SNAGS, CAVITY-NESTING BIRDS, AND SILVICULTURAL TREATMENTS IN WESTERN OREGON

Author(s): SCOTT T. WALTER and CHRIS C. MAGUIRE
Source: Journal of Wildlife Management, 69(4):1578-1591.
Published By: The Wildlife Society
https://doi.org/10.2193/0022-541X(2005)69[1578:SCBAST]2.0.CO;2
URL: http://www.bioone.org/doi/full/10.2193/0022-541X%282005%2969%5B1578%3ASCBAST%5D2.0.CO%3B2

SNAGS, CAVITY-NESTING BIRDS, AND SILVICULTURAL TREATMENTS IN WESTERN OREGON

SCOTT T. WALTER,[1] Department of Forest Science, Oregon State University, Corvallis, OR 97331-5752, USA
CHRIS C. MAGUIRE,[2,3] Department of Forest Science, Oregon State University, Corvallis, OR 97331-5752, USA

Abstract: We examined cavity-nesting bird use of natural snags ($n = 221$) and 10- to 12-year-old snags ($n = 836$) created by topping mature conifers in 3 silvicultural treatments (group-selection cuts, 2-story regeneration harvests, clearcuts with retained trees) and 2 snag arrangements (clustered, scattered) in 30 Douglas-fir (*Pseudotsuga menziesii*) stands in the Oregon Coast Range. Eight bird species nested in created snags. Open-canopy stands (2-story and clearcut treatments) had higher levels of avian nesting, species richness, and species diversity compared to closed-canopy, group-selection stands. We did not find a difference in nesting levels between clustered and scattered snags. In created snags, most active nests were in the top 25% of the bole, cavity entrances typically faced northeast, and the presence of dead branches did not alter use of snags for nesting. Topped conifers that remained alive ($n = 102$) were rarely used for nesting or foraging. Since the last survey 6 years prior to our survey, the number of cavities per created snag per silvicultural treatment increased 3.3- to 6-fold, and we observed 4 additional avian species nesting; 3 were secondary cavity nesters. Total cavities per snag averaged 5.1, 4.3, and 2.5 for created snags, natural snags >12 years old, and natural snags <12 years old, respectively. Only 1 created snag fell in the decade since topping. Natural new snag recruitment resulting from residual green tree mortality was highest in 2-story stands (0.76 snag/ha) and lowest in clearcuts (0.20 snag/ha). Snags created by topping large conifers provided nesting and foraging structures for cavity-nesting birds under a range of silvicultural conditions, and use was influenced more by residual green tree density than snag arrangement. In addition, created snags increased in value for birds through their first decade (88% had cavities). Because snags created by topping last long and are readily used by birds, they should be considered a management option to improve avian habitat in managed forests.

JOURNAL OF WILDLIFE MANAGEMENT 69(4):1578–1591; 2005

Key words: cavity-nesting birds, Douglas-fir, green-tree retention, Oregon Coast Range, *Pseudotsuga menziesii*, snags.

In the 1970s, trends in forest management practices on public lands in the Pacific Northwest began to shift from clearcuts and high timber production goals to multiple-objective management regimes based on partial harvests that focused on sustainable ecosystems (Swanson and Franklin 1992). One objective of forest ecosystem management, initially called New Forestry (Franklin 1989), is to maintain viable wildlife populations, including those of cavity-nesting birds (Grumbine 1994, Perry 1998). Primary cavity-nesting birds excavate nest cavities each breeding season then abandon them after nesting. In subsequent years, these cavities are available to nonexcavating secondary cavity nesters. In conifer forests with a limited hardwood component, the ability of nonexcavating birds to find a nest cavity may be largely dependent on the presence of excavating species (Bull et al. 1997, Hansell 2000).

Cavity-nesting birds use a variety of decayed trees and snags for nesting, foraging, and roosting; however, large snags (diameter at breast height [dbh] >50 cm and height >15 m) are used disproportionately more than small snags when they are available (Mannan et al. 1980, Schreiber and deCalesta 1992, Lehmkuhl et al. 2003). Furthermore, large cavity-nesting birds such as the pileated woodpecker (*Dryocopus pileatus*) require large snags to accommodate cavity creation (Bull et al. 1990). Both scattered and clustered snags created by natural tree mortality agents (e.g., fire, insects, root disease) offer nesting sites for some cavity-nesting bird species (Raphael and White 1984, Zarnowitz and Manuwal 1985, Li and Martin 1991). Although clustered snags may attract birds because of abundant foraging opportunities in a concentrated area (Raphael and White 1984, Li and Martin 1991), clustered snags occupied by territorial woodpeckers may limit nesting of other competing individuals of the same species within the cluster (Bull et al. 1997).

Cumulative forestry practices over time precipitated reductions in the historic range of snag size, density, and distribution pattern to the general detriment of many snag dependent species (Cline et al. 1980). During timber harvest, snags frequently are

---

[1] Present address: USDA Forest Service, Bent Creek Experimental Forest, Asheville, NC 28806, USA.

[2] Present address: Oregon Department of Transportation, Technical Services, 355 Capitol Street NE, Salem, OR 97301, USA.

[3] Corresponding author e-mail: christine.c.maguire@odot.state.or.us

removed to reduce fire risks and safety hazards. Following harvest, regeneration efforts focus on fast-growing, healthy trees that in turn result in low rates of natural snag recruitment (Peet and Christensen 1987, Bull et al. 1997, Showalter and Whitmore 2002). In addition, short harvest rotations (40 to 50 years) limit the availability of large trees and the source of future large snags (Cline et al. 1980).

Following widespread recognition of the importance of snags for many wildlife species, forest managers began to intentionally kill trees to increase snag numbers depleted in managed forests over past decades. Methods used to kill trees include chainsaw or dynamite topping, girdling, herbicide injection, and pheromone application to attract bark beetles (Bull and Partridge 1986, Ross and Niwa 1997). No method is consistently effective at killing trees, and each method provides snags with different durability.

The wood must be sufficiently decayed for birds to nest in or forage on snags (Bull et al. 1997). Snag decay and the length of time a snag persists is influenced by the cause of death, tree species, age, amount of heartwood, diameter, height, and local environmental conditions, including stand density (Franklin et al. 1987, Everett et al. 1999). Because snags naturally decay and fall with time, snag longevity is the primary factor for determining the number of green trees to retain during harvest to maintain a desired snag supply over time. Although snag fall rates are quantified for some geographic regions (e.g., Dickson et al. 1983, Bull and Partridge 1986, Morrison and Raphael 1993, Everett et al. 1999), few studies have evaluated the persistence of natural or created snags or their suitability to cavity-nesting species under different silvicultural treatments in the moist forests of western Oregon.

Our study goal was to better understand interactions between snags, cavity-nesting birds, and multiple-objective silvicultural practices. Our research objectives were to (1) test for differences in snag use by cavity-nesting birds across 3 silvicultural treatments and 2 snag arrangements in the Oregon Coast Range 1 decade after treatment implementation, (2) compare avian use of created snags at 5 vs. 10 years after creation, (3) evaluate associations between snag characteristics and cavity nest site location, and (4) quantify snag persistence and recruitment over a 10- to 12-year period.

