SNAGS, WILDLIFE, AND FOREST MANAGEMENT IN THE SIERRA NEVADA

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Abstract.

Snags (standing dead trees) are an important habitat component for wildlife in the Sierra Nevada, especially for cavity-using birds and mammals. We estimate that about 31 percent of the bird species, and about 32 percent of the mammal species, that live in the forests of the Sierra Nevada use snags for nesting or denning, foraging, roosting, communication, or perching. Size (diameter and height), tree species, age (time standing since tree death) and condition, and location (exposure, microclimate, and surrounding habitat) are major factors that contribute to the relative value of individual snags to wildlife. The abundance of cavity-nesting birds, in particular, largely depends upon the abundance of suitable snags. Successful management and conservation of snag-using wildlife depend upon maintenance of a sufficient number (unknown at present) of large-diameter snags (greater than 15 inches DBH) per acre on a continuing basis. Providing for snag recruitment will be a particular challenge because increased demand for fuel and fiber has led to increased salvage efforts, improved technology for commercial utilization of dead wood, and increased cutting of snags for fuel wood, as other energy sources become more expensive. Improved mill technology allows harvest of smaller trees, which is leading to shorter rotation periods. Short rotations reduce the potential for replacement of large snags unless particular trees or stands are designated and left to grow beyond the normal rotation age. We urge that snags, especially large ones, be retained for wildlife. To provide replacement of snags as they decay and fall, we recommend leaving and/or killing cull trees in coordination with other forest management practices. Unmerchantable trees, damaged or diseased trees, genetically inferior trees, and some seed and shelterwood over-story trees can be left for snags, or killed for snags. In heavily harvested areas a few merchantable trees can be left when needed. Retaining scattered patches of mature forest will provide snags and produce additional wildlife and other forest benefits.

INTRODUCTION

Snags (standing dead trees) are an important habitat component for wildlife in the Sierra Nevada, yet certain forest management practices and trends produce conflicts between the use of snags for wildlife and for other products including fuel, lumber or fiber. For example, a recent issue of Forestry Research, a publication highlighting current Forest Service research activities, described two studies: One recommended the retention of snags as habitat for wildlife (Bull and Meslow 1977) and the other suggested harvest of snags as raw material for the pulp and paper industry (Lowery et al. 1977). Both authors recognized that snags are a valuable resource; the question is, for whom and for what?

This conflict is not new. More than 50 years ago, Grinnell and Storer (1924) decried the practice of felling dead trees as a sanitation procedure during forest management operations. They recommended leaving these trees for the benefit of wildlife. In the past 5 years, however, the value of snags to wildlife has become much more widely appreciated. The removal of nearly all large snags to reduce fire and safety hazards during timber operations on private land was required by the California Forest Practice Rules from 1947 until 1976. It was the recognition of the value of snags for wildlife which led to revision of these rules in 1976 to allow for snag retention, yet the current rules allow the taking of any snag of merchantable quality (Study Committee on Snags 1976).

Forest managers face the difficult challenge of meeting the increasing demands for timber products and conserving habitat for wildlife. Multiple-use forest management requires adequate information on the likely response of wildlife to proposed actions. In the case of snags and snag-dependent wildlife in the Sierra Nevada, managers need answers to such questions as: which wildlife species use snags, and for what purposes? What kinds of snags are required by these species? How many snags are required to meet their needs? We do not have complete answers to these questions at present, but we do have sufficient information to suggest guidelines until better information becomes available. The purpose of this report is to briefly summarize available information about these topics, to discuss some of the trends in management practices affecting the quantity and quality of snags, and to suggest practices to minimize conflicts between these practices and the conservation of snag-dependent wildlife.

Snag-Wildlife Relationships

In a separate report, based upon a review of literature (Raphael and White 1978), we have estimated that approximately 67 bird and 29 mammal species on the west slope of the Sierra Nevada use snags. Of these, 53 bird and 12 mammal species use snags frequently; the others use them occasionally. Snag-using species represent approximately 31 percent of the total bird and 32 percent of the total mammal fauna of this area. These species use snags for nesting and denning, foraging, roosting, communicating, and as hunting and resting perches. Some reptiles and amphibians use the lower parts of snags, but little information is available on the importance of snags for these species. Therefore, this report emphasizes birds and mammals.

Nesting

Snags are the usual nesting substrate for about 45 cavity-nesting bird species and 10 mammal species on the west slope of the Sierra Nevada (Raphael and White 1978). These are primary cavity-nesters (PCN), those which excavate their own cavities, and secondary cavity-nesters (SCN), those which use existing cavities, or other spaces such as behind bark. In studies at Sagehen Creek, near Truckee, California, we found 75 percent of 384 cavity nests in snags and 22 percent in dead portions (usually in dead tops) of live trees. The remaining 3 percent were in logs or other objects. In Oregon, Miller and Miller (1976) found 70 percent of all cavity nests in snags and 18 percent in partially dead traees, and Balda (1975) reported 87 percent snag use for nests in an Arizona study.

The literature suggests that availability of nest sites limits many SCN bird and mammal populations, based on experiments with artificial nest boxes, evidence of competition for nest sites, and the effects of snag removal upon hole nesting bird populations (see reviews by Beebe 1974, Balda 1975, Jackman 1975, Thomas et al. 1976, and Raphael and White 1978). It is apparent from these studies that most SCN species are dependent on nest cavities excavated by PCN species (see Raphael and White 1978), although some species frequently use cavities created by natural decay processes.

