MONITORING INITIAL PLANT SUCCESSION FOLLOWING FIRE IN A SUBALPINE SPRUCE-FIR FOREST

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ABSTRACT

The importance of large fire events in shaping the structure and composition of subalpine forests has recently gained a great deal of attention from resource managers. High elevation forests dominated by Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) are widespread in the Rocky Mountains, yet little is known about the ecology of large fires within these forest systems. Postfire monitoring at multiple spatial and temporal scales is important to improve our understanding of postfire dynamics. Therefore, we initiated a long-term study following the Corral-Blackwell Fire in 1994. Our objectives were to determine the effects of fire severity and seed fall on postfire tree recruitment, to develop a set of long-term projections based on initial postfire variability, and to utilize remote sensing to classify broad-scale vegetation and fire patterns of the entire burn. Permanent plots were established in different levels of fire severity (based on duff consumption) and seed fall and seedling establishment were sampled for each species. A potential range of successional vegetation development was projected based on initial postfire variability. A conceptual model was developed to serve as a reference for future monitoring. Prefire species composition, vegetation density, and fire intensity were classified using Landsat Thematic Mapper (TM) satellite imagery and incorporated into a relational GIS database. The first year results indicated that seedling establishment differed significantly among different levels of fire severity and that seed fall was correlated with seedling establishment in burned plots. The successional projections produced a wide range of basal area values for each species, suggesting that postfire succession can be a highly variable process in these forests. The TM imagery was useful for classifying broad-scale vegetation and fire intensity characteristics, but lacked the resolution to detect finer scale ecological patterns such as fire severity. Continued monitoring of vegetation development within the Corral-Blackwell Fire will enhance our understanding of postfire dynamics in spruce-fir forests.

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INTRODUCTION

Subalpine forests dominated by Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) are widespread throughout the Rocky Mountains (Green and Van Hooser 1983). Fire is an infrequent but important stand initiating disturbance in these cool, mesic forests (Peet 1988). Mean fire-return intervals vary between 150 and 400 years but are probably not cyclical (Arno 1980, Crane and Fischer 1986, Peet 1988, Romme and Knight 1981, Turner and Romme 1994). During periods of severe drought, fires have the potential to become very large and erratic and may result in highly variable burn patterns across the landscape (Turner and Romme 1994, Turner et al. 1994, Bessie and Johnson 1995, Nash and Johnson 1996). Although smaller fires are more frequent, it is these large, infrequent weather-driven fire events that burn the most area. Therefore, these infrequent fires are considered to be most important in shaping the overall structure and composition of the landscape (Bessie and Johnson 1995, Turner and Romme 1994, Agee 1993, Johnson and Wowchuk 1992).

Relatively little is known about the ecology of large fires in spruce-fir forests, especially regarding initial postfire environments and broad-scale successional patterns. In addition, long-term data on postfire stand development is generally lacking (Rebertus et al. 1992). This poses a major challenge to resource managers responsible for assessing the consequences of large fires in wilderness and roadless areas managed with prescribed natural fire (Kilgore 1990). Several factors have contributed to this knowledge gap. These include that large fires are infrequent, subalpine forests typically occur in remote and rugged terrain, the complex spatial patterns produced by large fires (Turner et al. 1994) are difficult to study from the ground, and postfire succession in the harsh subalpine environment can be slow and involve multiple successional outcomes (Habeck and Mutch 1973). As a result, postfire monitoring across large landscapes is rarely attempted and fire management plans are nonexistent or vague.

Effective postfire monitoring at multiple spatial and temporal scales is important to accurately assess the effectiveness of fire management plans and to improve our understanding of long-term successional dynamics in spruce-fir forests. Remote sensing and Geographic Information Systems (GIS) are tools that may help to overcome some of the above mentioned barriers and aid in gathering important baseline data for long-term monitoring. Remote sensing provides an efficient and economic method of analyzing and storing spatial data for very large areas. However, the spatial resolution of the satellite sensors imposes limitations on the scale of the ecological patterns examined. Stand-level data, which may be necessary to understand fine-scale successional mechanisms, should be linked with landscape-level data to provide a more complete understanding of spruce-fir dynamics following large fires.

