activity in lichens since thalli would dry less rapidly (Nash and Moser, 1982), and winter daytime temperatures in the Page area are well within the range for photosynthetic activity in desert lichens tested (Nash and Moser, 1982; Kershaw, 1983; Nash et al., 1982; Lange, 1969). Winter months are also the time when ground fumigation events from the power plant are most likely to occur, given the greater atmospheric stability and the frequent temperature inversions experienced in winter in the Page basin during these months (Anonymous, 1975). These factors, combined with a greater relative humidity from Lake Powell that may increase time available for metabolic activity of lichens in this area, could result in greater of damage to lichens in the study area than at sites outside the Page basin.

It is not clear what pollutants are causing the observed damage. Coal-fired power plants are known sources of sulfur dioxide, nitrogen dioxide, and heavy metals. Exposure of lichens to sulfur dioxide and nitrogen dioxide have been previously implicated in degradation of chlorophyll (Garty et al, 1985; LeBlanc and Rao, 1973; Nash, 1976; Nash, 1973), reduction of photosynthetic rates (Pearson and Skye, 1965; Hallgren and Huss, 1975; Moser et al, 1982; Sheridan and Rosentreter, 1973) and electrolyte leakage (Fields and St. Clair, 1984; Henriksson and Pearson, 1981; Pearson and Rodgers, 1982). High concentrations of some trace metals have been shown to cause chlorophyll degradation, chlorosis, and reduced photosynthetic activity (Garty et al., 1985; LeBlanc and Rao, 1973; Nash, 1971, 1975). This study demonstrates that some particular

pollutant, or combination of pollutants, is affecting both chlorophyll degradation and electrolyte leakage, which may be a clue in pinpointing the causal agent.

Fumigation Chambers

Crusts were taken to dry fumigation chambers in Riverside, CA, where they were exposed for eight weeks. Treatments included ambient air, charcoal filtered ambient air with 95 percent of particulates scrubbed, ambient air with 95 percent of particulates scrubbed, and ambient air with 60 percent of particulates scrubbed. Preliminary results on the effects of dry deposition on these crusts indicate that while crusts on the different substrates seem to experience some fertilization effects, perhaps due to increased nitrates, chlorophyll degradation is significantly higher only on limestone substrates. Sandstone crusts were very close to demonstrating a significant amount of damage ($p = .06$). Gypsiferous crusts, on the other hand, showed a decrease in degradation when compared to controls. Metabolic rates were significantly higher on gypsiferous crusts than controls, while sandstone and limestone crusts showed increases that were not statistically significant. It may be that gypsum is able to buffer the effects of the pollutants more effectively than the limestone or sandstone. These treatments will be repeated, and the effects of wet deposition on crusts and rock lichens will be examined.

Efforts so far have answered some questions, and raised many more. The more pressing ones center around obtaining a more complete picture of the types of damage being done to lichens and cyanobacteria around the Navajo Generating Station. It would be of great value to examine other non-vascular plant species to see if, in fact, the observed damage to Rhizplaca melanopthalma and cryptogamic crusts is prevalent throughout the non-vascular plant community, and if other species in the area could act as even more sensitive biological monitors. Another important area of inquiry would be an examination of which pollutants are responsible for the damage observed, using chronic low levels of fumigation in controlled chambers.

Continued efforts in these directions give us an excellent opportunity to obtain information relevant to the management of public and private lands throughout the desert Southwest. This information is critical in providing land managers a basis from which to make informed decisions regarding on-going or proposed activities that would affect public lands, as well as to provide data with which to evaluate the alternatives and options presented.

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Table 1. Electrolyte leakage values and chlorophyll degradation ratios for Rhizoplaca melanopthalma at different distances from the Navajo Generating Station. Differences between means was analyzed using Duncan's multiple range test.

SITE NO.	DISTANCE FROM PLANT (km)	ELECTROLYTE LEAKAGE (umhos/mg/ml) x ± S.D.	OD 435/415 (nm) x ± S.D.
1	7	1.38 ± .89 a	0.794 ± .100 a
2	12	1.24 ± .20 a	0.715 ± .061 a
3	21	0.17 ± .09 b	0.957 ± .144 b
4	42	0.13 ± .17 b	1.07 ± .039 b
5	225	0.28 ± .17 b	

*a: Values are significantly different from sites 3, 4, and 5 in the same column at the .01 level
*b: Values are significantly different from sites 1 and 2 in the same column at the .01 level