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# Decay Dynamics and Avian Use of Artificially Created Snags

## Abstract

The loss of standing dead trees (snags) from logging has led to artificial creation of snags to help maintain cavity-nesting species. We compared two methods of snag creation: cutting tops and girdling. A total of 1,189 trees of 10 coniferous species was treated between 1991 and 1997 on timber sales in northeastern Washington. We monitored 1,108 trees at approximately 2-yr intervals to determine degree of decay (on a nine-point scale), signs of foraging, and presence of cavities. Nearly 7% of the girdled trees were still alive after 4-7 yr, whereas all but one topped tree died. Initial decline (i.e., reaching decay class 2) was faster for ponderosa pine and western larch than for Douglas-fir. Western larch lost bark (decay class 4) earlier than other species. Topped trees declined more quickly than girdled trees, but girdled trees reached decay class 4 faster. The proportion of trees with evidence of foraging and cavities increased with decay class. Western larch was used more for foraging than other species, and there was no effect of treatment on foraging use. In contrast, topped Douglas-fir and grand fir were used more for foraging than girdled trees at later decay classes. Cavities were observed only in trees that were topped. Interspecific differences in presence of cavities were not observed before decay class 4; western larch had the lowest frequency of cavities, whereas grand fir had the highest. The use of specific treatments for creating snags and selection of species may make these habitat elements available over long time periods.

## Introduction

Standing dead trees (snags) are important resources for many species of wildlife because they provide foraging, roosting, perching, denning, and nesting habitat (McClelland and Frissell 1975, Ohmann et al. 1994, Campbell et al. 1996, Bull et al. 1997, Harrod et al. 1998, Lee 1998, McComb and Lindenmayer 1999). Primary cavity-nesting species (e.g., woodpeckers, nuthatches, and chickadees) excavate cavities in snags each year, and secondary cavity users (e.g., wrens, American kestrels, flying squirrels, and marten) may occupy these cavities in following years. Cavity-nesting birds play important roles in forest ecosystems, including reducing the magnitude of pest outbreaks by foraging on insects (McClelland et al. 1979, Mannan et al. 1980, Bull et al. 1997, Ganey 1999). The availability of suitable snags is considered to be the most important factor in sustaining populations of cavity-nesting species (McClelland et al. 1979, Scott 1979, Cline et al. 1980, Mannan et al. 1980, Zarnowitz and Manuwal 1985, Li and Martin 1991).

Snags are naturally produced by lightning strikes, forest fires, insect infestations, tree diseases, and suppression (McClelland and Frissell 1975, Mannan et al. 1980, Moorman et al. 1999). Snag density varies widely depending on stand age, forest type, location, disturbance regime, and degree of management (Cline et al. 1980, Zarnowitz and Manuwal 1985, McComb and Lindenmayer 1999). For example, old-growth ponderosa pine forests in Arizona had an average of 11.5 snags/ha (Scott 1978), whereas historical snag densities in ponderosa pine forests east of the Cascade Mountains in Washington were estimated to be between 14.5 to 34.6 snags/ha (Harrod et al. 1998). Intensive silvicultural management may greatly reduce the density of snags (Cline et al. 1980, Zarnowitz and Manuwal 1985). Snags have often been removed as fire and safety hazards during harvesting operations (Scott 1978, Mannan et al. 1980, Runde and Capen 1987). Although removal of snags may be offset somewhat by the death of mechanically injured trees, the natural recruitment of snags is disrupted and generally results in lower snag densities over time (Cline et al. 1980).

Various prescriptions have been suggested for providing adequate snag densities for different forest types (McClelland and Frissell 1975, Mannan 1977, Scott 1978, McClelland et al. 1979, Scott 1979, Cline et al. 1980, Steeger and Hitchcock 1998). State and federal regulatory agencies have responded by developing rules for the number of snags or green trees to be retained after harvest. To augment snag densities for wildlife, managers began experimenting with methods to create snags artificially ~30 yr ago (Lewis 1998). A recent survey of forest managers in the Pacific Northwest found that common methods used to create snags included fully or partially removing the crown of trees with chainsaws or explosives (i.e., topping), girdling in or near the base of the crown, and fungal inoculation (Lewis 1998). Although the use of these methods has become more widespread in the western U.S., their effectiveness has not been well documented (Parks et al. 1999).

