

Fire Effects Monitoring of the 1992 Rainbow Fire, Devils Postpile National Monument: Vegetation Response Ten Years Postfire

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Introduction

Prior to the mid-1800's, fire ignited by lightning, Native Americans, and on rare occasions volcanic eruptions, had an integral role in shaping the Sierra Nevada ecosystem. The attributes of an area's fire regime (such as frequency, intensity, severity, size) significantly affect plant communities by selecting for species-specific fire adaptive traits, influencing plant dominance, diversity, and mosaic patterns (i.e. spotty fire spread leading to patchy plant distribution). Fire occurrence patterns and fire severity varied among plant communities and often from drainage to drainage within the same type of vegetation resulting in a complex local mosaic (Bond and Wilgen 1996; Kilgore and Taylor 1979; Skinner and Chang 1996). Prior to EuroAmerican settlement, fires were of predominantly low- and moderate-severity and resulted in patchy tree regeneration (Kilgore 1971, 1973), although uncommon high-severity fires have been documented (Caprio et al. 1994).

Many plant communities in the Sierra Nevada have undergone dramatic changes in composition and structure since about 1860. At that time the influence of Native American populations on Sierran ecosystems was declining and EuroAmericans began heavy grazing of nearly all accessible areas in the mountains (Dilsaver and Tweed 1990). Another more subtle influence on vegetation during this period were background changes in climate from cooler and wetter to warmer and drier (Graumlich 1993; Bradley 1999). As a result, fire's role in the ecosystem changed. Some species increased whereas others have declined. Overall, most forest communities have become denser although some areas of formerly dense shrubland have converted to conifer forest. Given the lag time due to the slow response of long-lived species, changes continue in some vegetation types.

Another result of fire's changing role has been the accumulation of dead material, litter and duff, causing an unprecedented buildup of surface fuels (Agee et al. 1978, van Wagendonk 1985). The burning of these heavy surface fuels may cause severe impacts to flora and fauna. Moreover, "ladder fuels" have increased, the result of increased forest tree densities and are now capable of carrying fire into the crowns of mature trees (Kilgore and Sando 1975; Parsons and DeBenedetti 1979). One of the more immediate consequences of these changes is an increased hazard of wildfires sweeping through mixed conifer forests with severities that were rarely encountered in pre-EuroAmerican times (Kilgore and Sando 1975; Stephens 1995, 1998).

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Description of the Study Area

Lands that were to become Devils Postpile National Monument were originally incorporated as part of Yosemite National Park (beginning in 1890) but were moved to the Inyo National Forest in 1905 when about 130,000 ha of mineral lands were withdrawn from the Yosemite. In 1911 Devils Postpile National Monument (DEPO) was established to protect the “postpile”, polygonal columnar basalt formations, and Rainbow Falls (31 m high) from a proposed dam (Sierra Club 2006; USDI 1982). The monument is small at 322 ha (796 ac), rectangular 0.79 km by 4.09 km, and sits astride the upper portion of the San Joaquin River (**Fig. 1**). Geographically the monument is located on the west slope of the Sierra Nevada but is situated near the eastern escarpment of the range at a low point where the San Joaquin nearly bisects the Sierra crest creating a low spot in the range. Elevations range from about 2182 to 2485 m (7,200 to 8,200 ft). Climate is predominately Mediterranean with wet-cool winters (most moisture falls as snow) and dry-warm summers although occasional summer thunderstorms can bring moisture and lightning to the area. In most portions of the Sierra, moisture from frontal storms is released on the west-side as it is being orographically lifted over the mountains, creating a drier climate and lower plant diversity on the east-side (Andrews 1994; Millar et al. 1998). However, the low elevation of the escarpment in the Devils Postpile N.M./Mammoth area allows moisture to pass further east, resulting in a unique region of wetter weather and richer plant diversity to the east.

Vulcanism has also had a pronounced influence on the landscape and biotic environments within the Devils Postpile N.M./Mammoth Lakes region. High concentrations of ash and tephra in the region’s soil can be attributed to the active Inyo/Mono Craters and Long Valley Caldera complex. The most recent eruptions were about 600 yr BP (Miller 1985). Some stand replacement disturbances and unusual stand age and structures in the neighboring Glass Creek region are thought to be the result of a large eruption (Millar et al. 1998). Recent activity in Long Valley has been limited to episodes of tree mortality, outside the monument area, resulting from release of CO₂ gas (Farrar et al. 1995).

Descriptions or documentation of plant and wildlife communities present in this area before fire exclusion are largely absent with little published information existing on east-side forest ecosystems in general. Current vegetation of Devils Postpile National Monument is described in detail in a recently completed plant inventory (Arnett and Haultain 2004). Flora is relatively rich with some 360 taxa recorded. Plant communities have affinities that mix characteristics of vegetation from both the wetter western and drier eastern slopes of the Sierra. Based on the Yosemite N.P. vegetation map (YOSE 2003 unpublished data) that covers this area, the monument is dominated by mixed-conifer forests, composed primarily of red fir (*Abies magnifica* Andr. Murray var. *magnifica*, ABMA), white fir (*A. concolor* (Gordon & Glend.) Lindley, ABCO) and lodgepole pine (*Pinus contorta* Loudon ssp. *murrayana* (Grev. & Balf.) Critchf., PICO). Jeffrey pine (*P. jeffreyi* Grev and Balf., PIJE) is moderately widespread in patches at lower elevations while on higher north-facing slopes mountain hemlock (*Tsuga mertensiana* (Bong.) Carriere, TSME) and western-white pine (*P. monticola* Douglas, PIMO) can be found. Whitebark pine (*P. Albicaulis* Engelm., PIAB) and western juniper (*Juniperus occidentalis* Hook. var. *australis* (Vasek) A. Holmgren & N. Holmgren, JUOC) are present but uncommon, the latter being restricted to warm dry sites protected from fire. Deciduous tree species include patches of quaking aspen (*Populus tremuloides* Michaux, POTR) and black cottonwood (*P. balsamifera* L. ssp. *trichocarpa* (Torrey & A. Gray) Brayshaw, POBA) in riparian areas. Red fir forests on the east side of the Sierra rarely exist in pure stands, and are usually associated with *Pinus contorta* and *P. jeffreyi* (Chang 1996).

According to the Devils Postpile Natural Resources Management Plan (USDI 1982), wildland fires in the valley are rare (based on written records of fire occurrence starting in 1890). However, preliminary results from a fire history study conducted in the summer of 2004 indicates that fires historically may have burned with moderate frequency (every 10-25 years) over much, but not all, of the monument (Caprio 2004; Caprio and Webster 2006); an exception being the northwest corner that appears to have had longer intervals and is an area where the relatively fire intolerant *Pinus monticola* and *T. mertensiana*, occur. North of the monument, on the drier east slope of the Sierra Nevada, Stephens (2001) reports a FRI of 24.7 and nine years respectively for montane conifer and Jeffery pine forest at two adjacent sites.

In 1992, after six years of drought, considerable tree mortality had occurred in the Mammoth Lakes and Devils Postpile National Monument area. Large stands of timber were dead or dying (6,000 - 8,000 ha). Within days of a warning about extreme fire danger, lightning ignited the Rainbow Fire on August 20, outside the monument in the Inyo National Forest, near Pond Lily Lake, but just three miles south and down canyon of Rainbow Falls (located in the south end of the monument). High winds (60+mph) combined with heavy fuel loads, dense conifer stands, and years of drought resulted in the fire's spreading to 2,430 ha (6,000 ac) within 24 hours (Hofmann and Strumsky 1992, Kessler 1992). Large areas of complete overstory mortality and 3,378 ha were burned by September 8, 1992. Approximately 265 ha of the monument's 322 ha were burned (82%) with varying degrees of severity² (**Fig. 1** and **Fig. 2**).

The Rainbow Fire offered an opportunity to monitor the postfire response of vegetation communities within the monument following a high severity wildfire. Sampling was initiated in October 1992 by the Sequoia and Kings Canyon N.P. fire effects crew (Cox 1998; Keifer 2002).

Methods

Fire Effects data were collected in eight 20-by-50 meter (0.1 hectare) plots (**Fig. 1**) following protocols specified in the National Park Service Fire Monitoring Handbook (USDI 2001) with some modifications unique to Sequoia and Kings Canyon National Parks (SEKI) fire effects monitoring program. Elevations of the plots ranged from 2,207 to 2,412 m (**Table 1**). The plots were distributed according to a stratified, random sample that placed two plots in a high severity burned area, two in moderate, and two in low severity areas (based on fire severity maps created on the Rainbow Fire incident). Because prefire samples do not exist for the burned sites, two unburned comparison plots were located at sites with similar slope and aspect to the burned plots. Slopes ranged from 0 to 22 degrees with varying aspects.

The data collected at each plot include:

- 1) fuel load measurements using Brown's transects (Brown 1974),
- 2) understory herbaceous, shrub, and seedling cover and height using a point-intercept method,
- 3) seedlings densities by species and height class in a subplot (10-by-25 m) within each plot,

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The area of high severity equaled 70.7 ha (classed as 0 to 10% of the original vegetation remaining), moderate 31.9 ha (10 to 50%), low 66.7 ha (50 to 90%), and very low 96.0 ha (90 to 100%) (Yosemite Vegetation Map 2003).

Illustrations of Burn Severity Categories



Unburned - Mixed red fir, lodgepole pine, and white fir.



Low Severity Burn - Mixed white and red fir.



Moderate Severity Burn - Mixed red and white fir with a few lodgepole pine



High Severity Burn - Mixed red and white fir with a few lodgepole pine.

Figure 2. Images of sites representative of the fire severity classes. Severity classes used were: severe with >90% overstory vegetation mortality, moderate with 50 to 90% mortality, and low with <50% mortality.

- 4) shrub densities were estimated using 1-by-50 m belt transects, and
- 5) tree densities and diameters at breast height (DBH), as well as tree damage, were sampled using full plots,
- 6) repeat photo points were established at each plot.

