Changes in Character and Structure of Apache/Sitgreaves Forest Ecology: 1850-1990

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Abstract. This analysis of the Apache/Sitgreaves National Forest in eastern Arizona was undertaken to evaluate changing ponderosa pine (*Pinus ponderosa*) overstory tree densities and their potential environmental and economic impacts. Assessment of 100 years of forest overstory data on the Apache/Sitgreaves reveals significant change in overstory character and structure. Evaluation of early written observations by explorers, surveyors and naturalists indicate that tree densities of the 1850s were low, and the forest floor had minimal fuel loads. Recent research on the Forest indicates pre-European settlement tree densities were originally as low as 34 trees per acre above 4" dbh. Analysis of surveys completed in 1911, 1967, 1988, and 1994 reveals that the number of trees per acre in ponderosa pine type has increased significantly from approximately 34 trees per acre above 4" dbh in 1911, to 133 trees per acre above 4" dbh in 1994. Tree density increases have occurred in all diameter classes up to 20" dbh. The analysis determined that approximately 21 trees existed in these classes in 1911 and over 127 trees exist today. This represents a 500 percent increase in tree densities between 4" and 20" dbh over the century. The analysis also determined that of the average of 13 trees per acre above 20" dbh in 1911, 7 exist today, a loss of approximately 50%. Computer simulated treatments to the forest overstory that approach presettlement conditions reveal significant enhancement of forest ecosystem resources as compared to no treatment alternatives. Further, implementation of restoration treatments would realize positive net present values from public investments.

Key words: Forest ecosystem impacts, presettlement, fire suppression, forest resource assessment, tree densities, stand density index, economic evaluation

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This document presents a summary of findings from a study of past, present and potential future forest overstory conditions on the Apache/Sitgreaves National Forest. Brevity required in this summary permits coverage of only the most significant findings from two more comprehensive technical reports. The reader is referred to the full reports cited below for in-depth coverage of the forest assessment.

INCREASING TREE DENSITIES IN PONDEROSA PINE FORESTS: A NATIONAL PROBLEM

In a 1994 hearing before Congress, Dr. Jack Ward Thomas, Chief of the USDA Forest Service, reported that the ponderosa pine region of the interior west United States was being severely impacted by declines in forest health. He also noted that these forests have high potential risk of loss to catastrophic insect, disease and wildfire. The current administration has placed specific emphasis on the northern interior west ponderosa pine region, due to significant insect, disease and wildfire losses. Comprehensive analysis of forest health has been initiated in the region to develop more effective forest management alternatives for combating extensive degradation to forest ecosystems (USDA Forest Service 1994, Sampson and Adams 1994).

As declared in Chief Thomas' testimony to Congress, increasing tree densities is the primary factor contributing to degraded ecosystems and declining health in interior west ponderosa pine forests. These forests are the most extensive coniferous forest ecosystems in the western United States, dominating millions of acres of terrestrial environments (Sampson and Adams 1994).

Ponderosa pine forests have been determined to be fire-driven forest ecologies (Pyne 1982, Covington and Sackett 1985, Swetnam 1990). Over thousands of years, wildfires, unbridled by the suppression activities of man, moved at regular intervals across entire western landscapes. Recurring fires would burn through almost all accessible pine acreages at intervals of three to twenty years, depending on the regional location. In the southwest region of the United States, these ground fires created a forest landscape of 25-50 trees per acre, dominated by 10" dbh and larger trees (White 1985, Covington and Moore 1994a, Garrett et al. 1997).

Intensities of these historical wildfires were low, because the short recurring intervals between fires maintained fuel loads well below 10 tons per acre (Covington and Sackett 1985, Swetnam 1990). Older trees, especially trees greater than 10" dbh with developed thick bark, were largely resistant to damage from these ground fires. Smaller trees, such as seedlings and trees up to 5" dbh, were normally destroyed, with only a few surviving to maintain the open forest overstory of the period (Woolsey 1911, Pearson 1923).

Introduction of fire suppression activities in western forests at the

turn of the century, combined with livestock grazing and other less significant factors, have contributed to the radical increases in tree densities noted in ponderosa pine forest stands today (Covington and Moore 1994b, Garrett et al. 1997). Critical concerns now exist that restraints on restoration management in this forest type could further aggravate already seriously overstocked conditions.

Increasing tree densities in ponderosa pine type and its impacts on forest health is now becoming a concern in the Southwest. For example, research completed in the past five years by university and government forest specialists have characterized significant increases in densities of ponderosa pine overstories in Arizona (Garrett et al. 1990, Ellenwood 1994, Johnson 1995). Selected research plots on the Kaibab and Coconino National Forests suggest that densities have increased across broad landscapes, from less than 50 trees per acre in the late 1800s to 300 or more trees per acre in the 1990s (Covington and Moore 1994b).

Assessments of changing overstory densities on all ponderosa pine forests in Arizona demonstrated that trees increased from an average of 272 per acre in 1962 to 314 per acre in 1985 (Garrett et al 1990). Analysis conducted on differing datasets for all species on all ownerships in Arizona and New Mexico reveals average trees per acre increased from 233 in 1962 to 296 in 1986 (Johnson 1995). In both assessments, the increases exceeded 10 percent in 23 years (Figs. 1 and 2). These increasing tree densities raise the specter of potential forest ecosystem degradation,

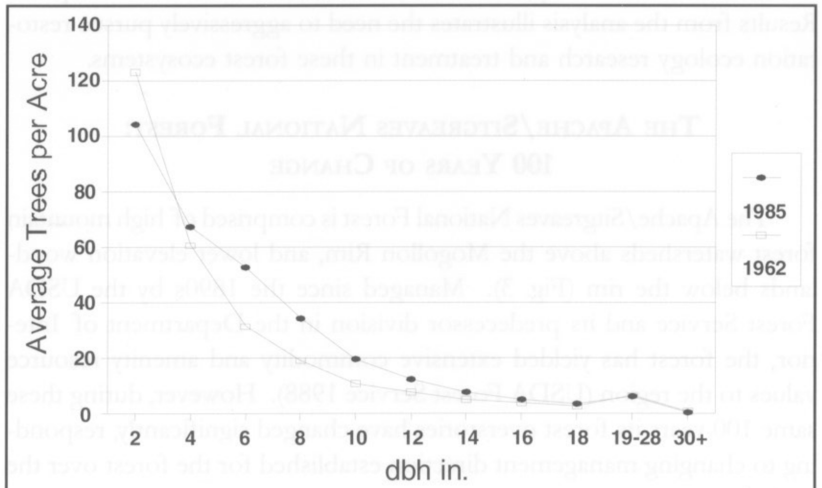

Figure 1. Comparison of average trees per acre on all Arizona ponderosa pine forests: 1962 and 1985. Adapted from Garrett et al. (1990).

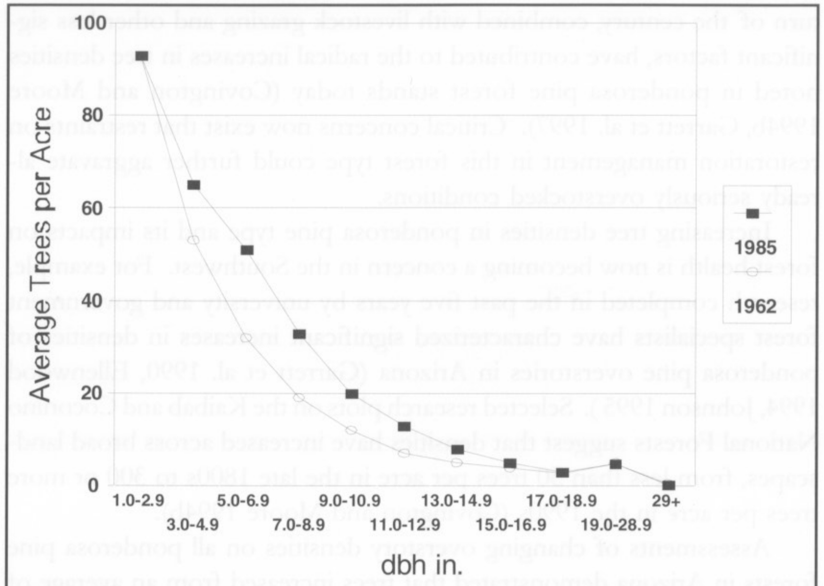

Figure 2. Comparison of average trees per acre for all species and all ownerships in Arizona and New Mexico: 1962 and 1985. Adapted from Johnson (1995).

due to expected impacts on other resources such as soil water, understory productivity, fuel loads, and wildlife habitat.

This analysis of the Apache/Sitgreaves National Forest in eastern Arizona was undertaken to evaluate changing ponderosa pine overstory tree densities and their potential environmental and economic impacts. Results from the analysis illustrates the need to aggressively pursue restoration ecology research and treatment in these forest ecosystems.

THE APACHE/SITGREAVES NATIONAL FOREST: 100 YEARS OF CHANGE

The Apache/Sitgreaves National Forest is comprised of high mountain forest watersheds above the Mogollon Rim, and lower elevation woodlands below the rim (Fig. 3). Managed since the 1890s by the USDA Forest Service and its predecessor division in the Department of Interior, the forest has yielded extensive commodity and amenity resource values to the region (USDA Forest Service 1988). However, during these same 100 years its forest overstories have changed significantly, responding to changing management direction established for the forest over the period.

