FINAL REPORT

RISKS TO CALIFORNIA FORESTS DUE TO REGIONAL OZONE POLLUTION

A Data Base and Ranking of Forest Sensitivity

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Contract No: A6-049-32

[PINES]

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1.0 INTRODUCTION

1.1 PURPOSE

Recent declines in growth and vigor, as well as elevated mortality of forest trees in California have generated increased concern that these changes have been caused by air pollution. The current consensus of the forest-science community is that ozone and other oxidants are influencing the structure and productivity of forest ecosystems in California and in other regions of the United States. The magnitude of ozone effects on tree species and forest ecosystems, however, is not known; nor have the exposures producing such effects been adequately characterized.

This study was designed to estimate risks to California forests and forest resources due to ambient ozone concentrations and to develop a data base of forest resources for use in future Air Resources Board analyses. To accomplish these objectives, three principal research tasks were performed:

1. **Construct a data base of forested resources in California.** This data base contains 91 variables describing forest resources in 3500 forest grid cells. Each grid cell covers approximately 30,000 acres. Data on forest tree species volume, ownership, elevation, soil type, watershed, recreation, and modeled ozone concentrations are included in the data base.

2. **Evaluate the sensitivity of California forest tree species to ozone.** While ozone caused forest injury has been widely described in California, the complexity of this injury has prevented a quantitative characterization of forest tree/ ecosystem response to elevated ozone concentrations. This task developed ozone sensitivity rankings for California forest tree species based on available literature and the expert judgment of Dr. Joseph McBride of the University of California at Berkeley

and Dr. Paul Miller of the USDA Forest Service and the University of California at Riverside.

3. **Perform risk assessment.** Using data contained in the data base and sensitivity rankings established in Task 2, this task evaluated the ozone caused risk to forest resources in California. These results are summarized across the state, by ownership category, watershed, county, air basin, and national forest.

1.2 LIMITATIONS OF THE STUDY

This study is unique in the scope of its coverage and detail. To our knowledge, no previous study has evaluated the ozone caused risk to so many California tree species, covered such a wide geographic area, and such a variety of forest resources. Data base development relied on available secondary information provided by the USDA Forest Service, the Forest and Rangeland Resources Assessment Program, the US Department of Interior, and other governmental and private sources. Data provided by these sources were incorporated into the data base without performing exhaustive quality assurance and verification.

This reliance on secondary data is not the major source of uncertainty. Estimated ozone concentrations in forested grid cells are based on 1977-1981 ozone monitoring data, and have very wide margins of error. In addition, knowledge of forest injury due to ozone is extremely limited and uncertain. The results of the risk analysis should, therefore, be interpreted as broad approximations. By defining four separate risk categories, we have avoided making overly precise judgments of risk, but have also provided the Air Resources Board with a useful taxonomy of forest risk due to ozone concentrations.

The results are defensible, but there is scope for much refinement and scientific research. We are careful to explain precisely what we did at each step of the analysis, and why we approached the research tasks as we did. This shows the reader the problems entailed in the analysis, provides a sense of the uncertainties involved, and suggests direction for further refinement and research.

More positively, the results are useful, providing one is cognizant about the uncertainties associated with them. The results provide explicit estimates of the risks to forest resources in California due to ambient ozone concentrations. The profile of forest tree sensitivity to ozone in California is also of considerable interest. Finally, the forest resources data base provides the Air Resources Board with a unique, flexible tool that can be used in a variety of future research projects.

1.3 ORGANIZATION OF THE REPORT

The report is organized as follows. The core of the report is in Chapters 2 through 5, although the Appendices contain useful summaries of the data and programs used in the risk analysis.

Chapter 2, **Air Pollutant Caused Forest Effects**, reviews in detail reported forest injury caused by ozone in California and assigns ozone sensitivity rankings to tree species found in California.

Chapter 3, **Description of the Forest Resources Data Base**, describes the steps taken in the design and construction of the data base. The chapter also describes the 91 variables contained in the data base and outlines the quality control procedures that were used in its development.

Chapter 4, **Risk Assessment**, documents the risk assessment calculations and presents summary results for the state, ARB Air Basins, counties, ownership groups, and national forests.

Chapter 5, **Non-Market Benefits of Forest Protection**, reviews potential non-market benefits associated with the reduction of ozone concentrations in

California forests. The focus of this chapter is on the review of studies that have estimated economic benefits associated with changes in forest quality.

1.4 APPENDICES

The remainder of the report consists of appendices that present documentation of variable names and codes, additional data, a summary of the forest resources data base, and SAS programs used in performing the risk assessment.

Appendix A, Cell Size Listing and Keys to Variable Codes, provides a listing of cell sizes and keys to variables used in the data base.

Appendix B, Definitions of USDA Forest Service Tree Classes and Timber Strata, defines tree classes and timber strata used in the calculation of forest volume.

Appendix C, Definitions of Photo Interpretation Classes, defines the photo interpretation classes that were used to calculate non-USDA Forest Service tree volume estimates.

Appendix D, Timber Value Tables for Inyo National Forest, provides timber data for the Inyo National Forest.

Appendix E, Breakdowns of USDA Forest Service Acreage by Site, Class, and Timber Strata, summarizes the area of available productive forest land by site and strata for each national forest.

Appendix F, SAS "Contents" and "Means" Printouts for the Forest Resources Data Base, presents statewide summaries of variables in the data base.

Appendix G, Summary Data Tables Stratified by Air Basin, presents summary data for all variables in the data base stratified by elevation and ARB Air Basin.

Appendix H, <u>**Summaries and Listings of SAS Programs Used in Risk Analysis**</u>, documents and contains all SAS programs used in the risk analysis.

2.0 AIR POLLUTANT CAUSED FOREST EFFECTS

2.1 INTRODUCTION

Recent declines in growth and vigor, as well as increased mortality, of forest trees in California (ARB, 1987; Peterson, et al., 1987), the eastern United States (Zahner, 1988; Bechtold, 1988), and Europe have generated increased concern that those changes have been caused by acid deposition, gaseous pollutants such as ozone and sulfur dioxide, or trace elements associated with the increased utilization of fossil fuels. A wide array of hypotheses have been proposed to explain these declines, see McLaughlin (1985) and Kulp (1987). However, research relating anthropogenic air pollutants to stress on forest trees has been limited in scope (ARB, 1987; U.S. EPA, 1987; Hogsett, 1988; and Kulp, 1987). These efforts have yet to develop a comprehensive explanation of the effects of chronic and acute exposures of forests to pollutants or to fully determine the extent of current forest damage from air pollutants.[1]

While adequate quantitative expressions relating air pollutant concentrations and forest ecosystem or mature tree response have not been developed, there are clear parallels in the expression of forest decline and dieback symptoms in parts of California, the eastern United States and in Europe. Significantly, affected trees exhibit synchronous reductions in annual increment growth and appear to be predisposed to attack by secondary

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[1] There are currently two primary research programs addressing the current and potential effects of air pollutants on forest trees in the United States. The Forest Response Program is a federal program jointly administered by the USDA Forest Service and the U.S. EPA that is conducting research regionally in the United States within four research cooperatives. The Western Conifers Research Cooperative is currently funding a number of research projects on the effects of atmospheric deposition and ozone on California tree species (Olson, 1987; 1988). The U.S. EPA has recently initiated a research program evaluating the effect of tropospheric ozone on forest types (Hogsett, 1988). The draft research plan for this five year program was recently peer-reviewed, and is expected to be finalized by November, 1988.

pathogens. Trees are exhibiting symptoms of decline at a variety of altitudes on different soil types, and in areas characterized by different climatic zones. Symptom expression has been correlated with air pollutant concentrations, and the deposition of acidic substances or presence of acidic fogs and cloud cover.

Research is currently focusing on the following pollutants as contributors to forest decline in California and in the United States:

1. ozone and other photo-oxidant pollutants;
2. sulfur and nitrogen compounds and their associated hydrogen ions; and,
3. trace metals, deposited as particulates or released in soil horizons by acidic deposition.

2.1.1 Ozone

The current consensus within the forest-science community is that ozone is influencing the structure and productivity of forest ecosystems in California (CARB, 1987; McBride, et al., 1985; U.S. EPA, 1986). Ozone may be influencing the structure and productivity of forest ecosystems in other natural ecosystems throughout the United States (Kulp, 1987; U.S. EPA, 1987).

The magnitude of ozone effects on tree species, however, is not known; nor have the exposures producing such effects been adequately characterized. The basis for scientific and regulatory concern regarding ozone caused forest injury is fourfold:

1. survey studies have found symptoms characteristic of ozone toxicity (both foliar pathologies and reduced growth) on tree species over broad regions of California and the United States;
2. controlled ozone exposures in both the field and laboratory have demonstrated that low levels of ozone reduce the growth of tree seedlings;
3. natural ecosystems in California and the United States are exposed to ozone concentrations known to be toxic to sensitive tree species; and,

4. in the San Bernardino and Angeles National Forests, changes in the composition and structure of ponderosa and Jeffrey pine stands have been related to elevated ozone concentrations. Prolonged oxidant exposure has been correlated with foliar injury and premature leaf fall in a number of species in the San Bernardino Mountains causing decreased photosynthetic capacity, suppressed radial growth of tree stems and reduced nutrient retention in the green biomass, all leading to weakened trees.

2.1.2 Acid Deposition

Potential forest injury due to deposition of sulfur and nitrogen compounds and their associated hydrogen ions (acidic deposition) is incompletely understood (NAPAP, 1987). While a number of hypotheses linking sulfur and nitrogen deposition (as sulfate and nitrate) to forest decline and dieback in the eastern United States and Europe have been developed, there is presently no evidence that acidic deposition is affecting tree growth or vigor in California.[2] However, because the impact of acidifying substances is regional and subtle over annual time scales, acid deposition may be affecting tree growth in California. While this possibility cannot be ruled out, uncertainties present in the current understanding of acid deposition injury to forest trees and ecosystems prevent the performance of quantitative risk assessment. Consequently, this report does not include a risk assessment of potential forest response due to acid deposition, either as sulfate or nitrate.

2.1.3 Trace Metals

Risks of forest injury related to the deposition of trace metals are not considered due to the absence of necessary air quality data and the lack of understanding regarding the potential effects of trace metals on forest trees and ecosystems.

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[2] The Ceanothus chaparral die-back that has been observed across 1×10^5 ha in the San Gabriel, Verdugo, and Santa Monica Mountains of Los Angeles County may be related to chronic exposure of air pollutants, including nitrate deposition and ozone, in conjunction with prolonged drought stress (Riggan, 1987).

Because of the unique phytotoxicant properties of ozone, the documentation of oxidant effects on forests in southern California, and the regional patterns of elevated oxidant concentrations over much of California, this report focuses on the risks of forest injury in California due to ambient ozone concentrations. Section 2.2 reviews ozone caused forest effects in California and Section 2.3 presents ozone sensitivity rankings for California tree species based on the available literature and expert judgment. Sensitivity values listed in 2.3 are used in Chapter 4 to assign vulnerability rankings to forested cells within the data base.

2.2 OZONE CAUSED FOREST EFFECTS IN CALIFORNIA

2.2.1 Description of Ozone Caused Tree/Forest Injury

Ozone effects on forest ecosystems range from the potentially insignificant to fundamental alterations in ecosystem relationships and processes, and are determined through: the genetically controlled resistance of individual ecosystem members; the influence of environmental conditions; and ozone-caused changes in inter and intra specific relationships. The complexity of these ozone-caused forest tree/ecosystem interactions prevents a simple characterization of ozone-caused forest injury. Readers interested in a comprehensive discussion of forest response to air pollution are referred to McLaughlin (1985), specific treatments of ozone-caused injury are found in Guderian, et al. (1985) and U.S. EPA (1986).

Ozone is absorbed by plants directly from the atmosphere. Uptake is practically limited to plant leaf structures and its rate is a function of the chemical and physical properties of the environment, see Tingey and Taylor (1982) and Guderian, et al. (1985). Once ozone has been absorbed by plants, effects at the cellular level are initially expressed through the altered permeability of membranes resulting in changes in cellular compartmentalization, and water and mineral relations. These effects as well as alterations in enzyme activity, plant metabolism, cellular structure, and organization cause cellular perturbation and may result in cell death.

Ozone-induced cellular alterations can reduce photosynthesis rates, elevate plant respiration, and disrupt plant-water relations. Numerous studies have described the effects of photochemical oxidants and ozone on plant photosynthesis (Guderian, et al., 1985). Associated with reduced photosynthate production is the altering of photosynthate partioning, causing a reduction in root growth and root processes (Miller, 1973). While photosynthesis is reduced shortly after elevated ozone exposures, net photosynthetic rate has been shown in some experiments to return to its original level when ozone exposures are ended.

Photosynthesis can be reduced without the appearance of visible foliar injury, but the appearance of visible symptoms is always associated with reductions in photosynthesis (Guderian, et al., 1985). Under chronic ozone exposures ozone has been reported to reduce soluble sugars and starch leading to decreased plant growth and yield.

2.2.2 Distribution of Ozone Caused Forest Injury in California

In southern California, the coastal chaparral ecosystem, dominated by chamise and manzanita or woodland species, and the coniferous forest ecosystem have received chronic exposure to elevated concentrations of ozone and other oxidants, while the desert ecosystems in the vicinity of mountain passes connecting the coastal and desert regions have also been exposed to elevated ozone concentrations. Oxidant injury has been extensively documented in the mixed-conifer ecosystem of the San Bernardino Mountains (Kickert and Gemmill 1980; Miller, et al., 1977; 1980; 1982). Early symptoms of injury in coniferous species were reported in 1970 by Miller and Millecan (1971). In the southern Sierra Nevada, Forest Service surveys conducted in 1974 detected increased injury in ponderosa pine at many locations in the Sequoia National Forest. Forest Service surveys conducted in Sierra and Sequoia National Forests indicate that oxidant injury symptoms are now widespread (Pronos, et al., 1978; Vogler, 1982a and b).

2.2.2.1 The San Bernardino Mountains

The mixed conifer forests in the San Gabriel and San Bernardino Mountain ranges east of Los Angeles have been exposed to oxidant air pollution since the early 1950s (Miller, et al., 1982). Most oxidants in the South Coast Air Basin are generated in the Los Angeles Basin. During the summer, a combination of weather patterns and topography contribute to average 24-hour ozone concentrations in the San Bernardino National Forest that range from a background of 3 to 4 pphm up to a maximum of 10 to 12 pphm (Miller, et al., 1977). The San Bernardino National Forest forms the principle northern and eastern barrier to the movement of oxidants out of the Los Angeles Basin, and reported oxidant concentrations at monitoring stations range up to 40 percent higher than at lower elevation windward urban monitoring stations (Miller, et al., 1977).

In 1971 Miller and Millecan utilized methods developed by Wert (1969) to determine the extent of oxidant injury to ponderosa and Jeffrey pines in diameter classes larger than 30 cm in the San Bernardino National Forest. Pine injury was categorized as heavy, moderate, light or negligible. Table 2.1 shows that while substantial percentages of the Jeffrey and ponderosa pine forest type were reported as damaged, the area represented a small fraction of the overall forest area. Miller (1971) estimated that of 1,298,000 affected trees, 82 percent were moderately affected, 15 percent severely, and three percent were dead. Miller (1973) subsequently ranked common California tree species for decreasing sensitivity to ozone following laboratory fumigation experiments, see Table 2.2.

Results of the San Bernardino National Forest Research Project conducted by the U.S. EPA from 1973 to 1978 in the pine and mixed conifer forests of the San Bernardino Mountains confirm the relative ozone sensitivities established by Miller (1973). Ponderosa pine was found to be very ozone sensitive, with

Table 2.1

Measured Ozone Damage to Pine in the San Bernardino National Forest - 1971

	Areas of Ponderosa-Jeffrey Pine Type	**% of Total Area of Ponderosa and Jeffrey Pine Type**	**% of Total Forest Area**
Total	160,950		
Heavy	46,230	29%	.7%
Moderate	53,920	34%	.8%
Light or negligible	60,800	38%	.9%

Source: Miller (1971)

Table 2.2

Sensitivity of Selected California Trees to Ozone Fumigation Experiments

Most Sensitive	**Intermediate Sensitivity**	**Tolerant Species**
ponderosa pine	Coulter pine	Incense cedar
Jeffrey pine x Coulter pine hybrid	Douglas Fir	sugar pine
Monterey x Knobcone pine	Jeffrey pine	giant sequoia
Western white pine	white fir	
	bigcone Douglas Fir	

Source: Miller (1973)

foliar injury occurring at 24 hour average May-September concentrations of 5 to 6 pphm (Kickert and Gemmill, 1980; Miller, et al., 1982). Jeffrey pine was also sensitive followed by, in decreasing order of sensitivity, white fir, black oak, incense cedar, and sugar pine (Miller, et al., 1982).

The San Bernardino National Forest research project (Miller, et al., 1977; 1982; Kickert, et al., 1980) examined oxidant stress along a gradient of decreasing oxidant concentrations from west to east. As elevation increases, this gradient is paralleled by a gradient of decreasing precipitation and air temperatures.

Sensitivity to ozone in the San Bernardino National Forest study was defined by the average number of annual needle whorls retained by trees. Pines exposed to hourly average ozone concentrations ranging from 6 to 12 pphm had their number of annual needle whorls decrease from 2.5 to 2.0 from 1973 to 1978 (Miller, et al., 1982). On the other hand, pines at plots with lower oxidant doses maintained the same number of annual needle whorls or showed slight increases in whorl retention. The average number of annual needles retained by white fir remained approximately the same during the 1973 to 1978 period, while California black oaks showed a sensitive leaf injury response to ozone each year. Incense cedar and sugar pines evidenced little foliar injury (Miller, et al., 1982).

Chlorotic mottle symptoms appeared on current year ponderosa pine needles before they were fully grown following an accumulated ozone dose ranging between 1.0 and 2.0 x 10^5 $\mu g/m^3$ excluding background ozone (Miller, et al., 1982). The results for 1973 to 1975 indicated that visible symptoms of injury increased in seven pine populations, while five remained the same, and six decreased in visible symptoms of injury (Miller, et al., 1977). The diminished photosynthetic capacity resulted in decreased stem diameter and height growth in affected trees. Needle shoot and main stem growth of ponderosa pine and Jeffrey pine saplings maintained in a carbon-filtered greenhouse compared with pine growth in an unfiltered greenhouse was much greater following an exposure period lasting from 1968 to 1973 (Miller, et al., 1977).

McBride (Miller, et al., 1977) studied two randomly selected populations of 19 dominant ponderosa pine (see Table 2.3). One population ranged in age from 55 to 71 years in 1971, and the other from 20 to 39 years. The influence of tree age on ring width growth was minimized by comparing rings of equivalent age in each population. Measured rings in the older group were produced from 1910 to 1940, and in the younger group from 1941 to 1971 under the influence of oxidant air pollution. After the influence of precipitation on growth was evaluated, there was a difference of 0.20 cm in average annual growth attributable to oxidant air pollution injury. In this sample, an average thirty year old tree subjected to air pollution (present conditions) was 7.0 m tall, 19.0 cm in diameter at breast height, and could produce one log 1.8 m long with a volume of 0.047 m^3. An average thirty year old tree grown in the absence of oxidant air pollutants, between 1910 and 1940, would be 9.1 m tall, 30.5 cm diameter at breast height, and could produce one log with a volume of 0.286 m^3. In other words, the merchantable volume of thirty year old ponderosa pine trees exposed to high levels of oxidant pollution, was reduced by 84 percent (Miller, et al., 1977). In recent investigations of San Bernardino National Forest plots, Miller has found that many trees have not produced annual incremental growth rings, an indication of extraordinarily low vitality.

Severity of ozone symptoms noted in the San Bernardino National Forest study was related to increased tree mortality. Between 1973 and 1975, the accumulated mortality of ponderosa and Jeffrey pines on the eighteen research sites ranged from 0 to 8.9 percent, and averaged 2.9 percent in plots categorized as having slight, moderate, and severe injury. Mortality was less than 0.3 percent in the remaining plots rated as having very slight or no visible injury. The increase in timber volume from low to high risk management categories was very large at two Forest Service plots between 1952 to 1972. The removal of high risk trees from oxidant damage stands on the San Bernardino National Forest is considered an oxidant-related mortality factor (Miller, et al., 1977).

Table 2.3

Average Annual Radial Growth of 19 Ponderosa Pine Trees in Two Levels of Oxidant Air Pollutants in the San Bernardino National Forest, California

High Pollution		Low Pollution	
Age* (years)	**Average Radial growth (cm) 1941 - 1971**	**Age* (years)**	**Average Annual radial growth (cm) 1910 - 1940**
20	0.20	60	0.52
21	0.33	55	0.49
29	0.22	55	0.61
22	0.33	57	0.34
25	0.30	64	0.40
35	0.23	63	0.55
27	0.29	60	0.44
28	0.31	65	0.46
35	0.26	60	0.75
22	0.43	71	0.67
39	0.21	63	0.71
35	0.34	71	0.65
29	0.37	66	0.78
33	0.37	63	0.53
35	0.34	60	0.33
36	0.37	70	0.38
36	0.35	61	0.32
36	0.33	62	0.37
34	0.36	59	0.37

Source: Miller, et al. (1977)

* Age at 1.4 m above ground in 1971.

Ozone damage contributes to pine mortality by predisposing pines to insect and pathogen invasion. Air pollution injured ponderosa and Jeffrey pines are more subject to invasion by _Fomes annosus_ root disease and western pine beetles (_Dendroctonus abrevicomis_). _Fomes annosus_ colonizes freshly cut stump surfaces of weakened trees and consequently accelerates the contact between stumps to proximate living root systems (Miller, et al., 1977). In addition, the fungus appears to spread more rapidly in weakened trees than in healthy trees (Miller, et al., 1977). Because _F. annosus_ is involved in a significant proportion of both the fir and pine pest mortality in southern California Forests, the predisposition of stressed trees to _F. annosus_ may lead to significantly increased ponderosa and Jeffrey pine mortality. As fewer western pine beetles are required to kill weakened trees, a given population of western pine beetles can be expected to kill more oxidant weakened trees and propagate at an accelerated rate (Miller, et al., 1977). _F. annosus_ and the western pine beetle were commonly noted to be present in the same tree in the San Bernardino National Forest.

Cobb and Stark (1970) presented data that confirmed the hypothesis that oxidant air pollution predisposes ponderosa pines to bark beetle infestations. They reported that thirty-six of 150 sampled trees were killed by western pine beetle or mountain pine beetle. The results also indicated that, under the conditions prevailing in the Lake Arrowhead Region of the San Bernardino Mountains, most pines are infested by beetles only after the ozone injury to the tree has become severe. Approximately 50 percent of the trees that were classified as healthy at the beginning of the three-year study had maintained that classification at the completion of the study; the remainder had developed either intermediate or advanced symptoms of ozone damage.

Reproduction is also affected by ozone concentrations, as cone production in oxidant injured ponderosa and Jeffrey pines was significantly reduced in trees older than 130 years of age. Severe injury to dominant ponderosa and Jeffrey pines resulted in fewer cone drops during the period of the San Bernardino study (Miller, et al., 1982). The drop in the proportion of trees producing cones was more significant for Jeffrey pine than for ponderosa. The decline in cone production coupled with the increased mortality on severely damaged pine plots may cause increased foraging pressure by indigenous squirrel populations, further heightening the selective disadvantages of ponderosa and Jeffrey pines (Miller, et al., 1977).

The advanced mortality and differential sensitivity of ponderosa and Jeffrey pine on the western slopes of the San Bernardino National Forest have led some investigators to suggest that changes in stand successional development will result in simplification of the forest ecosystem (Miller, et al., 1982). In sites significantly affected by ozone damage, pine needle litter accumulation and a heavy layer of combustible litter accumulation following pine mortality may contribute to crown fires, eliminating the majority of pines (Miller, et al., 1982). Even without catastrophic crown fires, pine succession has been hindered by lower seed production of injured trees and predisposition of ozone stressed trees to pest infestation.

Successional changes may result in the replacement of less tolerant Jeffrey and ponderosa pine with more tolerant conifers, for example fir and incense cedar. McBride, et al. (1985) used plot data from stands dominated by ponderosa pine in the San Bernardino National Forest to predict long term successional change in forest composition, assuming continuation of current levels of ozone pollution. Plots were divided into two classes (severe and slight injury) based on foliar injury symptoms to compare tree survival and seedling establishment on the plots. Model projections indicate a shift away from dominance by ponderosa pine by the year 2074 on both severe and slight injury plots. For example, ponderosa pine's percentage composition of the mature age class group was predicted to drop from 85.8 in 1974 to 65.8 percent in 2024 to 13.5 percent in 2074 on severe injury plots. The authors suggest eventual changes in succession from ponderosa pine dominated stands to stands dominated by incense cedar. If, however, the pine dominated forest is replaced by shrub and oak species, which rapidly sprout after a fire, less desirable shrub communities may become the dominant species type (Miller, et al., 1982). While the risk of successional changes in the San Bernardino National Forest is difficult to evaluate, there is considerably less evidence available for remaining California forests.

If successional changes are caused, in part, by ozone concentrations, significant economic damage could result from the loss of harvestable timber and water resources. The increased risk of catastrophic fires could also cause significant economic damage to property owners in the urban-wildland interface. Recreational use values would certainly be affected, as would values deriving from the preservation of the ecosystem for the use of future generations and motives related to environmental preservation.

2.2.2.2 Remaining California Forests

Severe ozone damage has occurred in the San Bernardino National Forest. However, ozone damage has also been reported in the remaining southern California national forests, including the Angeles National Forest, the Los Padres National Forest, and the Cleveland National Forest located principally within the South Coast, South Central Coast, and San Diego Air Basins respectively.

The results of a 1970 aerial survey (within the Angeles National Forest) indicate that 260,689 pines were affected by oxidant air pollutants. Of the affected trees, 20.1 per cent were severely damaged and 79.9 percent were moderately damaged (Smith, 1979). Ozone injury symptoms have also been reported in the Cleveland National Forest, but the extent of the damage has not been systematically determined. Damage has been reported at a number of sites within the Laguna Mountains. The absence of a strong inversion layer in the Cleveland National Forest prevents the accumulation of high oxidant concentrations found in the San Bernardino and the Angeles National Forests, and may be responsible for the reported lower damage levels (Smith, 1979).

Oxidant injury to pines was first discovered in the southern Sierra Nevada Mountains in 1970 (Vogler, 1982b). Oxidant injury symptoms to ponderosa pine and Jeffrey pine are now widespread on the Sierra and Sequoia National Forests (Pronos, et al., 1978; 1981). Results of ozone-injury surveys conducted in the southern Sierra Nevada Mountains are summarized in Table 2.4

Table 2.4

Summary of Ozone Damage (% Affected) to Selected California National Forests and Sequoia and Kings Canyon National Parks

	Sequoia and Sierra NF (1977)	Sequoia and Sierra F (1979)	Sequoia and Sierra NF (1983)	Sequoia and Kings C.NP. (1980-82)	Stanislaus (1981)
Very severe	0	0	0	0	0.4
Severe	0	22	12	7.4	6.4
Moderate	6	22	12	25.9	15.7
Slight	52	37	52	42.6	6.5
Very slight or no damage	42	19	24	24	70.4

In 1977 a cooperative ozone injury survey was conducted on the Sierra and Sequoia National Forests. Because the majority of commercial pine stands in the southern Sierra Nevada are found between 4000 and 8000 feet, the survey established 242 plots containing ponderosa and/or Jeffrey pine between these elevations. Ozone symptoms were evaluated and rated by examining branches from the lower crown of each tree. The scoring system was based on the severity of chlorotic mottle present on the pine foliage. The extent of injury ranged from "very severe" to "no symptoms". Combining the results for the two national forests, 68 percent of the plots contained symptoms of ozone injury. Forty-two percent of the plots had "very slight injury" or "no symptoms", 52 percent had "slight injury" and six percent had "moderate injury". No plots were assigned "severe" or "very severe" ozone injury ratings. Approximately 40 percent of the plots within the Sequoia National Forest were classed as having "no symptoms", compared with 22 percent of the plots within the Sierra National Forest (Pronos, et al., 1978).

Ozone damage was reported to be generally higher in the Sierra National Forest than in the Sequoia National Forest. No reported "moderate" injury occurred at the 8000 foot contour. Most plots with oxidant injury symptoms, and all of the "moderate" injury plots were located on the western slope mountains adjacent to the San Joaquin Valley (Pronos, et al., 1978).

In 1979 and 1980 fifty-two of the original 242 plots within the Sierra and Sequoia National Forests were re-examined for ozone damage symptoms. The overall trend in 1979 and 1980 was one of increasing ozone injury (Pronos and Vogler, 1981). In 1977 there were no plots with severe injury ratings, while six were classified as severe in 1979 and three in 1980. Only 50 percent of the plots classified as having "no injury" symptoms in 1977 could be similarly classified in 1979 and 1980. The sites with the greatest oxidant injury were located along the western slopes adjacent to the San Joaquin Valley, and along the major river drainages in the national forests. While the amount of ozone injury on pine foliage increased annually since 1977, the concentrations of ozone monitored in the forest actually decreased (Pronos and Vogler, 1981). Pronos and Vogler speculated that this relationship suggests the threshold level for ozone injury to pine foliage is lower than the state and federal pollution standards which they used to summarize their data. While assuming that sensitive pines will continue to be affected in the southern Sierra Nevada, Pronos and Vogler attributed no tree mortality to ozone concentrations.

Vogler (1982) conducted a survey of five ponderosa pine plantations on the Hume Lake Ranger District within the Sequoia National Forest. Approximately 50 percent of the trees on the plantations had ozone injury symptoms, with about 15 percent injured on second-year needles. He examined the height growth of ponderosa pine utilizing the oxidant injury scoring system developed within the San Bernardino National Forest Study (Miller, et al., 1977), and the ozone symptoms rating system used to characterize ozone damage by the USDA Forest Service. Vogler concluded that the severity of needle symptoms was unrelated to the height growth of the young pines at the injury levels present on the plantations. While the pines did decline in height growth in 1977 and 1978, Vogler attributed that decline to drought, brush competition, and insect injury.

Allison (1982) conducted a ground survey of ozone injury to ponderosa and Jeffrey pines in the Stanislaus National Forest in September and October, 1981. Ozone symptoms were reported to be widespread on the 46 plots surveyed. Eighty-three percent of the plots had ozone symptoms, with 70 percent listed as having "slight injury", and 13 percent "moderate injury". "Moderate" damage was confined to plots between 3,000 and 4,900 feet, with the level of injury decreasing at both higher elevations and in areas further removed from the Central Valley. On the basis of these results, oxidant damage appears to be more widespread in the Stanislaus than in the Sierra and Sequoia National Forests. Unlike the Sierra and Sequoia National Forests, where ozone damage occurred at all elevations except 8,000 feet, the most severe ozone symptoms occurred below 5,000 feet in the Stanislaus. Allison stated that while ozone injury symptoms are widespread on the Stanislaus, that ozone is not presently causing significant damage to the pines on a forest-wide basis.

A survey conducted between 1980 and 1982 in Sequoia and Kings Canyon National Parks indicates that 36 percent of the sampled ponderosa and Jeffrey pine trees had foliar ozone injury symptoms (Wallner and Fong, 1982). Work recently performed by Peterson, et al. (1987) in Sequoia and Kings Canyon National Parks indicates that the mean annual radial increment growth of Jeffrey pine trees with visible symptoms of foliar ozone injury was 11 percent less than trees at sites without ozone injury. Larger trees and older trees had greater decreases in growth than smaller and younger trees. These results are the first evidence of forest tree growth reduction associated with ozone injury in North America outside the Los Angeles Basin.

According to Bennett (1986), in 1980-1982, 48 percent of 280 sampled ponderosa pine trees exhibited foliar injury in Sequoia National Park. By 1985, 58 percent of 300 sampled ponderosa pines in Yosemite expressed foliar injury symptoms. While numerous trees were reported to exhibit foliar injury, the foliar area of the injury was quite small. Duriscoe (1986b) reported that of the foliar symptoms observed in Yosemite National Park, 2.8 percent, 10.2 percent, and 14.6 percent of the total leaf area was classified as ozone mottle, other abiotic injury, or biotic injury respectively.

2.3 TREE SPECIES SENSITIVITY TO OZONE

Tree species sensitivity to ozone damage was evaluated for use in the forest risk assessment, see Chapter 4. Results of this evaluation are shown in Table 2.5. Evaluations were based on available literature and the expert judgment of the investigators, Dr. Joseph McBride of the University of California at Berkeley and Dr. Paul Miller of the USDA Forest Service and the University of California at Riverside.

Tree species were assigned to one of four sensitivity classes: tolerant, intermediate, sensitive, and no available information. Citations are included as part of the Table.

Table 2.5

Sensitivity of California Tree Species to Ozone

(1=tolerant; 2=intermediate; 3=sensitive; 0=insufficient information to rank)

Code USFS Lands	Code non-USFS Lands	Species	Ozone Sensitivity	Source
1	202	Douglas-fir (*Pseudotsuga menziesii*)	2	5,8,9, 21,27,31
2	201	Big Cone Douglas-fir (*Pseudotsuga macrocarpa*)	2	28,30
5	211	Redwood (*Sequoia sempirvirons*)	1	9
6	212	Giant Sequoia (*Sequoiadendron giganteum*)	1	9,21,27, 30,31
11	122	Ponderosa pine (*Pinus ponderosa*)	3	1,2,3,5 6,7,8,9 11,12,16, 17,21,22, 23,25,26, 27,28,29, 30,31,32 33,34,35, 36,37,38 39,44,45 46,49,51, 52,53,54
12	116	Jeffrey pine (*Pinus jeffreyi*)	3	1,2,9,11, 21,25,27, 28,29,30, 31,33,34, 35,38,39, 44,49
13	117	Sugar pine (*Pinus lambertiana*)	1	9,11,21, 25,26,27, 29,30,31, 33,34,35
14	119	Western white pine (*Pinus monticola*)	3	15,21,27, 30,31
15	108	Lodgepole pine (*Pinus contorta*)	1	5,9
21	109	Coulter pine (*Pinus coulteri*)	2	9,11,21, 27,30,31

Table 2.5 (Continued)

Sensitivity of California Tree Species to Ozone

(1=tolerant; 2=intermediate; 3=sensitive; 0=insufficient information to rank)

23	127	Digger pine (*Pinus sabiniana*)	1	9
24	108	Knobcone pine (*Pinus attenuata*)	2	9,21,27 30,31
25	120	Bishop pine (*Pinus muircata*)	1	*
26	101	Whitebark pine (*Pinus albicaulis*)	1	*
27	---	Single leaf pinyon pine (*Pinus monophylla*)	0	
29	113	Limber pine (*Pinus flexilis*)	1	15
30	104	Foxtail pine (*Pinus balfouriana*)	0	
31	15	White fir (*Abies concolor*)	2	5,9,[illegible]23, 25,[illegible],27, 28,29,30, 31,33,34, 35,48,52, 54
32	20	Red fir (*Abies magnifica*)	2	30
33	17	Grand fir (*Abies grandis*)	1	*[9]
34	102	Bristlecone pine (*Pinus aristata*)	0	
41	93	Englemann spruce (*Picea engelmannii*)	1	*[9],[15]
46	92	Brewer spruce (*Picea breweriana*)	1	*[9],[15]
47	264	Mountain hemlock (*Tsuga mertensiana*)	1	*[5],[9], [15]
48	263	Western hemlock (*Tsuga heterophylla*)	1	*[[illegible] [9] [1[illegible]]

Table 2.5 (Continued)

Sensitivity of California Tree Species to Ozone

(1=tolerant; 2=intermediate; 3=sensitive; 0=insufficient information to rank)

51	81	Incense cedar (<u>Calocedrus</u> <u>decurrens</u>)	2	9,21,23, 25,26,27, 28,29,30,31,34,35
53	41	Port-Orford-Cedar (<u>Chamaecyparis</u> <u>lawsoniana</u>)	0	
54	242	Western Red Cedar (<u>Thuja</u> <u>plicata</u>)	0	
61	251	California nutmeg (<u>Torreya</u> <u>californica</u>)	0	
62	231	Pacific yew (<u>Taxus</u> <u>brevifolia</u>)	1	*[5],[9]
63	64	Western juniper (<u>Juniperus</u> <u>occidentalis</u>)	1	5,9
64	50	Cypress (<u>Cupressus</u> spp.)	0	
--	42	Alaska yellow cedar (<u>Chamaecyparis</u> <u>nootkatensis</u>)	0	
--	98	Sitka spruce (<u>Picea</u> <u>sitchensis</u>)	1	*[9]
--	14	Santa Lucia fir (<u>Abies</u> <u>venusta</u>)	0	
--	21	Short red fir (<u>Abies</u> <u>magnifica</u> var. <u>shastensis</u>)	2	*[30]
--	22	Noble fir (<u>Abies</u> <u>nobilis</u>)	2	*[30]
--	124	Monterey pine (<u>Pinus</u> <u>radiata</u>)	3	9,21,27, 31
--	62	California juniper (<u>Juniperus</u> <u>californica</u>)	0	
--	65	Utah juniper (<u>Juniperus</u> <u>californica</u> var. <u>utahensis</u>)	0	
--	133	Pinyon pine (<u>Pinus</u> spp.)	0	

Table 2.5 (Continued)

Sensitivity of California Tree Species to Ozone

(1=tolerant; 2=intermediate; 3=sensitive; 0=insufficient information to rank)

71	351	Red Alder (*Alnus rubra*)	0	
72	---	Ash (*Fraxinus* spp.)	3	*[9]
73	746	Aspen (*Populus tremuloides*)	3	4,9,18, 47,48,50
--	542	Oregon ash (*Fraxinus oregona*)	3	*[9],[14]
75	747	Black cottonwood (*Populus trichocarpa*)	3	9,13,40 41,42,43
76	312	Bigleaf maple (*Acer macrophyllum*)	1	*[5],[9], [14]
81	818	California black oak (*Quercus kelloggii*)	2	23,35,38, 29,33
82	801	Coast live oak (*Quercus agrifolia*)	0	
83	821	California white oak (Valley oak) (*Quercus lobata*)	3	*[9]
84	805	Canyon live oak (*Quercus chrysolepis*)	0	
85	839	Interior live oak (*Quercus wislizenii*)	0	
86	815	Oregon white oak (Garry oak) (*Quercus garryana*)	3	*[9]
87	---	Tanoak (*Lithocarpus densiflorus*)	0	
88	807	Blue oak (*Quercus douglassii*)	0	
91	981	California laurel (*Umbellularia californica*)	0	
93	431	Giant chinquapin (Golden chinquapin) (*Castanopsis chrysophylla*)	0	

Table 2.5 (Concluded)

Sensitivity of California Tree Species to Ozone

(1=tolerant; 2=intermediate; 3=sensitive; 0=insufficient information to rank)

94	361	Madrone (Arbutus menziesii)	0	
95	492	Pacific dogwood (Cornus nuttallii)	2	*[9]
96	730	Sycamore (Platanus racemosa)	3	[14],[19], [20]
--	352	White Alder (Alnus rhombifolia)	0	
--	374	Water birch (Betula occidentalis)	1	*[5],[9]
--	811	Engelmann oak (Quercus engelmannii)	0	
--	330	California buckeye (Aesculus californica)	2	*[5]
--	748	Fremont cottonwood (Populus fremonti)	2	*[5],[9]
--	510	Eucalyptus (Eucalyptus spp.)	0	
--	600	Walnut (Juglans spp.)	1	*[9],[14]
--	660	Apple (Malus spp.)	0	
--	760	Cherry (Prunus spp.)	3	9,10,24, 47
--	920	Willow (Salix spp.)	0	

* ranking base on close phylogenetic relationship to species with known sensitivity.

