Development of Ecological Restoration Experiments in Fire Adapted Forests at Grand Canyon National Park

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Abstract—The management of national park and wilderness areas dominated by forest ecosystems adapted to frequent, low-intensity fires, continues to be a tremendous challenge. Throughout the inland West and particularly in the Southwest, ponderosa pine (*Pinus ponderosa*) and mixed conifer forests have become dense and structurally homogeneous after periods of intense livestock grazing, followed by more than 100 years of fire suppression. Prior to the late 1800s, pine-dominated forests at Grand Canyon National Park were structurally diverse, averaging 45 to 90 trees per acre, with frequent, low-intensity fires burning across the landscape every 7 to 11 years. Today, much of the historic landscape heterogeneity has been replaced by dense, contiguous stands averaging 600 to 900 trees per acre. The beneficial reintroduction of fire to these areas is difficult and often results in fire effects that are uncharacteristic of those produced by historic fire regimes. In response, park managers have called for the exploration of restoration approaches using combinations of prescribed fire and understory thinning. The goal of this approach is to achieve more natural and sustainable forest structures while conserving the most fragile elements of the existing ecosystem such as old-growth trees and native herbaceous communities. This paper describes the approach, rationale and preliminary results of a project designed to examine the utility and ecological effects of three, small-scale restoration experiments on a suite of forest structure attributes.

Ponderosa pine (*Pinus ponderosa*) and mixed conifer forests throughout western North America have undergone striking changes since the cessation of a high-frequency, low-intensity fire regime in the late 1800s (Swetnam and Baisan 1996; Barrett and others 1997; Covington and others 1997a). At Grand Canyon National Park increasingly dense forest structures have enveloped meadows, homogenized landscapes, and now provide a conduit for the development of large-scale, high intensity fires (GRCA 1992; Moore 1994; Nichols and others 1994). Recent attempts to reintroduce fire into these dense forests have been costly to prepare, difficult to control and often produce damaging fire effects, particularly in mixed conifer forests on the North Rim of the Park (Nichols and others 1994). The most notable effect of these high intensity fires is a marked loss of old-growth trees due to excessive crown scorch and pockets of stand replacing fire. These effects are of particular concern since Grand Canyon National Park contains some of the largest remaining tracts of unharvested old-growth forest in the Southwest.

Interagency fire management reviews have called for the exploration of methods to mechanically thin understory trees and remove forest floor fuels before widespread application of prescribed fire (Davis 1981; Nichols and others 1994; Botti and others 1997). In consultation with Park managers, we designed a project to explore alternative approaches to deal with this management problem (Covington and others 1997b). This approach is based on evidence that, for ecosystem restoration to be successful, tree understories must be thinned prior to the application of fire, because underburning is insufficient to thin the dense stands that have developed since fire regime disruption (Sackett and others 1996). Restored tree structures that reflect historic variability as expressed by densities, spatial patterns and species composition should result in more sustainable growing conditions for native plant communities and the habitats they provide (Kaufmann and others 1994).

Fire managers at Grand Canyon are highly proficient and have been proactive in their attempts to return the natural role of fire to the Park's forests. In recent years with the adoption of more flexible fire-use policies, significant acreages (primarily in the ponderosa pine type) are being burned. These management fires do exhibit some benefits such as a measurable decrease in forest floor organic matter and the consumption of ladder fuels. However, due to heavy fuel concentrations, these fires also have the potential to create locally intense fire effects that are likely to be detrimental to native plants and animals (sensu Neary and others 1999). These adverse effects which include old growth tree mortality, pockets of crown fire, and intense soil heating are particularly apparent in the mixed conifer forests on the North Rim and prevail even though prescribed burns are applied conservatively and with great skill (Nichols and

