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INITIAL RESULTS FROM SIMULATION OF ALTERNATIVE FOREST MANAGEMENT STRATEGIES FOR TWO NATIONAL FORESTS OF THE SIERRA NEVADA

ABSTRACT

The Sierra Nevada Ecosystem Project (SNEP) has, as part of its charge, the purpose of developing management strategies to maintain the health and sustainability of Sierra Nevada ecosystems while providing resources to meet human needs. Based on the problems identified in SNEP's analysis of Sierra Nevada ecosystems, we focused on forest management strategies to achieve five goals relative to that purpose: 1) rebuilding late-successional forests, 2) reducing the potential for severe (stand-replacing) fire, 3) restoring riparian areas and watersheds, 4) reintroducing historical ecosystem processes, and 5) producing a sustainable supply of timber in a cost-effective manner.

We developed 10 alternatives that varied in the relative emphasis that would be placed on the five goals and on the management activities that would be used to achieve them, especially the mix of prescribed fire and timber harvest. To reflect possible federal budget restrictions, we also developed modifications of the alternatives that limit the investment that would be available for management activities. We applied these alternative management strategies to two national forests of the Sierra Nevada, the Eldorado and Plumas, to illustrate their potential for improving ecosystem health and sustainabililty while meeting human needs.

We employed a simulation model, called SAFE FORESTS, in the analysis. SAFE FORESTS was built specifically to integrate the concepts and quantitative models developed in the SNEP process to address forest ecosystem goals such as those mentioned above.

Our analysis suggests that much of the pine and mixed conifer forests on the two national forests examined is currently susceptible to severe (stand replacing) fire if the stands burn. Without active management, the extent of these forests susceptible to severe fire if they burn will increase. Fuel treatments (prescribed fire or a combination of prescribed fire and timber harvest), though, can significantly decrease the potential for these forests to suffer severe fire. Much progress could be made within 20 years.

The building of defensible fuel profile zones (quarter-mile strips on which the overstory canopy closure would be maintained at low levels) on these two national forests could reduce the size of wildfires as a first step toward limiting the extent of severe fires and also could reduce the potential for escape of prescribed fires. In addition, they could increase safety of fighting wildfires. With an aggressive fuel-reduction program, however, little long-term difference was found between alternatives that used defensible fuel profile zones and those that did not use them.

Late-successional, old-growth forests (LS/OG forests) on these two national forests can be rebuilt at the same time that the susceptibility of these forests to severe fire is reduced, but it will take somewhat longer to rebuild late-successional complexity. Over fifty years, the amount of high-ranked late-successional forest doubled in many alternatives. Many different combinations of

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prescribed fire and timber harvest rebuild late-successional complexity at about the same rate.

One alternative focused on the goal of minimizing the potential for severe fire in the pine and mixed conifer forests. The strategy of minimizing the potential for severe fire most rapidly reduced the area prone to this kind of fire but, as modeled here, did not rebuild late-successional characteristics.

Keeping watershed disturbance within commonly suggested limits for federal forests could significantly affect the role of timber harvest in achieving the goals of the analysis. Existing watershed condition and expected action on nonfederal land were especially important in determining the amount of action on federal land consistent with limits on watershed disturbance.

Timber harvest could generally pay for itself in the different alternatives, although the net revenue fluctuates widely depending on the size and species harvested. Sizeable investments, however, would be needed for prescribed fire as it appears that most strategies would require a significant increase in the use of prescribed fire.

While the analysis concentrates on federal lands, management of intermingled and adjacent nonfederal lands could have an impact on the success of any strategy for federal lands. Management of nonfederal lands could affect the performance of defensible fuel profile zones, the functioning of late-successional forests on federal land, and the level of watershed disturbance in watersheds shared with federal lands.

We suggest at least six cautions in using these results: 1) Prescribed fire appears well suited to address many of the issues of health and sustainability in Sierra Nevada ecosystems. A number of considerations, though, suggest caution in relying on prescribed fire as the only solution, including the difficulty of applying prescribed fire in stands that have experienced a build up in fuels. 2) Timber harvest cannot be relied upon as a complete substitute for prescribed fire as it does not fulfill all roles of fire in the ecosystem. Also, timber harvest can have negative ecosystem impacts of its own such as those that occur through mechanical disturbance. 3) The simulations suggest that forest inventories will increase under all the alternatives. Some caution should be used in putting too much credence in this result as we may have not accurately modeled periodic mortality from insects, especially in the larger trees. 4) We have used a set of generic prescriptions based on the goals of the analysis and general landscape condition. We find these adequate for our modeling exercise, but realize that more site-specific prescriptions will be needed in actual land management. The simulations are intended to illustrate the ways in which the management strategies could, in aggregate, play out on the landscape. They are not intended to preempt the development of detailed allocations and prescriptions in the field. 5) It is unclear how much active management in terms of prescribed fire or timber harvest can occur near streams and still meet objectives of limiting watershed disturbance. Here, perhaps more than any other part of the landscape, it is hard to portray accurately the implications of the different alternatives. 6) A relatively small number of simulations were employed in developing these results. More analysis is needed, especially an analysis of the variability of wildfire and its effects and a testing of the conclusions drawn here on other national forests of the Sierra Nevada.

INTRODUCTION

The Sierra Nevada Ecosystem Project (SNEP) was commissioned by Congress to undertake a "scientific review of the remaining old growth in the national forests of the Sierra Nevada in California, and for a study of the entire Sierra Nevada ecosystem . . . (Appendix A, Sierra Nevada Ecosystem Project 1994)."

In addition, the Steering Committee guiding the work of SNEP charged the Science Team, in part, "to develop a range of alternative management strategies to maintain the health and sustainability of Sierra Nevada ecosystems while providing resources to meet human needs (Appendix E, Sierra Nevada Ecosystem Project 1994)." The importance of developing management strategies for late-successional forests and watersheds was emphasized in numerous letters from Congress and in a bill considered by the Agriculture Committee of the House that became, in part, a model for the SNEP assignment. That bill (HR 6013) requested "recommendations of alternative management strategies to protect and enhance each ecosystem of the Sierra Nevada forests and the resources thereof, including the watersheds and late-successional forests and their dependent and associated species, including a determination of whether late-successional reserves are necessary for the maintenance of the health of the Sierra forest ecosystems and if such reserves are necessary, what lands should be included in such reserves." The bill also requested that ecological, timber harvest, economic, and social effects of alternative management strategies be specified (See Appendices A through E of Sierra Nevada Ecosystem Project 1994 for more details.)

In response to this assignment, SNEP assessed the state of Sierra Nevada ecosystems from a variety of perspectives (Sierra Nevada Ecosystem Project 1996a, 1996b). Analyses were conducted on the state of late-successional forests, riparian areas, watersheds, air quality, wildlife, plants, range land, economic vitality, community well-being and many other aspects of these ecosystems. Also, analyses were conducted on actions and processes that influence the health and well-being of these ecosystems including drought, fire, insects, diseases, timber harvest, grazing, dams and mining. Finally, SNEP scientists attempted to suggest and evaluate "management strategies to maintain the health and sustainability of these ecosystems while meeting human needs (SNEP, 1994)."

This report summarizes the results from a set of simulations of alternative management strategies for two national forests of the Sierra Nevada that attempt to address some of the issues surrounding health and sustainability uncovered in the SNEP assessments. These strategies are expressed in terms of different goals for the forests and watersheds of the Sierra and in terms of the activities that could be employed to achieve these goals.

While this analysis is heavily quantitative in form, it is intended to render largely qualitative conclusions such as whether reducing the potential for severe fire is compatible with rebuilding late-successional forests and whether timber harvest can assist in rebuilding these forests without degrading watersheds. We hope that the report will be read in that vein.

LATE SUCCESSIONAL FORESTS AND FIRE: FOCUS OF THE ANALYSIS

In response to the Congressional direction for a scientific review of the remaining late-successional/old-growth (LS/OG) forest on the national forests of the Sierra Nevada, Franklin and Fites-Kaufmann (1996) led an extensive assessment of the state of these forests. Their analysis found a significant decline in the amount and complexity of LS/OG forest in the commercial forest types, especially mixed conifer and east-side pine. They found that key structural features of LS/OG forests--such as large diameter trees, snags, and logs--were generally at low levels. Furthermore, much of the remaining high quality LS/OG forest on national forests is unreserved and potentially available for harvest. On the positive side, they found that the forest cover in most areas was not heavily fragmented by clear-cutting and stands have sufficient structural complexity to provide at least low levels of LS/OG forest function.

Franklin, et al. (1996) then proposed and evaluated the potential for a number of different conservation strategies for late-successional forests relative to their ability to: (1) provide sufficient, well-distributed high-quality late-successional/old-growth forest to sustain the organisms and functions associated with such ecosystems for the next century and (2) provide conditions which facilitate connectivity for organisms moving between old-growth forest areas.

These conservation strategies all involve increasing the general extent and complexity of late-successional forests in the Sierra Nevada. Some involve identifying relatively large Areas of Late Successional Emphasis (ALSEs) where late-successional forests will be emphasized and also increasing the late-successional attributes of the intervening forest (called the "matrix"). Variations on this strategy call for more or less prescribed fire and mechanical treatment (timber harvest) in the ALSEs to accelerate development of these characteristics. Other strategies call for a more dispersed late-successional system. Finally, one strategy uses the concept of a "regulated forest" to achieve levels of late-successional forests over the landscape without concern over concentration of the late-successional areas in contiguous blocks.

From the beginning of the SNEP assessment of late-successional forests, it was clear that the threat of severe fire from the build up in fuels and decrease in fire periodicity in some types would be major considerations in any strategy to rebuild the late-successional forests of the Sierra Nevada (Franklin and Fites-Kaufmann 1996, McKelvey, et al. 1996, Skinner and Chang 1996, Weatherspoon 1996, and Weatherspoon and Skinner 1996). While opinions may vary somewhat as to the degree of the current extent of the threat of severe fire, it is clear that we need to understand the survivability of late-successional forests, and the forest in general, under different forest management strategies including strategies explicitly aimed at reducing fuels and limiting the extent of fires that do occur (Weatherspoon and Skinner 1996).

Therefore, we have undertaken an analysis to assess the likelihood that various policies will achieve late-successional goals while simultaneously reducing the potential for high severity fire. This paper examines a number of strategies for achieving these two goals, and other goals discussed below, and presents some of the ecological and economic implications of these strategies. Some of the strategies use the ALSE approach mentioned above in which attempts to rebuild late-successional forests are concentrated in specific areas with an associated emphasis on maintaining at least some minimum levels of these characteristics on the forest between these areas (“the matrix”). Others aim at achieving late-successional goals across the landscape. Still others try to minimize the likelihood of severe fire as the overriding objective. Some allow timber harvest and prescribed fire, others allow only prescribed fire on part or all of the landscape, and still others allow neither.

Developing Integrated Conservation Strategies for Forests, Streams, and Watersheds

SNEP has assessed the state of Sierra Nevada ecosystems from a variety of perspectives. Numerous issues relative to the health and sustainability of these ecosystems have been identified beyond the issues mentioned above relative to late-successional forests and fire. Other issues identified in SNEP that intersect with the issues surrounding forest management relative to late-successional forests and fire are:

-- declines in aquatic biodiversity and existing and potential threats to riparian-associated species and ecosystems (Erman 1996, Kattelmann and Embury 1996, Knapp 1996, Kondolf, et al. 1996, Jennings 1996, Moyle 1996a, Moyle, et al. 1996a, Moyle, et al. 1996b, Yoshiyama, et al. 1996).
-- existing and potential difficulties from watershed disturbance (Berg, et al. 1996, Kattelmann 1996, Kondolf, et al. 1996, Menning, et al. 1996).
-- declines in terrestrial biodiversity and existing and potential threats to terrestrial wildlife species and ecosystems (Graber 1996, Shevock 1996, Davis and Stoms 1996).
-- production of timber as an objective on some lands including the sizes and species that might be harvested and the associated costs and revenues (Ruth 1996).
-- the potential effect of budget constraints on fuel treatments and other activities on federal lands (Ruth 1996).
-- management of existing roadless areas (Ruth 1996).

We wish to consider strategies for addressing these issues simultaneously with strategies for late-successional forests because the strategies to deal with the different identified issues potentially influence each other. Mechanical treatment to improve LS/OG rank, decrease fuel loadings, and/or produce timber can impact riparian areas and watersheds. Aquatic goals for riparian zones can affect the amount of LS/OG forest and the freedom to treat the zones to reduce fire hazards. LS/OG goals for ALSEs and the matrix can influence fire hazard there and the distribution of acres among seral stages and among different wildlife habitats. Creation of defensible fuel profile zones (fuel breaks) can increase the survivability of the ALSEs and the forest in general and produce timber volume and value, but at the cost of reducing LS/OG rank and negatively affecting the functioning of ecological systems. Wildlife goals can influence the amount and distribution of LS/OG. Budget constraints can influence the ability to undertake activities of any sort.

Consideration of Wildlife

Under the subheading "Loss of Riparian and Old-growth Habitat," the SNEP Summary Report discusses the major causes of decline in Sierran wildlife: "The most important identified cause of the decline of Sierran vertebrates has been the loss of habitat, especially foothill and riparian habitats and late-successional forest. In the Sierra, eighty-two terrestrial vertebrate species are considered dependent upon riparian (including wet meadow and lake shore) habitat; twenty of these are considered at risk. Eighteen species are dependent upon late-successional forests; five of these are at risk. Although few Sierran species appear to require closed forest canopies, many more are dependent upon large old trees, snags, and downed logs in all Sierran woodland and forest communities for some part of their life cycle (Sierra Nevada Ecosystem Project 1996a, p. 5)."

