

SNAGS AND PARTIAL SNAGS IN MANAGED, RELICT, AND RESTORED  
PONDEROSA PINE FORESTS OF THE SOUTHWEST

by Justin D. Waskiewicz

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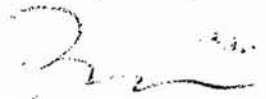
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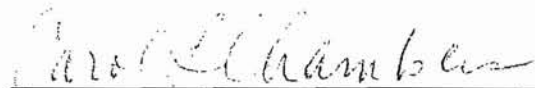
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## ABSTRACT

### SNAGS AND PARTIAL SNAGS IN MANAGED, RELICT, AND RESTORED PONDEROSA PINE FORESTS OF THE SOUTHWEST

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Snags form an important habitat resource in ponderosa pine forests, but are susceptible to destruction in wildfires. Partial snags – live trees bearing dead parts – have been suggested as a more fire-resistant alternative to snags that may have played an important role in pre-settlement forests and may become important following treatments designed to emulate pre-settlement forest structure and function. I studied snags and partial snags in a managed forest receiving restoration treatments at Mt. Trumbull, Arizona to learn how restoration treatments affect the densities, characteristics, and use of snags by wildlife. I studied partial snags at four unmanaged relict sites in Arizona and New Mexico to estimate their quantity, quality, and use in relatively undisturbed forests, and to establish a protocol for their future measurement and description.

At Mt. Trumbull, snag loss was five times higher in treated than in control plots. Newly recruited snags outnumbered losses in both treatment and control plots, leading to net snag density increases 10 times higher in treatment than control plots. Partial snags were destroyed at the same rate in both treatment and control plots, but were more likely to remain standing than snags in treatment plots. Cavity-bearing snags decreased slightly in both control and treatment plots. Trees bearing evidence of woodpecker foraging

increased slightly in control plots and by almost four times in treatment plots. Trees bearing ant colonies increased by half in control plots and decreased slightly in treatment plots.

Partial snag densities at relict sites ranged from 2.13 to 3.18 per ha and spike-topped trees were the most common type at all four. The managed site had 1.70 partial snags per ha and lightning scars were the most common type. At relict sites, 19% of partial snags contained excavated cavities, while at the managed site, 42% did. Partial snags with greater-than-median surface area of dead wood, distance to nearest neighboring snag and dbh, and less than median crown-base height were disproportionately selected from partial snags at relict sites. I developed models for estimating dead wood surface areas in spike-topped and in lightning-scarred trees that do not require time-consuming measurements or heavy equipment.

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## PREFACE

Chapters 3, 4 and 5 of this thesis are formatted for submission to peer-reviewed scientific journals. Redundancy in information among chapters is a result of combining these articles within the university formatting requirements.

Raw individual-tree data used in chapters 3, 4 and 5 will be archived with the Ecological Restoration Institute for use by future researchers.

## CHAPTER 1

### INTRODUCTION

Snags (standing dead trees) are an important component of wildlife habitat in ponderosa pine forests (Scott 1978, Cunningham et al. 1980), providing many species of birds, mammals, reptiles and invertebrates with food and cover (Thomas et al. 1979, Davis 1983). The structure and composition of snag populations has likely changed since European-American settlement (about 1875) just as have the forests that contain them (Covington and Moore 1994, Ganey 1999, Fulé et al. 2002). Frequent fires prior to the turn of the century probably consumed many snags before they reached advanced stages of deterioration; so current populations may be both more dense and more heavily skewed toward older deterioration classes than would be seen under a historic fire regime (Boucher et al. 1999, Ganey 1999).

Ecosystem restoration treatments, consisting of understory thinning followed by prescribed surface burning, are used to create forest structures and functions more consistent with pre-settlement conditions in the Southwest (Covington et al. 1997). Restoration efforts do not explicitly address wildlife habitat, rather aiming at broad ecosystem goals that are implicitly assumed to improve native wildlife habitat conditions (Reynolds et al. 1996, Long and Smith 1998, Wagner et al. 2000, Block et al. 2001). Treatments dramatically and abruptly alter forest structure, but achieving final desired conditions and desired ecosystem function may take decades or even centuries. There is some concern about the effects of the initial treatment and recovery period on wildlife

at least European-American settlement. I expected the partial snag resources at these sites to be representative of that available prior to settlement and after successful restoration.

The objectives of this study were: 1) to estimate the density, size, condition, and wildlife use of snags in a managed forest, and compare the snag resource there to published standards, 2) to record the quantitative and qualitative changes in snag and partial snag populations and their use following restoration treatments, and 3) to estimate the quantity, quality and use of partial snags in relict sites of the Southwest and establish a protocol for their measurement and description.

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## CHAPTER 2

### LITERATURE REVIEW

#### **Ecological Importance of Snags**

Jefferies (1878) was first to note the ecological importance of snags, describing their use by owls, woodpeckers, nuthatches, creepers and swallows, as well as beetles, woodlice and other insects, and advocating that snags and hollow trees should be “permitted to linger awhile safe from the axe.” Grinnel and Storer (1924) were also early to recognize the utility of snags, though the subject was not widely investigated until the 1970’s (Neitro et al. 1985). Standing dead trees are now known to be important to many bird species as sites for foraging (Raphael and White 1984, Morrison et al. 1987, Weikel and Hayes 1999), roosting (Sydeman and Güntert 1983, Cooper 1999), display, communication, and other uses (Miller and Miller 1980, Davis 1983). Mammal species also use snags (Armijo 1979, Thomas et al. 1979, Smith and Mannan 1994, Chambers et al. 2002); some species of forest bats depend on them for roost sites (Rabe et al. 1998). Dead trees act as growth substrates for fungi, mosses and lichens, and are used by invertebrates as food and cover (Thomas et al. 1979, Neitro et al. 1985, McComb and Lindenmayer 1999).

Snag removal reduces cavity-nesting bird numbers (Scott 1979, Scott and Oldemeyer 1983, Lohr et al. 2002). In northern Arizona, over 25 species of bird, ranging in size from the pygmy nuthatch to the threatened Mexican spotted owl depend on dead trees for nesting sites (Scott and Patton 1975). In ponderosa pine forests, these cavity-nesting species may constitute over a third of total bird diversity and their population

densities are significantly correlated with snag densities (Cunningham et al. 1980).

Whether snags are limiting to bird populations depends on the species in question as well as the stand in question (Welsh and Capen 1992, Brush 1983, Brawn and Balda 1988).

#### Wildlife selection of snags

Birds disproportionately select larger snags for nesting (Scott 1978, Thomas et al. 1979, Cline et al. 1980, Cunningham et al. 1980, Mannan et al. 1980, Raphael and White 1984, Raphael and Morrison 1987). Forest bats also roost disproportionately in larger than average pine snags Rabe et al. (1998). Larger diameter snags provide more insulating volume as well as more surface area in which to locate nest or roost sites (Miller and Miller 1980). Larger snags are also heavily selected for foraging sites, presumably because their larger volume and surface areas provide habitat for more invertebrate prey (Raphael and White 1984). Thomas et al. (1979) suggested that a relatively large snag could always be substituted for a smaller one, but not vice-versa. The habitat value of small snags should not be discounted, however; Horton and Mannan (1988) noted heavy foraging use of small snags produced following prescribed fire and Thomas et al. (1979) noted that snags of deciduous species, though often smaller than pine snags, are heavily used wherever they occur.

Soft (rotten) snags with high bark retention are heavily used by birds for both nesting and foraging (Thomas et al. 1979, Cunningham et al. 1980, Raphael and White 1984, Neitro et al. 1985), although Miller and Miller (1980) stress an important distinction between heartwood decay, which is of high value, and sapwood decay, which is of lesser importance. Hard (fresh) snags are very important as well, since they serve as

a recruitment pool for soft snags and also because they are used directly by bark-gleaners and some stronger-billed cavity-nesters (Mannan et al. 1980). Bark retention is an important parameter in wildlife use; bats, brown creepers, and invertebrates seek food and shelter directly in, on or under bark (Scott and Patton 1975, Neitro et al. 1985), and it can play an important role in retaining moisture which influences rate of decay (Raphael and White 1984). Forest bats disproportionately select snags with loose patches of bark (Rabe et al. 1998), and Cunningham et al. (1980) found that many active cavity-nesting bird nest holes were surrounded by bark. Broken tops are also often associated with cavity nests, possibly because bole breakage facilitates the entrance of wood-decay fungi (McClelland and Frissel 1975).

Wildlife selection of snags may ultimately depend on factors that are undetectable to human observers (Schepps et al. 1999). Bole hardness and the presence of heart-rot fungi are apparently very important in determining both the selection of a tree for cavity-building and in the location of cavities but are nearly impossible to determine without dissection of the tree (Conner et al. 1976, Miller and Miller 1980, Schepps et al. 1999).

#### Snag management guidelines

Representation of a variety of decay states and size classes, with enough young (recently died) snags to provide for future old snags, is an appropriate habitat management goal (Neitro et al. 1985). Cunningham et al. 1980 recommended 5.2 snags (>33 cm dbh X 6 m height) per ha in southwestern ponderosa pine forests to maintain "natural" cavity nester populations. U.S. Forest Service guidelines for the same type recommend 4.9 large (> 46 cm X 9 m) snags per ha (Reynolds et al. 1992). Ganey (1999)



observed only (1.0-2.0) large snags/ha in northern Arizona ponderosa pine forests, and found that most were highly decayed. Large snag densities were lower than USFS recommendations even in stands that had never been logged, with a median density of only 2.0 large snags per ha. Ganey (1999) and Boucher et al. (1999) cast doubt on the appropriateness of Forest Service guidelines, suggesting that natural snag densities under a frequent fire regime might have been much lower, given the propensity for snags to be destroyed by fire.

## **Snag Dynamics**

### Recruitment

Snags are recruited from live trees by mortality, which has many causes. Pearson (1938) estimated mortality rates of 1% per year in southwestern ponderosa pine over 30 cm in diameter breast height (dbh), listing wind, lightning, dwarf mistletoe, and insects as the primary mortality factors, with smaller losses attributed to fire and competition. Lightning and wind together account for about 70% of the mortality in northern Arizona pine forests (Gaines and Shaw 1959). Wind is more likely to produce logs than snags, so lightning, which alone accounts for about a third of mortality, is the largest single source of new snags (Wadsworth 1943). Bark beetles are the third largest mortality factor, also leaving individual or small groups of snags (Pearson 1933, Gaines and Shaw 1959, Avery et al. 1976). Wildfires and large insect outbreaks – particularly prevalent in Arizona in the summer of 2002 – can recruit millions of snags at high densities. These are undoubtedly important snag recruitment factors on a landscape scale, but are not a consistent contributor to stand-scale snag populations.

Competition induces mortality among smaller trees and is likely an important factor as the dominant cohort of pines passes through the stem exclusion stage of stand development (Oliver and Larson 1996, Boucher et al. 1999, Mast and Veblen 1999). Ganey (1999) found that small snags (<30cm dbh) dominated snag populations in southwestern ponderosa pine forests. Asymmetric competition between the dense regeneration and the overstory may also induce mortality in large size classes (Biondi 1996, Mast et al. 1999).

### Deterioration

As snags decay, they lose needles, twigs, branches, bark and eventually sections of bole (Thomas et al. 1979, Bull 1983, Cline et al. 1980, Neitro et al. 1985). Numerous authors have devised systems to classify snags by their level of decay, based on observations of bark cover, twig and limb retention, wood quality, or some combination (Keen 1955, Gale 1973, Scott 1978, Thomas et al. 1979, Cline et al. 1980, Raphael and White 1984, Horton and Mannan 1988, Boucher et al. 1999, Waskiewicz and Fulé in review). Classification systems are used to model future snag numbers and quality (Neitro et al. 1985), to predict wildlife selection (Raphael and White 1984), to describe management impacts (Horton and Mannan 1988), and to model past forest structure (Mast et al. 1999). Decay rates (progression through a given class system) are likely influenced by a host of factors, including size (Keen 1929, Kimmey and Furniss 1943, Basham and Belyea 1960, Cline et al. 1980, Bull 1983), soil conditions (Keen 1955), cause of death (Morrison and Raphael 1993), ring density (Kimmey and Furniss 1943,

Basham and Belyea 1960), exposure (Raphael and Morrison 1987), species (Clark 1957, Fulé et al. 2002) and breakage (Mannan et al. 1980, Raphael and Morrison 1987).

### Loss

Snags are lost from a population when they collapse (either break or fall over), are cut down, or are consumed by fire. Microbes and wood boring insects consume dead wood until a snag becomes too weak to support its weight or the stresses of wind and weather (Keen 1929, Kimmey and Furniss 1943). Keen (1955) estimated the falling rates of beetle-killed pine in southeastern Oregon and northeastern California, finding a sigmoid pattern in which the majority of snags fell between 5 and 15 years after tree death. A similar pattern was reported by Keen (1929, 1955), Dahms (1949), Cunningham et al. (1980), Bull (1983) and Chambers (2002) with a high initial treefall dominated by smaller snags, followed by a tapering off of treefall as larger trees are lost more gradually. Prior to the 1970's, management focused on removing snags to increase growing space for live trees, and reduce fire hazard (Woolsey 1911, Keen 1929, Pearson 1938, Dahms 1949, Keen 1955).

## **Fire-Altered Snag Dynamics and Use**

### Dynamics

Fire killed trees that remain standing add to a snag population (Gaines et al. 1958). Surface fires may kill trees through crown injury, cambium injury or root injury (Reinhart and Ryan 1988). Larger trees and trees with thick bark are more likely to survive fire, though deep basal litter and debris piles can kill otherwise resistant trees by

burning hotter or smoldering longer than the tree bark can withstand (Reinhardt and Ryan 1988, Sackett et al. 1996). In the Coronado National Forest, Horton and Mannan (1988) reported that most new snags created by a prescribed surface fire in ponderosa pine were small - less than 15 cm dbh. Gordon (1996), found that 69% of new snags created following prescribed burns in Coconino and Kaibab national forests were 15 to 20 cm in diameter (she did not measure those below 15 cm).

Fire can radically alter a snag's decay state without destroying it completely by causing breakage, burning off leaves, twigs, or limbs, or burning away bark cover (Gordon 1996). Snags recruited from fire-killed timber may deteriorate more rapidly than those killed by other causes (Laudenslayer 2002).

Gaines et al. (1958) did not specifically report on the destruction and creation of snags following the two fall burns in Arizona's Blue Mountains, but did report net changes in numbers of small (5-29 cm dbh) and large (30+ cm dbh) snag numbers as part of an assessment of fuels. The cooler fire resulted in a net loss and the hotter fire a net gain of snags, particularly those of small size.

Horton and Mannan (1988) provided a detailed assessment of snag population changes following a controlled burn in the Coronado National Forest. Snags greater than 30 cm dbh, and those in the fourth decay class (of their six) were destroyed in higher proportion than the remainder of the population. They speculated that larger and more decayed snags had developed deeper litter and debris layers around their bases than smaller or younger snags, but that the debris piles of snags in classes 5 and 6 had decayed enough that they contained less caloric content than those in class 4. Snags in classes 1-3 were apparently protected from flames by both a smaller debris pile and by the retention

of fire-resistant bark. In Horton and Mannan's (1988) study, fires created fewer snags than were destroyed, and mostly from smaller (<15 cm) size trees, resulting in a net 45% loss of snags by one year after treatment.

Gordon (1996) found that 65% of ponderosa pine snags remained "useful to wildlife" following prescribed fire. She found that snags on slopes or with deeper litter piles at their bases were more likely to be destroyed than those on level ground or with less basal debris. She also found that raked buffers that exposed mineral soil around snags improved survival (27% of raked snags were destroyed, versus 50% of un-raked).

#### Wildlife use

Horton and Mannan (1988) studied changes in cavity-nesting bird populations following a prescribed burn. They found a reduction in violet-green swallow and northern flicker populations, and an increase in mountain chickadee numbers in treated areas one year after burning. Dwyer and Block (2000) found that moderately intense wildfires caused non-significant decreases in most cavity-nesting species (western bluebirds increased). They found no secondary cavity-nesting birds in severely burned plots. Lowe et al. (1978) reported changes in snag dependent species following high-intensity fires. They classified birds by foraging type. Drillers briefly increased in numbers, then leveled off, while timber gleaners decreased.