In 1994, a series of large fires burned several thousand hectares of spruce-fir forests in central Idaho. These fires provided a valuable opportunity to study various aspects of initial postfire environments and to initiate long-term monitoring on different spatial scales. One of the goals of this study was to quantify initial seed fall and seedling establishment patterns in different levels of fire severity and to make some long-term projections based on what is known about spruce-fir dynamics. Another goal was to use remote sensing to obtain baseline fire and vegetation data and develop a database for monitoring broad-scale vegetation patterns over time. Our specific objectives were to 1) determine the influence of fire severity and seed fall on initial postfire tree recruitment, 2) develop a set of baseline predictions (quantitative and conceptual) of long-term succession based on initial postfire variability that can be tested over time, and 3) to classify prefire vegetation composition, vegetation density, and fire intensity patterns for the entire burn. The first year results are presented in this paper.

METHODS

Study Area

The Corral-Blackwell Complex Fire was ignited by lightning on August 3, 1994, on the Payette National Forest in central Idaho. The fire burned approximately 83,200 hectares before it was extinguished by precipitation on October 6, 1994, and was relatively unaffected by fire suppression activities. Elevations ranged from approximately 700 meters to 2,735 meters, but more than 85% of the burned area was between 1,800 meters and 2,300 meters in subalpine spruce-fir forests. Lodgepole pine (*Pinus contorta* Doug. Ex Loud. Var *latifolia*) is the most common associate throughout the spruce-fir zone and forms extensive mixed species forests with spruce and fir in the study area (Steele et al. 1981). Soils are generally characterized by moderately- to well-drained sandy loams of granitic origin (Steele et al. 1981).

Fire Severity

Fire severity is referred to here as the downward penetration of heat into the soil and is expressed indirectly by the amount of litter and duff consumed (Schimmel and Granström 1996, Rowe 1983). It is distinguished from fire intensity, which is the heat released upward into the canopy from a flaming front (commonly expressed indirectly as the amount of foliage consumption). Two discrete levels of fire severity were used for this study: 1) high-severity burns are areas where 100% of the litter, duff, and humus were consumed and 2) low-severity burns are areas where the surface litter was burned but the duff and humus layer remained intact.

Plot Selection

Sixteen permanent 30 × 30 meter plots were randomly established in the burn in 1994 and georeferenced using a global positioning system. Four plots were established in high-severity burns, four in low-severity burns, and eight in unburned forests. All burned plots were established where crown fires consumed all above ground foliage. The overstory composition consisted exclusively of Engelmann spruce, subalpine fir, and lodgepole pine (minimum 20% basal area of each species) and each plot was located on similar aspects (250° to 290°), elevations (within 130 meters), and slopes (<30% on midslope positions). Stand composition in burned areas was estimated from standing dead trees.

Seed Fall and Seedling Establishment

Seed fall was sampled by randomly placing eight to ten metal seed traps (1 × 1 meters) covered by a mesh screen in each plot immediately after the fire and recording the number and species of captured seeds in the spring (tests for viability were not conducted). First-year seedling densities were measured at the end of October utilizing a series systematic belt transects so that 100% of each plot was surveyed. Differences in seed fall and seedling establishment between burn severities were tested using the Kruskal Wallis test (Kruskal and Wallis 1952) and a nonparametric Tukey-type multiple comparison described in Zar (1990). A Spearman rank correlation procedure (Spearman 1904) was used to test the correlation between seed fall and first-year seedling establishment and the Student's t-test was used to test whether coefficients were significantly greater than zero (Zar 1990).