In this analysis, we have attempted to address the causes of wildlife decline, as identified in the SNEP Report, through the goals of rebuilding late-successional forests, restoring riparian areas and watersheds, and reintroducing historical ecosystem processes. Rather than focusing on particular wildlife species, we have focused on restoring habitats that have been identified as a key to recovery of Sierran wildlife. Further analysis, though, is needed that evaluates how well the different management strategies meet the requirements of particular species.

Problems not Addressed

SNEP scientists identified many problems and issues with maintaining the health and sustainability of Sierra Nevada ecosystems beyond those addressed here and suggested strategies for overcoming the problems that they found. Some of these other problems and strategies are:

-- potential vulnerability of some native plant communities, especially non-forest communities and native plant communities not represented on federal land because areas dedicated to their maintenance are lacking (Davis and Stoms 1996). Procedures for selecting biodiversity management areas to address this problem can be found in Davis, et al. (1996). Davis and his colleagues have developed an allocation model that selects watersheds in the Sierra Nevada, under different objectives and constraints, on which to emphasize maintenance of native vegetation to ensure the continued existence of the variety of plant communities that now exist in the Sierra Nevada. The selected areas are called Biodiversity Management Areas (BMAs). We did not include this approach to conserving plant communities in our analysis for two reasons. First, the approach taken by Davis, et al. uses a flexible procedure that can react to the placement of LS/OG emphasis areas and other land use zones in determining where to place BMAs. Thus, it might best be used interactively with different strategies for late-successional forests. Second, forest structure goals and limits on activities have not been identified for the different community types considered in the analysis by Davis, et al.; therefore, it is not clear how designation of a watershed as a BMA will affect management.

-- air pollution from outside the region or from urban areas inside the region (Cahill, et al. 1996). Suggestions for addressing these air quality problems are discussed in Cahill, et al. Cahill et al. also discussed potential air quality issues surrounding prescribed burning.

-- adverse effects on native aquatic organisms from changed water-flow regimes, introduction of exotics, and dumping of pollutants (Jennings 1996 and Moyle, et al. 1996b). Suggestions for addressing these problems are discussed in Moyle (1996b).

-- fire and settlement issues on private land in the region (McKelvey, et al. 1996, Husari and McKelvey 1996, Weatherspoon and Skinner 1996, Duane, 1996, McBride, et al. 1996). Suggestions for addressing these issues are covered in Weatherspoon and Skinner (1996) and Duane (1996).

-- condition of rangelands (Menke, et al. 1996). Options for improving rangelands conditions can be found in Menke, et al.

-- the leakage of value out of the region with little reinvestment (Stewart 1996). Options for addressing this issue can be found in Sierra Nevada Ecosystem Project (1996b).

-- institutional capacity to implement strategies for addressing the issues identified in Sierra Nevada Ecosystem Project (1996b).

GENERAL APPROACH

Based on the problems identified in SNEP's analysis of Sierra Nevada ecosystems, we focused on forest management strategies to achieve five goals relative to that purpose: 1) rebuilding late-successional forests, 2) reducing the potential for severe (stand-replacing) fire, 3) restoring riparian areas and watersheds, 4) reintroducing historical ecosystem processes, and 5) producing a sustainable supply of timber in a cost-effective manner.

We developed 10 alternatives that varied in the relative emphasis that would be placed on the five goals and on the management activities that would be used to achieve them, especially the mix of prescribed fire and timber harvest. To reflect possible federal budget restrictions, we also developed modifications of the alternatives that limit the investment that would be available for management activities. We applied these alternative management strategies to two national forests of the Sierra Nevada, the Eldorado and Plumas, to illustrate their potential for improving ecosystem health and sustainabililty while meeting human needs.

Simulation Methodology

In our analysis, we use a model specially built for this work called Simulation and Analysis of Fire Effects in the FORESTS of the Sierra Nevada (SAFE FORESTS). SAFE FORESTS is a strategic planning model that emphasizes the analysis of strategies for late-successional forests in fire-prone landscapes, but that can also measure and limit effects on riparian areas and watersheds. The model can also accept goals for, or limits on, timber harvest and develop reports that can provide a basis for assessing the adequacy of wildlife habitat and seral stage representation. Also, it reports likely costs and revenues associated with different strategies. See Sessions, et al. (1996) in this volume for a detailed explanation of SAFE FORESTS and an example of its use on the Eldorado National Forest.

Relation to Other Recent Studies of Federal Forests

A number of analyses of federal forests in the West have been done in recent years such as FEMAT (1993) and the CAL OWL DEIS (USDA Forest Service 1995). Our approach here differs from these other approaches in a number of ways.

First, these other studies presented alternatives that were readily translatable into management plans, or changes in management plans, for federal forests. The "alternatives" in this study do not allow for this ready translation. Rather, they are meant to broadly examine different goals for the federal forests of the Sierra, and strategies to achieve them, and to suggest the implications of these goals and strategies. As such, they do not have the detail of the previous efforts nor the concern that they mesh with current agency policies.

Second, this analysis does not contain a "preferred" choice identified from among the alternatives as done in the CAL OWL DEIS and implied through the special attention given Option 9 in the FEMAT Report. Each of the choices achieves different goals to a lesser or greater degree; none dominates the others in simultaneously meeting all goals to a higher degree than achieved for each goal by the other alternatives.

Third, we make no claim that we have developed a comprehensive and exhaustive set of choices for the issues at hand. Rather, we have chosen to highlight choices that we believe illustrate differing emphases on the goals and strategies that appear particularly promising in addressing problems with health and sustainability uncovered by SNEP. Many other goals and management strategies could be easily imagined. We hope that such work will follow our efforts.

Fourth, we explore the implications of the different management strategies on only two national forests in the Sierra Nevada. The other studies applied the alternatives they considered to all administrative units in the relevant area while we applied our alternatives to only a few of them.

IMPROVING HEALTH AND SUSTAINABILITY: DEFINING, MEASURING, AND ATTAINING ECOSYSTEM GOALS

As mentioned above we have defined five goals to guide the analysis: 1) rebuilding late-successional forests, 2) reducing the potential for severe (stand-replacing) fire, 3) restoring riparian areas and watersheds, 4) reintroducing historical ecosystem processes, and 5) producing a sustainable supply of timber in a cost-effective manner. In addition, other goals can be pursued by the types of activities that are allowed, such as minimizing disturbance to certain strata or allowing only certain types of disturbance such as prescribed fire.

In each analysis, these goals are specified in hierarchical fashion such that achievement of the higher order goal cannot be compromised by attempting to achieve a lower order goal. In our analysis, the primary goal generally is control of watershed disturbance, the secondary goal is achievement of some LS/OG rank, and the tertiary goal is achievement of an even-flow timber harvest (to the degree that timber harvest is permitted). In all cases, the problem is structured such that we try to achieve as much of the secondary goal as possible given that achievement of the primary goal is not compromised and, in turn, that we try to achieve as much of the tertiary goal as possible given that achievement of the secondary goal is not compromised. Thus, the optimization problem is stated such that we try to "maximize" (or "minimize") the achievement of the lowest order goal after first achieving specified values for the higher order goals.

We believe that this approach is consistent with recent direction established by the USDA Forest Service for management of the national forests. As an example, a recent directive (USDA Forest Service 1996) states that forest structure goals are primary goals. Timber harvest occurs as needed to meet the structural goals if its use is consistent with the multiple use goals for the area. Timber production is a secondary goal on areas designated for timber harvest to the degree it is cost-efficient and does not compromise attainment of the primary (forest structure) goal. We have taken much the same approach here.

To understand the tradeoffs associated with choosing particular levels for the goals, alternative management strategies use different levels. As an example, some alternatives use very high LS/OG goals for the matrix lands. Other alternatives use more modest LS/OG goals. At least one alternative does not have LS/OG goals for the matrix.

Measures of Goal Attainment

Late-successional Goals

Franklin and Fites-Kaufmann (1996) assessed late-successional and old-growth (LS/OG) forest conditions for the Sierra Nevada using stand structural criteria as measures of the level of LS/OG forest function. Larger landscape units, called LS/OG polygons, which were relatively uniform in type and distribution of vegetation patches, were mapped using imagery, maps, ground-based information, and the expert interpretations of resource specialists. This analysis resulted in 180 LS/OG polygons in the Eldorado National Forest and 216 on the Plumas National Forest.

Characteristics of the major patch types in each polygon were identified and tabulated by local experts and a composite late-successional structural ranking was calculated for each polygon on a scale that extended from 0 (no contribution to LS/OG forest function) to 5 (very high level of contribution to LS/OG forest function). This approach drew heavily on the local expertise to determine rank.

To determine starting LS/OG rank for the simulations, we took a slightly different approach. We needed a quantitative description of the forest within the LS/OG polygons that could be used to determine initial rank and rank though time, and be useful for simulating stand dynamics over time with growth, mortality and harvest.

We therefore established rank though a four-step process. First, we used the USDA Forest Service Region 5 forest classification of species type, size class, and percent of crown closure (USDA 1994) to define forest vegetation condition classes. Second, we used Forest Inventory Analysis plot information for each forest class to estimate existing forest condition in each vegetation class in terms of a tree list by species and diameter class, and other information.

Third, we evaluated each vegetation class within each polygon for LS/OG rank using criteria provided by Franklin and Fites-Kaufmann as to the number of large trees, canopy closure, and intermediate canopy. We used a “rangewide structural standard” for rank determination for mixed conifer and ponderosa pine types and a "normalized structural standard" for other types which modified the rangewide structural standard to account for the attributes of higher elevation forests. The series-normalized standard generally ranks LS/OG polygons higher than does the rangewide standard (See Franklin and Fites-Kaufmann (1996) for more information).

Finally, we estimated LS/OG polygon rank as the acre-weighted average rank across all land types and conditions within the LS/OG polygon. This process gave similar, but not identical rankings, for the LS/OG polygons compared to those originally estimated by Franklin and Fites-Kaufmann. See Sessions, et al. (1996) and Cousar, et al. (1996) for details.

ALSEs

Clusters of LS/OG polygons have been identified as Areas of Late Successional Emphasis (ALSEs). These LS/OG polygons generally have above-average levels of late-successional characteristics and are the focus areas for maintaining high levels of late-successional characteristics in many of the analyses listed below. They were identified by Franklin and Fites-Kaufmann (1996). The alternative management strategies in this study often specify different LS/OG rank goals for the ALSEs and the matrix.

Fire Severity and LS/OG forests

Achievement of LS/OG goals can be assisted by stand growth, prescribed fire, or certain types of timber harvest. Without attention to understory structure and canopy density, however, achievement of high levels of late-successional structural complexity can be associated with high likelihoods of severe fire. Therefore, attention was paid in prescription development to developing late-successional structures that would have moderate to low levels of basal area consumed by wildfire (see Cousar, et al. 1996 for more details).

Potential Damage from Severe Fire

Potential damage from extreme weather wildfires is measured by percent of basal area which would be killed if a fire should occur (See Sessions, et al. (1996) for discussion of this approach). We generally assume that a total mortality of more than 60 percent of the basal area in a stand destroys the stand. Reducing the percent of basal area that will be killed under extreme-weather wildfires can be done through prescribed fire and certain kinds of timber harvest. Fuel treatments through timber harvest, though, can retard achievement of late-successional goals or cause excessive watershed disturbance. Thus, treatments involving harvest are often limited by pursuit of other goals.

Fire Size

Large fires account for most of the area burned in forest fires. Strauss et al. (1989) concluded in a study of several climatic regions of the western United States that the proportion of area burned by the 1% of the largest fires ranged from 80%-96% of the area burned. In our simulations we model only large fires. Our definition of large fires varied by forest from 1000 acres on the Plumas National Forest to 3000 acres on the Eldorado National Forest (Bahro 1996).

Defensible Fuel Profile Zones (DFPZs)

Eldorado and Plumas National Forest LS/OG polygons were overlain with a GIS coverage of defensible fuel profile zones (DFPZs) often called “fuel breaks.” These zones would be 1/4 mile wide and were developed in cooperation with Forest Service personnel (Bahro 1996, Weatherspoon and Skinner 1996) based in part on the research of van Wagtendonk (1996). They permit simulation of fuel management strategies. In alternatives that use DFPZs, these strips of land are modified to reduce fire intensity, flame length, spotting, and crown fire and increase the safety of fire fighters. They require periodic maintenance to remain effective. They are placed mainly on dominant ridge lines or strong intermediate ridges on the Eldorado National Forest and on ridges or adjacent to major roads and/or large streams on the Plumas National Forest. In both cases, they have suitable access to facilitate safe fire suppression.

Watershed Goals

We recognize three riparian influence zones that exhaustively divide the landscape outside of reserved areas to help measure watershed disturbance. They are based on Kondolf, et al. (1996).

The SNEP GIS team mapped three zones to capture the concepts of Kondolf, et al: (1) a zone of approximately 150 feet on each side of all streams called the Community/Energy Zone, (2) a zone of variable width that begins approximately 150 feet from the stream, just outside the Community/Energy Zone called the Land Use Influence Zone that is calculated on the basis of stream width and adjacent slope steepness, and (3) the remainder of the watershed called the Uplands.