In: Cole, David N.; McCool, Stephen F.; Borrie, William T.; O'Loughlin, Jennifer, comps. 2000. Wilderness science in a time of change conference—Volume 5: Wilderness ecosystems, threats, and management; 1999 May 23–27; Missoula, MT. Proceedings RMRS-P-15-VOL-5. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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others 1994). Attempts to reintroduce fire to the Park's ponderosa pine forests produce fewer adverse effects, but in general, management ignitions in this forest type typically do not adequately thin sapling and pole sized trees, as they have already developed fire-resistant bark (Sackett and others 1996). When fires of sufficient intensity to thin small diameter ponderosa pine trees are prescribed, the result is increased old growth tree mortality and soil heating (Nichols and others 1994; Sackett and others 1996; and Neary and others 1999). In an attempt to surmount these difficult issues, we proposed to test alternative methods that utilize combinations of process restoration (fire) and structure restoration (tree thinning), to restore forest structures that will be more sustainable upon the reintroduction of frequent fires.

The development of any relevant, ecologically sound restoration approach relies upon a solid understanding of the historic range of variability of the ecosystem (Morgan and others 1994; Moore and others 1999). For this project, target conditions were quantified for experimental restoration approaches based upon reconstructions of forest structures and disturbance regimes that existed at the time of fire regime disruption. Reconstructions of forest conditions in the Southwest are quite feasible given a continuous period of fire suppression since the late 1800s, coupled with extremely slow rates of decomposition. This combination of factors has maintained most evidence of the tree structure that existed at the time of fire regime disruption allowing for an accurate reconstruction of tree density, spatial pattern, and species composition (Fulé and others 1997; Huffman and others 1999). It is important to realize that while initial restoration treatments are directed toward a particular point in time, we do not view such a treated condition as a static structure to be maintained in perpetuity. Instead, we view this restored condition as merely a sustainable starting point for the reintroduction of fire that is consistent with historic fire regimes and the forest structures they produced. It will be the effects of future fires burning in the restored fuel matrix that will shape and maintain more natural forest structures and processes.

The development of specific restoration prescriptions has been a lengthy process that was shaped by public comments and feedback from park managers, scientists and environmental groups. In particular, this relates to restoration experiments in mixed conifer forests on the North Rim, which are within areas proposed for wilderness designation. While the overall goals of restoration based management are compatible with wilderness management, there are several short-term effects associated with restoration activities that create temporary conflicts with wilderness values. These may include tree thinning and associated stumps, forest floor fuel manipulation, and the operation of mechanized equipment. The artifacts of restoration activities, such as stumps and slash, are usually erased following several prescribed burning cycles (5–15 years). When compared to the hundreds of years it takes to re-establish old growth tree structures that are lost to high intensity fires, a one to two decade visual effect may prove to be an acceptable alternative. Through consultation with Park managers, we continue to develop and refine approaches that seek to make short-term restoration practices as compatible as possible with wilderness values.

Objectives

The specific objectives of this project are to quantify historic forest structures and fire regimes, and measure current forest structures. Secondly, we will examine the operational utility and effects on forest structure of several restoration treatments using combinations of prescribed fire and understory tree thinning. Since experiments are ongoing, this paper is limited to a discussion of current and reconstructed presettlement conditions, as well as the development of experimental treatments.

Study Area

Grand Canyon National Park is located in north central Arizona, approximately 70 miles north of Flagstaff. Elevations range from 1,650 to 9,165 feet, with vegetation communities that range from desert scrub to subalpine forests. The Park consists of two management units, South Rim and North Rim, bisected by the vast inner canyon carved by the Colorado River. Our project focuses on the forest ecosystems above the rims and includes ponderosa pine - Gambel oak (*Quercus Gambelii*) and mixed conifer forests. Mixed conifer forests at the Grand Canyon contain combinations of ponderosa pine, Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*) and quaking aspen (*Populus tremuloides*). Though none of the Park is designated wilderness, much of the North Rim is proposed wilderness, which requires management actions that will maintain wilderness character.