Long-term Successional Projections

Initial variability in postfire seedling establishment among plots was used to establish a set of baseline predictions of potential long-term successional variability. The fire succession model FIRESUM (Keane et al. 1989) was used to project the basal area development of each species. The model was calibrated using local stand inventory plots and diameter and growth developed from the study area. The same growth, site, and mortality parameters were used so that differences between stands would represent only the different starting points of the plots.

Conceptual Successional Model

Due to a lack of information on postfire succession in the study area, we developed a conceptual model that could be assessed over time and compared with our quantitative successional projections. The model was based on a review of the literature, field observations of burned and unburned forests in the study area, local stand inventory data, and input from field personnel. Fire severity was selected as the primary determinant of postfire succession because most fires in spruce-fir forests are stand lethal regardless of the overstory intensity (Crane and Fisher 1986) and because of its direct influence on seedling substrates (Schimmel and Granström 1996).

Classification of Postfire Vegetation Characteristics

Landsat Thematic Mapper (TM) satellite imagery was used to classify prefire and initial postfire vegetation characteristics of the burn. TM imagery has a spatial resolution of 30 meters and a spectral resolution of 7 bands (Lillesand and Kiefer 1994). Two TM images encompassing the Corral-Blackwell fire were acquired: a prefire image from September 23, 1993, and a postfire image from October 7, 1994 (one day after the last period of active fire spread). The classification was conducted as part of the Payette National Forest Integrated Resource Inventory Program (see Boudreau and Maus 1996).

An unsupervised classification approach (Jensen 1996) was used to classify fire intensity using the ISODATA clustering routine in ERDAS IMAGINE (v. 8.2) image processing software. Eighty-two spectral clusters were identified and subsequently coded into four intensity classes: 1—high-intensity (complete crown consumption), 2—moderate-intensity (scorched needles remaining on 50–100% of the tree crowns or shrubs), 3—low-intensity (only occasional scorched trees), and 4—unburned (see Wirth et al. 1996 for more detail). A supervised classification approach (Jensen 1996) was used to classify prefire species composition and cover (including density) from the prefire TM image. Spectral characteristics for each class were obtained from more than 200 photo interpreted training polygons randomly distributed throughout the study area. Three subalpine forest composition classes were delineated: 1) lodgepole pine (>90% lodgepole cover), 2) high elevation conifer (Engelmann spruce, subalpine fir, and lodgepole pine), and high elevation conifer with whitebark pine (*Pinus albicaulis* Engelm.). Coniferous forest density was classified into 1) open conifer (0–33% crown closure), 2) medium conifer (34–66% crown closure), and 3) dense conifer (67–100% crown closure).

Classification accuracy was assessed using an error matrix (Jensen 1996) to compare the classified data to reference data collected from the field. Field plots were established using a stratified random sampling approach, with the number of plots in each class ranging from 17 to 65. Two types of accuracy are calculated from the error matrix: 1) producer's accuracy, which is probability that a known class on the ground is classified correctly on the map, and 2) user's accuracy, which is the probability that an area on the map correctly depicts the corresponding area on the ground (Jensen 1996).

Postfire Database

A relational GIS database was created in ARC/INFO v7.1 to link remotely sensed data layers with digital elevation models (DEM) and existing GIS data from the study area (such as daily fire perimeters). A USGS Digital Elevation Model (DEM) was used to stratify burned areas with the same physical and vegetative characteristics of the study plots so field data could be linked and extrapolated spatially.

RESULTS

Seed Fall and Seedling Establishment

First year seedling establishment differed significantly among high-severity, low-severity, and unburned plots for lodgepole pine and subalpine fir, but not Engelmann spruce (alpha = 0.05). Lodgepole pine establishment was highest in the high-severity plots and lowest in unburned plots, whereas subalpine fir establishment was highest in low-severity plots and lowest in the high-severity plots. Lodgepole pine accounted for the majority of first year seed fall in 1994, but differences between burned and unburned plots were not significant (alpha = 0.05). Lodgepole pine is primarily nonserotinous in the study area (Steele et al. 1981, Lotan 1975) and first year seed fall was relatively low compared to some other burned areas (Anderson and Romme 1991, Lotan and Critchfield 1990, Lyon 1976). Few spruce and fir cones were observed in the study area in 1994 indicating that it was probably a poor seed production year for both species.

