Final Report

Review of Fire Management Program for Sequoia-Mixed Conifer Forests of Yosemite, Sequoia and Kings Canyon National Parks

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TABLE OF CONTENTS

SUMMARY

The Leopold Panel Report of 1963 awoke us to the reality that artificial suppression of natural fire cycles results in successional changes in mixed coniferous forest ecosystems such that they no longer resemble their primeval counterparts, the probability of catastrophic disturbance is increased, and their scenic beauty, which first attracted concern for their preservation, is diminished. The fire management programs for the sequoia-mixed conifer forests in Yosemite, Sequoia, and Kings Canyon National Parks were established in response to this situation to "maintain or restore natural fire regimes to the maximum extent possible so that ecosystems can function essentially unimpaired by human interference" (Appendix I).

Fire Responses and Regimes in Sequoia Mixed-Conifer Ecosystems

Successful regeneration and survival of many sequoia mixed-conifer species depends on relatively frequent light to moderate surface fires. For example, the giant sequoia has serotinous (closed) cones which are opened by fire's heat releasing large quantities of seed. Fire removes litter and duff exposing a mineral seedbed necessary for successful giant sequoia and pine seedling establishment. Populations of many understory shrubs and herbs are also enhanced by fire.

Fire suppression favors establishment and growth of shade-tolerant trees such as white fir and incense-cedar. Competition from these trees limits establishment of other tree species and obscures vistas of the giant canopy trees in many areas. Furthermore, these invading trees and the accumulation of woody debris have created fuel conditions that favor intense and high consumption fires that result in considerable scorching of giant sequoia bark.

Extensive study of fire frequency in sequoia-mixed conifer forests has been done in only a single grove where average fire return intervals in the period 1478-1870 were 9.2 years on southwest-facing slopes and 16.4 years on southeast-facing slopes (Kilgore and Taylor, 1979). Most of these fires were probably set by Native Americans; the lightning-ignited fire return interval is probably greater than 50 years on most sites. There is little doubt that the fire regime of the sequoia-mixed conifer forests during the two millenia prior to the period of active fire suppression was dominated by Indian-set fires. Kilgore and Taylor's data also suggest that fires within groves may have been limited in spatial extent and that there was considerable variation in fire return intervals within and among locations. Most of these fires were actually ignited in ecosystems adjacent to sequoia-mixed conifer groves. Localized areas may well have escaped fire sufficiently long to allow invasion of late succession species and accumulation of woody debris; fires that eventually occurred in these areas were undoubtedly more intense than average. Thus, fire suppression during the past 80 years

has created fuel conditions over a wide area that existed only in localized areas during the Native American Period.

Fire return intervals did (and do) vary among locations within the sequoia-mixed conifer forest type owing to variations in landscape features and simple chance. Fire regimes and forest structures were not precisely regulated to particular average values; at any given time forest structure must have varied from location to location and at any particular location forest structure changed considerably from time to time. The accuracy with which we can determine past forest structure and composition decreases dramatically with increasing spatial area and time span. Thus, it is neither practical nor desirable to recreate a structure in each stand that existed at an arbitrarily-chosen past time and then hope to maintain each stand in that state indefinitely through the use of prescribed fire. We can, however, use prescribed fire to adjust fuel conditions back into the natural range of variation and to simulate the process that maintained the diversity of forest structure characteristic of the primeval landscape.

There is no doubt that the ingrowth of shade tolerant trees during the period of fire suppression resulted in striking changes in the general appearance of many giant sequoia groves. The Leopold Panel described the resulting "vegetative tangle" as "depressing, not uplifting." One goal of the burn management program, particularly in areas with high vistor use, was to correct this situation. Concern has been expressed that prescribed burns, as a consequence of scorching and charring of giant sequoia bark and the leaving of burned snags and woody debris, have also altered the appearance of sequoia groves from that seen by the first European vistitors. There is no doubt that charring of sequoia bark has occurred in the past and that in localized areas with dog-hair thickets of fir or heavy accumulations of woody debris such charring might have been extensive. Nonetheless, we feel that the charring in some prescribed burn units in Sequoia/Kings Canyon National Park may be more extensive than would have been expected in typical fires a century ago. This is due to the more widespread invasion of fir and the accumulation of woody fuel.

Fire Management Policies

The general policy goals of the National Park Service encompass the conservation of scenic resources and natural ecosystems. The specific reasons vary for preserving particular areas vary among and within parks. With respect to natural area management, Park Service managers came to recognize that in order to preserve particular ecosystems, the natural processes such as fire that maintain those ecosystems must be preserved as well. Current Park Service fire management policy recognizes the dynamic nature of primeval landscapes and patterns of natural disturbance (USDI, 1978) and states that the goal of fire management should not be the recreation and perpetuation of a particular ecosystem configuration, but rather the maintenance of the "full spectrum of ... dynamic natural vegetative patterns." The goal of process, as opposed to object, maintenance is explicit in park-specific fire-management plans as well. "It is not a goal to return [sequoia-mixed conifer forests] to some historic point in time, but rather to allow fire to operate as a process as fully as possible."

We strongly endorse policies for the management of natural ecosystems based on the recognition that such systems were in the past, are, and forever will be dynamic. Such policies are not only ecologically sound, but they present the only practical management alternatives for natural ecosystems in which disturbances such as fire are important. The dynamic ecosystem concept is most clearly stated and incorporated into park-specific management plans; it is less explicit in Park Service-wide policy statements. We recommend that a panel of appropriate experts be assembled to examine changes in our understanding of ecosystem structure and function since the Leopold Report and to evaluate current Park Service-wide policy in light of these changes.

The following points are implicit in Yosemite and Sequoia/Kings Canyon National Park Burn plans. 1. Prescribed fire may be used to restore an ecosystem to a structure within which natural fire may be allowed to occur and/or used to maintain (simulate) the natural fire regime. 2. The natural fire regime is defined as that which would occur in the absence of human interference; Indian-set fires are explicitly defined as <u>not</u> natural. 3. Specific fire management guidelines may vary within specific zones demarcated within each park. 4. The effects of prescribed fire on stand appearance are not explicitly considered in the Sequoia/Kings Canyon burn plan (with the notable exception of "showcase" areas), whereas such concerns are explicit criteria for development and execution of burn plans in Yosemite. The panel recommends the following:

1. Prescribed burns planned for areas managed as natural ecosystems should be classified as "restoration fires" or "simulated natural fires." Restoration fires are carried out in order to manipulate fuel conditions judged to be "unnatural" whereas simulated natural fires are intended to maintain the primeval fire regime (whether or not such fire regimes should include Indian-set fires requires further study). Specific areas within a heterogeneous burn unit might be classified differently. (See below for specific criteria for implementation.)

2. The showcase designation be continued for areas where scene management is of primary management concern. Showcase areas should not be perceived as static museums, but rather as areas where simulations of primeval conditions may be influenced to a greater extent by scenic concerns. Manipulations in such areas should be extended to include judicious preburn cutting of understory trees, particularly

where ignition of such trees might have a negative effect on stand appearance and/or when their removal would enhance the visual effect of adjacent specimen trees.

3. Return intervals for lightning-caused fires are considerably longer than those during the Native American Period and may be roughly equivalent to the period of active fire suppression which was responsible for the current fuel conditions in sequoia mixed-conifer forests. The current policy that estimates of natural fire return intervals be based only on lightning-caused fires should be reevaluated.

4. Individuals with education in landscape architecture should be consulted in the development of burn plans, especially in showcase areas. We feel that such consultation will also be valuable in determining relationships of burn units to one another and burn unit boundaries. Such input should not involve scene management *per se* nor should ecological goals or impacts of the burn plan be compromised for purely aesthetic reasons. Rather, such an individual may identify specific aesthetic concerns and aid in selecting from among ecolologically acceptable alternatives.

5. All Park Service management plans would benefit from periodic external review. We recommend the establishment of a formal external review program.

Burn Plans and Their Implementation

The fire management personnel at both park units displayed a firm understanding of general Park Service goals and policies and sensitivity to the specific role and impact of the the fire management program in sequoia-mixed conifer forests. We believe the following recommendations will improve the process of burn plan formulation and implementation:

1. Judicious preburn cutting of live trees (especially young white firs) be permitted in showcase areas. Such cutting should be consistent with ecological guidelines and used in conjunction with removal of heavy fuels and fuel ladders and wetting of burning trees to minimize bark char of large trees.

2. In burn units or portions of burn units designated for "restoration burns," fuels should be manipulated to ameliorate unnatural extensive or widespread charring of dominant trees that might result from unnatural fuel conditions. Such manipulations may include movement of heavy fuels from the base of large giant sequoias and judicious felling of living late successional species when population densities of such invaders are judged to be in excess of the normal range of variation expected on the presettlement landscape. For example, scattered dense

populations of such invaders of limited spatial extent were present on the primeval landscape and require no manipulation. In restoration burns where specific management criteria, such as bark scorch height or understory and fuel reduction exist, burn objectives should be as quantitative as possible. Recording of effects can then be used to modify prescriptions and/or objectives.

3. Prefire fuel manipulation in burn units designated for simulated natural fire should involve only that necessary to contain the fire within designated boundaries and to guarantee safety of personnel.

4. To the extent possible, simulated natural fires should be ignited as a single burning front and allowed to burn at will through the stand. No special effort should be made to ignite isolated snags or logs. Experience shows that such fires may burn very slowly. Contingencies such as heavy visitor use, smoke control, or personnel limitations during the fire season may require multiple ignitions to hasten the burn process.

5. Areas designated for restoration burning should be ignited so as to best accomplish restoration goals. Multiple spot ignitions are advisable and it may be necessary to specifically ignite piles of brush or woody debris.

6. Manipulation of debris following simulated natural fires should be unnecessary. However in restoration burn areas where fuel accumulations are abnormally heavy, a single prescribed fire may actually exacerbate heavy dead fuel conditions. Such areas may require additional fuel manipulation and burning.

7. All pre- and post-fire fuel manipulation (regardless of burn classification) should be done so as to minimally disturb the soil or subordinate vegetation.

8. Burn plans should be formulated with consultation from a person educated in landscape architecture as described above. Such consultation is intended to explicitly include aesthetic criteria in the selection of burn unit locations and boundaries as well as site preparation. In all cases, ecological values are paramount and are not to be compromised for aesthetic reasons.

