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CAVITIES IN SNAGS ALONG A WILDFIRE CHRONOSEQUENCE IN EASTERN WASHINGTON

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Abstract: We sampled occurrence of bird-excavated cavities in snags in a chronosequence of 26 wildfire burns (ages 1–81 years) on the east slope of the Washington Cascade Range, USA. Cavities occurred in 5.5% of the 1,867 recorded snags; most (69%) were in burns <20 years old. Cavities occurred at higher rates in ponderosa pine (*Pinus ponderosa*; 28%) and Douglas-fir (*Pseudotsuga menziesii*; 8.4%) snags than in snags of other tree species (≤5%). Few or no cavities were found in large samples ($n > 250$) of subalpine fir (*Abies lasiocarpa*; 0.2%) and lodgepole pine (*Pinus contorta*; 0.0%) snags. Cavities occurred in about 4% of the small samples ($n < 100$) of Engelmann spruce (*Picea engelmannii*; $n = 48$) and western larch (*Larix occidentalis*; $n = 74$) snags. Large diameter, burn age ≥20 years, soft-decay condition (Class 3+), broken-top condition, and moderate height were important predictors of cavities in ponderosa pine and Douglas-fir snags. Cavity-bearing ponderosa pine snags were best characterized as large-diameter (>34 cm diameter at breast height [dbh]) snags >2 m tall and located in middle-age to older burns (>19 years old). Cross-validated accuracy of the classification tree model was 97% for cavity snags and 82% for snags without cavities. Cavity-bearing Douglas-fir snags were best characterized as large-diameter snags (>33 cm dbh), or as smaller soft snags (Class 4, 5) at elevations <1,200 m. Accuracy of the classification tree model was 88% and 73% for snags with and without cavities, respectively. In burns <20 years old, Douglas-fir snags with broken tops had higher cavity excavation rates (6%) than snags with whole tops (0.25%). Aspect, slope, slope position, and elevation had negligible or no value for classification. To ensure good post-fire snag habitat, manage pre-fire green stands for tree species, large size, defect (e.g., broken tops), and spatial pattern that will provide cavity snags in short and long terms. When salvaging burns, retain snags with defects incurred prior to fire, especially broken tops, and large-diameter snags of species known to be most suitable for cavity excavation in that area.

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Key words: *Abies lasiocarpa*, Cascade Range, cavity occurrence, Douglas-fir, lodgepole pine, *Pinus contorta*, *Pinus ponderosa*, ponderosa pine, *Pseudotsuga menziesii*, snags, subalpine fir, Washington.

Snags are important structural and functional elements of forest ecosystems that are vital wildlife microhabitats (Thomas et al. 1979, Harmon et al. 1986, Rose et al. 2001). Maintenance or restoration of snags in managed forests requires information to model the recruitment, persistence, decay characteristics, and wildlife use of different snag species (Raphael and Morrison 1987, Morrison and Raphael 1993, Rose et al. 2001). In the Pacific Northwest, those data are relatively well known for mesic Douglas-fir forests of western Oregon and Washington. Models have been developed to help managers maintain and recruit snags to meet wildlife and ecosystem objectives (Rose et al. 2001). Those data are limited or unavailable for development of snag models for most of the dry interior forests east of the Cascade Range (Rose et al. 2001). Moreover, snag dynamics and avian use in wildfire burns are even less well known than for green forests (Hutto 1995, Saab et al. 2002, Kotliar et al. in press). Effective management of burned areas, particularly with respect to the controversial impacts of salvage logging on birds and other ecosystem components (Hutto 1995, McIver and Starr 2000), will require area-specific data on snag dynamics and avian use over the regenerative life of forests (Bull et al. 1997, Everett et al. 1999, Rose et al. 2001, Kotliar et al. in press).

Considerable research has explored the dynamics and avian use of snags in green stands within the interior Columbia River basin (Bull et al. 1997) and elsewhere in similar dry forests

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(Raphael and White 1984, Raphael and Morrison 1987, Ganey and Balda 1994). A growing body of research is beginning to address snag dynamics and avian use in burned areas (Hutto 1995, Finch et al. 1997, Kotliar et al. in press). In the western part of the Columbia River Basin along the east slope of the Cascade Range in Washington, where little work on wildfire has been done, Everett et al. (1999) described fall and decay rates for several snag species in a chronosequence of 26 wildfire burns. We extended Everett's analysis by quantifying cavity occurrence by snag species, height, diameter, decay class, and environmental attributes in those burns. We developed cross-validated classification models to characterize and predict cavity occurrence in ponderosa pine and Douglas-fir snags. The results will allow ecologists and resource managers in the interior Northwest to more effectively model dynamics of snags with high wildlife value to better maintain or restore snag habitat in burned areas.