There appeared to be a positive correlation between seed fall and first year seedling establishment in the burned plots one year after the fire. Correlation coefficients for each species ranged from 0.92 to 0.988 ($P < 0.05$) in the high- and low-severity plots, with the exception of subalpine fir in the high-severity plots (0.19) where seedling establishment was low regardless of seed fall. In contrast, there was little or no correlation between seed fall and seedling establishment in the unburned plots (< 0.312 for all species, $P > 0.05$). These results suggest that seedling establishment may be more closely related to seed availability in burned areas than in unburned areas during the first year. Due to the loss of two plots to salvage logging, complete seed fall estimates were only obtained for three high-severity plots, so these results should be interpreted conservatively.

Simulation of Successional Variability

The basal area projections from first year tree and seedling data revealed a wide range of values for each species (Figure 1). Projected basal area for lodgepole pine ranged from 2 to 15 square meters per hectare at 50 years and from less than 5 to almost 20 square

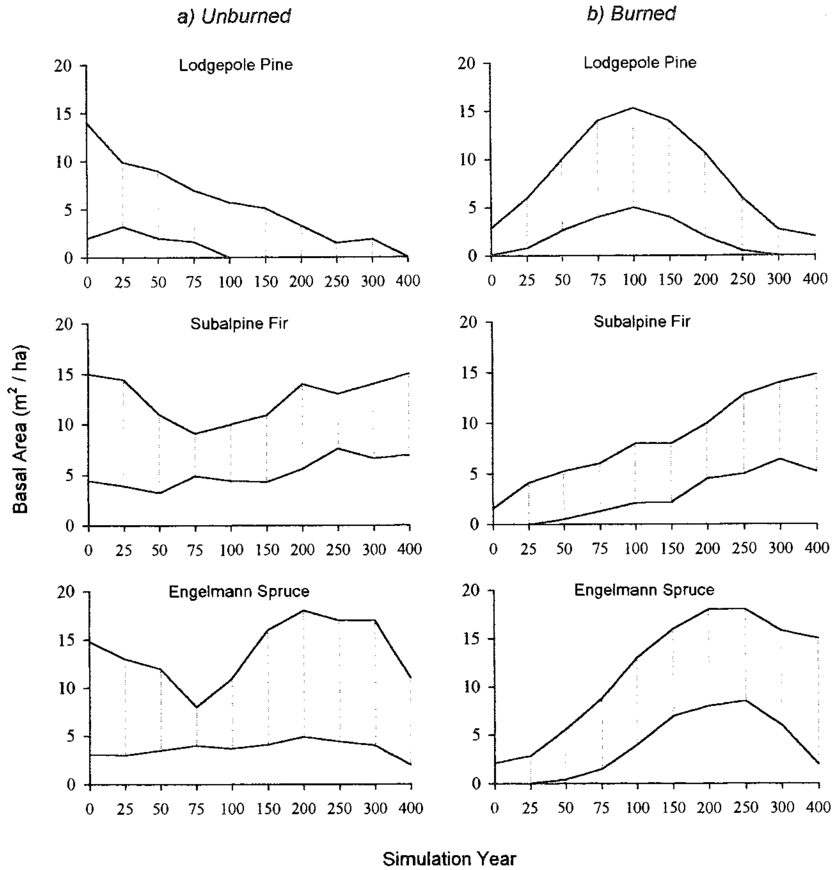

Fig. 1. Projected basal area development of lodgepole pine, Engelmann spruce, and subalpine fir in burned and unburned plots in the Corral-Blackwell Fire. The burned projections represent a composite of both high-severity and low-severity plots (all plots were burned by crown consuming fires). The projections were calculated based on initial postfire recruitment variability after only one year using FIRESUM. Additional projections will be developed and tested over time as more data are collected.

meters per hectare at 100 years. Values for spruce ranged from 2 to 12 square meters per hectare at 100 years and from 4 to 15 square meters per hectare at 200 years. Because all variables except initial seedling density were held constant, differences in projected basal area are assumed to be primarily the result of differences in fire severity.