Monitoring

Monitoring of prefire fuel, fire weather, fire behavior, fuel consumption, and fire effects is an important part of the Park Service's fire management program. In recent years, this program has been broadened to include the establishment of permanent plots to monitor long-term changes in fuel and vegetation. In showcase areas aesthetic concerns should also be monitored. We feel that specific goals of this long-term monitoring program need to be clarified. Furthermore, a clear schedule and mechanism by which all monitoring data are processed, analyzed, and fed back into the burn plan formulation process needs to be established. We recommend that the Park Service convene a workshop involving fire management and research personnel along with scientists from outside the Park Service expert in vegetation analysis, fuel evaluation, statistics, and data management. The goals of this workshop would be to identify and detail specific monitoring goals, to discuss methodological and analytical alternatives, and to develop uniform monitoring protocols.

Interpretation

There is clearly excellent communication between fire management personnel and park interpreters and naturalists; we were impressed with general level of understanding of the fire management program displayed by park naturalists, as well as the clarity of their presentation to the public. The interpretive program is an important channel of communication between the public and the Park Service. However, public reaction to the burn program expressed to the interpretive staff may not be representative of total public opinion or understanding. A representative evaluation of public reaction to the burn program would be useful to the interpretive program and to the management of showcase areas.

Research

We encourage the Park Service to continue its support of both in-house and collaborative research on fire in sequoia mixed conifer ecosystems. We believe the following areas deserve special attention.

1. Fire history. A more detailed understanding of variations in past fire regimes is needed over a much broader geographic area. Special emphasis should be placed on increasing our understanding of role and patterns of past Indian-set fires.

2. Demographic and Life History Studies. More information is needed on the behavior of tree, shrub, and herb species in response to a variety of fire regimes, including fire suppression.

3. Fuel dynamics. Considerable research is needed on the effects of fire and fire suppression on accumulation and degradation of fuels.

4. Computer simulation models. Models of fuel dynamics, fire occurrence and behavior, and forest succession will be important tools for management decisions in the future.

5. Visitor response. A study of visitor response to the burning program will provide a measure of public understanding of and reaction to the burn program.

6. Fire effects. The specific effects of variations in fire regimes on plant pathogens, nutrient cycling and litter dynamics, understory plant regeneration, and fauna are needed.

Funding

We feel it is most important that the sequoia-mixed conifer fire management programs in Yosemite, Sequoia and Kings Canyon National Parks be given permanent status with a long-term funding horizon. This will allow fire managers to incorporate time- and labor-intensive site preparation and burning techniques into burn plans and provide the needed flexibility to schedule fires when conditions are most ideal.

We view the above recommendations as adjustments in an essential management program for sequoia-mixed conifer forests. We appreciate the Park Service's willingness to suspend prescribed burning during our deliberations and certainly support the reinitiation of this program.

Like the problems encountered in the management of large mammal populations, the maintenance of natural disturbance cycles in wilderness ecosystems is a persistent reminder that our national parks are tiny islands in a sea of development and urbanization. In the best of all possible worlds our islands would be sufficiently large that we could adopt a "let it be" strategy for their preservation and maintenance. However, fire regimes are landscape phenomena that operate on scales exceeding the size of most parks. The problem is further complicated by the fact that fire regimes must be managed in the context of increasingly intense public visitation and use, especially in the sequoia-mixed conifer forests. Thus, there will be a continuing need for fire management programs in these ecosystems. However, we expect the goals and policies of these programs to evolve from the restoration of landscape variability that typified the sequoia-mixed conifer forest prior to settlement to an active program to simulate the natural fire regimes that maintained that primeval landscape.

INTRODUCTION

In 1963 the Special Advisory Board on Wildlife Management, better known as the Leopold panel, asserted that national parks should represent a "vignette of primitive America" (Leopold et al. 1963). Citing specific cases where park management had fallen short of that goal, the Leopold panel made the following statement.

> "When the forty-niners poured over the Sierra Nevada into California, those that kept diaries spoke almost to a man of the wide-spaced columns of mature trees that grew on the lower western slope in gigantic magnificence. Deer and Bears were abundant. Today much of the west slope is a dog-hair thicket of young pines, white fir, incense cedar, and mature brush -- a direct function of overprotection from natural ground fires. Within the four parks -- Lassen, Yosemite, Sequoia and Kings Canyon -- the thickets are even more impenetrable than elsewhere. Not only is this accumulation of fuel dangerous to the giant sequoias and often mature trees but animal life is meager, wildflowers are sparse, and to some at least the vegetative tangle is depressing, not uplifting. Is it possible that the primitive open forest could be restored, at least on a local scale? And if so, how? We cannot offer an answer. But we are posing a question to which there should be an answer of immense concern to the National Park Service."

Research during the mid and late 1960s suggested that the answer to this question was yes and that the best means of achieving the "primitive vignette" was through prudent use of prescribed fire. Since 1969 prescribed fire has been part of the sequoia-mixed conifer management program in Yosemite, Sequoia, and Kings Canyon National Parks. The general goal to this program "is to maintain or restore natural fire regimes to the maximum extent possible so that ecosystems can function essentially unimpared by human interference" (Appendix I). The general charge to this review panel is "to evaluate the effectiveness of the NPS fire management program in accomplishing this goal." "We feel it is timely to conduct a review of the program to be certain this widely accepted practice is being carried out at the highest possible standards. It is imperative that this program be (1) ecologically sound and (2) economically feasible; we would also like it to be as responsive to aesthetic concerns as possible without compromising the overall objective" (Appendix I).

Four specific objectives were proposed for the panel review:

1. Review the history and evaluate the current status of the fire management program for the sequoia-mixed conifer forests of Sequoia, Kings Canyon and Yosemite National Parks.

2. Evaluate the scientific basis for the program (with emphasis on giant sequoia groves).

3. Evaluate the impacts of prescribed as opposed to natural fire on individual giant sequoia and on sequoia groves, keeping in mind the imperative that any actions taken must be ecologically sound.

4. Prep are a preliminary report by July 31, 1986 summarizing your findings and recommendations involving:

   --Historical background, scientific basis, and current status of the program.

   --Evaluation of operational aspects of the program.

   --Recommendations about alternatives/options for future courses of action for the National Park Service at Sequoia, Kings Canyon, and Yosemite National Parks involving implementation of the programs.

THE PANEL REVIEW PROCESS

The panel received its charge in a letter dated 29 April 1986 from Mr. Howard Chapman, Regional Director, Western Region of the National Park System. Prior to its public meeting, the panel received a variety of documents from Park Service personnel, including management statements and plans, burn plans, monitoring information, and technical papers, as well as letters and supporting documents from interested citizens and conservation groups. The panel met at Sequoia National Park 30 June - 2 July. A public forum on 30 June, during which Park Service policy and procedures were outlined and public comment was solicited, was followed on 1 July with a walking tour of prescribe burned areas in the Giant Forest. Panel discussion on 2 July focused on the identification of specific panel tasks and needs, and outlining our mode of operation. After additional research, the Panel met (8-10 October) to discuss its recommendations and agree on the structure of this final report.

FIRE AND THE ECOLOGY OF SEQUOIA MIXED-CONIFER ECOSYSTEMS

Ecology and Natural Disturbance

Our understanding of the role of natural disturbance in ecosystems has changed since the Leopold Report. In 1963 it was clear that protection of wilderness ecosystems from natural fire was resulting in seemingly undesirable changes; indeed, some of those changes, as in the case of fuel accumulations, were resulting in increased likelihood of catastrophic disturbance. During the past two decades, ecologists who had been fascinated with concepts such as "successional convergence" and "climax community stability" were beginning to talk in terms of "multiple stable points" and "pulse stability." Terms such as "fire cycle" and "fire return interval" became part of the lexicon of every ecologist. Research on the consequences of natural fire with regard to species populations, plant communities, and ecosystem fluxes has convinced us that fire is not a destructive force that always sets succession back, but rather must be considered to be a regulatory process, important to the maintenance of many natural ecosystems.

Recognizing the need to maintain or reintroduce natural fire regimes in wilderness ecosystems, considerable research has focused on the identification of optimal fire regimes in various plant community types and the understanding of the factors that regulate those fire regimes. Implicit in much of this research is the notion that fire is a homeostatic control mechanism--fuel accumulation leads to increased likelihood of ignition, which, in turn, leads to fire and fuel reduction. Such processes are quite ammenable to modelling using digital computers. Mathematical models predicting fuel accumulation can be coupled to similar models of fire behavior and spread based on fuel conditions (see for example Kessell 1979 and van Wagtendonk 1985). Perhaps one of the most important conclusions to emerge from this research is that, even when large areas of wilderness are allowed to burn when natural ignition occurs, constraints such as dissection of the landscape and fire suppression in communities managed for other purposes may result in fire return intervals considerably longer than expected.

The past two decades have also taught us that short-term (decade, century) disturbance cycles are superimposed on longer-term shifts in environment. Although general climatic patterns have remained relatively constant across North America for the past 8,000 years, this period has been punctuated by significant shifts in precipitation and temperature sufficient to alter fire regimes over time scales as long as several centuries. These have undoubtedly resulted in changes in the distribution, structure and composition of many plant communities. We have no reason to believe that such shifts have ceased; ecosystem processes governing community structure will continue to be dynamic.

We have just begun to confront the reality that succession and natural disturbance are variable processes and that chance events (in addition to the homeostatic feedbacks envisioned by ecosystem ecologists of the 1960s) play a major role in determining the status of a particular location at any point in time. Thus, computer models may allow us to predict average fire return intervals and behavior over large areas and significant time periods, but may be of little help in predicting events at a particular location, as for example a single sequoia grove. Furthermore, this chance variation should not be viewed as "white noise" which can be ignored in any management scheme--rather, it is part of the process that must be protected. Not only was such variability a part of the "primitive vignette," but it may be an important contributor to the diversity of fire-prone ecosystems.

How are we to interpret the much cited Leopold Report phrase "vignette of primitive America?" If "vignette" is taken to be synonymous with "snapshot, " then it is the role of the Park Service to discern what that snapshot ought to be and to intervene if necessary to recreate and maintain it. Alternatively, much of current Park Service policy implicitly and explicitly interprets vignette to mean "motion picture." The role of the stewards of our National Parks in this view is to create conditions which allow the process to operate that keep that motion picture rolling.

