IMPLEMENTING THE EXPANDED PRESCRIBED FIRE PROGRAM ON THE GILA NATIONAL FOREST, NEW MEXICO: IMPLICATIONS FOR SNAG MANAGEMENT

Paul F. Boucher
Gila National Forest, 3005 Camino del Bosque, Silver City, NM 88061

William M. Block
U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Southwest Forest Science Complex, 2500 Pine Knoll Drive, Flagstaff, AZ 86001

Gary V. Benavidez and L.E. Wiebe
Gila National Forest, 3005 Camino del Bosque, Silver City, NM 88061

ABSTRACT

Efforts to return natural fire to the Gila National Forest, New Mexico, have resulted in controversy regarding management of snags (standing dead trees). The importance of snags for wildlife, especially cavity-dependent birds, is well documented. Although general uses of snags by birds are known (nesting, roosting, perching, and foraging), we know little about the optimal number of snags needed to sustain populations of snag-dependent species. We know less of the types, numbers, sizes, and vigor of snags that would persist under a natural fire regime. Recently, efforts were initiated to understand relationships among snags, birds, and fire in fire-adapted ponderosa pine forests of the southwestern United States. Preliminary results suggest that fire exclusion has resulted in large numbers of old snags (dead ≥6 years), but few recent snags (dead <6 years). In contrast, fewer old snags but more recent snags were found on areas experiencing a recent fire. Understanding snag dynamics under conditions that emulate natural fire regimes is key to understanding the ramifications of management efforts. For example, snags may need to be removed in order to hold a prescribed fire within the maximum manageable area. Although some existing snags are lost, replacement snags are created as a result of the fire. Information that details the range of variation of snag dynamics following natural fire events may help guide key management decisions made during the fire and satisfy ecological and safety concerns.

keywords: fire, ponderosa pine forests, snags, Southwest, wildlife.

Citation: Boucher, P.F., W.M. Block, G.V. Benavidez, and L.E. Wiebe. 2000. Implementing the expanded prescribed fire program on the Gila National Forest, New Mexico: implications for snag management. Pages 104–113 *in* W. Keith Moser and Cynthia F. Moser (eds.). Fire and forest ecology: innovative silviculture and vegetation management. Tall Timbers Fire Ecology Conference Proceedings, No. 21. Tall Timbers Research Station, Tallahassee, FL.

INTRODUCTION

Fire Ecology of Ponderosa Pine Forests in the American Southwest

The historical role of fire, including fire frequencies, within many ponderosa pine (*Pinus* ponderosa) forests of the American Southwest is well documented (Moir and Dieterich 1988, Swetnam 1990, Moody et al. 1992, Covington and Moore 1994). These studies converge on a paradigm emphasizing that fire has maintained an open. parklike forest structure with a characteristic herbaceous understory (but see Shinneman and Baker [1997] for an alternate view). Heavy livestock grazing during the late 1800's. followed by aggressive tire suppression and accelerated logging. altered forests from open parks consisting of single-storied stands with a continuous bunchgrass understory cover to multistoried stands with dense. downed woody material and sparse live ground cover (Covington and Moore 1993).

Prior to the late 1800's. frequent low-intensity surface fires helped to maintain a ponderosa pine and Gambel oak (Quercus gambelii) forest on xerophytic sites. Ponderosa pine, Douglas-fir (Pseudotsuga *menziesii*), and Gambel oak occupied moister sites (Moir et al. 1997). Early records from the 1800's describe these forests as more open, with little downed woody material (White 1985, Covington and Moore 1992, 1994, Johnson 1994, Moir et al. 1997). Ground cover was a continuous grass savanna composed of Arizona fescue (Festuca *arizonica*) and mountain muhly (*Muhlenbergia montana*) on the Mogollon Plateau in Arizona and New Mexico, and screw-leaf muhly (*Muhlenbergia virescens*) on pine-covered mesas within the Gila Wilderness in southwest New Mexico. These grasses become dormant during the dry periods of May and June. The accumulated leaf biomass of several fire-free years provided fine fuels to carry low-intensity ground fires with little damage to the parent plant. These grasses recover quickly with the arrival of moisture from the tropics during the summer monsoon period. The herbaceous component was thought to have been fairly continuous. growing up to and against the trunks of trees (Baisan and Swetnam 1990, Deiterich and Hibbert 1990, Moir 1992, Swetnam et al. 1992, Fulé and Covington 1995, 1996, Barton 1995, Caprio and Zwolinski 1995, Grissino-Mayer et al. 1995, Villanueva-Diaz and McPherson 1995).

Tree ring analysis of burn scars has been used to estimate fire frequencies within the mesophytic and xerophytic stands of ponderosa pine in the Southwest (Swetnam 1990, Moir et al. 1997). It is generally accepted that fire occurred at 2- to 12-year intervals for the xerophytic sites and at up to 15-year intervals for mesophytic sites (Cooper 1961, White 1985, Covington and Moore 1994). Stand-replacement crown fires were considered rare and were typically confined to small thickets when they occurred (Woolsey 1911, Pyne 1996). Because of these frequent fire events, it is believed that the species of plants and animals within this vegetation type have evolved with fire. It is also quite possible that they or their habitats require frequent fires to remain viable. Much remains unknown about the soil microbial community and their interdependence with fire (Carrara and Carroll 1979, Moir and Deiterich 1988, Moody et al. 1992, Baker et al. 1994, Covington and Moore 1994, Boucher and Moody 1996, Ganey et al. 1996).

Snag Management in Southwestern Ponderosa Pine Forests

It was not until the 1970's that biologists and managers recognized the ecological importance of snags for wildlife in western coniferous forests (Thomas et al. 1979). Snags meet numerous life requisites for birds, including nest substrates during the breeding season and roosts during the winter (Marshall 1957, Ffolliott 1983, Hay and Guntert 1983, Sydeman and Guntert 1983, Szaro and Balda 1986). They also provide sites for hawking, feeding, perching, vocalizing, and food storage for many species of birds, mammals, reptiles, amphibians, and invertebrates.

Snags within the ponderosa pine forests of the Southwest became a focal point during the mid-1970's as researchers began to examine this habitat element. Prior to 1975, little information existed on the number of snags required to support healthy populations of cavity-dependent species within southwestern coniferous systems (Balda 1975, Scott 1978, 1979, Szaro and Balda 1979, 1982, 1986, Cunningham et al. 1980, Ffolliott 1983, Hay and Guntert 1983, Szaro et al. 1990, Hall et al. 1997). Although the exact numbers vary among studies, it appears that 4.2–7.9 snags per hectare are needed to sustain populations of most cavity-nesting birds (see Hall et al. [1997] for a review of studies). Numbers of snags needed for other avian needs such as foraging substrates, or numbers of snags needed by other taxa for their life requisites, are largely unknown. Cunningham et al. (1980) suggested that large ponderosa pine snags >43 centimeters diameter at breast height (DBH), with 40% bark cover, and which have been dead 5–29 years provide the best habitat for birds.

