Reducing Crown Fire Hazard in Fire-Adapted Forests of New Mexico

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Abstract—*Analysis of FIA data for New Mexico shows that 2.4 million acres of ponderosa pine and dry mixed conifer forests rate high for fire hazard. A restoration treatment designed to address altered ecological conditions in these forests increased average crowning index (i.e., the wind speed necessary to maintain a crown fire) by 50 mph, compared to only 23 mph for a thin-from-below approach designed to reduce hazard. After we projected treated stands forward 30 years, only one-eighth of the acres receiving the thin-from-below treatment remained low hazard, compared to over half receiving the restoration treatment.*

Introduction

Recent wildfires provide harsh testimony to the hazardous forest conditions that exist over large areas of New Mexico. 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. 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 millions 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 understanding the forest conditions most vulnerable to fire and the effectiveness of alternative hazard reduction treatments.

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 Forest Inventory and Analysis (FIA) data, which are collected using consistent inventory protocols across all ownerships, made possible this strategic assessment of fire hazard at a statewide level.

Objectives

The goals of this study were to assess existing forest conditions and fire hazard in New Mexico and to evaluate the potential effectiveness of hazard reduction treatments. Specific objectives were to:

- Quantify occurrence of short-interval, fire-adapted forests in New Mexico.
- Evaluate existing forest conditions for crown fire hazard.
- Develop alternative treatment prescriptions and evaluate their effectiveness in reducing hazard.
- Project existing and treated conditions 30 years into the future and reevaluate fire hazard.

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Methods

Forest Inventory and Analysis data were used to profile existing conditions of forestland in New Mexico. FIA data are collected using a systematic grid, with each inventory point or "cluster" representing approximately 6500 acres. The FIA inventory includes forestlands in national parks and other reserved lands, such as designated wilderness areas. The initial analysis of FIA data for this study included lands classified as "timberlands" (i.e., primarily stocked with traditional timber species) and "woodlands" (i.e., primarily stocked with pinyon pine [*Pinus edulis*], juniper [*Juniperus* spp.], or hardwoods other than aspen [*Populus tremuloides*] or cottonwood [*Populus* spp.]).

The assessment of fire hazard reported here was conducted exclusively on short-interval, fire-adapted forests. In New Mexico, these are primarily comprised of ponderosa pine (*Pinus ponderosa*) and dry mixed conifer forest types. Fire-adapted forests were identified as the highest priority for treatment in "Protecting People and Sustaining Resources in Fire-Adapted Ecosystems — A Cohesive Strategy" (DOI 2001). Frequent, low-intensity fires were the primary agent that shaped these forests historically and kept them resistant to severe fires (Agee 1998). 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).

Fire Hazard

Potential fire hazard was analyzed for individual inventory clusters (n = 261) using the Fire and Fuels Extension (FFE: Beukema et al. 1997, Scott and Reinhardt 2001) to the Forest Vegetation Simulator (FVS: Crookston 1990, Stage 1973, Van Dyck 2001). The FFE 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. Model runs were made assuming a 20-foot wind speed of 20 mph, a moisture level of one (driest condition), air temperature of 90 degrees F, and a wildfire rather than prescribed burning situation.

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. Crowning index is largely driven by canopy bulk density, which FFE calculates from individual tree biomass summed to the stand level (Scott and Reinhardt 2001). High-hazard forest conditions were defined as having a crowning index less than 25 mph, moderate hazard from 25 to 50 mph, and low hazard greater than 50 mph. The Central Rockies variant of the FVS model was used to project post-treatment forest conditions 30 years into the future, at which time crown fire hazard (i.e., crowning index) was again assessed using FFE. Two model types were used—model type 1 (southwestern mixed conifer) and model type 2 (southwestern ponderosa pine) for the dry mixed conifer and ponderosa pine forest types, respectively. Default site index values were used (DF 70 for model type 1, and PP 70 for model type 2), and regeneration was turned "on."

Hazard Reduction Treatments

A variety of management approaches can potentially be used to address hazardous conditions in short-interval, fire adapted forests; three contrasting ones are compared in this paper. One approach is low thinning to a given diameter limit, a treatment that has been widely recommended (Dombeck 1997). A diameter limit of 9 inches was used in this analysis (thin-from-below to 9 inches).

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

A third approach is aimed at initiating restoration of sustainable structure and composition (and ultimately, ecological function). It 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 (restoration), 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 basal area is comprised of larger trees, although some trees are marked for leave throughout the diameter distribution, if available. Silvicultural treatments involved in the restoration 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. The multiple objectives of the restoration treatment are to reduce fire hazard, increase tree vigor, spur development of large trees, and induce regeneration of seral species.