Species Responses to Fire and Fire Suppression

Sequoiadendron giganteum is distributed in the central Sierra Nevada in relatively discrete groves often with white fir (*Abies concolor*), sugar pine (*Pinus lambertiana*), incense-cedar (*Calocedrus decurrens*), and black oak (*Quercus kelloggii*) (for a complete description of the flora of representative groves, see Rundel, 1969, 1972, and Harvey et al., 1980). The present disjunct distribution of the giant sequoia is considerably restricted compared to its range in Tertiary (pre ice-age) times when it was a dominant tree over much of temperate North America. The present boundaries of the sequoia groves are thought to be regulated by the interaction of soil moisture, temperature and the vicissitudes of seedling establishment (Rundel, 1969, Harvey et al., 1980).

The natural role of fire in sequoia groves was first described by John Muir (1878) who clearly distinguished between the impact of natural surface fires, which creep slowly across the forest floor and do not involve tree crowns, and the crown-killing fires started in the late nineteenth century as a consequence of the activities of European man in this region. Considerable subsequent research (see Harvey et al., 1980 and Kilgore, 1981 for extensive reviews) leaves no doubt that periodic surface fires have always been an integral part of the sequoia-mixed conifer ecosystem. Although these fires were generally light, they varied considerably both spatially and temporally as the fuels, topography, and weather changed. They even occasionally flared up causing local stand destruction. Most of the dominant tree species in this commmuninity, and most especially the giant sequoia, possess morphological features that protect them from fire. Given the antiquity of many of these species, these characteristics may have evolved in the context of plant communities much different than our present-day sequoia-mixed conifer forests. Nonetheless, these adaptations have permitted these species to survive in an environment which was characterized by frequent fires during the past few millenia.

The giant sequoia is not only resistant to frequent fires, but in many ways dependent on them. Its thick bark provides excellent insulation from heat, although it easily chars, and with sufficient radiant heat, it may ignite and slowly burn (Harvey et al. 1980). Surface fires, even when intense, do not appear to significantly alter the survival probabilities of mature trees (Lambert and Stohlgren, unpublished).

Sequoiadendron cones are serotinous, i.e. they remain closed following maturation for as long as 20 years. A single tree may therefore have an accumulation of 20 years of cones and seeds at any time. These cones are opened by the heat produced during fires, causing seed release. Thus, it is clear why seed fall following fire may be twenty times in excess of that in nonfire years.

Seeds germinate as soon as conditions are favorable. Successful establishment of seedlings generally occurs only on mineral soil or ash; thick layers of litter and duff dry out quickly and seedlings desiccate. Seedlings of many of the conifers in the sequoia groves, including pines and incense cedar, share this requirement for a mineral seedbed. Given the high giant sequoia seed rain following fire, it is not uncommon to see dense carpets of seedlings in particularly favorable sites such as beds of ash or moist mineral soil. Hartesveldt and Harvey (1967) noted very rapid attrition of seedlings, 98.6% mortality after two growing seasons. Factors or conditions contributing to successful survival from seedling to pole-size tree are poorly understood, however, seedlings first established on highly heated substrates (e.g. burn piles) survived at a rate several times that of seedlings on lightly burned or unburned substrates after 20 years (Harvey and Shellhammer, unpublished).

Fire has been alleged to have other beneficial effects with respect to establishment and survival of the giant sequoia. Heat and chemical-laden ash from the fire may sterilize surface soil layers, killing potentially pathogenic fungi; this apparently does not influence the establishment of mycorrhizal symbioses (Harvey et al. 1980). At public discussions with this panel the suggestion was frequently made that fire might reduce the mortality of mature giant sequoias by killing potential pathogens in fire scars. Although such beneficial effects of cauterization have been documented in certain fungal diseases of pine, other diseases may be intensified by fire. There are no published data regarding the influence of fire on pathogens in giant sequoia.

The behavior of white fir in response to fire contrasts sharply with that of giant sequoia. Seed production and release are not dependent on fire; rather there is relatively steady dispersal of fir seeds into sequoia groves from natural cone disintegration or squirrel predation. Seedlings are able to grow, even in relatively dense shade (less than 10% of full sun). White fir saplings, poles, and even mature trees are often killed by fires. Mortality in the larger trees is due in part to the even distribution of foliage and branches up the fir bole which may carry even light surface fires into the tree canopy. Scarring of true firs by fire may lead to earlier mortality because scars allow microbial and arthropod invasion, rot, and mechanical weakening.

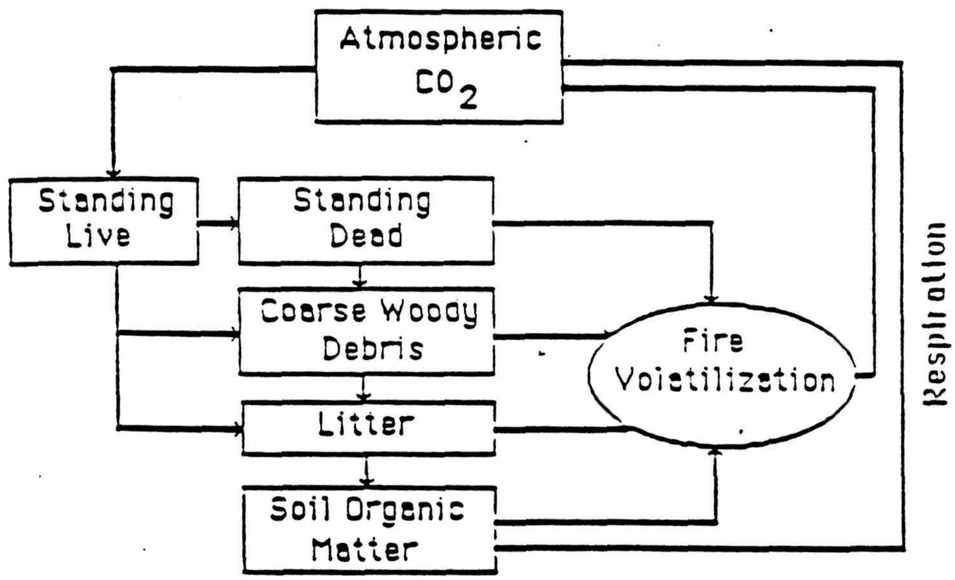
Herb and shrub species of the sequoia groves are also well adapted to frequent fires. Deerbush (*Ceanothus integerrimus*) produces seeds that remain dormant in the soil and are stimulated to germinate by soil heating. Kilgore and Biswell (1971) reported that light surface fires resulted in high densities of deerbush seedlings, intense fires resulted in lower germination, and germination was absent in unburned areas. Deerbush is a nitrogen-fixing shrub and may contribute significantly to the nitrogen economy of sequoia groves. The specific responses to fire of most sequoia-mixed conifer forest herb species are unknown, although the open canopy conditions maintained by frequent fires clearly favor herb growth (Harvey et al. 1980). There is no evidence that prescribed fire has any negative effect on this component of the ecosystem.

Fire and Ecosystem Processes

A conceptual model of carbon cycling for a typical forest ecosystem is shown in Figure 1. There is no question that fire in sequoia-mixed conifer forests produces important changes in the biomass of the forest floor, as well as that of small sapling trees and other woody fuels. Prescribed burning of the forest floor with a headfire at 10% analog fuel moisture has been shown to reduce fine fuels in the litter and duff by 60-70% (Agee et al. 1978). Fire intensity and fuel moisture content can, of course, considerably alter the magnitude of these fuel reductions. In the pine-dominated mixed conifer forests, needles (because of their geometry) remain loosely packed. Thus, these fuels dry sufficiently to burn in early spring. Fir and giant sequoia needles pack much more densely, however, and will often not carry surface fires until drier summer or fall conditions.

What is the extent of the impact of surface fires in sequoia-mixed conifer forests on carbon and nutrient pools? While litter and duff comprise about 30-52 Mg/ha (metric tons per hectare) in mixed conifer forests of Sequoia National Park (Agee et al. 1978), an impressive sum, this is only a small fraction of the total biomass pool of these communities. Coarse woody debris (including down logs and snags) add up to 50-100 Mg/ha and, where giant sequoia logs are present, these values may exceed 400 Mg/ha

Figure 1. A conceptual model of carbon cycling in a sequoia-mixed conifer forest. See text for discussion.



(Harmon et al. 1986). The largest biomass category is that in living trees, which in mature stands is 400-970 Mg/ha. Surface fires may consume a large part of the fine fuel biomass and a significant portion of the coarse woody debris, but the effect on the total system carbon pool is relatively small. We estimate that only rarely would more than 10% of total stand biomass be affected by a surface fire and values less than 5% would be typical. This estimate will of course vary depending on the intensity of the fire, the amount of accumulated woody debris, and the density of subcanopy trees.

Fewer data are available to assess the impact of fire on mineral nutrient pools of nitrogen, phosphorus, potassium and other elements. Organic litter and duff, as well as coarse woody debris and understory plants, contain biologically important nutrients which are affected by combustion. Because most of these materials are woody tissues or senesced foliage which are carbon rich, but relatively low in nutrients, the impact of fire on total fluxes of nutrients must be less than its effect on total carbon flux.

The effects of fire as a nutrient mineralizing agent in coniferous forests have been described in several studies (Rundel 1981) and have been specifically studied in the mixed conifer stands of Kings Canyon National Park. Whereas fire significantly lowers soil total nitrogen, carbon, and cation exchange capacity, it increases the availability of inorganic nitrogen, soluble phosphorus, and cations (St. John and Rundel, 1976). The net effect of this change is that plant growth is enhanced following fire. Total soil nutrient pools are restored rapidly to prefire conditions by accelerated litterfall in the first few months following fire. Furthermore, continued litterfall maintains a relatively stable concentration of exchangeable cations and high nitrogen content in the soil (Zinke and Crocker, 1962).