Feeding

As listed by Raphael and White (1978), approximately 47 bird species and 17 mammals forage on prey living on or in snags, use snags as food storage sites, or use snags as hunting perches on the west slope of the Sierra. Foraging styles vary among bird species. For example white-breasted nuthatches and brown creepers (Certhia familiaris) glean insects from bark-surface, hairy and black-backed three-toed woodpeckers chip bark to expose insects in the cambium or shallow sapwood areas, and pileated woodpeckers excavate deep into sapwood or heartwood to feed on carpenter ants (Camponotus spp.), wood borers (Buprestidae and Cerambycidae), and other forms. These varying foraging patterns, and the fact that insects and other prey are associated with snags during all stages of snag decomposition, indicate that nearly all snags, regardless of their condition, are of value to wildlife as feeding habitat.

We know that most woodpeckers and other bark gleaning birds feed heavily on prey associated with snags, but we do not know the proportion of the total diet which these birds derive from snags. Some measure is obtained by recording the percentage of foraging time individuals spend on snags versus other feeding substrates. Raphael and White (1978) summarize various foraging studies reported in the literature. One obvious shortcoming of these data is the lack of information on the relative availability of snags in the study areas. Such information is necessary to assess the relative preference of the birds for snags. But, assuming the data are representative, it is obvious that species vary in their snag dependency. Pileated, hairy, and black-backed three-toed woodpeckers appear to be especially dependent on snags for foraging; more than 50 percent of their foraging takes place on snags, while common flickers, sapsuckers, nuthatches, and chickadees are much less dependent.

Woodpeckers often are highly opportunistic in their feeding habits. They concentrate in areas of high prey density and they can change their diet to include a larger proportion of abundant prey. Therefore, utilization of snags for feeding can vary over time depending on the abundance of prey and woodpecker density. For example, Koplin (1969) observed a dramatic concentration of northern three-toed (Picoides tridactylus) and hairy woodpeckers feeding on insects infesting timber which had been killed recently by fire in Colorado. Other workers (Yeager 1955, Blackford 1955, Baldwin 1960) reported similar concentrations in response to fire, flooding, or insect outbreaks, and Bock (1970) reported the sporadic occurrence of Lewis woodpeckers in areas when insect populations reached high densities. In addition, Koplin (1972) has shown that bark beetles made up a higher proportion of the diet of downy, hairy, and northern three-toed woodpeckers when these beetle populations are at epidemic densities versus endemic, or low, densities.

Various mammals (6 species listed in Raphael and White 1978) also feed on prey living on or in snags. Black bears (Ursus americanus) dig out carpenter ants, other arthropods, birds, and small mammals from snags, logs and stumps (see Dixon 1927, De Weese and Pillmore 1972, Franzreb and Higgins 1975). Racoons (Procyon lotor), weasels (Mustela spp), and other furbearers take small birds and mammals from nest cavities (Kilham 1971, Dunn 1977).

Snags are used as hunting perches by about 30 bird species on the west slope of the Sierra. Lewis woodpeckers forage during the breeding season by flycatching from a snag perch. Raphael and White (1976) found that 91 percent of 64 foraging flights of Lewis woodpeckers were launched from snags, and Bock (1970) reported that 72 percent of 662 foraging perches were snags, utility poles, or fenceposts.

Food storage is another important function of snags—16 bird and mammal species use them for this purpose on the west slope of the Sierra Nevada (Raphael and White 1978), including the American kestrel (Balgooyen 1976) acorn and Lewis woodpeckers (Bock 1970), chickadees (Haftorn 1974), chipmunks, and tree squirrels. Acorn storage is especially important to wintering acorn woodpeckers. In one California study, 80 percent of 54 storage sites were large snags and only 20 percent were live trees (Gutierrez and Koenig in press).

Roosting and Denning

Shelter provided by tree or snag cavities reduces over-winter and other weather-related mortality of birds and mammals. Cavity-nesting bird species which roost in cavities tend to dominate the resident wintering avifauna in colder regions including higher elevations (von Haartman 1968). Kendeigh (1961) demonstrated that the insulation features of wood and bark reduce metabolic heat loss of cavity inhabitants and temperature fluctuation within the tree cavity.

Some species roost in existing cavities and others excavate new holes. Woodpeckers generally excavate roosting holes and rarely roost in the nest cavity. Some species (three-toed, downy, pileated woodpeckers, and flickers) are known to excavate new roost holes in fall (Jackman 1975).

Mammals that den in snags include some of the larger carnivores such as black bears (Beeman et al. 1977), fishers, and martens. Suitable den sites may limit the distribution or abundance of mammal species. Several bats roost in tree and snag cavities or behind loose bark (Orr 1954, Christian 1956, Fassler 1975). Humphrey (1975) suggested that the distribution of most bats in North America is correlated with the availability of suitable roost structures.

Communication

Snags have a role in both interspecific and intraspecific communication among birds. Drumming on dead wood is an integral part of territorial and courtship display among woodpeckers, but the importance of snags in this behavior is poorly documented. Our observations in the Sierra suggest that most drumming occurs on snags and, to a lesser extent on dead-topped trees and on the larger dead branches of live trees. Bull (1975) found that 19 of 21 drum trees used by pileated woodpeckers in Oregon were dead; the other 2 had dead tops. In addition, many passerine species sing from perches on dead trees as part of their territorial display. In two brushfields resulting from a fire in a conifer forest at Sagehen Creek, 63 percent and 81 percent of all observed singing events took place from snags (Raphael, unpublished data).

Perching

Snags are used as perching sites by many species for hunting (as discussed above) or for resting or surveillance (Raphael and White 1978). We do not know how important this use of snags is. Many raptors utilize tall snags or dead-topped trees near the nest trees for hunting, nest access, or resting. Snags along ridge tops appear to be especially important as perches (U.S. Forest Service 1977).