The character of the extensive ponderosa pine ecosystems of the

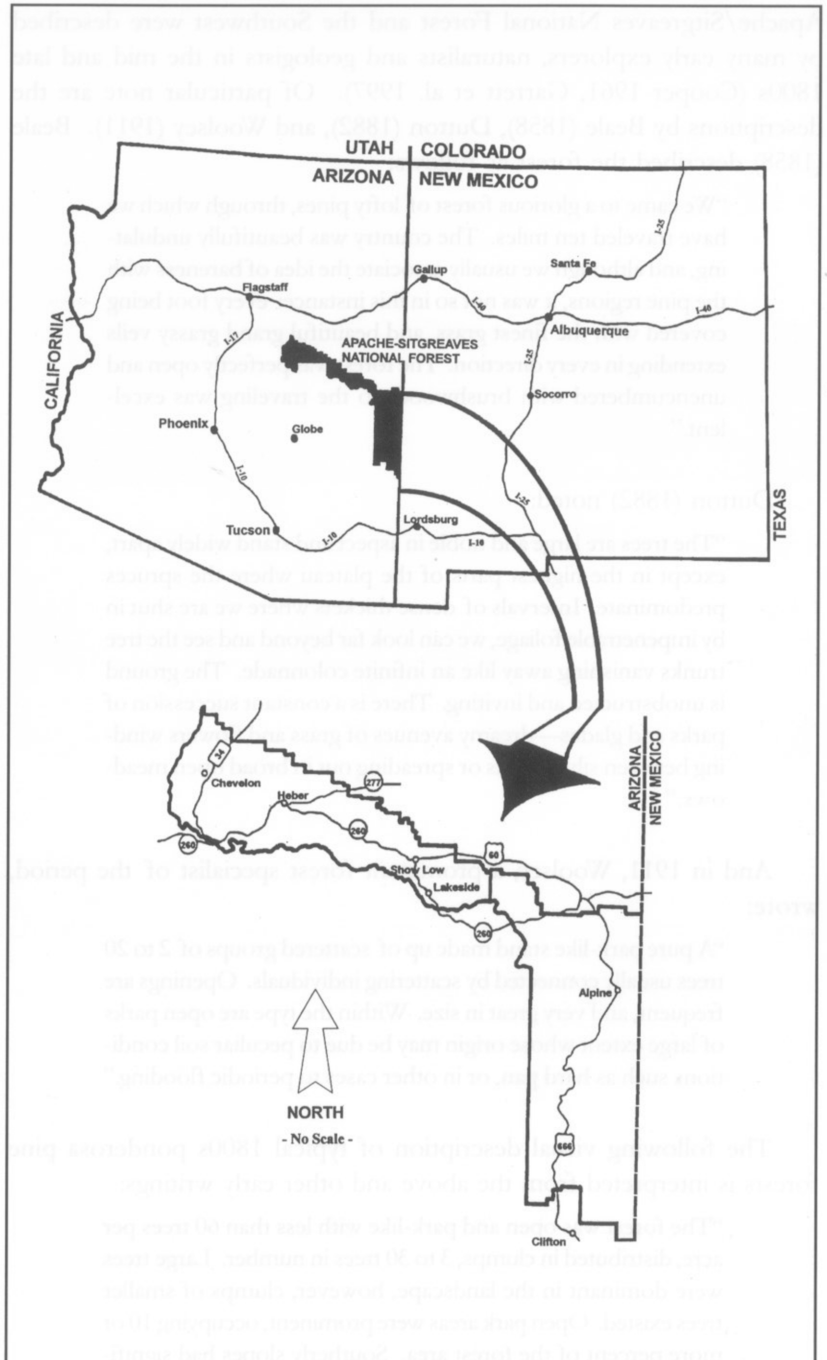

Figure 3. Location of the Apache/Sitgreaves National Forest in the Southwestern Region.

Apache/Sitgreaves National Forest and the Southwest were described by many early explorers, naturalists and geologists in the mid and late 1800s (Cooper 1961, Garrett et al. 1997). Of particular note are the descriptions by Beale (1858), Dutton (1882), and Woolsey (1911). Beale (1858) described the forest as follows:

> "We came to a glorious forest of lofty pines, through which we have traveled ten miles. The country was beautifully undulating, and although we usually associate the idea of bareness with the pine regions, it was not so in this instance: every foot being covered with the finest grass, and beautiful grand grassy veils extending in every direction. The forest was perfectly open and unencumbered with brushwood, so the traveling was excellent."

Dutton (1882) noted:

> "The trees are large and noble in aspect and stand widely apart, except in the highest parts of the plateau where the spruces predominate. Intervals of dense thickets where we are shut in by impenetrable foliage, we can look far beyond and see the tree trunks vanishing away like an infinite colonnade. The ground is unobstructed and inviting. There is a constant succession of parks and glades—dreamy avenues of grass and flowers winding between silvan walls or spreading out in broad open meadows."

And in 1911, Woolsey, a prominent forest specialist of the period, wrote:

> "A pure park-like stand made up of scattered groups of 2 to 20 trees usually connected by scattering individuals. Openings are frequent, and very great in size. Within the type are open parks of large extent whose origin may be due to peculiar soil conditions such as hard pan, or in other cases to periodic flooding."

The following visual description of typical 1800s ponderosa pine forests is interpreted from the above and other early writings:

> "The forest was open and park-like with less than 60 trees per acre, distributed in clumps, 3 to 30 trees in number. Large trees were dominant in the landscape, however, clumps of smaller trees existed. Open park areas were prominent, occupying 10 or more percent of the forest area. Southerly slopes had significant gamble oak and drainages, especially on northerly slopes, would have notable presence of aspen, Douglas fir and concolor fir. Forest floor debris was minimal, averaging less than 10 tons per acre across broad landscapes. Understory vegetation was dominated by grasses and forbs."

Early descriptions of the forest overstory have been recently corroborated by scientists involved in restoration ecology research and conservation biology (Covington and Moore 1994b, White 1985). Forest ecology specialists have, through scientific procedure, been able to reconstruct and successfully define the forest overstories of the southwest ponderosa pine type that existed 150 or more years ago. This research has documented the original pre-European settlement forest to have maintained less than 50 trees per acre across regional landscapes. Selected forest areas studied and the overstory densities determined for these areas are presented in Table 1. As noted, the general average range in tree stocking is approximately 25 to 50 trees per acre (Table 1). Two forest specialists of the period, Pearson and Woolsey, conducted surveys and evaluations of the southwest ponderosa pine type during the first decade of the century (Woolsey 1911, Pearson 1910, 1920). Woolsey (1911) summarized inventory assessments of southwest ponderosa pine forests that were conducted over the period 1900 to 1910. Figure 4 presents a graphic of the average number of trees per acre from surveys on six forests in the Southwest during the 1900-1910 period. Included is the Black Mesa Forest Reserve, known today as the Apache/Sitgreaves National Forest.

Woolsey's (1911) inventory analysis of the Black Mesa Forest Reserve revealed an average of 34 trees per acre above 4" dbh. This number of trees per acre lies at the mean of current assessments by restora-

Table 1. Density of southwestern ponderosa pine presettlement or yellow pine trees reported in the literature.[1]

Location	Trees/acre
Specific studies in Southwest:	
Ft. Valley, Coconino N.F.	15
Bar-M, Coconino N.F.	23
North Kaibab R.D., Kaibab N.F.	56
North Kaibab R.D., Kaibab N.F.	40-45
White Mountains, Apache/Sitgreaves N.F.	35-45
Southern Utah, Zion N.P.	22.7

[1]Adapted from Covington and Moore 1994, White 1985, Covington and Moore 1994a, Covington and Moore 1994b, Rasmussen 1941, Cooper 1960, and Madany and West 1983.

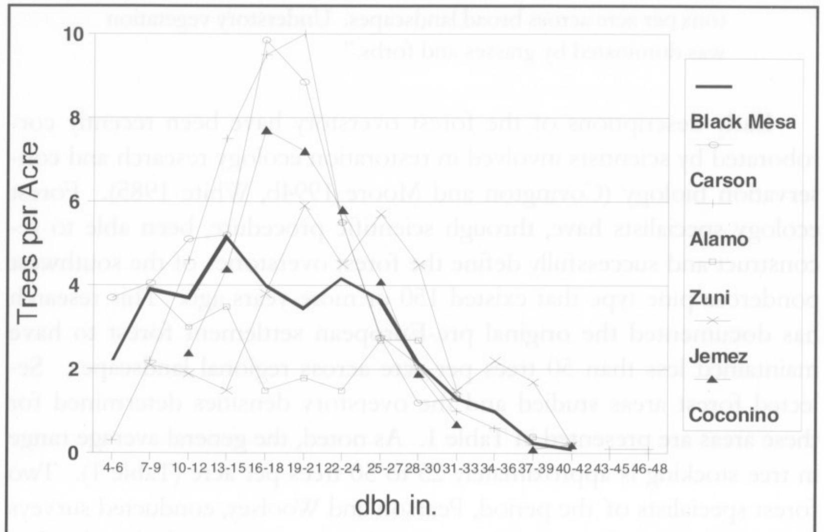

Figure 4. Trees per acre by diameter class from maximum stands of Western Yellow Pine on six southwest forests in 1911. Derived from Woolsey (1911).

tion ecologists (Table 1), and as noted in Figure 4, somewhat at the mean for the differing forest inventories evaluated by Woolsey (1911).

It is difficult to determine from these early surveys the average number of stems per acre below 6" or 4" dbh, because inventory specialists used differing techniques to determine the number of small trees. More importantly, data taken on 1"-6" trees in the first decade of this century might significantly overstate the number of trees that existed during the earlier presettlement period. This is due to the fact that in many forest areas, Anglo settlers' efforts to suppress ground fires had occurred for 10 to 30 years by 1910 (Pyne 1982, Swetnam 1990). This permitted time for establishment of not only seedlings, but trees up to 4" and 6" by 1910. Due to the above noted uncertainties in early data collection on small trees, most of our analysis focused on evaluating changes in tree densities over 4" dbh.