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Table 2.5

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3.0 DESCRIPTION OF THE FOREST RESOURCES DATA BASE

3.1 INTRODUCTION

The forest resources data base is a geographically-based data archive that provides quantitative information concerning California's forests and related resources. Data intended for many different uses and stored in many different formats by a variety of public agencies have been brought together to create this archive. A primary source of information for the data base is the Forest and Range Resources Assessment Program (FRRAP) geographic information system data base recently created by the California Department of Forestry, with the assistance of the University of California at Berkeley, the USDA Forest Service, and other agencies (Tosta and Davis, 1985).[1]

Information from the FRRAP data base included in the forest resources data base consists of county locations, vegetation cover types, soil associations, watershed locations, and land ownership data. In addition, photo-interpretation and ground plot data from the FRRAP data base were used in the calculation of timber volume on non-USDA Forest Service lands.

Ozone monitoring data were obtained from the U.S. EPA, ARB and USDA Forest Service, but the U.S. EPA data were not used due to data completeness problems.[2] Data used in the calculation of timber volume for national forest lands were obtained from timber inventories archived by the USDA Forest

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[1] We wish to acknowledge the cooperation and assistance of FRRAP personnel in responding to our requests for data, which were made at an early stage in the public use of the FRRAP data base.

[2] U.S. EPA SAROAD data for the 1977-1981 period were obtained from the U.S. EPA. SAROAD data included very few rural or high elevation stations. Many of the special forest ozone field programs were not included in SAROAD due to the limited period of monitor operation and to the lack of information regarding the monitored sites.

Ozone data used in the analysis were obtained directly from the ARB. These data contained most of the sites where ozone had been monitored during the 1977-1981 period.

Service, Region 5, Timber Plans and Silviculture Division, San Francisco. Recreational use data for national forests in California were obtained from the Recreation Information Management System (RIMS) at the USDA Forest Service Recreation Division in Washington, D.C., through a request made to the Region 5 office in San Francisco. Recreational data for California State Parks were acquired from the California Department of Parks and Recreation in Sacramento. Other recreation data were collected from the National Park Service, the Bureau of Land Management, the California Department of Fish and Game, the Army Corps of Engineers, and the Pacific Gas and Electric Company.

3.1.1 The Data Base Grid

The ARB forest resources data base is organized on a geodetic grid system with a common origin at 32 N (north latitude) and 125 W (west longitude) (Figure 3.1). West longitude is denoted as negative on Figure 3.1 because it decreases from left to right. The grid spans 11 degrees of longitude in the x-direction and 10 degrees of latitude in the y-direction.

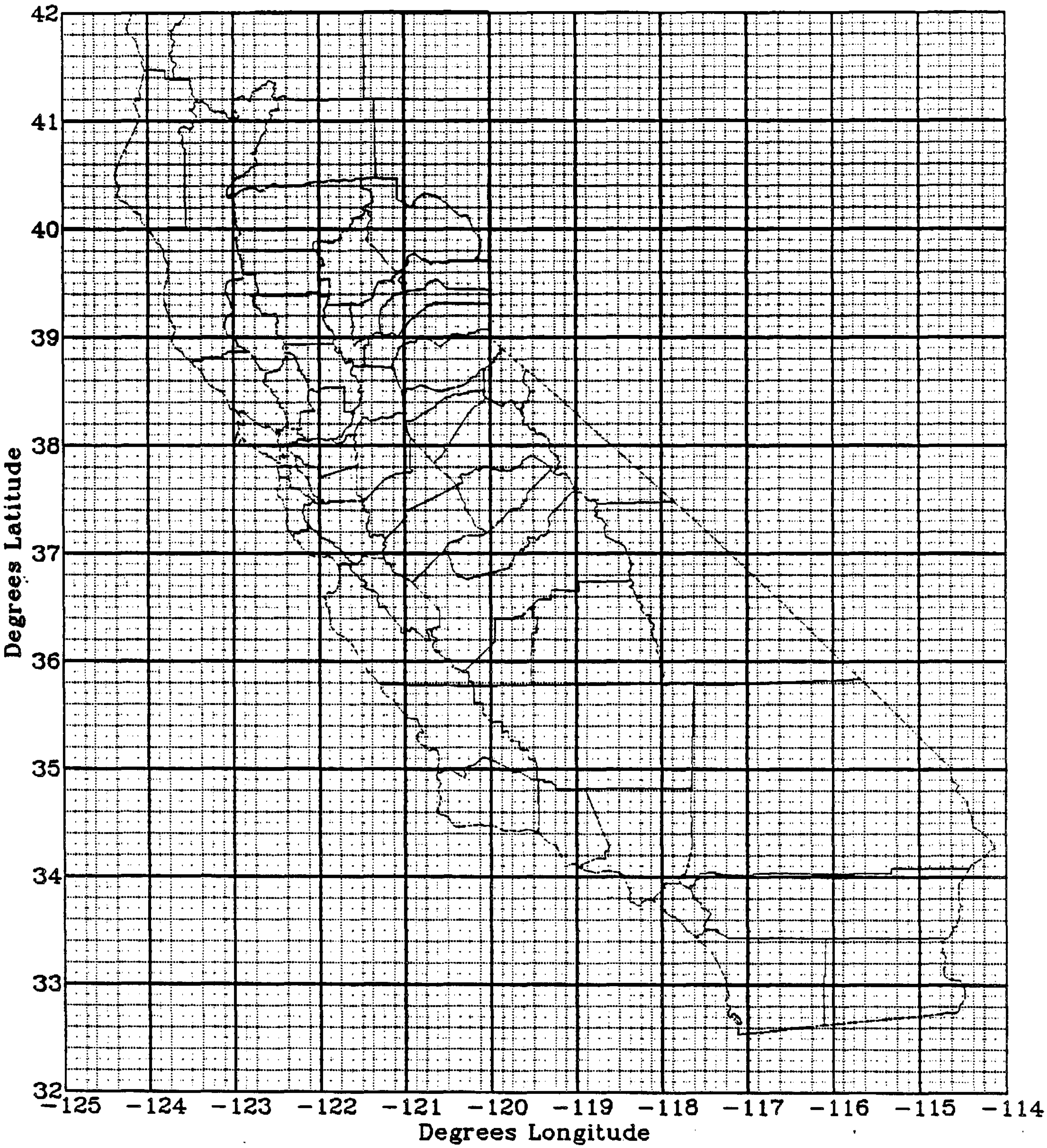
The grid contains 8800 grid cells, each being 0.125 degree latitude by 0.100 degree longitude. However, only about 3500 cells actually fall within California's boundaries (and only these 3500 are archived in the data base). The cells are numbered from left to right and bottom to top; that is, cell (1,1) is in the lower left corner of the grid and cell (88,100) is in the upper right. Since the distance spanned by a degree longitude varies inversely with latitude, the area encompassed by a grid cell decreases with increasing latitude. The average cell size is about 30,000 acres. Cell sizes for U.S. Geological Survey 1:250,000 quadrangles in California are provided in Appendix A. The 30,000-acre cell size was selected after consultation with FRRAP and ARB personnel.

3.1.2 The Basic and Extended Data Records

Areas in California that contain forest resources are of primary interest in future economic and risk analyses of forest response to air pollutants; areas that do not contain forest resources are of secondary interest. Therefore,

Figure 3.1

Grid System Used in the ARB Forest Resources Database



The dotted squares represent actual database grid cells, while the heavy, solid lines delineate degrees of latitude and longitude. Cells are located by means of an x-coordinate (longitudinal) and a y-coordinate (latitudinal).

grid cells representing unforested areas are covered by a less detailed "basic" data record, while those in forested areas are covered by an "extended" data record. A grid cell is considered to contain forest land if one or more of the Wildlife Habitat Relationship (WHR) cover types shown in Table 3.1 are ranked among the top five in the cell in terms of area covered. Figure 3.2 shows forested grid cells covered by extended data records.

All grid cells in the data base have a header record and a basic data record (Table 3.2). The header record serves as a geographic locator for the cell. The basic data record provides information on cell area and elevation, vegetative cover, soil type, hydrologic drainages, land ownership and ozone concentrations. Cells meeting the requirements for our definition of a forested cell have the header record and the extended data record, which includes the basic data record plus data on timber volume and recreational use.

3.2 DESCRIPTION OF VARIABLES

3.2.1 Header Record

The header record consists of an (x,y) grid locator, air basin indicator, latitude/longitude coordinates of the cell center, and a county code distribution. The (x,y) grid locator identifies a cell by location on the data base grid (Figure 3.1). The x-coordinate comes first and refers to the longitudinal, or horizontal axis; the y-coordinate is next and refers to the latitudinal, or vertical axis. For example, the cell in the lower left corner of the grid is cell (1,1), and the cell in the upper right corner is (88,100).

The air basin indicator is a number from one to 14 that indicates in which ARB air basin the cell resides. The numbering convention is like that used in the ARB air quality bulletins, and is shown in Appendix A. The appropriate air basin for each cell was determined by manually overlaying the grid of cells with a plot of California air basin boundaries. If a cell fell into

Table 3.1

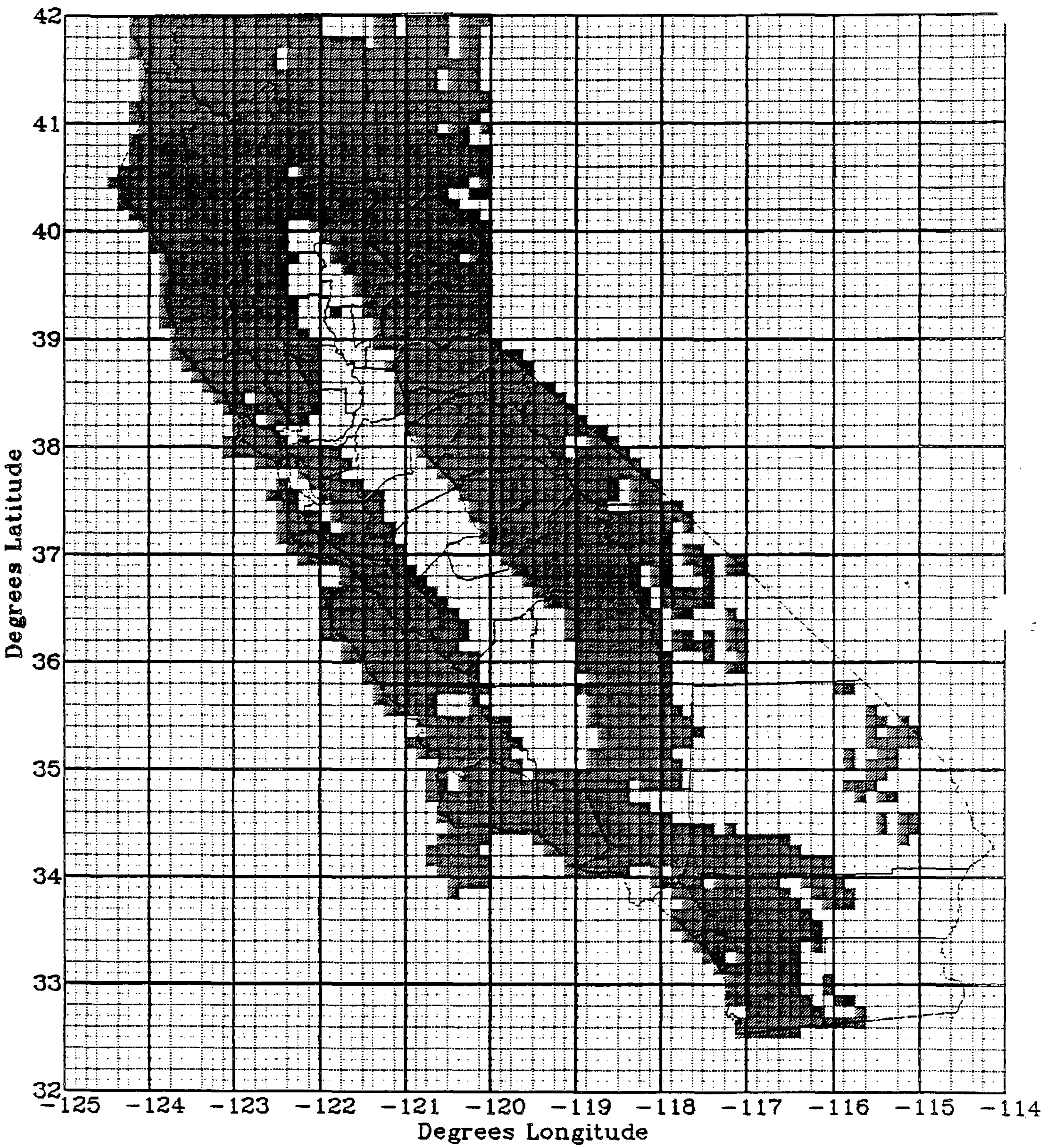
WHR Cover Classes That Are Classified As "Forest"

In The ARB Forest Resources Data Base

Douglas fir
Jeffrey pine
Lodgepole pine
Mixed conifer
Ponderosa pine
Redwood
Red fir
White fir
Closed-cone pine-cypress
Juniper
Pinyon-juniper
Subalpine conifer
Montane hardwood
Valley foothill hardwood-live oak
Deciduous oak
Montane hardwood-conifer
Chamise-red shank chaparral
Coastal scrub
Mixed chaparral
Montane chaparral
Montane riparian
Valley foothill riparian
Joshua tree

Figure 3.2

"Forested" Areas in the ARB Forest Resources Data Base



Shaded cells have at least one forested WHR code in the top five in terms of area covered.

Table 3.2

List of Variable Categories Included in the Header, Basic and Extended Data Records

Variable	**Units**
(Header)	
Grid locator	x,y
Latitude/longitude of cell center	Deg.
Air basin indicator	--
County code distribution (up to 4)	--
(Basic data)	
Area of cell	Acres
Average elevation of cell	Meters
WHR cover type distribution (up to 5)	--
Soil series distribution (up to 5)	--
Watershed distribution (up to 5)	--
Ownership distribution (up to 5)	--
Ozone concentrations (24-,12-,9-,and 7-hour averages over growing season)	pphm
(Extended data)	
Timber volume by species - USDA Forest Service (top 5 species)	1000s ft^3
Timber volume by species group - other lands (top 5 species groups)	1000s ft^3
Recreational usage total for each reporting agency 1981-1985 (1 total for each agency; up to 7 agencies)	user-days/yr
Recreational usage totals for USDA Forest Service lands, broken down by 5 activity classes, 1985 only (5 totals)	user-days/yr

two or more air basins, the air basin covering the most area within the cell was selected.

The latitude/longitude coordinates of the center of the cell were calculated using the (x,y) grid locator and a conversion program to translate the grid locator into geodetic coordinates.

The county code distribution was provided by U.C. Berkeley as part of the FRRAP data base. There are 58 counties in California, and each has a unique identifier. The Federal Information Processing Standards (FIPS) coding scheme, issued by the National Bureau of Standards, is used and is shown in Appendix A. Up to four county codes occur within a cell, and the fraction of a cell's area within each county is calculated in the data record.

3.2.2 Basic Data Record

The basic data record consists of the area of the cell, the elevation of the cell center, the WHR cover type distribution, the soil series distribution, the watershed distribution, the ownership distribution, and ozone concentration statistics. The area of the cell was entered into the data base using a table provided by Davis (1987), see Appendix A.

The elevation of the cell center was calculated using United States Geological Survey (USGS) terrain files that cover California at a resolution of about 1 km. The USGS grid values were aggregated and translated to the present data base grid to obtain an elevation value for each grid cell.

Distributions of WHR cover type, soil series and watershed indicators were supplied by Dr. Davis of U.C. Berkeley from the FRRAP data base. For each of these variables, the five codes that rank highest in terms of area covered are reported for each cell along with the percentage of the cell's area covered by each. Keys to the codes are shown in Appendix A. The WHR classification scheme describes land use and vegetation cover in 40 categories. The level of aggregation present in WHR coding allows for the resolution of major forest types such as ponderosa pine, douglas fir, and redwood, as well as non-forest types such as urban-agriculture, grassland, desert scrub, and alpine tundra vegetation. As an example of WHR data, Figure 3.3 shows the coverage of the ponderosa pine cover type in the database.

Soil types are coded in terms of 154 broad associations. FRRAP personnel originally derived these data from a statewide mapping of soils done on hydrologic basins (Tosta and Davis, 1985).

The FRRAP watershed indicator codes consist of five digits: the first three signify the hydrologic basin; the last two digits the sub-basin (see Appendix A).

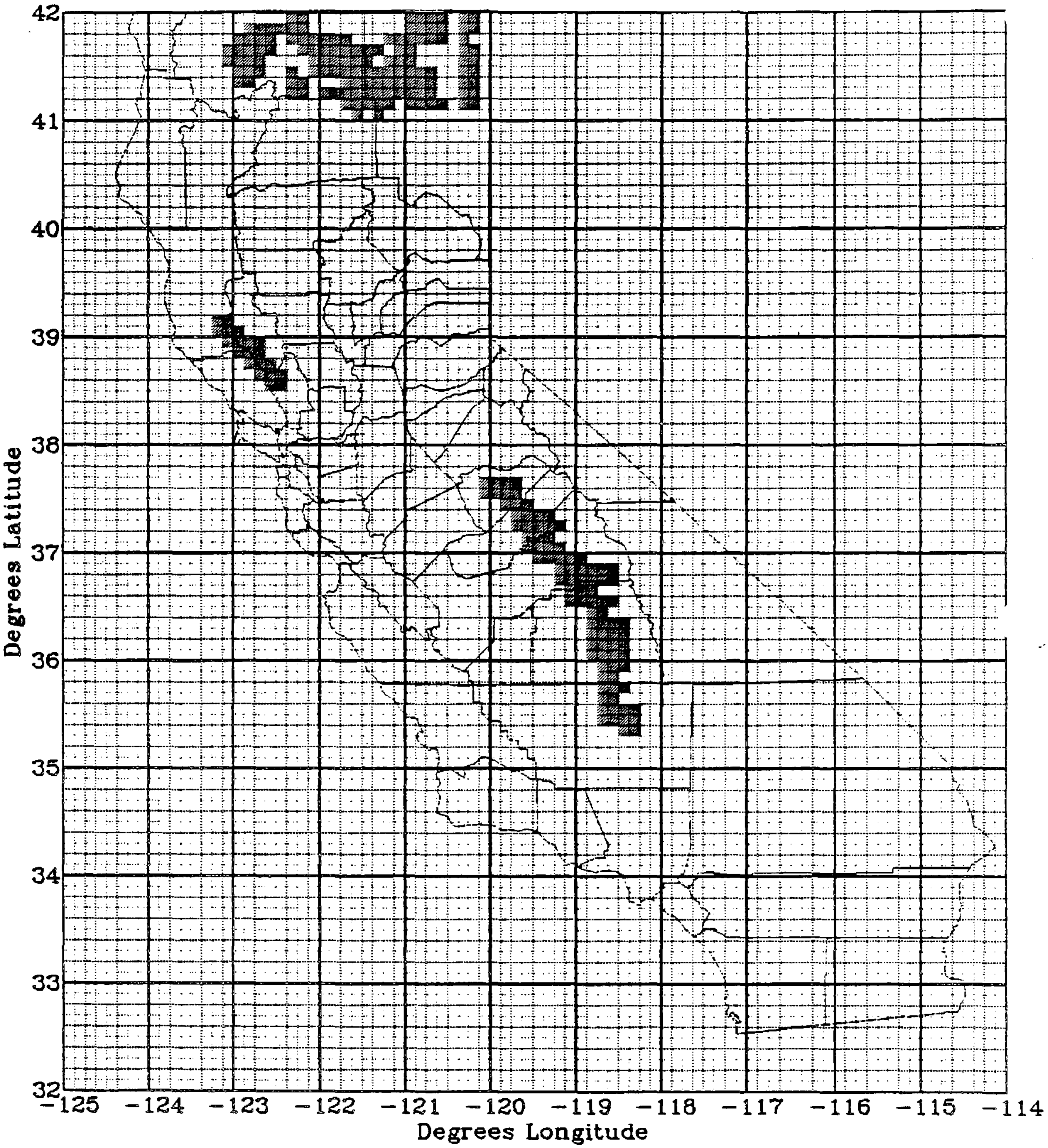
Over fifty ownership codes are reported in the data base. Private lands are classified into lands owned by forest industry, corporate forest lands, non-industrial forest lands, other private lands, and range industry lands. Public lands are broken into many categories, including individual national forests and parks in California. These ownership data were obtained by FRRAP personnel from a map produced by the Bureau of Land Management in 1978 (Tosta and Davis, 1985). As an example, Figure 3.4 shows those areas covered by the Sequoia National Forest ownership code.

Ozone concentrations are reported as four statistics: 7-, 9-, 12-, and 24-hour means averaged over the growing season. The statistics represent ozone conditions during the period 1977-1981. This period was chosen to make maximum use of USDA Forest Service monitoring data that were collected in the southern Sierra during the late 1970s; many of these stations are not operating at present. By using ozone data from these stations, we were able to obtain a better representation of ozone concentrations in forested areas than if we used more recent, but less complete data.

Hourly ozone data for the analysis were obtained on magnetic tape from the ARB and on hard copy from the USDA Forest Service. The Forest Service data, totaling about 97,000 hours from seven sites, were double-entered by keypunch operators. Many of the 147 ARB sites could not be used in the analysis, because site information (i.e., location and elevation) was not available.

Figure 3.3

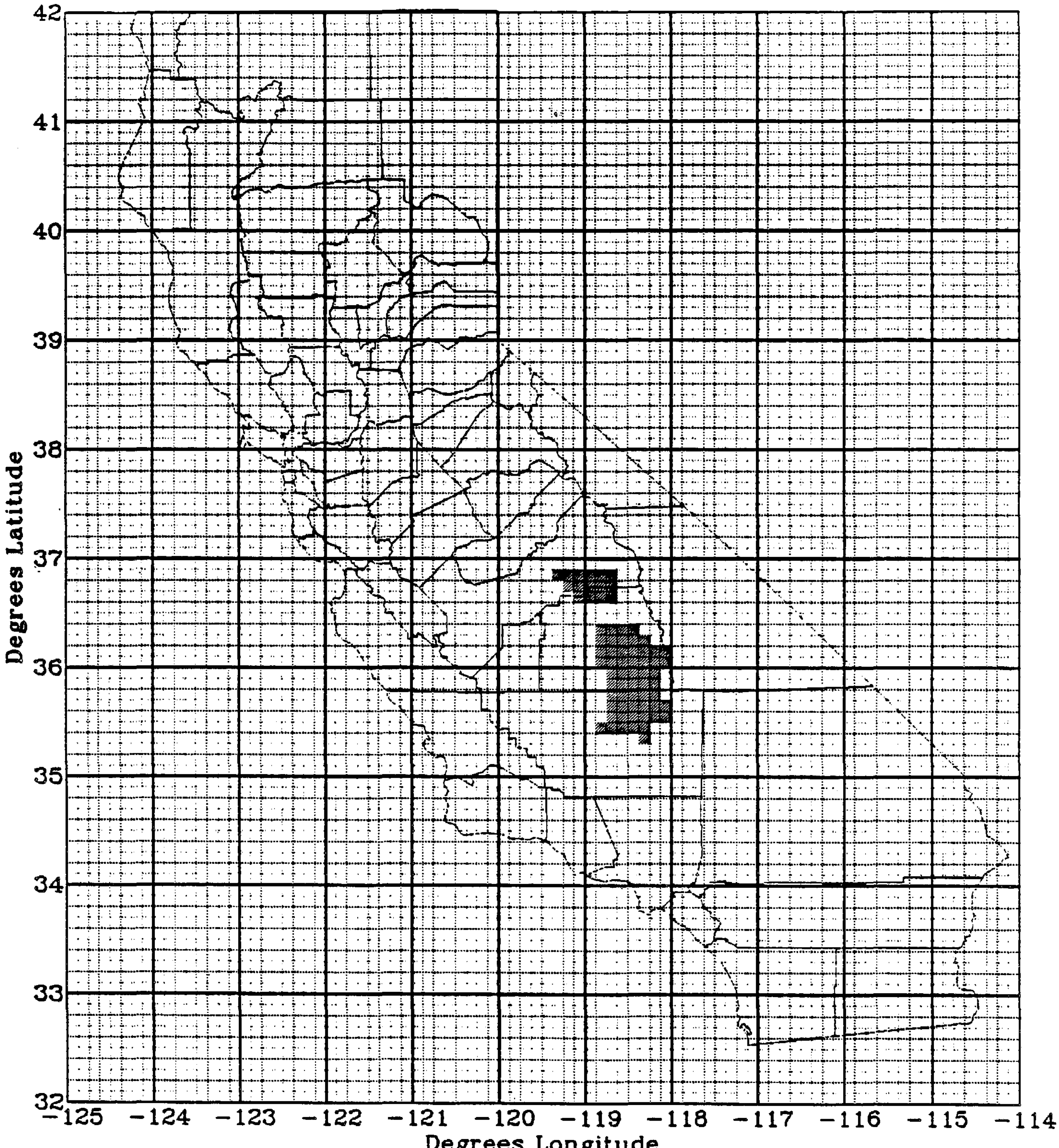
The Distribution of Ponderosa Pine Cover Type in California



All grid cells having a ponderosa pine WHR cover type (code = 15) in the top five in terms of areas covered are stippled. The coverage shown in this figure appears limited, because most ponderosa pine in California probably grows in the mixed conifer forest type and not as pure stands.

Figure 3.4

The Location and Extent of Land within Sequoia National Forest



All grid cells having a Sequoia National Forest ownership code (codes = 920-929) in the top five in terms of area covered are stippled.

About a dozen sites had incorrect information, but they were subsequently corrected using updated information provided by the ARB project officer.

The data were first reduced by computing the 7-, 9-, 12- and 24-hour means and variances for each day. A mean and variance were calculated for a day only if at least two-thirds of the hours had valid data. The growing season varies with latitude and elevation, and was defined as shown in Table 3.3. The means and variances for each day were then averaged to estimate a growing season average and a standard deviation at each of the stations for all years during the period 1977-1981. Stations having less than two-thirds of the growing season days present in the 1977-1981 period were not included in the analysis.

The spatial density of ozone monitoring stations is much higher in urban areas than in rural areas. The regions of most importance to this study are the higher elevation rural areas. Available techniques for reducing the sampling bias depend on the process used to select stations for interpolation. Three options for station selection were:

1. selecting the highest elevation stations;
2. selecting the stations with the most data; and,
3. selecting stations with the highest ozone concentrations.

Selecting stations on the basis of elevation seemed most plausible, as most forests are located at moderate elevations. After conferring with the contract officer, we decided that elevation would be the station discriminator.

The selection process involved searching along rows and columns. If two stations were found within two grid cells of one another, the lower elevation station was omitted. This procedure ensured that stations at higher elevations, where presumably more forest coverage would be present, would remain in the data set. The two grid cell sphere of influence seemed to work quite well (Figure 3.5). After the selection process, the data set consisted of 104 stations scattered relatively uniformly throughout California. Further

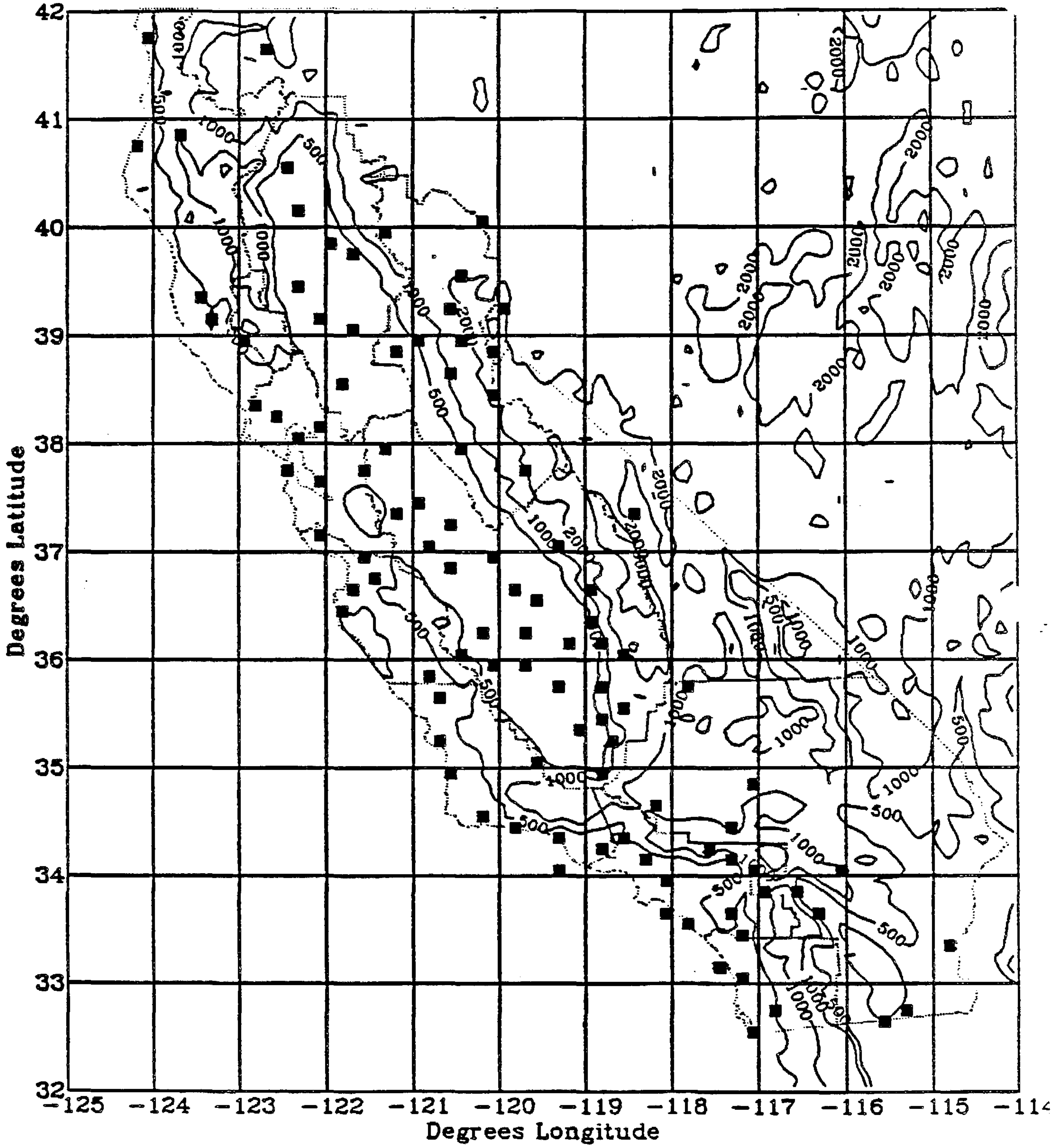
Table 3.3

The Length of the Growing Season as Determined By Elevation and Latitude the Periods Indicated Were Used in the Calculation of Growing Season Ozone Statistics

	Latitude		
Elevation	**32-36N**	**36-39N**	**39-42N**
0-1000 m	Apr-Oct	Apr-Oct	Apr-Sep
1km-2km	Apr-Oct	May-Sep	May-Sep
2km +	May-Sep	Jun-Sep	Jun-Sep

Figure 3.5

Locations of Ozone Monitoring Stations Used in the Kriging Procedure



The grid cells encompassing the coordinates of the stations are shaded. Contours represent elevation, expressed in meters.

reduction either by searching along diagonals or by increasing the distance of separation leaves too few stations, and also eliminates some of the Forest Service high elevation sites.

Kriging is an objective interpolation method that uses and attempts to preserve the spatial persistence of a quantity, such as concentration, which is present in set of point samples. Most interpolation methods require that interpolated estimates depend on the sum of products of the observed values multiplied by some weighting factor. The kriging interpolation scheme uses the information on the distance dependence of the interstation concentration variance (variogram) to obtain an optimal set of weighting factors. The least mean squares serves as the optimizing principle from which a unique set of weighting factors is determined. An additional benefit of kriging is a quantitative estimate of the uncertainty of the interpolated estimate. The 7-, 9-, 12-, and 24-hour growing season statistics were interpolated using the same kriging methodology described in Lefohn, et al. (1987).

The computer software used in that study was obtained from Peter Knudsen of the Montana School of Mines and applied in the present analysis. The station average concentrations were used to estimate a variogram, which describes how the variance in the difference between two stations changes with increasing separation distance. The parameters of an analytic model built into the software were fitted to the observed variogram data by eye and by trial and error. This model was tested with various subsets of data and was found to be sufficiently robust. A regression analysis was performed on the average concentrations as a function of the station elevation; no statistically significant systematic relation of ozone concentration with elevation was found. Average concentrations were kriged at each grid cell in the database with the assumption that the stations resided on a flat surface.

Quality assurance was conducted through several procedures. Tables of average concentrations were inspected to assure that 24-hour averages were less than 7-, 9- or 12-hour averages. In remote areas it is possible for the kriging approach to produce unreliable concentrations when forced to extrapolate, but no such problem was found. The concentration fields were plotted and visually inspected (Figures 3.6-3.9). The 12-hour average concentration fields appear similar to those hand-drawn by Thompson and Olszyk (1986) for 1984. Distinguishing features such as the minimum over the San Francisco Bay area, a maximum in the South Coast Air Basin, and the tongue of elevated concentrations extending into the lower San Joaquin Valley are reproduced accurately.

3.2.3 Extended Data Record

The extended data record includes all basic data record information, plus volume estimates for forest tree species or species groups and recreational usage totals reported by seven agencies. A series of calculations were required to produce most of these variables, and the procedures followed are discussed in detail.

3.2.3.1 Forest Volume

Forest volume estimates were made using two methods: one method was applied to lands within national forests, and the other was applied to lands outside national forests.