Snag management in the Southwest is based largely on studies conducted by Balda (1975), Scott (1978), and Cunningham et al. (1980). Indeed, the most recent amendments to Forest Land Management Plans in the Southwestern Region of the U.S. Department of Agriculture (USDA), Forest Service, include snag guidelines based on the results of these studies (USDA Forest Service 1996). The guidelines suggest that an average of 6.2 snags per hectare (2.5 snags per acre) is needed in ponderosa pine forests to sustain populations of secondary cavity-nesting birds. This guideline is loosely based on Balda's (1975) recommendations, which suggested that 4.2 snags per hectare (1.7 snags per acre) were required for average populations of cavity-dependent birds within the ponderosa pine type, and 7.9 snags per hectare (3.2 snags per acre) were needed to sustain maximum densities of these birds.

The validity of these guidelines has not been systematically and objectively tested. Whether the guidelines provide enough or excessive numbers of snags for wildlife is not really known. The earliest information on snag densities in southwestern coniferous forests was from the Kaibab Plateau (Lang and Stewart 1909) and the Fort Apache Indian Reservation (Gutches 1910) in the White Mountains located in north-central and central Arizona, respectively. Average snag densities from these 2 studies ranged from approximately 0.10 snags per hectare (Kaibab Plateau) to about 0.75 snags per hectare (Fort Apache). Presumably, these densities indicate those existing prior to intensive management (timber harvest, grazing, fire suppression), and they are far lower than existing management targets. Regardless, the Southwestern Region continues to apply guidelines calling for greater numbers of snags.

Interpretations of the guidelines are inconsistent, leading to confusion and controversy. Recent controversy on the Gila National Forest involved the removal of snags as part of efforts to contain a prescribed natural fire within the perimeter of the maximum manageable area. Snags ignite with relative ease, providing burning materials that can be blown across control lines, or the entire tree may fall. They are also a health and safety risk to personnel managing or controlling an incident. Debate centers around questions about historical snag abundance. Further controversy throughout the Southwestern Region surrounds the cutting of residual trees after stand-replacement fires. This type of fire has become more frequent over the past decade (R. Moody, L. Buchanan, R. Melcher, and H. Wistrand, U.S. Department of Agriculture, Forest Service, Southwestern Region, unpublished report, 1992, Swetnam and Baisan 1996, Moir et al. 1997, Boucher and Moody 1998).

Without intending to downplay the ecological importance of snags, we conducted a pilot study to evaluate whether ponderosa pine snags could have occurred in the densities we observe today on a landscape visited by frequent fires. The objectives of this study were to evaluate snag numbers at selected sites both within and outside of the Gila Wilderness. The selected sites would include those that have had a recent fire, those that have had fire exclusion, and those

Table 1. Management and activity status for the 7 study sites where snags were sampled in Arizona and New Mexico in 1997.

	Management activities/status				
Transect	Grazed	Timber harvest	Fire suppression	Research	Wilderness
Gila National Forest					
Gila Wilderness					
Clayton Mesa	Until 1952	No	1 fire: 1994	No	Yes
Turkeyfeather	Until 1952	No	100+ years	No	Yes
Iron Creek Lake	Until 1952	No	1 fire: 1993	No	Yes
Iron Creek Mesa	Until 1952	No	2 fires: 1993, 1980's	No	Yes
Silver City Ranger District, Pinos Altos Mountains					
Meadow Creek	Until 1996	1 entry, early 1900's	Yes	No	No
Aztec Mesa	Until 1996	1 entry, early 1900's	Yes	No	No
Rocky Mountain Research Station					
Fort Valley Experimental Forest					
Gus Pearson	No	No	100+ years	Yes	No

that have been involved with timber products removal. Snag density was also calculated at the Gus Pearson Natural Area in the Coconino National Forest in central Arizona. This site was used during the development of the snag policy for the Southwestern Region of the Forest Service.

STUDY AREAS

We sampled snags within 3 areas supporting ponderosa pine forests in the Southwest: Gila Wilderness, Pinos Altos Mountains, and Gus Pearson Natural Area. These areas represent a range of land use histories from no timber extraction or livestock grazing to historical timber harvest and livestock grazing. They also represent variations in environmental conditions and disturbance histories, although until recently fire suppression was common to all 3 areas (Table 1).

The Gila National Forest, located in southwest New Mexico, contains 1,335,000 hectares, including 356,000 hectares of wilderness. The Gila Wilderness has been managed as such since 1924. Elevation ranges from 1,300–3,300 meters above sea level. Vegetation types include spruce-fir and mixed conifer at high elevation, 2,400–3,300 meters along the Black Range and Mogollon Mountains, with ponderosa pine the primary species near 2,100 meters. A mixed woodland of evergreen oak, pinyon pine (*Pinus* edulis), and juniper (Juniperus spp.) is found below 2,000 meters. The desert grassland subtends the woodland. Precipitation is derived from winter frontal systems and from summer thunderstorms generated by a monsoon flow from the tropics.

The Pinos Altos Mountains are located approximately 20 kilometers north and east of Silver City, New Mexico. The area is separated from the Mogollon Mountains and the Gila Wilderness by the Gila River Canyon. The highest peak is 2,800 meters and supports mixed conifer forest. Vegetation at lower elevations consists of ponderosa pine and Gambel oak. The area was logged during the early 1900's and has also been used for livestock grazing since the creation of the Gila Forest. Like most of the Southwest, fire suppression has been standard procedure for these mountains.

The Gus Pearson Natural Area, within the Coconino National Forest in north-central Arizona, was established in 1909. Situated at 2,300 meters, it contains ponderosa pine and Gambel oak. Temperature and diurnal weather patterns are similar to those for the Gila National Forest with 1 exception: the summer moisture usually comes several weeks later than that for southwest New Mexico.

Within these study areas we estimated snag densities along 7 transects described below. The transect sites were selected because of past events, or the lack thereof, at each site, i.e., fire suppression, livestock grazing, timber harvest. A fixed point was selected on a road or trail for each starting point. Randomness was achieved by spinning a compass dial for the transect direction. The length of the transect was determined after the tally of 40 snags. The width was determined by the snag tallied at the greatest distance to the left and right from the center line at right angles. Only snags visible from the center compass line, at right angles, were counted.