SNAG CHARACTERISTICS

Snags differ in height and diameter, species, age and condition (degree of decay), and location, and these factors influence the value of a particular snag to wildlife. Each wildlife species selects snags that fall within a range of these characteristics to meet its needs for nesting, roosting, feeding, communication, or perching (Gale 1973, Bull 1975, McClelland and Frissell 1975, Conner et al. 1975, Raphael and White 1976). We know very little about the snag requirements of mammals, and even less about those of reptiles and amphibians in the Sierra Nevada. It is likely, however, that meeting the needs of birds will satisfy most of the requirements of other vertebrates. Furthermore, management for birds will probably be most effective if concentrated on the requirements of the primary cavity-nesting species. These birds are the most dependent upon snags. Each pair requires 1 to 3 snags for nesting and roosting, and an additional number for feeding and drumming. Also, primary cavity-users select nest sites according to the characteristics of the snag. They are the species which do the "choosing." Secondary cavity-nesters select nest sites on the basis of the qualities and location of the nest cavity. Because most secondary cavity-nesters use holes excavated by PCN species, management to maintain populations of PCN species should result in adequate production of cavities suitable for SCN group. Table 1 (based on McLaren 1962, Jackman 1975, and our observations) lists SCN species in groups according to the cavity entrance size they require and the PCN species that excavate cavities of that size. SCN species that use small holes may be able to use larger holes, but the reverse is not true. The following discussion of snag characteristics, then, emphasizes requirements of the primary cavity-nesting species.

Size

Snag diameter appears to be the single most important variable in nest site selection, assuming that the snag is in appropriate habitat for a given species. Larger diameter and taller snags are generally selected as nest sites (Gale 1973, McClelland and Frissell 1975, Miller and Miller 1976, Mannan 1977, and Scott 1978). Except for those of the white-headed woodpecker, most nests are located near the top of a snag. The upper height limit for location of a nest cavity is at the point where diameter of the snag approaches the diameter of the nest cavity. Larger diameter snags can, therefore, accommodate higher nest cavities, and higher nests are less vulnerable to losses from ground predators.

Raphael and White (1978) summarize available data on the height and diameter of nest trees selected by PCN species occurring in the Sierra Nevada. This summary shows considerable variation in reported nest tree sizes among bird species and also among the same species in different areas. Most species, however, appear to select trees 20-70 feet hgigh and 15-30 inches in diameter. Hardwood nest trees are smaller in diameter than conifer nest trees, probably because cavity walls can be thinner in the stronger hardwood trunk.

The interrelationship between tree height and diameter makes it difficult to determine which of these factors is more important in nest site selection, but our preliminary analysis of data on nest tree size in relation to availability by size from Sagehen Creek suggests that diameter is the more important of the two. Birds in this area avoid trees less than 16 inches DBH, but show a strong positive selection for trees greater than 16 inches. Snags which are both over 16 inches in diameter and taller than 40 feet are only slightly more preferred than those over 16 inches but less than 40 feet tall (Raphael, unpublished data). Among the 9 PCN species studied, the coefficient of variation (standard deviation divided by mean) for tree height averages

Table 1. Associations of non-excavating wildlife species (SCN) with excavating species (PCN) in the Sierra Nevada.

Excavators (PCN)	Non-excavators (SCN)
Small holes (diameter of cavity entrance 20-35 mm)	
*Mountain chickadee (*Parus gambeli*)	*Mountain chickadee
Red-breasted nuthatch (*Sitta canadensis*)	*Chestnut-backed chickadee
Pygmy nuthatch (*Sitta pygmaea*)	
*Chestnut-backed chickadee (*Parus rufescens*)	
Downy woodpecker (*Dendrocopus pubescens*)	
Medium holes (diameter of cavity entrance 36-50 mm)	
Acorn woodpecker (*Melanerpes formicivorus*)	Flammulated owl (*Otus flammeolus*)
Yellow-bellied sapsucker (*Sphyrapicus varius*)	Saw-whet owl (*Aegolius acadicus*)
Williamson sapsucker (*Sphyrapicus thyroideus*)	Pygmy owl (*Glaucidium gnoma*)
Hairy woodpecker (*Dendrocopus villosus*)	Violet-green swallow (*Tachycineta thalassina*)
Nuttall woodpecker (*Dendrocopus nuttallii*)	Tree swallow (*Iridoprocne bicolor*)
White-headed woodpecker (*Dendrocopus albolarvatus*)	Purple martin (*Progne subis*)
Black-backed three-toed woodpecker (*Picoides arcticus*)	*Plain titmouse
*Plain titmouse (*Parus inornatus*)	*White-breasted nuthatch
*White-breasted nuthatch (*Sitta carolinensis*)	House wren (*Troglodytes aedon*)
	Winter wren (*Troglodytes troglodytes*)
	Bewick wren (*Thryomanes bewickii*)
	Western bluebird (*Sialia mexicana*)
	Mountain bluebird (*Sialia currucoides*)
	House sparrow (*Passer domesticus*)
	Chipmunks (*Eutamias* spp)
	Mice (Various)
	Tree squirrels (*Sciurus* and *Tamiasciurus*)
Large holes (diameter of cavity entrance > 50 mm)	
Pileated woodpecker (*Dryocopus pileatus*)	Wood duck (*Aix sponsa*)
Common flicker (*Colaptes auratus*)	Barrow goldeneye (*Bucephala islandica*)
Lewis woodpecker (*Asyndesmus lewis*)	Common goldeneye (*Bucephala clangula*)
	Bufflehead (*Bucephala albeola*)
	Harlequin duck (*Histrionicus histrionicus*)
	Hooded merganser (*Lophodytes cucullatus*)
	Common merganser (*Mergus merganser*)
	Merlin (*Falco columbarius*)
	American Kestrel (*Falco sparverius*)
	Screech owl (*Otus asio*)
	Great horned owl (*Bubo virginianus*)
	Spotted owl (*Strix occidentalis*)
	Ash-throated flycatcher (*Myiarchus cinerascens*)
	Starling (*Sturnus vulgaris*)
	Woodrats (*Neotoma* spp)
	Raccoon (*Procyon lotor*)
	Ringtail (*Bassariscus astutus*)
	Marten (*Martes americana*)
	Fisher (*Martes pennanti*)

*These species excavate holes in decayed wood occasionally.