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 hazard conditions (i.e., those with a crowning index <25 mph) in the ponderosa pine and dry mixed conifer forest types. The thin-from-below to 9 inch prescription was only applied to stands that had greater than 50 ft^2/acre of trees larger than 9 inches. For the 16 inch diameter-limit prescription, all trees larger than 16 inches dbh were left, so long as the basal area of these trees was 50 ft^2/acre or greater. If there were less than 50 ft^2/acre of basal area in trees >16 inches , then trees <16 inches were retained from the biggest on down (i.e., 15 inches, 14 inches, 13 inches, etc.) until a basal area density of 50 ft^2/acre was reached.

The restoration 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.

Results

Fire Hazard: Existing Conditions

Analysis of FIA data shows that there are approximately 16.6 million acres of woodlands/forestlands in New Mexico. The short-interval, fire-adapted forests that are of greatest concern in terms of fire hazard collectively occupy

4.0 million acres. Approximately 61%, or 2.4 million acres, of these historically fire-adapted forests classify as high hazard, 31% as moderate hazard, and only 8% as low hazard, based on crowning index (figure 1).

The trends in crowning index across density and structural classes were especially notable. For example, focusing on short-interval, fire-adapted forests only, average crowning index declined (i.e., hazard increased) across the range of densities from 39 mph at low density, to 22 mph at moderate density, to 18 mph at high density. In stands with multi-storied structures, 85% were rated high hazard if they were also in the high-density category, whereas only 15% of moderate-density and no low-density stands with multi-storied structure received this rating.

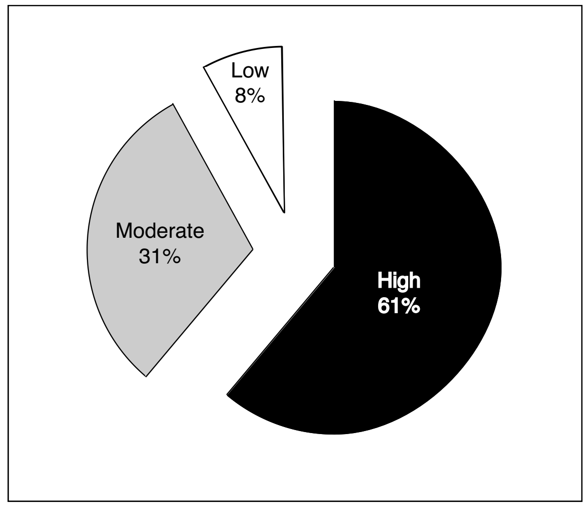

Figure 1—Proportion of New Mexico's short-interval, fire-adapted forests (4.0 million acres) by fire hazard rating.

Fire Hazard: Treated Conditions

Evaluation of the effectiveness of hazard reduction treatments focused on 1.7 million acres of high hazard forests within short-interval, fire-adapted ecosystems (i.e., ponderosa pine and dry mixed conifer forest types). The average composition of these high-hazard conditions is shown in figure 2. Approximately 0.7 million acres were not evaluated because stand composition was such that less than 50 ft^2/acre of basal area would remain following application of one or more of the treatment prescriptions. Both treatment effectiveness and the durability of effects varied by prescription (table 1). For example, thinning-from-below increased average crowning index from 16 to 39 mph, or 23 mph over existing conditions, compared to increases of 45 and 50 mph for the diameter-limit and restoration treatments, respectively (table 1). The Friedman test found significant differences ($p<0.001$) among the distributions of crowning indexes for the four treatments (i.e., existing conditions and three hazard reduction treatments). Multiple comparison tests (Hochberg and Tamhane 1987) also found that all three treatments significantly increased crowning indexes (i.e., reduced crown fire hazard) relative to untreated conditions ($p=0.001$). In addition, both the 16 inches diameter-limit and restoration treatments significantly increased crowning indexes ($p=0.001$) relative to either the thin-from-below to 9 inches treatment or untreated conditions.

