Reforestation after the Fountain Fire in Northern California: An Untold Success Story

Jianwei Zhang, Jeff Webster, Robert F. Powers, and John Mills

ABSTRACT

Forest fires have been burning "hot" across the United States and particularly in the West in recent years. So, too, will the debate on postfire management strategies. In this article, we present a successful reforestation project after a catastrophic fire in 1992. Sixteen years later, most lands are covered with vigorous young forest stands. These regenerated stands have sequestered a large amount of atmospheric carbon, although still not to the level of previous stands. Furthermore, these managed stands will provide wood to consumers and support the local economy in the future. In contrast, adjacent lands without reforestation are fully occupied with shrubs and a few hardwood tree species, going through a long process of natural succession. We conclude that in this particular case active reforestation is the most effective method to quickly restore forest cover.

Keywords: forest fires, reforestation, carbon storage and sequestration, plant diversity

Wildland fire has annually affected about 4.2 million ac of forests across the United States since 1980, with rates increasing in the last 10 years (National Interagency Fire Center [NIFC] 2007). In California alone, an average of 7,000 wildfires have occurred and about 154,000 ac of forestlands have burned annually since 1980 (California Department of Forestry 2007). Land managers face the challenge of land restoration while the controversy over salvage logging and forest recovery continues. Proponents of salvage logging favor harvesting useable wood and planting tree seedlings if a fire kills trees but does not completely consume them. This has been a long-standing forestry practice that helps support local economies and ensures rapid reforestation. Furthermore, wildfire hazard is lowered if logging residues are treated and competing vegetation is controlled as plantations develop. Opponents argue that logging operations interrupt natural recovery by removing dead, standing structures with wildlife value. Still, others argue that natural regeneration may be sufficient to preclude the need for site preparation and planting (Donato et al. 2006). Regardless of postfire management pros and cons on both sides, regeneration is inevitable, but differences in rates of tree recovery can be substantial. Landowner decisions and actions are based on management goals. If wood production is a primary goal, decisions must follow quickly and be based on regulations and management knowledge to avoid wood decay in salvageable material and site occupancy of aggressive shrub vegetation. Here, we report a successful reforestation project after a 1992 wildfire devastated 64,000 ac of forests in northeastern California. Sixteen years later, after salvage logging, site preparation, and planting, forest canopies have closed and precommercial thinning has been conducted. In contrast, adjoining untreated lands are fully occupied with naturally regenerating shrubs and a few hardwoods. In this article we briefly present the reforestation processes and focus mainly on stand productivity using Roseburg Forest Products' (Roseburg, thereafter) measured and modeled growth and yield from previ-

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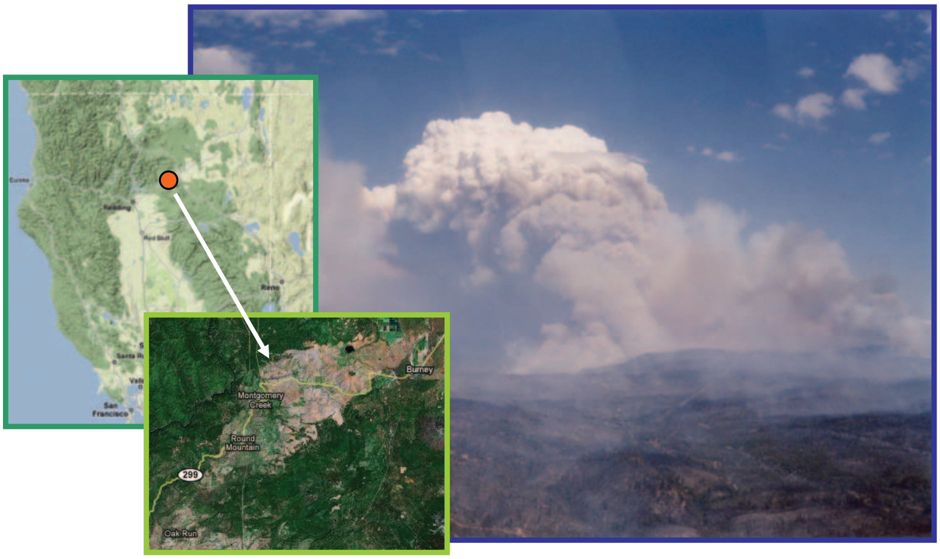

Figure 1. Geographic location (from Google.com) of the Fountain Fire in northeastern California, which burned 100 mi^2 on Aug. 20–28, 1992. (Photograph taken by Jeff Webster.)

ous stands and regenerated young stands. We use Roseburg's data because they are the single largest landholder within the burned area. So, the growth rate from their lands would represent the average tree growth rate for the entire burned area. Furthermore, they have a complete inventory of their forests before the fire.