Conceptual Model

The conceptual successional model presented in Figure 2 is a modification of existing multiple pathway models from subalpine forests in Utah (Schimpf et al. 1980), Colorado (Stahelin 1943), and Wyoming (Anderson 1994). Key elements of the model are that fire severity directs the range of potential postfire successional pathways, each successional pathway can occur on any single site over time, and that successional pathways are not restricted to unidirectional development toward a fir-spruce "climax" in the absence of fire.

Satellite Imagery Analysis

The TM imagery was very useful for mapping broad-scale fire and vegetation patterns. Approximately 26% of the area within the fire perimeter was classified as unburned. Of the burned area, approximately 40% was classified as high-intensity, 30% as moderate-intensity, and 30% as low-intensity. The high-intensity burn class had the highest accuracy, yielding a producer's accuracy of 86% and a user's accuracy of 81%. These are very good results for an unsupervised classification. The low-and moderate-intensity classes were more difficult to differentiate so soon after the fire. The producer's and user's accuracy of the low-intensity and moderate-intensity classes were less than 65%. When the two classes are combined into one moderate/low-intensity class the user's accuracy increases to 77% and the overall accuracy of the fire intensity classification is 70% (Wirth et al. 1996).

The majority of the prefire vegetation was composed of high elevation conifer (48%) and lodgepole pine (32%). An additional 8% consisted of grassland or shrub communities within the subalpine forest zone. Classification accuracy varied widely among vegetation classes but was fairly high overall for the subalpine classes. The lodgepole pine class had a producer's accuracy of 74% and a user's accuracy of 70%. The accuracy of the high elevation conifer class was slightly higher, yielding a producer's and user's accuracy of 80%. This class was widespread in the study area and was clearly distinguished from the lodgepole pine type. Approximately 60% of the prefire forest area was classified as dense, 28% as medium, and 12% as open,