On both the Eldorado National Forest and Plumas National Forest, the three zones divide the landscape approximately as follows: 1) Community/Energy Zone (13%), 2) Land use Influence Zone (34%) and 3) Uplands (53%). Initial tests suggest that the stream layer used by SNEP underestimates the miles of stream that will be found on federal forests. We would expect that field work would result in less acreage in the uplands and more in the other two zones.

Watershed disturbance is measured by the percentage of equivalent roaded acres (ERA) in the watershed by riparian influence zone. ERA is an index of watershed disturbance used extensively by the national forests of California. Each proposed activity is given an ERA coefficient to measure its disturbance potential as is the existing condition of the landscape (For a discussion of the ERA method, see Menning, et al. (1996) and Sessions, et al. (1996)). We recognized two sets of limits on the ERA level in the analysis:

Riparian Influence Zone	% Area	Set #1	Set #2
Community/Energy Zone	13	.05	.10
Land-use Influence Zone	35	.10	--
Uplands	52	.15	--

Each alternative management strategy was assigned one of these sets of ERA limits.

The first set of ERA limits were based on four considerations: 1) the SNEP findings that riparian areas are the most impacted portions of the landscape in the Sierras (Sierra Nevada Ecosystem Project 1996a, 1996b), 2) research that suggests that aquatic macro invertebrates start to decline in the Community/Energy Zone at even very low ERA levels (Menning, et al. 1996), 3) a desire to reflect that the nearer an activity is to the stream the more likely that disturbance from the activity will impact the riparian environment, and 4) a desire for the acre-weighted ERA to equal .11-.12 to approximate the average ERA “threshold of concern” on the Eldorado National Forest (Menning, et al. 1996).

The second set of ERA limits were based on the desire to release the ERA limits to measure their effect while still providing special protection for Community/Energy Zone.

In our analysis, watershed conditions are controlled by LS/OG polygon. LS/OG polygons are of the appropriate scale (3000-10,000 acres) recommended by Chatoian (1995) for use with the ERA method. The existing condition of the watershed was taken into account in establishing the initial ERA levels. Future activities then contributed ERA amounts based on their projected degree of disturbance.

The relationship between watershed disturbance and timber harvest was derived from the ERA model that we employed (Menning, et al. 1996) which, in turn, was derived from expert opinion and the modest amount of data that is available. A number of assumptions have the potential of an especially significant effect on timber harvest.

For nonfederal lands, we used ERA coefficients of 0.1 in the Community/Energy Zone and 0.2 in the other two riparian-influence zones. There is at least some evidence/logic to support these assumptions (see Menning, et al. 1996). We further assumed that the federal forests would react to actions on private lands within the watershed (here LS/OG polygon) by limiting their actions so as not to violate overall watershed limits. Given the cumulative effect considerations required of federal forest managers, we feel this is a reasonable assumption. Our more restrictive set of limits had an acreage weighted average of about .11. Where-non federal forests covered more than half of a LS/OG polygon, therefore, very little federal action that contributes ERA coefficients, such as timber harvest, could occur.

For lands outside of roadless reaches (roadless areas mapped by SNEP), Wilderness, and plantations, we used a background ERA level of .05 based on the assumption that all forest outside Wilderness had experienced salvage at some time. This assumed background leaves little room for timber harvest activity in the Community/Energy Zone under both sets of disturbance limits. It also limits activity in the other two zones under the more restrictive set of limits.

We assumed that prescribed fire did not create ERA effects. While this assumption might be challenged, we have not seen data to refute it. The net effect of this assumption combined with the assumptions about the ERA effects associated with timber harvest activity causes significant reliance on prescribed fire to reach ecosystem goals in all alternatives that had disturbance limits on all three zones.

Reintroducing Historical Ecosystem Processes

This goal is addressed in two ways. First, rebuilding late -successional forests, reducing the threat of severe fire (where it historically did not occur) and restoring streams and watersheds should help reintroduce historical ecosystem processes. Second, the methods used to achieve these goals can also contribute to restoring historical ecosystem processes. Employing prescribed fire and silvicultural methods that simulate, to some degree, the historical effect of wildfires on Sierra Nevada forests should also help achieve this last goal.

Sustainable, Cost-effective Timber Harvest

The highest sustainable timber harvest for fifty years, compatible with watershed disturbance limits and late-successional targets, can be specified as a goal. A wide variety of intensities and timing of harvest are available to help find the highest sustainable level given other goals. The choices can be limited to timber sales that pay for themselves (“commercial timber sales”) or also include those that involve submerchantable material and thus may not pay for themselves.

The highest sustainable level is calculated before wildfires occur. Stands that experience severe fire mortality before their scheduled harvest are deducted from the estimated sustainable level. Salvage after a wildfire can occur, in areas where “green” timber harvest can occur, if the salvage is consistent with overall goals. Thus, the timber harvest volume available for any period is the sum of two components: 1) "green" timber harvest associated with the estimation of a sustainable timber harvest for fifty years and 2) salvage timber harvest associated with reaction to wildfire. Therefore, the overall expected harvest for a period can vary somewhat depending on the extent of severe fires.

ALTERNATIVE MANAGEMENT STRATEGIES

Activities Considered

As discussed above, two general types of human intervention (activities) can be used to meet stated goals on the national forests: (1) timber harvest, and (2) prescribed fire.

Three types of commercial timber harvest can be considered to reach the goals of an alternative: 1) commercial timber harvest in which trees too small to be merchantable are left, 2) “biomassing” associated with commercial harvest in which these smaller trees are also taken, and 3) DFPZ harvest in which a linear path 1/4 mile-wide is treated to reduce canopy closure below a certain percentage and to reduce ground and ladder fuels.

One type of prescribed fire is considered. Estimates of its impact on stand structure are found in Cousar, et al. (1996).

Undisturbed growth is also considered a possible "activity.”

The outcomes and effects associated with each activity in each decade are represented in the analysis by the contribution to forest structure (LS/OG rank), contribution to watershed disturbance (ERA), flame length in fires that burn under extreme weather, and contribution to timber production (board feet harvested). Activities are strung together for five decades to form what we call a "prescription.” Two examples of prescriptions are: (1) let the forest grow without intervention for five decades and (2) alternate commercial timber harvest with prescribed fire over the five decade.

Each stratum within each polygon receives a set of prescriptions, consistent with the alternative being analyzed, which can be considered to meet the goals of the alternative. Development of prescriptions is described in Cousar, et al. (1996).

Silvicultural Methods Employed

We have modeled all harvests, other than fire salvage, as individual tree selection. Each stratum is represented by a list of trees with different species, sizes, and characteristics. This list is compared to the desired condition, based on the goals of the alternative, to decide whether certain trees need to be removed. Even-aged regeneration harvest, such as shelterwood and clear-cut harvest, in which the entire overstory is removed over a relatively brief period of time is not contemplated except for fire salvage. Rather, a significant proportion of the trees in the strata are retained after treatment.

We took this approach for two reasons. First, we simulate individual tree selection because it enables us to address achievement of the late-successional goals associated with most alternatives. These goals call for a continuous presence of large trees across the landscape, to varying degrees, except for where fire has killed them (Franklin and Fites-Kaufmann 1996). Second, the work by Helms and Tappeiner (1995, 1996) done for SNEP that summarizes the state of silvicultural knowledge of Sierra Nevada forests supports the use of this silvicultural method, although they point out that planting may be needed to supplement the natural regeneration that we count on to replenish the supply of small trees. (See Sessions, et al. (1996) for more discussion of these points).

Application of Prescribed Fire

Many of the strategies made extensive use of prescribed fire. The rate of application of prescribed fire varies by National Forest and forest type (P= application of prescribed fire to all acres in the type that do not have timber harvest in a decade):

National Forest / forest type	...............Decade.............				
	1	2	3	4	5
Eldorado NF					
Ponderosa pine	P	P	P	P	
Mixed conifer	P	P	P	P	
White fir-mixed conifer	P	P	--	P	--
Hardwood	P	P	P	P	P
Plumas NF					
Ponderosa pine	P	P	P	P	P
Jeffery pine	P	P	P	P	P
Westside mixed conifer	P	P	--	P	--
Eastside mixed conifer	P	P	P	P	P
Hardwood	P	--	P	--	P

These rates of application came from discussions with forest ecologists and fire experts slightly modified by experimentation with the SAFE FOREST model relative to rates that would reduce the potential for severe fire. Other forest types, such as subalpine fir, did not receive prescribed fire.

Alternatives Considered

Ten alternative management strategies for the Eldorado and Plumas National Forests are analyzed in this section (Table 1). They reflect differing emphases among five goals for forest management to maintain the health and sustainability of Sierra Nevada ecosystems that emerged from the SNEP analysis.

The emphases among these goals are varied in two ways (Table 1): 1) Through explicit alteration of the target for that goal. We vary the LS/OG rank goal in the ALSEs and the matrix, the level of watershed disturbance permitted, and the emphasis on reducing fire severity. 2) Through the types and levels of activities that are permitted. We vary the areas where timber harvest is permitted, often limiting it in ALSEs and the matrix. In addition, we allow DFPZs in only some of the alternatives and vary the degree to which biomassing (harvest of small, nonmerchantable trees) is required. Finally, we look at variations of the alternatives in which little prescribed fire is allowed.

The general themes illustrated by the alternatives are described below. All assume that the historical intensity of fire suppression will continue into the future.

The goals emphasized in the alternatives and the activities used to accomplish these goals are as follows:

Alternative 1 does not use active management such as prescribed fire and timber harvest to achieve the goals, but rather relies on undisturbed growth.

Alternative 2 attempts to use prescribed fire to achieve late-successional forests everywhere, reduce fire severity, and reintroduce natural processes.

Alternatives 3-4 attempt to achieve late-successional forests everywhere, reduce fire severity, and restore historical processes through prescribed fire in the ALSEs and a combination of prescribed fire and timber harvest in the matrix. Alternative 3 allows only prescribed fire in roadless reaches (roadless areas mapped by SNEP) while alternative 4 allows a combination of prescribed fire and timber harvest in roadless reaches in the matrix. The more restrictive set of watershed disturbance limits are employed.

Alternatives 5-8 attempt to achieve a LS/OG rank of 4 in the ALSEs and a

LS/OG rank of 3 in the matrix. These alternatives all use prescribed fire; they differ in where and how timber harvest can occur. Alternative 5 allows timber harvest in the matrix but not the ALSEs. Alternative 6 allows DFPZs in the ALSEs and matrix and commercial timber harvest in the matrix. Alternatives 7 and 8 allow timber harvest and DFPZs in both the ALSEs and the matrix. The alternatives also differ in the watershed disturbance limits used: alternatives 5-7 use the more restrictive set; alternative 8 uses the less restrictive set.

Alternative 9 is similar to alternative 8 except the LS/OG rank goal for the "uplands" in the matrix is reduced from a 3 to a 2.

Alternative 10 focuses on minimizing fire hazard. It allows the use of prescribed fire, timber harvest, and DFPZs as needed throughout the forest. It does not give any special consideration to the ALSEs.

All 10 alternatives were applied to the Eldorado National Forest; six of them (1, 2, 4, 5, 8, 10) were applied to the Plumas National Forest.

Treatment of Wildfire

In each period, we generate a series of wildfires under extreme weather conditions from a probabilistic simulator that considers weather, fire size and ignition probability. Average decadal amount of wildfire and the range in this amount from national forest records were used to help construct the probability distribution of fire size (Bahro 1996):

Parameter	Eldorado NF	Plumas NF
	...Thousands of acres/decade...	
Average fire amount	15	62
Range in fire amount	3.5-32	17-105

We assumed that this fire acreage occurred under extreme weather conditions as those are the conditions that often enable fire to escape initial attempts at suppression.

In our simulations, the fires apply to all acres within the boundaries of each national forest. With the large amount of private land within the boundaries of the Eldorado National Forest, we increased the average amount of fire per decade on that Forest under extreme weather conditions to approximately 20,000 acres.

We used one pass of the wildfire simulator to create the results reported here on forest structure, outputs, and effects. In total, we simulated 88,000 acres of wildfire within the administrative boundaries of the Eldorado National Forest and 261,000 acres of wildfire within the administrative boundaries of the Plumas National Forest over the first four decades. Period-by-period, the wildfire acres were:

Period	Eldorado NF	Plumas NF
	Thousands of acres/decade	
1	16	20
2	33	86
3	13	26
4	26	130
Total	88	261
Ave/period	22.0	65.5

As discussed above, these are acreages of large wildfires burning under extreme weather conditions.

For a subset of alternatives, we did 10 passes of the wildfire simulator to create an average and range of wildfire. As discussed below, the average effects from those 10 simulations closely approximate the sample set of wildfires used for the results reported here.

Forest Types Emphasized

In the discussion below, we emphasize results for pine and mixed conifer forests as did Franklin and Fites-Kaufmann (1996) in their analysis. These forest types have experienced the largest decline in late-successional complexity among the types on the Eldorado and Plumas National Forests (Franklin and Fites-Kaufmann 1996). They have also experienced an increase in fuel loadings and a reduction in fire frequency. The composition of the pine and mixed conifer forests on these two national forests is as follows:

Forest Type	Eldorado NF	Plumas NF
	.....Thousands of acres.....	
Ponderosa pine	73	82
Jeffrey pine		96
Westside mixed conifer	143	160
Eastside mixed conifer		251
White fir mixed conifer	121	
Total	337	589
Total forested acres that could receive active management	435	694

On the Eldorado National Forest, most of the other acres that could receive active management were in the red fir types; on the Plumas National Forest, most of these other acres were in the white fir type.