Plots have been sampled five times since the Rainbow Fire; immediately postfire (YR00 - 1992), and again at one-year (YR01 - 1993), at two-years (YR02 - 1994), at five-years (YR05 - 1997), and at 10-years (YR10 - 2002). Further monitoring will take place at ten-year intervals unless the area burns again.

Results and Discussion

Since no prefire data were collected, the two unburned plots were originally established to provide data on prefire conditions. Subsequent evaluation of the 1992 comparison plot locations indicated they may not be wholly comparable due to differences in vegetation composition, elevation, and past disturbance patterns between areas that burned and those that remained unburned. Both unburned plots are located in an area that was largely protected from the fire by natural barriers and is reflected in the species composition of the area (**Fig. 3**). *A. concolor* was nearly absent and both *Pinus monticola* and *T. mertensiana* were present in or in the vicinity of the unburned plots (both only moderately to poorly resistant to fire). The latter were not found in areas (even preburn) where burn plots were established. In 2005 a new unburned “control” plot will be established near park headquarters and should be more representative. A fourth unburned pre-treatment plot will also be established in the headquarters area but this plot will then undergo mechanical fuel reduction and pile burning.

Of the eight postburn plots established, two were located in an area of high severity burn at lower elevations of the monument (**Fig. 1**). The moderate severity plots were highest in elevation and the low severity plots were intermediate. Since somewhat different vegetation types exist at different elevations (Yosemite National Park vegetation map) within the monument, care must be used in interpreting the results. Reconstruction of prefire tree density by species (**Fig. 3**, using records of both live and dead stems) suggests differences in species composition although overall densities were approximately equivalent (700 - 925 tree·ha⁻¹). At the high intensity/lower elevation plots, *P. jeffreyi* was the most abundant tree species. *P. contorta* was abundant in both the high severity/low elevation and low severity/moderate elevation plots, but the two *Abies* species were codominant in the moderate severity/high elevation sites. The low severity plots were located adjacent to a meadow area which could explain the dominance of *P. contorta* as well as the resulting low burn severity. The weather (wind, relative humidity, temperature) combined with different vegetation types most likely resulted in different burn severity patterns.

Surface Cover Values

Comparisons of burned and unburned cover values for litter and duff, bare ground, woody debris, and understory vegetation showed distinct changes over time at burned sites relative to unburned sites (**Fig. 4**). There was a fairly continuous cover of surface fuels in the unburned plots with little understory vegetation. In contrast, burned plots had little surface fuel or understory vegetation immediately following the fire, but these components changed rapidly within a few years. Cover components in unburned plots showed no definite trends over the 10 year period.

Ground surface exposed as bare mineral soil (bare ground) was low in unburned plots (3.6%) but averaged nearly 76.6% in burned plots immediately postfire (YR00 - 1992). In contrast, litter and duff cover was 79.5% and 17.6% respectively. In burned plots these two components changed rapidly the first year following the fire, reversing importance. Bare ground declined to 29.9% and litter and duff together rose to 66.3% by YR01 (1993). Bare ground continued to decline rapidly through YR02 (1994) followed by a slow decline to 10.7% through YR05 (1997), with little change through YR10 (2002). Litter and duff cover peaked one year postfire (YR01) and then slowly declined to 47.0% at YR10 (but see section on fuel loads that indicated fuel weights continued to increase). The high value in YR01 may be a result of the fall of needle and other fine fuels following crown scorch. There was little woody fuel accumulation in burned plots for the first five years postfire (through YR05), but accumulations were noticeable by YR10 (**see also Table 2**). This was probably the result of the standing dead components, such as larger trees and branches, decaying and beginning to fall. These fuels will probably continue to increase over the next decade. Understory vegetation on burned plots increased several fold between YR01 (0.9%) and YR02 (21.0%). Cover continued to increase slightly over the next eight years to 27.9% by YR10. On unburned plots fuels changed little. If the burned and unburned plots are comparable these data show a dramatic increase in understory vegetation (herbaceous and shrubs) following fire in burned areas. Species composition is discussed in detail in the following section on understory vegetation. [This rapid postfire response is obvious on most sites



Figure 5. Characteristic shrub and herbaceous species filling in and dominating areas of overstory mortality. Common shrub species include whitethorn, manzanita, and wild current. Photograph was taken at a location east of plot 7, near monument boundary, and is looking northwest.

during on-site visits.] Many areas that were once dominated by forest are now dominated by shrubs or herbaceous vegetation (**Fig. 5**).

Fuel Load

Postfire fuel accumulation rates were low in burned plots during the first five years postfire when the mean total fuel load increased from $2.4 \text{ kg}\cdot\text{m}^{-2}$ to $3.7 \text{ kg}\cdot\text{m}^{-2}$. However, from five-years to ten-years postburn there was a substantial increase in fuel accumulation. The average fuel load increased to $14.31 \text{ kg}\cdot\text{m}^{-2}$ (**Fig. 6**). The four-fold increase between YR05 and YR10 was primarily in the woody debris and duff categories. Larger wood material, such as dead standing trees, fell and became surface fuel, increasing woody debris loads. Substantial duff accumulation also occurred during this period ($0.7 \text{ kg}\cdot\text{m}^{-2}$ at YR05 to $2.8 \text{ kg}\cdot\text{m}^{-2}$ at YR10). We cannot fully explain the decrease in fuel load five-years postburn in the unburned plots (from 34.6 to $18.2 \text{ kg}\cdot\text{m}^{-2}$). It may be the result of inconsistencies in sampling of 1000 hr and duff fuels.

There was some woody debris and duff remaining postfire although specific pre- and postfire fuel reduction comparisons are not possible without prefire data. Remnant postfire fuel loadings may be explained by immediate postfire tree mortality, as well as incomplete consumption of existing dead and downed woody material. Studies in west side red fir forests generally show woody fuels (1hr and greater fuels) carrying the fire rather than litter and duff (Skinner and Chang 1996). The Rainbow Fire was a wind driven event (Hoffmann and Strumsky 1992). Wind pushed the fire into the canopies as it made its runs but as soon as the wind died, it dropped onto the forest floor where it burned in more “normal” conditions.

Overstory Trees

Prefire pole and overstory tree density and basal area for the burned plots were reconstructed from YR00 postfire sampling of live and dead standing trees killed by the fire (**Fig. 3**). These data were then used to compare compositional differences between burned and unburned plots and pre- and postfire overstory changes in burned plots. Some pole and overstory trees could not be identified to species and are listed as “unknown”. The proportion of these increased with burn severity. Dead *Calocedrus decurrens* (incense cedar) were recorded in one plot the first year postfire although there is no documentation of *C. decurrens* occurring in this portion of the upper San Joaquin drainage (see Arnett and Haultain 2004). We believe these dead trees were mis-identified and have thus redefined them as “unknown”. Tree density in the unburned plots averaged a little over half that of the burned. *P. contorta* and *A. magnifica* dominated unburned plots, but *P. contorta*, *A. magnifica*, and *A. concolor* were common in the burned plots. *P. jeffreyi* was only common in the high severity burned plots. This indicates prefire difference in forest type and reduces the effectiveness of the unburned plots as “controls” for making comparisons among treatments. Prefire overstory tree composition also varied considerably between plots within burn severity categories (unburned, low, moderate, and high severity) although total densities were more comparable among the three sets of burned plots. Species composition was similar in both low and high severity plots. However, more *P. jeffreyi* were found in the higher severity plots. The moderate severity plots had more *A. concolor* and *A. magnifica* and little *P. contorta*.

Postfire decreases in density and changes in species composition were directly related to fire severity in comparison to prefire values (**Fig. 7**). Little change occurred in areas experiencing a low severity

burn either in overall density or species composition. Areas burned with moderate severity underwent large declines in density (87.2%) and changes in species composition with most firs, particularly *A. concolor*, being killed. Even more striking were the changes observed in high severity areas where density declined from 1260 trees·ha⁻¹ to five trees·ha⁻¹ and only a few *P. jeffreyi* survived the fire.

Decreases in density occurred in burned plots but not in the unburned plots from YR00 to YR10 (**Fig. 8**). Postfire changes in density were obvious at low and moderate severity sites between YR00 and YR05. This indicates delayed mortality of pole and overstory trees occurring postfire through YR05. Reductions at low and moderate severity sites were 40% and 73% respectively between YR00 and YR05. Little or no change was observed between YR05 and YR10. The number of surviving trees changed from 285 to 250 trees·ha⁻¹ at low severity sites and no change was observed at moderate severity sites. Most injured trees had apparently died by YR05. No change in density was observed in the high severity sites. Most susceptible trees were probably killed outright by the fire although the sample size was small at only five trees.

Changes in basal area largely mirrored changes in density of pole and overstory trees (**Fig. 9**). The greatest changes in basal area occurred in high severity plots (90.6% reduction from YR00 to YR01 with no additional reduction through YR10) relative to reconstructed preburn basal area estimates and smallest in low severity plots (4.5% reduction from YR00 to YR01 but 41.2% by YR05 and 45.5% by YR10). Changes in basal area were not quite as dramatic as density changes (**Fig. 7 and 8**) in moderate and high severity sites because surviving trees tended to be large. Depending on severity, changes in basal area by species as well as changes with time as delayed mortality were also observed. The most dramatic changes occurred between YR00 and YR05 with little change between YR05 and YR10. At the low severity plots little change in basal area by species was observed in YR00 relative to prefire estimates but noticeable reductions in *P. contorta* and *P. jeffreyi* occurred by YR05. Between YR05 and YR10 a small amount of additional *P. contorta* mortality occurred in the trees that remained in low severity areas. Immediate postfire decreases in basal area and density were obvious in moderate severity plots (all trees were killed in plot 2) with mortality of both *Abies* species. Delayed mortality resulted in all *P. contorta* and *A. magnifica* dying by YR05. In the high severity plots, all species except *P. jeffreyi* were killed immediately by the fire (*P. jeffreyi* only survived in plot 8). Little delayed mortality was observed among the few surviving trees.