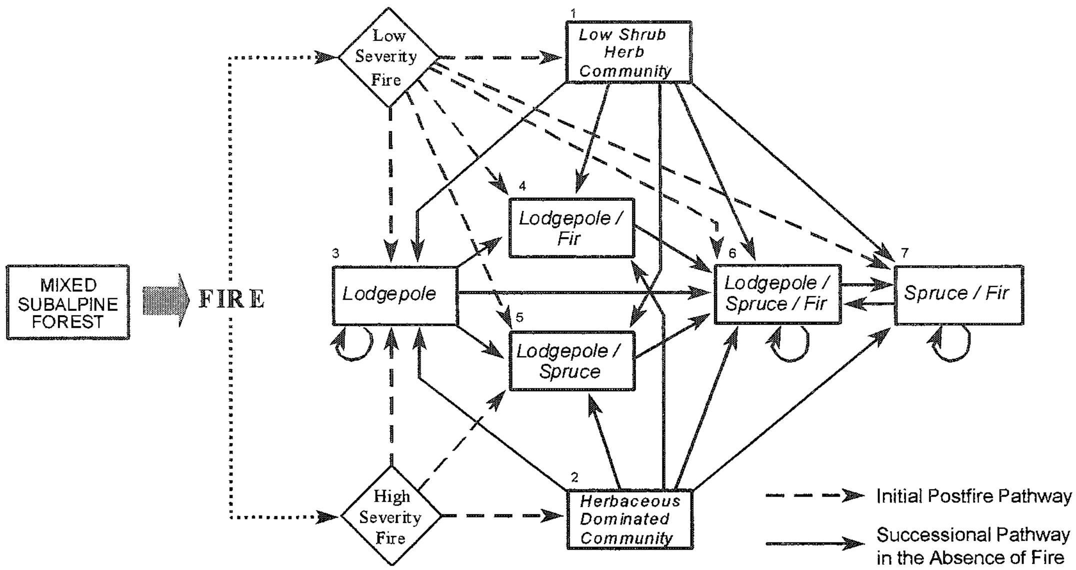

Fig. 2. Conceptual model of postfire successional pathways in Engelmann spruce-subalpine fir forests in central Idaho. The mixed subalpine forest represents any combination of spruce, fir, or lodgepole pine. High-severity fires are areas where 100% of the litter, duff and humus are consumed and low-severity burns are areas where the duff and humus layer were left intact.

although the error matrix indicated that the high density class was slightly overestimated.

Vegetation classes delineated from the satellite image that correspond to successional communities in the conceptual model included low shrub-herbaceous, herbaceous dominated, lodgepole pine, and mixed spruce-fir-lodgepole (high elevation conifer).

DISCUSSION

A number of studies that have characterized postfire succession in spruce-fir forests have stressed the existence of a single, deterministic successional pathway (Stromberg and Patten 1991, Johnson and Fryer 1989, Aplet et al. 1988, Day 1972, Oosting and Reed 1952, Bloomberg 1950), or have attributed postfire variability primarily to differences in site quality and/or topographic position (Hansen 1940, Whipple and Dix 1979, Peet 1981, Romme and Knight 1981, Veblen 1986). Less attention has focused on potential within site variability over time. Although our results are preliminary, we observed a very wide range of variability between plots. The importance of early postfire environments on shaping long-term succession should not be discounted. This notion is consistent with the results of Jull (1992), who found unpredictable patterns of postfire recruitment in young spruce-fir forests in British Columbia, and Anderson and Romme (1991) who suggested that initial variation in seedling establishment may explain large differences in stand structure observed in older forests of similar age in Yellowstone. Based on findings in other regions, it appears that postfire succession in subalpine forests may not always conform to generalized stand models (Huff and Agee 1991) .

Because the seedling comparisons and successional projections are based only on first year data, they are not intended as precise predictions of future communities. Rather, they are meant to provide a framework for interpreting the potential importance of initial postfire variability and to serve as baseline references for future monitoring. Seedling survival can be extremely low in harsh subalpine environments (Alexander 1983, Fiedler et al. 1985), and because of the long period between fires, other disturbances such as wind (Veblen et al. 1989) and insects (Alexander 1987, Baker and Veblen 1990) can be very important in shaping stand development. However, using projections that incorporate different mortality routines can provide insight into potential stand development patterns that would otherwise be difficult to interpret at such an early stage. Additional projections that include variable postfire climate, insect and disease scenarios, and additional successional parameters are currently being developed to address these questions.

Continued monitoring of seed fall and seedling establishment will be important to ultimately determine the role of initial postfire variability and fire severity on long-term stand development. For example, the preliminary seed fall estimates for the second year indicate that seed fall was absent in two burned plots and virtually absent in two others, despite the fact that it was an excellent seed production year for each species in the study area. This suggests that the first year seed came primarily from seed in cones that "survived" the fire, and that these sites may not receive more seed for several years until existing seedlings (assuming they exist) mature to cone bearing age. It is not uncommon for postfire tree regeneration to extend over a period of 70 years or more in harsh subalpine environments, indefinitely prolonging a highly variable period of stand development (Agee and Smith 1984, Habeck and Mutch 1973, Little and Peterson 1993). In some cases, initial colonizers may die long before a second cohort reaches the overstory (Huff and Agee 1991, Johnson and Fryer 1989). We are currently in the process of monitoring other aspects of recruitment such as survival, microsite availability, competition, size and spatial patterns.

