D. NORTH CASCADES NATIONAL PARK

1. Description

Nicknamed the "American Alps", the North Cascades National Park encompasses 271700 ha of rugged mountain scenery in north-central Washington, about 80 km east of Bellingham. The complex includes North Cascades National Park (est. 1959), and the Ross Lake/Chelan Lake National Recreation Areas (est. 1968). The enabling legislation for NOCA recognizes the spectacular mountains and associated features:

In order to preserve for the benefit, use, and inspiration of present and future generations certain majestic mountain scenery, snowfields, glaciers, alpine meadows, and other unique natural features in the North Cascade Mountains...there is hereby established the North Cascades National Park ...

The North Cascades National Park extends north from Snoqualmie Pass to the Canadian border. The area has extensive topographic relief. Mountain summits rise abruptly 1800-2600 m above the valley floor. Towering above this crest are two dormant volcanoes - Mount Baker and Glacier Peak. An outstanding feature of the main eastward and westward-flowing streams is their low gradient to within 6-7 km of the main divide. Another striking feature is the relatively uniform elevation of ridgetops.

The North Cascades rank among the world's great mountain ranges and comprise the wildest, most impenetrable reaches of the Cascade Range in northwestern Washington State. To provide additional legislative protection for the region, Congress designated about 92% of the park complex as the Stephen Mather Wilderness, in 1988. The park complex is flanked on the south, east, and west by national forests, and to the north, by provincial lands of British Columbia.

a. Geology and Soils

Unlike the southern Cascades, the North Cascades are to a large extent comprised of ancient sedimentary rocks, folded and at least partially metamorphosed. Intrusions of large granitic batholiths also are common. The geology of the area is a complicated interplay of tectonics, volcanism, metamorphism, erosion, and deposition. Crystalline rocks consisting of schist, gneiss, and granite comprise the primary rock types in the park. Many of the peaks are granite-gneiss with areas of homogeneous massive granites (Harris and Kiven 1985). Detailed geochemical analysis of the watershed of South Cascade Lake about 8 km west of the park showed the bedrock consists of hornblende-quartz-plagioclase gneiss, migmatic gneiss (~ 40% plagioclase, 20% quartz, 20% amphibole, 10% biotite, and 10% K-feldspar), quartz diorite (55% plagioclase, 25% quartz, 10% hornblende + biotite, and 3% K-feldspar), and basaltic dikes (Drever and Hurcomb 1986). Perhaps most important with respect to the sensitivity of the waters in the area, Drever and Hurcomb (1986) reported the presence of trace amounts of calcite in joint planes in the quartz diorite, in veins, and in marble bands.

Extreme variability of parent materials combines with effects of extensive glaciation to produce an extremely complex soil pattern in the North Cascades. Residual rock is frequently covered by or mixed with glacial materials. The rapid pace of geologic erosion on steep slopes also restricts soil formation over large areas where rocky/stony soils predominate. Knowledge of soils in this area generally are limited, but work done on the Mount Baker National Forest classified soils into four groups: (1) deep glacial, (2) deep-glacial, lake-deposited, (3) deep residual, and (4) shallow residual. The deep glacials included gravelly loams to loams in valleys and side slopes to elevation of 1375 m. Lake deposits in valley bottoms and toeslope positions tended to be finer-textured loams to silty clay loams. Deep residual soils derived from sedimentary, schist, and granitic rocks were found on steep midslope and toeslope landforms and were gravelly sandy loam to silt loam in texture. Shallow residual soils were situated on ridgetops and steep side slopes unaffected by glacial deposits over sedimentary and metamorphic rock types. Soils east of the crest reflect the drier conditions and are influenced to some extent by volcanic ash, or loess. Textures range from stone-free loams to cobbly loams.

b. Climate

Steep topography and orographic climatic influences produce a diverse range of biogeoclimatic zones and ecosystems. The average annual precipitation ranges from 280 cm on the western side, to only 90 cm on the eastern side of the park complex. The heavy precipitation and cold, harsh winters of the area have produced an abundance of alpine lakes, ice caps, and more than 300 glaciers.

c. Biota

Vegetation distribution patterns are strongly influenced by edaphic and climatic factors, primarily the east-west precipitation gradient and conditions associated with increasing elevation from valley bottom to ridgetop -- shallow soil, reduced air temperature, steep slopes, and shorter growing season. On the western side, lower elevation forests of deep valleys support stands of giant western red cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), and Douglas-fir (*Pseudotsuga menzyiesii*) to about 550 m. Pacific silver fir (*Abies amabilis*) replaces western red cedar in the western hemlock-silver fir zone, which grades to mountain hemlock (*Tsuga mertensiana*), subalpine fir (*Abies lasiocarpa*), and Alaskan yellow cedar (*Chamaecyparis nootkatinsis*) in the subalpine zone and extends up to the alpine zone, about 1800 m above sea level. Understory shrubs and herbs are most abundant in open forests. Riparian areas also support a rich diversity of shrubs and herbs. At higher elevations, alpine and subalpine habitats support lush wildflower meadows, for which the Park is renown.

On the eastern slopes of the park, larch (*Larix* species) and white bark pine (*Pinus albicaulis*) grows in subalpine meadows above stunted Engelmann spruce (*Picea engelmanii*) and subalpine fir (*Abies lasiocarpa*). Douglas-fir dominates at the mid elevations on the east side, whereas hemlock and silver fir occur on the west side. On the driest sites of the lowest eastern foothills, ponderosa pine (*Pinus ponderosa*) predominates. A comprehensive listing of the park flora is available through the NPFLORA database (Waggoner 1989). Vegetation communities have been plotted on a 1:175,000 scale topographic map by using Landsat MSS data. These maps are available at park offices.

Vegetation types as discussed by Franklin and Dyrness (1988) include the western hemlock zone, the Pacific silver fir zone, and the mountain hemlock zone. In the western hemlock zone (to 1000 m elevation), large areas are dominated by forests of Douglas-fir (*Pseudotsuga menziesii*), often in mixture with western red cedar (*Thuja plicata*) and mountain hemlock (*Tsuga mertensiana*). The climate of this zone is wet, mild, and maritime, but differs widely with elevation, latitude, and orographic influences. Precipitation averages 150-300 cm and occurs mainly during winter. The Pacific silver fir zone lies between the temperate mesophytic western hemlock zone and the subalpine mountain hemlock zone at about 900-1300 m in elevation. Species composition differs widely depending on stand conditions and history. This zone is cooler and wetter than lower elevations and receives considerably more precipitation as snow. The mountain hemlock zone is the highest forested zone along the western slope of the Cascades to elevations of 1300-1700 m. It consists of a lower subzone of closed forest and an upper parkland subzone. Mountain hemlock (*Tsuga mertensiana*) predominates in the lower subzone, and a mosaic of forest patches and tree groups interspersed with shrub and herbaceous plants forms the upper subzone. This zone is the coolest and the wettest of the forested types in western Washington, and has the highest snow accumulation.

Wetmore (1983), Esserlieu and Olson (1986), and Matthews (1992) have compiled lists of lichen and bryophyte species for NOCA and the surrounding region.

Indigenous wildlife in the park includes black bear, mountain lion, bobcat, mountain goat, and 120 bird species year-round. Thirteen species of amphibians are present, mostly in lowland habitats, and some in subalpine lakes or creeks. Reptiles are relatively more abundant than amphibians on the drier eastern slopes of the park complex. Locations of endangered, threatened, and sensitive wildlife species sighted from 1967-1988 have been overlayed on the vegetation maps. Rare or threatened bird species include the northern spotted owl, the bald eagle, and the peregrine falcon (Bjorklund 1983). Rare or threatened mammals include the grizzly bear. A more complete listing for both T&E plants and animals is given in Bjorklund (1993).

d. Aquatic Resources

Three dams impounding Ross, Diablo, and Gorge Lakes provide electrical power totalling 694000 kilowatts for Seattle. Construction on the dams began in 1919, and continued to 1949. The reservoirs are an important recreational element in the park, in part, because of their accessibility. In contrast, the 245 natural lakes in the park are in subalpine and alpine settings, and are accessible only on foot. The natural lakes and stream valleys were formed by glacial action which is still evident throughout the park. Most of the lakes have been sampled for basic information on the fisheries (R. Wassem, unpublished data) and another 56 lakes have been sampled for an ongoing research effort related to the effects of fish stocking (Liss et al. 1991).

2. Emissions

The emissions in the three counties adjacent to NOCA and King County to the south (Figure 18, Table 32) indicate a potential for air quality degradation in the park. In addition, emissions from British Columbia have the potential to impact the park. Although emissions are currently low adjacent to the park, contributions from midrange source areas such as Seattle and Vancouver pose a potential future problem.

3. Current Monitoring and Research Activities

a. Air Quality/Deposition

(i) Wet Deposition

NOCA has a NADP/NTN site located at Marblemount immediately to the west of the park at an elevation of 123 m. The site has operated since February 1984. Precipitation-weighted mean

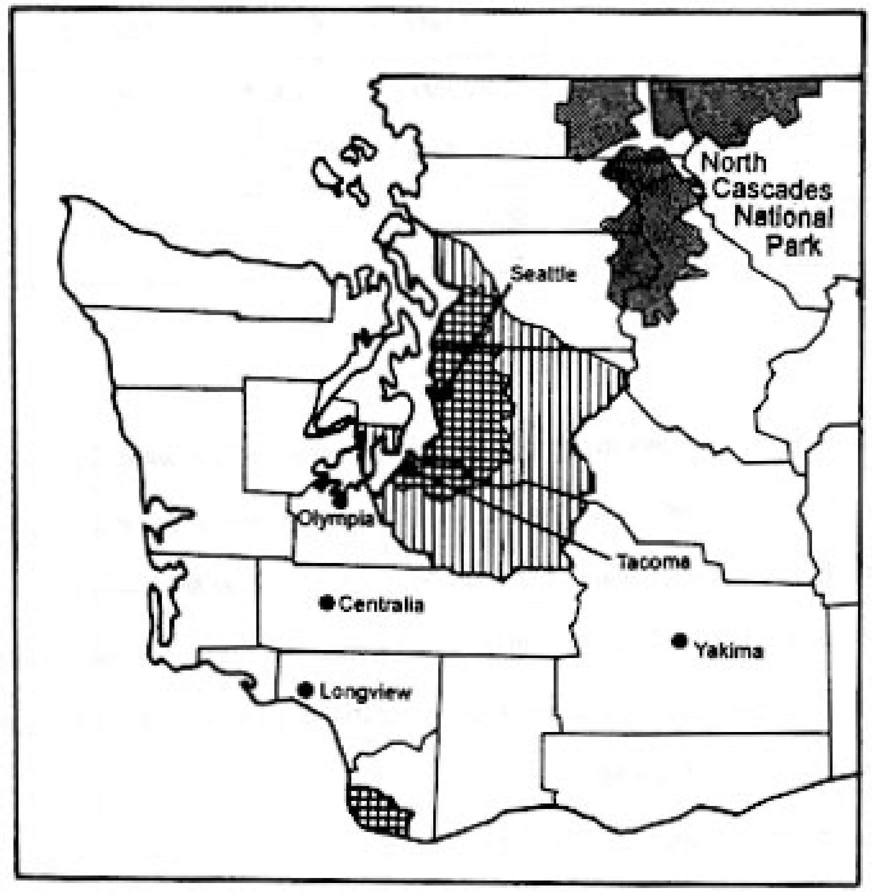

Figure 18. North Cascades National Park and proximity of urban areas in Washington. Nonattainment areas outside the park are shaded with vertical lines.

Figure 18.North Cascades National Park and proximity of urban areas in Washington. Nonattainment areas outside the park are shaded with vertical lines.

Table 32. Emissions in the counties adjacent to NOCA. Emissions from the province of British Columbia also are provided.

County	PM_{10}	SO_x	NO_x	VOC	CO
Skagit	4,959	8,365	12,367	67,039	14,234
Snohomish	22,989	2,773	23,615	229,201	44,882
Whatcom	6,627	9,470	12,862	120,633	15,637
King	72,828	8,683	87,108	719,141	124,856
Washington Total	107,403	29,291	135,952	1,136,014	199,609
British Columbia	2,456,000	104,000	269,000	--	--

Sources: WDOE (1993), Placet et al. (1990).

annual chemistry at this site shows that the site receives precipitation with slightly elevated levels of SO_4^{2-} and NO_3^- (Table 33). As a result, pH is slightly less than that experienced at other Pacific Northwest sites such as the Hoh Valley in OLYM. The NADP site at Marblemount is located at an elevation of 123 m and probably is representative of deposition in the low elevations on the west side of the park. Precipitation volume increases at higher elevations on the west side of the park and decreases dramatically to the east.