Size-class distributions show both species and size-related mortality patterns compared to the reconstructed preburn size-class distributions in these plots (**Fig. 10**). Comparison of the size distributions in the unburned to the prefire burned plots indicates a greater number of trees in the smallest size class (<10 cm DBH). The fire directly effected trees in size classes <50 cm DBH with the greatest impacts on trees <20 cm DBH. Continued mortality occurred through YR05 particularly in the <20 cm DBH size classes. Delayed mortality had the greatest impacts on *P. contorta* and *A. concolor*. Within burned plots, considerable mortality occurred in the <30 cm DBH *P. contorta* between YR01 and YR05 (all *P. contorta* died in moderate severity plots). Between YR05 and YR10 overall mortality declined although ten-years postburn we observed a decrease in the number of individuals within the 50 cm size class. *Pinus contorta* dominated the 10-60 cm size classes while dominance was mixed in the largest size class (>90 cm) where *P. jeffreyi* had a slight dominance. *Pinus jeffreyi* was conspicuously absent in all other size classes.

Seedlings

The success of postfire tree regeneration can vary depending on overstory mortality (high fire intensity or severe drought eliminates the seed source) and density of the surrounding trees, as well as postfire response of the species. Within the burned plots, of the four tree species that are regenerating, fir--especially *A. concolor*--had the greatest pulse of postfire establishment (**Fig. 11**). Both fir species were regenerating well and were the dominant seedling species 10-years postburn (some problems were encountered in identifying young fir seedling to species). Seedling regeneration was greatest in low severity areas immediately postburn. On high severity plots, ten-years postfire, some *A. concolor* and *A. magnifica* seedlings appear but *P. jeffreyi* maintained its seedling/sapling dominance. *P. contorta* seedlings within the plots show slow recovery relative to fir but approached nearly 120 individuals·ha⁻¹ by YR05 (**Fig. 11**). They only occurred in areas of low severity fire where some prefire overstory individuals survived and probably provided a local seed source.

The seed source for *P. contorta* appears to have been eliminated in moderate and high severity plots (no live overstory trees remaining). This suggests little cone serotiny in this population of *P. contorta*. Unlike its Rocky Mountain counterpart, the opportunistic *P. contorta* in the Sierra Nevada of California is reported to have non-serotinous cones and to be less dependent on fire for regeneration (Parker 1986). Instead of establishing after large stand replacing fires, Sierra *P. contorta* (var. *murrayana*) often establishes in openings created by wind throw and small fires. Parker also indicates long fire-free intervals for Sierran lodgepole although recent work on fire history in Devils Postpile N.M. and further to the south in the upper Kern River watershed suggests this may not be the case in all locations (Keifer 1991; Caprio in press). Long-term presence of *P. contorta* in an area with a 15-30 year fire-return interval may require that most fires be of low or mixed-severity allowing some overstory trees to survive as seed sources. This may also account for the mixed forest composition that includes *P. jeffreyi* individuals, many exhibiting evidence of multiple fire (catfaces with many lesions), in juxtaposition with *P. contorta* that are intolerant of fire. Fire history data that is being developed from a variety of locations and vegetation assemblages in the monument will help us better understand these patterns and the dynamics of the ecosystem that went into shaping them.

Overall the seedling data suggested good tree regeneration across the sites sampled from low to high severity. However, observations from the monument in 2002 indicated little regeneration was occurring in some areas of high severity. Review of the fire effects plot locations indicated that all high severity plots were located adjacent to areas of moderate-to-low severity where at least some overstory trees had survived. It seems these trees may be providing a seed source for nearby sites. In contrast, at sites more distant from areas with remaining trees, very limited tree regeneration seems to be occurring. Such areas may not have an adequate seed source. Most regeneration from these areas appears to be *P. jeffreyi* that established soon after the fire. This regeneration frequently occurred in the form of small clumps of seedlings or saplings that seemed to have originated from buried seed caches that survived the fire. Little subsequent regeneration appears to be occurring. Loss of this pine regeneration in a subsequent fire would probably limit re-establishment of pine-dominated forest vegetation (or pine codominant with *Abies* spp.). The forest community that would eventually develop (30 to 50+ years) would probably be dominated by shade tolerant *A. concolor* or *A. magnifica* that could establish under a shrub overstory (Tappeiner and McDonald 1996).

To more fully understand regeneration patterns a set of 46 "regeneration plots" were sampled in 2004. These were randomly located in, 1) unburned forest, 2) low-to-moderate severity sites within 100 m of an area of high severity, 3) high severity sites within 100m of an area of low-to-moderate severity, and 4) high severity sites greater than 100 m from a low-to-moderate severity area (or areas where overstory trees remained alive postfire). These data are currently being analyzed.

Understory Vegetation

Prefire most burned sites probably had an open understory with few shrubs or herbaceous species if the two unburned plots are representative (**Fig. 3** and **Table 2**). Ninety-plus percent of the surface was open with most of this covered by litter (73-88%). Little change occurred in understory vegetation of the unburned plots from YR00 to YR10 with total understory cover values ranging from 0 to 7.4%. Little understory vegetation (<1% cover) was observed in the burned plots until YR02 when a dramatic increase was recorded (total understory cover 20.8%). This increase was primarily the result of increases in forb species (18.7% cover) between YR01 and YR02. Total cover continued to increase to 28.2% through YR10. However, forb cover declined over the next eight years to 11.1 % while graminoid and woody understory vegetation (shrubs and seedlings) increased (10.4% and 6.7% respectively).

We observed more herbaceous and shrub species on the burned plots relative to unburned plots (**Tables 2** and **Table 3**). The number of understory herbaceous species increased from two to 36 in burned plots between YR00 and YR10. There was also a sharp increase in the number of forb species (12) in YR02 that followed cover values. In contrast to cover the number of forb species continued to increase through YR10, greatly exceeding the number of graminoids (six species). Number of shrub species also more than doubled between YR05 and YR10 with the appearance of two *Ribes* species (gooseberry) and an additional species of *Chrysothamnus* (rabbitbrush). *Ceanothus cordulatus* (white thorn) exhibited the greatest increase in percent cover of any species during this interval. Cover of western needlegrass (*Acnatherum occidentale*+*Acnatherum* sp.) also increased substantially from 1.46% to 6.90%. Other herbaceous species with appreciable cover in YR10 include *Eriogonum nudum* (buckwheat), *Carex rossii*, and *Gayophytum diffusum*. In contrast, there was an overall decrease in cover of *Gayophytum racemosa* from 8.74% in YR05 to 0.25% in YR10. No patterns of change were observed on the unburned plots.

One "species of concern", *Hulsea brevifolia* (short-leaved alpinegold), that appeared 10-years postfire was encountered during sampling. One exotic, *Cirsium vulgare* (bullthistle), was also noted (one plant in one plot) 10-years postfire. *Bromus tectorum* (cheatgrass) was reported from the Rainbow Falls area but was not observed in any plot.

Photo Points

A set of repeat photos for at least one photo point at each plot are presented in **Appendix 1**. The points selected for view had been photographed during at least four of the five sample trips represented (burn plots) and provided a representative view of each plot and the vegetation changes that have occurred from 1992 through 2002. The photographs vividly illustrate some of the striking changes in vegetation composition and structure that have taken place on the burned plots, particularly in the moderate and high severity burn areas (plots 2, 5, 7, and 8). The loss of overstory and increased cover of herbaceous species is obvious. So is the breakdown of many of the snags (former overstory) between 1997 and

2002 that resulted in the increased coarse woody debris fuels. Some postfire tree regeneration is apparent in some images by 2002 (plots 5 and 7) as well as increases in shrubs (particularly plot 7). Inspection of the photographs also suggested that much of the prefire forest cover in the form of fairly young trees that may have been present as a result of fire exclusion in the later part of the nineteenth century. However, specific tree establishment dates are unknown from any of the plot locations. Two stand-age structure sites were established in 2004 as part of the fire history sampling conducted in the monument and (Caprio 2004, 2005) and should provide some sense of how forest structure changed with fire exclusion.

Summary and Conclusions

In August 1992 the Rainbow fire burned 82% of the monument. Most of the fire burned at moderate to high severity and dramatically affected forest vegetation. A century of fire exclusion had resulted in increased surface fuel loads and greater forest density, with many young trees creating greater surface-to-crown fuel continuity. This led to a fire in which the magnitude and extent of moderate and high severity fire effects were much greater than would have been expected under pre-EuroAmerican settlement conditions.

Immediately postfire, fire effects plots were established in burned and unburned sites. Burn sites represented low, moderate and high severity. Although the lack of prefire data and a small sample size make the drawing of firm conclusions difficult, these data do provide a baseline for monitoring long-term postfire recover of vegetation. The results from these monitoring plots indicate that fuels (duff and dead and down woody debris) increased substantially from 5 years to 10 years postfire. Trees are regenerating, especially in low severity burn areas (but see comments about regeneration away from surviving prefire overstory trees). White fir is the most prevalent species. Understory plant cover and diversity continue to increase 10 years postburn, especially the cover of grass and shrub species. Vegetation regeneration among different burn intensity plots can be quite varied.

In burned plots there was little surface fuel or understory vegetation immediately postfire (YR00). These, however, changed rapidly on the burned plots with no change on the unburned. Litter and duff increased substantially between YR00 and YR01 (18% to 66%), which was probably the result of needle cast from scorched trees. Cover of understory vegetation increased considerably between YR01 and YR02 on burned plots (with no change on unburned) and then more slowly through YR10. Between YR02 and YR10 cover shifted from dominance by forbs to dominance by graminoids and shrubs, although diversity of forbs continued to increase and exceed graminoids and shrubs.

