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Heavy Metal Concentrations in a Lichen of Mt. Rainier and Olympic National Parks, Washington, USA

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It is commonly assumed that the larger National Parks in the United States are pristine places which can provide baseline environmental conditions for comparisons with more developed areas. However, recently it has been recognized that many National Parks are threatened by atmospheric pollution (Stottlemyer 1987). Because of well-documented concerns about air quality in the vicinity of Seattle and Tacoma, Washington (Crecelius and Piper 1973, Crecelius et al. 1974, Larson et al. 1975, Rambo and Powers 1981), this study was conducted as part of an ongoing effort to determine whether air pollutants are significant threats to National Parks of the region.

Until 1985, a copper smelter at Tacoma, Washington, 50 km northwest of Mount Rainier National Park, Washington (Fig. 1) emitted 30 tons of lead annually, along with high levels of arsenic and other metals (Puget Sound Air Pollution Control Agency 1981). Other nearby sources of airborne heavy metals include a coal-fired generating plant at Centralia, 80 km west of the Park, and automobiles within the Seattle-Tacoma metropolitan area 50-100 km to the northwest. Heavy metals are a potential threat because they may effect ecosystems by decreasing nutrient cycling rates and impairing overall productivity (Hogan and Wotton 1984). The objective of this study was to test the hypothesis that an arboreal lichen (Alectoria sarmentosa) within Mt. Rainier National Park contained elevated levels of heavy metals from these sources. This lichen species was chosen because it is common throughout forested areas of the region, and lichens are excellent indicators of heavy metal fallout (Nieboer et al. 1972).

Olympic National Park was selected as an experimental control area because it is located on the relatively undeveloped Olympic Peninsula west of Seattle-Tacoma. The western portion of Olympic National Park receives primarily westerly winds from the Pacific Ocean and is topographically isolated, by the Olympic Mountains, from urban and industrial areas along Puget Sound to the east.

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MATERIALS AND METHODS

Three sampling sites were selected at each park (Fig. 1): Deer Lake (elevation: 1160m MSL), Appleton Pass (1525m), and Hurricane Ridge (1615m) in Olympic National Park; and Golden Lakes (1585m), Tolmie Peak (1757m) and Windy Gap (1755m) in Mount Rainier National Park. Sites ranged from subalpine parkland to moderately forested southwest to northwest facing slopes, generally dominated by mountain hemlock (*Tsuga mertensiana*) and subalpine fir (*Abies lasiocarpa*) with grass-forb or ericaceous openings. Prevailing winds at sites in Olympic National Park were generally from the west to southwest; sites in Mount Rainier National Park generally received west to west-northwest winds. Mean distance of Mount Rainier National Park sites from Tacoma was 58 km to city center (54-61 km). Mean distance of Olympic National Park sites from Tacoma (vicinity of the copper smelter) was 115 km (110-121 km). The Olympic site closest to a large metropolitan area was Hurricane Ridge, 92 km from Seattle city center. Distances of the sampling sites from roads ranged from 1 to 6 km, and averaged 3.5 km.

Lichen samples were collected from branches of approximately 70 subalpine fir trees at each site during August 1983. Samples were stored in labeled plastic bags.

Determinations of concentrations of Arsenic (As), Cadmium (Cd), Copper (Cu), Lead (Pb), and Zinc (Zn) were done on an inductively coupled argon plasma spectrometer (Jarrell-Ash ICAP-9000). Samples were unwashed to prevent loss of surface particles which may be significant in bioaccumulation (Crecelius et al 1974, Koeppe 1981). Plant tissues were dried at 70°C for 48 hours and ground through #20 mesh screen prior to re-drying at 60°C. Samples were dry ashed at 500°C for 6 hours and digested in 20% HNO_3 after cooling. Blanks and tissue standards whose values were determined by comparison to National Bureau of Standards (NBS) Reference Material 1571 (orchard leaf tissue) was analyzed every 24 samples, and occasionally a NBS standard sample was run as a check. Concentrations are expressed in parts per million (ppm) on a dry weight basis. Theoretical detection limits (ppm) were 0.21 for As, 0.02 for Cd, 0.09 for Cu, 0.15 for Pb, and 0.04 for Zn.