Wet deposition chemistry also has been measured at four sites in the park, some since 1980. These data consist of event and weekly bulk deposition data collected and measured by NOCA staff. Measurements consisted of pH and conductivity. These data have been summarized for 1980-1986 in an internal park report.

Snow samples were collected in the park in 1983 as part of a study of snow chemistry along the crest of the Cascades/Sierra Nevada. The average concentration of snow chemistry in the North Cascades based on five sites sampled in 1983 (Laird et al. 1986) show that the snow chemistry (Table 34) is more dilute than the precipitation at Marblemount. Sulfate and nitrate concentrations in the snow are only 30 to 50% of concentrations in the rain.

Table 34. Snow chemistry (μeq/L) for NOCA based on five samples collected in 1983 (Laird et al. 1986).

Parameter	Concentration
H^+	5.0
Ca^{2+}	1.1
Mg^{2+}	0.4
K^+	1.1
Na^+	4.1
NH_4^+	0.4
NO_3^-	3.0
Cl^-	7.2
SO_4^{2-}	3.5
SO_4^*	2.8

* non-marine

Other studies of snow and precipitation chemistry in and near the park support similar values to those cited earlier. Duncan (1992) measured weekly bulk precipitation at Stevens Pass located about 75 km south of NOCA. The deposition chemistry at this pass was measured from 1984 to 1991; for 1991, the deposition at Stevens Pass was 7.6 kg/ha for SO_4^{2-} (2.5 kg/ha as S), 0.9 kg/ha for NO_3-N, and 0.3 kg/ha for NH_4-N. Stevens Pass had a total of 207 cm precipitation in 1991. Average volume-weighted concentrations were 8.4 μeq/L for SO_4^{2-}, 6.1 μeq/L for NO_3^-, and 2.7 μeq/L for NH_4^+. Chloride concentrations averaged 5.0 μeq/L. These concentrations were somewhat similar to volume-weighted values from the Marblemount NADP/NTN site for 1991 which were 6.7 μeq/L SO_4^{2-}, 5.0 μeq/L for NO_3^-, and 1.7 μeq/L for NH_4^+. Chloride at Marblemount was 7.0 μeq/L, reflecting the higher marine aerosols at lower elevation.

In 1974 and 1975, 50 precipitation events were measured by Dethier (1979) in the Copper Lake Basin, a subalpine site west of NOCA. These data were used by Drever and Hurcomb (1986) to develop a mass balance for South Cascade Lake located about 8 km from the west park boundary. Precipitation pH never exceeded 5.15 during the study, and SO_4^{2-} averaged 21.6 μeq/L. Measured SO_4^{2-} deposited was 47 kg/ha/yr. Dethier (1979) attributed the acidic precipitation to S emissions from the Puget urban corridor. Schermerhorn (1967) showed a strong relation between elevation and precipitation volume for this portion of western Washington, approximately by PRECIP (mm) = 1.94 ELEVATION (m) + 703, = 0.97, n = 8 (from Figure 3 in Dethier 1979). Although precipitation volume increases with elevation in this area, Dethier (1979) found no consistent chemical differences between precipitation collected at a range of elevations. Snow chemistry also was collected near NOCA in the Mount Baker/Snoqualmie National Forest at an elevation of 1800 m to study the effects of snowmelt on Bagley Lake (Loranger and Brakke 1988). The eight snow samples collected at three sites in 1984 and 1985 showed low acidity (pH 5.3-5.5) and low concentrations of SO_4^{2-} (1.7-4.4 µeq/L). They concluded that these acid anion concentrations were too low to result in significant pH depression during snowmelt.

Snow chemistry also was measured about 100 km north of NOCA in British Columbia during 1982 (McBean and Nikleva 1986). The two sites closest to NOCA had NO_3^- concentrations of 5.5 and 4.8 µeq/L and pH values of 4.9 and 5.0. The sites with excess nonmarine SO_4^{2-} were located downwind of Vancouver, British Columbia.

(ii) Occult/Dry Deposition

Cloudwater chemistry was measured at four sites in or near the NOCA during summer 1988 (Basabe et al. 1989a). Eighteen samples were collected from the four sites which ranged in elevation from 50 to 1900 m. The low-elevation sites had significantly greater NH_4^+ concentrations which were attributed to agricultural sources. The poor charge balance in the low elevations samples was attributed to bicarbonate ions which were not measured. The higher elevation sites had greater concentrations of H^+. The sites in NOCA generally had lower concentrations of S and N in the cloudwater than sites located to the south (east of Seattle).

(iii) Gaseous Monitoring

Ozone is currently being monitored at Marblemount and at Lyman. A third site operated by the Washington State Department of Ecology is located at Lynden. Of the three sites, Marblemount exhibited the highest O_3 concentrations in 1992 with a maximum episode of 92 ppb (Basabe 1993). Back trajectories implicated Vancouver, B.C. as the source area for this event. Basabe et al. (1989a) also measured ozone concentrations in excess of 120 ppb at monitoring stations directly west of NOCA.

Tables 35-37 (also see Figures 19 and 20) summarize gaseous monitoring data from the EPA AIRS monitoring sites in Washington during 1985-1992. Ozone concentrations (Table 36) throughout the region generally were low, although several sites east of Puget Sound recorded values approaching 100 ppb during 1985-1992.

Table 35.Summary of nitrogen dioxide data from the EPA AIRS (Aerometric Information Retrieval System) Monitoring Sites within 100 km of the class I national parks in Washington during the period 1985-1992. Sites are identified in Figures 19 and 20.

	Annual Arithmetic Mean (ppb)		
Site #	1985	1986	1987
53-033-0080	19	18	13
53-033-0082	34	32	35

Table 36.Summary of ozone data from the EPA AIRS (Aerometric Information Retrieval System) Monitoring Sites within 100 km of the class I national parks in Washington during the period 1985-1992. Sites are identified in Figures 19-20.

	1-hour Maximum (ppb)							
Site #	1985	1986	1987	1988	1989	1990	1991	1992
53-009-0012	-	-	70	40	65	64	56	63
53-011-0011	-	-	-	120	98	124	102	121
53-011-1001	100	100	-	-	-	-	-	-
53-033-0010	120	130	110	140*1	90	126*1	109	94
53-033-0018	-	-	-	-	100	119	-	-
53-033-0088	-	-	-	-	-	102	101	-
53-033-2001	90	80	-	-	-	-	-	-
53-033-7001	100	120*1	140	110	100	149*3	112	108
53-053-0004	90	100	-	-	-	-	-	-
53-053-0005	100	110	100	110	-	-	-	-
53-053-1001	110	100	110	110	-	-	-	-
53-053-1008	-	-	110	110	103	130*2	99	103
53-053-1009	-	100	110	110	-	-	-	-
53-061-2001+	110	90	-	-	-	-	-	-
53-073-0005+	-	-	-	-	52	83	82	72

*(#) - Number of exceedances of primary standards (NAAQS) for a pollutant (see Table 1).
\+ - Indicates ozone monitors in closest proximity to NOCA.

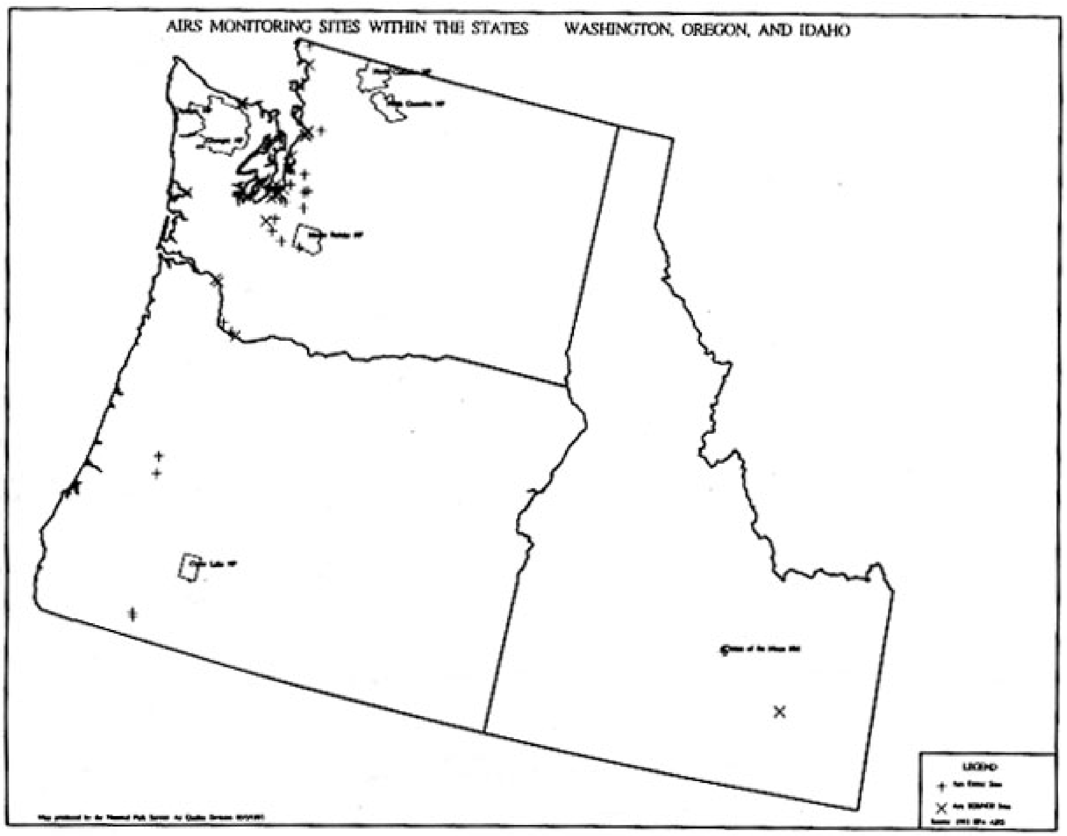

Figure 19. Location of EPA AIRS monitoring sites within the states of Washington, Oregon, and Idaho.

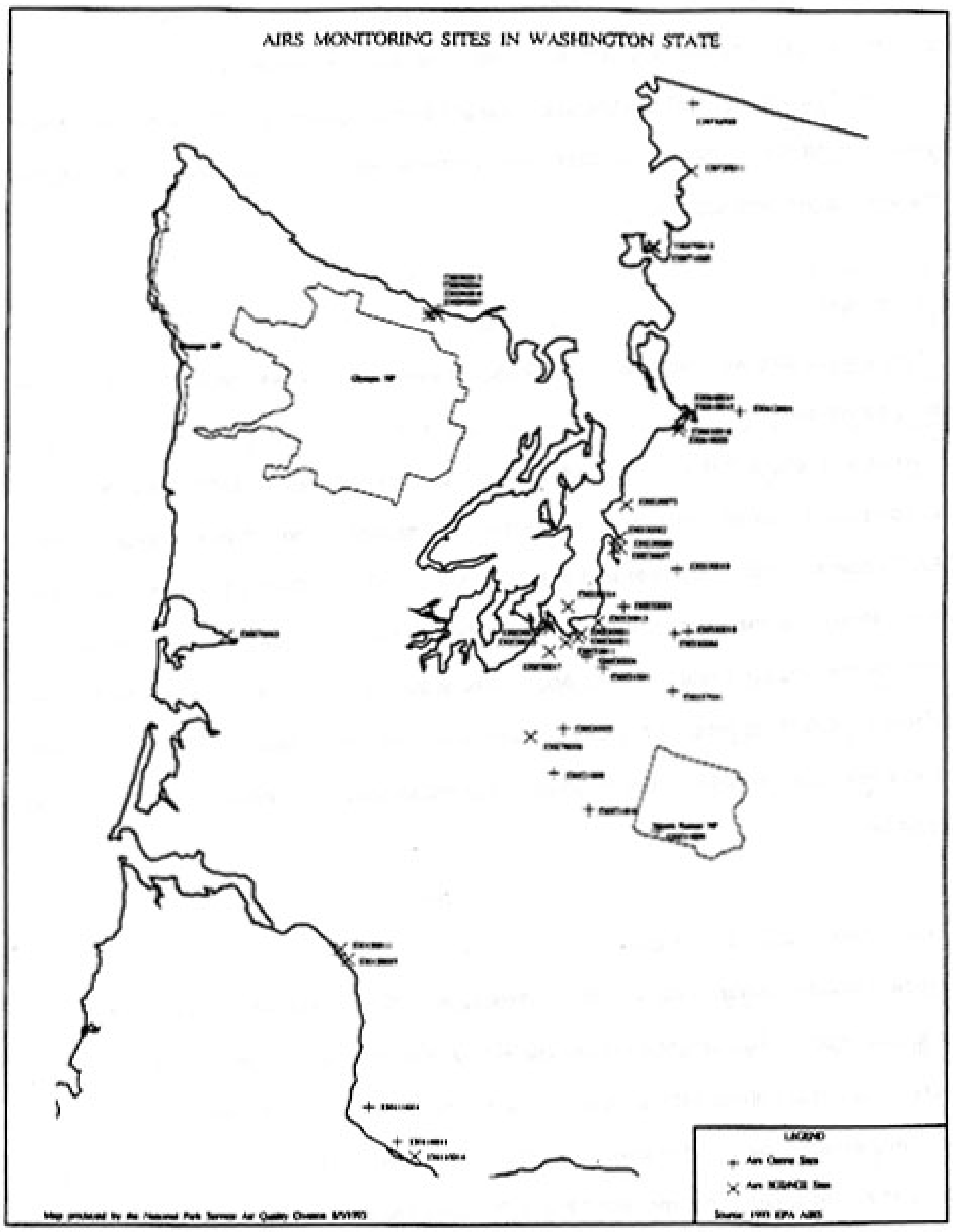

Figure 20. Location of EPA AIRS monitoring sites within the state of Washington.