#### **Partial snags**

Live trees bearing deadwood components, such as lightning scars, dead ("spike") tops, large dead limbs and other types of wounds or scars are called partial snags or

“living snags” (Mast et al. 1999). Lightning damage is common in ponderosa pine forests of northern Arizona (Pearson 1938, Wadsworth 1943). Besides lightning, partial snags may be created by mistletoe, bark beetles, competition, fungal infection, or drought stress (Pearson 1938). Animal damage (especially girdling by porcupines) and logging damage may also create some partial snags. Fulé et al. (2002) noted that Gambel oak often die gradually, in sections, and heart rot is common in larger oak (Reynolds et al. 1970). Gaines et al. (1958) reported unspecified damage to residual live trees from prescribed burns in the fall, suggesting that non-lethal fire damage may also create partial snags.

Partial snags may be used by many of the same wildlife species and for many of the same purposes as “full” snags (Boucher et al. 1999, Ganey 1999). Rabe et al. (1998) noted bats roosting in lightning scars, Raphael and White (1984) found 21% of avian cavity nests in live trees, and Li and Martin (1991) found 38% in live trees. Miller and Miller (1980) noted that 40 percent of the cavities found in 6 published and unpublished studies were in live trees. Scott et al. (1978) found cavities in dead tops and scars on the Fraser experimental forest (CO) and Cunningham et al. (1980) reported numerous active cavities in spike-topped trees, particularly broken ones. Partial snags may also have an important role to play as a ready recruitment pool for future snags, as they are often already under stress (Mast et al. 1999).

“Trees are excavated because of what is going on inside them, not because they are dead” (Miller and Miller 1980, p. 340). Partial snags with dead or especially with broken tops (Cunningham et al. 1980) may be particularly useful for nesting sites, because the introduction of heart rot within a sound shell of sapwood is more likely

(Miller and Miller 1980) and produces a structure of great utility to wildlife (McClelland and Frissel 1975, Miller and Miller 1980, Cunningham et al. 1980). Snags that were partial snags before their complete death may be more valuable than snags that were killed instantly, also because of the introduction of heart rots while alive (Miller and Miller 1980, p. 340 – “whether a tree will be a good potential nest tree is actually determined before the tree dies...”).

Partial snags may be more likely to survive (at least remain standing, if killed) after a fire than snags, because they retain a living layer of insulating bark at the base. Because of this, some have suggested an important habitat role for partial snags prior to the disruption of the pre-settlement fire regime (Boucher et al. 1999, Ganey 1999, Mast et al. 1999).

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## CHAPTER 3

### INVENTORY OF SNAGS AT MT. TRUMBULL, ARIZONA PRIOR TO INITIATION OF ECOSYSTEM RESTORATION TREATMENTS

**Abstract:** Snags are important habitat components for a variety of wildlife species in northern Arizona. I inventoried the quality, quantity, and wildlife use of ponderosa pine (*Pinus ponderosa*) snags at Mt. Trumbull, AZ. Pine snag densities ranged from 2.1 to 5.6 per ha, with populations dominated by small snags. Snag populations failed to meet the density criteria recommended by the US Forest Service and cavity-nesting bird literature. Snag populations were dominated by snags of recent condition, but among large ( $\geq 33$  cm dbh) snags separately, the most advanced condition dominated. Larger diameter snags of both species were disproportionately used as excavated cavity sites, foraging sites, and ant colony sites. Excavated cavity presence was also associated with taller snags.

## INTRODUCTION

In northern Arizona, over 25 species of forest birds, ranging in size from the pygmy nuthatch to the threatened Mexican spotted owl, depend on dead trees for nesting sites (Scott and Patton 1975). In ponderosa pine (*Pinus ponderosa* var. *scopulorum*) forests, these birds may constitute over a third of total avian biodiversity and their population sizes are strongly correlated with snag density (Cunningham et al. 1980). Standing dead trees are also important to many bird species as sites for foraging (Raphael

and White 1984, Morrison et al. 1987, Weikel and Hayes 1999), roosting (Sydeman and Güntert 1983, Cooper 1999), display, communication, and other uses (Miller and Miller 1980, Davis 1983). Mammal species are also known to use snags (Armijo 1979, Smith and Mannan 1994, Thomas et al. 1979); some species of forest bats depend on snags for roost sites (Rabe et al. 1998). Dead trees act as growth substrates for fungi, mosses and lichens, and are used by invertebrates for food and cover (Thomas et al. 1979, Neitro et al. 1985).

Invertebrates that use snags for sustenance or shelter include species important to forest ecosystems. Wood borers (*Buprestidae*) and bark beetles (*Scolytidae*) are important food items for woodpeckers, together making up over 40% of the diet of hairy woodpeckers (*Picoides villosus*) in Otvos and Stark's (1985) California study. Ants (*Formicidae*), including carpenter ants (*Camponotus* species), also form a large part of the hairy woodpecker diet and form a majority of the food volume consumed by northern flickers (*Colaptes auratus*). Carpenter ants are also very important to the diets of sapsuckers (*Sphyrapicus*) and acorn woodpeckers (*Melanerpes formicivorus*) (Scott and Patton 1975, Otvos and Stark 1985), and they may additionally play an important role in regulating the numbers of other insects (Sanders 1970).

Birds disproportionately select relatively larger snags for nesting (Scott 1978, Thomas et al. 1979, Cline et al. 1980, Cunningham et al. 1980, Mannan et al. 1980, Raphael and White 1984, Raphael and Morrison 1987). Forest bats also roost disproportionately in larger than average pine snags Rabe et al. (1998). Larger diameter snags provide more insulating volume as well as more surface area in which to locate nest or roost sites (Miller and Miller 1980). Larger snags are also heavily selected for

foraging sites, presumably because their larger volume and surface areas provide habitat for more invertebrate prey species (Raphael and White 1984, Weikel and Hayes 1999). Cline (1977) found that carpenter ant colonies were most common in large diameter snags. Thomas et al. (1979) suggested that a large snag could always be substituted for a smaller one, but not vice-versa. The habitat value of small snags should not be discounted, however; Horton and Mannan (1988) reported heavy foraging use of small snags produced following prescribed fire, and Thomas et al. (1979) noted that snags of deciduous species, though often smaller than pine snags, are heavily used wherever they occur.

Soft (rotten) snags with high bark retention are heavily used by birds for both nesting and foraging (Thomas et al. 1979, Cunningham et al. 1980, Raphael and White 1984, Neitro et al. 1985), although Miller and Miller (1980) stress an important distinction between heartwood decay, which is of high value for nest construction, and sapwood decay, which is of lesser value. Heavily decayed snags may be more likely to harbor carpenter ants (Cline 1977). Hard (fresh) snags are very important as well, since they serve as a recruitment pool for soft snags and also because they are used directly by bark-gleaners and some stronger-billed cavity-nesters (Mannan et al. 1980). Bark retention is an important parameter in wildlife use. Bats, brown creepers (*Certhia americana*), and invertebrates seek food and shelter directly in, on or under bark (Scott and Patton 1975, Thomas et al. 1979, Neitro et al. 1985), and bark can play an important role in retaining moisture, which influences rate of decay (Raphael and White 1984). Forest bats disproportionately select snags with loose patches of bark (Rabe et al. 1998), and Cunningham et al. (1980) found that many active cavity-nesting bird nest holes were



surrounded by bark. Broken tops are also often associated with cavity nests, possibly because bole breakage facilitates the entrance of wood-decay fungi (McClelland and Frissel 1975).

Higher snag densities are significantly correlated with higher cavity-nesting bird densities in southwestern ponderosa pine forests (Cunningham et al. 1980), and snag removal is known to reduce cavity-nesting bird numbers (Scott 1979, Scott and Oldemeyer 1983). However, whether snags are limiting to bird populations depends on the species in question as well as the stand in question (Welsh and Capen 1992, Brush 1983, Brawn and Balda 1988). McComb and Lindenmayer (1999) suggested establishing deadwood or cavity tree goals as the first step in managing for these resources.

Cunningham et al. 1980 recommended 5.2 snags (>33 cm dbh X 6 m height) per ha in southwestern ponderosa pine forests to maintain "natural" cavity nester populations. In addition, they recommended that snags should have  $\geq 40\%$  bark cover. U.S. Forest Service (USFS) guidelines for the same type recommend 4.9 snags (> 46 cm X 9 m) per ha (Reynolds et al. 1992). Ganey (1999) found that only 6.7% of ponderosa pine plots surveyed in northern Arizona forests met or exceeded Forest Service standards, and that median large snag densities ranged from 1.0 to 2.0 per ha (95% CI). Even on un-logged sites, only 30% (of 10) of plots met or exceeded USFS snag guidelines.

I inventoried ponderosa pine snags on five 7.6 to 10.4 ha plots in a managed forest in Northern Arizona in 1998 and 1999. I recorded the size, condition, and wildlife use of all snags greater than 10 cm dbh and 1.8 m in height within the five plots. My objective was to estimate the number and characteristics of snags and cavity-bearing snags of different size and condition classes prior to implementation of restoration

treatments within the plots (McComb and Lindenmayer 1999). I hypothesized that, as in the managed forests in Ganey's (1999) study, snag populations at Mt. Trumbull would not meet the density requirements of either Cunningham et al. (1980) or the USFS. I also hypothesized that bird-created cavities would be concentrated in snags of larger diameter classes (Scott 1978, Cunningham et al. 1980, and others), taller height classes (diameter is directly related to height), and in closer proximity to other snags (Miller and Miller 1980). I expected that evidence of foraging on the bole by birds would show similar associations with diameter, height, and proximity to other snags. I expected ant colonies to be concentrated in snags of larger diameter and more decayed condition, but to be unrelated to height or proximity to other snags.

## METHODS

The study area for this project was between Mt. Trumbull and Mt. Logan, north of the Colorado River in Arizona, 36° 22' N, 113° 7' W, within the Grand Canyon-Parashant National Monument. Elevation ranged from about 2,000 to 2,300 m, with volcanic-derived soils. Precipitation fell mostly in winter and in Monsoon season (July-September) thunderstorms, averaging 50.5 cm annually (1977-1997). Vegetation was dominated by ponderosa pine and Gambel oak (*Quercus gambelii*), with some Utah juniper (*Juniperus osteosperma*), Colorado pinyon (*Pinus edulis*), and New Mexican locust (*Robinia neomexicana*). The area experienced frequent surface fires prior to 1870, when grazing, logging, and fire suppression altered the natural structure and disturbance regime, leading to the pathological tree densities and fuel levels now typical of southwestern forests (Moore et al. 1999).

Five blocks (designated "EB" 1-5) of approximately 14 ha each were established in 1997, representing the range of elevations and forest structures at the Mt. Trumbull site (Table 1.1). Forty permanent points (plot centers for another study) were established in each block, at 60 by 60 m spacing, and permanently marked with steel rebar stakes driven into the ground (Fulé et al. 2001). I established snag inventory plots as the polygons formed by connecting the outermost points in each block.

Within each plot, all standing dead ponderosa pine trees greater than 10cm in diameter breast height (dbh) and 1.8m in total height were defined as snags. These limits are the smallest dimensions reported (Thomas et al. 1979) for nest trees of any species found in the area (the mountain chickadee, *Poecile gambeli*), and are consistent with a personal experience-based estimate of the minimum size of snag likely to be used. Gambel oak snags occurred in some EBs, but at variable and often low density. They were not included in this inventory.

In the summers of 1998 and 1999, I marked each snag within the 5 plots with a uniquely-numbered aluminum tag and recorded its measurements. For each tree I measured dbh with a metric steel diameter-tape, height using a clinometer, and polar coordinate location from the nearest permanent grid point using a hand-compass and metric tape measure. Diameter is an important parameter for describing snag population characteristics, and is likely to be closely related to wildlife use. Height may also be related to wildlife use. Location data make nearest neighbor distances calculable and may be useful in the future to find snags in resurveys. Nearest neighbor distances help to quantify snag distribution, and may also be a factor in wildlife selection.

I classified each snag into one of three condition classes, a modified version of Thomas et al.'s (1979) system for snags in the Blue Mountains of Oregon. Fresh snags, retaining most bark and twigs were classified as "recent." Snags missing patches of bark, and with gaps between remaining bark and wood were classified as "loose-bark." Snags that were missing most to all of their bark were classified as "clean." These designations correspond to chronological deterioration of pine snags at Mt. Trumbull (Waskiewicz and Fulé in review), but do not correspond to wood condition. Bole breakage was recorded separately.

In each snag, I visually inspected the bole to determine the presence of cavities excavated by primary cavity-nesting birds. At Mt. Trumbull, these species include the hairy woodpecker (*Picoides villosus*), northern flicker (*Colaptes auratus*), acorn woodpecker (*Melanerpes formicivorus*), Williamson's sapsucker (*Sphyrapicus thyroideus*) and pygmy nuthatch (*Sitta pygmaea*). Abandoned cavities at Mt. Trumbull may be used again by the western bluebird (*Sialia mexicana*), white-breasted nuthatch (*Sitta carolinensis*), violet-green swallow (*Tachycineta thalassia*) and mountain chickadee, but I made no attempt to ascertain cavity occupation, defining snags with  $\geq 1$  excavated cavity as "cavity-bearing" (Scott 1978, Swallow et al. 1986). Most primary cavity-nesting birds excavate at least one new cavity each year, and often use more than one in a given year for roosting (Short 1979). They may also initiate, but not finish, many cavities (Jackson 1976), which would be indistinguishable from complete cavities by an observer on the ground. Cavities may also persist long after creation, and even after occupation has ceased. Cavity-bearing trees cannot, therefore, be used to estimate bird density, and can be used to indicate nest site selection only with caution. Snags bearing

cavities may no longer possess some attributes that occurred at the time of bird selection. Snag condition class, in particular, is likely to change in the years following cavity excavation.

I also visually inspected snag boles for evidence of foraging. Visible foraging evidence consisted of bark scaling on the surface of, or deep drilling into the bole. At Mt. Trumbull, hairy woodpeckers are most likely to be responsible for both types of foraging evidence as they harvest bark beetles and wood borers, although northern flickers and nuthatches may be responsible for some evidence. Like excavated cavities, foraging evidence, especially drilling, can persist long after the conditions present at its creation have changed, so it can only be compared to relatively permanent or slow-changing snag attributes, such as diameter, height, and nearest-neighbor distance, not condition.

Some snags were vigorously defended by ants (most likely *Camponotus* sp.) and I interpreted this behavior as an indicator of ant colony presence. Ant use of snags was current at the time of inventory, so I considered all snag attributes to be potential indicators of selection.

For each plot, I calculated the density of pine snags meeting first Cunningham et al.'s (1980), then the USFS size criteria. One-sample t-tests ( $H_0$ : Density at Mt. Trumbull  $<$  recommended density,  $n = 5$ ,  $\alpha = 0.05$ ) compared snag densities at Mt. Trumbull to recommended densities.

Snags used by wildlife were infrequent, so I pooled use data across the five plots before testing selection. I tested wildlife selection of snags using an ad hoc distribution free exact test:  $\sum_{i=n}^N [N! / ((i!) * (N - i)!)] / 2^N = P(n+ | N)$ , where  $N$  is the total number of snags with a characteristic of interest (cavity-bearing trees, for example), and  $n$  is the

total number of those trees whose variable of interest (diameter, for example) exceeds the population median for that measurement. The test yields the exact probability of randomly selecting  $n$  number of snags greater than the population median for a given variable from  $N$  number of snags bearing a given characteristic (for example, the probability that 30 of 31 cavity-bearing snags will be larger than the median snag diameter is  $1.49 * 10^{-8}$  if selection is random with respect to diameter). I used this test on the following hypotheses for each type of wildlife use (cavity presence, foraging evidence presence and ant colony presence) and for each of three continuous variables (dbh, height and distance to nearest neighbor): 1) selection for the given use among the whole population is random with respect to the given variable, 2) selection for the given use among the segment of the population that has a value of the given variable  $\geq$  the minimum value of that variable for used snags is random with respect to the variable, 3) selection for the given use among the segment of the population that has dbh  $\geq$  minimum dbh of used snags is random with respect to the given variable. The first hypothesis test determined if a relationship might exist between a given use and variable. The second and third tests were used only when hypothesis 1 was rejected for a given use - variable combination and test whether the relation exhibits a threshold pattern (2) or is driven by diameter (3), which is considered to be the most important factor in snag selection (Thomas et al. 1979). All tests had  $\alpha = 0.05$ .