The distribution of treated acres in terms of crowning index also varied among prescriptions. While all three hazard reduction approaches increased

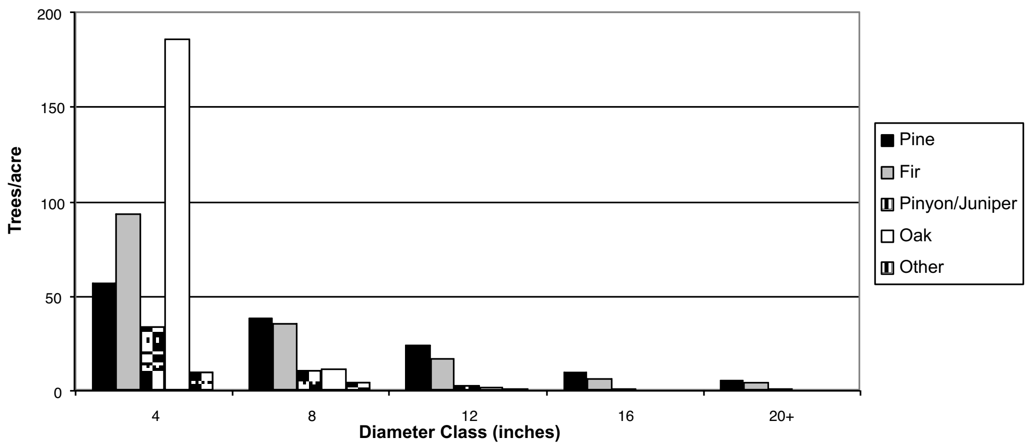

Figure 2—Average composition of existing high-hazard conditions in terms of trees per acre by diameter class and species.

Table 1—Effectiveness of hazard reduction treatments for increasing crowning index within short-interval, fire-adapted forests in New Mexico.

Hazard reduction treatment	Average crowning index before treatment (std. dev.)	Average crowning index after treatment (std. dev.)	Average crowning index 30 years after treatment (std. dev.)
Thin-from-below	16 (6.0)	39 (12.7)	37 (11.0)
Diameter-limit	16 (6.0)	61 (20.6)	57 (18.8)
Restoration	16 (6.0)	66 (20.3)	56 (16.6)

crowning indexes compared to existing conditions, the greater effectiveness of the diameter-limit and restoration treatments is apparent (figure 3).

Crown fire hazard was reevaluated after projecting post-treatment conditions 30 years into the future. Although the effectiveness of all treatments diminished somewhat, differences among treatments tended to persist through time (figure 3). On average, stands that received thinning-from-below remained in the moderate-hazard range 30 years after treatment, with average crowning index declining slightly to 37 mph (table 1). Diameter-limit and restoration treatments retained an overall low-hazard rating, with average crowning indexes above 50 mph (table 1).

The thin-from-below treatment was only effective in moving 18% of treated acres to a low hazard rating (table 2). The diameter-limit and restoration treatments, in contrast, created low hazard conditions on 72% and 79% of treated acres, respectively. The limited effectiveness of thinning-from-below is further illustrated by the small number of treated acres (13%) that remained low-hazard 30 years following treatment. Over 60% retained that classification for the diameter-limit and restoration treatments (table 2).

Table 2—Effectiveness of hazard reduction treatments for creating low hazard conditions in short-interval, fire-adapted forests in New Mexico.

Hazard reduction treatment	Acres rated low hazard after treatment (percent)	Acres rated low hazard 30 years after treatment (percent)
Thin-from-below	18	13
Diameter-limit	72	62
Restoration	79	62