Transect 1

Clayton Mesa is located within the Gila Wilderness, Gila National Forest. The Glenn grazing allotment was closed in 1952, and the mesa has not had livestock grazing since that time. A well-established pine-bunchgrass community exists with screw-leaf muhly (Muhlenbergia virescens) as the dominant species. The mesa consists of a mature ponderosa pine and Gambel oak forest. The pines appear to be uneven-aged but of even size (Biswell 1972, Covington and Moore 1994). This site would be classified as xerophytic ponderosa pine (Moir et al. 1997). The Clayton fire burned the entire mesa during the fall of 1995. This fire was considered a moderate understory burn and was the first fire for this area in 75 years of fire exclusion.

Transect 2

Turkeyfeather Pass, opposite Clayton Mesa, is again within the Gila Wilderness and the Glenn grazing allotment. The forest floor has sparse herbaceous vegetation except where small openings or wet meadows persist. The site would be classified as mixed conifer forest with an overstory of ponderosa pine. The dominant snag species is ponderosa pine. This site would be considered mesophytic ponderosa pine by Moir et al. (1997). The last fire entry is thought to have occurred >100 years ago.

Transect 3

Iron Creek Lake is located at the north end of the Gila Wilderness and is situated below and at the west end of Iron Creek Mesa. This site is ponderosa pine forest adjacent to a small lake, approximately 4 hectares in size. Because of its proximity to water, the pine/bunchgrass community is mixed with hydrophytic sedges, rushes, and forbs not found at dry sites. This site last burned on 19 June 1993 during the Iron/Galita Fire. During this fire, special efforts were made to keep existing snags in this area from burning, e.g., by removal of combustible materials from the ground at the base of the snag.

Transect 4

Iron Creek Mesa is located east of Iron Creek Lake above Snow Lake. The area is within the Gila Wilderness. It is a xerophytic pine site that was last burned in June 1993. The area has also had 4 additional fires since the late 1890's (data on file, Gila National Forest).

Transect 5

Meadow Creek is located in the Silver City Ranger District, Gila National Forest, within the Pinos Altos Mountains. A small tributary canyon adjacent to Meadow Creek was sampled, and this site would be considered a mesophytic ponderosa pine site by Moir et al. (1997). The site has had livestock grazing throughout its postsettlement history. Large pines were harvested at the turn of the last century for commercial use, and aggressive fire suppression has been successful at preventing fires over the past 100 years. The overstory consists of ponderosa pine. Mid-story trees are Douglas-fir and Gambel oak. The forest floor is covered with large downed woody material with sparse vegetative cover.

Transect 6

Aztec Mesa is east of Meadow Creek in the Silver City Ranger District, and is again within the Pinos Altos Mountains. This site would be considered a xerophytic ponderosa pine site by Moir et al. (1997). The history of commercial timber harvest and livestock grazing is the same as that mentioned for Meadow Creek. Heavy downed woody material exists at this site with little vegetative cover on the forest floor. Gambel oak is becoming senescent because of competition for light with conifers. However, all snags recorded in this study were ponderosa pine. Fire suppression has prevented wildfire over the last 100 years at this site.

Transect 7

Gus Pearson Natural Area is located on the Fort Valley Experimental Forest in the Coconino National Forest. The site would be considered a xerophytic ponderosa pine by Moir et al. (1997). Commercial harvest has not occurred through standard timber sales; however, it was noted that selected trees had been cut in the past. Livestock grazing has been excluded, but the dense canopy cover limits herbaceous vegetation. All snags recorded were ponderosa pine. Fire suppression has been the standard for Fort Valley over the last 100 years.

METHODS

Snags were sampled in each area using a line-transect methodology (Anderson et al. 1979, Burnham et al. 1980, Buckland et al. 1993). This method entailed walking along a straight compass line and recording the perpendicular distance from the transect to all snags observed. The starting point and direction of each transect was decided randomly. As this was a pilot effort, we collected the minimum sample of 40 detections recommended by Anderson et al. (1979) for estimating objects using line-transect methods. The total length depended on the distance needed to tally 40 snags and ranged from 440–930 meters. Snags were placed into 3 categories:

1. Type 1 snags. These trees had been dead for <6 years and had small branches and occasional needles remaining.
2. Type 2 snags. These trees had been dead for 6–30 years and had lost most of the twigs and smaller branches.
3. Type 3 snags. These were carbon cores of residual snags that survived the most recent fire or were snags resulting from a single-tree lightning fire during the summer wet period.

We recorded all observed snags >30 centimeters DBH and >3 meters tall.

We used program DISTANCE (Laake et al. 1996) to estimate snag densities. We compared the fit of the distribution of snag detection distances to 3 models—uniform, half-normal, and hazard functions—to determine the best estimator for estimating densities. The model that fit the data best as measured by Akaike's Information Criterion (AIC) was used to estimate snag densities. More detailed information on the models evaluated and use of AIC can be found in Buckland et al. (1993).

We also used an ad hoc method to estimate snag densities to compare with the estimates derived from program DISTANCE. This method entailed calculating the maximum area sampled, which was defined as the product of the transect length and twice the maximum detection distance, and then estimating the density of snags detected within this area. The maximum detection distance was the distance to the snag that was farthest from the transect line. Estimates derived using this method would be biased low given that detection

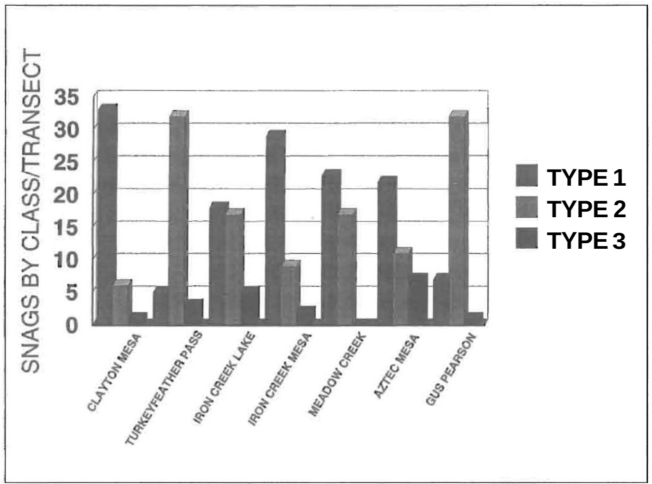

Fig. 1. Frequencies of snags by type found on 7 transects in Arizona and New Mexico, 1997. Type 1 snags are <6 years old; type 2 snags are 6-30 years old; and type 3 snags are carbon cores of snags that have experienced multiple fires.

probabilities decrease with increasing distance from the transect line; thus, some snags would go undetected. Nonetheless, it provided a semi-quantitative assessment of whether the estimates derived from DISTANCE were reasonable.

