



## Research Article

# Use of Created Snags by Cavity-Nesting Birds Across 25 Years

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**ABSTRACT** Snags are important habitat features for many forest-dwelling species, so reductions in the number of snags can lead to the loss of biodiversity in forest ecosystems. Intentional snag creation is often used in managed forests to mitigate the long-term declines of naturally created snags, yet information regarding the use of snags by wildlife across long timescales (>20 yr) is lacking and prevents a complete understanding of how the value of created snags change through time. We used a long-term experiment to assess how harvest treatment (i.e., small-patch group selection, 2-story, and clearcut) and snag configuration (i.e., scattered and clustered) influenced nesting in and foraging on 25–27-year-old Douglas-fir (*Pseudotsuga menziesii*) snags by cavity-nesting birds. In addition, we compared our contemporary measures of bird use to estimates obtained from historical surveys conducted on the same group of snags to quantify how bird use changed over time. Despite observing created snags for >750 hours across 2 consecutive breeding seasons, we found limited evidence of nesting activity. Only 11% of created snags were used for breeding, with nesting attempts by 4 bird species ( $n = 36$  nests); however, we detected 12 cavity-nesting species present on our study sites. Furthermore, nearly all nests (94%) belonged to the chestnut-backed chickadee (*Poecile rufescens*), a weak cavity-excavating species that requires well-decayed wood for creating nest cavities. Our surveys also recorded few observations of birds using created snags as foraging substrates, with only 1 foraging event recorded for every 20 hours of observation. We detected 82% fewer nests and recorded 7% fewer foraging observations during contemporary field work despite spending >7.5 times more effort observing created snags relative to historical surveys. We conclude that 25–27-year-old created Douglas-fir snags provided limited opportunities for nesting and foraging by most cavity-nesting birds, and that the period of greatest use by this group occurred within 5–15 years of creation. © 2018 The Wildlife Society.

**KEY WORDS** cavity-nesting birds, created snags, Douglas-fir, Oregon Coast Range, *Pseudotsuga menziesii*, snag longevity, woodpeckers.

Standing dead trees (i.e., snags) are common features of forested ecosystems that can form naturally through a range of disturbances, including fire, wind damage, insect kill, and disease (Morrison and Raphael 1993, Rose et al. 2001). Snags are especially important features within forests because they provide habitat that is used by nearly a third of all forest-dwelling organisms (Thomas 1979, Newton 1994). Snags are often deemed critically important for cavity-nesting birds because members of this group use snags for nesting and foraging (Hallett et al. 2001, Walter and Maguire 2005, Cooke and Hannon 2012, Hane et al. 2012), and snag availability can limit cavity-nesting bird populations (Li and Martin 1991, Schreiber and DeCalesta 1992). Strong cavity-excavating bird species, namely woodpeckers (family Picidae), exert a disproportionate effect on the ecological community through

their foraging activities and via the creation of nesting and roosting cavities within snags which, in turn, supports a diversity of species that require cavities but cannot create them on their own (e.g., secondary cavity nesters; Drever et al. 2008, Hane et al. 2012, Bunnell 2013). Because of this, reductions in woodpecker populations that follow the loss of snags may lead to additional reductions in biodiversity and exert negative consequences for forest health within managed landscapes.

Despite their ecological value, the number of snags on the landscape has been significantly reduced over the last several decades largely through anthropogenic activities (Lewis 1998, Kroll et al. 2012). In many regions, snag removal during timber harvest has been undertaken to comply with safety regulations and because of the commercial value of snags (Chambers et al. 1997, Kroll et al. 2012). This has led to a reduction in snag availability in such managed landscapes, particularly within intensively managed second-growth forests (Spies et al. 1988, Swanson and Franklin 1992, Hayes et al. 1997, Lewis 1998, Wilhere 2003). To counter the loss of snags, forest managers can intentionally

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create snags from live trees, typically at the time of harvest, via several methods (Bull and Partridge 1986); topping live trees with a chainsaw is perhaps the most common management technique used in contemporary silviculture. Snag creation has therefore been implemented across a diversity of land ownerships including federal, state, and private industrial lands, and several studies have evaluated the response of cavity-nesting birds to created snags (Schreiber and DeCalesta 1992, Chambers et al. 1997, Hallett et al. 2001, Walter and Maguire 2005, Arnett et al. 2010). Although these previous investigations have found that use of created snags by cavity-nesting birds generally increases over time, they have been limited to  $\leq 10$  years after snag creation and typically have been conducted during the period when snags are in open-canopy conditions, such as shortly after clearcut harvest. Given that created snags can stand for  $>25$  years (Barry et al. 2017) and natural snags can stand for  $>100$  years (Cline et al. 1980), past studies provide only a partial understanding of the value of created snags as habitat for wildlife over long timescales. In particular, gaps in our knowledge remain about the duration that created snags provide suitable habitat for cavity-nesting birds as they proceed through decay stages and as stand structure and surrounding vegetation changes over time (Schepps et al. 1999, Blanc and Martin 2012, Edworthy and Martin 2014, Lorenz et al. 2015). Nevertheless, such information is critical for resource managers who use intentional snag creation as a form of habitat mitigation for snag-associated species within managed forest landscapes (Kroll et al. 2012).

