A STRATEGIC ASSESSMENT OF FIRE HAZARD IN NEW MEXICO

Carl E. Fiedler[1]
Charles E. Keegan III[2]
Stephen H. Robertson[1]
Todd A. Morgan[2]
Chris W. Woodall[1]
John T. Chmelik[1]

[1]School of Forestry, University of Montana, Missoula, MT 59812
[2]Bureau of Business and Economic Research, University of Montana, Missoula, MT 59812

Final report submitted to the Joint Fire Sciences Program, February 11, 2002. This project was supported by the Joint Fire Sciences Program, in cooperation with the USFS Pacific Northwest Research Station.

<u>Technical Contact Team</u>

Regis Cassidy	USFS Region 3
Sam Loftin	Los Alamos National Laboratory
Hal Luedtke	BIA Southwest Area
Bev Schwab	BIA Southwest Area
Charlie Wicklund	State of New Mexico-Forestry Division

EXECUTIVE SUMMARY

Problem And Approach

Severe wildfires in 2000 testify to the hazardous forest conditions over large areas of New Mexico. The costly consequences of these fires have served to strengthen public support for management actions. However, developing plans to address hazardous conditions at a strategic level requires a fundamental understanding of the problems at hand, and the potential effectiveness and costs of treatments to address them.

Consequently, we designed this study to meet the following objectives:

- Profile forest conditions in New Mexico
- Assess fire hazard
- Evaluate effectiveness of hazard reduction treatments
- Estimate treatment costs.

Forest Inventory and Analysis (FIA) data for the state of New Mexico provided us the means to profile forest conditions statewide, and then assess fire hazard. We evaluated fire hazard using the Fire and Fuels Extension (FFE) to the Forest Vegetation Simulator (FVS). Hazard was quantified in terms of Crowning Index, which is the windspeed necessary to sustain a crown fire once a fire has reached the main canopy. Crowning Index values less than 25 miles per hour (mph) were rated high hazard, 25-50 mph as moderate hazard, and greater than 50 mph as low hazard.

Fire hazard was evaluated for nine major forest types; however, our analysis primarily focused on short-interval, fire-adapted ecosystems. In New Mexico, these are the Ponderosa Pine and Dry Mixed Conifer (PP/DMC) forests where people and property are especially at risk.

We collaborated with representatives from federal, state, and tribal land management entities to develop three treatment prescriptions for reducing fire hazard:

1) Thin-from-Below: remove all trees smaller than 9"
2) Diameter-Limit: reserve all trees >16”; however, if reserve BA <50 ft^2/ac, reserve additional trees <16” until BA=50 ft^2/ac
3) Comprehensive: ecologically-based; reserve a target basal area of 40-50 ft^2/ac, primarily comprised of larger trees.

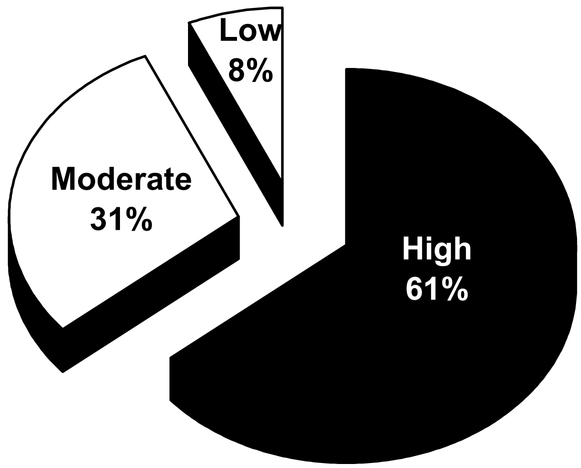
Fire hazard (i.e., Crowning Index) for each of the three treatments was evaluated immediately after treatment using FFE. Treatment costs and revenues for New Mexico were estimated using a harvest cost model and data bases maintained at the University of Montana. Land management agencies and the private sector provided cost estimates for treating activity fuels.

We used FVS to project post-treatment conditions forward 30 years for each of the treatment alternatives, and then evaluated Crowning Index again using FFE. Projection allowed us to evaluate the durability of hazard reduction treatments through time.

Findings

New Mexico has 16.5 million acres of woodlands/forestlands, 84 percent of which rate high/moderate for crown fire hazard. Nearly four million acres are classified as short-interval, fire-adapted ecosystems. About 3.7 million acres (or 92 percent) of these are in high/moderate fire hazard condition (Figure 1).

Figure 1. Proportion of New Mexico's Ponderosa Pine and Dry Mixed-Conifer Forest Types by Fire Hazard Rating



Our analysis shows that hazard reduction treatments differ substantially in their potential to reduce crown fire hazard. The Thin-from-Below treatment increases average Crowning Index in treated stands from 21 to 43 mph (Table 1), but moves only 29 percent of treated acres into the low hazard category (Table 2). The Comprehensive treatment, in contrast, increases average Crowning Index to 61 mph, and moves 69 percent of treated acres into a low hazard condition (Table 2).

Table 1. Average Crowning Index, average net revenue, and percentage of acres with positive net revenues, for three hazard reduction treatments.

Hazard Reduction Treatment	Crowning Index Pre-Treatment	Crowning Index Post-Treatment	Net Revenue per Acre	Percent of Acres with Revenues Exceeding Costs
Thin-from-Below	21	43	-$439	0%
Diameter-Limit	21	59	-$368	1%
Comprehensive	21	61	$8	25%

We also found that the value of timber produced as a byproduct of implementing the Comprehensive prescription would on average pay for all treatment and haul costs (Table 1). Most stands would require an expenditure, but the value of timber products removed would exceed harvest costs, fuels treatment, and haul costs on about 25 percent of the acres treated. In contrast, net revenues averaged -$368 and -$439 for the Thin-from-Below and Diameter-Limit prescriptions, respectively, and were negative for virtually all acres treated under either prescription (Table 1).

Table 2. Average Crowning Index and percent of acres rated low hazard immediately after treatment, and 30 years after treatment.

Hazard Reduction Treatment	Crowning Index: Immediately post-treatment	Crowning Index: 30 Years post-treatment	% of treated acres rated low hazard post- treatment	% of treated acres rated low hazard 30 years post-treatment
Thin-from-Below	43	41	29%	20%
Diameter-Limit	59	54	67%	56%
Comprehensive	61	53	69%	52%

Our reevaluation of Crowning Index 30 years after treatment showed that long-term effects still varied among hazard reduction treatments (Table 2). Average Crowning Index following the Thin-from-Below treatment decreased 2 mph (43 to 41 mph), and remained in the moderate hazard category. In contrast, the average Crowning Index for the Comprehensive treatment decreased the most (from 61 to 53), but still remained in the low hazard category. Long-term effects of the Diameter-Limit treatment were similar to those of the Comprehensive treatment.

One striking effect associated with the Thin-from-Below prescription aimed at removing only small trees is that substantial acreages would again need hazard reduction treatment at the end of the 30-year period. Just 20 percent of the acres receiving the Thin-from-Below treatment would remain in the low hazard category (Table 2). In contrast, over half of the acres treated with the Diameter-Limit or Comprehensive prescription would still have a low fire hazard rating 30 years later.

The effect on crown fire hazard of removing woodland species (i.e., pinyon and juniper) is substantial, with average post-treatment Crowning Indexes improving by 15 to 24 mph, depending on treatment.

Conclusions

Results of this study show that the fire hazard problem in New Mexico is best addressed by management approaches that recognize the broader ecological context within which it occurs. Whether the problem is viewed from the standpoint of hazard reduction, ecological condition, or treatment cost, a comprehensive approach that considers the density, structure, and species composition of the reserve stand is superior to prescriptions that focus only on the size of trees removed. The comprehensive prescription evaluated in this analysis achieves greater hazard reduction, improves ecological condition, and is less expensive to employ than alternative treatments. It is particularly superior when compared to the prescription with a singular focus on small-tree removal.

HIGHLIGHTS

- Over 80% of all forested lands in New Mexico rated high/ moderate for crown fire hazard.

- Four million acres of New Mexico forestland were classified within short-interval, fire adapted ecosystems – 3.7 million acres of which were high/moderate hazard.

- A Comprehensive prescription designed to initiate restoration of sustainable ecological conditions was superior to prescriptions designed solely to remove smaller trees.

- Nearly 70% of the acres receiving the Comprehensive treatment rated low hazard following treatment, whereas only 29% rated low hazard following the Thin-from-Below treatment.

- The Comprehensive prescription not only achieved the greatest hazard reduction; it also cost about $400 per acre less to implement than either the Thin-from-Below or Diameter-Limit prescriptions.