Because ant colony presence is a direct and current, rather than indirect and retrospective measure of use, I tested ant selection of snags against the more ephemeral characteristics of condition class and bole breakage. I used Chi-square tests of independence (Pearson 1900) to test the null hypotheses of 1) independence between ant

colony presence and snag condition 2) independence between ant colony presence and bole breakage ( $\alpha = 0.05$ ).

## RESULTS

I tagged and measured 184 pine snags across the five plots. Snag densities averaged 4.1 per ha (95% CI: 2.3 to 6.1)(Table 1.2). The distribution of pine snag diameters across the five plots was skewed, with large numbers of small snags, but appeared to approximate a normal distribution for sizes greater than about 30cm (Fig. 1.1). There was no relationship between total snag density and the density of “large” (by either recommendation standard) snags – large snags constituted neither a constant proportion of the snag populations, nor did they occur at a constant density.

Snags meeting Cunningham et al.’s (1980) size criteria had an average density of 1.6 per ha (95% CI: 0.6 to 2.6), which was significantly lower ( $P = 0.001$ ) than the recommended density of 5.2 per ha. When Cunningham et al.’s bark cover recommendations were also considered, Mt. Trumbull snag densities were still more deficient (Table 1.2). Snags meeting USFS size criteria had an average density of 1.0 per ha (95% CI: 0.1 to 1.9), which was significantly lower ( $P < 0.001$ ) than the recommended density of 4.9 per ha.

Almost 55% of Mt. Trumbull snags bore at least one type of wildlife use; 17% contained excavated cavities, 38% displayed foraging evidence and 27% harbored ant colonies. Wildlife use types were not mutually exclusive; 41% of the trees that were used by wildlife exhibited use of more than one type.

Distribution free exact test results failed to reject hypothesis 1 for cavity presence relative to nearest neighbor distance, and foraging evidence relative to height and nearest neighbor distance, but rejected the random selection hypothesis for the other six use – variable combinations (Table 1.3). Birds at Mt. Trumbull disproportionately selected snags in the broader and taller halves of the population for nesting, and in the broader half of the population for foraging. Ants disproportionately selected snags in the broader and taller halves of the population and beyond the median distance from other snags.

Tests of hypothesis 2 indicated that the minimum diameters of cavity-bearing (42.6 cm) and ant colony-bearing (22.7 cm) snags were threshold levels. For each use, selection among snags equal to or exceeding the minimum diameter did not differ from expectations of random chance allocation ( $P = 0.141$  and  $P = 0.101$ , respectively). Such threshold values did not appear for cavity site selection by height ( $P = 0.015$ ), forage selection by diameter ( $P = 0.046$ ), nor for ant selection by height ( $P = 0.033$ ) and nearest neighbor distance ( $P = 0.008$ ).

Tests of hypothesis 3, performed for use-variable combinations not already including dbh, indicated that dbh was driving the apparent ant selection by height and nearest neighbor distance. When minimum diameter thresholds were satisfied, ant colonies were found no more often than expected on either side of the median height ( $P = 0.336$ ) or the median distance ( $P = 0.336$ ). Cavity nesting birds, however, still disproportionately selected taller snags even among those that met the minimum diameter threshold ( $P = 0.015$ ). A similar test showed that, among snags that met or exceeded both the minimum height (4.2) and minimum diameter of used snags, selection was no longer disproportionately distributed around the median height ( $P = 0.360$ ).



Because diameter was a factor in snag selection by ants, I entered only snags meeting or exceeding the minimum used diameter into Chi-square analysis of selection by condition class and bole breakage. Smaller snags tend to be of younger condition and are less likely to be broken than larger snags because they are more likely to fall over before they reach advanced states of decay and are less exposed to wind. Including smaller snags in the test might have confounded the known diameter effect on snag selection with possible condition or breakage effects. Ant colony presence was independent of condition class in snags for the 122 snags  $\geq 22.7$  cm dbh ( $\chi^2 = 1.413$ ,  $P = 0.493$ ). It was also independent of bole breakage among the same snags ( $\chi^2 < 0.001$ ,  $P = 0.990$ ).

## DISCUSSION

Pine snag densities at Mt. Trumbull were well below the density recommendations of both Cunningham et al. (1980) and the USFS. They were also somewhat lower than those reported in Ganey (1999). Many of the smaller snags in the five Mt. Trumbull plots likely represent competition-induced mortality, as the dense reproduction that followed settlement activities here and elsewhere in the southwest (Covington et al. 1997) passes through the stem exclusion stage of stand development (Oliver and Larson 1996). The lack of a relationship between total snag density and the density of large snags suggests that distributions could neither be characterized as a consistent large snag population surrounded by a variable population of small snags, nor as large snags making up a consistent proportion of the population.

Both Ganey (1999) and Boucher et al. (1999) found that older condition classes dominated the snag populations of southwestern ponderosa pine forests. At Mt. Trumbull, I found the opposite to be the case, with "recent" snags being the most common and "loose-bark" snags being least common (Table 1.4). Among larger snags, however, the "recent" condition was the least common. Most recent snags were small. Smaller snags do not stand as long as larger snags (Thomas et al. 1979), and so are less likely to reach the more advanced stages of decay before falling. The dominance of older snags among the large snag population is not strong, but is consistent with others' findings.

Over half of all snags at Mt. Trumbull have been used by wildlife at some time. This is likely a very conservative estimate of the actual number. Some signs of wildlife use were probably missed and not recorded. Other signs have probably disappeared as bark sloughed off and boles broke. Less obvious use of snags, such as foraging by bark gleaners, nesting by secondary cavity nesters, and use by insects other than ants were not recorded but certainly took place.

Nearest neighbor distances did not appear to be important in the selection of snags used for foraging or nesting, and height did not appear to be related to foraging. Diameter was closely related to all three types of wildlife use, but cavities and ants displayed a threshold pattern, wherein no snags below a minimum diameter were used, and those above that diameter were used in equal proportions. For cavity nests, the minimum appeared to be ~40 cm; for ant colonies, ~20 cm. Foraging use also showed a threshold pattern, with proportional use among snags above 33 cm dbh ( $P = 0.284$ ) at a higher rate (43% vs. 28%) than the proportional use ( $P = 0.250$ ) among snags below 33

cm. The apparent relationships between ant colonies and height and nearest neighbor distance were artifacts of those variables' relationships to diameter, but height remained important in cavity presence even after diameter was accounted for. Diameter was the only important factor in wildlife use by foraging birds and ants, even after condition class and bole breakage were considered for ants. Diameter and height were both important in cavity presence. This is consistent with earlier literature (Scott 1978, Thomas et al. 1979, Cunningham et al. 1980). Ant colonies in larger diameter snags may also be better insulated from weather and protected from predators, and so be more likely to survive.

Cunningham et al.'s (1980) and the USFS snag density recommendations and size criteria are built around the requirements of cavity-nesting birds. I found that Cunningham et al.'s size criteria to be more appropriate at Mt. Trumbull. About 17% of all pine snags at Mt. Trumbull bore excavated cavities (95% CI: 9.2 to 24.9%)(Table 1.5). The proportion of cavities in trees meeting Cunningham et al.'s (1980) size criteria was 11 to 37% higher (95% CI,  $P = 0.007$ , paired t-test) than the proportion in the general population, but the proportion of cavities in trees meeting the USFS size criteria was not significantly higher than for the Cunningham et al. criteria ( $P = 0.051$ ). Over 90% of cavity-bearing snags met Cunningham et al.'s size criteria, while nearly a third (32%) of them were smaller than the USFS size standards.

The fact that 90% of cavity-bearing trees met Cunningham et al.'s (1980) size criteria suggests that these criteria are appropriate for nesting birds at Mt. Trumbull. The minimum cavity-bearing tree diameter was 42.6cm, so an even higher diameter standard may also be appropriate. Almost a third of cavity-bearing trees did not fit the USFS criteria, not because of small diameter but because of insufficient height. Over two-thirds

(67.7%) of cavity-bearing trees have broken tops, compared to 51.1% of the snag population generally, and to only 44.2% of trees meeting USFS size criteria. All but one of the cavity-bearing snags that met Cunningham et al.'s criteria but failed to also meet USFS criteria lacked only height.

## MANAGEMENT IMPLICATIONS

The Mt. Trumbull snag resource is understocked, according to two important standards of appropriate snag density. In future management prescriptions, efforts should be made to preserve all snags, especially large ones, and consideration should be given to snag creation. Though small snags are less important to wildlife than large ones, they currently make up the majority of the population and should be retained whenever possible.

Boucher et al. (1999) and Ganey (1999) both suggested that USFS guidelines for snag retention were unrealistic, particularly in the presence of a frequent fire regime such as that believed to have existed prior to settlement and prescribed as part of future ecosystem restoration efforts. Good conservation practice demands prudence, which would advocate erring on the side of snag preservation, even if we believe that the current densities are above that found in the natural forest (Ganey 1999). Prescribed fires are known to destroy snags, particularly when unprotected (Gaines et al. 1958, Horton and Mannan 1988, Gordon 1996, Laudenslayer 2002), so there is considerable risk of reducing the snag resource when fire is reintroduced into an ecosystem. With the heavy fuel loading in current ponderosa pine forests, it is advisable to rake duff away from the bases of any snags in areas prescribed for restoration or other fire-oriented treatments.

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## TABLES AND FIGURES

Table 1.1: Site characteristics, size, and year of survey for five snag inventory plots at Mt. Trumbull, northern Arizona.

Plot	Elevation (m)	Aspect	Soil <sup>a</sup>	Live pine density <sup>a</sup> (#/ha)	Area surveyed (ha)	Year of survey
EB 1	2050	Level	Lava / cinder	540	8.28	1998
EB 2	2100	East	basaltic	480	7.56	1998
EB 3	2250	Southeast	cinder	560	10.44	1998, 1999
EB 4	2100	Northwest	basaltic	1690	8.28	1999
EB 5	2050	North	basaltic	NA <sup>b</sup>	10.08	1999

a: From Waltz et al. (in press).

b: Data for EB 5 were not available.

Table 1.2: Densities of ponderosa pine snags (at least 10cm dbh X 1.8m height) and ponderosa pine snags meeting four size and bark-retention criteria on five plots inventoried at Mt. Trumbull, northern Arizona in 1998 and 1999.

Plot	Pine snag density (#/ha)				
	All snags	Snags $\geq 3$ cm dbh and $\geq 6$ m height <sup>a</sup>	Snags $\geq 3$ cm dbh and 6 m height in condition 3+4 <sup>b</sup>	Snags $\geq 3$ cm dbh and 6 m height with >50%bark <sup>c</sup>	Snags $\geq 6$ cm dbh and $\geq 9$ m height <sup>d</sup>
EB 1	5.0	3.0	2.3	1.7	2.2
EB 2	5.6	1.5	0.7	0.7	0.9
EB 3	5.2	1.3	1.0	0.7	0.8
EB 4	3.1	1.2	0.8	0.5	0.7
EB 5	2.1	1.0	0.5	0.3	0.4
MEAN <sup>e</sup>	4.1	1.6	1.0	0.7	1.0

a: Cunningham et al.'s (1980) recommended snag size standards.

b: A liberal estimate of snags meeting Cunningham et al.'s (1980) size standards, and retaining > 40% bark cover. "Condition" refers to Thomas et al. (1979).

c: A conservative estimate of snags meeting Cunningham et al.'s (1980) size standards, and retaining >40% bark cover.

d: USFS snag size standards.

e: Weighted means.

Table 1.3: Results of a distribution-free exact test of probability that the given wildlife use (cavity presence, foraging evidence, ant colony presence) is randomly selected with respect to the given variable (dbh, height, distance to nearest neighbor) measured on ponderosa pine snags at Mt. Trumbull, northern Arizona in 1998 and 1999.

Variable	Median value of variable (M)	# of cavity-bearing snags > M (of 31)	P <sup>a</sup>	# of foraging evidence-bearing snags > M (of 69)	P <sup>a</sup>	# of ant colony-bearing snags > M (of 50)	P <sup>a</sup>
dbh	46.2	30	<0.001	45	0.008	43	<0.001
height	9.3	24	0.002	35	0.500	32	0.033
distance to nearest neighbor	22.7	19	0.141	39	0.168	34	0.008

a: P is the probability of the previous column's value, assuming a null hypothesis that use is random with respect to variable in first column.

Table 1.4: Distribution of ponderosa pine snags (at least 10 cm dbh X 1.8 m height) and the subset of a larger category of snags into three condition classes at Mt. Trumbull, northern Arizona in 1998 and 1999.

Plot	% of total snags in class			% of snags >33 cm dbh and 6 m height in class		
	Recent	Loose bark	Clean	Recent	Loose bark	Clean
EB 1	34.1	36.6	29.3	36.0	40.0	24.0
EB 2	42.9	14.3	42.9	36.0	9.1	42.9
EB 3	44.4	25.9	29.6	28.0	42.9	35.7
EB 4	50.0	19.2	30.8	20.0	50.0	30.0
EB 5	38.1	14.3	47.6	30.0	20.0	50.0
Mean <sup>a</sup>	41.8	23.4	34.8	31.4	34.3	34.3

a: Weighted means.

Table 1.5: Density of cavity-bearing pine snags and percent of three size categories of pine snags (at least 10 cm dbh X 1.8 m height) bearing excavated cavities at Mt. Trumbull, northern Arizona in 1998 and 1999.

Plot	cavity tree density(#/ha)	% of pine snags with cavities		
		all snags	>33 cm dbh and 6 m height	>46 cm dbh and 9 m height
EB 1	1.1	22	32	39
EB 2	0.5	10	36	57
EB 3	1.0	19	57	63
EB 4	0.4	12	30	33
EB 5	0.5	24	50	75
MEAN <sup>a</sup>	0.7	17	34	49

a: Weighted mean.

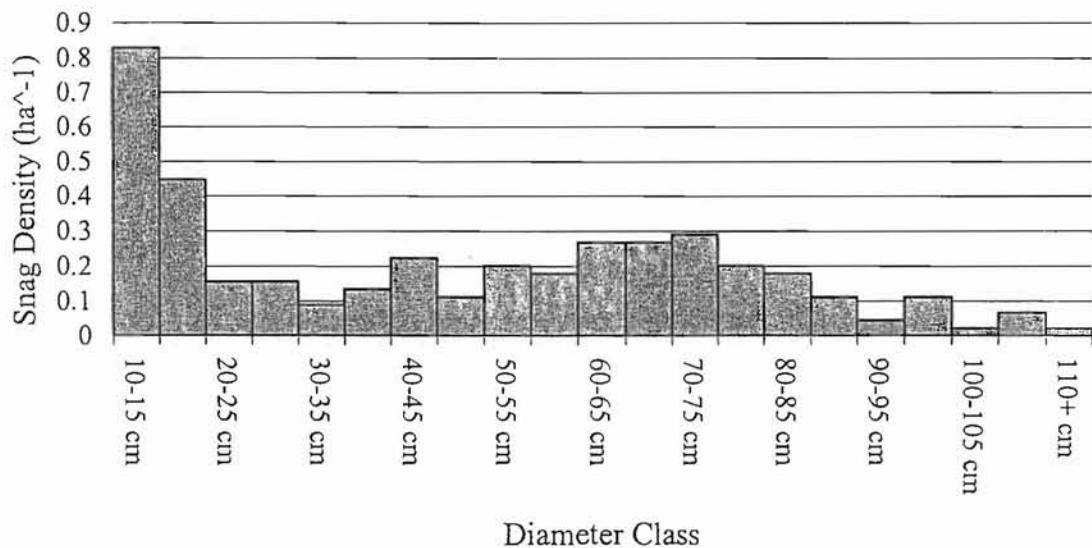


Figure 1.1: Distribution of ponderosa pine snags at Mt. Trumbull, northern Arizona across 5 cm diameter classes in 1998 and 1999.