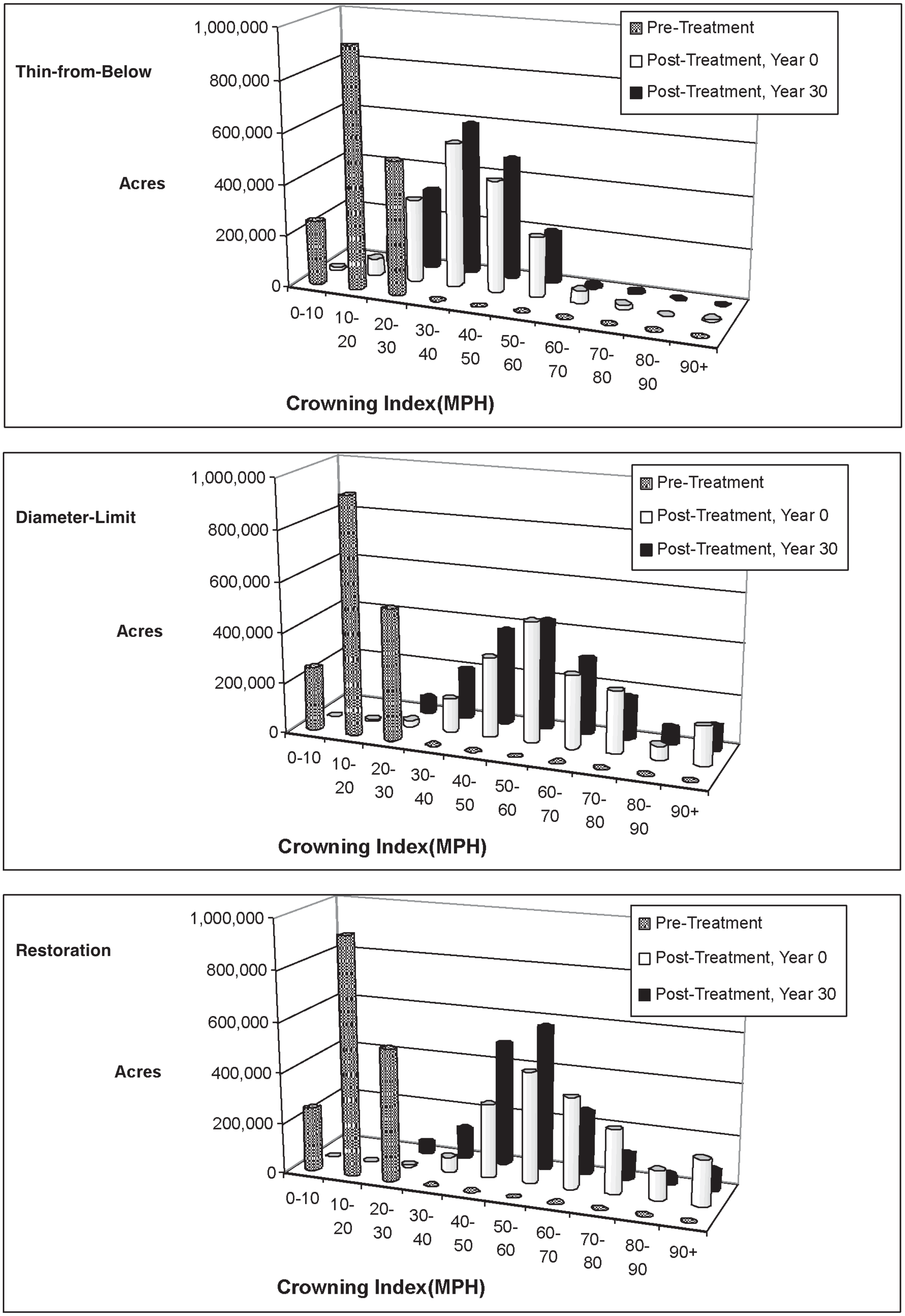

Figure 3—Crowning indexes for pre-treatment, post-treatment year 0, and post-treatment year 30, for three hazard reduction prescriptions applied to high-hazard stands (woodland species removed).

Fire Hazard: Effects of Woodland Species

Pinyon pine and juniper are a common stand component in the ponderosa pine and dry mixed conifer forest types. 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 (*Quercus gambelii*) is typically retained on all ownerships to serve a variety of amenity and wildlife habitat objectives. However, retention of woodland species may have an undesirable effect in terms of increased crown fire hazard. For this reason, post-treatment crowning index values were evaluated for two scenarios—one with woodland species retained and the other with these species removed (table 3). The effect of removing woodland species is substantial, with average post-treatment crowning indexes increasing (i.e., hazard decreasing) by 16, 30, and 26 mph compared to the "retention" scenario for the thin-from-below, diameter-limit, and restoration treatments, respectively (table 3).

Table 3—Effectiveness of hazard reduction treatments for increasing crowning index (C.I.) with woodland species retained and removed.

Hazard reduction treatment	Average C.I. before treatment (std. dev.)	Average C.I. after treatment, woodland species retained (std. dev.)	Average C.I. after treatment, woodland species removed (std. dev.)
Thin-from-Below	16 (6.0)	23 (10.3)	39 (12.7)
Diameter-Limit	16 (6.0)	31 (16.6)	61 (20.6)
Restoration	16 (6.0)	40 (24.0)	66 (20.3)

Discussion

This study represents the first statewide effort in New Mexico to estimate fire hazard and evaluate the effectiveness 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 treatments at the project level.

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 inch prescription to high hazard ponderosa pine and dry mixed conifer forests has only a modest effect on lowering average crown fire hazard (i.e., increasing crowning index). Furthermore, this prescription moves fewer than 20% of treated stands into a low hazard condition after treatment, compared to 72% and 79% for the 16 inches diameter-limit and restoration prescriptions. These results underscore the importance of evaluating pre- and post-treatment conditions (stand tables) for fire hazard during the process of prescription development.

Crowning indexes associated with the 16 inch diameter-limit and restoration treatments differed little—either immediately after 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 restoration 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 enhancing sustainability. In contrast, the 16 inch diameter-limit approach neither prescribes nor allows removal of late-seral trees greater than 16 inches 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 inch diameter threshold and become unavailable for cutting. Crown fire hazard will increase, and the resulting conditions will favor establishment of 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 of overstory pines greater than 16 inch diameter will limit establishment and early development of young pines, with fire hazard and vulnerability to beetles increasing commensurately.