STUDY AREA

We conducted our study on the Oregon State University College of Forestry Integrated Research Project (CFIRP) site. CFIRP was initiated in 1989 in McDonald-Dunn Research Forest in the foothills of the Coast Ranges northwest of Corvallis, Oregon. This project was designed to assess effects of a range of silvicultural harvest intensities and patterns on vegetation, wildlife, and societal responses. It consists of 30 managed stands in 3 blocks: Dunn, Peavy, and Lewisburg Saddle (Fig. 1). Stand sizes range from 5.5 to 17.8 ha, and elevations range from 120 to 400 m. Douglas-fir between 85 and 125 years old dominated the stands, but other tree species included grand fir (*Abies grandis*), big leaf maple (*Acer macrophyllum*), Oregon white oak (*Quercus garryana*), Pacific madrone (*Arbutus menziesii*), red alder (*Alnus rubra*), Pacific dogwood (*Cornus nuttallii*), Oregon ash (*Fraxinus latifolia*), and bitter cherry (*Prunus emarginata*). Common understory plants included vine maple (*Acer circinatum*), red huckleberry (*Vaccinium parvifolium*), salal (*Gaultheria shallon*), Oregon-grape (*Berberis nervosa*), and sword fern (*Polystichum munitum*). McDonald-Dunn Research

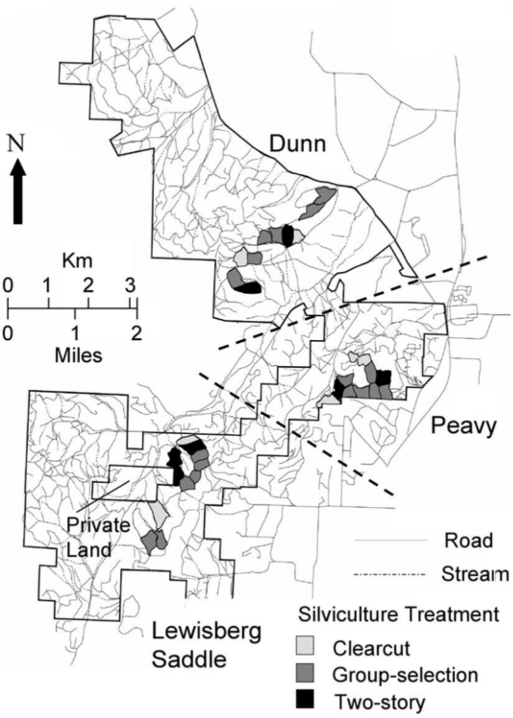


Fig. 1. Location of College of Forestry Integrated Research Project (CFIRP) managed stands (n = 30) in 3 blocks within the Oregon State University McDonald-Dunn Research Forest, north of Corvallis, Oregon, USA, where bird use of snags was examined in 2001. Dashed lines delineate the 3 CFIRP blocks: Dunn, Peavy, Lewisburg Saddle. (Figure is modified from Walter and Maguire 2004; used with permission from NRC Research Press: Canadian Journal of Forest Research.)

Forest typically has warm summers with an average of 5 cm of rain and cool winters with approximately 95 cm of precipitation between October and June (Franklin and Dyrness 1988:111). For additional study area and harvest information, see Kellogg et al. (1996), Chambers et al. (1999*b*), and Maguire and Chambers (2005).

Each of the 30 CFIRP stands received 1 of 3 silvicultural treatments and 1 of 2 snag treatments in a complete block design; 1 block was treated each year in 1989, 1990, and 1991. Silvicultural treatments were group-selection cuts (18 stands), 2-story regeneration harvests (6 stands), and clearcuts with retained green trees (6 stands). Treatments were designed to simulate different levels and patterns of natural forest disturbances (Chambers et al. 1999*b*). Group-selection stands had 33% of the timber volume removed in 0.2- to 0.6-ha patches. Two-story stands had 75% of the volume removed uniformly across the area resulting in the retention of 20 to 30 scattered mature trees/ha. All but 1.2 trees/ha were harvested in clearcut stands. Douglas-fir and a minor component of grand fir were planted after harvest.

Snag treatments consisted of clustered or scattered arrangements (15 stands each) at a target density of 3.8 snags/ha. Each silvicultural treatment received clustered and scattered snags with 1 arrangement per stand. Individual clusters contained 8 to 12 snags, and there were 3 to 5 clusters per stand. Natural snags were included when available ($n = 87$), but most snags were created by topping large (dbh ≥ 53 cm) Douglas-fir ($n = 925$) and grand fir ($n = 14$) trees with a chainsaw approximately 17 m above ground, which was a height close to the 18-m average height of cavity nests observed in the Oregon Coast Range (Mannan et al. 1980). In group-selection stands, snags were restricted to the residual forest.

METHODS

Terminology

Most trees topped at the initiation of CFIRP died by the time of our study (89%, $n = 839$); we identified these dead trees as created snags, and they were 10 to 12 years old during our study. Some topped trees that retained live foliage below the point of topping did not die (11%, $n = 102$); we identified these trees as live topped-conifers. We identified natural snags encountered during treatment implementation as natural-old snags. In clustered snag treatments in the original CFIRP design, created snags were grouped around natural-old snags if they were present. We identified large trees (dbh ≥ 53 cm and height ≥9.7 m) that died between treatment implementation and 2001 ($n = 134$) as natural-new snags. Natural-new snags were not present in the clustered snag arrangement. We individually identified all snags and live topped-conifers with aluminum tags, and we filed their Global Positioning System (GPS) locations in the McDonald-Dunn Forest research office.

Active Cavities and Foraging

During the 2001 breeding season, we observed all snags and live topped-conifers for the number and species of cavity-nesting birds engaged in nesting (e.g., excavating a cavity, feeding young) or foraging activities on the snag bole or branches. After arriving at each observation point, we allowed 1 min to pass before we recorded 5 min of bird activity. We determined height and aspect of active cavities with a clinometer and compass. Between 12 April and 12 July, we observed each snag and live topped-conifer 3 times at approximate 1-month intervals for a total of 96.6 observation hours. We made observations between 0630 and 1700 hr because cavity-nesting birds were active and readily visible throughout the day while breeding and rearing young. We did not conduct surveys when rain hindered our ability to detect birds.

Cumulative Cavities and Foraging Excavations

Between 19 July and 7 November 2001, we counted the number of cavities and estimated the abundance of foraging excavations in each snag and live topped-conifer. These counts included cavities and foraging excavations from past years plus those we observed during the spring survey. We identified cavities as circular openings that appeared to have adequate depth for a nest of the house wren (*Troglodytes aedon*), the smallest cavity-user in the study area, or rectangular openings created by the pileated woodpecker, the largest cavity-nesting bird in the region (Chambers et al. 1997). Foraging excavations were irregularly shaped, superficial openings too small for a house wren nest or ≥7.5-cm diameter (Chambers et al. 1997). We counted cavities and foraging excavations from 3 viewpoints around each snag or live topped-conifer when possible (94% of observations) using binoculars. When vegetation blocked 1 or 2 views, we calculated an adjusted cavity number with the following formula to estimate a complete count: (3/no. of viewpoints) × (no. of cavities in that snag or live topped-conifer). Foraging excavations were numerous and difficult to individually count; therefore, we grouped estimates into 7 abundance categories: 0, 1–10, 11–25, 26–50, 51–75, 76–100, and >100 excavations.

Snag/Live Topped-conifer Characteristics and Snag Recruitment

Between July and November 2001, we visually estimated whether each snag and live topped-conifer had no, low, moderate, or advanced decay based on the amount of retained bark and firmness of the exterior wood. Intact bark and hard wood suggested no decay; little bark and extensive wood decomposition suggested advanced decay (Cline et al. 1980). We also estimated the number of dead branches (diameter >10 cm and length >0.3 m) on each snag and live topped-conifer, and we assigned them to 7 abundance categories: 0, 1–10, 11–25, 26–50, 51–75, 76–100, and >100 branches. Furthermore, we recorded if the snag had fallen or broken since CFIRP was implemented. Finally, we quantified residual green tree (dbh ≥ 53 cm) mortality across all treatments as new snags or blowdowns (i.e., trees that had fallen).

Statistical Analyses

Cavity-nesting Bird Community.—We calculated separate Shannon-Weiner Diversity Indices, their associated theoretical minimum and maximum values, and species evenness (Krebs 1999:444) for birds actively using nest cavities in the 3 silvicultural treatments. We also compared the similarity of bird communities among silvicultural treatments using Morisita's Index (Krebs 1999:390). This measure gives the probability that 2 randomly selected individuals from a community will be the same species. Larger Morisita's numbers in the range 0-1 indicate greater similarity in species composition between 2 communities.

Created Snags.—We used randomized block, 2-factor Analysis of Variance (ANOVA; SAS Institute 1999, PROC MIXED) to assess effects of the 3 silvicultural treatments and 2 snag arrangements on number of active cavities of all bird species, cumulative cavities, and foraging excavations in created snags (Table 1). To standardize bird use among stands of different sizes and numbers of snags, we used mean bird use per snag per stand as the response variable. We calculated mean foraging excavations per stand from the mean value of the abundance category range for each snag, with the exception of the >100 category where we used 125 excavations as the mean. We tested for significant differences in bird use between silvicultural treatments and snag arrangements at $\alpha = 0.05$, and we used Tukey's multiple comparison tests when appropriate. We log-transformed cumulative cavities and foraging excavations response variables to adhere to statistical requirements of data normality and equality of variance. We present these estimates as log back-transformed median values.