Bull and Partridge (1986) evaluated six methods of snag creation in ponderosa pine (*Pinus ponderosa*) forests in northeastern Oregon. Over a 5-yr period, they compared rates at which trees died and subsequently fell over and avian use of snags created by girdling, topping with chainsaw, topping with dynamite and inoculating with fungi, girdling and inoculating with fungi, injecting with herbicide, and baiting with an insect pheromone. Although topping trees by chainsaw was the second most costly method, trees treated by this method died the fastest, remained standing the longest, and were most used by cavity nesters (Bull and Partridge 1986). From a safety standpoint, however, topping trees with chainsaws is considered the most dangerous method (Lewis 1998).

Further evaluation of methods to create snags must consider differences between tree species. For example, because ponderosa pine has a higher sapwood to heartwood ratio than many other conifers, woodpeckers typically excavate their cavities entirely within the sapwood (Bull et al. 1997). Therefore the effectiveness of methods that promote sapwood rot (e.g., girdling) versus those that promote heartwood rot (e.g., fungal inoculation) might vary between species (Lewis 1998). Recent studies comparing snag creation methods in western forests have been conducted in ponderosa pine (Bull and Partridge 1986, Parks et al. 1999). There is a clear need for similar studies in other forest types (Parks et al. 1999).

Our objective was to evaluate the effectiveness of artificially created snags by examining the effects of method of snag creation, tree species, and rate of decay on use by cavity-nesting birds in mixed coniferous forests. Specifically, we addressed the following questions: How quickly do trees decay following treatment, and how does this vary between snag creation methods and among tree species? How is foraging and nesting use by cavity nesters affected by the method of snag creation and degree of decay?

## Methods

### Study Area

The study was conducted on 23 different timber sales in the Sullivan Lake Ranger District on the 77,000-ha Colville National Forest, located in the northeastern corner of Washington State. The second-growth coniferous forests of this region vary in species composition (Table 1) and may have a small deciduous component. Most harvest units were in the western redcedar-western hemlock (*Thuja plicata-Tsuga heterophylla*) (81% of 120 units) or Douglas-fir-grand fir (*Pseudotsuga menziesii-Abies grandis*) (17%) associations with a few in the subalpine fir/Oregon boxwood (*Abies lasiocarpa/Pachistima myrsinites*) (2%) association. The terrain is rolling hills and the sales were at elevations of 750 to 1,500 m.

### Creation of Snags

To meet the USDA Forest Service requirements of ≥10 snags per harvested hectare (Lowe 1995), snag creation was initiated in 1990. We selected trees that were representative of each stand and that were >28-cm diameter at breast height (dbh). We chose larger diameter trees because some species of cavity-nesting birds require them (Thomas et al. 1979), and because they are likely to remain standing over a longer time period than small diameter trees (Morrison and Raphael 1993). We treated fewer ponderosa pine later in the study because of the relative rarity of large diameter trees of this species in this region.

Snags were created by cutting the tops of trees or by girdling above the first whorl of live branches at a height >10 m. Girdles were created by using

TABLE 1. Tree species, number of trees treated by girdling and topping, mean diameter at breast height (cm), and mean height (m) at the time of treatment.