- Over 50% of the acres receiving the Comprehensive treatment remained low hazard 30 years after treatment, compared to only 20% of those receiving the Thin-from-Below treatment.

- Woodland species contribute substantially to fire hazard; removing these species from PP/DMC stands improves average Crowning Index 15-24 mph.

TABLE OF CONTENTS

INTRODUCTION

Recent severe wildfires in New Mexico (e.g., Cerro Grande, Viveash) provide harsh testimony to the hazardous forest conditions that exist over large areas of the state. The fires of 2000 are especially notable, not just in terms of acres burned, but particularly because of the significant damage to property and associated threats to people.

Several major fire seasons in a dozen years have raised public and agency consciousness about wildfire to unprecedented levels. There is now both the public support and political will for major initiatives to address this regional concern (Western Governors' Association 2001). For example, tens of million of dollars have been distributed through the National Fire Plan, much of it dedicated to reducing hazardous fuels. However, planning to address fire hazard at a strategic level requires a fundamental understanding of the nature and scope of the problem at hand. For example, what forest types and conditions are most vulnerable to fire? How many acres are impacted? What kinds of treatments are most effective in reducing fire hazard, and how much do they cost? How durable are the effects of these treatments over time?

Absence of a detailed, systematic, and uniform forest inventory for all acres and ownerships has heretofore precluded a comprehensive analysis of fire hazard in New Mexico. However, recent availability of consistent inventory data across all ownerships made possible this strategic assessment of fire hazard at a state-wide level.

Objectives

The overall goals of our project were to profile forest conditions and fire hazard in New Mexico and evaluate the potential effectiveness and costs of hazard reduction treatments. Specific objectives were to:

1. Describe and quantify forest conditions in New Mexico, and rate for fire hazard
2. Develop alternative treatment prescriptions and evaluate their effectiveness in reducing hazard, both now and 30 years in the future
3. Determine harvest and slash reduction costs associated with treatments
4. Determine the potential revenue from timber products generated by the hazard reduction treatments

METHODS

Forest Industry and Analysis (FIA) data on the composition and condition of forestlands in New Mexico were obtained from the USDA Forest Service Interior West Resource Inventory, Monitoring, and Evaluation (IWRIME) program based in Ogden, Utah. This unit conducts permanent plot inventories in New Mexico and other Rocky Mountain states.

The land base for this study consists of lands classified by IWRIME as "timberlands" (lands stocked predominantly with traditional timber species), and "woodlands" - lands stocked primarily with pinyon pine, juniper, or hardwoods other than aspen and cottonwood. This inventory includes forestlands in national parks, and other reserved lands, such as designated wilderness areas.

Data for forestlands on all ownerships, and woodlands on National Forest System (NFS) and reserved lands, were largely collected between 1997 and 1999. Some data for non-NFS woodlands come from inventories conducted in 1986 and 1987.

The most important characteristics of IWRIME data are their uniformity and comprehensiveness. While forest conditions can vary greatly, the IWRIME data set allows description and comparison within and across regions and ownerships, using common measures gathered through consistent and scientific sampling methods.

We worked with data from 2,519 sample points in New Mexico. A sample point, or "cluster," was our basic unit of analysis. Each cluster was regarded as a stand, and typically represents about 6,000 acres. Variables recorded at each sample point fall into one of four categories:

- Location variables: owner, elevation, distance to road, etc.
- Condition variables: slope, aspect, land use, etc.
- Tree/stand variables: diameter, height, basal area, volume, species, etc.
- Understory vegetation variables: cover of trees, shrubs, forbs, and grass

Fire Hazard

Potential fire hazard was analyzed for each cluster using the Fire and Fuels Extension (FFE: Beukema et al. 1997, Scott, and Reinhardt 2001) to the Forest Vegetation Simulator (FVS: Stage 1973, Crookston 1990, Van Dyck 2000). This model (extension) estimates crown fire hazard based on tree, stand, and site characteristics, and expresses fire hazard/effects in terms of Crowning Index, Torching Index, and Basal Area Mortality.

Crowning Index, defined as the wind speed necessary for a fire that reaches the canopy to continue as a crown fire, was the primary variable used to report hazard in this study. We defined high-hazard forest conditions as having a Crowning Index <25 mph, moderate hazard from 25 to 50 mph, and low hazard >50 mph. Crowning Index values can theoretically reach into the 100-200 mph range (or higher) with particularly "safe" combinations of density, structure, and site conditions (Scott 2001). However, Crowning Index values greater than 80 to 90 mph are not meaningful from a practical standpoint, since they are at or above the upper end of a cumulative probability distribution of actual wind speeds from weather records (Scott 2001). For this reason, we assigned all Crowning Index values greater than 90 mph a value of 90 to prevent undue influence of "off the chart" index values on the computation of means.

Once the Crowning Index was calculated for each cluster, the entire inventory was sorted by various combinations of woodland/forest type, density, structure, and ownership to display fire hazard by categories of general interest. In addition, FVS was used to project forest conditions 30 years into the future, at which time fire hazard was again assessed using FFE.

Woodland/Forest Types

Vegetative conditions vary greatly across the millions of acres and broad elevation range of woodlands/forestlands in New Mexico. These highly diverse forest conditions were subdivided into nine woodland/forest types that would be recognizable and meaningful to managers. We then assigned one of the nine types to each of the more than 2,500 FIA sample clusters in New Mexico based on species occurrence and majority (or plurality) basal area composition of key tree species. Sample clusters not meeting minimal requirements for any of the nine woodland/forest type designations were designated as "Non-stocked."

Density

FIA clusters (stands) were assigned to one of three density categories (Low, Moderate, or High) using a two-step process. Data were first sorted by woodland/forest type, then density classes were formulated by subdividing the population of clusters within each type into thirds based on the full range of basal area densities for that specific woodland/forest type.

Structure

Each FIA cluster was assigned to one of four structural classes (Scattered, One-story, Two-story, or Multi-story). We formulated structural classes for each woodland/forest type primarily based on size class and basal area attributes. Five general size classes of trees were recognized: Sapling (<5.0" DBH), Pole (5.0"-8.9"), Medium (9.0"-14.9"), Large (15.0"-19.9"), and Very Large (≥20"). Clusters with <25 ft^2/acre of basal area were assigned to Scattered structures, since such conditions are too open to recognize distinct layers or strata. Clusters with only one recognizable size class were assigned One-storied structures; clusters with two distinct size classes were assigned to Two-storied structures; and clusters with three or more size classes were assigned to Multi-storied structures. A minimum basal area of 10 ft^2/acre was required for Pole, Medium, Large, or Very Large size classes to be recognized as individual size classes or stratum. For Saplings, a minimum of 5 ft^2/acre was required to be recognized as a distinct size class.

Hazard Reduction Treatments

We focused our evaluation of fire hazard on short-interval, fire-adapted forests. In New Mexico, these ecosystems are primarily comprised of Ponderosa Pine (PP) and Dry Mixed Conifer (DMC) forest types. Short-interval, fire-adapted forests were identified as highest priority for treatment in "Protecting People and Sustaining Resources in Fire-Adapted Ecosystems -- A Cohesive Strategy" (USFS 2000, DOI 2001). Frequent, low-intensity fires were the primary agent that shaped these forests historically, and kept them resistant to severe fires. Effective fire-suppression efforts and some logging practices over the last century have resulted in density and structural changes that leave these forests vulnerable to severe damage from wildfire (Covington and Moore 1994). Consequently, the Technical Contact Team assembled for this project (see cover) deemed the short-interval, fire-adapted forests highest priority for detailed evaluation.

There are several approaches to reducing hazard in short-interval, fire adapted forests, and we analyze and compare three in this report. One approach is low thinning to a given diameter limit, a treatment that has been widely recommended (Dombeck 1997). We used a diameter limit of 9″ in our analysis (Thin-from-Below to 9″).

A second approach retains all trees larger than 16″. This prescription (16″ Diameter-Limit) is influenced by concerns that there may be a deficit of trees in the Southwest greater than 16″ compared to historic levels, and that cutting trees larger than 16″ is economically rather than ecologically motivated.

A third approach is aimed at initiating restoration of sustainable structure and composition (and longer term, ecological function), and therefore focuses on the trees to leave in terms of a target density, diameter distribution, and species composition (Fiedler et al. 1999, Fiedler et al. 2001). Under this prescription (Comprehensive), trees are marked for leave in the sizes, numbers, species, and juxtaposition that will go furthest toward restoring a sustainable structure, given existing stand conditions. Most of the 40 to 50 ft^2/acre target reserve density is comprised of larger trees, although some trees are marked for leave throughout the diameter distribution, if available. This density range is sufficiently low to reduce fire hazard, increase tree vigor, spur development of large trees, and induce regeneration of seral species (Fiedler 2000). Silvicultural treatments involved in the Comprehensive approach include a low thinning to remove small trees, improvement cutting to remove late-successional species (if present), and selection cutting to reduce overall density and promote regeneration of ponderosa pine.