In this study, we leveraged a long-term study initiated in 1989 to assess long-term ( $\geq 25$  yr) changes in the use of created snags by cavity-nesting birds for foraging and nesting. As part of the original project objectives, snags were created among 3 harvest treatments that were designed to mimic small-, medium-, and large-scale disturbances (i.e., group selection, 2-story, and clearcut harvest, respectively), and in 2 spatial configurations (i.e., clustered and scattered snags; Chambers et al. 1997). Given that indicators of decay (e.g., bark loss, cavity creation by cavity-nesting birds) were more common in harvest treatments in which snags were created within an open canopy (i.e., 2-story and clearcut) relative to those created under a closed canopy (i.e., group selection; Barry et al. 2017), we hypothesized that these characteristics would influence the composition of species nesting among treatments. Specifically, we predicted that we would detect more strong cavity-excavating birds (i.e., woodpeckers) using snags in the group selection treatment, and detect more weak cavity-excavating and secondary cavity-nesting birds in the 2-story and clearcut treatments. Similar to harvest treatment, the spatial configuration in which snags are created may also influence bird use. For example, snags created in clusters may provide concentrated foraging opportunities, but territorial activity could exclude other individuals from using those structures (Raphael and White 1984, Li and Martin 1991). Therefore, we hypothesized that cavity-nesting bird use of snags (i.e., nesting and foraging) in clusters would be lower than on scattered snags because clustered snags may be more easily defended than scattered snags (Raphael and White 1984, Li and Martin 1991).

Our previous work found that snags during contemporary sampling (2016) were substantially more decayed than they were during the time of the most recent historical avian surveys that were conducted in 2001 (Barry et al. 2017). Therefore, we hypothesized that decay, along with the change of all stands to closed canopy conditions, would influence the composition of species using snags for nesting and foraging relative to historical surveys. We predicted that we would detect an increase in cavity-nesting species that use softened wood and closed-canopy stands for excavating nest sites and foraging relative to previous surveys. Finally, natural snags of varying ages were present on our study sites and simultaneously available to cavity-nesting birds, so we also quantified characteristics of natural snags to provide context for bird use of intentionally created snags.

## STUDY AREA

We conducted this work during the 2015–2016 breeding seasons (Apr–Aug) at study sites located within Oregon State University's McDonald-Dunn Research Forest (123°15'W, 44°35'N) near Corvallis, Oregon on the lower east slope of the Coast Range. The McDonald-Dunn Research Forest consists of approximately 4,550 ha of predominantly forested land managed for timber production, research, and recreation. The Oregon Coast Range has a maritime climate, characterized by dry summers (Jun–Sep) and mild, wet winters (Oct–Mar; Franklin and Dyrness 1988), and our study area resides in a rain shadow created by the Coast Range such that it experiences an average of 5 cm of rain during the summer months, and 95 cm of precipitation between November and June (<http://cf.forestry.oregonstate.edu/mcdonald-dunn-forest>, access date 1 Nov 2017).

The original study design comprised 30 stands (5–18 ha), ranging in elevation from 120 m to 400 m and dominated by Douglas-fir (*Pseudotsuga menziesii*) that had naturally regenerated before harvest treatments were implemented (Chambers et al. 1997). Stands included 2 understory plant association types: hazel (*Corylus cornuta* var. *californica*)-brome (*Bromus vulgaris*) and vine maple (*Acer circinatum*)-salal (*Gaultheria shallon*; Franklin and Dyrness 1988). Stands were the product of natural regeneration following burning by Native Americans (Maguire and Chambers 2005). At the time of harvest, dominant trees were 45–150 years old and stands were similar in plant species composition among treatments (Chambers 1996). Mean density of live conifers was approximately 540 trees/ha, live hardwood tree density averaged 165 trees/ha, and natural snag density averaged  $<1.9$  snags/ha (Chambers 1996) at the initiation of the study. Our study sites were dominated by fauna typical of managed forests in the Pacific Northwest, including forest-dwelling birds, amphibians, and mammals.