Since the first descriptions and inventories of the presettlement forests, there have been nearly 100 years of USDA Forest Service management activity on the Apache/Sitgreaves National Forest. The general guiding principles for this management direction was derived from the first U.S. Forest Service Chief Forester, Gifford Pinchot (1947). He defined his management principle as "wise use." The concept proposes perpetual protection of the basic biological and physical resources of forest ecosystems, while managing for "wise use" of forest resources such as timber, water, forage, etc. Pinchot's general philosophy and management concept is sustained today on declared "multiple use" areas of National Forests. The current philosophy of "ecosystem management," adopted in the 1990s, places more intensive focus on protection of basic biotic and physical resources, and to restore health and diversity of ecosystems (USDA Forest Service 1994).

The wise use overstory management philosophy was implemented via a silviculture method known as "selection harvest," and was used on National Forests up until the 1970s (Pinchot 1947, Pearson 1950, Schubert 1974). This procedure resulted in discriminate selection of diseased, deformed and overmature trees for harvest, and the removal of approximately 1500 board feet per acre during an entry (Pearson 1950, Schubert 1974).

In the presettlement pine forest many trees were overmature and 200-300 years in age. Since the average biological life of ponderosa pine is approximately 250 years, many presettlement trees would have succumbed to natural mortality over the first 100 year management cycle (i.e., 1900-2000). As such, a management direction was undertaken to remove the oldest and most susceptible trees to loss, during the first 100 year management period (Lang and Stewart 1910). This management regime was expected to yield a younger healthier forest at the end of the management period.

By the 1970s and 1980s, forest managers began to recognize that forest stands were becoming increasingly more dense due to regeneration and ingrowth. Insect and disease, especially dwarf mistletoe, was increasing, requiring modification in management regimes.

New integrated resource and integrated stand management (IRM, ISM) prescriptions were adopted in the 1970s and 1980s to reduce increasing densities. When implemented, these prescriptions removed nearly 3500 bd. ft. per acre from acres entered. This heavier removal of trees to address forest health issues was met by considerable resistance from segments of the general public. ISM prescriptions were discontinued by forest managers in the late 1980s in favor of current ecosystem management prescriptions.

The above noted management practices implemented over the past century, especially managed fire suppression and some harvest activities, have resulted in a changed forest overstory character and structure, which is clearly evident in Figure 5. This figure presents average trees per acre on the Apache/Sitgreaves National Forest from several survey years, rang-

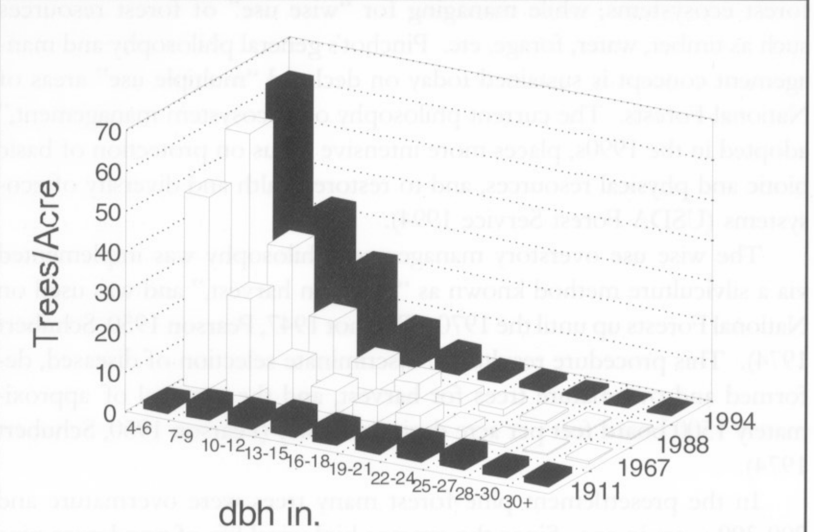

Figure 5. Comparison of average trees per acre on the Apache/Sitgreaves in 1911, 1967, 1988 and 1994.

ing from 1911 to the current forest assessments of 1994. Three general findings are obvious from these inventory assessments:

1. The number of trees per acre has increased significantly from approximately 34 trees per acre above 4" dbh in 1911, to 133 trees per acre above 4" dbh in 1994.
2. Tree density increases have occurred in all diameter classes up to 20" dbh.
3. A reduction in trees per acre has occurred in diameters over 20" dbh.

The analysis demonstrates that there have been significant increases in trees per acre from 4" to 20" dbh. The approximately 21 trees that existed in these classes in 1911 has increased to over 127 trees today. This represents a 500 percent increase in tree densities between 4" and 20" dbh over the century.

In the presettlement period, an average of approximately 10-13 trees existed above 20" dbh. Approximately 6-8 trees existed between 20"-25" dbh, and 4-5 trees above 25" dbh. Evaluations of early surveys indicate that an average of only 0.5-1.5 trees per acre existed above 30" dbh (Lang and Stewart 1910, Woolsey 1911, Pearson 1950).

There has been a decline in trees per acre over 20" dbh. Although the decline represents only 6-8 trees per acre on average, it is a loss of over 50 percent of the original numbers of trees that existed above 20" dbh. Most of the loss (2-4 trees) are in the 22"-27" dbh diameter classes. Losses are due primarily to harvests and natural mortality.

Today an average of only six trees exist above 20" dbh, indicating the above noted loss of 6-8 trees in these size classes. Some caution is noted regarding this conclusion. Woolsey's (1911) surveys on the Black Mesa Forest were of "maximum stands," indicating that average overall stocking across the forest might have been lower in large diameter classes. For example, an early comprehensive survey on the North Kaibab revealed an average of only 7-9 trees per acre greater than 20" dbh (Lang and Stewart 1910, Ellenwood 1994, Garrett et al. 1997).

FOREST ECOSYSTEM IMPACTS OF PAST FOREST MANAGEMENT DIRECTIONS

The Forest Service new "ecosystem management" direction purports to focus more attention on the protection of intrinsic biophysical values associated with the land base. Protection of threatened and endangered plant and wildlife species is a critical part of ecosystem management (USDA Forest Service 1994). In so doing, standards and guidelines are written to accommodate increased levels of protection and, therefore, impose greater restrictions on management and use activities.

Protection activities for threatened and endangered flora and fauna and associated habitat has become a primary component of land resource management. However, excessive constraints on management activities in these habitats may not embody the basic philosophical intent of ecosystem management. For example, the current underlying management philosophy for threatened, endangered, or sensitive (TES) species is single species management, a concept potentially incongruent with ecosystem management. The USDA Forest Service mandate to protect intrinsic values of forest ecosystems may well become the basis for the Forest Service to implement aggressive and comprehensive restoration science and management activities in the western ponderosa pine type.

There are reasons to be concerned about the current status of southwest ponderosa pine forests. Scientific documentation now exists to not only characterize increasing tree densities, but also define the potential impacts of these densities to other resources of the forest ecosystem, such as water, soils, forage, wildlife habitat, and basic intrinsic values such as health, diversity and sustainability.

Research on southwest pine forests has demonstrated fully that increasing densities in this forest type is not a "natural phenomenon" (Cooper 1961, Schubert 1974, Ellenwood 1994, Covington and Moore 1994b). In fact, it is a phenomenon driven by man's imposed management activities. Suppression of natural, low-intensity ground fire in these forest ecosystems and other management activities previously noted, have created the current character and structure of the forest overstory.

Research on the resource impacts of increased tree densities has demonstrated that moderate and high tree densities in this forest type significantly impact soil water, fuel loads, understory plant productivity, wildlife habitat, etc. (Brown et al. 1974, Rogers et al. 1984, Covington and Moore 1994b). In general, these abnormally high densities have been demonstrated through science to:

1. Significantly increase intra-tree competition for moisture and nutrients so as to impose significant stress on all trees.
2. Increase the probability of loss of larger, over-mature trees, due to their inability to sustain themselves under the increased stress from intra-tree competition.
3. Increase the vulnerability of all trees in the stand to insect and disease infestation, and the spread of infestations once established.
4. Decrease average soil moisture content.
5. Decrease water movement to seeps, springs and instream flows in the forest environment.
6. Increase fuel loads.
7. Decrease grass, forb and shrub production.
8. Increase factors contributing to higher risk of catastrophic insect and disease outbreaks.
9. Increase factors contributing to higher risk of intense catastrophic wildfire on larger acreages.

POTENTIAL FUTURE OUTCOMES FROM ALTERNATIVE OVERSTORY MANAGEMENT REGIMES

To evaluate potential implications of permitting increased densities to be maintained on the Apache/Sitgreaves National Forest, we simulated 50 years of changing forest conditions associated with two different management regimes. The regimes and associated prescriptions selected for the simulations are deliberately divergent. This was done to demonstrate the wide matrix of opportunities and outcomes that exist in managing the diverse forest landscape.

Like all modeling efforts, the management alternatives are made simplistic to permit clear measure of impacts of the different treatments. Actual treatments applied across broad forest landscapes would be much more complex and involve a mosaic of overstory character and structure. Tree densities would also vary significantly. However, in many forest areas, average forest structure and tree densities can be significantly changed with restoration treatments, as they are changed in our computer derived examples.

The treatments that were implemented are as follows:

- A no management treatment to the forest overstory. This treatment assumes no removals of any overstory trees through the selected management period of 50 years. Thinnings, harvest removals, and timber stand improvement removals are all excluded as management activities. Regeneration occurs through the period, as well as minimal insect and disease control.
- A Pre-European settlement overstory treatment. This management alternative restores the forest overstory to the presettlement character and structure defined by overstory surveys at the turn of the century. It requires implementation of several management activities including prescribed burns, fuel removals, thinnings, harvests, etc.

Using the southwest ponderosa pine ECOlogy SIMulator; ECOSIM, forest overstories and associated resources (i.e., understory forage, instream water, fuel loads, wildlife habitat, scenic quality, etc.) can be projected into the future (Rogers et al. 1984, Covington et al. 1986). The system is driven by management activities selected by the manager and/or analyst. The choice of management activities are broad, and can include overstory and understory treatments, watershed improvements, wildlife habitat improvements, prescribed burns, etc.

