

AN ABSTRACT OF THE THESIS OF

Amy Marie Barry for the degree of Master of Science in Forest Ecosystems and Society presented on March 9, 2017.

Title: Created Snag Dynamics and Influence on Cavity-nesting Bird Communities over 25 years in Western Oregon.

Abstract approved:

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Snags provide critical habitat for nearly one-third of wildlife species in forests of the Pacific Northwest, so historic declines in snags are thought to have had a strong impact on biodiversity. Resource managers often create snags to mitigate the scarcity of snags within managed forests, but information regarding the function and structure of created snags across long time periods (>20 years) is absent from the literature. Using snags that were created by topping mature Douglas-fir trees (*Pseudotsuga menziesii*) as part of the OSU College of Forestry Integrated Research Project, we measured characteristics of 731 snags and quantified foraging and breeding use of snags by birds 25-27 years after their creation. We also examined whether different harvest treatments (i.e., group selection, two-story, clearcut) and snag configurations (i.e., scattered and clustered) influenced snag characteristics or avian use for foraging and nesting. In addition, we conducted point count and call play-back surveys to calculate naïve occupancy estimates for cavity-nesting bird species. Finally, we compared current estimates of snag condition and avian use to estimates from historic surveys to assess changes over time. We found that 91% of created snags remained standing and 65% remained unbroken during the

period of our study. We also found that 54% of snags had bark peeling away from the bole of the snag and mean bark cover was 82%. Relative to historic surveys of the same pool of snags, we found that breaking and peeling bark has greatly increased compared with historic surveys. Furthermore, decay characteristics and historic use of snags (cavity-cover) differed among the three harvest treatments. Snags created in the group selection treatment exhibited lower amounts of bark loss and cavity cover than snags created in the two-story or clearcut treatments, whereas characteristics between snag configurations were generally similar.

Despite observing snags for >750 h throughout the course of two breeding seasons, we observed that only 11% of snags were used by cavity-nesting birds for nesting across harvest treatments. Of eight bird species detected during surveys, only four species were detected using created snags for nesting (n=36 nests). Compared with historic surveys, use of snags for nesting has decreased in both proportion of snags used and species richness. In particular, the proportion of woodpecker species using snags for nesting has decreased from 23% in 1996 to 3% by 2016. Additionally, we observed foraging by nine bird species although the rate of foraging observations was low (0.05 observations/h). Extent of foraging also decreased 8× from the most recent historic surveys conducted in 2001. Our results suggest that ≥25-year old created snags in managed forests provided limited nesting and foraging opportunities for cavity-nesting birds, and their use has declined markedly since 2001. If management for biodiversity is a goal of snag creation, then retaining or creating a variety of age classes of snags on the landscape is expected to support the full diversity of species that depend on snags for nesting or foraging.

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Created Snag Dynamics and Influence on Cavity-nesting Bird Communities over 25 years in  
Western Oregon.

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## TABLE OF CONTENTS

	<u>Page</u>
Chapter 1 -- Introduction .....	1
Chapter 2— Long-term dynamics and characteristics of snags created for wildlife habitat management .....	4
Abstract .....	4
Introduction.....	5
Methods.....	10
Site description.....	10
Study design .....	11
Quantification of Snag characteristics .....	12
Comparison with historic data .....	13
Statistical methods .....	14
Results.....	15
Comparison with historic data .....	17
Discussion .....	18
Conclusions and management implications.....	22
Chapter 3 – Avian use of intentionally created snags across 25 years in managed forests .....	34
Abstract .....	34
Introduction.....	35
Methods.....	40
Site Description.....	40
Experimental Design.....	40
Observations of avian use of snag.....	41

Avian Point Counts and Call-Playback Surveys.....	43
Comparison with historic data .....	44
Statistical analysis .....	45
Results.....	46
Contemporary avian use of created snags for nesting.....	46
Contemporary avian use of snags for foraging .....	47
Naïve occupancy rates for cavity-nesting species.....	48
Comparison with historic avian use data .....	48
Availability and characteristics of natural vs. created snags .....	49
Discussion .....	50
Conclusions and management implications.....	54
Chapter 4 – Conclusion.....	66
Literature Cited.....	68
Appendices.....	74
Appendix A: Initial characteristics measured for all created snags in 1991 .....	74
Appendix B: Naïve occupancy estimates for all birds detected during point counts in CFIRP stands, 2016. ....	75

## LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
Figure 2.1. Map of study location and designation of blocks and stands for the CFIRP within the McDonald Dunn Research Forest, Corvallis, OR (Walter & Maguire, 2005). .....	24
Figure 2.2. The proportion of created snags that were standing within each treatment (95% confidence intervals) in 2016. Point estimates not sharing the same letter represent means that statistically significant at P=0.05. ....	25
Figure 2.3. The proportion of created snags that were standing within each configuration (95% confidence intervals) in 2016. Point estimates not sharing the same letter represent means that statistically significant at P=0.05. ....	26
Figure 2.4. The proportion of created snags that were broken within each treatment (95% confidence intervals) in 2016. Point estimates not sharing the same letter represent means that statistically significant at P=0.05 .....	27
Figure 2.5. The proportion of created snags that were broken within each configuration (95% confidence intervals) in 2016. Point estimates not sharing the same letter represent means that statistically significant at P=0.05. ....	28
Figure 2.6. Distribution of bark cover extent on snags created in different silvicultural treatments.	29
Figure 2.7. Distribution of cavity cover (%) on created snags among three harvest treatments $\geq 25$ years after snag creation. ....	30
Figure 2.8: Mean proportion (95% CI) of created snags with peeling bark within each configuration 25-27 y after creation. Point estimates not sharing the same letter represent means that statistically significant at P=0.05. ....	31
Figure 3.1. Map of study location and designation of blocks and stands for the CFIRP within the McDonald Dunn Research Forest, Corvallis, OR. ....	56
Figure 3.2. Mean height (95% CI) of created and natural snags among three harvest treatments in the CFIRP stands, 2016. ....	57
Figure 3.3. Mean DBH (95% CI) of created and natural snags among three harvest treatments in the CFIRP stands, 2016. ....	58

## LIST OF TABLES

<u>Table</u>	<u>Page</u>
Table 2.1. Number of stands with each treatment combination (harvest treatment/snag configuration) in each block in 2016. ....	32
Table 2.2. Snag characteristic measurements for snag subset (n = 238) among silvicultural harvest treatments in CFIRP stands in 2016. ....	33
Table 3.1: Number of stands with each treatment combination (harvest treatment/snag configuration) in each of the three blocks in the CFIRP during 2015 and 2016. Treatments that had number of stands decrease from 2015 to 2016 are in bold. ....	59
Table 3.2. Distribution of bird foraging observations collected during focal observations on 136/204 created snags in the CFIRP from May-July 2015/2016 relative to among harvest treatment. ....	60
Table 3.3. Comparison among snag configurations of number of avian nests detected during focal surveys on created snags in the McDonald-Dunn Forest, Oregon from May-July 2015/2016. ....	61
Table 3.4. Comparison among harvest treatments of number of avian foraging events during focal surveys on created snags from May-July 2015/2016.....	62
Table 3.5. Naïve occupancy (i.e. the percentage of points at which birds were detected) for each cavity-nesting species detected in CFIRP stands, 2016. Occupancies of strong excavators were calculated using call playback data only, while occupancies of other species were calculated based on point count data.....	63
Table 3.6. The number of nests for each species found during three survey periods (1996, 2001, and 2015/2015) in the CFIRP stands and the % of total nests that each species represents.....	64
Table 3.7. Estimates of natural snags natural snag densities ( $\pm$ standard error) for 2001 and 2016 among harvest treatment in the McDonald-Dunn Forest, Oregon.....	65

Created Snag Dynamics and Influence on Cavity-nesting Bird Communities over 25 years in  
Western Oregon.

## **CHAPTER 1 -- INTRODUCTION**

Snags, or standing dead trees, are critical components of forest ecosystems throughout the world. Natural snags are created through disturbances such as fire and wind damage, and through biological agents such as insects and fungi (Morrison & Raphael, 1993; Rose et al., 2001). Snags serve as important habitat features that promote biodiversity by providing critical habitat for many wildlife species including mammals, amphibians, and birds (Harmon et al., 1986; Newton, 1994; Rose et al., 2001; Seibold et al., 2016; Thomas, 1979). There are >1000 species of wildlife in the United States, including one third of all forest dwelling species, that rely on snags (Newton, 1994; Thomas, 1979). In addition to their value as habitat, snags also provide ecosystem services by storing terrestrial carbon and slowly releasing nutrients to the forest floor as they decompose over time. These processes ultimately influence the development of nutrients in soil, which in turn plays a crucial role in long-term forest health and productivity (Angers et al., 2012; Harmon et al., 1986; Rose et al., 2001).

Despite their ecological importance, snags are often removed during timber harvest for their commercial value and to comply with safety regulations (Kroll et al., 2012; Lewis, 1998). The removal of snags from managed forests has reduced the amount of suitable habitat in these areas for many species that use snags (Cline, et al., 1980; Hayes et al., 1997; Lewis, 1998; Spies & Franklin, 1988). This is especially true for cavity-nesting bird species, which rely on snags for both nesting and foraging. Cavity-nesting birds are important predictors of ecosystem health because their activity (foraging and nesting) has been shown to predict both abundance and

richness of other forest bird species (Drever et al., 2008). Given the importance of these species, a loss of snags creates a serious threat to native biodiversity by reducing or eliminating critical wildlife habitat (Hane et al., 2012).

To mitigate the loss of natural snags from managed stands, forest management practices on public lands in the 1970's began to incorporate wildlife habitat structures on these landscapes (McComb et al., 1993). This included leaving green (i.e., live) trees and creating snags from living trees to replace snags that were removed during timber harvest. Creating snags from live trees provided a safer alternative for timber harvesters than leaving natural snags that may be prone to fall, and has since become an established practice throughout much of the Pacific Northwest. Snags can be created through a variety of methods including removal of the top with a chainsaw or explosives, girdling in and around the base of the crown, and fungal inoculation (Lewis, 1998).

Many studies have reviewed short-term function of created snags (Arnett et al., 2010; Chambers et al., 1997; Russell, et al., 2006; Schreiber et al., 1992; Walter & Maguire, 2005), but long-term (>20y) studies are missing from the literature. As snags decay, they change in form and also in their usefulness as wildlife habitat; thus long-term studies are needed to understand how created snags change as they decay, and how these changes impact the wildlife that depend on snags. Our study used a long-term silvicultural project (the College of Forestry Integrated Research Project, or CFIRP) to investigate the influence of created snags on avian communities 25-27 y after creation. CFIRP was initiated in 1989, and was designed to test the impact of different types of silvicultural harvest on vegetation, wildlife, and societal perception (Chambers et al., 1997). Stands were subjected to one of three silvicultural harvest treatments: group

selection, two-story regeneration, and clearcut with retained green trees. The silvicultural harvest treatments were intended to mimic variations in natural disturbance patterns, and were used to explore alternatives to clearcutting (Chambers et al., 1999). Researchers created snags within each harvested stand in one of two spatial configurations (i.e., clustered and scattered) to test the effects of fine-scale disturbance on bird use.

Our goal in this study was to test the effect of harvest treatment and snag configuration on long-term changes in created snag condition, and the subsequent influence on cavity-nesting bird communities. Specifically, our objectives were to (1) compare characteristics and condition of snags among silvicultural harvest treatments and snag configurations, (2) quantify foraging and nesting use of snags by birds and compare use among silvicultural harvest treatments and snag configurations, and (3) compare current condition of created snags and use by birds to historic data to assess changes over time.

## CHAPTER 2— LONG-TERM DYNAMICS AND CHARACTERISTICS OF SNAGS CREATED FOR WILDLIFE HABITAT MANAGEMENT

### Abstract

Snags provide habitat for nearly one-third of wildlife species in forests of the Pacific Northwest, so these structures are critical for the long-term maintenance of biodiversity. Resource managers often use snag creation to mitigate the scarcity of snags within managed forests, but information regarding how the characteristics of created snags change over long time scales (>20 years) is absent from the literature. In this study, we re-visited snags that were created by topping mature Douglas-fir trees (*Pseudotsuga menziesii*) 25-27 years after their creation to measure how snag characteristics changed over time. We also examined whether different harvest treatments (i.e., group selection, two-story, clearcut) and snag configurations (i.e., scattered and clustered) had an influence on current-day snag characteristics.

We found that of 731 created snags, 91% remained standing during contemporary surveys, and 65% remained unbroken. Although most snags remained standing after  $\geq 25$  y, we found advanced decay was indicated on snags by greater amounts of breaking and peeling bark compared with historic surveys. Although characteristics between snag configurations were generally similar, we found that snags in the group selection treatment exhibited lower amounts of external decay and historic use by birds, as indicated by bark loss and cavity cover, than snags created in the two-story or clearcut treatments. Our results indicate that although most created snags were standing in managed forests after  $\geq 25$  y, the advanced decay we detected may limit their value to wildlife that use snags in later stages of decay. If management for biodiversity is a goal of snag creation, then creating a diversity of snag age classes on the landscape is likely to provide snags across a range of decay states that would support the broadest number of species.

Key words: snag-dependent birds, created snags, decay, Douglas-fir, Oregon Coast Range, *Pseudotsuga menziesii*, silviculture, snag configuration, snag longevity

## **Introduction**

Snags, or standing dead trees, are created through natural disturbances such as fire and wind damage, and through biological agents such as insects and fungi (Morrison & Raphael, 1993; Rose et al., 2001). Snags provide many ecosystem services, and play a crucial role in long-term forest health and productivity (Angers et al., 2012; Harmon et al., 1986; Rose et al., 2001). Snags store terrestrial carbon and contribute to soil development by providing an input of nutrients to the forest floor as they decompose over time. In addition, snags promote biodiversity by providing critical habitat for many wildlife species including mammals, amphibians, and birds (Harmon et al., 1986; Newton, 1994; Rose et al., 2001; Seibold et al., 2016; Thomas, 1979).

As a live tree transitions to a snag, it progresses through many stages of decay resulting in habitat for a range of wildlife species. Over time, decay in sapwood and heartwood contributes to limbs falling off, bark sloughing away, and breaking occurring along the snag bole (Franklin, Shugart, & Harmon, 1987; Harmon et al., 1986). In turn, these changes create habitat features upon which different species of wildlife rely. For example, many woodpeckers (family Picidae) require softened heartwood to create nesting cavities (Bunnell, 2013; Lorenz et al., 2015; Melletti & Penteriani, 2003). Other wildlife species, such as bats and Brown Creeper (*Certhia americana*), require loose slabs of bark for roosting and nesting (Chambers et al., 2002;

Geleynse et al., 2016). The rate at which decay characteristics develop on snags ultimately determines their usefulness to different wildlife species across time.

The rate of snag decay is influenced by both biotic and abiotic factors, including physical characteristics of trees, environmental conditions, and the composition of decomposer organisms (Cline et al., 1980; Harmon et al., 1986; Rose et al., 2001). For example, tree species and size (e.g., diameter), are important predictors of rate of decay and snag longevity (Angers et al., 2012; Hallett et al., 2001; Onodera & Tokuda, 2015; Parish et al., 2010). Environmental factors, such as solar radiation and precipitation, can also influence decay rate of snags by changing temperature and moisture content within wood. Rapid changes in moisture content of wood cells can influence wood integrity, causing bark and sapwood to break away from the bole (Harmon et al., 1986). Environmental conditions influencing snag decay can be altered by the density of trees and vegetation surrounding snags, consequently affecting snag longevity (Garber et al., 2005). Density of trees and vegetation within a stand can influence moisture content and temperature of wood in snags, which impacts both wood integrity and regulation of microbial decomposer activity in snags (Harmon et al., 1986; Seibold et al., 2016). Composition of microbial decomposer is one of the most significant factors that contributes to internal heartwood softening, and subsequent deterioration of snags (Harmon et al., 1986)

Wood and bark-boring beetles that colonize snags (e.g., Curculionidae, Scolytinae, Buprestidae and Cerambycidae) expedite decay by mineralizing wood and providing pathways for fungi, bacteria, and other invertebrates to access heartwood (Angers et al., 2012; Harmon et al., 1986; Seibold et al., 2016). The presence of insects also attracts species that forage on snags such as woodpeckers. As they forage, woodpeckers further contribute to snag decay and

characteristics by fragmenting wood and by providing opportunities for the establishment of fungi as woodpeckers drill through bark and sapwood to create cavities (Harmon et al., 1986; Jusino et al., 2016; Lorenz et al., 2015). These processes ultimately influence the rate at which snags decay, and are important for enhancing ecosystem diversity and resilience (Franklin et al., 1987; Kilgo & Vukovich, 2014; Rose et al., 2001).