RESULTS

The relative frequency of snag types differed among study areas (Figure 1). Type 3 snags were relatively uncommon on all study areas. The Gus Pearson Natural Area and Turkeyfeather Pass sites both contained more type 2 than type 1 snags, whereas Iron Creek Mesa and Clayton Mesa sites contained substantially more type 1 than type 2 snags. Although Aztec Mesa, Meadow Creek, and Iron Mesa Lake had more type 1 than type 2 snags, the difference was not as great as for Iron Creek and Clayton mesas.

Estimates of snag densities from program DISTANCE ranged from 1.70 snags per hectare (CV = 15%) for Aztec Mesa to 81.43 snags per hectare (CV = 41%) for Iron Creek Lake (Table 2). Ad hoc density estimates ranged from 1.70 snags per hectare (Aztec Mesa) to 22.8 snags per hectare (Turkeyfeather Pass; Table 1).

DISCUSSION

Where Have All the Snags Come From?

The Gila National Forest is actively trying to restore natural disturbance regimes to the Gila Wilderness with the return of fire (Brown et al. 1994, Boucher and Moody 1996). It is predicted that this management direction will result in stand structures that approximate those that occurred prior to fire suppression and other postsettlement management practices (Kurmes 1989, Harrington and Sackett 1990, Sackett et al. 1994, Warshall 1995, Fulé and Covington 1996). Based on historical information collected at other locations in the Southwest, snag numbers under natural conditions may be lower than what exists today.

Although the earliest studies (Lang and Stewart 1909, Gutches 1910) did not classify forests as xerophytic or mesophytic, they referred to pure ponderosa pine forest (likely xerophytic) and ponderosa pine forest with a mixed conifer understory (mesophytic). These early surveys counted snags because of their potential value as timber. The density of snags for all 30 townships on the Kaibab Plateau averaged <0.10 snags per hectare. This survey included ponderosa pine, mixed conifer, and spruce-fir zones. Pure ponderosa pine forest was estimated to be 60% of the survey area (Lang and Stewart 1909). Densities of snags on the Fort Apache lndian Reservation in the White Mountains averaged about 0.75 per hectare (Gutches 1910).

The 3 areas we studied encompassed substantial variation in forest structure, past management, and fire history. Snag densities along all transects in all areas exceeded densities reported in the historical accounts of Lang and Stewart (1909) and Gutches (1910). Our 7 transects illustrate some of the variation that occurs in ponderosa pine forests and how local conditions and past management practices have influenced snag densities.

For example, areas with no timber harvest or recent livestock grazing but where fire has been suppressed until recently, such as Clayton and Iron Creek mesas, exhibit similar snag characteristics. The area sampled on Clayton Mesa had experienced 1 fire this century, in 1994, and the Iron Creek Mesa area had had 2 fires this century, one in 1985 and the other in 1993. The pine overstory remained intact, indicating

Table 2. Density estimates of snags >30 centimeters diameter at breast height from 7 locations in New Mexico and Arizona in 1997.

Study site	Density[a] estimates (number per hectare)	Coefficient of variation (CV)	Range	Ad hoc estimates (number per hectare)
Clayton Mesa	6.8	20%	4.5–10.1	4.5
Turkeyfeather	29.9	22%	19.4–46.0	22.8
Iron Creek Lake	81.4	41%	36.8–180.0	19.5
Iron Creek Mesa	3.6	18%	2.5–5.3	2.1
Meadow Creek	8.7	22%	5.7–13.5	4.6
Aztec Mesa	1.7	15%	1.2–2.3	1.7
Gus Pearson	5.6	18%	3.9–8.1	2.4

[a] Based on output from program DISTANCE (Laake et al. 1996).
[b] Equals [line length *2(maximum detection distance)].

that the fire intensity was low to moderate. Few type 2 snags (dead 6–30 years) were found on either mesa. Most snags found on both mesas were type 1, or those created by the last fire. With fire exclusion, debris piles form at the base of large mature trees. Ponderosa pines typically cast 33% of their needles each fall, and with the addition of fallen twigs and sloughed bark, these piles increase in biomass. Without frequent fires (2- to 12-year intervals) and with the slow decomposition rates, a substantial amount of material can accumulate and become compacted. When an ignition finally occurs, these debris piles burn much hotter than areas farther away from the base of trees (Harrington and Sackett 1992). The heat intensity may kill mychorrizal fungi associated with the roots or may kill the roots themselves, leading to tree mortality and snag development (Harrington and Sackett 1992).

One major difference between the two mesas, however, was in snag densities. Clayton Mesa had nearly twice the snag density of Iron Creek Mesa (Table 2). Recall that 1 fire had burned Clayton Mesa, whereas two had burned the Iron Creek Mesa site. We postulate that the first fire entry resulted in a large number of type 1 snags at both sites. However, when the second fire burned Iron Creek Mesa, it likely consumed most existing snags while creating new type 1 snags. Fewer snags were probably created at Iron Creek Mesa after the second fire because there was far less time after the last fire for the duff layer to accumulate at the base of trees. This hypothesis may explain why frequent or recurring fires would limit the number of snags that could be sustained over time. Data from locations that have experienced repeated fires close to natural fire frequencies would allow us to test this hypothesis.

Turkeyfeather Pass and Gus Pearson Natural Area represent sites that have had little or no recent timber harvest or livestock grazing, and where fires have been excluded during the 1900's. Both areas exhibited a distribution of snag types opposite that found at Clayton and Iron Creek mesas; that is, there were more type 2 than type 1 snags (Figure 1). The lack of fire in these areas has allowed snags to persist longer than if fire were present, explaining the large number of type 2 snags. Some type 1 snags found at Turkeyfeather Pass and Gus Pearson probably resulted from recent tree mortality due to lightning. However, a greater cause of mortality could be competition from the dense understory—pine in both areas, and white fir and Douglas-fir at Turkeyfeather Pass—that has developed in the absence of fire.