Defining The Current Forest Condition

Before one can proceed to project future change with the computer model ECOSIM, one must first define the current state of the forest. Figure 6 is a characterization of the average number of trees per acre by diameter class that currently exist on the Apache/Sitgreaves National Forest. This average stand condition is developed from a sample of 15 analysis areas on the forest, representing over 130,000 acres (Fig. 7).

Table 2 provides descriptive data on the current average stand conditions on six of the above noted analysis areas (Fig. 7). Baca, South Fork, Middle Mountain, Grapevine, Cottonwood and Blue Ridge Morgan analysis units were selected for evaluation of various future resource impacts under our two proposed management alternatives. The average

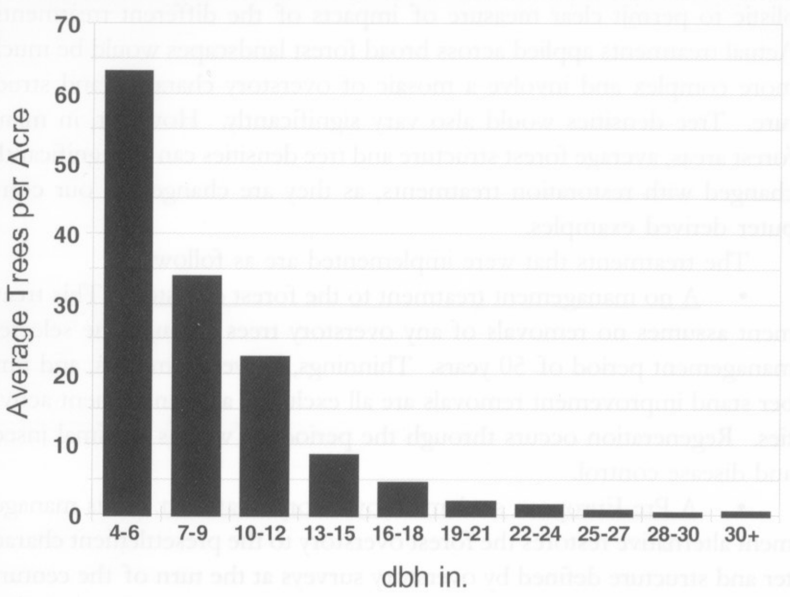

Figure 6. Average trees per acre on the Apache/Sitgreaves National Forest, 1994.

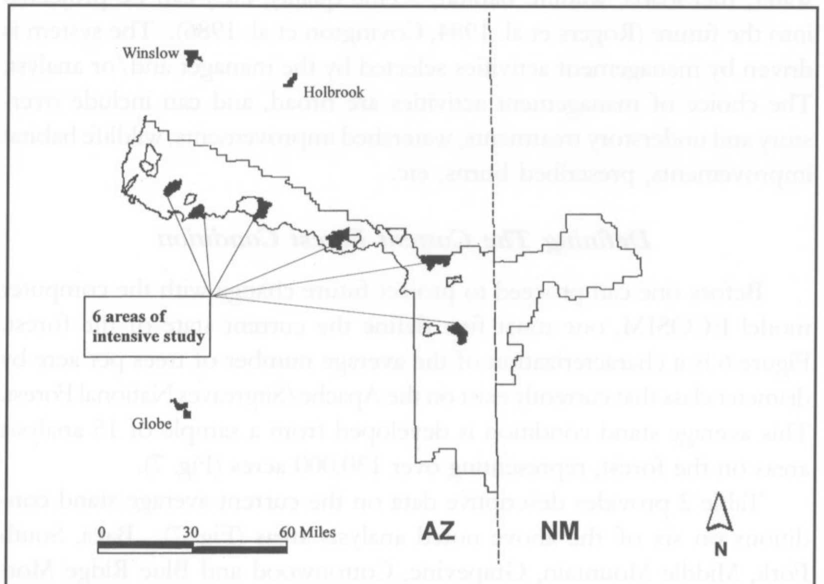

Figure 7. Location of 15 analysis areas and the six areas used for more intensive study.

Table 2. Current average stand conditions per acre on six selected analysis areas on the Apache/Sitgreaves National Forest.

Analysis Area	% of PP in Stand	Average Basal Area	Average SDI	Percent Max-SDI	Average Trees/ac	Acres
Baca	71.01	130	267	59.33	942.2	9,570
Blue-Ridge Morgan	63.25	140	326	72.44	457.1	17,034
Cottonwood	69.10	91	204	45.33	1022.0	18,725
Middle Mt.	67.62	101	200	44.44	333.7	13,110
Southfork	59.70	109	226	50.22	509.0	16,807
Grapevine	86.22	96	103	42.89	940.9	9,240

overstory conditions across the forest and on the six individual analysis areas are similar.

Forest ecologists utilize differing measures to both monitor densities, and relate increasing densities to degradation in other resources. Basal area, the measure of square foot cross sectional area of tree stems on a site, has been used to assess increasing densities, intra-tree competition, shading, etc. (McTague 1991). A second measure used by forest specialists is stand density index, a factor that takes into effect the relative incidence of differing diameter trees in the stand (Ellenwood 1994, Garrett et al. 1997, McTague 1991).

When evaluating the overall average basal area on the six analysis areas, it was found to be greater than 100 square feet per acre, or in the upper middle range of basal areas for this forest type in the Southwest. Basal areas determined for average forest conditions on the Black Mesa Forest Reserve at the turn of the century, ranged between 50 and 80 square feet per acre.

More importantly, the computed percentage of maximum stand density index for the Apache/Sitgreaves National Forest is determined to now be 45 percent. This is more than double the average of 22 percent that existed on the Black Mesa Forest Reserve in 1911 (Table 3).

Percent of maximum stand density indexes determined for the Black Mesa Forest Reserve (Apache/Sitgreaves) and other forests at the turn of the century ranged from 12-30 percent (Table 3). These are considered to be low, and very safe levels by forest specialists, and would contribute to more healthy forest ecosystem conditions (Schmid et al. 1994).

Table 3. Comparison of average percent of maximum stand density index on southwest forests in 1911 and on the Apache/Sitgreaves National Forest in 1994.

	Quadratic Mean Diameter	SDI	Percent Maximum SDI
Carson	19.5	111	25
Alamo	19.6	137	30
Zuni	18.7	54	12
Jemez	21.7	122	27
Coconino	20.8	111	25
Datil	19.9	72	16
Apache	22.3	105	23
Sitgreaves	19.9	93	21
Apache/ Sitgreaves 1994	**7.9**	**200**	**45**

Forest specialists have determined that percent of maximum SDIs exceeding 54 are considered high and damaging to health, diversity and sustainability of ponderosa pine forest ecosystems (Schmid et al. 1994). Stands with 34-54 percent of maximum SDI are considered to have moderate to high tree densities, which are negatively impacting other resources on site. Overstory treatments to reduce densities are advised for all stands above 35 percent of maximum SDI. As noted above, percent of maximum SDI below 33 is not considered a threat to other resources.

Figure 8 presents the average percent of maximum SDI for 15 selected analysis areas across the forest. The 15 analysis areas represent a range in percent of maximum SDI from 27-72 percent, and an average of 45. Two are in the low range, 12 are in the moderate range, and one is in the high range.

As noted previously, given the current state of tree densities, restoration ecology management prescriptions should be evaluated for potential application on the forest. The following evaluations of no management and restoration management options characterize probable impacts of "doing nothing" or "restoring" the forest landscapes.

Forest Ecosystem Change Under No Overstory Treatment

The no overstory treatment alternative restricts the forest manager from implementing any overstory management actions during the 50

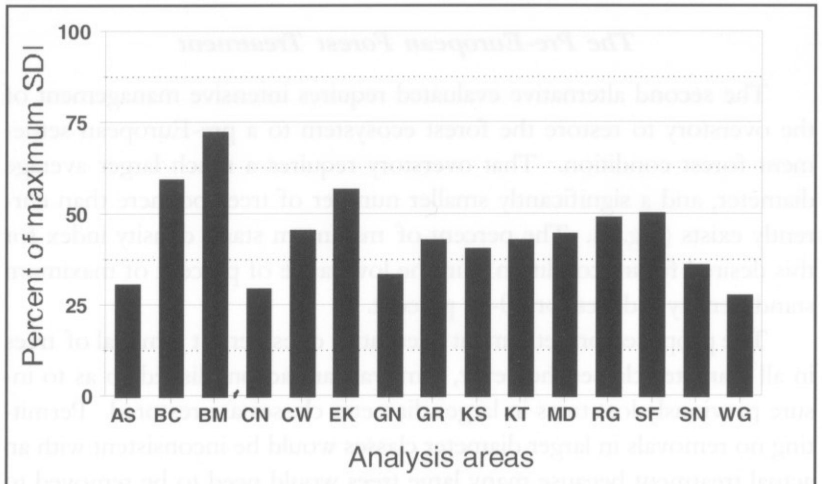

Figure 8. Average percent of maximum SDI's in 1994 for fifteen study areas across the Apache/Sitgreaves National Forest.

year analysis period. No tree thinnings or harvests can occur. The initial stand conditions are as described for the six analysis areas in Table 2. Each of these analysis areas already have high tree densities.

Figure 9 characterizes average changes in critical resources on the six analysis areas over a 50 year projection period without treatment. Stand density index, fuel loads, forage production, and water yield are projected, as well as changes in percent of maximum SDI.