National Forest Volume Estimates

In national forests, the following procedure was used:

1) Hard copy tables of tree volume per acre by species and by timber stratum were obtained from the USDA Forest Service and keypunched (data on an electronic medium were not available). One table was available for each timber stratum for each national forest.[3]

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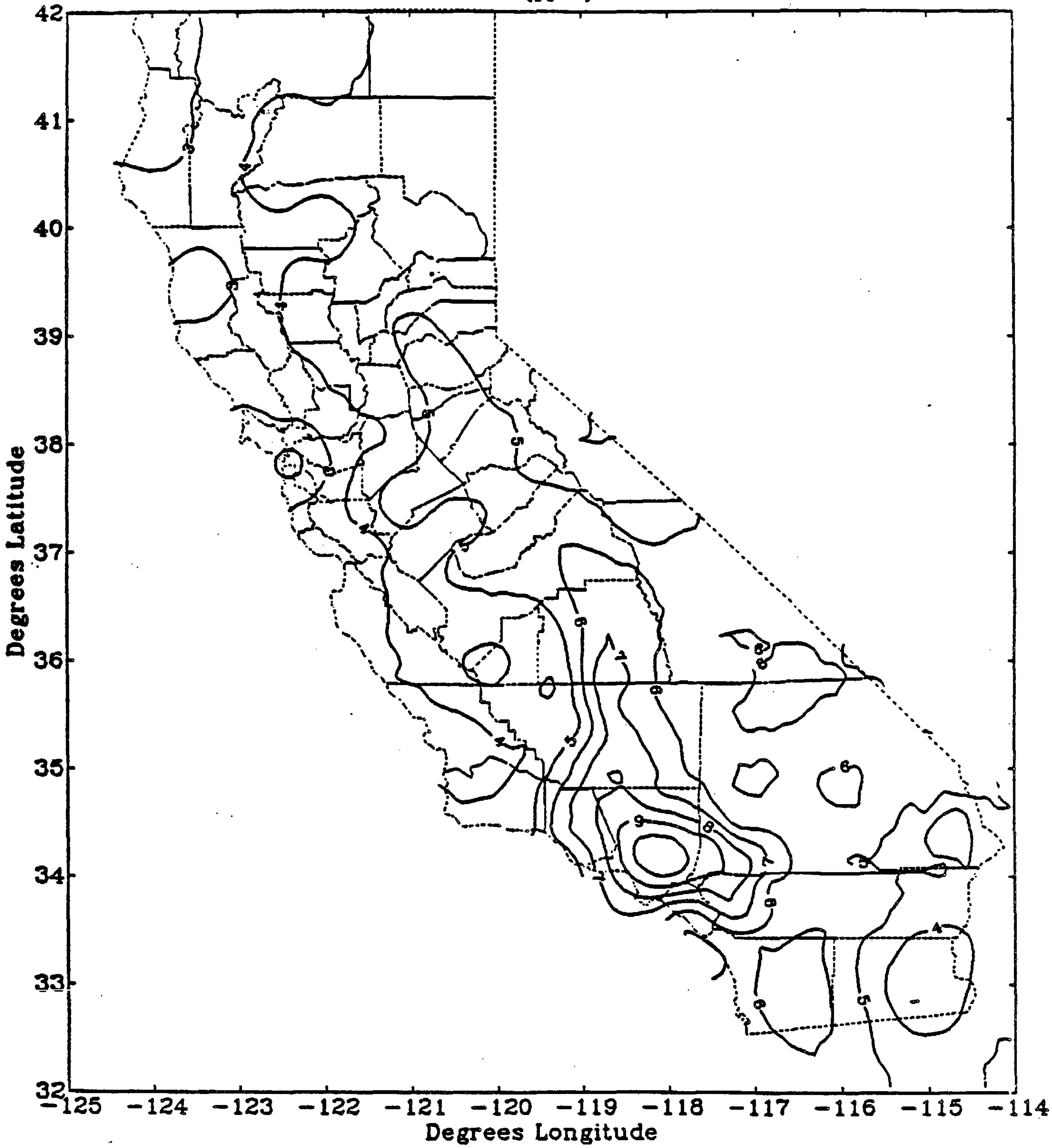
[3] Due to scheduling difficulties at their San Francisco office, the USDA Forest Service was unable to provide us with data for Inyo National Forest (which includes a thin strip of forest land on the eastern slope of the Sierra) in time for keypunching. These data appear in Appendix D.

Figure 3.6

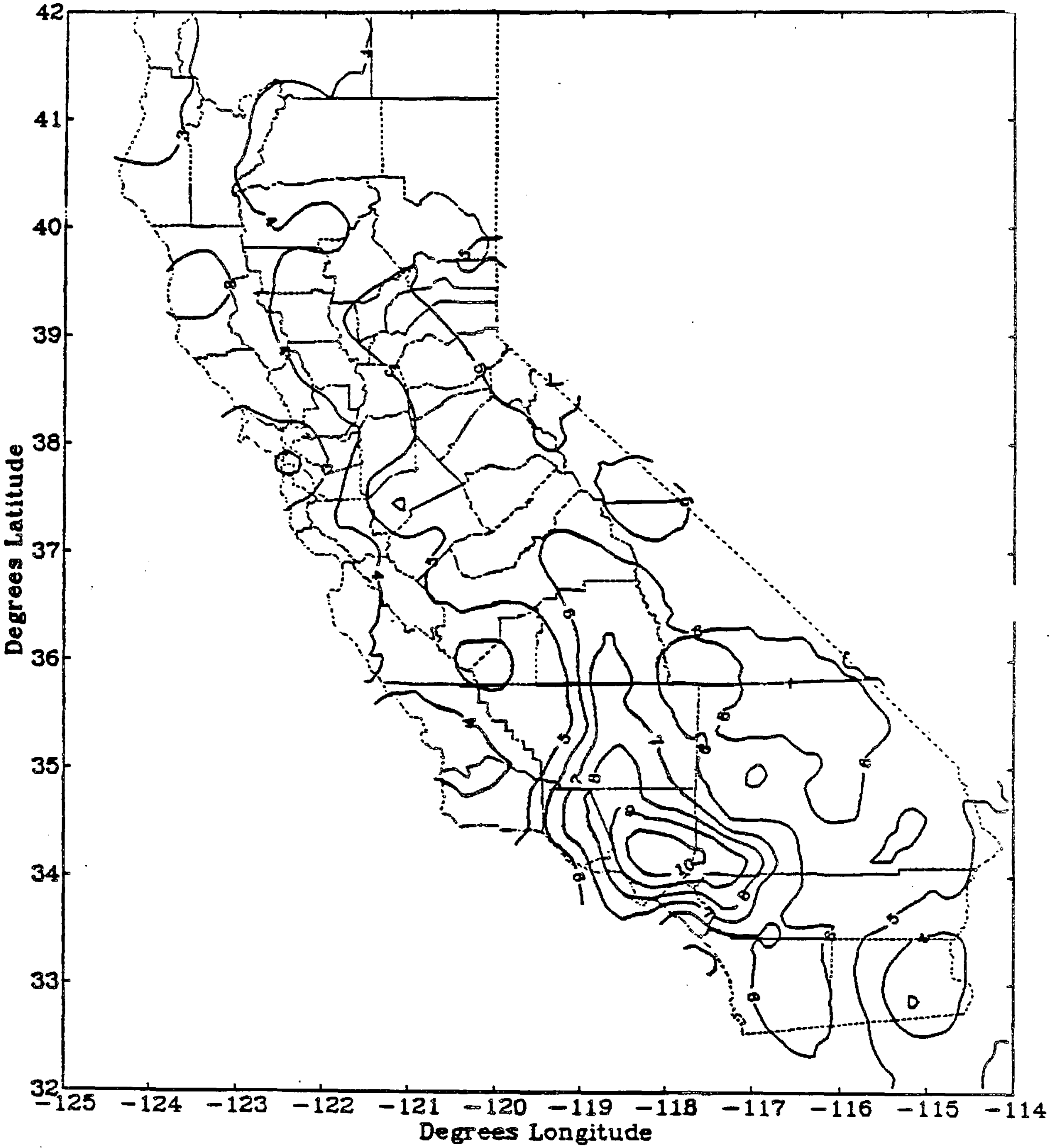
Isopleths of the 7-Hour (0900-1559 PST) Growing Season Mean Ozone Concentration (pphm) In California



Average ozone data from 104 sites with observations between 1977 and 1981 were krigged to produce the concentration fields.

Figure 3.7

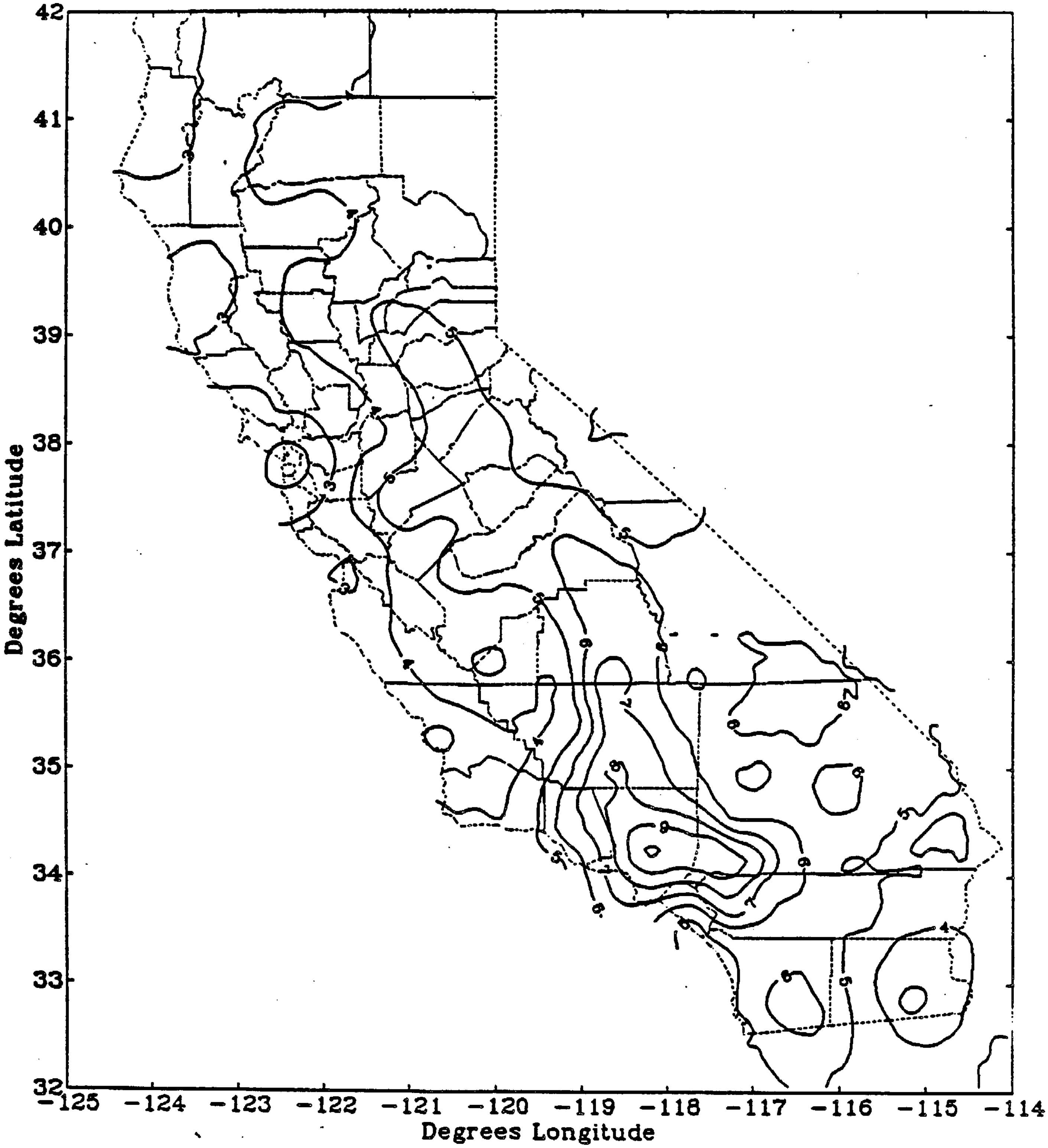
Isopleths of the 9-Hour (0900-1759 PST) Growing Season Mean Ozone Concentration (pphm) In California



Average ozone data from 104 sites with observations between 1977 and 1981 were krigged to produce the concentration fields.

Figure 3.8

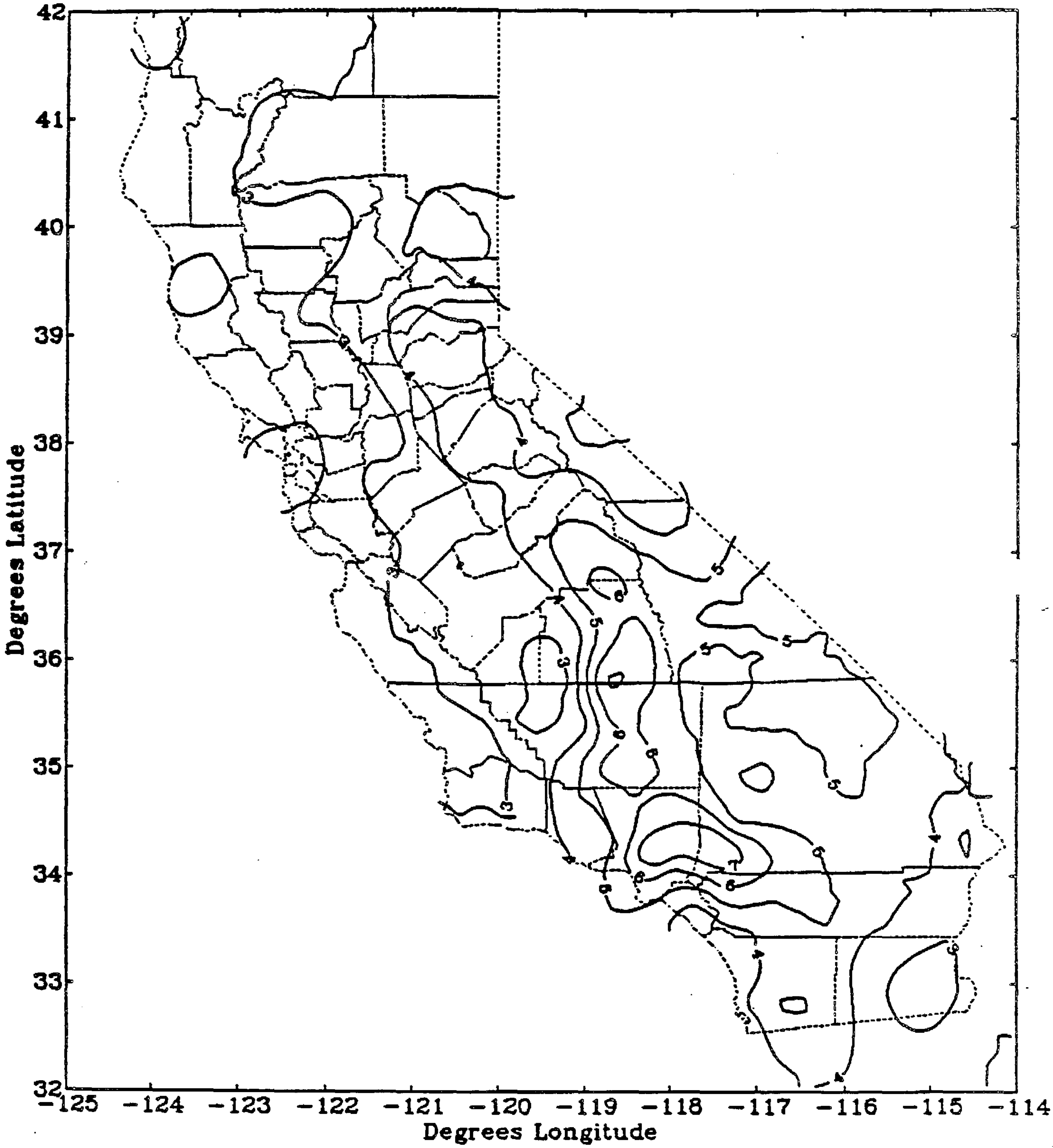
Isopleths of the 12-Hour (0800-1959 PST) Growing Season Mean Ozone Concentration (pphm) In California



Average ozone data from 104 sites with observations between 1977 and 1981 were krigged to produce the concentration fields.

Figure 3.9

Isopleths of the 24-Hour Growing Season Mean Ozone Concentration (pphm) In California



Average ozone data from 104 sites with observations between 1977 and 1981 were krigged to produce the concentration fields.

An example of a timber volume table is shown in Figure 3.10; the information enclosed by boxes was entered by a keypunch operator. In Figure 3.10, the "10" is a numerical identifier for the national forest. "D1X" is the timber stratum (the "D" refers to a Douglas fir stratum). Volume per acre subtotals shown for species 1, 11, 13, 31, and 51 includes desirable ("D") and acceptable ("A") grade timber. Only desirable and acceptable tree volumes were used, because they represent most usable timber volume and would be most comparable to the volume estimates for non-USDA Forest Service lands (Bowlin, 1987 and Marose, 1987). Overall, approximately 400 tables were keypunched. Appendix B contains definitions of timber strata and definitions of desirable and acceptable trees. Dates of the timber inventories from which the USDA Forest Service tables were prepared are listed in Table 3.4.

2) The first letter (e.g., B, C, D, G, etc.) of the USDA Forest Service timber strata designator is the regional forest type, and it was matched to a WHR cover type. The two designators are compatible and easily matched in most cases (Bowlin, 1987). Timber strata without matching WHR cover types occurred on less than one percent of the area covered by the data base. These strata included brewer spruce, coulter pine, giant sequoia, knobcone pine, and mountain hemlock. These strata were matched with another layer of the FRRAP data base called CalVeg. It is an alternate cover classification that is too finely disaggregated to be of use in the present data base, but did provide matching cover types in this situation. The matching scheme is shown in Table 3.5.

3) An average species volume per acre total for a regional forest type was calculated by assuming that all the strata in the regional forest type covered an equal amount of area.[4] The regional forest type was then converted to a WHR cover designation based on the matching

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[4] It is possible that better estimates would result by weighting the volume per acre totals by area covered. Tables providing such information are in Appendix E.

Figure 3-10

Example of a USDA Forest Service Printout of Timber Volume Per Acre Estimates For A Douglas Fir Stratum in the Six Rivers National Forest

SIXRIVERS NATIONAL FOREST

NATIONAL FOREST 1C   WORKING CIRCLE 0   DISTRICT 1

OUTPUT FROM PRISM TREES FOR SOFTWOODS FOR ALL POINTS

EACH CELL CONTAINS CV4 = (100'S CUBIC FEET PER ACRE TO 4 INCH TOP)

SPECIES ARE LISTED ON Y AXIS

OUTPUT IS FOR STRATUM 01X

TOTAL AREA = 1.00

SEEDLINGS PER ACRE = 340.000   BASAL AREA PER ACRE = GROSS 17.571 GROWING 14.857

TREE CLASSES:

SPECIES	D	A	SUBTOTAL	R	C	SUBTOTAL	LIVE-TOTAL	E	S	X	Y	DEAD-TOTAL	TOTAL
01	.181	1.421	1.602	.000	.000	.000	1.602	.000	.000	.468	.000	.468	2.071
11	.080	.016	.095	.000	.000	.000	.095	.000	.000	.000	.000	.000	.095
13	.153	.659	.812	.000	.000	.000	.812	.000	.000	.100	.000	.100	.912
31	.000	.148	.148	.000	.000	.000	.148	.000	.000	.062	.000	.062	.209
51	.000	.000	.000	.000	.000	.000	.000	.000	.000	.058	.000	.058	.058
SUBTOT	.414	2.243	2.657	.000	.000	.000	2.657	.000	.000	.687	.000	.687	3.345
TOTAL	.414	2.243	2.657	.000	.000	.000	2.657	.000	.000	.687	.000	.687	3.345

Table 3.4

Years when the USDA Forest Inventories were Taken

Dates are the Latest that appear for any Entry

in the Forest Inventory Data

Eldorado	1984	Sierra	1972
Inyo	1979	Stanislaus	1981
Klamath:		Tahoe	1980
Westside	1980	Trinity	1980
Eastside	1980	Tahoe Basin	1981
Lassen	1981	Angeles	1975
Mendocino	1981	Cleveland	1975
Modoc	1980	Los Padres	1975
Six Rivers	1978	San Bernardino	1974
Plumas	1980	Shasta	1980
Sequoia	1980		

Table 3.5

Listing of USDA Forest Service Timber Stratum Regional Types (First Letter of Stratum Identifier) and Matching WHR or CalVeg Identifiers

USDA Regional Type	Code	Matching WHR or CalVeg type	Code
Brewer spruce	B	Brewer spruce*	22
Coulter pine	C	Coulter pine*	33
Douglas fir	D	Douglas fir	11
East side pines	E	Jeffrey pine	12
East side mixed conifer	F	Mixed conifer	14
Giant sequoia	G	Big tree*	32
Hardwoods	H	Valley, live, decid. oaks	32,33,34
Jeffrey pine	J	Jeffrey pine	12
Knobcone pine	K	Knobcone pine*	24
Lodgepole pine	L	Lodgepole pine	13
Mixed conifer	M	Mixed conifer	14
Port-Orford-Cedar	O	-- Not reported in California --	
Ponderosa pine	P	Ponderosa pine	15
Red fir	R	Red fir	17
Redwood	S	Redwood	16
Mountain hemlock	T	Mountain hemlock*	19
White fir	W	White fir	18

* Denotes a CalVeg rather than a WHR identifier was used.

matching scheme shown in Table 3.5. The process was repeated for all unique first letter identifiers.

4) Once the species volume per acre estimates were converted to WHR cover types, the number of acres covered by each estimate were calculated by using the total area of each cell and the distribution of WHR cover types within each cell. The average area of a cell within each of the thirty 1:250,000 USGS quadrangless was provided by Dr. Davis at U.C. Berkeley and is included in Appendix A. The distribution of WHR cover types is included in the basic data record.

5) The volume per acre estimates for each species for each stratum, now converted to WHR cover type, were multiplied by the number of acres covered by that cover type. This yielded volume for that species and WHR cover type. This was done for all WHR cover types in a cell. Since many species occurred in more than one WHR cover type, volumes for each species were then summed over all cover types within the cell to yield total volume estimates. The species ranking in the top five in terms of total volume for each cell were reported in the data base. Figure 3.11 shows the spatial distribution of USDA Forest Service forest volume in the database.

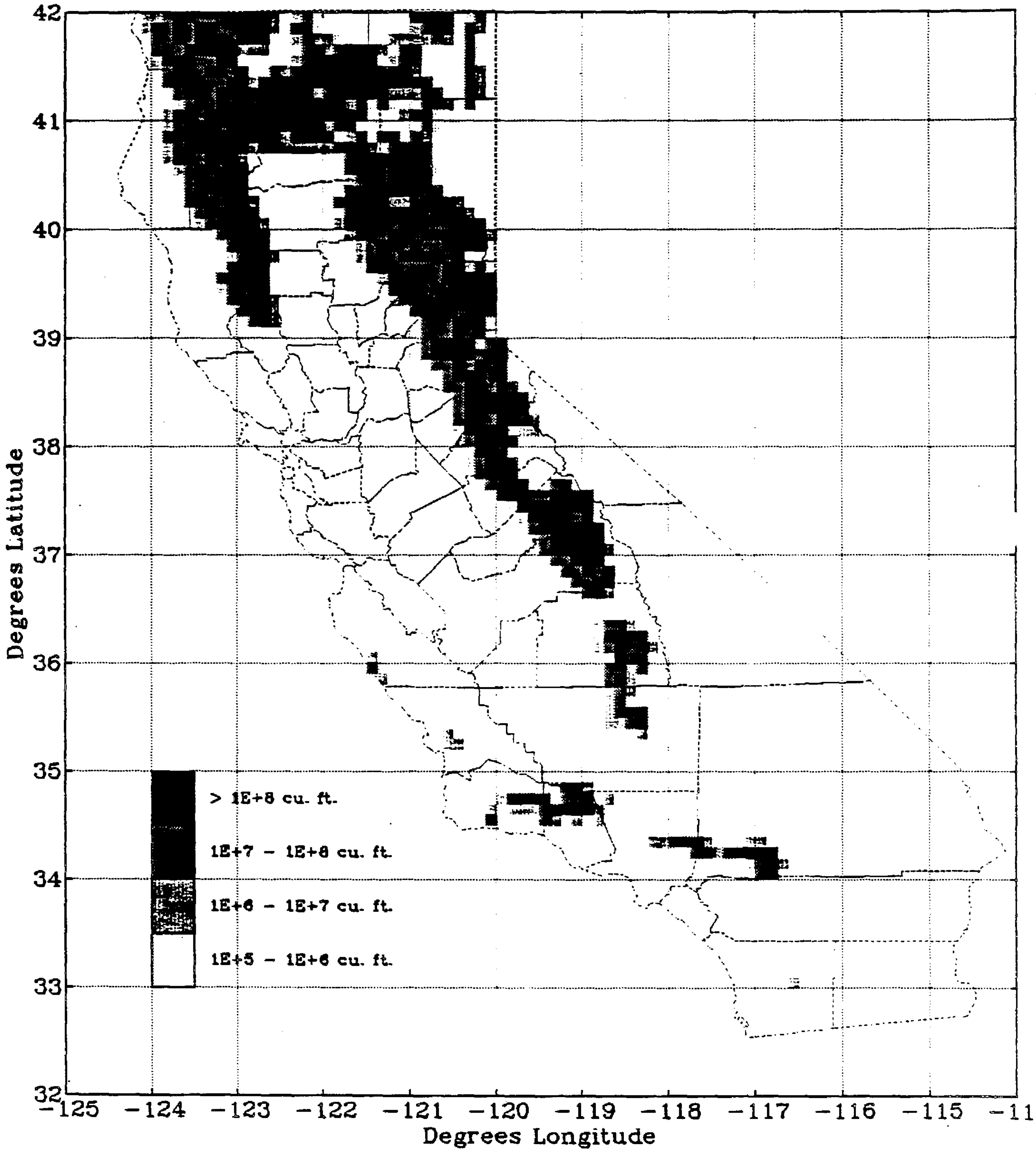
Non-National Forest Volume Estimates

For lands that lie outside of national forest boundaries, a method for estimating timber volume was adopted from the procedures used by the California Department of Forestry in the recent FRRAP assessment (Marose, 1987). Data used to make the volume calculations were obtained from the USDA Forest Service and the California Department of Forestry, and include forest ground plot descriptions, photo interpretation classifications of ground cover, and resource area designations.

For purposes of assessing forest status in areas outside national forests, the USDA Forest Service maintains approximately 1,500 ground plots statewide. In

Figure 3.11

Spatial Distribution of Timber Volume on USDA Forest Service Lands in California (All Species)



each plot, trees are mapped and sampled. In addition to the ground plots, a grid of approximately 80,000 photo interpretation (PI) points have been established by the Forest Service on non-national forest lands; at these points the ground cover is classified on the basis of composition, density and site factor (see Appendix C for PI guidelines). Data from both the ground plots and the PI grid have been entered into the FRRAP data base. California is divided into the six resource areas shown in Figure 3.12. The areas are large, but it is felt that in general forests within a given resource area that appear to be similar in density and structure from the air will be similar in species composition and volume when examined on the ground (Bolsinger, 1987 and Marose, 1987).

Information necessary to estimate timber volume on lands outside of national forests could only be obtained after formal approval from the USDA Forest Service, stating that the information included in the data base was of sufficiently coarse resolution to prevent a detailed description of the holdings of individual private land owners. The procedure used to perform the volume calculations on lands outside of national forests is as follows:

1) Listings of timber volume for 14 species groups (see Appendix A for definitions of species groups) were obtained from FRRAP. These listings were developed during the recent FRRAP assessment and included information from all ground plots in the state. In each resource area, timber volume estimates were calculated for each ground plot with the CATS stand development model. Each plot had previously been assigned a PI classification, and volume estimates from plots with the same PI classification were averaged. The final form of the listing was a series of tables of volume estimates for species groups, stratified by FRRAP PI group (Table 3.6) and resource area. Forests in the Southern California resource area contribute very little to the state's timber volume; therefore, volume estimates for non-USDA Forest Service lands in this resource area were not calculated by FRRAP personnel and do not appear in the data base.

Figure 3.12

California Resource Areas

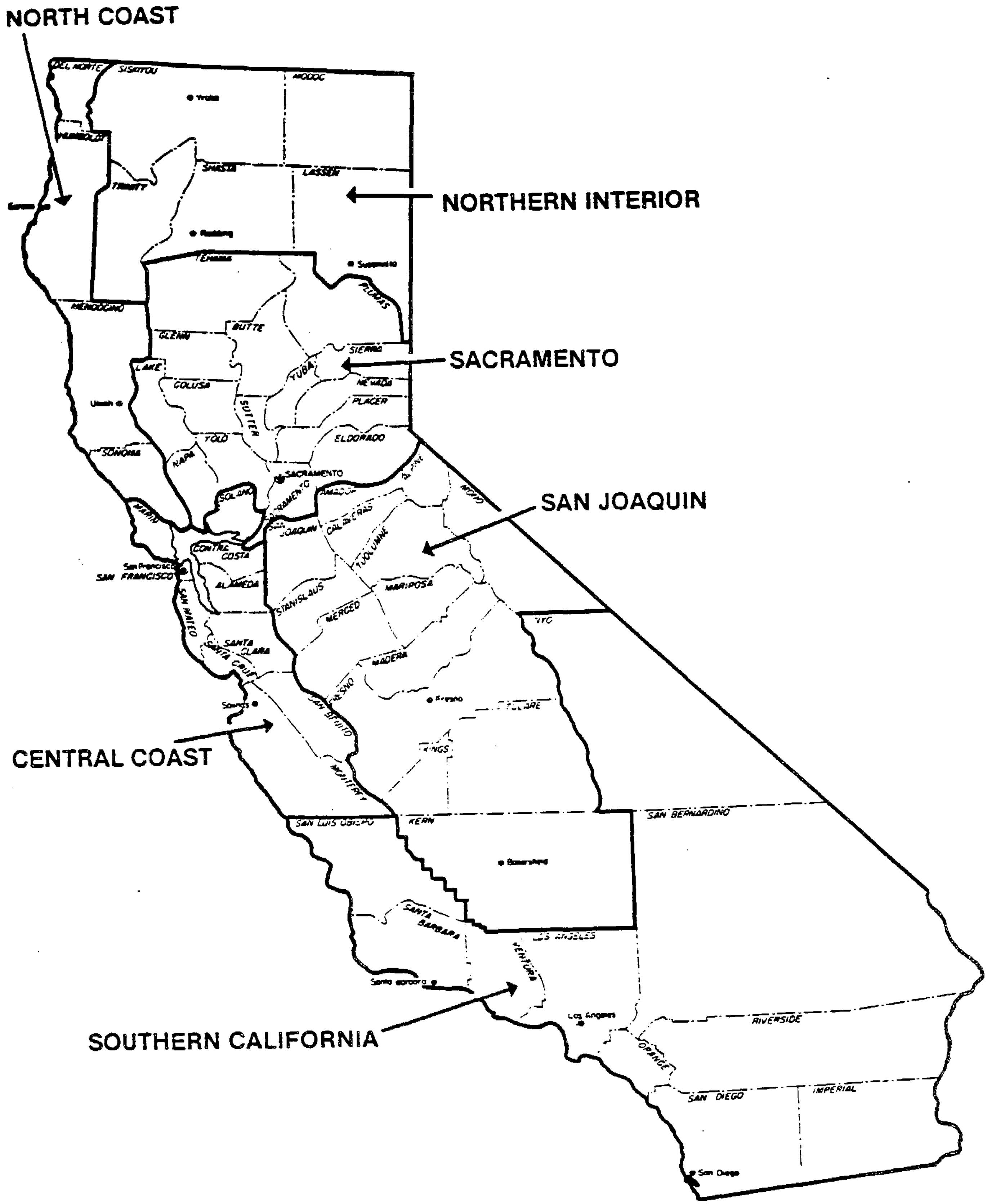


Table 3.6

Photo-Interpretation Class Groups

PI Group	Associated PI classes
1	21
2	22
3	23
4	24
5	25
6	26
7	27
8	41, 42, 49
9	43
10	44
11	45, 46

2) The frequency distribution of PI classes in each of our data base cells was obtained from Dr. Davis at U.C. Berkeley. The cells had varying numbers of PI points depending on land ownership patterns; the maximum was approximately 25. The PI classes, and corresponding PI groups used by FRRAP, relevant to timber volume calculations are shown in Table 3.6. Since PI points are located on a regularly-spaced grid over the state, it was assumed that each point represented a fraction of the area of the non-national forest land in a cell, dependent on the number of points in the cell. For example, each PI point in a cell with 20 PI points was assumed to represent 5 per cent of the area.

3) The resource area designation of a cell was found by manually overlaying the data base grid onto a map of California resource areas. If a cell fell into two or more resource areas, the resource area covering the most area within the cell was selected.

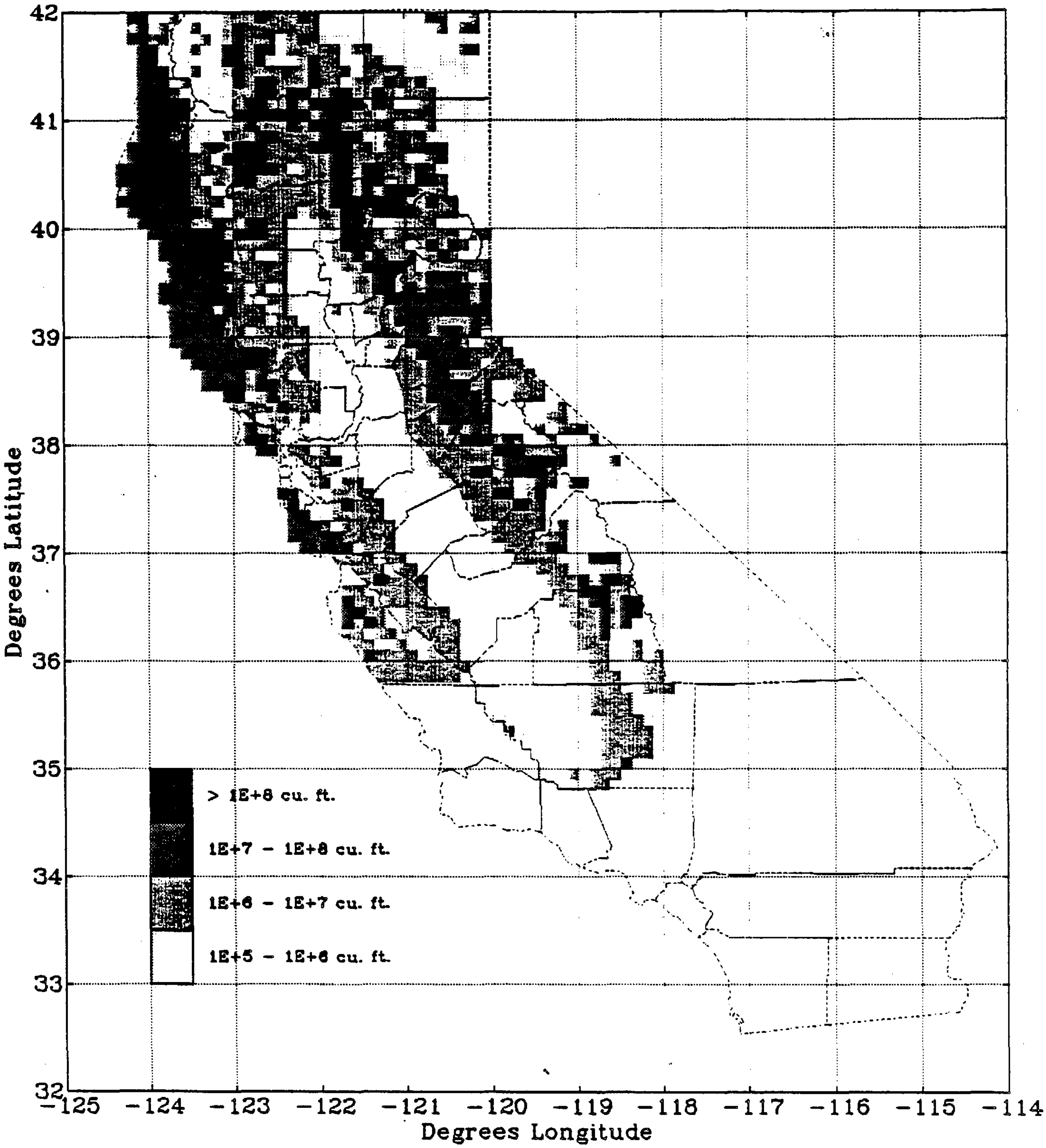
4) Timber volume was calculated for each cell by using the resource area designation of the cell, the PI distribution in the cell, and volume estimates from FRRAP. FRRAP volume estimates for the correct resource area were weighted based on the area represented by each class in the cell, and summed over all PI classes that occurred in the cell. The final volumes that are reported in the data base consist of a list of species groups and volume estimates for each group. Figure 3.13 illustrates the spatial distribution of timber volume on non-U.S.D.A. Forest Service lands in the database.

3.2.3.2 Recreational Use

Recreational use information included in the data base represent lands owned by the USDA Forest Service (USFS), National Park Service (NPS), Bureau of Land Management (BLM), Army Corps of Engineers (ACE), California Department of Parks and Recreation (DPR), California Department of Fish and Game (DFG), and Pacific Gas and Electric Company (PG&E). All of these owners are federal or state agencies, except PG&E. Recreation facilities owned by other utility

Figure 3.13

Spatial Distribution of Timber Volume on Non-Forest Service Lands in California (All Species Groups)



companies, water districts and government agencies are either located on USFS or other federal land, or their usage is relatively small or poorly documented. For example, California Department of Water Resources facilities are under DPR jurisdiction, and all but four ski areas in the state are on USFS land and usage is reported by the USFS. The Sacramento Municipal Utility District has camping facilities for its 500 employees, but resultant usage totals are small. Repeated requests for recreation data from the Bureau of Reclamation were never filled. However, all but two reservoirs owned by the Bureau of Reclamation are managed by the USFS, NPS, or individual water districts, so the net loss of data is small.

Use totals reported in the data base represent a large percentage of the total recreation in forested areas in California, but insufficient information exists to calculate the exact percentage. Recreational facilities not included are primarily privately owned, and use data are scattered among hundreds of organizations. Organizations operating facilities for profit were unwilling to provide data because of the financial nature of the information.