During the first five years (YR00 to YR05) following the fire, total fuels ($\text{kg}\cdot\text{m}^{-2}$) increased slowly then accelerated with a four-fold increase over the next five years (YR10). The accelerated rate of accumulation between YR05 and YR10 was attributed to the falling of dead standing trees killed by the fire, beginning to fall. Total fuel load remained about 40% of the amount recorded in unburned plots. Coarse woody debris will probably continue to accumulate at a significant rate through at least YR20 (the next scheduled sampling in 2012) as remaining standing dead snags fail.

Unburned “comparison” plots and reconstructed species composition based on standing dead snags sampled immediate postfire allowed us to assess changes in overstory tree density and tree species

composition relative to fire severity. Little change occurred in the two low severity sites, but at moderate severity sites there was a substantial decline in tree density, particularly of the two fir species (*A. concolor* and *A. magnifica*). The greatest change occurred on the high severity sites where only a few *P. jeffreyi* survived. *P. contorta* survived only at the sites experiencing a low severity burn. Delayed mortality of trees through YR05 was observed at the low and moderate severity sites. Patterns of changes in basal area mirrored changes in density.

Observations of tree seedlings indicated overall good regeneration within the fire effects plots with some species by severity interactions apparent. Firs tended to be more common at low-to-moderate severity sites while *P. jeffreyi* regeneration was more pronounced at high severity sites. *Pinus contorta* regeneration was only observed at low severity sites, which indicates a lack of a seed source on sites. This also suggests non-sorotiny in the cones of this population. Observations from areas outside the fire effects plots indicate limited regeneration in many of the large high severity patches following the fire. Additional sampling of a suite of "regeneration plots" in 2004 is addressing these observations.

The data indicate that before the fire most sites had little understory vegetation (cover or number of species on shrubs or herbs) and were primarily covered by litter and duff. Following the fire understory vegetation increased dramatically between YR01 and YR02 on the burned plots, with cover, primarily of forbs, exceeding 20%. Cover continued to increase, although slowly, through YR10. Forb cover declined during this interval while the cover of graminoid and woody vegetation increased. Patterns of species numbers generally paralleled cover. However, the composition of forbs continued to diversify during this interval (as did graminoids and shrubs but to a lesser degree) as more species were found on the plots.

Fire management concerns related to the postfire recovery of the Rainbow Burn include the lack of a local seed source in areas burned by moderate and high severity fire in 1992. Of particular concern are areas where large unnatural patches of overstory were killed. In these areas another fire would kill most regenerating trees and severely limit future tree establishment because no local seed source would be present. However, areas where low severity fire occurred in 1992, or that have some seed source remaining, might benefit from a second introduction of fire. A "second entry" management fire would help maintain fuel and forest density at a pre-EuroAmerican settlement level. This is an important consideration for preventing future severe fires and maintaining fire as a process in these forest communities.

Acknowledgments

We thank Peter Rowland and John Austin for comments on versions of this report and Deanna Dulens and DEPO employees for assistance while working in DEPO over the years. Many individuals on the SEKI fire effects field crews assisted in the data collection over the decade.

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Table 1. Database code for fire effects DEPO plots is "FDEPO1T08". UTM coord. Given in table are for Zone 11 and Datum NAD27.

Plot	Severity	Elev. Meters (ft)	Aspect	Slope (%)	UTM E	UTM N
1	low	2,371 (7,823)	E	12	315831	4165799
2	moderate	2,422 (7,888)	E	20	315654	4165434
3	low	2,327 (7,680)	S	0	316234	4165643
4	unburned	2,315 (7,640)	E	0 - 5	315785	4166796
5	moderate	2,417 (7,848)	NE	18	315602	4165515
6	unburned	2,412 (7,961)	NE	4	315334	4166722
7	high	2,207 (7,284)	WNW	~22	315939	4163080
8	high	2,245 (7,407)	E	~14	316204	4164108

Table 2. Percent cover and species count summaries (shaded) by life form for understory vegetation in burned and unburned plots (n=6 and n=2 respectively)

Category/Lifeform	Burned					Unburned				
	YR00	YR01	YR02	YR05	YR10	YR00	YR01	YR02	YR05	YR10
Litter + Bare Grnd. + Woody	99.7	98.9	78.5	77.6	73.3	98.3	100.0	92.3	96.4	97.4
Litter	17.6	64.3	57.9	60.6	48.1	75.3	73.0	74.7	88.7	87.0
Bare Ground	78.1	31.9	17.5	14.4	15.7	4.2	12.3	6.3	0.2	0.3
Woody Fuel	2.7	1.7	1.4	1.4	8.4	15.8	12.2	8.4	4.8	7.8
Understory Vegetation	0.3	0.9	20.8	21.4	28.2	1.5	0.0	7.4	3.6	2.6
# Understory Species	2	1	21	29	36	2	0	9	9	7
Woody Vegetation	0.0	0.0	0.3	1.3	6.7	1.4	0.0	2.7	2.1	1.5
# Woody Species	0	0	4	5	9	1	0	3	4	3
Forb	0.2	0.0	18.7	14.8	11.1	0.0	0.0	4.4	1.5	0.6
# Forb Species	1	0	12	16	21	0	0	5	5	3
Graminoid	0.1	0.9	1.8	5.4	10.4	0.2	0.0	0.3	0.0	0.5
# Graminoid Species	1	1	5	8	6	1	0	1	0	1
Exotics	0.1	0.1	0.4	0.8	1.1	0.0	0.0	0.0	0.0	0.0

Table 3. Percent cover by species on burned and unburned plots (n=6 and n=2 respectively). Species specific data were not collected in YR01. Species highlighted in shading are species of concern (exotic or sensitive).

Category/Species	Burned				Unburned			
	YR00	YR01	YR05	YR10	YR00	YR01	YR05	YR10
<i>Graminoid sp.</i>	0.10	0.86	1.16					
<i>Acnatherum sp.</i>			1.21					
<i>Acnatherum occidentale</i>			0.25	6.90				
<i>Elymus elymoides</i>			0.25	0.55				
<i>Bromus laevipes</i>				0.25				
<i>Elymus glaucus</i> ssp. <i>glaucus</i>				0.10				
<i>Hordeum sp.</i>			0.15					
<i>Carex rossii</i>			2.06	2.20				0.20
<i>Carex geyeri</i>			0.10					
<i>Carex sp.</i>			0.05					
<i>Ceanothus cordulatus</i>			0.45	3.20				
<i>Ribes cereum</i>				0.10				
<i>Ribes roezlii</i>				0.40				
<i>Ribes viscosissimum</i>							0.15	
<i>Ribes sp.</i>							0.15	
<i>Chrysothamnus parryi</i>			0.30	0.25				
<i>Chrysothamnus nauseous</i>				0.10				
<i>Abies magnifica</i>			0.35	0.50	1.21		1.20	0.50
<i>Pinus contorta</i>				0.30			0.60	
<i>Abies concolor</i>			0.10	1.00				
<i>Pinus jeffreyi</i>			0.05	0.70				
perennial forb (D)					0.15			
<i>Arenaria congesta</i>	0.15							
<i>Gayophytum racemosa</i>			8.74	0.25				
<i>Gayophytum diffusum</i>			2.51	4.70				
<i>Gayophytum decipiens</i>				0.80				
<i>Gayophytum eriospermum</i>			0.05					
<i>Gayophytum sp.</i>							0.30	
<i>Phacelia mutabilis</i>			0.30	0.10				
<i>Phacelia hastata</i> ssp. <i>compacta</i>				0.25				
<i>Stephanomeris tenuifolia</i>			0.30	0.45				
<i>Linanthus montanus</i>			0.25					
<i>Linanthus ciliatus</i>			0.05	0.10				
<i>Pteridium aquilinum</i> var. <i>pubescens</i>				0.10				
<i>Eriogonum nudum</i> var. <i>deductum</i>				3.10				
<i>Eriogonum nudum</i> var. <i>nudum</i>				0.15			1.20	0.20
<i>Eriogonum nudum</i>			1.81	0.10				
<i>Arabis platysperma</i>			0.20				0.20	0.20
<i>Arabis sp.</i>							0.15	
<i>Chaenactis douglasii</i>			0.15	0.10				
<i>Eriodictyon californicum</i>			0.15					
<i>Antennaria corymbosa</i>			0.05					
<i>Antennaria rosea</i>				0.05				
<i>Apocynum sp.</i>			0.05					
<i>Lupinus fulcratus</i>			0.05					
<i>Monardella odoratissima</i>				0.05				
<i>Hulsea brevifolia</i>				0.05				
<i>Hieraceum alibiflorum</i>				0.10				
<i>Hieracium horridum</i>							0.15	
<i>Galium bifolium</i>				0.80				
<i>Pedicularis semibarbata</i>							0.15	
<i>Streptanthus tortuosus</i>			0.05					
<i>Cirsium vulgare</i> **exotic**				0.05				
<i>Kellogia galloides</i>				0.05				
unknown		0.05	0.70	0.05	0.15			

Figures

Figure 1. Map of Devils Postpile National Monument and vicinity showing the eight plot locations. Also shown in the Rainbow Fire perimeter (south of thick black boundary line) and fire severity based on the 2003 Yosemite National Park vegetation map that included the monument. Red is high severity (>90% vegetation mortality), orange is moderate (50 to 90% mortality), yellow-green is low (10 to 50% mortality), and light green is very low severity (<10% mortality). The two low classes were grouped into "low" for this report.

Figure 3. Prefire live overstory tree density by species for unburned plots (n=2) and burned plots (n=6) with the latter estimated from living and dead trees present on the plots immediately postfire (YR00). Error bars are ± 1 SE of the total by severity.

Figure 4. Change in percent cover by the major understory components (litter, bare ground, woody debris, understory vegetation) from 1992 (YR00) to 2002 (YR10) in burned and unburned plots.

Figure 6. Fuel load (kg/m²) in burned (n=6) and unburned (n=2) plots broken into woody, duff, and litter fuels. Error bars are ± 1 SE of the total by year.