The obvious result of implementing the no treatment alternative is that basal area and intra-tree competition for nutrients and water continue to increase. Tree stagnation occurs, increasing litter fall and the buildup of ground fuels to what fire ecologists would consider dangerous levels, exceeding 20 and 30 tons per acre. Soil moisture and instream flows are decreased. Herbage productivity in the form of grass, forbs and shrubs is suppressed, decreasing the pounds of forage produced per year for both wildlife and domestic stock. And, reduction in ground plant cover contributes to increased sedimentation.

Nutrients and water resources are withheld from the understory as tree density increases. As a result, flora diversity of the stand is lowered, which impacts diversity of fauna. Declines in vigor occur in both overstory and understory plants, as well as wildlife that use the forest environment as a source of energy. Declining health, although not explicitly defined in the model prediction, increases the vulnerability of the stand to catastrophic insect and disease attack. Such attacks create even higher fuel loads and standing dead inventory of trees, greatly increasing the risk of catastrophic wildfire loss.

The Pre-European Forest Treatment

The second alternative evaluated requires intensive management of the overstory to restore the forest ecosystem to a pre-European settlement forest condition. That overstory requires a much larger average diameter, and a significantly smaller number of trees per acre than currently exists (Fig. 4). The percent of maximum stand density index for this desired future condition is in the low range of percent of maximum stand density indexes, or 20-30 percent.

The proposed presettlement alternative does permit removal of trees in all diameter classes; however, removals are accomplished so as to insure previously lost trees in larger diameter classes are restored. Permitting no removals in larger diameter classes would be inconsistent with an actual treatment because many large trees would need to be removed to assure forest health, decreased fire risks, and plant diversity.

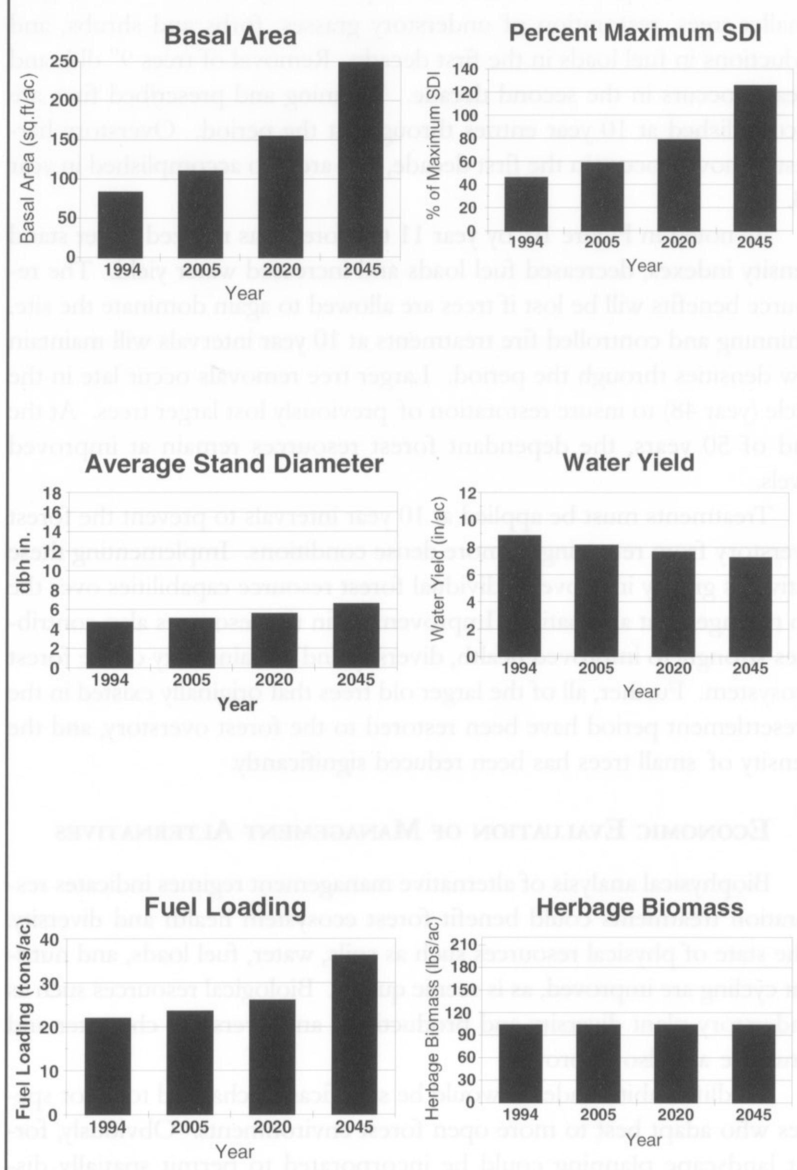

Figure 9. Changes in resource outputs on six selected analysis areas under no treatment alternative.

Figure 10 presents the levels of the various resources predicted when the forest is returned to the presettlement forest condition over the 50 year restoration period. This is accomplished by intensive thinning of smaller trees, restoration of understory grasses, forbs and shrubs, and reductions in fuel loads in the first decade. Removal of trees 9" dbh and greater occurs in the second decade. Thinning and prescribed fires are accomplished at 10 year entries throughout the period. Overstory harvest removals occur in the first decade, and are also accomplished in year 48.

As noted in Figure 10, by year 11 the forest has realized lower stand density indexes, decreased fuel loads and increased water yield. The resource benefits will be lost if trees are allowed to again dominate the site. Thinning and controlled fire treatments at 10 year intervals will maintain low densities through the period. Larger tree removals occur late in the cycle (year 48) to insure restoration of previously lost larger trees. At the end of 50 years, the dependant forest resources remain at improved levels.

Treatments must be applied at 10 year intervals to prevent the forest overstory from returning to more dense conditions. Implementing these activities greatly improves individual forest resource capabilities over the no management alternative. Improvement in the resources also contributes strongly to improved health, diversity and sustainability of the forest ecosystem. Further, all of the larger old trees that originally existed in the presettlement period have been restored to the forest overstory, and the density of small trees has been reduced significantly.

ECONOMIC EVALUATION OF MANAGEMENT ALTERNATIVES

Biophysical analysis of alternative management regimes indicates restoration treatments could benefit forest ecosystem health and diversity. The state of physical resources such as soils, water, fuel loads, and nutrient cycling are improved, as is scenic quality. Biological resources such as understory plant diversity and productivity, and overstory character and structure are also improved.

Wildlife habitat indexes would be significantly changed to favor species who adapt best to more open forest environments. Obviously, forest landscape planning could be incorporated to permit spatially dispersed dense stands to accommodate species requiring these type habitats.

Overall, the restoration treatments would return the forest to a more open, natural state. Scientific inquiry in ponderosa pine type would indi-

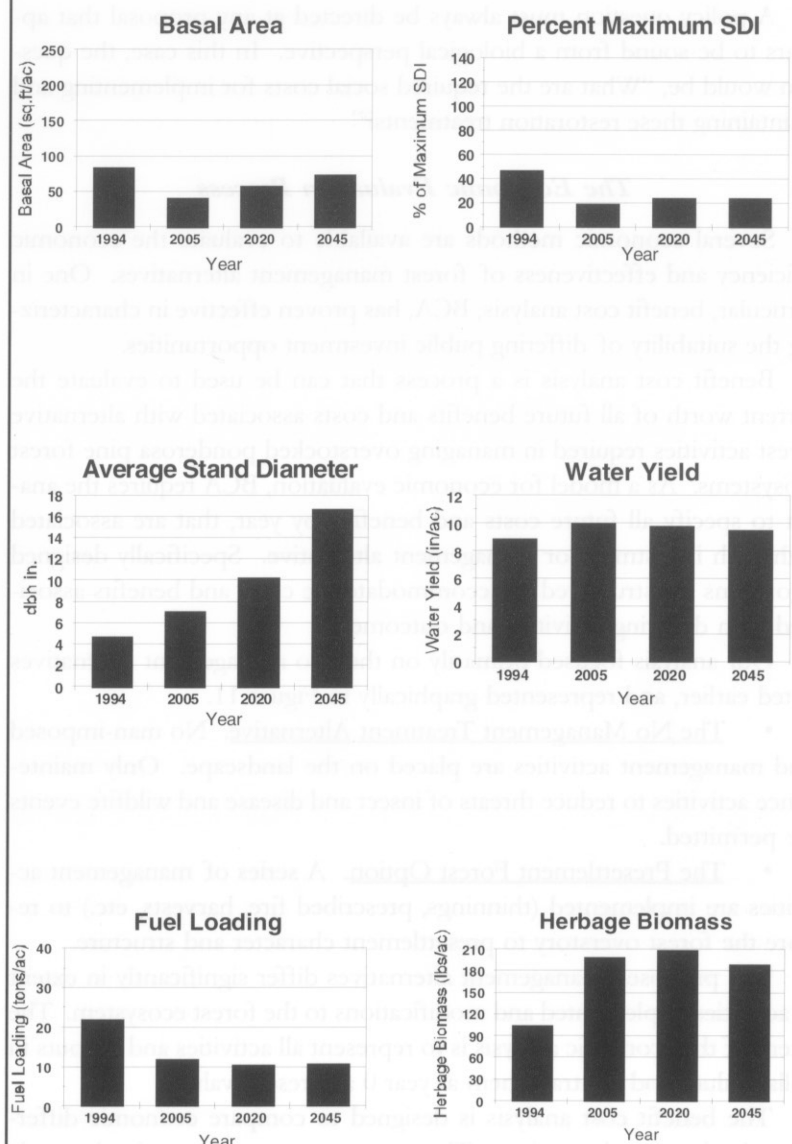

Figure 10. Changes in resource outputs on six selected forest analysis areas under the presettlement forest treatment alternative.

cate that conditions that approach a more open forest support healthier, more diverse and more easily sustained forest ecosystems (Brown et al. 1974, Rogers et al. 1984).

A policy question must always be directed at any proposal that appears to be sound from a biological perspective. In this case, the question would be, "What are the required social costs for implementing and maintaining these restoration treatments?"