## METHODS

### Study Design

Our study consisted of a randomized, complete block design implemented by the original research group, with 3 study

blocks each harvested in a separate year (i.e., Lewisburg block in 1989, Peavy block in 1990, Dunn block in 1991) and planted the spring following harvest. Each block contained 10 treated stands in which snags were intentionally created at the time of harvest. Within each block, each stand was assigned randomly to 1 of 3 harvest treatments, and to 1 of 2 created snag configurations. Harvest treatments and snag configurations were designed to mimic variation in natural disturbance patterns and test the effects of operational alternatives to traditional clearcutting on a range of ecological responses (Chambers et al. 1999). Harvest treatments included group selection, which represented localized, low intensity disturbance and resulted in 33% of the tree volume removed in 0.2-ha patches; 2-story, which represented evenly distributed, moderate disturbance and resulted in 75% of the tree volume removed uniformly; and clearcut, which represented high intensity, stand-replacing disturbance and resulted in all tree volume removed except for 1.25 live trees/ha. Control stands were established as part of the original experimental design but were not assessed in this study because no control stands contained created snags. All stands were replanted with Douglas-fir seedlings at a density of 625–865 trees/ha depending on harvest treatment, and each received herbicide applications 2–5 years after harvest to control competing vegetation (Chambers et al. 1997).

At the time that stands were harvested, snags were created such that they were either scattered uniformly throughout each stand (i.e., scattered) or were clustered with 3–5 discrete snag groups per stand (i.e., clustered). In both configurations, created snag density averaged 3.8 snags/ha at the stand scale. Snags were created throughout each stand except for the group selection treatment, where the small size of the harvested patches limited snag creation to unharvested, closed-canopy areas (Maguire and Chambers 2005). When possible, natural snags were included in clusters of created snags (Chambers et al. 1997). Snags were created by topping live Douglas-fir trees ( $\bar{x}$  diameter at breast height [DBH] = 75 cm; range = 33–198 cm) with a chainsaw at a mean height of 17 m; all snags were a minimum of 15 m. Each snag was marked with a uniquely coded aluminum tag, allowing us to relocate individual snags and assess how they changed across time. Because of modification of treatments between the initiation of the study and the time of our sampling, 26 of the 30 original stands were available at the start of our study in 2015 (group selection:  $n = 16$ , 2-story:  $n = 5$ , clearcut:  $n = 5$ ). Three additional stands were lost because of additional silvicultural treatments undertaken during winter 2015, resulting in 23 stands being available during the 2016 breeding season (group selection:  $n = 15$ , 2-story:  $n = 5$ , clearcut:  $n = 3$ ).

### Contemporary and Historical Use of Snags by Cavity-Nesting Birds

During the 2015–2016 breeding seasons (mid-Apr through Jun) we conducted focal observations on a randomly selected subset of created snags. We distributed our sample of created snags evenly among the 3 harvest treatments, and we only

surveyed created snags that were  $\geq 2.5$  m tall at the time of our surveys. In 2015, we surveyed 136 created snags; in 2016, we resurveyed the same group of snags and added 68 additional snags to increase our sample by approximately 50% ( $n = 204$  individual snags). We conducted focal observations for cavity-nesting birds on each snag once per week across the approximately 10-week breeding season in each year. We purposefully varied the time of day that we surveyed each snag in each successive visit so that our observations took place throughout the day (0700–1600). We split each 15-minute focal observation period evenly between 2 locations that faced the opposite sides of each snag (7.5 minute per side) to maximize visibility of the entire snag during each survey; most survey locations were  $\geq 10$  m distance from each snag to minimize disturbance to birds. We did not undertake focal observations on rare occasions when rain was heavy enough to interfere with accurate recording of bird activity.

During observation periods, we recorded all activities of cavity-nesting birds that were observed using focal snags (including the bark-nesting brown creeper [*Certhia americana*]); this included foraging, nesting, and other behaviors (i.e., perching, calling, and singing). Foraging activity was indicated by birds gleaning insects from the bark or drilling for prey on the snag, whereas nesting activities included nest cavity excavation or entering a cavity with materials indicative of nesting (i.e., food, nest material). Given that the incubation and provisioning bouts of cavity-nesting birds may last  $>15$  minutes, we rapped at the base of each snag with a stick at the end of each observation period to flush any birds that may have been present but were not observed (i.e., birds incubating eggs in cavities) to maximize detection. Although we are confident that we observed most nesting attempts because we observed each snag 9–10 times each season, some nesting attempts may have been missed if they failed or were abandoned before an observation took place. We determined nest stage based on observations of adult behavior around the nest site (e.g., adults carrying food into the cavity) and auditory detections of nestling begging vocalizations. Finally, we compared our contemporary data regarding snag use (2015–2016) to historical surveys conducted in 1996 and 2001 on the same group of snags (Chambers et al. 1997, Maguire and Chambers 2005, Walter and Maguire 2005) to assess potential changes in how snags were used for foraging and nesting activities over time.