| Species | Treatment type (n) | | | Mean | Mean |
|---|---|---|---|---|---|
| | Girdled | Topped | Total | dbh | height |
| Douglas-fir | 351 | 138 | 489 | 52.9 | 28.1 |
| Western larch | 331 | 94 | 425 | 49.0 | 33.2 |
| Grand fir | 38 | 29 | 67 | 50.5 | 27.9 |
| Western redcedar | 15 | 42 | 57 | 56.3 | 22.0 |
| Lodgepole pine | 34 | 5 | 39 | 37.5 | 27.0 |
| Western hemlock | 12 | 21 | 33 | 51.5 | 24.1 |
| Ponderosa pine | 1 | 31 | 32 | 62.1 | 22.3 |
| Engelmann spruce | 10 | 18 | 28 | 56.9 | 26.3 |
| White pine | 1 | 11 | 12 | 59.8 | 19.5 |
| Subalpine fir | 3 | 0 | 3 | 47.8 | 34.5 |
| All species | 796 | 389 | 1185 | 51.5 | 29.3 |

a hand saw to make two parallel cuts (about 15 cm apart) around the tree and then removing the intervening bark and cambium with an axe. We do not consider treatment of trees by fungal inoculation, which began in 1998, because insufficient time had elapsed for decay to occur. Treated trees were tagged with a wildlife sign and unique number, painted with an orange stripe and "T" at breast height on the tree, and located on area maps of each individual stand to aid in returning to them. Height of each tree was estimated with a clinometer before treatment, and species and dbh were recorded.

Treated trees were usually located near the boundary of a harvest unit, although in some cases they were spread across the entire unit. To the extent possible, treated trees were in areas that would reduce the likelihood of their loss to firewood cutters (e.g., steep slopes or away from access roads).

### Monitoring

Trees were revisited at roughly 2-yr intervals between 1992 and 1999. At the time of monitoring, we measured height with a clinometer and noted any breakage of the trunk. We examined the bark of each tree for obvious evidence of foraging (i.e., presence of drill holes) by cavity-nesting birds. We used binoculars to scan each tree for signs of cavity excavation and for conks (fruiting bodies of fungi). We recorded foraging, nesting, and fungi as present or absent. Tree decay was evaluated on a scale consisting of nine sequential, non-overlapping stages as described by Thomas et al. (1979). The stages proceed from live tree (class 1) to decline (2–browning of needles), death (3–loss of needles, but fine branching still evident), loose bark (4–loss of fine branching, cracks in bark), bark lost (5–few branches remain), broken (6–top of tree lost), decomposed (7–advanced decay, additional breakage of the trunk), down material (8–most of trunk is on the ground), and stump (9).

## Data Analysis

To examine the effects of tree species, method of snag creation, and species × method interaction on time to reach each decay class, we conducted separate two-way analyses of variance (ANOVA) for each decay class. We also considered models with dbh included as an additional covariate to assess the effects of tree size on time to decay. Following a significant analysis, we used Hochberg's GT2 multiple comparisons test to determine differences between tree species means. This method is appropriate for unequal sample sizes (Sokal and Rohlf 1995).

We examined changes in the frequencies of trees with conks between decay classes and between snag creation methods using $\chi^2$-tests (Sokal and Rohlf 1995). Similarly, we used $\chi^2$-tests to examine changes in frequency of foraging and nesting use by cavity-nesting birds between decay classes, snag creation methods, and tree species.

Tests were considered significant at $P \leq 0.05$. All analyses were conducted with the Statistical Analysis System (SAS Institute Inc. 1988).

## Results

We girdled 797 trees and topped 392 to create 1,189 snags between 1990 and 1997 (mean = 51.7 trees/sale; range, 10-138 trees/sale). Topping was used initially in 1990 and 1991 (n = 387), but in 1992 only five trees were treated this way. Girdling became the principal method for creating snags from 1992 to 1997 (n = 797). Only four deciduous trees were treated and are not considered further. Douglas-fir and western larch (*Larix occidentalis*) accounted for 77% of all trees treated, and grand fir, western redcedar, and lodgepole pine (*Pinus contorta*) accounted for an additional 14% (Table 1).

Of the 1,189 treated trees, 67 were not monitored and 14 could not be located subsequently.

We revisited 1,108 treated trees an average of 2.3 times (range, 1-6 times) and at an average interval of 2.4 yr. Trees were monitored for an average period of 5.5 yr (range, 1-8 yr). Only a few of the monitored trees were lost during the study period: 17 fell over (five at one site) and nine were cut for firewood. Twelve trees revisited at least once after treatment could not be located in subsequent visits, and these trees probably had fallen over or were cut.