A common objective of all three treatments is to reduce density (in varying degrees) and create a discontinuity in the vertical fuel profile by cutting the sapling- and pole-sized ladder fuels. Reducing the hazard associated with these smaller cut trees, as well as the tops and limbs of merchantable-sized trees (if any) that are harvested as part of the overall treatment, is an integral part of each prescription. The resulting slash is lopped and scattered, broadcast burned, or piled and burned depending on volume, reserve stand density, landowner objectives, and cost considerations.

All three prescriptions were applied to high/moderate hazard conditions in the Ponderosa Pine and Dry Mixed Conifer forest types. The Thin-from-Below to 9″ prescription was only applied to stands that had greater than 50 ft^2/acre of trees larger than 9″. For the 16″ Diameter-Limit prescription, all trees larger than 16″ dbh were left, so long as the basal area of these trees were 50 ft^2/acre or greater. If there were less than 50 ft^2/acre of basal area in trees >16″, then trees <16″ were retained from the biggest on down (i.e., 15″, 14″, 13″, etc.) until a basal area density of 50 ft^2/acre was reached.

The Comprehensive prescription differed from the other two prescriptions in that it set a target reserve density of 50 ft^2/acre in all stands designated for treatment. Most of the basal area marked for leave was concentrated in the larger trees, but smaller amounts of basal area were reserved in trees across the full diameter distribution, if available.

Two woodland species, pinyon pine and juniper, are a common stand component in the ponderosa pine and dry mixed conifer forests of New Mexico. Whether these species are retained or removed in a given project depends upon treatment objectives, ownership, and the stand context within which they occur. In contrast, Gambel oak is typically retained on all ownerships to serve a variety of amenity and wildlife habitat objectives. However, retention of non-timber species can have undesired effects in terms of the contribution these species make toward increased crown fire hazard. For this reason, the Technical Contact Team recommended that we report post-treatment Crowning Index values for treated stands with non-timber species removed as well as retained.

Treatment Costs and Product Revenues

The treatments we evaluated are either commonly used for hazard reduction, or were designed specifically to reduce hazard and enhance sustainability. Because cost is a major factor influencing the potential implementation of hazard reduction treatments, we also analyzed costs after the prescriptions were developed and the treatment effects modeled. In calculating net revenues we examined both treatment costs and the potential value of timber products generated as a by-product of treatments.

Treatment Costs

Costs associated with implementing hazard reduction treatments include costs of removing timber to reduce fuel loading, slashing activity fuels, and prescribed burning of slash. We estimated costs using existing cost data and models, with additional cost data being gathered from the private sector and various land management agencies.

Specifically, the Bureau of Business and Economic Research (BBER) at the University of Montana has developed predictive logging cost models applicable to fire hazard reduction or restoration treatments for the major harvest systems used in Montana (BBER 2001a, Keegan et al. 2001c). These equations were updated and modified to reflect logging infrastructure and timber quality in New Mexico based on in-depth discussions with logging managers and land management specialists throughout the state. We assumed treatments would occur on sites already accessed; therefore no road-building costs were included in the analysis. Data gathered from land management agencies and the private sector provided an additional basis for estimating costs associated with treating activity fuels.

Timber Product Values

Based on a recent census of New Mexico mills, timber harvested in New Mexico has a number of potential uses (Keegan et al. 2001a), including:

- Timber manufactured into lumber and other sawn products, referred to as sawtimber
- Pulpwood used to produce chips for pulp and paper production
- Southwestern style beams (vigas) and cross members (latillas) for homes
- House logs and log homes
- Posts and poles

All of the trees to be removed in hazard reduction treatments could find product uses in one or more of the above categories. However, the lumber manufacturing/sawmill industry in New Mexico consumes about 90 percent of the timber used for industrial production - approximately 16 million cubic feet (mmcf) annually (Keegan et al. 2001a). It is the only segment large enough to absorb substantial quantities of timber from a restoration treatment program. Since sawtimber is the major timber use, we developed prices by species and one-inch diameter classes for trees 10” through 24”. Trees larger than 24” were valued the same as 24” trees.

Values were assigned to trees suitable for sawtimber based on diameter and species under a market scenario reflecting 1997-1999 lumber prices. This was a period of mixed markets, with very strong markets in the first half of 1997 and most of 1999, and substantially weaker markets particularly in 1998 due to the impact of the Asian financial crisis.

There is little detailed price information available on New Mexico timber. However, the BBER has recently completed censuses of the forest products industry in Montana as well as New Mexico (Keegan et al. 2001a, Keegan et al. 2001b). These censuses provide mill-level data on production equipment and capacity, raw material use by species, product recovery, and sales value. The BBER also maintains extensive log price information on Montana, which was used to profile sawtimber values for that state (BBER 2001b). In developing data for New Mexico, we adjusted Montana tree values to reflect differences between the two states in tree form and quality, the kinds and capabilities of sawmills, and market opportunities.

Of particular note is the lack of markets in New Mexico for mill residue that results from the manufacture of lumber. Mill residue can potentially generate a significant amount of a sawmill's income, and represents a substantial portion of tree value, especially for smaller-diameter sawtimber. In Montana, there has been a market for mill residue that generates a net income of $10 to $30 per hundred cubic feet of logs processed by sawmills. In New Mexico, residues are a breakeven proposition at best, and more typically represent a problem because of disposal costs.

An initial set of prices based on adjustments to Montana prices and mill simulations (Wagner et al. 1998; Wagner et al. 2000) was developed and reviewed by mill managers from several New Mexico mills - including the largest sawmills. This process allowed us to further refine New Mexico log and tree values and update milling capacities.

The relationship between milling capacity and the volume of timber available to the industry was assumed to remain constant. If a substantial proportion of acres rated high/moderate for fire hazard were treated over a reasonably short period, large volumes of additional material could potentially come on the market, thus dampening not only log prices, but also prices for such specialty items as fuelwood, vigas, and latillas. However, we assumed that any increases in harvested timber volume would phase in gradually and reach a sustainable level. This in turn would lead to a gradual and commensurate increase in associated industry capacity.

RESULTS

Forest Types

Our analysis of FIA data for New Mexico shows that in the year 2000 there were approximately 16.6 million acres of woodlands/forestlands in the state (Table 1). The two forest types (Ponderosa Pine and Dry Mixed Conifer) of greatest management concern in terms of fire hazard collectively occupied nearly 4 million acres. About 62,000 acres were classified as "Non-stocked" since they did not support a sufficient number of trees to be classified within any woodland/forest type. Five of the woodland/forest types (PP, DMC, JU, PJ, and OK) comprised at least one million acres each in New Mexico (Table 1).

Table 1. Acreages of major woodland/forest types in New Mexico.

Forest Type	**Acres**
Juniper (JU)	3,628,814
Pinyon/Juniper (PJ)	6,201,187
Ponderosa Pine (PP)	2,484,636
Dry Mixed Conifer (DMC)	1,509,893
Moist Mixed Conifer (MMC)	772,830
Spruce/Fir (S/F)	575,703
Aspen (AS)	248,561
Oak (OK)	1,098,797
Riparian (RI)	71,267
Total stocked acres	**16,591,688**
Non-stocked (NS)	61,978
Total forestland	**16,653,666**

Detailed breakdowns by acres of woodland/forest types state-wide and by ownership, density, and structure are shown in Appendixes 1, 2, and 3. The federal government owns 9.5 million acres (57 percent) of the 16.6 million stocked woodland/forestland acres in New Mexico, 26 percent is privately owned, and the remaining 17 percent is in other ownerships, primarily tribal and state.

No clear patterns in forest conditions (i.e., density or structure) could be discerned by ownership alone. However, some interesting observations relative to ownership of different forest types did surface in our analysis. For example, about 70 percent of New Mexico's 3.99 million acres of short-interval fire-adapted forests (PP and DMC types) are federally-owned. The federal government also owns over two-thirds of the Spruce/Fir forests in the state, and over 80 percent of Aspen forests.

Density and Structure

Currently, 28 percent of New Mexico's forests are in a Low density condition. The remaining 72 percent are split evenly between Moderate and High density categories.

