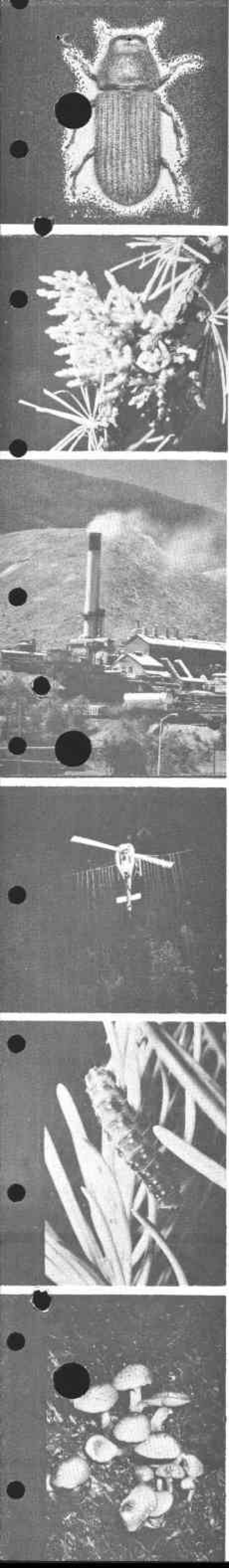

FOREST INSECT & DISEASE MANAGEMENT

USDA • FOREST SERVICE • NORTHERN REGION
State & Private Forestry • Missoula, MT 59801

Report No. 78-9 5200
May 1978

THE EFFECT OF LOW-LEVEL SULFUR DIOXIDE ON SENSITIVE VEGETATION

A Background Document for Use in Assessing Air Quality Redesignation for Primitive Areas as Required by the Clean Air Act Amendments of 1977 (P.L. 95-95)

by

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SUMMARY

In 1977 the USDA Forest Service was legally mandated by the Amendments to the Clean Air Act to determine if the maintenance of existing air quality is important in the management of National Forest Primitive Areas.

Published data on the effects of SO_2 on forest vegetation show that only a Class I air designation would be consistent with Forest Service management policy and guidelines for these areas. If Primitive Areas remain designated as Class II, SO_2 could reach concentrations high enough to induce ecological change or a decline in the stability of ecological systems. Conifers, lichens, and microorganisms would be directly impacted by the degradation, and changes in plant communities, mineral and nutrient cycling, nitrogen fixation, levels of insect and disease attack, food chains, and watershed stability could result.

The policy of the Forest Service is to manage primitive areas for their wilderness values and prevent any human-caused disruption in ecological succession. A Class I air quality is necessary to ensure that protection for these areas.

INTRODUCTION

The 1977 Amendments to the Clean Air Act (P.L. 95-95) direct the Forest Service to review Primitive Areas and determine if air quality related values are important in the management of these areas. If the maintenance of existing air quality is important, the Forest Service shall recommend to the States and Congress that Primitive Areas be redesignated to Class I to prevent significant deterioration of air quality.

In accordance with this legal mandate, the USDA Forest Service, Region 1 Air Pollution Group, has reviewed the literature concerning sulfur oxides relative to the impact of Class I versus Class II designation on Primitive Areas. This document presents a synopsis of relevant literature and a damage scenario at two assumed baseline SO_2 concentrations relative to Class I vs. Class II redesignation.

FOREST SERVICE MANAGEMENT OF PRIMITIVE AREAS

National Forest Primitive Areas, formed in the 1930's under the U-2 regulations, are currently under administrative review for classification to Wilderness. Because additions to the National Wilderness System require an Act of Congress, this is a lengthy, complex process.

Until the review process is complete, the policy of the Forest Service is to manage Primitive Areas to maintain their wilderness resource values. Title 2300 of the Forest Service Manual describes the administrative policies and procedures that guide Forest Service decisionmakers in their management of Wilderness and Primitive Areas.

These guidelines provide for management of these areas to ensure that wilderness values are dominant and above compromise. If any choice must be made between wilderness value and other values, the decisionmaker will favor the maintenance of the wilderness resource. The Forest Service has interpreted the Wilderness Act as a legal mandate to preserve these wild areas in their pristine condition, nondegraded for present and future use. Human activities will not interfere with natural forces nor disrupt the process of ecological succession.

In addition to the value of wilderness for its recreational use, the Forest Service recognizes the importance of Wilderness and Primitive Areas for their scientific value. These areas provide a benchmark for ecological studies, provide gene pools for animal and plant species, and are important preserves of historic and natural features.

Designation of Wilderness and Primitive Areas to Class I air quality is consistent with the policy and objectives of the Forest Service in maintaining these areas in their pristine and nondegraded state. In the 1977 Amendments to the Clean Air Act, Congress mandated Class I for Wilderness Areas. Primitive Areas under consideration for Wilderness designation should also be given that protective status.