### Avian Point Counts and Call-Playback Surveys

Our initial observations made in 2015 indicated low use of created snags by cavity-nesting birds, so during the 2016 breeding season we undertook point counts and call-playback surveys to evaluate whether members of this group were present on stands and available to use created snags. A single observer (AMB) conducted each survey from 0500 to 1000 to quantify naïve occupancy rates by primary cavity-nesters. We calculated naïve occupancy rates as the proportion of stands within each harvest treatment on which a given species was detected in 2016. We positioned point count stations randomly within each stand under the constraints that they

had to be situated  $\geq 100$  m from stand edges and located  $\geq 250$  m from other point count sampling locations to minimize double-counting birds. Point counts followed the protocol of Ralph et al. (1995) and consisted of a 10-minute aural and visual count period. Most stands could accommodate only a single survey station ( $n = 21$  stands), except for 1 stand that was large enough for 2 survey stations and 1 stand that had 3 survey stations; for analysis, we calculated naïve occupancy rates separately for each harvest treatment (see below). Immediately following each point count survey, we conducted a 5-minute call-playback survey (Kumar and Singh 2010) to enhance detection of 5 primary cavity-nesting species that were previously recorded on our study sites (Chambers et al. 1997): downy woodpecker (*Picoides pubescens*), hairy woodpecker (*Picoides villosus*), red-breasted sapsucker (*Sphyrapicus ruber*), northern flicker (*Colaptes auratus*), and pileated woodpecker (*Dryocopus pileatus*). Call-playback surveys consisted of broadcasting a 30-second recording of a call and a territorial drumming from each species in succession, with a 30-second listening interval between species; all recordings were made from individuals in the Pacific Northwest region of North America. We visited each point count location 5 times throughout the breeding season to maximize detections of individuals, each time recording all individuals detected within 100 m of the observer. We did not conduct surveys during heavy rain or wind speeds  $>30$  km/hour.

For woodpeckers, we calculated stand-level naïve occupancy rates using call-playback data because it provides a more accurate estimate of presence or absence than using point count data alone (Kumar and Singh 2010); for other cavity-nesting species, we used point count data for this measurement. Although occupancy rates can be more accurate when detection probability estimates are incorporated, we did not use this approach in our study for 2 reasons. First, imperfect detection is of concern when different land cover types are being compared directly; in contrast, we were interested in comparing the results of our audio-visual surveys to naïve occupancy rates within each of our harvest treatments. Adopting this approach allowed us to understand which species were available to use snags within each treatment but were undetected by our focal observations. Second, audio-visual surveys that do not account for detectability are conservative, so accounting for detectability in our study would result in even greater estimates of occupancy rates for species whose naïve occupancy rates were  $<100\%$ . Given that the rates of naïve occupancy were multiple times higher than estimates for nesting or foraging for many species, correcting for detection would not change our finding that strong excavators were present on stands and available to use created snags even though we rarely detected them doing so.

### Surveys of Natural Snags

Because stand structure can influence use of created snags by birds and had changed markedly in our stands since the implementation of the study (Barry 2017), we also measured natural snags on all stands during summer 2016. To estimate

density, we used  $40 \times 100$ -m belt transects that were centered on point count stations, with the azimuth of each transect selected randomly. We tallied each natural snag that had  $\geq 50\%$  of its basal stem within 20 m of the center of the belt transect. We defined natural snags as entirely dead standing trees that were  $\geq 2.5$  m tall, 20 cm DBH, and were not intentionally created by humans. For each natural snag we recorded the tree species, DBH, and height (to the highest point on the snag) for comparison with created snags; additional analysis regarding characteristics of created snags can be found in Barry et al. (2017).