The Economic Evaluation Process

Several economic methods are available to evaluate the economic efficiency and effectiveness of forest management alternatives. One in particular, benefit cost analysis, BCA, has proven effective in characterizing the suitability of differing public investment opportunities.

Benefit cost analysis is a process that can be used to evaluate the current worth of all future benefits and costs associated with alternative forest activities required in managing overstocked ponderosa pine forest ecosystems. As a model for economic evaluation, BCA requires the analyst to specify all future costs and benefits, by year, that are associated with each investment or management alternative. Specifically designed algorithms are structured to accommodate the costs and benefits associated with differing activities and outcomes.

Our analysis focused primarily on the two management alternatives noted earlier, and represented graphically in Figure 11.

- The No Management Treatment Alternative. No man-imposed land management activities are placed on the landscape. Only maintenance activities to reduce threats of insect and disease and wildfire events are permitted.
- The Presettlement Forest Option. A series of management activities are implemented (thinnings, prescribed fire, harvests, etc.) to restore the forest overstory to presettlement character and structure.

The proposed management alternatives differ significantly in extent of activities implemented and modifications to the forest ecosystem. The intent of the economic analysis is to represent all activities and outputs in dollar values and contrast them at year 0 as present values.

The benefit cost analysis is designed to compare economic differences in the two alternatives. The no management alternative has only protection activities to help mitigate increasing insect and disease and wildfire risks. These risks increase as the forest gets more dense over the 50 year period. Benefits, such as forage production and water, are mea-

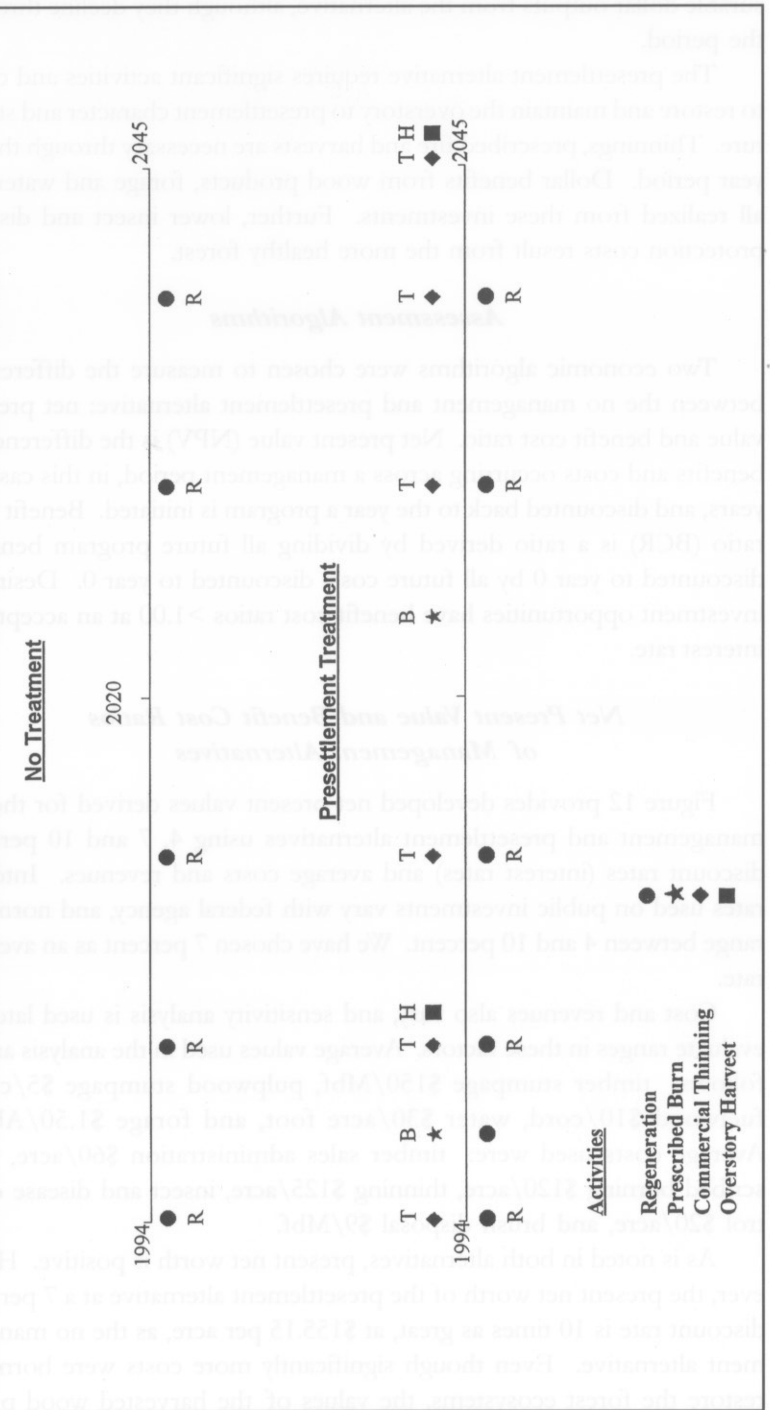

Figure 11. Time sequence of activities in the no management and presettlement management alternatives: 1994-2045.

surable dollar outputs from the alternative, although they decline through the period.

The presettlement alternative requires significant activities and costs to restore and maintain the overstory to presettlement character and structure. Thinnings, prescribed fire and harvests are necessary through the 50 year period. Dollar benefits from wood products, forage and water are all realized from these investments. Further, lower insect and disease protection costs result from the more healthy forest.

Assessment Algorithms

Two economic algorithms were chosen to measure the differences between the no management and presettlement alternative: net present value and benefit cost ratio. Net present value (NPV) is the difference in benefits and costs occurring across a management period, in this case 50 years, and discounted back to the year a program is initiated. Benefit cost ratio (BCR) is a ratio derived by dividing all future program benefits discounted to year 0 by all future costs discounted to year 0. Desirable investment opportunities have benefit cost ratios >1.00 at an acceptable interest rate.

Net Present Value and Benefit Cost Ratios of Management Alternatives

Figure 12 provides developed net present values derived for the no management and presettlement alternatives using 4, 7 and 10 percent discount rates (interest rates) and average costs and revenues. Interest rates used on public investments vary with federal agency, and normally range between 4 and 10 percent. We have chosen 7 percent as an average rate.

Cost and revenues also vary, and sensitivity analysis is used later to evaluate ranges in these factors. Average values used in the analysis are as follows: timber stumpage $150/Mbf, pulpwood stumpage $5/cord, fuelwood $10/cord, water $30/acre foot, and forage $1.50/AUM. Average costs used were: timber sales administration $60/acre, prescribed burning $120/acre, thinning $125/acre, insect and disease control $20/acre, and brush disposal $9/Mbf.

As is noted in both alternatives, present net worth is positive. However, the present net worth of the presettlement alternative at a 7 percent discount rate is 10 times as great, at $155.15 per acre, as the no management alternative. Even though significantly more costs were borne to restore the forest ecosystems, the values of the harvested wood prod-

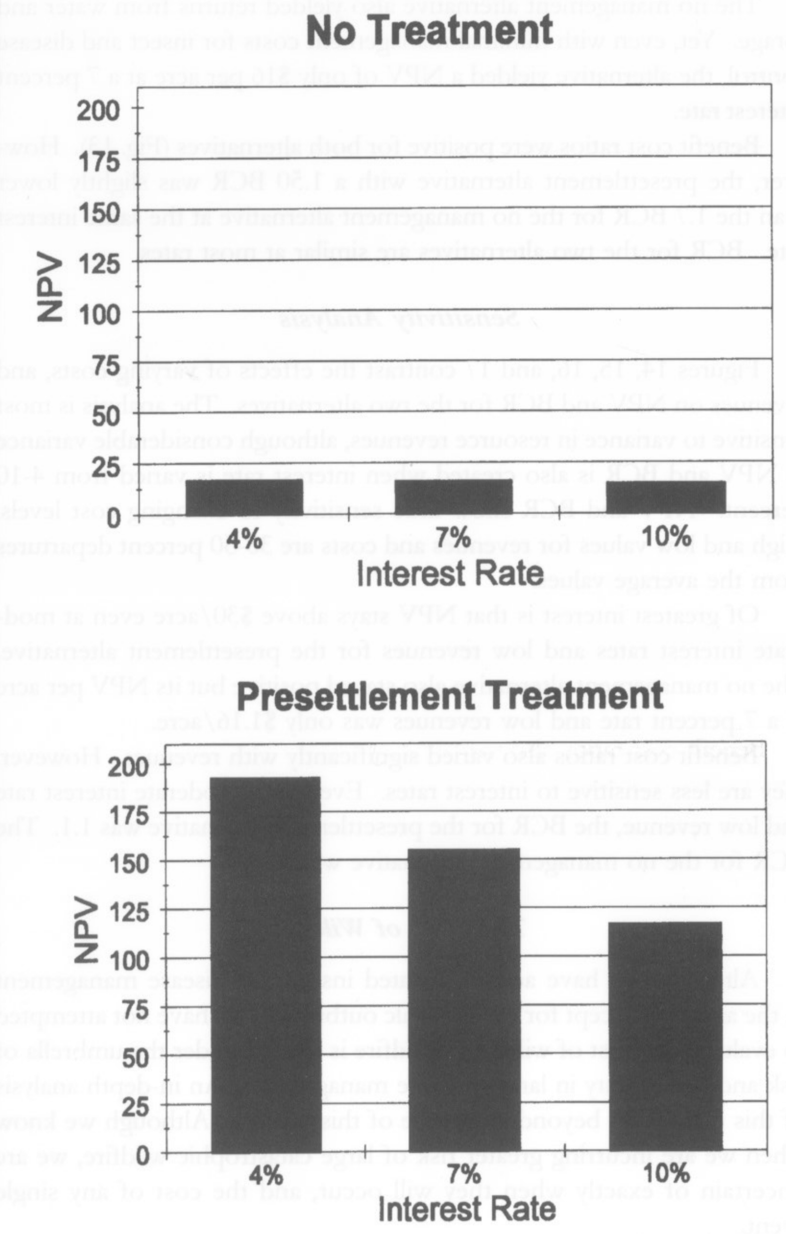

Figure 12. Net present values per acre for the no treatment alternative and the presettlement alternative using average costs and revenues.

ucts and the increased incremental returns from forage and water more than offset these costs.