Some trees (n = 131) showed no sign of decline by the end of the study. Of these, a greater proportion of trees treated by girdling (6.8% of 797) were still alive 4 yr after treatment (range 4 to 7 yr) than those treated by topping (0.3% of 392 trees; $\chi^2 = 36.6$, $P < 0.001$). In several cases, the girdle appeared to be healing over. The remaining 76 live trees were treated by girdling in 1996 and 1997, and sufficient time may not have elapsed for the trees to decline.

## Decay Trajectories

Only 13 trees reached decay classes >4 and consequently we focus on decay classes 2 to 4. For each decay class, the overall ANOVA examining the effects of tree species, method of snag creation, and species × method interaction on time to reach the decay class was significant ($P < 0.001$ for all classes). Diameter at breast height was significant only for decay class 2 ($F = 8.1$, df = 1, 434, $P < 0.005$). Larger diameter trees declined faster initially, but subsequent decay was unaffected by tree size. There were interspecific differences in the time required to reach each decay class ($P < 0.001$ for all classes). Method of snag creation and species × method interaction were significant for decay classes 2 and 4 (method of snag creation: decay class 2, $F = 97.8$, df = 1, 434, $P < 0.0001$; decay class 3, $F = 1.84$, df = 1, 590, $P < 0.17$; decay class 4, $F = 102.5$, df = 1, 225, $P < 0.0001$; interaction: decay class 2, $F = 2.53$, df = 6, 434, $P < 0.02$; decay class 3, $F = 1.72$, df = 6, 590, $P < 0.11$; decay class 4, $F = 2.43$, df = 5, 225, $P < 0.04$).

Hochberg's GT2 comparisons between pairs of means revealed relatively few significant differences between species in the time to reach a decay class. In part, this was due to differences in variances and sample sizes across species (Table 2). Douglas-fir took significantly longer to reach decay class 2 than western larch or ponderosa pine. These differences disappeared by decay class 3. Western hemlock, however, took significantly longer to reach decay class 3 than western larch or white pine. The time required to reach decay class 4 was similar for most species, but significantly less time was required for western larch than for Douglas-fir, grand fir, or Engelmann spruce. We further examined the effects of snag-creation method on time to decay by conducting separate analyses for the three species with the largest sample sizes for each decay class (Table 3). For each species, initial decline (decay class 2) proceeded more quickly for trees treated by topping. Time to decay to class 3 was generally similar for both treatments. For class 4, however, time to decay was longer for trees created by topping for all three species (Table 3).

Conks were absent from live trees and rare on declining trees for both treatments (Table 4). The proportion of trees with conks increased significantly from decay class 2 to decay class 3 for

TABLE 2. Mean time (years) since treatment to reach decay classes 2 to 4 for each species. Means are not corrected for snag-creation method (i.e., topping or girdling). Sample sizes are the number of trees observed at each decay class.

| | Decay class | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2 | | | 3 | | | 4 | | |
| Species | $\bar{x}$ | SE | n | $\bar{x}$ | SE | n | $\bar{x}$ | SE | n |
| Western hemlock | 2.0 | 0.4 | 14 | 5.4 | 0.7 | 15 | | | |
| Douglas-fir | 2.0 | 0.1 | 185 | 3.9 | 0.1 | 274 | 5.9 | 0.2 | 58 |
| Lodgepole pine | 1.9 | 0.2 | 12 | 3.5 | 0.5 | 17 | 4.8 | 0.9 | 6 |
| Grand fir | 1.9 | 0.3 | 21 | 4.1 | 0.5 | 22 | 6.1 | 0.4 | 20 |
| Western redcedar | 1.7 | 0.3 | 29 | 4.3 | 0.6 | 23 | 7.0 | 1.0 | 2 |
| Western larch | 1.5 | 0.1 | 170 | 3.6 | 0.1 | 208 | 4.9 | 0.2 | 123 |
| Engelmann spruce | 1.3 | 0.2 | 7 | 3.3 | 0.4 | 18 | 6.5 | 0.5 | 13 |
| Ponderosa pine | 1.0 | 0.0 | 15 | 3.4 | 0.6 | 23 | 5.1 | 0.6 | 9 |
| White pine | 1.0 | 0.0 | 1 | 2.3 | 0.3 | 6 | 5.8 | 0.9 | 8 |