### Statistical Analysis

We used a mixed linear modeling approach in the R statistical environment (version 3.3.1, R Development Core Team 2010) to quantify contemporary differences in avian nesting and foraging use among harvest treatments and snag configurations. We constructed generalized linear mixed models with a binomial distribution and a logit link to separately compare the proportion of snags used for nesting and for foraging relative to harvest treatment (3 levels: group selection, 2-story, clearcut) and snag configuration (2 levels: clustered, scattered). Our models included the fixed effects of harvest treatment, snag configuration, and block; an interaction of treatment  $\times$  configuration; and a random stand effect. All models met assumptions of normality and equal variance. We report least-squares marginal means for effect sizes and their 95% confidence intervals; significance levels for all tests were  $P < 0.05$ .

To assess how use of created snags changed over time, we compared the proportion of snags used for nesting and the rate of foraging on created snags between the 2001 and 2015–2016 breeding seasons. We also qualitatively assessed how species composition changed from 1996 and 2001 relative to our contemporary surveys. Sampling effort can influence the number of nests encountered and foraging observations recorded, and it varied between surveys conducted in different years. Therefore, we standardized the number of nests located and foraging observations recorded by the number of hours of observation made in each year of study.

## RESULTS

Across both nesting seasons 11% of the created snags we examined contained nests, with those nests belonging to 4 cavity-nesting species: chestnut-backed chickadee (*Poecile rufescens*, 32 nests), red-breasted nuthatch (*Sitta canadensis*, 2 nests), red-breasted sapsucker (1 nest), and northern flicker (1 nest; Table 1). We did not detect an effect of harvest treatment ( $\chi^2 = 1.94$ ,  $P = 0.34$ ) or snag arrangement ( $\chi^2 = 0.1$ ,  $P = 0.82$ ) on the proportion of created snags used for nesting. We detected nests from 3 species (i.e., chestnut-backed chickadee, red-breasted nuthatch, and northern flicker) in the group selection treatment, 1 species (i.e., chestnut-backed chickadee) in the 2-story treatment, and 2 species (i.e., chestnut-backed chickadee and red-breasted sapsucker) in the clearcut treatment. The number of snags used for nesting was equal between the 2 snag

**Table 1.** The number of nests for each cavity-nesting bird species found during 3 survey periods (1996, 2001, and 2015–2016) in the Oregon State University McDonald-Dunn Research Forest, near Corvallis, Oregon, USA.

Species	1996		2001		2015–2016	
	Number of nests	% total	Number of nests	% total <sup>a</sup>	Number of nests	% total <sup>a</sup>
Northern flicker	5	6	7	4	1	3
Red-breasted sapsucker	13	16	21	12	1	3
Hairy woodpecker	1	1	1	1	0	0
Chestnut-backed chickadee	6	7	56	33	32	89
Red-breasted nuthatch	1	1	15	9	2	6
European starling	3	4	28	16	0	0
House wren	46	57	31	18	0	0
Violet-green swallow	5	6	10	6	0	0
Western bluebird	1	1	0	0	0	0
All species combined	81		169		36	
Hours of observation			97		750	
Nests/hour observation			0.57		0.05	

<sup>a</sup> Values do not add to 100% because of rounding error.

configurations, and nearly all (97%) of the nests we monitored successfully produced offspring (Table S1, available online in Supporting Information).

Across both years, we detected cavity-nesting birds foraging on 11% of created snags during >750 hours of focal observations (Table 2), and 18% of snags were used for either foraging or nesting. Foraging events were rare, however, with a detection rate of 1 foraging observation for every 20 hours of snag observation. We observed 7 cavity-nesting species foraging on created snags on 39 separate occasions across all treatments and snag configurations (Table 2). We recorded most foraging observations from the chestnut-backed chickadee (41%) or pileated woodpecker (26%). We observed 15 foraging events in the group selection treatment, 8 in the 2-story treatment, and 16 in the clearcut treatment; however, we did not detect an effect of treatment ( $\chi^2 = 2.6$ ,  $P = 0.27$ ) or snag configuration ( $\chi^2 = 0.1$ ,  $P = 0.71$ ) on the proportion of snags used for foraging by cavity-nesting birds.

We found that the proportion of created snags that contained an active nest decreased from 20% in 2001 to 11% in 2015–2016 despite >7.5 times more effort during contemporary surveys (2001: 97 hr, 2015–2016: 750 hr). Similarly, the number of cavity-nesting species that were using snags for nesting also decreased from 9 species in 1996 to only 4 species at the time of contemporary surveys (Table 1). Nearly all nests located during our surveys (94%) were occupied by weak-excavating species, and the proportion of nests occupied by strong excavators and secondary cavity nesters generally declined over time (Table 1). The one exception was the European starling (*Sturnus vulgaris*), a non-native, open-canopy species that increased from 1996 to 2001. The rate of foraging observations on created snags decreased 5.6 times over the past 15 years. The number of species observed foraging on snags also decreased during that period, from 10 species observed foraging on snags in 2001 to 8 species during contemporary surveys (Table 2).