CLASSES OF AIR QUALITY

The Prevention of Significant Deterioration Regulations in the Clean Air Act distinguish the three different classes of air quality. Specific maximum allowable increases in ambient air concentrations of SO_2 and particulate over the baseline, or existing levels, separate the classes. These categories are further delineated by specific measurement intervals--3-hour, 24-hour, and annual averages associated with the given concentrations. This is because air pollution damage is a function of both duration of exposure as well as absolute concentration, as well as many other factors.

Under Class I air designation, only a slight increase in pollution by sulfur dioxide and particulate matter is allowed. The intention of Congress was to provide for the preservation of existing air quality in areas in which almost any change in air quality would be considered significant.

Class II air designation allows a fairly substantial increase in air pollution over existing levels. This increase would allow for the deterioration in air quality that is usually associated with moderate industrial growth and development.

Class III air designation would apply to areas where degradation up to the national standards would be acceptable.

Because of the voluminous scientific literature on SO_2 pollution, this paper will focus on the impact of low levels of SO_2 on plant life and ecosystem stability. The Prevention of Significant Deterioration Regulations for SO_2 are summarized in Table 1.

Table 1.--Clean Air Act, Prevention of Significant Deterioration Regulations for Sulfur Dioxide (Amended 1977)

	Maximum allowable increase over baseline	
	ug/m^3	ppm
Class I		
Annual arithmetic mean	2	0.00070
24-hour maximum	5	.00175
3-hour maximum	25	.00874
Class II		
Annual arithmetic mean	20	.00699
24-hour maximum	91	.03182
3-hour maximum	512	.17902
Class III		
Annual arithmetic mean	40	.01399
24-hour maximum	182	.06364
3-hour maximum	700	.24476

SUPPORTING EVIDENCE FOR RECLASSIFICATION

Ecological systems have evolved and become established through the selective pressures of the environment. A plant community is in equilibrium with its environment. The addition of a new stress, such as SO_2 pollution, will upset this delicate balance.

SO_2 pollution can affect ecosystems in several distinct ways:

1. Direct action of SO_2 on plants can impair growth and function, including the reproductive capacity of the plant.

2. The biological environment of the plant habitat may be modified by the influence of SO_2 on plant-parasite biota, microflora and fauna, and soil mycorrhiza.

3. Acid precipitation, formed when atmospheric SO_2 is oxidized to SO_3 and reacts with water to form sulfuric acid, may alter plant communities by changing soil chemistry, nutrient cycling, and by directly damaging susceptible plant species.

Direct Action of SO_2 on Plants

Sulfur is an essential element for plants. It is an important component of many proteins and some vitamins. Although plants normally meet their requirement for sulfur through uptake from the soil, plants may utilize atmospheric SO_2 absorbed through the stomates in their leaves. However, if sulfur in excess of the plant's requirements enters, even if very slowly, chronic injury may result (Malhotra and Hocking 1976).

This threshold level for injury varies between species and even between individuals of the same species. It is dependent upon the plant's ability to metabolize or detoxify SO_2 (CARB 1977). Fujiwara (1970) and others hypothesize that it is the accumulation of SO_2 as sulfite (SO_3), a strong reducing agent, which causes the injury.

When this biochemical threshold level is exceeded, fundamental cellular processes, such as photosynthesis and respiration, are disrupted (Malhotra and Hocking 1976). Malhotra suggests that low concentrations of SO_2 can result in injury at the molecular level by interfering with cell membrane structure and permeability as well as enzyme configuration.

Biochemical studies conducted by Ionescu and Grow (1971) focused on the effect of changes in plant hydrogen ion concentration caused by SO_2 pollution. They showed that SO_2 and sulfuric acid, H_2SO_4, modify the composition of amino acids. This results in reduced production of hormones and enzymes needed for plant growth.

These disruptions at the cellular level can cause reductions in growth and seed viability without producing visible foliar symptoms (Malhotra and Hocking 1976; CARB 1977). However, as concentration or duration of exposure increases, injury to the plant becomes visible. This injury, in the form of chlorosis or necrosis, may be regarded as a summation of the injury to individual cells. This injury ultimately leads to the death of the leaf, the plant, and finally, to the population (CARB 1977).

Lichens are the most SO_2-sensitive members of the plant kingdom. A lichen is a symbiotic fungal-algal partnership, a delicately balanced partnership that is easily altered by small environmental changes.