Iron Creek Lake represents a unique situation. Here we recorded the highest density of snags (Table 1) and similar numbers of type 1 and type 2 snags (Figure 1), relationships attributable to site conditions and management actions targeted to save existing snags. This site burned for the first time in many years during June 1993. Although many of the type 2 snags on Clayton and Iron Creek mesas were consumed, the type 2 snags at Iron Creek Lake remained standing. The site is located adjacent to Iron Creek Lake and contains moist soils associated with mesic and hydric conditions. These moist conditions may have kept fire from spreading and reaching many of the existing snags. The large number of type 2 snags, however, was not solely the result of natural events. A management decision was made to protect existing snags at this location (L. Garcia, Gila National Forest, personal communication). Before the fire reached the site, members of the Sacramento Hotshot crew manually cleared an area around each snag to minimize the possibility of ignition when the fire reached the area. This action preserved those snags, resulting in the large number of older, type 2 snags. Without these actions, most of the older snags would have burned, as they did at Clayton and Iron Creek mesas.

Meadow Creek and Aztec Mesa represent mesic and xeric sites, respectively, which have experienced timber harvest, livestock grazing, and fire suppression during most of this century. Given the lack of fire, both sites contained relatively large numbers of older, type 2 snags. High tree densities and recent drought conditions have allowed for an outbreak of western pine beetle (Dendroctonus brevicomis) over the past several years. Trees recently killed as a result represent most of the type 1 snags. Without the recent mortality from beetle-killed trees, snag densities would have been much lower. However, trees killed by beetle infestation tend to develop a brown cubical decay, causing them to break at the ground level in only a few years (Moir et al. 1997). Thus, the longevity of these snags might be limited. An additional complication comes in the form of high fuel loading in already stressed sites, increasing the risk of catastrophic fire. Further, Aztec Mesa is flat and exposed, and spring frontal winds may be responsible for the brief existence of type 2 snags there.

Thus, snag densities in the areas we sampled exceeded historical densities. Whether these snag densities are sustainable in the absence of active management and constant human intervention is doubtful. A clearer understanding of effects of management practices on snag sustainability requires implementation of well designed and replicated experiments in order to distinguish cause-and-effect relationships from environmental variations.

How Many Snags Do We Really Need?

Existing guidelines in the Southwestern Region of the Forest Service are based largely on Balda's (1975) work. Balda (1975) notes that virgin or undisturbed forests have the highest numbers of snags, but he mentions logging as the only disturbance factor. Balda did not list fire exclusion as a human disturbance, although fire suppression has influenced forest structure and composition throughout the Southwest. Thus, we are compelled to point out that Balda's virgin or undisturbed forests are likely not "natural"; therefore, they lack the characteristics of presettlement forests, where fire was a major ecosystem process.

Fire is the primary disturbance factor within the xerophytic and mesophytic stands of ponderosa pine in the Southwest (Moir and Dieterich 1988, Moody et al. 1992, Covington and Moore 1994). The ecological roles of fires have been well studied since the early 1930's (Weaver 1943, 1967, Ahlgren and Ahlgren 1960, Cooper 1960, Biswell 1972, Biswell et al. 1973, Habeck and Mutch 1973, Wright 1978, Moir and Dieterich 1988, Morgan 1994, Moir 1995, Allen 1996, Pyne 1996). Within the dry climate zone of the southwestern United States, frequent low-intensity surface fires recycled nutrients in an area where fungal breakdown would be too slow to keep up with annual biomass production (Moir et al. 1997).

The widely accepted models of snag and log dynamics provided by Thomas et al. (1979) may not apply to ponderosa pine forests of the Southwest. Thomas et al.'s (1979) models portrayed snags as going through stages of decay corresponding to the length of time the dead tree has been standing, which eventually would lead to "snag mortality" when the snag falls. Fallen snags then become downed logs, which go through another series of stages ending in decomposition and decay resulting from weathering, fungi, and a variety of faunal activities.

Weather conditions and disturbance regimes in southwestern ponderosa pine forests, however, are very different from the northwestern forests that Thomas et al. (1979) studied. Frequent fires in ponderosa pine forests tend to bum snags before they can go through stages of decay and fall. Moir et al. (1997) state that ponderosa pine snags may persist for only a short time. The few fallen snags that do become logs often burn before decaying, especially given that decay rates are much slower in the arid environments of the Southwest. Early accounts and photos indicate that large downed woody debris was kept at a minimum by these frequent fires. The newly burned areas tend to provide an opening in the pine-bunchgrass community that allows for seedling development. Frequent fires may have been one of the few ways large continuous stands of ponderosa pine were able to regenerate themselves. Thus, we conclude that overall snag numbers in presettlement ponderosa pine forests may have been lower than the minimum standards provided in Forest Land Management Plans throughout the Southwestern Region of the Forest Service.

We suggest that substrates used by wildlife typically ascribed to snags in ponderosa pine forests may have been provided by alternative sources, such as spike-topped trees, dead branches, lightning-scarred live trees with fungal heart rot, and large hardwoods like Gambel oak. These habitat types are utilized today where available. All of these forest elements could survive frequent low- to moderate-intensity surface fires. Unfortunately, past and current management practices have reduced the availability of these habitat elements (Nagiller et al. 1991, Moir et al. 1996).

For example, large Gambel oaks are being lost at an alarming rate. These trees are a valuable resource used by many birds and mammals (Moir et al. 1997). They are being removed for firewood near urban centers (Nagiller et al. 1991), but most importantly, they are being replaced by more shade-tolerant conifers. Before 1890, frequent surface fires helped maintain a pine and oak codominance (Moir 1982, Dieterich and Hibbert 1990, Swetnam et al. 1992). If large oak trees are desired on a given site, then over-topping by conifers must be prevented (Moir et al. 1997). Further, tighter regulations may be needed to minimize the loss of oaks to fuelwood harvest. Moreover, given that remaining oaks now exhibit heart rot and are surrounded by flammable fuels, they may be particularly vulnerable to mortality by fire. Without directed efforts to line and protect these trees, the increased use of managed fire to reduce fuels to prevent catastrophic wildfires may lead to excessive loss of this valued component of wildlife habitat.

Lightning is a key component within the southwestern ponderosa pine ecosystem. Lightning was considered to be the chief cause of mortality of large ponderosa pine in presettlement forests. It was also responsible for partial mortality, leaving dead treetops and open scars. These dead areas are often used by primary cavity-nesting birds and other vertebrates and invertebrates. These partially dead trees were routinely removed as a standard part of timber harvest. They were considered a threat to other healthy trees because of the potential for attracting insect pests and fungal heart rot. Furthermore, past timber harvest practices selected large trees for removal, the very trees with high probabilities of being struck by lightning and becoming spike-topped trees or snags.