**Table 2.** The number of foraging events recorded on created snags by cavity-nesting birds during historical (2001) and contemporary (2015–2016) surveys in the Oregon State University McDonald-Dunn Research Forest near Corvallis, Oregon, USA.

Species	2001		2015–2016	
	Number of foraging observations	% total <sup>a</sup>	Number of foraging observations	% total <sup>a</sup>
Pileated woodpecker	4	7	10	24
Northern flicker	0	0	1	2
Red-breasted sapsucker	22	37	3	7
Hairy woodpecker	8	14	2	5
Downy woodpecker	3	5	0	0
Chestnut-backed chickadee	4	7	16	39
Red-breasted nuthatch	10	17	5	12
Barred owl ( <i>Strix varia</i> )	0	0	1	2
Brown creeper	5	8	2	5
European starling	1	2	0	0
House wren	1	2	0	0
Bewick's wren ( <i>Thryomanes bewickii</i> )	1	2	0	0
All species combined	59		40	
Hours of observation	97		750	
Foraging events/hour observation	0.61		0.05	

<sup>a</sup> Values do not add to 100% because of rounding error.

**Table 3.** Naïve occupancy rates (i.e., the percentage of stands on which a species was detected during audio-visual surveys) for cavity-nesting birds for each of 3 harvest treatments (group selection:  $n = 15$  stands; 2-story:  $n = 5$  stands; clearcut:  $n = 3$  stands) in the Oregon State University McDonald-Dunn Research Forest near Corvallis, Oregon, USA during the 2016 breeding season. Occupancy rates of strong excavators were based on data from call-playback surveys whereas occupancy rates of weak excavators and secondary cavity nesters were based on data from point count surveys.

Nesting classification	Species	Naïve occupancy rate (%)		
		Group selection harvest	2-story harvest	Clearcut harvest
Strong cavity excavators	Pileated woodpecker	67	60	33
	Northern flicker	67	100	67
	Red-breasted sapsucker	80	40	67
	Hairy woodpecker	73	20	0
Weak cavity excavators	Chestnut-backed chickadee	100	100	100
	Black-capped chickadee ( <i>Poecile atricapillus</i> )	20	20	33
	Red-breasted nuthatch	100	100	100
Secondary cavity nesters	Brown creeper	100	100	67
	Barred owl	0	20	0
	Bewick's wren	20	0	0
	House wren	13	0	33
	Northern pygmy-owl ( <i>Glaucidium gnoma</i> )	7	0	0

We detected 12 cavity-nesting bird species during point count and call-playback surveys on stands containing created snags (Table 3), with relatively high occupancy rates across harvest treatments for many species. We detected 3 species in all harvest treatments: chestnut-backed chickadee, red-breasted nuthatch, and brown creeper. Only 4 of the 12 species we detected during point count and call-playback surveys were detected nesting in created snags.

Natural snags were comprised of Douglas-fir (64%), Oregon white oak (*Quercus garryana*; 10%), and big-leaf maple (*Acer macrophyllum*; 11%); extensive decay prevented us from identifying the tree species on the remaining snags we encountered (15%). Mean density of natural snags in the group selection treatment was  $10.6 \pm 1.9$  (SE) snags/ha compared to the 2-story treatment, which had a mean density of  $6.4 \pm 2.2$  snags/ha and the clearcut treatment, which had a mean density of  $13.3 \pm 5.1$  natural snags/ha. Because the mean density of created snags was standardized at the start of the study and few created snags had fallen by 2016 ( $n = 67$ , 9% of total), the variation in the number of total snags (i.e., created + natural snags) was due largely to the recruitment of natural snags since the time of harvest. Although natural snag density was greater than the density of created snags for each treatment, natural snags were smaller in diameter on average in all treatments (Fig. 1A) and were shorter on average in group selection and clearcut treatments (Fig. 1B).