The long term balance of fluxes and pool sizes for mixed conifer forests shown in Figure 1 are poorly understood. Recent National Park Service data indicate that litterfall restores fine fuels to prefire levels in about 7 years; litter and duff, and intermediate twig and branch fuels may require decades to reach prefire levels (Parsons, 1978). On the other hand, fires which kill but do not consume small and intermediate-size trees may actually increase the size of woody debris pools. Over the period of a few decades the carbon budget may appear not to balance in these forests. However, in the long term fire undoubtedly operates in a steady-state fashion with fuel consumption and fuel production in balance. Such long term processes must certainly be affected by slow climatic changes.

Fire History

Our knowledge of the fire history of the sequoia-mixed conifer forest type for the past several hundred years is limited to a few studies based on analysis of tree rings and fire scars

(Presnall, 1933; Rundel, 1967; Kilgore and Taylor, 1979). Additional inferences may be drawn from studies of adjacent mixed conifer and ponderosa pine forests (Boyce, 1922; Show and Kotok, 1924; Wagener, 1960; Warner, 1980). Kilgore and Taylor's (1979) study in Kings Canyon National Park covers a time period extending back as far as 1478. Although this is a relatively brief period in the long history of sequoia groves, it does span four important periods in regard to land use of the sequoia-mixed conifer forest: 1) The Native American Period (prior to 1865); 2) The Native American-American Settler Period (1866-1875); 3) The American Settler Period (1876-1899); 4) The Modern Period (1900 to present). Prior to 1876, fire return intervals in small clusters (0.4-0.8 ha) averaged 9.2 years on southwest-facing slopes and 16.4 years on southeast-facing slopes (Kilgore and Taylor 1979). Only two trees recorded fires after 1875, and these were at higher elevation. The Kilgore and Taylor data show that the average fire return intervals increased slightly during the transition from the Native Americans to American Settlers. Elimination of Native American activity and the initiation of fire suppression activities in 1890 account for the subsequent drop in fire occurrence. Using records from 1921 to 1972 for lightning-caused fires in this region, Kilgore and Taylor concluded that lightning alone could not account for the short fire return intervals prior to 1875.

Generalizations regarding fire history of particular forest types or for particular regions must be advanced with caution. Variations in physiographic conditions and the distribution in both time and space of fires recorded by fire scars or more recently by fire control officers limit our capacity to extrapolate. In fact, Moir (1980) has questioned the extrapolation of fire history data beyond the particular locality where it was gathered. Also, because very low intensity and low fuel consumption fires occur when the period between fires is shortest, trees at a given location are not always scarred and estimates of fire return intervals based on such data probably over estimate actual intervals. With these reservations, we suggest that fire return intervals during the Native American period averaged about 13 years. In the American Settler and Modern Periods the fire return interval had increased to over 50 years. It is important to note that, even during the Native American Period, many tree clusters escaped fire for periods in excess of 50 years.

Although we may calculate an average fire return interval for stands or portions of stands, the variance in that average may be as important ecologically as the average itself. Olson and Martin (1981) found that the frequency distribtion of fire return intervals could be described by standard statistical models such as the normal distribution or Weibull function.

What was the fire regime in these forests prior to the advent of Native Americans (ca. 4000 BP; although recent evidence from Eldorado National Forest suggests human residence 17,000 years ago)? This may be a moot question. The fire-free interval since the end of the Native American Period does not give us an accurate indication because of fire suppression. Lightning has started fires at elevations above and below the sequoia groves, and these fires have usually been supressed before they burn into the groves. Given fuel discontinuities, local climatic patterns, and the vagaries of fire behavior, we cannot easily estimate what the current fire frequency would be in sequoia groves if lightning were the sole ignition source. We can say that it would be considerably longer than 9-16 year fire return interval documented by Kilgore and Taylor (1979) for the Native American Period and may be in excess of 50 years.

The period of Native American influence was relatively brief in relation to the evolutionary history of long-lived species such as Sequoiadendron. This is a rather different situation from the evolutionqry role of human-caused fires in parts of Africa or Mediterranean Europe.

Ecological Methodology and the Limits of our Understanding

Our understanding of the primeval structure and composition of sequoia-mixed conifer forests, as well as the nature of the processes responsible for that structure, is constrained by methodology. It is essential to clearly differentiate what we do know from what we do not know but can discover given appropriate research effort and what we do not know and cannot know because the evidence simply does not exist or methodology is insufficient to the task (see Stephenson, 1986).

The most widely used method for reconstructing past fire regimes is construction of fire chronologies based on tree fire scars and ring counts. Such determinations can be made on tree stumps or sections removed from living trees (McBride, 1983). To be successful, trees must be relatively long-lived, have basal fire scars, and be free of heart rot. Giant sequoia, incense-cedar, and sugar pine, dominants in most sequoia-mixed conifer forests, meet these requirements.

In order to use ring counts to determine fire scar age, one must be able to correctly identify fire scars and recognize abnormalities in pattern of annual ring production. Other types of wounds, such as frost crack, insect damage, and root rots, may superficially resemble fire scars. Rowe et al. (1974) suggested four distinguishing fire scar features: 1.) triangular shape, 2.) presence of charcoal flecks, 3.) dramatic change in ring width following fire, and 4.) black crust on scar margins.

Annual ring abnormalities include missing, discontinuous, or false rings. Such abnormalities arise as a consequence of climatic variations, defoliation by insects or fire, or damage to the tree crown. Discontinuous rings are common and can be particularly vexing in giant sequoia. Cross-dating among samples can solve some of these problems (Stokes, 1980).

Fire frequency diagrams, fire chronologies, or composite fire intervals can be prepared for an area by combining data from individual trees (Arno and Sneck, 1977; Dieterich, 1980). Mean fire-free intervals (i.e. the time period between successive fires in a specified area) can be calculated on scales ranging from single trees to forest regions. Kilgore and Taylor (1979) noted considerable small scale (single tree and small groups of trees) variation in fire chronologies and warned against extrapolation of such chronologies beyond the area from which the sample was taken. To date, fire chronological research has been focused in a few sequoia groves and little is known of the regional fire history of sequoia-mixed conifer forests.

Fire history maps can be prepared based on the fire chronologies of individual trees. Maps for each fire year are prepared by mapping the location of each tree with a dated fire scar for that particular year. Although stand age data and topographic maps may assist in these efforts, extrapolation of fire boundaries beyond the sample area is subject to considerable error. Problems, such as the fact that not all trees are scarred during every fire, increase the uncertainty in estimates of regional fire-free intervals or boundaries of particular fires. Indeed, when fires are very frequent (and therefore of low intensity and fuel consumption) no trees may be scarred.

Recent innovations in reconstructing past fire regimes include dating charcoal in cores taken from bogs and lakes (Swain, 1973; Byrne et al., 1977). However useful these methods are in determining long-term trends or answering other paleoecological questions, they have very limited spatial and temporal resolution and will be of little use in reconstructing stand fire chronologies. New techniques, such as examination for production of traumatic resin canals (Zackrisson, personal communication) or variations in tree ring mineral content may provide future alternatives to the fire scar dating method.

How can we determine the past structure and composition of sequoia-mixed conifer forests? Among the tools available for historical reconstruction are pollen analysis, phytolith analysis, macrofossil analysis, historical photographs, historical descriptions in land survey records, characteristics of present day forest ecosystems (including stand population structure and nature of woody debris), and computer simulations based on forest succession models. Despite this variety of methods, we should be clear at the outset that the accuracy and detail of our determination of past forest structure will always diminish rapidly as we look further back in time and as we increase the size of the area we wish to understand. In addition, we must constantly recognize that the sequoia-mixed conifer forests did not exist in a particular static structure prior to the intervention of settlers; rather they were undergoing constant change. Thus, in asking what past forest configurations were, we are shooting at moving targets.

Analysis of lake and bog cores for changes in pollen and other plant micro- and macro-fossils has provided us with important measures of long-term vegetation change and, by inference, climatic change (Davis, 1986). However, these analyses are severely limited by the distribution of lakes and bogs with appropriate stratigraphic features and of proper age (there are very few such lakes in the middle elevations of the Sierra Nevada). Furthermore, they provide a very broad brush picture of regional vegetation composition, and only under the most extraordinary circumstances can they resolve time periods shorter than centuries. For example, it is unlikely that the successional changes observed in post settlement sequoia-mixed conifer forests would be statistically discernable in the pollen record of a lake surrounded by such forest. These data do, however, provide us with an understanding of long-term climatic and vegetational variation that is necessary in interpreting other data.

Ecologists have recently explored the use of phytoliths (silica crystals, often opal, formed plant cells) to document historic vegetation change (e.g. Kalisz and Stone, 1984). However, this method is only useful in discerning major changes in physiognomic type (e.g. grassland vs. forest) and would not be sensitive to the variations in structure and composition of forest types of interest here.

Photographic and archival historical records have been used to great advantage in evaluating past stand structure in many forest ecosystems. Indeed, Vankat and Major (1978) made extensive use of this approach to determine historical changes in fire patterns for the Sequoia National Park (see also Gruell (1983) for a similar study in the northern Rocky Mountains). Several problems limit the use of these methods. First, they have a limited temporal and spatial perspective; such records exist for relatively few sites and often for only a few localities within a particular stand. Second, such records have a number of built-in biases. Survey crews are known to have "favored" particular tree species or tree size classes in survey records and as witness trees. Photographers were invariably influenced by aesthetic considerations and probably avoided areas with dog-hair thickets of white fir or charred trees. Even experienced naturalists, such as John Muir, presented an often unrepresentative picture of the landscape. While we can take allowance for some of these biases, they severely limit our ability to extrapolate beyond the specific areas photographed or described.

The characteristics of existing vegetation coupled with conceptual or computer models of successional change have been used by Bonnicksen and Stone (1982) to reconstruct past structure in the sequoia-mixed conifer stands of Redwood Mountain. In their study, homogeneous groups or aggregations of trees were identified and their age structure (based on size-age regressions) were determined. Dead woody debris was used to supplement this data set. On the basis of assumptions regarding the nature of thinning in even-aged cohorts, patterns of ingrowth, and other successional changes, current stand configurations were projected backward to arrive at a description of stand structure at some earlier time. Bonnicksen and Stone (1985) have advocated this method to acquire site-specific data necessary to restore stands to primeval structures. Furthermore, they express concern that the current fire management program in these forests, by consuming woody debris and some trees, is destroying potential information necessary for such reconstructions.