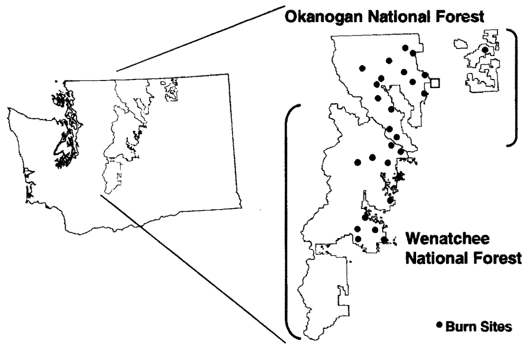

Fig. 1. Location of 26 wildlife burn sites used for chronosequence analysis of snag ecology and cavity excavation on the east slope of the Washington Cascades, USA, during 1995.

METHODS

Sampling Design

We sampled a chronosequence of 26 stand-replacement wildfire burns on the eastern slope of the Washington Cascade Range in Chelan and Okanogan counties during 1995 (Fig. 1). Burns were 1–81 years old and had not been salvage logged or reburned after the initial stand-replacement fire. Burns ranged from 30 to 23,600 ha in area, with a median 1,578-ha area. Study areas were predominantly within the Douglas-fir Series and Subalpine Fir Series (Lillybridge et al. 1995) between 1,000 and 2,100 m elevation.

Details of sample site selection within burns and data-collection protocols are in Everett et al. (1999). Briefly, we first stratified and mapped burns by aspect (north vs. south) and terrain (sloped vs. flat) into land types. We then mapped from aerial photographs (1:15,480) snag stands with homogeneous snag densities or sizes at a minimum resolution of 2 ha within each land type. We randomly selected a single-snag stand type within each land type on a burn for sampling. Sampling within a snag stand was done where burn severity (trunk and branch scorch and snag decay conditions) was homogeneous. This reduced variability due to confounding effects of partial burns and prolonged delay in tree mortality after fire.

We sampled 2–4 locations within each selected snag stand with 2 concentric circular plots of 0.02 ha (1/20 acre) and 0.1 ha (1/4 acre). We recorded all snags in 0.02-ha plots, and snags >23 cm dbh in the 0.1-ha plot. Data from each plot size were pooled for this analysis. In each plot, we measured elevation, slope, slope position (ridgetop, mid-slope, or riparian), and aspect. For individual snags, we measured diameter, height, decay condition class (Cline et al. 1980), top condition (broken or whole), and occurrence of excavated nest cavities. We considered nest cavities to be round excavations >2.5 cm diameter and deep enough to have been potentially used for nesting, as observed from the ground. We did not speculate on the potential bird species that could have excavated cavities. We used burn age as a proxy for snag age and minimized potential differences in post-fire mortality by selecting snag stands with uniform burn severity. We excluded from analysis all snags that existed before the fire-based on the presence of sapwood char. We grouped snags into diameter classes of 3–13 cm, 14–23 cm, 24–41 cm, 42–64 cm, and >64 cm dbh.

Analytical Procedures

We calculated the percentage of all snags with cavities by tree species across the chronosequence of burns. For ponderosa pine and Douglas-fir snags, we calculated cavity occurrence by height, diameter class, decay condition class, burn age, and top condition. Those 2 species had both relatively large sample sizes ($n > 100$) and high cavity occurrence (>5%).

We used classification tree analysis (CART; Breiman et al. 1984, Steinberg and Colla 1998) to identify snag and environmental attributes that best predicted cavity occurrence in ponderosa pine and Douglas-fir snags. Classification tree analysis is similar to discriminant function analysis. With

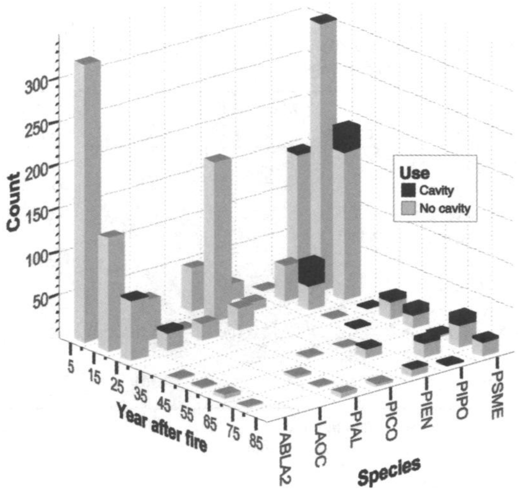

Fig. 2. Tree species, burn age, and cavity occurrence in snags in a chronosequence of wildfire burns in the eastern Washington Cascades, USA. Species codes: ABLA2 = subalpine fir; LOAC = western larch; PIAL = whitebark pine; PICO = lodgepole pine; PIEN = Engelmann spruce; PIPO = ponderosa pine; PSME = Douglas-fir.