We used additional ANOVAs to test for silvicultural and snag arrangement effects on the number of active cavities per created snag for native species only (all species observed except European starlings [*Sturnus vulgaris*]) and for primary cavity-nesters only. Because we found active cavities of secondary cavity-nesters in fewer than half of the stands ($n = 13$), we did not analyze this group. Similarly, we did not analyze individual species because we did not observe any species using cavities in created snags in more than 22 of the 30 stands.

We used a 2 × 2 contingency table (Ramsey and Schafer 1997:556) to test for differences in the number of created snags with and without branches that had active cavities regardless of bird species, silvicultural treatment, or snag arrangement. Branched and branchless snags were present in all silvicultural and snag treatments; this allowed for independent analysis of their use for nesting. We used the Rayleigh test (Zar 1999:616) to test for directionality in active cavity placement in created snags.

Natural Snags and Live Topped-conifers.—Due to low sample sizes, we used contingency tables

Table 1. Randomized block, 2-factor Analysis of Variance model structure used to assess effects of silvicultural treatment and snag arrangement on cavity-nesting bird use of 836 created snags 10 to 12 years after their creation (trees were topped between 1989 and 1991), and to test for increases in accumulated cavities from 1995 to 2001 in the same snags. Silvicultural treatments consist of group-selection ($n = 18$), 2-story ($n = 6$), and clearcut ($n = 6$) stands in 3 blocks in McDonald-Dunn Research Forest, western Oregon, USA. Snags were clustered or scattered in 15 stands apiece.

Source of variation	df
Block	2
Silvicultural treatment	2
Snag arrangement treatment	1
Silviculture × arrangement	2
Error (block × treatments)	10
Block × silviculture = 4	
Block × arrangement = 2	
Block × silviculture × arrangement = 4	
Replication (block)	12
Total	29

Table 2. Cavity-nesting birds observed during the 2001 breeding season nesting and/or foraging on created (n = 836) and natural (n = 221) snags, and live topped-conifers (n = 102) in McDonald-Dunn Research Forest, western Oregon, USA. Trees were topped between 1989 and 1991 to create snags; some trees did not die due to retained green branches.

Species	Abbreviation	Scientific name
Primary cavity excavators		
Chestnut-backed chickadee	CBCH	*Parus rufescens*
Downy woodpecker	DOWO	*Picoides pubescens*
Hairy woodpecker	HAWO	*Picoides villosus*
Northern flicker	NOFL	*Colaptes auratus*
Pileated woodpecker	PIWO	*Dryocopus pileatus*
Red-breasted nuthatch	RBNU	*Sitta canadensis*
Red-breasted sapsucker	RBSA	*Sphyrapicus ruber*
Secondary cavity users		
Brown creeper	BRCR	*Certhia americana*
European starling	EUST	*Sturnus vulgaris*
House wren	HOWR	*Trogolodytes aedon*
Violet-green swallow	VGSW	*Tachycineta thalassina*

instead of ANOVAs to test for differences in the number of natural-old snags with and without active cavities, irrespective of bird species, among silvicultural treatments (2 × 3 table) and between snag arrangements (2 × 2 table), and for differences in natural-new snags with and without active cavities across silvicultural treatments (2 × 3 table). We did not observe active cavities in live topped-conifers. We also used a 2 × 3 contingency table to test for differences in the numbers of natural-old snags, natural-new snags, and live topped-conifers with and without cavities regardless of cavity age. Because these structures typically were widely spaced, we assumed that bird use observations were independent.

Temporal Comparison of Cavity Abundance.—We used a randomized block, 2-factor ANOVA to test for silvicultural treatment and snag arrangement effects on the mean increase in cavities per snag from 1995 to 2001, expressed as the ratio 2001/1995 cavities. We used data for 1995 from Chambers et al. (1997) with permission.

RESULTS

Cavity-nesting Birds

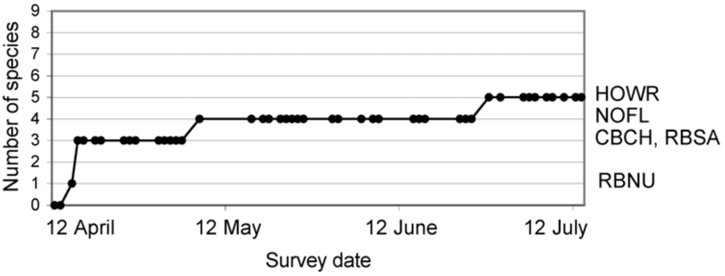
Community Characteristics.—We observed 11 cavity-nesting bird species using snags and live topped-conifers for nesting or foraging (Table 2). We observed 1 additional primary (black-capped chickadee [*Parus atricapillus*]) and 2 secondary (American kestrel [*Falco sparverius*], tree swallow [*Tachycineta bicolor*]) cavity-nesters perching on snags. Species accumulation curves suggest that we encountered most cavity-nesting bird species nesting in the area (Fig. 2). Species richness of birds with active cavities in created snags was lowest in group-selection stands and highest in clearcuts; species diversity and evenness were highest in 2-story and lowest in group-selection stands (Table 3). More than half of the nesting species we observed were present in all silvicultural treatments and both snag arrangements (Fig. 3). The community composition of species with active cavities was most similar between 2-story and clearcut stands (Morisita's Index = 0.89), followed by 2-story and group-selection stands (Morisita's Index = 0.78). Group-selection and clearcut stands were least similar (Morisita's Index = 0.42).

Active Cavities.—We observed cavity-nesting birds nesting in 19.9% of created snags, in 12.6% of natural-old snags, and in 6.0% of natural-new snags (Table 4). We did not observe active cavities in live topped-conifers. We observed multiple active cavities in only 1.8% of all snags (Table 4). However, 3 bird species simultaneously nested within a single snag cluster in 2 different 2-story stands. In the first cluster, species included the chestnut-backed chickadee, house wren, and red-breasted nuthatch; in the second cluster, species included the chestnut-backed chickadee, house wren, and European starling. On average, we located 1 active cavity for every 4.9 created snags (mean = 0.2 active cavity per created snag).

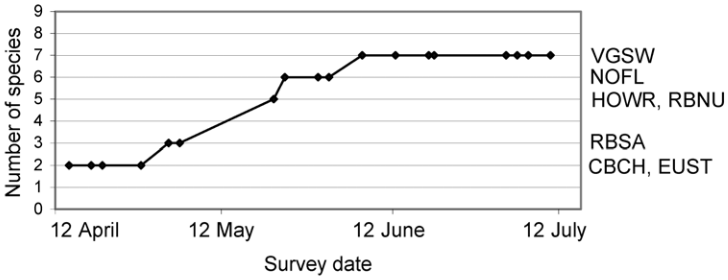
Silvicultural treatment had a significant effect on the number of active cavities of all species observed in created snags ($F_{2,10}$ = 5.05, P = 0.03; Fig. 4a). Active cavities were 2.9 times more abundant in clearcuts than in group-selection stands (t_{10} = 3.13, P = 0.01). However, the number of active cavities was similar between group-selection and 2-story stands (t_{10} = 1.86, P = 0.09) and 2-story and clearcut stands (t_{10} = 1.22, P = 0.25). An increasing trend in active cavity numbers was apparent going from group-selection to 2-story to clearcut stands (Fig. 4a). We did not observe a difference in the number of active nests between clustered and scattered snags ($F_{1,10}$ = 0.08, P = 0.79; Fig. 4b). There was no interaction between silvicultural treatment and snag arrangement ($F_{2,10}$ = 1.47, P = 0.28).