## CHAPTER 4

# CHANGES IN THE STANDING DEADWOOD RESOURCE FOLLOWING RESTORATION OF A PONDEROSA PINE FOREST IN NORTHERN ARIZONA

**Abstract:** Snags provide habitat structures for many vertebrate and invertebrate species in northern Arizona ponderosa pine forests. Living trees bearing deadwood components (“partial snags”) such as lightning scars and spike tops also provide wildlife use opportunities. The effects of ecosystem restoration treatments on the standing deadwood resource (snag and partial snags) have not previously been studied. I inventoried snags and partial snags before and after restoration treatments at Mt. Trumbull, Arizona to assess changes in standing deadwood quantity, quality, and use by wildlife. Plots treated for forest restoration experienced a rate of pine and oak snag loss five times that in untreated controls. New snag creation in both treated and control plots exceeded loss, with treated plots netting a 60 – 1714% increase in pine snag density and 69% increase in oak snag density to the controls’ 12 – 33% increase in pine and 13% increase in oak. After treatment, treated plot snag populations of both species were skewed toward recent snags. Pine partial snags in treatment plots were as likely to die or be destroyed in those in controls. Oak partial snags in treatment plots died at 2.5 times the rate of control plots, and were destroyed at 9 times the rate of controls. Snags and partial snags used by wildlife were destroyed at higher rates in treatment than control plots. Densities of cavity-bearing and ant-infested trees in treatments experienced little net change, while the density of trees bearing foraging evidence quadrupled. Many of the

large snags created in treatment areas resulted from unexpectedly intense prescribed fires. Future restoration treatments may show much lower levels of snag recruitment than observed at Mt. Trumbull.

## INTRODUCTION

Ponderosa pine (*Pinus ponderosa* var. *scopulorum*) and Gambel oak (*Quercus gambelii*) snags are important to many southwestern forest wildlife species for a variety of uses (Scott and Patton 1975, Davis 1983), including foraging (Raphael and White 1984, Morrison et al. 1987), roosting (Sydeman and Güntert 1983, Rabe et al. 1998), display, communication and other uses (Miller and Miller 1980, Davis 1983). Cunningham et al. (1990) found a significant positive correlation between snag density and cavity-nesting bird populations. Both birds and bats disproportionately select larger snags for nesting and roosting (Scott 1978, Cunningham et al. 1980, Rabe et al. 1998). Thomas et al. (1979) recommended that a larger snag could always be substituted for a smaller one in management decisions, although smaller snags are often used for foraging (Horton and Mannan 1988), and smaller deciduous species are often strongly selected (Thomas et al. 1979). Soft, particularly heart-rotten, snags with loose bark clinging to the bole are heavily used for nesting, roosting and foraging (Thomas et al. 1979, Cunningham et al. 1980, Miller and Miller 1980, Raphael and White 1984, Rabe et al. 1998), but Neitro et al. (1985) recommended that managed forests should have snags of a variety of decay states, with enough young snags to provide for future old snags.

Partial snags (living trees with dead wood components like lightning scars, spike tops, and other wounds) are potentially also an important source of standing dead wood

for wildlife (Mast et al. 1999). Wildlife use of partial snags has been recorded in a number of studies (Scott et al. 1978, Cunningham et al. 1980, Raphael and White 1984, Li and Martin 1991, Rabe et al. 1998), and the role of partial snags as recruitment pools for future snags is likely also important (Miller and Miller 1980, Mast et al. 1999). Mast et al. (1999), Boucher et al. (1999) and Ganey (1999) have suggested that partial snags might have had an important role to play in the pre-settlement forest, where fully dead trees (hereafter, "snags") may have been less common due to the frequent fire regime. As frequent fire regimes are reintroduced to southwestern forests through restoration and other fuel-reduction treatments, partial snags may again take on a prominent role.

Fire and forest treatments can change both the numbers and the qualities of snags and partial snags present in a stand. Horton and Mannan (1988) found a net decrease in snag abundance following prescribed fire in the Coronado National Forest. They also found that larger and more decayed snags were more likely to be destroyed than younger and smaller ones. They attributed this to the larger accumulation of litter and debris at the bases of the former type. Gordon (1996) also found that basal fuel depths were a strong predictor of snag destruction. New snags in both Horton and Mannan's (1988) and Gordon's (1996) studies were disproportionately of smaller size classes, likely because smaller trees are less fire resistant than mature ones (Reinhardt and Ryan 1988). Because cavity nesting bird populations are closely associated with the density of large (>46cm) snags (Cunningham et al. 1980), a disproportionate loss of large snags followed by disproportionate gain of small snags is likely to be important to wildlife.

Restoration treatments, consisting of small-tree thinning followed by prescribed surface fire, are being employed throughout the southwestern ponderosa pine-Gambel

oak type to restore ecosystem structure and function and to ameliorate fire and disease risks resulting from overstocking (Covington et al. 1997, Lynch et al. 2000). Restoration treatments have the potential to greatly alter the snag resource, as old snags are burned up, cut down (for safety reasons), or blown over after exposure to wind, while new snags are created by fire mortality.

Restoration treatments differ from the prescribed burns in Horton and Mannan's (1988) and Gordon's (1996) studies in a number of respects. First, small pine trees are dramatically thinned (approximately 85% reduction –Waltz et al. in review), leaving fewer small trees from which snags may be recruited. Secondly, efforts are made to protect large, old-growth pine (>37.5cm dbh, or displaying the yellow, plated bark of maturity) by thinning around them and raking away litter and duff accumulations at their bases (Covington et al. 1997). Lastly, large snags are retained whenever possible during thinning and many of these also receive duff-raking to protect them from flames.

Gambel oak snags and partial snags, which are also used by cavity-nesting birds and other wildlife (Leidolf et al. 2000), have received less attention in the literature than the larger pine snags, but are also likely to be affected by treatments. Oak are not explicitly thinned in restoration treatments (though some are cut to expedite operations), but are much more susceptible to fire mortality than pine, as they lack thick, protective bark. The effects of fire on oak snags have not yet been explored.

I tagged, measured, and recorded wildlife use of ponderosa pine and Gambel oak snags and partial snags on four restored and three control plots at Mt. Trumbull, northern Arizona before and after restoration treatments. My objective was to record the quantitative and qualitative changes in the standing dead wood resource (snags and



partial snags) resulting from restoration treatments. Changes resulted from standing deadwood loss and recruitment. I hypothesized that loss would exceed recruitment in treated areas, with larger and older (in time since death) snags more susceptible to destruction than smaller and younger ones. Such results would be consistent with previous literature (Horton and Mannan 1988, Gordon 1996, Laudenslayer 2002). I further hypothesized that partial snags would be more resistant to destruction than full snags, because they maintain a protective layer of bark. I predicted that recruitment would be dominated by small-sized trees, though less so than in previous studies because of the reduced small tree recruitment pool available after thinning operations that is typical of restoration. New partial snags in treatment areas were not expected to make up for losses of old ones, since restoration activities include no mechanism capable of creating spike tops or lightning scars. Post-restoration plots were expected to have relatively lower standing deadwood density and size, and to have reduced density of older condition snags. I anticipated a net loss of cavity-bearing and ant colony-bearing trees, but expected a net gain of trees displaying evidence of use for foraging, with new snags being scaled for insect larvae.

## METHODS

### Study area

The study area for this project was located between Mt. Trumbull and Mt. Logan, north of the Colorado River in Arizona, 36° 22' N, 113°7' W, within the Grand Canyon-Parashant National Monument. Elevation ranged from about 2000 to 2300m, on volcanic-derived soils. Precipitation fell mostly in winter and in Monsoon season (July-

September) thunder storms, averaging 50.5cm annually (1977-1997). Precipitation during the years of the study (1998 – 2002) was 56, 28, 36, 33, and 19 cm, respectively. Vegetation was dominated by ponderosa pine and Gambel oak, with some Utah juniper (*Juniperus osteosperma*), Colorado pinyon (*Pinus edulis*), and New Mexican locust (*Robinia neomexicana*). The area experienced frequent surface fires prior to 1870, when grazing, logging, and fire suppression altered the natural structure and disturbance regime, leading to the pathological tree densities and high fuel levels now typical of southwestern forests (Moore et al. 1999).

Four experimental blocks (“EB’s” 1 - 4), each consisting of two separate units (control: C and treatment: T) of approximately 7 ha each, were established in 1997, representing the range of elevations and forest structures at the Mt. Trumbull site (Table 2.1). Twenty permanent points (plot centers for another study) were established in each unit, at 60 by 60m spacing, and permanently marked with steel rebar stakes driven into the ground (Fulé et al. 2001). Standing deadwood inventory plots were established by the polygons formed from connecting the outermost points in each unit. Plot sizes ranged from 2.88 to 5.04 ha. Control-treatment plot pairs in each block were separated by a buffer of approximately 100 m.

### **Initial inventory**

Within each plot, all standing dead trees greater than 10 cm in diameter breast height (dbh) and 1.8 m in total height were defined as snags. These limits are the smallest dimensions reported (Thomas et al. 1979) for nest trees of any species found in the area (the mountain chickadee, *Poecile gambeli*). In the summers of 1998 (EB 1, EB

2, EB 3T) and 1999 (EB 3C, EB 4), I marked all snags within the eight plots with uniquely-numbered aluminum tags and recorded measurements for each. I also marked and measured all partial snags bearing deadwood of equal or greater dimensions (1.8 m height or length X 10 cm diameter or width) in spike tops, lightning scars, or other substantial wounds. In EB4, I marked and measured only pines. For each tree I recorded species, dbh using a steel metric diameter tape, polar coordinate location from the nearest grid point using a hand compass and metric tape measure, wildlife use (excavated cavities, evidence of woodpecker foraging on the bole, and ants) and condition (classes 3-5, following Thomas et al. 1979, where 3 = "recent" 4 = "loose bark" 5 = "clean"). Thomas's condition class 6, "broken above breast height," was not recorded as a separate class, as it is probably unrelated to fire resistance or age (Waskiewicz and Fulé, in review). I recorded wildlife use as presence or absence for three types of use: excavated cavities, foraging evidence, and ant colonies. Excavated cavities in this area are most likely to be created by the hairy woodpecker (*Picoides villosus*), northern flicker (*Colaptes auratus*), or pygmy nuthatch (*Sitta pygmaea*) although acorn woodpeckers (*Melanerpes formicivorus*) and Williamson's sapsuckers (*Sphyrapicus thyroideus*) also inhabit the study area and construct cavity nests (Scott and Patton 1975). Excavated cavities are distinguished from natural holes by a round or oval shape with smooth edges. Foraging evidence was defined as scaling of bark or drilling into the surface of a tree bole, an activity likely to be engaged in primarily by hairy woodpecker seeking bark beetles (*Scolytidae*) or wood borers (*Buprestidae*) (Otvos and Stark 1985). Ants (*Formicidae*) inhabit many snags, logs, and live trees on the study site. Their presence was determined by observing aggressive defense behavior while trees were being tagged

and measured. The same information was taken for partial snags, with condition values assigned to dead portions alone. Lightning scars and other wounds were noted; spikes were described in terms of base and top height using a clinometer.

### Treatments

Thinning of treatment units took place in 1999. All pine displaying the reddish-yellow, plated bark characteristic of mature trees ("pre-settlement" trees) were retained. For each snag, log, or stump encountered, three replacement trees within a 10 to 20m radius were also retained (Fulé et al. 2001, Waltz et al. in review). Deciduous species were not thinned. Slash was lopped and scattered. Litter and duff were raked back 0.3 to 1m from the boles of old-growth pine and large pine snags. Prescribed burns were conducted in the fall of 1999 and spring of 2000 (Fulé et al. 2001). In EB 4, there was more logging slash than expected and more trees were left standing than prescribed. As a result, the prescribed burn caused high mortality (Waltz et al. in review). In EB 3, fires escaped control lines and burned through the adjacent control area, rendering it unacceptable for its original purpose. No results are therefore reported here for EB 3C.

### Re-measurement

In 2001, I relocated all snags and partial snags, or their remains, and recorded their new condition. During the re-measurement, I sought to avoid bias in classification by not looking at the previous inventory's designations for each tree. Snags that no longer met the minimum qualifications for measurement were considered "destroyed." I coded destroyed snags with a modified version of Thomas' (1979) conditions: "broken above bh, but below 1.8 m", "broken below bh", "downed," taken to mean tipped out by

the roots, rather than broken off low to the ground, “cut stump” and “stump hole,” which remained after complete consumption of the wood by fire. For some snags, no trace remained, and their loss was also recorded. Many broken snags in treatment areas actually burned off, and it is possible that snags re-classified as stump holes were initially destroyed by another means before fire consumed their remains.

In 2002 (allowing another year for latent mortality and injury to manifest – Swezy and Agee 1991), I collected data on new recruits to the snag and partial snag populations, recording the same information as in 1998 and 1999 for trees that died (or partially died) in the interim period. There were so many new pine snags in EB4 that I could not tag and measure all of them, so I consulted sample data collected from 0.04 ha plots laid out at the permanent grid points placed in each plot (for another study - Waltz et al. in review) to estimate their quantity and qualities, but not their use.

### **Data analysis**

Each snag was classified as destroyed (present in 1998/9, gone in 2001), created (present in 2002, not present in 1998/9) or surviving (present in 1998/9, still present in 2001). I created 90% confidence intervals for the number per ha and percent of destroyed snags, the number of created snags per ha, and the post-treatment number per ha and percent net change of snag numbers in control (3) and treatment (4) plots. Paired-samples t-tests were used to compare destruction of large ( $\geq 37.5$  cm dbh) and small pine snags in treatments and in control areas separately. Since diameter and destruction seemed to be related in treatment units, I built a logistic regression model of probability of destruction based on diameter.

I used an independent samples t-test ( $n = 4$ ) to compare the percent destruction of pine full snags to that of partial snags within treatment units ( $\alpha = 0.10$ ). Partial pine snags were on the whole rather uncommon, so I pooled their numbers within C and within T, and reported changes in their density without statistical comparison. The same was done for trees used by wildlife, because they were also uncommon. Oak snags and oak partial snags were common only in EB 2, so all comparisons of change in the oak snag and partial snag resource were based on that block alone.

## RESULTS

### Snag and partial snag fates following treatment

In control units, 14.5% (90% CI: 5.8 – 23.1%) of the original pine snags were destroyed between the initial inventory (1998 and 1999) and the re-measurement (2001). Over the same time period, treatment units lost 76.2% (90% CI: 46.8-105.5%,  $N = 4$ ) of their original snags (Table 2.2). In control units, all (100% of 8) of the pine snags that were destroyed were lost to falling. In treatment units, a plurality of the pine snags was lost to burning (35% of 60). Other large proportions were lost to cutting (28.3%) or without a trace (21.7%)(Table 2.3).

Pine snags  $\geq 37.5$  cm dbh had lower rates of destruction than smaller snags in both treatment (59% versus 95%) and in control units (6% versus 19%), but the difference was statistically significant only in treatment units ( $P = 0.088$ ). In treatment units, 37 of 60 destroyed snags were smaller than the median diameter; the probability of this occurring if destruction is random with respect to diameter is 0.050 (distribution-free exact test described in Chapter 3). In control units, 6 of 8 destroyed snags were smaller

than the median diameter ( $P = 0.145$ ). When cut snags were eliminated from analysis in treatment areas, 23 of 43 destroyed snags were larger than the median diameter ( $P = 0.40$ ); large snags in treatment units had a higher rate of survival only because they were less likely to be cut down. Cut snags do represent a real loss, even if unintended, so they were not excluded from further analysis of snag destruction.

Pine snags in more advanced condition classes in control units appeared to be lost in lower proportions than those in lower condition classes, but the effect is inconclusive since only 8 such snags were destroyed in all. (Table 2.4). In treatment units, condition class had a less obvious impact on fate, and the outcome varied by size class. In treatment units, 80 to 100% of small pine snags were destroyed following treatment, independent of condition class. Large loose bark and clean pine snags were destroyed in higher proportions than large recent snags ( $\chi^2 = 3.34$ ,  $P = 0.068$ ).

Because 92% (of 59) of pine partial snags were large ( $\geq 37.5$  cm dbh), my analysis excluded the five partial snags small enough to have been cut down as part of thinning operations. On average, 8% of large partial snags in treatment areas were destroyed (no longer standing) following treatments (90% CI: -4 – 21%,  $N = 4$ ). This is a significantly lower rate of destruction than the 60% rate for large pine snags ( $P = 0.009$ ), but did not differ from the 0% destruction rate for partial snags in control units. Some partial snags that were not destroyed were killed but remained standing, adding to the snag population. In treatment units, 23% (of 35) of the original partial snags became full snags (90% CI: -3 – 48%); in controls, 5% (1 of 19) died and remained standing.