10 percent greater than that for tree diameter. These observations indicate that PCN species are probably more flexible regarding tree height than tree diameter when selecting a nest site. Figure 1 shows the average height and diameter of nest trees utilized by PCN species at the Sagehen Creek study area.

Snag diameter, then, is a critical factor in determining the potential of a given tree as a nest site. Thomas et al. (1976) present a snag management plan based on minimum diameters used by nesting birds. Until more is known about reproductive success and population response of birds in relation to nest tree diameter we believe management should be based upon average rather than minimum diameters. Based upon our literature survey (Raphael and White 1978) and field studies (Figure 1), we believe that snags less than 11 inches in diameter are of little value for nesting, although they will provide feeding habitat. Snags 11 to 15 inches in diameter provide nesting habitat for some species, notably three-toed and hairy woodpeckers, and snags 15 to 20 inches are suitable for all species except the pileated woodpecker. Snags greater than 20 inches in diameter will meet the needs of all the cavity nesting species and are, therefore, the most useful.

In some habitats, snag height is particularly important. As mentioned earlier, raptors including bald eagles (Haliaeetus leucocephalus) and goshawks (Accipiter gentilis) may require one or more snags near their nests which protrude above the forest canopy for perching, surveillance, or hunting. In pine-oak woodlands, communally territorial acorn woodpeckers need both large diameter snags for acorn storage (Gutierrez and Koenig in press) and snags taller than the surrounding canopy for territory defense (Walter Koenig, personal communication). Special requirements such as these demonstrate the need for land managers to be wary of simple generalizations regarding snag size. Wildlife inventories are essential so that managers will be aware of the presence of species having special requirements.

Species

Cavity nesting birds nest and feed in a wide variety of tree species. Studies indicate apparent preferences for particular tree species in a given forest type, but these preferences are not consistent. For example, Lawrence (1967) found most common flicker nests in aspen trees in Ontario, Kelleher (1963) found most in Douglas Fir in British Columbia, Miller and Miller (1976) report a preference for ponderosa pine in Oregon, and we found a preference for white fir in the central Sierra of California (Raphael and White 1976). Similar patterns occur among other species as well. Because of this variability it is not possible at present to specify the most valuable snag species for each forest type in the Sierra. A few species, however, are especially important where they occur. Oaks and other hardwoods stand a long time, and are subject to decays which create natural cavities which are used by mammals and birds. Aspen is a consistently favored nesting tree, especially when infected with Fomes igniarius, a heart rot (Flack 1976, Winkler and Dana 1977).

Species and diameter interact to determine the length of time a tree will stand after it dies. In the mixed conifer type, firs stand longer than pines, and large diameter trees stand longer than small diameter trees (Figure 2). Longer standing trees, such as hardwoods and large trees, are of great value to wildlife; they provide food over a longer time period, and they allow more opportunities for nesting.

Age and Condition

Snags change continually from the time the tree dies. Needles fall, branches break