All but two agencies provided recreation data on hard copy; USFS RIMS (Recreation Information Management System) data and DPR data were provided in electronic form. Most agencies reported only a few or none of the geographical coordinates of their facilities. As a result, 114 coordinates were estimated visually from maps. These included 34 DFG recreation areas, fish hatcheries and wildlife areas; 25 PG&E recreation areas; 13 ACE facilities; 20 NPS parks; 12 BLM resource areas; and 10 DPR parks. Much existing geographical information was in the form of directions (e.g., "10 miles west of the East 250 turnoff") or plotted on crude maps of California. We were informed that locations on the plotted maps were hand drawn by personnel familiar with the area. The accuracy of the estimates is unknown. Exceptions were the USFS RIMS data, which were provided in a gridded form that matched our data base grid, and DPR park location data, which were provided on hard copy (in the form of latitude/longitude coordinates) for most of the park units.

Use statistics reported in the data base are stated as average user-days per year in each grid cell over the period 1981-1985, except PG&E and DFG; these agencies did not provide data for 1981 and 1982, so the period 1983-1985 was included in the database. A user-day is defined as 12 hours of use by one visitor.

USDA Forest Service: USFS data were already available as user-days per year for each grid cell and were entered directly into the data base. The USFS also provided user-day totals for each grid cell in five activity classes for 1985: land-based activities, camping and lodging, water-based activities, motor-based travel and recreation, and winter recreation.

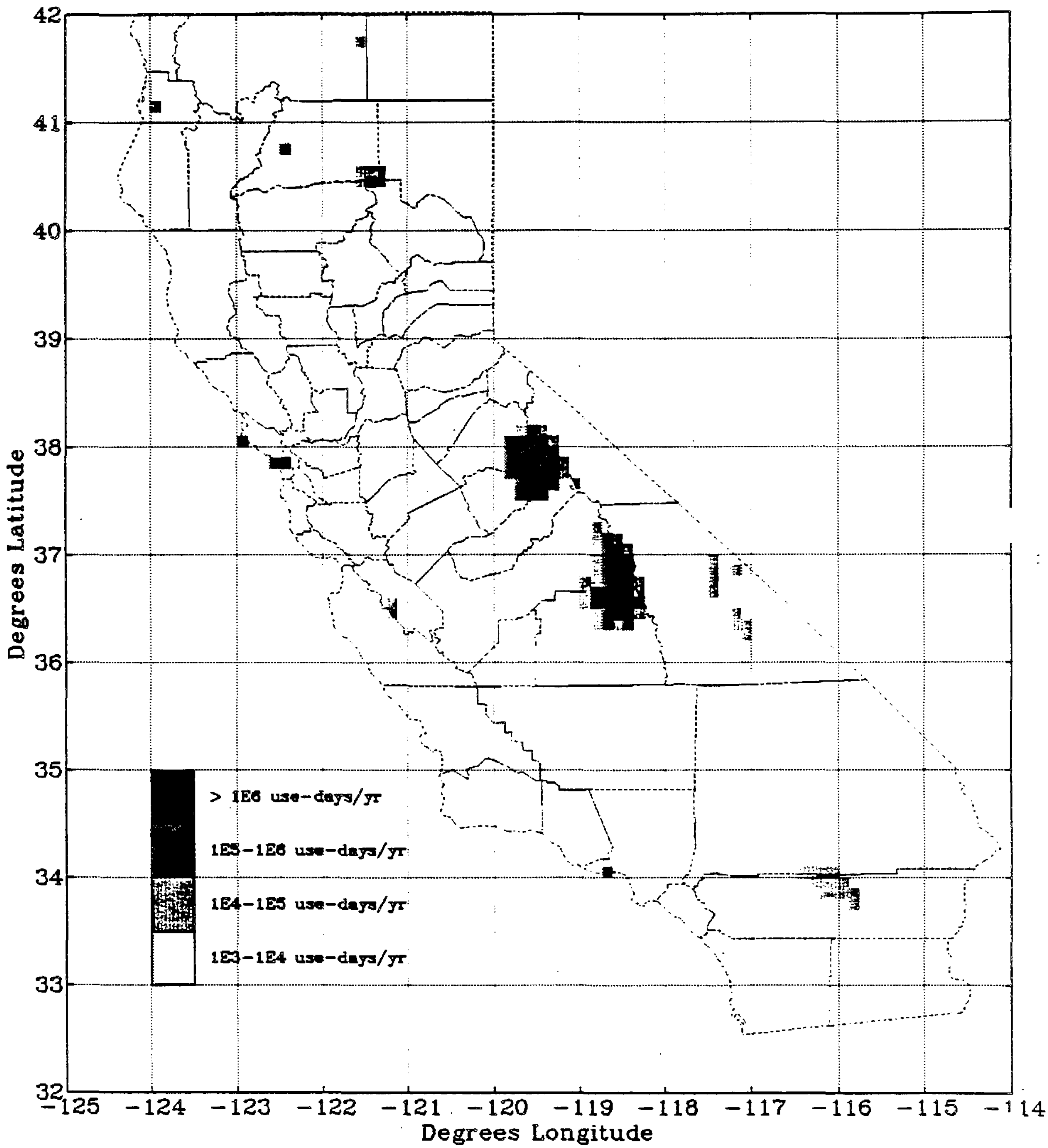
California Department of Parks and Recreation: DPR reported use as user-days per month; the months were added to obtain user-days per year. DPR provided us with geodetic coordinates for the headquarters of most of their park units. Those not reported were estimated visually from maps. All user-days for a particular park were entered into the grid cell in which the reported coordinates fell.

National Park Service: NPS reported total use by park in visitor-hours; we divided these numbers by 12 to obtain user-days. User-days in those parks having unique ownership codes in the basic data record (see Appendix A for ownership codes) were spread over the appropriate cells according to the areas covered by the codes. Other NPS locations were estimated visually from maps. Figure 3.14 depicts the distribution of National Park Service recreation use in forested cells.

Pacific Gas and Electric: For PG&E, 1985 data were provided as user-days for each facility. However, 1983 and 1984 data were provided as user-days for all facilities combined. Facility-specific user-days for these years were calculated by estimating the average percent contribution of each facility in 1985 and multiplying the use totals in 1983 and 1984 by these percentages. Locations of PG&E facilities were estimated visually from maps. User-day

Figure 3.14

Spatial Distribution of National Park Service Recreation Use



totals were entered into the grid cell representing the approximate center of the facility.

Army Corps of Engineers: ACE data were reported as user visits. The ACE began reporting use in visitor hours in 1986. We obtained the 1986 data, although 1986 data are not included in our data base. We found that on average, the number of 1986 user-hours was three times the number of user visits in 1985. This suggested a four-hour visit, assuming that visitor attendance was similar between the two years. Consequently, the 1981-1985 user visits were divided by three to arrive at user-days. Locations of ACE facilities were estimated visually from maps. User-day totals were entered into the grid cell representing the approximate center of the facility.

Bureau of Land Management: BLM data were reported in the same fashion as the ACE data. The average length of a visit was estimated to be 9 hours, so each visit was multiplied by 0.75 to obtain user-days. The original data provided by the BLM was aggregated by state. Subsequent negotiations with BLM produced data by BLM resource area, but information for the Susanville district, covering northeastern California, was not available. User-days in each resource area were apportioned over the grid cells in that resource area, according to the amount of land owned by BLM in each cell. BLM land has a unique ownership code in the basic data record (see Appendix A). No information on the spatial patterns of recreational usage were available, so user-day totals for each resource area were evenly distributed over the BLM land in that resource area.

California Department of Fish and Game: DFG use totals were reported by fiscal year (July 1 - June 30). To obtain calender year totals, we averaged the totals for the two fiscal years covering those periods. The DFG reported user-visits. After discussions with Bill Griffith at DFG, we estimated that each visit lasted an average of four hours, but this estimate is highly uncertain. User-visits were divided by three to arrive at 12-hour user-days. Data for 1981 and 1982 were provided as totals and not by recreation area, as were the other years. To distribute the totals, we calculated the percent contribution of each recreational area to the total in 1983 and applied these percentages to the totals for 1981 and 1982. Locations of DFG facilities were estimated visually from maps. User-day totals were entered into the grid cell representing the approximate center of the facility.

The final form of the recreational usage data is a list of the seven agencies with average user-days per year during 1981-1985 (1983-1985 for DFG and PG&E) for each. In addition, five aggregate activity categories for 1985 only are reported for USFS lands.

3.3 DATA QUALITY

Data intended for many different uses and stored in a many different formats have been brought together to create this data base. While the varied nature of the data sources makes the data base unique, it also increases the potential for quality assurance problems. Per the study work scope, we have clearly delineated our role as data base assemblers, not as experts imposing judgments on data suppliers. We have therefore relied throughout on the accuracy of the data as supplied to us. While careful adherence to our role precludes our guaranteeing the underlying accuracy of the data supplied to us, we have taken substantial quality assurance steps to ensure that our manipulation of the data has not introduced errors into the data base.

During the course of preparing the data base, we performed the following quality assurance procedures:

(1) Careful checking of all in-house data manipulations and calculations to ensure that errors were not introduced into the data base.

(2) Limited spot-checking of the data to examine general data quality.

Checking of in-house procedures began with data entry; large volumes of data requiring keypunch entry were double-entered, the two data sets compared, and any discrepancies resolved. Computer programs written to manipulate and calculate variables were initially run on small subsets of data to allow for the identification and correction of errors before the final production runs. Computer graphics were used extensively to check the spatial characteristics of variables. Limited project resources did not permit independent critique of the calculated variables (e.g., timber volume); additional quality assurance activities are recommended in this regard.

Spot-checking procedures to examine general data quality covered about 10 per cent of the data. The data were found to be generally of high quality, but certain discrepancies were noted. Two problems deserving of further attention are outlined below.

3.3.1 Point Conception

3.3.1.1 Problem

An area of about 22 cells in the ocean south of Pt. Conception is the site of errors in the basic data record. Codes representative of land areas instead of oceanic areas are reported, see Figure 3.2.

The FRRAP data base is based on 1:250,000 USGS quadrangles (see Figure 3.2). Most quadrangles are 1° latitude by 2° longitude, and are covered by 10 rows and 16 columns of cells in the forest data base. Two quadrangles are 2° latitude by 1° longitude, and have 20 rows and 8 columns of cells. The quadrangle encompassing the Pt. Conception area (Santa Maria quadrangle) is one of these two; the other is the Eureka quadrangle (which is in the extreme upper left corner of Figure 3.2). Specifically, the Santa Maria quadrangle is bounded by 33° and 35° latitude and -120° and -121° longitude.

U.C. Berkeley assumed these dimensions when aggregating FRRAP cells into larger cells used in the forest resources data base. When the data were plotted, the Eureka quadrangle looked correct, but the Santa Maria quadrangle did not. U.C. Berkeley was unaware that FRRAP personnel had not coded the cells in the lower half of the Santa Maria quadrangle, because it was all water. U.C. Berkeley's automated cell aggregation algorithm, not programmed to accommodate this exceptional situation, "stretched" the upper half of the quadrangle to fit the full 2° of latitude. The result was a coastline that extended twice as far south as it should have.

3.3.1.2 Correcting the Data Base

This problem can be easily corrected, and corrective measures need only be taken within the Santa Maria quadrangle. Since a row of cells within the quadrangle now covers twice as much latitudinal area as it should, every two rows must be collapsed into one. For example, starting at the top of the quadrangle, rows 1 and 2 become row 1, rows 3 and 4 becomes row 2 ... rows 19 and 20 become row 10. Once this is done, the lower half of the quadrangle that now has no data is filled with missing data codes.

3.3.2 Missing Data

3.3.2.1 Problem

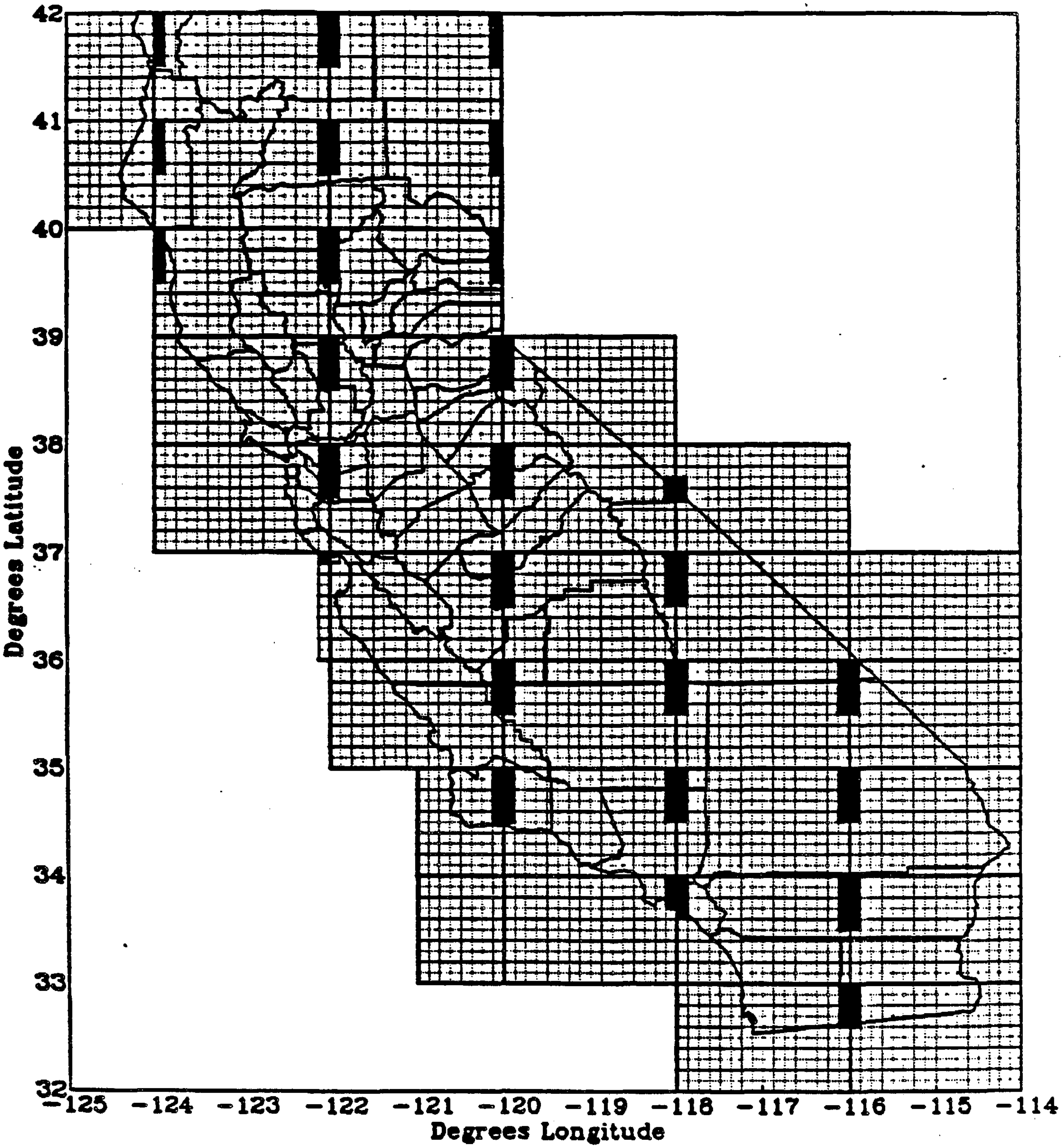
The FRRAP data base is based on 1:250,000 USGS quadrangles (Figure 3.15). Mylars of the quadrangles were optically scanned by the USDA Forest Service to produce the database. Each mylar was tapered at the upper left and upper right corners to accommodate meridional convergence, but the FRRAP grid of cells was defined as perfectly rectangular. Therefore, a strip of cells in each corner of the quadrangle appears to be empty. This phenomenon appears in our database in each quadrangle as two strips of cells, each 5 rows by 1 column, in which 10 per cent of the area in each cell is designated as having no data.

3.3.2.2 Proposed Solution

Presently, these "gaps" in the data are coded as missing, using the same code as the one that indicates parts of cells that are not in California (-9). The gaps cannot be easily filled with valid data. We suggest that a special missing code, indicating "no data, but within the state" be given to these areas (e.g., -8).

Figure 3.15

United States Geological Survey 1:250,000 Quadrangle System Used as the Geographical Basis for the FRRAP Data Base



Based on spot-checks of 6 quadrangles, the blackened cells are expected to contain 10 per cent missing data in our database.

3.3.2.3 Estimated Impact

The total area of missing data is less than one per cent of the area covered by the data base. The size of a data gap is never more than ten per cent of a cell, and the locations of the gaps are known. The overall impact on the data base should be small.

3.4 FORMAT AND ORGANIZATION OF THE DATA

The database is archived in SAS format (SAS Institute Inc., 1985), and is approximately 2 megabytes in size. The records are sorted by grid cell, and the y-coordinate varies faster than the x-coordinate. SAS listings of "PROC CONTENTS" and PROC MEANS" are in Appendix F. The CONTENTS file contains all the information necessary to read and manipulate the variables. The SAS programmer accessing this database should run a PROC MEANS program and compare the results with those in Appendix F to assure that the data were successfully transmitted. As shown in Table 3-2, each grid cell has a header record and a basic record. The extended record variables are set to missing values if the cell is not considered "forested."

Programmers should note that code variables, such as FIPS1, FIPS2, STP1, etc. are archived as character variables in this database. The codes are left-justified. Therefore, when performing comparisons, use the SAS function LEFT( ) to ensure the variables compared are left-justified. If it is necessary to use the code variable as a numeric variable, the conversion is easily accomplished by defining a numeric variable and setting it equal to the code variable. For example, use the following SAS statements to convert FIPS1 to a numeric value:

```
LENGTH FIPN1 4;
FIPN1 = FIPS1;
```

Summary tables of the database are in Appendix G. The tables are sorted by air basin, and provide a condensed overview of the data.

4.0 RISK ASSESSMENT

4.1 INTRODUCTION

This chapter estimates risks to forested resources due to modeled ambient ozone concentrations in California. Risk estimates are based on data contained in the forest data base and on the estimated sensitivity of California tree species to ozone, see Chapters 2 and 3. While the current consensus within the forest-science community is that ozone is influencing the structure and productivity of forest ecosystems in California, it has not been possible to determine answers to the following questions:

1. How severe and widespread is ozone injury in natural and managed forests in California?

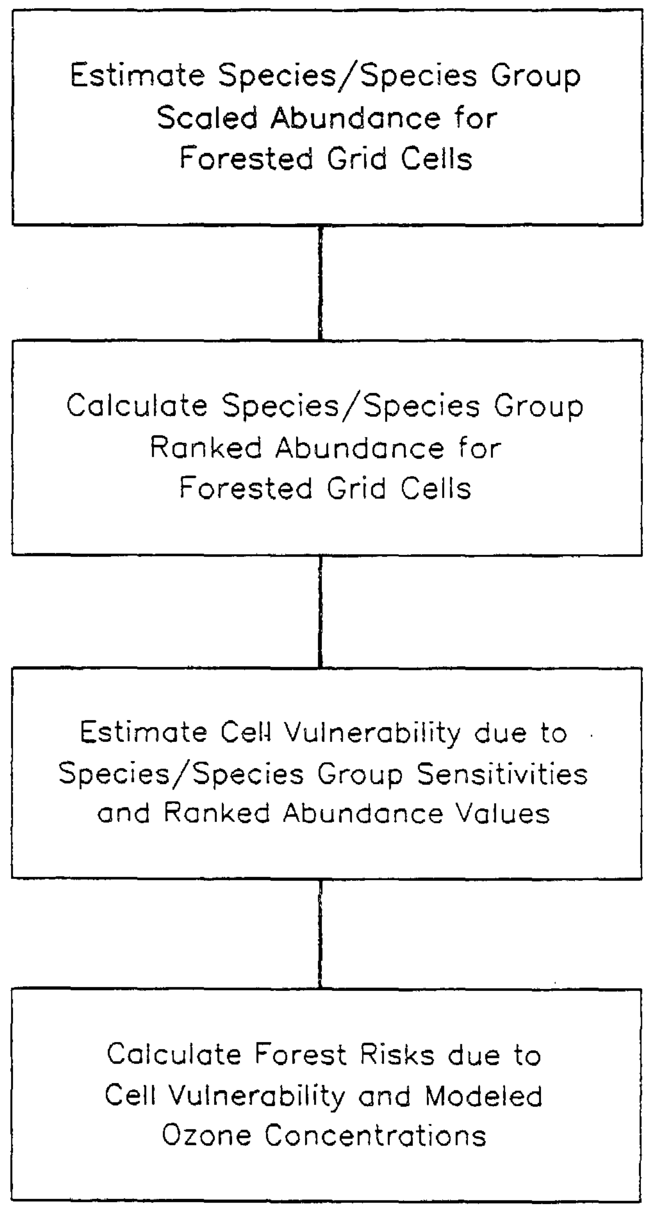
2. What are the exposure-response relationships for forest trees, when response is defined in terms of growth, biomass, reproductive capacity, resistance to pests, and capacity to compete?

3. What are the current and long-term ecological and economic effects of the exposure of ozone to forests in California?

In lieu of a rigorous answer to the above questions, this chapter provides the ARB with an assessment of California forest sensitivities and estimated exposures to ozone. Information on forest sensitivity and exposure can be coupled with resource information contained in the data base to provide a preliminary assessment of the ozone caused risk to forest resources in California and to guide future research. Section 4.2 discusses the methods and data used to derive risk estimates, and Section 4.3 summarizes and discusses results of the risk analysis.

Figure 4.1

Risk Assessment Tasks



4.2 METHODS

Risk estimates were developed for each forested grid cell within the data base in four principal tasks, see Figure 4.1. While the data base contains 3,500 grid cells, only 1,578 cells contained both necessary forest volume and ozone data.[1] All risk calculations were performed in SAS (SAS, 1985). Documented SAS programs used in the analysis are contained in Appendix G.

4.2.1 Calculating Scaled Abundance

Scaled abundance values were calculated for USDA Forest Service and non-Forest Service lands using species and species group volume, and cell area data contained in the forest data base. Scaled abundance was estimated by:

$$A_i = \frac{B_i}{a} \tag{4.1}$$

Where:

A = the scaled abundance species or species group i,
B = the volume for species or species group i,
a = the area of the grid cell.

Procedures used in the calculation of species and species group volumes are reviewed in Chapter 3. Note that cell volume estimates (B) are available in the data base for the five most common tree species and tree species groups within every cell. Hence, cell volume estimates do not reflect species/species group volumes not included in the top 5 species/species groups in each cell. The data base contained 4,232 records of tree species volume and 7,010 records of tree species group volume. Eight hundred sixty-seven cells contained records of tree species volume and 1466 contained records of tree

---

[1] Seventy-eight cells contained no ozone data. These cells form a column bounded by grid cells 35,88 and 40,100. Cells within this range were assigned missing values for ozone data by the kriging program because of their distance from available monitoring sites.

species group volume. Six hundred seventy-three cells had records of both tree species and tree species group volumes, indicating USDA Forest Service and non-Forest Service ownership within the cell.

4.2.2 Calculating Ranked Abundance

After scaled abundance values were calculated for each reported species and species group in all forested grid cells, maximum abundance factors were calculated for both species and species group volume estimates. These were derived by summing the reported species or species group volume estimates within each cell in the data base, and dividing total volume estimates for each cell by that cell's estimated area. The calculated maximum abundance factor for tree species scaled abundance's was 7.18884697; the calculated maximum abundance factor for tree species group scaled abundance was 3.79298754. Figures 4.2 and 4.3 summarize the distributions of scaled abundance values for tree species and tree species groups, respectively.

The scaled abundance values were assigned to three abundance classes and given a ranked abundance ($A_{r(i)}$) based on the distributions.[2] Ranked abundance, $A_{r(i)}$, is 3 for the upper one-third, 2 for the middle third, and 1 for the lower one-third of each distribution. The cut-points on the distributions were:

Tree Species

$A_{r(i)} = 1$	$A_{r(i)} = 2$	$A_{r(i)} = 3$
<0.013271	>0.01371, <0.0461	>0.0461

Tree Species Groups

$B_{r(i)} = 1$	$Br(i) = 2$	$Br(i) = 3$
<0.0034702	>0.0034702, <0.0168	>0.0168

[2] Ranked abundance values for species groups are denoted with $B_{r(i)}$ in the SAS programs (Appendix G) and in the remainder of this chapter.

Figure 4.2

USFS Species Scaled Abundance Values

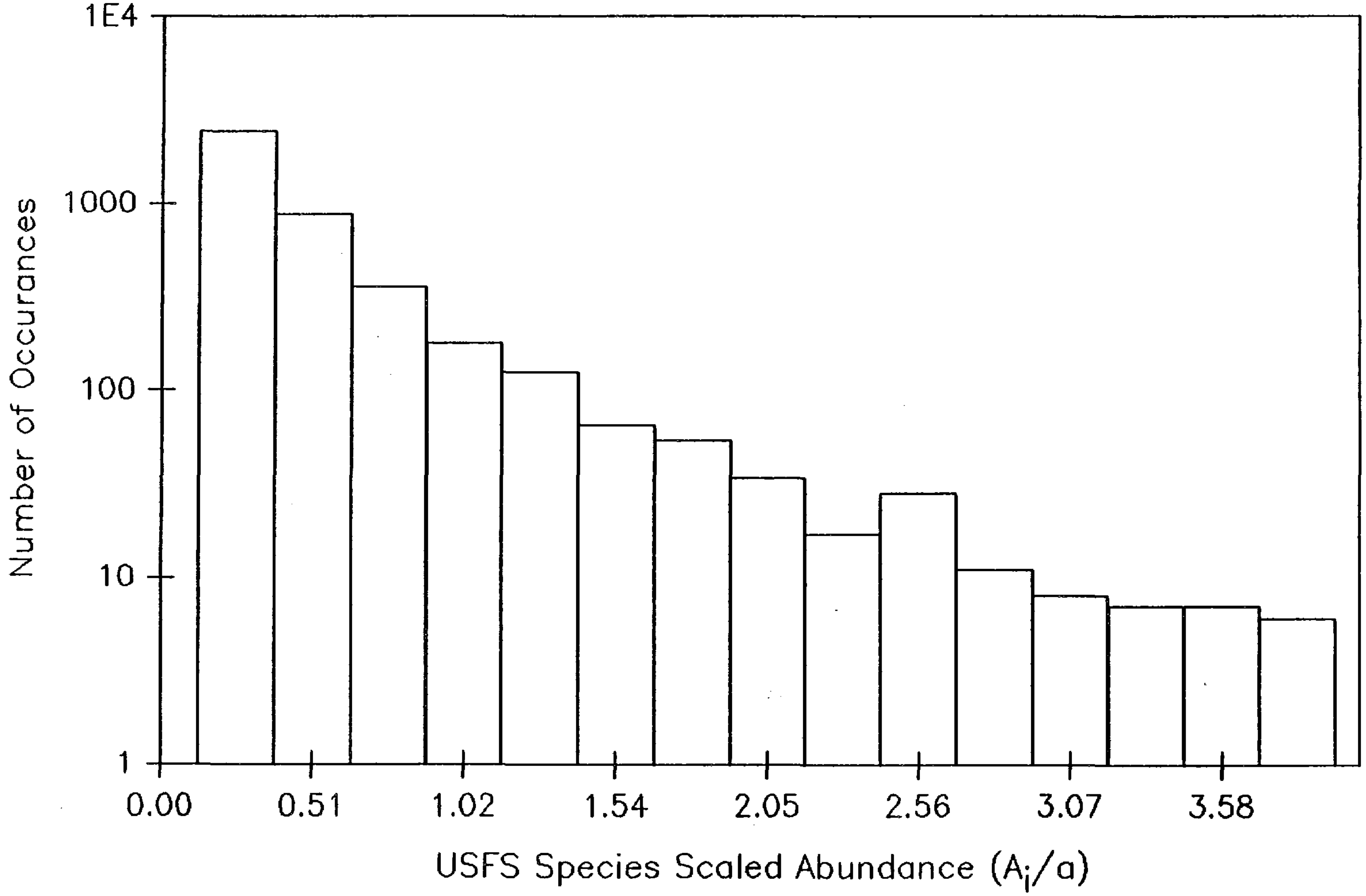
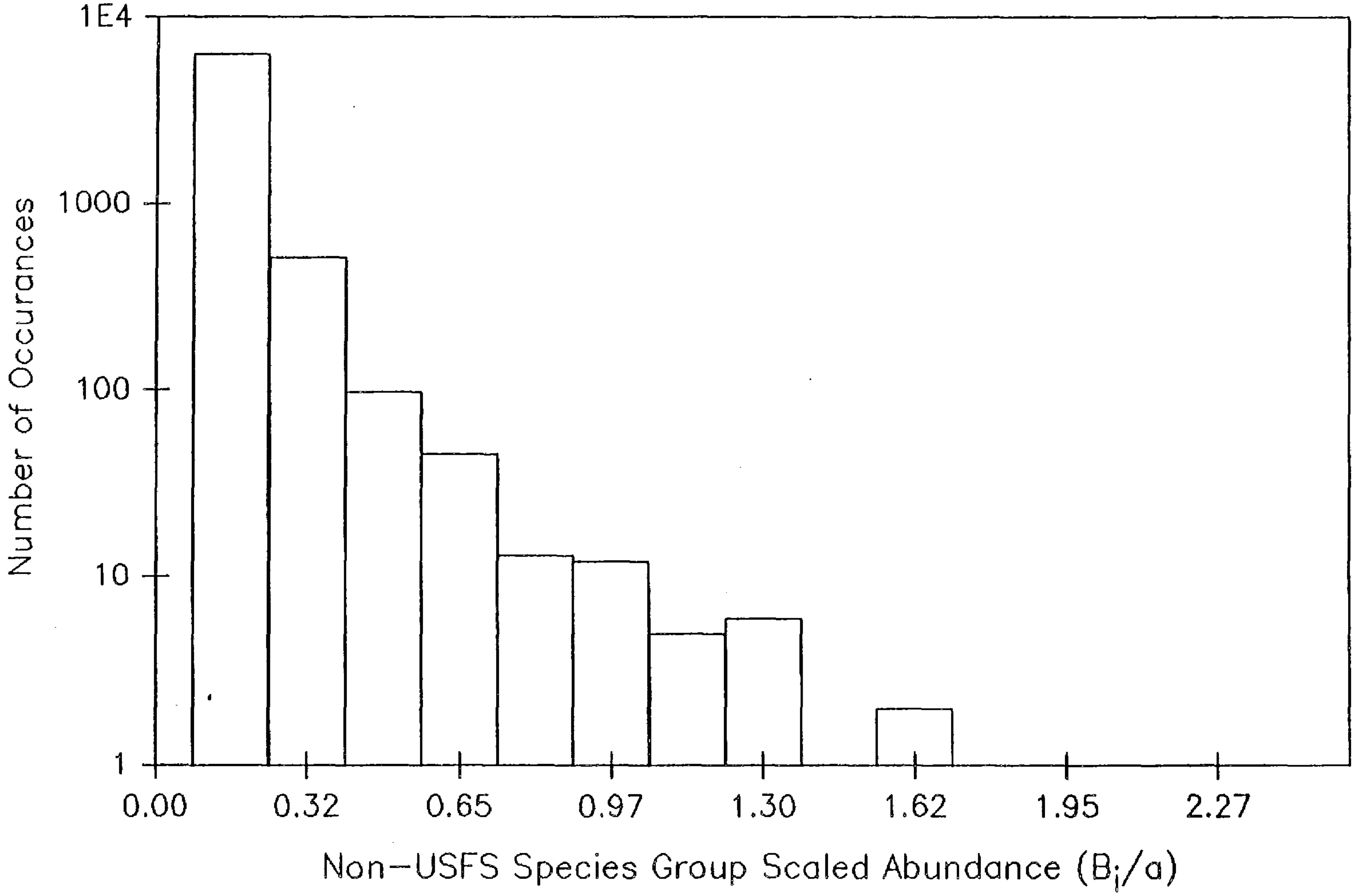


Figure 4.3

Non-USFS Species Group Scaled Abundance Values



Ranked abundance values provide a simple measure of the abundance of a given species/species group per unit area in a grid cell relative to other species/species groups and grid cells in the data base, allowing for simple and consistent comparisons of abundance across species/species groups. Figures 4.4 and 4.5 summarize the distribution of ranked abundance values for tree species and species groups, respectively.

4.2.3 Estimating Vulnerability

Vulnerability of the forest in grid cells was estimated by multiplying ranked abundance and sensitivity for each species or species group present in the cell and summing them, then dividing by the number of species/species groups for which ozone sensitivity has been ranked in Chapter 2 (Bennett, et al., 1985).

$$V = \frac{\sum_{i=1}^{n} A_{r(i)} S_i}{m}$$

Where:

V = the vulnerability of the forest

$A_{r(i)}$ = the ranked abundance of species i (1 = lower 1/3, 2 = middle 1/3, 3 = upper 1/3 of the distribution of tree species ranked abundance)[3],

S_i = the sensitivity of species i (1 = tolerant, 2 = intermediate, 3 = sensitive), and

m = the number of species/species groups for which ozone sensitivity has been ranked.

Because species groups are aggregates of tree species, species sensitivities shown in Chapter 2 are not directly applicable. Sensitivity values were

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[3] $B_{r(i)}$ for species groups.