The no management alternative also yielded returns from water and forage. Yet, even with minimal management costs for insect and disease control, the alternative yielded a NPV of only $16 per acre at a 7 percent interest rate.

Benefit cost ratios were positive for both alternatives (Fig. 13). However, the presettlement alternative with a 1.50 BCR was slightly lower than the 1.7 BCR for the no management alternative at the same interest rate. BCR for the two alternatives are similar at most rates.

Sensitivity Analysis

Figures 14, 15, 16, and 17 contrast the effects of varying costs, and revenues on NPV and BCR for the two alternatives. The analysis is most sensitive to variance in resource revenues, although considerable variance in NPV and BCR is also created when interest rate is varied from 4-10 percent. NPV and BCR show little sensitivity to changing cost levels. High and low values for revenues and costs are 30-50 percent departures from the average values.

Of greatest interest is that NPV stays above $30/acre even at moderate interest rates and low revenues for the presettlement alternative. The no management alternative also stayed positive but its NPV per acre at a 7 percent rate and low revenues was only $1.16/acre.

Benefit cost ratios also varied significantly with revenues. However, they are less sensitive to interest rates. Even with moderate interest rate and low revenue, the BCR for the presettlement alternative was 1.1. The BCR for the no management alternative was 1.0.

The Risk of Wildfire

Although we have accommodated insect and disease management in the analysis (except for catastrophic outbreaks), we have not attempted to evaluate the cost of wildfire. Wildfire is treated under the umbrella of risk and uncertainty in land resource management. An in-depth analysis of this factor was beyond the scope of this project. Although we know when we are incurring greater risk of large catastrophic wildfire, we are uncertain of exactly when they will occur, and the cost of any single event.

However, as noted in the analysis, we have knowledge of increased probabilities of large wildfires associated with increasing tree densities. For example, there is a much greater probability that a large wildfire will

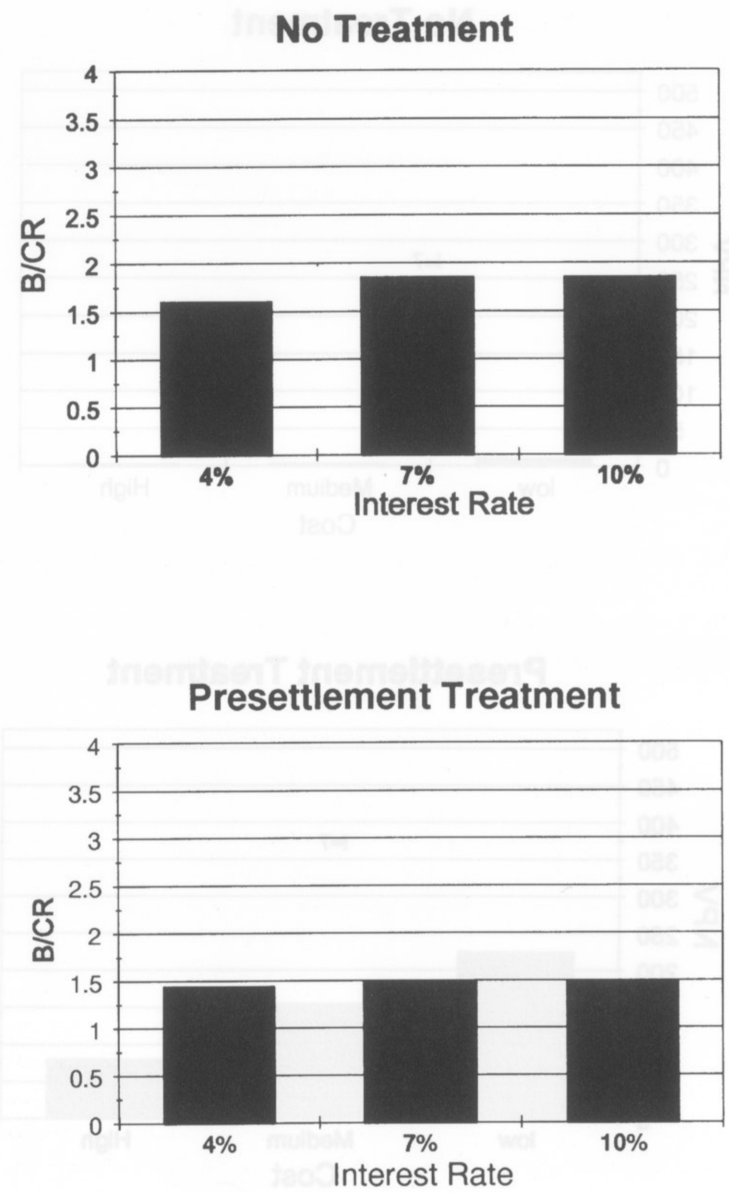

Figure 13. Benefit cost ratio for the no treatment alternative and the presettlement alternative using average costs and revenues.

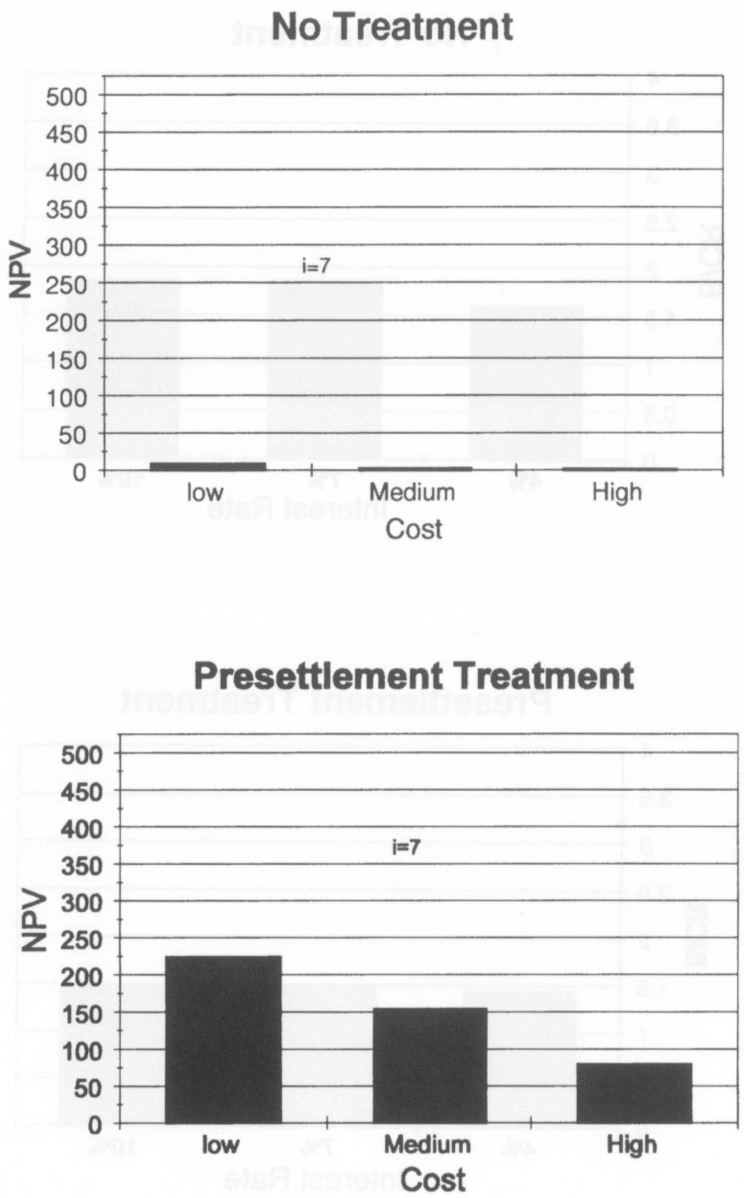

Figure 14. Net present values per acre at low, medium and high costs; revenues average.