TABLE 3. The effects of snag-creation method on decay time (years) for three tree species.

| Species | Decay class | Girdled | | | Topped | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $\bar{x}$ | SE | n | $\bar{x}$ | SE | n | F | *P* |
| Douglas-fir | 2 | 2.30 | 0.10 | 143 | 1.02 | 0.02 | 46 | 57.5 | 0.0001 |
| | 3 | 4.04 | 0.09 | 160 | 3.41 | 0.23 | 114 | 8.0 | 0.005 |
| | 4 | 5.30 | 0.14 | 33 | 6.64 | 0.28 | 25 | 20.9 | 0.001 |
| Western larch | 2 | 1.70 | 0.08 | 122 | 1.04 | 0.03 | 48 | 28.5 | 0.001 |
| | 3 | 3.53 | 0.23 | 70 | 3.41 | 0.11 | 138 | 0.26 | 0.61 |
| | 4 | 4.44 | 0.13 | 104 | 7.26 | 0.20 | 19 | 75.3 | 0.001 |
| Grand fir | 2 | 2.73 | 0.43 | 11 | 1.00 | 0.0 | 10 | 14.7 | 0.001 |
| | 3 | 4.21 | 0.68 | 14 | 3.87 | 0.23 | 8 | 0.13 | 0.72 |
| | 4 | 4.33 | 0.49 | 6 | 6.86 | 0.46 | 14 | 10.7 | 0.001 |

TABLE 4. Frequency of occurrence of conks and of evidence of foraging by cavity-nesting birds across all tree species by treatment and decay class. Differences between snag creation methods at each decay class were determined by $\chi^2$.

| Tree condition | Decay class | Girdled | | Topped | | | |
|---|---|---|---|---|---|---|---|
| | | % | n | % | n | $\chi^2$ | *P* |
| Conks | 2 | 1.6 | 316 | 0.7 | 147 | | |
| | 3 | 17.5 | 326 | 32.3 | 282 | 19.5 | <0.0001 |
| | 4 | 28.0 | 150 | 33.7 | 89 | 0.86 | 0.35 |
| Foraging | 2 | 17.8 | 309 | 16.3 | 147 | 0.15 | 0.70 |
| | 3 | 60.9 | 312 | 65.2 | 282 | 1.20 | 0.27 |
| | 4 | 86.0 | 150 | 86.5 | 89 | 0.13 | 0.91 |

both treatments (topping, $\chi^2 = 58.9$, $P < 0.0001$; girdling, $\chi^2 = 46.5$, $P < 0.0001$), although the proportion was greater for trees treated by topping by decay class 3. Topped trees showed no significant difference in the proportion with conks from decay class 3 to decay class 4 ($\chi^2 = 0.02$, $P = 0.9$), whereas girdled trees increased significantly ($\chi^2 = 6.9$, $P = 0.009$). The proportion of trees with conks did not differ significantly between the two treatments at decay class 4 (Table 4).

Only six (0.8%) of the girdled trees had broken tops by the end of our monitoring period. All of these trees were decay class 3 or 4, and the loss of the top was observed 4-6 yr after treatment.