Lichens are the first plants to inhabit exposed rock surfaces and play a major role in the slow conversion of rock to soil. They increase the stability of erodable soils; the blue-green algae contribute to the nitrogen economy of the plant community (MGB 1975). Wiley (n.d.) notes that recent studies have indicated that lichens contribute a significant portion of the nitrogen added to some northwest coniferous forest ecosystems. Because nitrogen is a major limiting factor for most microbial decomposition, any reduction in nitrogen can be expected to cause a decrease in the decomposition of organic matter. This slow-down in nutrient cycling would, in turn, cause a decline in the overall productivity of the ecosystem. Lichens are also important as a food source for a number of insects and microorganisms (Skye 1968), as well as for some vertebrate animals.

Lichens are very susceptible to SO_2 because, unlike higher plants, they are not protected by a cuticle layer with stomates controlling gas exchange. They are extremely slow growing and are very efficient at absorbing nutrients from the atmosphere and from rainwater (Smith 1960). However, they possess no mechanism to reject toxic substances, so in time accumulate various pollutants to lethal levels. Skorepa and Vitt (1976) conclude that a given lichen flora reflects the average cumulative effects of air pollution over a long period of time.

The increase in SO_2 pollution allowed under Class II air quality would cause detrimental change to lichen populations in Primitive Areas. Skye (1968) and LeBlanc and Rao (1973) found that the threshold level for injury to lichens was less than 0.005 p.p.m. SO_2 annual average concentration. LeBlanc and Rao state that an average concentration of SO_2 between 0.006 and 0.03 p.p.m. would result in chronic injury to lichens. A Class II air quality designation would allow the annual average SO_2 concentration to increase approximately 0.007 p.p.m. Therefore, even at a pollution-free, 0.0 baseline level, one could expect a decline in the health and survival of this integral component of Primitive Area ecosystems. Food webs, community stability, mineral and nutrient cycling, and patterns of succession could be changed (MGB 1975).

Among the higher plants, conifers appear to be the most sensitive to SO_2 pollution. Young needles, pollen production and germination, as well as the general health and vigor of the tree are particularly vulnerable and could be impacted at the SO_2 levels allowed by Class II air quality.

Tissue damage has been observed on new needles of eastern white pine *(Pinus strobus)* after a single 1-hour treatment with 0.05 p.p.m. SO_2 (Costonis 1971). At a 0.0 baseline level, Class II would allow 3-hour exposures of SO_2 at 0.179 p.p.m.

Ma et al. (1973) showed that a 30-minute exposure to 0.075 p.p.m. SO_2 caused damage to *Tradescantia* pollen tubes starting to germinate. He states that SO_2 at 0.1 p.p.m. or higher inhibits mitotic activity, tube growth, and pollen germination. Therefore, the short-term fumigations allowed by Class II may also affect a plant's ability to reproduce and maintain its place in the plant community if the fumigations occur during this crucial period.

Houston (1974) found that necrosis to elongating needles of eastern white pine occurred after a 6-hour fumigation with 0.025 p.p.m. SO_2. Class II allows an increase over baseline of 0.0318 p.p.m. SO_2 for a 24-hour average concentration.

Although long-run averages mask short-term high concentration fumigations, a field study in the Sudbury region of Ontario reported extensive SO_2 caused damage to eastern white pine in an area that had SO_2 concentrations as low as 0.004 p.p.m. for a 7-year average (Linzon 1971).

Materna (1973) showed that annual average SO_2 concentrations ranging from 0.006 p.p.m. to 0.009 p.p.m. caused a reduction in the wood growth of fir trees. He concluded that visible necrosis to the foliage and premature needle casting caused this loss of productivity. He also noted an associated reduction in ground cover vegetation at this level of pollution, causing the watershed to be seriously degraded by increased runoff and erosion.

Many researchers have pointed out that even if no injury to the plant, visible or hidden, can be detected, SO_2 pollution adds another stress pressure on the plant. This increases the plant's vulnerability to being injured by other environmental factors such as drought and frost damage and predisposes the plant to insect and disease attack.

Modification of the Biological Environment of the Plant Habitat

The biotic components of the environment, the microflora and microfauna, may be far more sensitive to pollution than the higher plants (Treshow 1968). Fungi, bacteria, viruses, and insects are all important in bringing a species into equilibrium with its environment and determining the ultimate plant population. Nameav (1964) found symbiotic organisms to be especially vulnerable to air pollution. He observed changes in the species composition of soil flora and fauna, pathogenic microorganisms, and both pollinating and damage-causing insects.

Mycorrhizal fungi, beneficial plant root symbionts, infecting 90 percent of all higher plants, are extremely sensitive to soil pollution (Namaev 1964). A growing season average of 0.005 to 0.01 p.p.m. SO_2, a range which includes the level of degradation allowed by Class II air quality over baseline, caused a change in mycorrhizal activity over that of pollution-free controls (Pye 1978).