Concentrations were transformed to common logarithms prior to statistical procedures to correct for skewed distributions (Garten et al. 1977, Hughes et al. 1980). Addition of 1 to values for As and Cd prior to transformation facilitated computing logarithms of zero values for those metals. After computations of mean log values, 1 was subtracted from the value

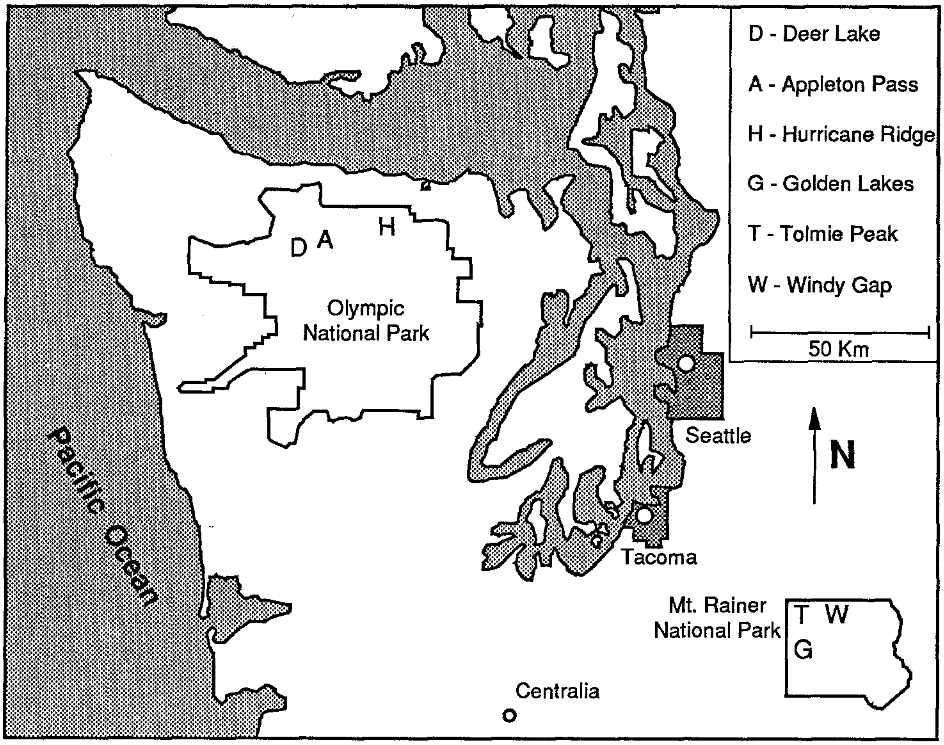

Figure 1. Sites sampled for heavy metal content of lichen.

of the antilogs (Ohlendorf et al. 1982). Means presented for concentrations are geometric. Differences in concentrations were compared using one-way analysis of variance (ANOVA). Scheffe's test was used to separate means if ANOVA showed significant differences (Kim and Kohout 1975). All statistical hypotheses were tested at the 0.05 level of significance; p values are presented where appropriate.

RESULTS AND DISCUSSION

Geometric means for concentrations of heavy metals, except for lead, were significantly greater in lichens from Mt. Rainier National Park than those from Olympic National Park (Table 1). For lead the converse was true.

Paired comparisons of site means generally reflected these differences (Table 2). For As, Zn and Cd the homogeneous subgroups with the greatest concentrations included either two or all three of the sites from Mt. Rainier National Park. For Cu, a single site from Olympic National Park, Hurricane Ridge, was included with the three Mt. Rainier sites as a homogeneous subgroup. Lichens from Hurricane Ridge consistently had the highest metal concentrations, except for Pb, of all sites in

Table 1. Concentrations of Heavy Metals (ppm) in Lichen in Olympic and Mount Rainier National Parks.

		Geometric Mean Dry Weight [95% C.I.]				
PARK and SITE	SAMPLE SIZE	ARSENIC	ZINC	COPPER	CADMIUM	LEAD
MOUNT RAINIER						
Windy gap	70	0.598 [0.532-0.666]	14.52 [13.73-15.35]	1.011 [0.963-1.061]	0.035 [0.028-0.042]	6.899 [6.275-7.586]
Golden Lakes	69	0.401 [0.341-0.464]	15.15 [14.13-16.24]	0.878 [0.828-0.932]	0.016 [0.011-0.021]	4.993 [4.534-5.500]
Tolmie Peak	70	0.296 [0.243-0.466]	15.31 [14.53-16.14]	1.097 [1.042-1.156]	0.039 [0.033-0.046]	8.892 [8.155-9.698]
	209	0.426 [0.388-0.466]	14.99 [14.48-15.51]	0.992 [0.960-1.025]	0.030 [0.027-0.034]	6.751 [6.347-7.181]
OLYMPIC						
Hurricane Ridge	73	0.287 [0.223-0.353]	11.48 [10.67-12.36]	0.920 [0.873-0.969]	0.018 [0.014-0.022]	7.617 [7.032-8.251]
Appleton Pass	71	0.260 [0.211-0.311]	9.818 [9.232-10.44]	0.594 [0.549-0.643]	0.013 [0.011-0.016]	8.172 [7.586-8.802]
Deer Lake	70	0.217 [0.171-0.265]	9.305 [8.578-10.10]	0.693 [0.640-0.750]	0.008 [0.005-0.011]	7.337 [6.543-8.224]
	214	0.255 [0.224-0.286]	10.18 [9.748-10.62]	0.725 [0.692-0.760]	0.013 [0.011-0.016]	7.702 [7.311-8.111]