Of the 171 active nests located in created snags, 28 (16.4%) belonged to the exotic European starling; 26 of these nests (93%) were in 2-story and clearcut stands in the Dunn block (Fig. 5). With the removal of starlings from the analysis, native cavity-nesting birds did not respond to silvicultural treatment ($F_{2,10}$ = 2.45, P = 0.14) or snag

a) Group-selection



b) Two-story



c) Clearcut

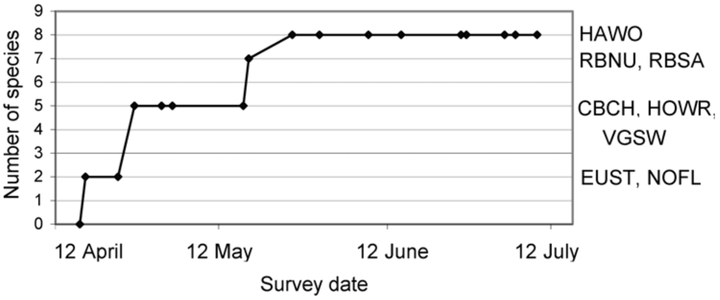


Fig. 2. Cumulative number of cavity-nesting bird species observed nesting in created and natural snags in (a) group-selection (*n* = 18), (b) 2-story (*n* = 6), and (c) clearcut (*n* = 6) stands in McDonald-Dunn Research Forest, western Oregon, USA. Each stand was surveyed 3 times in spring 2001 and points represent stand survey dates. Species abbreviations (Table 2) coincide with the first date when each species was observed.

arrangement ($F_{1,10}$ = 0.01, P = 0.92; Fig. 4), but an increasing trend in active cavity numbers was evident going from group-selection to 2-story to clearcut stands. No interaction between silvicultural and snag treatments was evident ($F_{2,10}$ = 0.85, P = 0.46). When we analyzed primary cavity-excavators in isolation, neither silvicultural treatment ($F_{2,10}$ = 0.85, P = 0.46) nor snag arrangement ($F_{1,10}$ = 0.14, P = 0.72) impacted the number of active cavities in created snags, nor was a trend across silvicultural treatments evident (Fig. 4). Again, there was no interaction effect ($F_{2,10}$ = 0.44, P = 0.66).

There was no difference in the number of natural-old snags with active nests of all species across silvicultural treatments (χ^2_2 = 3.18, P = 0.21) or between snag arrangements (χ^2_1 = 0.08, P = 0.9; Table 4). The number of natural-new snags with active nests also was not different across silvicultural treatments (χ^2_2 = 1.89, P = 0.5; Table 4).

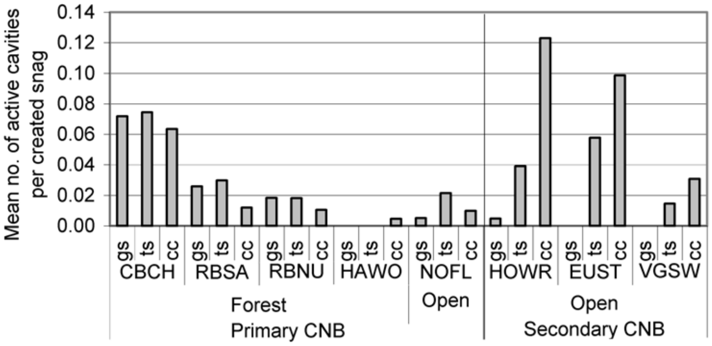
Overall, 60% of created snags retained dead branches. We found little evidence to suggest that cavity-nesting birds disproportionately used created snags with or without dead branches for nesting (χ^2_1 = 1.37, P = 0.24; Table 5). Among created snags with active cavities, 56% had dead branches. The mean height of active cavities in the 17-m created snags was 13.3 m (Table 6). Active cavities faced predominantly northeast (mean angle = 49°; Z_{171} = 7.62, P = 0.0001; Fig. 6).

Cumulative Cavities.—We found cavities in 88% of created snags, and there were 5.1 mean cavities per snag 10 to 12 years after creation. Mean number of

Table 3. Shannon-Weiner species diversity indices (H') bracketed by theoretical minimum (H' min.) and maximum (H' max.) values and associated evenness indices (H'/H' max.) for birds nesting in cavities in created snags in 3 silvicultural treatments in McDonald-Dunn Research Forest, western Oregon, USA, Apr–Jul 2001.

Silvicultural treatment	Total observations	Species richness	H' min.	H'	H' max.	Evenness
Group-selection	65	5	0.32	1.13	1.61	0.70
Two-story	58	7	0.52	1.80	1.94	0.93
Clearcut	73	8	0.50	1.61	2.08	0.78

a) Silvicultural treatments



b) Snag arrangements

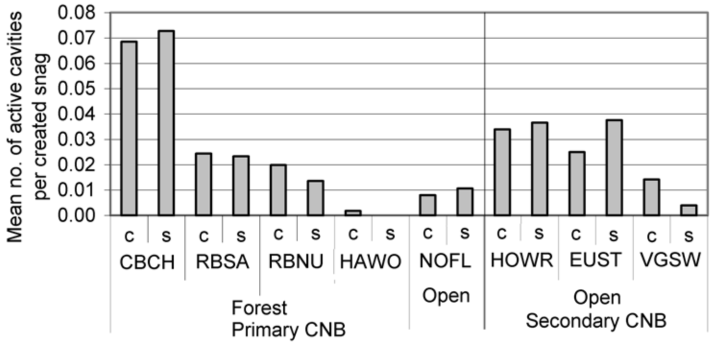


Fig. 3. Mean number of cavities used by birds for nesting in each 10- to 12-year-old created snag (n = 836) across (a) 3 silvicultural treatments (gs = group-selection, ts = 2-story, cc = clearcut) and (b) 2 snag arrangements (c = clustered, s = scattered) in 30 stands in McDonald-Dunn Research Forest, western Oregon, USA. Bird species abbreviations are defined in Table 2. Forest and open refer to the typical habitat conditions of the species (Kaufman 1996), and CNB = cavity-nesting bird.

cavities differed among silvicultural treatments ($F_{2,10}$ = 5.08, P = 0.03; Fig. 7a). Snags in 2-story stands had 1.7 times more cavities than snags in group-selection stands (t_{10} = 2.9, P = 0.04). No difference was evident between group-selection and clearcut stands (t_{10} = 2.13, P = 0.13) or between 2-story and clearcut stands (t_{10} = 0.66, P = 0.79). Cumulative cavity number did not differ between snag arrangements in 2001 ($F_{1,10}$ = 0, P = 0.95; Fig. 7b). There was no interaction between silvicultural treatment and snag arrangement ($F_{2,10}$ = 0.22, P = 0.81).

Total increases in cavities per snag from 1995 to 2001 differed among silvicultural treatments ($F_{2,10}$ = 8.09, P = 0.008; Fig. 7a). The increase in cavities in group-selection stands (6.0 times more cavities in 2001 than in 1995) was significantly greater than the increase in either 2-story stands (3.3-fold increase, t_{10} = 3.35, P = 0.02) or clearcuts (3.5-fold increase, t_{10} = 3.02, P = 0.03). There was no difference in the increase in cavities per snag between 2-story and clearcut stands (t_{10} = 0.27, P = 0.96). Snag arrangement did not impact cumulative cavity increases between 1995 and 2001 ($F_{2,10}$ = 0.02, P = 0.89; Fig. 7b). There was no interaction between silvicultural treatment and snag arrangement ($F_{2,10}$ = 0.14, P = 0.87).

We found differences among the number of natural-old snags, natural-new snags, and live topped-conifers with and without excavated cavities (χ^2_2 = 85.7, P < 0.001; Table 7). Although more than half of natural-old (69.8%) and natural-new snags (56.7%) had cavities, only 7.8% of live topped-conifers contained cavities. Natural-old and natural-new snags averaged 4.3 and 2.5 cavities per snag, respectively, while live topped-conifers averaged 0.2 cavities.

Active Foraging and Foraging Excavations.—We only observed foraging 43 times during 96.6 observation hours of created, natural-old and natural-new snags, and live topped-conifers. Birds foraged on the bole as opposed to branches in 83% of these observations, although 64% of snags and topped live-conifers retained branches. Neither silvicultural treatment ($F_{2,10}$ = 2.83, P = 0.11) nor snag arrangement ($F_{1,10}$ = 1.15, P = 0.11) affected the number of foraging excavations per created snag (Fig. 8), and there was no interaction between variables ($F_{2,10}$ = 0.03, P = 0.97). Natural-old snags had twice as many cumulative foraging excavations as natural-new snags (76 vs. 35 foraging excavations per snag, respectively). Live topped-conifers were seldom used for foraging (mean = 2 excavations per tree).