It is clear that much remains unknown about the biotic and abiotic functions of presettlement ponderosa pine forests. We have learned of the ecological importance of fire and have begun to understand the importance of frequent low- to moderate-intensity surface fires. The interrelationships between cavity-dependent species and forest health has also become a focal point. We need a better understanding of wildlife use of snags or ecological equivalents, and relationships between sustainable populations of wildlife that require these unique habitat elements and the quantity and distribution of snags, spike-topped trees, and hardwoods. We must avoid misperceptions about what should be, and continue to gather and compile good data to aid in management decisions in the future. Much remains to be learned about what constitutes the best habitat for cavity-dependent species in fire-regulated systems of the Southwest.

Thus, past and present management practices have not only directly targeted snags for removal, but they have also resulted in the loss of alternative sources of standing dead or decaying wood as provided by hardwoods and partially dead conifers. Consideration of how many snags are needed must also take into account alternative substrates. It may very well be that snag numbers reported in historical accounts are adequate to sustain populations of wildlife species that depend on dead or decaying woody substrates if and only if those substrates are provided by other sources. Clearly, we need additional information that elucidates the relative importance of snags, hardwoods, and other sources of standing dead and decaying wood to sustain populations of the dependent wildlife species.

It is noteworthy to point out that any surface fire near the base of a ponderosa pine snag will probably ignite that snag. This observation comes from the 65 years of the authors' combined firefighting experience. The assumption can then be made that if the pine-bunchgrass communities were continuous and fire frequencies were 2–7 years, then the number of ponderosa pine snags reaching the minimum usable age of 6 years suggested by Balda (1975) would be limited. At the upper end of 7–12 years, the snag densities may be closer to those encountered on the Fort Apache Indian Reservation in 1910 at 0.75 snags per hectare.

CONCLUSIONS

The limited number of transects sampled precludes us from extending our results too far. At this point, our results likely evoke more questions than they answer. However, the preliminary data suggest that to manage for 6–30 dead standing trees per hectare may not be practical as we return fire to the watersheds of the Southwest. Recently killed trees are much more common after a burn, and only scattered old dead standing snags survive. We believe that issues of snag numbers and snag management are critically important to the conservation of many species of wildlife. Given this importance, we require a stronger empirical basis for developing management policies. We need to understand snag dynamics in natural and managed forests and how snag dynamics influence populations of key wildlife species. Furthermore, it is important to note that the life history of snags in the xeric ponderosa pine zones of the Southwest may differ from that of other regions. Finally, study of snag dynamics must include study of substrates that may serve the same or similar ecological roles as snags, such as spike-topped trees and hardwoods.

ACKNOWLEDGMENTS

We thank W. H. Moir and an anonymous reviewer for commenting on earlier versions of this manuscript. The fire crew from the Wilderness District, Gila National Forest, deserves special recognition for providing support during data collection. We would also like to thank J. Monzingo for help in data collection and preparation.

LITERATURE CITED

Ahlgren, I.F., and C.E. Ahlgren. 1960. Ecological effects of forest fires. Botanical Review 26:483–533.

Allen, C.D. (technical editor). 1996. Fire effects in Southwestern forests, proceedings of the second La Mesa fire symposium. General Technical Report RM-286, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Anderson, D.R., J.L. Laake, B.R. Crain, and K.P. Burnham. 1979. Guidelines for line transect sampling of biological populations. Journal of Wildlife Management 43:70–78.

Baisan, C.H., and T.W. Swetnam. 1990. Fire history on a desert mountain range: Rincon Mountain Wilderness, U.S.A. Canadian Journal of Forest Research 20:1559–1569.

Baker, M. B. Jr., L.F. DeBano, and P.F. Ffolliott. 1994. Soil loss in pinyon-juniper ecosystems and its influence on site productivity and desired future condition. Pages 9–15 in D.W. Shaw, E.F. Aldon, and C. LoSapio (technical coordinators). Proceedings: desired future conditions for pinyon-juniper ecosystems. General Technical Report RM-258, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Balda, R.P. 1975. The relationship of secondary cavity nesters and snag densities in western coniferous forests. Forest Wildlife Habitat Technical Bulletin 1, U.S. Department of Agriculture, Forest Service, Southwestern Region, Albuquerque, NM.

Barton, A.M. 1995. Fire adaptations in pine and oaks: tree population responses to fire suppression in Arizona's Madrean forests. Pages 159–163 in J.K. Brown, R.W. Mutch, C.W. Spoon, and R.H. Wakimoto (technical coordinators). Proceedings: symposium on fire in wilderness and park management. General Technical Report INT-320, U. S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT.

Biswell, H.H. 1972. Fire ecology in ponderosa pine-grassland. Tall Timbers Fire Ecology Conference Proceedings 12:69–96.

Biswell, H.H, H.R. Kallander, R. Komarek, R.J. Vogl, and H. Weaver. 1973. Ponderosa pine forests of central Arizona. Miscellaneous Publications 2, Tall Timbers Research Station, Tallahassee, FL.

Boucher, P.F., and R.D. Moody. 1998. The historical role of fire and ecosystem management of fires: Gila National Forest, New Mexico. Tall Timbers Fire Ecology Conference Proceedings 20:374–379.

Brown, J.K., S.F. Arno, S.W. Barrett, and J.P. Menakis. 1994. Comparing the prescribed natural fire program with presettlement fires in the Selway-Bitterroot Wilderness. International Journal of Wildland Fire 4:157–168.

Buckland, S.T., D.R. Anderson, K.P. Burnham, and J.L. Laake. 1993. Distance sampling: estimating abundance of biological populations. Chapman and Hall, London.

Burnham, K.P., D.R. Anderson, and J.L. Laake. 1980. Estimation of density from line transect sampling of biological populations. Wildlife Monograph 72.

Caprio, A.C., and M.J. Zwolinski. 1995. Fire and vegetation in a Madrean oak woodland, Santa Catalina Mountains, southeastern Arizona. Pages 389–398 in L.F. Debano, P.F. Ffolliott, A. Ortega-Rubio, G.J. Gottfried, R.H. Hamre, and C.B. Edminster (technical coordinators). Biodiversity and management of the Madrean Archipelago: the Sky Islands of the southwestern United States and northwestern Mexico. General Technical Report RM-264, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Carrara, P.E., and T.R. Carroll. 1979. The determination of erosion rates from exposed tree roots in the Piceance Basin, Colorado. Earth Surface Proceedings 4:307–317.

Cooper, C.F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. Ecological Monographs 30:129–164.

Cooper, C.F. 1961. Pattern in ponderosa pine forests. Ecology 42:493–499.