Methods

In order to measure the treatment effects of restoration experiments, we established small-scale (80-acre) experimental blocks on both rims of the Park. One experimental block was located in the North Rim mixed conifer forest, and two were located within South Rim ponderosa pine—Gambel oak forests. One of the South Rim experimental blocks is located adjacent to the Park boundary on the Tusayan District of the Kaibab National Forest. Each experimental block was divided into four, twenty-acre units that were randomly assigned one of four experimental treatments. Within each unit, we installed twenty, 0.1-acre permanent plots, where we measured tree ages, tree overstory (species, condition, diameter, height, and crown characteristics), seedling structure, evidence of insects and pathogens, forest floor fuel loadings, and herbaceous/shrub community structure. Reconstructions of presettlement forest structure are based on a dendroecological model described in (Covington and Moore 1994; and Fulé and others 1997).

To obtain fire history information, we collected partial cross sections from fire-scarred trees, snags, stumps and logs located throughout the study areas. Samples were surfaced, cross-dated and years were assigned to specific fire events as indicated by fire scarred tree-rings (Stokes and Smiley 1968). Fire event determinations were verified by a second dendroecologist and fire events were then compiled to illustrate the dynamics of the historic fire regime at each study site (Fulé and Heinlein, this volume).

Results and Discussion

Presettlement and Contemporary Forest Structures and Fire Regimes

Prior to fire regime disruption, presettlement ponderosa pine/Gambel oak forests on the South Rim experimental blocks (EB1 and EB2) averaged 45.2 and 48.4 trees per acre with a total basal area of 40.5 to 60.8 ft^2/acre (table 1). There have been no widespread fires on these sites since 1887. However, prior to 1887, fires occurred on average, every 7 to 9 years (Covington and others 1998). Current forest structures have changed substantially, both in terms of tree density and basal area. The same areas now average 580.3 to 897.4 trees per acre with a total basal area of 98.5 to 102.5 ft^2/acre (table 1). Current tree densities are significantly different between experimental blocks and this trend is likely attributable to contrasting land-use histories. For example, EB1, which is located on the Kaibab National Forest, was logged in the early 1900s, continuously grazed by domestic livestock and is a fuelwood harvesting area. In contrast, no logging, fuelwood harvesting or livestock grazing has occurred on EB2.

Forest structures have also changed substantially within the North Rim mixed conifer experimental block (EB3). Prior to fire regime disruption, this site averaged 93.1 trees per acre with a total basal area of 101.1 ft^2/acre (table 1). There have been no widespread fires on this site since 1879. Prior to 1879, fires occurred every 7 to 11 years (Covington and others 1998). Today, the same area contains 571.1 trees per acre with a total basal area of 188.7 ft^2/acre (table 1). In addition to these large density increases, species composition has shifted from a ponderosa pine dominated mixed conifer forest to a white fir dominated forest (table 1).

Experimental Treatments

In light of the ecological trends occurring in Grand Canyon forests, we propose to test the effects of three treatments and a control on a suite of ecological variables, including fire behavior and fire effects on tree structure, herbaceous plant community structure and forest floor fuels. Within the Park, thinning activities will exclusively target trees less than 5 inches dbh, with all cut material remaining on-site. Thinned material on the Kaibab National Forest experimental block (EB1) will be sold to a fuelwood contractor. Hand tools are proposed for thinning the North Rim site (EB3), while chain saws are proposed for thinning the South Rim sites (EB1 and EB2). In addition, fences have been constructed around EB1 to exclude future livestock grazing. Detailed descriptions of experimental treatments are as follows:

Control—No thinning or prescribed fire treatments will take place. Forest structure will be monitored over time to track the continued effects of fire exclusion. Deliberate protection from wildfire or prescribed burning will continue on control sites in perpetuity.

Prescribed Fire—This treatment will test the effects of using prescribed fire without any manipulation of understory trees or forest floor fuels. This approach represents current management practices being applied at Grand Canyon National Park (GRCA Fire Management Plan 1992).

Table 1—Comparison of presettlement and current overstory tree density and basal area. Presettlement forest structures are based on reconstructed conditions at the time of fire regime disruption. Historic fire regimes were disrupted in 1887 on experimental block 1 and 2. The last widespread fire on experimental block 3 occurred in 1879. Data is derived from 80, 0.1-acre plots per experimental block.