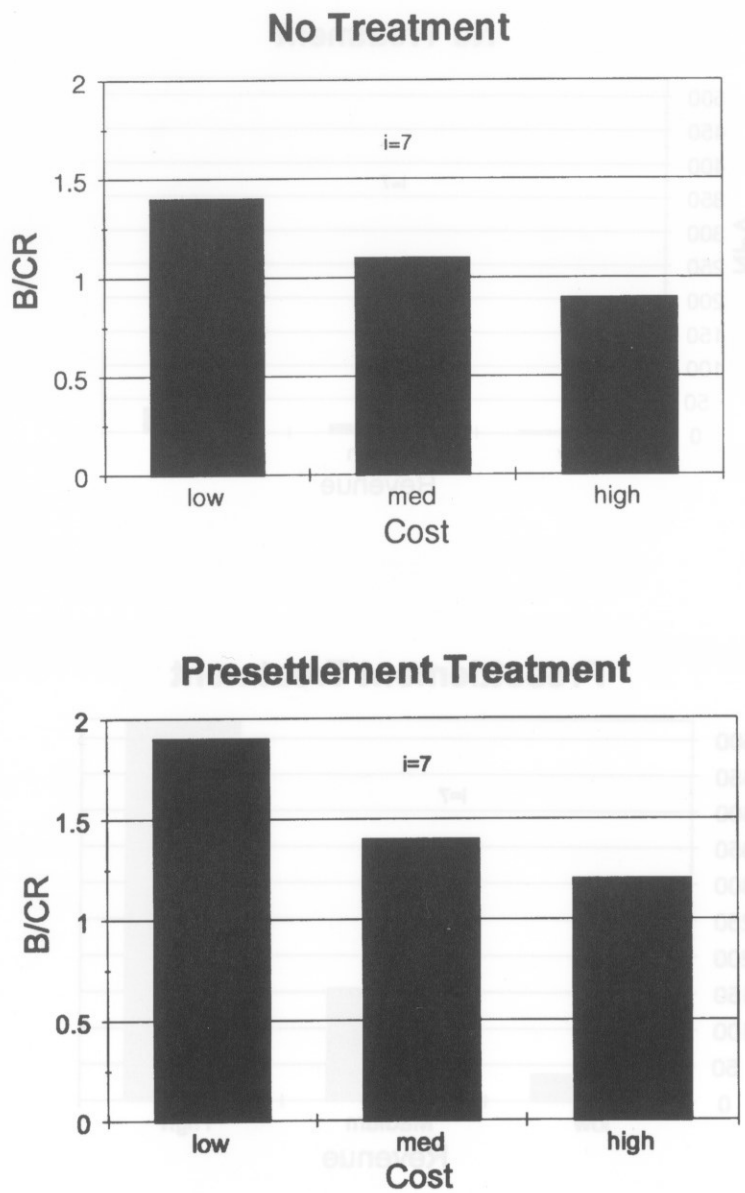

Figure 15. Benefit cost ratio at low, medium and high costs; revenues average.

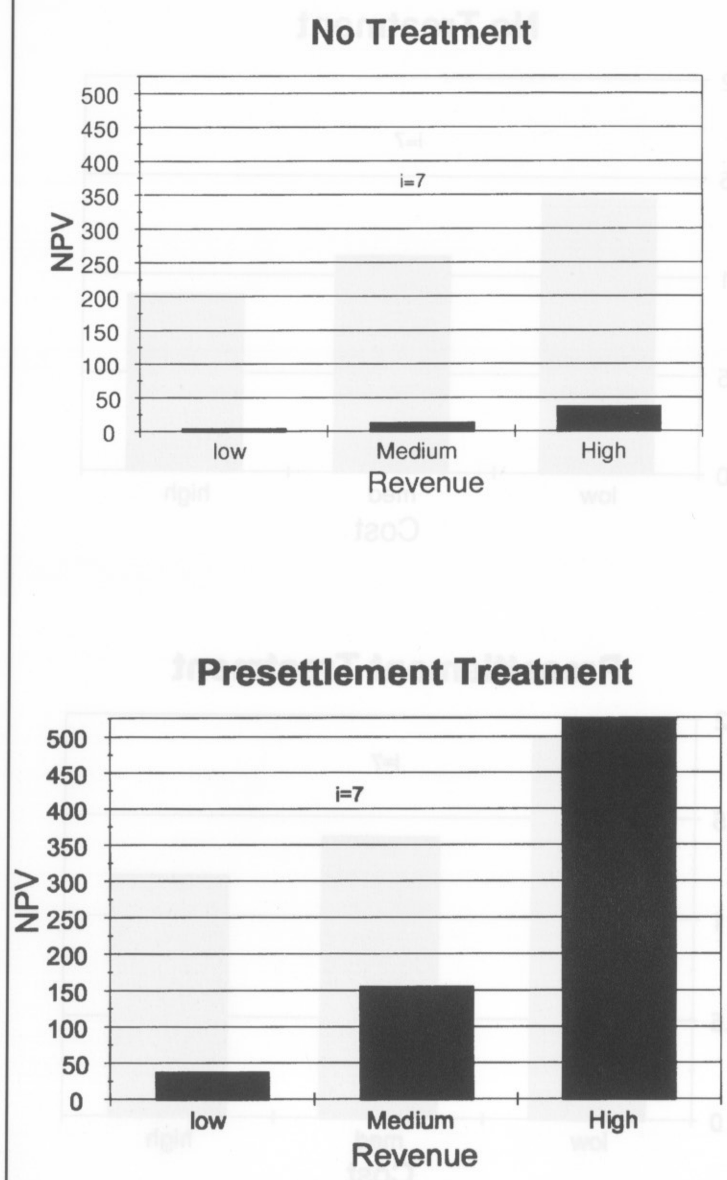

Figure 16. Net present value per acre at low, medium and high revenue; cost average.

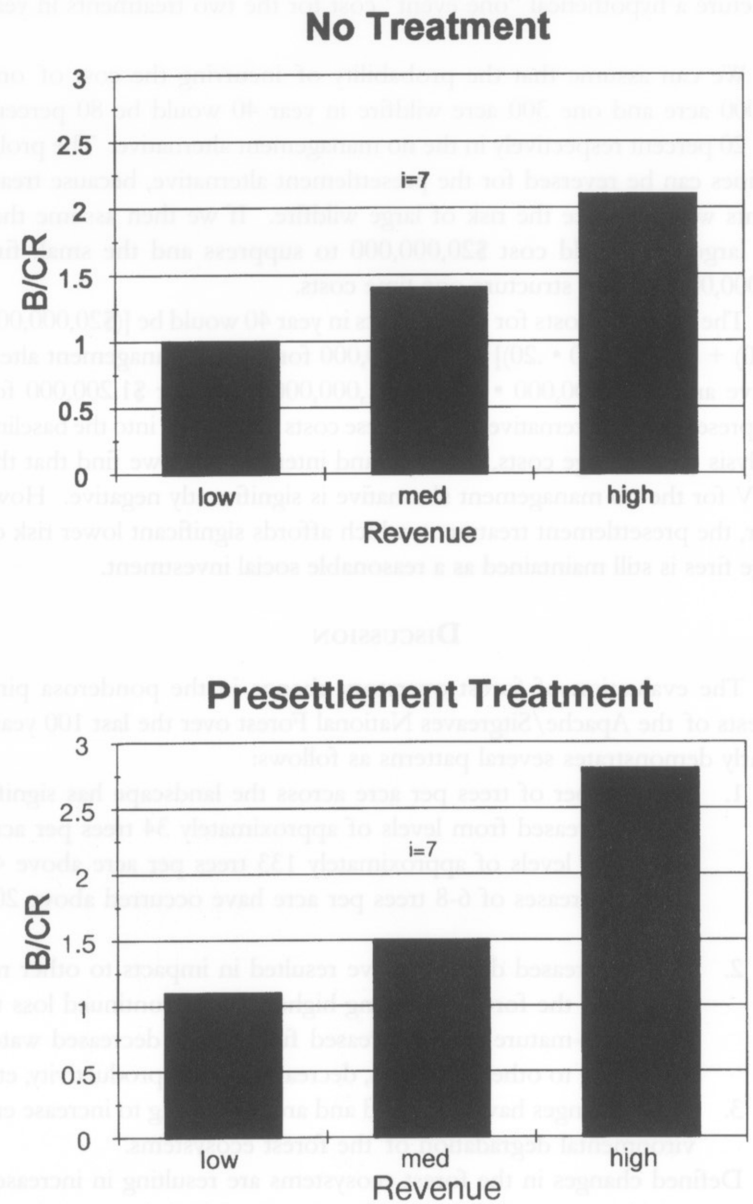

Figure 17. Benefit cost ratio at low, medium and high revenue; cost average.

occur sometime between year 30 and 50 in the no management alternative than in the presettlement alternative. Using this knowledge, we can structure a hypothetical "one event" cost for the two treatments in year 40.

We can assume that the probability of incurring the cost of one 15,000 acre and one 300 acre wildfire in year 40 would be 80 percent and 20 percent respectively in the no management alternative. The probabilities can be reversed for the presettlement alternative, because treatments would reduce the risk of large wildfire. If we then assume that the large fire would cost $20,000,000 to suppress and the small fire $1,000,000, we can structure one time costs.

The expected costs for these events in year 40 would be [($20,000,000 • .80) + ($1,000,000 • .20)] or $16,200,000 for the no management alternative and [($20,000,000 • .20) + ($1,000,000 • .80)] or $1,200,000 for the presettlement alternative. When these costs are entered into the baseline analysis (i.e., average costs, revenues and interest rates), we find that the NPV for the no management alternative is significantly negative. However, the presettlement treatment, which affords significant lower risk of large fires is still maintained as a reasonable social investment.

DISCUSSION

The evaluation of forest overstory change in the ponderosa pine forests of the Apache/Sitgreaves National Forest over the last 100 years clearly demonstrates several patterns as follows:

1. The number of trees per acre across the landscape has significantly increased from levels of approximately 34 trees per acre to current levels of approximately 133 trees per acre above 4" dbh. Decreases of 6-8 trees per acre have occurred above 20" dbh.
2. These increased densities have resulted in impacts to other resources in the forest, including higher risk of continued loss to large over-mature trees, increased fuel loads, decreased water availability to other resources, decreased forage productivity, etc.
3. These changes have increased and are continuing to increase environmental degradation of the forest ecosystems.

Defined changes in the forest ecosystems are resulting in increased occurrence of insect and disease infestations and high-intensity, larger wildfires. The overall comprehensive changes in resources is resulting in decreases in forest health, diversity, and sustainability of the forest.

As such, there is an urgent need for adaptive management/science programs to evaluate restoration approaches that could be undertaken in these ecosystems. If restoration to presettlement overstory conditions or some similar level were to occur, there would be significant improvements in health, diversity and sustainability.

Computer simulated treatments to the forest overstory that approach presettlement conditions, reveal significant enhancement of forest ecosystem resources as compared to no treatment alternatives. On site water as well as understory plant productivity is increased, while fuel loads are decreased. Further, implementation of restoration treatments would realize positive net present values as public investments. Pursuing a no management alternative will greatly increase the risk of high-cost, larger wildfires and significant losses in public investments in forest resources.

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