Figure 20.Location of EPA AIRS monitoring sites within the state of Washington.

Nitrogen dioxide (Table 35) and sulfur dioxide (Table 37) values generally were low in the region and no exceedances occurred for either of the primary standards.

These data indicate that currently ozone is the primary gaseous pollutant posing a threat to vegetation in NOCA. Furthermore, ozone levels may increase in the future as urban populations to the west of the park expand.

(iv) Particulates

Fine particulates were measured at NOCA, but the monitoring was discontinued because of funding constraints.

NOCA was also a PREVENT site (Malm et al. 1993 [in review]). PREVENT was a short-term study conducted to apportion atmospheric aerosols to scattering/extinction and to source types at MORA (Tahoma Woods, Paradise) and at NOCA (Marblemount). During the measurement period (summer 1990), fine mass concentrations were relatively high at NOCA, compared to other locations in the western United States. About 60% of the fine mass was associated with carbon compared to 20-30% in most rural areas elsewhere in the United States. About 60% of the fine mass was attributed to sulfates, 5% to nitrates, and 5% to soils. The standard visual range was about 54 km.

(v) Trace Metals/Toxics Deposition

Trace metal deposition is not monitored directly at NOCA. However a study was initiated under an Interagency Agreement between the NPS (AQD) and the Los Alamos Laboratory to measure trace metal concentrations in various terrestrial receptors. Samples were collected from 20 randomly selected plots in the park for soils, subalpine fir needles, surface duff, and lichens (Gladney et al. 1993, Duriscoe and Stitt 1993). The samples were analyzed for metals and S, but an interpretive report has not been completed.

Trace metal (arsenic [As] and lead [Pb]) deposition was assessed in the park by collecting hair from mountain goats (Frenzel and Starkey 1987). Concentrations of As and Pb in the park were relatively low, although the values were greater than those measured in MORA. The presumption was that most of the metals were deposited close to the smelter. A sample of lichen species from NOCA (Frenzel et al. 1990) indicated that concentrations of trace metals were similar to remote nonindustrialized areas. Similarly, pesticides/herbicides have not been measured in deposition, but samples have been collected of surface waters, fish tissue, and sediment samples from lakes Chelan, Ross, and Diablo (Funk et al. 1987). Water and fish samples generally had pesticide concentrations at or below the detection limits for trace contaminants. Concentrations in the lake sediments generally were slightly above detection limits. Trace metals in fish from these waters also were low (Funk et al. 1987).

b. Water Quality

NOCA staff have developed a High Lakes Database from surveys of about 115 of the 245 natural lakes in the park. The data were collected over the last two decades and include site assessments for fisheries and measurements of pH, alkalinity, and conductivity. The data have not been summarized. Analytical protocols were appropriate for fisheries assessments.

The first complete assessment of the acid-base chemistry of lakes in the NOCA was conducted in 1983 in which six NOCA lakes were sampled (Brakke 1984). Eight additional NOCA lakes were sampled in 1984 (Brakke 1985). A probability sample of lakes during EPA's Western Lake Survey resulted in six NOCA lakes being sampled (Landers et al. 1987, Eilers et al. 1987).

Synoptic surveys of 56 lakes in 1989 and 31 lakes in 1990 were conducted by Liss et al. (1991). The primary focus of this study was to evaluate the effects of lake stocking on biota in these lakes. Most of the effort was devoted to sampling the biological components of the lakes including fish, amphibians, benthic invertebrates, and plankton. Minimum lake alkalinity values measured in these two years were 6 and 8 µeq/L. Because the focus of this study was on the biota, sulfate, chloride, and silica were not measured in these synoptic surveys of 1990-91.

Unlike many other lakes in the West which have moderately high Na^{+} concentrations, many NOCA lakes had comparatively high Ca^{2+} concentrations (Figure 21) which supports the results of Drever and Hurcomb (1986) who studied weathering in South Cascade Lake near the southwestern boundary of NOCA. Drever and Hurcomb (1986) attributed the high Ca:Si and Ca:Na ratios to dissolution of calcite; silicate weathering was judged insufficient to account for the base cation production.

Loranger and Brakke (1986) in a study of six area lakes concluded that Si weathering was insufficient to account for base cation production in their study lakes. Excess SO_4^{2-} in one of the lakes was attributed to weathering of pyrite present in the watershed.

Lake Chelan was the subject of a water quality assessment study related to nutrient enrichment from watershed studies (Patmont et al. 1989). An estimated 75 to 90% of the phosphorus (P) load to the lake is from natural sources. The anthropogenic sources are from agriculture, stormwater runoff, and septic systems located outside the park.

Funk et al. (1987) studied baseline water quality in lakes Ross, Diablo, and Chelan. These are relatively high alkalinity lakes (500 to 800 µeq/L) and were considered highly pristine systems by the investigators (Funk et al. 1987).

c. Terrestrial

A partial species inventory of the park flora is maintained on the NPFLORA database (Waggoner 1989), and the park maintains a plant herbarium. Lichens, bryophytes, alpine, and subalpine flora have been well described. A study of the ecology of alpine lichens is currently underway. Fire ecology has been studied, as well as forest disturbances and primary succession on glacial soils. Vegetation cover types have been mapped (Agee and Kertis 1986) and transferred to topographic maps. Several vegetation surveys have been carried out in the Silver Lake and Stetattle Creek Research Natural Areas. Threatened, endangered, and sensitive

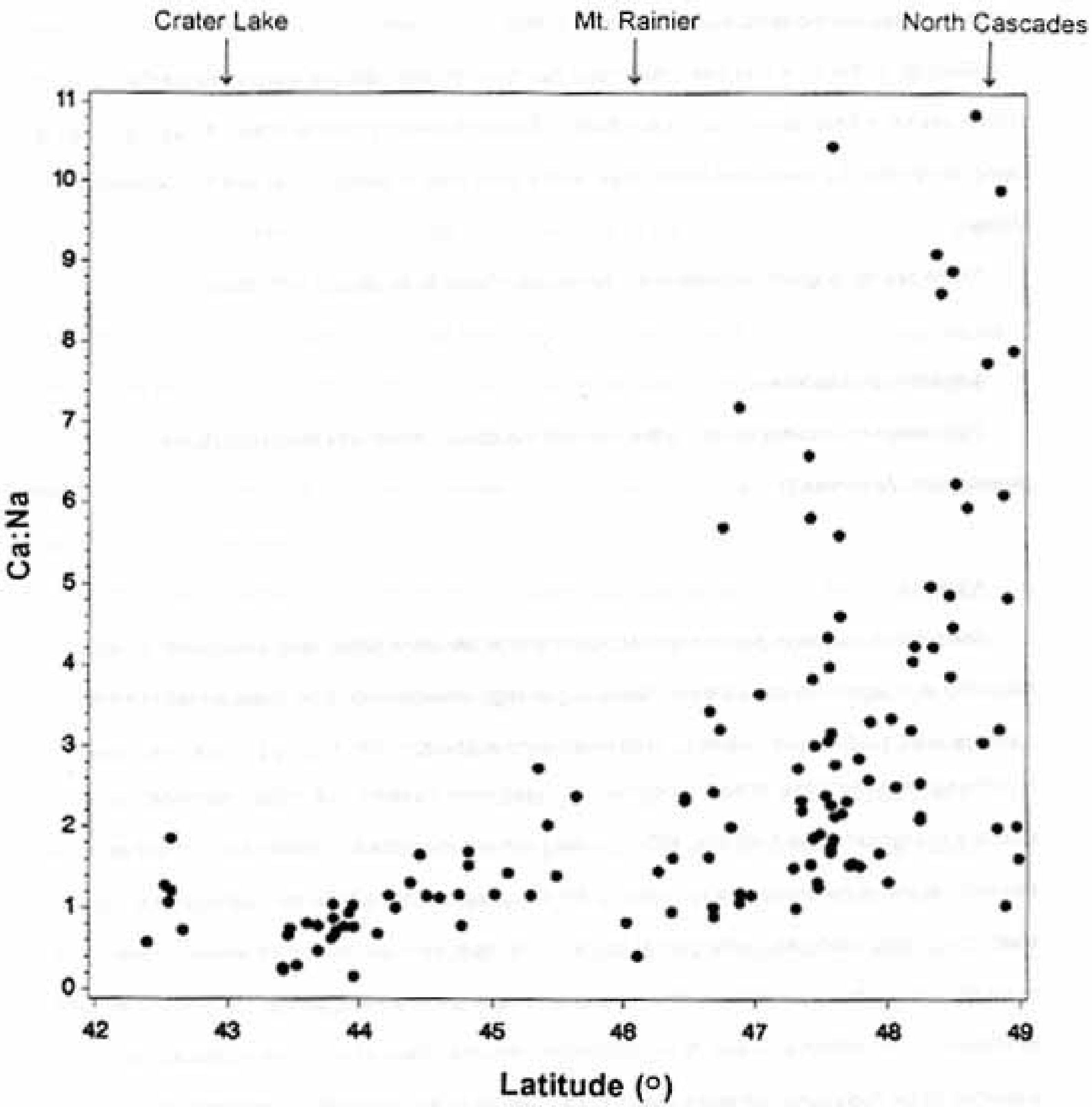

Figure 21. Molar ratio of sea-salt corrected calcium and sodium in Cascade lakes. (Data from Eilers et al. 1987).

Figure 21.Molar ratio of sea-salt corrected calcium and sodium in Cascade lakes. (Data from Eilers et al. 1987).

vascular plants were inventoried by Wasem (1989). Wildlife species have been inventoried with the cooperation of the surrounding National Forest personnel. Rare, threatened, and cryptic wildlife species were described by Bjorklund (1993).

Geology in the park has been described by Harris (1990). Several studies of glacial processes have been carried out in the Boston Glacier Research Natural Area. A geologic map is being developed for the Mount Baker area, and a soils map is being developed for the Stehekin Valley.

There are no ongoing studies of the terrestrial effects of air quality in NOCA.

4. Sensitive Receptors

The review of relevant literature that formed the basis for these recommendations is presented in Appendix D.

a. Aquatics

The primary sensitive receptors in NOCA are high-elevation lakes (and associated biota) not receiving drainage from glacial melt. Sampling of high-elevation lakes by Brakke (1984, 1985), Landers et al. (1987), and Liss et al. (1991) shows that low-ANC (~ 10 μeq/L) lakes are present and presumably sensitive to acidic deposition. Headwater streams in the high-elevation areas also are presumed to be sensitive, although data are not available to confirm this. Lakes and streams receiving meltwater are not likely to be sensitive receptors because of the high physical weathering rates associated with glacial action. The most sensitive receptors would be expected to be located on the west side of NOCA because of the much greater precipitation and likelihood of enhanced deposition of S and N in cloudwater. Another class of sensitive receptors are expected to be high-elevation lakes that are ice-covered more than eight or nine months of the year. These lakes may not achieve water temperatures > 10 ^{o}C and therefore may be sensitive to accumulating inorganic N.