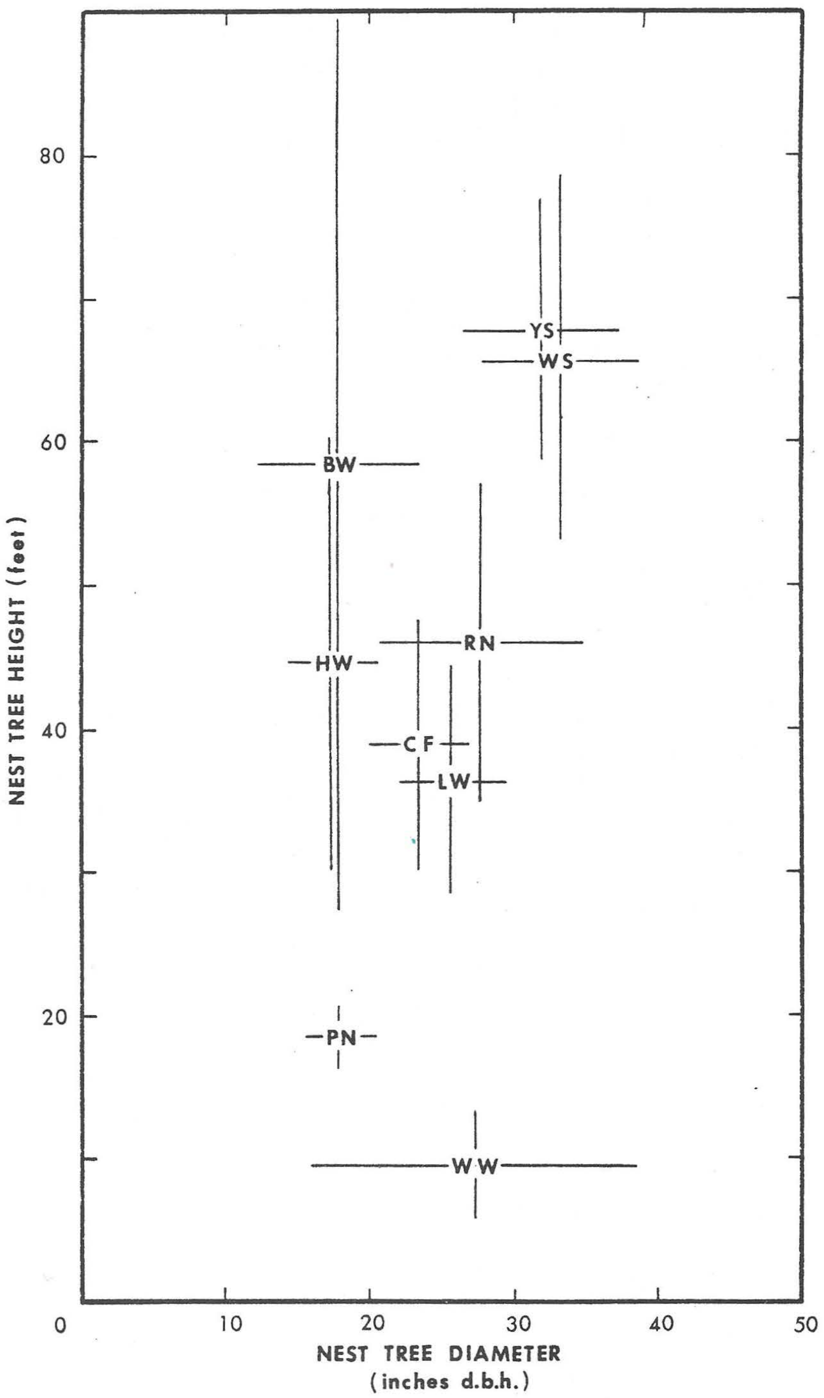

FIGURE 1. Mean height and diameter of trees selected as nest sites by primary cavity-nesting birds (excavators) at Sagehen Creek, California. Bars indicate 95% confidence intervals. The species shown are white-headed woodpecker (WW, N = 8), pygmy nuthatch (PN, N = 23), Lewis woodpecker (LW, N = 29), common flicker (CF, N = 42), hairy woodpecker (HW, N = 13), red-breasted nuthatch (RN, N = 19), black-backed three-toed woodpecker (BW, N = 5), Williamson sapsucker (WS, N = 27), and yellow-bellied sapsucker (YS, N = 33).

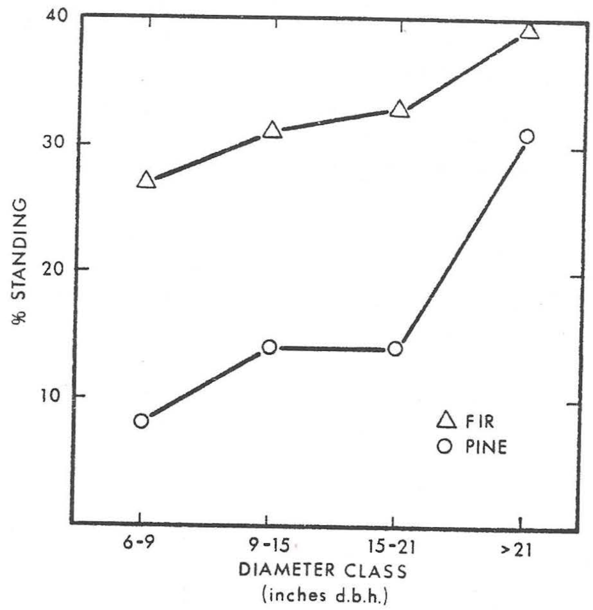

FIGURE 2. Proportion of total snags on a burned study plot at Sagehen Creek, California, which are still standing 15 years after death of the trees.

Table 2. Maximum breeding densities (pairs per 100 acres) of primary cavity-nesting (PCN) bird species (excavators) in Sierra Nevada habitat types. Data represent maximum values reported for censuses conducted in similar habitats in California published in American Birds, 1948-1976. No data were available for Lewis woodpeckers.

	Oak-pine woodland	Riparian-Deciduous	Mixed conifer	Jeffrey-ponderosa pine	True fir
Common flicker	16	17	12	12	12
Pileated woodpecker			1	1	1
Acorn woodpecker	12			12	
Yellow-bellied sapsucker		20	20	20	
Williamson sapsucker			20		20
Hairy woodpecker		10	20	20	20
Downy woodpecker		25			
Nuttall woodpecker	18	20			
White-headed woodpecker			5	5	5
Black-backed three-toed woodpecker			1		1
Red-breasted nuthatch			12	12	12
Pygmy nuthatch			36	36	
Number of species	3	5	9	8	7

off, bark falls away and the wood softens with increasing decay. The rate at which these changes occur is highly variable, depending on such factors as climate, exposure, soil depth, tree species, size, and cause of death. Some PCN species are adapted for nest excavation in harder snags while others, notably common flickers and Lewis woodpeckers, require older, softer snags. Bock (1970), for example, determined that Lewis woodpeckers in the Sierra do not nest in snags that have been dead less than 15 years.

Woodpeckers have a strong preference for trees that are infected with heart-rot fungi or other decay organisms (Shigo and Kilham 1968, Conner et al. 1976, Jackson 1977). These decay the heart-wood, allowing excavation of the nest cavity while leaving a firm sapwood shell which surrounds the cavity. Broken topped trees, both live and dead, are especially susceptible to decays which enter through the exposed top (McClelland and Frissel 1975). These trees provide excellent nesting habitat, providing they are large enough.