The ranges of basal area densities that were classified as High, Moderate, and Low varied among forest types. Basal area densities in the PP and DMC types are shown in Table 2 to provide a frame of reference as to "How dense is dense." Two phases (grass and shrub) of the Ponderosa Pine forest type were recognized, based on presence or absence of Gambel oak. The somewhat higher basal area densities in the shrub (oak) phase are due to higher average site qualities. Because of differences between phases in basal area density, each phase was first analyzed separately. Results were then combined and presented for the PP forest type as a whole.

Table 2. Basal area ranges for Low, Moderate, and High density classes, for fire-adapted forests (i.e., PP and DMC types) in New Mexico.

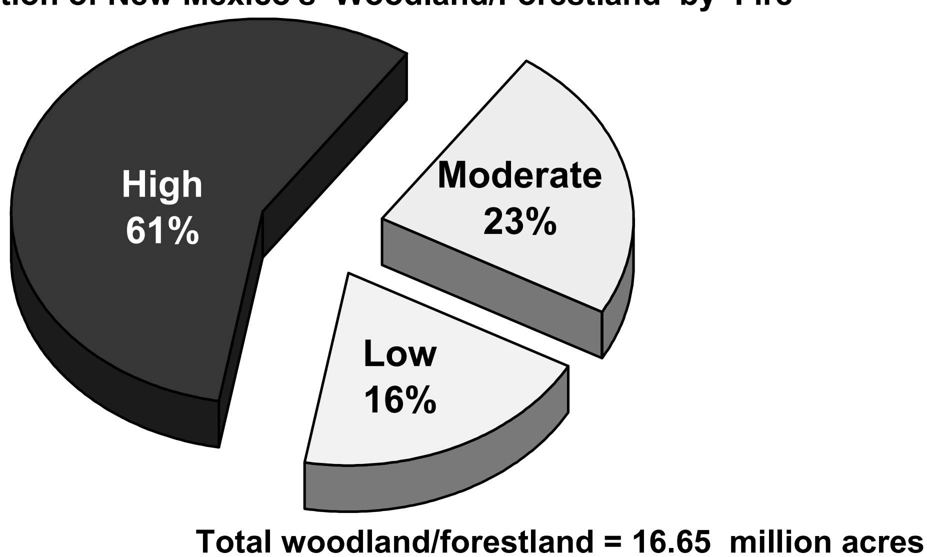
	Basal Area (ft^2/ac)		
Forest Type	**Low**	**Moderate**	**High**
PP (grass)	≤50	51-90	>90
PP (shrub)	≤80	81-110	>110
DMC	≤80	81-130	>130

The 16.6 million woodland/forestland acres in the state were classified within one of four structural types: Scattered, One-storied, Two-storied, or Multi-storied. Approximately 5.1 million acres, or 31 percent of the forested acres, occurred in Multi-storied structures. About 29, 31, and 9 percent occurred in Two-storied, One-storied, and Scattered structures, respectively.

Fire Hazard - Existing conditions

Results of our statewide analysis of crown fire hazard shows that 61 percent of New Mexico's forests were classified as high hazard, about 23 percent as moderate hazard, and 16 percent as low hazard, based on Crowning Index (Figure 1).

Figure 1. Proportion of New Mexico's Woodland/Forestland by Fire Hazard Rating

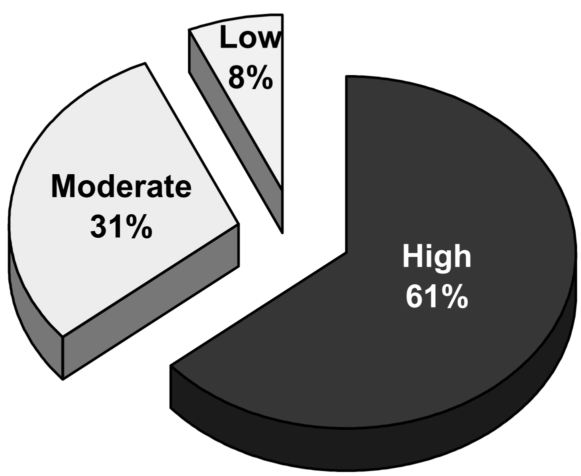


Conditions across the 4 million acres of short-interval, fire-adapted forests in New Mexico were slightly more hazardous than for the state's woodlands/forestlands as a whole. Sixty-one (61) percent of the fire-adapted forests were rated high hazard, 31 percent as moderate hazard, and only 8 percent as low hazard (Figure 2).

The trends in Crowning Index across density and structural classes were especially notable (Appendix 4). For example, looking at all forest types combined, average Crowning Index declined (i.e., hazard increased) across the range of densities from 41 mph at Low density to 27 mph at Moderate density, to 18 mph at High density. Similarly, average Crowning Index declined (and hazard increased) with increasing complexity in stand structure for all forest types except Juniper and Pinyon/Juniper (Appendix 5).

The potent effect of density is further demonstrated in the following example. In stands with Multi-storied structures, 91 percent were rated high-hazard if they were also in the High density category, whereas only about half of Low density stands with Multi-storied structure received a high hazard rating. The influence of stand density on Crowning Index is not unexpected, given that the calculation of Crowning Index within FFE is primarily dependent upon canopy bulk density.

Figure 2. Proportion of New Mexico's Ponderosa Pine and Dry Mixed-Conifer Forest Types by Fire Hazard Rating



Total PP and DMC forestland = 3.99 million acres

The average Crowning Index for New Mexico's forests is 28 mph. The average Crowning Index of 26 mph on federal lands is slightly lower (and hazard higher) than on private (29 mph) and "other" (32 mph) ownerships (Appendix 6). Of New Mexico's nearly 9.6 million acres of federal woodlands/forestlands, 87 percent have a high or moderate fire hazard rating. This is somewhat higher than the private and "other" ownership categories, where 81 and 79 percent of the forests rate high or moderate for fire hazard, respectively.

Fire Hazard - Treatment Effectiveness

Short-term Effects on Fire Hazard

Hazard reduction treatments were evaluated for effectiveness if applied to the 3.7 million acres of high/moderate fire hazard forests in the short-interval, fire-adapted ecosystems (PP and DMC forest types). Our analysis showed that both treatment effectiveness and the number of potentially treatable acres varied by prescription (Table 3). The Thin-from-Below treatment increased average Crowning Index by 22 mph over existing conditions, while the Diameter-Limit and Comprehensive treatments created 38 and 40 mph increases over untreated conditions, respectively (Table 3). Furthermore, the Thin-from-Below to 9" treatment shifted only 29 percent of treated stands to a Low hazard rating (Table 3, Appendix 7). The Diameter-Limit and Comprehensive treatments, in contrast, created low hazard conditions on 67 and 69 percent of treated acres, respectively.

Table 3. Effects of hazard reduction treatments in PP and DMC forest types.

Hazard Reduction Treatment	Pre-treatment Crowning Index	Post-treatment Crowning Index	% of treated acres rated low hazard post-treatment	High/ moderate hazard acres treated
Thin-from-Below	21	43	29%	2.4 million
Diameter-Limit	21	59	67%	3.1 million
Comprehensive	21	61	69%	3.4 million

The number of forested acres potentially treatable varied as a result of silvicultural constraints placed on the different prescriptions (Table 3). The Thin-from-Below to 9" prescription could only be applied to 2.4 of the 3.7 million acres rated high/moderate hazard, while the Diameter-Limit and Comprehensive treatments could potentially be applied to as many as 3.1 and 3.4 million acres, respectively. The lower acreage associated with the Thin-from-Below prescription primarily arises from a restriction to treat only those stands that have at least 50 ft^2/acre of basal area in trees larger than 9", a constraint not associated with the other two prescriptions. Without this constraint, unacceptably low stand densities would result on many acres receiving the Thin-from-Below treatment.

The post-treatment Crowning Index values shown in Table 3 and Appendix 7 reflect the effects of each of the three hazard reduction treatments, including the removal of all non-timber species consistent with other prescription parameters. Non-timber species are sometimes retained to serve various cultural, amenity, or wildlife objectives. The management question that arises is "What effect does removing vs. retaining these non-timber species have on crown fire hazard?" The effect is substantial (Appendix 8), with average post-treatment Crowning Indexes increasing by 15, 24, and 21 mph for the Thin-from-Below, 16" Diameter-Limit, and Comprehensive treatments, respectively.