Oak snags were too rare to analyze in any unit except in EB 2. There, 43.2% (of 289) of the original oak snags were destroyed by 2001 in the treatment unit; in the control

unit, only 8.1% (of 219) were lost. Cutting accounted for 72.2% (of 18) of the oak snag destruction in the control. Non-anthropogenic losses were divided between breakage and falling (11.1 and 16.7%, respectively). In the treatment unit, 50.4% (of 125) of oak snag losses were due to bole breakage. Most of these broken boles resulted as flames burned most of the way through the base, leaving insufficient supporting wood though logging equipment broke some off. Falling claimed 18.4% of oak snags, 24.0% left no trace (most of these were probably completely consumed by fire and left no visible stump hole; some were obliterated by skid trails), 4.0% were cut, and 4.8% were incinerated.

In EB 2C, 15 of the 18 destroyed oak snags were larger than the median oak snag diameter ( $P = 0.004$ ). When the 13 cut snags are excluded from analysis, however, only 4 of 5 are larger than the median diameter ( $p = 0.188$ ), so the apparent relationship between size and destruction probably reflects the preferences of a woodcutter, rather than any natural proclivity. There was no tendency for destroyed oak snags in the treatment unit to be larger or smaller than the median, even when cut snags were excluded. There was also no apparent difference in proportions of oak snags destroyed in each of the three condition classes, in either control or treatment units.

In EB 2C, 15.3% (of 137) oak partial snags died between 1998 and 2001, and 1.5% were destroyed (all cut illegally). In the treatment unit, 39.4% (of 99) oak partial snags were killed, and 13.1% were destroyed. Because oak partial snags were much smaller than pine partial snags, and because there were only 7 large ( $>37.5$ cm dbh) oak partial snags, these rates are not directly comparable to those for pine partial snags.



### Snag and partial snag recruitment

Control plots gained, on average, 1.8 new pine snags per ha, while treatment plots gained 13.5 per ha (Table 2.5). In control areas, new pine snags averaged slightly smaller in diameter than those present prior to treatment (90% CI for mean difference: 0.9 – 11.1cm,  $P = 0.084$ ). In treatment units there was no difference in diameter between new and old pine snags. Of the new pine snags, 94% (17 of 18) in control units, and 99% (153 of 154) in treatment units were of recent condition – the other two snags were classed as loose bark.

Very few pine partial snags were created between 1998 and 2002. No data were available for new partial pine snags in EB 4, but EBs 1 through 3 gained only 5 new pine partial snags on treatment and control plots combined, and one of these was < 37.5 cm dbh. There appeared to be no tendency for more pine partial snags to be created in treatments than controls (2 new in treatment, 3 new in control).

EB 2C gained 11.9 oak snags per ha, while EB 2T gained 90.0 per ha. New oak snags in the control were approximately the same size as those present in 1998, but new oak snags in the treatment unit were larger (90% CI for difference: 1.5 – 2.7 cm,  $P < 0.001$ ), averaging 15.2 cm dbh. As expected, almost all new oak snags in EB 2 were of recent condition (94% in C, 90% in T). The remaining oak snag recruits were in the loose bark class, except for a single snag in the treatment unit that was clean.

Fifty-four new oak partial snags were created in treatment and control units of EB 2. In 2002, there were 7.1 new partial oak snags per ha in EB 2C, and 7.2 new partial oak snags per ha in EB 2T.

### Net changes in the standing dead wood resource

Between the pre-treatment inventory and 2002, both treatment and control units experienced a net gain in total pine snag density (Table 2.6). On average, control units had 1.7 more pine snags per ha in 2002 than at initial inventory, and treatment units had 7.8 more per ha. In 2002, I detected no change in average pine snag size ( $P > 0.10$ ) since initial inventory.

Net numbers of recent and loose bark snags increased over 25% in control areas and clean snag numbers decreased trivially (Table 2.7), causing a shift toward fresher snag condition classes. Increases in snag number were not expected in control areas, but probably resulted from drought conditions in 2000 and 2002. In treatment units, loose bark and clean snags both decreased by about 67%, while recent snag numbers almost quadrupled (Table 2.7). As a result, the post-treatment distribution of snag classes in treatment areas was skewed toward younger classes, with 92% of post treatment pine snags classified as recent (Table 2.7).

Pine partial snag numbers decreased in 2 of 3 treatment units (by 1 in EB 2 and by 8 in EB 3; no post-treatment partial snag data are available for EB 4), and increased in 2 of 3 control areas (EB 1T by one tree and EB 2C by one). Numbers for net change in partial snag numbers are too low to draw any statistically valid conclusions.

Oak snag numbers increased by 13.2% (to 62.6 per ha) in the EB 2C, and by 68.9% (to 135.6 per ha) in EB 2T. Average oak snag diameters remained unchanged in the control unit, but increased by 1.2 cm in the treatment unit. In the control unit, recent and loose bark oak snag numbers increased by about 20%, but clean oak snag numbers decreased by 55% (Table 2.8). The decrease in clean oak snag numbers was not caused

by the loss of any of the 22 clean oak snags. Instead, 12 snags on the borderline of the class definitions (having very small amounts of bark remaining) were re-assigned to the loose-bark class in the re-measurement (during the re-measurement, I sought to avoid bias in classification by not looking at the previous inventory's designations for each tree), and no new snags advanced into the clean category. Only one loose bark snag was reclassified as recent. In the treatment unit, loose bark and clean snag numbers decreased by 22% and 7% (respectively), while recent oak snag numbers increased by 288% (Table 2.8). Numbers of oak partial snags increased by a net 3.6% (to 142) in the EB 2 control unit, but decreased by a net 26.3% (to 73) in the treatment unit.

#### Changes in wildlife use of standing dead wood

Snags and partial snags bearing signs of wildlife use were subjected to the same destructive forces as other trees – no special effort was made to preserve wildlife trees during treatment. Loss of wildlife trees occurred when previously used trees were destroyed or ceased to show evidence of use. For all three types of wildlife use, loss tended to be higher, as a proportion of initial number, in treatment than in control plots (Table 2.9). New wildlife use was recorded in surviving snags and partial snags, and in newly created snags (recruited both from formerly pristine live trees and from former partial snags) and new partial snags. New cavity trees were created at about the same density in both control and treatment units, and both treatments and controls experienced a small net loss of cavity trees. New forage trees were created at five times the density in treatment than control areas. Control units netted an 12% increase in forage tree numbers, while treatment units gained a net 392% increase (Table 2.9). New ant

infestations occurred in 3.5 trees per ha in control units, but only in 2.2 per ha in treatment areas. There was a 43% net gain in ant infested tree numbers in control units, while treatment units experienced a 9% loss.

## DISCUSSION

### Snag and partial snag fates

Restoration treatments may cause the destruction of snags through mechanical damage during harvesting operations (knocked over or broken off by equipment), cutting for safety reasons or by accident (misidentification of a snag as a live tree scheduled for removal), burning by prescribed fire, or windthrow following live tree density reduction (Lyon 1977). In control areas, pine snags were lost to falling. Several snags and partial snags in one clump of oak in EB2C were harvested by a woodcutter, accounting for much of the oak snag loss in the control.

In treatment areas, snags over 37.5cm dbh were less likely to be destroyed. This contrasts with Horton and Mannan's (1988) results, in which larger snags were more susceptible to destruction, but smaller pine snags in restoration treatments were often cut down (though this is not called for in the prescription), inflating small snag rates of loss compared to the effects of fire alone. In addition to their greater resistance to decay (Thomas et al. 1979), large pine snags under restoration treatment practices were much less likely to be cut, and many were granted a fuelbreak at their base, which is known to improve survival during prescribed fire (Gordon 1996, Boucher et al. 1999). Like Horton and Mannan (1988), I did find a relationship between destruction and condition in large pines, with recent snags less likely to be destroyed than loose-bark or clean snags.

Though treatments may certainly kill or destroy partial snags through many of the same means as for snags, treatment apparently did not have an effect on pine partial snag destruction (with only 8% destroyed in treatments and 0% in controls) nor on the fate of those that did not survive. It is possible that the sample sizes in this case were simply too small, disguising a real effect in pines that did show up in oak. On the other hand, pine are much more fire resistant than oak, so it is quite possible that a treatment effect on partial snags exists only for oak.

Following treatment, partial snags of both species were more likely to remain standing (even if dead) than full snags, suggesting that they may play an important role in providing habitat where frequent fire precludes the long-term maintenance of snag populations (Ganey 1999, Boucher et al. 1999). The importance of partial snags in restored forests is also suggested by their abundance in relict sites (Chapter 5).

#### Snag and partial snag recruitment

New snags are created when trees are killed by lightning, insect attack, drought, disease, competition, fire, or some other cause. Often causes of death are not readily apparent, and they were not recorded in this study. More snags were recruited than lost in both treatment and control years between 1998 and 2002. The years following 1998 all experienced below average precipitation, with precipitation for 1999 just over half and precipitation for 2002 just over a third the previous two-decades' average. Drought likely contributed to mortality in both treatment and control areas.

In treatment areas, average snag recruitment per ha was 7.6 times that in controls (Table 2.5). This result may not be typical for restoration projects, because of

abnormally high recruitment in EBs 1T and 4T. Treatment did not follow prescription in EB 4 T, resulting in high mortality, especially among pole-sized trees (Waltz et al. in review). In EB 1, unusually shallow soil conditions resulted in high mortality via root-killing of large-diameter trees (Fulé et al. 2002). Although EB 1T and 4T make up a small proportion of the total area subject to restoration at Mt. Trumbull (~10%), these plots make up 50% of the treatment sample, so their influence is magnified, exaggerating the apparent snag recruitment (Fulé et al. 2002).

Horton and Mannan (1988) and Gordon (1996) found that most new snags recruited by prescribed fire were of small size. I found no size difference between created and original pine snags within treatment units, while in controls, new snags tended to be smaller than average. New oak snags were larger than originals in the treatment unit. My results are likely due to the heavy thinning of small trees prior to burning; this reduced the small-tree pool of potential pine snag recruits. For oaks, which were not mechanically thinned, the resulting size difference may be due to the small sample size (1 plot).

Few partial snags of either species were created, and creation was unrelated to treatment or control plot designation. Elements that create partial snags are largely stochastic events unrelated to treatment. Though fire may have the potential to create dead streaks and other wounds (Gaines et al. 1958), it did not appear to do so at Mt. Trumbull, unless such wounds require more time to become visible.

### Net changes in the standing dead wood resource

The net effects of restoration treatment on the snag resource were increased pine and oak (EB2) snag density, with no significant change in mean diameter of pine snags and an increase in diameter of oak snags.

Nearly all new snags created following treatments were of recent condition, though some (<10%) lost some to all of their bark in the process of being killed and were classified as class loose-bark or clean. The large influx of fresh snags, combined with the large losses of loose-bark and clean snags, increased the relative representation of recent snags in treatment areas; in controls, recent snags also increased compared to other classes, although less so.

Restoration treatments did not seem to have a net adverse effect on any measures of wildlife use of snags. In pre-treatment measurements, the presence of a cavity or foraging sign in a snag only indicates that it was used at some time, possibly years ago. An unknown fraction of the cavity or forage trees recorded prior to treatment were in active use during the pre-treatment inventory. After treatment, new cavities and foraging sign necessarily represent recent activity. Because I re-measured original snags in 2001, but inventoried only new recruits in 2002, any use of original snags occurring between 2001 and 2002 was not recorded. Wildlife use following treatment is therefore probably underestimated. The large increase in trees bearing foraging evidence may reflect an increase in hairy woodpecker activity and numbers at Mt. Trumbull since treatment (J. Battin, personal communication). The stability of excavated cavity numbers and the relatively high density of new holes in treatment units indicates that woodpecker breeding was not adversely affected by treatment. This is consistent with the findings of Koplín

(1969) and Lowe et al. (1978), that drilling species (including the HAWO) briefly increased in numbers, then leveled off following fires.

Ant use of snags increased in control units, suggesting an increase in ant populations. I cannot, however, exclude the possibility that infestations recorded in new snags also existed when the trees were alive, nor can I suggest a plausible cause for an increase in ants in the control units. The net decrease in snags infested by ants in the treatment areas was surprisingly slight, given that > 75% of the original ant-bearing snags were lost following treatment. Establishment of new ant colonies (per ha) in treatment areas was lower than that in controls, but still nearly offset the loss of snags that had been used by ants before treatment. Established ant colonies act as points of dispersal from which queens establish new colonies (Ross 1948). In control units, 1.5 new colonies were added for each 1 original colony remaining in 2001. In treatment units, the ratio was 2.9:1. It is unknown whether new ant colonies established in the treatment units are established from founding colonies inside or outside the units, but either way, snags in treatment units were likely in proximity to fewer potential colonization points than snags in control units. This suggests a greater success rate for ant colony establishment in treatment units, perhaps due to the increase in suitable substrates (more snags). Without data on ant colonies in logs, however, any analysis of ant use of deadwood is incomplete.

## **MANAGEMENT IMPLICATIONS AND FUTURE RESEARCH**

The results of this study suggest that initial restoration treatments do not have negative impacts on the standing deadwood resource or its use by wildlife. However, this



statement must be interpreted with caution for several reasons. First, the disproportionate destruction of large snags in conditions classes above 3 is important. Large snags in the loose bark condition are particularly value to wildlife (Cunningham et al. 1980, Rabe et al. 1998), so the full impact of treatments will depend partly on how rapidly the new, recent condition recruits advance in deterioration and make up for the loss of loose bark snags. A second caveat is that the mortality (snag recruitment) of large pines during treatment was not desired nor expected at such high levels. The snag recruitment which compensated for snag loss in treatment areas does not represent intended results, and should not be typical in future restoration treatments, especially in non-drought conditions and on non-lava rock soils (Fulé et al. 2002). Finally, this study reflects the impact of initial restoration treatments only. Full restoration is a decades-long process, which includes continuing periodic prescribed fires intended to mimic a natural fire regime. Because of large changes in overstory structure and fuel loading (Fulé et al. 2001), snag loss and recruitment in future burns may be lower than what I observed.

The lack of a significant relationship between size and survival (for un-cut snags) is likely due to the practice of raking fuel lines around larger snags (Gordon 1996). I suggest that this practice be continued in future restoration treatments, perhaps increasing the line width to as much as 8m (Gordon 1996) for particularly high-value snags (large, loose-bark or cavity-bearing), or snags at high risk of destruction by fire (loose-bark or on steep slopes). Snag cutting accounted for over a quarter of snag loss, and nearly half the loss of smaller snags. In treatments, cutting probably resulted from workers mis-identifying snags, especially small ones, as live trees. The largest pine snag destroyed by cutting was 22.6 cm dbh. Pine snags of such sizes are below the threshold of use by both

ants and cavity-nesting birds (Chapter 3), but are used for foraging. In the interest of maintaining the full complement of snags through the initial treatment period, it may be worthwhile to identify snags during timber marking to avoid accidental cutting (this is currently done only for snags believed to represent pre-settlement trees – general > 37.5 cm dbh). Without better protection of existing snags, future treatments that avoid mortality levels of this study will experience a net loss of pine snag density. Oaks were not thinned during treatment and mortality was anticipated; the burn was used to accomplish thinning. Duff raking around oak snags should not be necessary, except in the case of particularly valuable individuals (>20-30cm dbh, or containing obvious cavities or hollows). Thirteen snags and partial snags in EB 2C and an unknown number in EB 2T were lost to illegal woodcutting. Efforts should be made in future to reduce this factor by placement of signs informing of regulations.

This study does not address the effects of other thinning, burning or fuels-reduction treatments on the deadwood resource - only the restoration treatments described. Results may also not be applicable on sites with other tree species, soil types or topography. For example, Gordon (1996) found greater snag loss on steep slopes than gradual ones.

Though my results suggest that treatments increase bird (most likely hairy woodpecker) foraging on snags, this should not be taken to imply that restoration is necessarily “good” for hairy woodpeckers. Density can be a misleading indicator of habitat quality (VanHorne 1983). For a more comprehensive examination of one cavity nesting species (western bluebird) fitness following restoration treatments, see Germaine and Germaine (2002).

This study has high potential for future research. All snags and partial snags used in the study are marked with aluminum tags, and also located relative to permanent grid points. Future re-measurements may address how restoration affects snag progression through condition classes (increased exposure likely accelerates deterioration, though, alternatively, it may cause drying and slowing of decay processes). It will also be interesting to examine how snags survive through future maintenance burns, when less fuel remains on the ground, how condition and size class proportions change given frequent fire and changes in the recruitment pool's characteristics, and how wildlife use progresses over time.