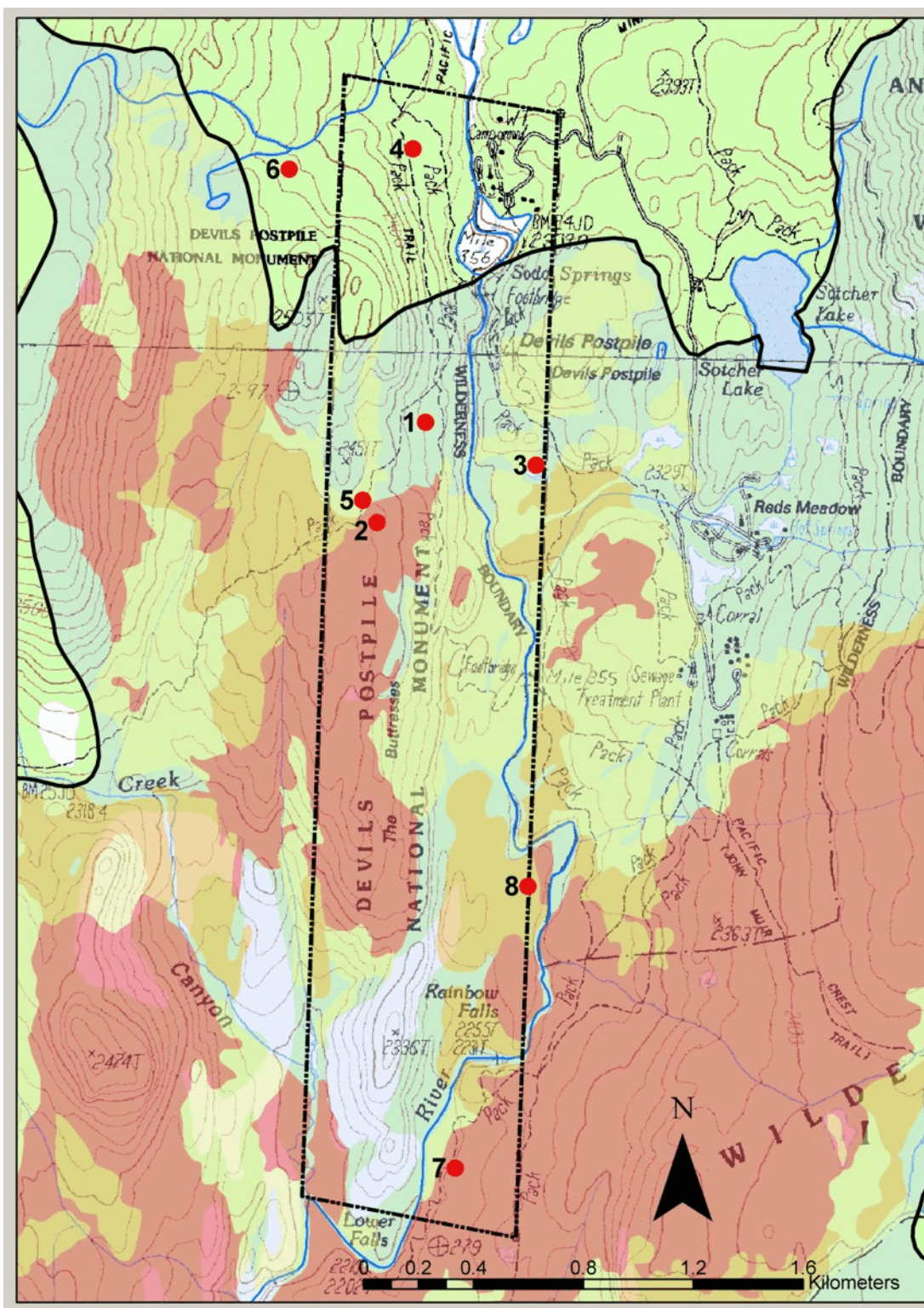
Figure 7. Comparison of pre- and postburn tree density by species on burned (n=6) and unburned plots (n=2) in 1992 (YR01). Reconstructed preburn overstory tree densities were determined by combining postburn live and dead in YR01. Error bars are ± 1 SE of the total by severity.

Figure 8. Pole and overstory tree density in unburned (n=2) and burned plots (n=6) by burn severity in 1992 (YR01), 1997 (YR05), and 2002 (YR10). Error bars are ± 1 SE of the total by severity.

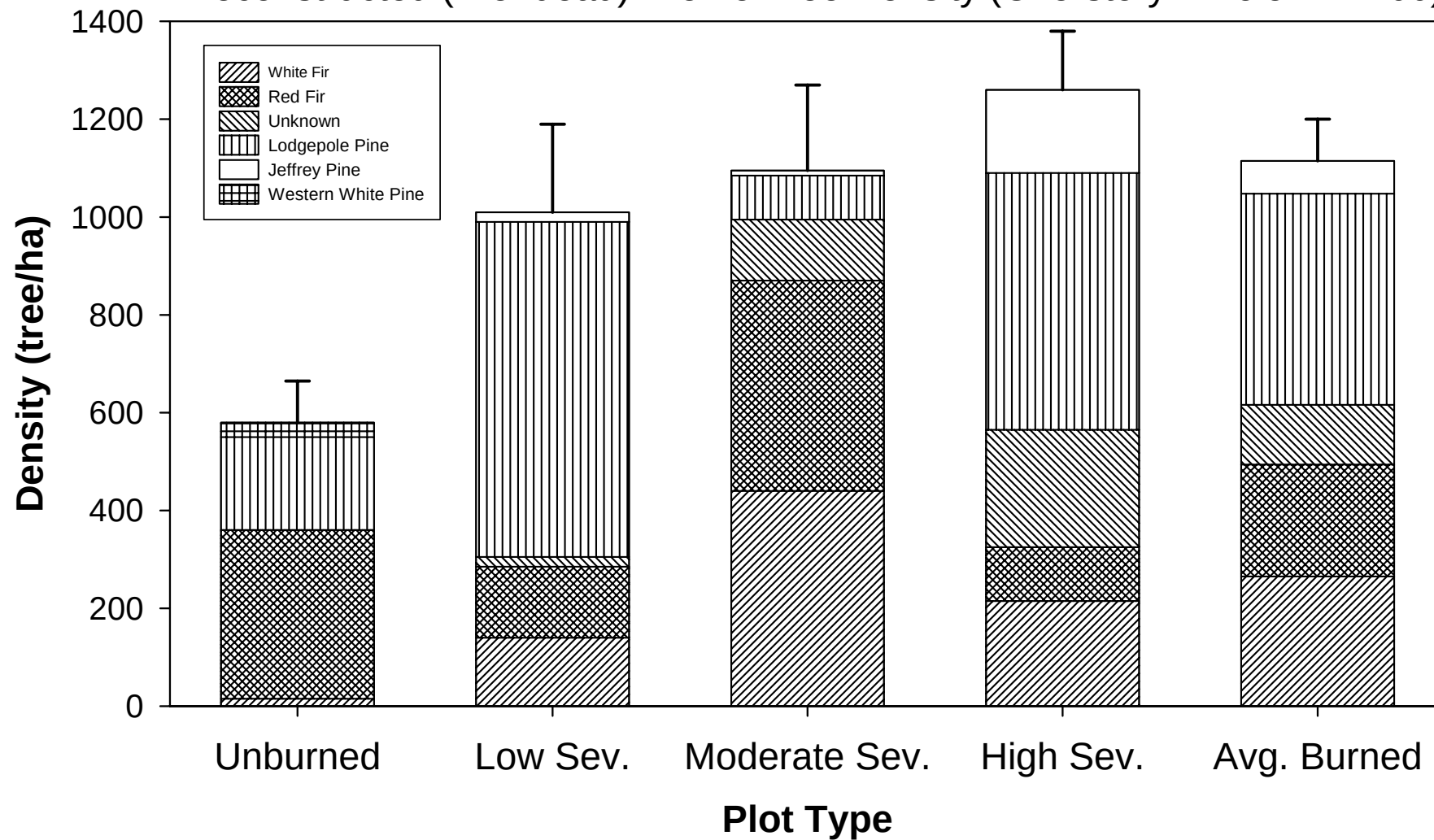
Figure 9. Live basal area (m²/ha) by severity and tree species (pole and overstory) in burned plots (n=6) preburn, 1992 (YR01), 1997 (YR05), and 10 years postburn in 2002 (YR10). Error bars are ± 1 SE of the total by severity.