Outcomes and Effects

We developed measures of attainment for each of the five goals (Table 2). We use these measures in the discussion below to characterize the results of the different alternatives.

Rebuilding Late-successional Forests

We measure success in meeting the goal of rebuilding late-successional forests through average structural LS/OG ranking over time and the distribution of the forest among LS/OG ranks (Franklin and Fites-Kaufmann 1996). In all alternatives but alternative 10 (minimize fire hazard), average rank in the pine and mixed conifer forests increases over time as does the amount of rank 4 and 5 (Tables 3a, 3b). Looking at the different alternatives, we see that a strategy of little or no active management (fire suppression, but no prescribed fire or timber harvest) results in the fastest increase over 50 years in late-successional complexity in pine and mixed conifer forests as measured by amount of high-ranked LS/OG forest. However, this alternative also resulted in the largest amount of low-ranked LS/OG forest due to severe fire during the simulation period.

Examining the individual forest types on the Eldorado National Forest, we found that alternatives with active management to achieve LS/OG objectives (alternatives 2-9) generally achieved greater amounts of high-ranked LS/OG forest in fifty years for the ponderosa pine and mixed conifer types than did alternative 1 (no active management) and lower amounts of high ranked LS/OG forest in the white-fir mixed conifer types. Severe fires limit the rank progression in ponderosa pine and mixed conifer without active management; prescribed fire associated with active management limits rank progression in the white fir-mixed conifer types.

Similarly, on the Plumas National Forest, alternatives with active management to achieve LS/OG objectives (alternatives 2-9) achieve slightly greater amounts of high-ranked LS/OG forest in the ponderosa pine, Jeffery pine, and Westside mixed conifer types while alternative 1 (no active management) achieves greater amounts for eastside mixed conifer.

In alternatives that have higher LS/OG goals for the ALSEs than for the matrix (alternatives 5-9), LS/OG rank in the ALSEs, as expected, increases more rapidly than does the average LS/OG rank for the forest (Compare alternatives 5 or 8 in Tables 3 and 4).

The distribution among LS/OG ranks is especially valuable in indexing how severe wildfire and activities affect the production of high, medium, and low ranks (Tables 3a, 3b). Without active management, much more acreage of low LS/OG ranks is created over time (ranks 0,1) with forest conditions created to potentially increase this even more in later periods. With active management, it is sometimes more difficult to create high LS/OG rank.

A number of factors limit the amount of increase in rank that can be achieved over the planning horizon. First, the 50 years studied here is a relatively short time for processes to occur that are needed to create late-successional forest complexity. Second, wildfires occur and, depending on the condition of the stand, can reduce stands several ranks. Even with the emphasis on late-successional forests in many of the alternatives, a distribution of forest among the lower ranks persists as would be expected in the forests of the Sierra Nevada. Third, application of prescribed fire, with the objective of reducing the likelihood of severe fire through reintroducing historical processes, can kill some large trees and can set back rank. Fourth, some of the alternatives have a matrix LS/OG goal that allows a decrease in rank for some LS/OG polygons.

Within each LS/OG polygon, average LS/OG rank in a period is calculated as the weighted average (based on area) of all strata within the polygons including forest, brush, and barren. As previously discussed, the simulations start with fewer high-ranked LS/OG polygons (rank 4/5) than came out of the mapping by experts. Over time, as the structural complexity of the strata increases, the LS/OG polygons increase in rank (Compare periods 1 and 5 in Figure 1).

Pine and mixed conifer forests are the major forest types in the montane mixed conifer polygons on the Eldorado National Forest along with brush and barren. Looking at LS/OG rank over time for these polygons (Table 5a), we see similar trends as those obtained for the pine and mixed conifer strata. The montane mixed conifer polygons (Table 5a) show proportionately less acreage in the high ranks than do the pine and mixed conifer strata (Table 3a) because brush and barren are averaged into the polygon ranks.

As mentioned above, 50 years is a relatively short time over which to measure progress in development of late-successional forests. We would expect the pine and mixed conifer forests to continue to rebuild their late-successional complexity under most alternatives well beyond the

50 years examined here (see example in Cousar, et al. 1996).

Reducing the Potential for Severe Fire

We measure potential for severe fire through the proportion of the basal area in a stand in any period that would be killed if the stand burned under severe weather. We consider severe fire to occur if more than 60% of the stand basal area would be killed by fire under these conditions.

Both national forests start with a considerable proportion of the pine and mixed conifer types having the potential for severe fire (see column 1 in Tables 6 or 7), including much of the 4 and 5 rank patches. This trend continues in Alternative 1 (undisturbed growth) through period 3 (Table 6) and period 5 (Table 7 and Figure 2a). By period 5, almost all of the pine and mixed conifer forests (Table 6) and almost all of the rank 4 and 5 patches within these forests have the potential for severe fire (Table 8).

All other alternatives greatly reduce the proportion of the pine and mixed conifer forest, and of late-successional forest within it, that are prone to severe fire over time (Tables 6, 7, 8). A typical decline in fire severity for these alternatives is shown by alternative 8 (Figure 2b).

We infer from the simulations that a wide variety of combinations of prescribed fire and timber harvest would reverse the trend toward high severity fire in the pine and mixed conifer forests of the Sierra Nevada. The results also suggest that a combination of prescribed fire and timber harvest will reduce the likelihood of severe fire more rapidly than prescribed fire alone.

Alternatives 6-10 call for building DFPZs in the first two periods. According to our simulations, the DFPZs reduce the extent of fire by up to 1/3 over fifty years. They do not, however, reduce the severity of the fires on the acres that do burn except within the DFPZs themselves. Thus they provide a useful first step in the first few decades until fuel treatments can reduce the extent of area susceptible to severe fires.

DFPZs have two effects on rebuilding late-successional forests that work in opposite directions. Where they are built, they often reduce rank because they can create stands too open-grown to qualify for the higher LS/OG ranks. On the other hand, they reduce the amount of wildfire and thus, potentially, they limit the amount of late-successional forest that burns severely enough to reduce its rank.

As they are built in the first decade, they provide significant volume and revenue. Some of the heaviest harvests under any prescription are done in DFPZs to bring the stands within them to less than 30% canopy closure.

Fires during the Simulation Period

The amount and location of fire varies over the five periods. The effects of the alternatives on the potential for severe fire in the pine and mixed conifer forest reported above are substantiated by the simulated wildfires projected to occur during the projection period. In terms of the distribution of wildfire acres among fire severity classes, Alternative 1 has an increasing proportion of severely burned acres over time. By period three or four, all other alternatives endure a relatively low proportion of severe burns.

Limiting Watershed Disturbance

Watershed disturbance associated with timber harvest could significantly affect the role of timber harvest in meeting the goals of the analysis. As discussed above, specified disturbance limits, in terms of maximum periodic ERA level permitted, are placed on each of the three riparian influence zones. We utilized two different levels of permitted disturbance in the analysis. One approximates the average threshold of concern on the Eldorado National Forest while recognizing the need for relatively tighter limits near the stream. The other places a limit only on the riparian influence zone closest to the stream. Comparing the timber harvest levels for alternatives 7 and 8 on the Eldorado (Table 9a), we see that, depending on which level was used, timber harvest could be affected by almost 50%.

The relationship between limits on watershed disturbance and timber harvest derive from the assumed relationships in the ERA model that we employed (Menning, et al. 1996) which in turn were derived from expert opinion and the modest amount of data that is available. A number of assumptions that we made in our ERA analysis had a significant effect on the timber harvest possible under the more restrictive set of ERA limits:. 1) We assumed that the federal forests would react to actions on private lands within the watershed (here LS/OG polygon) by limiting their actions so as not to violate watershed limits. Given the ERA levels we assumed on private land, relatively little federal action that contributes ERA coefficients, such as timber harvest, could occur under the more restrictive ERA limits when private lands occupy a majority of the watershed. 2) The background ERA levels we assumed for most of the federal forest limited activity in all riparian influence zones. 3) We did not react to reaching

ERA limits by shifting to very low impact methods for harvest and site preparation.

It should be noted that the national forests do not necessarily stop activities when they are estimated to contribute to ERA levels for watersheds that might violate their thresholds. Such a finding usually triggers a more detailed analysis and, perhaps, a revision of the project in question. Still, we thought that setting ERA limits in some alternatives would help in understanding their potential effect.

Providing Sustainable Timber Harvests

The "green" timber harvest level for the next fifty years varies among the alternatives from 0-113 million board feet per year on the Eldorado National Forest and 0-200 million board feet per year on the Plumas National Forest. In addition, fire salvage could be obtained under some alternatives.

Timber harvest, in most alternatives in which it is allowed, would be concentrated in the smaller diameter classes, at least for the next few decades. This is especially true in those alternatives in which LS/OG rank 4 is sought, such as alternatives 3 or 4 or the ALSE portions of alternatives 6-9. In alternatives that have the goal of a LS/OG rank three in the matrix, however, considerable harvest of larger trees (trees over 30") could occur if this harvest does not interfere with achieving LS/OG goals.

DFPZs are built in the first period in alternatives 6-10. In these linear 1/4 mile areas, canopy closure is reduced to 30%, and, in the process, many small trees and some large trees could be removed.

Timber harvest consumes only a small proportion of overall growth under most alternatives with much of the remainder going toward rebuilding late-successional forests. Also, a significant amount is consumed by prescribed fire and wildfire. Once the forests are rebuilt, over the next 50-150 years, we would expect that the timber harvest level consistent with maintaining late-successional structures could increase.

Three major factors determine the timber harvest level: 1) the area of land over which timber harvest is permitted, 2) the LS/OG rank sought, and 3) the watershed disturbance permitted. In our analysis, limits on watershed disturbance outside of the near-stream zone (Community/Energy Zone) can have an especially significant influence on timber harvest as discussed above. Finding and applying low-impact harvesting techniques appears to be one key to greater timber harvests from the two national forests we studied.

Reintroducing Historical Ecosystem Processes into Pine and Mixed Conifer Forests

"Historical ecosystem processes" typically refers to the disturbance regimes which were characteristic of these forests prior to western settlement and the ecological consequences of those disturbances. The most important of these disturbance processes is believed to have been fire of light to moderate intensity, but high-intensity fire, windthrow, and insects and diseases were also factors affecting forest composition and processes. Such disturbances also displayed a very high level of spatial heterogeneity--i.e., they were extremely nonuniform in their impacts on forests--and occurred at variable time intervals.

Both types of activities included in the simulations--timber harvest and prescribed fire--reintroduce some of the effects of historical disturbance regimes. Both activities also display significant differences from historical processes, however.

<u>The Role of Timber Harvest</u>

Under many alternatives, much of the timber harvest has the goal of removing smaller-diameter trees and reducing overall stand density, effects comparable to those of low- to moderate-intensity fire. This harvest can also assist in development of late-successional forest structural complexity, such as by speeding the development of large-diameter trees or favoring regeneration and development of shade-intolerant tree species such as pines.

The effects of timber harvest, though, can offer significant contrast to those of fire and/or other historical disturbance processes. With many logging methods, there can be significant mechanical disturbance to soil and litter layers, compaction, and damage to the bole and root systems of the residual stand. We assume in this analysis that low-impact tractor or cable logging will be used, but the possibility of disturbance and damage still exists.

In logging, unlike fire, organic material (stems and, perhaps, branches) are removed from the site with some loss of nutrients. Unless burning follows harvest, ash seed beds characteristic of burned sites are not created. In this analysis, we assumed that fuels created by logging (activity fuels) would be burned after logging; otherwise, commercial timber harvest could significantly increase fire hazard.

As a final contrast, silvicultural treatments are often applied more uniformly than occur though historical disturbance processes.

The Role of Prescribed Fire

Prescribed fire is obviously an extremely important technique for reintroducing the important historical processes of fire disturbance to the pine and mixed conifer forest types in which low- to moderate-intensity fire played an important role. It is possible to simulate many of the biological effects, such as in preferential removal of smaller-diameter and shade-tolerant trees, as well as to approximate the frequency and intensity that were characteristic of historical disturbance regimes.

Effects of prescribed fire can differ significantly from natural wildfires, however. Natural wildfires would have occurred under a much wider range of conditions than the narrowly defined conditions of current prescribed fires. Most prescribed fire, on the other hand, is carried out during cooler, moister periods, such as during the spring or fall. The level of comparability in ecological effects of hot season burns vs. cool season burns has not been documented for the Sierra Nevada. A reasonable inference, though, is that significant differences exist in their effects on biota and ecosystem processes, such as nutrient cycling.

Our modeling of prescribed fire has utilized the simplistic approach of a constant rate of prescribed fire within a forest type. We realize that a more sophisticated approach might vary the fire return interval with slope, aspect, and other variables, in addition to forest type. Also, a more sophisticated approach might vary the return interval at each site. Nonetheless, we believe that the approach applied here provides useful insights for initial development of forest policies.

Overall Levels of Activity and Investment

A substantial amount of prescribed fire is assumed in all alternatives except for Alternative 1 (Table 10) with the annual rate in pine and mixed conifer forests for the first decade being 18-32 thousand acres on the Eldorado and 33-59 thousand acres on the Plumas National Forest.

It is difficult to precisely estimate the acres that would be needed to be burned under each alternative without site specific examination. Still it appears that these amounts of prescribed fire are considerably above current and planned levels. According to Husari and McKelvey (1996), recent experience and planned levels for the two national forests are (almost all in the pine and mixed conifer forests):

	Acres burned 1993	1994	Planned future acres to burn per year
Eldorado NF	4267	3225	7000
Plumas NF	5099	4443	10000

If even 75% of the acres estimated in the alternatives would need prescribed fire to achieve the objectives of the alternative, a doubling or tripling of prescribed fire over planned programs would be needed.