Despite their ecological significance, snags are often removed during timber harvest for their commercial value and to comply with safety regulations. Intensive forest management has reduced the number of snags in managed compared with unmanaged landscapes (Cline et al., 1980; Swanson & Franklin, 1992; Wilhere, 2003). A reduction in snag abundance can reduce native biodiversity by diminishing or eliminating habitat that snags create for wildlife as they decay over time (Hane et al., 2012). Therefore, snag creation has been implemented to replace wildlife habitat that is lost when natural snags are removed from managed stands. Snag creation is typically undertaken at the time of harvest and mitigates the risk associated with leaving natural snag that may be prone to falling if they are left standing during harvest operations. Snags are created in a variety of ways, including removal of the top with explosives or a chainsaw, girdling in or around the base of the crown, or inoculating with fungi and subsequent snag decline and use of snags by birds has been shown to vary among creation methods (Bull & Partridge, 1986; Hallett et al., 2001; Lewis, 1998). Snag are also commonly created in different distribution patterns, such as in clustered groups or scattered evenly across a stand. Snag distribution is thought to influence use of snags by birds and may also impact snag decay by attracting insects to clusters that accelerate wood decay and use by birds as foraging substrates (Angers et al., 2012; Chamberlin, 1918; Seibold et al., 2016). Creation of snags across managed

stands is intended to restore mature forest features that will benefit wildlife over long time periods (McComb et al., 1993).

A number of prior studies have assessed characteristics of creation snags in relation to their use by wildlife  $\leq 10$  y after creation (Arnett et al., 2010; Chambers et al., 1997; Hallett et al., 2001; Schreiber & DeCalesta, 1992; Walter & Maguire, 2005), and use of snags by cavity-nesting birds has been found to generally increase with snag age. However these studies are limited to short time-frames, and natural snags are known to stand for at least 100 y (Cline et al., 1980). Data are lacking regarding the rate at which created snags remain standing over time (i.e., longevity) and how characteristics that are linked to use by forest wildlife change throughout the lifespan of a created snag. Understanding how characteristics of created snags change as a result of contemporary management practices as snags move through the decay process will provide the most useful information for resources managers who are charged with creating snags.

In this study, we quantified characteristics of snags that were intentionally created 25-27 y ago as part of a long-term silvicultural experiment (the Oregon State University College of Forestry Integrated Research Project, hereafter CFIRP). Snags were created at the time of harvest in one of three silvicultural harvest treatments applied at the stand level: group selection, two-story regeneration, and clearcut with retained green trees (Chambers et al., 1997). Snags within each treatment were also assigned to one of two different spatial configurations (clustered and scattered). The harvest treatments and snag configurations were intended to mimic variations in natural disturbance patterns, such as a localized, low intensity disturbance (i.e., group selection), a moderate disturbance (i.e., two-story), or a high intensity disturbance (i.e., clearcut). Harvest treatments were also used to explore operational alternatives to traditional clearcutting

(Chambers et al., 1999). Using the CFIRP snags, our objectives were to (1) compare longevity of created snags among silvicultural harvest treatments and between snag configurations, (2) compare current characteristics of snags, including breaking, bark characteristics, and cavity cover, among silvicultural harvest treatments and snag configurations, and (3) compare current-day snags to historic data to assess changes in characteristics of individual created snags across a 25-y period.

Since different harvest treatments were correlated to different levels of harvest intensity (i.e., green tree removal), the treatments varied in respect to level of canopy retention and surrounding tree densities in stands. Given that tree densities and vegetation are thought to influence rate of decay (Garber et al., 2005; Harmon et al., 1986; Seibold et al., 2016), we hypothesized that greater harvest intensity would be correlated with greater levels of decay. We predicted that the likely-hood of snags being fallen or broken and the amount of bark loss on snags would be greatest in the clearcut treatment (i.e., high intensity harvest), followed by the two-story treatment (i.e., moderate intensity harvest), and then the group selection treatment (i.e., low intensity harvest). Based on data from previous surveys (Chambers et al., 1997; Walter & Maguire, 2005), we hypothesized that snags created in the clearcut and two-story treatments would have received more use over time when compared with snags created in group selection. If this is true, then we predicted that snags in the clearcut and two-story treatments would have greater cavity-cover when compared with snags in the group selection treatment. With respect to snag configuration, we hypothesized that snags created in clusters would have experienced greater use compared with scattered snags because proximity of snags in clusters may provide concentrated foraging opportunities. If snags in clusters received more use, then we predicted

that clustered snags would have greater levels of cavity cover. Consequently, we expected the impact of foraging to result in greater external decay (Harmon et al., 1986; Jusino et al., 2016; Lorenz et al., 2015). Given that foraging is thought to influence snag decay, we also predicted that snag in clusters would have greater levels of breaking and bark loss from decay than scattered snags. The existing experimental study design (Chambers et al., 1997) and the availability of historic data provided an opportunity to assess long-term characteristics of individual created snags from over 25 years within managed forests.

## **Methods**

### Site description

CFIRP stands were located within Oregon State University's McDonald-Dunn Research Forest (123°15'W, 44°35'N) northwest of Corvallis, Oregon on the lower east slope of the Coast Range (Figure 2.1). Originally, 30 stands (5-18 ha) were selected that were dominated by Douglas-fir (*Pseudotsuga menziesii*) with two understory plant association types: hazel (*Corylus cornuta* var. *californica*)/brome (*Bromus vulgaris*) and vine maple (*Acer circinatum*)/salal (*Gaultheria shallon*; Franklin and Dyrness 1973). Stands had naturally regenerated since prior management. Stands were between 45 and 150 years old at the time treatments were applied, and stands were similar in plant species composition prior to harvest (Chambers, 1996). Prior to harvest, 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. At the time of our research, natural snag densities varied among treatments: group selection harvest: n=16

stands, 10.6 snags/ha (SE  $\pm$  1.9), two-story harvest: n=7 stands, 6.4snags/ha (SE  $\pm$  2.2), clearcut harvest: n=3 stands, 13.3 snags/ha (SE  $\pm$  5.1; Barry et al., unpublished data).

### Study design

Our study consisted of a randomized, complete block design with three study blocks (i.e. Lewisburg, Peavy, and Dunn). Each block was harvested in a separate year from 1989-1991 (Lewisburg: fall 1989, Peavy: 1990, Dunn summer 1991) and then planted the spring after harvest. Each block contained ten treatment stands, which were harvested and experienced snag creation. Stands within each block were first assigned to one of three silvicultural harvest treatments, and then to one of two created snag configurations; treatment and configuration assignments were applied randomly within each block. Harvest treatments included (1) a group selection treatment (i.e., 33% of the woody plant volume removed in 0.2 ha patches) (2) a two-story treatment (i.e., 75% of the woody plant volume removed uniformly) and (3) a clearcut treatment (i.e., all woody volume removed except for 1.25 live trees/ha retained). After harvest, all stands were replanted with Douglas-fir seedlings (625-865 trees per hectare depending on harvest treatment). All treatments received herbicide applications 2 to 5 years after harvest to control competing vegetation (Chambers et al., 1997).

At the time stands were harvested, snags were created in either a clustered configuration, with groups of 8-12 snags, or in a scattered configuration where snags were created uniformly throughout each stand. Mean density of created snags was equal in both configurations (3.8 snag/ha). Stands with snag clusters had 3-5 clusters and natural snags were left in clusters when available (Chambers et al., 1997). All snags were created by topping live Douglas-fir  $\geq$ 15 m in

height with a chainsaw at a mean height of 17 m and a mean DBH of 75 cm (range: 33-198 cm). Each snag was individually marked with an aluminum tag, allowing us to re-visit individual snags across points in time. Due to modification of treatments in some stands over time, a subset ( $n = 26$ ) of the original stands were available for our study (Table 2.1).

### Quantification of Snag characteristics

During January-March 2016, we revisited all individually marked created Douglas-fir snags ( $n = 731$ ) to assess their status (i.e., fallen or standing, hereafter persistence). From this total, 41 snags lacked covariate data needed for our models (see Statistical Methods below) which still left us with a large number of snags in our analyses ( $n=690$ ). We defined a snag as standing if the snag was at least 2.5 m in height. If a snag was standing, we also recorded whether it had broken along its bole. We classified a snag as broken by the appearance of a jagged or uneven top which contrasted sharply with the smooth, evenly cut top that was characteristic of snags at the time of creation.

Of the pool of snags that were still standing, we selected a random subset ( $n = 238$ ) to quantify additional snag characteristics. We used external characteristics to indicate level of decay and past use by cavity-nesting birds, and only one observer estimated all snag characteristic to minimize error due to sampling bias. Progression of decay was indicated by increasing amounts of breaking/falling and bark peeling and decreasing bark cover. Thus, we categorized bark peeling (i.e. whether a snag contained bark that was still covering, but was peeling away from  $\geq 1$  m<sup>2</sup> of the bole), and estimated bark cover (extent of bark covering the bole, to the nearest 5%) and cavity cover (extent of cavities on the bole, to the nearest 10%). For

the purposes of estimating bark cover, bark was considered missing only where it had sloughed away from the snag as a result of processes other than cavity formation (i.e. no cavities were present where bark was missing). To increase the accuracy of our cavity-cover estimates, we trained on cavity-cover estimation by calculating exact cavity-cover from photographs of snags overlaid with a cell grid before conducting field measurements. Because the origin of each cavity becomes difficult to ascertain with certainty over time, and cavities may be used for multiple ecologically relevant functions, we did not attempt to distinguish between foraging, nesting, and natural cavities (i.e. caused from limb loss or fungal decay), and therefore included all cavities into one estimate. This approach provides a relative estimate of use by wildlife, with greater amount of cavity-cover representing greater historic use of snags.

#### Comparison with historic data

Characteristic data were collected from our created snags (Appendix A) in 1990 and 1991, approximately three months after each block was harvested. Created snags were then revisited at four points in time (1995, 2001, 2008, and 2016 [this study]) to provide longitudinal assessment of snag characteristics (Chambers et al., 1997; Huff & Bailey, 2009; Walter & Maguire, 2005). To assess changes over time, we compared contemporary estimates of snag characteristics (i.e., persistence and bark peeling) to data from published reports (i.e. Chambers et al., 1997; Huff & Bailey, 2009; Walter & Maguire, 2005; hereafter, historic data). We note that historic data included individual cavities counted on each snag, but these measurements were difficult to obtain during contemporary surveys because decay in the intervening years

prevented a strict delineation of some individual cavities. Thus, we were unable to provide direct comparisons of historic and contemporary estimates of cavity cover.

### Statistical methods

We used a mixed linear modeling approach in the R (v3.3.1) statistical environment to quantify treatment and time-specific variation in snag characteristics. We constructed generalized linear mixed models with a binomial distribution and a logit link to examine snag persistence, proportion of snags broken, and bark peeling. All models included silvicultural treatment (3 levels: group selection, two-story, clearcut), snag configuration (2 levels: clustered, scattered), a treatment x configuration interaction, and study block as fixed effects; stand as a random effect; and initial DBH and slope as covariates. Initial DBH and slope were included in models because they are linked to snag persistence (Huff & Bailey, 2009). All models met assumptions for normality and equal variance, and no evidence of overdispersion was found.

We constructed linear mixed models to test for differences among estimates of mean bark cover and mean cavity cover among harvest treatments and snag configurations. All models met assumptions for normality and equal variance, and no evidence of overdispersion was found. We log transformed mean bark cover and mean cavity-cover to adhere with assumptions of normality and constant variance, and back-transformed results for interpretation.

To assess how snag characteristics have changed over time, we qualitatively compared historic data to data collected at the time of our study. We compared snag persistence, breaking, and bark cover across all 4 time periods. We also compared current estimates of bark peeling to estimates from 2001.

We used Tukey adjustments for all models with multiple comparisons. Covariates were set to their mean value, and we report least-squares marginal means (lsmeans) for effect sizes and their 95% confidence intervals (CIs).

## Results

### Contemporaneity characteristics of created snags

Across all treatments, 91% of snags were still standing  $\geq 25$  y after creation, and 65% of standing snags remained unbroken and were completely intact. The mean height of standing snags was 15.9 m (95% CI: 15.4, 16.5). Snags that had fallen were broken near their base, and none showed evidenced of having been uprooted.

We detected differences in created snag persistence among harvest treatments ( $X^2_2 = 7.12$ ,  $P = 0.03$ , Figure 2.2); the odds of a created snag remaining in the group selection treatment were 2.7 $\times$  greater (95% CI: 1.1, 6.4,  $z = 2.7$ ,  $P = 0.02$ ) than in the clearcut treatment. In contrast, we did not detect a difference in the odds of a created snag standing in the two-story treatment compared with either the group selection ( $z = 1.4$ ,  $P = 0.34$ ) or clearcut treatments ( $z = 1.1$ ,  $P = 0.52$ ) or between snag configurations ( $X^2_2 = 0.02$ ,  $P = 0.88$ , Figure 2.3).

Less than half of created snags were broken within each harvest treatment by the time of contemporary surveys (Figure 2.4), and the odds of a created snag being broken differed among harvest treatments ( $X^2_2 = 6.46$ ,  $P = 0.04$ ). The odds of a created snag being broken in the two-story treatment were 1.9 $\times$  greater (95% CI: 1.1, 3.2,  $z = 2.9$ ,  $P = 0.01$ ) than in the group selection treatment. We did not detect a difference in the odds of a created snag being broken between the

clearcut treatment and either the two-story ( $z = -2.0$ ,  $P = 0.11$ ) or the group selection treatments ( $z = 0.34$ ,  $P = 0.94$ ) or between snag configurations ( $X^2_2 = 0.09$ ,  $P = 0.77$ , Figure 2.5).

From the subset of created snags for which we quantified detailed snag characteristics ( $n = 238$ ), the treatments with greater harvest intensity that ultimately led to an open-canopy (i.e., two-story and clearcut) were more similar to each other compared to the low harvest intensity treatment that retained a closed canopy (i.e., group selection). Generally, created snags in the group selection treatment exhibited less external decay (i.e. bark peeling and bark loss) and had less evidence of historic use (i.e. cavity-cover) than snags in either the two-story or clearcut treatments (Table 2.2). Bark cover also had a higher range of variability in the two-story and clearcut treatments, whereas the group selection treatment did not have any snags with less than 50% bark cover (Figure 2.6). Cavity-cover had a higher range of variability in two-story and clearcut treatments compared with the group selection treatment, and never exceeded 60% in any treatment (Figure 2.7).

Over half (54%) of snags had bark that was peeling away from the bole, and bark peeling differed among harvest treatments ( $X^2_2 = 38.27$ ,  $P < 0.001$ ). The odds of a snag having peeling bark in the clearcut treatment were 14.5× greater (95% CI = 5.0, 41.8;  $z = 5.92$ ,  $P < 0.001$ ) than in the group selection treatment. The odds of a snag having peeling bark in the two-story treatment were 9.0× greater (95% CI: 3.1, 25.9,  $z = 4.86$ ;  $P < 0.001$ ) than in the group selection treatment. We did not detect a difference in the odds of a snag having peeling bark between clearcut and two-story treatments ( $z = 1.27$ ,  $P = 0.41$ ). Bark peeling also differed between snag configurations ( $X^2_2 = 5.90$ ,  $P = 0.02$ , Figure 2.8). The odds of a snag in a clustered configuration having peeling bark were 2.6× greater (95% CI: 1.2, 5.6,  $z = 2.54$ ;  $P = 0.01$ ) than in a scattered configuration.