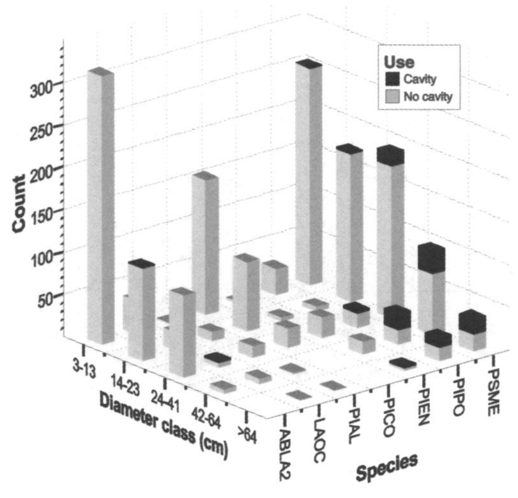

Fig. 3. Tree species, diameter class, and cavity occurrence in snags in a chronosequence of wildfire burns in the eastern Washington Cascades, USA. Species codes: ABLA2 = subalpine fir; LOAC = western larch; PIAL = whitebark pine; PICO = lodgepole pine; PIEN = Engelmann spruce; PIPO = ponderosa pine; PSME = Douglas-fir.

classification trees, however, the independent predictor variables can be categorical or continuous. The classification procedure tests all possible combinations of the dependent and independent variables to split the dependent variable into homogeneous groups or to minimize the "impurity" of membership in tree nodes. The resulting classification rules and tree are similar to familiar plant identification keys. We used the Gini index of node impurity as the splitting rule. We weighted the cavity versus noncavity snag-misclassification rate 2:1 because we believed that accurate classification of cavity snags was more important to managers than accurate classification of snags unlikely to have cavities.

We used *V*-fold cross-validation to construct and validate classification trees (Breiman et al. 1984, Steinberg and Colla 1998). We selected the minimum-cost tree (lowest miscalculation error) calculated by cross-validation to classify ponderosa pine snags. For Douglas-fir snags, we used the 1-SE (standard error) rule, which chose the most parsimonious tree within 1 SE of the minimum-cost tree for that species. The 1-SE tree was simpler than the minimum-cost tree (4 terminal nodes vs. 10 nodes) with no loss of prediction accuracy for cavity snags. Prediction error of noncavity Douglas-fir snags with the 1-SE tree, however, was approximately 10% higher than with a minimum-cost tree. We calculated cross-validated model accuracy as the percentage of observed snags correctly classified with and without cavities.

Classification tree analysis estimated the importance of each variable in building the predictive classification tree with a score based on how often and with what significance it served as a primary or surrogate splitting variable throughout each snag species' tree. Surrogate variables were those that had lower improvement scores than primary splitting variables used to construct the final tree, but that closely mimicked the action of primary splitting variables. Surrogate splitters can be used to classify snags in cases in which data are missing for primary splitters (Steinberg and Colla 1998). Improvement scores were summed over each node, then scaled relative to the best performing variable for each snag species.

RESULTS

All Species

Cavities occurred in only 5.5% of the 1,867 measured snags, mostly in Douglas-fir (62%) and ponderosa pine (32%) snags (Fig. 2). Most snags (69%) were in burns ≤20 years old (Fig. 2). Almost half the snags (43%) were pole size (<14 cm dbh), and 87% were medium or smaller (<42 cm dbh) size (Fig. 3). Large (>42 cm dbh) snags

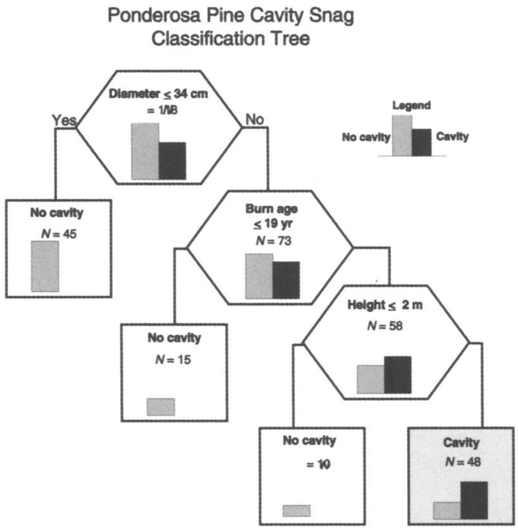

Fig. 4. Classification tree for predicting cavity occurrence in ponderosa pine snags sampled in wildfire burns in the eastern Washington Cascades, USA. Labels within hexagons indicate splitting variable and sample size. Cases meeting splitting criterion flow to left, others to right. Bar figures represent the number of snags without (left) and with (right) cavities in each box.

Table 1. Accuracy and misclassification error rates of classification trees for predicting cavities in snags of ponderosa pine and Douglas-fir in wildfire burns on the east slope of the Washington Cascades Douglas-fir, USA.