Figure 4.4

USFS Species Ranked Abundance Values

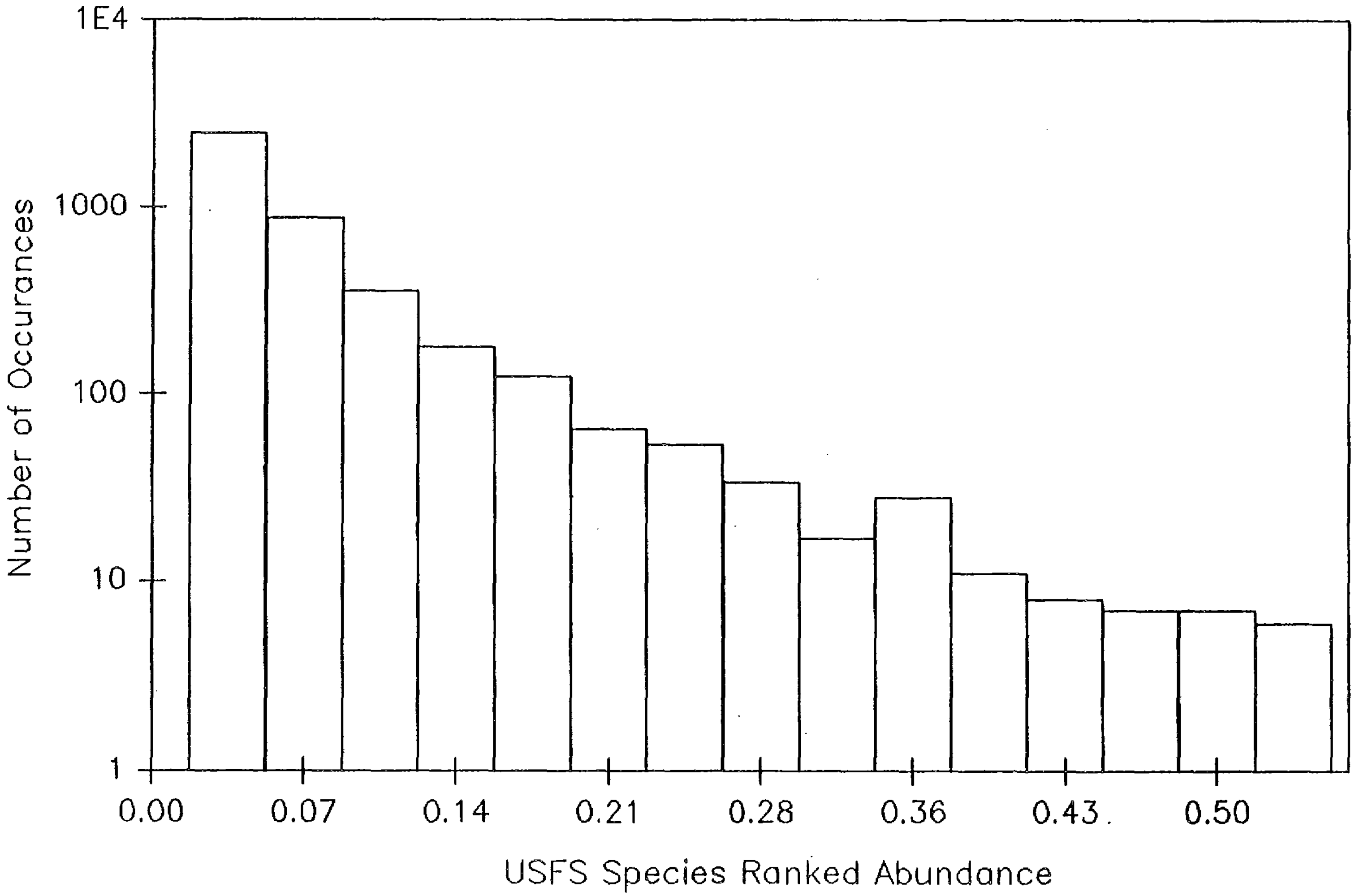
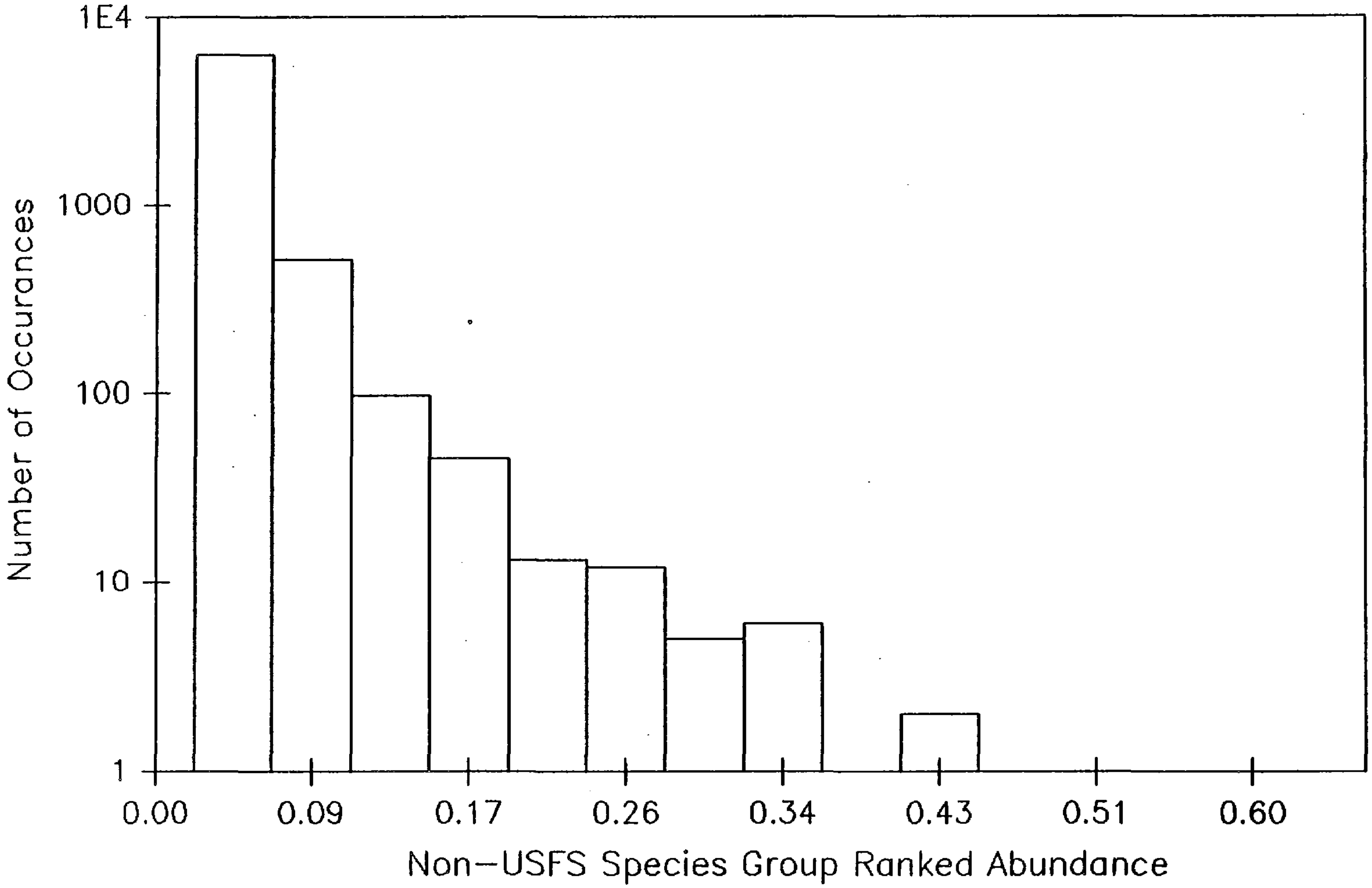


Figure 4.5

Non-USFS Species Groups Ranked Abundance Values



assigned to species groups by selecting the most sensitive value of the species group. For example, the sugar pine species group is comprised of sugar and white pine. Sensitivity values shown in Chapter 2 for sugar and white pine are 1 and 3, respectively. Consequently a sensitivity value of 3 was assigned to the sugar pine species group. This procedure provides an upward bias to the resulting species group vulnerability measures, however, this seemed preferable to underestimating the species group risk. Sensitivity values for species groups and their constituent tree species are shown in Table 4.1.

Species not ranked for ozone sensitivity were assigned a value of zero for the variable S. Therefore, the presence or absence of unranked species/species groups did not enter into the calculation of cell vulnerability. Forest vulnerability, as calculated in Equation 4.2, could have a range from 0 to 9. A value of 9 would depict forest tree species/species groups most vulnerable to ozone, and would occur when all ranked species/species groups within a heavily forested grid cell were classified as sensitive to ozone. A value of 0 would indicate that no information on species/species group sensitivity is available in that cell. A low (nonzero) value occurs when sensitive species are not abundant.

Figures 4.6, 4.7, and 4.8 represent the distribution of vulnerability values for tree species within cells, species groups in cells, and aggregate cell vulnerability values, respectively. Aggregate vulnerability measures, which were used in the final risk analysis, were calculated by:

If a and not b, then c = a;

If b and not a, then c = b;

If a and b, then $c = \frac{(a + b)}{2}$; and,

If not a and not b, then c = missing.

Table 4.1

Species Group Composition and Sensitivity Class

Species Group	Species
1. REDWOOD (1)	211. REDWOOD (1)
2. DOUGFIRC: DOUGLAS FIR - COASTAL (2)	14. SANTA LUCIA fIR (BRISTLECONE) (0)
7. DOUGFIRI: DOUGLAS FIR - INTERIOR (2)	202. DOUGLAS FIR (2)
3. OCOMCONC: OTHER COMMERCIAL CONIFERS (COASTAL) (1)	17. GRAND FIR (2) 42. ALASKA YELLOW CEDAR (0) 93. ENGLEMANN SPRUCE (1) 98. SITKA SPRUCE (1) 120. BISHOP PINE (1) 242. WESTERN REDCEDAR (0) 263. WESTERN HEMLOCK (1)
4. ONONCOMC: OTHER NON-COMMERCIAL CONIFERS (COASTAL) (1)	50. CYPRESS (0) 231. PACIFIC YEW (1) 251. CALIFORNIA TORREYA (NUTMEG) (0)
5. WHITEFIR: WHITE FIR (2)	15. WHITE FIR (2)
6. REDFIR: RED FIR (2)	20. CALIFORNIA RED FIR (2) 21. SHASTA RED FIR (2) 22. NOBLE FIR (2)
8. PONDPINE: PONDEROSA PINE (3)	116. JEFFREY PINE (3) 122. PONDEROSA PINE (3)
9. SUGARPIN: SUGAR PINE (3)	117. SUGAR PINE (1) 119. WHITE PINE (3)
10. INCENCED: INCENCSE CEDAR (2)	41. PORT ORFORD CEDAR (0) 81. INCENSE CEDAR (2)
11. OTHERPIN: OTHER PINES (3)	103. KNOBCONE PINE (2) 108. LODGEPOLE PINE (1) 124. MONTEREY PINE (3)
12. OCOMCONI: OTHER COMMERCIAL CONIFERS (INTERIOR) (1)	92. BRESER SPRUCE (1) 212. GIANT SEQUOIA (1) 264. MOUNTAIN HEMLOCK (1)

Table 4.1 (Continued)

Species Group Composition and Sensitivity Class

Species Group	Species
13. ONONCOMI: OTHER NON-COMMERCIAL CONIFERS (INTERIOR) (2)	62. CALIFORNIA JUNIPER (0) 64. WESTERN JUNIPER (1) 65. UTAH JUNIPER (0) 101. WHITEBARK PINE (1) 102. BRISTLECONE PINE (0) 104. FOXTAIL PINE (0) 109. COULTER PINE (2) 113. LIMBER PINE (1) 127. DIGGER PINE (1) 133. PINYON PINE (0) 201. BIGCONE DOUGLAS FIR (2)
14. OLDREDWC: OLD GROWTH REDWOOD (1)	REDWOOD YIELD, TREES OVER 200 YEARS
15. OLDDFRRC: OLD GROWTH DOUGLAS FIR (2)	DOUGLAS FIR OVER 200 YEARS
16. TANOAK: TANOAK (0)	631. TANOAK (0)
17. ALDERRIP: ALDER & RIPARIAN SPECIES (1)	351. RED ALDER (0) 352. WHITE ALDER (0-1) 374. WATER BIRCH (1)
18. BLACKOAK: BLACK OAK (2)	818. CALIFORNIA BLACK OAK (2)
19. OTHEROAK: OTHER OAKS (3)	801. CALIFORNIA (COAST) LIVE OAK (2) 805. CANYON LIVE OAK (2) 807. BLUE OAK (0) 811. ENGELMANN OAK (0) 815. OREGON WHITE OAK (3) 821. CALIFORNIA (VALLEY) WHITE OAK (3) 839. INTERIOR LIVE OAK (0)
20. OTHERHDS: OTHER HARDWOODS (2)	312. BIGLEAF MAPLE (1) 330. BUCKEYE (0-2) 361. PACIFIC MADRONE (0) 431. GOLDEN CHINQUAPIN (0) 492. PACIFIC DOGWOOD (2) 510. EUCALYPTUS (0)

Figure 4.6

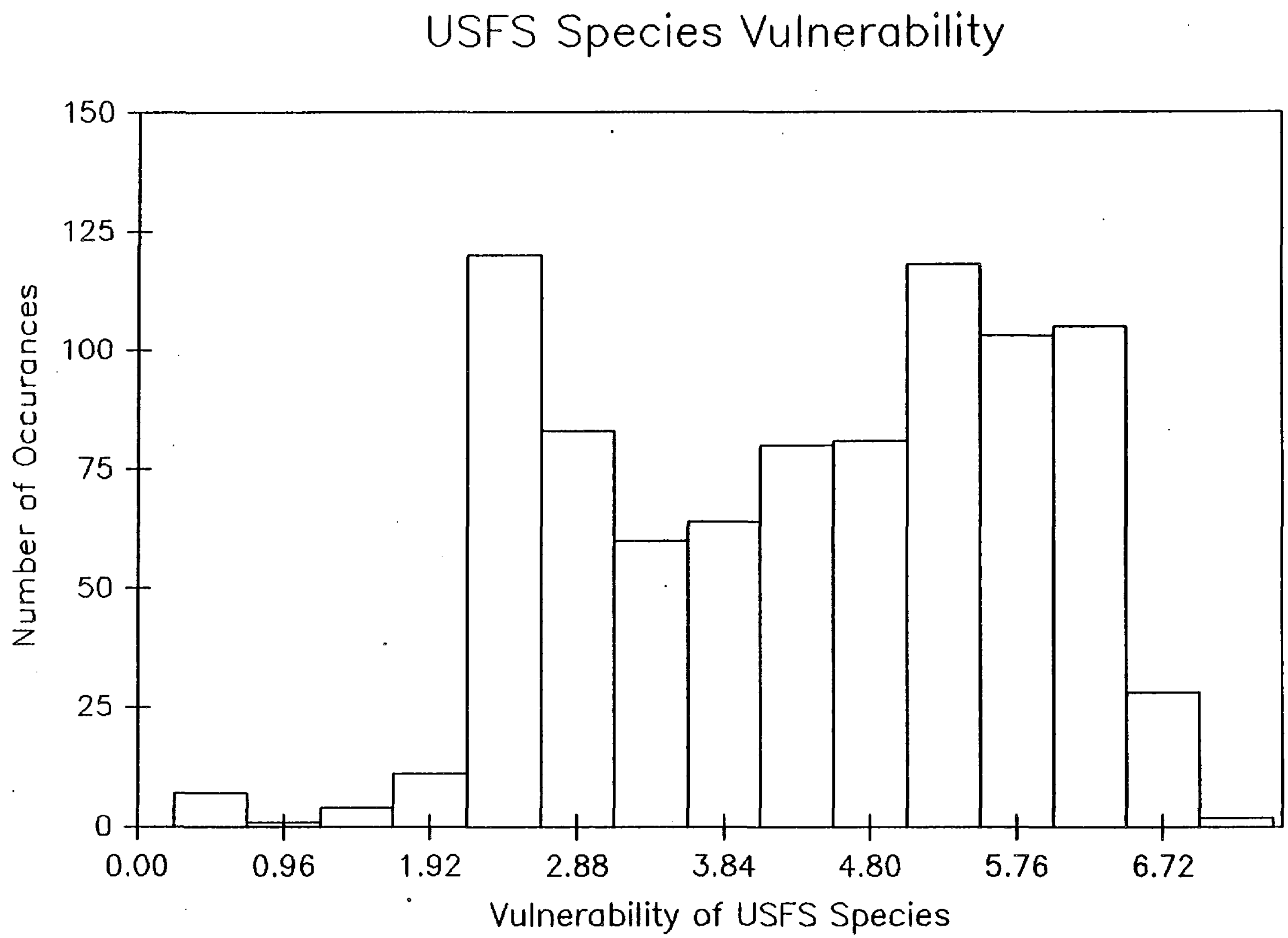

USFS Species Vulnerability
Number of Occurances
150
125
100
75
50
25
0
0.00
0.96
1.92
2.88
3.84
4.80
5.76
6.72
Vulnerability of USFS Species

Figure 4.7

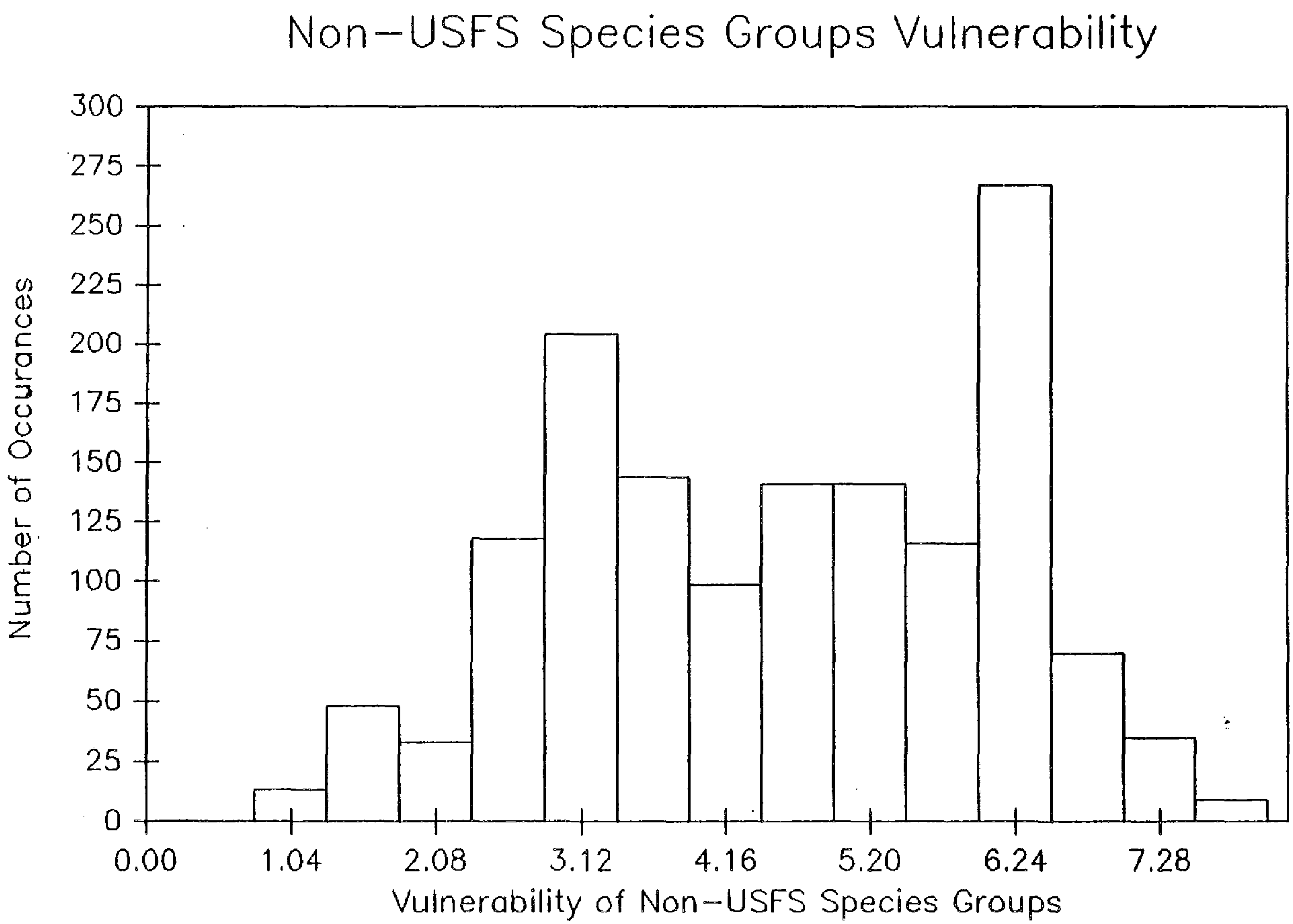
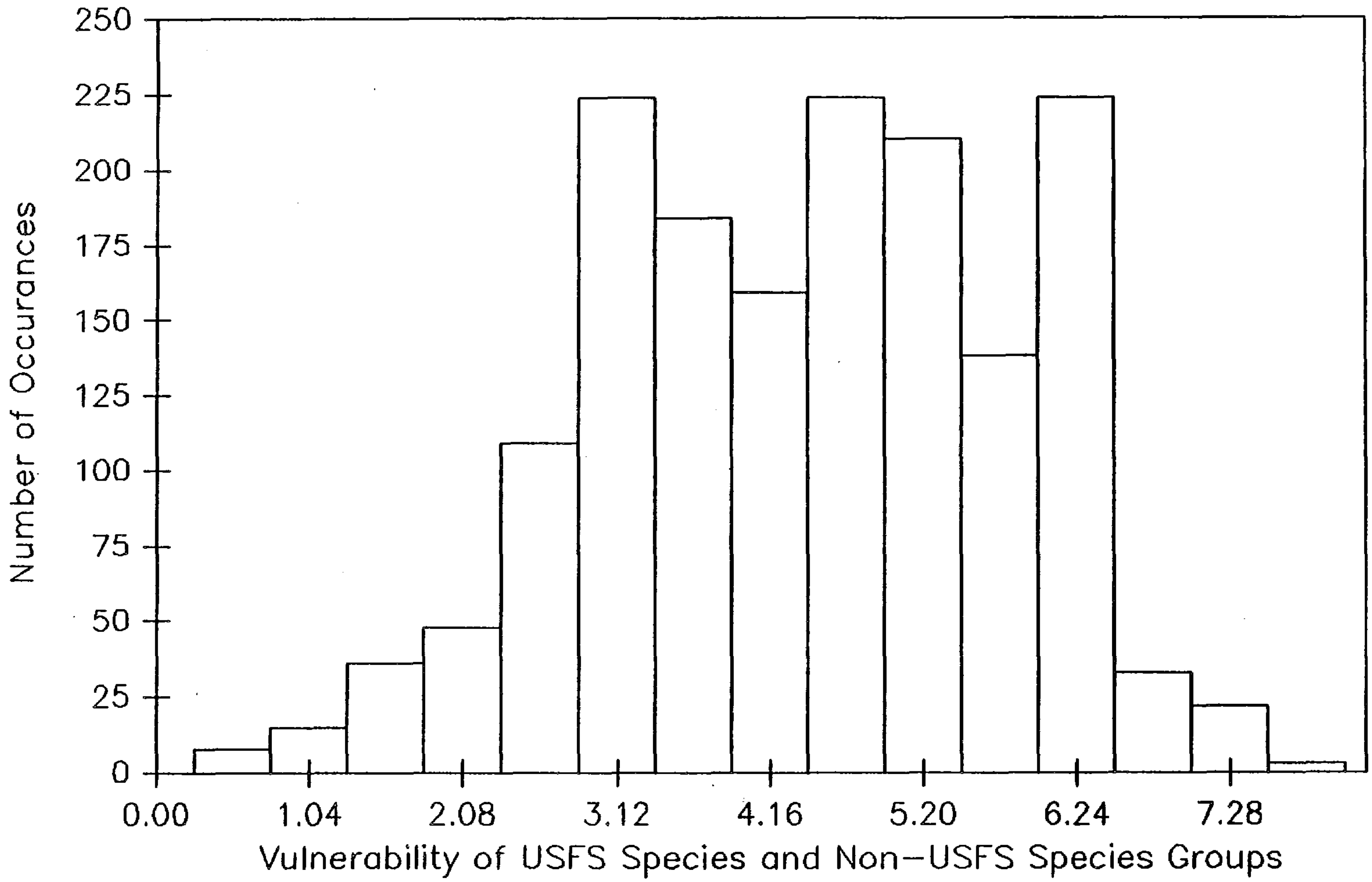

Non-USFS Species Groups Vulnerability
Number of Occurances
300
275
250
225
200
175
150
125
100
75
50
25
0
0.00
1.04
2.08
3.12
4.16
5.20
6.24
7.28
Vulnerability of Non-USFS Species Groups

Figure 4.8

USFS Species and Non–USFS Species Groups Vulnerability



Where:

a = tree species vulnerability[4]

b = species group vulnerability[5]

c = cell vulnerability measure used in risk analysis.

If a cell contained only USDA Forest Service land or contained no USDA Forest Service land, that cell's vulnerability value was based either on the tree species vulnerability score, or the species group vulnerability score. If a cell contained both USDA Forest Service and non-USDA Forest Service land, it was assigned a vulnerability score equal to the average of both the tree species and species group vulnerability scores.

4.2.4 Estimating Risks

Risks of forest injury due to ozone concentrations were calculated by combining rankings based on a cell's vulnerability score and estimated ozone exposure.

Four separate risk measures were developed:

Class 1: Highest Risk--high ozone exposure and high vulnerability;
Class 2: High Risk--currently low ozone exposure but high vulnerability;
Class 3: Low Risk--high ozone exposure but low vulnerability; and,
Class 4: Lowest Risk--low ozone exposure and low vulnerability.

To separate the vulnerability rankings into two separate classes, cells with vulnerability values found in the lower 50 percent of the distribution of cell vulnerabilities were classified as "low vulnerability" cells. Cells with vulnerability values found in the upper half of the distribution were assigned "high vulnerability" values. See Figure 4.8 for the distribution of aggregate cell vulnerability values.

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[4] Calculated for USDA Forest Service lands.

[5] Calculated for non-USDA Forest Service lands.

The threshold separating low and high ozone exposures was based on the ARB Report Effect of Ozone on Vegetation and Possible Alternative Ambient Air Quallity Standards (ARB, 1987) and the modeled 12-hour ozone concentrations shown in Figure 3.8.

The ARB report compared four different seasonal 12-hour ozone standards on the basis of their ability to protect vegetation from adverse effects due to ozone. The four concentrations ranged from a high three-month, 12-hour mean of 0.06 ppm to a low three-month, 12-hour mean of 0.04 ppm. The report concluded that the 0.06 ppm concentration "is not very protective of vegetation." (p. 273) The 0.05 ppm concentration was considered "slightly protective of vegetation...(although it was recognized that it would not) significantly protect natural vegetation such as the forest trees of the Sierra Nevada and Southern California." (p. 273) 0.045 was recognized to provide "some protection for forest trees." (p. 274)

Reference to Figure 3.8 indicates that 12-hour seasonal mean ozone concentration isopleths range from a high value of 0.09 ppm in southern California to values as low as 0.03 ppm in northwestern California. A total of 1509 cells in the data base have records for seasonal 12-hour ozone concentrations. These records range from a low of 1.58 pphm to a maximum value of 9.72. The mid-point of the distribution is 4.3 pphm. The first and third quartiles are 3.44 pphm and 4.97 pphm, respectively. 4.5 pphm had a cumulative percent of 58.3, indicating that approximately 42 percent of the cells had higher 12-hour seasonal mean ozone values. 5.0 pphm had a cumulative percent of 75.5, indicating that approximately 25 percent of the cells had higher 12-hour seasonal mean ozone values. 5.5 pphm had a cumulative percent of 84.8, with approximately 15 percent of the cells having higher ozone values.

Risk analyses were performed with three different ozone threshold values. These values are 4.5 pphm, 5.0 pphm, and 5.5 pphm 12-hour seasonal averages.[6] For example, for a threshold of 4.5 pphm, grid cells with ozone concentrations less than 4.5 pphm were classified as being exposed to "low" ozone exposures. If ozone concentrations were above 4.5 pphm, then grid cells were classified as being exposed to "high" ozone concentrations.

To illustrate this calculation, consider Figure 4.9, which represents a plot of cell vulnerability values versus seasonal 12-hour ozone concentrations. The figure is divided into four quadrants representing the four risk categories discussed above. The Y axis, ozone concentration, is bisected at 5 pphm, which is the cut point between high and low ozone exposures for this scenario. The X axis, VULC, is cut at 4.375, which is the midpoint in the distribution of aggregate vulnerabilities across the state. Risk category 1, which corresponds to the highest risk, is found in the upper right quadrant. Similarly, risk category 2, which corresponds to high risk, is found in the lower right quadrant. Risk categories 3 and 4, representing lower vulnerabilities, are found to the left of the 4.375 line on the X axis.

The four point risk ranking enables the ARB to identify those forested areas at different levels of risk due to ozone concentrations. While the data used to create these risk indices are more finely resolved than simple "high" and "low" estimates, a simple, clearly defined risk index is both more understandable and more easily justified, given uncertainties in the existing data, when used in subsequent decision-making and research planning procedures.

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[6] In future analyses, the ARB may want to select different threshold values using the 12 hour average, or use a different averaging time. The data base contains seasonal means for the 7 hour, 9 hour, 12 hour, and 24 hour averages.

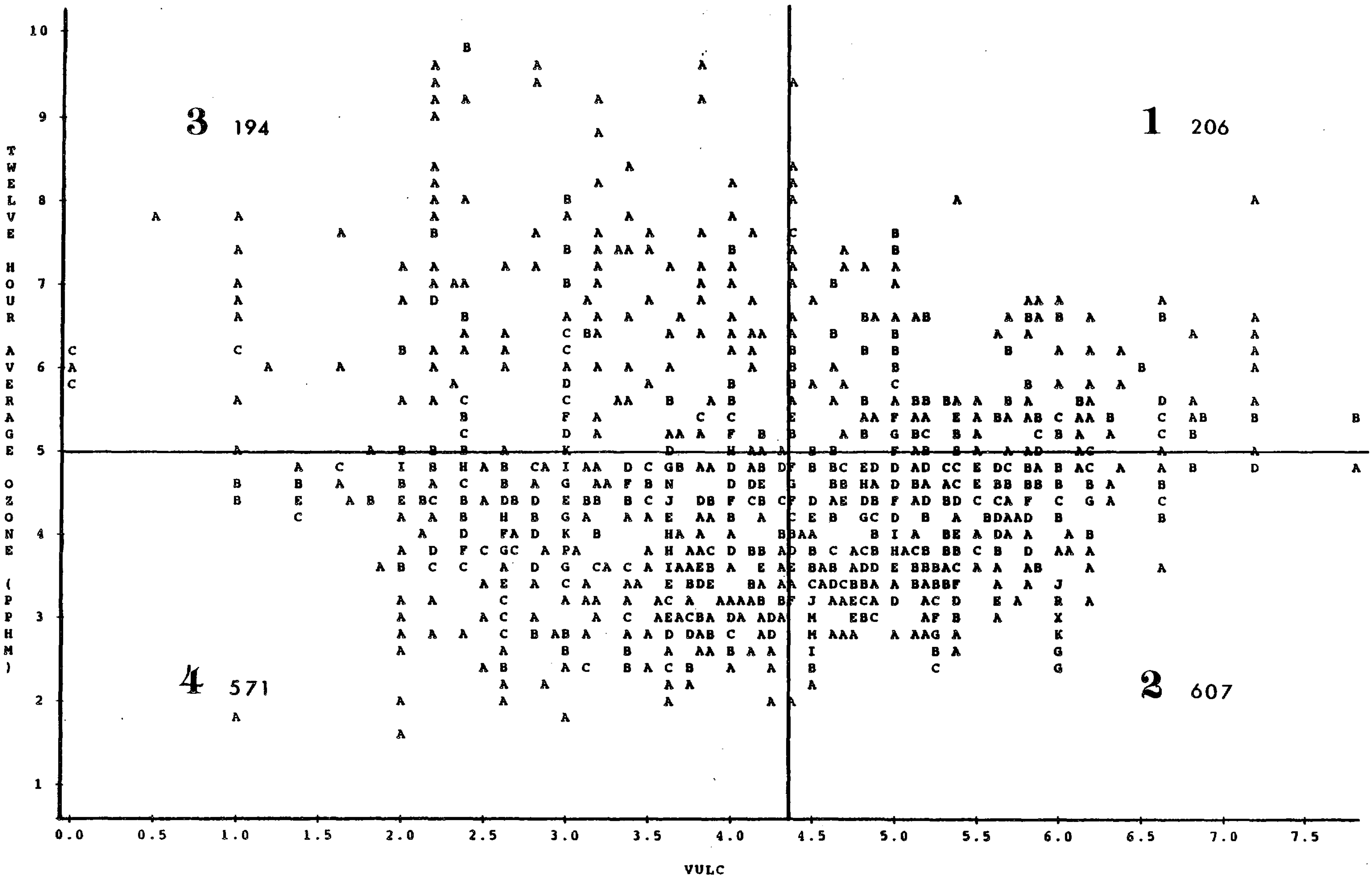

Figure 4.9

Plot of Cell Vulnerability Values versus 5.0 pphm

Seasonal 12-Hour Ozone Concentrations

4.3 RESULTS AND DISCUSSION

Results of the risk analysis are presented at five different levels:

- o state-wide;
- o ARB air basin;
- o county;
- o ownership category; and
- o National Forest.

For each of the above levels of resolution, analyses were performed at each of three ozone thresholds, 4.5 pphm, 5.0 pphm, and 5.5 pphm, expressed as 12-hour seasonal means.

4.3.1 State-wide Results

The total number of cells in the highest risk category (Category 1) ranged from 339 when the lowest ozone threshold (4.5 pphm) was used to 112 when the highest threshold (5.5 pphm) was used. These results are summarized in Table 4.2, along with summaries for the remaining risk categories and the middle, or 5.0 pphm scenario. X-Y plots for each ozone scenario are shown in Figures 4.10, 4.11, and 4.12.

In the 4.5 pphm scenario, 21.5 percent, 30.0 percent, 21.4 percent, and 27.1 percent of the forested cells were classified as highest risk, high risk, low risk, and lowest risk, respectively. Under the 5.0 pphm scenario, the percentage of cells in the highest and high risk categories remained the same, but the percentage of cells in the highest risk category declined to 13.1 percent. As expected, the percentage of cells in the low risk category declined, while the percentage of cells in the lowest risk category increased. In the 5.5 pphm scenario, the shift of cells out of the high ozone risk categories is even more emphatic, with only approximately 16 percent of the cells remaining in risk categories 1 and 3.

Table 4.2

Distribution of Risk Categories by Ozone Scenario

Ozone = 4.5 pphm

RISK	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
1	339	21.5	339	21.5
2	474	30.0	813	51.5
3	338	21.4	1,151	72.9
4	427	27.1	1,578	100.0

Ozone = 5.0 pphm

RISK	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
1	206	13.1	206	13.1
2	607	38.5	813	51.5
3	194	12.3	1,007	63.8
4	571	36.2	1,578	100.0

Ozone = 5.5 pphm

RISK	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
1	112	7.1	112	7.1
2	701	44.4	813	51.5
3	146	9.3	959	60.8
4	619	39.2	1,578	100.0