Covington, W.W., and M.M. Moore. 1992. Postsettlement changes in natural fire regimes: implications for restoration of old-growth ponderosa pine forests. Pages 81–99 in M.R. Kaufmann, W.H. Moir, and R.L. Bassett (technical coordinators). Old-growth forests in the Southwestern and Rocky Mountain regions: proceedings of a workshop. General Technical Report RM-213, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Covington, W.W., and M.M. Moore. 1994. Postsettlement changes in natural fire regimes and forest structure: ecological restoration of old-growth ponderosa pine forests. Journal of Sustainable Forestry 2:153–181.

Cunningham, J.B., R.P. Balda, and W.S. Gaud. 1980. Selection and use of snags by secondary cavity-nesting birds of the ponderosa pine forest. Research Paper RM-222, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Deiterich, J.H., and A.R. Hibbert. 1990. Fire history in a small ponderosa pine stand surrounded by chaparral. Pages 168–173 *in* J.S. Krammes (technical coordinator). Proceedings, effects of fire management of southwestern natural resources. General Technical Report RM-191, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Ffolliott, P.F. 1983. Implications of snag policies on management of southwestern ponderosa pine forests. Pages 28–32 *in* J.W. Davis, G.A. Goodwin, and R.A. Ockenfels (technical coordinators). Proceedings of the snag habitat management symposium. General Technical Report RM-99, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Fulé, P.Z., and W.W. Covington. 1995. Changes in fire regimes and forest structure of unharvested Petran and Madrean pine forests. Pages 408–415 *in* L.F. Debano, P.F. Ffolliott, A. Ortega-Rubio, G.J. Gottfried, R.H. Hamre, and C.B. Edminster (technical coordinators). Biodiversity and management of the Madrean Archipelago: the Sky Islands of the southwestern United States and northwestern Mexico. General Technical Report RM-264, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Fulé, P.Z., and W.W. Covington. 1996. Conservation of pine oak forests in northern Mexico. Pages 80–88 *in* W.W. Covington and P.K. Wagner (technical coordinators). Conference on adaptive ecosystem restoration and management: restoration of cordilleran conifer landscapes of North America. General Technical Report RM-278, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Ganey, J.L., W.M. Block, and P.F. Boucher. 1996. Effects of fire on birds in Madrean forests and woodlands. Pages 146–154 *in* P.F. Ffolliott, L.F. Debano, M.B. Baker Jr., G.J. Gottfried, G. Solis-Garza, C.B. Edminster, D.G. Neary, L.S. Allen, and R.H. Hamre (technical coordinators). Effects of fire on Madrean province ecosystems. General Technical Report RM-289, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Grissino-Mayer, H.D., C.H. Baisan, and T.W. Swetnam. 1995. Fire history in the Pinaleno Mountains of southeastern Arizona: effects of human related disturbance. Pages 399–407 *in* L.F. Debano, P.F. Ffolliott, A. Ortega-Rubio, G.J. Gottfried, R.H. Hamre, and C.B. Edminster (technical coordinators). Biodiversity and management of the Madrean Archipelago: the Sky Islands of the southwestern United States and northwestern Mexico. General Technical Report RM-264, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Gutches, G.A.1910. Report of G.A. Gutches on Fort Apache Indian Reservation. U.S. Department of the Interior, Bureau of Indian Affairs, Indian Office Files, White River, AZ.

Habeck, J.R., and R.W. Mutch. 1973. Fire-dependent forests in the northern Rocky Mountains. Quaternary Research 3: 408–424.

Hall, L.S., M.L. Morrison, and W.M. Block. 1997. Songbird status and roles. Pages 69–88 *in* W.M. Block and D.M. Finch (technical coordinators). Songbird ecology in southwestern ponderosa pine forests. General Technical Report RM-292, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Harrington, M.G., and S.S. Sackett. 1990. Using fire as a management tool in the southwestern ponderosa pine. Pages 122–133 *in* J.S. Krammes (technical coordinator). Proceedings, effects of fire management of southwestern natural resources. General Technical Report RM-191, U.S. Department of Agriculture, Forest Service, Rocky Mountain. Forest and Range Experiment Station, Fort Collins, CO.

Harrington, M.G., and S.S. Sackett. 1992. Past and present fire influences on southwestern ponderosa pine old growth. Pages 44–50 *in* M.R. Kaufmann, W.H. Moir, and R.L. Bassett (technical coordinators). Old-growth forests in the Southwestern and Rocky Mountain regions: proceedings of a workshop. General Technical Report RM-213, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Hay, D.B., and M. Guntert. 1983. Seasonal selection of tree cavities by pygmy nuthatches based on cavity characteristics. Pages 117–120 *in* J.W. Davis, G.A. Goodwin, and R.A. Ockenfels (technical coordinators). Proceedings of the snag habitat management symposium. General Technical Report RM-99, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Johnson, M.A. 1994. Changes in southwestern forests: stewardship implications. Journal of Forestry 94:16–19.

Kurmes, E.A. 1989. The development of thinning practices of southwestern ponderosa pine. Pages 23–25 *in* A. Tecle, W.W. Covington, and R.H. Hamre (technical coordinators). Multiresource management of ponderosa pine forests. General Technical Report RM-185, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Laake, J.L., S.T. Buckland, D.R. Anderson, and K.P. Burnham. 1996. DISTANCE user's guide. Version 2.2. Colorado Cooperative Fish Wildlife Research Unit, Colorado State University, Fort Collins.

Lang, D.M., and S.S. Stewart. 1909. Reconnaissance of the Kaibab National Forest. Timber inventory of the North Kaibab Plateau on file at the Kaibab National Forest Supervisor Office, Williams, AZ.

Marshall, J.T., Jr. 1957. Birds of the pine oak woodland in southem Arizona and adjacent Mexico. Pacific Coast Avifauna 32:1–125.

Moir, W.H. 1992. Ecological concepts in old-growth forest definition. Pages 18–23 in M.R. Kaufmann, W.H. Moir, and R.L. Bassett (technical coordinators). Old-growth forests in the Southwestern and Rocky Mountain Regions: proceedings of a workshop. General Technical Report RM-213, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Moir, W.H. 1995. Persistence of uncommon cryopedic plants in the Chiricahua Mountains spruce forest island. Pages 214–218 *in* L.F. Debano, P.F. Ffolliott, A. Ortega-Rubio, G.J. Gottfried, R.H. Hamre, and C.B. Edminster (technical coordinators). Biodiversity and management of the Madrean Archipelago: the Sky Islands of the southwestern United States and northwestern Mexico. General Technical Report RM-264, U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Moir, W.H., and J.H. Dieterich. 1988. Old-growth ponderosa pine from succession on pine-bunchgrass habitat types in Arizona and New Mexico. Natural Areas Journal 8:17–24.