Table 2. Statistical comparisons of heavy metal concentrations.[1]

PARK-SITE	Element As	Zn	Cu	Cd	Pb
Mt. Rainier-Windy Gap	a	a	a	a	a
Mt. Rainier-Golden Lakes	ab	a	a	b	b
Mt. Rainier-Tolmie Peak	bc	a	a	a	c
Olympic-Hurricane Ridge	bc	b	a	b	a c
Olympic-Appleton Pass	c	c	b	b	a c
Olympic-Deer Lake	c	c	c	b	a

[1]Sites are ranked in descending order of arsenic concentrations. Sites with the same letters for a given element are not significantly different (P > .05, Scheffe's Test)

Olympic National Park. Cadmium levels found at Golden Lakes in Mt. Rainier National Park were not significantly different than those from the Olympic National Park sites.

For lead, the lichens from Tolmie Peak at Mt. Rainier contained the highest levels, as was also true for Zn, Cu, and Cd. However, mean Pb concentrations from two Olympic National Park sites, Appleton Pass and Hurricane Ridge, were not significantly different from the Tolmie Peak mean. Golden Lakes, in Mt. Rainier, had the lowest Pb values, and its mean was significantly different than all others.

Thus, we conclude that sites in northwest Mt. Rainier National Park have been exposed to greater levels of As, Zn, Cu and Cd than sites in northwest Olympic National Park. The most important source of these elements has probably been the copper smelter at Tacoma. Strong inverse relationships were found between the distances of sample sites from the smelter and concentrations of Cd, Cu, and Zn in lichens (r=0.80, 0.80, 0.97, respectively). However, other sources could include the coal-fired electric power generator at Centralia, and general industrial activity in the Puget Sound area.

For lead, the primary regional source is the automobile. Even during periods of smelter operation, lead emissions from automobiles in Tacoma exceeded that of the smelter (Crecelius et al. 1974). Prevailing westerly winds from the Pacific Ocean may also contain significant concentrations of Pb originating in the Portland-Willamette Valley metropolitan area of Oregon to the south. (Fox and Ludwick 1976). Furthermore, no inverse relationship between distance to the smelter and Pb concentration was found (r= -0.198), and lead concentrations were not significantly correlated with concentrations of the other four metals ($-.04 \leq r \leq .21$). Thus the relatively higher than expected levels of lead at Olympic National Park sites may not be a result of contamination from industrial activities in the Seattle-Tacoma area, but may be caused by dispersed regional and global sources.

Although both Parks are apparently being exposed to heavy metals from a variety of sources, concentrations in lichens are generally similar to or less than those reported for remote and undeveloped areas. For example, Doyle et al. (1973) found mean Zn concentrations of 12-18 ppm, and Cu concentrations of 4-7 ppm in Alectoria lichens from a pristine area of northwest Canada, compared to means of about 9-15 ppm and 0.6-1.0 ppm for Zn and Cu in this study. In an undeveloped area of Wyoming and Montana, Erdman and Gough (1986) found mean background levels of As, Cd and Pb in a terricolous lichen (Parmelia chlorochroa) to be 1.0, 3.4, and 97 ppm, respectively. Although there are significant differences in heavy metal concentrations of various lichen species, even under the same levels of exposure (Folkeson 1979), the mean concentrations observed in this study for As, Cd, and Pb are all lower than those reported by Erdman and Gough.

The heavy metal concentrations reported in this study are far below toxic levels for plants (Martin and Coughtrey 1982). However, with increasing industrialization and human development of the Puget Sound area, the potential will exist for serious contamination of Olympic and Mt. Rainier National Park by airborne heavy metals. It is important to establish baseline levels of heavy metal concentrations in the National Parks and to monitor trends over time (Stottlemyer 1987). This study has provided reference concentrations so that future changes in heavy metal deposition can be detected.

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