Class	N cases	Misclassified (N)	Error[a] (%)	Accuracy[b] (%)
Ponderosa pine				
Cavity	33	1	3.0	97.0
No cavity	85	15	17.7	82.3
Total	118	16		
Mean			10.3	89.7
Douglas-fir				
Cavity	64	8	12.5	87.5
No cavity	697	190	27.3	72.7
Total	761	198		
Mean			19.9	80.1

[a] Percentage misclassified.
[b] Percentage correctly classified.

were nearly all Douglas-fir and ponderosa pine. Cavity excavation rates were higher in ponderosa pine (28%; n = 118) and Douglas-fir (8.4%; n = 671) snags than for other species (≤5%). Among those other species with relatively robust sample sizes, only 0.2% of subalpine fir (n = 527) and no lodgepole pine (n = 261) snags had cavities. Cavities were recorded in 4.1% of the western larch snags (n = 74), 4.2% of the Engelmann spruce snags (n = 48), and in none of the whitebark pine (*Pinus albicaulis*) snags encountered (n = 27). Samples of grand fir (*Abies grandis*), subalpine larch (*Larix lyallii*), and western red cedar (*Thuja plicata*) snags were too small (n < 15) to report.

Ponderosa Pine and Douglas-fir

Classification Trees.—Cavities in ponderosa pine snags were predicted to occur most often in large-diameter (>34 cm dbh) snags that were >2-m tall and located in middle-age to older burns (>19 years old; Fig. 4). Mean accuracy of the model was 89.7%, with 97.0% accuracy for cavity snags and 82.3% accuracy for snags without cavities (Table 1). Burn age was the most important predictor of cavity occurrence, as both a primary and a surrogate splitting variable, followed by snag diameter, height, condition class, and top condition (Table 2). Aspect, slope, slope position, and elevation had negligible or no importance for predicting cavity occurrence in ponderosa pine snags.

Cavities in Douglas-fir snags were predicted to occur most often in large-diameter snags (>33 cm dbh) or in smaller snags of very soft condition (Class 4 or 5) at elevations <1,200 m (Fig. 5). Mean accuracy of the Douglas-fir cavity model was about 10% less than for ponderosa pine, but still high at 80.1%. The model was more accurate

Table 2. Relative importance and rank comparison of variables for classifying ponderosa pine and Douglas-fir snags with cavities in wildfire burns on the east slope of the Washington Cascades, USA.

Ponderosa pine			Douglas-fir	
Score[a]	Variable	Rank comparison	Variable	Score
100	Burn age[b]		Condition[c]	100
78	Diameter[b]		Diameter[c]	97
78	Height[b]		Burn age	95
60	Condition		Broken top	84
43	Broken top		Elevation[c]	61
4	Riparian		Height	25
0	Elevation		Aspect	11
0	Slope		Riparian	0
0	Aspect		Slope	0
0	Ridge		Ridge	0

[a] The importance score of each variable in the classification tree was based on how often and with what significance it served as a primary or surrogate splitting variable throughout each snag species' tree. Improvement values were summed over each node, then scaled relative to the best performing variable for each snag species.
[b] Primary splitting variables in ponderosa pine classification tree.
[c] Primary splitting variables in Douglas-fir classification tree.

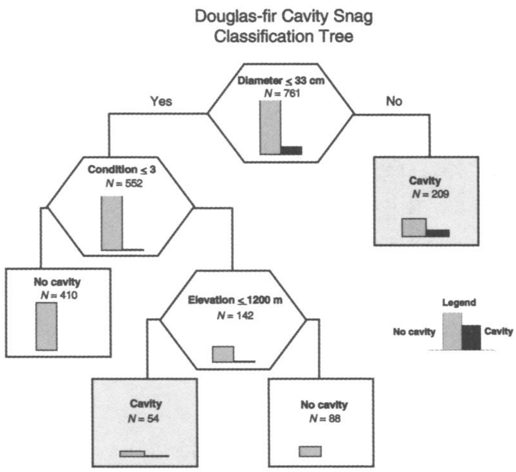

Fig. 5. Classification tree for predicting cavity occurrence in Douglas-fir snags sampled in wildfire burns in the eastern Washington Cascades, USA. Labels within hexagons indicate splitting variable and sample size. Cases meeting splitting criterion flow to left, others to right. Bar figures represent the number of snags without (left) and with (right) cavities in each box.

at predicting cavities in Douglas-fir snags (87.5%) than for predicting snags without cavities (72.7%; Table 1). Condition class, diameter, and burn age were nearly of equal importance as primary or surrogate predictors of cavity occurrence in Douglas-fir snags, followed by top condition, elevation, and height (Table 2). As with ponderosa pine, aspect, slope, and slope position had negligible or no importance for predicting cavity occurrence in Douglas-fir snags.

Cavity Predictor Variables.—Medium to large diameter (>33 cm dbh) was an important predictor (splitting variable) of cavity occurrence in both ponderosa pine and Douglas-fir snags (Table 2; Figs. 4, 5). Thirty-seven percent ($n = 45$) of ponderosa pine snags were ≤34 cm dbh, but all the cavities were found in larger snags (Fig. 6). Large size, however, did not guarantee cavity occurrence since 55% of the large ponderosa pine snags had no cavity. Cavities in Douglas-fir snags also were recorded primarily in medium to large (≥33 cm dbh) snags (Fig. 6). Only 11% of the Douglas-fir cavities were observed in smaller snags, which nevertheless made up 72% of the sample. Only 23% of the large Douglas-fir snags had cavities.