The Fountain Fire Site

The area is located in eastern Shasta County, southeast of Mount Shasta within the southern Cascade Range in California (Figure 1; latitude, 40°42′N; longitude, 122°00′W; elevation, 1,620–5,400 ft). The climate is typically Mediterranean with hot, dry summers and cold, wet winters. The mean annual temperature is 45°F. Annual precipitation averages 62 in., mainly falling during winter, of which at least 70% is snow. The predominant soils are of the Cohasset-Windy-McCarthy soil association with well-drained sandy or clay loams formed from basic volcanic rocks (USDA 1974). Included are well-drained clays or clay-loam soils of the Kilarc-Sites association formed from sedimentary and metamorphic rocks. The predominant forest cover type was Sierra Nevada mixed conifer (SAF 243; Eyre 1980) with a small portion of Pacific ponderosa pine cover type (SAF 245) at the lower elevations. Prefire overstory species include ponderosa pine (*Pinus ponderosa* P.&C. Lawson), sugar pine (*Pinus lambertiana* Dougl.), Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco), white fir (*Abies concolor* [Gord.&Glend.] Lindl. ex Hildebr.), incense-cedar (*Calocedrus decurrens* [Torr.] Florin), and California black oak (*Quercus kelloggii* Newberry). There had been selective cutting before the fire. Understory shrubs are mainly *Arctostaphylos* spp. and *Ceanothus* spp. The entire forest before the fire was naturally regenerated after the areas were harvested by railroad logging between 1886 and 1923. The forest was variable and stocking was much less than site quality potential (R.F. Powers, pers. observations, 1992). The old landings and skid trails were fully occupied with shrubs.

The Fountain Fire was ignited by a suspected arsonist in dry grass along Buzzard Roost Road, Oak Run (Figure 1) at midday on Aug. 20, 1992. The area had experienced 6 years of drought and 22 consecutive days of temperatures of 100°F or more. Winds were up to 25 mph the day of the fire—perfect for high-severity fire (Skinner and Taylor 2006). By the next morning, 10,000 ac were consumed and by the evening a total of 38,000 more ac were ablaze. Almost all trees in the fire path were killed. In all, the fire severely burned 64,000 ac of prime timberland and destroyed many rural residences before it was contained on Aug. 28, 1992. Within the area, 272 homes and 489 other buildings were also consumed. The total estimated value lost was more than $138 million.

Nearly all of the lands in the Fountain Fire were in private ownership. Of these, 41,300 ac were industrial ownership—an amount equivalent to 1% of the industrial land base in California. Of these 64,000 ac, 41% were owned by Roseburg, 15% were owned by Sierra Pacific Industries, 9% were owned by Fruit Growers Supply, and 34% were owned by small private landowners, farmers, and residences. The remaining 1% was state and federal holdings.

Figure 2. After the fire, salvage logging started immediately and the site was prepared and planting started in the following year. (Photographs taken by Ted Silbersteins.)

Salvage and Reforestation

For the sake of investment return, the local economy, and reforestation, all forest industry companies decided to log and replant their land although this is not a legal requirement. California forest practice law states that if the lands are determined to be "substantially damaged," they are not required to be planted (Forest Practice Rules 1080.1[2]). Two weeks after the fire while the ashes still smoldered, companies began to log the dead timber before it was degraded (Figure 2). Large trees were harvested as sawlogs and smaller materials were exported as chips. These companies used the guidelines set forth by the California Forest Practices Act to ensure environmental integrity; stream buffers were established, archaeological surveys were completed, erosion mitigation measures were taken, and local citizens and other interest groups were consulted before the harvesting. Along the major streams, check dams were built in some areas and grass seed was applied in others. After salvage on slopes of less than 25–30%, above the riparian zone, much of the industrial land was subsoiled along contours to break up soil compaction and possible hydrophobicity.

To prepare for reforestation of unprecedented magnitude, all companies rushed their stored seeds to commercial nurseries in the area. In March 1993, about 7 months after the fire, Roseburg planted the first seedlings near Hatchet Creek (Figure 2). Within the next 5 years, approximately 17 million seedlings were planted on industrial lands previously supporting timber. Roseburg planted a combination of ponderosa pine, Douglas-fir, and white fir with 10-ft spacing. Incense-cedar was planted along the stream buffers.