We found that mean bark cover on all created snags was 82.4% (95% CI: 79.7, 85.1) and differed among harvest treatments ( $F_{(2,18)} = 28.35$ ,  $P < 0.001$ ). Mean bark cover in the group selection treatment was 1.4× greater (95% CI: 1.2, 1.6,  $t = 5.15$ ;  $P < 0.001$ ) than in the clearcut treatment and 1.2× greater (95% CI: 1.0, 1.4,  $t = 2.93$ ,  $P = 0.02$ ) than in the two-story treatment. We did not detect a difference in mean bark cover between two-story and clearcut stands ( $\beta = 1.1$ ,  $t = 2.01$ ,  $P = 0.08$ ). Mean bark cover estimates were similar among snag configurations ( $\beta = 1.1$ ,  $t = 1.67$ ,  $P = 0.15$ ).

All created snags contained cavities, and cavity-cover on created snags averaged 11.4% (95% CI: 10.2, 12.6). Mean cavity-cover on created snags differed among harvest treatments ( $F_{(2,18)} = 10.30$ ,  $P = 0.01$ ). Mean cavity-cover in the clearcut treatment was 1.4× greater (95% CI: 1.1, 1.9,  $t = 2.65$ ;  $P = 0.03$ ) than in the group selection treatment. Mean cavity-cover in the two-story treatment was 1.4× greater (95% CI: 1.0, 1.9,  $t = 2.46$ ;  $P = 0.04$ ) than in the group selection treatment. We did not detect a difference in mean cavity-cover between the two-story and clearcut treatment ( $\beta = 1.0$ ,  $t = -0.12$ ,  $P = 0.92$ ). Mean cavity-cover was similar among snag configurations ( $\beta = 1.1$ ,  $t = 0.44$ ,  $P = 0.68$ ).

### Comparison with historic data

Created snags had an increase in fall rate over time, with the greatest increase between 2008-2016. No snags fell within the first 4-6 y after creation, and by 2001 (10-12 years after creation) only a single snag (0.1%) had fallen. By 2008 (15-17 years after creation) there were only 4 snags (0.5%) that were considered fallen or broken off too low for nesting by cavity-nesting birds. By the time of our study (25-27 years after snag creation) the percentage of snags

that were broken below a useful height for birds increased to 9%. Furthermore, no snags broke within the first 4-6 y after creation, and only 1 snag broke by 2001. By 2008, the percentage of snags that were broken was still low (3.1%). The percentage of snags that had broken was greater in 2016 compared with 2008 with an increase to 35% of snags that had broken anywhere along the bole.

Additionally, decay characteristics have starting advancing in the second decade since snag creation. Bark peeling has increased from 8% of snags with bark peeling in 2001 to 54% of snags in 2016. Mean bark cover on snags remained high (97%) in 2001 and has now decreased to 82% across treatments. The number of snags that contain evidence of cavities has also increased since 2001, from 88% of snags to 100% in 2016.

## **Discussion**

Our study found that most topped Douglas-fir snags were standing  $\geq 25$  y after creation. The snags in our study were all large diameter ( $>50$ cm) and large diameter natural Douglas-fir trees have been shown to remain standing for  $>100$  y in the Oregon Coast Range (Cline et al., 1980). Douglas-fir trees may remain standing for longer than other tree species, in part because they have a higher ratio of heartwood to sapwood (Harmon et al., 1986; Kimmey & Furniss, 1943). Heartwood in Douglas-fir may not decay as quickly as sapwood because it has a higher resistance to fungi (Hallett et al., 2001; Harmon et al., 1986; Kimmey & Furniss, 1943). Furthermore, natural snags that lack tops may remain standing for longer than natural snags with tops (Morrison & Raphael, 1993). This suggests that topping trees to create snags may make them more resistant to falling than snags created via other methods (e.g. girdling or fungal

inoculation) which may help to explain why most of our snags were still standing  $\geq 25$  y after creation.

Although persistence of snags was high, we did find that harvest treatment, and to a lesser extent snag configuration, influenced contemporary characteristics of created snags. Greater levels of harvest intensity were linked with increased external decay characteristics on snags, and greater levels of use by cavity-nesting birds (i.e., cavity-cover). Previous surveys on the same sample of snags (Chambers et al., 1997; Walter & Maguire, 2005) showed similar patterns of avian use among treatments, with higher estimates of bird-mediated cavities and observations of use by cavity-nesting birds in the two-story and clearcut treatments compared with the group selection treatment. Snags in treatments with greater harvest intensity were subjected to open canopy conditions that may have historically provided better habitat for some woodpecker species, such as the Northern Flicker (*Colaptes auratus*), that prefer open canopy stands for nesting (Aitken et al., 2002; Elchuk, et al., 2003; Walter & Maguire, 2005; Warren et al., 2005). Snags created in open canopy treatments may have also initially provided better foraging resources than snags in group selection stands since some food sources. A recent study found that saproxylic beetle species richness was higher in dead wood in open forest plots compared with closed forest plots (Seibold et al., 2016). An increase in wood boring beetles in dead wood could attract species that forage on snags (i.e. woodpeckers), thus contributing the greater estimates of cavity cover we observed in more open stands (Harmon et al., 1986; Jusino et al., 2016; Lorenz et al., 2015).

Historic differences in use of created snags by cavity-nesting birds among harvest treatments may also have contributed to the contemporary differences in snag characteristics we

observed. Foraging and nesting by woodpeckers changes the structure of snags as they drill through large portions of bark and sapwood to find food and create nesting cavities (Bull et al., 1983). In the process of excavating, woodpeckers also directly expose heartwood to fungi and other decay organisms (Jusino et al. 2016). The role of cavity excavators in accelerating physical and biological snag decay through cavity formation could have contributed to the differences in created snag characteristics among silvicultural harvests  $\geq 25$  y after they were created.

Variation in surrounding vegetation and the density of trees in stands at the time of harvest snags were created may have also contributed to differences in snag characteristics. Surrounding vegetation and canopy densities influence microclimate conditions that could affect snag decay (Garber et al., 2005; Harmon et al., 1986). Mature forest canopy cover in the group selection treatment may have provided a more stable environment with reduced cycles of wetting and drying. In contrast, open canopy stands provide little buffer from saturation by rain and expose snags to more drying from sun and wind. These extremes between wet and dry cycles may result in higher levels of physical decay by causing more stress to wood cells, thus influencing bark detachment and sloughing from the bole of the snag (Harmon et al., 1986). Furthermore, tree density has been shown to be negatively correlated with snag longevity (Garber et al., 2005) and snags created in the two-story and clearcut treatment also had higher regenerating conifer densities in the most recent survey on these sites (Huff, 2008).

The minimal effect that we observed of snag configuration is consistent with other findings (Arnett et al., 2010; Chambers et al., 1997; Hane et al., 2012; Walter & Maguire, 2005), except for our estimates of bark integrity. Clustered snags may be more likely to attract beetles or decomposer organisms that accelerate decay and cause sapwood to break down more quickly

(Angers et al., 2012; Chamberlin, 1918; Seibold et al., 2016), contributing to a greater propensity for bark to peel away from created snags. More insects may also attract more foraging species, such as woodpeckers, that drill for prey (Li & Martin, 1991; Raphael & White, 1984), that would have a similar effect. We did not, however, detect any differences in cavity-cover or bark cover among configurations, so differences in bark integrity are likely due to other factors. To the best of our knowledge, there are no similar studies that compared created snag characteristics among different configurations, and this question warrants further exploration.

When historic data is considered (Chambers et al., 1997; Huff & Bailey, 2009; Walter & Maguire, 2005), it is evident that the rate of decay of snags across all harvest treatments was initially slow and increased in the second decade since creation. In the last eight years, breaking and bark peeling has substantially increased among all harvest treatments (Huff & Bailey, 2009). Bark loss and breaking are external characteristics that are typically indicative of more advanced stages of snag decay (Cline et al., 1980), and our findings match other studies of natural Douglas-fir snags in Western Oregon, which have described extensive breaking and bark loss when snags were between 19-50 years old (Cline et al., 1980). Although we were not able to assess changes in cavity-cover over time, current estimates of cavity cover did not exceed 60% which suggests there may be a threshold amount of cavity cover that a snag can have yet still remain standing. Given that snag persistence may be limited by cavity cover, and that the proportion of snags that have fallen has substantially increased since 2008 (Huff & Bailey, 2009), we suspect that cavities have continued to form on snags. Also, some cavities were difficult to delineate due to advanced decay and use, which provides further support that cavities are likely more abundant than they were during historic surveys (Walter and Maguire, 2005).

In our study, we used external snag characteristics, and not internal hardness, as an indicator of availability of habitat for birds. Due to the height and location of nest sites on snags, we were unable to measure hardness near nesting sites on snags, but some studies have found internal wood hardness to be the strongest predictor of bird use of snags for nesting and may not be accurately reflecting using external characteristics alone (Lorenz et al., 2015; Schepps et al., 1999). Our results also suggest that internal decay may not have been accurately reflected by some of our external decay indicators. Percent bark cover, for example, varied among treatments and yet a concurrent study (Barry et al., unpublished data) found that use of snags was low across all treatments and did not vary in accordance with predicted species preference based on external characteristics alone. Future studies should combine aspects of external snag characteristics with measurements of internal wood hardness to better understand the relationship between these variables and habitat quality.

### **Conclusions and management implications**

Although most of the snags we examined were still standing >25 y after creation, the increased rate of breaking and changes in snag characteristics that are associated with advanced decay suggests that the value of these snags for a wide array of wildlife that use snags in early stages of decay may vary among treatments and may begin to decline through time. Nevertheless, some species that use snags in later stages of decay, such as cavity-nesting birds that are weak excavators, may benefit from older created snags in harvested stands (Barry et al., unpublished data). Harvest treatment may also be an important consideration when evaluating the longevity of created Douglas-fir snags because we found that snags that were created in

treatments with greater harvest intensity exhibited greater signs of decay and greater use by birds over time. In contrast, after 25-27 y, snags created under a mature forest matrix were more likely to be standing, and less likely to be broken than snags in treatments with greater harvest intensity. Snags created under a mature forest matrix may represent important long-term structures that can be used for a longer period than snags created in the open. If management for biodiversity is a goal of snag creation, then retaining or creating a variety of age classes of snags on the landscape would support species that depend on different stages in snag decay for nesting or foraging.

Figure 2.1. Map of study location and designation of blocks and stands for the CFIRP within the McDonald Dunn Research Forest, Corvallis, OR (Walter & Maguire, 2005).

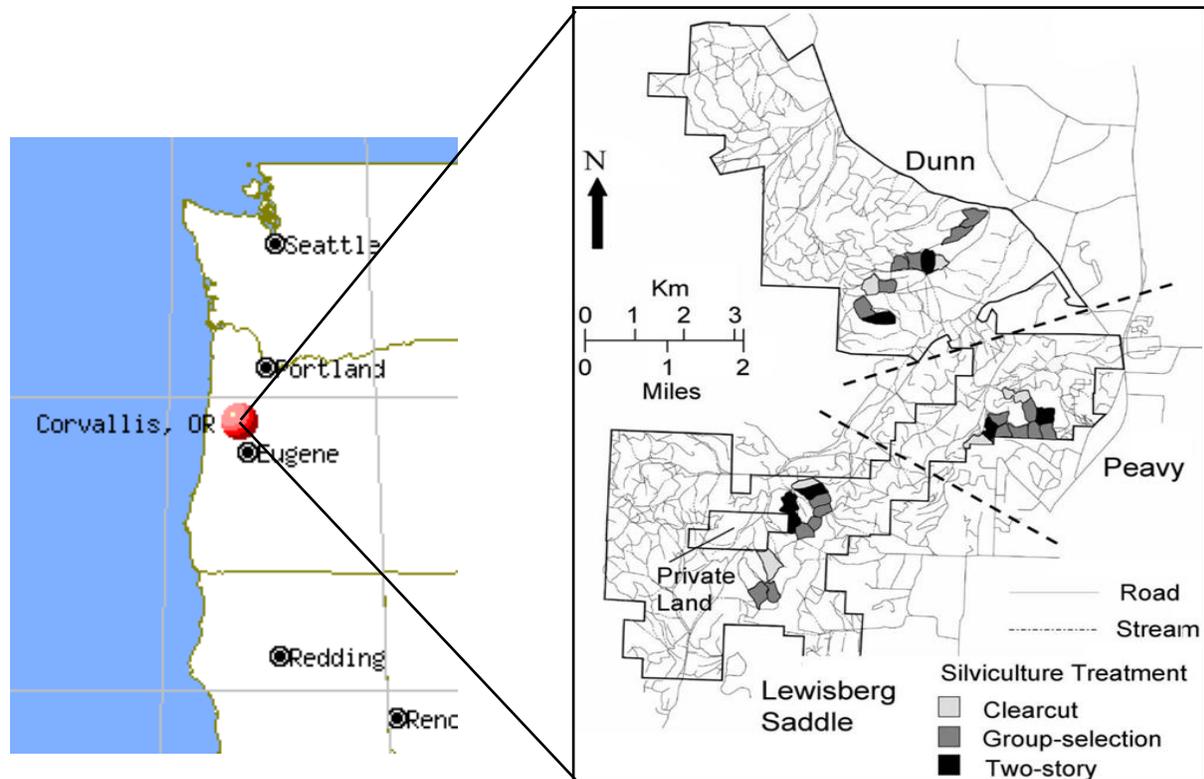


Figure 2.2. Mean proportion (95% CI) of created snags that were standing within each treatment in 25-27 y after creation. Point estimates not sharing the same letter represent means that statistically significant at  $P=0.05$ .