The satellite imagery analysis shows that remotely sensed data can be an effective tool to obtain broad-scale vegetation data where current inventories are lacking or are incomplete. This baseline data will serve as an important reference point for future studies. The TM imagery was also very useful for classifying and analyzing the complex landscape mosaics resulting from different levels of fire intensity. The development of a relational GIS database to link digital elevation models and other sources of available data (such as daily burn perimeters or plot data) provides resource managers with a powerful tool to monitor postfire landscape patterns and to address a number of other management issues. We are currently utilizing this data to examine the relationship between prefire and postfire landscape patterns and to determine the relationship of fire intensity to fuels, topography, and weather. The development of this baseline data following such a large fire represents a significant contribution of remote sensing, and would probably not have been acquired otherwise.

The TM imagery lacked the resolution to detect some finer scale patterns observed in the burn, such as fire severity. Overall the variability in fire severity on the ground was too fine grained to be detected with the 30 meter resolution of the TM imagery. More importantly, a far greater area than expected burned with a high fire severity but only low- to moderate-fire intensity, making it impossible to accurately analyze the surface characteristics through the canopy (both live and scorched). An initial assessment of the intensity and severity data from the field plots revealed a poor relationship between fire intensity and severity within the burn, so modeling associations between intensity and severity was not attempted. In addition, we could not accurately classify many of the vegetation classes because they could not be delineated with 30 meter TM data.

The use of more traditional stand based methodologies are probably required to analyze ecological patterns at the level of our proposed conceptual model. However, a scaled down version of the model that is calibrated to the spatial resolution of the classified TM imagery can also be applied (Figure 3). This level of detail can still provide important landscape-level information regarding postfire succession among four major community types: shrub communities, herbaceous communities, pure lodgepole pine, and mixed subalpine forests of lodgepole-spruce-fir. We have stratified the burn by topography and vegetation and linked existing field plots to the database so that these patterns can be monitored over time. Eventually, more components could be added to the model to incorporate differences in fire intensity and topography.

The Corral-Blackwell Fire is an example of a large, infrequent disturbance event that will shape the landscape for centuries. Understanding the initial postfire dynamics of spruce-fir forests following these infrequent but important fire events will help to enhance our understanding of long-term dynamics in this type (Rebertus et al. 1992). Almost all of what is currently known regarding early postfire dynamics has been inferred from stand reconstruction and chronosequences of older stands, rather than projecting forward from known starting points such as we have attempted. Both approaches are limited by many assumptions. However, the data obtained from each method should be complimentary. A combination of these approaches will improve our knowledge of long-term succession.

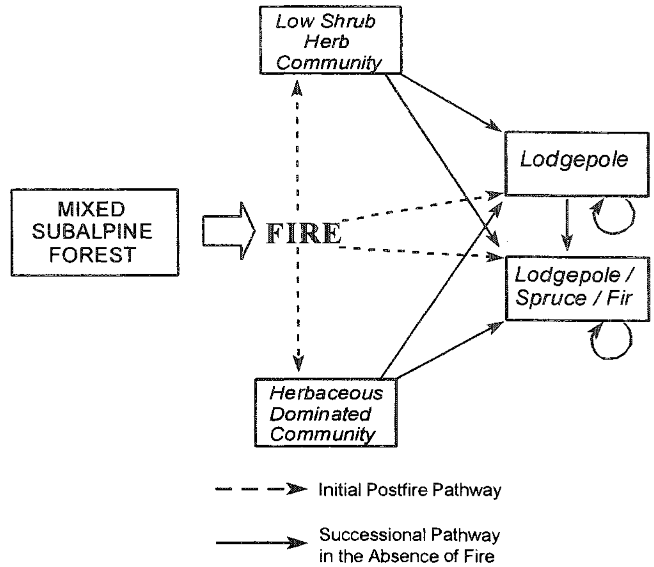

Fig. 3. A conceptual model of postfire successional pathways scaled to correspond with the vegetation classes delineated from Landsat Thematic Mapper imagery in the Corral-Blackwell Fire.

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