At $75-200/acre, a sizable annual investment would be required. It can be argued, though, that these costs should decline considerably over time (C. Skinner, 1996, personal communication). As fuels are treated and DFPZs are constructed, costs should decline because the risk of escape and necessary manpower will decline while the amount of area that could be treated by each project will likely increase. Also, as managers become more experienced with prescribed fire, and develop more confidence in prescriptions, costs should decline.

We measured overall timber harvest activity in terms of the number of times a stand was entered for harvest over 50 years (Tables 11a, 11b). We focused here, as elsewhere, on pine and mixed conifer forests. Depending on the alternative, 0-68 percent of these forests would be entered at least once on the Eldorado National Forest and 0-61 percent of these forests would be entered at least once on the Plumas National Forest. The forests that would be harvested were entered up to three times with two entries being the most common in most alternatives.

Variable Effects of Wildfire

The results reported so far have been based on one set of wildfires through time as discussed above. To assess how representative these fires would be, and to understand the variability in wildfires that might occur, we did ten simulations of wildfire on the Eldorado National Forest for a subset of alternatives. Each of these simulations reflects a different weather stream and selection of fire size and area of occurrence based on the probabilistic fire simulator.

The distribution of forest among late-successional ranks under the 10 simulations are reported in Table 12. The set of wildfires used for the results reported in Tables 3-11 create late-successional conditions that closely approximate the averages shown in Table 12 suggesting that the results in Tables 3-11 give an “average” result.

In terms of the range of fire effects on LS/OG rank, we found the highest variability in the lowest and highest ranks. Generally, the higher the level of severe fire that occurs, the greater the acreage in the lowest rank (0) and the lessor the acreage in the highest ranks (4/5). By and large, the middle ranks (2,3) showed considerable stability within an alternative across the different fire streams.

In terms of severe fire, alternatives 2-10 were most susceptible in the early periods before the effect of treatments took hold. Alternative 1, on the other hand, was susceptible to severe fire in all periods.

Using 10 wildfire simulations for one alternative on the two Forests enabled us to develop a map showing probability of wildfire under extreme weather conditions during a fifty year period (Figure 3) (Note: this map includes the wildfires for all five periods). Looking in detail at the pine and mixed conifer forests of the Eldorado National Forest, these simulations suggest that over 2/3 of these forests have at least a 10% chance of fire under extreme weather conditions in the next fifty years and almost 20% of them have at least a 40% chance without DFPZs (Table 13). Adding DFPZs to the simulations reduces the overall probability that these forests burn.

Effect of DFPZs

These fire simulations help to portray the influence of DFPZs on limiting the spread of fire. We simulated the extent of fire without DFPZs and with them (Table 14).

Total acreage burned over the 10 simulations was reduced by 26% on the Eldorado National Forest. This percentage varies from simulation to simulation depending on where the fire started relative to the location of the nearest DFPZs that it would encounter. In our analysis, the effect of DFPZs on acres burned varied from 8 to 49%.

In addition, we can judge the effectiveness of DFPZs in terms of how they change the likelihood of a LS/OG polygon being burned by wildfire over the fifty years (Table 13).

Achieving Ecosystem Goals With Little or No Prescribed Fire

Given the possibility that relatively little prescribed fire might occur, we reexamined some alternatives (alternatives 5-8) on the Eldorado National Forest. We allowed prescribed fire only when needed to maintain DFPZs assuming that such a focused strategy would have a high chance of being funded. This resulted in an average annual level of prescribed fire which varied from 0 in alternatives lacking DFPZs (alternative 5) to about 2000 acres per year in alternatives that include them (alternatives 6-8). In these latter alternatives, relatively few acres of prescribed fire would be needed until the second decade.

Without the fuel treatments across the landscape provided by prescribed fire, the likelihood of severe fire can be reduced in two ways. Timber harvest with slash treatment can reduce wildfire severity and DFPZs can reduce the extent of wildfire. Our analysis of the effects of prescribed fire, and the ability of timber harvest to compensate for its loss, is summarized in Table 15 for the pine and mixed conifer forests of the Eldorado National Forest.

Average LS/OG rank is higher in period five without the general use of prescribed fire than with it. Prescribed fire was applied in the original analysis at a set interval; it often retards rank development under our assumptions because some large trees were killed. A higher proportion of pine and mixed conifer forests are in the lowest rank (rank 0) and the high ranks (ranks 4, 5) without the general use of prescribed fire than with it. More severe fire causes the increase in low ranks; mortality in large trees caused by prescribed fire is absent which allows the increase in high ranks.

The proportion of the stand with the potential for severe fire is much higher without prescribed fire than with it. As timber harvest is allowed to play a larger part in forest management (moving from alternative 5 to 8) when prescribed fire is not generally available, the proportion of the forest subject to severe fire decreases as expected but still stays considerably above the case when prescribed fire is available.

Looking at rank 4 and 5 mixed conifer forests in the fifth period, we see that the total extent of these forests is higher without the general use of prescribed fire, but that the proportion with the potential for severe fire is much greater. Allowing extensive use of timber harvest through release of the watershed disturbance limits (alternative 8), when prescribed fire is not generally available, halves this potential but it still remains considerably above the situation when prescribed fire is generally available.

Unlike prescribed fire which was applied at set intervals in the original analysis, timber harvest is allowed only when it is consistent with the LS/OG rank goals. Also, commercial harvests do not remove very small stems. Thus, timber harvest is not necessarily a perfect replacement for prescribed fire in reducing the potential for severe fire. Pushing harder on “biomassing” might further reduce the potential for severe fire, but at the cost of more watershed disturbance and the need for more investment.

Timber harvest increases somewhat with the removal of prescribed fire as a widespread tool. Its greatest increase occurs when limits on watershed disturbance have been removed.

Without general availability of prescribed fire, and the associated higher amount of acres subject to severe fire, the importance of DFPZs correspondingly increases as a way to reduce the extent of severe fire.

In our analysis, it would be difficult to reintroduce historical ecosystem processes fully without the use of prescribed fire. As discussed above, timber harvest, when it can occur, provides some but not all of the functions that were historically provided by prescribed fire.

The Role of Nonfederal Lands

This analysis has focused on federal forests of the Sierra Nevada. Almost one third of the SNEP study area, though, is nonfederal (mostly private) land. Nonfederal lands are often intermingled with federal lands and form their outer boundary (Figures 1-3).

We have discussed a number of alternatives for maintaining the health and sustainability of Sierra Nevada ecosystems (Table 1). Nonfederal intermingled and adjacent lands are especially important to the success of these strategies:

1) DFPZs are employed in some strategies. They inescapably cross intermingled and adjacent nonfederal land in many places and we have assumed they will be built on non-federal lands in strategies that employ DFPZs. If DFPZs are not completed in nonfederal lands, much of their effectiveness would be lost.
2) Late successional goals for federal forests are employed in most strategies. We have made no special assumptions about management of the intermingled and adjacent nonfederal forests relative to late-successional characteristics, but management of these lands can influence the effectiveness of a LS/OG strategy for federal forests. This may be especially true in the ALSEs.
3) Limits on watershed disturbance are employed in most strategies. They inescapably include the nonfederal land within the areas on which limits are applied. We have recognized this feature in carrying nonfederal land, mostly private land, through the analysis for the purpose of reflecting an assumed contribution to watershed disturbance. In addition, we have assumed that private activity takes precedence over federal activity, in that we allow timber harvest to occur on federal land in an area only if assumed private activities have not exceeded the limit on watershed disturbance. Thus, the level and type of activity on private land can have a controlling effect on federal activity in adjacent areas.
4) Expected population growth in the Sierra Nevada (Duane 1996) on adjacent and intermingled nonfederal land could increase the ignition probabilities for the federal forests and the size and frequency of large fires beyond those assumed here.

To deal with these and other issues, a number of approaches could be taken including collaborative planning, regulation, and monetary and nonmonetary incentives (Sierra Nevada Ecosystem Project 1996b). Our purpose here is to point out that, in addressing the issues of health and sustainability of Sierra Nevada ecosystems, the federal forests cannot be treated as islands isolated from the rest of the Sierra Nevada landscape. The management of intermingled and adjacent nonfederal lands will have a large impact on achievement of ecosystem goals for federal lands.

Cautions in Interpretation

Potential Over-Reliance on Prescribed Fire

Our results suggest that prescribed fire can be used for landscape-level fuel reduction while simultaneously restoring fire as an ecosystem process, helping to rebuilding late-successional forests, and allowing watersheds to recover. A variety of practical and political considerations, though, suggest caution in reliance on prescribed fire as the only solution including difficulty in obtaining adequate funding and personnel, air quality restrictions, and the danger of the occasional escaped fire (see McKelvey, et al. (1996) for more discussion). Major increases in prescribed fire in the Sierra Nevada would call for patience and understanding by the people who own property there and the millions of tourists who have grown accustomed to the spectacular vistas provided by this mountain range.

Initially, prescribed fire in many instances will be applied to stands that have experienced a build up in fuels. The difficulty of successful application, i.e., avoiding the killing of the overstory trees that the treatment is intended to help protect, should not be overlooked. Also, the difficulty of successful application without fuel breaks should not be overlooked. Fuel breaks and mechanical treatment, including timber harvest, may be needed in these initial entries to reduce the probability of damage to mature trees and of escape. While our analysis assumes that some large trees will be killed by prescribed fire, it is impossible to capture the dynamics of each particular site in a broad analysis such as this one.

Potential Over-Reliance on Timber Harvest

Caution is also suggested in reliance solely on timber harvest to substitute for prescribed fire as timber harvest does not serve all the functions of fire in the ecosystem. As stated in the SNEP summary (Sierra Nevada Ecosystem Project 1996a, p. 5): "Although silvicultural treatments can mimic the effects of fire on structural patterns of woody vegetation, virtually no data exist on the ability to mimic ecological functions of natural fire. Silvicultural treatments can create patterns of woody vegetation that appear similar to those that fire would create, but the consequences for nutrient cycling, hydrology, seed scarification, nonwoody vegetation response, plant diversity, disease, and insect infestation, and genetic diversity are mostly unknown."

Also, timber harvest can cause negative impacts of its own. Watershed impacts, as measured by ERA, limit the use of timber harvest in some of our alternatives.

Potential Overestimates of Forest Growth

The simulations suggest that forest inventories will increase under all the alternatives. Some caution should be used in putting too much credence in these results as we may have not accurately modeled periodic mortality from insects, especially in the larger trees. Forest growth models, such as the PROGNOSIS model used here, have traditionally had difficulty in realistically portraying stand mortality, especially the episodic mortality associated with fire and insects. We feel that the SAFE FOREST model makes progress in adjusting forest growth for wildfire. Questions can still be raised, though, about how realistically we portray periodic insect outbreaks that have historically occurred in the Sierra Nevada (Ferrell 1996). Caution should be used in interpreting our projections of forest growth, especially in how many large trees might be surplus to other goals in the future and available for harvest.

The Need for Site-specific Prescriptions

We have used a set of generic prescriptions based on the goals of the analysis and general landscape condition. We find these adequate for our modeling exercise, but realize that more site-specific prescriptions will be needed in actual land management.

The options described here, in attempting to address the problems named at the start of this section, emphasize the specification of land, stream, and watershed management goals, and strategies to meet these goals. The detailed land allocations, prescriptions, and constraints developed in each option are intended to illustrate the ways in which these objectives and strategies could play out on the landscape. They are not intended to preempt the development of detailed allocations and prescriptions that would occur in the field.

The Difficulty of Actively Managing Near Streams

It is unclear how much active management in terms of prescribed fire or timber harvest can occur near streams and still meet objectives of limiting watershed disturbance. Yet, the build up of fuels near streams can be troublesome. Here, perhaps more than any other part of the landscape, it is hard to portray accurately the implications of the different alternatives.

The Need for More Analysis to Draw Firm Conclusions

A relatively small number of simulations were employed in developing these results. More analysis is needed, especially an analysis of the variability of wildfire and its effects and a testing of the conclusions drawn here on other national forests of the Sierra Nevada.

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ADDENDUM

Table 1 . Description of some forest management alternatives for the Eldorado National Forest and Plumas National Forest.

