# Lichen Growth Responses to Stress Induced by Automobile Exhaust Pollution

Abstract. *Growth rates were significantly suppressed in juvenile thalli (less than 0.1 square millimeter in initial size) of the saxicolous lichen* Pseudoparmelia baltimorensis *from a Potomac River island with high atmospheric lead burden as compared to the case for a similar island with a lower lead burden. However, larger thalli showed no significant changes in growth response as a result of atmospheric pollution stress. Disruptions in lichen growth thus appear to affect life stages when growth is most rapid and food reserves are low. Once a minimum thallus size is attained, the stress tolerance of the lichen increases.*

The competitive ability of a lichen population in any habitat is related to the establishment and growth rates inherent in the individual lichen population and to the level of tolerance exhibited by the population to various kinds of disturbances. Because many species of lichens are long-lived and exhibit a wide range of tolerances to natural and man-caused environmental stresses, they are often used as indicators of environmental quality.

We report here the results of a 5-month study of the growth of thalli of the saxicolous foliose lichen *Pseudoparmelia baltimorensis* (Gyel. & For.) Hale on two Potomac River islands which exhibit significant differences in the atmospheric pollution burden. We found that juvenile thalli exhibited significant reductions in growth and mature thalli exhibited no growth changes due to pollution stress. These results suggest that stress tolerance commonly associated with lichen populations is a characteristic only of slow-growing mature lichen thalli.

The study areas were two Potomac River islands, Bear Island and Plummers Island, Maryland. Plummers Island is located immediately below the Cabin John Bridge which supports the Capital Beltway (Interstate 495) between Maryland and Virginia. Bear Island is located approximately 6 km upstream of the bridge, remote from surrounding highways.

Because of the close proximity of the two islands and the fact that the habitat conditions are the same on both, we have assumed that the islands are similar in every detail except for the effects of automobile exhaust. In the time since the Cabin John Bridge was built (1965), the annual mean number of vehicles crossing the bridge has steadily increased (*1*). Because there are no nearby industrial sites or coal-fired power plants to contribute pollutants, the two habitats constitute an experimental system which can be used to study responses of lichens to pollutants in automobile exhaust.

Thalli of *P. baltimorensis* were photographed at monthly intervals at Bear and Plummers islands from April to September 1978. Details of the photographic procedure used are presented elsewhere (*2*). A total of 85 lichen thalli were photographed each month. Most of these thalli were initially 1 $mm^2$ or less in surface area.

Increases in thallus surface area were expressed as the percentage of thallus increase (based on the initial surface area). Using these methods, we were able to compare lichen growth for the two habitats and for different initial thallus sizes (*3*).

Table 1 shows the mean thallus increases observed for thalli of three size classes from Plummers and Bear islands. A significant ($P < .05$) increase in the mean thallus size was observed for thalli from Bear Island $< 0.1$ $mm^2$ when compared with thalli of the same size class from Plummers Island. No significant differences in growth response from the two habitats were observed for thalli larger than 0.1 $mm^2$.

The relationship between the initial thallus size and the thallus increase (Fig. 1) is generally a negative exponential one, and natural logarithmic transformations of initial thallus size data exhibit the best fit to regression lines of initial size versus area increase. Thalli from Bear Island exhibit good fit to the regression line calculated. However, thalli from Plummers Island consistently fall below the regression line, an indication that thalli of small size tend to exhibit deviations in growth response as a result of pollution stress. No significant linear relationship between thallus size and thallus growth could be found for the pollution-stressed thalli, an indication that stress effects may influence juvenile thalli to various degrees.