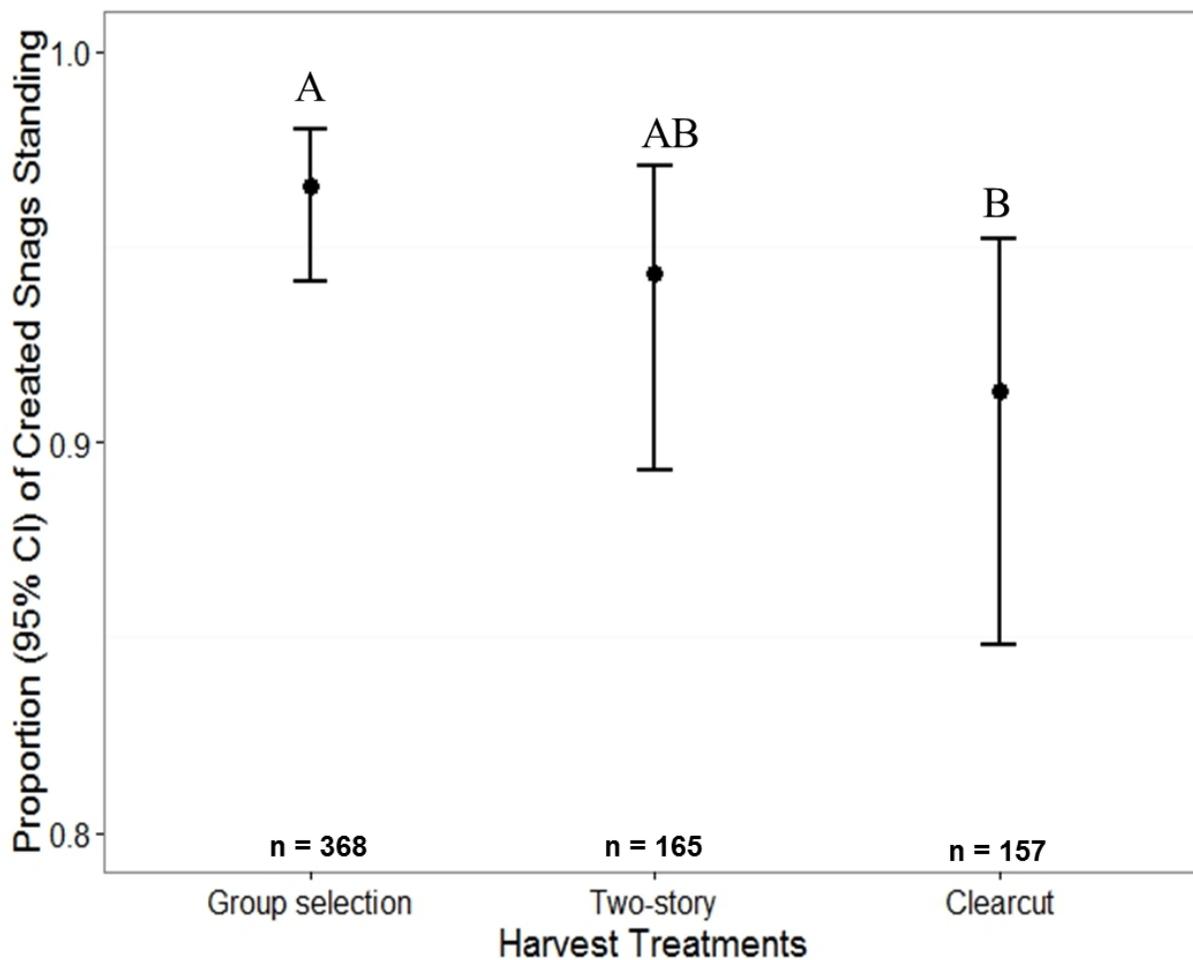


Figure 2.3. Mean proportion (95% CI) of created snags that were standing within each configuration 25-27 y after creation. Point estimates not sharing the same letter represent means that statistically significant at  $P=0.05$ .

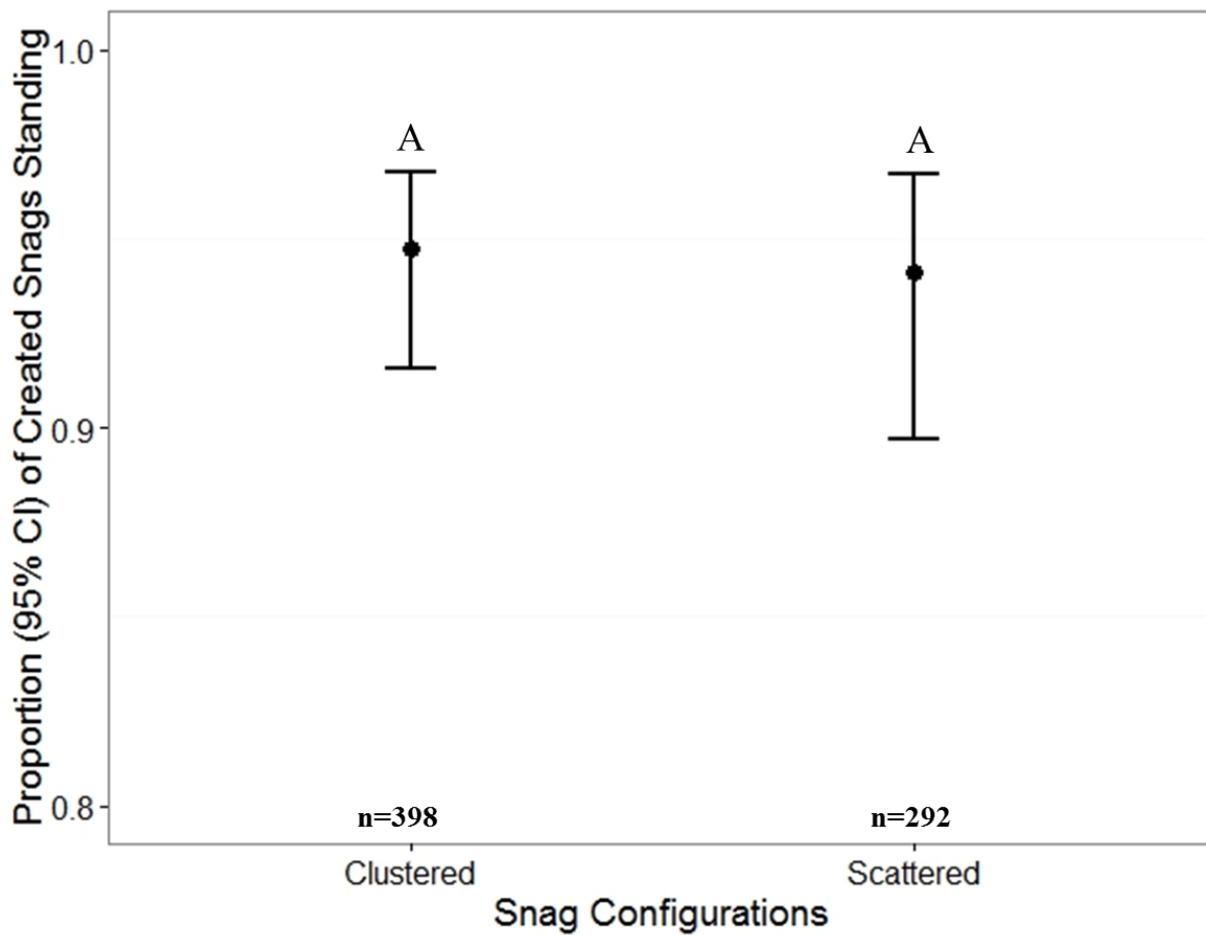


Figure 2.4. Mean proportion (95% CI) of created snags that were broken within each treatment 25-27 y after creation. Point estimates not sharing the same letter represent means that statistically significant at  $P=0.05$ .

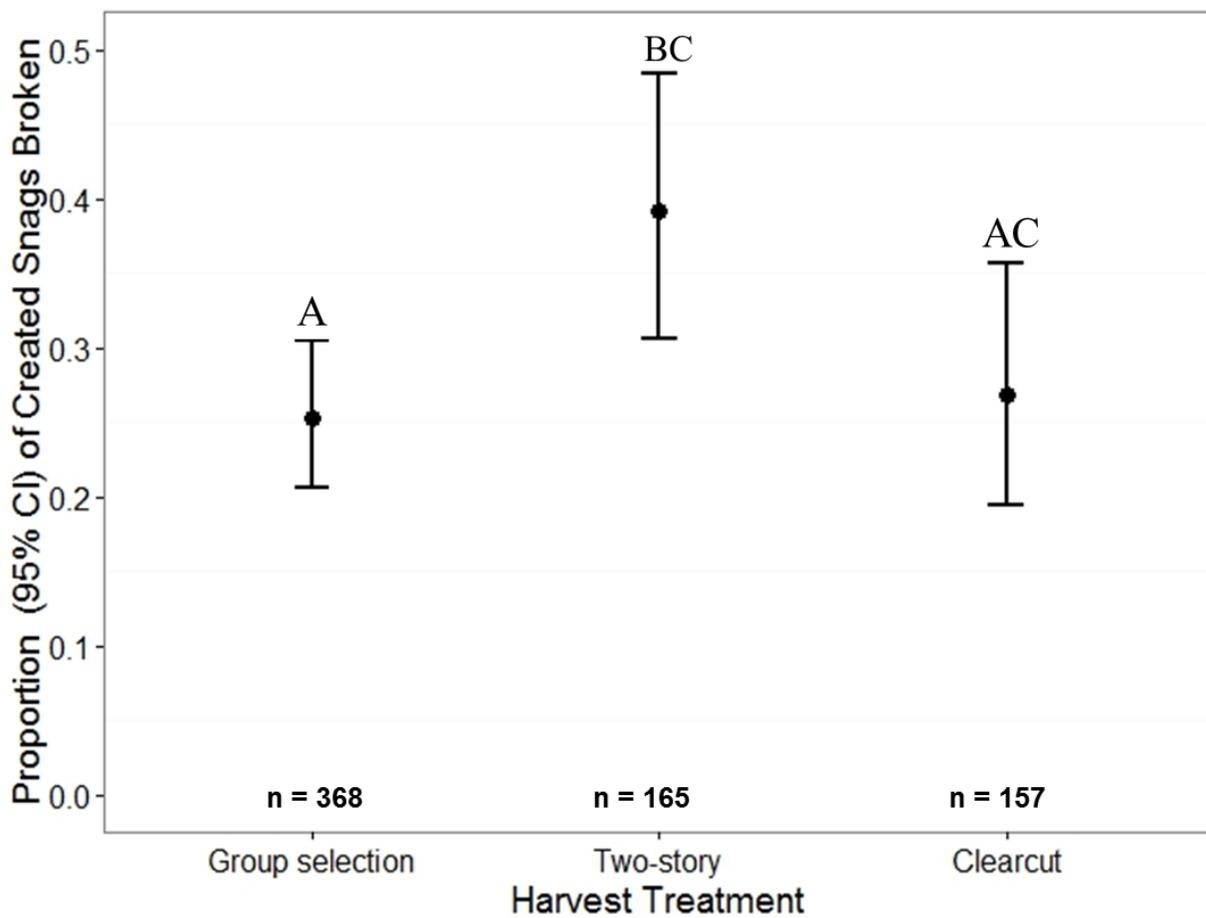


Figure 2.5. Mean proportion (95% CI) of created snags that were broken within each configuration 25-27 y after creation. Point estimates not sharing the same letter represent means that statistically significant at  $P=0.05$ .

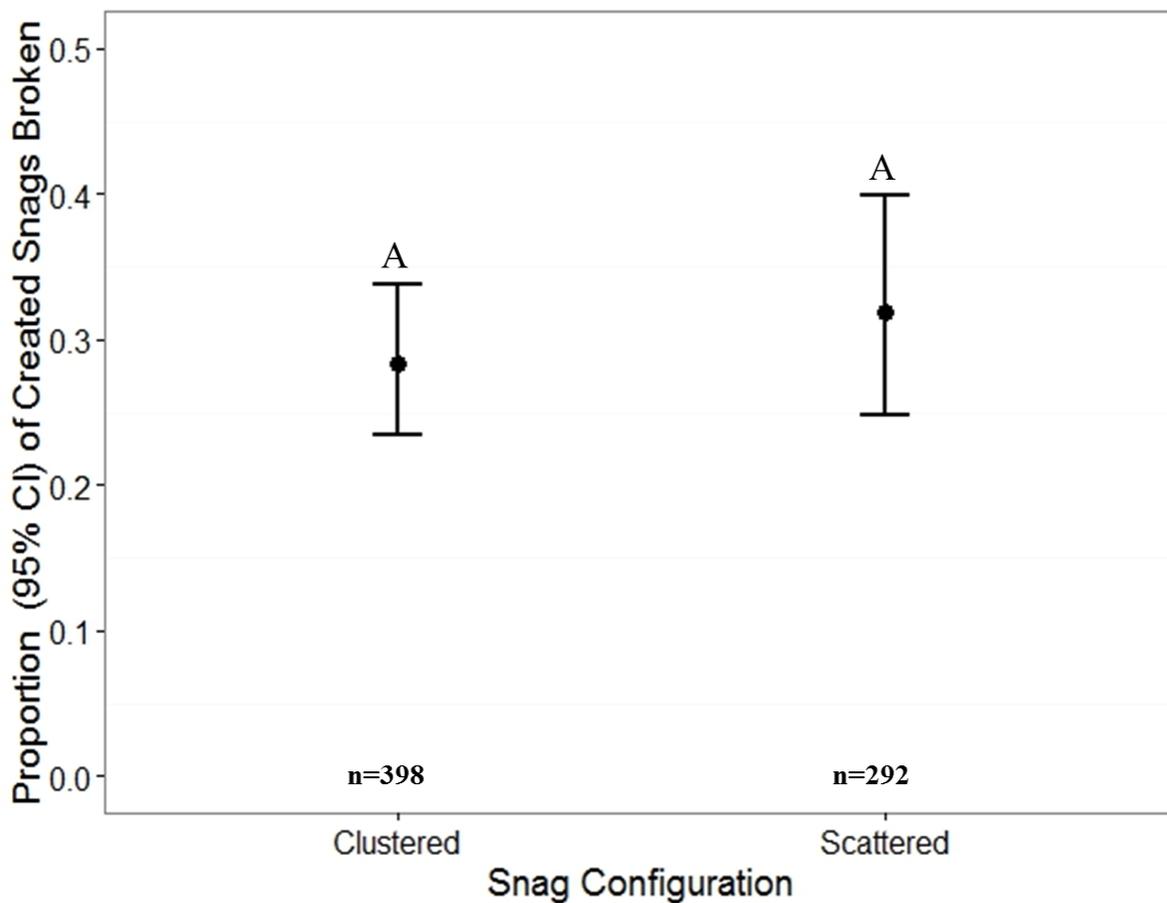


Figure 2.6. Distribution of bark cover on snags created in different silvicultural treatments.

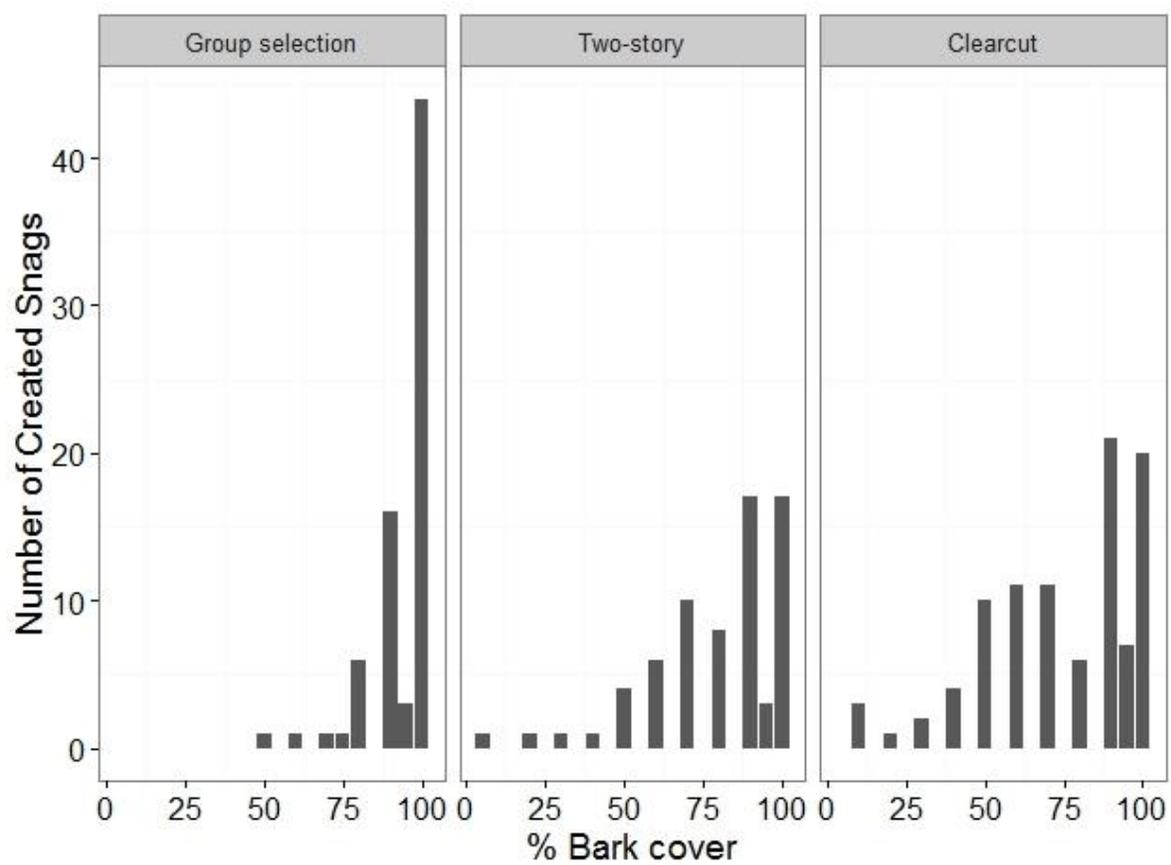


Figure 2.7. Distribution of cavity cover (%) on created snags among three harvest treatments 25-27 y after snag creation.