This approach has received criticism on several points (see especially Stephenson, 1986). The uncertainty of predictions from any sort of time-dependent model of a process in which chance factors play a role must increase with the length of time over which predictions are made; this applies to models run backward as well as forward in time (see Shugart, 1984 and Dale et al., 1985 for a complete discussion of the limitations of simulation models of plant succession). This is not a fault of the models, but an accurate picture of reality. Just as a variety of factors may cause the successional trajectory of relatively similar forest communities to diverge, stands with widely varying structures may, for a variety of reasons, converge to a particular structure. For example, Peet and Christensen (1980) found that pine stands varying over two orders of magnitude in density when established converged to nearly uniform density after 60 years. Given the rapid decay of downed wood in the region they studied, very little information regarding the past history of these stands is encoded in their current structure. Stephenson (1986) also notes that it is likely that thinning results in contraction in the size of aggregations with age. At the very least, current succession models for sequoia-mixed conifer forests are predicated on a variety of untested assumptions regarding the nature of establishment and mortality in all component species. Small variations in some of these assumptions result in large variations in predictions. Stephenson (1986) and Harmon et al. (1987) expressed concern that the decay of logs and other woody debris is highly variable and often too fast to allow meaningful reconstruction. Standing giant sequoia snags may persist for over 2000 years (Harvey et al., 1980), whereas downed boles of white fir are totally decayed after only 60 years (Harmon et al., 1987). Thorough reconstructions based on such debris, such as that done by Henry and Swan (1974), are prohibitively site intensive (Henry and Swan studied a 10x10 meter area) and certainly limited in temporal resolution.

Despite their shortcomings, computer simulation models of forest succession will be useful in future planning and policy development. Such simulations can be used to predict probabilities of past landscape configurations and to provide estimates of variability in successional change and probabilities of particular successional trajectories. We can certainly use such predictions (allowing for assumptions) to determine whether a particular stand structure and composition is within the range of such structures expected as a consequence of natural successional processes. Importantly, simulation models provide a theoretical framework within which research on the population dynamics of sequoia-mixed conifer species can be carried out.

Fire and the Appearance of Sequoia Groves

One consequence of burning, regardless of the origin of the fire, is the potential charring of bark and scarring of the cambium and wood at the base of trees. The change in the appearance of trees as a result of charring and scarring can result in decreased scenic quality ratings and reduced recreational acceptability (cf. study of fire in ponderosa pine forests by Taylor and Daniel, 1985). Bark char is especially striking on the surface of trees with light-colored bark such as the giant sequoia.

Careful observation of giant sequoia boles indicates a repeated history of fire scar formation and bark charring. Owing to erosion and sloughing of charred bark scales during the extended fire-free interval since the establishment of parks, few trees, except those in prescribed burn areas, currently show extensive areas of charred bark. The charring that has resulted from the current prescribed burning program is especially dramatic because of the contrast between the relatively char-free trunks of trees in adjacent unburned areas. Recollection of previously uncharred trunks in recently prescribed fire areas familiar to observers also contributes to the visual impact of such charring. Hammett (1979) documented a high correlation between familiarity and visual preference.

The appearance of forest stands is also altered by changes in return intervals of surface fires which reduce the numbers of seedlings and saplings of shade-tolerant species. In the giant sequoia-mixed conifer groves, considerable ingrowth of white fir has occurred as a consequence of fire control. This dense understory (dog-hair thickets in places) has reduced visual penetration into the forest (visual penetration is highly correlated with scene quality in forest stands {Bacon and Twonbly, 1979}). Prescribed burning programs can increase visual penetration when fires are able to reduce saplings in the understory. Improved visual penetrance may require 2-3 years following a prescribed burn as foliage is shed from killed saplings.

Was the visual impact of natural fires prior to the American Settler Period different from that observed today in prescribed burns? Extensive charring of giant sequoia trunks occurs primarily as a consequence of radiant and convective heat generated by the combustion of nearby fuels, such as piles of woody debris, snags, and white firs growing in the understory. Greater than average snow damage in recent years has added to the accumulation of heavy woody debris at the base of many giant sequoias. In the high-frequency fire regime of the Native American Period, accumulation of such heavy fuels was minimized and charring would have been considerably reduced. It is quite likely that particular groves or portions of groves may have had heavy fuel accumulations or dog-hair thickets of white fir during the Native American Period as a consequence of longer-than-average fire free intervals, and charring would have been extensive in such locations. Thus the visual changes caused by the current prescribed burning program are within the range of those that might have been observed in natural fires prior to the American Settler Period, but charring and other visually striking consequences of locally intense burning are probably more widespread in some burn units than might have been seen on average prior to settlement.

NATIONAL PARK SERVICE FIRE POLICY

The charge to this panel states that "the goal of the fire management program in the Sierran sequoia-mixed conifer forests ... is to maintain or restore natural fire regimes to the maximum extent possible so that ecosystems can function essentially unimpaired by human interference. This goal is based in NPS policy." Here, we examine current Park Service fire management policy with respect to the following questions:

1. Are policies explicit and operational? Are fire program aims and goals consistent?

2. What assumptions regarding the role(s) of National Parks and the nature of ecosystems are explicit and implicit in current policy?

3. Is NPS fire management policy consistent with our current understanding of fire effects and ecosystem function in sequoia-mixed conifer forests?

4. Is current policy consistent with legislative regulatory statutes, including legislation aimed directly at the National Park Service and the National Environmental Protection Act?

5. To what extent do aesthetic, liability, political, and economic factors influence fire management policy? To what extent should they?

Two specific criticisms of NPS fire policy were raised quite emphatically with the panel. 1.) Concern was expressed that aesthetic and scenic considerations are a minor component (at best) of current fire policy and its execution by managers. 2.) Rather than managing sequoia-mixed conifer forests to recreate or maintain a particular structure representative of their primitive state, current policy is directed toward maintenance of ecosystem processes. Included in this criticism are concerns that: a) the Park Service has abandoned the "vignette of primitive America" concept; b) that processes such as fire may not behave "naturally" in ecosystems altered by 70 years of fire supression; and c) that prescribed fires may destroy evidence (age structure, downed wood, etc.) that might be useful in determining the primeval structure of sequoia-mixed conifer forests.

General Policy

The National Park Service Act of 1916 states that "the fundamental purpose of [National Parks] is to conserve the scenery and, the natural and historic objects and the wildlife therein and to provide for enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations." It is clear that "objects" were to be preserved, and parks, monuments and reservations were to be set aside for the People to enjoy scenery and natural and historic objects. Interpretation of this mandate into specific National Park Service policy has clearly evolved to keep step with current ecological understanding and changing philosophies of conservation management.

The specific reasons for preserving particular objects vary. The vistas of the Blue Ridge Parkway are clearly maintained for their scenic beauty, Cade's Cove in the Great Smoky Mountain National Park is preserved for its historical merit, and large areas of our parks are conserved as special representatives of natural features and ecosystems.

Park Service policy in the early part of this century clearly focused on preservation of "objects" per se; Park Service officials perceived the urgent need to protect park resources from any form of disturbance, natural or man-caused. Experience with conflagrations resulting from timber cutting and settlement convinced most land managers of the 1900-1940 period that fire in any form was undesirable with respect to this goal (Pyne, 1982). Certainly, few ecologists of this era appreciated the successional consequences of excluding fire from coniferous forest communities. Between 1916 and 1968, Park Service policy was to strictly suppress wildfire and to eschew the use of prescribed fire. Although not officially adopted, the U.S.D.A. Forest Service's so-called "10 AM policy" was adhered to; fires should be supressed by 10 AM of the morning following their report.

The fact that the absence of fire or other natural disturbance would initiate successional changes in some plant communities became obvious to some ecologists in the period 1940-1950 and was widely accepted by 1960. This point was especially prominent in the 1963 Leopold Report (although the mandate of that panel was to examine issues related to wildlife management). The Leopold Report, which was adopted by then Interior Secretary Udall as official policy, emphasized the importance of understanding "natural or man-caused process of ecological succession" in managing ecosystems. In response to that report, as well as other research findings, Park Service policy toward fire was dramatically changed in 1968. Fires of natural origin (i.e. not man-caused) were recognized as "natural phenomena" and prescribed burning was accepted as a means of achieving resource objectives (Butts, 1985). Implicit in this policy change was the recognition that, in order to preserve certain "natural objects" as mandated by the 1916 Act, natural processes must be preserved as well. Management of the sequoia-mixed conifer forests has been a paradigm for this change in policy (Kilgore 1987).

In the years immediately following 1968, Park Service policy permitted considerable innovation. New fire-management programs were initiated in the absence of clearly-stated guidelines or policy. In response to this situation, Park Service wide management policies were rewritten in 1975 (U.S.D.I., 1975). In 1978, NPS-18 Fire Management Guidelines (U.S.D.I., 1978) became the first codified instructions for National Park fire programs. Fire policy in parks was tied to park-specific management objectives. NPS-18 (1986 revision) states as follows. "The fire management program of all parks must be designed around park objectives. In regards to natural systems, this may include the need for some portions of all parks to proceed through succession towards climax while others are set back by natural fire. Large parks managed as natural zones should represent the full spectrum of their dynamic natural vegetative patterns. Sharply defined zones or blocks of vegetation limited to certain species, arbitrarily locked in over time, are not natural and only rarely are justified." Biological, ecological, and physical problems are the central concerns of NPS-18; there is no direct reference to management of scenery. Human considerations are limited to minimization of resource damage owing to fire suppression activities and liability for air quality, human life and safety, property protection, threatened or endangered species, fire escape or exceeding fire prescriptions.

Since 1963, we have learned that ecological communities are not only changing, but that those changes are not nearly so deterministic as envisioned earlier, even by the Leopold Panel. Although we may speak of average return intervals, intensities, and behavior patterns, natural disturbances such as fire do not occur with precise regularity; rather, return intervals, intensities and spatial extent vary considerably about regional averages. Thus, the variation in environmental factors, rather than average conditions, may be important driving factors of ecosystem structure and function. Furthermore, climatic shifts over centuries and millenia have resulted in changes in those averages and variances. Thus, at any given time on the presettlement landscape, particular ecosystems, such as the sequoia-mixed conifer forests, varied from location to location in precise successional state; similarly, a particular location might experience a variety of disturbance regimes over the life time of a long-lived tree such as the giant sequoia. Thus, the "objects" envisioned in the 1916 Act were by no means static.