Snag/Live Topped-conifer Condition and Snag Recruitment

Most snags had low decay (98%), and most live topped-conifers had no decay (94%). Since treatment implementation in 1989, only 1 (0.1%) of

Table 4. Numbers of created, natural-old, and natural-new snags with active bird cavities in 3 silvicultural treatments (group-selection = GS, 2-story = TS, clearcut = CC) and 2 snag arrangement (clustered, scattered) treatments in 30 stands in McDonald-Dunn Research Forest, western Oregon, USA, in 2001. Created snags were 10 to 12 years old, natural-new snags were <12 years old, and natural-old snags were >12 years old when data were collected in 2001.

		Maximum no. of	Snags with 1 cavity		Snags with >1 cavity		Total snags with cavities	
	Snags	cavities per snag	No.	%	No.	%	No.	%
Silvicultural treatments								
GS	Created	2	53	12.1	1	0.2	440	12.3
TS		3	45	22.3	6	3.0	202	25.3
CC		4	53	27.3	8	4.1	194	31.4
All		4	151	18.1	15	1.8	836	19.9
GS	Natural-old	1	3	6.7	0	0.0	45	6.7
TS		3	4	16.7	1	4.1	24	20.8
CC		2	1	5.6	2	11.1	18	16.7
All		3	8	9.2	3	3.4	87	12.6
GS	Natural-new	1	3	4.3	0	0.0	70	4.3
TS		2	4	7.3	1	1.8	55	9.1
CC		0	0	0.0	0	0.0	9	0.0
All		2	7	5.2	1	0.8	134	6.0
All	All	4	166	15.7	19	1.8	1,057	17.5
Snag treatments								
Clustered	Created	3	81	18.4	8	1.8	441	20.2
Scattered		4	70	17.7	7	1.8	395	19.5
Both		4	151	18.1	15	1.8	836	19.9
Clustered	Natural-old	3	4	9.1	1	2.3	44	11.4
Scattered		2	4	9.3	2	4.7	43	14.0
Both		3	8	9.2	3	3.5	87	12.7
All	Natural-new	2	7	5.2	1	0.8	134	6.0
All	All	4	166	15.7	19	1.8	1,057	17.5

the 939 topped conifers (created snags and live topped-conifers) fell, and another broke; both were in clearcuts. Six of 95 (6.3%) natural-old snags either broke or fell; 5 of the 47 (10.6%) in group-selection stands broke, and 1 of the 21 (4.8%) in clearcuts fell.

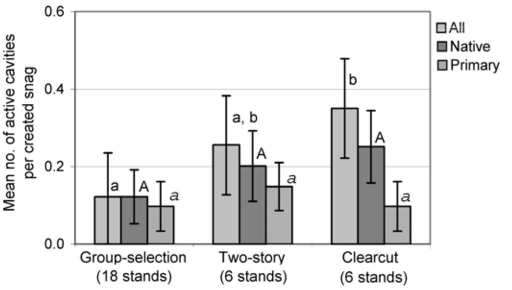
In the 12 years since initiation of the CFIRP study, 134 residual green trees died and remained standing as snags. Natural-new snags in 2-story stands (0.76 snag/ha) were 1.9 and 3.8 times more numerous per hectare than in group-selection (0.40 snag/ha) and clearcut stands (0.20 snag/ha), respectively. Also, 185 residual green trees blew down. Two-story stands experienced the highest rate of tree fall per hectare (1.12 trees/ha); this rate was 2.3 and 6.6 times higher than in group-selection stands (0.48 tree/ha) and clearcuts (0.17 tree/ha), respectively. However, percent mortality of residual green trees was greatest in clearcuts (15.3%). When blowdowns and new snags were combined, trees in clearcuts died a proportional 6.4 times more than trees in 2-story stands (2.4%) and 153.2 times more than trees in group-selection stands (0.1%).

DISCUSSION

Silvicultural Treatments

Research suggests that variations in forest structure influence the abundance and species composition of cavity-nesting birds and impact their foraging opportunities (Li and Martin 1991, Lundquist and Mariani 1991, Hansen et al. 1995, Hagar et al. 1996). In our study and in an earlier study on the same sites (Chambers et al. 1997), 2-story and clearcut stands with open canopies and similar snag densities had more cavity nests, higher species richness, greater species diversity, and more similar communities of cavity-nesting birds compared to group-selection stands with closed-canopy residual forest. Open-canopy stands typically experience increased vertical and horizontal structural diversity from increased light levels that stimulate vegetative growth (Hayes et al. 1997,

a) Silvicultural treatments



b) Snag arrangements

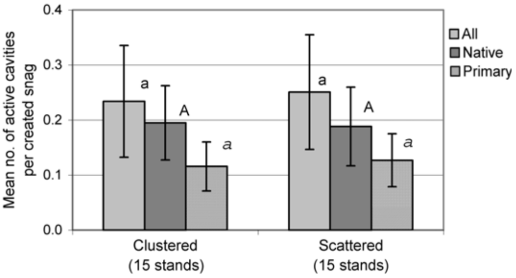


Fig. 4. Mean number of active nests observed in 2001 for all, native, and primary cavity-nesting birds per 10- to 12-year-old created snag in (a) 3 silvicultural treatments and (b) 2 snag arrangements in McDonald-Dunn Research Forest, western Oregon, USA. Native birds were all cavity nesters with the exception of European starlings (*Sturnus vulgaris*). Each error bar represents the 95% confidence interval around the mean. Significant differences ($\alpha = 0.05$) across silvicultural treatments and snag arrangements were determined from Tukey's multiple comparison tests and are represented by different letters; each bird group comparison across treatments is distinguished by a different font.

Table 5. Numbers of created snags with and without dead branches (>10-cm diameter and >0.3 m long) and with and without active bird cavities in 30 experimental stands in McDonald-Dunn Research Forest, western Oregon, USA. Snags were created by topping mature conifers 10 to 12 years prior to the survey.

	With branches	Without branches	Total
With cavities	84	66	150
Without cavities	416	264	680
Total	500	330	830

Bailey and Tappeiner 1998, Buermeyer and Harrington 2002) and promote longer tree crowns (through retention of the lower crown) and epicormic branching (Van Pelt and North 1996, Collier and Turnblom 2001, Ishii and Wilson 2001, Walter and Maguire 2004). These structures, in addition to snags, harbor insects that many cavity-nesting birds consume (Sharpe 1996, Weikel and Hayes 1999, Halaj et al. 2000). The low number of foraging events we observed on snags suggests that much feeding activity occurred elsewhere.

Bird guilds based on habitat use can be broadly divided into species groups associated with either open- or closed-canopy forests (Hansen et al. 1995). Although open-canopy stands supported the majority of cavity-nesting birds in our study, mature, dense-crowned forests were valuable for the closed-canopy nesting guild of cavity-nesting birds (e.g., red-breasted nuthatch, chestnut-backed chickadee; Mannan et al. 1980, Carey et al. 1991, Chambers et al. 1999*a*). In western Oregon, closed-canopy, mature forest stands (>100 years old) are less abundant than short-rotation plantations. Consequently, cavity-nesting birds associated with closed-canopy forests may be more vulnerable to forest management practices that create breaks in the canopy than the guild of open-canopy nesting species (Chambers et al. 1999*a*).

Snag Arrangements

Snags in unmanaged Pacific Northwest conifer forests occur in both clustered and scattered

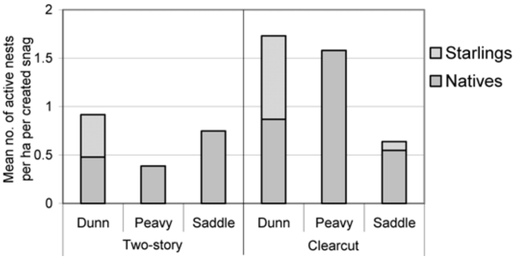


Fig. 5. Cumulative number of active nests of European starlings and native cavity-nesting birds in 2001 in 10- to 12-year-old created snags per hectare in 2 open-canopy silvicultural treatments (2-story, clearcut) in 3 blocks (Dunn, Peavy, Lewisburg Saddle) in McDonald-Dunn Research Forest, western Oregon, USA.