	Alternatives										
	1	2	3	4	5	6	7	8	9	10	
Goals											
Attain LS/OG Rank											
ALSE	4	4	4	4	4	4	4	4			
Matrix	4	4	4	3	3	3	3	2			
Limit watershed disturb.			1	1	1	1	1	1	2	2	
Risk of severe fire											
reduce	x	x	x	x	x	x	x	x			
minimize								x			
Timber harvest											
Even-flow		x	x	x	x	x	x	x	x		
Max. amount (matrix)		x	x	x	x	x	x	x	x		
Permitted mgt. practices											
ALSE											
Prescribed fire			x	x	x	x	x	x	x	x	x
DFPZs (Fuel breaks)					x	x	x	x	x		
Comm. timb. harvest						x	x	x	x		
Biomassing (required)*						x	x	x	x		
Wildfire salvage						x	x	x	x		
Matrix											
Prescribed fire	x	x	x	x	x	x	x	x	x		
DFPZs (Fuel breaks)					x	x	x	x	x		
Comm. timb. harvest											
All matrix avail		x	x	x	x	x	x	x			
Outside RR	x										
Biomassing (avail.)*		x	x	x	x	x	x	x	x		
Biomassing (required)*								x			
Wildfire salvage		x	x	x	x	x	x	x	x		

Note: Watershed disturbance limits: 1 = .05/.10/.15; 2 =. 10/.99/.99. RR = roadless reaches. The code for each alterative has three parts: 1) the number of the alternative, 2) the presence (b) or absence (a) of a fuel break and 3) the watershed disturbance limit. The LS/OG goal of a "4" refers to an ALSE 4 and the LS/OG goal of a "3" refers to a matrix 3. The riparian influence zone called the Community/Energy Zone receives a LS/OG rank goal of an ALSE 4 in all alternatives. The riparian influence zone called the Land Use Influence Zone receives the LS/OG goal stated in the Table unless that goal drops below a 3; then, it receives an LS/OG goal of a 3.
* on slopes less than 40%

Table 2. Measures of goal attainment

Goal	Measures of goal attainment
Rebuild late-successional forests	Average rank; distribution of forest among LS/OG ranks
Restore streams and watersheds	ERA level in three riparian influence zones; LS/OG rank in riparian influence zones
Reduce the potential for severe fire	Distribution of forest severity fire among severity classes; distribution of forest that burns among severity classes
Produce a sustainable supply of timber in a cost-effective manner	Timber harvest level; distribution of harvest among diameter classes; net revenue
Restoring historical processes	Reintroduction of frequent, low-moderate intensity fire; use of timber harvest methods that simulate low-moderate intensity fire

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Table 3a. Distribution of pine and mixed conifer forest among LS/OG ranks (excluding brush) on the Eldorado National Forest in period 1 and by alternative in period 5.

LS/OG Rank	Per 1 %	Alternatives 1	2	3	4	5	6	7	8	9	10
		(% of acres in period 5)									
0	8	10	2	2	2	2	2	1	1	2	2
1	1	7	7	7	7	7	7	7	7	7	23
2	45	4	14	17	15	15	21	21	21	31	34
3	25	12	21	26	26	30	27	27	31	27	21
4	20	65	56	48	50	45	43	43	38	32	21
5	0	3	0	0	0	0	0	0	0	0	0
Avg	2.46	3.24	3.20	3.11	3.15	3.11	3.02	3.02	2.97	2.79	2.35

Table 3b. Distribution of pine and mixed conifer forest among LS/OG ranks (excluding brush) on the Plumas National Forest in period 1 and by alternative in period 5.

LS/OG rank	Per 1 %	Alternatives 1	2	3*	4	5	6*	7*	8	9*	10
		(% of acres in period 5)									
0	11	11	2		2	2			3		3
1	2	5	6		6	6			6		7
2	25	3	4		4	4			5		33
3	35	6	25		25	37			43		26
4	27	72	62		62	50			43		30
5	0	3	1		1	1			1		1
Avg	2.64	3.31	3.44		3.40	3.29			3.19		2.74

* Not available.

Table 4a. Distribution of pine and mixed conifer forest among LS/OG ranks (excludes brush) on the Eldorado National Forest (ALSE only) in period 1 and by alternative in period 5.

		Alternatives									
Rank	Per 1 %	1	2	3*	4*	5	6*	7*	8	9*	10*
		(% of acres in period 5)									
0	5	15	3			3			2		
1	0	3	5			5			5		
2	33	1	11			11			17		
3	37	12	11			12			14		
4	25	66	70			70			61		
5	0	4	0			0			0		
Avg.	2.79	3.04	3.41			3.41			3.28		

Table 4b. Distribution of pine and mixed conifer forest among LS/OG ranks (excludes brush) on the Plumas National Forest. (ALSE only) in period 1 and by alternative in period 5.

		Alternatives									
Rank	Per 1 %	1	2	3*	4*	5	6*	7*	8	9*	10*
		(% of acres in period 5)									
0	6	10	0			1			1		
1	3	5	5			5			5		
2	27	4	5			6			7		
3	36	6	26			25			25		
4	28	72	61			60			61		
5	0	4	2			2			1		
	2.74	3.36	3.49			3.42			3.40		

* Not available.

Table 5a. Acreage-weighted distribution of "montane mixed conifer" polygons among LS/OG ranks in the first period and by alternative in period five on the Eldorado National Forest.

				Alternatives						
Per 1	1	2	3	4	5	6	7	8	9	10
Rank	%	% in period five								
All montane mixed conifer polygons										
0,1	11	9	1			1			1	
2	56	23	13			18			27	
3	33	44	72			73			67	
4		24	13			8			5	
5										
Ave Rank	2.16	2.78	2.95			2.92			2.75	
Non-ALSE polygons only										
0,1	15	9	1			1			2	
2	61	23	15			22			34	
3	24	49	77			76			64	
4		18	8			1				
5										
Ave Rank	2.01	2.70	2.91			2.88			2.61	
ALSE polygons only										
0,1		8	3			3				
2	47	22	9			9			12	
3	53	30	61			65			73	
4		39	27			23			15	
5										
Ave Rank	2.6	2.95	3.08			3.06			3.03	

Table 6a. Distribution of pine and mixed conifer forest among basal area severity classes on the Eldorado National Forest in period 1 and by alternative in period 3. The severity classes estimate the percentage of basal area which would be killed if a fire occurred.

		Alternatives									
%basal area	Per 1 %	1	2	3	4	5	6	7	8	9	10
		(% of acres in period 3)									
0-20	2	3	46	47	44	43	45	44	40	36	47
20-40	15	4	22	28	28	28	28	29	36	43	38
40-60	30	35	6	3	5	7	6	6	6	5	4
60-80	7	5	1	1	1	1	1	1	1	1	1
80+	48	52	25	21	22	22	21	21	18	15	11

Table 6b. Distribution of pine and mixed conifer forest among basal area severity classes on the Plumas National Forest in period 1 and by alternative in period 3. The severity classes estimate the percentage of basal area which would be killed if a fire occurred.

		Alternatives									
%basal area	Per 1 %	1	2	3*	4	5	6*	7*	8	9*	10
		(% of acres in period 3)									
	0	2	32		31	33			32		40
20-40	25	11	44		45	44			43		40
40-60	33	17	9		10	8			9		8
60-80	4	13	0		1	2			3		1
80+	38	57	14		13	14			14		11

* Not available.

ADDENDUM

Table 7a. Distribution of pine and mixed conifer forest among basal area severity classes on the Eldorado National Forest in period 1 and by alternative in period 5. The severity classes estimate the percentage of basal area which would be killed if a fire occurred.

		Alternatives									
%basal area	Per 1 %	1	2	3	4	5	6	7	8	9	10
		(% of acres in period 5)									
0-20	2	1	80	81	78	74	77	77	70	59	81
20-40	15	7	15	16	18	21	19	19	25	36	14
40-60	30	10	0	0	0	1	1	1	1	1	0
60-80	7	24	1	0	1	1	1	1	1	1	1
80+	48	59	4	2	3	4	3	3	3	3	3

Table 7b. Distribution of pine and mixed conifer forest among basal area severity classes on the Plumas National Forest in period 1 and by alternative in period 5. The severity classes estimate the percentage of basal area which would be killed if a fire occurred.

		Alternatives									
%basal area	Per 1 %	1	2	3*	4	5	6*	7*	8	9*	10
		(% of acres in period 5)									
0-20	0	2	56		57	54			55		57
20-40	25	6	22		24	26			31		30
40-60	33	22	2		2	2			2		3
60-80	4	5	0		0	0			0		0
80+	38	66	20		18	17			11		9

* Not available.

Table 8a. Distribution of mixed conifer LS/OG rank 4 and 5 among basal area severity classes on the Eldorado National Forest in period 1 and by alternative in period 5. The severity classes estimate the percentage of basal area which would be killed if a fire occurred.

Alternatives %basal area	Per 1 %	1	2	3	4	5	6	7	8	9	10
					(% of acres in period 5)						
0-20	0	0	98	99	97	90	93	95	83	83	93
20-40	0	0	0	0	0	7	5	4	13	13	0
40-60	0	0	0	0	0	0	0	0	0	0	0
60-80	0	9	1	0	1	0	1	0	1	1	2
80+	1	91	1	0	2	2	2	2	3	3	5

Table 8b. Distribution of eastside mixed conifer LS/OG rank 4 and 5 among basal area severity classes on the Plumas National Forest in period 1 and by alternative in period 5. The severity classes estimate the percentage of basal area which would be killed if a fire occurred.

Alternatives %basal area	Per 1 %	1	2	3*	4	5	6*	7*	8	9*	10
					(% of acres in period 5)						
0-20	0	1	93		93	91			91		80
20-40	0	1	0		2	2			3		3
40-60	73	35	1		1	1			1		3
60-80	0	5	1		0	1			1		1
80+	27	57	5		3	5			5		12

* Not available.

ADDENDUM

Table 9a. Average green timber harvest over five decades on the Eldorado National Forest.

		Alternatives									
		1	2	3	4	5	6	7	8	9	10
		(Millions of board feet/year)									
Total		0	0	12	14	43	43	44	85	113	110
ALSE											
	per 1	0	0	0	0	0	10	14	25	25	*
	ave	0	0	0	0	0	2	7	13	14	*

* ALSEs not recognized

Table 9b. Average total green timber harvest over five decades on the Plumas National Forest.

	Alternatives									
	1	2	3*	4	5	6*	7*	8	9*	10
	(Millions of board feet/year)									
	0	0		52	75			143		200

* Not available.

Table 10a. Acres burned with prescribed fire in pine and mixed conifer forests of the Eldorado National Forest.

	Alternatives									
	1	2	3	4	5	6	7	8	9	10
	(Thousands of acres/year)									
1st Decade	0	32	30	30	30	28	27	23	21	18
Ave. For 5 decades	0	28	27	27	27	27	26	24	22	21

Table 10b. Acres burned with prescribed fire in pine and mixed conifer forests of the Plumas National Forest.

	Alternatives									
	1	2	3*	4	5	6*	7*	8	9*	10
	(Thousands of acres/year)									
1st Decade	0	59		41	45			34		33
Ave. For 5 decades	0	50		40	42			38		34

* Not available.

Table 11a. Percent of acres entered different number of times for harvest over 5 decades in pine and mixed conifer forests of the Eldorado National Forest.

	Alternatives									
Number of times	1	2	3	4	5	6	7	8	9	10
entered for timber	%									
harvest over 5 decades										
0 times	100	100	84	83	85	79	77	59	42	32
1 times			5	8	4	7	7	9	12	8
2 times			8	8	8	12	11	20	33	35
3 times			3	2	3	2	5	12	13	25

Table 11b. Percent of acres entered different number of times for harvest over five decades in pine and mixed conifer forests of the Plumas National Forest.

	Alternatives									
Number of times	1	2	3*	4	5	6*	7*	8	9*	10
entered for timber	%									
harvest over 5 decades										
0 times	100	100		70	71			48		39
1 times				6	6			10		5
2 times				18	16			27		29
3 times				6	7			13		27

* Not available.

Table 12. Percentage distribution of pine and mixed conifer forests among LS/OG ranks and average LS/OG rank in 10 wildfire simulations on the Eldorado National Forest.

	Alternatives							
	1		2		5		8	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
LS/OG Rank	---%							
0	9	5-12	2	1-6	3	1-4	2	1-3
1	6	6-7	7	7-7	7	7-7	7	7-8
2	4	3-4	14	14-15	15	15-17	21	21-22
3	13	13-14	21	20-21	30	29-31	32	31-33
4	65	63-70	55	52-57	45	43-47	38	36-39
5	3	3-3	0	0	0	0	0	0
Ave.	3.13	3.08-3.29	3.19	3.05-3.26	3.08	2.95-3.13	2.96	2.89-3.00

Table 13. Occurrence of wildfire under extreme weather conditions in the montane mixed conifer LS/OG polygons over fifty years based on 10 wildfire simulations with and without DFPZs (fuel breaks) on the Eldorado National Forest.

	Occurrence of wildfire (percent of area)	
Number of burns	Without fuel breaks	With fuel breaks
0	28	32
1-3	52	56
4-6	12	8
7-9	5	3
10+	2	0

Table 14. Total acres burned in 10 wildfire simulations with and without DFPZs (fuel breaks) on the Eldorado National Forest.

	Without fuel breaks	With fuel breaks	Diff	% diff
	Ave. Wildfire/decade (Thousands of acres)			
Simulation #				
1	17.6	12.2	5.4	31
2	30.0	20.0	10.0	33
3	20.0	10.1	9.9	49
4	10.0	7.5	2.5	25
5	23.4	19.3	4.1	18
6	18.5	13.9	4.6	25
7	18.8	17.3	1.5	8
8	23.5	14.9	8.6	37
9	23.2	15.9	7.3	18
10	27.2	25.0	2.2	8
Ave.	21.2	15.6	5.6	26.6
Range	10.0-30.0	7.5-25.0	1.5-10.0	8-49

Table 15. Effects of the general use of prescribed fire as a management tool in pine and mixed conifer forests in selected alternatives (all comparisons use period 5) (1 = with prescribed fire and 2 = without prescribed fire; MC = pine and mixed conifer).