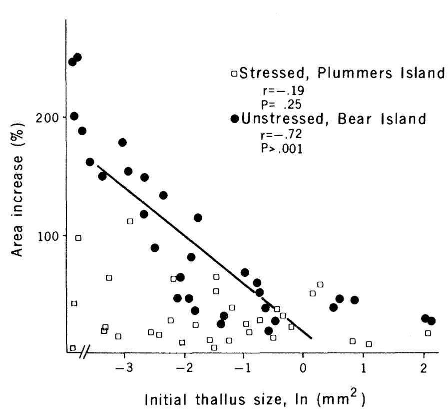


Fig. 1. Thallus increase (in percent) for *Pseudoparmelia baltimorensis* from Plummers Island (□) and Bear Island (●). The regression line indicates the linear relationship between thallus increase and transformed (natural logarithm) initial size data for lichen thalli from unstressed habitats (Bear Island) only. No significant relationship was found for pollution-stressed thalli from Plummers Island.

Although Bear Island and Plummers Island are relatively close together, their atmospheric lead burdens are significantly different. Table 2 illustrates the degree to which atmospheric lead has affected *P. baltimorensis* from Plummers Island relative to other habitats (*4*). Thalli of *P. baltimorensis* from Plummers Island contain significantly higher ($P < .05$) concentrations of lead than thalli from Bear Island or Skyline Drive in western Virginia. A comparison of lead concentrations from herbarium samples of *P. baltimorensis* and from recently collected thalli also demonstrates that the lead content has increased since the Cabin John Bridge was built. Background concentrations of lead appear to be relatively high (approximately 200 $\mu g$ per gram of thallus) in the United States by comparison with lead concentrations in Panama (*5*).

Increased automobile exhaust fallout from the Cabin John Bridge is thus associated with significant increases in the lead content of *P. baltimorensis* thalli from Plummers Island. Thalli from Bear Island are affected only by the normal background fallout.

Lead is an easily measured component of automobile exhaust fallout, and it is used in this study as an indicator of total pollution burden for environmental comparisons of the two island habitats. The growth responses exhibited by *P. baltimorensis* thalli to changes in the pollution burden thus may be due to the effects of a wide variety of pollutants on lichen growth, not only lead. Indeed, lead tolerance in lichens has been shown to be related to the nature of the binding characteristics of lead on lichen cell walls (*6*).

A review of some of the effects of air pollution on lichen growth (*7*) suggests a relationship between lichen growth and air pollution which can be used for bio-


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Table 1. Increase in the thallus area during a 5-month growth interval for *Pseudoparmelia baltimorensis* thalli from Plummers Island and Bear Island, Maryland.

| Initial thallus size ($mm^2$) | Percent increase* | |
|---|---|---|
| | Plummers Island | Bear Island |
| < 0.1 | 44.9 ± 22.7 (11) | 141.3 ± 30.7 (16) |
| 0.1 to 1.0 | 42.9 ± 8.8 (20) | 47.9 ± 15.8 (18) |
| > 1.0 | 35.7 ± 14.7 (10) | 34.7 ± 8.6 (10) |

*Mean percent increase in the area ± 95 percent confidence intervals. The sample size is given in parentheses.

Table 2. Elemental lead contents observed for thalli of *Pseudoparmelia baltimorensis* collected from various locations.

| Location | Collection date | Lead* (μg/g) |
|---|---|---|
| Plummers Island, Maryland | 1974–1978 | 1131.0 ± 179.3 |
| Plummers Island, Maryland | 1938 | 106.0 |
| Bear Island, Maryland | 1974–1978 | 273.0 ± 50.6 |
| Skyline Drive, Virginia | 1974–1978 | 218.5 ± 100.9 |
| Litchfield County, Connecticut | 1971 | 198.0 |
| Barro Colorado Island, Panama | 1975 | 7.0 |

*Elemental values of the lead mean ± 95 percent confidence intervals (sample size, five). Values without confidence limits are single observations.

logical monitoring of atmospheric quality. Lichens near roads and densely populated areas accumulate lead and other metals (*8*).

Our study demonstrates in addition that lichens of varying age and size classes exhibit differences in growth responses to environmental stress. Newly established thalli appear to exhibit the greatest sensitivity to environmental disturbances, and experiments designed to study only large thalli may not be as useful as those designed to examine a wide range of thallus sizes.