Snags of mostly sound wood - the hard snags - require the greatest consideration by land managers for several reasons. First, hard snags have a higher "life expectancy" than older decayed snags and therefore can provide more wildlife "use-years" (animal use per year times number of years of use). Secondly, a hard snag provides habitat for species adapted for excavation in sound wood, and, when it decays, it provides habitat for soft wood excavators. Therefore, fresh snags have the potential to serve the needs of both a larger number of individuals and a greater diversity of species than an older decayed snag. Unfortunately, these recently killed trees are still of some commercial value and are more likely to be salvaged than older unmerchantable snags. Furthermore, as Thomas et al. (1978) point out, we cannot create soft snags but we can create hard snags by selectively killing live trees. We have more management control over hard snags.

Location

The location of a snag, including exposure, microclimate, and surrounding habitat, affects its value to wildlife. Snags in exposed areas are more subject to windfall. Exposure also may affect the rate of wood decay, which in turn may affect the suitability of a tree for nesting. Microclimate may have a similar effect. More important, however, is the structure of the vegetation near the tree. Pileated woodpeckers prefer to nest in older stands; flickers nest and feed in open areas. A species' general habitat requirements must be met before it chooses a specific nest site; Table 2 shows the occurrence and density of PCN species in selected Sierra Nevada habitat types. The Forest Service is compiling a wildlife-habitat relationships document summarizing habitat requirements of all vertebrates occurring on the west slopes of the Sierra Nevada. We will not attempt to present any of these data here, but we emphasize that snags near streams or meadow areas, along edges between forests and brushfields, and in old-growth forests are particularly important.

SNAG DENSITY

How many snags do wildlife need? As important as this question is, we do not yet have information to provide a complete answer. Several workers have provided estimates based on a combination of field work and literature review.

Based on his California studies, Gale (1973), recommended leaving all snags. Where some snag removal is necessary, he suggested leaving a minimum of 330 and 430 snags larger than 15 inches diameter per 100 acres in true fir and mixed conifer types, respectively.

Balda (1975), studied secondary cavity nesting birds in ponderosa pine forests of Arizona. According to estimates of the number of snags needed per pair, and the number of pairs expected per 100 acres, he recommended leaving 268 snags (10 inches or larger) per 100 acres.

The most detailed analysis of snag densities required by wildlife is that of Thomas and his colleagues (Thomas 1975, Thomas et al. 1976 and Thomas et al. 1978), resulting from studies in the Blue Mountains of Oregon and Washington. Their estimates for each vegetation type are based on the density of PCN species in that type, an assumed number of snags required per pair, and minimum snag diameter. Their calculated totals of snags required to maximize bird populations range up to 300 hard snags, 6 inches or larger, per 100 acres in aspen and riparian types and 225 snags, 10 inches or greater, in mixed conifer, pine and fir types.

We have investigated the relationship between snag and bird density in two ways. One approach included constructing a computer model to simulate bird responses to snag density. The model takes into account each PCN species' preference for tree species and diameter, rate of fall of snags by size and species, minimum territorial requirements of the PCN and SCN species, and assumptions similar to those of Thomas et al. (1976, 1978) about the number of snags required per pair (15-48) and the number of cavities excavated per pair per year (1-3). We ran this model to simulate a 50 year time period using initial snag densities ranging from 0 to 15 snags greater than 15 inches per acre (plus additional snags less than 15 inches). Totalling the number of birds nesting each year until all snags have fallen gives an estimate of the wildlife value in "bird-years" of each starting density. This computation (Figure 3) indicates that the total value continues to increase at densities of more than 10 snags per acre, but that snag densities of only 3-6 snags per acre appear to provide more than 75 percent of the use in "bird-years". Models such as this one are useful to test management alternatives and to help understand relationships, but we cannot be confident that they will predict actual responses of wildlife. There are too many interacting factors such as habitat, snag condition, prey fluctuations, and other unknowns.

The other approach is based upon field data from our Sagehen Creek studies. We censused all cavity nesting birds on 7 20.9-acre study plots and measured all snags greater than 5.0 inches DBH and 5 feet tall. Figure 4 describes a relationship between total cavity-nesting bird density and numbers of snags greater than 15.0 inches DBH. This figure suggests that bird populations may continue to increase at snag densities of 4 per acre. However, these plots differ in ways other than snag density; 2 were burned, 2 were logged, 2 are unmanaged and 1 is in an East-side pine type. Therefore, we must be cautious in interpreting the results. The density estimates of Gale, Balda, and Thomas et al. are all similar to the results of our modelling and field studies, but the diameter specifications of these studies vary. If we count snags greater than 11.0 inches DBH on our study plots we find snag densities ranging up to 10.2 snags per acre.

Obviously, more research is needed. Managers should be careful to avoid arbitrarily assigning or accepting minimum standards for snag density and characteristics until wildlife needs are more fully understood. But, where intensive management may eliminate all snags unless some minimum standard is adopted, the above estimates may be useful. The California Region of the U.S. Forest Service is considering habitat quality standards which define minimum snag densities and sizes for different forest