Amphibians would be among the most sensitive native aquatic biological receptors to air pollution stress in NOCA (cf Baker et al. [1990] or Eilers et al. [1984] for an assessment of biota sensitive to acid stress), although other factors such as fish stocking may exert a greater role in influencing their current abundance in the park (Liss et al. 1991).

b. Terrestrial

With regard to ambient air quality near NOCA, sulfur and nitrogen deposition presently are too low to cause much concern about effects on terrestrial resources. Regionally, the highest potential for air quality to impact terrestrial resources is associated with ozone near industrialized urban areas and rural areas downwind. To date, there has been no research to determine the effects of ozone on terrestrial resources in NOCA. Consequently, this assessment of potentially sensitive species in the park is based on research conducted in other ecosystems, on related species or taxa of organisms.

Much of the research effort over the past 50 years to document air quality effects on terrestrial vegetation has focussed on documenting forest growth and physiological condition in relation to "forest decline", and on establishing dose-response functions for economically important tree species (Smith 1990). Less effort has been directed to the study of mosses and lichens, except near heavily-polluted areas of Great Britain, Europe and Canada (Bates and Farmer 1992). There are only a few studies of the effects of pollution on lichens in the Pacific Northwest (Denison and Carpenter 1973, Hoffman 1974, Denison et al. 1977, Johnson 1979, Taylor and Bell 1983, Rhoades 1988). Physiological studies of dose-response functions have yielded the most conclusive results, but the high cost of these studies has limited their applicability.

More information is available on ozone effects than on N and S effects. The most comprehensive ozone research has been conducted in the mixed-conifer forest and other vegetation types of California, on the dominant, commercially important tree species (Miller et al. 1989; Peterson et al. 1987, 1991, 1992 a,b; Horner and Peterson 1993). Few data are available to relate ozone dose or exposure to mature trees, and almost no data exist for herbaceous species.

Provisional lists of potentially sensitive vascular plant species indigenous to NOCA are presented in Table 38. A listing for lichen and moss species is provided in Table 39. This list of potentially sensitive species is only a preliminary compilation of known or suspected sensitive plants. The information should be viewed as largely preliminary, due to the limited database. Sensitivity classes for vascular plants, lichens, and bryophytes have been developed to summarize the high variability in response to different pollutants that has been documented within plant species. The wide range of variability in plant responses to pollutants is attributable to differences in research methodology, environmental conditions, and to natural variability in species sensitivity. Specific values for pollutant sensitivity are listed where data exist. The application of much of this sensitivity data to the Pacific Northwest must be undertaken with caution because the data are mostly from laboratory fumigation experiments on seedlings and have not been field tested on mature trees. The reliability of extrapolating pollutant responses from the laboratory to the field and from seedlings to mature trees is questionable, and studies are currently underway at EPA, Corvallis to compare results (Bates and Farmer 1992; Peterson et al. 1992a,b; Stolte et al. 1993a,b).

In general, reliable data on the sensitivities of vascular plants, bryophytes, and lichen flora to air quality in NOCA are lacking. Limitations of the existing data on terrestrial vegetation include: (1) lack of park-specific or regional data, (2) lack of testing for laboratory dose-response data under field conditions, (3) poor correspondence between visual injury estimates and dose-response functions, and (4) lack of information on noncommercial species. Esserlieu and Olson (1986) attempted to rank the vulnerability of national parks to atmospheric pollutants by evaluating the potential sensitivities of park flora and surface waters to pollutants. However, limitations of the emissions and deposition data, as well as the plant sensitivity data compromised

Table 38. Partial list of potentially sensitive vascular plant species in NOCA.

		Sensitivity[a]		
Common Name	Scientific Name	Ozone[b]	Sulfur	Nitrogen
Pacific silver fir	*Abies amabilis*	UK	L	UK
Rocky Mountain maple	*Acer glabrum*	X	M	UK
Box elder	*Acer negundo*	M	M	UK
Alders	*Alnus* species	M (120-300)	H	UK
Serviceberry	*Amelanchier alnifolia*	L	H	UK
	Betula occidentalis	UK	M	UK
Paper birch	*Betula papyrifera*	H (60-80 ppm)	H	UK
Ceanothus	*Ceanothus sanguineus*	UK	M	UK
and	*Ceanothus velutinus*	UK	L	UK
Dogwood	*Cornus stolonifera*	L	M	UK
Hazel	*Corylus corruta*	L	M	UK
Hawthorn	*Crataegus columbiana*	UK	M	UK
Black hawthorn	*Crataegus douglasii*	UK	L	UK
One-seed hawthorn	*Crataegus monogyna*	UK	L	UK
	Holodiscus discolor	UK	H	UK
Junipers	*Juniperus* species	L	L	UK
Alpine larch	*Larix lyalli*	UK	H	UK
Honeysuckle (twinberry)	*Lonicera involucrata*	L	L	UK
(Utah honeysuckle)	*Lonicera utahensis*	X	UK	UK
Lupines	*Lupinus* (any species)	X	UK	UK
Myrtle pachistime	*Pachistima myrsinites*	L	UK	UK
Lewis mock-orange	*Philadelphys lewisii*	UK	H	UK
Engelmann spruce	*Picea engelmanni*	UK	M	UK
Sitka spruce	*Picea sitchensis*	UK	M	UK
Whitebark pine	*Pinus albicaulis*	UK	UK	UK
Lodgepole pine	*Pinus contorta*	M	M (SO_2 40 ppb)	H
W. white pine	*Pinus monticola*	M (100 ppb)	M	UK
Ponderosa pine	*Pinus ponderosa*	H (80-100)	M/H (SO_2 40 ppb)	H
Balsam poplar	*Populus balsamifera*	H	M	UK
Quaking aspen	*Populus tremuloides*	H (40 ppb)	H	UK
Choke cherry	*Prunus virginiana*	X	M	UK
also	*Prunus emarginata*	X	M	UK
Douglas-fir	*Pseudotsuga menziesii*	L/M (100 ppb)	M/H (SO_2, 65 ppb)	H
Smooth sumac	*Rhus glabera*	L	M	UK
Golden currant	*Ribes cereum*	X	UK	UK
Straggly currant	*Ribes divaricatum*	X	UK	UK
Black locust	*Robinia pseydoacacii*	L	H	UK
Wild rose	*Rosa woodsii*	X	UK	UK
Salmonberry	*Rubus spectabilis*	UK	M	UK
Blueberried elder	*Sambucus caerulea*	X	UK	UK
Mountain ash	*Sorbus scopulina*	UK	M	UK
and	*Sorbus sitchensis*	UK	H	UK
Pacific yew	*Taxus brevifolia*	UK	L	UK
Western red cedar	*Thuga plicata*	UK	L	UK

Western hemlock	*Tsuga heterophylla*	UK	M	UK
Mountain hemlock	*Tsuga mertensiana*	UK	H	UK

[a] X = known or suspected; H = high; M = moderate; L = low; UK = unknown.
[b]A general range of sensitivities to ozone is 60-90 ppb for conifers, 70-120 ppb for hardwoods, 7-h growing season means.
Source:Esserlieu and Olson (1986); Lefohn; Peterson et al. (1992a,b); Horner and Peterson (1993); Forest Health Monitoring Program (1993).

Table 39. Partial list of lichen and moss species that have documented responses to pollutants.

Species	ID[a]	Pollutant[b]	Study Type[c]	Source[d]	Park[e]	Reference
- *Alectoria sarmentosa*	L	O_3 (H) PAN	F	CA, USA	3,5	Sigal and Nash (1983)
- *Bryoria abbreviata* *B. fremontii* *B. oregana*	L	O_3 (H) PAN	F	CA, USA	1,2,3,4 1,2,3,4,5 1,3	Sigal and Nash (1983)
- *Calicium viride*	L	O_3 (H) PAN SO_2 (L-M)	F	CA, USA	1,2,3,4,5	Sigal and Nash (1983)
- *Cetraria islandica*	L	NH_4 NO_3 O_3 (H) SO_2 (M) F (M)	F	SWED	1,2,3,4,5	Gerhardt and Kellner (1986)
C. canadensis	L	O_3 (H) PAN	F	CA, USA	2,4	Sigal and Nash (1983)
- *Cladina portentosa*	L	NO_x	F	NETH	1	Sochting and Johnsen (1990)
C. rangiferina	L	NH_4 SO_2 (M-H) F (M) NO_3	F	SWED	1,3,4,5	Gerhardt and Kellner (1986)
		HNO_3	F	FRG, USA CAN		Scott and Hutchinson (1989)
		H_2SO_4/HNO_3 pH 2.5-3.0	L			Scott and Hutchinson (1987)
C. stellaris	L	H^+	L		4	Lechowicz (1982)
		H_2SO_4/HNO_3 pH 2.5-3.0	L			Scott and Hutchinson (1987)
- *Evernia prunastri*	L	O_3 (H)	F	CA, USA	1,3,4,5	Sigal and Nash (1983)
		PAN F (H)	L, F	CA, USA		Nash (1988)
		S	F			
		SO_2 (3.0 ppb, L-M)	F	USA		Johnson (1979)

- *Hylocomium splendens*	M	H^+ SO_2 (H) F (M)	F	UK	1,3,4,5	Farmer et al. (1992a)
- *Hypogymnia enteromorpha*	L	O_3 (L-M)	F	CA, USA	1,2,3,4,5	Sigal and Nash (1983)
		PAN	L, F			Nash (1988)
		O_3 (800 ppb, L-M)	L			Nash and Sigal (1979)
SO_2 (L-M)						

Table 39. Continued

Species	ID[a]	Pollutant[b]	Study Type[c]	Source[d]	Park[e]	Reference
- *Isothecium myosuroides*	M	H^+	F	UK	1,3,4,5	Pitkin (1975)
- *Lobaria pulmonaria*		O_3 (L-M)				
	L	H^+	F	UK	1,2,3,4,5	Gilbert (1986)
		H_2SO_4 SO_2 (H)				Denison et al. (1977)
- *Nephroma arcticum*	L	NH_4^+ O_3 (H) SO_2 (H) NO_x PAN (H)	L, F	SWED	3	Nohrstedt et al. (1988)
- *Parmelia caperata*	L	SO_2	F	UK	1,2,3,4,5	Gilbert (1992)
		O_3 (800 ppb) PAN	L			Nash and Sigal (1979)
		O_3 (200 ppb)				Ross and Nash (1983)
P. sulcata	L	NO_x PAN (M-H) SO_2 (70 ppb, L-H) F (M-H)	L, F	SWED	1,2,3,4,5	von Arb et al. (1990)
		O_3 (500 ppb, M-H)	L			Nash and Sigal (1979)
- *Peltigera aphthosa polydactyla*	L	H^+ O_3 (H) SO_2 (M) NO_x/PAN (M-H)	L		1,2,3,4,5	Fritz-Sheridan (1985)
	L	NH_4^+ SO_2 (M)	L, F	SWED		Nohrsted et al. (1988)
- *Physodes* species	L	SO_2 SO_4 NO TM		FRG, USA CAN	1,2,3,4,5	Scott and Hutchinson (1989)
- *Platismatia glauca*	L	O_3 (H) PAN	F	CA, USA	1,2,3,4,5	Sigal and Nash (1983)
		SO_2 (10 ppb,M)	F	EST		Trass (1973)

- *Pleurozium schreberi*	M	H^+	F		3,4,5	Kellner and Marshagen (1991)
		SO_2 (700 ppb, M-H)	L	CAN		Winner and Bewley (1983) Winner (1988)

Table 39. Continued

Species	ID[a]	Pollutant[b]	Study Type[c]	Source[d]	Park[e]	Reference
- *Pseudevernia* species	L	SO_2 SO_4 NO_3 TM	F F F F	FRG, USA, CAN	4	Scott and Hutchinson (1989)
- *Rhytidiadelphus triquetrus*	M	H^+	F	UK	1,3,4,5	Farmer et al. (1992b)
- *Sphagnum* species	M	SO_2 (H) F (H) bisulphite	F	UK	1,3,4,5	Ferguson and Lee (1983)
- *Tortula ruralis*	M	H^+ SO_2 (L)	L		1,2,3,4,5	Sheridan and Rosentreter (1973)
- *Usnea* species	L	O_3 (H) S	L, F	CA, USA	1,2,3,4,5	Nash (1988)
		SO_2 (3.0 ppb)	F	USA		Johnson (1979)
		(10.0 ppb, M-H)	F	EST		Trass (1973)

Footnotes:

[a] L = lichen, M = moss.