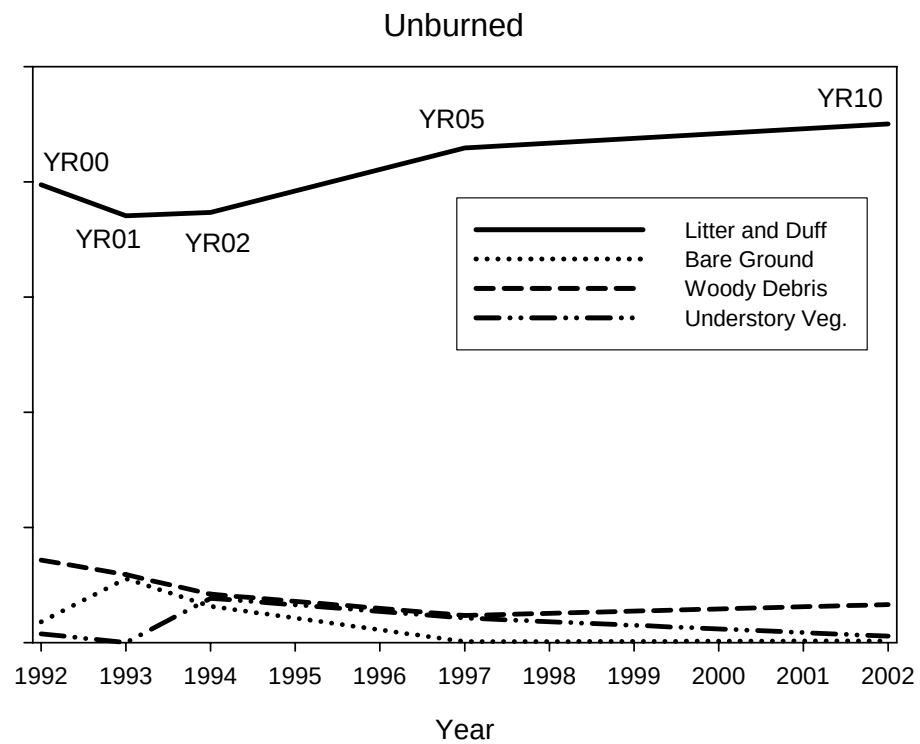
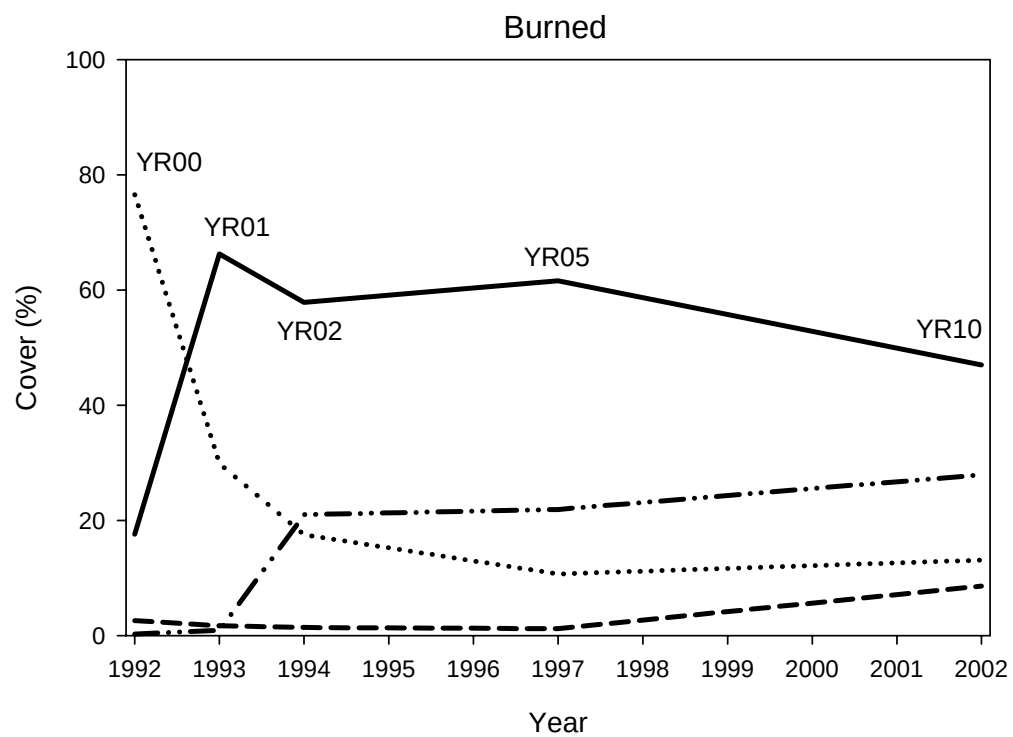
Figure 10. Live overstory trees by species and diameter class in burned plots (n=6), pre- and postfire, and the unburned plots (n=2).

Figure 11. Numbers of seedlings/hectare by species and height class in burned plots (n=6) in 1992 (YR00), 1997 (YR05), and 2002 (YR10) and the unburned plots (n=2).

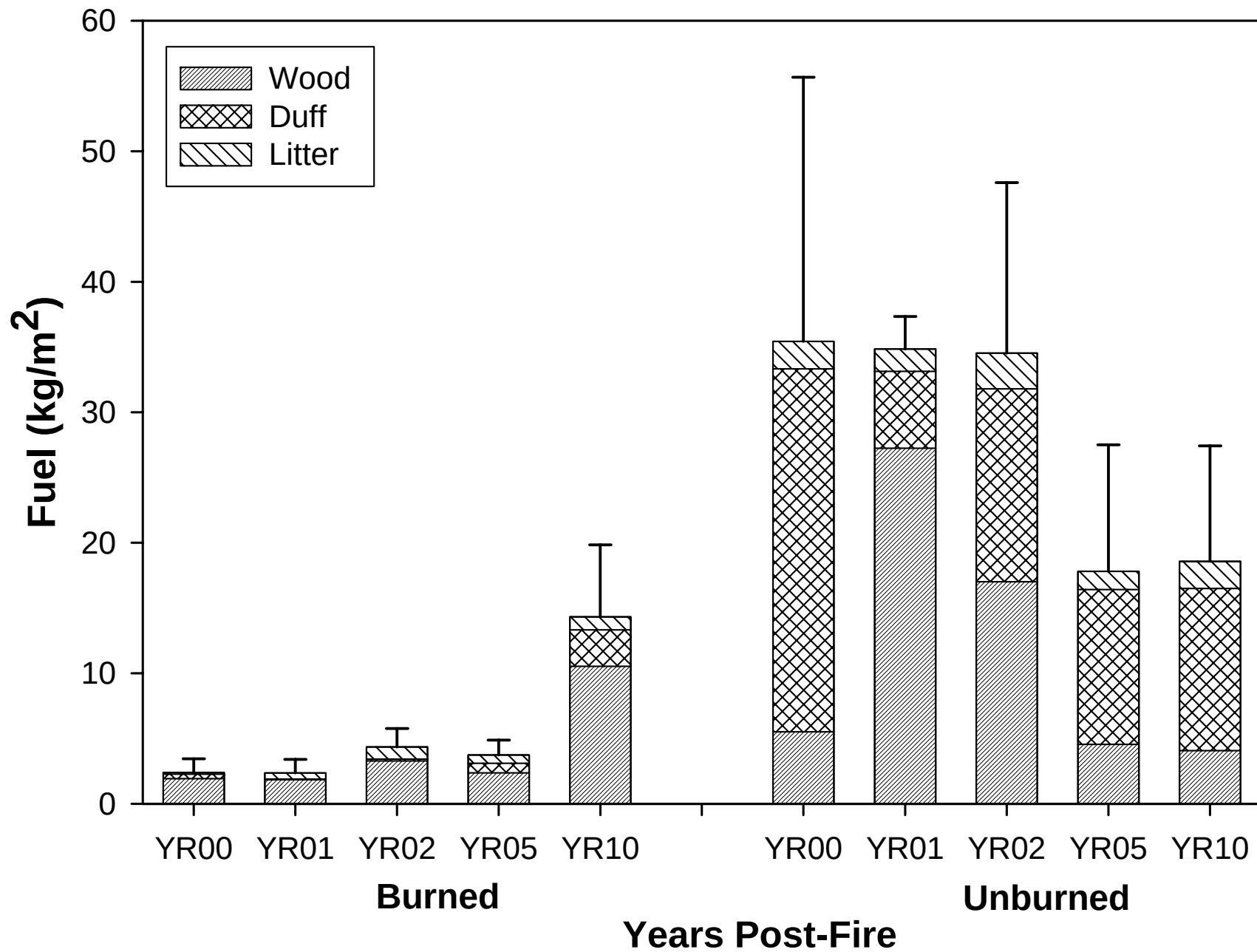


Reconstructed (live+dead) Prefire Tree Density (Overstory + Pole in YR00)