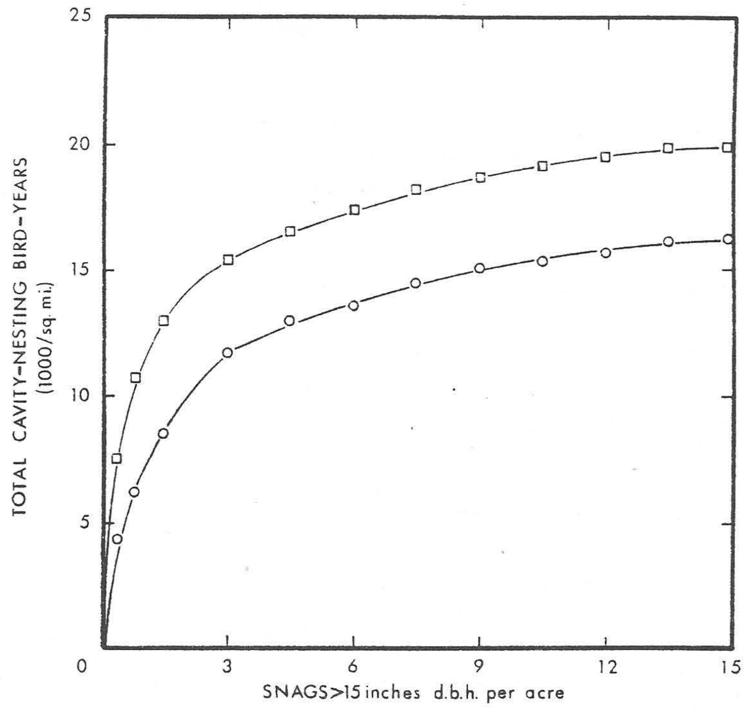

FIGURE 3. Simulated relationship of total cavity-nesting bird use in "bird-years" during the standing life of snags and snag density. The upper curve (squares) was computed assuming that each pair of primary cavity-nesters excavates 3 cavities per year, and requires at least 15 snags per territory. The lower curve (circles) assumes 1 cavity per year, and 48 snags per territory.

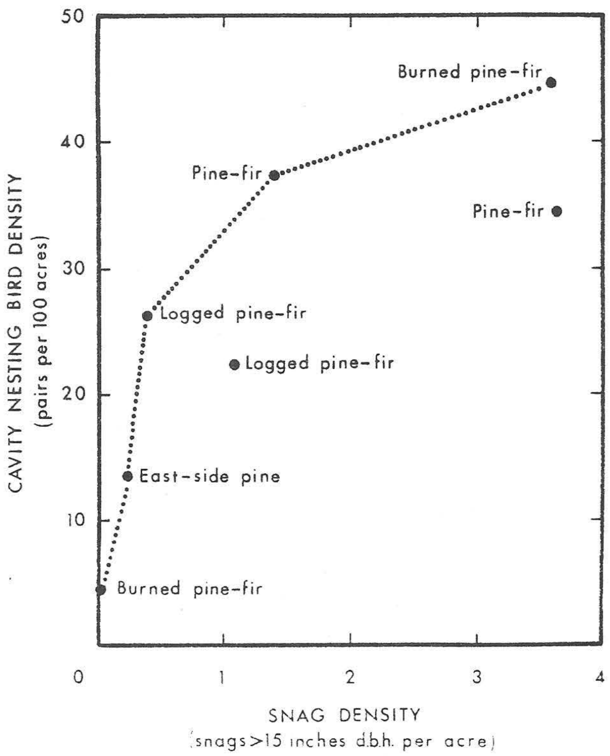

FIGURE 4. Relationship of total cavity-nesting bird population density to snag density on census plots at Sagehen Creek, California.

types in the Sierra, using methods similar to those of Thomas et al. (1976). Once minimum snag densities are assigned, it may be tempting to assume that needs of wildlife for snags are known. Wildlife needs are complex; any standards that are set now should be reviewed periodically as more information becomes available. Monitoring of wildlife populations should be an essential part of this continuing evaluation process.

SNAG MAINTENANCE AND RECRUITMENT

Demand for timber products has increased 65 percent during the last 3 decades, and demand continues to increase (U.S. Forest Service 1973). Increased demand leads to higher economic values for forest products and creates incentives for more intensive forest management in the Sierra Nevada. Rotations will shorten, more land will be under management, stocking will be more carefully controlled, and utilization of forest residues will increase. All of these trends can have serious, negative impacts on snag-dependent wildlife unless snag management plans are implemented. The major tasks are to maintain enough large-diameter snags to meet wildlife needs, and to provide for the replacement of snags that fall naturally.

Maintenance

Snag maintenance on managed lands is subject to constraints imposed by safety and fire hazards. State and federal safety regulations require felling of any hazardous snag in the logging area. What constitutes a hazardous snag is a matter of the professional discretion of the logging operator and/or the safety inspector. At present, snags along roads or near buildings are most often felled as safety hazards. On private lands in California, snags greater than 16 inches DBH and 20 feet tall which are located along ridgetops or within fuelbreaks must be felled to reduce fire hazards. Wildlife habitat can be maintained under these circumstances by leaving snags in well distributed clumps or patches away from roads, ridgetops, etc.

A more difficult problem involves the conservation of merchantable snags. On federal lands there is a clear mandate to maintain wildlife populations through such legislation as the Multiple-Use Sustained Yield Act and the National Forest Management Act of 1976. Conserving snags of merchantable quality means foregoing the revenues these trees could produce. On federal forest land these costs can be interpreted as the price the public is willing to pay to conserve wildlife. But on private land no such opportunity exists. Private commercial forestry is a highly competitive business. Wildlife conservation on private land is not mandated, it is merely encouraged. Wildlife considerations really depend on the interest and financial status of the timber owner. Therefore, private landowners need legislation providing financial incentives to encourage conservation of snags and other key wildlife habitat components on their lands.