Although the 2 classification trees differed somewhat in splitting variables, burn age, condition class, top condition, and snag height were important in both classifications as splitting or surrogate variables, i.e., as general predictors of cavity occurrence in both species (Table 2). Burn age was the most important variable based on its mean importance score of 97.5. All the cavities in ponderosa pine snags were found in burns ≥20 years old, even

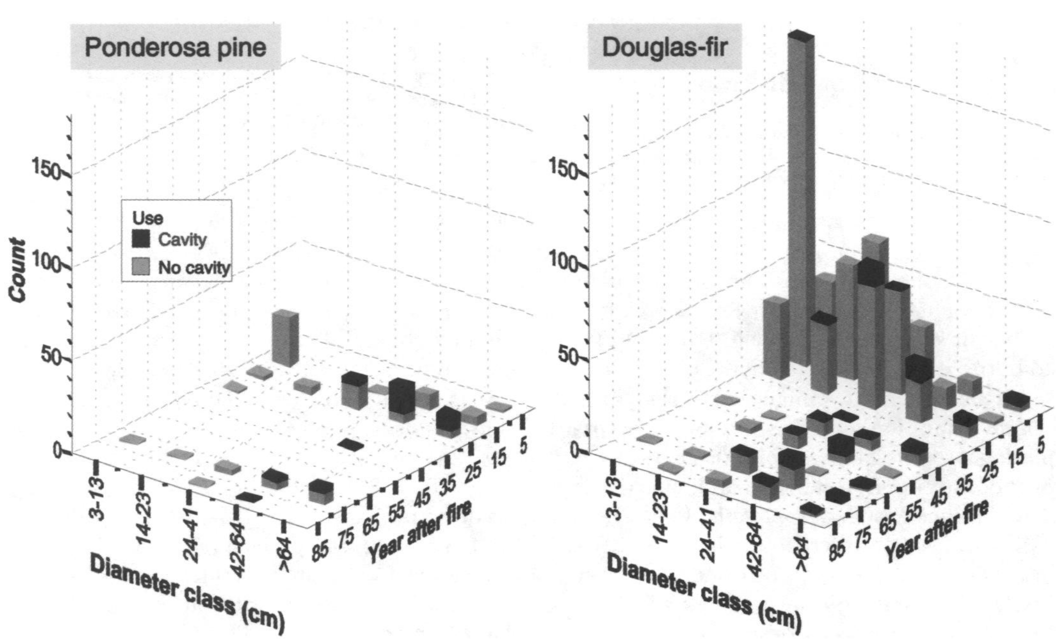

Fig. 6. Burn age, snag diameter, and cavity occurrence in ponderosa pine and Douglas-fir snags sampled in a chronosequence of wildfire burns in the eastern Washington Cascades, USA.

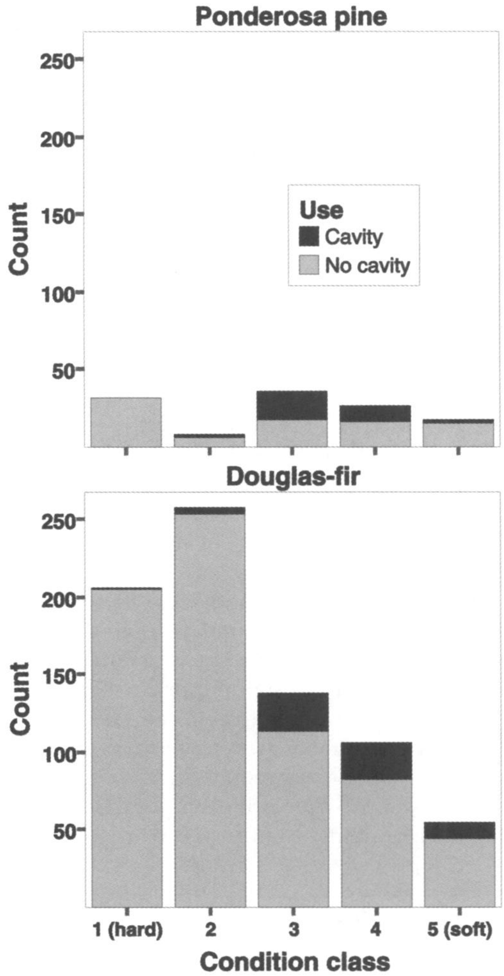

Fig. 7. Condition class and cavity occurrence in ponderosa pine and Douglas-fir snags sampled in a chronosequence of wildfire burns in the eastern Washington Cascades, USA.