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## TABLES

Table 2.1: Site characteristics of seven plots used to inventory snags and partial snags at Mt. Trumbull, northern Arizona.

Plot	Elevation (m)	Aspect	Slope (%)	Soil <sup>a</sup>	Live pine density <sup>a</sup> (#/ha)	Area surveyed (ha)	Year of survey
EB 1C	2050	Level	0	lava / cinder	609	2.88	1998
EB 2C	2150	East	5	basaltic	681	3.96	1998
EB 4C	2150	Northwest	5	basaltic	1665	4.32	1999
EB 1T	2050	Level	0	lava / cinder	476	4.68	1998
EB 2T	2100	East	5	basaltic	276	3.60	1998
EB 3T	2250	Southeast	20	cinder	621	5.04	1998
EB 4T	2100	Northwest	5	basaltic	1713	3.96	1999

a: Data from Waltz et al. (in review).

Table 2.2: Destruction of pine snags in control (EB 1C, 2C and 4C) and treatment (EB 1T – 4T) plots at Mt. Trumbull, northern Arizona following restoration treatment.

Plot	Pre-treatment		% of population	Destroyed	
	Density (#/ha)	dbh (cm)		Density (#/ha)	dbh (cm)
EB 1C	5.2	47.4	13.3	0.7	55.5
EB 2C	8.1	38.6	9.4	0.8	16.7
EB 4C	3.5	43.0	20.0	0.7	12.6
Control mean <sup>a</sup>	5.6	43.0	14.2	0.7	28.3
EB 1T	4.5	57.7	42.7	1.9	45.2
EB 2T	2.8	53.5	100	2.8	53.5
EB 3T	7.3	38.3	89.2	6.5	33.8
EB 4T	2.8	41.9	72.7	2.0	36.4
Treatment mean <sup>a</sup>	4.4	47.9	76.2	3.3	42.2

a: Unweighted means.

Table 2.3: Fates of ponderosa pine snags in control and restored areas following restoration treatment at Mt. Trumbull, northern Arizona.

Treatment type	Size category	% (n) of sample destroyed	% of destroyed by fate				
			Broken	Fallen	Cut	Burned	No trace
Control	Small <sup>a</sup> pine	19 (31)	0	100	0	0	0
Control	Large <sup>b</sup> pine	7 (31)	0	100	0	0	0
Control	All pine	13 (62)	0	100	0	0	0
Restoration	Small <sup>a</sup> pine	95 (37)	3	9	49	9	31
Restoration	Large <sup>b</sup> pine	60 (42)	12	8	0	72	8
Restoration	All pine	76 (79)	7	8	28	35	22

a: Snags < 37.5cm dbh.

b: Snags ≥ 37.5cm dbh.

Table 2.4: Loss of ponderosa pine snags in three condition and two size classes in control and treatment areas after restoration treatment at Mt. Trumbull.

Treatment type	Condition class <sup>a</sup>	% of snags destroyed in class and size category		
		All snags	Small <sup>b</sup> pine snags	Large <sup>c</sup> pine snags
Control	Recent	25	29	14
Control	Loose-bark	8	0	14
Control	Clean	0	0	0
Treatment	Recent	84	97	29
Treatment	Loose-bark	72	80	69
Treatment	Clean	65	100	64

a: Thomas et al. (1979)

b: Snags < 37.5cm dbh.

c: Snags ≥ 37.5cm dbh.



Table 2.5: Density and diameter of ponderosa pine snag recruits in control and treatment plots at Mt. Trumbull, northern Arizona following restoration treatment.

Plot	New snags	
	Density (#/ha)	Mean dbh (cm)
EB 1C	1.4	40.6
EB 2C	3.5	33.4
EB 4C	1.3 <sup>a</sup>	13.5 <sup>b</sup>
Mean <sup>c</sup> for control plots	1.8	29.2
EB 1T	12.6	59.8
EB 2T	11.1	48.5
EB 3T	10.9	46.4
EB 4T	50.0 <sup>a</sup>	20.1 <sup>b</sup>
Mean <sup>c</sup> for treatment plots	13.7	43.7

a: Densities were determined from unpublished data (Fulé et al.) collected in 2000. Many to most trees recorded in 2000 as condition 2 (“declining”) died by 2002. Density estimates of new snags including trees classed as declining in 2000 are 5.0 and 211.3 for EB 4C and EB 4T, respectively.

b: If trees classed as declining in 2000 are included, mean diameters become 15.6 and 23.4 for EB 4C and EB 4T, respectively.

c: Unweighted means.

Table 2.6: Post treatment and net changes in ponderosa pine snag density on control and treatment plots following restoration treatment at Mt. Trumbull, northern Arizona.

Plot	Post treatment density (#/ha)	net change in density (#/ha)
EB 1C	5.8	+0.6
EB 2C	10.8	+2.7
EB 4C	4.1 <sup>a</sup>	+0.6 <sup>b</sup>
Mean <sup>c</sup> for control plots	6.6	+1.0
EB 1T	15.3	+10.8
EB 2T	11.1	+8.3
EB 3T	11.7	+4.4
EB 4T	50.8 <sup>a</sup>	+48.0 <sup>b</sup>
Mean <sup>c</sup> for treatment plots	14.7	+10.4

a: Densities were determined from unpublished data (Fulé et al.) collected in 2000. Many to most trees recorded in 2000 as condition 2 (“declining”) died by 2002. Post treatment density estimates including trees classed as declining in 2000 are 7.8 and 212.1 for EB 4C and EB 4T, respectively.

b: If trees classed as declining in 2000 are included, net changes in density become +5.0 and +209.3 for EB 4C and EB 4T, respectively.

c: Unweighted means.

Table 2.7: Distribution of and net changes in ponderosa pine snag conditions before and after restoration treatment at Mt. Trumbull, northern Arizona, reflecting the combined effects of snag destruction, recruitment and condition class advancement between 1998 and 2002.

Condition class <sup>a</sup>	Control plots EB 1C and EB2 C			Treatment plots EB 1T, EB 2T and EB 3T		
	Pre-treatment density	Post-treatment density	% change in density	Pre-treatment density	Post-treatment density	% change in density
Recent	4.1	5.4	+32	2.5	12.2	+391
Loose-bark	1.8	2.2	+25	1.4	0.5	-67
Clean	3.2	2.9	-9	1.7	0.6	-65

a: Thomas et al. (1979).

Table 2.8: Distribution of and net changes in Gambel oak snag conditions before and after restoration treatment at Mt. Trumbull, northern Arizona, reflecting the combined effects of snag destruction, recruitment and condition class advancement between 1998 and 2002.

Condition class <sup>a</sup>	Control plot EB 2C			Treatment plot EB 2T		
	Pre-treatment density	Post-treatment density	% change in density	Pre-treatment density	Post-treatment density	% change in density
Recent	21.0	24.8	+18	23.3	90.5	+288
Loose-bark	28.8	35.4	+23	53.1	41.4	-22
Clean	5.6	2.5	-55	3.9	3.6	-7

a: Thomas et al. (1979).

Table 2.9: Density of snags and partial snags bearing evidence of wildlife use before restoration treatment, percent lost after treatment, density of new use after treatment, net density after treatment and net change in density after treatment at Mt. Trumbull, northern Arizona.

	Trees <sup>a</sup> bearing excavated cavities		Trees <sup>a</sup> bearing evidence of foraging		Trees <sup>a</sup> with ant colonies	
	Control <sup>b</sup>	Treatment <sup>c</sup>	Control <sup>b</sup>	Treatment <sup>c</sup>	Control <sup>b</sup>	Treatment <sup>c</sup>
Density before treatment (#/ha)	3.2	2.0	5.0	3.8	4.1	3.2
% lost post-treatment	45	59	59	73	43	77
Density of trees <sup>a</sup> with new use post treatment	1.2	1.1	3.5	17.8	3.5	2.2
Density post-treatment	2.9	2.0	5.6	18.8	5.8	2.9
Net change in density (%)	-9	-4	+18	+392	+54	-9

a: Includes full and partial snags of both pine and oak.

b: EB 4C was excluded because post-treatment data on wildlife use were not collected.

c: EB 4T was excluded because post-treatment data on wildlife use were not collected.

## CHAPTER 5

### QUANTIFYING THE DEADWOOD RESOURCE IN LIVING TREES ("PARTIAL SNAGS") IN MANAGED AND RELICT PONDEROSA PINE SITES OF THE SOUTHWEST

**Abstract:** Living trees bearing deadwood components ("partial snags"), such as lightning scars and spike tops provide habitat values similar to snags. Pre-settlement era frequent-return fire regimes in the Southwest may have limited snag densities in ponderosa pine forests, and may present a problem for maintaining snag numbers as ecosystem restoration projects are implemented in the future. The contribution of partial snags to pre-settlement habitat structure and their potential role in future restored forests is unknown. I inventoried one managed and four relict ponderosa pine sites in the Southwest to describe partial snag quantity, qualities, and use by cavity-nesting birds, and to establish a protocol for future partial snag inventories. Partial snag densities at relict sites ranged from 2.13 to 3.18 per ha, with spike-topped trees being the most common type. At the managed site, partial snags occurred at 1.70 per ha, and lightning scars were most common. At relict sites, 19% of partial snags contained excavated cavities, while at the managed site, 42% did. At relict sites, cavities were more likely to occur in partial snags with less than median crown-base height, and greater-than-median surface area of dead wood, distance to nearest snag and diameter. I developed models for estimating surface areas of exposed dead wood in spike-topped and in lightning-scarred trees that do not require time-consuming measurements, and suggested a simplified protocol to improve efficiency in future partial snag surveys.

## INTRODUCTION

Snags (standing dead trees) are an important component of southwestern ponderosa pine forest wildlife habitat (Scott 1978), providing many species of birds and mammals, reptiles and invertebrates with food and cover (Thomas et al. 1979, Davis 1983). The habitat structures provided by snags are not exclusive to dead trees. Live trees bearing dead portions, such as dead ("spike") tops, lightning scars, dead limbs and other types of wounds and scars are called partial snags or "living snags" (Mast et al. 1999) and are an understudied but probably important component of forest habitat (Mast et al. 1999, Boucher et al. 1999, Ganey 1999).

Partial snags are used by wildlife for many of the same purposes as snags (Miller and Miller 1980). Rabe et al. (1998) noted bats roosting in lightning scars, Raphael and White (1984) found 21% of avian cavity nests in live trees, and Li and Martin (1991) found 38% in live trees. Miller and Miller (1980) noted that 40% of cavities in six studies of cavity nesting birds were located in live trees.

Lightning damage is common in ponderosa pine forests of the Southwest (Pearson 1938, Wadsworth 1943). In addition to lightning, partial snags may be created by dwarf mistletoe, bark beetles, competition, fungal infection or drought stress. Gaines et al. (1958) reported unspecified damage to residual live trees following prescribed burns in the fall, suggesting that non-lethal fire damage may also create partial snags.

Partial snags may be more likely to survive (at least remain standing, if killed) after a fire than snags because they retain a living layer of insulating bark at the base (Chapter 4). Some authors have suggested an important role for partial snags in wildlife

habitat prior to settlement, when frequent surface fires visited the ponderosa forests and are likely to have consumed nearly all full snags (Boucher et al. 1999, Ganey 1999).

“Trees are excavated because of what is going on inside them, not because they are dead” (Miller and Miller 1980, p. 340). Partial snags with dead or broken tops (Cunningham et al. 1980) may be particularly useful for nesting sites, because the introduction of heart rot within a sound shell of sapwood is more likely (Miller and Miller 1980) and produces a structure of particular utility (Miller and Miller 1980, McClelland and Frissel 1975).

Partial snags may also have an important role as potential future snags, as they are often already under stress (Mast et al. 1999). Snags that were partial snags before their complete death may be more valuable than snags that were killed instantly, also because of the introduction of heart rots while alive (Miller and Miller 1980).

Fire suppression, livestock grazing, logging, and unusual climatic conditions have caused changes in the structure and function of modern southwestern ponderosa pine forests (Fulé et al. 2002). These changes are characterized by increased small-tree density, decreased growth and increased mortality of old trees, decreased herbaceous biomass and diversity, replacement of the 2 to 7 year interval low-intensity fire regime with infrequent high-intensity fire, and increases in susceptibility to insect, disease and drought mortality (Covington and Moore 1994). Scattered across the southwest, there remain a few sites that have been sheltered from the usual disturbances by inaccessibility or special land use designation (Moore et al. 1999, Fulé et al. 2002). These “relict” sites are generally un-logged, often ungrazed, and some have experienced multiple surface fires in the last century. Relict sites are often isolated, or otherwise unusual in some

respect, and often have been altered indirectly by the changes in adjacent lands. However, relict sites do retain the full old-growth component, and have not been subjected to direct management actions, so they are often used to help designate “reference conditions” (Moore et al. 1999, Fulé et al. 2002). Reference conditions are the basis for ecosystem restoration treatments, which aim to improve ecosystem health by emulating the structure and function of pre-settlement era forests (Covington et al. 1997).

If partial snags were an important part of the pre-settlement forest’s structure and function, as suggested by Ganey (1999) and Boucher et al. (1999), then they are an important consideration in establishing reference conditions for restoration goals. I surveyed partial snags on five ponderosa pine sites (one managed and four relict) in Arizona and New Mexico. My objectives were to determine the quantities and qualities (especially with respect to risk of fire mortality) of partial snags occurring in managed and unmanaged forests, and to determine if partial snags used by cavity-nesting birds share any common features. To facilitate inclusion of partial snags in assessments of wildlife habitat, I developed a protocol to efficiently measure partial snags.

## METHODS

### Study areas

I conducted partial snag inventories at one managed site (Mt. Trumbull) and four relict ponderosa pine-dominated sites in the Southwest: the Gus Pearson Natural Area, Fire Point, Galahad Point, and Iron Creek Mesa. The five sites represent a range of fire and management histories, and site conditions across the southwestern ponderosa pine type (Table 3.1).

The Mt. Trumbull site (MT) lies between Mt. Trumbull and Mt. Logan, north of the Colorado river in Arizona, 36° 22' N, 113° 10' W, within the Grand Canyon Parashant National Monument. The area experienced frequent surface fires prior to 1870, when grazing, logging, and fire suppression altered the forest's natural structure and disturbance regime, leading to the pathological tree densities and high fuel levels now typical of southwestern forests (Moore et al. 1999). Vegetation is dominated by ponderosa pine and Gambel oak (*Quercus gambelii*), with some Utah juniper (*Juniperus osteosperma*), Colorado pinyon (*Pinus edulis*), and New Mexican locust (*Robinia neomexicana*). In 1998 and 1999 I established five plots of 7.6 to 10.4 ha, totaling 44.6 ha.

The Gus Pearson Natural Area (GPNA) is located about 16 km north of Flagstaff, Arizona in the Fort Valley Experimental Forest in the Coconino National Forest, 35° 16' N, 111° 44' W. Grazing between 1876 and 1910, and fire suppression since 1876 have resulted in small tree densities typical of southwestern forests (Covington et al. 1997), but the retention of all old-growth trees makes it valuable as a relict site nevertheless. The GPNA overstory is dominated by ponderosa pine, with a sparse understory. US route 180 runs through the middle of the GPNA. The road's pavement and a thinned buffer on either side of it account for a total of approximately 3 ha. In 2001, the entire area was sampled as one plot of 21 ha, not including the road or its buffer.

Fire Point (FP) is within National Park boundaries on the northwestern edge of the North Rim of the Grand Canyon (36° 21' N, 112° 20' W). The site has never been logged. FP experienced frequent fires until 1879, then two large surface fires in 1923 and 1999, with fires in 1926, 1931, and 1989 burning over smaller areas of the site (Fulé et al.



2003). The site is dominated by ponderosa pine, with some New Mexican locust occurring in the understory. In 2001, a single plot of 27 ha was established and inventoried as a rectangle of approximately 300 X 900m (oriented east-west) following the flat top of a ridge.

Galahad Point (GP) is also within National Park boundaries on the North Rim (36° 16' N, 112° 14' W), and has never been logged. Fires burned GP frequently until 1879. Since then, several small fires – > 12ha, and most > 3.7ha – burned (Fulé et al. in press) until 2001, when a surface fire burned across most of the site. The site was dominated by ponderosa pine, but quaking aspen (*Populus tremuloides*), Gambel oak, white fir (*Abies concolor*), and Douglas-fir (*Pseudotsuga menziesii*) also occurred. In 2002, I established and inventoried three square (300 X 300m) plots of 9 ha each, approximately 300m apart (to avoid drainages, where other tree species were more common and ponderosa pine less so).