Moir, W.H., B. Geils, M.A. Benoit, and D. Sculock 1997. Ecology of the southwestern ponderosa pine. Pages 3–27 *in* W.M. Block and D.M. Finch (technical editors). Songbird ecology in southwestern ponderosa pine forests. General Technical Report RM-292, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Morgan, P. 1994. Dynamics of ponderosa and Jeffrey's pine forests. Pages 47–73 *in* G. D. Hayward and J. Verner (technical editors). Flammulated, boreal, and great gray owls in the

United States: a technical conservation assessment. General Technical Report RM-253, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO.

Nagiller, S., H. Green, and M. Whitney. 1991. Wildlife habitat damage assessment—U.S. vs. Thompson et al. On file at U.S. Department of Agriculture, Forest Service, Coconino National Forest, Flagstaff, AZ.

Pyne, S.J. 1996. Nouvelle Southwest. Pages 10–16 *in* W.W. Covington and P.K. Wagner (technical coordinators). Conference on adaptive ecosystem restoration and management: restoration of cordilleran conifer landscapes of North America. General Technical Report RM-278, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Sackett, S.S., S. Haase, and M.G. Harrington. 1994. Restoration of southwestern ponderosa pine ecosystems with fire. Pages 115–121 *in* W.W. Covington and L.F. DeBano (technical coordinators). Sustainable ecological systems: implementing an ecological approach to land management. General Technical Report RM-247, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Scott, V.E. 1978. Characteristics of ponderosa pine snags used by cavity-nesting birds in Arizona. Journal of Forestry 76: 26–28.

Scott. V.E. 1979. Bird response to snag removal in ponderosa pine. Journal of Forestry 77:26–28.

Scott, V.E., and D.R. Patton. 1975. Cavity-nesting birds of Arizona and New Mexico forests. General Technical Report RM-10, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Shinneman, D.J., and W.L. Baker. 1997. Nonequilibrium dynamics between catastrophic disturbances and old-growth forests in ponderosa pine landscapes of the Black Hills. Conservation Biology 11:1276–1288.

Swetnam, T.W. 1990. Fire history and climate in the southwestem United States. Pages 6–17 *in* J.S. Krammes (technical coordinator). Proceedings, effects of fire management of southwestern natural resources. General Technical Report RM-191, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Swetnam, T.W., C.H. Baisan, A.C. Caprio, and P.M. Brown. 1992. Fire history in a Mexican pine-oak woodland and adjacent montane conifer gallery forest in southeastern Arizona. Pages 165–173 *in* P.F. Ffolliott, G.J. Gottfried, D.A. Bennett, V.M.C. Hernandez, and A. Ortega-Rubio (technical coordinators). Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico. General Technical Report RM-218, U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO.

Swetnam. T.W., and C.H. Baisan. 1996. Fire histories of montane forests in the Madrean borderlands. Pages 15–36 *in* P.F. Ffolliott, L.F. Debano, M.B. Baker, G.J. Gottfried, G. Solis-Garza, C.B. Edminster, D.G. Neary, L.S. Allen, and R.H. Hamre (technical coordinators). Effects of fire on the Madrean Province ecosystem. General Technical Report RM-289. U.S. Department of Agriculture. Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO.

Sydeman, W.J., and M. Gubtert. 1983. Winter communal roosting in the pygmy nuthatch. Pages 121–124 in J.W. Davis, G.A. Goodwin, and R.A. Ockenfels (technical coordinators). Proceedings of the snag habitat management symposium. General Technical Report RM-99, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range, Fort Collins, CO.

Szaro, R.C., and R.P. Balda. 1979. Bird community dynamics in a ponderosa pine forest. Studies in Avian Biology 3:1–66.

Szaro, R.C., and R.P. Balda. 1982. Selection and monitoring of avian indicator species: an example from a ponderosa pine forest in the Southwest. General Technical Report RM-89, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Szaro, R.C., and R.P. Balda. 1986. Relationships among weather, habitat structure, and ponderosa pine forest birds. Journal of Wildlife Management 50:253–260.

Szaro, R.C., J.D. Brawn, and R.P. Balda. 1990. Yearly variations in resource-use behavior by ponderosa pine forest birds. Studies in Avian Biology 13:226–236.

Thomas, J.W., R.G. Anderson, C. Maser, and E.L. Bull. 1979. Snags. Pages 60–77 *in* J.W. Thomas (technical editor). Wildlife habitats in managed forests in the Blue Mountains of Oregon and Washington. Agriculture Handbook 553, U.S. Department of Agriculture, Forest Service, Washington, DC.

U.S. Department of Agriculture, Forest Service. 1996. Record of decision for amendments of forest plans: Arizona and New Mexico. U.S. Department of Agriculture, Forest Service, Southwestern Region, Albuquerque, NM.

Villanueva-Diaz, J., and G.R. McPherson. 1995. Forest stand structure in mountains of Sonora, Mexico and New Mexico, USA. Pages 416–423 in L.F. Debano, P.F. Ffolliott, A. Ortega-Rubio, G.J. Gottfried, R.H. Hamre, and C.B. Edminster (technical coordinators). Biodiversity and management of the Madrean Archipelago: the Sky Islands of the southwestern United States and northwestern Mexico. General Technical Report RM-264, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Warshall, P. 1995. The Madrean Sky Islands Archipelago: a planetary overview. Pages 6–18 *in* L.F. Debano, P.F. Ffolliott, A. Ortega-Rubio, G.J. Gottfried. R.H. Harnre, and C.B. Edminster (technical coordinators). Biodiversity and management of the Madrean Archipelago: the Sky Islands of the southwestern United States and northwestern Mexico. General Technical Report RM-264, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Weaver, H. 1943. Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific slope. Journal of Forestry 41:7–15.

Weaver, H. 1967. Fire and its relationship to ponderosa pine. Tall Timbers Fire Ecology Conference Proceedings 6:127–149.

White, A.S. 1985. Presettlement regeneration patterns in a southwestern ponderosa pine stand. Ecology 66:589–594.

Woolsey, T.S., Jr. 1911. Western yellow pine in Arizona and New Mexico. Bulletin 101, U.S. Department of Agriculture, Forest Service, Washington, DC.

Wright, H.A. 1978. The effect of fire on vegetation in ponderosa pine forests: a state-of-the-art review. Science Publication T-9–99, Texas Technical University, College of Agriculture, Lubbock.