Table 6. Mean heights and numbers of cavities in created snags ($n = 836$) used for nesting by birds in McDonald-Dunn Research Forest, western Oregon, USA. Snags were 10 to 12 years old when data were collected in 2001; snags were created between 1989 and 1991 by topping conifers ≥53 cm dbh at 17 m.

Species	Mean cavity height (m)	No. of cavities
Chestnut-backed chickadee	14.2	56
European starling	14.0	28
Hairy woodpecker	9.8	1
House wren	12.6	31
Northern flicker	15.6	7
Red-breasted nuthatch	13.2	15
Red-breasted sapsucker	13.0	21
Violet-green swallow	14.1	10
Overall	13.3	169

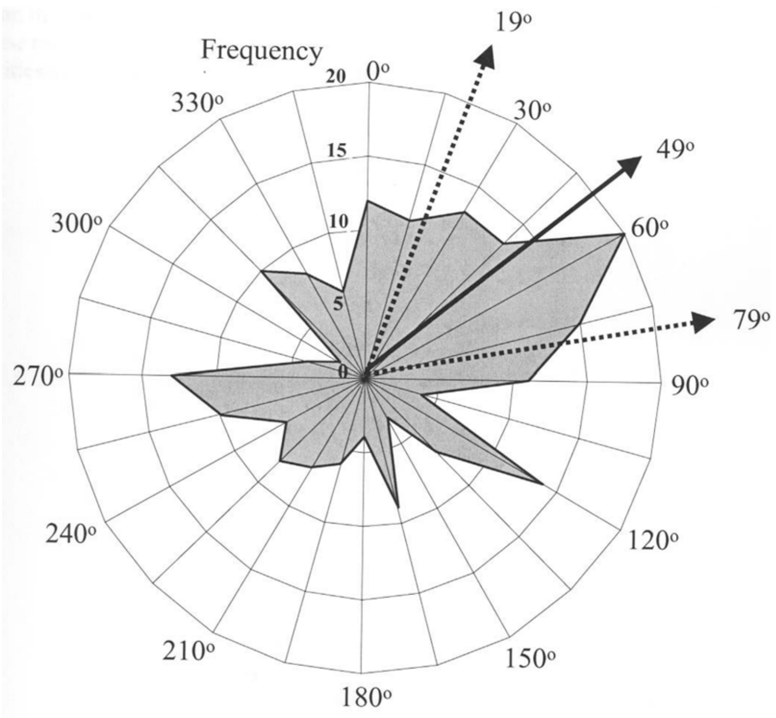


Fig. 6. Aspect of the cavity face for 171 active bird nests in 10- to 12-year-old created snags in McDonald-Dunn Research Forest, western Oregon, USA. Aspects were graphed in 15° intervals. Significant directionality at 49° ($P = 0.0001$) was found when aspects were analyzed with the Rayleigh test. Dashed arrows represent the 95% confidence interval around the mean aspect.

arrangements because of a host of tree mortality agents that kill individuals and groups of trees (Franklin et al. 1987, Ohmann et al. 1994, Bull et al. 1997). In our study, cavity-nesting birds utilized clustered and scattered snags equally for nesting and foraging, and multiple species nested concurrently within clusters. Our results, and similar ones obtained 6 years earlier on the same sites (Chambers et al. 1997), appear to counter the suggestion by Bull et al. (1997) that territorial woodpeckers in clustered snags may restrict nesting by other birds. Many of the 10- to 12-year-old created snags in our study, however, were not used for nesting during our study (1 active nest per 4.9 snags), and these results could mean that competition was limited because CFIRP snag densities exceeded requirements. Alternatively, because 88% of the snags over the last decade contain cavities, competition may limit the number of snags used in any 1 year. Although our data cannot settle the competition issue, unless bird response to snag arrangement diverges as the CFIRP snags age, clustered snags may be preferential to scattered snags in managed forests because they are more easily avoided during timber harvest and thereby better meet worker safety goals while simultaneously providing habitat for cavity-nesting species.

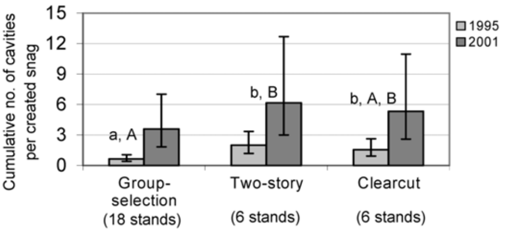
Temporal Change in Snag Use

The chainsaw-topped CFIRP snags began to be used for nesting within 4 to 6 years after creation (Chambers et al. 1997), and we recorded a several-fold increase in cavities 6 years later. In addition, the number of observed cavity-nesting birds increased from 5 species (reported in Chambers et al. 1997) to 14 species over the same period; many of these were secondary cavity nesters. Typically at least 5 years must pass before snags possess sufficient decay for extensive cavity excavation (Mannan et al. 1980, Bull et al. 1997). Decay development depends on several factors, in particular, the source of tree mortality (Franklin et al. 1987). Studies that compared conifer snag creation techniques in the Pacific Northwest demonstrate that snags created by topping consistently result in higher foraging and nesting use within the first 9 years because of accelerated decay

Table 7. Numbers of natural-old snags, natural-new snags, and live topped-conifers with and without bird cavities in 30 stands in 2001 in McDonald-Dunn Research Forest, western Oregon, USA. Natural-new snags were <12 years old and natural-old snags were >12 years old. Live topped-conifers were the result of trees topped to create snags 10 to 12 years prior to this study, but they did not die.

	With cavities	Without cavities	Total
Natural-old snags	60	26	86
Natural-new snags	76	58	134
Live topped-conifers	8	94	102
Total	144	178	322

a) Silvicultural treatments



b) Snag arrangements

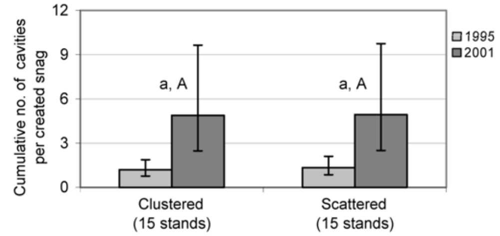
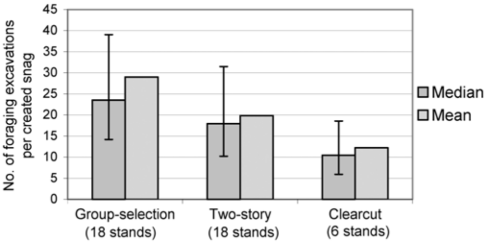


Fig. 7. Median number of cumulative cavities per created snag in 1995 and 2001 in (a) 3 silvicultural treatments and (b) 2 snag arrangement treatments in McDonald-Dunn Research Forest, western Oregon, USA. Snags were created between 1989 and 1991; cumulative cavities in 1995 were recorded by Chambers et al. (1997). Error bars represent 95% confidence intervals around log back-transformed median values. Significant differences at $\alpha = 0.05$ as determined from Tukey's multiple comparison tests are represented by different letters; lower-case letters are for the mean increase in cavities per snag across treatments from 1995 to 2001 (expressed as the ratio: 2001/1995 cavity numbers) and upper-case letters are for 2001 median cavities/snag treatment comparisons.

a) Silvicultural treatments



b) Snag arrangements

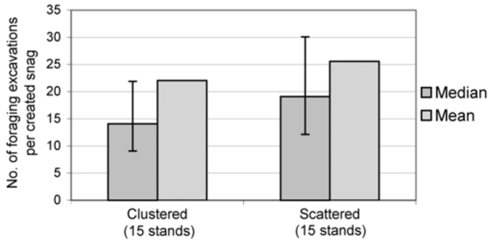


Fig. 8. Estimated number of bird foraging excavations in 10- to 12-year-old created snags ($n = 836$) in (a) 3 silvicultural treatments and (b) 2 snag arrangements in McDonald-Dunn Research Forest, western Oregon, USA. Error bars represent 95% confidence intervals around log back-transformed median values. We found no significant differences at $\alpha = 0.05$ as determined from Tukey's multiple comparison tests.

resulting from exposure of the inner wood following crown loss (Bull and Partridge 1986, Hallett et al. 2001, Brandeis et al. 2002).