Long-term Effects on Fire Hazard

Average Crowning Indexes for the Thin-from-Below and Diameter-Limit approaches were only slightly lower 30 years after treatment (Table 4). Stands treated with the Comprehensive prescription changed the most, with the average Crowning Index declining from 61 to 53 mph. The somewhat greater decline in Crowning Index for the Comprehensive prescription is understandable, given the retention of some trees throughout the diameter distribution, including some smaller trees. A hallmark of the Comprehensive prescription is the focus on creating sustainable structures (and ultimately ecological functions) through time, and on the reserve basal area density that will help achieve this objective. Because some existing stands have few larger trees to leave, the 50 ft^2/acre reserved after treatment in such stands is necessarily comprised of smaller trees. Smaller trees change more in size and crown dimensions over time than larger trees, especially given the fairly open conditions that are created following implementation of the Comprehensive prescription. Increases in crown size contribute to the slightly greater decline in average Crowning Index observed for this treatment over time.

Table 4. Characteristics and long-term effects of three hazard reduction treatments in PP and DMC forest types.

Hazard Reduction Treatment	Average Crowning Index immediately after treatment	Average Crowning Index 30 years after treatment	% of treated acres rated low hazard 30 years after treatment
Thin-from-Below	43	41	20%
Diameter-Limit	59	54	56%
Comprehensive	61	53	52%

One measure of long-term treatment effectiveness is the percent of treated acres with a low hazard rating 30 years after treatment. More than half of the acres treated with the 16" Diameter-Limit and Comprehensive prescriptions retained this rating, whereas only 20 percent of the acres receiving the Thin-from-Below treatment remained in the low hazard category 30 years later.

Financial Aspects of the Prescriptions

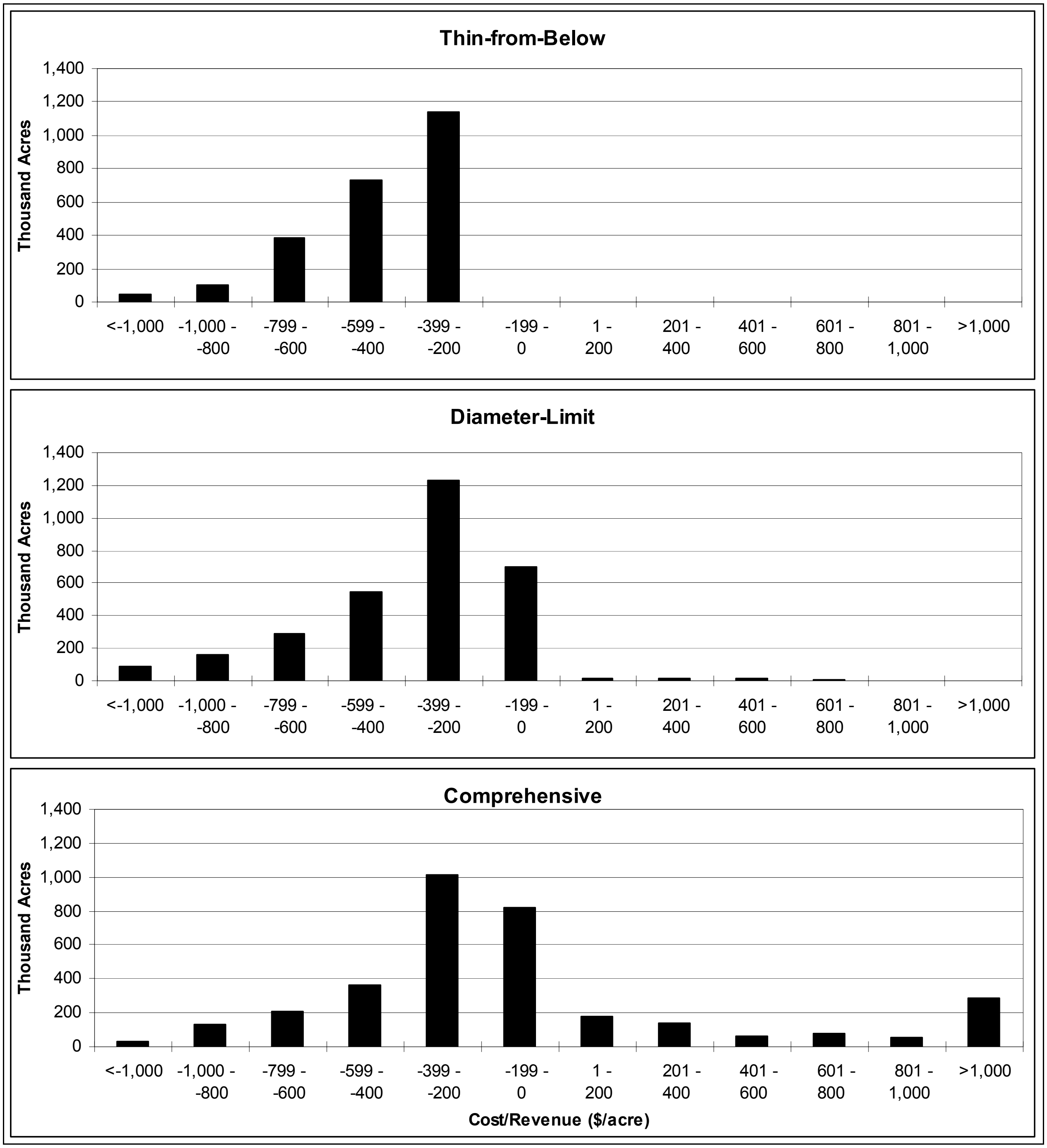
The three prescriptions differed greatly in terms of the volumes and value of timber products recovered in the process of treatment implementation. Indeed, only the Comprehensive treatment regime on average generated sufficient revenue from derivative timber products to cover all on-site treatment costs. Applying the Comprehensive prescription to the suite of PP/DMC acres with high/moderate fire hazard would generate an average positive net revenue of $8/acre (Table 5). The range of revenues was substantial, with a few stands costing over $1000 per acre to treat, and a number of others yielding positive net revenues of more than $1000 per acre (Figure 3). About one-fourth of the acres treated would yield a net value in timber greater than all on-site fire hazard treatment costs.

Table 5. Net revenues per acre treated, and percent of treated acres with positive net revenue, for hazard reduction treatments in high/moderate hazard stands in New Mexico's PP and DMC forest types (1997-1999 market conditions; woodland species removed).

Hazard Reduction Treatment	Net revenue per acre treated	Percent of treated acres with net revenue ≥ $0
Thin-from-Below	-$439	0%
Diameter-Limit	-$368	1%
Comprehensive	$8	25%

The 16" Diameter-Limit prescription, which limits removals to trees less than 16" diameter, was considerably more costly to implement (i.e., net negative revenue of $368/acre) (Table 5). The Thin-from-Below treatment was the most expensive, requiring an average expenditure of $439 per acre treated. Furthermore, values of derivative timber products exceeded costs on only 1 percent of the acres treated under the 16" Diameter-Limit prescription, and on none of the acres that received the Thin-from-Below treatment (Table 5, Figure 3).

Figure 3. Net revenue distributions for hazard reduction treatments in high/moderate hazard stands in New Mexico's PP and DMC forest types (1997-1999 market conditions; non-timber species removed).



DISCUSSION

Recent major wildfires in New Mexico have raised concerns about the vulnerability of the state's forests to even larger and more severe events. However, developing plans to address hazardous conditions, whether at a project or strategic level, requires an understanding of the potential effectiveness and costs of proposed treatments.

Treatment Effectiveness

It is critical that managers carefully evaluate treatment effectiveness before selecting and applying hazard reduction treatments. For example, applying the Thin-from-Below to 9" prescription to high/moderate hazard PP/DMC stands (i.e., short-interval, fire-adapted ecosystems) has only modest effect on lowering average crown fire hazard. Furthermore, this prescription only moves 29 percent of treated stands into a low hazard condition after treatment, compared to nearly 70 percent for the 16" Diameter-Limit and Comprehensive prescriptions. These results underscore the importance of evaluating pre- and post-treatment conditions (stand tables) for Crowning Index during the process of prescription development.

The effects of the Diameter-Limit and Comprehensive treatments evaluated in this study differed little in terms of Crowning Index, either immediately post-treatment or 30 years later. However, the ecological conditions and potential sustainability associated with these two treatments will likely differ substantially over time. Under the Comprehensive approach, late-seral species (if present) are preferentially cut to eliminate them as a seed source, and overall reserve density is prescribed sufficiently low to induce regeneration of ponderosa pine, thereby ensuring sustainability. In contrast, the 16" Diameter-Limit approach neither prescribes nor allows removal of late-seral trees >16" in diameter – trees large enough to be primary seed-producers. Furthermore, density will generally increase over time under this treatment regime, as more and more trees pass over the 16" diameter threshold and become unavailable for cutting. Crown fire hazard will likely increase, and the resulting conditions will favor establishment of shade-tolerant, late-seral species in the understory. Over decades, the result could be a fundamental shift in forest type from ponderosa pine to more shade-tolerant (and fire-, insect-, and disease-prone) species. Even if late-seral species are not present, burgeoning density in overstory pines >16" diameter will severely limit establishment and early development of young pines.