[b] Pollutant type: O_3 = ozone, NO_3 = nitrate, H^+ = acidity, SO_4 = sulfate, H_2SO_4 = sulfuric acid, PAN = peroxyacetyl nitrate, NH_4 = ammonium, NO_x = nitrogen oxides, SO_2 = sulfur dioxide, TM = trace metals, HNO_3 = Nitric acid

Values in parentheses include the pollutant concentration used in the study. Letters in parentheses refer to ratings of low (L), medium (M), or high (H) sensitivity to a specific pollutant, as listed by Peterson et al. (1992a), Appendix B.

[c] Study type: F = field; L = Laboratory; blank = unknown.

[d] Source: location where study was performed.

[e] Species occurrence in a class I national park. 1 = CRLA, 2 = CRMO, 3 = MORA, 4 = NOCA, 5 = OLYM.

the validity of the conclusions. Therefore, we have not included this study in the present analysis. For a general overview of ecosystems and plants that exhibit general sensitivities to various pollutants, see Appendix D.2.

Relatively little information is available on the effects of air quality on wildlife. Most studies have focused on the hazards of toxic contaminants, mainly heavy metals and industrial solvents in water (Kilkelly Environmental Associates 1989). Furthermore, there are few data with which to assess specific impacts of air quality on wildlife in the class I national parks, with the exception of Frenzel and Starkey (1987). They examined concentrations of heavy metals in goat hair from OLYM, NOCA, and MORA. Concentrations were considered low and were not indicative of potentially toxic accumulations.

Based on the data evaluated in this report, we conclude that presently air pollutants posing a significant threat to terrestrial resources in NOCA include ozone and potentially, acid deposition in cloud water or fog. Ozone values above 60-80 ppb can be assumed to effect many plant species. Acidic fog (< pH 4.0) due primarily to SO_4^{2-}, can potentially harm vegetation in the park, although data on exposure and dose-response functions for plants are not adequate to assess current risk.

5. Monitoring and Research Needs

Characterization and inventory of resources and air quality in NOCA is perhaps the least complete of any of the class I national parks in the Pacific Northwest. Monitoring and research needs in NOCA related to assessing impacts from air pollution stress are summarized in Table 40 and described in more detail below.

Table 40. Monitoring and research needs for NOCA related to assessing impacts from atmospheric deposition.

Component	Current Status	Data Assessment	Recommended Action
DEPOSITION 1. Wet	NADP/NTN site @ Marblemount	Collected since 1984; Site at low elevation (123 m)	Continue, however recognize that data may not be fully representative of deposition in park
			Repeat snow sampling every 5 to 10 years or install bulk deposition stations
	Snow sampled in 1983	3 sites sample	
	Ad hoc precipitation events measured by park staff	QA/QC questionable, no systematic design or interpretation	Discontinue
2. Occult/Dry	Cloud-water chemistry collected	Data base sparse; evidence of increased acidity at higher elevations	May want to repeat as resources permit
3. Gaseous	Ozone monitoring	Evidence of elevated ozone on western side of park	Continue
4. Particulates			As needed for visibility effects
5. Trace Metal/ Contaminants	Trace metals & pesticides sampled in fish and sediment of major reservoirs	Contaminants generally below detection limits	None at this time
	Soil samples analyzed for trace metals	Analyses completed, but no interpretive report available	Prepare interpretive report
TERRESTRIAL 1. Soils	Basic descriptive inventory	Incomplete	Continue, inventory, map, GIS
2. Inventory Flora & Lichen species	Basic inventory	Incomplete	Continue and expand
2. T&E Plant and Animal Species	Basic Inventory	Incomplete	Continue and expand inventory
3. Dose-response - Vascular Plants	None	Not applicable	Initiate studies of plant response to O_3 and acidic fog

a. Deposition

Nearly all of the atmospheric and precipitation monitoring for NOCA is performed west of the park at low elevation (e.g., 123 m). The Marblemount NADP/NTN site probably provides a general indication of deposition in the interior of the park, but there is some uncertainty because of the differences in monitoring rainfall at Marblemount compared to measuring snow in the park. The logistical convenience afforded by the Marblemount site makes it likely that the site will continue to be serviced regularly. There is a need, however, to resolve the uncertainty associated with the deposition chemistry at high elevations in the park. Some consideration should be given to conducting one or more studies on the differences in deposition chemistry in the park as a function of elevation. Consideration should be given to an east-west transect, although emissions in British Columbia and Puget Sound also provide justification for a north-south transect in addition.

b. Aquatics

The monitoring and research needs in NOCA are basic and extensive. Because the park is extremely difficult to access, considerable work remains to be done, particularly with respect to detailed chemical characterization of the alpine lakes and streams. The proposed research program (Glesne et al. 1993) would be a major step toward a systematic investigation of the chemical characteristics of these systems. The complex mineralogy of NOCA, as evidenced in the wide range of the ratio of dissolved Ca:Na in the lakes in the region (Figure 21), make the task of predicting effects of atmospheric deposition very difficult. Data from Brakke (1984) and Liss et al. (1991) illustrate the existence of some low-alkalinity (< 10 μeq/L) waters in the park that may be very susceptible to acidification. A recommended monitoring strategy would be to place the greatest emphasis on low-alkalinity lakes in the west side of the park.

Little is known about the seasonal variation of these lakes and streams, and virtually no data have been collected on episodic responses associated with snowmelt. The highest priority for seasonal and episodic response again is on the west side of the park. High discharge events downstream from glaciers are expected to be neutralized by the high weathering rates associated with glaciers. Monitoring and research needs should be first oriented toward watersheds with little or no soil and without glaciers present.

Future monitoring and research programs in the dilute aquatic systems need to be conducted to provide complete characterization of the acid-base chemistry. This requires, at a minimum, measurement of the following parameters:

pH	sulfate
ANC (Gran)	chloride
calcium	fluoride
magnesium	dissolved organic carbon
sodium	silica
potassium	iron
ammonium	aluminum
nitrate	

Many previous studies have failed to provide the complete characterization needed for an assessment of acid-base status. The analytes need to be measured with instruments and methods that provide for sufficiently low-detection limits (cf. EPA 1987). Failure to recognize these requirements will result in collection of data that will not be sufficient to detect impacts from atmospheric deposition.

c. Terrestrial

Baseline data on soil types would help to determine which areas might be most at risk from pollutant inputs. A key question for soils is whether cation leaching rates are higher than the historic average due to weathering. Soil cation exchange capacity and mineral weathering figures into the determination of critical loads, especially for S. Soil survey data is used in the MAGIC model to calculate critical loads of sulfur for forest soils (Frogner et al. 1992). More intensive monitoring and inventory of T&E plants and animal species also is needed. Research emphasis on the terrestrial effects of air quality should focus on vegetation dose-response functions associated with exposure to acidic fog and ozone. Due to inherent limitations in the methods, however (see Appendix D), lichen chemistry studies may be used more effectively to determine the source or cause of severe N or S pollution (isotope analysis) than to detect gradual deterioration in air quality before significant impacts occur to ecosystems.

We offer a general approach to study ozone effects on terrestrial vegetation in class I national parks, based primarily on information presented in Olson et al. (1992), Bates and Farmer (1992), and Stolte et al. (1993a,b). Key points include the selection of (1) sensitive receptor(s) and (2) study methods.

Given funding limitations, it is practical to focus efforts on the most sensitive organism or component of an ecosystem. This can also save time and money in the design of monitoring programs. Candidate species should be selected based on ozone sensitivities and plant geographic distribution in relation to known pollutant exposures in class I areas. These decisions should be based on exhaustive reviews of existing literature by technical experts.

Physiological studies of plant dose-response usually provide the most quantitative results, although they are more expensive and time-consuming, and thus too costly to implement at many field locations. Plant physiological processes are usually affected first by pollutants, but visible symptoms are easier to measure. On the other hand, although descriptive studies such as injury surveys are easier to implement on a large scale, they are more subjective and easily confounded by factors other than air quality (especially in natural ecosystems).

In our opinion, the best approach for studying vegetation response to ozone would be to combine quantitative dose-response and descriptive approaches beginning with carefully controlled physiological studies in both the laboratory and field (for trees, include seedlings and larger trees). Descriptive data on morphological symptoms of plant injury due to pollutant exposure should also be collected. Once dose-response functions and injury symptoms have been documented, the findings should be tested using natural gradients in pollutant exposure in the field. If the experimentally measured dose-response functions and visual symptoms of injury agree in the lab and field, the data can then be manipulated through modeling to test individual species responses at population and landscape levels.

The primary monitoring needs to protect terrestrial vegetation int he Pacific Northwest at the present time include improved monitoring of ozone at rural locations near class I areas, and cloud chemistry at higher elevations in the Cascade Range. Protocols should be established for data collection and analysis to ensure high-quality results. With regard to injury surveys, problems, opportunities to improve field-level research.

Additional needs for research and monitoring also include the dispersion of pollutants in relation to the complex meteorology and terrain of the Cascades. Local conditions in the Cascades generally result in elevated ozone south and east of major metropolitan areas below elevations of 1200 m. Exceptions occur when a temperature inversion dissipates with a marine frontal intrusion that pushes pollutants over the Cascades. This event is less common than pollution episodes at lower elevations, but there is the potential for high ozone levels (> 100 ppb) in class I areas of western

Washington when it happens. Additional research and monitoring of these meteorological events is needed to determine which geographic areas may be at highest risk from ozone damage.

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E. OLYMPIC NATIONAL PARK

1. Description

Olympic National Park is situated in the center of the Olympic Peninsula of Washington State. In 1897, President Grover Cleveland issued a proclamation creating the Olympus Forest Reserve. President Theodore Roosevelt created the Olympus National Monument in 1909. But national monuments could be reduced in size, and three such reductions between 1912 and 1929 left the monument with only half its original area. Then in 1938, Congress approved the 363420 ha Olympic National Park, signed into law by President Franklin Roosevelt. Relevant phrases from the Congressional report (H.R. 2247) accompanying the enabling legislation identifies some of the key values of the park.

The purpose of the proposed national park is to preserve....the finest sample of primeval forests of Sitka spruce, western hemlock, Douglas fir, and western red cedar in the entire United States; to provide...permanent protection for the herds of native Roosevelt elk and other wildlife indigenous to the area; to conserve...this outstanding mountainous country, containing numerous glaciers and perpetual snow fields, and a portion of the surrounding verdent forests..."

The 50-mile coastal strip was added to the park in 1953.

The Olympic Peninsula is comprised of a central core of the rugged Olympic Mountains surrounded by almost level lowlands. Most ridges of the Olympic Mountains are 1200 to 1500 m in elevation with the highest peaks reaching to 2100 to 2420 m. Glaciation has strongly influenced landforms. All main river valleys are broad and U-shaped, and all major peaks are ringed with cirques, many containing active glaciers. The high precipitation has caused rapid downcutting by streams, thereby resulting in many precipitous mountain slopes.

a. Geology and Soils

The Olympic Mountains were formed from sea floor sediments thrust upward by subduction of the Pacific Ocean Plate beneath the continental plate. Rocks containing marine fossils are evident today along the mountain summits of the interior region. The interior sedimentary rocks (mostly graywacke, with some interbedded argillite, and volcanic rocks) are enriched by two volcanic belts on the north and east sides, and as far west as Lake Quinault on the south. The less mountainous area along the north edge of the peninsula is a complex of Oligocene and Miocene sandstones, some interbedded with siltstone and conglomerates. Glacial drift occurs in fairly large deposits near Sequim and Port Angeles and west of Ozette Lake. The broad, level areas along the western and southern margins of the peninsula have been interpreted as marine terraces or glacial outwash fans. Tabor (1987) gives a detailed account of the geology of Olympic National Park.

The mountains also were shaped by the Pleistocene glaciers beginning between 1 and 2 million years ago. The continental ice sheet retreated about 12,000 years ago, leaving behind a mass of mountains, carved by ice. Today, about 60 glaciers remain. The Olympic Mountains form a circular cluster with thirteen rivers radiating outward from the center like the spokes of a wheel. The radial drainage pattern confirms that the Olympic Mountains uplifted as a single unit. Limited mining activity for manganese and copper occurred from 1906 until 1941, but the Olympics yielded little valuable ore.