Because controlling competing vegetation is a key to plantation success in these forest types (McDonald and Powers 2003, Powers et al. 2004), a comprehensive vegetation management plan was established from the very beginning. Areas with herbicide restrictions, such as stream buffers, were logged and planted first to take advantage of the site preparation created by the fire. Where resprouting evergreen shrubs developed after the fire primarily *Arctostaphylos* and *Ceanothus* spp., planting was suspended for 2–3 years until growth regulator herbicides could be applied to shrubs attaining sufficient crown volume for effective herbicide control (Webster and Fredrickson 2005). Hexazinone was applied as a site preparation treatment on virtually every unit.

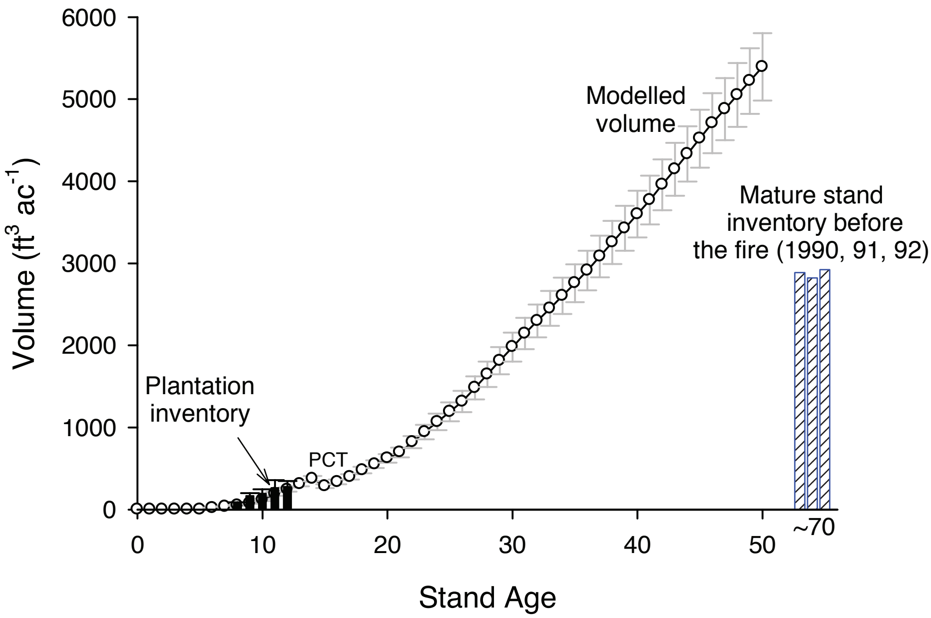

Figure 3. Stand volume inventory for (1) the original natural stands (bar only), at about 70 years old, in 1990, 1991, and 1992, before the Fountain Fire; (2) for some regenerated young plantations (bar + standard error [SE]) at the age of 8–12 years after the fire; and (3) means (±SE) of modeled volume (circle and line) based on the combinations of site quality and planted species with the Forest Projection Systems for up to 50 years. Precommercial thinning (PCT) has been assumed to be conducted at the age of 14 years.

Growth and Stand Development

Before the fire, Roseburg had systematically inventoried for their lands. Plots were placed on a systematic, square grid across each legal section. Minimum plot coverage was one plot for each 10 ac. Plot design called for point samples with a 20 basal area factor (BAF) prism recording all trees of merchantable size (6-in. or more diameter inside bar at small end, 16-ft log). Measurements of species, dbh, total height, form class, and defect were recorded for all "in" trees on all plots. Site index (60–110 ft at the age of 50 years) was generated from site trees gathered across each legal section. Summarizing these data using tract acreage as a weighting factor, we calculated an average of 2,922 ft^3 ac^{-1} in stem wood in 1992 (Figure 3), which is very close to the 1994 volume (3,073 ft^3 ac^{-1}) for an average mixed conifer forest (dbh of 5 in. or more) in Shasta county calculated from the Forest Inventory Data (Forest Inventory Analysis [FIA] 2008). If we had only included trees of 11 in. or more dbh in the FIA data by matching Roseburg's tree size, stem volume would have been 2,550 ft^3 ac^{-1}, lower than the volume calculated on Roseburg lands. This may be caused by lower site quality of public lands than private ones.