## Foraging Use

With the exception of the few Englemann spruce (*Picea engelmannii*) and white pine (*Pinus monticola*) monitored at decay class 2, some evidence of foraging was observed on all species at all decay classes (Table 5). A few trees were used for foraging as early as 1 yr after treatment. The percentage of trees used for foraging increased significantly between decay class 2 (17.2% of 454 trees) and decay class 3 (63.1% of 593 trees; $\chi^2 = 220.7$, $P < 0.0001$) and between decay class 3 and decay class 4 (86.5% of 237 trees; $\chi^2 = 44.1$, $P < 0.0001$). Compared across all species, there were no differences in the frequencies of foraging use between the different methods of snag creation at any stage of decay (Table 4).

Comparisons of foraging activity and snag creation method for the three most common tree species, western larch, Douglas-fir, and grand fir, revealed more frequent foraging activity on topped than girdled trees at some decay classes for the latter two species. For Douglas-fir, 60.5% of 114 of the topped trees and 39.0% of 154 girdled trees had signs of foraging activity at decay class 3 ($\chi^2 = 7.59$, $P = 0.006$). At decay class 4, 88.0% of 25 topped Douglas-fir trees had signs of foraging, compared to 63.6% of 33 girdled trees ($\chi^2 = 4.40$, $P = 0.04$). Although few grand fir trees were observed at decay class 4, topped trees had more frequent foraging activity (85.7% of 14 trees) than girdled trees (33.3% of 6 trees; $\chi^2 = 5.49$, $P = 0.02$).

TABLE 5. Frequency of foraging activity on each tree species by decay class. Trees were considered to be used for foraging if signs of foraging activity were observed at any time while in a given decay class.

| | Decay class | | | | | |
|---|---|---|---|---|---|---|
| | 2 | | 3 | | 4 | |
| Species | Trees used (%) | n | Trees used (%) | n | Trees used (%) | n |
| Western larch | 28.8 | 170 | 88.1 | 202 | 96.8 | 123 |
| Western hemlock | 21.4 | 14 | 86.7 | 15 | | |
| Western redcedar | 20.7 | 29 | 30.4 | 23 | | |
| Ponderosa pine | 13.3 | 15 | 65.2 | 23 | 100.0 | 9 |
| Douglas-fir | 8.7 | 185 | 50.8 | 268 | 74.1 | 58 |
| Lodgepole pine | 8.3 | 12 | 35.3 | 17 | 100.0 | 6 |
| Grand fir | 4.8 | 21 | 38.1 | 21 | 70.0 | 20 |
| Engelmann spruce | 0.0 | 7 | 50.0 | 18 | 61.5 | 13 |
| White pine | 0.0 | 1 | 33.3 | 6 | 75.0 | 8 |

TABLE 6. The number of trees with nest cavities for each species by decay class and method of snag creation, and the proportion of trees with cavities and the number of trees examined for each treatment and decay class. Trees were considered to be used for nesting if signs of cavity building were observed at any time while in a given decay class.

| | Decay class | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | | | | 3 | | | | 4 | | | |
| Species | Girdled (%) | n | Topped (%) | n | Girdled (%) | n | Topped (%) | n | Girdled (%) | n | Topped (%) | n |
| Douglas-fir | 0 | 139 | 1 (2.2) | 46 | 0 | 154 | 9 (7.9) | 114 | 0 | 33 | 12 (48.0) | 25 |
| Western larch | 0 | 122 | 0 | 48 | 0 | 132 | 4 (5.7) | 70 | 0 | 104 | 1 (5.3) | 19 |
| Lodgepole pine | 0 | 12 | | | 0 | 14 | 0 | 3 | 0 | 4 | 0 | 2 |
| Western redcedar | 0 | 12 | 0 | 17 | | | 1 (4.3) | 23 | | | 1 (50.0) | 2 |
| Grand fir | 0 | 11 | 1 (10.0) | 10 | 0 | 7 | 4 (28.6) | 14 | 0 | 6 | 10 (71.4) | 14 |
| Western hemlock | 0 | 7 | 0 | 7 | | | 3 (20.0) | 15 | | | | |
| Engelmann spruce | 0 | 3 | 0 | 4 | 0 | 3 | 2 (13.3) | 15 | 0 | 2 | 3 (27.3) | 11 |
| Ponderosa pine | 0 | 1 | 0 | 14 | 0 | 1 | 2 (9.1) | 22 | | | 1 (11.1) | 9 |
| White pine | 0 | 1 | | | 0 | 1 | 0 | 5 | 0 | 1 | 3 (42.9) | 7 |

When compared against all other species combined, western larch was used for foraging to a greater extent than other species at all decay classes (decay class 2, $\chi^2 = 25.9$, $P < 0.0001$; decay class 3, $\chi^2 = 82.5$, $P < 0.0001$; decay class 4, $\chi^2 = 23.0$, $P < 0.0001$).