The soils in the mountainous interior region of the Olympic Mountains developed from both coniferous forest and subalpine meadow vegetation and the sedimentary parent materials (Franklin and Dyrness 1988). Forested soils were reported to be Brown Podzolics (Spodosols) and Lithosols (Entisols). A large variety of soils of variable texture have formed in glacial till and outwash. Alluvial soils of terraces along west-flowing rivers such as the Quinault, Queets, Hoh, and Solduc, differ in texture from silt loam to sandy loam and are moist throughout the year. A detailed listing of soil groups is given in Franklin and Dyrness (1988). A detailed description of the geology and soils of the Olympic National Forest is given in Henderson et al. (1989).

b. Climate

The climate of the region is dominated by warm Pacific air masses, heavily laden with moisture. As the warm air moves eastward, rising up over the mountains, abundant precipitation results. The seaward slopes of the Olympics receive more precipitation than any other place in the contiguous United States. Between 300 and 400 cm of precipitation fall annually at the Hoh and Queets Valleys. East of the mountains in Sequim, annual rainfall declines to only 45 cm, in the rain shadow of the Olympic Mountains. Temperatures at the lower elevations are moderate year-round, seldom falling below freezing in winter, nor rising above 27 ^{o}C in summer. Climate summaries for the Olympic Peninsula are given in Henderson et al. (1989).

c. Biota

The mild climate, abundant precipitation, and persistent fog of the Olympic Peninsula produce a temperate rainforest, exemplified in the southwest-facing valleys of the Quinault, Queets, and Hoh River valleys. As generally recognized, the Olympic rain forests are old growth dominated by Sitka spruce (*Picea sitchensis*), along with western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*). Shrubs, herbs, ferns, and mosses grow abundantly in the forest understory, particularly in windthrow gaps. Among the distinctive characteristics of these forests on the older land surfaces (usually river terraces) are (1) abundance of *Acer macrophyllum* and *A. circinatum*, (2) abundant cover of epiphytic plants, and (3) abundant large woody debris and nurse logs. Trees are of massive size, but the stands have relatively open canopies and low tree densities. At elevations above 240 to 300 m, grand fir (*Abies grandis*) replaces the Sitka spruce. Western red cedar diminishes above 600 m in elevation, whereas western hemlock continues to 1000 m. Other tree species include Pacific silver fir (*Abies amabilis*), forming dense stands at upper elevations, and Douglas-fir (*Pseudotsuga menziesii*), a fire-resistant species common to the drier eastern slopes. A comprehensive inventory and description of vascular and nonvascular plants of the Olympic National Forest is provided in Henderson et al. (1989) and Buckingham and Tisch (1979).

Black bear, black-tailed deer, and Roosevelt elk range widely throughout the Park; coyote and mountain lions are less abundant. Heavy seasonal usage by elk is important to vegetation dynamics in the forest understory. Mountain goats and red fox were both introduced to the peninsula, the former is now abundant, the latter is rare. A partial listing of the fauna and flora of the Olympic Peninsula is provided by Henderson et al. (1989) and Moorhead (1991). A comprehensive listing of park flora is available through the NPFLORA database (Waggoner 1989).

d. Aquatic Resources

The dominant aquatic feature of the park is the 13 major rivers flowing from the Olympic Mountains in all directions. These are well buffered systems draining from sedimentary bedrock and glaciers with high silt loads. There are many high-elevation lakes, some of which have been sampled, and several large low-elevation lakes that have been studied in some detail.

2. Emissions

Most of the emissions in counties adjacent to OLYM are relatively low (Table 41, Figure 22). The primary emissions of concern for OLYM are on the east side of Puget Sound in counties such

Table 41. Emissions in the counties adjacent to OLYM. Units are in tons/yr.

County	PM_{10}	SO_x	NO_x	VOC	CO
Clallam	3,524	1,754	5,238	51,783	7,061
Grays Harbor	6,153	1,507	7,993	83,479	8,882
Jefferson	1,727	775	2,147	21,613	2,764
Mason	2,772	219	3,755	40,289	4,896
TOTAL	14,176	4,255	19,133	197,164	23,603

Source: WDOE (1994).

Figure 22. Olympic National Park and proximity of urban areas in Washington.

Figure 22.Olympic National Park and proximity of urban areas in Washington.

as King and Pierce and to the south in Lewis County (Figures 23 and 24). The air quality-related major local emissions sources in Port Angeles are monitored within the city of Port Angeles by WDOE and near park headquarters south of the city.

3.Current Monitoring and Research Activities

a. Air Quality/Deposition

(i) Wet Deposition

The park has a NADP/NTN monitoring site located near the Hoh Ranger Station on the west side of the peninsula. The precipitation in the park is noteworthy for its volume which can exceed 4 m on the west side of the park. The precipitation chemistry is dominated by marine aerosols at the Hoh Valley site. Nitrate, ammonium, and nonmarine sulfate concentrations are low and pH is generally is near 5.4 (Table 42). The precipitation chemistry at this site can be characterized as pristine.

Through-fall chemistry in the Hoh River Valley has been measured by the University of Washington as part of an eight-year ecosystem study of West Twin Creek Watershed (Edmonds et al. 1992). Project publications include Edmonds et al. (in press); Edmonds et al. 1991; Edmonds and Thomas 1990; Thomas and Edmonds 1990a,b; and Thomas et al. 1988. This research is currently being funded through the NBS, NERC, Fort Collins, Colorado.

(ii) Occult/Dry Deposition

Fog and cloudwater chemistry samples were collected at three sites in/near the Olympic National Park as part of a regional study in 1987 and 1988 (Basabe et al. 1989a). The three sites consisted of Hoh River, Hurricane Ridge, and Cheeka Peak. Samples from sites west of Puget Sound, and particularly Cheeka Peak, contained substantially lower concentrations of SO_4^{2-}, NH_4^+, NO_3^-, and H^+ than the sites east of Puget Sound. When the wind was from the west, significantly

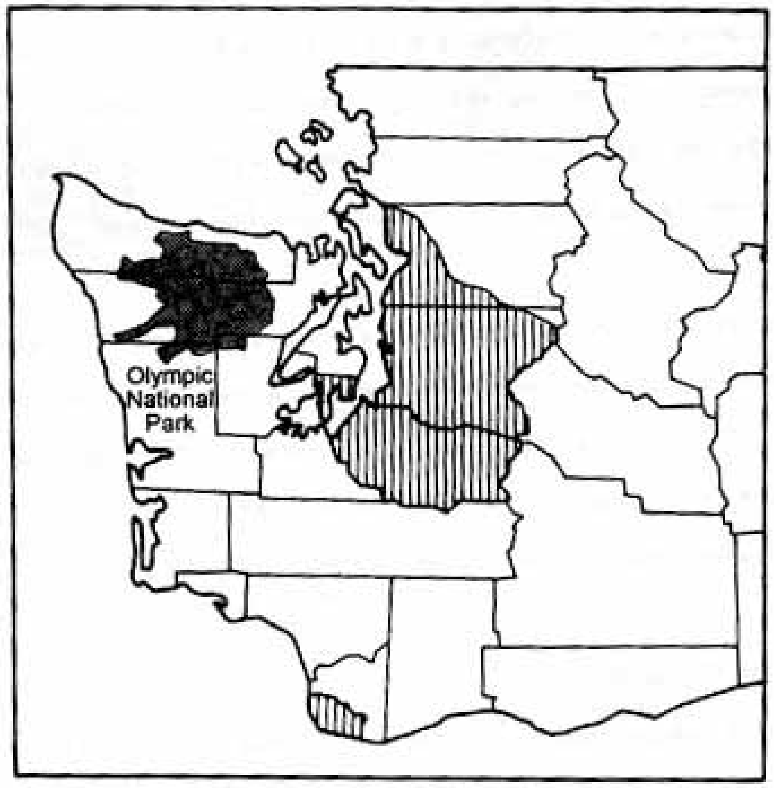

Figure 23. Nonattainment areas (lined areas) for O_3 in Washington State in relation to Olympic National Park.

Figure 23.Nonattainment areas (lined areas) for O_3 in Washington State in relation to Olympic National Park.

Figure 24. Nonattainment areas (lined areas) for CO in Washington State in relation to Olympic National Park.

Figure 24.Nonattainment areas (lined areas) for CO in Washington State in relation to Olympic National Park.

higher concentrations were measured at Cheeka Peak, although values still remained relatively low (Basabe et al. 1989a).

The NADP site at Hoh Valley is scheduled to be upgraded in 1995 to include a NDDN site (T. Maniero, pers. comm.).

(iii) Gaseous Monitoring

Ozone is monitored at an NPS site within the park, near Port Angeles. Sulfur dioxide currently is monitored at three WDOE stations near the park headquarters in Port Angeles and at the NPS site. Local emission sources in Port Angeles include a pulp mill, a paper mill and plywood manufacturing plant. The Olympic Peninsula (northern side) has some of the lowest O_3 in the West (5-16 ppb hourly growing season mean), although maximum hourly values of 60 ppb have been recorded (Böhm 1992).

Tables 43-45 (also see Figures 25 and 26) summarize gaseous monitoring data from the EPA AIRS monitoring sites in Washington during 1985-1992. Ozone concentrations (Table 44) throughout the region generally were low. Washington State, however, had several exceedances of the primary ozone standard to the east and southeast of Seattle. Sulfur dioxide (Table 45) and nitrogen dioxide (Table 43) values generally were low throughout the region. These data indicate that concentrations of gaseous pollutants at OLYM are below levels known to be injurious to plants.

Table 43. Summary of nitrogen dioxide data from the EPA AIRS (Aerometric Information Retrieval System) Monitoring Sites within 100 km of the class I national parks in Washington during the period 1985-1992. Sites are identified in Figures 25 and 26.

	Annual Arithmetic Mean (ppb)		
Site #	1985	1986	1987
53-033-0080	19	18	13
53-033-0082	34	32	35

(iv) Particulates

Particulates currently are not monitored in OLYM.

Table 44. Summary of ozone data from the EPA AIRS (Aerometric Information Retrieval System) Monitoring Sites within 100 km of the class I national parks in Washington during the period 1985-1992. Sites are identified in Figures 25 and 26.

	1-hour Maximum (ppb)							
Site #	1985	1986	1987	1988	1989	1990	1991	1992
53-009-0012+	-	-	70	40	65	64	56	63
53-011-0011	-	-	-	120	98	124	102	121
53-011-1001	100	100	-	-	-	-	-	-
53-033-0010	120	130	110	140*1	90	126*1	109	94
53-033-0018	-	-	-	-	100	119	-	-
53-033-0088	-	-	-	-	-	102	101	-
53-033-2001	90	80	-	-	-	-	-	-
53-033-7001	100	120*1	140	110	100	149*3	112	108
53-053-0004	90	100	-	-	-	-	-	-
53-053-0005	100	110	100	110	-	-	-	-
53-053-1001	110	100	110	110	-	-	-	-
53-053-1008	-	-	110	110	103	130*2	99	103
53-053-1009	-	100	110	110	-	-	-	-
53-061-2001	110	90	-	-	-	-	-	-
53-073-0005	-	-	-	-	52	83	82	72

*(#) - Number of exceedances of primary standards (NAAQS) for a pollutant (see Table 1).
\+ - Indicates ozone monitor in closest proximity to OLYM.

(v) Trace Metals

Deposition of As and Pb was measured from hair removed from mountain goats captured in the park as part of a relocation program. Concentrations of the metals were considered low (Frenzel and Starkey 1987). In addition, citing limited data on lichen tissues, Frenzel et al. (1990) suggested that there might be elevated deposition of lead at OLYM from dispersed regional and global sources. Additional baseline data, however, must be collected to determine if this is true.

b. Water Quality

Three lakes were sampled in the park as part of EPA's Western Lake Survey (Landers et al. 1987, Eilers et al. 1987). The lakes were moderate to high-alkalinity systems with extremely high Na^+, Cl^-, and SO_4^{2-} from marine aerosols.

Hoh Lake was sampled intermittently from 1985 to 1987 as part of the Hoh River Valley study (Edmonds et al. 1992).