Beginning at the age of 8 years, Roseburg sampled about one-quarter of their young plantations. Plantations within the Fountain Fire were delineated using previous harvest and planting unit information in conjunction with digital orthophotography, establishing land types similar with respect to species, size, density, or other characteristics. Stands ranged in size from 20 to 200 ac. Plots were laid out on a systematic rectangular grid across the stand, with a minimum coverage of one plot for every 5 ac.

Fixed area plots were established, sized to take approximately 5 trees/plot. Species and dbh were taken on each plot, and height, live crown ratio, damage, and site information were taken on approximately one-third of the plots. Site index was derived using the height intercept method (Powers and Oliver 1978) on a minimum of 6 trees/stand. Of Roseburg's burned land, 26% had a site index of 70–79 ft at the age of 50 years, 61% with 80–89 ft, 7% with 90 ft and above, and 6% with less than 70 ft. Depending on the site quality and species composition, we calculated that 12-year-old stands averaged 277 ft^3 of stem wood per acre from these inventory data (Figure 3) with a mean annual increment (23 ft^3 ac^{-1} per year).

Forest projection and planning systems

Table 1. Stand mean volume from inventory before the fire, timber volume, chips and fuels during salvage logging after the fire, and modeled volume for the new plantations from the Forest Projection System up to 50 yr old.

		Mean carbon density (metric tons of C ac^{-1})					
Age (yr)	Mean volume[a] (ft^3 ac^{-1})	Live tree	Standing dead tree	Understory	Down deadwood	Forest floor	Soil organic
Before the fire (70 yr)	2,921.8	42.8	4.3	0.6	4.3	14.1	19.9
Salvaged	2,400.0		16.4[b]				
After the fire							
0	0.0	0.0	0.0	0.0	0.0	0.0	15.1
5	0.0	1.7	0.1	1.9	0.2	2.1	15.2
15	284.3	7.9	0.8	2.3	0.8	8.7	16.8
25	1,191.2	21.0	2.1	1.0	2.1	12.0	18.9
35	2,757.6	40.9	4.1	0.6	4.1	14.0	19.9
45	4,519.8	61.4	6.2	0.5	6.2	15.1	20.1
50	5,392.5	71.2	7.2	0.4	7.2	15.5	20.1

For the salvaged materials, total carbon is calculated directly from materials shipped to forest factories. Other carbon densities were extrapolated from Smith et al (2006) based on either measured or modeled stem volume. The Fountain Fire occurred in Shasta County, California, in 1992.

[a]Volume before the fire was from Roseburg's complete 1992 inventory; salvaged volume was saw log removed from Roseburg's land.

[b]Carbon tonnage contained in stems (13.6), directly calculated from stem volume using specific gravity (0.40) as a conversion factor assuming that 50% biomass is carbon, and fuel and pulp chips (2.8) removed into a power plant or a pulp mill.

developed by Forest Biometrics Research Institute (Corvallis, OR) was used to predict future stand growth and development on Roseburg land. Because site quality varied across the entire burned area and species composition differed, we ran nine combination stands with three site qualities by three species compositions. Then, similar tracts with one of nine stands were grouped. Total volume was the mean of nine stands with real acreage as a weighted factor within Roseburg land across the burned areas. The results indicate that by the age of 36 years, the young plantations will carry as much stem volume as the prefire stands at about the age of 70 years (Figure 3), indicating that a fully stocked plantation with understory vegetation controlled grows much more bole wood than a natural stand does on the same land. Even for plantations in northeastern California, McDonald and Powers (2003) found that a stand on a poorer site with competing vegetation control could produce 126 times more stem volume than a stand without vegetation control after 40 years of stand development. Although the duration of vegetation competition shortens as site quality improves (Powers and Reynolds 1999, Zhang et al. 2006), tree seedlings can be suppressed for decades if competing vegetation is not controlled (Conard and Radosevich 1982, Powers et al. 2004). By the age of 50 years, these plantations would produce 5,392 ft^3 of stem volume per acre with a stand density index of 329, reaching a threshold for a zone of imminent bark beetle mortality for the pure ponderosa pine stands in northern California (Oliver and Uzoh 1997).

Implications

Carbon Storage and Sequestration. Global climate change research has shown that warming trends are correlated with the rise in greenhouse gases, most notably, carbon dioxide (IPCC 2007). Forests play a significant role in offsetting CO_2 emissions by converting CO_2 into wood through photosynthesis and storing it for decades or centuries. Despite uncertainties, annual carbon sequestration is estimated to vary between 149 and 330 million ton of C per year by forests in the United States, which offsets 10% of US CO_2 emissions in 2005 (Woodbury et al. 2007). Therefore, the question of whether active or passive postfire management strategies affect carbon uptake rates and pools is important.