The recent detection of European starlings in 2-story and clearcut Dunn stands neighboring 780 ha of agricultural land is noteworthy because this exotic species can usurp cavities from native cavity nesters (Peterson and Gauthier 1985, Weitzel 1988, Ingold 1996). Koenig (2003), however, provided evidence that in the long-term over large areas, starlings do not contribute significantly to population declines for most cavity-nesting species with whom they overlap. One decade after harvest, CFIRP stands with starlings still supported other cavity-nesting species.

Snag/Live Topped-conifer Characteristics and Nest Site Location

In the decade following snag creation, the availability of dead branches did not significantly affect cavity nesting, although a trend was evident for more cavities when branches were present. Some researchers suggest that branches on snags are beneficial because they shelter nest cavities (McEllin 1979) and provide foraging substrates (Lundquist and Mariani 1991, Weikel and Hayes 1999). We observed approximately 20% of foraging events on dead branches. Although we did not compute surface area ratios for dead branches to boles, use of branches for foraging appeared to outweigh their availability. This occurred even though insect food sources often are more common in snag boles than in less-decayed branches with their denser wood (Cline et al. 1980, Ross and Niwa 1997).

In contrast to snags with dead branches, topped-conifers with live branches contained no active nests, they rarely were used for foraging, and sapwood decay was uncommon. Birds rarely excavate cavities in live trees because of the hard structural properties of the wood (Mannan et al. 1980, Lundquist and Mariani 1991, Spies and Franklin 1991) and because most insect food sources are found in decayed compared with hard wood (Neitro et al. 1985).

Cavity-nesting birds often position nests to minimize their exposure to wind and rain (Hansell 2000). Most of the cavities we located faced northeast, away from prevailing spring winds from the south and west (Oregon Climate Service 2003). In addition, most active nests were in the upper quarter of the 17-m tall created snags.

It is advantageous for cavity nesters to locate nests at the tallest height where decay and diameter requirements are met (Bull et al. 1997) because lower nests experience higher predation rates than higher nests (Li and Martin 1991).

Snag Persistence and Recruitment

One decade following CFIRP treatment implementation, nearly all created and natural snags remained standing. Among tree species, Douglas-fir snags, particularly those >50 cm dbh, decay relatively slowly, and they can maintain structural integrity and resist falling for >100 years in the Oregon Coast Range (Cline et al. 1980, Neitro et al. 1985, Bull et al. 1997). Additionally, because crown removal reduces snag wind resistance, topping may limit the susceptibility of snags to blowdown (Bull and Partridge 1986).

Tree mortality resulted in new snags in most study stands, and it outweighed snag loss by 19.1% in the first decade since harvest (Walter and Maguire 2004). Logging damage was 1 possible cause of the mortality we observed. Residual trees in the 2-story and clearcut stands exposed to intense harvest operations experienced higher mortality rates (2.4% and 15.3%, respectively) than trees in group-selection stands (0.1%) where skid trail coverage was only 3 to 4% of the total area (Kellogg et al. 1991).

MANAGEMENT IMPLICATIONS

Our results suggest that silvicultural treatments that create open-canopy conditions in mature conifer forests of the Oregon Coast Range promote diverse stand structures that support more species and a greater abundance of cavity-nesting birds than are found in closed-canopy forest when snag densities are equal. However, because some cavity-nesting species only nest in closed-canopy forests, a mix of stand conditions is required to support all species capable of populating an area. Additionally, within the clearcut, 2-story, and group selection treatments, few of the snags created were lost to breakage or blowdown, and cavity-nesting birds continued to increase their snag use 1 decade after creation. This demonstrates that topping of large live trees by chainsaw is an effective strategy for creating persistent snags for wildlife when natural snags are limited. Although the presence of dead branches on snags did not alter cavity nester use, topped trees with live branches did not contain cavities, most likely because the trees had not died or sufficiently decayed.

ACKNOWLEDGMENTS

Our project was funded by the Oregon State University College of Forestry Fish and Wildlife Research Program and a J. Richard Dilworth Scholarship for Forestry. We thank B. C. McComb and J. C. Tappeiner for creating long-term research opportunities through their initiation of CFIRP. We also thank C. L. Chambers for access to her 1995 CFIRP bird data; L. M. Ganio and M. M. P. Huso for statistical advice; D. L. Johnson and D. A. Zahler for map assistance; S. Roberts, T. G. Smith, M. A. Stoddard, A. S. Turple, D. L. Waldien, and D. A. Zahler for discussion and editorial reviews throughout the project; T. Manning for field assistance; W. H. Emmingham, D. A. Maguire, R. A. Schmitz, and J. C. Tappeiner for technical advice and/or for reviewing earlier versions of the manuscript; and D. J. Flaspohler and 2 anonymous reviewers for many helpful editorial suggestions.

LITERATURE CITED

Bailey, J. D., and J. C. Tappeiner. 1998. Effects of thinning on structural development in 40- to 100-year-old Douglas-fir stands in western Oregon. Forest Ecology and Management 108:99–113.

Brandeis, T. J., M. Newton, G. M. Filip, and E. C. Cole. 2002. Cavity-nester habitat development in artificially made Douglas-fir snags. Journal of Wildlife Management 66:625–633.

Buermeyer, K. R., and C. A. Harrington. 2002. Fate of overstory trees and patterns of regeneration 12 years after clearcutting with reserve trees in southwest Washington. Western Journal of Applied Forestry 17:78–85.

Bull, E. L., R. S. Holthausen, and M. G. Henjum. 1990. Techniques for monitoring pileated woodpeckers. U.S. Forest Service General Technical Report PNW-GTR-269.

———, C. G. Parks, and T. R. Torgersen. 1997. Trees and logs important to wildlife in the interior Columbia River basin. U.S. Forest Service General Technical Report PNW-GTR-391.

———, and A. D. Partridge. 1986. Methods of killing trees for use by cavity nesters. Wildlife Society Bulletin 14:142–146.

Carey, A. B., M. M. Hardt, S. P. Horton, and B. L. Biswell. 1991. Spring bird communities in the Oregon Coast Range. Pages 123–141 *in* L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. H. Huff, technical coordinators. Wildlife and vegetation of unmanaged Douglas-fir forests. U.S. Forest Service General Technical Report PNW-GTR-285.

Chambers, C. L., T. Carrigan, T. E. Sabin, J. Tappeiner, and W. C. McComb. 1997. Use of artificially created Douglas-fir snags by cavity-nesting birds. Western Journal of Applied Forestry 12:93–97.

———, W. C. McComb, and J. C. Tappeiner II. 1999*a*. Breeding bird responses to three silvicultural treatments in the Oregon Coast Range. Ecological Applications 9:171–185.

———, ———, ———, L. D. Kellogg, R. L. Johnson, and G. Spycher. 1999*b*. CFIRP: what we learned in the first ten years. The Forestry Chronicle 75:431–434.

CLINE, S. P., A. B. BERG, AND H. M. WIGHT. 1980. Snag characteristics and dynamics in Douglas-fir forests, western Oregon. Journal of Wildlife Management 44:773–786.

COLLIER, R. L., AND E. C. TURNBLOM. 2001. Epicormic branching on pruned coastal Douglas-fir. Western Journal of Applied Forestry 16:80–86.

DICKSON, J. G., R. N. CONNER, AND J. H. WILLIAMSON. 1983. Snag retention increases bird use of a clear-cut. Journal of Wildlife Management 47:799–804.

EVERETT, R., J. LEHMKUHL, R. SCHELHAAS, P. OHLSON, D. KEENUM, H. RIESTERER, AND D. SPURBECK. 1999. Snag dynamics in a chronosequence of 26 wildfires on the east slope of the Cascade Range in Washington state, USA. International Journal of Wildland Fire 9:223–234.

FRANKLIN, J. 1989. Toward a new forestry. American Forests 95:37–44.

———, AND C. T. DYRNESS. 1988. Natural vegetation of Oregon and Washington. Oregon State University Press, Corvallis, USA.