The relationship between the initial thallus size and the growth rate has been discussed in recent reviews (*9*). Thallus growth rate has been thought to consist of three phases: (i) a juvenile "prelinear" phase characterized by rapid exponential growth, (ii) a "linear" phase characterized by constant growth, and (iii) a "postlinear" phase during thallus senescence. Proctor (*10*) has developed a simple model of lichen growth based on the assumption that the relative growth rate is proportional to the area of a thallus in an annulus of constant width within the growth margin. This model predicts that the relative growth rate will be constant after a certain minimum size is achieved.

Our data generally fit this model, inasmuch as *P. baltimorensis* thalli from Bear Island exhibit exponential relative growth rates and juvenile thalli (< 0.1 $mm^2$) exhibit significantly greater increases in relative growth than larger thalli. A comparison of the thallus growth of all thallus size classes from Plummers Island, however, shows no difference in growth between juvenile thalli and all other size classes. Thus, the growth behavior of juvenile (prelinear) thalli of *P. baltimorensis* from Plummers Island suggests that prelinear growth may be suppressed in suboptimal environmental conditions. This would ultimately affect the lichen age-class distribution and the colonization potential in disturbed habitats.

Grime (*11*) has recently considered evidence for the existence of three primary strategies in plants that are associated with the degree to which competition, stress, and disturbance influence plant fitness. Of these three strategies, stress tolerance was thought to be most characteristic of lichens. Characteristics of lichens that are associated with stress tolerance are slow growth rates, long periods of physiological inactivity, longevity, and opportunism. These characteristics make it possible for lichens to maintain themselves for prolonged periods of time under adverse conditions and to resume activity rapidly when conditions improve.

*Pseudoparmelia baltimorensis* thalli exhibited growth under both high and low lead conditions. Juvenile thalli from high lead habitats exhibited obvious reductions in growth compared to those from low lead habitats. However, only one thallus was found to exhibit measurable growth in both habitats. After thalli achieved a minimum size (approximately 1 $mm^2$), the relative growth rates of thalli from both habitats were not significantly different. These results suggest that the slow thallus growth of *P. baltimorensis* affords mature thalli a certain degree of stress tolerance. Slow growth rates in mature thalli would be dependent upon the accumulation of a minimum food reserve and thus a minimum size. Juvenile thalli, however, exhibited reduced growth rates at a life stage when growth is normally rapid and food reserves are low. These thalli are thus less tolerant of stress and would be expected to exhibit a greater degree of instability in environmentally stressed conditions.

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**References and Notes**

1. The annual mean number of vehicles crossing the Cabin John Bridge ranged from 40,000 in 1965 to nearly 100,000 in 1977 (data are from the Maryland Department of Transportation).
2. M. E. Hale, Jr., *Bryologist* **73**, 72 (1970); J. D. Lawrey and M. E. Hale, Jr., *Proc. Biol. Soc. Wash.* **90**, 698 (1977).
3. We removed much of the subjectivity associated with studies of lichen growth by expressing lichen growth in terms of area increases rather than radial increases. We also expressed growth in terms of the biomass available to sustain growth during the measurement interval. Thus, area increases (in percent) reflect the amount of lichen growth relative to the initial surface area. We determined the differences in growth rate statistically, using a one-way analysis of variance and Duncan's multiple range test.
4. Samples were digested in acid; lead concentrations were determined for all lichen samples by atomic absorption spectrophotometry.
5. The highest reported lead concentrations in lichen thalli [12,045 parts per million (ppm), dry weight] were obtained for *Cornicularia muricata* from mine spoil material in the Pennines, Derbyshire, England [D. W. Shimwell and A. E. Laurie, *Environ. Pollut.* **3**, 291 (1972)]. Background lead concentrations in England are perhaps lower than those in the United States. Background lead concentrations of approximately 50 to 100 ppm (dry weight) were reported for lichens collected from a rural area in North Yorkshire by M. R. D. Seward [*Lichenologist* **6**, 158 (1974)].
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12. Financial support was provided by the Washington Biologist's Field Club.

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