This fact presents a major policy dilemma which has yet to be completely resolved. We could select a particular structure for the objects we wish to preserve and use a specific disturbance regime to "freeze them in time." This would be equivalent to treating parks as museums (the use of the term "museum" in this context is not synonymous with Bonnicksen's (1987) "living museum concept"). Alternatively, we could accept the landscape as a mutable entity and attempt to preserve the processes that maintained it in its primeval state. We refer to this as the "dynamic ecosystem concept." Formulation of management policies based on the museum concept demands that we decide (either arbitrarily or based on ecological criteria) exactly which state we wish to preserve and that we identify the disturbance regime necessary to maintain that state. Policies based on the dynamic ecosystem concept demand an understanding of the variability of disturbance cycles and the means to allow them to occur or properly simulate them.

This panel is firmly in favor of policies based on the dynamic ecosystem concept. It may not be possible to manage restricted areas such as campsites, areas immediately surrounding human-built structures, and showcase areas (see below) entirely as dynamic ecosystems, allowing the full range of fire effects to occur. However, within the specific constraints placed on those areas, we feel that such management is the proper goal. Certainly, wherever preservation of natural ecosystems is the primary goal, policies must be consistent with the reality that such ecosystems are dynamic.

The dynamic ecosystem concept is most clearly stated in park-specific management plans and is less explicit in Park Service-wide policy statements. The Leopold Report, particularly in the use of its oft-cited catch phrase "vignette of primitive America," is ambiguous on this issue. We recommend that a panel of appropriate experts be assembled to examine changes in our understanding of ecosystem structure and function and landscape ecology since the Leopold Report and to evaluate current Park Service-wide policy in light of these changes.

Park-Specific Policies

Sequoia and Kings Canyon National Parks were established to "protect the natural resources but especially their wilderness character and their vegetation, with emphasis on the giant sequoia forest." Sequoia-mixed conifer forests are less extensive in Yosemite and, therefore, play a less significant part in that park's mandate.

Fire management plans were prepared for all three Parks in 1979 and have been periodically updated since then. The goal of the fire management for all three parks is summarized in the Sequoia-Kings Canyon plan: "to restore or maintain the natural range of fire behavior and effects (i.e. fire regime) to the maximum extent possible so that natural ecosystems can operate essentially unimpaired by human interference. It is not a goal to return to some historic point in time, but rather to allow fire to operate as a process as fully as possible." Several important points are implicit and/or explicit in both burn plans. 1.) Prescribed fire may be used for either or both of two purposes: i.) to restore an ecosystem to a structure within which natural fire may be allowed to occur and ii.) to maintain (simulate) the natural fire regime when constraints prevent the natural fire regime from occurring. 2.) The natural fire regime is defined as that which would occur in the absence of human interference. Indian-set fires are explicitly defined as not natural. 3.) Emphasis is on maintenance of natural processes and not to restore ecosystems to a particular configuration characteristic of a particular point in time. 4.) Specific fire management guidelines may vary within specific zones demarcated in each park. 5.) Aesthetic consequences of fire management are not explicitly considered in the Sequoia/Kings Canyon burn plan with the notable exception of "showcase" areas; concerns for visual impacts are explicit criteria for the development and execution of burn plans for the sequoia-mixed conifer forests of Yosemite.

It is important to decide whether the primary goal of each particular fire is to restore the ecosystem to a natural status or to maintain an already established status. Fire management plans repeatedly refer to "unnatural fuel loads" in sequoia-mixed conifer forests. Certainly today's widespread heavy fuel loading is a skewed representation of presettlement conditions (although local heavy accumulations of fuels were always present). The goal of fire in this situation will be to reduce the fuel load while minimizing the potentially negative impact of "unnaturally" high fire intensities that such fuel loads might generate. Given that fuels in such situations are not representative of natural conditions to begin with, fire managers need not be particularly concerned that extensive site preparation involving movement or manipulation of heavy fuels or raking of litter will result in unnatural fire behavior. Restoration fire can be viewed as a means to an end, that end being the creation of conditions in which fires may burn naturally. Although it is not necessary or even desirable that fuel manipulation be minimized when the ultimate goal is restoration, it is of course important that any negative impacts of such manipulations (e.g. disruption of root systems by skidding of debris) be minimal. Where fuel conditions are judged to be natural and the goal of prescribed fire is to maintain the natural regime, fuel manipulation should be minimized. We recognize that specific areas within a burn unit may be classified differently with respect to the above categories; site preparation within the burn unit can be adjusted accordingly.

Several participants in this review have questioned whether current fuel conditions should be viewed as unnatural. Dog-hair thickets of white fir and accumulations of woody debris were also part of the presettlement landscape. While this is true, it is our conclusion that such fuel situations represent an unnaturally large part of our current landscape and that the impacts of the intense fires that result from such fuel conditions are more widespread in some burn units of this type than would have been expected on the primeval landscape. Fuel conditions may be judged to be natural in burn units where heavy fuel conditions are infrequent and scattered; manipulation of fuel in such situations is not warranted.

How large or widespread should such conditions be to qualify for restoration burning? We feel this should be studied and a firm policy developed by fire management personnel. For example, areas of heavy fuel accumulation exceeding a given size (e.g. 0.1 hectare) or burn units in which over 10% of the area is judged to have an abnormal accumulation of fuel could be classified for restoration burning.

Natural fire regimes are explicitly defined in park-specific fire management plans to exclude fires set by Indians during the Native American period. However, NPS-18 and general Park Service policy make no such restrictions.

All research to date points to the fact that the large majority of ignitions for the middle elevation forests of the Sierra Nevada over the past several thousand years were set by Native Americans. This time period includes the lifetimes of all extant giant sequoia trees. Thus, the sequoia-mixed conifer forests described by the early commentators were ecosystems that had a very long history of development under a burning regime dominated by Indian-set fires. Excluding such fires from consideration might greatly lengthen the fire return intervals compared to estimates of such intervals in the 400 years preceding the American Settlement Period. Because of methodological problems (see pp. 10-13), we cannot make precise estimates of what fire return intervals would be if lightning were the sole ignition source. Based on fire return times since the elimination of Native American-set fires, on the frequency of lightning on the west slope of the Sierra, and on the natural and human-caused dissection of the landscape which impedes fire spread, lightning-caused fire return intervals may be in excess of 50 years. This time period is quite similar to the time of active fire supression in the Parks which has led to the "unnatural accumulation of fuels." It is unlikely that these groves experienced such lengthy average fire return intervals in the several thousand years preceding settlement.

The following reasons are given for this exclusion in the Sequoia/Kings Canyon Fire Management Plan.

1. The season, techniques, and pattern of Indian burning in these areas are too poorly understood to mimic with any degree of accuracy.

2. The Indians burned for specific benefits, such as better hunting and food gathering. If Indian burning is mimiced, these uses should also be mimiced, if the total Indian influence is to be recreated.

3. The emphasis on resources management is on the preservation of processes which influence ecosystems, and is not generally on scene management, in which a static point in time is maintained. The Indians were a relatively recent influence, and it is not the goal of these Parks to freeze ecosystems at the Indian era.

We question these reasons and suggest that this policy be reconsidered. 1.) All of the direct estimates of fire return intervals in sequoia-mixed conifer stands are based on the Native American Period. We can develop and refine our knowledge of fire regimes during the 1000 years preceding settlement using direct empirical evidence such as that presented by Kilgore and Taylor (1979). We strongly support continued research to gather such data. 2.) That the total Indian influence must be recreated is a non sequitur. First, there is no evidence that the benefits that Indian populations derived from burning were, in themselves, important to the maintenance of the structure and composition of mixed conifer ecosystems. Second, most Indian-set fires which burned Sequoia-mixed conifer forests were probably not initially ignited in these groves, but rather in adjacent ecosystems where benefits of wildfire to Indian populations were considerable. 3.) It is not clear that adoption of a burning regime that includes fires set by Native Americans would necessitate "freezing" an ecosystem at some point in time. It is unlikely that these systems were in any sense frozen during the Native American Period. Fire management plans should include the variance in fire return times, as well as estimates of the average.

We recommend that the Park Service reevaluate its policy of using lightning-caused fire frequencies as the proper management goal. In particular, we must determine that exclusion of Indian-set fire from fire management plans will not result in fire return intervals nearly as long as the fire suppression era. We recognize that incorporation of Native American activities into burn plans will present more difficulties to Park Managers than a policy based entirely on "natural" fire (see Phillips 1985 for a cogent review of the problems involved in including Indian-set fire in burn management plans). If inclusion of Indian-set fires in burn management plans is deemed desirable, implementation of such a fire management plan will require considerably more data regarding fire behavior in sequoia-mixed conifer forests throughout the Park system. Most important, long-term management strategies will need to be developed that include the spatial and temporal variation in fire regimes that must have existed. This is not a matter that must be decided immediately. Indeed, development of long-term management plans that incorporate Native American Period fire return intervals will require considerably more research and discussion.

This question raises the broader issue of whether sequoia mixed conifer forests should be treated as museums, preserved by whatever means necessary in some a priori determined structure, or "dynamic ecosystems," in which the processes that maintained these forests prior to some point in time are perpetuated with the knowledge that periodic change will occur. We consider a strict interpretation of the museum policy to be both impractical and undesirable. Given the range of variability in stand structure and composition that has existed at all points in time, an extreme interpretation of this policy would require that such reconstructions be done on a stand-by-stand basis (indeed, for large heterogeneous groves reconstruction would need to vary within the stand). We have already discussed the methodological problems inherent in determining past stand structure (see pages 12-13); suffice it to say here that such stand-by-stand reconstruction is surely impractical, if not impossible. Alternatively, all stands could be managed to match an estimate of their average structure and composition at some arbitrarily selected point in time. This form of management would lead to monotony among stands which would be undesirable from both an ecological and scenic standpoint. Such a strategy would give the phrase "if you've seen one redwood, you've seen them all" truthful meaning.