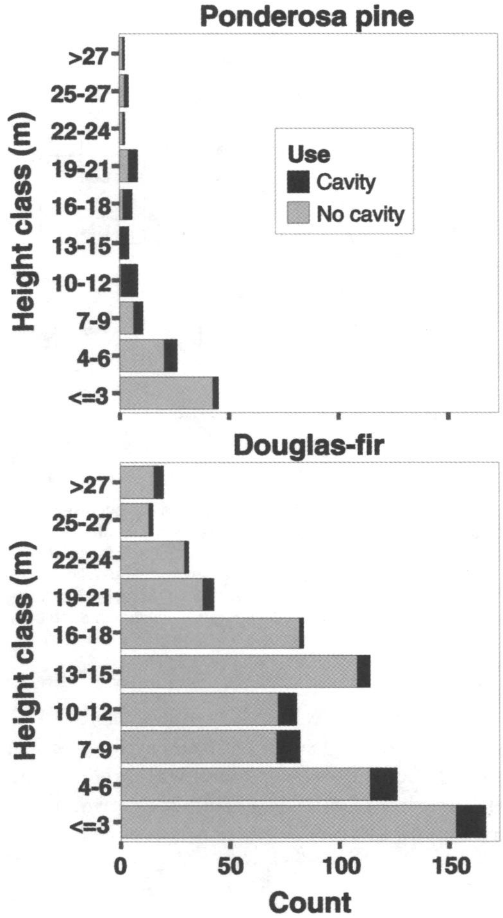

Fig. 8. Height class and cavity occurrence in ponderosa pine and Douglas-fir snags sampled in a chronosequence of wildfire burns in the eastern Washington Cascades, USA.

though 35% of the ponderosa pine snags were measured in younger burns (Fig. 6). Similarly, cavities in Douglas-fir snags were nearly all (94%) in ≥20 year old burns, even though 60% of the observed Douglas-fir snags were in younger burns (Fig. 6).

Decay condition class was the most important splitting or surrogate variable for characterizing cavity occurrence in Douglas-fir and ranked fourth in importance for ponderosa pine (Table 2). Most of the cavities (94%) were found in soft (≥Class 3) snags of those species (Fig. 7). Condition class was closely correlated with burn age ($r = 0.783$, $P = 0.01$). Also, where splits occurred on condition class or burn age in classification trees, the other variable was indicated as the strongest competitor or surrogate for splitting, indicating similar information value. Soft snags (≥Class 3) were scarce (5%) in burns <20 years old, whereas they were 90% of the snags in older burns. Soft snags were found in burns as young as 8 years old, but the mean burn age for Class 3 snags was 28 years.

Snag height >2 m was a relatively important variable in classifying ponderosa pine cavity snags but was less important for classifying Douglas-fir snags (Table 2). Cavities in ponderosa pine snags occurred primarily in snags 4–21-m tall, with more cavities in snags 10–21-m tall relative to their availability (Fig. 8). A pattern of selection for Douglas-fir snags is less obvious, with cavity snags well distributed across all height classes (Fig. 8).

Top condition was a relatively important variable in the classification analysis as a surrogate

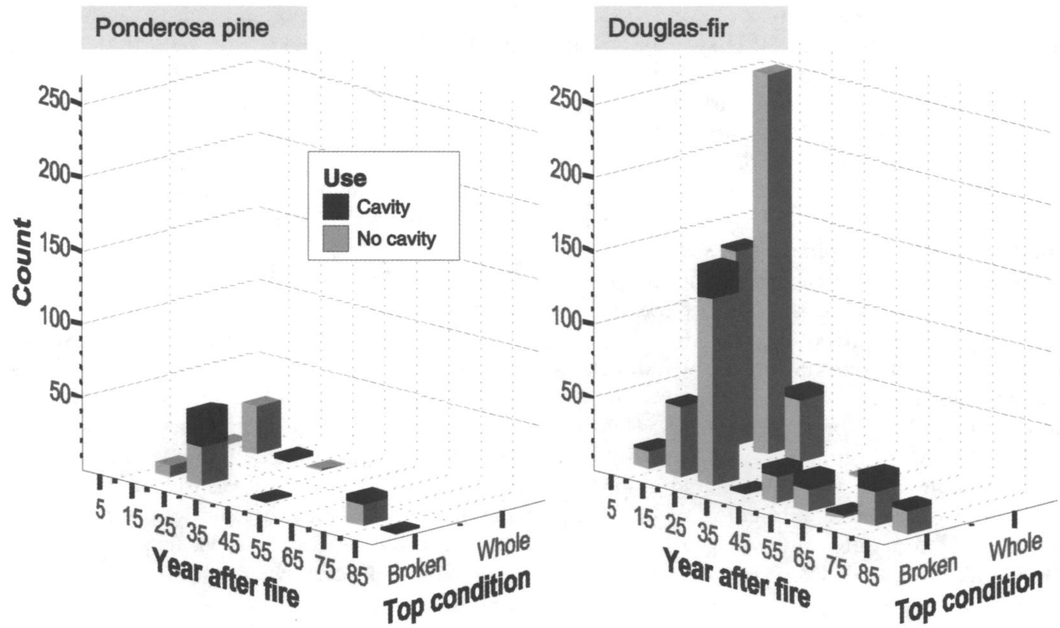

Fig. 9. Top condition, burn age, and cavity occurrence in ponderosa pine and Douglas-fir snags in a chronosequence of wildfire burns in the eastern Washington Cascades, USA.

splitting variable, particularly for Douglas-fir snags (Table 2). For both ponderosa pine and Douglas-fir, cavities occurred primarily in snags with broken tops in burns >20 years old (Fig. 9); but few whole trees remained in burns of that age. In burns <20 years old, cavities in Douglas-fir snags were more frequent in snags with broken tops (6%) than in whole trees (0.25%; Fig. 9).