	Presettlement forest				Current forest			
Study area/tree species	**Trees per acre**		**Basal area (Ft^2/Ac)**		**Trees per acre**		**Basal area (Ft^2/Ac)**	
	Mean	*(S.E.)*	*Mean*	*(S.E.)*	*Mean*	*(S.E.)*	*Mean*	*(S.E.)*
Experimental Block # 1 Tusayan								
Pinus ponderosa	26.9	4.3	55.1	10.8	738.8	196.5	77.4	9.83
Juniperus osteosperma	4.3	2.2	2.2	1.3	25.1	9.64	4.4	2.4
Pinus edulis	0.1	0.1	0.1	0.1	3.2	1.5	0.2	0.2
Quercus Gambelii	17.1	4.7	3.4	1.6	130.3	34.7	16.5	17.5
Total:	**48.4**	**6.8**	**60.8**	**10.8**	**897.4**	**202.2**	**98.5**	**9.9**
Experimental Block # 2 Grandview								
Pinus ponderosa	25.3	4.6	35.9	8.1	402.6	85.4	84.3	10.9
Juniperus osteosperma	0.6	0.4	0.3	0.2	6.6	2.9	0.6	0.4
Pinus edulis	0.3	0.3	0.1	0.1	2.1	1.3	0.1	0.1
Quercus Gambelii	19	7.7	4.2	2.1	169.1	60.6	17.5	4.6
Total:	**45.2**	**7.9**	**40.5**	**7.8**	**580.4**	**103.4**	**102.5**	**9.6**
Experimental Block # 3 Swamp Ridge								
Pinus ponderosa	50.6	7.2	73.6	10.1	79.8	12.2	89.9	15.2
Abies concolor	19.6	4.5	22.1	6.3	370.1	47.1	67.7	10.1
Populus tremuloides	20.3	7.1	3.4	1.2	63.5	15.8	18.1	6.1
Pseudotsuga menziesii	2.5	1.3	1.9	1.1	55.4	16.2	10.9	3.7
Picea engelmanii	0.1	0.1	0.1	0.1	2.9	1.3	2.1	1.2
Total:	**93.1**	**8.4**	**101.1**	**10.8**	**571.7**	**59.8**	**188.7**	**12.8**

Minimal Thinning—This treatment will involve thinning the minimum number of trees necessary to reintroduce prescribed fires without significant mortality to old-growth trees. The focus of thinning activities is to break up ladder fuels and remove small trees in close proximity to presettlement-era trees. The extent of thinning around targeted old-growth trees will vary, and will be based on existing research results focused on the effects of accumulated fuels and associated fire effects (Ryan and Reinhardt 1988; Ryan and others 1998). Additionally, thick accumulations of duff and litter will be raked from around the base of all presettlement trees to minimize adverse effects from smoldering combustion (Ryan and Frandsen 1991; Swezy and Agee 1991; Sackett and others 1996). Prescribed fire will then be applied to consume existing fuels and to promote additional thinning of fire intolerant postsettlement trees (Thomas and Agee 1986; Mutch and Parsons 1997). Additional prescribed fires are planned in perpetuity, based on reconstructed fire regimes (Covington and others 1998).

Full Restoration Treatment—This treatment will use a diameter-limit understory tree thinning to reconfigure stand structures and spatial patterns to more closely resemble those that existed at the time of fire regime disruption (Covington and others 1997). This alternative focuses on the conservation of presettlement-era trees and the maintenance of specific spatial structures. This will be accomplished through the thinning of small diameter trees (up to 5 inches at dbh), raking of accumulated forest floor fuels around the base of presettlement trees and the reintroduction of repeated frequent, low-intensity fires. Fires will be prescribed following reconstructed intervals and seasonalities.