A common management view of non-timber species (e.g., juniper, pinyon pine) in PP or DMC stands is that they are relatively innocuous in terms of their effects on timber production, while providing a variety of ecological, visual, and wildlife values. Results of this analysis show that regardless of hazard reduction treatment, the additional removal of non-timber species leads to a 15 to 24 mph increase in average Crowning Index. For this reason, managers should weigh the substantial reduction of fire hazard that would result from removing these species, against the benefits that would accrue by retaining them.

Treatment Costs and Industry Infrastructure

The Comprehensive treatment approach aimed at initiating ecological restoration, and not just reducing fire hazard, can generate substantial revenue from timber products – enough on average to offset treatment costs. In contrast, the value of timber products (if any) from the Thin-from-Below and Diameter-Limit treatments fails to offset treatment costs on virtually every acre.

The scale of the need for fire hazard reduction and the limited volume of timber currently processed in New Mexico could create a dilemma for managers wanting to effectively and efficiently reduce fire hazard in the state. Two potentially problematic situations exist: a relatively large "break-even" diameter, and limited milling capacity.

Although a few mills have the ability to recover lumber from trees as small as 9" dbh, New Mexico mill operators indicate that trees smaller than 12" typically do not have sufficient value to offset harvest and haul costs. This is due primarily to equipment at the mills and the lack of markets for mill residue. Only about 40 percent of the wood fiber in logs becomes finished lumber; the remainder, referred to as mill residue, generally finds use as a fiber product or fuel (BBER 2001c). For small trees, the proportion that becomes mill residue is even greater. However, there are virtually no profitable outlets for mill residue in New Mexico at present, thus deflating the price of small timber.

In recent years, the sawmill industry in New Mexico has used approximately 16 million cubic feet (mmcf) of timber annually (Keegan et al. 2001 and WWPA 1999). The scenario that follows illustrates the potential contribution that materials produced by hazard reduction treatments could make compared to the size of the current industry. For example, the Comprehensive treatment yields an average of about 800 cubic feet of sawtimber per acre treated. If the Comprehensive treatment regime were eventually implemented on just one-fourth of the 3.7 million acres of high/moderate hazard PP/DMC forests at a 35-year harvest interval (which is equivalent to operating on less than 1% of the area annually), the output would be 21.1 million cubic feet annually, or over 30 percent more timber than is currently used each year.

Much of New Mexico's annual unutilized capacity (17 mmcf) is concentrated at a few larger mills, which could add a second shift if market conditions permitted and raw material was available (Keegan et al. 2001a). However, even if the industry operated at 100 percent of capacity, it probably could not consume all the timber made available from the combination of hazard reduction treatments and current commercial harvesting. A large-scale hazard reduction program in New Mexico would therefore likely lead to lower log prices, if additional milling capacity did not come on-line. On the other hand, an enduring large-scale program could spur development of additional capacity as well as investment in new technology to better utilize small timber. This could include not just sawmills, but also facilities capable of using mill residue.

Conclusions

This study represents the first state-wide effort in New Mexico to describe forest conditions, estimate fire hazard, and evaluate the effectiveness and costs of various hazard reduction treatments. It can be used both as a strategic planning tool to address broad-scale fire hazard concerns, and as a tactical guide to help managers design effective, cost-efficient treatments at the project level.

Results of this study show that the fire hazard problem in New Mexico is best addressed by management approaches that recognize the broader ecological context within which it occurs. Whether the problem is viewed from the standpoint of hazard reduction, ecological condition, or treatment cost, a comprehensive approach that considers the density, structure, and species composition of the reserve stand is superior to prescriptions that focus only on the size of trees removed. The Comprehensive prescription evaluated in this analysis achieves greater hazard reduction, improves ecological condition, and is less expensive to employ than alternative treatments. It is particularly superior when compared to the prescription (Thin-from-Below to 9”) with a singular focus on small-tree removal.

LITERATURE CITED

(BBER) Bureau of Business and Economic Research. 2001a. Harvest cost data system. The University of Montana, Missoula, MT.

(BBER) Bureau of Business and Economic Research. 2001b. The log price reporting system. The University of Montana, Missoula, MT.

(BBER) Bureau of Business and Economic Research. 2001c. Forest Industries Data Collection System. The University of Montana, Missoula, MT.

Beukema, S.J.; Greenough, D.C.; Robinson, C.E.; Kurtz, W.A.; Reinhardt, E.D.; Crookston, N.L.; Brown ,J.K.; Hardy, C.C.; Stage, A.R. 1997. An introduction to the Fire and Fuels Extension to FVS. In: Teck, R.; Moeur, M.; Adams, J., eds. Proceedings of the Forest Vegetation Simulator Conference; 1997 February 3-7; Fort Collins, CO. Gen. Tech. Rep. INT-373. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 191-195.

Covington, W.W., and M.M. Moore. 1994. Southwestern ponderosa pine forest structure: Changes since Euro-American settlement. Journal of Forestry 92: 39-47.

Crookston, N.L. 1990. User's Guide to the Event Monitor: Part of Prognosis Model Version 6. Gen. Tech. Rep. INT-275. U.S. Department of Agriculture. Forest Service. Intermountain Research Station. Ogden, UT. October 1990. 21 pp.

(DOI) Department of the Interior. 2001. "Integrating Fire and Natural Resources Management – A Cohesive Strategy for Protecting People by Restoring Land Health"(http://fireplan.gov/references).

Dombeck, M. 1997. Statement to Senate Committee on Energy and Natural Resources, Feb. 25, 1997. U.S. Congress, Washington, DC.

Fiedler, C.E. 2000. Understanding the Ecosystem: Its Parts and Processes - Silvicultural Treatments. In Proceedings: The Bitterroot Ecosystem Management Research Project: What We Have Learned. RMRS-P-17. U.S. Department of Agriculture. Forest Service. Rocky Mountain Research Station. p. 19-20.

Fiedler, C.E., C.E. Keegan, S.F. Arno, and D.P. Wichman. 1999. Product and Economic Implications of Ecosystem Restoration. Forest Products Journal 49: 19-23.

Fiedler, C.E., S.F. Arno, C.E. Keegan, and K.A. Blatner. 2001. Overcoming America's Wood Deficit: An Overlooked Option. BioScience 51: 53-58.

Keegan, C.E., A.L. Chase, T.A. Morgan, S.E. Bodmer, D.D. Van Hooser, and M. Mortimer. 2001a. New Mexico's Forest Products Industry: A Descriptive Analysis 1997. The University of Montana-Missoula, Bureau of Business and Economic Research, Missoula, MT.

Keegan, C.E., K. Gebert, A.L. Chase, T.A. Morgan, S.E. Bodmer, D.D. Van Hooser. 2001b. Montana's Forest Products Industry: A Descriptive Analysis 1969-2000. The University of Montana-Missoula, Bureau of Business and Economic Research, Missoula, MT in press.

Keegan, C.E., M.J. Niccolucci, C.E. Fiedler, J.G. Jones, R.W. Regel. 2001c. "Harvest Cost Collection Approaches and Associated Equations for Restoration Treatments on National Forests." Accepted for Publication Forest Products Journal.

Scott, J.H. 2001. Personal communication.

Scott, J.H. and E.D. Reinhardt. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior. Res. Pap. RMRS-RP-29.Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 59 p.

Stage, A.R. 1973. Prognosis Model for stand development. Research Paper INT-137. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station.

(USFS) United States Forest Service. 2000. "Protecting People and Sustaining Resources in Fire-adapted Ecosystems – A Cohesive Strategy" (http://www.fs.fed.us/pub/fam/).

Van Dyck, M. 2000. Keyword Reference Guide for the Forest Vegetation Simulator. WO-TM Service Center, USDA Forest Service. Fort Collins, CO. June 6, 2001. 97 pp.

Wagner F.G., C.E. Fiedler, and C.E. Keegan. 2000. Processing Value of Small-diameter Sawtimber at Conventional Stud Sawmills and Modern, High-speed Small-log Sawmills in the Western U.S.--A Comparison. Western Journal of Applied Forestry 15: 208-212.

Wagner, F.G., C.E. Keegan, R.D. Fight, and S.A. Willits. 1998. Potential for Small-diameter Sawtimber Utilization by the Current Sawmill Industry in Western North America. Forest Products Journal 48: 30-34.

Western Governors' Association. 2001. "A Collaborative Approach for Reducing Wildland Fire Risks to Communities and the Environment – 10-Year Comprehensive Strategy" (http://www.westgov.org/wga/initiatives/fire/final_fire_rpt.pdf).