	Alternatives							
	5		6		7		8	
Criteria	1	2	1	2	1	2	1	2
LS/OG ranks								
Ave. Rank	3.1	3.35	3.0	3.23	3.0	3.16	3.0	3.18
% in lo rank (0)	2	6	2	6	1	7	1	5
% in hi rank (4/5)	45	66	43	31	43	59	38	53
% in high severity class								
Entire MC forest	5	77	4	68	4	63	4	51
Of MC LS/OG rank 4+	3	95	3	90	3	80	3	40
Acres in MC LS/OG 4+	67	80	62	75	61	75	55	53
% acres not entered for harvest	85	81	79	71	77	69	59	55

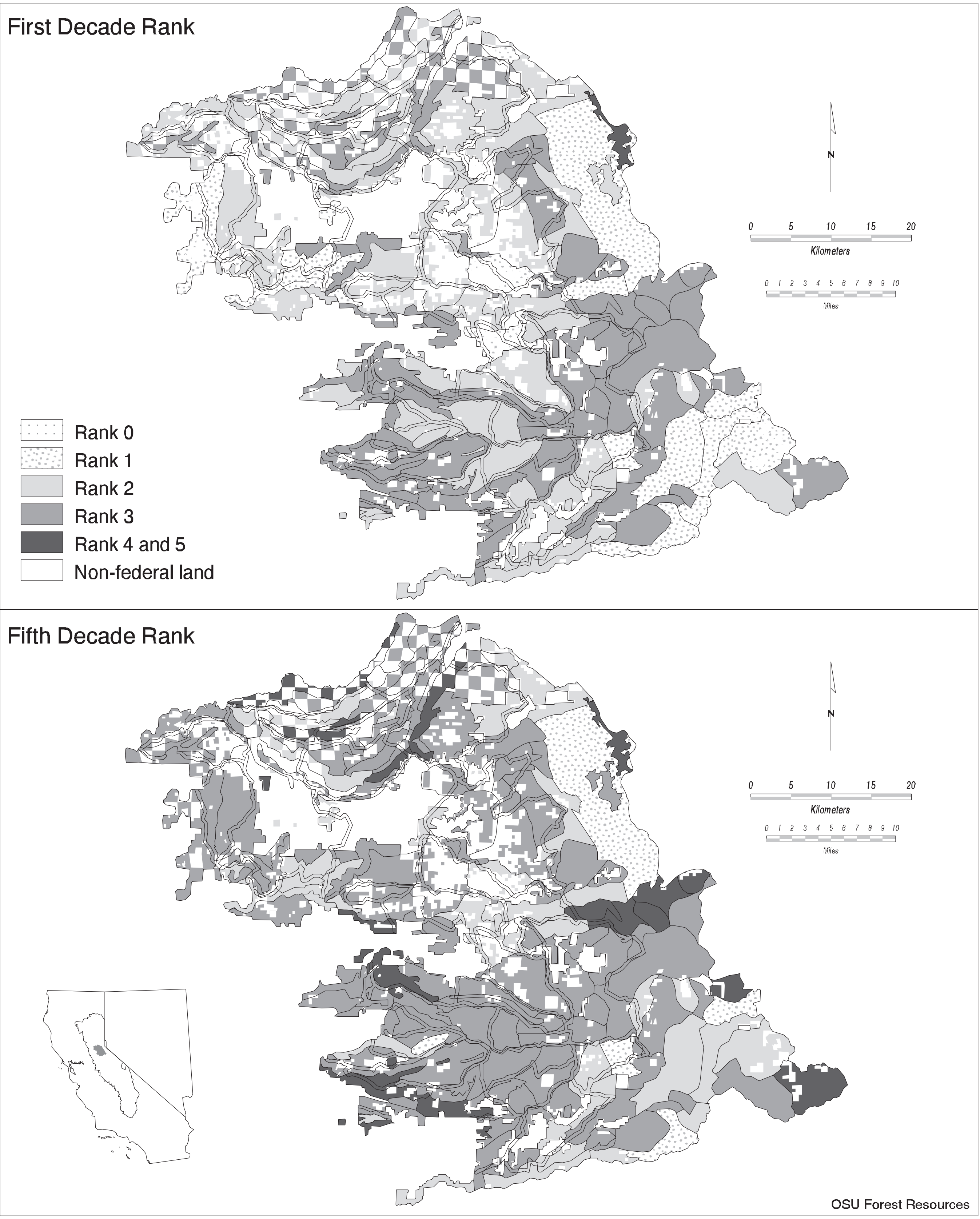


Figure 1

Eldorado National Forest: LS/OG polygon rank through time. LS/OG polygons ranked as to degree of LS/OG structural complexity and contribution to late successional forest function by evaluating each vegetation class within each polygon (rangewide structural standard for mixed conifer and ponderosa pine types and series-normalized structural standard for higher elevation types).

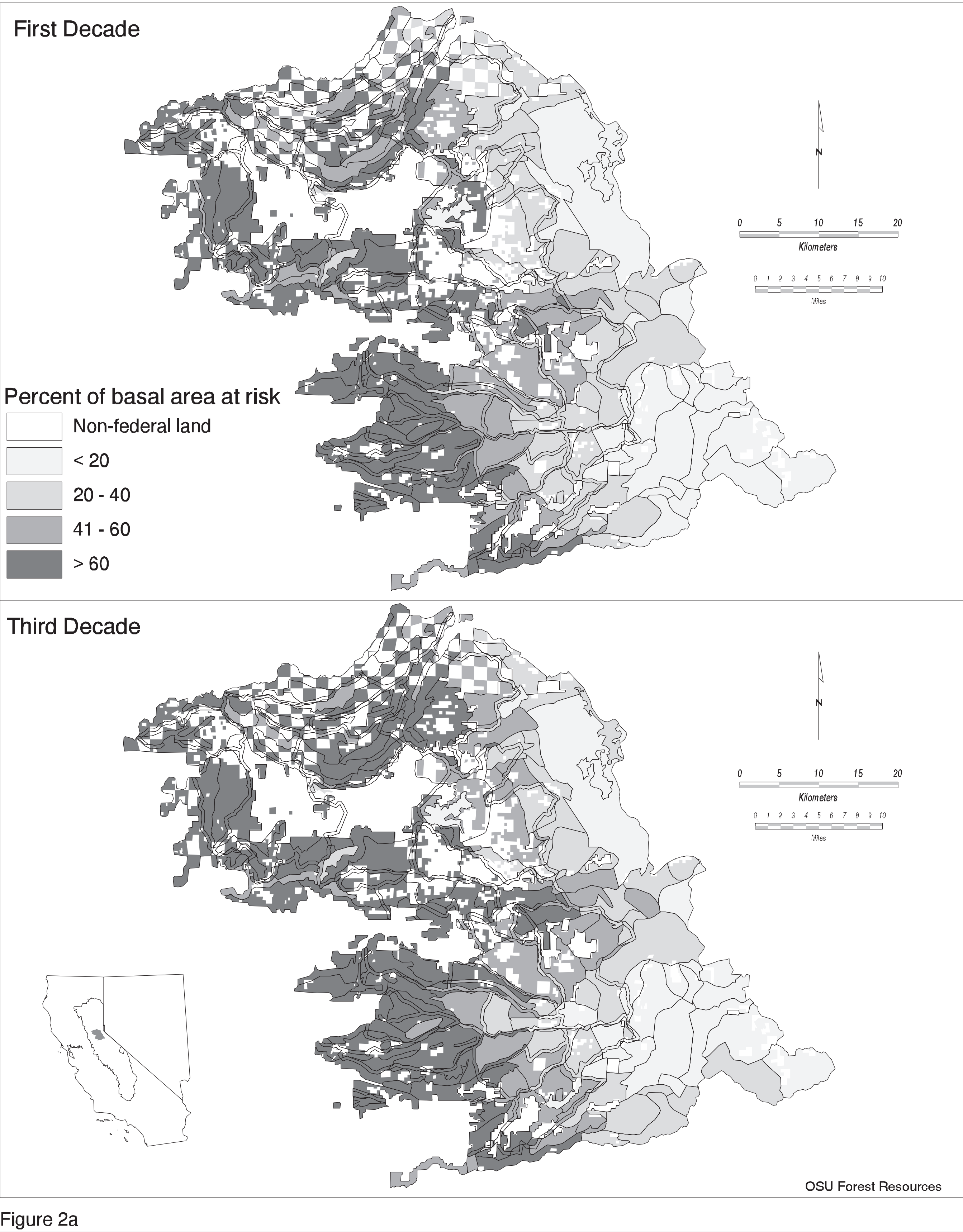


Figure 2a

Eldorado National Forest: Alternative One, fire severity potential.

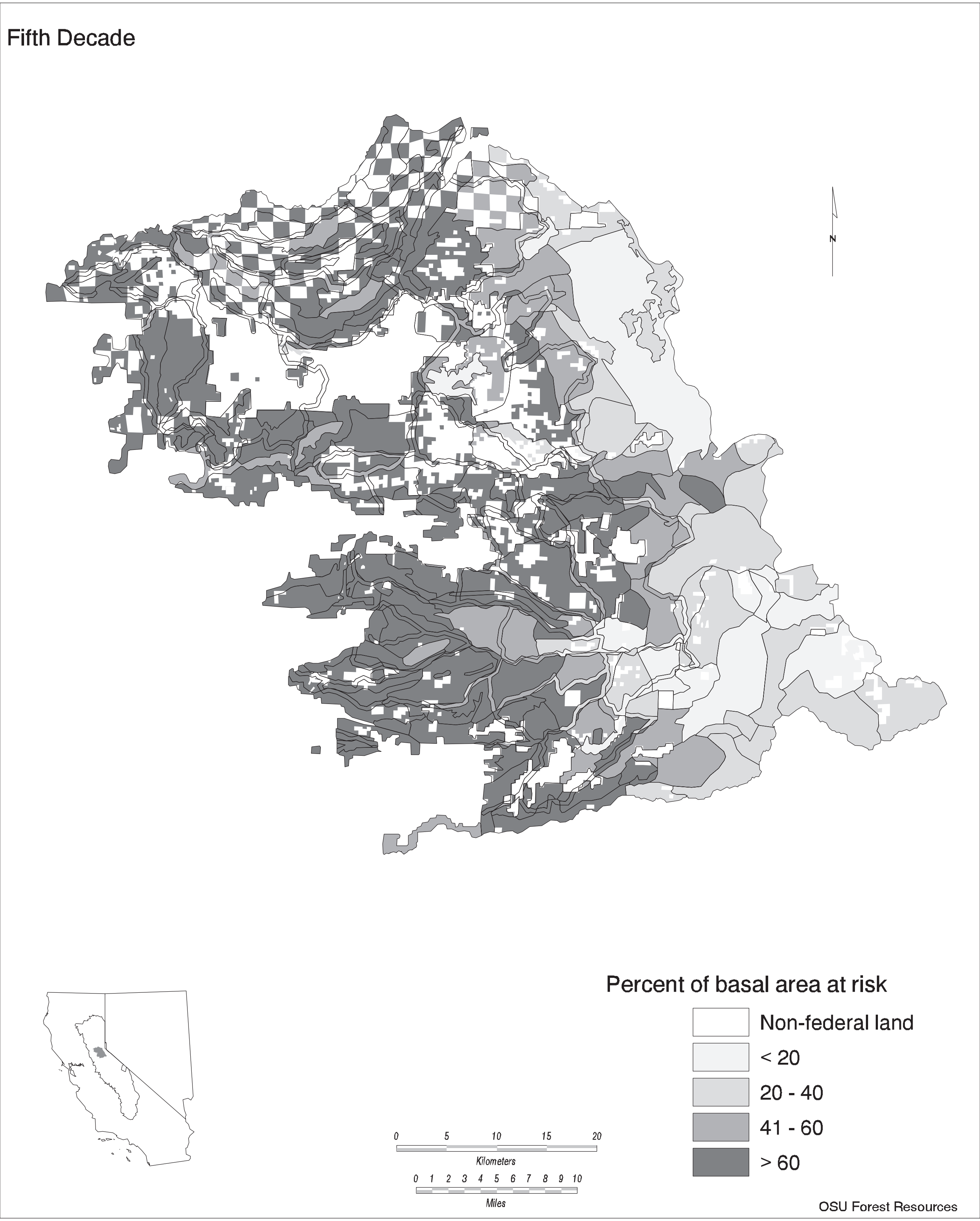


Figure 2a (cont.)

Eldorado National Forest: Alternative 1, fire severity potential.