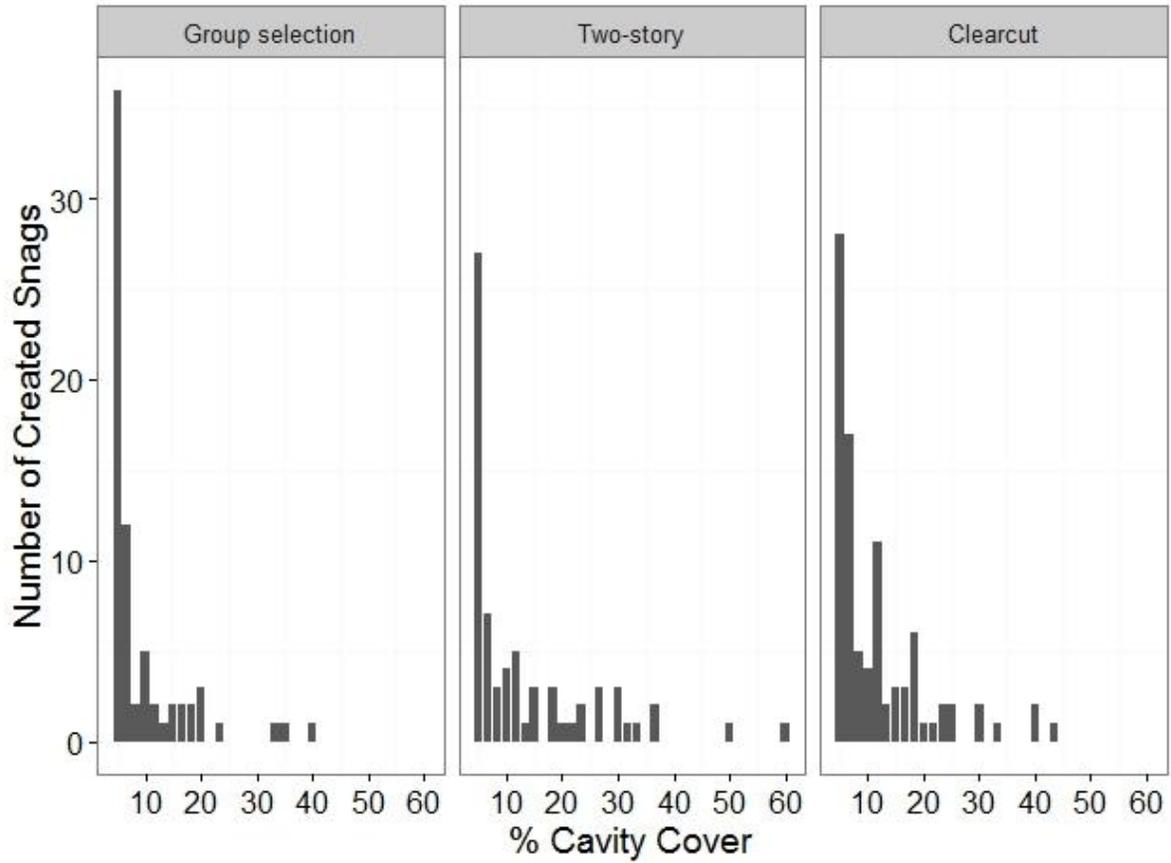


Figure 2.8: Mean proportion (95% CI) of created snags with peeling bark within each configuration 25-27 y after creation. Point estimates not sharing the same letter represent means that statistically significant at  $P=0.05$ .

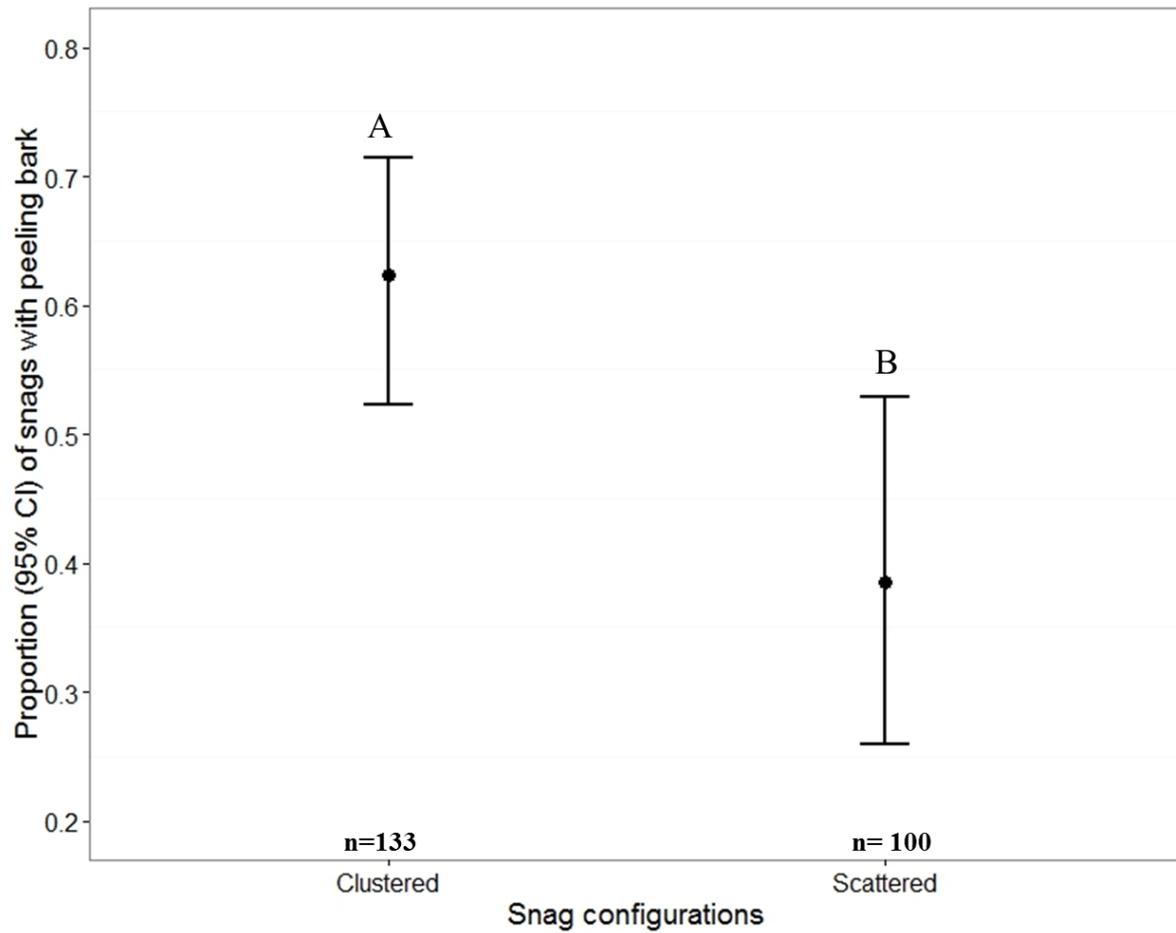


Table 2.1. Number of stands with each treatment combination (harvest treatment/snag configuration) in each block in 2016.

<b>Treatment combination</b>	<b>Block</b>		
	<i>Lewisburg</i>	<i>Peavy</i>	<i>Dunn</i>
Group selection/clustered	2	3	3
Group selection/scattered	2	3	3
Two-story/clustered	1	1	1
Two-story/scattered	0	1	1
Clearcut/clustered	1	1	1
Clearcut/scattered	0	1	1

Table 2.2. Snag characteristic measurements for snag subset (n = 238) among silvicultural harvest treatments in CFIRP stands in 2016.

<b>Silvicultural harvest treatment</b>	<b># snags</b>	<b>Mean cavity cover (<math>\pm</math> SE)</b>	<b>Mean bark cover (<math>\pm</math> SE)</b>	<b>Proportion of snags with peeling bark (<math>\pm</math> SE)</b>
<i>Group Selection</i>	73	9.8 ( $\pm$ 0.11)	99.1% ( $\pm$ 0.06)	0.17 ( $\pm$ 0.05)
<i>Two-story</i>	69	13.7 ( $\pm$ 0.13)	81.1% ( $\pm$ 0.06)	0.64 ( $\pm$ 0.06)
<i>Clearcut</i>	96	13.9 ( $\pm$ 0.13)	71.1% ( $\pm$ 0.06)	0.74 ( $\pm$ 0.05)

## CHAPTER 3 – AVIAN USE OF INTENTIONALLY CREATED SNAGS ACROSS 25 YEARS IN MANAGED FORESTS

### Abstract

Snags are globally important habitat for forest species, so historic declines in snags are thought to have had a strong impact on biodiversity. Snags are often created to mitigate the historic loss of snags within managed forests, but information regarding the use of created snags by birds across long time periods (>20 years) is lacking and prevents a complete understanding of the ecological value of these habitat features through time. In this study, we quantified avian foraging and breeding use of snags created by topping mature Douglas-fir trees (*Pseudotsuga menziesii*) 25-27 years after their creation. We also examined whether different harvest treatments (i.e., group selection, two-story, and clearcut) and snag configurations (i.e., scattered and clustered) were linked to avian use. Finally, we compared current estimates of avian use to estimates from historic surveys to assess changes over time.

We observed 11% of snags were used for nesting across harvest treatments despite observing snags for >750 h throughout the course of two breeding seasons. Of seven cavity-nesting avian species detected regularly during surveys, only four species used created snags for nesting (n=36 nests), with 94% of these being a weak excavating specie: Chestnut-backed Chickadee (*Poecile rufescens*). Compared to historic surveys, use of snags for nesting has decreased in both proportion of snags used and species diversity. The proportion of strong excavators has declined from historic surveys from 23% to 3% over the last 19-20 y. Additionally, we observed foraging on created snags by nine avian species but the rate of foraging was low (0.05 observations/h), a decrease of 8× since 2001. Our results suggest that

≥25-year old created snags in managed forests provide limited opportunities for nesting and foraging by cavity-nesting birds, and that their use by these species has declined over time.

Key words: cavity-nesting birds, created snags, Douglas-fir, Oregon Coast Range, *Pseudotsuga menziesii*, silviculture, snag configuration, snag longevity

## Introduction

Standing dead trees, or snags, are created naturally through disturbances such as fire, wind damage, and disease (Morrison & Raphael, 1993; Rose et al., 2001). Snags are important ecological structures that provide habitat for nearly one-third of all forest-dwelling species throughout the world including fungi, insects, mammals, and birds (Newton, 1994; Thomas, 1979). Snags are especially important for cavity-nesting bird species because members of this group rely on them for both foraging and reproduction (Cooke & Hannon, 2012; Hallett et al., 2001; Hane et al., 2012; Walter & Maguire, 2005); indeed, snag availability is considered to be a limiting factor for sustaining cavity-nesting bird populations (Li & Martin, 1991; Schreiber et al., 1992). One group of cavity-nesting birds, the woodpeckers (family *Picidae*) serve as keystone species that create habitat for other species, including secondary cavity-nesters that are unable to create their own cavities (Bunnell, 2013). Furthermore, woodpeckers serve as indicators of forest health (Drever et al., 2008; Hane et al., 2012), so reductions in their populations has the potential to reduce biodiversity within forested ecosystems.

Despite being a critical resource for cavity-nesting birds, the abundance of snags on the landscape has been significantly reduced through anthropogenic activities (Kroll et al., 2012;

Lewis, 1998). In many regions, snags have been removed during timber harvest for their commercial value and to comply with safety regulations, resulting in a large reduction of snag abundance in second-growth forests, especially those subjected to intensive forest management practices (Cline et al., 1980; Hayes et al., 1997; Lewis, 1998; Spies & Franklin, 1988). Many studies have demonstrated that intensive forest management practices have reduced the abundance of snags in managed stands compared with unmanaged stands in early and late stages of succession (Cline et al., 1980; Swanson & Franklin, 1992; Wilhere, 2003). For example, experimental removal of snags from burned forest has been shown to decrease cavity-nesting bird density by as much as 77% (Raphael and White, 1984), with downstream consequences for the many organisms that depend of foraging and nesting activities of cavity-nesting birds for providing them with suitable habitat (Drever et al., 2008).

To counter the loss of snags, resource managers often create snags from live trees to mitigate the risk associated with leaving natural snags that are prone to falling during harvest operations. Created snags are intended to restore mature forest features in managed stands over time (McComb et al., 1993). Created snags have been generated from live trees in a variety of ways, including removal of the top part of the bole with explosives or a chainsaw, girdling in or around the base of the crown, or inoculating with fungi (Lewis, 1998). Created snags can also be produced in various distribution patterns, such as in clustered groups or scattered, to mimic variation in natural snag distribution patterns.

The ability of cavity-nesting birds to use snags in different decay stages as nesting or foraging sites is closely linked with life history traits (Bunnell, 2013; Martin et al., 2004). Primary cavity-nesting birds are species that create their own nesting cavities, typically

excavating breeding cavities within softened heartwood (Bunnell, 2013; Daily, 1993; Lorenz et al., 2015; Schepps et al., 1999). Strong excavators, such as many woodpecker species, have morphological features that make them well adapted to drilling nesting cavities and foraging for prey in wood (Spring, 1965) and have been shown to use recently dead trees or living trees with decay for nesting more often than entirely dead trees (Blanc and Martin, 2012). Many strong excavators are considered keystone species because they often abandon previous nesting sites to create a new cavity each season, providing critical resources for species that cannot create their own cavities but depend on them for nesting (Bunnell, 2013; Drever et al., 2008; Martin & Eadie, 1999). Weak excavators, such as chickadees (*Poecile*) and nuthatches (*Sitta*), are not well adapted to drilling and often glean or probe prey from wood and pick through softened wood to create nesting cavities. Secondary cavity-nesters cannot excavate their own cavities, and instead rely on natural cavities and those created by primary-cavity nesters (Martin & Eadie, 1999). This group includes niche nesting species such as Brown Creeper (*Certhia americana*), that nest under slabs of loose bark. Cavity-nesting bird species exhibit considerable variation in selection for snag characteristics such as wood hardness, height, diameter, and bark cover (Schepps et al., 1999; Schreiber & DeCalesta, 1992).

Snag decay is influenced in part by environmental conditions, such as changes brought about by both residual tree densities and vegetation cover as stands regenerate over time (Harmon et al., 1986; Huff & Bailey, 2009). Snags created under different types of silvicultural harvest and configurations may vary their suitability due to decay related factors. In fact, our previous work found that external decay and rates of falling and breaking of created snags increased with the amount of basal area removed on stands during timber harvest (Barry et al.,

unpublished data). Snags created in different configurations may also influence avian use by providing different foraging substrates and nest sites. For example, snags created in clusters may provide concentrated foraging opportunities, but if occupied by territorial woodpeckers, clustered snags may also exclude other species from using those structures (Li, Pingjun; Martin, 1991; Raphael & White, 1984). Therefore, both harvest type and snag configuration are important considerations when creating snags to replace natural snags that have been lost due to harvest.