Using a simple extrapolation from the latest carbon-pool methods for forest ecosystems (Smith et al. 2006) and Roseburg's inventory data, we estimate that there were about 86 metric tons (MT; 1 MT = 2,205 lb; we use MT to avoiding a confusion of the difference between American and British tons) of C per acre in original natural forests before the fire, separated to various carbon pools (Table 1). Because the smallest trees that Roseburg measured were much larger than the minimum tree size (dbh $\geq 1''$) that Smith et al. (2006) used, carbon stocks could be substantially underestimated for the prefire stands on these lands.

After the fire, neighboring industrial land owners chose to log the trees with commercial value as Roseburg did. Fire-killed trees lose commercial value quickly. White fir and ponderosa pine usually lose their value completely within 3 years (California Forest Stewardship Program 2002). However, commercially processed wood has an estimated annual decomposition rate of less than 1% (Birdsey 1996). An average of 2,400 ft^3 of timber was salvaged per acre, equivalent to 13.6 MT of C per acre if we assume that specific gravity is 0.40 (Smith et al. 2006). In addition, one load of wood chips per acre was removed from about 12,000 ac on flatter ground with less than 10% slope. Approximately 70% of these loads were fuel chips for electricity and dry weight was 12.7 MT/load. Thirty percent of these loads were pulp chips and dry weight was 10.9 MT/load. On average, across the entire Roseburg burned areas (26,240 ac), 2.8 MT of C per acre were recovered from these chips. If we assume that little soil organic carbon was affected by the fire, we calculate that 66.1 MT of C per acre would have been released into the atmosphere including 49.7 MT from smoke (forest floor, down deadwood, understory, standing dead trees, and portion of live trees before the fire) during the fire and 16.4 MT from decomposition in the following decade if these lands had not been salvaged. By salvage logging these lands, landowners not only recovered some commodities, but also delayed a subsequent release of 16.4 MT of C per acre to the atmosphere.

By planting trees and controlling the competition, we estimate that the plantations store about 37.3 MT C per acre at the age of 15 years (Table 1). The estimates of the potential carbon stocks in Table 1 are comparable with an estimate of the potential carbon stock from an afforestation project in