Discussion

With the exception of several remote areas in the northwest corner of the Park (Fulé and others, this volume), forests throughout the Grand Canyon have become much denser, have heavier fuel loads than in the past and are at tremendous risk for stand-replacing fires. While there is general agreement among ecologists and ecologically-trained managers that restoration strategies must be developed and implemented, the selection of an appropriate management approach remains the subject of much debate (Parsons and others 1984; Bonnicksen and Stone 1985; Stephenson 1999). A process restoration approach that involves the reintroduction of fire and a structure restoration approach that requires tree thinning prior to the application of fire, are the two methods we will explore. The process restoration method, in the form of prescribed natural and manager ignited fires, has been implemented in many national parks and wilderness areas (Parsons and Landres 1998). Ecologically and economically, this approach has been most beneficial in areas that contain large contiguous tracts of forest that have evolved with infrequent, high-intensity stand replacement fire regimes (primarily mesic mixed conifer and subalpine forests). In other areas, such as sequoia groves (*Sequoiadendron giganteum*) in the Sierra Nevada, modern fire suppression has not impacted historic stand structures to the point where the reintroduction of fire is detrimental (Stephenson 1999). Unfortunately, these same approaches have proven to be of limited utility in the lower-elevation ponderosa pine dominated ecosystems found throughout the interior West (Sackett and others 1996). Large increases in stand densities and successional advances by shade-tolerant tree species coupled with steady accumulations of forest floor fuels make the reintroduction of prescribed fire in these areas a very complex, costly and potentially damaging endeavor.

Compared to other ongoing restoration projects in the Southwest (Covington and others 1997a), the experiments being applied within the Park experimental blocks (EB1 and EB2) are more conservative in their approach. The major differences are the extent of structural manipulation prior to the reintroduction of fire and the amount of time it will take to restore presettlement structures. This project proposes to mechanically thin trees smaller than 5 inches dbh and will rely more on the thinning effects of fire to achieve forest structures that resemble target conditions. In both the ponderosa pine and mixed conifer areas, the vast majority of trees occur within the 1-5 inch diameter class (fig. 1), but for several reasons, the effects of this thinning will likely differ. In the South Rim ponderosa pine/Gambel oak forests there will be a substantial number of residual postsettlement ponderosa pines, particularly in the 5-9 inch diameter class, that may be difficult to thin with prescribed fires (Sackett and others 1996). In the North Rim mixed conifer forest, there will also be a sizeable number of residual trees in the 5-9 inch diameter class (fig. 1). However, the majority of these trees are fire-intolerant white fir, Douglas-fir, and Engelmann spruce, all of which are easily killed by low-intensity fires (Thomas and Agee 1986; Ryan and Reinhardt 1988; and Mutch and Parsons 1997). In summary, we expect a more rapid return to presettlement conditions in the North Rim mixed conifer forest and a longer process in the South Rim ponderosa pine/Gambel oak areas.

The application of structure restoration, in combination with prescribed fire, should be viewed as a flexible management tool that can be used in many situations to accomplish a variety of goals. For example, fire managers could initially use operational-scale restoration thinning to accomplish components of their current workload, including the preparation of control-lines for large prescribed burns, securing boundaries with adjoining land owners, reduction of fuels in old-growth areas and the protection of administrative sites. The completion of this preliminary work would provide a monitored, incremental step toward the expansion of structure restoration that would be of immediate utility. Once implemented and refined, managers could further apply the methodology with greater confidence and efficiency.

Regardless of the rationale presented in this paper, restoration through management intervention is controversial and remains a relatively untested concept in national parks. There are critics who argue that a hands-off management approach is entirely appropriate and most closely aligned with Park Service mandates. Even among those who agree that intervention is needed, there are many additional issues surrounding the choice of an appropriate method that must be resolved. This research project is intended to more fully inform debate on these issues by providing information on the effects of both process and structure/process restoration on vegetation structure, fuel loadings, operational utility and social reaction.