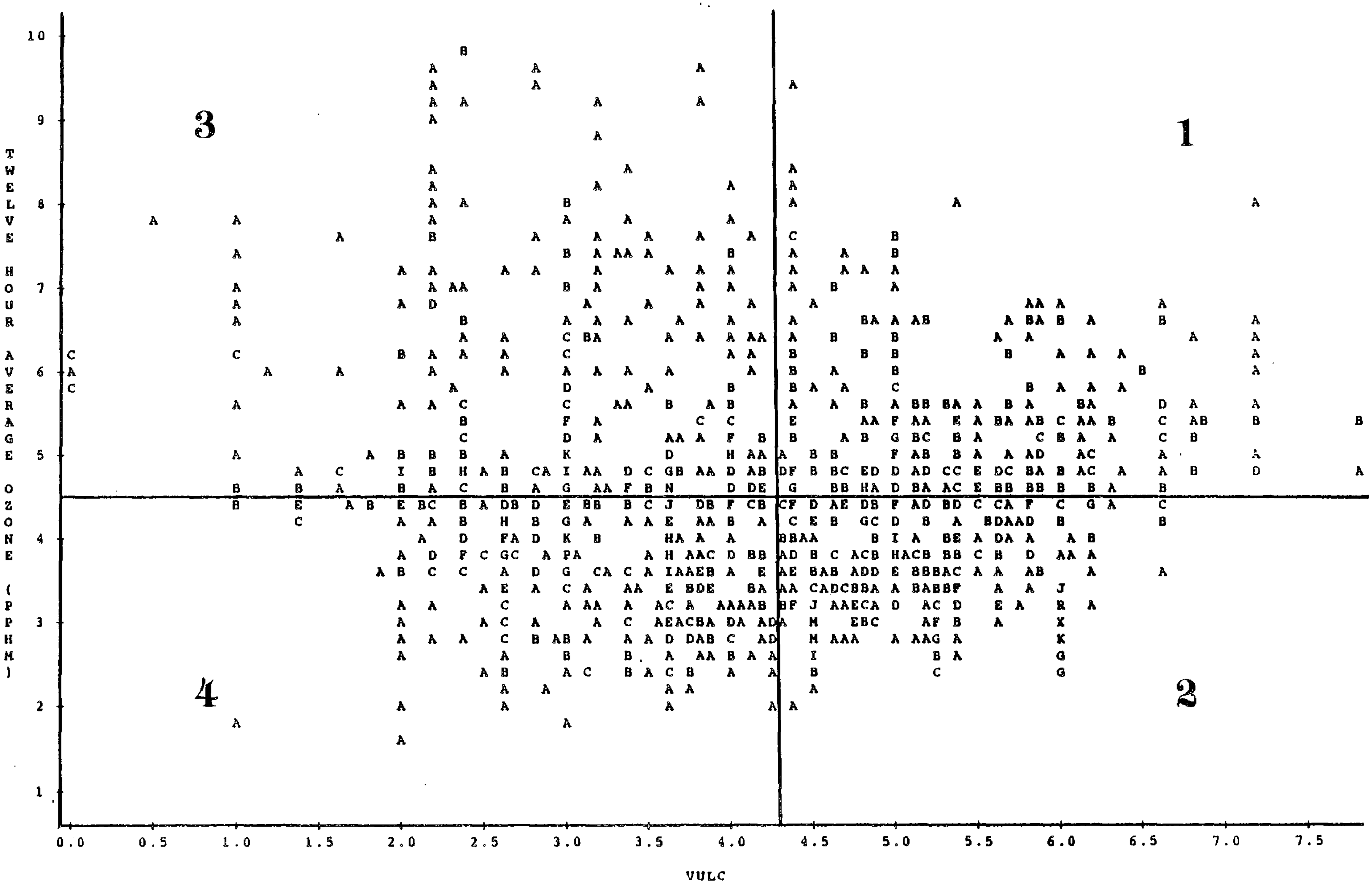

Figure 4.10

Plot of Cell Vulnerability Values versus 4.5 pphm

Seasonal 12-Hour Ozone Concentrations

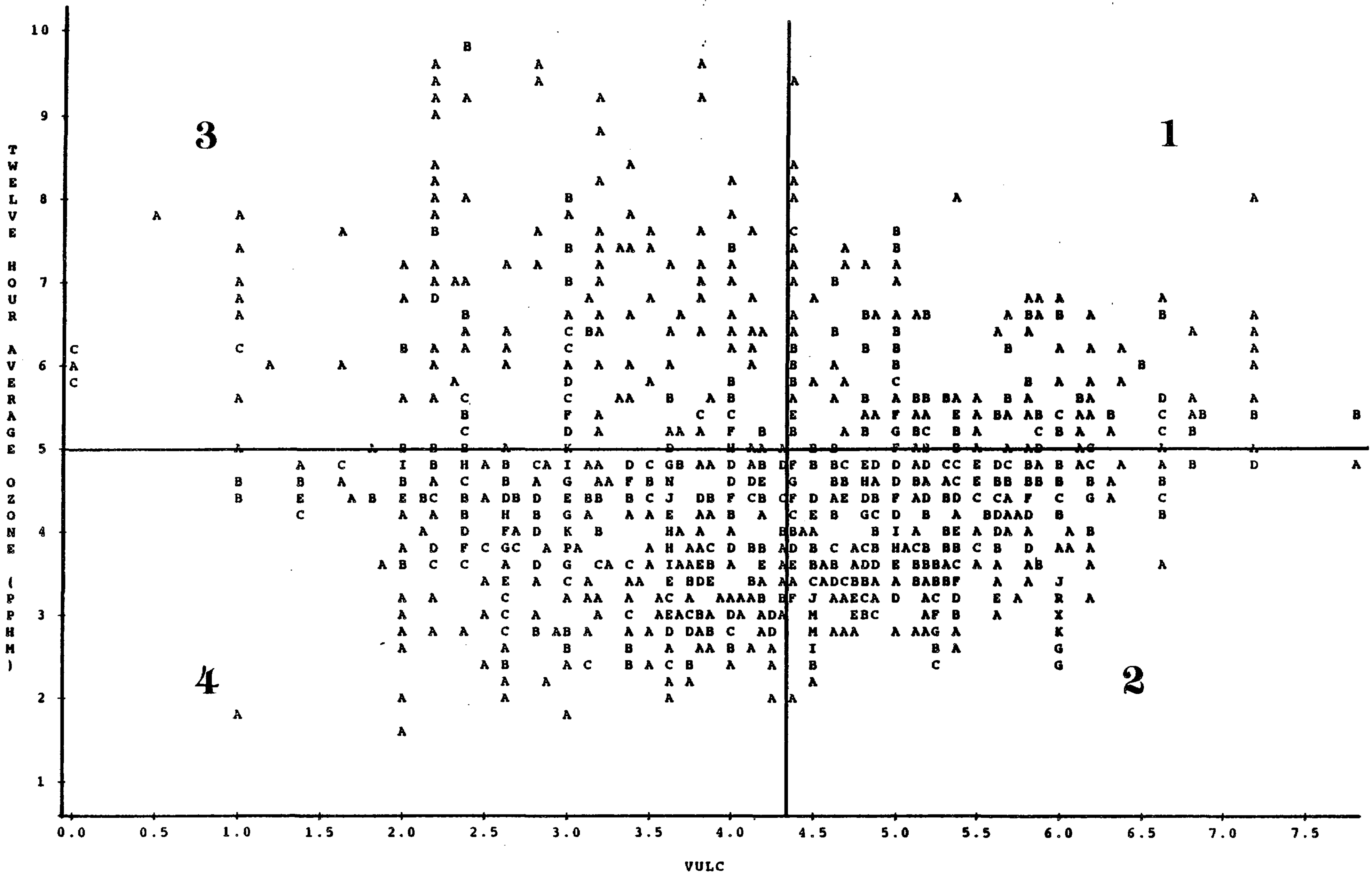

Figure 4.11

Plot of Cell Vulnerability Values versus 5.0 pphm

Seasonal 12-Hour Ozone Concentrations

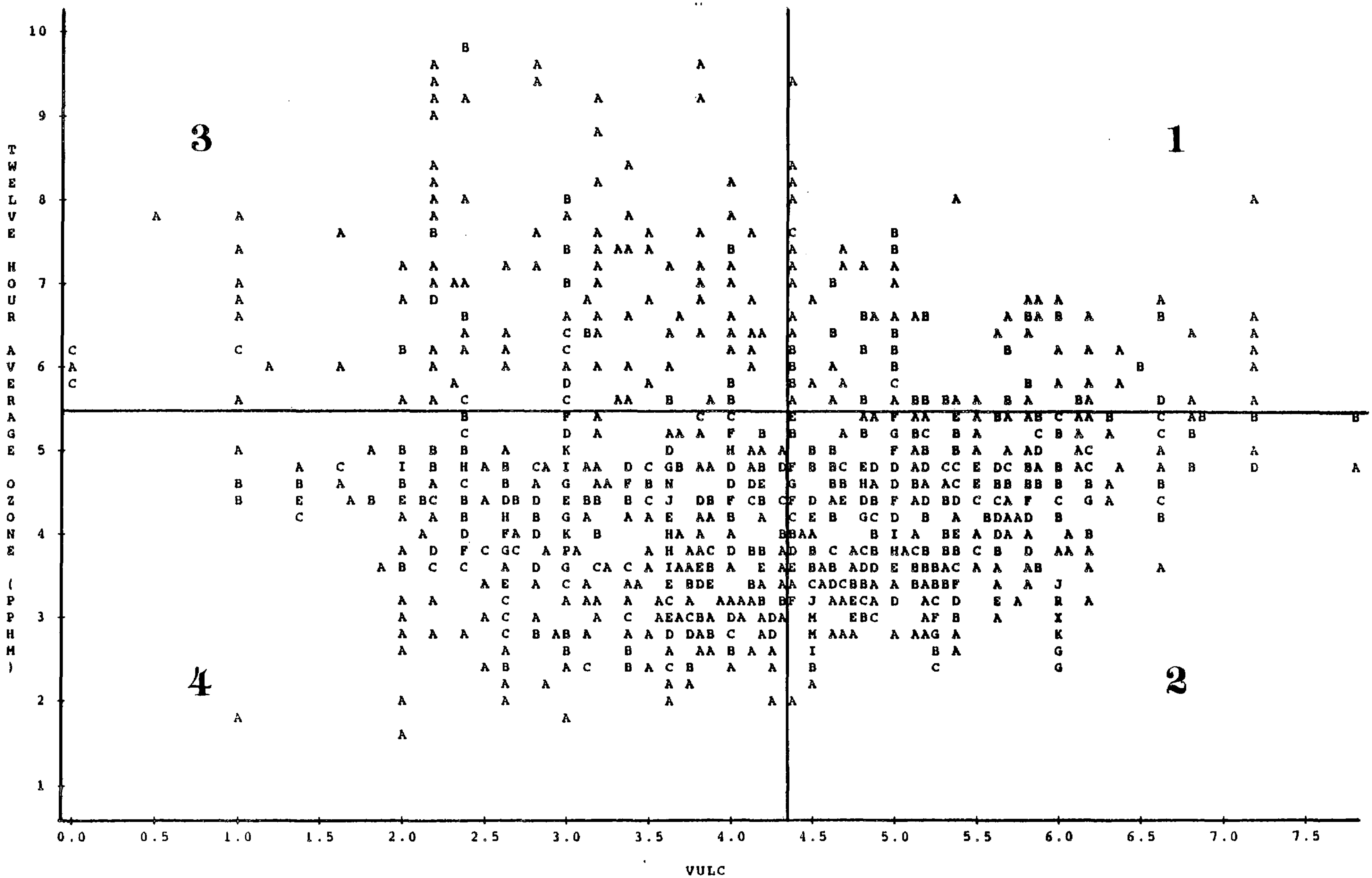

Figure 4.12

Plot of Cell Vulnerability Values versus 5.5 pphm

Seasonal 12-Hour Ozone Concentrations

Figures 4.13, 4.14, and 4.15 map the distribution of risk categories over California by grid cell for each of the three ozone scenarios. Figure 4.14 represents the statewide distribution of ozone-caused forest risk, assuming the 5.0 pphm ozone scenario. In this scenario, Northern California is generally represented as being at "high" and "lowest" risk. These categories denote lower ozone exposures, coupled with higher and lower cell vulnerability values, respectively. Numerous cells in the central and southern sierras are classified as being at "highest" risk, meaning that cells were exposed to high ozone concentrations and that they possessed high vulnerability values. Cell vulnerability is a function of species sensitivity and abundance. Forested cells in southern California are shown as being exposed to high ozone concentrations, but because of their lower productivity, they were assigned lower ranked abundance values.

As expected, the 5.5 pphm scenario (Figure 4.15) shows a smaller number of forested cells being classified in the "highest" risk category. In the 4.5 pphm scenario, Figure 4.13, the highest risk category extends further into forested cells representing northern sierras.

4.3.2 ARB Air Basin

Tables 4.3, 4.4, and 4.5 summarize the percent of forested area in the four different risk categories for each ARB Air Basin for ozone scenarios 4.5 pphm, 5.0 pphm, and 5.5 pphm, respectively. From examining Table 4.3, which represents ozone risks associated with the 4.5 pphm scenario, it can be seen that the Air Basins can be divided into two principal groups: those with high ozone exposures (risk categories 1 and 3) and those with low ozone exposures (risk categories 2 and 4). Air Basins with high ozone exposures and high vulnerability rankings exhibit a higher percentage of forested area in the highest risk category (1). Air Basins with the largest percentages of area in the highest risk category include the Mountain Counties (66.7 percent), the San Joaquin Valley (45 percent), and the Great Basin Valleys (21.3 percent) Air Basins.

Air Basins with the the large percentages of their forested area in the lowest risk category (4) include the San Fransisco Bay Area (71.9 percent), the North Central Coast (67.7 percent), and the Lake Tahoe (50.0 percent) Air Basins. Note that the San Diego Air Basin has 100 percent of its forested area in the low risk category, indicating high ozone and low vulnerability values. The South Coast, Southeast Desert, and Great Basin Valleys Air Basins also have large fractions of their forested area in the low risk category.

Ozone caused forest damage has been widely reported in parts of the South Coast and Southeast Desert Air Basins, with the majority of reported injury occuring in the San Bernardino National Forest. While the South Coast and Southeast Desert Air Basins have high ozone concentrations and a number of sensitive tree species, estimated tree species volume is considerably less per grid cell than in other Air Basins, for example, the Mountain Counties and San Joaquin Valley Air Basins. Because cells containing tree species with relatively low ranked abundance values are unlikely to be assigned high vulnerability values, careful attention should be paid to forest areas classified in risk category 3 in less productive southern California forests.

Tables 4.4 and 4.5 indicate the expected shift of forested lands out of risk categories 1 and 3, which represent high ozone exposures, and into risk categories 2 and 4. For example, comparison of the 5.5 pphm scenario with the 4.5 pphm scenario shows that the percent of forested lands in risk category 1 dropped from 66.7 percent (4.5 pphm scenario) to 8.9 percent (5.5 pphm scenario) in the Mountain Counties Air Basin. Note that the percent of forested lands in risk category 1 declined only by about 9 percent in the San Joaquin Valley Air Basin, and did not decline in the South Central Coast, South Coast, and Southeast Desert Air Basins.

4.3.3 Counties

Risk to forests in California counties are summarized in Tables 4.6, 4.7, and 4.8 for ozone scenarios of 4.5 pphm, 5.0 pphm, and 5.5 pphm, respectively. Referring to Table 4.6, we can see that forested area in the northern counties is predominantly classified as either high risk or lowest risk. The large

Figure 4.13

Statewide Distribution of Forest Risk Categories

Assuming 4.5 pphm Ozone Scenario

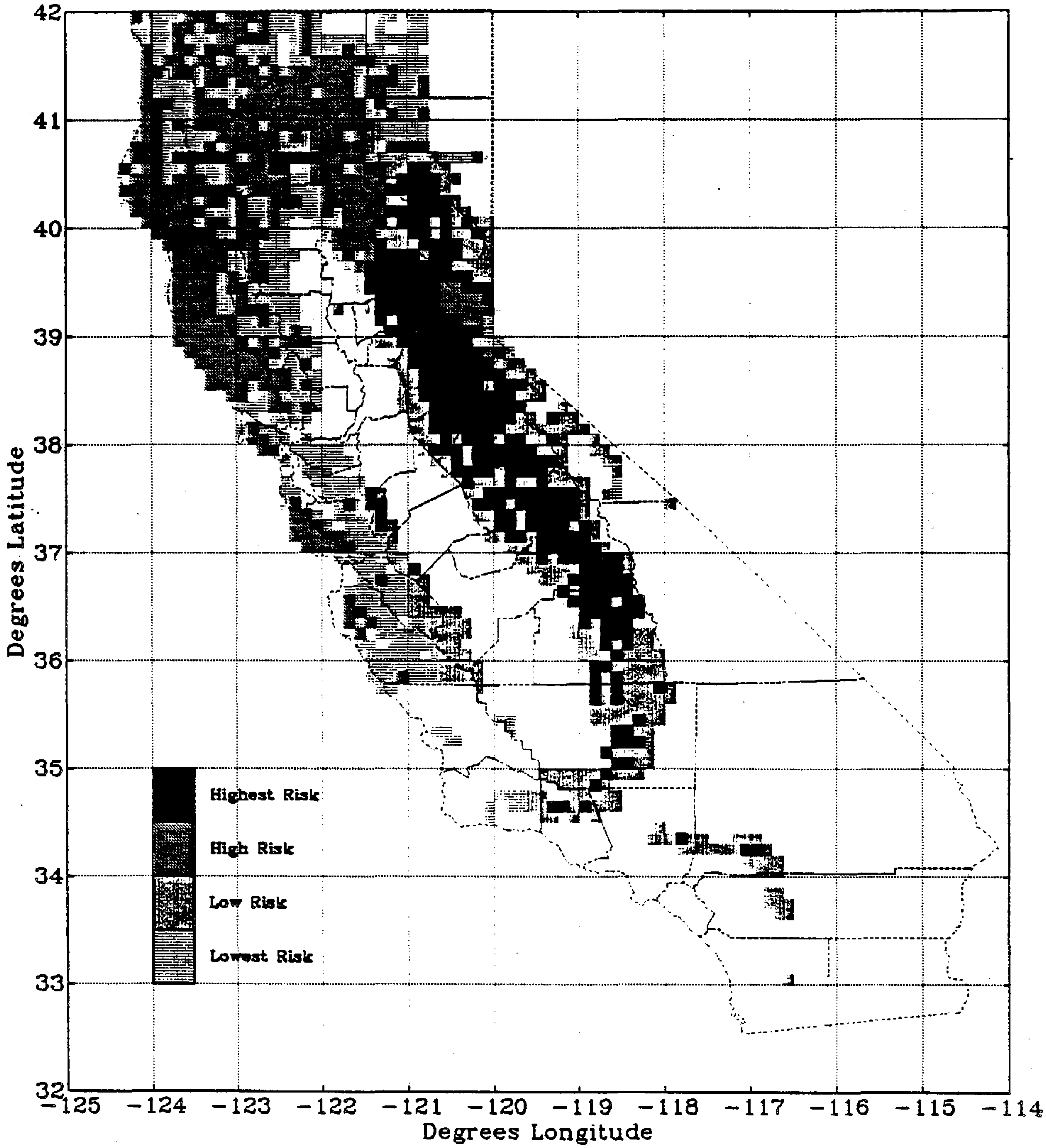

Figure 4.14

Statewide Distribution of Forest Risk Categories

Assuming 5.0 pphm Ozone Scenario

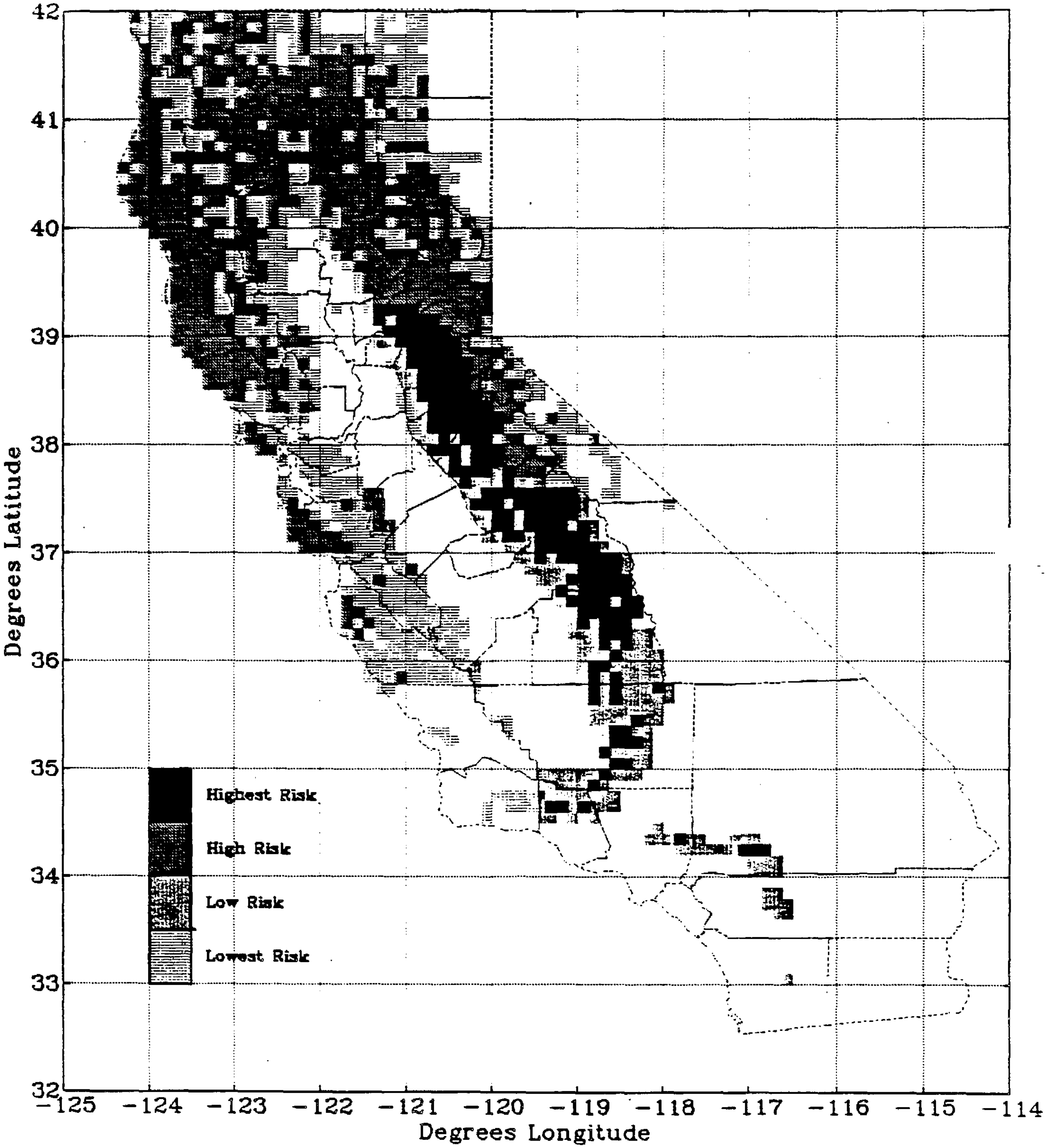

Figure 4.15

Statewide Distribution of Forest Risk Categories

Assuming 5.5 pphm Ozone Scenario

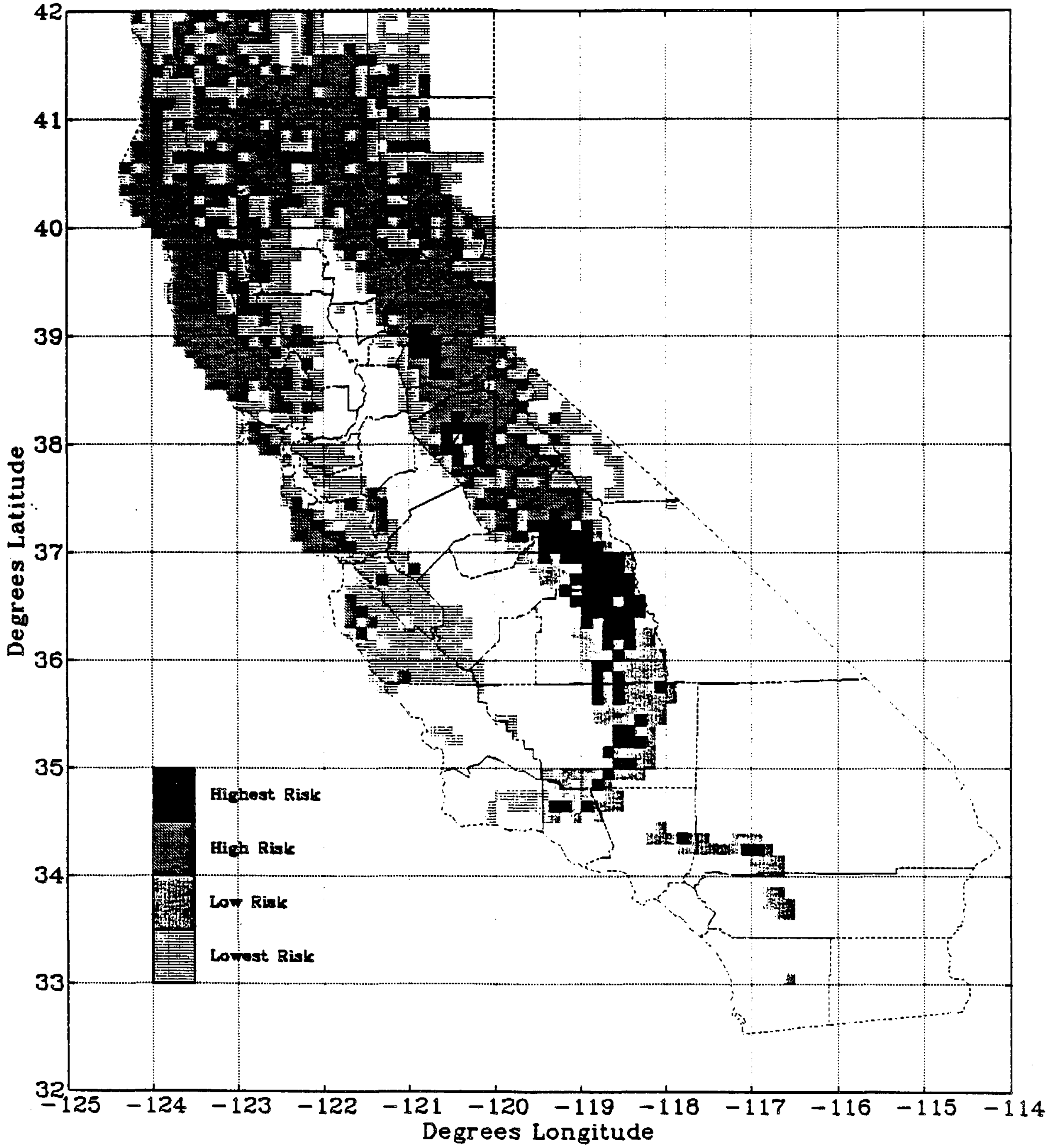

Table 4.3

Air Basin Risks for Ozone Scenario 4.5 pphm

Air Basin	Percent of Forested Area in Risk Category 1	2	3	4
North Coast	-	70.5%	-	29.5%
San Fransisco Bay Area	-	28.1%	-	71.9%
North Central Coast	-	15.6%	16.7%	67.7%
South Central Coast	9.7%	-	45.2%	45.2%
South Coast	12.0%	-	88.0%	-
San Diego	-	-	100.0%	-
Northeast Plateau	4.2%	40.7%	8.5%	46.6%
Sacremento Valley	11.8%	50.5%	6.4%	31.4%
San Joaquin Valley	45.0%	-	52.4%	2.6%
Great Basin Valleys	21.3%	2.1%	68.1%	8.5%
Southeast Desert	11.8%	-	88.2%	-
Mountain Counties	66.7%	7.0%	25.9%	0.4%
Lake County	-	60.0%	-	40.0%
Lake Tahoe	25.0%	25.0%	-	50.0%

Table 4.4

Air Basin Risks for Ozone Scenario 5.0 pphm

Air Basin	Percent of Forested Area in Risk Category 1	2	3	4
North Coast	-	70.5%	-	29.5%
San Fransisco Bay Area	-	28.1%	-	71.9%
North Central Coast	-	15.6%	-	84.4%
South Central Coast	9.7%	-	35.5%	54.8%
South Coast	12.0%	-	88.0%	-
San Diego	-	-	100.0%	-
Northeast Plateau	-	44.9%	-	55.1%
Sacremento Valley	1.0%	61.3%	0.5%	37.3%
San Joaquin Valley	42.8%	2.2%	41.9%	13.1%
Great Basin Valleys	-	23.4%	4.3%	72.3%
Southeast Desert	11.8%	-	88.2%	-
Mountain Counties	35.6%	38.1%	11.5%	14.8%
Lake County	-	60.0%	-	40.0%
Lake Tahoe	-	50.0%	-	50.0%

Table 4.5

Air Basin Risks for Ozone Scenario 5.5 pphm

Air Basin	Percent of Forested Area in Risk Category 1	2	3	4
North Coast	-	70.5%	-	29.5%
San Fransisco Bay Area	-	28.1%	-	71.9%
North Central Coast	-	15.6%	-	84.4%
South Central Coast	9.7%	-	25.8%	64.5%
South Coast	12.0%	-	88.0%	-
San Diego	-	-	100.0%	-
Northeast Plateau	-	44.9%	-	55.1%
Sacremento Valley	-	62.3%	-	37.7%
San Joaquin Valley	34.1%	10.9%	34.9%	20.1%
Great Basin Valleys	-	23.4%	2.1%	74.5%
Southeast Desert	11.8%	-	88.2%	-
Mountain Counties	8.9%	64.8%	1.5%	24.8%
Lake County	-	60.0%	-	40.0%
Lake Tahoe	-	50.0%	-	50.0%

Table 4.6

County Risks for Ozone Scenario 4.5 pphm

County	Percent of Forested Area in Risk Category			
	1	2	3	4
Northern Counties				
Butte	40.0%	42.9%	8.6%	8.6%
Colusa	-	31.6%	-	68.4%
Del Norte	-	43.8%	-	56.3%
Glenn	-	21.7%	-	78.3%
Humboldt	-	65.6%	-	34.4%
Lake	-	52.2%	-	47.8%
Lassen	22.9%	12.9%	30.0%	34.3%
Mendocino	-	81.4%	-	18.6%
Modoc	-	21.7%	-	78.3%
Nevada	77.1%	17.1%	5.7%	-
Placer	55.8%	25.6%	14.0%	4.7%
Plumas	53.2%	14.3%	31.2%	1.3%
Shasta	8.8%	68.6%	5.9%	16.7%
Sierra	65.6%	6.3%	28.1%	-
Siskiyou	-	63.2%	-	36.8%
Sutter	-	-	100.0%	-
Tehema	-	62.5%	-	37.5%
Trinity	-	76.2%	-	23.8%
Yuba	81.3%	-	18.8%	-
Central Counties				
Alameda	11.1%	5.6%	-	83.3%
Alpine	48.0%	8.0%	32.0%	12.0%
Amador	61.5%	-	38.5%	-
Calaveras	66.7%	-	33.3%	-
Contra Costa	-	-	-	100.0%
El Dorado	72.5%	3.9%	15.7%	7.8%
Fresno	45.3%	-	53.5%	1.2%
Inyo	28.6%	-	71.4%	-
Kings	-	-	100.0%	-
Madera	60.5%	-	39.5%	-
Marin	-	38.5%	-	61.5%
Mariposa	65.1%	-	34.9%	-
Merced	6.7%	-	60.0%	33.3%
Mono	10.0%	-	85.0%	5.0%
Monterey	-	9.7%	16.7%	73.6%
Napa	-	39.3%	-	60.7%
Sacramento	-	-	100.0%	-
San Benito	-	2.6%	30.8%	66.7%
San Fransisco	-	-	-	100.0%
San Joaquin	28.6%	-	42.9%	28.6%

Table 4.6 (Continued)

County Risks for Ozone Scenario 4.5 pphm

San Mateo	-	60.0%	-	40.0%
Santa Clara	2.9%	26.5%	5.9%	64.7%
Santa Cruz	-	78.6%	-	21.4%
Solano	-	16.7%	-	83.3%
Sonoma	-	69.0%	-	31.0%
Stanislaus	36.8%	-	47.4%	15.8%
Tulare	50.6%	-	49.4%	-
Tuolumne	68.1%	-	31.9%	-
Yolo	-	33.3%	-	66.7%
Southern Counties				
Imperial	-	-	-	-
Kern	22.9%	-	72.9%	4.3%
Los Angeles	11.1%	-	88.9%	-
Orange	-	-	-	-
Riverside	-	-	100.0%	-
San Bernardino	10.0%	-	90.0%	-
San Diego	-	-	100.0%	-
San Luis Obispo	-	-	20.0%	80.0%
Santa Barbara	-	-	41.7%	58.3%
Ventura	16.7%	-	83.3%	-

Table 4.7

County Risks for Ozone Scenario 5.0 pphm

County	Percent of Forested Area in Risk Category 1	2	3	4
Northern Counties				
Butte	-	82.9%	-	17.1%
Colusa	-	31.6%	-	68.4%
Del Norte	-	43.8%	-	56.3%
Glenn	-	21.7%	-	78.3%
Humboldt	-	65.6%	-	34.4%
Lake	-	52.2%	-	47.8%
Lassen	-	35.7%	-	64.3%
Mendocino	-	81.4%	-	18.6%
Modoc	-	21.7%	-	78.3%
Nevada	31.4%	62.9%	5.7%	-
Placer	34.9%	46.5%	11.6%	7.0%
Plumas	-	67.5%	-	32.5%
Shasta	-	77.5%	-	22.5%
Sierra	-	71.9%	-	28.1%
Siskiyou	-	63.2%	-	36.8%
Sutter	-	-	-	100.0%
Tehema	-	62.5%	-	37.5%
Trinity	-	76.2%	-	23.8%
Yuba	18.8%	62.5%	6.3%	12.5%
Central Counties				
Alameda	-	16.7%	-	83.3%
Alpine	-	56.0%	-	44.0%
Amador	50.0%	11.5%	11.5%	26.9%
Calaveras	63.6%	3.0%	21.2%	12.1%
Contra Costa	-	-	-	100.0%
El Dorado	52.9%	23.5%	9.8%	13.7%
Fresno	45.3%	-	29.1%	25.6%
Inyo	28.6%	-	57.1%	14.3%
Kings	-	-	20.0%	80.0%
Madera	55.8%	4.7%	25.6%	14.0%
Marin	-	38.5%	-	61.5%
Mariposa	46.5%	18.6%	30.2%	4.7%
Merced	6.7%	-	40.0%	53.3%
Mono	2.5%	7.5%	2.5%	87.5%
Monterey	-	9.7%	-	90.3%
Napa	-	39.3%	-	60.7%
Sacramento	-	-	20.0%	80.0%
San Benito	-	2.6%	-	97.4%
San Fransisco	-	-	-	100.0%
San Joaquin	28.6%	-	14.3%	57.1%

Table 4.7 (Continued)

County Risks for Ozone Scenario 5.0 pphm

San Mateo	-	60.0%	-	40.0%
Santa Clara	-	29.4%	-	70.6%
Santa Cruz	-	78.6%	-	21.4%
Solano	-	16.7%	-	83.3%
Sonoma	-	69.0%	-	31.0%
Stanislaus	15.8%	21.1%	36.8%	26.3%
Tulare	50.6%	-	49.4%	-
Tuolumne	40.6%	27.5%	13.0%	18.8%
Yolo	-	33.3%	-	66.7%
Southern Counties				
Imperial	-	-	-	-
Kern	22.9%	-	70.0%	7.1%
Los Angeles	11.1%	-	88.9%	-
Orange	-	-	-	-
Riverside	-	-	100.0%	-
San Bernardino	10.0%	-	90.0%	-
San Diego	-	-	100.0%	-
San Luis Obispo	-	-	-	100.0%
Santa Barbara	-	-	25.0%	75.0%
Ventura	16.7%	-	83.3%	-

Table 4.8

County Risks for Ozone Scenario 5.5 pphm

County	Percent of Forested Area in Risk Category 1	2	3	4
Northern Counties				
Butte	-	82.9%	-	17.1%
Colusa	-	31.6%	-	68.4%
Del Norte	-	43.8%	-	56.3%
Glenn	-	21.7%	-	78.3%
Humboldt	-	65.6%	-	34.4%
Lake	-	52.2%	-	47.8%
Lassen	-	35.7%	-	64.3%
Mendocino	-	81.4%	-	18.6%
Modoc	-	21.7%	-	78.3%
Nevada	2.9%	91.4%	-	5.7%
Placer	11.6%	69.8%	-	18.6%
Plumas	-	67.5%	-	32.5%
Shasta	-	77.5%	-	22.5%
Sierra	-	71.9%	-	28.1%
Siskiyou	-	63.2%	-	36.8%
Sutter	-	-	-	100.0%
Tehema	-	62.5%	-	37.5%
Trinity	-	76.2%	-	23.8%
Yuba	-	81.3%	-	18.8%
Central Counties				
Alameda	-	16.7%	-	83.3%
Alpine	-	56.0%	-	44.0%
Amador	-	61.5%	-	38.5%
Calaveras	18.2%	48.5%	6.1%	27.3%
Contra Costa	-	-	-	100.0%
El Dorado	17.6%	58.8%	-	23.5%
Fresno	39.5%	5.8%	20.9%	33.7%
Inyo	28.6%	-	57.1%	14.3%
Kings	-	-	-	100.0%
Madera	14.0%	46.5%	4.7%	34.9%
Marin	-	38.5%	-	61.5%
Mariposa	-	65.1%	-	34.9%
Merced	-	6.7%	-	93.3%
Mono	-	10.0%	-	90.0%
Monterey	-	9.7%	-	90.3%
Napa	-	39.3%	-	60.7%
Sacramento	-	-	-	100.0%
San Benito	-	2.6%	-	97.4%
San Fransisco	-	-	-	100.0%
San Joaquin	-	28.6%	-	71.4%

Table 4.8 (Continued)

County Risks for Ozone Scenario 5.5 pphm

San Mateo	-	60.0%	-	40.0%
Santa Clara	-	29.4%	-	70.6%
Santa Cruz	-	78.6%	-	21.4%
Solano	-	16.7%	-	83.3%
Sonoma	-	69.0%	-	31.0%
Stanislaus	-	36.8%	-	63.2%
Tulare	50.6%	-	49.4%	-
Tuolumne	14.5%	53.6%	5.8%	26.1%
Yolo	-	33.3%	-	66.7%
Southern Counties				
Imperial	-	-	-	-
Kern	22.9%	-	68.6%	8.6%
Los Angeles	11.1%	-	88.9%	-
Orange	-	-	-	-
Riverside	-	-	100.0%	-
San Bernardino	10.0%	-	90.0%	-
San Diego	-	-	100.0%	-
San Luis Obispo	-	-	-	100.0%
Santa Barbara	-	-	-	100.0%
Ventura	16.7%	-	66.7%	16.7%

percentage of high risk forest area indicates that cells comprising these counties were commonly assigned high vulnerability values.

Central California counties had the largest percentage of forested area in the highest risk category, with Fresno County having 39.5 percent and Inyo County 28.6 percent. With the exception of Fresno and Inyo Counties, very little forested area in the central counties was exposed to ozone values above 5.5 pphm. Four counties had 100 percent of their forested area classified as "lowest risk".

Southern California counties were generally assigned risk values indicating high ozone exposures in forested areas, however, San Luis Obispo and Santa Barbara Counties had 100 percent of their forested area assigned a value of "lowest risk". Forest area in southern California counties was assigned, in part, to the "low risk" category because of lower tree species and tree species group volume estimates, which results in lower cell vulnerability values.[7] Actual risks to forests in certain southern California counties are probably larger than reflected in Tables 4.8 through 4.10. Counties with large percentages of forest area within the "low risk" category (reflecting high ozone and low vulnerability) include: Kern, Los Angeles, Riverside, San Bernardino, San Diego, and Ventura. No risk estimates were performed for Imperial and Orange Counties due to the absence of forest volume estimates for these counties.

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[7] For example, forest volume in Los Angeles County was estimated as 76,774,720 cubic feet. Forest volume, by comparison, in Yuba County was estimated as 269,331,986 cubic feet.

Table 4.9

Ownership Group Risks for Ozone Scenario 4.5 pphm

Ownership Group	Percent of Forested Area in Risk Category			
	1	2	3	4
Forest Industry, Corporate Forest	14.4%	61.9%	5.8%	17.9%
Non-Industrial Forest, Other Private	16.0%	28.7%	23.8%	31.5%
Other (reserved)	-	58.3%	-	41.7%
County, City, Regional Lands	-	29.8%	4.3%	66.0%
State of California Lands	9.4%	47.7%	15.6%	27.3%
US Department of Defense Lands	17.8%	8.9%	31.1%	42.2%
USDI BIA, BR, and FWS Lands	2.6%	38.5%	20.5%	38.5%
USDI National Monuments, Seashores, Recreation Areas, and Parks	45.6%	22.4%	19.2%	12.8%
USDI BLM Lands	17.8%	25.6%	29.6%	27.0%
USDA Forest Service Lands	25.2%	28.6%	22.0%	24.3%

Table 4.10

Ownership Group Risks for Ozone Scenario 5.0 pphm

Ownership Group	Percent of Forested Area in Risk Category 1	2	3	4
Forest Industry, Corporate Forest	4.5%	71.8%	0.6%	23.1%
Non-Industrial Forest, Other Private	10.3%	34.4%	14.0%	41.4%
Other (reserved)	-	58.3%	-	41.7%
County, City, Regional Lands	-	29.8%	4.3%	66.0%
State of California Lands	5.5%	51.6%	8.6%	34.4%
US Department of Defense Lands	17.8%	8.9%	28.9%	44.4%
USDI BIA, BR, and FWS Lands	2.6%	38.5%	20.5%	38.5%
USDI National Mounuments, Seashores, Recreation Areas, and Parks	28.8%	39.2%	6.4%	25.6%
USDI BLM Lands	12.8%	30.6%	14.7%	41.9%
USDA Forest Service Lands	13.8%	39.9%	13.2%	33.0%

Table 4.11

Ownership Group Risks for Ozone Scenario 5.5 pphm

Ownership Group	Percent of Forested Area in Risk Category 1	2	3	4
Forest Industry, Corporate Forest	1.6%	74.7%	0.3%	23.4%
Non-Industrial Forest, Other Private	5.2%	39.5%	10.0%	45.4%
Other (reserved)	-	58.3%	-	41.7%
County, City, Regional Lands	-	29.8%	-	70.2%
State of California Lands	2.3%	54.7%	6.3%	36.7%
US Department of Defense Lands	11.1%	15.6%	24.4%	48.9%
USDI BIA, BR, and FWS Lands	2.6%	38.5%	17.9%	41.0%
USDI National Monuments, Seashores, Recreation Areas, and Parks	24.0%	44.0%	4.8%	27.2%
USDI BLM Lands	6.2%	37.3%	11.3%	45.3%
USDA Forest Service Lands	7.5%	46.2%	11.5%	34.8%

4.3.4 Ownership Groups

Tables 4.9, 4.10, and 4.11 summarize the percent of forested land in different risk categories by ownership groups.[8] Referring to Table 4.13, which summarizes results from the 5.5 pphm scenario, USDI National Monuments, Seashores, Recreation Areas, and Parks have the largest percentage of their area in the highest risk category (24.0 percent). With the exception of Department of Defense areas (11.1 percent), other ownership groups have relatively small percentages of their total forested area in the highest risk category. In this scenario, the majority of forested area is found in risk category 2, characterized by high vulnerability and low ozone exposures, see Forest Industry and Corporate Forest (74.7 percent), Other (reserved) (58.3), and State of California Lands (54.7 percent).