West Twin Creek in the Hoh

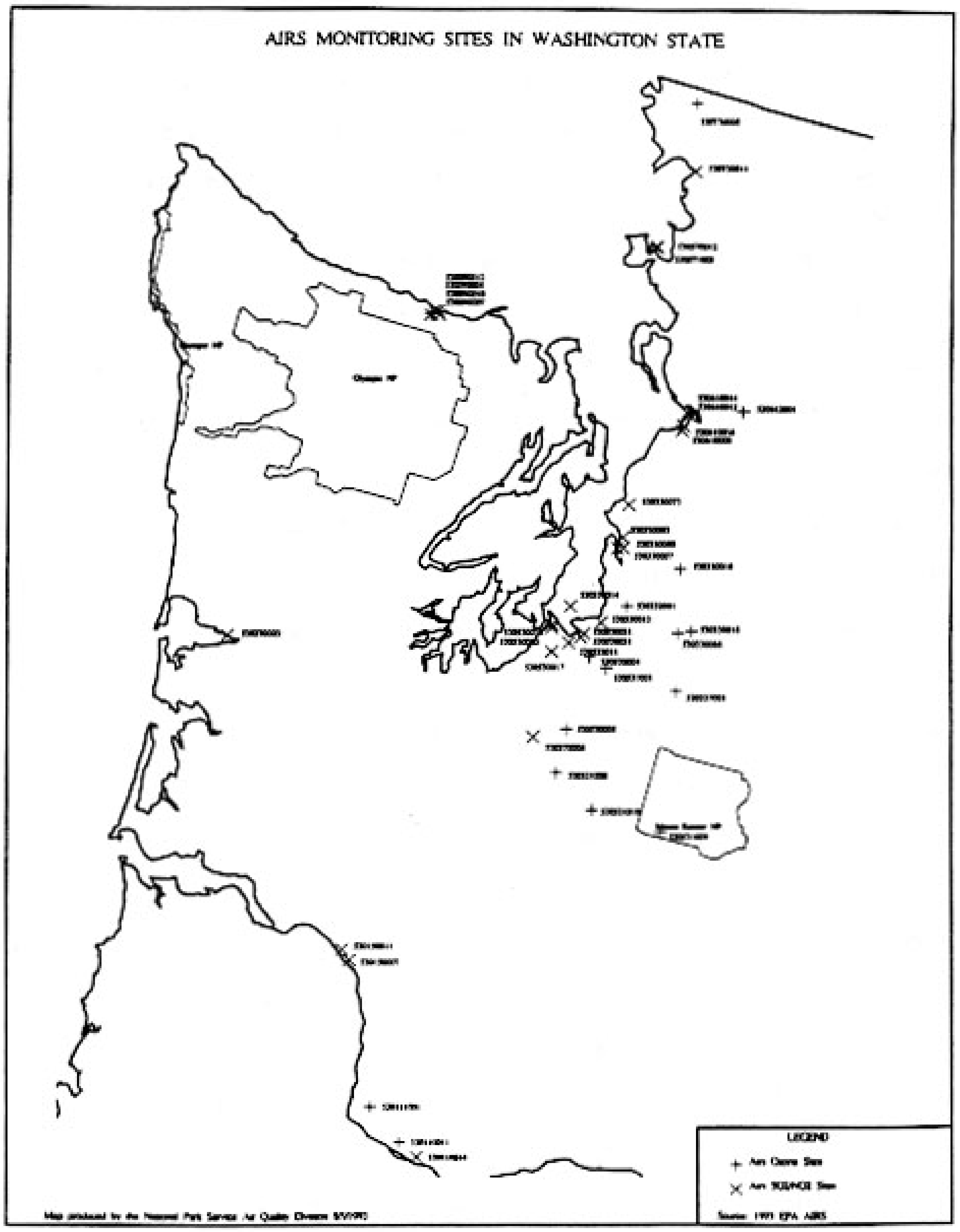

Figure 26. Location of EPA AIRS monitoring sites within the state of Washington.

Figure 26. Location of EPA AIRS monitoring sites within the state of Washington.

Valley has been sampled weekly by using a stage-proportional sampler from 1984 to present (Edmonds et al. 1992).

Seven lakes were sampled in the OLYM as part of the Washington DOE High Alpine Lake sampling program from 1983-1985. One of the lakes had an ANC between 100-200 μeq/L, whereas the remaining lakes had ANC > 200 μeq/L (D. Roberts, WDOE, pers. comm.). Nitrate concentrations averaged 5.5 μeq/L in the lakes.

The park staff initiated a study of seven lakes in 1992, continuing into 1993. The focus of this high lake survey is the fisheries, although baseline chemistry also is being collected (G. Larson, pers. comm.). An additional investigation of three lakes in the Seven Lakes Basin was conducted to evaluate the efforts of fish stocking on plankton. The three lakes had high ANC (181-438 μeq/L) and high SO_4^{2-} (41-104 μeq/L); no NO_3^- data were reported (Banks 1991).

Lake Crescent, the largest lake in the park, was the site of a nonpoint source assessment by the NPS (Boyle and Beeson 1991). They concluded that Lake Crescent was nitrogen-limited and there was little evidence for serious nutrient enrichment from anthropogenic watershed sources at this time.

Another investigation is being conducted on Lake Ozette, a large lowland lake on the northwestern corner of the peninsula. The study is evaluating the sockeye salmon fisheries in cooperation with a Native American tribe (G. Larson, pers. comm.).

c. Terrestrial

A partial species inventory of the park flora is maintained on the NPFLORA database (Waggoner 1989) and plant species and vegetation associations have been described by Henderson et al. (1989). The inventory of lichen and bryophyte flora is fairly complete. Several ecosystem studies have been carried out in the Hoh River drainage, including alpine and subalpine tree ecology, lichen productivity, and nutrient cycling. Additional vegetation studies have been conducted in Hades Creek, Higley Creek, Jackson Creek, and Twin Creek Research Natural Areas.

The inventory of park fauna is fairly complete (Henderson et al. 1989). Studies of mountain goat effects on vegetation are continuing. Additional inventories of the amphibians, reptiles, and T&E plant and animal species are continuing, and new studies are soon to be initiated. Extensive studies of forest ecosystem processes including stand dynamics, hydrology, and nutrient cycling were conducted in the Hoh River Valley with funding from NAPAP through the

National Park Service's Small Watershed Program (Edmonds et al. 1992). Many other studies of forests, streams, and wildlife have been conducted by academic institutions (Starkey et al. 1982).

The geology and soils of OLYM are described in Harris (1990) and Henderson et al. (1989), and several studies of glaciation have been carried out in the Research Natural Areas.

Recent studies of air quality effects on terrestrial ecosystems have examined heavy metal accumulation in lichens (Frenzel et al. 1990). Heavy metal concentrations were low in lichen tissues, but the potential for additional pollution was considered important. Rhoades (1985, 1988) has remeasured permanent plots for the cover and chemical composition of arboreal lichens. Increases in the heavy metal concentrations of lichen tissues were localized near roads, although the quality of the data was limited by the small sample size. Also, there was limited evidence for increasing sulfur concentrations in lichens near Port Angeles in the northern end of the park. Baseline values on the chemical composition of one lichen species were established by Wiersma et al. (1987). Recently, two old-growth stands in OLYM were part of a study to determine if forests in the Puget Sound area exhibited radial growth reductions due to ozone (Brubaker and Ford 1993). Tree growth patterns did not exhibit an ozone effect, however, we consider the results to be inconclusive.

4. Sensitive Receptors

a. Aquatics

All analyses of lakes and streams in OLYM have shown them to be well buffered and insensitive to stress from acidic deposition. This is expected given the sedimentary bedrock and the high rates of weathering associated with glacial meltwaters. If sensitive aquatic receptors are present in the park, they most likely would be ephemeral ponds serving as breeding sites for amphibians. The only area of the park considered potentially vulnerable to atmospheric pollution would be the eastern portion which would be expected to receive deposition of pollutants from the Puget Sound area.

b. Terrestrial

With regard to ambient air quality near OLYM, sulfur and nitrogen deposition presently are too low to cause much concern about effects on terrestrial resources. The highest potential for air quality to impact terrestrial resources is associated with ozone on the east side of the park near industrialized urban areas of Seattle. To date, there has been no research to determine the effects of ozone on terrestrial resources in OLYM. Consequently, this assessment of potentially sensitive species in the park is based on research conducted in other ecosystems, on related species or taxa of organisms.

Much of the research effort over the past 50 years to document air quality effects on terrestrial vegetation has focussed on documenting forest growth and physiological condition in relation to "forest decline", and on establishing dose-response functions for economically important tree species (Smith 1990). Less effort has been directed to the study of mosses and lichens, except near heavily polluted areas of Great Britain, Europe, and Canada (Bates and Farmer 1992). There are only a few studies of the effects of pollutants on lichens in the Pacific Northwest (Denison and Carpenter 1973, Hoffman 1974, Denison et al. 1977, Johnson 1979, Taylor and Bell 1983, Rhoades 1988). Physiological studies of dose-response functions have yielded the most conclusive results, but the high cost of these studies has limited their applicability.

More information is available on ozone effects than on N and S effects. The most comprehensive ozone research has been conducted in the mixed conifer-forest and other vegetation types of California, on the dominant, commercially important tree species (Miller et al. 1989; Peterson et al. 1987, 1991, 1992 a,b; Horner and Peterson 1993). Few data are available to relate ozone dose or exposure to mature trees, and almost no data exist for herbaceous species.

Provisional lists of potentially sensitive vascular plant species indigenous to OLYM are presented in Table 46. A listing for lichen and moss species is provided in Table 47. This list of potentially sensitive species is only a preliminary compilation of known or suspected sensitive plants. The information should be viewed as largely preliminary, due to the limited database. Sensitivity classes for vascular plants, lichens, and bryophytes have been developed to summarize the high variability in response to different pollutants that has been documented within plant species. The wide range of variability in plant responses to pollutants is attributable to differences in research methodology, environmental conditions, and to natural variability in species sensitivity. Specific values for pollutant sensitivity are listed where data exist. The application of much of this sensitivity data to the Pacific Northwest must be undertaken with caution because the data are mostly from laboratory fumigation experiments on seedlings and have not been field tested on mature trees. The reliability of extrapolating pollutant responses from the laboratory to the field and from seedlings to mature trees is questionable, and studies are currently underway at EPA, Corvallis to compare results (Bates and Farmer 1992; Peterson et al. 1992a,b; Stolte et al. 1993a,b).

In general, reliable data on the sensitivities of vascular plants, bryophytes, and lichen flora to air quality in OLYM are lacking. Limitations of the existing data on terrestrial vegetation include: (1) lack of park-specific or regional data, (2) lack of testing for laboratory dose-response data under field conditions, (3) poor correspondence between visual injury estimates and dose- response functions, and (4) lack of information on noncommercial species. Esserlieu and Olson (1986) attempted to rank the vulnerability of national parks to atmospheric pollutants by evaluating the potential sensitivities of park flora and surface waters to pollutants. However,

Table 46. Partial list of potentially sensitive vascular plant species in OLYM.

Common Name	Scientific Name	Sensitivity[a] Ozone[b]	Sulfur	Nitrogen
Pacific silver fir	*Abies amabilis*	UK	UK	UK
Rocky Mountain maple	*Acer glabrum*	X	M	UK
	Acer glabrum douglasii	UK	M	UK
Bigtooth maple	*Acer macrophyllum*	X	UK	UK
Alders	*Alnus* species	M (120-300)	H	UK
Ceanothus	*Ceanothus sanguineus*	UK	M	UK
and	*Ceanothus velutinus laevigatus*	UK	L	UK
Dogwood	*Cornus stolonifera occidentalis*	L	M	UK
Hazel	*Corylus cornuta californica*	UK	H	UK
Black hawthorn	*Crataegus douglasii*	UK	L	UK
Junipers	*Juniperus* species	L	L	UK
Honeysuckle (twinberry)	*Lonicera involucrata*	L	L	UK
(Utah honeysuckle)	*Lonicera utahensis*	X	UK	UK
Lupines	*Lupinus* (any species)	X	UK	UK
	Picea engelmannii	UK	M	UK
	Picea sitchensis	UK	M	UK
Whitebark pine	*Pinus albicaulis*	UK	UK	UK
Lodgepole pine	*Pinus contorta*	M (100 ppb)	M (SO_2 40 ppb)	H
W. white pine	*Pinus monticola*	M (100 ppb)	M	UK
Ponderosa pine	*Pinus ponderosa*	H (80-100)	M/H (SO_2 40 ppb)	H
Balsam Poplar	*Populus balsamifera trichocarpa*	H	M	UK
Cottonwoods	*Populus trichocarpa*	UK	UK	UK
Quaking Aspen	*Populus tremula tremuloides*	H (40 ppb)	H	UK
Choke cherry	*Prunus emarginata*	UK	M	UK
also	*Prunus virginiana*	UK	M	UK
Douglas-fir	*Pseudotsuga menziesii*	L/M (100 ppb)	M/H (SO_2 ppb)	UK
Golden currant	*Ribes divaricatum*	X	UK	UK
Western thimbleberry	*Rubus parviflorus*	X	UK	UK
Scouler willow	*Salix scouleriana*	X	UK	UK
Blueberried elder	*Sambucus cerulea*	UK	UK	UK
Pacific yew	*Taxus brevifolia*	UK	L	UK
Western red cedar	*Thuja plicata*	UK	L	UK
Western hemlock	*Tsuga heterophylla*	UK	M	UK
Mountain hemlock	*Tsuga mertensiana*	UK	H	UK
Big huckleberry	*Vaccinium membranaceum*	X	UK	UK

[a] X = known or suspected; H = high; M = moderate; L = low; UK = unknown.
[b]A general range of sensitivities to ozone is 60-90 ppb for conifers, 70-120 ppb for hardwoods, 7-h growing season means.
Source: Esserlieu and Olson (1986); Lefohn 1992; Peterson et al. (1992a,b); Forest Health Monitoring Program (1993); Horner and Peterson (1993).