In contemporary forest management, the creation of snags is a widespread practice and there are many studies that have examined avian use of created snags  $\leq 10$  years after creation (Arnett et al., 2010; Chambers et al., 1997; Russell, et al., 2006; Schreiber et al., 1992; Walter & Maguire, 2005). However, long-term studies, especially those that examine the impact of varying harvest treatments on created snag use over time, are absent from the literature. This knowledge gap is important because as created snags go through the process of decay, they change in habitat quality and suitability for cavity-nesting bird species (Blanc & Martin, 2012; Edworthy & Martin, 2014; Lorenz et al., 2015; Schepps et al., 1999). Moreover, harvest intensity influence environmental conditions that in turn impact snag decay and use of snags by birds. Given their importance to forest communities (Drever et al., 2008), it is critical to understanding the long-term ecological value of created snags.

In this study, we used a long-term silvicultural experiment, to investigate use of created snags by foraging and nesting birds 25-27 y after their creation. Snags were intentionally created in two different spatial configurations (i.e., clustered, scattered) and were subjected to one of three harvest treatments (i.e., group selection, two-story regeneration, and clearcut) representing variations in harvest intensity (Chambers et al., 1997). Within this framework, our objectives

were to (1) compare contemporary use of created snags by cavity-nesting birds among silvicultural harvest treatments and snag configurations and (2) compare current-day use of created snags to historic data to assess long-term changes in use. We did this by re-visiting individual snags that were previously surveyed at 2 distinct points in time (1996, when snags were 5-7 y old and 2001, when snags were 10-12 y old) and quantifying foraging and breeding activities. These data are the first to provide information about the use of created snags in managed forests under different silvicultural harvests and snag configurations over 25-27 y.

Given that harvest treatments are thought to influence snag decay (Barry et al., unpublished data), we hypothesized that species using snags for nesting and foraging would differ among treatments that reflected different harvest intensities, and would be correlated with their excavating ability and foraging strategy. If species use varied among harvest treatments and was due to snag decay, then we predicted that more strong excavating species would use snags in the treatment with lower decay of snags that was subjected to lower harvest intensity (i.e., group selection) and weak excavating and secondary cavity users would use snags in treatments with greater decay of snags that were subjected to greater harvest intensity (i.e., two-story and clearcut). We also hypothesized that species use of different snag configurations would be lower in clustered snags because they are thought to be defendable resources (Li & Martin, 1991; Raphael & White, 1984). If species use of created snags was lower in clustered snags, then we predicted that we would see less nesting and foraging on snags in clusters compared with scattered snags. Since snags across treatments have substantially decayed since the most recent avian surveys (Barry et al., unpublished data), we hypothesized that there would be greater abundance of nests from species that rely on softened wood for creating nest sites (i.e., primary

cavity-nesters). We predicted that there would be a greater representation of strong and weak excavating species currently using snags for nesting when compared with historic data.

## **Methods**

### Site Description

CFIRP stands were located within Oregon State University's McDonald-Dunn Research Forest (123°15'W, 44°35'N) northwest of Corvallis, Oregon on the lower east slope of the Coast Range (Figure 2.1). Stands were dominated by Douglas-fir (*Pseudotsuga menziesii*) with two understory plant association types: hazel (*Corylus cornuta* var. *californica*)/brome (*Bromus vulgaris*) and vine maple (*Acer circinatum*)/salal (*Gaultheria shallon*; Franklin and Dyrness 1973). Stands had naturally regenerated since prior management. Stands were between 45 and 150 years old at the time treatments were applied, and stands were similar in plant species composition prior to harvest (Chambers, 1996). Prior to harvest, 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.

### Experimental Design

Our study consisted of a randomized, complete block design with three study blocks (i.e. Lewisburg, Peavy, and Dunn). Each block was harvested in a separate year from 1989-1991 (Lewisburg: fall 1989, Peavy: 1990, Dunn summer 1991) and then replanted the spring after harvest. Each block contained ten treatment stands that were between 5-18 ha in size; each was harvested and experienced snag creation. Within each block, each stand was first assigned to one

of three silvicultural harvest treatments, and then to one of two created snag configurations; treatment and configuration assignments were applied randomly within each block. Harvest treatments included (1) a group selection treatment (i.e., 33% of the woody plant volume removed in 0.2 ha patches) (2) a two-story treatment (i.e., 75% of the woody plant volume removed uniformly) and (3) a clearcut treatment (i.e., all woody volume removed except for 1.25 live trees/ha retained). After harvest, all stands were replanted with Douglas-fir seedlings (625-865 trees per hectare depending on harvest treatment). All treatments received herbicide applications 2 to 5 years after harvest to control competing vegetation (Chambers et al., 1997).

At the time stands were harvested, snags were created in either a clustered configuration, with groups of 8-12 snags, or in a scattered configuration where snags were created uniformly throughout each stand. Mean density of created snags was equal in both configurations (3.8 snag/ha). Stands with snag clusters had 3-5 clusters and natural snags were left in clusters when available (Chambers et al., 1997). All snags were created by topping live Douglas-fir  $\geq 15$  m in height with a chainsaw at a mean height of 17 m and a mean DBH of 75 cm (range: 33-198 cm). Each snag was individually marked with an aluminum tag, allowing us to re-visit individual snags across points in time. Due to modification of treatments in some stands over time, a subset ( $n = 26$ ) of the original stands were available for our study (Table 3.1).

#### Observations of avian use of snag

During the 2015-2016 breeding seasons (mid-April through June) we conducted focal observations on a randomly selected group of created snags. We only selected created snags that were still standing trees and  $\geq 2.5$  m tall and selected snags were distributed evenly among the

three harvest treatments. In 2015 we surveyed 136 created snags; in 2016, we resurveyed the same group of snags but surveyed at 68 additional snags to increase our sample by approximately 50% ( $n = 204$ ). We conducted focal observations on each snag once per week during the 9-10 wk local breeding season for cavity-nesting birds. Our observations took place throughout the day (07:00 to 16:00) because cavity-nesting birds are active throughout the day, and we purposefully varied the time of day that each snag was surveyed in each successive visit. We split our 15-min focal observation period evenly between two locations around each snag (7.5-min per side). We selected viewing locations to optimize visibility of the entire snag between the two locations. Most locations were at least 10 m from the snag to minimize disturbance to birds, except when dense vegetation inhibited visibility, in which case only one location or a closer distance was used for the entire survey. Focal observations were paused or canceled on rare occasions if rain was heavy enough to interfere with bird detection or activity, but otherwise took place.

During observation periods, we recorded all avian activities observed using focal snags; this included nesting, foraging, and other (e.g. perching or vocalization). Nesting activities included excavating a cavity, or entering a cavity with food and/or nesting material. Foraging activity included gleaning insects from the bark and drilling for prey on the snag. Given that the incubation bouts of cavity-nesting birds may be >15 min, observers scratched at the base of each snag with a stick in an attempt to flush any birds that may have been present but were not observed (i.e. birds incubating eggs in cavities) at the end of each observation period. For active nests located during focal observations, we determined nest stage based on observations of adult behavior around the nest site (i.e. adults carrying food into the cavity) or by auditory detections

of nestling begging vocalizations, and we quantified the cavity orientation and height using a compass, clinometer, and range finder.

### Avian Point Counts and Call-Playback Surveys

During the 2016 avian breeding season (May-July), we conducted point count and call-playback surveys from dawn until 10:00 to quantify occupancy by primary cavity-nesters. Point count stations were positioned randomly in each stand under the constraints that they had to be  $\geq 100$  m from stand edges and  $\geq 250$  m from other point count sampling locations to avoid double-counting birds. Point counts followed the protocol of Ralph et al. 1995 and consisted of a 10-min aural and visual count period.

Immediately following each point count survey, we conducted a 5-min call-playback survey with a portable playback unit to increase detection of primary cavity-nesting species (Kumar & Singh, 2010) thought present on stands based on historical data (Chambers et al., 1997): Downy Woodpecker (*Picoides pubescens*), Hairy Woodpecker (*Leuconotopicus villosus*), Red-breasted Sapsucker (*Sphyrapicus ruber*), Northern Flicker (*Colaptes auratus*), and Pileated Woodpecker (*Dryocopus pileatus*). Our surveys consisted of a 30-sec vocalization followed by a 30-sec listening interval; vocalizations were recorded from individuals in the Pacific Northwest region of North America and included both a call and a territorial drumming.

For both point counts and call-playback surveys, distances to birds were estimated to the nearest 10 m up to 100 m from the observer. We visited each location five times throughout the breeding season to account for seasonal variation in breeding phenology. We did not conduct surveys during inclement weather, defined as heavy rain and/or wind speeds  $>30$  km/h. We

recorded all birds during point counts, however we only report occupancy for cavity-nesting species for the purposes of analysis (see Appendix B for occupancy of all species).

### Natural Snag Surveys

From mid-June-July 2016, we used belt transects (40 x 100 m) to estimate the density of natural snags in all stands. Transects were centered on point count stations, with the azimuth of each transect selected randomly. We walked the full length of the transect (100m) while counting each natural snag with at least  $\frac{1}{2}$  of basal stem located within 20 m on either side of the transect. We defined a natural snag as entirely dead, standing trees at least 2.5 m tall that were not created via silvicultural practices. For each natural snag we recorded the tree species, diameter at breast height (DBH), total height (to the highest point on the snag), decay class (following Cline et al., 1980), tree species, and whether or not cavities were present.

### Comparison with historic data

In addition to our contemporary surveys (2016-2016), we also used estimates of historic avian use in 1996 and 2001 (Chambers et al., 1997; Walter & Maguire, 2005) to assess changes in use of snags over time. We used historic specifically to assess differences in species composition and abundance over time. We compared densities of natural snags between time periods to assess the effect of harvest treatment on rates of natural snag recruitment. Our methods differed from methods used by previous investigators in that we intensively sampled a subset of created snags to provide a more accurate estimate of use of individual snags. We

increased the number of visits to each individual snag, and the amount of time that was spent at each snag, resulting in  $\sim 3\times$  as many hours of overall effort.

### Statistical analysis

We used a mixed linear modeling approach in the R (v3.3.1) statistical environment to quantify 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 among harvest treatments (3 levels: group selection, two-story, clearcut) and two snag configurations (2 levels: clustered, scattered). Our models included harvest treatment, snag configuration, a treatment x configuration interaction, and study block as fixed effects; stand as a random effect. All models met assumptions for normality and equal variance, and no evidence of overdispersion was found.

Naïve occupancy (the proportion of points at which each species was detected) for all avian species was calculated using point count data, except for woodpecker species. Occupancy for woodpecker species was calculated using call-playback data only because it provides a more accurate estimate of presence or absence than using point count data alone (Kumar & Singh, 2010).

We qualitatively compared the proportion of snags used for nesting between 2001 and 2015/2016. The number of nests found and birds observed foraging is a function of sampling effort, which varied across studies. Specifically, our study encompassed multiple years whereas previous studies did not, so we compared proportion of snags used for nesting by summing the

total number of snags over both years, thus resulting in a sample sizes of 340 snags observed across in 2015-2016. We compared effort between studies by quantifying the total number of hours each snag was monitored. For snags monitored in successive years, we summed the number of hours of observation time spent at each snag, resulting in a total of 210 hours of observation in 2001 and >750 hours of observation in 2015-2016.

For all models, we report least-squares marginal means (lsmeans) for effect sizes and their 95% confidence intervals (CIs); significance levels for all tests were set at  $P < 0.05$ .

## Results

### Contemporary avian use of created snags for nesting

Across both nesting seasons, 11% of created snags contained active nests. We detected 36 nests belonging to four forest species: Chestnut-backed Chickadee (*Poecile rufescens*, n=32 nests), Red-breasted Nuthatch (*Sitta canadensis*, n=2 nests), Red-breasted Sapsucker (n=1 nest), and Northern Flicker (n=1 nest). We also detected 17 additional nests work in created snags that were not part of our random sample during regular field work: Chestnut-backed Chickadee (n=12), Northern Flicker (n=2 nest), Red-breasted Sapsucker (n=1), Red-breasted Nuthatch (n=1) and Northern Pygmy Owl (*Glaucidium gnoma*, n=1). In 2015, 9.6% of snags were used for nesting and we detected nests belonging to two forest species: Chestnut-backed Chickadee (n=12) and Red-breasted Nuthatch, (n=1). With a 50% increase to our sample size in 2016, we detected a slightly higher percentage of snags used for nesting (11.5%). We also detected a single nest of each of two additional woodpecker species: Red-breasted Sapsucker and Northern Flicker. All but one (i.e., 97%) of the nests we monitored appeared to successfully produced

offspring, with the exception being a Chestnut-backed Chickadee nest in 2016. All snags used for nesting contained only one active nest during both nesting seasons with only 2 exceptions. One snag was re-used for nesting by the same species (Chestnut-backed Chickadee) in consecutive years. One snag was used in 2016 for nesting by both a Chestnut-backed Chickadee and a Red-breasted Sapsucker simultaneously.

We were unable to detect a difference in contemporary use of snags for nesting among silvicultural harvest treatments ( $X_2^2 = 1.94$ ,  $P = 0.34$ ) or between clustered and scattered snags ( $X_2^2 = 0.1$ ,  $P = 0.82$ ), which was likely due to the low number of nests detected. Nevertheless, the greatest number of nests and number of species were in the group selection treatment compared with the two-story and clearcut treatment (Table 3.2). We detected nests from three species (i.e., Chestnut-backed Chickadee, Red-breasted Nuthatch, and Northern Flicker) in the group selection treatment, one species (i.e., Chestnut-backed Chickadee) in the two-story treatment, and two species (i.e., Chestnut-backed Chickadee and Red-breasted Sapsucker) in the clearcut treatment. The number of nests and number of species was the same between the two snag configurations (Table 3.3).

#### Contemporary avian use of snags for foraging

Across both years, we observed nine avian species foraging on created snags on 41 separate occasions across all treatments and snag configurations (Table 3.4). We detected foraging on 11% of created snags during our focal observations, but foraging events were rare with a detection rate of 0.05 observations/h which equates to one observation of foraging activity for every 20 hours of snag observation. Most foraging observations were from Chestnut-

backed Chickadee (39%) and the Pileated Woodpecker (24%). We did not detect a difference in the proportion of snags that were used for foraging among harvest treatments ( $X_2^2=2.6$ ,  $P=0.27$ ) or snag configurations ( $X_2^2=0.1$ ,  $P=0.71$ ). However, we observed more foraging events in clearcut stands than in group selection and two-story stands (Table 3.4). Species richness of birds foraging on snags was highest in the group selection treatment (n=7) compared with the two-story (n=5) and clearcut treatment (n=4).

#### Naïve occupancy rates for cavity-nesting species

Eight cavity-nesting species were detected in stands during point count and call-playback surveys, three of which were detected in all harvest treatments (Chestnut-backed Chickadee, Red-breasted Nuthatch, and Brown Creeper). Red-breasted Sapsucker was the most commonly detected species and was present at over half (54%) of the survey locations (Table 3.5). Of species that were detected in stands, half were not observed nesting in created snags.

#### Comparison with historic avian use data

The proportion of snags being used for nesting decreased from 19.9% of created snags with active nest cavities in 2001 to 11% during our study. The number of species observed using snags for nesting also decreased by five species since 1996 and by four species since 2001 (Table 3.4). The majority of nests (94%) were occupied by weak excavating species in 2015/2016 and the proportion of nests that were occupied by strong excavators and secondary cavity-nesters has continued to decline over time (Table 3.4). Secondary-cavity nesting species have all proportionally decreased in nesting over time, except for European Starling (*Sturnus vulgaris*), a

non-native, open-canopy species, which showed a marked increase from 1996 to 2001 (Table 3.4).

Rate of foraging decreased from 0.40/h in 2001 to 0.05/h in 2015/2016, an 8-fold decrease over the past 15 years. Species richness was relatively similar over time; 11 avian species were observed using snags for foraging or nesting in 2001, whereas we observed 9 species during contemporary surveys, including one non-cavity-nesting species not detected during the 2001 surveys (Dark-eyed Junco [*Junco hyemalis*]).