## Nesting Use

After 7 yr, none of the girdled trees in any decay class showed any evidence of nesting use as determined by the presence of cavities (Table 6). Some topped trees, however, had cavities as early as decay class 2 (1.4% of 146 trees of all species) with the first cavities observed 3 yr after treatment. The proportion of topped trees with cavities increased both at decay class 3 (8.9%, n = 281, $\chi^2 = 9.2$, $P < 0.002$) and at decay class 4 (34.8%, n = 89, $\chi^2 = 35.4$, $P < 0.0001$).

Of the five most common species observed with cavities at decay class 2 ($\chi^2 = 6.3$, df = 4, $P = 0.177$) and the seven most common species observed with cavities at decay class 3 ($\chi^2 = 10.6$, df = 6, $P = 0.10$), there were no significant differences between species in the frequency of trees with cavities (Table 6). In contrast, at decay class 4, there were significant differences among the six most common tree species in the frequency of trees with cavities ($\chi^2 = 20.1$, df = 5, $P = 0.001$; Table 6). Western larch had lower nesting use than Douglas-fir ($\chi^2 = 9.5$, $P = 0.002$), grand fir ($\chi^2 = 15.9$, $P < 0.0001$), and white pine ($\chi^2 = 5.6$, $P = 0.02$). The frequency of grand fir trees with cavities was greater than western larch, ponderosa pine ($\chi^2 = 7.99$, $P = 0.005$), and Engelmann spruce ($\chi^2 = 4.8$, $P = 0.03$).

## Discussion

The creation of snags by killing healthy trees is one of several management strategies for maintaining wildlife species that require these habitat elements in managed forests. Cavity-nesting species use artificially created snags for foraging and nesting, but there are differences in this use due to treatment method, degree of decay, and tree species (Tables 5, 6). In the following, we consider these differences and suggest strategies for future snag creation given our current state of knowledge.

The two treatments differed somewhat in their success at killing trees. Nearly 7% of the trees treated by girdling remained vigorous after 4 yr, whereas only one tree (<1%) treated by topping remained alive after 4 yr. Bull and Partridge (1986) reported similar success with topped ponderosa pine trees in northeastern Oregon, but poorer success with girdling trees (<50% of girdled trees died). Parks et al. (1999), however, had close to 100% mortality of girdled ponderosa pine after 3 yr. The latter two studies both placed the girdle at 1 m above ground, but the procedure that Parks et al. (1999) used to girdle trees was similar to ours. Bull and Partridge (1986) girdled trees with two parallel saw cuts, but did not remove the bark and cambium.

Losses of trees to wind throw or woodcutters were minor (<3.5%). Even including the cut trees, the proportion of trees lost was less than the 13% of girdled trees in 5 yr observed by Bull and Partridge (1986) or the 27-43% girdled trees after 6-7 yr observed by Parks et al. (1999). These differences may be attributable to their inclusion of smaller diameter trees, which may be more susceptible to wind throw, or to the lower placement of the girdle where breakage usually occurs. Girdling trees above the first whorl of branches, as in our study, does not result in loss of the entire snag due to wind-shear breaks at the wound site (Lewis 1998).