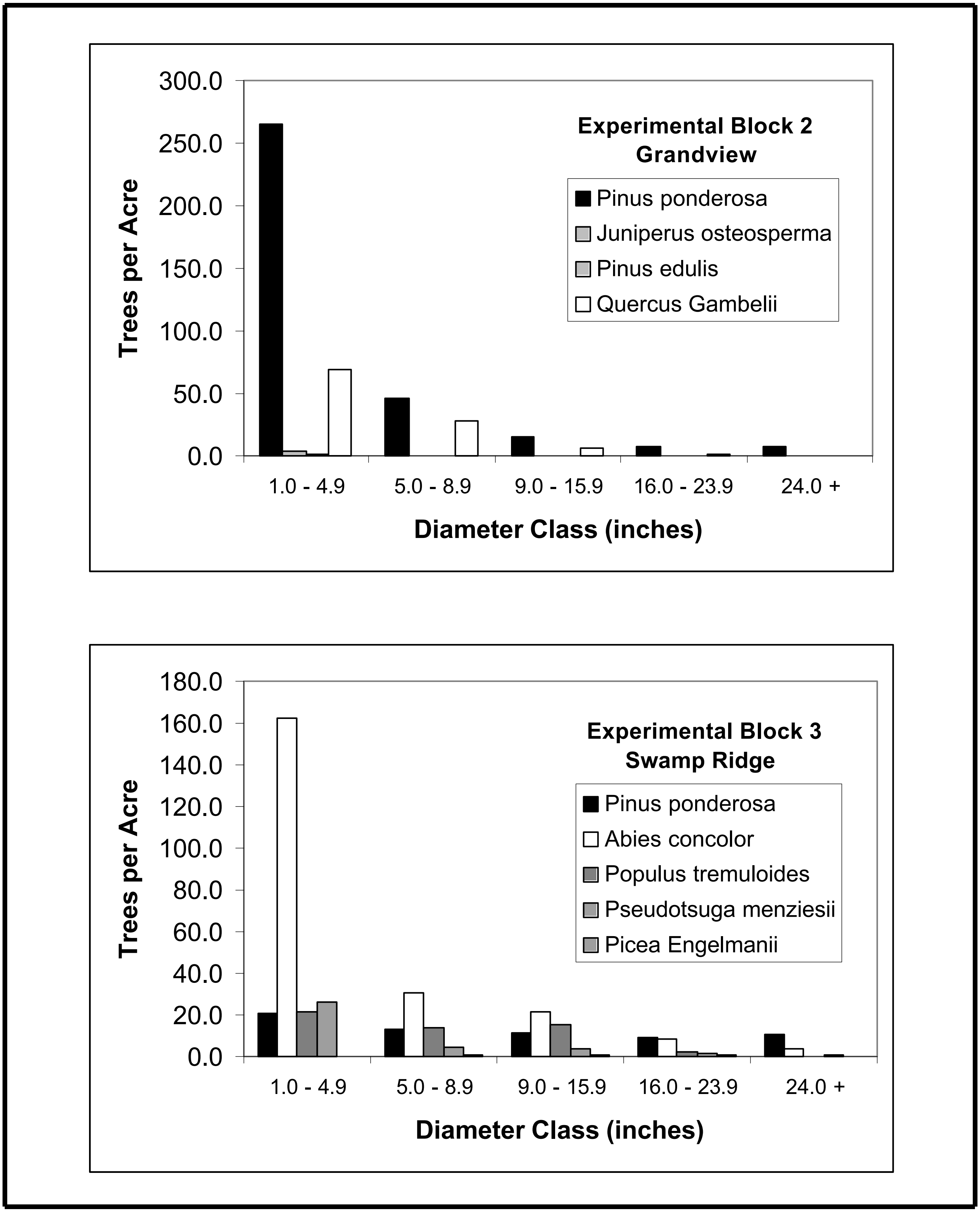

Figure 1—Current diameter distribution of live trees within Grand Canyon National Park experimental blocks. n = 80, 0.1-acre plots per experimental block.

Acknowledgments

We thank Grand Canyon National Park staff assisting with this research, especially R. Winfree, K. Kerr, D. Oltrogge, D. Spotskey, M. Schroeder, J. Schroeder, K. Crumbo, N. Bryan, J. Balsam, R.V. Ward, A. Horn-Wilson, and D. Bertolette. We also thank Kaibab National Forest staff including Renee Thakali, David Mills, and Keith Menasco. Northern Arizona University's Ecological Restoration Program students and staff, especially A.E.M. Waltz and J.P. Roccaforte, supported data collection, analysis and sample preparation. This work was funded by a grant from the U.S. Department of Interior.

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