Appendix 1. Acres by woodland/forest type, density, and structure - New Mexico.

Structure/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	TOTAL
Scattered	143,502	474,738	658,538	12,214	5,426	25,113	13,090	156,435	33,955	1,523,011
One	48,955	2,409,020	2,224,886	24,192	18,292	20,707	61,434	255,217	19,054	5,081,757
Two	456,498	745,056	2,882,102	111,189	63,912	28,947	74,700	466,775	5,842	4,835,021
Multi-storied	1,835,681	NA	435,661	1,362,298	685,200	500,936	99,337	220,370	12,416	5,151,899
All	2,484,636	3,628,814	6,201,187	1,509,893	772,830	575,703	248,561	1,098,797	71,267	16,591,688

Density/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	TOTAL
Low	802,203	1,015,472	1,816,212	258,373	204,596	125,646	62,526	364,426	53,009	4,702,463
Moderate	806,547	1,286,969	2,346,384	714,971	303,101	149,736	82,681	349,577	5,987	6,045,953
High	875,886	1,326,373	2,038,591	536,549	265,133	300,321	103,354	384,794	12,271	5,843,272
All	2,484,636	3,628,814	6,201,187	1,509,893	772,830	575,703	248,561	1,098,797	71,267	16,591,688

Appendix 2. Acres by ownership, woodland/forest type, density, and structure - New Mexico.

FEDERAL

Structure/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	TOTAL
Scattered	124,320	242,426	395,593	12,214	5,426	25,113	13,090	108,887	5,865	932,934
One	37,481	981,917	933,341	18,825	12,307	6,130	56,152	144,896	6,894	2,197,943
Two	328,638	343,178	1,621,781	72,811	35,747	18,383	37,075	324,518	5,842	2,787,973
Multi-storied	1,222,998	NA	336,427	931,193	526,491	325,788	94,055	152,580	6,429	3,595,961
All	1,713,437	1,567,521	3,287,142	1,035,043	579,971	375,414	200,372	730,881	25,030	9,514,811

Density/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	TOTAL
Low	569,695	464,811	909,205	141,929	132,074	67,464	51,259	267,177	12,759	2,616,373
Moderate	553,592	549,671	1,139,645	494,254	256,187	74,150	63,011	222,180	NA	3,352,690
High	590,150	553,039	1,238,292	398,860	191,710	233,800	86,102	241,524	12,271	3,545,748
All	1,713,437	1,567,521	3,287,142	1,035,043	579,971	375,414	200,372	730,881	25,030	9,514,811

PRIVATE

Structure/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	TOTAL
Scattered	12,645	118,159	178,649	NA	NA	NA	NA	28,839	11,455	349,747
One	5,365	731,350	742,094	5,367	5,985	14,577	5,282	84,556	12,160	1,606,736
Two	88,381	279,569	770,308	11,970	28,165	10,564	37,625	84,219	NA	1,310,801
Multi-storied	430,398	NA	61,160	195,898	92,937	154,767	5,282	21,259	5,987	967,688
All	536,789	1,129,078	1,752,211	213,235	127,087	179,908	48,189	218,873	29,602	4,234,972

Density/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	TOTAL
Low	167,863	316,460	564,223	31,752	58,967	58,182	11,267	59,694	23,615	1,292,023
Moderate	160,808	452,677	705,902	117,934	19,620	68,400	19,670	80,970	5,987	1,631,968
High	208,118	359,941	482,086	63,549	48,500	53,326	17,252	78,209	NA	1,310,981
All	536,789	1,129,078	1,752,211	213,235	127,087	179,908	48,189	218,873	29,602	4,234,972

OTHER

Structure/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	TOTAL
Scattered	6,537	114,153	84,296	NA	NA	NA	NA	18,709	16,635	240,330
One-story	6,109	695,753	549,451	NA	NA	NA	NA	25,765	NA	1,277,078
Two-story	39,479	122,309	490,013	26,408	NA	NA	NA	58,038	NA	736,247
Multi-storied	182,285	NA	38,074	235,207	65,772	20,381	NA	46,531	NA	588,250
All	234,410	932,215	1,161,834	261,615	65,772	20,381	NA	149,043	16,635	2,841,905

Density/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	TOTAL
Low	64,645	234,201	342,784	84,692	13,555	NA	NA	37,555	16,635	794,067
Moderate	92,147	284,621	500,837	102,783	27,294	7,186	NA	46,427	NA	1,061,295
High	77,618	413,393	318,213	74,140	24,923	13,195	NA	65,061	NA	986,543
All	234,410	932,215	1,161,834	261,615	65,772	20,381	NA	149,043	16,635	2,841,905

NA = no clusters recorded

Appendix 3. Acres by ownership, density, and structure - New Mexico.

Structure

	Federal	Private	Other	All
No Structure	NA	NA	NA	NA
Scattered	932,934	349,747	240,330	1,523,011
One-story	2,197,943	1,606,736	1,277,078	5,081,757
Two-story	2,787,973	1,310,801	736,247	4,835,021
Multi-storied	3,595,961	967,688	588,250	5,151,899
All	9,514,811	4,234,972	2,841,905	16,591,688

Density

	Federal	Private	Other	All
Low	2,616,373	1,292,023	794,067	4,702,463
Moderate	3,352,690	1,631,968	1,061,295	6,045,953
High	3,545,748	1,310,981	986,543	5,843,272
All	9,514,811	4,234,972	2,841,905	16,591,688

Structure/Density

	Federal	Private	Other	All
Scattered, low	932,934	349,747	240,330	1,523,011
Scattered, moderate	NA	NA	NA	NA
Scattered, high	NA	NA	NA	NA
One-story, low	731,632	517,446	331,555	1,580,633
One-story, moderate	919,839	679,983	518,525	2,118,347
One-story, high	546,472	409,307	426,998	1,382,777
Two-story, low	508,934	221,890	104,188	835,012
Two-story, moderate	1,011,895	594,437	320,615	1,926,947
Two-story, high	1,267,144	494,474	311,444	2,073,062
Multi-storied, low	442,873	202,940	117,994	763,807
Multi-storied, moderate	1,420,956	357,548	222,155	2,000,659
Multi-storied, high	1,732,132	407,200	248,101	2,387,433
All	9,514,811	4,234,972	2,841,905	16,591,688

Appendix 4. Average Crowning Index (mph) by ownership, density, and structure - New Mexico.

Structure

	Federal	Private	Other	All
No Structure	NA	NA	NA	NA
Scattered	53	51	52	52
One-story	39	40	42	40
Two-story	17	19	16	17
Multi-storied	19	18	18	19
All	26	29	32	28

Density

	Federal	Private	Other	All
Low	42	39	43	41
Moderate	25	30	30	27
High	16	20	23	18
All	26	29	32	28

Structure/Density

	Federal	Private	Other	All
Scattered, low	53	51	52	52
Scattered, moderate	NA	NA	NA	NA
Scattered, high	NA	NA	NA	NA
One-story, low	45	45	50	46
One-story, moderate	39	42	44	41
One-story, high	31	31	34	32
Two-story, low	28	24	25	27
Two-story, moderate	18	21	15	19
Two-story, high	12	14	15	13
Multi-storied, low	29	20	20	26
Multi-storied, moderate	21	20	20	21
Multi-storied, high	15	14	15	15
All	26	29	32	28

Appendix 5. Average Crowning Index (mph) by woodland/forest type, density, and structure - New Mexico.

Structure/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	Mean
Scattered	65	68	40	66	43	31	90	45	NA	52
One	49	59	22	50	31	49	43	22	NA	40
Two	33	29	12	26	19	21	27	13	NA	17
Multi-storied	26	NA	16	16	14	14	22	13	NA	19
All	30	54	19	18	15	16	32	19	NA	28

Density/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	Mean
Low	41	71	32	27	19	27	51	32	NA	41
Moderate	28	59	17	17	17	16	37	18	NA	27
High	21	36	11	15	11	12	18	10	NA	18
All	30	54	19	18	15	16	32	19	NA	28

NA = too few clusters to be meaningful

Appendix 6. Average Crowning Index (mph) by ownership, woodland/forest type, density, and structure - New Mexico.