Iron Creek Mesa (ICM) is located at the northeast end of the Gila Wilderness of New Mexico, above Snow Lake (33° 24' N, 108° 33' W). The area was never logged, and has experienced 5 fires since the late 1890's, most recently in 1993 (Boucher et al. 1999). An L-shaped (to avoid a meadow) plot of 24 ha was established and inventoried in 2002.

#### Data collection

At MT, I defined partial snags to be living pine trees  $\geq 37.5$  cm dbh (diameter breast height, 1.37 m above ground on the uphill side of the bole) bearing dead wood of dimensions equal to or greater than approximately 1.8 m height by 10 cm width in spike

tops, lightning scars, or other wounds. I chose these dimensions because they are the minimum reported size for snags used by any cavity-nesting bird in the area (the mountain chickadee, *Poecile gambeli*) (Thomas et al. 1979). I tagged each partial snag with a uniquely-numbered aluminum tag and recorded its measurements. For each, I recorded dbh, height, polar coordinate location from the nearest grid point, and type(s) of dead wood feature displayed. For spike-topped trees, I recorded the height of the spike base and top, and whether it was broken. For lightning scars and other wounds, I recorded presence only. For wildlife use, I recorded the presence of excavated cavities, but not their number.

At the four relict sites, I took more detailed data, focused on obtaining three kinds of information: the surface area of deadwood available to cavity-nesting birds in live trees, variables that might be correlated with nesting use, and variables that might influence partial snag fate in a prescribed or low-intensity natural fire.

I collected data on all partial snags at least 37.5 cm in dbh or bearing the yellow-red colored bark of mature trees (these criteria are commonly used to establish "pre-settlement" age trees in restoration reconstructions). I ignored smaller partial snags, or those of species other than ponderosa pine. I counted and measured spike tops at least 10 cm in diameter at the base and at least 30 cm tall (the relaskop was used to check questionable trees), and lightning scars that averaged 10 cm or more in width. Other deadwood features that meet the general requirement of rising at least 1.8 m above ground level and having a width of at least 10 cm were also measured. Fire scars rising at least 1.8 m above ground level and having a width of at least 10 cm, and dead limbs at least 10 cm in diameter and 30 cm long were measured only if they occurred on a tree

bearing other features (otherwise the numbers tallied could have become impractically large).

Each measured tree was assigned a number, but not tagged (those at Gus Pearson are already tagged). Except at GPNA, I used a GPS unit to record each tree's UTM coordinates. Because Miller and Miller (1980) suggested that proximity to a snag may be a nest selection criteria, I measured the distance from each partial snag to its nearest (full) snag neighbor by pacing. I measured height to the nearest 0.5 m with a relaskop and recorded lean if  $< 80$  degrees from horizontal using the clinometer on a hand compass. I measured tree diameters at breast height to the nearest 0.1 cm using a steel diameter tape, and estimated diameters at  $\frac{1}{4}$ ,  $\frac{1}{2}$ , and  $\frac{3}{4}$  of height to the nearest 1 cm using a relaskop stabilized on a tripod. All sufficiently sized deadwood features were noted (and measured separately, as described below). I measured crown base height (ground to bottom of continuous crown), dead wood exposure at the base of the bole (centimeters of circumference in exposed dead wood), and the vertical extent of exposed dead wood above ground level. These all may be potential risk factors for fire mortality. I also measured litter depths at the base of each tree (at four cardinal directions from the bole). Woody debris near the tree base, another potential mortality risk factor, was also tallied for thousand-hour fuels ( $\geq 7.5$  cm in diameter) touching, within half the debris diameter's distance, its diameter's distance, and twice its diameter's distance of the tree bole.

For spike tops, the height of the spike's base and top (which may differ from the tree's highest point) were measured with a relaskop. The diameter of each spike was estimated at the base, mid-point, and top (since some are broken) using a relaskop. I

tallied the number of excavated cavities (usually distinguishable by being round and relatively smooth-edged) in each spike top.

For each lightning scar, I measured the height of the scar base and top with a relaskop, and measured or estimated the width of the approximate base, middle, and top of the scar either with a measuring tape for reachable measuring points, or visually for unreachable points. I classified each scar as continuous (scar is uninterrupted from top to bottom) or discontinuous (scar is interrupted by live bark). Lastly, I tallied excavated cavities found on the scar.

Other deadwood features, including wounds from mechanical injury, disease or unknown cause and non-lightning dead streaks, were described and measured to provide information on their surface area and condition. I tallied excavated cavities for each feature separately.

I tallied and measured large dead limbs and fire scars only on trees with some other feature (spike top, lightning scar, or other wound). For dead limbs, I estimated limb length, diameter and bark cover visually, and counted number of excavated cavities per limb. Fire scars were classified as either convex or concave. Their height was measured, and their width at 1.8m above ground. I tallied any cavities found in fire scars.

### Data analysis

I calculated the density of partial snags for each relict site and for each partial snag type. Because sites differed in a number of features, I presented results on a site-by-site basis. I reported density of cavities, average litter depth, deadwood exposure, crown-base height, diameter, and other variables for each partial snag type separately.

I used geometric formulas to calculate the surface areas of each deadwood feature on each partial snag at the relict sites. For spike tops, I used base, middle, and top diameter measurements with top and base height measurements to calculate the surface area of each spike from its base to the point where either its taper indicated it would be less than 10 cm in diameter, or to where it broke off (if its top diameter was greater than 10 cm). Depending on the characteristics of taper and breakage, spike surface areas were calculated differently for different spikes. Formulas for the lateral surface areas of cones and truncated cones ( $A = \pi * basal\ radius * \sqrt{[(basal\ radius)^2 * (height)^2]}$  and  $A = \pi * (basal\ radius + top\ radius) * \sqrt{[(basal\ radius - top\ radius)^2 * (height)^2]}$ , respectively) formed the basis for spike surface area calculations.

For lightning scars at GPNA and FP, I first used  $\frac{1}{4}$ ,  $\frac{1}{2}$ , and  $\frac{3}{4}$  height diameters to estimate taper and the length of the scar from 1.8 m to the point where taper indicated the bole diameter would be less than 10 cm. I then multiplied half the scar length by the average width of the upper half of the scar plus the average width of the lower half of the scar ( $A = \frac{1}{2} scar\ height * [((scar\ top\ width + scar\ middle\ width)/2) + ((scar\ middle\ width + scar\ bottom\ width)/2)]$ ). The surface area of discontinuous scars was halved. When taper was estimated using all intermediate diameters scar length calculations never differed by more than 0.009 m from that when taper was estimated from only the dbh and total tree height. I used the simpler scar length calculation (using top to bottom, rather than section-by-section taper) for trees at Galahad and Iron Creek Mesa.

The surface area of other wounds and scars was calculated from length and width measurements taken in the field. In all calculations, the measures of height were corrected to actual bole length for leaning trees.

I calculated the surface area of each dead branch as the lateral surface area of a cylinder with diameter and length given by field estimates ( $A = \pi * diameter * length$ ). Branch surface areas were summed per tree. Fire scars were assumed to form an approximate triangle and surface area above 1.8m was estimated by  $A = 0.5 * width at 1.8m * (height - 1.8)$ .

I tested cavity tree selection of partial snags using an ad hoc distribution free exact test:  $\sum_{i=n}^N [N! / ((i!) * (N - i)!)] / 2^N = P(n+ | N)$ , where N is the total number of partial snags bearing cavities, and n is the total number of those trees whose variable of interest (diameter, for example) exceeds the population median for that measurement. The test yields the exact probability of randomly selecting n number of partial snags greater than the population median for a given variable from N number of snags bearing cavities (for example, the probability that 30 of 31 cavity-bearing partial snags will be larger than the median snag diameter would be  $1.49 \times 10^{-8}$  if selection were random with respect to diameter). I used this test ( $\alpha = 0.05$ ) to evaluate cavity tree selection based on height, diameter, distance to nearest snag neighbor, surface area of dead wood, crown base height, and litter depth. Then I used binary logistic regression to create a model predicting probability of cavity presence given the parameters found to be important in the previous test..

Some measurements used in this survey were more difficult to obtain than others and I noted which were most difficult or time consuming. To find easier to obtain, but still important variables for estimating the surface areas of spike tops and lightning scars, I used simple linear regression models to test correlations between actual surface area and surface area calculated using simpler measurements and calculations.

For partial snags at MT, I calculated density and proportions of partial snag types at each plot separately, then estimated means across the five plots. I could not estimate surface areas for lightning scars and other deadwood features. I used the exact test (above) to evaluate cavity selection based on height, diameter, and distance.

## RESULTS

### Characteristics of partial snags

#### Relict sites

Among the four relict sites GPNA had the lowest density of live old-growth and highest densities of spike tops and lightning scars (Table 3.1). It also had the largest mean tree diameters for all partial snag types. ICM had the lowest partial snag densities and sizes, though no information was available on live old-growth densities or sizes at that site.

Spike tops were the most common type of partial snag at all four relict sites (Table 3.2), and were also the largest in terms of surface area of deadwood (Table 3.3). Spike tops consistently occurred on smaller trees (both in diameter and in height) than lightning scars. Compared to lightning scars, spike-topped trees had slightly lower crown base heights at all sites (mean difference = 1.1 m), but were less likely to have an overlap between the vertical extent of deadwood exposed at the ground and the crown base. The percent of spike tops with cavities ranged from 0% at ICM to 30% at FP.

Lightning scars were the second most common type of partial snag (except at FP, where other wounds were more common), and their density varied more than the other

types (Table 3.4). Lightning scarred trees were taller and thicker in diameter than other partial snags, but the scars themselves had smaller surface areas than spike tops. Cavities were found in lightning scars at all sites, from 9% at GP to 33% at FP. The average cavity-bearing lightning scar was smaller than the average cavity-bearing spike top, but had more cavities per m<sup>2</sup> of surface area.

Partial snags with other wounds and scars were not a coherent group. Other types included small wounds resulting from mechanical injury or the breaking away of a fork, and large dead streaks of indeterminate origin, which sometimes covered over half the tree. They did not share any characteristics as a group, but contained cavities more often than either lightning scars or spike tops at both GPNA and FP, and more often than spike tops at GP.

Large dead limbs occurred on 14% (ICM) to 55% (GPNA) of partial snags that had some other feature. Their presence added an average of 1.75 m<sup>2</sup> of deadwood to a partial snag. There appeared to be no tendency for either spike tops or lightning scars to have dead limbs more often. Of trees with dead limbs, 0 (ICM, GP) to 4.5% (GPNA) had cavities in those limbs.

Fire scars large enough (>1.8 m high X 10 cm across at 1.8 m from ground) to be included in the survey were rare. Only 0 (GP) to 7% (FP) of partial snags bearing some other feature also had such fire scars. The surface area of dead wood available above 1.8m on large fire scars averaged 0.01 (ICM) to 0.17 m<sup>2</sup> (FP), and not one scar bore an excavated cavity. It is possible that some of the large dead streaks classified as "other" features originated from fire, but were not classified as fire scars.



### Managed site

At Mt. Trumbull, partial snag densities ranged from 0.8 to 3.1 per ha across the five plots (average: 1.7 / ha)(Table 3.2). Lightning scars were more common than spike tops on all five plots ( $p = 0.03$ ). The two types showed no tendency to differ in size across the plots, but the overall average spike-topped tree was 12.6 cm broader and 0.7 m shorter than the average lightning-scarred tree.

### Wildlife use of partial snags

#### Relict sites

No cavities were found in partial snags displaying less than  $0.64 \text{ m}^2$  of total deadwood, although the smallest single feature to contain a cavity was a lightning scar with surface area of  $0.53 \text{ m}^2$ . The exact test indicated that total surface area, distance to nearest snag, crown base height, and dbh were all important in nest site selection (Table 3.4). I entered these values into a logistic regression model. The model correctly classified 15% of cavity-bearing trees and had  $r\text{-square} = 0.17$ .

### Managed site

Cavities were present in 42% of MT partial snags: 65% of spike tops bore cavities, 64% of other types, and 30% of lightning scars. Nineteen of 32 ( $p = 0.2$ ) cavity-bearing trees were greater than the median dbh, 17 ( $p = 0.4$ ) were greater than the median height, and 20 ( $p = 0.1$ ) were beyond the median distance from the nearest large snag.

## Models for simplifying future partial snag surveys

### Measurement effort

Partial snag surveys at each of the four sites required approximately 60 to 70 man-hours to complete. Ten to 20 minutes was required to complete measurements on each tree, excluding search time, depending on the complexity of its features. By far the most time consuming measurements were diameters taken above bh, using the relaskop. Considerable effort was needed to measure out the correct viewing distance in a direction from which the feature was readily visible, set up the tripod, and read and record the measurements. It was sometimes necessary to measure a tree from multiple angles, to provide unobstructed views of the bole. Height measurements were also taken with the relaskop, but could have been taken with a much lighter clinometer, which would not have required a tripod for stability. Litter depth measurements were the next most time consuming measures, requiring the observer to measure radial directions from the bole, then kneel and measure four separate times for each tree. Distance to nearest full snag was measured by pacing – it often took longer to locate the nearest snag than to pace its distance. Ocular estimates of scar widths and debris proximity took the least time of all measurements.

### Spike-topped tree model

I created two groups of spike-topped trees from which to build models of spike surface area based on simple measurements (specifically, measurements not requiring the use of the relaskop). Group 1 included spike tops at GPNA and GP and group 2 included FP and ICM. I chose these groups so that each would contain nearly equal numbers of

spike tops, and each would contain near the full range of their size. I eliminated forked spikes (2) and one unusually narrow and tall spike (at ICM) to eliminate potential outlier values caused by these unusual shapes. Eighty-two trees remained in group 1 and 81 in group 2. In both groups, tree diameter and tree height by themselves were poor predictors of spike surface area. Spike height (distance from spike base to spike top) performed much better. About 71% of the variability in group 1 and 63% of the variability in group 2 was explained by (approximately)  $A = 0.72 * \text{spike height} - 1$ . Next I created an equation to take into account spike height, tree diameter, and whether the spike was broken. The equation  $A = \pi * (0.5 + (0.5 * \text{broken})) * (\text{spike height} / \text{total height}) * (\text{dbh} / 100) * \text{spike height}$  estimates spike base diameter as a proportion of the dbh equal to the proportion of the spike height to the total height. It estimates surface area of the spike as a cone if it is unbroken, as a column if broken. This equation explained 88.5% of the variability in spike surface areas in group 1, 84.1% in group 2, using linear regression. For both groups, the equation underestimated spike surface areas, by a factor of  $1.15 (\beta) + 0.49 (\alpha)$  in group 1 and by a factor of  $1.52 (\beta) + .45 (\alpha)$  in group 2. To determine which model was better overall, I used model 1 ( $1.15 * \text{equation} + .49$ ) on group 2 spikes, and model 2 ( $1.52 * \text{equation} + .45$ ) on group one spikes, and compared based on how well each model predicted surface areas in the spikes not used to build it. When the model predictions were regressed against actual surface areas, I found that model 1 performed better in group 2 than model 2 did in group 1 ( $\beta$  closer to 1,  $\alpha$  closer to 0). When applied to all spike-topped trees in both groups, model 1 explained 83.4% of the variability in surface area, with predicted values slightly lower than actual values ( $\beta = 1.10, \alpha = 0.04$ ).

### Lightning scar model

Estimates of surface area for lightning scars were virtually the same regardless of whether scar length (from 1.8 m above ground to the point where either the scar ends or diameter goes below 10 cm, given bole taper), or simple scar height (from top to bottom) was used as the vertical measurement. Whether scar width was estimated as a single average, or as the average of the upper and lower halves also apparently made little difference. Scar surface area estimates given by  $A = (top\ height - bottom\ height) * average\ width * (1 / (discontinuous + 1))$  explained over 99% of the variability in the meticulously calculated scar surface areas. This was true for trees at GPNA and ICM (47, eliminating one forked tree) and at FP and GP (47, eliminating one forked tree). In both groups, the equation slightly overestimated surface areas ( $\beta = 0.92$  in both groups).