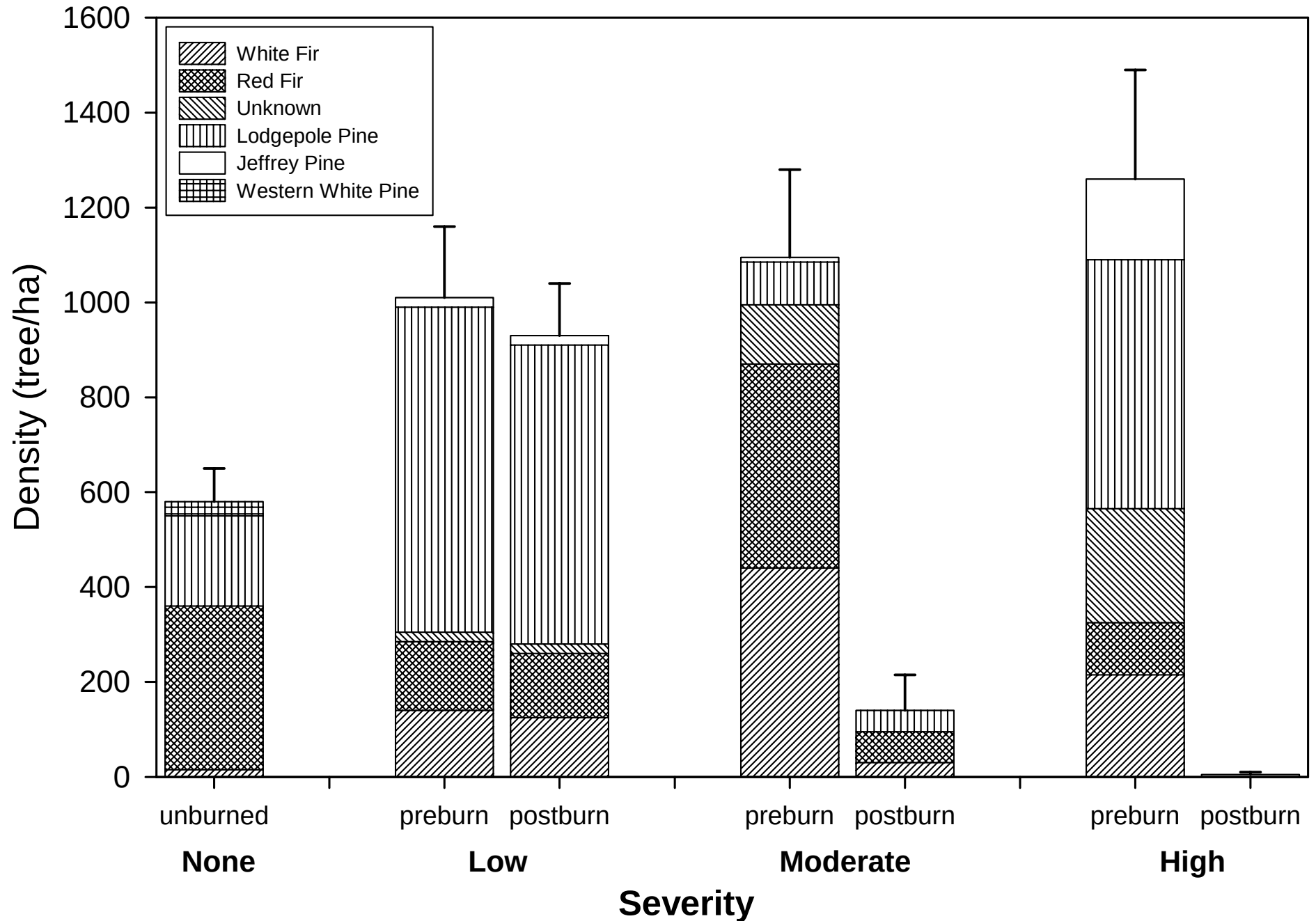




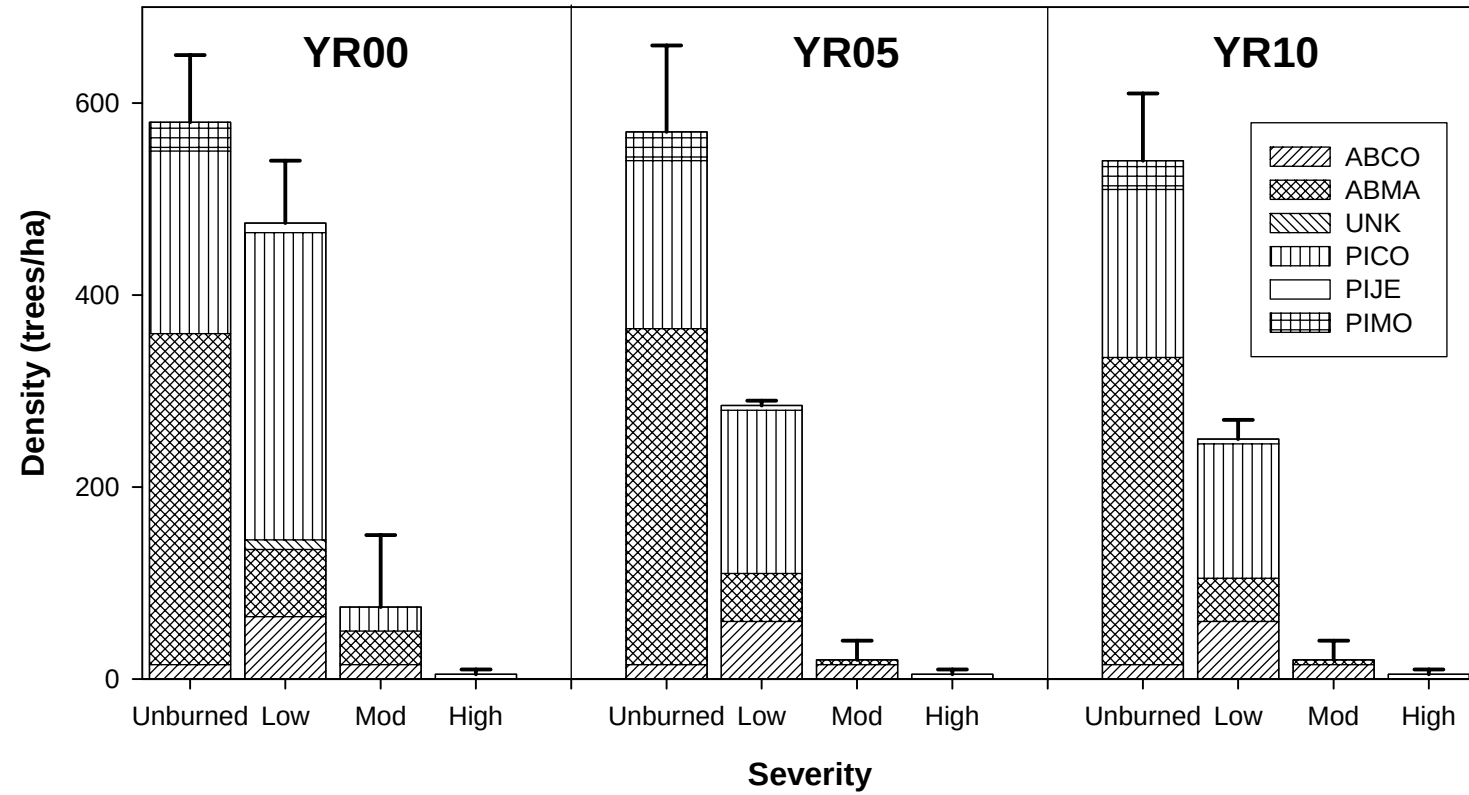
Fuel Loads - Burned and Unburned Plots



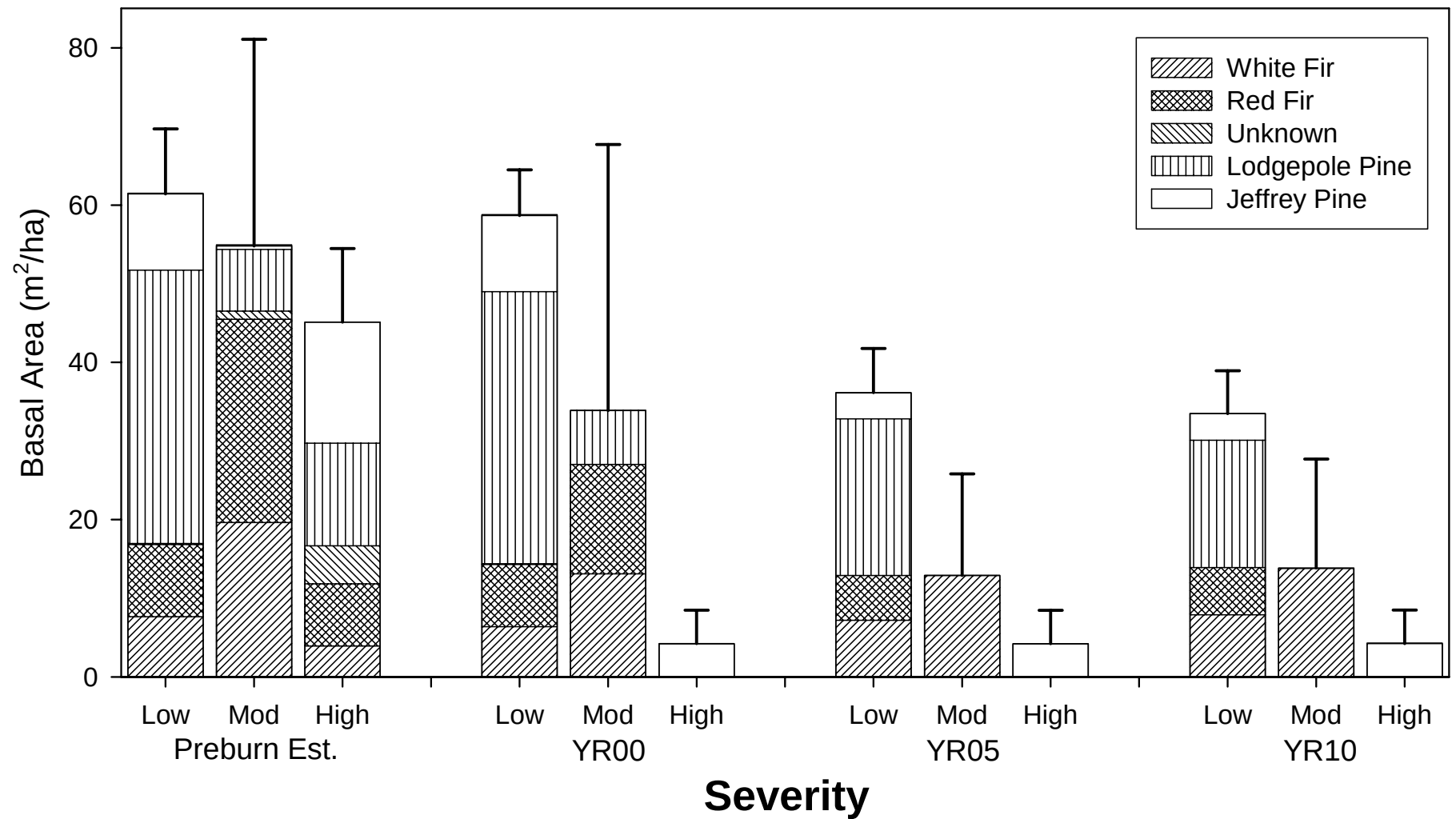
Comparison Pole+Overstory Reconstructed Preburn vs YR00 Postburn