A common management view of woodland species in ponderosa pine or dry mixed conifer forests is that they are relatively innocuous in terms of their effects on the growth and vigor of timber species, while providing a variety of ecological, visual, and wildlife values. Results of this analysis show that regardless of hazard reduction treatment, the retention of woodland species leads to a 16 to 30 mph decrease in average crowning index. For this reason, managers should weigh the benefits that would accrue by retaining these species against the substantial reduction of fire hazard that would result from removing them.

Results of this study show that the fire hazard problem in New Mexico is best addressed by forest restoration approaches that recognize the broader ecological context within which hazard occurs. Indeed, Fule et al. (2001) point out that hazard reduction may be viewed as an incidental benefit of restoration treatments given the multiple ecological benefits that accrue to even a partially successful restoration program. Whether degraded, fire-adapted forests are viewed from the standpoint of hazard reduction or ecological condition, an approach that centers on the density, structure, and species composition of the reserve stand is superior to prescriptions that focus only on the size of trees removed. The restoration prescription evaluated in this analysis achieves greater hazard reduction and creates more sustainable conditions than alternative treatments. It is particularly superior when compared to prescriptions with a singular focus on removal of small trees.

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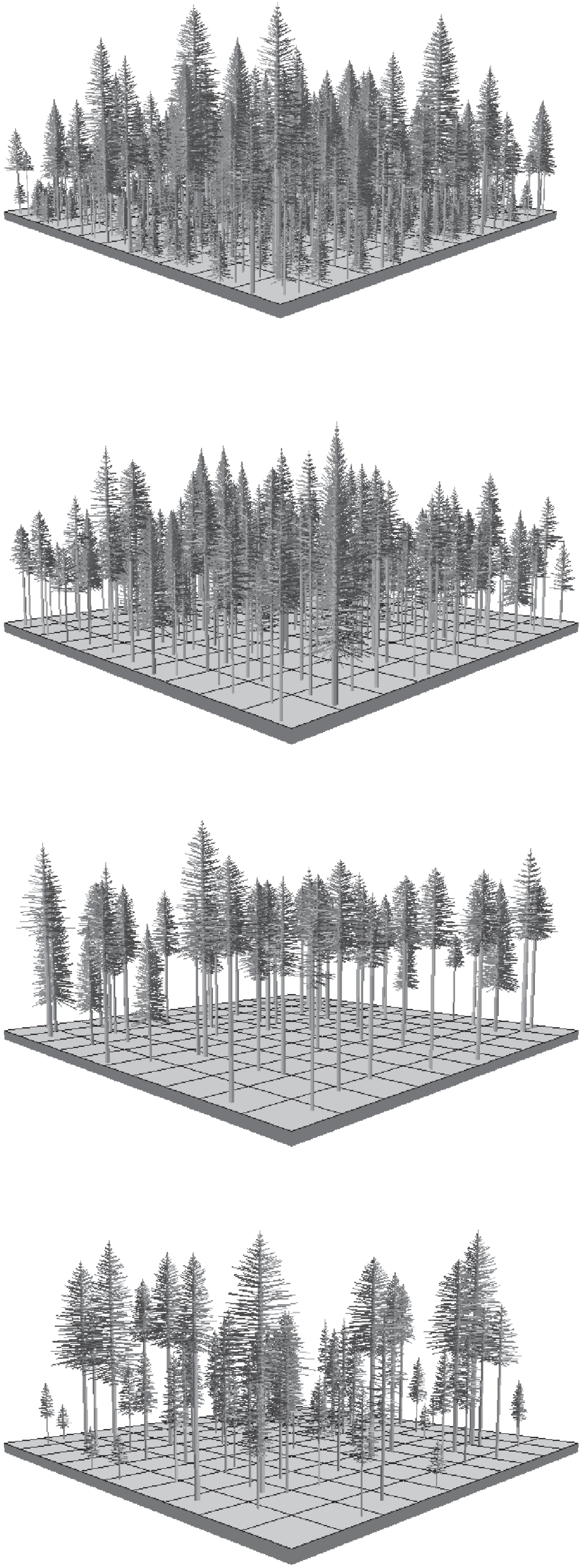

Figure 4—Stand visualizations of:

a) existing conditions in forests rated high for crown fire hazard,

b) after applying a thin-from-below to 9″ prescription,

c) after applying a 16″ diameter-limit prescription, and

d) after applying a restoration prescription.

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