A decline in microbial decomposition of organic matter could have a major effect on nutrient availability in an ecosystem. Treshow (1968) emphasizes that microflora play such an important role in determining the ultimate composition of a plant community that any factor influencing their ecology would have a secondary impact on the vigor and population of higher plants.

Impact of Acid Precipitation

Acid rain is a regional SO_2 pollution problem affecting wide areas hundreds of miles around industrial centers (Nordo 1975; MGB 1975).

Because of differences in the ability of an ecosystem to buffer, or neutralize, the acid, the effects of acid precipitation will be much greater on some plant communities than on others. The composition of the soil parent material and differences in the stage of development of the plant-soil system account for the variation in buffering capacity (Dochinger and Seliga 1976).

Forest soils, which are naturally slightly acid, have little buffering capacity and can be adversely changed by the effects of acid rainfall. The nutrient reserves of an ecosystem can be lost from the system by the acid rains leaching nutrients from the soil matrix (Ferenbaugh 1974). Reduction in soil pH reduces nitrogen fixation by bacteria and blue-green algae and slows microbial decomposition of organic matter (Denison et al. 1975).

Tamm and Cowling (1975) suggest that the entire soil ecosystem can be drastically altered by acid precipitation. Since the soil ecosystem is the basis for the development of plant communities, there is no question that the entire ecosystem would be affected.

Additionally, acid rains can cause direct injury to a plant (Tamm and Cowling 1975). Ferenbaugh (1974) found that different plant species showed different susceptibility to the deleterious effects of acid rain. He concluded that a change in plant composition was very likely given the competitive disadvantage of susceptible plants.

A summary of maximum SO_2 concentrations that would be allowed under Class II redesignation is shown in Table 2. Two baseline concentrations were assumed, 0.0 and 50 $\mu g/m^3$. Relevant data on SO_2 concentrations that are known to cause injury to biological systems are also given. There is little question that Class II designation is not compatible with Wilderness or Primitive Area management philosophy.

Table 2.--SO_2 concentrations allowed under two baseline conditions and Class 2 designation compared to concentrations known to cause plant injury

SO_2 concentration allowed by Class 2			SO_2 concentration causing injury		
Baseline	Baseline	Averaging time	Concentration p.p.m.	Averaging Time	Injury response
0 $\mu g/m^3$	50 ug/m^3				
512 $\mu g/m^3$	572 ug/m^3	3 hours	0.008	30 min.	Photosynthesis inhibited in blue-green algae (Wodzinski et al. 1977).
0.17902 p.p.m.	0.20000 p.p.m.		.075	30 min.	Damage to pollen of *Tradescantia* (Ma et al. 1973).
			.050	1 hour	Necrosis to new needles of eastern white pine (Costonis 1971).
91 $\mu g/m^3$	141 ug/m^3	24 hours	.025	6 hours	Necrosis to new needles of eastern white pine (Houston 1974).
.03182 p.p.m.	.04930 p.p.m.				
20 $\mu g/m^3$	70 $\mu g/m^3$	Annual	.004-.045	Annual	Extensive damage to eastern white pine (Linzon 1971).
.00699 p.p.m.	.0245 p.p.m.		.006-.009	Annual	Poor needle retention, necrosis to needles, decrease in reproductive capability, decrease in wood growth of fir trees, damage to watershed (Materna 1973).
			.005	Annual	Foliose lichens absent (Skye 1968).
			.006	Annual	Chronic injury to lichens LaBlanc and Rao 1973).
			.018	Annual	Average lethal dose for all lichens (Skye 1964).

CONCLUSION

Plant communities are in a state of dynamic equilibrium with their environment. The increases in SO_2 pollution allowed by a Class II air designation would have a significant impact on the ecosystems of Primitive Areas by upsetting this delicate balance and would result in pollution-induced changes to the ecosystem.

Lichens, conifers, microorganisms, fungi, and insect populations would be seriously impacted by the degradation allowed by Class II air quality. Mineral and nutrient cycling, nitrogen fixation, levels of insect and disease attack, food webs, watershed stability, and the overall health and productivity of the plant community would be altered.

Even if only a few species are sensitive to the effects of air pollution, the stability of a plant community may rest on a few key matrix species (Treshow 1968). Any simplification of an ecosystem tends to increase its instability and makes it more vulnerable to damage from other stress (Smith 1972). Retrogression, reverse ecological succession, is a spiraling process and once set in motion may continue unchecked until a new balance is reached.

The policy of the Forest Service is to maintain the wilderness resource of Primitive Areas and prevent any disruption in ecological succession. It is clear that only a Class I air quality will ensure that Primitive Areas will be protected from degradation by SO_2 pollution.

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