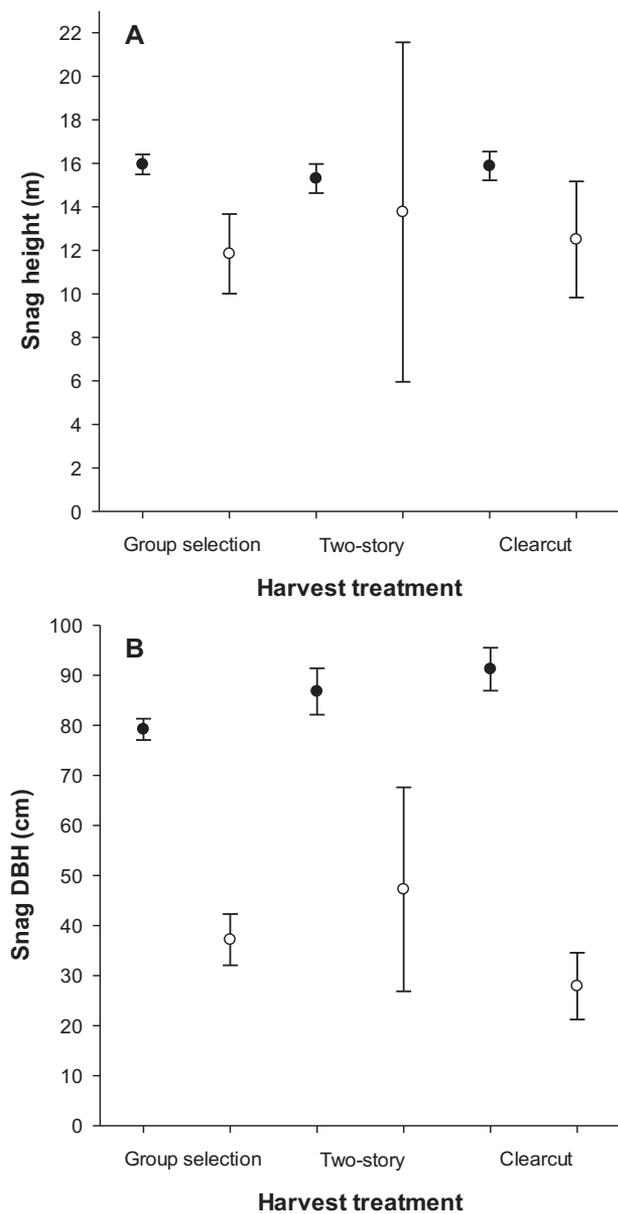
## DISCUSSION

Despite extensive survey effort across 2 consecutive breeding seasons, we found limited use of 25–27-year-old created Douglas-fir snags by cavity-nesting birds. Although the low number of nests and limited foraging events that we observed may have hampered our ability to detect differences in use of snags for nesting and foraging over time, 2 additional lines of evidence indicate that the created snags in our study were no longer useful for most cavity-nesting bird species. First, our point counts and call-playback surveys detected a diversity of cavity-nesting birds on our study sites that depend on snags during the breeding season, yet we rarely, if ever, observed most of these species using created snags during contemporary surveys despite >750 hours of

observation. Second, created snags in our system were regularly used by a range of cavity-nesting birds at different points in time prior to our study (Chambers et al. 1997, Maguire and Chambers 2005, Walter and Maguire 2005), including species that we did not detect using created snags during contemporary surveys. Collectively, these lines of evidence indicate that although created snags in our study provided habitat for cavity-nesting birds in the past, they no longer experienced widespread use by the broader cavity-nesting bird community 25–27 years after creation. Instead, they are used primarily by a subset of cavity-nesting species that require well-decayed wood for creating nesting cavities, such as the chestnut-backed chickadee (Mahon et al. 2007) or those that forage on insects in especially decayed wood within closed-canopy forests (e.g., pileated woodpecker; Fleming et al. 1999).

We found that nearly all active nests that we detected in created snags were those of the chestnut-backed chickadee, a weak cavity-excavating species that breeds in closed-canopy forest. Although the number of nests of this species increased proportionally from 1996, another weak cavity-excavating species associated with closed-canopy forest, the red-breasted nuthatch, decreased its nesting use of created snags since 2001 despite being common on our study sites. Unlike strong cavity excavators, both the red-breasted nuthatch and the chestnut-backed chickadee nest in dead trees with broken tops more often than live, diseased trees (Mahon et al. 2007). The red-breasted nuthatch, however, uses snags with intermediate heartwood decay (Steeger and Hitchcock 1998), whereas chickadees use snags with advanced decay for nesting (Martin et al. 2004). The greater proportion of weak to strong cavity-excavating species that we detected using snags for nesting compared to previous surveys suggests the created snags we examined were beyond the threshold of decay for most strong cavity-excavating species (Blanc and Martin 2012).