Is the current burn management program destroying useful information as suggested by Bonnicksen and Stone (1985)? We suggest this is not happening in most cases. First, most of the woody material consumed in prescribed burns postdates the beginning of the fire supression era. Second, we consider it unlikely that intensive analysis of woody debris such as that carried out by Henry and Swan (1974) is practical over large areas. In most cases the costs of halting or altering the program for these reasons are not balanced by doubtful potential benefits.

We are convinced that the best practical method to maintain the diversity characteristic of the primeval landscape is to perpetuate the natural processes that maintained that diversity. With regard to the sequoia-mixed conifer forests, this will require continual management intervention rather than simply passively allowing natural processes to operate. Dissection of the evironment by human activities and human-built structures (roads, developments, etc.), as well as fire suppression off of Park Service property, limit the spread of natural fires. Furthermore, concerns for public safety and liability will continually limit the Park Service's ability to allow natural ignitions to burn at will in middle elevation forests. Therefore, the prescribed burning program for these forests should not be viewed as a temporary means of returning them to a state in which natural fires will simply be allowed to occur. Rather, it should be permanent program with long-term funding. The goals of the program will need to gradually shift from fuel management to simulation of the primeval burning regimes.

This is not to say that every sequoia-mixed conifer stand should be managed in this fashion or with these goals in mind. For a variety of reasons, including specific scenic goals, campsites, proximity to commercial structures, or liability problems, specific stand structures might be maintained. This sort of management is already imbedded in current management plans by means of explicitly identified management zones and showcase areas.

The "Showcase Concept" developed for specific areas of Sequoia and Kings Canyon National Parks deserves special mention. Fire management in these areas is overtly directed toward aesthetic goals compared to maintenance of natural processes. Ecological concerns are not neglected in designated showcase areas, but subjectively determined aesthetically negative effects of fire are minimized by fuel manipulation and removal of charred saplings and small trees. We support this policy so long as it pertains to clearly defined areas where scene management should be the primary management concern. A similar policy should be implemented more widely in the National Park system. However, we feel the prohibition on preburn cutting of trees unnecessarily limits opportunities for scenic enhancement. We recommend that judicious preburn cutting be allowed in showcase areas. Showcase areas currently include the General Sherman Tree and nearby Congress Trail, Crescent Meadow, and the General Grant Tree and vicinity. Additional areas, such as restricted scenic overlooks along major paved roads might also be considered for showcase status.

To what extent and in what fashion should aesthetic concerns be integrated into overall park fire management plans? The Yosemite Fire Management Plan mandates that scenic consequences be considered in burn plan development and execution, whereas there is no explicit mention of such considerations in the Sequoia/Kings Canyon plan. It is clear, however, that, to a greater or lesser extent, fire management personnel incorporate scenic values into burn plans for sequoia-mixed conifer forests in all parks.

We do not view this as a scene management versus natural process management issue. Rather, we recognize that fire managers often select among a variety of ecologically equivalent burn plan alternatives that include such variables as spatial and temporal arrangement of burn units relative to one another, aerial extent of burn units, definition of burn unit boundaries, nature and extent of site preparation, mode of fire application, and post-fire clean up procedures. Assuming a set of fire plan alternatives equally consistent with long-term ecological goals, specific burn plans are selected based on a variety of "nonecological" criteria, including personal safety, cost, liability, ease of execution, and scenic impact.

We recommend that long-term fire management planning explicitly include input from individuals trained in landscape architecture. In making this recommendation, we do not advocate "scene management," but rather suggest that persons with formal training in the aesthetic consequences of landscape manipulations can identify specific concerns and aid in selecting from among ecologically acceptable alternatives. Such consultation will be most important in burning planned in showcase areas. Nevertheless, such professionals may be helpful in aspects of planning for restoration and simulated natural fires, such as identification of burn unit boundaries and location of burn units relative to one another.

The specific mechanism by which a person trained in landscape architecture should be integrated into the process of burn plan development was not clear to us. The Park Service may wish to consider a system used by the Forest Service in which burn plans and logging plans are reviewed by an interdisciplinary committee that includes input from resource management, research, landscape architecture, and recreation personnel. When burning is planned for areas of high public interest, interpretive staff might also be represented on such an interdisciplinary committee.

Concern was raised at the public meeting of the Panel in July 1986 that the fire management program might not be consistent with legislative regulatory statutes. While a few already-discussed inconsistencies between general Park Service policy and park-specific management plans require attention, we do not find the fire management program to be at odds with the legislative mandate for either the entire Park Service or the individual parks.

We have reviewed the statutes related to the requirements of the National Environmental Policy Act (NEPA). The Panel's comments on this issue are offered with the caveat that no member of the Panel has legal training and the Panel did not consult legal counsel.

It is not clear to us that all fire management activities, particularly those involving maintenance of natural processes, require preparation of formal environmental impact statements. However, a general environmental impact statement was prepared for the Park Service-wide Fire Management Program in 1975. Management plans and environmental assessments which included the fire management programs were prepared by Sequoia and Kings Canyon National Parks in 1976 and Yosemite National Park in 1979, with appropriate opportunity given for public comment. These policies and management plans have been subjected to periodic review over the past decade. Indeed, this panel's evaluation is consistent with the review process mandated in the NEPA statutes. It is the view of fire management personnel in the Park Service that the fire management programs in the sequoia-mixed conifer forests have been executed within NEPA gudielines and this panel concurs in that view.

As a matter of general principle, we suggest that all Park Service fire management plans will benefit from periodic review by experts from outside the National Park Service. We encourage the Park Service to establish formal external review programs.

BURN PLAN PREPARATION AND IMPLEMENTATION

The Panel was impressed with the expertise and professional attitude of the fire management personnel in both Yosemite and Sequoia/Kings Canyon National Park units. Each member of these teams displayed an understanding of general Park Service goals and policies and a sensitivity to the specific role of the fire management program in the sequoia-mixed conifer ecosystems. The Park Service is indeed fortunate to have attracted such an outstanding staff.

With the exception of those reservations discussed in the preceding section, we feel the process of burn plan preparation and execution suffers no major problems. However, in the context of those reservations, we make the following recommendations regarding the specifics of burn plans.

1. In burn units specifically designated as showcase areas and within which aesthetic concerns are a prominent feature in the goals of the burn plan, we recommend that judicious preburn cutting of live trees (especially young white firs) be permitted to broaden scene management options. Such cutting should be consistent with ecological goals. We recommend that practices such as removal of heavy fuels and "fuel ladders" from giant sequoias and wetting of burning trees to minimize bark char be continued in showcase areas.

2. Where prescribed burning is being done in areas managed primarily as natural ecosystems, such burns should be classified as either "restoration fires" or "simulated natural fires." Restoration fires are carried out in order to manipulate fuel conditions judged to be unnatural (see preceding discussion), whereas simulated natural fires are intended primarily to maintain the primeval fire regime. Based on variability in fuel conditions, some areas within a particular burn unit may be designated for restoration burning and others for simulated natural fire. Recommended differences in site preparation, ignition procedures, and postfire treatment between these two categories are discussed below.

3. In burn units or portions of burn units designated for restoration burns, fuels should be manipulated to ameliorate extensive or widespread charring of dominant trees that might result from unnatural fuel conditions. Such manipulations may include movement of heavy fuels from the base of large giant sequoias and judicious felling of living late successional species, such as white fir, when population densities of such invaders are judged to be in excess of the normal range of variation expected on the presettlement landscape. Scattered dense populations of such invaders of limited spatial extent (a few hundred square meters) were present on the primeval landscape and require no manipulation. Prefire fuel manipulation in burn units designated for simulated natural fire should have only that manipulation of fuel required to control the fire within designated boundaries and guarantee safety of personnel.

4. The specific ecological consequences of differences in ignition procedures (e.g. head fires, backing fires, spot fires, etc.) are not well understood. To the extent possible, simulated natural fires should be ignited in as natural a manner as is reasonable within the constraints of personal safety and fire

control. This will usually mean a single burning front allowed to burn as it will through the stand. Experience with natural wildfires in two giant sequoia groves this past summer suggests that such fires may burn very slowly; complete burning of a unit may vary from a few hours or days to several weeks. Other contingencies such as heavy visitor use, smoke management, or personnel limitations during the fire season may not permit burning to continue over such protracted periods. When this is the case, we recommend that burning may be hastened by multiple ignitions. In areas designated for restoration burning fires should be ignited in a manner consistent with site-specific goals. Multiple spot ignitions are advisable under these circumstances. Indeed, it may be necessary to specifically ignite piles of brush or woody debris in order to achieve management goals. In areas were fuel accumulations were abnormally heavy, a single prescribed fire may actually exacerbate heavy fuel conditions. Such areas may require additional fuel manipulation and burning.

5. Manipulation of debris should be unnecessary following simulated natural fires.

6. All pre- and post-fire manipulation of fuels (regardless of burn classification) should be done so as to minimally disturb the soil or subordinate vegetation.

7. As indicated earlier, burn plans should be formulated with the explicit participation of a person trained in landscape architecture. In making this recommendation we emphasize that ecological values are paramount and are not to be compromised for purely aesthetic reasons. Rather, input from such a professional is intended to facilitate identification and selection of the most aesthetically pleasing alternatives from among the ecologically equivalent alternative burn plans for a unit (see pages 23-24). We believe that this person can provide useful input on burn unit locations and boundaries, as well as advice on specific situations where fire management may especially affect scenic and recreational quality. We recommend that the consequences of this change be reviewed after an appropriate period of time (3-5 years).

MONITORING

The gathering of data regarding preburn fuel, fire weather, fire behavior, fuel consumption, and fire effects has been part of the Parks' fire management programs to a greater or lesser extent since their inception. During the early 1970s monitoring focused on short-term pre- and post-burn data specifically relevant to burn prescriptions. Over the past 4-6 years, fire managers in the Parks have recognized the need to systematically evaluate long-term changes in fuel and vegetation associated with the burn program. The monitoring program for Sequoia and Kings Canyon is detailed in Haggerty (1986) and that for Yosemite is described in Sydoriak (1985).