Environmental variables in general had little value in characterizing cavity occurrence in ponderosa pine or Douglas-fir snags (Table 2). Elevation below 1,200 m had some minor value in discriminating Douglas-fir snags with cavities, but most cavity snags were more simply characterized by large diameter (Fig. 5). Slope, aspect, and slope location had negligible or no apparent value for characterizing cavity snags.

DISCUSSION

Selection of snag species for cavity excavation in wildfire burns in the eastern Washington Cascades varied in some respects from other locations in the interior Columbia River Basin. Like many other studies in the basin (Bull et al. 1986, 1997; Hutto 1995; Bate 1995; Saab and Dudley 1998), we found ponderosa pine used most frequently for cavity excavation. Western larch also is an important cavity snag in some areas of the basin (Hutto 1995, Bull et al. 1997), but we found low use in our study area. Our sample of western larch was poor, however, being mostly (80%) small-diameter snags (<24 cm dbh) in hard condition (70%). We ranked Douglas-fir second in importance for cavity excavation. Although generally not ranked highly for cavity excavation across the basin (Bull et al. 1997), Douglas-fir snags are important in some burned or unburned areas (Bevis 1994, Hutto 1995, Saab and Dudley 1998).

Although we found little cavity excavation in lodgepole pine and western larch, these species can be important foraging snags in recent burns (Bevis 1994, Bate 1995, Hutto 1995, Bull et al. 1997). Douglas-fir and ponderosa pine snags also are important foraging snags in some areas (Hutto 1995, Bull et al. 1997). Foraging activity is closely linked to bark beetle and wood-boring beetle attacks during the first 5 years after fire (Hutto 1995). In the eastern Cascades, intense foraging activity on western larch snags was attributed to high wood borer infestations during the first 5 years after fire (Hadfield and Magelssen 2000).

Snag-species selection was largely a function of decay dynamics. Thick-barked ponderosa pine and Douglas-fir snags took about 25 years to reach Class 3, when most cavity excavation occurs. Thin-barked subalpine fir and lodgepole pine snags took 65 years to reach Class 3, but only about 10% of those snags (23–41 cm dbh) remained standing by that time (Everett et al. 1999). Rapid decay in thick-barked species is facilitated by retention of bark, which keeps sapwood moist and decay conditions good (Harmon et al. 1986, Lowell et al. 1992). High sapwood volume relative to the more decay resistant heartwood in ponderosa pine also facilitates rapid decay and subsequent cavity excavation (Bull et al. 1986, 1997; Lowell et al. 1992). Bark of thin-barked species sloughs off rapidly after fire, particularly with fragmentation by woodpeckers searching for insects, which causes rapid drying, slow decay, and little breakage of snags (Harmon et al. 1986). More rapid decay at the base than along the bole of the tree is facilitated by ground moisture, so that the combination of intact top and butt rot generally causes snags to fall entire (Bull et al. 1986, 1997; Everett et al. 1999).

Our results for ponderosa pine and Douglas-fir snags confirm that cavity excavators mostly select large-diameter (>33 cm) and soft (≥Class 3) snags for cavity excavation (Thomas et al. 1979; Raphael and White 1984; Bull et al. 1986, 1997; Saab and Dudley 1998). One apparent anomaly was finding few cavity snags in burns <20 years old (6% and only in Douglas-fir snags). Research in burned areas in Idaho (Saab and Dudley 1998) and Montana (Hutto 1995) reported abundant cavity excavation in Douglas-fir and ponderosa pine snags within the first 5 years after moderate intensity wildfires. Trees with the highest probability of cavity excavation by most bird species had tops broken before the fire and heavy decay. For example, Hutto (1995) reported 73% of cavities in young burns in broken-top snags, which made up only 8% of the available snags. Black-backed woodpeckers (*Picoides arcticus*) are an exception by excavating cavities in snags with light to moderate decay, often with whole tops (Hutto 1995, Saab and Dudley 1998). In our young burns, we likewise found that snags with broken tops had more cavities (6%) than snags with whole tops (0.25%), but the total number of cavities was very few.