#### Availability and characteristics of natural vs. created snags

The majority (64%) of natural snags were also Douglas-fir with the rest being Oregon white oak (*Quercus garryana*) and big-leaf maple (*Acer macrophyllum*). Mean density of created snags was the same across all treatments at the time of creation (3.8 snags/ha) and few (n=67) snags had fallen across all treatments thus variation in the number of snags was due exclusively to the recruitment of natural snags since harvest. Natural snags had a mean density of 9.8 (95% CI: 6.8, 12.8) snags/ha across all harvest treatments. Although densities of natural snags in treatments were higher than densities of created snags, natural snags were shorter in both group selection and clearcut treatments (Figure 3.2) and were smaller in diameter in all treatments (Figure 3.3).

The clearcut treatment had the highest density of natural snags (13.3 [SE  $\pm$  5.1]) when compared to the group selection (10.6 snags/ha [SE  $\pm$  1.9]) and the two-story treatment (6.4 snags/ha [SE  $\pm$  2.2]). Natural snags in the clearcut treatment also had a smaller mean DBH than those in the group selection and two-story treatments (Figure 3.2).

Natural snags densities have substantially increased over the last 15y. Natural snag densities were 26.5x greater in the group selection treatment, 9.1x greater in the two-story treatment, and 66.5x greater in the clearcut treatment than in 2001 (Table 3.7).

## **Discussion**

We found that Douglas-fir snags created by topping experienced limited use by cavity-nesting birds 25-27 y after creation. We were unable to detect a difference in use of created snags among harvest treatments or created snag configurations, probably due to the low number of nests and foraging events that we observed. Other studies have found that avian use of snags created by topping is initially low, but increases with increasing created snag age and decay class until ~10 y post-creation (Arnett et al., 2010; Hallett et al., 2001). However, ours is the first study to extend beyond 20 y, and the advanced decay of snags in our study (Barry, 2017), appears to explain the reduction in use. Thus, snags created by topping begin to decline in their usefulness for a wide-array of cavity-nesting species as both nesting and foraging substrates sometime between 15-25 y after creation. Although natural snags may stand for 100 y or longer, it is unknown how long created snags may remain standing. Even if they stand for a fraction of the time of natural snags, it may be that the value of created snags to cavity-nesting birds is limited throughout much of the time that they are standing.

Although they were present on our study sites, strong excavator species were rarely detected using snags for nesting. We detected four species from this group (i.e. Pileated Woodpecker, Hairy Woodpecker, Red-breasted Sapsucker, Northern Flicker) in stands during surveys, indicating that they were present in stands during the breeding season and therefore

available to use created snags. A likely explanation for the lack of use of created snags for nesting by strong excavators is that they frequently nest in live trees or snags with less advanced decay than were present in our study (Blanc & Martin, 2012; Robles et al., 2007; Schreiber et al., 1992; Spiering & Knight, 2005). In contrast, nearly all of active nests that we detected were from the Chestnut-backed Chickadee, a weak excavating species. Chestnut-backed Chickadee will use snags with more advanced decay for nesting (Martin et al., 2004), and unlike other cavity-excavating species, Chestnut-backed Chickadees may nest in entirely dead nest trees with broken tops more often than live, diseased trees (Mahon et al., 2007). The majority (54%) of created snags in our study showed signs of advanced decay, such as breaking or bark loss (Barry et al., unpublished data), and the ability of chickadees to utilize snags in later stages of decay may have contributed to the high proportion of nests of this species that we detected.

The number of secondary-cavity nesting species using snags also declined relative to historic surveys. Although snag characteristics, especially the degree of decay (Lorenz et al., 2015), may limit use by most cavity-excavating species, changes in vegetation in stands may have contributed to the reduction in secondary-cavity nesters that we observed using snags. Most of the secondary-cavity nesting species using snags during historic surveys were open-canopy associated species (e.g., swallow, starling, house wren, bluebird; Maguire et al., 2005; Walter & Maguire, 2005). Furthermore, the only species from this group (i.e., house wren) that we detected during point counts (Appendix B) was detected along road sides or in areas where disturbance created a canopy opening. Thus, the vast majority of the habitat on our study sites is now unsuitable for these species because regeneration of planted conifers in two-story and clearcut stands has created dense cover of tall vegetation surrounding created snags.

In addition to snags in our study providing poor nesting resources for most avian species, they also were likely to have limited food resources. Many strong excavators rely on wood and bark boring insects and beetles for food, and these insects are generally most abundant following disturbance and within  $\leq 3$  years of tree death (Angers et al., 2012; Farris, 2002; Hanks, 1999; Harmon et al., 1986). The contemporary condition of our created snags has moved beyond the stage at which most insect activity is expected. Pileated Woodpecker and Chestnut-backed chickadee were the most commonly detected species foraging on snags. Pileated Woodpeckers may have been foraging on snags because carpenter ants, their key food source, are often present in wood with greater levels of decay (Flemming et al., 1999). Chestnut-backed Chickadee forage by gleaning insects from the bark and branches of trees rather than drilling through wood, which may have increased the opportunity to find insects on snags (Bunnell, 2013; Mahon et al., 2007). Overall, foraging detections were rare (0.05/hr), and opportunities for foraging were limited on snags  $\geq 25$  y old created snags.

Densities of natural snags were 2-4  $\times$  higher than densities of created snags, and appear to have provided alternate nest sites for cavity-dependent species that were present in stands but not observed nesting in created snags. Suppression of young conifers and hardwoods by other conifers in densely planted clearcut and two-story stands, along with natural snag formation in mature group selection stand most likely contributed to new snag recruitment over time. Although they were considerably smaller in diameter than created snags, they were used for nesting by three strong excavating species, Hairy Woodpecker (n=3), Red-breasted Sapsucker (n=3), and Northern Flicker (n=1). This is noteworthy, especially given that we had no detections of nesting or foraging activities by the Hairy Woodpecker on any created snags, yet this species

was present in previous studies on the same sample of snags (Walter and Maguire, 2005).

Younger snags with less decay, or living trees with heart rot, may provide a more important resource for strong excavating species because they provide more supportive structures for large cavities (Blanc & Martin, 2012; Lorenz et al., 2015). In addition to more supportive cavities, living trees may also provide better insulation for nests than entirely dead trees because the former have less extreme temperature fluctuations (Wiebe, 2001), which can have important implications for growth and development of altricial young. This pattern is evident in our study through the reduction of nests occupied by strong excavator species as created snags have decayed over time.

Although we observed a substantial decrease in the use of snag by cavity-nesting birds, snags in later stages of decay can still provide important habitat for other forest wildlife species for nesting, roosting, and/or storing food (Fabianek et al., 2015; Meyer et al., 2005). We incidentally detected 7 non-avian species (3 mammals, 2 amphibians, and 2 mollusks) using snags on multiple occasions. The Douglas squirrel (*Tamiasciurus douglasii*) was the most commonly detected non-avian species using snags, having been observed on 24 occasions. In particular, the presence of large diameter, older created snags may be important for forest mammal species such as flying-squirrels and bats (Chambers et al., 2002; Fabianek et al., 2015; Meyer et al., 2005). Furthermore, we conducted surveys during the avian breeding season, so could not assess the use of snags as winter roosting habitat. Created snags in later stages of decay may provide winter roost sites for woodpeckers (Covert-bratland et al., 2007; Paclík & Weidinger, 2007). Created snags may also provide nesting sites for more species of secondary-cavity nesters, which rely on existing cavities for nesting, if snags were under different forest

conditions (i.e. open-canopy; Martin et al., 2004). Furthermore, as bark begins to crumble and part of the snag bole break off, nutrients from the snag contribute to soil development. Downed wood also creates sheltering, nesting, and foraging habitat for a wide array of mammals, amphibians, birds, and insects (Angers et al., 2012; Harmon et al., 1986; Rose et al., 2001). Although use of created snags by cavity-nesting birds during the breeding season was low in our study, older snags still play an important role in long-term forest productivity as they decay over time.

### **Conclusions and management implications**

The limited contemporary use of snags by cavity-nesting birds we observed suggests that Douglas-fir snags created by topping may not retain characteristics needed by a diverse range of cavity-nesting bird species for foraging and nesting by  $\geq 25$  y after creation. Our study indicates that although snag diameter is often highlighted as an important characteristic for avian use (Schreiber & DeCalesta, 1992), snag decay can also exert a strong influence on use for some avian species. Managers should create or retaining large snags in a range of decay classes and snag ages on the landscape to support species that depend on different stages in snag decay for nesting or foraging. Retaining live trees or living trees with decay may also be important to provide resources for strong excavator species in particular (Blanc & Martin, 2012; Robles et al., 2007; Schreiber & DeCalesta, 1992; Spiering & Knight, 2005).

Although we did not detect differences in use of snags among harvest treatments, historic surveys found that snags in the two-story treatment received the highest use (Chambers et al., 1997; Walter & Maguire, 2005). A concurrent study (Barry et al., 2017 unpublished data) found

supporting evidence that snags in the two-story treatment have received the most use over time based on estimates of cavity-cover on snags. Density of trees within a stand at the time that snags are created can have substantial impacts on snag longevity, external decay characteristics, and use by birds (Barry et al., unpublished data, Walter and Maguire, 2005, Garber et al., 2005), and is an important consideration when creating snags as wildlife habitat.

Finally, the rate of decay of snags created by topping may vary from that of natural snags, which could have strong implications for use of snag by cavity-nesting birds over time. When a live tree loses its top, the exposed top provides direct access to colonization of the heartwood and sapwood by fungi and other decay organisms. This could cause softening throughout the bole of the snag earlier than in snags that retain their tops (Hallett et al., 2001). Unlike living trees that sustain and injury, entirely dead trees may not be able to localize pockets of decay. Localized decay may be particularly important for some species because it could provide softened heartwood for excavating while still maintaining a supportive exterior (Blanc & Martin, 2012; Lorenz et al., 2015). Future research should focus on the differences between created snags natural snags in decay rate of heartwood and sapwood, and localization of decay pockets.

Figure 3.1. Map of study location and designation of blocks and stands for the CFIRP within the McDonald Dunn Research Forest, Corvallis, OR (Walter and Maguire, 2005).

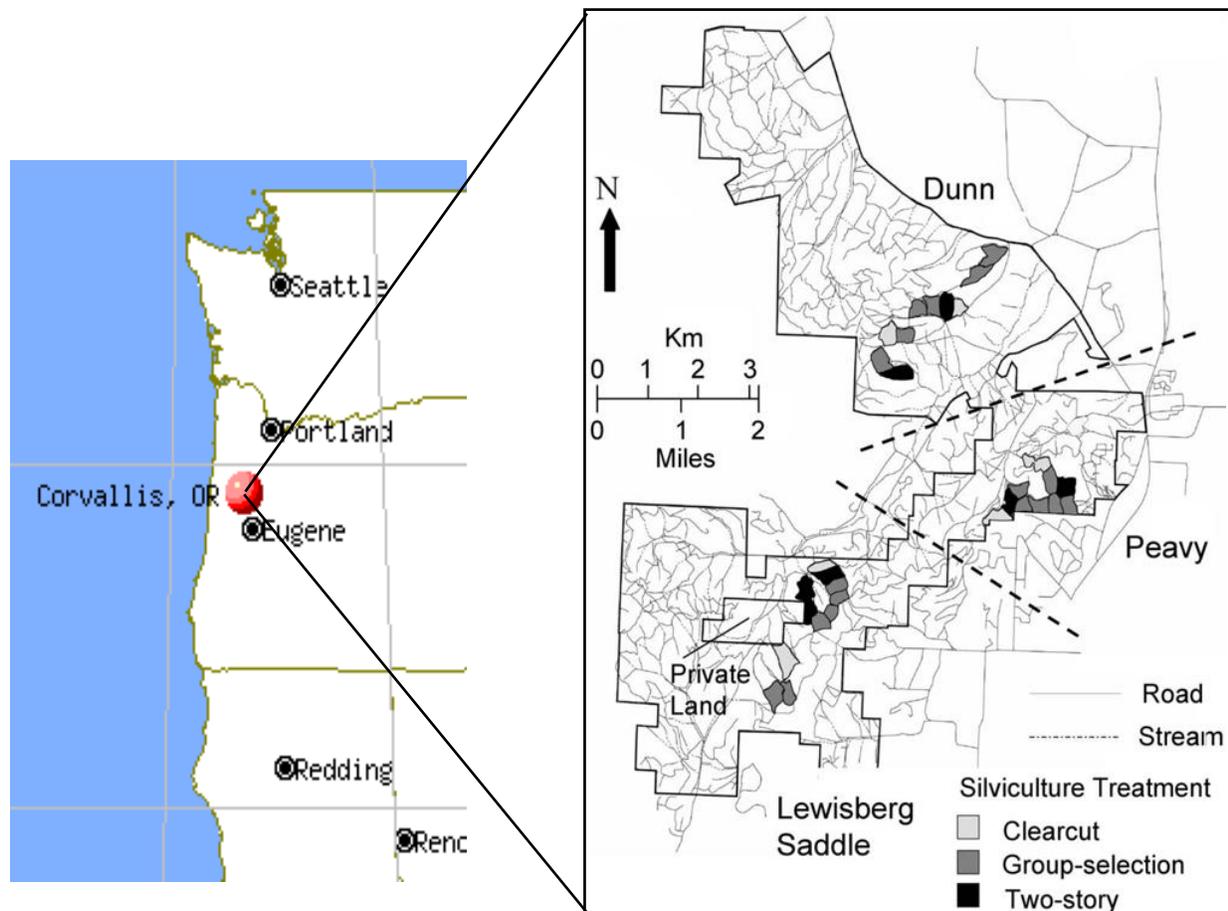


Figure 3.2. Mean height (95% CI) of created and natural snags among three harvest treatments in the CFIRP stands, 2016.

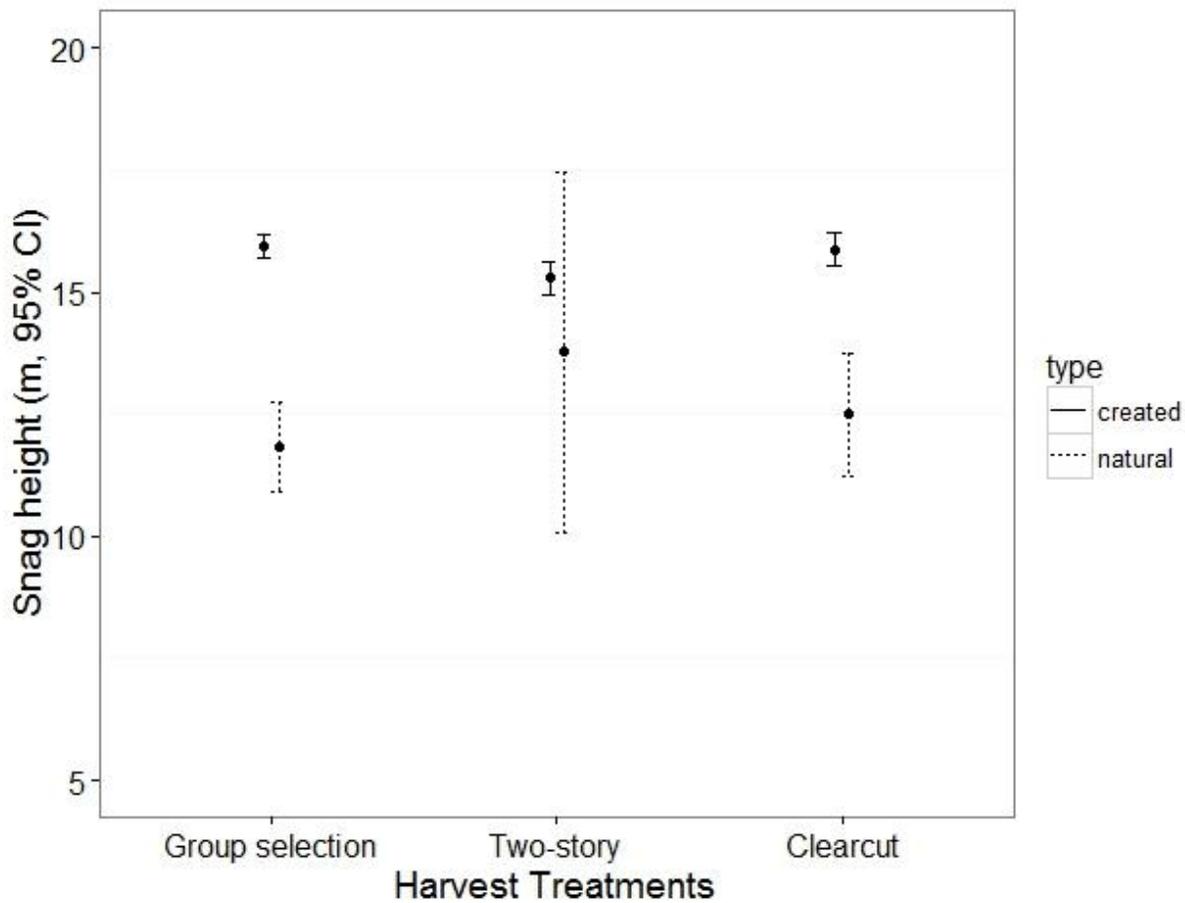


Figure 3.3. Mean DBH (95% CI) of created and natural snags among three harvest treatments in the CFIRP stands, 2016.