Table 47. Partial list of lichen and moss species that have documented responses to pollutants.

Species	ID[a]	Pollutant[b]	Study Type[c]	Source[d]	Park[e]	Reference
- *Alectoria sarmentosa*	L	O_3 (H) PAN	F	CA, USA	3,5	Sigal and Nash (1983)
- *Bryoria abbreviata* *B. fremontii* *B. oregana*	L	O_3 (H) PAN	F	CA, USA	1,2,3,4 1,2,3,4,5 1,3	Sigal and Nash (1983)
- *Calicium viride*	L	O_3 (H) PAN SO_2 (L-M)	F	CA, USA	1,2,3,4,5	Sigal and Nash (1983)
- *Cetraria islandica*	L	NH_4 NO_3 O_3 (H) SO_2 (M) F (M)	F	SWED	1,2,3,4,5	Gerhardt and Kellner (1986)
C. canadensis	L	O_3 (H) PAN	F	CA, USA	2,4	Sigal and Nash (1983)
- *Cladina portentosa*	L	NO_x	F	NETH	1	Sochting and Johnsen (1990)
C. rangiferina	L	NH_4 SO_2 (M-H) F (M) NO_3	F	SWED	1,3,4,5	Gerhardt and Kellner (1986)
		HNO_3	F	FRG, USA CAN		Scott and Hutchinson (1989)
		H_2SO_4/HNO_3 pH 2.5-3.0	L			Scott and Hutchinson (1987)
C. stellaris	L	H^+	L		4	Lechowicz (1982)
		H_2SO_4/HNO_3 pH 2.5-3.0	L			Scott and Hutchinson (1987)
- *Evernia prunastri*	L	O_3 (H)	F	CA, USA	1,3,4,5	Sigal and Nash (1983)
		PAN F (H) S	L, F F	CA, USA		Nash (1988)
		SO_2 (3.0 ppb, L-M)	F	USA		Johnson (1979)

- *Hylocomium splendens*	M	H^+ SO_2 (H) F (M)	F	UK	1,3,4,5	Farmer et al. (1992a)
- *Hypogymnia enteromorpha*	L	O_3 (L-M)	F	CA, USA	1,2,3,4,5	Sigal and Nash (1983)
		PAN	L, F			Nash (1988)
		O_3 (800 ppb, L-M)	L			Nash and Sigal (1979)
SO_2 (L-M)						

Table 47. Continued

Species	ID[a]	Pollutant[b]	Study Type[c]	Source[d]	Park[e]	Reference
- *Isothecium myosuroides*	M	H^+	F	UK	1,3,4,5	Pitkin (1975)
- *Lobaria pulmonaria*		O_3 (L-M)				
	L	H^+	F	UK	1,2,3,4,5	Gilbert (1986)
		H_2SO_4 SO_2 (H)				Denison et al. (1977)
- *Nephroma arcticum*	L	NH_4^+ O_3 (H) SO_2 (H) NO_x PAN (H)	L, F	SWED	3	Nohrstedt et al. (1988)
- *Parmelia caperata*	L	SO_2	F	UK	1,2,3,4,5	Gilbert (1992)
		O_3 (800 ppb) PAN	L			Nash and Sigal (1979)
		O_3 (200 ppb)				Ross and Nash (1983)
P. sulcata	L	NO_x PAN (M-H) SO_2 (70 ppb, L-H) F (M-H)	L, F	SWED	1,2,3,4,5	von Arb et al. (1990)
		O_3 (500 ppb, M-H)	L			Nash and Sigal (1979)
- *Peltigera aphthosa polydactyla*	L	H^+ O_3 (H) SO_2 (M) NO_x/PAN (M-H)	L		1,2,3,4,5	Fritz-Sheridan (1985)
	L	NH_4^+ SO_2 (M)	L, F	SWED		Nohrsted et al. (1988)
- *Physodes* species	L	SO_2 SO_4 NO TM		FRG, USA CAN	1,2,3,4,5	Scott and Hutchinson (1989)
- *Platismatia glauca*	L	O_3 (H) PAN	F	CA, USA	1,2,3,4,5	Sigal and Nash (1983)
		SO_2 (10 ppb,M)	F	EST		Trass (1973)

- *Pleurozium schreberi*	M	H^+	F		3,4,5	Kellner and Marshagen (1991)
		SO_2 (700 ppb, M-H)	L	CAN		Winner and Bewley (1983) Winner (1988)

Table 47. Continued

Species	ID[a]	Pollutant[b]	Study Type[c]	Source[d]	Park[e]	Reference
- *Pseudevernia* species	L	SO_2 SO_4 NO_3 TM	F F F F	FRG, USA, CAN	4	Scott and Hutchinson (1989)
- *Rhytidiadelphus triquetrus*	M	H^+	F	UK	1,3,4,5	Farmer et al. (1992b)
- *Sphagnum* species	M	SO_2 (H) F (H) bisulphite	F	UK	1,3,4,5	Ferguson and Lee (1983)
- *Tortula ruralis*	M	H^+ SO_2 (L)	L		1,2,3,4,5	Sheridan and Rosentreter (1973)
- *Usnea* species	L	O_3 (H) S	L, F	CA, USA	1,2,3,4,5	Nash (1988)
		SO_2 (3.0 ppb)	F	USA		Johnson (1979)
		(10.0 ppb, M-H)	F	EST		Trass (1973)

Footnotes:

[a] L = lichen, M = moss.

[b] Pollutant type: O_3 = ozone; NO_3 = nitrate; H^+ = acidity; SO_4 = sulfate; H_2SO_4 = sulfuric acid; PAN = peroxyacetyl nitrate; NH_4 = ammonium; NO_x = nitrogen oxides; SO_2 = sulfur dioxide; TM = trace metals; HNO_3 = Nitric acid

Values in parentheses include the pollutant concentration used in the study. Letters in parentheses refer to ratings of low (L), medium (M), or high (H) sensitivity to a specific pollutant, as listed by Peterson et al. (1992a), Appendix B.

[c] Study type: F = field; L = Laboratory; blank = unknown.

[d] Source: location where study was performed.

[e] Species occurrence in a class I national park. 1 = CRLA, 2 = CRMO, 3 = MORA, 4 = NOCA, 5 = OLYM.

limitations of the emissions and deposition data, as well as the plant sensitivity data, compromised the validity of the conclusions. Therefore, we have not included this study in the present analysis. For a general overview of ecosystems and plants which exhibit general sensitivities to various pollutants, see Appendix D.2.

Information on the effects of air quality on wildlife is scarce. Most studies have focused on the hazards of toxic contaminants, mainly heavy metals and industrial solvents in water (Kilkelly Environmental Associates 1989). Furthermore, few data exist with which to assess specific impacts of air quality on wildlife in the class I national parks, with the exception of Frenzel and Starkey (1987). They examined concentrations of metals in goat hair from OLYM. Concentrations of heavy metals were low and did not indicate potentially toxic accumulations.

Based on data evaluated in this report, we conclude that currently no air pollutants pose a significant threat to terrestrial resources in OLYM. There may be, however, a potential threat from ozone and acidic fog on the eastern side of the park. This concern is based only on known meteorological processes and pollutant emissions in Puget Sound. There are currently no air quality data or monitoring stations near the east side of the park.

5.Monitoring and Research Needs

The monitoring and research needs in OLYM relative to assessing impacts from atmospheric deposition are summarized in Table 48 and discussed below.

a.Deposition

Most of the deposition monitoring takes place in the Hoh River valley on the west side of the park, although ambient air monitoring is conducted at park headquarters in Port Angeles on the northern perimeter of the park. The NADP/NTN site at the Hoh Ranger Station is a low-elevation site (173 m) and provides valuable information on relatively pristine precipitation entering the ecologically important temperate rainforest. The primary polluted air masses of concern, however, enter the park from the east and south. There is no information to currently assess the severity of these pollution sources, although deposition data to the west would suggest that this threat is currently low to moderate. The NPS may want to consider supplementing the wet deposition monitoring with limited-duration monitoring (e.g., 1 yr) on the eastern and southern boundaries of the park by using NADP sampling protocols. In addition, snow sampling at high- elevation areas on the east side of the park would provide useful information on nitrogen and sulfur deposition in the snow zone. The need for snow monitoring in OLYM is not as urgent as elsewhere in the region because of the relatively high neutralization capacity of surface waters in the park.

b. Aquatics

The information on acid-base chemistry for lakes in the OLYM suggests that there are few systems with ANC < 100 μeq/L. Most of the rivers drain glaciers and are expected to be well buffered. The only possible need at this time for monitoring of aquatic systems in OLYM relative to air quality concerns is to evaluate potential impacts of elevated N deposition on the productivity of N-limited lakes.

c. Terrestrial

Additional information is needed on the status of T&E plant species in the park. Efforts to inventory amphibians and reptiles should be expanded. Information on soil types would benefit possible future studies to assess pollutant impacts on soil acidification and cation leaching. Soil cation exchange capacity and mineral weathering figures into the determination of critical loads, especially for S. Soil survey data is used in the MAGIC model to calculate critical loads of sulfur for forest soils (Frogner et al. 1992). Due to inherent limitations in the methods, however (see Appendix D), lichen chemistry studies may be used more effectively to determine the source or cause of severe N or S pollution (isotope analysis) than to detect gradual deterioration in air quality before significant impacts occur to ecosystems. Ozone dose-response studies could be initiated for selected vascular plant species, although air quality data do not indicate that this is an urgent need.

We offer a general approach to study ozone effects on terrestrial vegetation in class I national parks, based primarily on information presented in Olson et al. (1992), Bates and Farmer (1992), and Stolte et al. (1993a,b). Key points include the selection of (1) sensitive receptor(s) and (2) study methods.

Given funding limitations, it is practical to focus efforts on the most sensitive organism or component of an ecosystem. This can also save time and money in the design of monitoring programs. Candidate species should be selected based on ozone sensitivities and plant geographic distribution in relation to known pollutant exposures in class I areas. These decisions should be based on exhaustive reviews of existing literature by technical experts.

Physiological studies of plant dose-response usually provide the most quantitative results, although they are more expensive and time-consuming, and thus too costly to implement at many field locations. Plant physiological processes are usually affected first by pollutants, but visible symptoms are easier to measure. On the other hand, although descriptive studies such as injury surveys are easier to implement on a large scale, they are more subjective and easily confounded by factors other than air quality (especially in natural ecosystems).

In our opinion, the best approach for studying vegetation response to ozone would be to combine quantitative dose-response and descriptive approaches beginning with carefully controlled physiological studies in both the laboratory and field (for trees, include seedlings and larger trees). Descriptive data on morphological symptoms of plant injury due to pollutant exposure should also be collected. Once dose-response functions and injury symptoms have been documented, the findings should be tested using natural gradients in pollutant exposure in the field. If the experimentally measured dose-response functions and visual symptoms of injury agree in the lab and field, the data can then be manipulated through modeling to test individual species responses at population and landscape levels.

The primary monitoring needs to protect terrestrial vegetation int he Pacific Northwest at the present time include improved monitoring of ozone at rural locations near class I areas, and cloud chemistry at higher elevations in the Cascade Range. Protocols should be established for data collection and analysis to ensure high-quality results. With regard to injury surveys, problems, opportunities to improve field-level research.

Additional needs for research and monitoring also include the dispersion of pollutants in relation to the complex meteorology and terrain of the Cascades. Local conditions in the Cascades generally result in elevated ozone south and east of major metropolitan areas below elevations of 1200 m. Exceptions occur when a temperature inversion dissipates with a marine frontal intrusion that pushes pollutants over the Cascades. This event is less common than pollution episodes at lower elevations, but there is the potential for high ozone levels (> 100 ppb) in class I areas of western Washington when it happens. Additional research and monitoring of these meteorological events is needed to determine which geographic areas may be at highest risk from ozone damage.

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