Created snags in our study also appeared to provide limited foraging opportunities for most species of cavity-nesting birds. Many strong excavators rely on wood- and bark-boring insects for food (e.g., Cerambycidae, Scolytidae; Murphy and Lehnhausen 1998, Raley and Aubry 2006) and these are



**Figure 1.** Mean ( $\pm$  95% CI) snag height (A) and mean ( $\pm$  95% CI) diameter at breast height (DBH; B) of natural snags (open circles) and created snags (filled circles) measured in 2015–2016, 25–27 years after creation in the Oregon State University McDonald-Dunn Research Forest, Oregon USA.

generally most abundant within 3 years of tree death (Harmon et al. 1986, Hanks 1999, Farris et al. 2002, Angers et al. 2012). The pileated woodpeckers we observed may have been foraging on created snags because carpenter ants (*Camponotus* sp.), their key food source, are often present in well-decayed wood (Flemming et al. 1999) long after most wood and bark-boring insects are absent. The chestnut-backed chickadee forages by gleaning insects from the bark and branches of trees rather than drilling through wood, so it was likely to have fed upon insects on the bark of snags and not internal boring species (Mahon et al. 2007, Bunnell 2013). The condition of created snags at the time of our study had likely moved beyond the stage at which most wood-boring insect activity would be expected. In sum, the rarity of

foraging observations during contemporary surveys suggests that availability of food resources within created snags  $\geq 25$  years old within a closed-canopy setting were limited.

Individual characteristics of snags, including hardness and the degree of decay, may limit use by some cavity-excavating species (Lorenz et al. 2015). However, changes in vegetation and stand structure can also contribute to changes in the species composition using snags, and this may have influenced the patterns we observed in our study. Most of the secondary cavity-nesting species using snags during historical surveys were open-canopy associates (e.g., violet-green swallow [*Tachycineta thalassina*], European starling, house wren [*Troglodytes aedon*], western bluebird [*Sialia mexicana*]; Maguire and Chambers 2005, Walter and Maguire 2005). Thus, most of the stands on our study sites are now unsuitable for these species because regeneration of planted conifers in 2-story and clearcut stands has resulted in dense cover of tall vegetation surrounding created snags. In addition, the density of natural snags on our stands appeared to be adequate to support nest populations of strong cavity-excavating birds that we detected on study sites but did not observe nesting in created snags. Indeed, we detected 3 strong cavity-excavating species, hairy woodpecker ( $n = 3$ ), red-breasted sapsucker ( $n = 3$ ), and northern flicker ( $n = 1$ ), nesting in natural snags. That the number of nests of cavity-nesting birds located in natural snags that we found opportunistically exceeded the number of nests observed in >750 hours of observation of created snags indicates created snags were beyond their useful lifespan for members of this group.

Although we observed a substantial decrease in the use of created snags by cavity-nesting birds across surveys covering 25 years, snags in later stages of decay can still provide important habitat for other forest wildlife species for nesting, roosting, or storing food (Meyer et al. 2005, Fabianek et al. 2015). We incidentally detected 7 non-avian species (3 mammals, 2 amphibians, and 2 mollusks) using snags on multiple occasions (Barry 2017). The presence of older, large diameter snags may be important for forest mammal species such as flying-squirrels (*Glaucomys* sp.) and bats (Chambers et al. 2002, Meyer et al. 2005, Fabianek et al. 2015), and created snags in later stages of decay could potentially provide roost sites for woodpeckers during the non-breeding season (Covert-Bratland et al. 2007, Paclík and Weidinger 2007). Moreover, after snags fall to the ground they provide nutrients that enhance soil development and nutrient cycling, and provide additional habitat for an array of ground-based organisms, such as nonvascular plants and insects (Harmon et al. 1986, Rose et al. 2001, Angers et al. 2012). Thus, older snags still have important functions after usefulness to breeding cavity-nesting birds comes to an end.

## MANGEMENT IMPLICATIONS

Snags provide important habitat for many forest-dwelling organisms, so historical declines in snags are thought to have had a strong effect on biodiversity. Our study found that although most created snags were still standing and available for use by cavity-nesting birds, they received limited use for foraging or

nesting by this group across all harvest treatments and snag configurations. These findings suggest that created conifer snags  $\geq 25$  years old are unlikely to meet the needs of most cavity-nesting bird species that inhabit closed-canopy Douglas-fir forests. Nevertheless, created snags were used for foraging and nesting at earlier points in time and therefore do serve as important habitat for cavity-nesting birds during their lifetime. Therefore, land managers whose goals are to create snags could consider staggering the time of snag creation within a stand to have a succession of snags that provide a temporally consistent series of food and nesting sites. Taking steps to retain natural snags and live trees with defects indicating possible decay (e.g., broken tops) may also be important within managed forests, particularly for strong excavator species.

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