Topped trees declined faster initially than girdled trees (Table 3), and evidence of decay (e.g., presence of conks) also occurred earlier in topped trees. Species-specific differences in the time to decline to decay class 2 were more pronounced for girdled trees (Table 3) with western larch and ponderosa pine declining more rapidly (Table 2). These differences largely disappeared by death of the tree (decay class 3). Interestingly, further decay after death of the tree was slower for topped trees than for girdled ones (Table 3). Although dbh also affects decay rates (Cline et al. 1980), trees in our study were large (>50 cm dbh on average) and dbh only affected initial decline.

As anticipated from other studies (Bull and Partridge 1986, Chambers et al. 1997), most trees that we treated by topping or girdling provided foraging habitat within 2-4 yr of treatment, and most trees showed evidence of foraging within 5-7 yr. Species-specific differences in decline were also associated with the proportion of trees used for foraging (Table 5). Western larch, in particular, declined quickly initially and was used most consistently for foraging.

Use of the artificial snags for excavation of cavities was not observed as early as foraging activity; only a small proportion of trees had cavities by decay class 4 (Table 6). Importantly, cavities were observed as early as 3 yr after topping, whereas none of the girdled trees had cavities after 7 yr. Bull and Partridge (1986) reported similar results, but they monitored trees over only 5 yr and had much poorer success killing trees by girdling. Parks et al. (1999) reported cavities in girdled ponderosa pine trees after 7 yr. We had only one girdled ponderosa pine in our study and can only speculate that species differences in the pattern of decay precluded use of girdled trees after 7 yr. Chambers et al. (1997) created Douglas-fir snags by topping and found a significant increase in cavities after 5 yr. However, their results are not directly comparable to ours because they reported the average number of cavities per tree, whereas we looked at presence or absence of cavities. Nest-site selection by primary cavity-nesting birds is influenced by dbh, sapwood and heartwood decay, and wood hardness (McClelland and Frissell 1975, Mannan et al. 1980, Swallow et al. 1986, Runde and Capen 1987, Harestad and Keisker 1989, Schepps et al. 1999). Topping exposes the upper heartwood to fungal attack and thus allows more rapid decay. This, in turn, makes it more readily accessible to primary cavity-nesting species. The greater proportion of grand fir trees with excavated cavities compared to several other species might reflect this species' relatively thin bark, soft wood, and susceptibility to fungal rot (Arno and Hammerly 1977). In contrast, the thick bark and dense wood of western larch (Arno and Hammerly 1977) might explain the fewer cavities observed in this species.

In conclusion, the results of our and other studies on artificial snag creation suggest that a strategy for creating snags that combines different treatment methods, a variety of species, and a staggered time schedule is appropriate until further monitoring and additional experiments are completed. The choice of snag creation method presents trade-offs in cost and safety versus effectiveness in providing habitat for cavity nesting species early on. The costs per tree for girdling are less than for topping (Lewis 1998), but girdling may be less cost-effective for two reasons: the kill rate is generally less than for topping, and girdled trees do not provide suitable conditions for cavity nesting as early as topped trees. Continued monitoring will be necessary to determine when girdled trees are used for cavity nesting, and if girdled trees remain standing longer than topped trees. Consequently, topping of some trees is advisable in the near term to ensure nesting habitat.

Bull and Partridge (1986) treated some girdled trees with fungal inoculation, but this was no more successful than girdling alone. Although our experiments-in-progress with fungal inoculation did not include a combined treatment with girdling, this may be an approach that could result in earlier use by cavity nesters. Other combined approaches (e.g., limbing and girdling) also need to be assessed.

The period of availability of artificial snags can be lengthened by selecting a mixture of tree species for snag creation and by staggering treatment. Western larch, for example, becomes useful for foraging earlier than other species, whereas species such as grand fir may provide nesting habitat earlier. Similar recommendations (Scott 1979; Mannen et al. 1980; Steeger and Hitchcock 1998; Zarnowitz and Manuwal 1985) have been made to forest managers to strive for high species richness, density, and diversity when selecting suitable habitat to preserve cavity nesters. It also would be advisable to stagger treatment of leave trees over a period greater than 10 yr. This strategy would ensure a more natural distribution of snags in all decay classes over a longer period of time.

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