———, H. H. SHUGART, AND M. E. HARMON. 1987. Tree death as an ecological process. BioScience 37:550–556.

GRUMBINE, R. E. 1994. What is ecosystem management? Conservation Biology 8:27–38.

HAGAR, J. C., W. C. MCCOMB, AND W. H. EMMINGHAM. 1996. Bird communities in commercially thinned and unthinned Douglas-fir stands of western Oregon. Wildlife Society Bulletin 24:353–366.

HALAJ, J., D. W. ROSS, AND A. R. MOLDENKE. 2000. Importance of habitat structure to the arthropod food-web in Douglas-fir canopies. Oikos 90:139–152.

HALLETT, J. G., T. LOPEZ, M. A. O'CONNELL, AND M. A. BORYSEWICZ. 2001. Decay dynamics and avian use of artificially created snags. Northwest Science 75:378–386.

HANSELL, M. 2000. Bird nests and construction behaviour. Cambridge University Press, New York, USA.

HANSEN, A. J., W. C. MCCOMB, R. VEGA, M. G. RAPHAEL, AND M. HUNTER. 1995. Bird habitat relationships in natural and managed forests in the west Cascades of Oregon. Ecological Applications 5:555–569.

HAYES, J. P., S. S. CHAN, W. H. EMMINGHAM, J. C. TAPPEINER, L. D. KELLOGG, AND J. D. BAILEY. 1997. Wildlife response to thinning young forests in the Pacific Northwest. Journal of Forestry 95:28–33.

INGOLD, D. J. 1996. Delayed nesting decreases reproductive success in northern flickers: implications for competition with European starlings. Journal of Field Ornithology 67:321–326.

ISHII, H., AND M. E. WILSON. 2001. Crown structure of old-growth Douglas-fir in the western Cascade Range, Washington. Canadian Journal of Forest Research 31:1250–1261.

KELLOGG, L. D., P. BETTINGER, AND R. M. EDWARDS. 1996. A comparison of logging planning, felling, and skyline yarding costs between clearcuttting and five group-selection harvesting methods. Western Journal of Applied Forestry 11:90–96.

———, S. J. PINKERTON, AND R. M. EDWARDS. 1991. Logging requirements to meet new forestry prescriptions. Pages 43–49 *in* J. F. McNeel and Björn Andersson, editors. Forestry operations in the 1990's, challenges and solutions: proceeding of the 14th Annual Meeting of the Council of Forest Engineering, July 22 to July 25, 1991, Nanaimo, British Columbia, Canada.

KOENIG, W. D. 2003. European starlings and their effect on native cavity-nesting birds. Conservation Biology 17:1134–1140.

KREBS, C. J. 1999. Ecological methodology. Second edition. Addison Wesley Longman, Menlo Park, California, USA.

LEHMKUHL, J. F., R. L. EVERETT, R. SCHELLHAAS, P. OHLSON, D. KEENUM, H. RIESTERER, AND D. SPURBECK. 2003. Cavities in snags along a wildfire chronosequence in eastern Washington. Journal of Wildlife Management 67:219–228.

LI, P., AND T. E. MARTIN. 1991. Nest-site selection and nesting success of cavity-nesting birds in high elevation forest drainages. Auk 108:405–418.

LUNDQUIST, R. W., AND J. M. MARIANI. 1991. Nesting habitat and abundance of snag-dependent birds in the southern Washington Cascade Range. Pages 221–239 *in* Wildlife and vegetation of unmanaged Douglas-fir forests. U.S. Forest Service General Technical Report PNW-GTR-285.

MAGUIRE, C. C., AND C. L. CHAMBERS, editors. 2005. College of Forestry Integrated Research Project: ecological and socioeconomic responses to alternative silvicultural treatments. Oregon State University, Forest Research Laboratory Research Contribution 46.

MANNAN, R. W., E. C. MESLOW, AND H. M. WIGHT. 1980. Use of snags by birds in Douglas-fir forests, western Oregon. Journal of Wildlife Management 44:787–797.

MCELLIN, S. M. 1979. Nest sites and population demographies of white-breasted and pigmy nuthatches in Colorado. Condor 81:348–352.

MORRISON, M. L., AND M. G. RAPHAEL. 1993. Modeling the dynamics of snags. Ecological Applications 3:322–330.

NEITRO, W. A., V. W. BINKLEY, S. P. CLINE, R. W. MANNAN, B. G. MARCOT, D. TAYLOR, AND F. F. WAGNER. 1985. Snags (wildlife trees). Pages 129–167 *in* E. R. Brown, editor. Management of wildlife and fish habitats in forests of western Oregon and Washington. Part 1: chapter narratives. Portland, Oregon, U.S. Forest Service Pacific Northwest Region, R6-F&WL-192-1985.

OHMANN, J. L., W. C. MCCOMB, AND A. A. ZUMRAWI. 1994. Snag abundance for primary cavity-nesting birds on nonfederal forest lands in Oregon and Washington. Wildlife Society Bulletin 22:607–620.

OREGON CLIMATE SERVICE. 2005 June 7. Oregon Climate Service home page. <http://www.ocs.orst.edu/>. Accessed 2003 Apr 15.

PEET, R. K., AND N. L. CHRISTENSEN. 1987. Competition and tree death. BioScience 37:586–595.

PERRY, D. A. 1998. The scientific basis of forestry. Annual Review of Ecology and Systematics 29:435–466.

PETERSON, B., AND G. GAUTHIER. 1985. Nest site use by cavity-nesting birds of the Cariboo Parkland, British Columbia. Wilson Bulletin 97:319–331.

RAMSEY, F. L., AND D. W. SCHAFER. 1997. The statistical sleuth. Duxbury Press, Belmont, California, USA.

RAPHAEL, M. G., AND M. WHITE. 1984. Use of snags by cavity-nesting birds in the Sierra Nevada. Wildlife Monographs 86.

ROSS, D. W., AND C. G. NIWA. 1997. Using aggregation and antiaggregation pheromones of the Douglas-fir beetle to produce snags for wildlife habitat. Western Journal of Applied Forestry 12:52–54.

SAS INSTITUTE. 1999. SAS OnlineDoc. Version 8. SAS Institute, Cary, North Carolina, USA.

SCHREIBER, B., AND D. S. DECALESTA. 1992. The relationship between cavity-nesting birds and snags on clearcuts in western Oregon. Forest Ecology and Management 50:299–316.

SHARPE, F. 1996. The biologically significant attributes of forest canopies to small birds. Northwest Science 70:86–93.

SHOWALTER, C. R., AND R. C. WHITMORE. 2002. The effect of gypsy moth defoliation of cavity-nesting bird communities. Forest Science 48:273–281.

SPIES, T. A., AND J. F. FRANKLIN. 1991. The structure of natural young, mature, and old-growth Douglas-fir forests in Oregon and Washington. Pages 91–109 *in* L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. H. Huff, technical coordinators. Wildlife and vegetation of unmanaged Douglas-fir forests. U.S. Forest Service General Technical Report PNW-GTR-285.

SWANSON, F. J., AND J. F. FRANKLIN. 1992. New forestry principles from ecosystem analysis of Pacific Northwest forests. Ecological Applications 2:262–274.

VAN PELT, R., AND M. P. NORTH. 1996. Analyzing canopy structure in Pacific Northwest old-growth forests with a stand-scale crown model. Northwest Science 70:15–30.

WALTER, S. T., AND C. C. MAGUIRE. 2004. Conifer response to three silvicultural treatments in the Oregon Coast Range foothills. Canadian Journal of Forest Research 34:1967–1978.

WEIKEL, J. M., AND J. P. HAYES. 1999. The foraging ecology of cavity-nesting birds in young forests of the northern Coast Range of Oregon. The Condor 101:58–66.

WEITZEL, N. H. 1988. Nest-site competition between the European starling and native breeding birds in northwestern Nevada. The Condor 90:515–517.

ZAR, J. H. 1999. Biostatistical analysis. Fourth edition. Prentice-Hall, New Jersey, USA.

ZARNOWITZ, J. E., AND D. A. MANUWAL. 1985. The effects of forest management on cavity-nesting birds in northwestern Washington. Journal of Wildlife Management 49:255–263.

Associate Editor: Flaspohler.