FEDERAL

Structure/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	All
Scattered	66	67	43	66	43	31	90	45	NA	53
One	50	57	22	50	40	39	43	22	NA	39
Two	34	28	12	24	20	16	27	13	NA	17
Multi-storied	27	NA	15	16	14	14	22	13	NA	19
All	32	52	19	18	15	16	33	19	NA	26

Density/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	All
Low	45	70	34	31	20	26	55	31	NA	42
Moderate	29	56	16	17	16	17	36	17	NA	25
High	21	33	10	15	11	12	18	9	NA	16
All	32	52	19	18	15	16	33	19	NA	26

PRIVATE

Structure/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	All
Scattered	52	70	35	NA	NA	NA	NA	55	NA	51
One	26	61	23	50	14	54	48	21	NA	40
Two	30	33	12	21	18	28	28	16	NA	19
Multi-storied	21	NA	14	16	14	14	19	13	NA	18
All	23	55	19	17	15	18	30	22	NA	29

Density/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	All
Low	29	69	29	28	18	29	33	40	NA	39
Moderate	24	60	18	15	18	16	40	22	NA	30
High	18	39	11	15	10	11	18	10	NA	20
All	23	55	19	17	15	18	30	22	NA	29

OTHER

Structure/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	All
Scattered	59	68	35	NA	NA	NA	NA	27	NA	52
One-story	63	60	22	NA	NA	NA	NA	23	NA	42
Two-story	26	24	13	32	NA	NA	NA	15	NA	16
Multi-storied	25	NA	27	15	14	NA	NA	11	NA	18
All	28	56	19	17	14	NA	NA	17	NA	32

Density/Forest Type	PP	Juniper	Pinyon/Juniper	Dry MC	Moist MC	Spruce/Fir	Aspen	Oak	Riparian	All
Low	39	77	29	20	11	NA	NA	27	NA	43
Moderate	25	66	18	16	18	NA	NA	15	NA	30
High	21	39	11	13	11	NA	NA	11	NA	24
All	28	56	19	17	14	NA	NA	17	NA	32

NA = too few clusters to be meaningful

Appendix 7. Average Pre- and Post-treatment Crowning Indexes (mph) associated with three hazard reduction treatments in PP and DMC forest types by ownership, density, and structure - non-timber species removed.

Treatment: Thin-from-Below to 9"

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	-/-	26/32	-/-	26/32
Two-story	29/46	16/33	20/40	25/43
Multi-storied	21/43	19/39	19/43	20/43
All	22/44	19/38	19/42	21/43

Density

	Federal	Private	Other	All
Low	33/55	24/45	32/59	32/55
Moderate	23/48	18/43	19/44	22/47
High	19/39	18/34	17/39	19/38
All	22/44	19/38	19/42	21/43

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	-/-	-/-	-/-	-/-
One-story, moderate	-/-	26/32	-/-	26/32
One-story, high	-/-	-/-	-/-	-/-
Two-story, low	24/37	-/-	-/-	24/37
Two-story, moderate	31/50	18/38	19/39	26/45
Two-story, high	30/46	14/29	24/42	25/41
Multi-storied, low	35/59	24/45	32/59	34/57
Multi-storied, moderate	22/48	18/44	19/46	21/47
Multi-storied, high	18/38	19/35	16/39	18/38
All	22/44	19/38	19/42	21/43

Treatment: Diameter Limit

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	-/-	26/47	-/-	26/47
Two-story	28/55	22/46	22/51	26/53
Multi-storied	21/61	18/53	19/60	20/59
All	21/60	19/52	19/59	21/59

Density

	Federal	Private	Other	All
Low	29/53	23/47	25/50	28/51
Moderate	23/59	20/52	19/56	22/57
High	19/63	17/53	17/65	18/61
All	21/60	19/52	19/59	21/59

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	-/-	-/-	-/-	-/-
One-story, moderate	-/-	26/47	-/-	26/53
One-story, high	-/-	-/-	-/-	-/-
Two-story, low	29/42	35/51	-/-	30/43
Two-story, moderate	28/55	26/45	21/48	27/53
Two-story, high	27/65	15/45	24/61	23/58
Multi-storied, low	29/55	21/46	25/50	27/53
Multi-storied, moderate	22/59	18/53	19/57	21/58
Multi-storied, high	18/63	18/54	17/65	18/62
All	21/60	19/52	19/59	21/59

Treatment: Comprehensive

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	-/-	26/50	-/-	26/50
Two-story	27/53	22/44	21/62	25/53
Multi-storied	21/62	18/56	18/66	20/63
All	21/61	19/55	18/65	21/61

Density

	Federal	Private	Other	All
Low	28/59	20/54	19/74	25/61
Moderate	22/59	19/53	19/65	21/59
High	19/64	17/57	17/61	18/63
All	21/61	19/55	18/65	21/61

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	-/-	-/-	-/-	-/-
One-story, moderate	-/-	26/50	-/-	26/50
One-story, high	-/-	-/-	-/-	-/-
Two-story, low	26/53	35/57	27/90*	27/57
Two-story, moderate	27/50	26/42	19/57	26/49
Two-story, high	27/65	15/44	24/53	23/57
Multi-storied, low	28/61	19/54	19/76	24/61
Multi-storied, moderate	21/60	18/55	19/66	21/60
Multi-storied, high	18/64	18/58	17/62	18/63
All	21/61	19/55	18/65	21/61

* n = 1

Appendix 8. Average Pre- and Post-treatment Crowning Indexes (mph) associated with three hazard reduction treatments in PP and DMC forest types by ownership, density, and structure - non-timber species retained.

Treatment: Thin-from-Below to 9"

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	-/-	26/27	-/-	26/27
Two-story	29/38	16/31	20/32	25/36
Multi-storied	21/29	19/26	19/25	20/28
All	22/29	19/26	19/26	21/28

Density

	Federal	Private	Other	All
Low	33/41	24/29	32/36	32/39
Moderate	23/32	18/27	19/29	22/30
High	19/26	18/25	17/22	19/26
All	22/29	19/26	19/26	21/28

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	-/-	-/-	-/-	-/-
One-story, moderate	-/-	26/27	-/-	26/27
One-story, high	-/-	-/-	-/-	-/-
Two-story, low	24/30	-/-	-/-	24/30
Two-story, moderate	31/42	18/35	19/34	26/39
Two-story, high	30/36	14/28	24/26	25/33
Multi-storied, low	35/43	24/29	32/36	24/41
Multi-storied, moderate	22/31	18/27	19/28	21/30
Multi-storied, high	18/26	19/25	16/21	18/25
All	22/29	19/26	19/26	21/28

Treatment: Diameter Limit

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	-/-	26/27	-/-	26/27
Two-story	28/39	22/40	22/44	26/39
Multi-storied	21/36	18/31	19/30	20/35
All	21/36	19/32	19/31	21/35

Density

	Federal	Private	Other	All
Low	29/37	23/28	25/34	28/35
Moderate	23/36	20/33	19/33	22/35
High	19/37	17/33	17/29	18/35
All	21/36	19/32	19/31	21/35

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	-/-	-/-	-/-	-/-
One-story, moderate	-/-	26/27	-/-	26/27
One-story, high	-/-	-/-	-/-	-/-
Two-story, low	29/36	35/36	-/-	30/36
Two-story, moderate	28/38	26/41	21/46	27/39
Two-story, high	27/43	15/40	24/39	23/42
Multi-storied, low	29/37	21/27	25/34	27/35
Multi-storied, moderate	22/35	18/31	19/31	21/34
Multi-storied, high	18/36	18/32	17/29	18/35
All	21/36	19/32	19/31	21/35

Treatment: Comprehensive

Structure

	Federal	Private	Other	All
No Structure	-/-	-/-	-/-	-/-
Scattered	-/-	-/-	-/-	-/-
One-story	-/-	26/33	-/-	26/33
Two-story	27/41	22/42	21/46	25/42
Multi-storied	21/41	18/37	18/35	20/40
All	21/41	19/38	18/36	21/40

Density

	Federal	Private	Other	All
Low	28/38	20/30	19/35	25/36
Moderate	22/38	19/37	19/39	21/38
High	19/45	17/41	17/34	18/44
All	21/41	19/38	18/36	21/40

Structure/Density

	Federal	Private	Other	All
Scattered, low	-/-	-/-	-/-	-/-
Scattered, moderate	-/-	-/-	-/-	-/-
Scattered, high	-/-	-/-	-/-	-/-
One-story, low	-/-	-/-	-/-	-/-
One-story, moderate	-/-	26/33	-/-	26/33
One-story, high	-/-	-/-	-/-	-/-
Two-story, low	26/42	35/38	27/46	27/42
Two-story, moderate	27/38	26/41	19/48	26/40
Two-story, high	27/50	15/44	24/41	23/47
Multi-storied, low	28/37	19/29	19/34	24/35
Multi-storied, moderate	21/38	18/37	19/37	21/38
Multi-storied, high	18/45	18/41	17/33	18/43
All	21/41	19/38	18/36	21/40