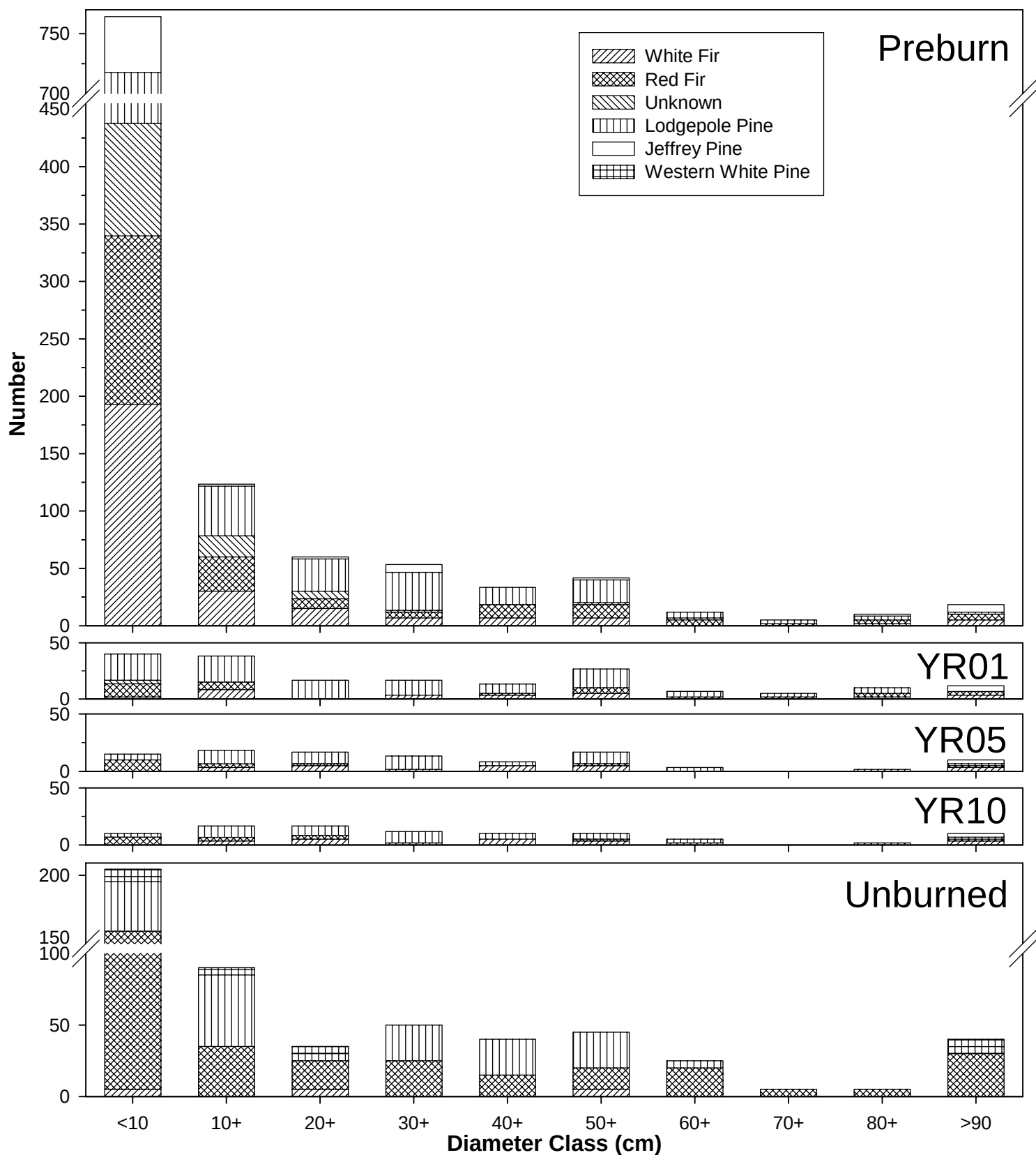
Overstory Tree Density - Delayed Mortality



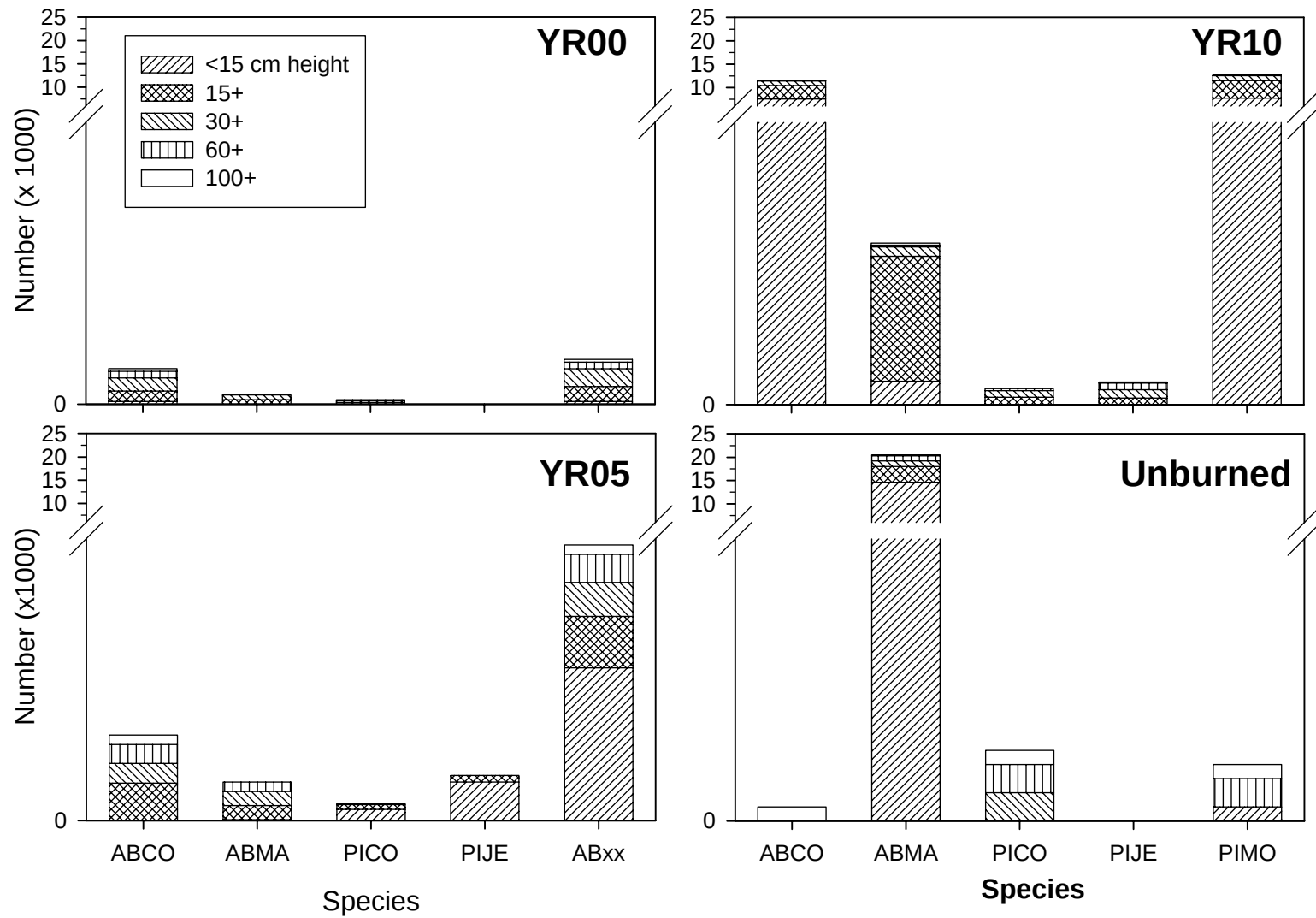
Basal Area Burned Sites



Diameter Size Class Distribution - Burned Plots Combined



Seedling Densities - Burned Plots Combined



Appendix 1

Repeat photos for at least one photo point at each plot (two points are shown for plot 5). At the burn plots (1, 2, 3, 5, 7, and 8) the images selected for view had at least four of the five sample trips represented (sites sampled in 1992 [YR00], 1993 [YR01], 1994 [YR02], 1997 [YR05], and 2002 [YR10]). In 1993 no images were taken at plots 7 and 8. Plots 1 and 3 are low severity, plots 2 and 5 moderate severity, and plots 7 and 8 high severity burn sites. One image taken in 2002 is shown for each of the two unburned plots (4 and 6). Photo points selected provided a representative view of each plot and the vegetation changes that have occurred from 1992 through 2002.



1992



1993



1994



1997



2002

Appendix 1a. Plot 1 classed as low severity (FDEPO1T08-Plot 1 photo point: Q3-Q2).



1992



1993



1994



1997

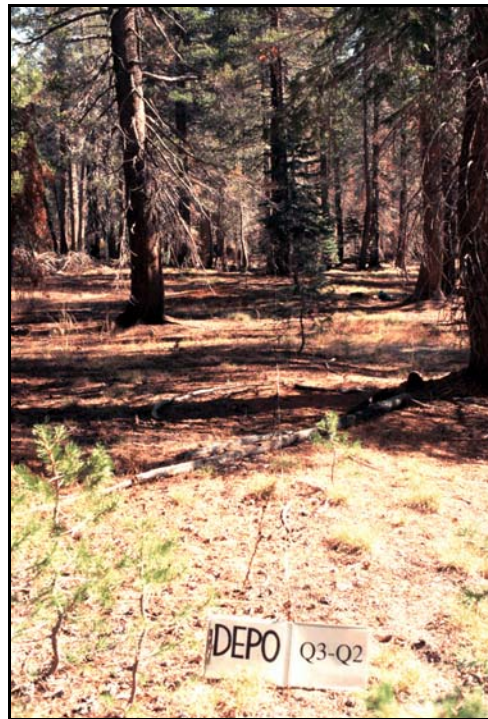


2002

Appendix 1b. Plot 2 classed as moderate severity (FDEPO1T08-Plot 2 photo point: Q4-Q1)



1992



1994



1997



2002

Appendix 1c. Plot 3 classed as low severity (FDEPO1T08-Plot 3 photo point: Q3-Q2).



1992



1993



1994



1997



2002

Appendix 1d. Plot 5 classed as moderate severity (FDEPO1T08-Plot 5 photo point: Q2-Q3)



1992



1993



1994



1997



2002

Appendix 1e. Plot 5 classed as moderate severity (FDEPO1T08-Plot 5 photo point: Q1-Q4)



1992



1993



1994



1997



2002

Appendix 1f. Plot 7 classed as high severity (FDEPO1T08-Plot 7 photo point: Q2-Q3)



1992



1994



1997



2002

Appendix 1g. Plot 8 classed as high severity (FDEPO1T08-Plot 8 photo point: P1).



2002

Appendix 1h. Plot 4 unburned (FDEPO1T08-Plot4 photo point: Repeat).



2002

Appendix 1i. Plot 6 unburned (FDEPO1T08-Plot 6 photo point: Repeat).