Comparing the 5.5 pphm scenario with the 4.5 pphm scenario, Table 4.11, shows that the Forest Industry, Other (reserved), and State of California Ownership Groups continue to have high percentages of their forested land within risk category 2. The USDI National Monuments, Seashores, Recreation Areas, and Parks have the highest percentage of forested area in the highest risk category (45.6 percent).

4.3.5 National Forests

Tables 4.12, 4.13, and 4.14 summarize ozone caused risks to California's National Forests. Considering the 5.5 pphm scenario, the Sierra and Sequoia

[8] Ownership groups are based on Ownership Classes contained in the data base. The forest industry and corporate forest group consists of FRRAP codes 002 and 003. The non-industrial forest and other private consists of FRRAP codes 004 and 005. Other (reserved) consists of FRRAP code 008. County, city and regional lands consist of FRRAP codes 100 and 110. State of California lands consist of all 200 FRRAP codes. Department of Defense lands consist of FRRAP codes 300 through 350. USDI Bureau of Reclamation, Bureau of Indian Affairs, and Fish and Wildlfe Service lands consist of FRRAP codes 360 through 500. USDI National Monuments, Seashores, Recreation Areas, and Parks are comprised of FRRAP codes 600 through 690. USDI Bureau of Land Management Lands consist of FRRAP codes 700 and 710. USDA Forest Service lands consist of FRAAP codes 800 through 990.

Table 4.12

National Forest Risks for Ozone Scenario 4.5 pphm

National Forest	Percent of Forested Area in Risk Category			
	1	2	3	4
Angeles National Forest	6.7%	-	93.3%	-
Cleveland National Forest	-	-	100.0%	-
Eldorado National Forest	88.1%	2.4%	4.8%	4.8%
Inyo National Forest	30.0%	-	70.0%	-
Klamath National Forest	-	68.3%	-	31.7%
Lassen National Forest	18.9%	20.0%	11.6%	49.5%
Los Padres National Forest	13.2%	-	39.5%	47.4%
Mendocino National Forest	-	54.5%	-	45.5%
Modoc National Forest	-	18.8%	-	81.3%
Plumas National Forst	75.3%	5.5%	16.4%	2.7%
San Bernardino National Forest	7.4%	-	92.6%	-
Sequoia National Forest	34.5%	-	65.5%	-
Shasta-Trinity National Forest	-	71.4%	3.0%	25.6%
Sierra National Forest	66.7%	-	33.3%	-
Six Rivers National Forest	-	33.3%	-	66.7%
Stanislaus National Forest	71.4%	-	28.6%	-
Tahoe National Forest	61.0%	18.6%	16.9%	3.4%
Toiyabe National Forest	28.6%	7.1%	50.0%	14.3%
Lake Tahoe Basin Management Unit	21.4%	35.7%	7.1%	35.7%

Table 4.13

National Forest Risks for Ozone Scenario 5.0 pphm

National Forest	Percent of Forested Area in Risk Category 1	2	3	4
Angeles National Forest	6.7%	-	93.3%	-
Cleveland National Forest	-	-	100.0%	-
Eldorado National Forest	54.8%	35.7%	-	9.5%
Inyo National Forest	30.0%	-	40.0%	30.0%
Klamath National Forest	-	68.3%	-	31.7%
Lassen National Forest	-	38.9%	-	61.1%
Los Padres National Forest	13.2%	-	34.2%	52.6%
Mendocino National Forest	-	54.5%	-	45.5%
Modoc National Forest	-	18.8%	-	81.3%
Plumas National Forst	1.4%	79.5%	-	19.2%
San Bernardino National Forest	7.4%	-	92.6%	-
Sequoia National Forest	34.5%	-	65.5%	-
Shasta-Trinity National Forest	-	71.4%	-	28.6%
Sierra National Forest	66.7%	-	27.0%	6.3%
Six Rivers National Forest	-	33.3%	-	66.7%
Stanislaus National Forest	51.8%	19.6%	16.1%	12.5%
Tahoe National Forest	5.1%	74.6%	5.1%	15.3%
Toiyabe National Forest	-	35.7%	-	64.3%
Lake Tahoe Basin Management Unit	-	57.1%	-	42.9%

Table 4.14

National Forest Risks for Ozone Scenario 5.5 pphm

National Forest	Percent of Forested Area in Risk Category 1	2	3	4
Angeles National Forest	6.7%	-	93.3%	-
Cleveland National Forest	-	-	100.0%	-
Eldorado National Forest	14.3%	76.2%	-	9.5%
Inyo National Forest	10.0%	20.0%	40.0%	30.0%
Klamath National Forest	-	68.3%	-	31.7%
Lassen National Forest	-	38.9%	-	61.1%
Los Padres National Forest	13.2%	-	26.3%	60.5%
Mendocino National Forest	-	54.5%	-	45.5%
Modoc National Forest	-	18.8%	-	81.3%
Plumas National Forst	-	80.8%	-	19.2%
San Bernardino National Forest	7.4%	-	92.6%	-
Sequoia National Forest	34.5%	-	65.5%	-
Shasta-Trinity National Forest	-	71.4%	-	28.6%
Sierra National Forest	39.7%	27.0%	11.1%	22.2%
Six Rivers National Forest	-	33.3%	-	66.7%
Stanislaus National Forest	10.7%	60.7%	8.9%	19.6%
Tahoe National Forest	-	79.7%	1.7%	18.6%
Toiyabe National Forest	-	35.7%	-	64.3%
Lake Tahoe Basin Management Unit	-	57.1%	-	42.9%

National Forests have the largest percentages of forested land in the highest risk category. Southern California National Forests, such as the Angeles and San Bernardino, have less of their forest area classified as highest risk, while the greatest percentage is classified as low risk. This is due to the differences in forest volume of the species that make up the grid cells in the Sierran National Forests and the Southern California National Forests. Note that the majority of forest area in the Southern California Forests is exposed to high ozone concentrations.

5.0 NON-MARKET BENEFITS OF FOREST PROTECTION

5.1 INTRODUCTION

Economists define value as the well-being, or utility, derived from the consumption of a good or service. Any change in the level of consumption has a value associated with it as long as someone's utility is affected. This change in utility may be viewed as either a benefit or damage depending upon whether the individual's well-being is enhanced or diminished. Goods and services that are bought and sold in the marketplace, such as timber, are easily recognized as having monetary value because individuals part with income to purchase them at market prices and forego purchasing other goods and services that could have also increased their well-being. The market price they are willing to pay for these goods represents a minimum monetary measure of value to consumers from their consumption in terms of alternative goods and services foregone.

Unlike timber, most environmental goods deriving from forest quality, such as forest ecosystem function or watershed quality are public goods. Once public goods are provided to one individual, it is difficult to exclude others from their consumption. Also, once provided to one individual, the additional cost of providing them to others is zero. For example, if forest recreational opportunities are improved for the benefit of one group of individuals, it would be hard to exclude others in the region from also sharing the benefits or to charge for the consumption of increased recreational opportunity. Consequently, public benefits of improved forest quality such as increased recreational opportunity are not exchanged on a market and do not have explicit prices. This does not mean they do not have value. People change their recreation patterns, move their residences, suffer increased risk of fire damage at the urban-wildland interface, and may face impending water shortages due to changes in forest quality in California. These non-market goods affect individuals' well-being, and consequently, have value. By analyzing how individuals react to changes in the non-market goods and services derived from forests, the value they place on forest quality may, in principle, be revealed.

There are three types of non-market values commonly addressed: activity value, option value, and existence value. Activity value (also called user value) is the value in use, eg., enjoyment of forest quality at a site when one is actually there. Option value is the value assigned to maintaining the option of enjoying a certain level of forest quality, or services derived from that quality, at a site given uncertainty about whether use of the site will be desired in the future. It is important to note that option value is a value above and beyond the activity value. Existence value is the value assigned to the existence of a certain level of forest quality, for example, ecosystem structure and function, at a site even though one does not intend to participate in activity at the site. This may be tied to the philanthropic goal of preservation so that future generations may have the option of enjoying consumption of the good, or to the belief that natural ecosystems possess qualities that are inherently valuable. Some authors also call this or related concepts "preservation value" or "bequest value".

This chapter reviews studies that have estimated non-market values associated with forest quality. Forest ecosystems provide important non-market goods to California society, including:

- watershed protection and surface water run-off;
- recreation;
- habitat preservation; and,
- ecosystem functions, such as, absorption and breakdown of pollutants, nutrient cycling, degradation of organic wastes, regulation of radiation balance and climate, and fixation of solar energy (Westman, 1977).

5.2 WATERSHED PROTECTION AND SURFACE WATER RUN-OFF

Water is California's most important and controversial resource. As population and water quality concerns increase, existing water supplies must be carefully preserved and allocated. Potential watershed degradation due to ambient ozone pollution could reduce surface water run-off and increase sediment erosion in sensitive forest areas exposed to elevated ozone concentrations.

California precipitation, on the average, equals about 193 million acre feet (MAF).[1] Vegetation evaporates and transpires approximately 119 MAF, while most of the remaining 74 MAF becomes stream runoff. Approximately 85 percent of California's average annual runoff, or about 60 MAF originates in conifer dominated or alpine watersheds. The Klamath and Eel River Basins provide almost one-third of the total runoff. With the exception of watersheds on the north coast, most conifer watersheds are administered by the USDA Forest Service. It is estimated that more than 33 MAF of water is produced on USDA Forest Service lands annually (Rector and McDonald [1987] in FRRAP [1988]). Another 7 to 9 MAF of annual runoff are derived from predominantly hardwood, shrub, and grassland watersheds. Desert, urban, and agricultural areas provide the remaining 2 to 4 MAF annual runoff.

We have located only one study relating ozone damaged forests and water quality or supply in California. Westman (1977) estimated the cost of erosion damage caused by ozone in the San Bernardino Mountains to be $27 million (1973) per year. Westman based his calculation on a USDA Forest Service estimate that 57 per cent of the trees in a 4000 hectare area in the San Bernardino National Forest were declining due to ozone caused mortality. Westman assumed that 50 percent of this area would be replaced by herbaceous successional vegetation, and that erosion would be comparable to that on a nearby hillside where native chaparral had been replaced with grasses, and that the resulting eroded sediment would be trapped equally in debris basins, sewers, and street edges. Using 1976 data for sediment removal costs from

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[1] Summary data and discussion rely on FRRAP (1988).

such structures, he estimated the annual repair cost from loss of soil binding function to be $27 million. In 1978 the San Bernardino Mountains experienced a wet year, causing creek beds to overflow. The resulting damage to houses and other structures was estimated as $5.2 million, Westman (1985).

Risks to the supply of surface water due to ozone damage in California forests may be evaluated by referring to Tables 5.1, 5.2, and 5.3 which summarize forest risk estimates by FRRAP watersheds for each of the three ozone scenarios. Table 5.1 indicates that 13 California watersheds have 50 percent or more of their area in the highest risk category. Three have 75 percent or more of their area in the highest risk category. These watersheds may be more sensitive to degradation due to ozone caused forest mortality than other, less sensitive watersheds. Tables 5.2 and 5.3 present watershed sensitivity summaries for the 0.05 ppm and 0.055 ppm ozone scenarios. Note that there is less watershed area in the highest risk category in these scenarios. For example Table 5.3 shows that only three watersheds have more than 50 percent of their area in the highest risk category. No watersheds have more than 75 percent of their area in the highest risk category.

5.3 RECREATION

Recreational use of California's forested lands amounted to approximately 120 million recreation visitor days (RVD) annually between 1981-1985.[2] One RVD represents 12 hours of participation in any activity. USDA Forest Service lands accounted for approximately 54.5 million RVDs, California State Park use accounted for approximately 43 million RVDs, National Park Service Lands

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[2] This total was derived from the Forest Data Base. See Chapter 3 for a discussion of the recreation variables and the procedures followed to calculate Recreation Visitor Days (RVDs). Note that FRRAP estimated total 1986 recreation participation on state and federal lands in California as being greater than 100 million RVDs (FRRAP, 1988).

Table 5.1

Watershed Risks for Ozone Scenario 4.5 pphm

Watershed	Percentage of Watershed in Risk Category 1	2	3	4
Ventura	-	-	100.0%	-
Santa Clara	15.8%	-	84.2%	-
Malibu	-	-	-	-
Barrett Creek	14.3%	-	85.7%	-
Santa Ana	13.3%	-	86.7%	-
San Jacinto	-	-	100.0%	-
Viego	-	-	-	-
Temecula	-	-	100.0%	-
San Luis Rey	-	-	-	-
Escondido	-	-	-	-
San Dieguitos	-	-	100.0%	-
Mirimar Res.	-	-	-	-
San Diego	-	-	100.0%	-
San Diego	-	-	-	-
Sweetwater	-	-	-	-
Dulzura	-	-	-	-
Smith	-	37.5%	-	62.5%
Redwood	-	55.6%	-	44.4%
Trinidad	-	100.0%	-	-
Mad	-	65.4%	-	34.6%
Eureka	-	90.0%	-	10.0%
Mattole	-	88.2%	-	11.8%
10 Mile River	-	90.9%	-	9.1%
Noyo River	-	81.8%	-	18.2%
Big River	-	90.9%	-	9.1%
Navarro River	-	100.0%	-	-
Garcia	-	100.0%	-	-
Garcia	-	100.0%	-	-
Gulala	-	100.0%	-	-
Bodega	-	42.9%	-	57.1%
Klamath	-	55.3%	-	44.7%
Salmon	-	66.7%	-	33.3%
Scott	-	74.1%	-	25.9%
Shasta	-	50.0%	-	50.0%
Butte	-	47.4%	-	52.6%
Lost	-	13.3%	-	86.7%
Trinity	-	72.0%	-	28.0%
Eel	-	76.8%	-	23.2%
Van Duzen	-	71.4%	-	28.6%
Russian	-	81.3%	-	18.8%
Goose Lake	-	-	-	-
Pit	1.9%	49.5%	5.7%	42.9%
Shasta Lake	-	66.7%	26.7%	6.7%
Upper Sacto	-	71.0%	-	29.0%
McCloud	-	89.7%	3.4%	6.9%
Redding	20.7%	41.4%	6.9%	31.0%

Table 5.1 (Continued)

Watershed Risks for Ozone Scenario 4.5 pphm

Cow Creek	10.0%	66.7%	6.7%	16.7%
Red Bluff	-	34.6%	-	65.4%
Eastside Creeks	-	70.6%	-	29.4%
#	-	76.9%	-	23.1%
Colusa	-	22.2%	7.4%	70.4%
Marysville	36.4%	9.1%	54.5%	-
Woodland	-	33.3%	-	66.7%
Sacremento	-	-	100.0%	-
Yolo	-	-	-	-
Cottonwood Creek	9.4%	65.6%	3.1%	21.9%
Elder Creek	-	64.3%	-	35.7%
Stony Creek	-	28.6%	-	71.4%
Clear Lake	-	51.4%	-	48.6%
Putah Creek	-	40.9%	-	59.1%
Feathr	52.0%	18.4%	27.6%	2.0%
Yuba	75.5%	14.3%	10.2%	-
Bear	87.5%	-	12.5%	-
American	72.9%	13.6%	11.9%	1.7%
Suprise Valley	-	-	-	-
Madeline Plains	-	33.3%	-	66.7%
Susanville	28.3%	6.5%	50.0%	15.2%
Truckee	37.5%	50.0%	12.5%	-
Lake Tahoe	21.4%	35.7%	7.1%	35.7%
Carson	29.4%	11.8%	41.2%	17.6%
Walker	15.0%	-	85.0%	-
Marin	-	55.6%	-	44.4%
Sonoma	-	40.0%	-	60.0%
Fairfield	-	6.7%	-	93.3%
Bay	-	33.3%	-	66.7%
Alameda	6.7%	6.7%	3.3%	83.3%
San Mateo	-	55.6%	-	44.4%
Coyote Creek	-	36.0%	4.0%	60.0%
Delta	-	-	-	-
Stockton	11.8%	-	88.2%	-
San Joaquin	30.8%	-	69.2%	-
Consumnes - Mokelumn	79.5%	-	20.5%	-
San Andreas	68.4%	-	31.6%	-
Stanislaus	78.4%	-	21.6%	-
Toulumne	61.5%	-	38.5%	-
Merced	69.4%	-	30.6%	-
Fresno	63.6%	-	36.4%	-
Upper San Joaquin	63.8%	-	36.2%	-
Westside Upland	17.6%	-	44.1%	38.2%
Tulare	8.5%	-	85.1%	6.4%
Kings	66.0%	-	34.0%	-
Kaweah	56.7%	-	43.3%	-
Tule	43.3%	-	56.7%	-
Kern	34.4%	-	65.6%	-
Westside Tulare	-	-	91.7%	8.3%
South Tulare	32.4%	-	67.6%	-
San Lorenzo	-	92.3%	-	7.7%
Castroville	-	-	-	100.0%

Table 5.1 (Continued)

Watershed Risks for Ozone Scenario 4.5 pphm

Carmel	-	62.5%	-	37.5%
Big Sur	-	20.0%	-	80.0%
San Luis Obispo	-	-	-	100.0%
#	-	-	-	100.0%
Santa Barbara	-	-	-	-
San Benito	-	9.1%	20.5%	70.5%
Salinas	-	8.0%	16.0%	76.0%
#	-	-	-	100.0%
Santa Maria	11.8%	-	47.1%	41.2%
Santa Ynez	-	-	37.5%	62.5%
Mono Lake	7.7%	-	92.3%	-
Adobe	-	-	100.0%	-
Owens	21.4%	-	64.3%	14.3%
Centinnial	-	-	-	-
Fisk Lake	-	-	100.0%	-
Deep Springs	-	-	100.0%	-
#	-	-	100.0%	-
Saline	-	-	-	-
Race Track	-	-	-	-
Panamint	-	-	-	-
Death Valley	-	-	-	-
Pahrump	-	-	-	-
Mesquite	-	-	-	-
Ivanpuh	-	-	-	-
Owels Head	-	-	-	-
Leach	-	-	-	-
Nelson	-	-	-	-
Bicycle	-	-	-	-
Goldstone	-	-	-	-
Coyote	-	-	-	-
Superior	-	-	-	-
Coso	-	-	-	-
Indian Wells	-	-	100.0%	-
Fremont	23.1%	-	76.9%	-
Searles	-	-	-	-
Cuddback	-	-	-	-
Mojave	18.2%	-	81.8%	-
Broadwell	-	-	-	-
Antelope Valley	22.2%	-	77.8%	-
Lucerne	-	-	100.0%	-
Johnson	-	-	100.0%	-
Bessemer	-	-	-	-
Lavil	-	-	-	-
Meanes	-	-	-	-
Emerson	-	-	100.0%	-
Deadman	-	-	-	-
Joshua Tree	-	-	-	-
Dale	-	-	-	-
Bristol	-	-	-	-
Cadiz	-	-	-	-
Ward	-	-	-	-
Needles	-	-	-	-

Table 5.1 (Concluded)

Watershed Risks for Ozone Scenario 4.5 pphm

Chemehuevis	-	-	-	-
Colorado	-	-	-	-
Yuma	-	-	-	-
Rice	-	-	-	-
Chuckwalla	-	-	-	-
Hayfield	-	-	-	-
Coachella	-	-	100.0%	-
Anza	-	-	100.0%	-
Imperial	-	-	-	-
Amosagilby	-	-	-	-

Table 5.2

Watershed Risks for Ozone Scenario 5.0 pphm

Watershed	Percentage of Watershed in Risk Category			
	1	2	3	4
Ventura	-	-	100.0%	-
Santa Clara	15.8%	-	84.2%	-
Malibu	-	-	-	-
Barrett Creek	14.3%	-	85.7%	-
Santa Ana	13.3%	-	86.7%	-
San Jacinto	-	-	100.0%	-
Viego	-	-	-	-
Temecula	-	-	100.0%	-
San Luis Rey	-	-	-	-
Escondido	-	-	-	-
San Dieguitos	-	-	100.0%	-
Mirimar Res.	-	-	-	-
San Diego	-	-	100.0%	-
San Diego	-	-	-	-
Sweetwater	-	-	-	-
Dulzura	-	-	-	-
Smith	-	37.5%	-	62.5%
Redwood	-	55.6%	-	44.4%
Trinidad	-	100.0%	-	-
Mad	-	65.4%	-	34.6%
Eureka	-	90.0%	-	10.0%
Mattole	-	88.2%	-	11.8%
10 Mile River	-	90.9%	-	9.1%
Noyo River	-	81.8%	-	18.2%
Big River	-	90.9%	-	9.1%
Navarro River	-	100.0%	-	-
Garcia	-	100.0%	-	-
Garcia	-	100.0%	-	-
Gulala	-	100.0%	-	-
Bodega	-	42.9%	-	57.1%
Klamath	-	55.3%	-	44.7%
Salmon	-	66.7%	-	33.3%
Scott	-	74.1%	-	25.9%
Shasta	-	50.0%	-	50.0%
Butte	-	47.4%	-	52.6%
Lost	-	13.3%	-	86.7%
Trinity	-	72.0%	-	28.0%
Eel	-	76.8%	-	23.2%
Van Duzen	-	71.4%	-	28.6%
Russian	-	81.3%	-	18.8%
Goose Lake	-	-	-	-
Pit	-	51.4%	-	48.6%
Shasta Lake	-	66.7%	-	33.3%
Upper Sacto	-	71.0%	-	29.0%
McCloud	-	89.7%	-	10.3%
Redding	-	62.1%	-	37.9%
Cow Creek	-	76.7%	-	23.3%

Table 5.2 (Continued)

Watershed Risks for Ozone Scenario 5.0 pph,

Red Bluff	-	34.6%	-	65.4%
Eastside Creeks	-	70.6%	-	29.4%
#	-	76.9%	-	23.1%
Colusa	-	22.2%	-	77.8%
Marysville	18.2%	27.3%	18.2%	36.4%
Woodland	-	33.3%	-	66.7%
Sacremento	-	-	83.3%	16.7%
Yolo	-	-	-	-
Cottonwood Creek	-	75.0%	-	25.0%
Elder Creek	-	64.3%	-	35.7%
Stony Creek	-	28.6%	-	71.4%
Clear Lake	-	51.4%	-	48.6%
Putah Creek	-	40.9%	-	59.1%
Feathr	-	70.4%	-	29.6%
Yuba	12.2%	77.6%	2.0%	8.2%
Bear	62.5%	25.0%	12.5%	-
American	45.8%	40.7%	8.5%	5.1%
Suprise Valley	-	-	-	-
Madeline Plains	-	33.3%	-	66.7%
Susanville	-	34.8%	-	65.2%
Truckee	-	87.5%	-	12.5%
Lake Tahoe	-	57.1%	-	42.9%
Carson	-	41.2%	-	58.8%
Walker	-	15.0%	-	85.0%
Marin	-	55.6%	-	44.4%
Sonoma	-	40.0%	-	60.0%
Fairfield	-	6.7%	-	93.3%
Bay	-	33.3%	-	66.7%
Alameda	-	13.3%	-	86.7%
San Mateo	-	55.6%	-	44.4%
Coyote Creek	-	36.0%	-	64.0%
Delta	-	-	-	-
Stockton	11.8%	-	41.2%	47.1%
San Joaquin	23.1%	7.7%	53.8%	15.4%
Consumnes - Mokelumn	59.1%	20.5%	11.4%	9.1%
San Andreas	68.4%	-	15.8%	15.8%
Stanislaus	56.8%	21.6%	10.8%	10.8%
Toulumne	36.5%	25.0%	15.4%	23.1%
Merced	47.2%	22.2%	22.2%	8.3%
Fresno	63.6%	-	36.4%	-
Upper San Joaquin	63.8%	-	25.5%	10.6%
Westside Upland	2.9%	14.7%	5.9%	76.5%
Tulare	8.5%	-	59.6%	31.9%
Kings	66.0%	-	34.0%	-
Kaweah	56.7%	-	43.3%	-
Tule	43.3%	-	56.7%	-
Kern	34.4%	-	65.6%	-
Westside Tulare	-	-	4.2%	95.8%

Table 5.2 (Continued)

Watershed Risks for Ozone Scenario 5.0 pphm

South Tulare	32.4%	-	64.7%	2.9%
San Lorenzo	-	92.3%	-	7.7%
Castroville	-	-	-	100.0%
Carmel	-	62.5%	-	37.5%
Big Sur	-	20.0%	-	80.0%
San Luis Obispo	-	-	-	100.0%
#	-	-	-	100.0%
Santa Barbara	-	-	-	-
San Benito	-	9.1%	-	90.9%
Salinas	-	8.0%	-	92.0%
#	-	-	-	100.0%
Santa Maria	11.8%	-	29.4%	58.8%
Santa Ynez	-	-	25.0%	75.0%
Mono Lake	-	7.7%	7.7%	84.6%
Adobe	-	-	16.7%	83.3%
Owens	21.4%	-	21.4%	57.1%
Centinnial	-	-	-	-
Fisk Lake	-	-	-	100.0%
Deep Springs	-	-	-	100.0%
#	-	-	-	100.0%
Saline	-	-	-	-
Race Track	-	-	-	-
Panamint	-	-	-	-
Death Valley	-	-	-	-
Pahrump	-	-	-	-
Mesquite	-	-	-	-
Ivanpuh	-	-	-	-
Owels Head	-	-	-	-
Leach	-	-	-	-
Nelson	-	-	-	-
Bicycle	-	-	-	-
Goldstone	-	-	-	-
Coyote	-	-	-	-
Superior	-	-	-	-
Coso	-	-	-	-
Indian Wells	-	-	100.0%	-
Fremont	23.1%	-	76.9%	-
Searles	-	-	-	-
Cuddback	-	-	-	-
Mojave	18.2%	-	81.8%	-
Broadwell	-	-	-	-
Antelope Valley	22.2%	-	77.8%	-
Lucerne	-	-	100.0%	-
Johnson	-	-	100.0%	-
Bessemer	-	-	-	-
Lavil	-	-	-	-
Meanes	-	-	-	-
Emerson	-	-	100.0%	-
Deadman	-	-	-	-

Table 5.2 (concluded)

Watershed Risks for Ozone Scenario 5.0 pphm

Joshua Tree	-	-	-	-
Dale	-	-	-	-
Bristol	-	-	-	-
Cadiz	-	-	-	-
Ward	-	-	-	-
Needles	-	-	-	-
Chemehuevis	-	-	-	-
Colorado	-	-	-	-
Yuma	-	-	-	-
Rice	-	-	-	-
Chuckwalla	-	-	-	-
Hayfield	-	-	-	-
Coachella	-	-	100.0%	-
Anza	-	-	100.0%	-
Imperial	-	-	-	-
Amosagilby	-	-	-	-

Table 5.3

Watershed Risks for Ozone Scenario 5.5 pphm

Watershed	Percentage of Watershed in Risk Category			
	1	2	3	4
Ventura	-	-	50.0%	50.0%
Santa Clara	15.8%	-	73.7%	10.5%
Malibu	-	-	-	-
Barrett Creek	14.3%	-	85.7%	-
Santa Ana	13.3%	-	86.7%	-
San Jacinto	-	-	100.0%	-
Viego	-	-	-	-
Temecula	-	-	100.0%	-
San Luis Rey	-	-	-	-
Escondido	-	-	-	-
San Dieguitos	-	-	100.0%	-
Mirimar Res.	-	-	-	-
San Diego	-	-	100.0%	-
San Diego	-	-	-	-
Sweetwater	-	-	-	-
Dulzura	-	-	-	-
Smith	-	37.5%	-	62.5%
Redwood	-	55.6%	-	44.4%
Trinidad	-	100.0%	-	-
Mad	-	65.4%	-	34.6%
Eureka	-	90.0%	-	10.0%
Mattole	-	88.2%	-	11.8%
10 Mile River	-	90.9%	-	9.1%
Noyo River	-	81.8%	-	18.2%
Big River	-	90.9%	-	9.1%
Navarro River	-	100.0%	-	-
Garcia	-	100.0%	-	-
Garcia	-	100.0%	-	-
Gulala	-	100.0%	-	-
Bodega	-	42.9%	-	57.1%
Klamath	-	55.3%	-	44.7%
Salmon	-	66.7%	-	33.3%
Scott	-	74.1%	-	25.9%
Shasta	-	50.0%	-	50.0%
Butte	-	47.4%	-	52.6%
Lost	-	13.3%	-	86.7%
Trinity	-	72.0%	-	28.0%
Eel	-	76.8%	-	23.2%
Van Duzen	-	71.4%	-	28.6%
Russian	-	81.3%	-	18.8%
Goose Lake	-	-	-	-
Pit	-	51.4%	-	48.6%
Shasta Lake	-	66.7%	-	33.3%
Upper Sacto	-	71.0%	-	29.0%
McCloud	-	89.7%	-	10.3%
Redding	-	62.1%	-	37.9%
Cow Creek	-	76.7%	-	23.3%

Table 5.3 (Continued)

Watershed Risks for Ozone Scenario 5.5 pphm

Red Bluff	-	34.6%	-	65.4%
Eastside Creeks	-	70.6%	-	29.4%
#	-	76.9%	-	23.1%
Colusa	-	22.2%	-	77.8%
Marysville	-	45.5%	-	54.5%
Woodland	-	33.3%	-	66.7%
Sacremento	-	-	-	100.0%
Yolo	-	-	-	-
Cottonwood Creek	-	75.0%	-	25.0%
Elder Creek	-	64.3%	-	35.7%
Stony Creek	-	28.6%	-	71.4%
Clear Lake	-	51.4%	-	48.6%
Putah Creek	-	40.9%	-	59.1%
Feathr	-	70.4%	-	29.6%
Yuba	-	89.8%	-	10.2%
Bear	6.3%	81.3%	-	12.5%
American	16.9%	69.5%	-	13.6%
Suprise Valley	-	-	-	-
Madeline Plains	-	33.3%	-	66.7%
Susanville	-	34.8%	-	65.2%
Truckee	-	87.5%	-	12.5%
Lake Tahoe	-	57.1%	-	42.9%
Carson	-	41.2%	-	58.8%
Walker	-	15.0%	-	85.0%
Marin	-	55.6%	-	44.4%
Sonoma	-	40.0%	-	60.0%
Fairfield	-	6.7%	-	93.3%
Bay	-	33.3%	-	66.7%
Alameda	-	13.3%	-	86.7%
San Mateo	-	55.6%	-	44.4%
Coyote Creek	-	36.0%	-	64.0%
Delta	-	-	-	-
Stockton	5.9%	5.9%	5.9%	82.4%
San Joaquin	-	30.8%	-	69.2%
Consumnes - Mokelumn	6.8%	72.7%	-	20.5%
San Andreas	26.3%	42.1%	-	31.6%
Stanislaus	27.0%	51.4%	5.4%	16.2%
Toulumne	11.5%	50.0%	7.7%	30.8%
Merced	-	69.4%	-	30.6%
Fresno	4.5%	59.1%	-	36.4%
Upper San Joaquin	34.0%	29.8%	12.8%	23.4%
Westside Upland	-	17.6%	-	82.4%
Tulare	8.5%	-	51.1%	40.4%
Kings	66.0%	-	30.0%	4.0%
Kaweah	56.7%	-	43.3%	-
Tule	43.3%	-	56.7%	-
Kern	34.4%	-	65.6%	-
Westside Tulare	-	-	-	100.0%

Table 5.3 (Continued)

Watershed Risks for Ozone Scenario 5.5 pphm

South Tulare	32.4%	-	61.8%	5.9%
San Lorenzo	-	92.3%	-	7.7%
Castroville	-	-	-	100.0%
Carmel	-	62.5%	-	37.5%
Big Sur	-	20.0%	-	80.0%
San Luis Obispo	-	-	-	100.0%
#	-	-	-	100.0%
Santa Barbara	-	-	-	-
San Benito	-	9.1%	-	90.9%
Salinas	-	8.0%	-	92.0%
#	-	-	-	100.0%
Santa Maria	11.8%	-	17.6%	70.6%
Santa Ynez	-	-	-	100.0%
Mono Lake	-	7.7%	-	92.3%
Adobe	-	-	-	100.0%
Owens	14.3%	7.1%	21.4%	57.1%
Centinnial	-	-	-	-
Fisk Lake	-	-	-	100.0%
Deep Springs	-	-	-	100.0%
#	-	-	-	100.0%
Saline	-	-	-	-
Race Track	-	-	-	-
Panamint	-	-	-	-
Death Valley	-	-	-	-
Pahrump	-	-	-	-
Mesquite	-	-	-	-
Ivanpuh	-	-	-	-
Owels Head	-	-	-	-
Leach	-	-	-	-
Nelson	-	-	-	-
Bicycle	-	-	-	-
Goldstone	-	-	-	-
Coyote	-	-	-	-
Superior	-	-	-	-
Coso	-	-	-	-
Indian Wells	-	-	100.0%	-
Fremont	23.1%	-	76.9%	-
Searles	-	-	-	-
Cuddback	-	-	-	-
Mojave	18.2%	-	81.8%	-
Broadwell	-	-	-	-
Antelope Valley	22.2%	-	77.8%	-
Lucerne	-	-	100.0%	-
Johnson	-	-	100.0%	-
Bessemer	-	-	-	-
Lavil	-	-	-	-
Meanes	-	-	-	-
Emerson	-	-	100.0%	-
Deadman	-	-	-	-

Table 5.3 (Concluded)

Watershed Risks for Ozone Scenario 5.5 pphm

Joshua Tree	-	-	-	-
Dale	-	-	-	-
Bristol	-	-	-	-
Cadiz	-	-	-	-
Ward	-	-	-	-
Needles	-	-	-	-
Chemehuevis	-	-	-	-
Colorado	-	-	-	-
Yuma	-	-	-	-
Rice	-	-	-	-
Chuckwalla	-	-	-	-
Hayfield	-	-	-	-
Coachella	-	-	100.0%	-
Anza	-	-	100.0%	-
Imperial	-	-	-	-
Amosagilby	-	-	-	-

approximately 17.4 million RVDs, and Bureau of Land Management recreation approximately 3.1 million RVDs.[3]

Recreational use in the southern California forests administered by the San Bernardino, Angeles, Los Padres, and Cleveland National Forests accounts for approximately 22 million RVDs, more than one-third of the national forest recreation in California. These forests, but particularly the San Bernardino and the Angeles National Forests, are exposed to elevated ozone concentrations throughout much of the year. Ozone damage to ponderosa and Jeffrey pine has also been reported in Sequoia and Yosemite National Parks. Forest damage due to elevated ozone exposures in the San Bernardino and other southern California forests was reviewed in Chapter 2.

There are few economic studies addressing the issue of valuing changes in recreation participation and visual forest aesthetics due to ozone caused forest damage. The most directly applicable efforts were by Peterson, et al. (1987) and Crocker and Vaux (1983) which examined ozone damage to ponderosa and Jeffrey pine in the San Bernardino and Angeles National Forests. An ongoing effort by Brown, et al. (1988) is attempting to link scenic beauty measurement and economic values for changes in many aesthetic forest attributes. Walsh and Olienyk (1981) conducted a Contingent Valuation Method (CVM) study of recreator values in forested areas in Colorado affected by mountain pine beetle. Loomis and Young (1987) also conducted a CVM study of recreator participation and values in different forest environments.

Each of these studies identifies research issues in conjunction with a forest aesthetic/recreation valuation study and provides information about the order of magnitude of values that might be associated with ozone caused aesthetic forest damages.

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[3] The FRRAP (1988) report estimates that California State Parks accounted for approximately 15.3 million RVDs in 1986. This number is 28.1 million RVDs less than the recreation participation estimate included in the Forest Data Base. There is much closer agreement between the Forest Data Base and FRRAP (1988) recreation participation estimates for other jurisdictions in California.

5.3.1 Peterson, et al.

Peterson, et al. (1987) used property value and CVM studies to estimate economic measures of visual ozone damage to ponderosa and Jeffrey pine forests in the San Bernardino and Angeles National Forests. The analyses relied on property characteristic data, two mail surveys, and estimates of ozone caused forest damage in different regions within the Angeles and San Bernardino National Forests.