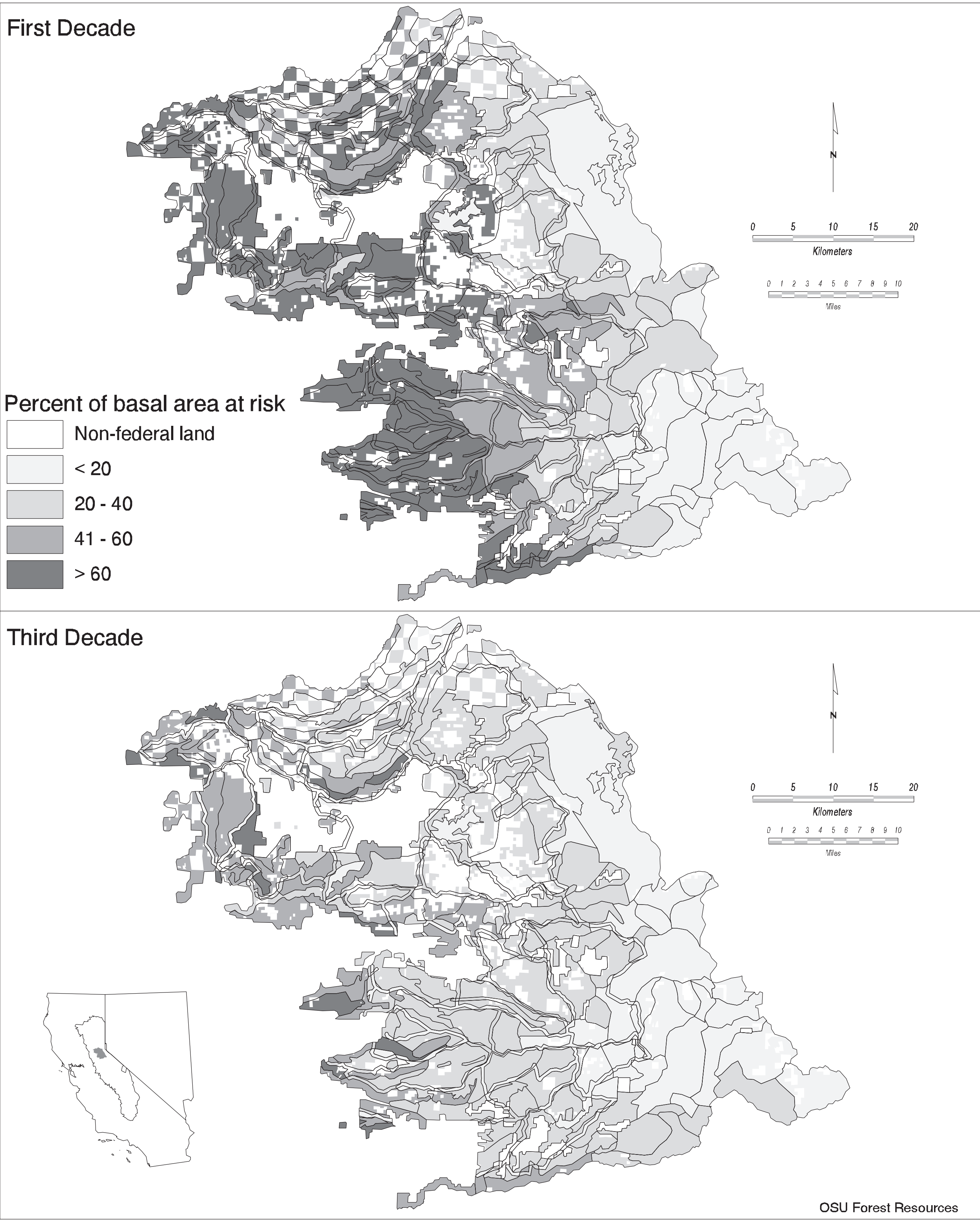


Figure 2b

Eldorado National Forest: Alternative Eight, fire severity potential.

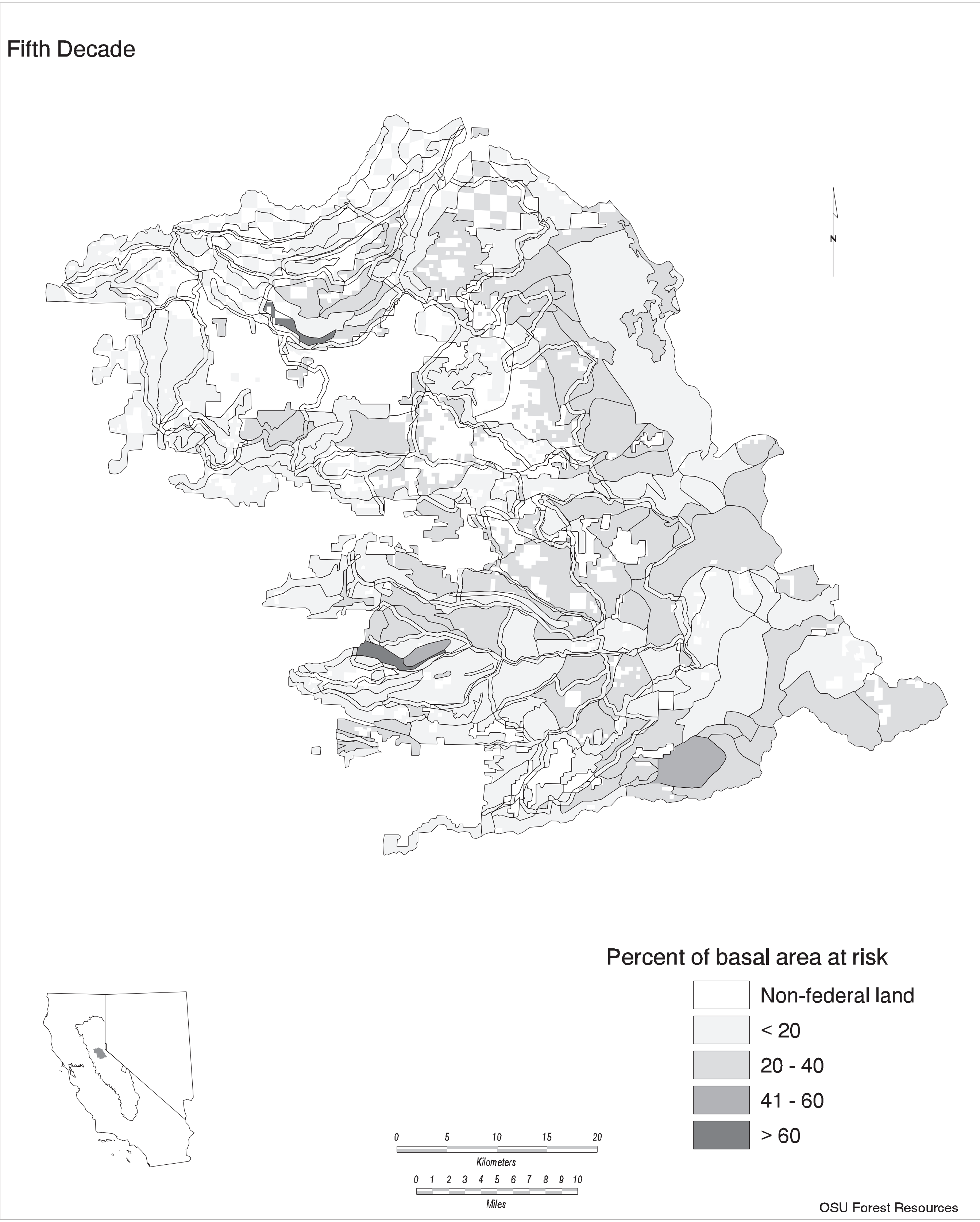
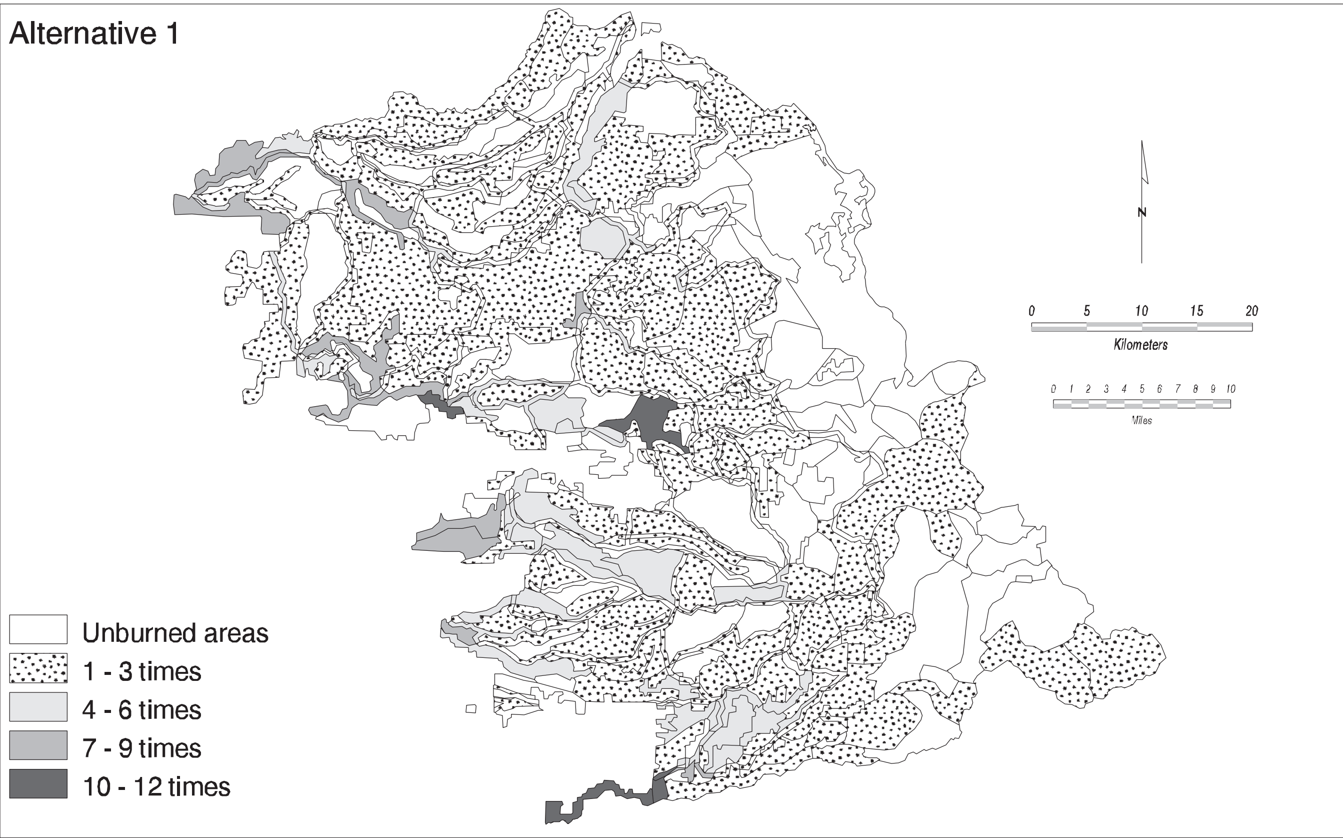


Figure 2b (cont.)

Eldorado National Forest: Alternative Eight, fire severity potential



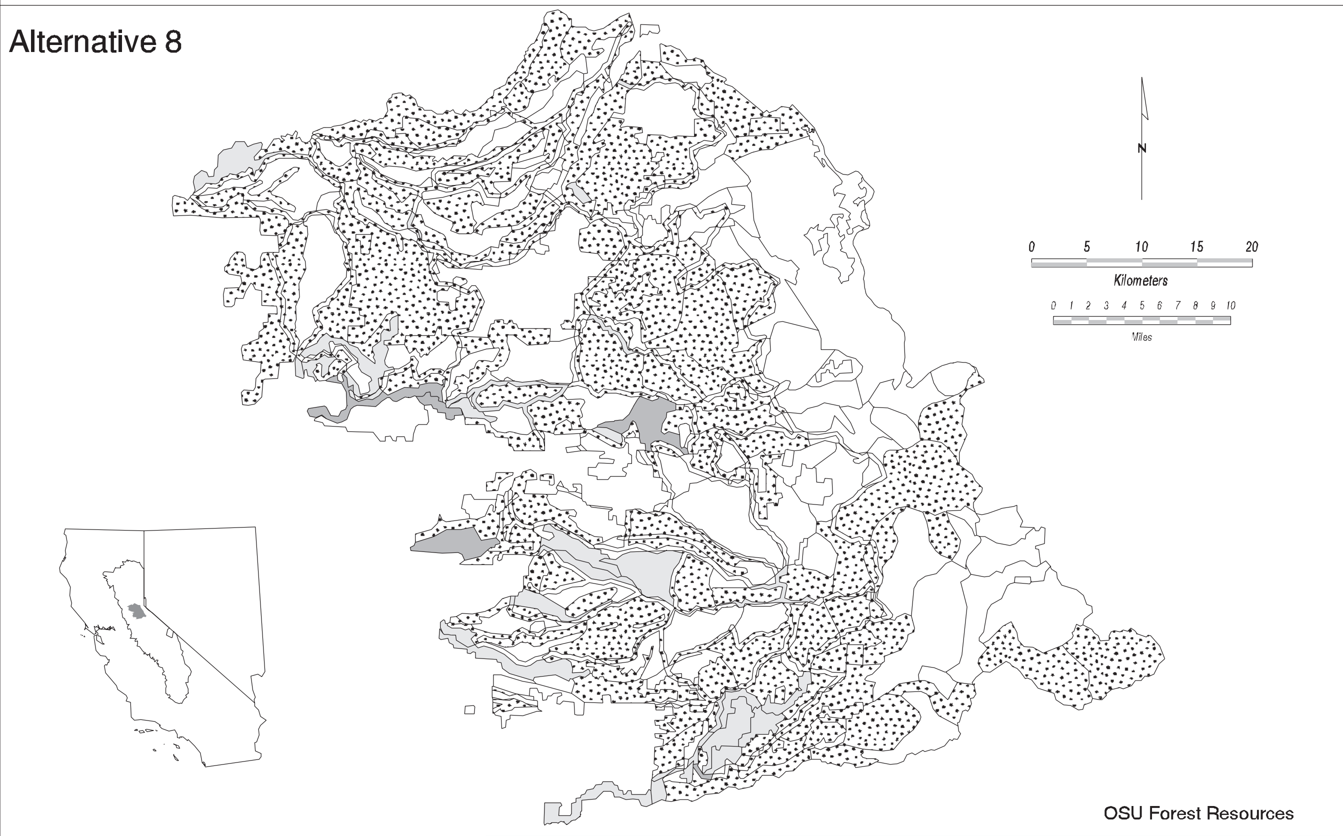


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Figure 3

Eldorado National Forest: number of times LS/OG polygons burned over ten simulations