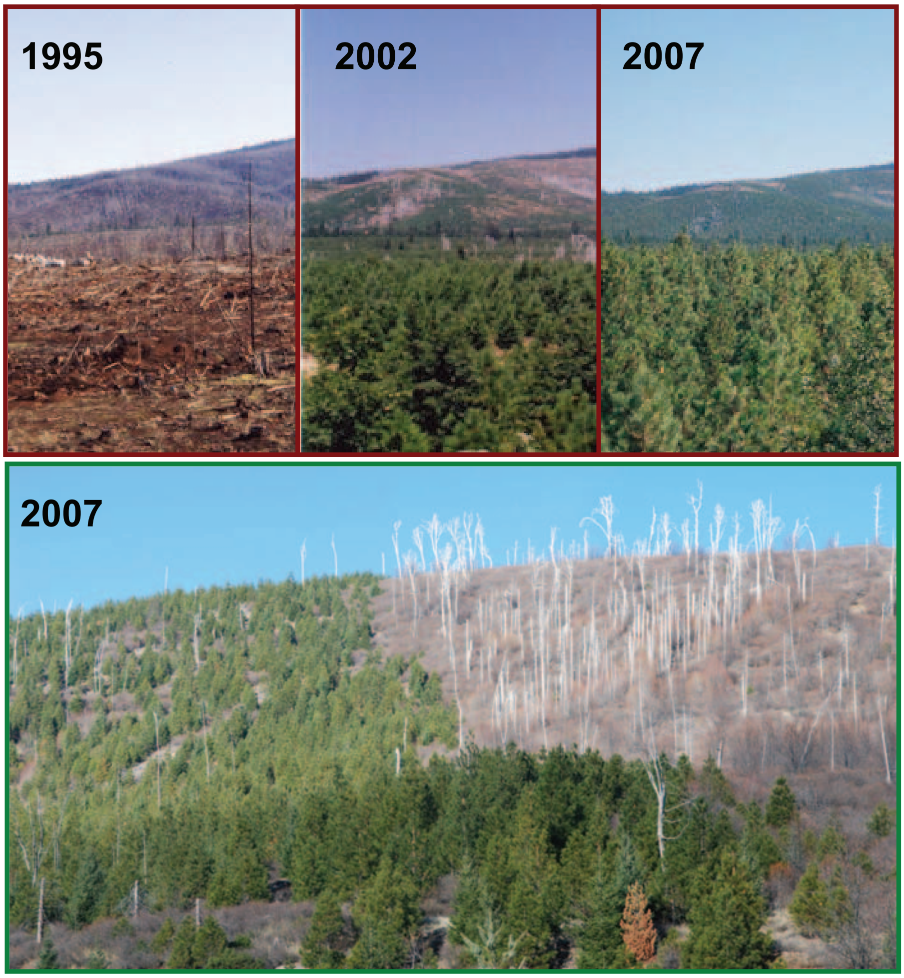

Figure 4. (Upper panels) plantation at the age of 0 years (1995), 7 years (2002), and 12 years (2007). (Photographs taken by Ted Silbersteins.) (Lower panel) A contrast of planted plantation and nonplanted ground on December of 2007. (Photograph taken by Jianwei Zhang.)

Shasta County (Martin et al. 2006). Because no biomass was measured for unplanted shrub fields within the Fountain Fire, we could not compare carbon storage between two contrasting management practices. We know that no conifer trees appear in the areas with no reforestation by 2007 (Figure 4). Even when plantation trees begin to produce seeds around these shrub fields, it will take decades for a conifer forest to emerge provided no recurrent wildfire.

Plant Biodiversity. Herbicides were used to control competing vegetation on the industrial lands, raising questions about native plant diversity. We did not measure this ourselves, but a chronosequence study on this site and two nearby burned sites (the Pondosa Burn of 1977 and the Tamarack Burn of 1986) indicated that initial plant diversity was richer in untreated plots. But diversity quickly fell as aggressive shrubs dominated the sites. Within 8 years, both species richness and diversity were greater in herbicide-treated areas (DiTomaso et al. 1997). Although untreated areas had similar or slightly higher levels of total vegetation cover than the reforested areas, vegetation was dominated with two major native shrubs: *Ceanothus* spp. and *Arctostaphylos patula*. The persistence of native forbs and grasses seem to be caused by early suppression of aggressive, woody shrubs. With increasing amounts of forbs and grasses, wildlife forage was presumably improved. In a long-term study on the Blodgett Forest in the Sierra Nevada, Battles et al. (2001) also found that plantations that had been treated with herbicide were as or more biologically diverse as other regeneration systems. Furthermore, Busse et al. (2001a, 2001b) found no lasting effect of herbicides on soil arthropods or microbiota in California studies on similar sites, and plantations have been found to provide complementary conservation services in the tropics (Barlow et al. 2007).

Future Wood and Local Economy. With an increasing demand for wood and forest products across the world, our forests, natural or planted, are the primary means of meeting that demand. Plantations are more efficient at growing wood than natural forests and are the principal means for meeting shortfalls in global wood demand (Nambiar 1999). In the Fountain Fire, only the active reforestation scenario will provide harvestable yields within about 30 years. We speculate that the passive approach will take decades, if not centuries, for the forest to emerge if no wildfire occurs again, which is very unlikely. Managed plantations are less susceptible to wildfire than unmanaged forests (Powers et al. 2004). At the age of 50 years, average stands will carry about 5,390 ft^3 of timber per acre. By assuming that 40,000 ac was planted, these plantations would produce about 1 bbf of lumber using Roseburg's conversion factor (1 bf = 0.21 ft^3). If an average single family house is still about 1,600 ft^2 in the United States and uses about 14,800 bf as it did from 1980 to 1992 (McKeever and Phelps 1994), the entire regenerated area can provide enough lumber at the age of 50 years to build about 69,000 single family homes. In addition, these plantations will not only support much local employment but also will provide other ecosystem services such as water and wildlife values for years to come.

Conclusions

As an ecosystem component, wildland fires will continue to burn in the forest and rangelands. The current fuel treatments and other silvicultural practices, which may change the fire behavior, are limited to small portions of forestlands. Therefore, forest managers will continue to face the dilemma of wildfire loss and postfire land management. The case that we presented here is one of the possibilities if the landowners choose to use active reforestation. It restores forests faster, sequesters and stores more carbon in forest trees, provides more forest products than passively managed postfire forests, and does so without sacrificing plant diversity. Although the planted postfire forest may lack the structural legacies of the passively managed forest, we may help the system to withstand the next natural wildfire.

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