Low cavity excavation in our young burns compared to some other studies is explained by differences in burn intensity and the origin of snags. Hutto (1995) and Saab and Dudley (1998) studied burns of moderate to high intensity that often had residual live vegetation and pre-fire snags, which they included in their nesting study. Our study sites were very high-intensity burns that had no residual vegetation and very few pre-fire snags. Only 2 (1.7%) ponderosa pine and 6 (0.8%) Douglas-fir pre-fire snags were recorded among approximately 1,900 snags sampled in 26 burns. For other snag species with low or insignificant cavity excavation rates, pre-fire snag numbers were somewhat higher: subalpine fir (4.9%), lodgepole pine (0.8%), Engelmann spruce (21.3%), and whitebark pine (57.1%).

MANAGEMENT IMPLICATIONS

Managers need to consider 3 time scales for managing snags in fire-prone forest ecosystems: current pre-fire, short-term post-fire, and long-term post-fire conditions. A goal of pre-fire management would be to manage forest composition, structure, and disturbance regimes within natural ranges of variation to ensure good post-fire snag habitat in both short and long terms (Saab and Dudley 1998, Kotliar et al. in press). Short-term habitat for cavity excavation requires the presence of favored tree species with defects acquired before the fire. Maintenance of natural disturbance regimes—such as insects, disease, and fire—will maintain or restore important pre-fire mortality or structural defects that ensure high-quality, short-term snag habitat (Hutto 1995, Kotliar et al. 2002). Management fostering the development of large trees, particularly early-seral ponderosa pine, Douglas-fir, and western larch in the interior Pacific Northwest, will ensure long-term persistence of snag habitat until new snags are created in the regenerated forest (Saab and Dudley 1998, Everett et al. 1999). Managing for variable tree density, rather than homogeneous spacing, in pre-fire green stands will result in patchy post-fire snag densities that might provide habitat for a broad range of cavity using species (Hutto 1995, Haggard and Gaines 2001, Kotliar et al. in press, Saab et al. 2002).

Where salvage logging might occur after fires, large-diameter ponderosa pine, Douglas-fir, and western larch clearly are key snags to retain because they meet the diameter, decay, and height requirements of most cavity-excavating species (Thomas et al. 1979, Bull et al. 1997), and have the longest residence times (Everett et al. 1999). We did find some large-diameter and soft snags without cavities. Those snags could have been case hardened after fire with subsequent decay significantly delayed (Harmon et al. 1986, Lowell et al. 1992). The location, spatial distribution, or context of those unused snags might not have matched the selection requirements of the bird species. Saab and Dudley (1998) found greater selection for snags among most bird species along edges and in dense clumps versus more evenly distributed snags across burns. Other species, such as Lewis's woodpecker (*Melanerpes lewis*), prefer large decayed snags in open conditions (Tobalske 1997, Saab and Dudley 1998). Haggard and Gaines (2001) concluded that patchy removal of snags by moderate salvage harvest (retention of 15–35 snags/ha) resulted in higher diversity and abundance of cavity using birds than in heavily salvaged (0–12 snags/ha) or unsalvaged (37–80 snags/ha) burns. The absence of topographic influence on cavity occurrence in our study indicates some flexibility for managers in patterning patchy snag retention in burns. Retention of important forage snags species, such as lodgepole pine and western larch, also is important for salvage harvest operations (Bull et al. 1997).

Snags remained hard and cavity excavation rates low during the first 20 years after intense wildfire in our study area. During that early period, cavities were mostly in snags with broken tops, where decay occurred before the fire, or developed more rapidly after fire, than in whole snags. That suggests a management strategy that retains broken-top and defective trees in green stands to serve as early cavity excavation sites in the case of fire (Hutto 1995, Saab and Dudley 1998). If burned areas will be salvage-logged, retention should focus on both short-term retention of defective, broken, or residual snags and long-term retention of large snags (Saab and Dudley 1998, Kotliar et al. in press).

Use of short snags (≤3 m) does not necessarily mean that small snags should be targeted for retention to meet snag-retention guidelines at the expense of harvesting tall snags. Nests in low cavities are more susceptible to predation by terrestrial carnivores (Li and Martin 1991), so these snags are poor habitat from the standpoint of population viability. In recent burns, the issue is largely irrelevant because most new snags will be whole trees. In older burns where most snags have fallen, the remaining short and moderate to large (>23 cm) diameter snags will be the primary nesting sites for cavity using species.

We designed our snag classification model to most accurately predict cavity snags by weighting the misclassification error rate higher for cavity snags than for noncavity snags. This produced a conservative estimate of snag characteristics suitable for cavities such that some noncavity snags would be classified as cavity snags. This conservative classification of cavity snags served our wildlife management purpose well, but at the cost of misclassifying noncavity snags that could be salvage harvested. We ran models with unweighted misclassification rates, but they proved overly complex with many fine splits of few snags. In those unweighted runs, the accuracy of classifying noncavity snags improved over the weighted version, but at the expense of about 10% lower accuracy classifying cavity snags, which was unacceptable. Hence, classification models that weight economic versus conservation goals might be formulated differently. However, we believe that our particular models adequately balance misclassification errors to provide an accurate tool for managers striving to maintain or restore snag habitat in interior Pacific Northwest forest ecosystems.

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