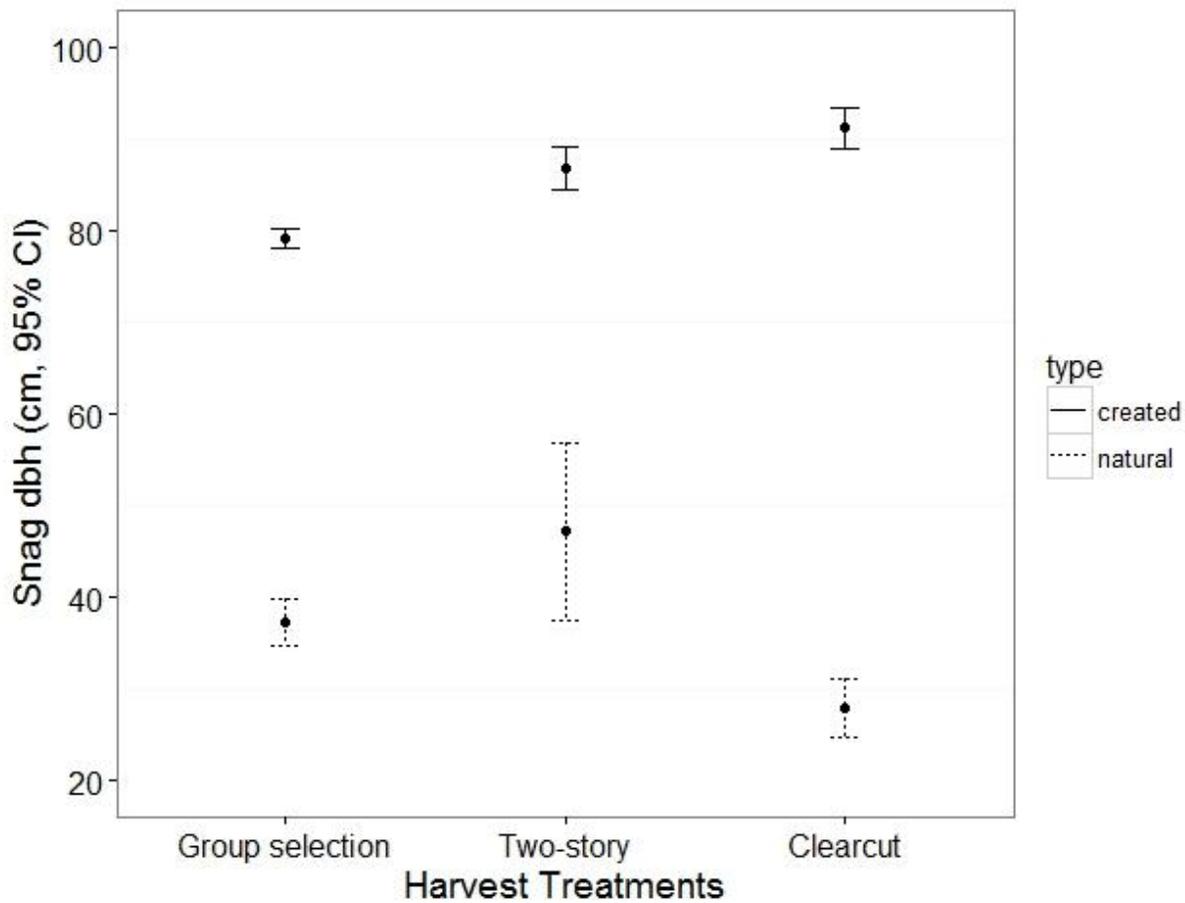


Table 3.1: Number of stands with each treatment combination (harvest treatment/snag configuration) in each of the three blocks in the CFIRP during 2015 and 2016. Treatments that had number of stands decrease from 2015 to 2016 are in bold.

Treatment Combination	Block					
	Lewisburg		Peavy		Dunn	
	2015	2016	2015	2016	2015	2016
<b>Group selection/clustered</b>	2	<b>1</b>	3	3	3	3
Group selection/scattered	2	2	3	3	3	3
Two-story/clustered	1	<b>1</b>	1	<b>1</b>	1	<b>1</b>
Two-story/scattered	0	<b>0</b>	1	<b>1</b>	1	<b>1</b>
<b>Clearcut/clustered</b>	1	<b>0</b>	1	<b>1</b>	1	<b>0</b>
Clearcut/scattered	0	<b>0</b>	1	<b>1</b>	1	<b>1</b>

Table 3.2. Comparison among harvest treatments of number of avian nests detected during focal surveys on created snags in the McDonald-Dunn Forest, Oregon from May-July 2015/2016.

<b>Species</b>	<b># of nests</b>		
	<b>Group selection</b>	<b>Two-story</b>	<b>Clearcut</b>
Chestnut-backed Chickadee	12	9	11
Red-breasted Nuthatch	2	0	0
Northern Flicker	1	0	0
Red-breasted Sapsucker	0	0	1
<b>All species combined</b>	<b>15</b>	<b>9</b>	<b>17</b>

Table 3.3. Comparison among snag configurations of number of avian nests detected during focal surveys on created snags in the McDonald-Dunn Forest, Oregon from May-July 2015/2016.

<b>Species</b>	<b># of nests</b>	
	<b>Clustered</b>	<b>Scattered</b>
Chestnut-backed Chickadee	16	16
Red-breasted Nuthatch	1	1
Northern Flicker	1	0
Red-breasted Sapsucker	0	1
<b>All species combined</b>	<b>18</b>	<b>18</b>

Table 3.4. Comparison among harvest treatments of number of avian foraging events during focal surveys on created snags from May-July 2015/2016.

Species	# of foraging observations		
	Group selection	Two-story	Clearcut
Pileated Woodpecker	0	2	8
Northern Flicker	1	0	0
Red-breasted Sapsucker	1	1	1
Hairy woodpecker	2	0	0
Chestnut-backed Chickadee	7	3	6
Red-breasted Nuthatch	4	0	1
Barred Owl ( <i>Strix varia</i> )	0	1	0
Brown Creeper	1	1	0
Dark-eyed Junco	1	0	0
<b>All species combined</b>	<b>17</b>	<b>8</b>	<b>16</b>

Table 3.5. Naïve occupancy (i.e. the percentage of points at which birds were detected) for each cavity-nesting species detected in CFIRP stands, 2016. Occupancies of strong excavators were calculated using call playback data only, while occupancies of other species were calculated based on point count data.

<b>Nesting Classification</b>	<b>Species</b>	<b>Naïve Occupancy</b>
Strong Excavators	Red-breasted Sapsucker	54%
	Northern Flicker	46%
	Hairy Woodpecker	42%
	Pileated Woodpecker	27%
	Downy Woodpecker	0%
Weak Excavators	Chestnut-backed Chickadee	100%
	Red-breasted Nuthatch	92%
Secondary cavity-nester	Brown Creeper	96%
	Northern Pygmy-Owl	6%

Table 3.6. The number of nests for each species found during three survey periods (1996, 2001, and 2015/2015) in the CFIRP stands and the % of total nests that each species represents.

Species	1996		2001		2015/2016	
	# nests	% total nests	# nests	% total nests*	# nests	% total nests*
House Wren ( <i>Troglodytes aedon</i> )	46	57%	31	18%	0	0%
European Starling	3	4%	28	16%	0	0%
Violet-green Swallow ( <i>Tachycineta thalassina</i> )	5	6%	10	6%	0	0%
Western Bluebird ( <i>Sialia mexicana</i> )	1	1%	0	0%	0	0%
Red-breasted Nuthatch	1	1%	15	9%	2	6%
Chestnut-backed Chickadee	6	7%	56	33%	32	89%
Northern Flicker	5	6%	7	4%	1	3%
Hairy Woodpecker	1	1%	1	1%	0	0%
Red-breasted Sapsucker	13	16%	21	12%	1	3%
All species combined	<b>81</b>	<b>---</b>	<b>169</b>	<b>---</b>	<b>36</b>	<b>---</b>

Table 3.7. Estimates of natural snags natural snag densities ( $\pm$  standard error) for 2001 and 2016 among harvest treatment in the McDonald-Dunn Forest, Oregon.

<b>Harvest Treatment</b>	<u>Year</u>	<u>Mean density of natural snags (individuals/ha)</u>
<b>Group selection</b>	<i>2001</i>	<i>0.4*</i>
	2016	10.6 ( $\pm$ 1.9)
<b>Two-story</b>	<i>2001</i>	<i>0.7*</i>
	2016	6.4 ( $\pm$ 2.2)
<b>Clearcut</b>	<i>2001</i>	<i>0.2*</i>
	2016	13.3 ( $\pm$ 5.1)

\*value taken from historic data, no estimate of confidence associated

## CHAPTER 4 – CONCLUSION

We found that although most created snags were still standing and available for use by birds, they received limited use for foraging or nesting by birds among all harvest treatments and both snag configurations. Based on comparisons between historic and current estimates of snag condition, we detected signs of advanced decay, such as bark peeling away from snags and snags breaking. Snags in advanced stages of decay and snags with broken tops have less evidence of bird use (i.e. cavities) compared with snags in earlier stages of decay and without broken tops (Spiering & Knight, 2005).

Although we observed signs of advanced decay, coupled with use of created snags for nesting by weak-excavating species, we did not use any direct measures of internal wood hardness to assess snag internal decay. Internal wood hardness has been found to be the most significant predictor of bird use, and has also been shown to be poorly correlated with both typical decay classification systems and external characteristics (Lorenz et al., 2015). Our results also suggest that internal decay may not have been accurately reflected by some of our external decay indicators. Percent bark cover, for example, was high on average (80%) and yet snags were almost exclusively used by weak excavators, suggesting that they may not be suitable for species that typically use a narrower range of decay in snags (i.e., woodpeckers). Although using measures of internal wood hardness may be more time consuming for land managers than using visual estimates, a better understanding of how external characteristics relate to wood hardness would greatly improve our management of snags as wildlife habitat.

Over time, we detected a strong decline in snag condition and the proportion of snags occupied that were used by birds for foraging or nesting during the breeding season. With

decline in snag condition over time, we also detected a decrease in species composition. However, stand condition was also changing over time, so changes in composition were likely due to stand-level vegetation changes as well as changes in snag condition. Although snags in these silvicultural harvest treatments received limited use by birds, the high proportion of created snags still standing after  $\geq 25$  y may lead to an over-estimate of suitable habitat by land managers.

Although our study focused on use of snags by birds, snags have many other functions on the landscape. Decaying wood provides inputs of nutrient to the soil, sequesters atmospheric carbon, and eventually provides habitat for species that utilize logs for foraging or loose bark for nesting (Adams & Morrison, 1993; Bull, 1975; Bunnell, 2013; Chambers et al., 2002; Geleynse et al., 2016; Harmon et al., 1986; Rose et al., 2001). Therefore older created snags still provide valuable habitat when in later stages of decay, but if management for diversity of cavity-nesting birds is a priority, then snags at different stages in decay should be retained on the landscape.

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## APPENDICES

### Appendix A: Initial characteristics measured for all created snags in 1991

Variable	Definition
DBH	Snag diameter (cm) at 1.4m height above ground
Height	Snag height (m)
Dead	Snag condition D = dead, A = alive
Bark cover	Percent of bole bark cover
Scorch	Percent of bole with scorch
Excav. Cavities	Number of excavated cavities
Forage cavities	Number of foraging cavities
Natural cavities	Number of natural cavities
Dead limbs	Number of dead limbs > 10 cm diameter, >30 cm length
% slope	Percent slope of ground averaged from 20 m upslope and down-slope from snag
Lean	Degrees of lean of snag from perpendicular to ground
Decay class	Decay class (Cline et al. 1980)
Standing	Snag condition: standing or fallen

**Appendix B: Naïve occupancy estimates for all birds detected during point counts in CFIRP stands, 2016.**

<i>Species</i>	Harvest Treatment(number of points)		
	<b>Group Selection (n=16)</b>	<b>Two-story (n=7)</b>	<b>Clearcut (n=4)</b>
American Crow	0.69	0.29	0.25
American Goldfinch	0.38	0.29	0.75
American Robin	0.69	0.71	0.75
Barred Owl	-	0.14	-
Black-capped chickadee	0.19	0.14	0.25
Bewick's Wren	0.19	-	-
Brown-headed Cowbird	0.19	0.14	0.25
Black-headed Grosbeak	0.94	0.86	0.75
Brown Creeper	1.00	1.00	0.75
Band-tailed Pigeon	0.50	0.71	0.50
Black-throated Grey Warbler	0.75	1.00	0.75

Canada Goose	0.13	0.14	-
Cassin's Vireo	0.19	-	-
Chestnut-backed chickadee	1.00	1.00	1.00
Cedar Waxwing	0.06	0.29	0.50
Common Raven	0.56	0.86	0.75
Common Yellowthroat	0.06	-	0.25
Dark-eyed Junco	1.00	0.71	0.75
Eurasian Collared Dove	0.06	-	-
Evening Grosbeak	0.69	0.43	0.50
Golden-crowned Kinglet	0.50	0.57	0.25
Hermit Thrush	0.56	0.71	0.50
Hermit Warbler	0.94	1.00	1.00
House Wren	0.13	-	0.25
Hutton's Vireo	0.62	0.57	0.25
Lazuli Bunting	0.06	0.14	-

MacGillivray's Warbler	0.19	0.29	-
Mourning Dove	0.13	-	-
Mountain Quail	0.06	-	-
Northern Pygmy Owl	0.06	-	-
Orange-crowned Warbler	1.00	1.00	0.75
Olive-sided Flycatcher	0.06	0.14	0.25
Pacific Wren	1.00	0.86	1.00
Pacific-slope Flycatcher	0.88	1.00	0.75
Purple Finch	0.63	1.00	0.50
Red-breasted Nuthatch	1.00	1.00	0.75
Red Crossbill	0.13	-	0.25
Red-tailed Hawk	0.25	0.14	0.25
Song Sparrow	0.19	-	-
Spotted Towhee	0.81	0.57	0.50
Steller's Jay	0.94	0.86	0.75

Swainson's Thrush	1.00	1.00	0.75
Townsend's Warbler	0.19	-	0.25
Warbler Vireo	0.06	0.29	-
White-crowned Sparrow	0.06	-	-
Western Tanager	1.00	0.86	1.00
Western Wood-Peevee	0.25	0.14	0.25
Wild Turkey	0.25	0.14	0.75
Wilson's Warbler	0.94	1.00	1.00
Wrentit	0.06	-	-