The general objective of the fire monitoring program is "to gather the data necessary to evaluate the effects of fire in different fuel types." Such evaluation "enhances the fire manager's ability to predict and interpret fire behavior, ... provides a defensible base for management actions and justification for goal and strategy modification, ...and provides necessary data for prescription development" (Sydoriak, 1985). Long-term monitoring data are to be used to monitor fuel and vegetation trends in burned areas compared to untreated areas. Although not explicitly stated by either Haggerty or Sydoriak, the long-term monitoring program is clearly our only direct long-term measure of program effectiveness with respect to the stated goals of the fire management program.

Neither monitoring guide is specific regarding program goals and objectives; i.e. measurements are not matched to specific questions or hypotheses. This is probably not a major problem with respect to short-term measurements of fire climate, fuel characteristics, fire behavior, etc., because standard protocols for measuring these factors are established and their relationship to burn plan formulation is reasonably clear. In contrast, a range of methodologies is available for sampling fuels and vegetation which could be used in long-term monitoring programs; the most appropriate methodology depends on the specific questions being asked and the nature of the fuel and vegetation being sampled. The long-term sampling methodologies employed in the two park systems differ rather markedly. In Sequoia/Kings Canyon the sampling system is focused specifically on mixed conifer forests, whereas the sampling regime in Yosemite is designed to be used across a range of fuel types. Permanent plot sizes and method of location differ considerably between these park systems. In the absence of a set of questions to which long-term monitoring data will provide answers, we are not in a position to evaluate the efficacy of either sampling scheme. For example, if we wish to know how average fuel conditions and understory vegetation cover are altered by fire in a particular burn unit, many comparatively small (0.01 ha) sample plots located in a spatially random fashion will provide the better estimator of such averages compared to fewer and larger subjectively-located plots. However, if our wish is to know how fuel and vegetation change following fire in specific portions of the habitat (e.g. heavy fuels or areas of particularly intense fire), then the latter methodology is appropriate.

There does not appear to be a clear schedule by which short-term or long-term data are processed, analyzed, and fed back into the burn plan formulation process. Furthermore, while the primary use of these data should be in program evaluation, they also represent a very valuable scientific resource; it would be advantageous to the Park Service and the scientific community at large if these data could be made widely available in a systematic fashion (for example, a computer data base, monitoring reports, and publications by monitoring staff). We certainly feel that the value of these data to those within and outside the Park Service will be greatly enhanced if uniform sampling and data management protocols were adopted by all parks.

We recommend that a workshop be held involving Park Service fire management and research personnel along with scientists from outside the Park Service who are expert in the areas of vegetation analysis, fuel and fire effects evaluation, statistics, and data management. The purposes of such a workshop would be to detail monitoring goals in specific terms, discuss methodological and analytical alternatives, and develop uniform monitoring protocols. While there would be great advantage to the development of Park Service wide protocols, the specific monitoring needs of particular burn programs should not be compromised. One additional benefit from such a workshop would be involvement of scientists from outside the Park Service in fire management research problems.

INTERPRETIVE PROGRAM

An evaluation of the Park Service interpretive program was not part of this panel's charge. Nevertheless, we did avail ourselves of the opportunity to see how the fire management program is presented to the public. It was clear to us that public perceptions and understanding of the fire management program are determined in large part by interpretive presentations. We were impressed with the general level of understanding of the role of fire in coniferous ecosystems displayed by interpretation staff; there is clearly excellent communication between the interpretive and fire management programs.

The interpretive program represents a conduit for feedback of public reaction to Park Service management. Interpretive staff should continue to solicit public reactions to management interventions and might even formalize opportunities for such feedback. However, we must also recognize that such feedback is biased in a variety of ways (for example, people are less likely to make negative comments to a uniformed park ranger) and the Park Service should not rely entirely on comments relayed to interpretive staff in determining public reaction to particular park management issues.

RESEARCH

Fire in sequoia-mixed conifer forests has been an important paradigm for our general understanding of the role of natural disturbance in wilderness ecosystems. Much of the research in this area has been sponsored by the National Park Service. We commend the research staffs of both Yosemite and Sequoia/Kings Canyon National Parks for their excellent records of in house and collaborative research. Based on our review of the literature and evaluation of the needs of the fire management program we identify here a number of specific areas where additional research is needed. We discussed these issues with Park Service research personnel and are aware that research on several of these projects is already in progress or in the planning stages.

1. Fire History. As indicated in the background section of this report, our understanding of the fire-regime history of sequoia-mixed conifer forests is restricted to the last few hundred years in a few groves. We need to understand more clearly how and why fire behavior and return intervals have varied over a much broader area. In particular, we feel considerable additional research is needed on role and patterns of burning by Native Americans in these ecosystems so that an informed decision can be made as to whether fire management policy should incorporate those activities.

One of the difficulties represented in such research is that dendrochronological and fire scar sampling is potentially destructive and, therefore, restricted in National Park groves. We suggest that advantage be taken of any cutting (e.g. hazard trees, windthrows, etc.) done within parks and adjacent areas to gather fire-history information, and that a database be developed to compile such data. This data base could also include information gathered from giant sequoia stumps left from 19th century logging activities. We understand that collaborative research with the Arizona Tree Ring Laboratory for such a project is already planned. The National Park Service rarely funds research that is done outside park boundaries; however, the proximity of extensive National Forest lands where some cutting of sequoias is still done provides a unique opportunity to gather fire chronological information not available within Park Service boundaries.

We support continued efforts to use palynological techniques to determine long-term changes in climate and fire occurrence. However, we must recognize that these data will give us only rough estimates of changes in regional fire frequency; thus, they provide us with a sense of how fire regimes might have changed over long time periods. They can not provide us with specific data on fire behavior and periodicity for specific ecosystems (such as the sequoia-mixed conifer forests) or specific locations or time periods.

2. Although general patterns are understood, more information is needed on life-history and demography of sequoia-mixed conifer species to variations in fire regime from frequent fires to complete fire supression. For example, it is known that hot spots created by the burning of heavy woody debris create ideal seed beds for giant sequoia, but little is known of the fate of seedlings once they are established except that attrition is very high. What conditions are necessary for seedling success and growth to pole-size trees? Very little is known regarding the population dynamics of other plants in the sequoia-mixed conifer forest. For example, what are the conditions necessary for regeneration of the pines, incense-cedar, or even white fir? Why do so-called late succession species such as white fir and incense cedar invade in dense thickets in some sequoia-mixed conifer stands and not in others, regardless of fire regime? The responses of understory plants such as the dogwood, buckbrush, manzanita, and various herbs have been studied only in a few groves and are at best poorly understood.

3. Considerable additional research is needed on the effects of fire and fire suppression on fuel dynamics (living and dead) and forest carbon budgets. This is especially important in deciding whether a proposed burn unit is to be classified as a restoration burn or a simulated natural fire. Such data are also necessary in deciding how intense restoration burns should be, how much fuel should be consumed, or how many restoration burns are required before an area can be classified for simulated natural fire. Data from the demographic studies proposed above are an important component of this research. In addition, information on rates of accumulation and degradation of all dead woody fuels (and the factors that influence variation in those rates) is needed. This research should be carried out in the context of the long-term monitoring program described above.

4. We encourage the Park Service research staff to continue their efforts in the development of computer simulation models for fuel dynamics, fire occurrence and behavior, and forest succession. Such models will be important tools for future management decisions. In addition, they provide a framework for tree population and fuel dynamics research.

5. We encourage the Park Service to sponsor independent research on park-user response to the burn program. The effects of fire on scenic ammenity, visual penetration and recreational potential, particularly in areas not managed specifically as natural ecosystems should be evaluated. Such a study will provide a better understanding than is currently available of visitor understanding and perception of the program.

6. Many of the details of the effects of fire on ecosystem properties remain unknown. We believe the following areas deserve special attention.

a. Fire effects on potential pathogens. For example, claims that fire may cauterize fire scars on giant sequoias, and thus neutralize potential pathogens are strictly anecdotal. Based on research in other conifers, fire may increase or decrease pathogen invasion. This question deserves special attention and its answer could influence decisions regarding site preparation around the base of sequoias with large fire scars.

b. Effects of fire intensity , fuel consumption, and seasonality on nutrient cycling and litter dynamics. Special attention should be payed to spatial variation.

c. Effects of fire intensity, fuel consumption, and seasonality on patterns of regeneration in understory plants. This could be incorporated into the monitoring program.

d. Effects of fire on fauna. Very little is known of fire effects on invertebrate or vertebrate animal populations.

FUNDING

It is perhaps fitting to close this report with a brief discussion of the "bottom line." We recognize that most National Park management programs would benefit from increased funding; the fire management program is no exception. However, a long-term commitment to the fire management program is far more important to its success than the program's annual budget. The burn management programs in Yosemite and Sequoia/Kings Canyon National Parks were initially conceived as temporary efforts to deal with the problem of "unnatural" fuels. Once these fuel conditions were corrected, "natural" fire would then be allowed to maintain the sequoia-mixed conifer forests in their primeval state. We now recognize that, for reasons documented earlier, prescribed burning will be necessary in some stands for the forseeable future. We anticipate that prescribe burns will gradually shift from an emphasis on restoration of normal fuel conditions to the simulation of natural fire. We do not feel that ecological considerations have been compromised in burning done to date, however, we do feel that the current short-term mode of funding has not allowed fire managers to incorporate time and labor intensive site preparation and burning techniques which might have diminished some of the negative scenic impacts of the prescribed burns. The assurance of continued long-term funding would also give fire managers needed flexibility in scheduling burns to occur under the most ideal conditions.

CONCLUDING REMARKS

We view these recommendations as adjustments to an essential management program for sequoia-mixed conifer forests. We appreciate the Park Service's willingness to suspend the prescribed burning program during our deliberations. We feel consideration and alteration of burn management plans will not delay continuation of the burning program in 1987.

Like the problems encountered in the management of large mammal populations, the maintenance of natural disturbance cycles in wilderness ecosystems is a persistent reminder that our national parks are tiny islands in a sea of development and urbanization. In the best of all possible worlds our islands would be sufficiently large that we could adopt a "let it be" strategy for their preservation and maintenance. However, fire regimes are landscape phenomena that operate on scales exceeding the size of most parks. Furthermore, fire regimes must be managed in the context of increasingly intense public visitation and use; this is especially the case in the sequoia-mixed conifer forests. Thus, there will be a continuing need for fire management programs in these ecosystems.

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