Two mail surveys were conducted to provide data for the property value and CVM analyses. A recreator survey, to support the CVM analysis, was mailed to 1200 addresses randomly selected in Los Angeles, Orange, and San Bernardino Counties. A property value survey, to support the property value analysis, was mailed to 800 addresses from within the boundaries of the Angeles and San Bernardino National Forests. Reported response rates were 49.5 percent for the recreators survey and 52.1 percent for the property owners survey.

5.3.1.1 Recreator Survey

The recreator survey consisted of 33 questions, and was supplemented by a forest quality ladder that represented a range of tree and stand health and ozone damage. Apparently healthy trees and stands were rated as 5, apparently stressed or damaged trees were ranked as low as 1. The photographs were provided by Dr. Paul Miller of the USDA Forest Service, and represented a range of Jeffrey and ponderosa pine tree and stand conditions in the San Bernardino and Angeles National Forests.

The first question in the recreation survey asked respondents to rate the tree quality of the six photos enclosed in the color supplement (forest quality ladder). Results were compared to the responses from a pretest group to determine if there was consistency in forest quality perception. There was general agreement between the respondents and pretest participants regarding photographs representing better tree quality; however, variation appeared between the recreator respondents and the pretest group with the remaining photos.

Question 2 asked respondents if they were aware of certain factors affecting the quality of the forest. Over 50 percent had seen, read, or heard about insects, disease, and drought, while over 90 percent were aware that fires and air pollution were factors affecting forest quality.

Question 3 asked respondents if they had ever visited the San Bernardino and Angeles National Forests. Ninety percent responded positively. Question 4 asked respondents what types of injury affect their enjoyment in the Angeles and San Bernardino National Forests. People were most adversely affected by dead or dying stands of trees, with 85 percent responding enjoyment was decreased greatly. Thin stands of trees and trees with discolored needles also decreased enjoyment, but to a lesser degree. This was followed by a moderate decrease in enjoyment from tree stumps and branches with fewer needles.

Questions 5 through 8 were designed to extract information about frequency of visitation to the forests. Respondents made an average of 3 trips per year to the Forests. Over 50 percent of the people made their trips on a weekend, accompanied by an average of 3.26 people.

Questions 9 and 10 centered on where the respondents travelled during their most recent visits to the San Bernardino and Angeles National Forests. Question 11 asked respondents to rate the forest quality in these regions.

Question 12 asked respondents how they allocated their time during their last trip. The average respondent spent 15.39 hours driving, 22 hours recreating or participating in outdoor activities, and 19 hours at indoor activities or lodging. The average trip was about 2 days.

Question 13 asked recreators who stopped in the mixed conifer forests to reveal details about the location, duration and activities during their stop. Questions 14 and 15 asked respondents which recreational activities they participated in while in the National Forests. The majority, 73.5 percent replied that sightseeing while driving was their primary activity, followed by hiking (42 percent) and shopping/dining (35.1 percent).

Question 16 was a three part question for respondents who had stayed overnight within the forests. From a sample size of 98, the majority spent 2 nights in the forests (46.9 percent) in varying kinds of lodging. Fifty percent spent under $20.000 on lodging.

Question 21 asked how a one step decrease in tree quality would affect a respondent's visitation to the Angeles and/or San Bernardino National Forests. Over 50 percent replied they would make the same number of trips but that their enjoyment would be less. The 23.3 percent who responded that they would make fewer trips to the forests would reduce their visitation by around 30 percent, stating they would compensate by taking similar trips to other forests/parklands.

Questions 22 through 24 presented the respondent with a situation in which the tree quality in 1) the Angeles and San Bernardino National Forests (question 22), 2) all California parks and forests (question 23) and 3) all forests of the United States (question 24) decrease by one step on the forest quality ladder. Respondents were asked to indicate how much they would be willing to pay for management efforts to offset this decrease. Recreators were willing to pay an average of $49.07 a year to offset a decrease in forest quality in the Angeles and San Bernardino National Forests, with more than 50 percent attributing existence value as the main reason for doing so. In addition to the money people were willing to pay in question 22, recreators would pay an additional $41.34 each year to prevent the quality of trees from declining in all California parks and forests. Respondents would also pay an additional average of $38.70 each year to preserve the quality of all forests in the United States.

5.3.1.2 Property Value Survey

The property value survey was very similar to the Recreator Survey, but consisted of 47 questions. It was also supplemented by a forest quality ladder identical to the one used in the Recreator Survey.

The first question of the survey asked respondents to rate the tree quality of the six photos enclosed in the color supplement. The results were compared to the responses from a pretest group to determine if there was consistency in forest quality perception.

Question 2 asked respondents if they were aware of certain factors affecting the quality of the forest. Over 85 percent of respondents had seen, read or heard about insects, fires, air pollution and disease, while 66.1 percent were aware of drought.

Question 3 asked respondents what type of injury affects their enjoyment in the Angeles and San Bernardino National Forests. People were most adversely affected by dead or dying stands of trees, with 86.3 percent responding enjoyment was decreased greatly. Trees with discolored needles decreased enjoyment greatly for 57.2 percent of the respondents. This was followed by branches with fewer needles, thin stands of trees, and tree stumps, consecutively.

Questions 4 through 7 were designed to locate, as precisely as possible, the respondents residence. Question 8 obtained the respondents perception of the quality of trees on their property. Over half of the respondents felt the trees in their neighborhood were better than average in quality.

Questions 9 through 17 and question 19 asked respondents for a variety of information about the size and type of residence they own. These questions were used to help form a profile of the mountain communities for the property value analysis.

In question 20, respondents were asked to rate the quality of various factors that contribute to their enjoyment of their mountain residence. Property owners rated views of mountains and peaks as the most important attribute of their residence, with 64.1 percent replying that it was excellent. Other important factors include lakes, streams and reservoirs; quality of schools; and access to restaurants, stores and services, respectively.

Mountain homes were the primary residence for 95.1 percent of respondents in question 21. Questions 22 through 25 were designed to extract information about frequency of visitation to second homes in the forests. From a sample size of 10, respondents made an average of 27.8 trips to their residence in the last year. Seventy percent made their trip on a weekend, accompanied by 2.3 people.

Question 26 asked second homeowners how they allocated their time on their most recent trip. Half of the respondents spent over 3 hours driving and 3 hours recreating or doing other outdoor activities, and 10 hours at indoor activities or lodging. The average trip was 2 days long.

Question 31 asked respondents how a one step decrease on the forest quality ladder would change the number of trips that they would make to their second home in the Angeles and San Bernardino National Forests. Eighty percent replied they would make the same number of trips, but that their enjoyment would be less. Question 32 asked respondents where their non-mountain resident is located.

Questions 35 through 38 presented the respondent with a situation in which the tree quality in 1) the neighborhood of their residence (question 35) 2) the Angeles and San Bernardino National Forests (question 36) 3) all California parks and forests (question 37) and 4) all forests of the United States (question 38) decrease by one step on the forest quality ladder. The respondents were asked to indicate how much they would be willing to pay for management efforts to offset this decrease. Property owners were willing to pay an average of $99.03 each year to offset the decrease of forest quality in the Angeles and San Bernardino National Forests, with the majority attributing existence value as the main reason for doing so. In addition to the money people were willing to pay in question 35, property owners would pay an additional $75.07 a year to prevent the quality of trees from declining in all California parks and forests. Respondents would also pay an average of $51.15 a year in addition to the previous amounts to preserve the quality of all forests in the United States.

Questions 39 through 47 gathered socio-demographic information about the respondents and their families.

5.3.1.3 Contingent Valuation Method Results

Table 5.4 provides summary statistics of CVM bids obtained in the recreator survey. Respondents' willingness to pay to avoid a 1-step reduction in forest quality for 1) the Angeles and San Bernardino National Forests 2) all California forests and 3) all U.S. forests are shown. All three of these bid categories are incremental. The table shows means for all bids, means of positive bids and the percentage of respondents who bid $0. The strong effect that zero bids have on the overall mean is evident by the $10 to $13 dollar increase in the mean when zero bids are excluded. About one quarter of the respondents chose to bid $0.

Summary statistics for the property owners survey are presented in Table 5.5. Respondents willingness to pay to avoid a 1-step reduction in forest quality for 1) areas around their residence, 2) the entire Angeles and San Bernardino National Forests, 3) all California forests and 4) all U.S. forests are shown. Again, all bids are incremental. Mean bids, means of positive bids and the percentage of $0 responses are indicated. Like the recreator survey data in Table 5.4, the large number of zero bids has a strong effect on the mean bids presented in this table. Zero bids account for 29.4 percent to 44.9 percent of the total bids in each of the willingness to pay categories. When zero bids are excluded, the value of the mean bids increases dramatically ($20-$29).

Peterson, et al. used a number of consistency checks to evaluate the CVM bids. The application of such consistency checks was motivated both by the surprisingly large number of zero bids obtained in responses to contingent value questions as well as by the presence of very large bids, which, though typically smaller in number, have a disproportionate impact on the mean bid. Consistency checks employed first removed zero bids resulting from the respondents rejection of the willingness to pay scenario. Then, remaining bids were checked against questions on impacts of well being and actions.

Table 5.4

Gross Recreator Bids ($)

	Angeles and San Bernardino N.F.		Incremental California Forests		Incremental All U.S. Forests	
Mean	36.71	n=250	29.47	n=244	25.21	n=241
Mean (<0)	49.07	n=187	41.34	n=174	38.71	n=157
% Zero	23.9		23.8		26.9	

Table 5.5

Gross Property Owner Bids ($)

	Neighborhood of Residence in Angeles and SBNF		Incremental Angeles and San Bernardino N.F.		Incremental California Forests		Incremental All U.S. Forests	
Mean	69.95	n=252	49.53	n=241	29.80	n=242	26.32	n=234
Mean (>0)	99.03	n=178	75.07	n=159	51.15	n=141	47.74	n=129
% Zero	29.4		34.0		41.7		44.9	

A final consistency check on the size of the respondents bid as a share of income had no effect on the results. In other words no bids could be rejected as being unreasonably large.

The results of the consistency checks for the recreator survey are shown in Tables 5.6 and 5.7. Table 5.6 shows mean recreator willingness to pay bids for the Angeles and San Bernardino National Forests after the "Scenario rejection" check. Bids are divided by the respondent's county of residence. Table 5.7 compares recreator willingness to pay bids by county before and after the second set of consistency checks as described above were applied. Bids are further divided into user, existence and bequest components. These categories are derived from part B of the contingent valuation questions where respondents indicated what percentage of their bid was for 1) preserving the forests for their own use (USER), 2) preserving the forests even if no one uses them (EXISTENCE) and 3) preserving the forest for others (BEQUEST). Since the consistency checks employed focused on questions about the respondents personal visitation and use of the forests, they are relevant only to the USER portion of the bid and not the existence and bequest portions.

The method used to approximate the aesthetic tree damage to the residents of Los Angeles, Orange, and San Bernardino Counties from ozone air pollution employed four steps. First, an estimate was made as to how much visible injury from all sources (including insects and disease) is apparent to visitors to the Angeles and San Bernardino National Forests. This estimate was generated from the perception of tree quality of recreators in each forest region. To obtain an overall estimate of the perceived loss in tree quality to the forests, these regional losses were weighted by visitation to each region. Second, these losses were adjusted for a high and low estimate of the portion of visible tree damage in each region attributable to ozone. Third, user, existence, and bequest values for a one-unit reduction in perceived tree quality (by county) were multiplied by the visitation weighted loss in tree quality due to ozone. Fourth, these estimates were multiplied by the number of households in each county and totaled.

Table 5.6

Recreator Bids ($) for Angeles and San Bernardino National Forests With Scenario Rejection Check

	Los Angeles County	**San Bernardino County**	**Orange County**
Mean	46.56	35.87	50.38
Mean (<0)	52.12	40.50	54.72
Zero Bids/ Sample Size	8/75	8/70	5/63

Table 5.7

Recreators WTP ($) For Angeles and San Bernardino National Forests With Scenario Rejection Before and After Consistency Checks

		LOS ANGELES		SAN BERNARDINO		ORANGE	
		Before Checks	After Checks	Before Checks	After Checks	Before Checks	After Checks
USER	Mean	11.40	12.53	8.49	13.99	17.79	30.57
	Mean (>0)	21.31	15.23	11.82	11.82	15.10	16.42
	Zero Bids/ Sample Size	21/66	0/36	22/56	0/34	20/57	0/31
EXIST	Mean	31.45	-	20.17	-	22.71	-
	Mean (>0)	25.70	-	16.96	-	22.14	-
	Zero Bids/ Sample Size	6/66	-	10/56	-	11/57	-
BEQUEST	Mean	8.67	-	11.61	-	12.85	-
	Mean (>0)	16.81	-	10.2	-	15.39	-
	Zero Bids/ Sample Size	28/66	-	16/56	-	17/57	-

Table 5.8 summarizes the results for each county by CVM bid category, and total. The final row is the sum of each county's user, existence, bequest, and total ozone-related damages. This gives a figure of $154,178,721 for high estimate of ozone related tree damage per year, and $54,477,884 per year for the low estimate of damage for the three county study area. These estimates were adjusted downward for non-response bias.

The damage estimates above were calculated on the assumption that the survey responses represented a random sample of households in the study area. This may not be a reasonable assumption given that the adjusted response rate for the survey was 49.5 percent. In the worst possible case, Peterson, et al. assumed that all people who did not respond would have had a willingness to pay of zero. An adjustment was made by multiplying both the high and low total damage by .495, which represented the fraction of people within the study area who responded or were able to respond to the survey. These numbers, $76,318,467 for high perceived ozone damage, and $26,966,522 for the low ozone estimate are reported in the third column of Table 5.7 under "LOW ESTIMATE."

The results of a telephone survey conducted to examine non-response bias indicated that such a large reduction was probably not correct. That survey showed that 78 percent of the people contacted by phone had visited either the San Bernardino or Angeles National Forest. This compares to a 90 percent reported visitation rate for the mail survey. The ratio of these two numbers was then used by Peterson, et al. to estimate that non-respondents visited the forests about 86.7 percent as frequently as respondents to the mail survey. Peterson, et al. assumed that non-respondents' willingness to pay would be about 86.7 percent. These adjusted estimates are reported in column 2 of Table 5.9, and are $143,848,747 and $50,827,866, respectively for the high and low ozone estimates. These results provide a range of damages across both the high and low perceived ozone damage estimates, and for a high and low estimate for non-response bias.

Table 5.8

Unadjusted Total Ozone-Related Damages ($) To San Bernardino and Angeles National Forest High/(Low)

County	User	Existence	Bequest	Total
Los Angeles	24,453,909 (8,640,604)	67,462,759 (23,837,455)	18,597,842 (6,571,407)	110,514,510 (39,049,465)
Orange	10,625,270 (3,745,359)	13,563,794 (3,754,359)	7,674,802 (2,711,833)	31,863,866 (11,258,856)
San Bernardino	2,487,830 (897,056)	5,910,428 (2,088,405)	3,402,086 (1,202,101)	11,800,345 (4,169,563)
Total	37,566,909 (13,274,019)	86,936,981 (29,680,219)	29,674,730 (10,485,341)	154,178,721 (54,477,884)

Table 5.9

Total Ozone Damage To San Bernardino and Angeles National Forests

Adjusted For Non-Response Bias

(24.3% Use Value, 56.3% Existence Value, 19.4% Bequest Value)

	High Estimate for Non-Response Bias	**Low Estimate for Non-Response Bias**
Adjusted Total Damage in Dollars High Ozone	$143,848,747	$76,318,467
Adjusted Total Damage in Dollars Low Ozone	$50,827,866	$26,966,552

5.3.1.4 Property Value Results

The property value analysis employed residential property sales data in a hedonic price function to reveal marginal willingness to pay (WTP) values for small changes in visual tree and stand quality. These marginal WTP estimates correspond conceptually to the marginal WTP estimates derived in the CVM analysis.

Data from four sources were employed, including:

1. Property characteristics and sale price for 1136 properties throughout the San Bernardino and Angeles National Forests during the interval between the fall of 1984 and the summer of 1985.

2. Distance variables to the nearest lakes and to the metropolitan area to the west of the San Bernardino and Angeles National Forests.

3. Mean quality variables of nine environmental amenities calculated from residential survey data aggregated to data cells no larger than three square miles.

4. A set of subjective forest quality and characteristic variables used for cross validation purposes.

Because selection of functional forms and variables to include can be important in estimating a hedonic price function, Peterson, et al. examined alternative functional forms. Different functional forms were found to have minimal impact on the general magnitude of estimated values for changes in mean tree quality (MQTREE), the variable of interest.

An incomplete principle components analysis was used to estimate a basic hedonic price function with housing characteristics, distance variables, forest size and density, and the mean tree quality variable, MQTREE. The eight remaining quality variables from the survey (Views, Wildlife, Recreation, Fishing, Lake, Air Quality, Schools, and Stores) were recombined into eight principle components and later added to the estimated equation.

For the full sample, using incomplete principle components analysis, the coefficient on MQTREE (or the value of a one unit change in MQTREE) ranged from $2,300, when no components were included, to $4,555 when all eight components were included, with most coefficients remaining statistically significant. This represents a 2.8 to 5.5 percent change in the average housing price for one unit change in MQTREE. Other specifications with different functional forms, variable sets and subsets of the data resulted in ranges of values for a one unit change in MQTREE from approximately $2,000 to $8,000, with central estimates clustering around $3,000 to $4,000.

5.3.2 Crocker and Vaux

Crocker and Vaux used a contingent valuation method (CVM) survey to estimate economic measures of visual ozone damage to ponderosa and Jeffrey pine forests in the San Bernardino National Forest. Interviews were conducted in June and July of 1983 at unstated locations with 36 weekday and 64 weekend respondents. However, there is some indication within the text which implies that the interviews were conducted at campgrounds.

Respondents were shown three photographs that represented distinct levels of visible ozone caused injury to ponderosa and Jeffrey pine trees. Respondents were asked which site most resembled the site typically visited, asked to rank the alternatives in terms of preferences, asked CVM bidding questions, and asked questions about congestion and substitution and other related variables. Photograph A was characteristic of no ozone injury or very slight ozone injury to Jeffrey and ponderosa pines. Photograph B depicted very severe ozone injury, and photograph C depicted moderate ozone injury. The degree of injury was assigned by Dr. Paul Miller of the USDA Forest Service. Presentation order of the photographs was not coincident with the order of magnitude of physical damages to reduce induced order effects in the responses.

The questionnaire length was kept short to limit interference with the respondents' recreational experience. Important to note is that respondents were told at the beginning of the interview that many scientists believe air pollution is damaging to the health of the forest. The CVM question asked:

> Suppose that the only way you can enter any environment like the one you most prefer is by paying a daily fee additional to any you are now paying. This additional fee will be used to finance special programs designed to protect this forest. Would you be willing to pay an additional $3.00 to assure entrance today to the environment you most prefer?

An interactive bidding procedures was used to obtain the maximum bid. Subsequently a one bid procedure was used for the bid to enter the next most preferred and the least preferred environment. Assuming nothing else changes in the environment but the quality, the differences in the bids (the bid for environment A minus the bid for environment B) are assumed by Crocker and Vaux to equal the compensating surplus measure of changes in visual tree quality. The questions obtained use value estimates only.

Results were reported for weekend and weekday visitors, but for simplicity, generally only aggregate results are reported for the 100 total respondents. Fifty-seven of the respondents indicated they typically recreate in environments represented by picture A (referred to hereafter as environment A and so forth), 9 said no environment was typical of where they recreated, 27 chose environment C and 7 chose environment B. Seventy-six respondents picked environment A as most preferred, 18 had no preference and 6 most preferred either B or C. When A was most preferred, the next most preferred environment was almost equally split between B and C, with 10 having no preference between either B or C.

Crocker and Vaux report mean incremental bids to recreate in each environment, as reported in Table 5.10. Implied per party differences in value for recreating in different environments are also presented in Table 5.10 and range from $1.35 to recreate in A rather than B, to not being statistically different from zero to recreate in C rather than B. The bids for C and B are not

Table 5.10

Crocker and Vaux Mean Bids For

Aesthetic Forest Quality*

I. Actual Bids

	Injury Level		
	Slight (A)	**Moderate (C)**	**Severe (B)**
Injury Score mid-point	4.5	18	32
Mean of Bids (x)	$2.09	$0.66	$0.74
Standard Deviation of X	$2.80	$0.78	$1.00

II. Implied Bids

Mean Bid for a move from Environment B to Environment A	$1.35
Mean Bid for a move from Environment C to Environment A	$1.43
Mean Bid for a move from Environment C to Environment B	-$0.08

* Mean for weekend and weekday recreators. Taken from Crocker (1986).

statistically different, but it is not stated whether any of the reported or implied values are statistically different from zero. Crocker (1986) subsequently notes that all zero bids by individuals who preferred environment A were eliminated on zero bid evaluation criteria. Apparently those who bid a positive number for A but not for other environments were retained. Neither Crocker and Vaux (1983) nor Crocker (1986) report the number of zero bids, or the total number of bids that are retained in the statistical analysis. This is an omission that makes it impossible to evaluate the statistical hypotheses.

The authors use the results of the mean bids to imply that "non-convexities" exist in the value function. This is to say that increases in forest quality have increasing positive marginal value. This would be a finding of interest, as traditional economic theory typically assumes decreasing marginal utility of goods and services. However, as we will discuss below, the Crocker and Vaux procedures may have been a significant factor causing rather than revealing, the non-convexity finding.

Crocker (1986) also reports results of a regression relating the bid measure to forest visual aesthetics and other variables. While this bid is not related to underlying utility theory, it appears that the functional form would require a utility function specification that forces the marginal utility of forest aesthetics to be "non-convex." It also appears that zero bids previously deleted are included in the regression analysis, this seems unwarranted. In this analysis visual aesthetic damage is statistically significant.

Respondents were asked to consider the importance of crowding in subsequent questions. Seventy-seven percent of respondents would have been willing to go from their most preferred to their least preferred environment if the former were perceived to be crowded. As Crocker indicates (page 252), "It seems that the compensation respondents would demand for crowding exceeds that which they would demand for air pollution damages," as 70 of the 77 were individuals who most preferred environment A.

The questionnaire also asked for the current number of visits per year to the San Bernardino National Forest and the number that would be taken if all the forest were similar to their least preferred environment. Respondents indicated that visitation would fall off by 10 to 20 percent, if all of the forest were similar to their least preferred environment.

Finally, Crocker and Vaux attempt to aggregate the individual findings to infer values for aesthetic changes on a per acre basis and for the forest as a whole (this work is not carried forward into the Crocker, 1986 paper). Unfortunately, the assumptions used have important flaws leading to a potential bias in estimated values. The reasons for this determination include:

- In their computations, Crocker and Vaux assume the sample (presumably of campers) is representative of all recreation use days in the San Bernardino National Forest; however, values are likely to differ by use type, with campers potentially being among those with the highest values for forest aesthetics.

- The bids by individual by day are applied to all recreation days, although the bids probably may best be interpreted as visitor party bids.

- Crocker and Vaux assume that part of each of the over 6 million recreation visitor days took place within those portions of the 161,000 acre are surveyed by Miller for oxidant damage to Jeffrey and ponderosa pine. This seems unrealistic as there are nearly 2 million acres in the San Bernardino National Forest with diverse vegetation cover and recreational use, although making alternative assumptions is equally difficult.

- The photos used in the survey present alternative forest conditions for stands that are predominately Jeffrey or ponderosa pine, while in those areas with these species, the percent of all trees of these species range from very small (10-20 percent) to very high (80-10 percent). The value (and certainly the value per acre) of injured ponderosa and Jeffrey pine may be less in those stands where they comprise a small portion of the trees in the stand.

- An offsetting potential problem is that values for changes in conditions may be understated due to the exclusion of negative bids (see next section).

The aggregate results Crocker and Vaux report range from $21 to $68 per acre of injured stand. They calculate the total forest-wide value for having environment A rather than environment C at about $9 million/year (or about $90 million present value at a 10 percent discount rate).

The main issues surrounding the use of the C&V work in policy application are: whether the "non-convexity" finding is meaningful; and whether the estimates of values per visitor party and the aggregate estimates are reasonable, and what they imply.

The non-convexity finding may be more related to the structure of the questionnaire than to the underlying values the researchers attempted to reveal. In particular, the questionnaire asked for the WTP of an additional amount above current fees to guarantee admission to the most preferred, next most preferred, and least preferred environment. As indicated by the visitation and congestion questions, many respondents would rather not take the trip to the San Bernardino National Forest if their preferred environment is not available. Therefore, Crocker and Vaux should have allowed respondents to state negative WTP (require reduced fees or compensation) to visit less preferred sites, rather than limiting WTP to a lower bound of zero. By limiting the lower bound of the bids to zero, the questionnaire truncates the difference between the value of visits to the most and the least preferred environments. This is evidenced by the substantial number of apparent zero bids for least preferred environments resulting in means less than $1.00. If negative bids were allowed, the non-convexity may have likely, although not necessarily, disappeared. More importantly, the calculated use values for changes in forest quality, calculated as the difference in the maximum WTP entrance fee for each environment type and which are limited to zero, are likely to be understated.

Other questionnaire design factors affecting the responses may well be sequencing and starting bids. The bid for the preferred environment was first, and respondents were given a starting bid of $3. The resultant mean bid of just under $3 suggests the starting bid may have had a strong influence on the responses. Further, the bids for the next most preferred and least preferred environment followed but did not have a starting bid. If this sequencing had been reversed, beginning with the least preferred environment and a starting bid of $3, followed by single bids for the more preferred environments, it is possible the non-convexities would again have disappeared. These sequencing and starting bid issues are perceived as less significant than the previous comments.

Turning to the value estimates, it is noticeable how relatively small they are: on the order of $1.35 per visitor party per day for changes from environment C or B (moderately to severely injured) to environment A (very slight injury). However, as noted above due to limits on negative values, the structure of the questionnaire artificially limits the estimates of the appropriate consumer surplus measure. Therefore, it is likely an improved use value estimate might be several times this magnitude, but not an order of magnitude larger. This is because questions on congestion and number of trips taken indicate that most trips would still be taken even if conditions worsened at the sites. On the other hand, it is possible that the reported values would have been even lower if the questionnaire had not identified the damage as probably air pollution induced.

5.3.3 Brown, et al.

Brown, et al. (1988) obtained estimates of willingness to pay from campers at 11 campgrounds in northern Arizona. Ponderosa pine is the predominant overstory species at each campground, but some of the campgrounds also have other tree species present. The survey was conducted in 1985. A total of 727 heads of households were interviewed.

Following questions about the general nature of the trip, respondents were asked about their household's expenditures for gas, food and beverages, and campground and rental fees for the current trip. Respondents were then asked how much they "would have been willing to spend on this trip before deciding not to come to this campground." The sum of expenditures and additional willingness to pay was used as the household's maximum willingness to pay for the trip.

Respondents were then presented with notebooks of color prints of similar campground environments. Respondents were reminded of their willingness to pay bids, and then asked to indicate for each of the 35 areas in the photos "the most you would have been willing to spend on this trip if forest conditions at this campground were like the forest area depicted in the photos."

Reported mean total willingness to pay values (per person per day) ranged from a high of $21.91 to a low of $10.95 for the non-photo based CVM questions. Willingness to pay values for the photo based CVM questions ranged from a high of $17.41 to $10.69. At all 11 campgrounds, mean direct (non-photo) based willingness to pay values exceeded photo based willingness to pay values. Brown, et al. reported that t-tests of subsamples showed that the above finding held whether or not respondents: (1) were at their first choice as a place to camp, (2) were only camping at that campground during their trip, and (3) had previously camped there.

The finding that respondent's consistently expressed greater willingness to pay to camp when estimates were based on directly perceived conditions at the chosen campground than when the campground was represented by photographs is inconsistent with other environmental preference studies that have tested the use of photographs as proxies for forest areas. While Brown, et al. considered numerous explanations for the difference, their finding suggests that photo-based willingness to pay values, for example Peterson, et al. (1987) and Crocker and Vaux (1983) may underestimate the value of recreation at forested sites.

5.3.4 Walsh and Olienyk

The purpose of this study was to develop measures of the effect of mountain pine beetle damages to ponderosa pine trees on demand for recreation use of forest resources in the front range of the Colorado Rocky Mountains. As a result of pine beetles, about 15 percent of the trees have been killed in the national Forests of this area, about 5,000 square miles. The damage per acre however, ranges from 0 to almost 30 percent depending upon the National Forest area being considered.

Mountain pine beetle infestation of ponderosa pine trees causes needle discoloration followed by tree mortality. The resulting mortality reduces stand density.

Walsh and Olienyk interviewed 435 recreator users on-site throughout the front range national forests during 1980, primarily at elevations between 6,000 and 8,000 felt. In these areas ponderosa pine trees are common in stands of, on average, 160 trees per acre with diameter at breast height of six inches or more.

The Walsh and Olienyk questionnaire asked respondents about the characteristics of the current trip including activities, expenditures and perceptions of on-site conditions. They also asked the importance of: congestion, tree density at the site and in the distant view, tree size, discolored needles and dead trees. About two dozen willingness to pay questions were also asked about these issues as were several contingent travel cost questions.

The questionnaire used six photographs representing different densities of healthy trees ranging from 0 to 300 per acre. No pictures of alternative levels of discoloration or standing or downed dead trees were included.

Among the important elements in the questionnaire design is that the WTP and contingent visitation questions are not always consistent or clear as to whether the proposed change is to occur at one site or throughout the entire forest. If the responses are applicable to impacts at only one site, they may misrepresent the values if the entire forest experiences similar impacts. Another element is that the questionnaire focuses most heavily on tree density as if the standing dead trees are removed without a trace and there are no discolored trees.

Unfortunately Walsh and Olienyk do not report the means or variances of individual WTP or contingent travel demand questions, but rather regressions examining responses to selected WTP or travel demand questions. As a result, determining changes in consumer's surplus from the analysis is a difficult task. They also do not report any results for many of the questions, including the congestion analysis.

Forest quality characteristics were uniformly found to be significant to recreation experience. About half of the respondents rated trees as being more important than views of mountains or rock outcroppings. Slightly less than half rated trees more important than topography or nearness of streams and lakes.

Tree density was found to have a significant effect on the demand for site visits. However, the relationship between tree density and demand for site visits varied greatly depending upon recreation use type (for example, fewer trees are preferred for off-road vehicle recreation). The relationship between tree density and visits increases up to 150 to 200 trees per acre (depending upon use type), levels off for the addition of 0 to 100 trees/acre, then declines. The interesting implication is that in moderate or densely forested areas, decreases in tree density may have negligible or positive effects on site demand. On average, across use types, and at the average density of 165 trees/acre, a 10 percent decline in tree density was associated with a 3.5 percent decrease in demand. This is comparable to estimates by Leuschner and Young (1978), who found an elasticity of .64 to .68 for trees at campgrounds located at reservoirs in Texas, and estimates of Michaelson (1975), who found an elasticity of .27 for trees at camping sites in Idaho forests.

The effects of visible discoloration (living but significantly discolored) and of standing dead trees (trees lacking needles) were found to be about the same. They are 6 to 7 times greater than that of tree density, with an elasticity of demand of 2.3, on average, across activities, at a medium tree density, in the range of 1 to 15 percent of trees damaged.

Using a travel cost model, the authors report changes in consumer surplus for changes in tree density. With these estimates and the above elasticity of demand, one can infer what the change in consumer surplus might be for changes in fully discolored and dead trees. From Walsh and Olienyk's figures (Table 42 in their text) a 10-15 percent change in tree density, at the mean density and averaged across use types, causes an average loss of consumer surplus of $5.42 to $8.59 per year ($1982). If the change in consumer surplus for dead or dying trees is 6 times as important, 10 to 15 percent of dead or dying trees would result in values of $32 to $50 per year. The comparable per trip estimate for 10 to 15 percent dead and dying trees (used O&W Table 43) would be about $8 to $11 per year.

The major issue for the current study is that no presentation of discolored and dead trees was made with visual graphics in the questionnaire. As a result, quantifications of the degree of injury inferred by the respondent cannot be ascertained or compared to the types of damage experiences. However, mountain pine beetle damage quickly discolors entire trees in groups which is generally a much more substantial effect than the effects of ozone damage alone. In addition, the issue of how respondents perceived the effects throughout the forests of the front range is unclear and clouds the interpretation of the results.

Another issue is the transferability of results of recreators in Colorado to California. However, this is less severe if one treats the values as order of magnitude estimates.

The results and issues identified suggest that the consumer surplus estimates of $8 to $11 ($1980) per recreation trip for 10 to 15 percent of all trees totally discolored or dead would overstate the effects from ozone in isolation of other confounding or subsequent effects (such as a resulting pest infestation due to predisposition by ozone). These estimates applied to trips of, on average, 6 hours. How the estimates should be adjusted to reflect that some costs are incurred by everyone in the group, yet the reported willingness to pay, may apply to the group as a whole, is unclear.

5.3.5 Loomis and Walsh

Loomis and Walsh (1987) used the survey data developed in the Walsh and Olienyk study to relate recreation visitation and willingness-to-pay to stand density and tree sizes. Results indicate that a few activities such as driving off-road vehicles are optimized when there are very few trees per acre. Hiking and fishing are activities that sampled recreationists preferred to engage in within moderately stocked forests. On the other hand, activities such as camping, picnicking and backpacking are optimized when tree density is higher.

Loomis and Walsh reported that the net economic value of recreation increases from less than $5 a day to more than $10 a day when the number of trees per acre triples. As tree size, expressed as diameter at breast height (dbh), increases, recreation use and benefits also increase. Recreation benefits in Colorado increase from $4 per day with trees 4" dbh to $11 per day with trees 13" dbh. Tree size was reported to have a much greater effect on the value of recreation than on the number of days of recreation participation. That is, recreation satisfaction, measured by willingness to pay, was reported as being more sensitive than recreation participation to changes in tree size.

5.3.6 Other Studies

Other studies have been completed addressing how trees and tree quality affects recreational value and property prices. These studies are not as directly applicable as those mentioned above for estimating the benefits of ozone control.

Recreational studies have included those by Michaelson (1975) addressing mountain pine beetle damage to ponderosa pine on the demand for recreation at campgrounds in the Targhee National Forest in Idaho. It was found that the degree of infestation significantly affects campsite demand. Leuscher and Young (1978) addressed southern pine beetle damage to ponderosa pine on the demand for campground recreation at two reservoirs in Texas. Again, reduced demand occurred at damaged sites. The damage to those still recreating at those sites was not considered.

Property value impacts have been assess through appraisals (Peters 1971, Morales, et al., 1976, Neely 1979 and others) and through willingness to pay surveys (Coursey and Brookshire 1985). These efforts have uniformly addressed issues of tree density and size on property values. They have not addressed characteristics of tree injury. Usually these studies look at the planting of trees in urban or suburban areas rather than within forest areas. Interestingly, these studies do suggest that properties with an abundance of trees are often on the order of 20 to 30 percent more valuable than lots with few or no trees.

5.4 OTHER NON-MARKET GOODS

Numerous other services are provided by forest ecosystems in California. These include the provision of animal habitat and numerous other ecosystem functions. While these services undoubtedly possess value to society, we have been unable to locate studies estimating these values for California forests.

The potential increased risks of catastrophic fires in ozone damaged chaparal and pine stands may be an important source of benefits deriving from ozone control in southern California. These benefits have yet to be quantified, and are likely to become more important as Californian's increasingly purchase and build homes within forested areas.

5.5 FUTURE RESEARCH

Future research to determine the economic value of ozone damage to California forests should be determined by the extent of the perceived or known ozone damage in California forests and the relationship of this damage to valued environmental commodities and services.

Presently, ozone damage perceptible to non-forest scientists has been largely limited to the San Bernardino and Angeles National Forests. While forest tree growth decrement and visible foliar injury have been reported in the southern Sierra Mountains, this injury is currently too subtle to be generally evident to forest visitors.

Consequently, additional economic damage estimates due to changes in the aesthetic characteristics of California forests should be deferred until that injury becomes perceptible. The work by Peterson, et al. can be used to estimate economic damages due to ozone caused forest damage in the San Bernardino and Angeles National Forests.

Caution should be exercised when extrapolating the results developed by Peterson, et al. to other forests and regions in California. Generally, these results are best applied to the forests over which they were developed. Extrapolation to forests outside of southern California is made problematic by the large differences between these forests and the San Bernardino and Angeles National Forests.

While ozone is causing changes in the structure and function of affected California forest ecosystems, current scientific understanding of these changes is not sufficient to allow additional or credible non-market damages to be derived.

However, changes in forest ecosystem structure and function may cause significant economic damage, and the state of the science should be carefully monitored regarding ozone-forest exposure response functions. This may be particularly true for non-market and market values deriving from changes in watershed quality. If changes in forest succession caused by ozone affect the volume or quality of surface water run-off, significant economic damages could result. Another potentially important source of economic damage could be the increased risk of catastrophic wildfires due to forest dieback and changes in forest succession. Changes in chaparral and pine forest composition and succession have been noted recently in southern California forests.

Recent data indicate that ozone injured Jeffrey pine trees have experienced growth declines outside of the Los Angeles Basin. While current scientific understanding is not sufficient to develop exposure response functions between ozone concentrations and tree growth decrement, useful research could be performed by applying a commercial timber model to estimate economic damages due to hypothetical changes in the growth of commercial trees caused by ozone in California. While not providing "actual" damage estimates, this research would provide useful additional information to policy makers by helping to define potential economic damages due to ozone caused timber growth losses in California.

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