Snags of formerly unmerchantable quality now are becoming commercially valuable with recent technological developments. Studies by the U.S. Forest Service (1976), Lowery et al. (1977), Maloney et al. (1976), Fahey (1977), and Snellgrove (1977) indicate that technologies exist to utilize dead trees for energy and chemicals, pulp, particle board, and lumber. Snellgrove's (1977) study of the lumber value of dead western white pine in Idaho showed that material dead 2 years or less was worth about 72 percent of live tree value. Trees dead 7 or more years were worth about 29 percent of live tree value. Worth increased with increasing tree diameter; the most valuable trees were large diameter (>20" DBH) and recently killed, precisely those trees of most potential value to wildlife. Should utilization of such material increase in the Sierra, a compromise will have to be forged between wildlife and wood products users.

Utilization of dead wood for fuel and chemicals is part of a recent effort by the U.S. Forest Service to step up its salvage program. A feasibility study is currently under way (U.S. Forest Service 1976) to determine the potential of converting dead material into energy through direct combustion or production of chemical substitutes. Tree mortality in the West is particularly high, and current salvage programs remove only about 7 percent of the total (U.S. Forest Service 1973). The Forest Service inventory for the Pacific Coast region shows that 72.9 million tons, or 35 percent of total residues, are in the form of merchantable dead trees. The forest industry is the fourth largest energy user in the U.S. As the price of fossil fuels increase, residue fuels are becoming economically competitive, and more dead trees are likely to be utilized. Wildlife losses can be minimized if such removals are limited to snags less than 11 inches diameter, and if greater emphasis is placed on the utilization of logging and mill wastes.

Finally, snags in accessible areas are being cut commercially and privately to supply fuelwood for home heating. Home heating costs in the Sierra, using fossil fuels, can be as high as $150 per month. Burning firewood as a substitute for gas or oil results in substantial savings. Snag conservation in areas under pressure by fuelwood cutting can be accomplished by administrative action. Forest Service district offices can ration cutting permits, permit the taking of dead and down wood only, limit cutting to trees less than 11 inches in diameter, or they can limit cutting to marked trees. The proper administrative alternative can be recommended by the forest biologist based on an evaluation of the status of snag dependent wildlife in the proposed cutting area. Restriction of cutting of snags near key wildlife habitats, such as near water, meadows, and edges is particularly important.

Recruitment

Providing for replacement of snags as they fall is critical to conservation of snag-dependent wildlife. The trends discussed above will halt snag recruitment if new snags are utilized for fuel, pulp, or lumber as fast as they are formed. Assuming that we can conserve enough snags to meet the present needs of wildlife, how can fallen snags be replaced under intensive forest management when natural morality is low and rotations are short? Opportunities for artificial snag recruitment exist with most common silvi-cultural practices.

Timber stand improvement includes removal of cull or damaged trees, and thinning to promote tree growth. Those trees greater than 15 inches d.b.h. which would otherwise be removed can be killed and left standing in place as snags. Those damaged or unmerchantable trees less than 15 inches d.b.h. that will not have an adverse affect on growing stock can be left alive until they are over 15 inches, and then killed. In this way snags will be created throughout a rotation cycle.

Even-aged management in the Sierra includes clearcutting, seed tree, and shelterwood harvesting systems. The usual practice following a clearcut is to cut and burn all nonmerchantable residual trees. The largest of these should be killed and left standing instead. These snags, if sufficiently large, will remain standing during most of the next rotation. If the clearcut has no suitable residuals, or if most snags within the clearcut have fallen early in the rotation, snags created (or maintained) along the edge of the cut can be used by the bird species foraging in the cut area. Seed tree and shelterwood systems provide the same opportunities for snag recruitment as in clearcuts. Additional large-diameter snags can be created by killing and leaving some of the seed or shelter trees during the final overstory cut.

Uneven-aged management includes selection cutting or small patch cuts. Snag management is much easier under this system than under the even-aged systems because the basic stand structure is maintained throughout the rotation cycle, and equipment (cable lines, tractors, etc.) is restricted to confined areas. Because mature trees are always present, natural mortality can produce new snags, and the intact canopy will protect existing snags against wind. As with the other systems, snags can be created with minimum financial loss by killing cull, genetically inferior, diseased, and other unmerchantable trees.

The length of the rotation cycle will have a major influence on suitability of the stand for snag-dependent wildlife. At present, merchantable trees are 16 d.b.h., or larger, in most areas but in the future, as more mills accept smaller stock, trees averaging 12 inches d.b.h. may be harvested commercially. These stands will not be capable of supplying the 15-inch or larger snags required by most wildlife unless portions of the stand are maintained and allowed to continue growing. On the best sites, an additional 10 to 20 years would be required, depending on the tree species.

Old-growth stand generally support larger numbers of cavity-nesting birds than younger stands (see Figure 3), primarily because of the higher density of large snags. Some cavity-nesting and other wildlife species require old-growth habitat per se; examples include pileated woodpecker, hermit warbler (Dendroica occidentalis), and marten. Of the 17.3 million acres of commercial forest area in California, 8.7 million acres are classified as old-growth, 2/3 of which are on National Forest lands (Oswald 1970). Most logging activity in the Sierra is concentrated on old-growth. Projections by the U.S. Forest Service (1973) indicate exhaustion of old-growth by the year 2000 on private lands, and by 2020 on public lands. Some Sierra Nevada old-growth, about 800,000 acres, is in wilderness or reserved status. We believe that the wildlife and other forest values of this habitat justify maintaining a portion of each timber compartment in old-growth at all times. Private landowners require financial incentive for maintaining such stands; we believe mechanisms should be developed to provide these incentives.

Conserving snag dependent wildlife, then, depends upon maintaining existing snags, and upon recruiting replacement snags. Snag management requires a balance between wildlife and other forest values. Long-range multiple-use planning can provide this balance. The major tasks ahead are to design and implement such plans before further losses of snag-dependent wildlife occur.

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