## DISCUSSION

At all of the relict sites surveyed in this study, snag density exceeded partial snag density by 3 to 5 times. At the managed site, snag density was only 1.4 times that of partial snags. The total surface area of deadwood on snags is surely also much greater on a per-ha basis than that for partial snags because each snag's entire surface area is of dead wood, not just part of it. The number of cavities found in partial snags is therefore almost certainly far out of proportion to the amount of deadwood they offer. At MT, for example, as many partial snags as full snags bore cavities, although partial snags occurred at only 71% the density of snags.

There may be several explanations for the differences in partial snag densities at the five sites in this study. Partial snag creation is obviously related to weather (lightning and drought, especially), but also mistletoe and insect outbreak. Partial snag loss is likely related to factors such as soil type, wind velocity, management and fire history. It is possible that the relative lack of lightning scars at FP and ICM to wildfire occurrence. It seems likely that lightning scars, with exposed wood at the base forming a fuel ladder into the crown, would be especially susceptible to death or destruction in a surface fire. It is also possible that the relative lack of partial snags at MT is due to management actions over the last century. Certainly, occurrence of partial snags depends on the presence of large live trees, so where these have been removed few partial snags are likely. Also, past management practices have often focused on removing “defective” trees. Comparison between sites where confounding factors have not been controlled is risky, however, so I must stress that this study does not support such conclusions.

Measures of potential fire mortality risk factors did not suggest that spike-topped trees should be expected to be any more susceptible to fire than lightning-scarred trees, although about 10% of lightning-scarred trees had an overlap between the upper extent of deadwood from the ground and the lower extent of the live crown, suggesting that they might be at greater risk of mortality or destruction in the event of a fire because of the fuel ladder to the crown provided by the often resinous scars.

Lightning-scarred trees did not appear to contain cavities relatively more or less than spike tops, but among those that were used, there were more cavities per m<sup>2</sup> of surface area. This suggests that lightning scars need not be as big as spike tops to attract a hole-making bird.

Over a third of snags bearing other wounds and scars also bore lightning scars and/or spike tops. Trees bearing other wounds and scars were heavily used when they also displayed lightning scars or spike tops (56% of trees containing an "other" wound in addition to lightning or spike contained a cavity) but not when other wounds occurred alone (19% bore cavities). It is possible that trees bearing other wounds in addition to spike tops or lightning scars are more likely to have heart rot.

Large dead limbs occurred on partial snags of all types and at all sites. They added considerable deadwood to a tree's total when present, but rarely bore cavities themselves. The horizontal orientation of most branches may make them less suitable for nesting sites than similarly-sized spike tops. Surface area may not be an appropriate measure for the availability of deadwood in branches because the upper half of the branch surface is not a likely location for a cavity entrance. Dead branches are used for foraging and perching, and so their presence may be a factor in nest site selection. Of partial snags having large dead limbs, 27% (of 91) also had cavities, compared to 19% (of 280) in partial snags generally.

Large fire scars were rarely encountered and never used as a nesting substrate by cavity-nesting birds. It seems unlikely that a cavity would ever be constructed in a concave fire scar, as these are usually charred and case-hardened. Convex scars, 6 of the 8 in this survey, are more likely to contain cavities, and I have seen this on a few occasions, but not at these study sites.

That surface area might be an important variable in nest site selection in partial snags was expected, given that snag size affects use of full snags (Thomas et al. 1979). Cavity-bearing partial snags appear at about the same number in each surface area size

class, regardless of the availability of trees in a size class (Fig. 3.1), so larger classes are over-represented in cavity trees. Crown base heights tend to be lower on spike-topped trees, which had larger surface area, so crown base height may appear to be important because it is correlated with surface area. I had anticipated that partial snags in closer proximity to full snags would be more likely to contain cavities, but the opposite appeared to be the case. As with surface area class, partial snags more distant from full snags are over-represented among cavity trees relative to their availability (Fig. 3.2). The poor predictive ability of the logistic regression model of cavity presence may reflect the fact that ultimate selection of cavity sites depends on internal tree characteristics that are impossible to observe from the ground, such as presence of heartrot (Conner et al. 1976, Miller and Miller 1980, Schepps et al. 1999).

All of the relict sites had higher density of partial snags than the managed forest at Mt. Trumbull. The ratio of lightning-scarred to spike-topped trees was the reverse (fewer lightning) at all four relict sites than at MT. For both spike tops and lightning scars, MT partial snags tended to be short but broad, probably a site effect not related to management.

Partial snags at MT were used much more heavily than at any of the relict sites. This may be related to the fact that the relict sites had many more snags than MT had. Partial snags at MT were used at a higher rate than full snags of similar minimum dbh (above 37.5 cm dbh, 30% were used), and spike-tops and trees with other wounds at a much higher rate (~65%). This result may reflect wildlife selection, longer persistence of partial snags, or both. The variables dbh, height, and distance to nearest snag did not appear to be good indicators of cavity presence at MT. Surface area and/or crown-base

height may be important, but that cannot be determined with the data collected in this study.

## MANAGEMENT IMPLICATIONS AND FUTURE RESEARCH

The results of this study imply that partial snags are an important component of the standing deadwood resource in relict forests, with almost a fifth of all types bearing cavities. The partial snag resource should be evaluated in wildlife habitat inventories, and also should be considered as part of post-restoration goals. Special efforts should be used to protect partial snags during the initial treatments of a restoration effort – they should certainly not be cut down and litter and duff should be raked back from their boles. Duff raking may be especially important for those with deadwood exposed at their base, such as lightning scars. At GP, which recently experienced a surface fire following a long fire-free period, I observed that many of the partial snags I measured were in the process of dying, and that a number of former partial snags were already dead. Killed partial snags may make particularly good quality snags (Miller and Miller 1980), but fires are probably much more likely to kill partial snags than to create them, diminishing one resource pool to feed another one. It would be better to attempt to preserve all standing dead wood through the critical initial treatment of a restoration effort (when snag and partial snag mortality is most likely because of high fuel loading), and consider supplementing the snag population through the use of nest boxes or artificially induced mortality in some post-settlement trees otherwise scheduled for removal. Creating partial snags through partial girdling or other intentional wounding may be possible, but partial snags created from any trees otherwise scheduled for removal would likely be rather



small in size, and intentionally wounding trees otherwise scheduled for retention is inadvisable for the risk of killing them.

Future partial snag surveys at the sites used in this study could provide information about the creation and mortality rates of partial snags under both natural conditions and restoration treatments. In future partial snag surveys, at these sites and at any other sites of interest, I recommend amending the protocol used here to improve efficiency. Fire scars probably do not need to be measured in future surveys, as they were relatively rare, and never bore cavities. In future, branches probably do not need to be measured individually either, since they rarely contained cavities, though it might be useful to note the presence or absence of large branches. Measurements using the relaskop appeared to be unnecessary. Measures of diameter above bh did not much improve the calculation of lightning scar surface area. Although they allowed better estimates of bole taper, and thus of scar length, scar lengths calculated given bole taper differed very little from scar heights from top to bottom. Measures of spike diameter had a bigger influence on calculating spike surface area, but model 1, given in the results, above, accounts for almost all of the differences in spike surface areas and uses easier-to-obtain measurements. Height measurements were important for calculating surface area in both spike tops and lightning scars, but could be obtained more easily with a much lighter, cheaper, and more portable clinometer rather than the relaskop. Partial snags in which dead wood occurs on multiple tops (forks) should be noted and measured carefully, with measurements on each fork taken separately, since such trees were not used in the surface area models for either lightning scars or spike tops, and are likely to contain relatively more dead wood. For surveys of wildlife habitat availability, the

measurements of fire mortality risk are unnecessary, though they may be of interest if a survey precedes a prescribed fire. Distance to nearest snag appeared to be important in wildlife selection and is not difficult to measure. Spike and lightning scar conditions and bark cover may be related to bird use, but if use is defined as cavity presence, these age related variables will be poor predictors because cavities may remain long after use has ceased and after condition has changed from when use was initiated.

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## TABLES AND FIGURES

Table 3.1: Site characteristics and survey information for 5 southwestern sites where ponderosa pine partial snags were inventoried.

Site	Elevation (m)	Year of most recent fire	Large <sup>a</sup> live pine density (#/ha)	Large <sup>a</sup> snag density (#/ha)	Area surveyed (ha)	Year of survey
MT	2150	1870's	56.5	2.4	44.6	1998, 1999
GPNA	2250	1870's	60.3	5.6	21	2001
FP	2350	1999	105.3	9.3	24.4	2001
GP	2400	2001	93.3	11.7	27	2002
ICM	2500	1993	-	3.6	24	2002

a: "Large" trees are  $\geq 37.5$ cm dbh, except for snags at ICM and GPNA, where all snags  $\geq 30$ cm dbh are included (data from Boucher et al. 1999).

Table 3.2: Ponderosa pine partial snag densities and densities of three types of partial snag at five southwestern sites.

Site	Density <sup>a</sup> (#/ha)			
	All partial snag types (n)	Spike-topped trees	Lightning-scarred trees	Trees bearing other wounds or scars
GPNA	3.8 (80)	2.2	1.7	0.3
FP	3.1 (75)	2.2	0.6	0.7
GP	2.8 (76)	1.4	1.2	0.7
ICM	2.1 (50)	1.3	0.5	0.5
MT	1.7 (76)	0.7	1.1	0.3

a: Densities for three partial snag categories do not sum to the density of all partial snags because categories are not mutually exclusive.

Table 3.3: Mean characteristics of spike-topped ponderosa pine at five sites in the Southwest.

Site	Dbh (cm)	Height (m)	Average surface area of dead wood (m <sup>2</sup> )	Litter depth at base (cm)	Crown -base height (m)	% with overlap between crown - base and dead wood	% with woody debris at base	% with cavities	Cavities per m <sup>2</sup> of dead wood
GPNA	68.4	25.4	3.47	13.1	8.1	0.0	34	21.3	0.11
FP	62.1	24.7	4.58	2.2	10.8	1.8	18.9	30.2	0.10
GP	62.7	26.0	3.41	1.3	12.6	0.0	16.2	5.4	0.01
ICM	46.8	21.6	1.47	3.1	10.2	0.0	16.1	0.0	-
Mean for relict sites	60.0	24.4	3.23	4.9	10.4	0.5	21.3	14.2	0.07
MT	85.7	20.3	-	-	-	-	-	64.5	-



Table 3.4: Mean characteristics of lightning-scarred ponderosa pine at five sites in the Southwest.

Site	Dbh (cm)	Height (m)	Average surface area of dead wood (m <sup>2</sup> )	Litter depth at base (cm)	Crown -base height (m)	% with overlap between crown - base and dead wood	% with woody debris at base	% with cavities	Cavities per m <sup>2</sup> of dead wood
GPNA	71.3	28.0	2.03	11.1	9.7	17	20	9	0.14
FP	76.7	30.4	2.13	2.0	11.2	7	0	33	0.15
GP	76.0	30.5	2.64	1.2	13.1	9	0	9	0.04
ICM	56.9	27.6	1.42	3.3	12.5	8	23	15	0.16
Mean for relict sites	70.2	29.1	2.06	4.4	11.6	10	11	17	0.12
MT	73.1	21.0	-	-	-	-	-	30	-



Table 3.5: Results of a distribution-free exact test of probability that cavity presence is randomly selected with respect to the given variable (surface area of deadwood, distance to nearest snag, dbh, height, crown base height) measured on ponderosa pine partial snags at four southwestern relict sites.

Variable	Median value (M)	# of trees cavity-bearing trees that exceed M <sup>a</sup>	P <sup>b</sup>
Surface area of deadwood (m <sup>2</sup> )	2.252	38	0.001
distance to nearest snag (m)	15	36	0.006
Dbh (cm)	64.5	35	0.014
Height (m)	27.5	25	0.392
Crown base height (m)	10	17	0.006

a: Out of 53 total cavity-bearing trees.

b: "P" is probability of equal or more extreme value in third column, given that selection is random with respect to variable in first column.

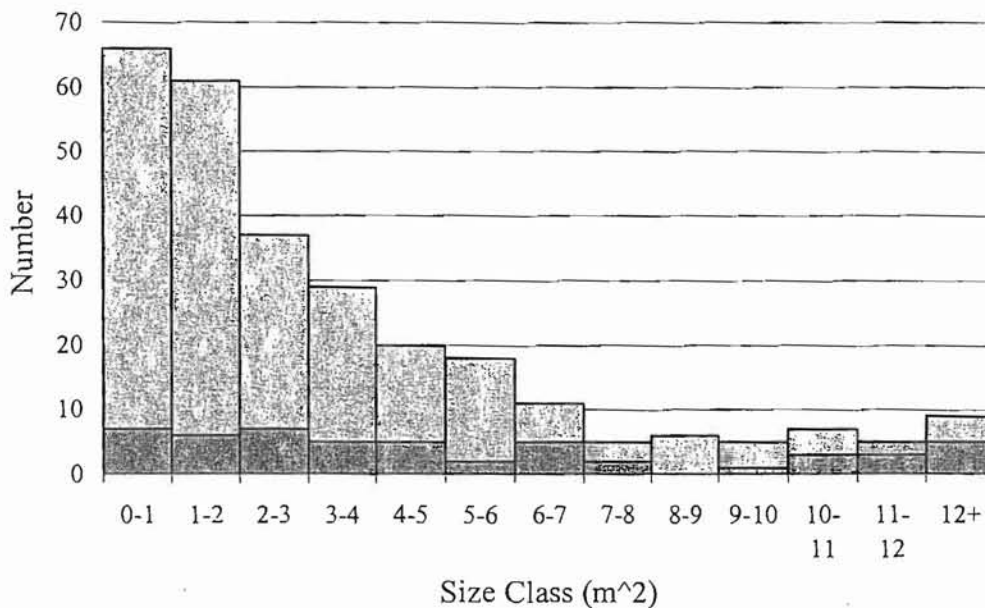


Figure 3.1: The distribution of ponderosa pine partial snags (light bars) and partial snags bearing cavities (dark bars) at four relict sites by total surface area size class.

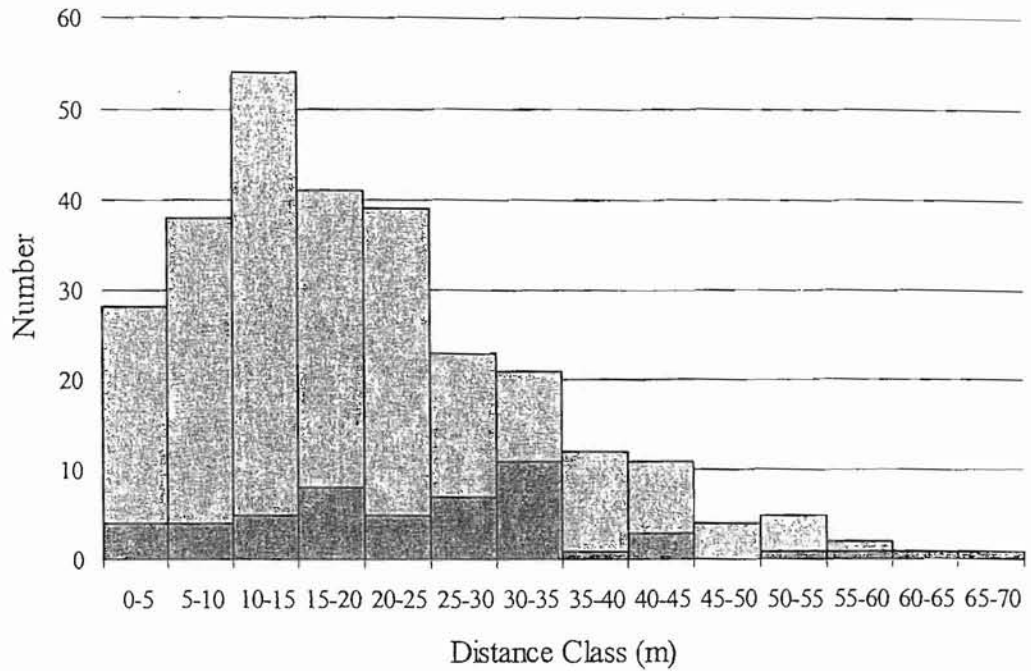


Figure 3.2: The distribution of ponderosa pine partial snags (light bars) and partial snags bearing cavities (dark bars) at four relict sites by class of distance to nearest snag.