Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Forest Ecology and Management 199 (2004) 323–332
Forest Ecology and Management
www.elsevier.com/locate/foreco

Characteristics of snags containing excavated cavities in northern Arizona mixed-conifer and ponderosa pine forests

Joseph L. Ganey*, Scott C. Vojta

USDA Forest Service, Rocky Mountain Research Station, 2500 S. Pine Knoll, Flagstaff, AZ 86001 USA

Received 31 December 2003; received in revised form 3 April 2004; accepted 16 May 2004

Abstract

Snags provide an important resource for a rich assemblage of cavity-nesting birds in the southwestern United States. To expand our knowledge of snag use by cavity-nesting birds in this region, we documented characteristics of snags with and without excavated cavities in mixed-conifer and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) forest in north-central Arizona. Snags were sampled in 113 square plots (1 ha each) randomly located within a study area covering approximately 73,000 ha across two National Forests. Density of snags was three times greater in mixed-conifer forest ($n = 53$ plots) than in ponderosa pine forest ($n = 60$ plots), but density of snags containing cavities and overall cavity density did not differ between forest types. In both forest types, snags containing cavities were larger in diameter and retained less bark cover than snags without cavities. Most cavities were in ponderosa pine and Gambel oak (*Quercus gambelii* Nutt.) snags, and most were in snags in advanced decay classes with broken tops. Our results are largely consistent with previous results from ponderosa pine forest, but differ from previous studies that documented heavy use of quaking aspen (*Populus tremuloides* Michaux) by cavity nesters in mixed-conifer forest. These results support management to protect and recruit large snags well distributed across the landscape. The relatively high use of ponderosa pine and Gambel oak snags in both forest types suggests that recruitment of large pine and oak snags should be emphasized, and previous studies suggest emphasizing aspen recruitment as well. This may require special management efforts in mixed-conifer forest. These species are relatively shade-intolerant seral species in this forest type, and are apparently declining in this forest type due to fire-suppression efforts and resultant patterns of ecological succession.

Keywords: Arizona; Cavities; Cavity-nesting birds; Gambel oak; Mixed-conifer; Ponderosa pine; Quaking aspen; Snags

1. Introduction

Snags provide a key resource for cavity-nesting birds as well as a wealth of other ecological services (e.g., Thomas et al., 1979; Harmon et al., 1986; Bull et al., 1997; Laudenslayer et al., 2002). As a result, snags have been the target of considerable interest among researchers and land managers (e.g., Thomas et al., 1979; Davis et al., 1983; Laudenslayer et al., 2002).

In the southwestern United States, a rich assemblage of birds is largely dependent on snags to provide nesting sites (e.g., Balda, 1975; Cunningham et al., 1980). A relatively large body of literature describes characteristics of snags used by cavity-nesting birds (e.g., Raphael and White, 1984; Swallow et al., 1986; Saab and Dudley, 1998; Lehmkuhl et al., 2003, see also Laudenslayer et al., 2002), with several studies

* Corresponding author. Tel.: +1 928 556 2156; fax: +1 928 556 2130.
E-mail address: jganey@fs.fed.us (J.L. Ganey).

0378-1127/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2004.05.042

specific to the southwestern United States. Despite these efforts, however, many questions remain. For example, most information on snag use in the southwestern United States refers to ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) forest (Scott, 1978; Cunningham et al., 1980; Horton and Mannan, 1988; Parks et al., 1999; but see Li and Martin, 1991; Conway and Martin, 1993), and patterns of snag use may differ among forest types. Similarly, existing studies of snag use in the southwestern United States generally cover limited geographic areas that were not randomly selected, and thus may not be representative of overall forest conditions in this region.

In conjunction with an effort to monitor dynamics of snags on permanent plots, we had an opportunity to sample characteristics of snags used and not used by cavity excavators in two major forest types (ponderosa pine and mixed-conifer) in north-central Arizona. Snags were sampled on square, 1-ha plots ($n = 113$) randomly located within a large study area (~73,000 ha, Ganey, 1999) that covered most of two National Forests (Fig. 1). These plots sampled an elevational gradient ranging from 1778 to 3050 m, and ranged from the transition zone between ponderosa pine forest and pinyon (*Pinus* spp.) – juniper (*Juniperus* spp.) woodland at lower elevations to the transition from mixed-conifer forest to spruce – fir forest at the highest elevations sampled (Brown et al., 1980). The resulting sample thus should be reasonably representative of the range of forest conditions in these forest types within this geographic region, and provided an opportunity to extend our knowledge of snag use in the southwestern US.

2. Methods

2.1. Field sampling

We sampled snags in summer 2002 in 1-ha plots originally established in 1997 to monitor snag dynamics (Ganey, 1999). Plots were scattered across six Ranger Districts in the Coconino ($n = 4$ districts) and Kaibab National Forests, in north-central Arizona. Plots were established in mixed-conifer ($n = 54$ original plots, 53 of which were re-sampled in 2002) and ponderosa pine ($n = 60$ plots, all re-sampled in 2002) forest using stratified random sampling (for details on plot selection, location, and establishment, see Ganey, 1999). Mixed-conifer forests were dominated by Douglas-fir (*Pseudotsuga menziesii* Mirb., Franco) and/or white fir (*Abies concolor* Lindl. ex Hildebr.). Other common species included ponderosa pine, limber pine (*P. flexilis* James), Gambel oak (*Quercus gambelii* Nutt.), and quaking aspen (*Populus tremuloides* Michaux). Ponderosa pine forest was dominated by ponderosa pine, but Gambel oak also was common. Alligator juniper (*Juniperus deppeana* Steud) Douglas-fir, quaking aspen, limber pine, and other species of juniper were present in small numbers in some stands.

During the 2002 inventory, we recorded species, diameter at breast height (dbh, in cm), height (m), decay class (Raphael and White, 1984; see Table 1), bark cover (percentage of trunk, based on a visual estimate), and top condition (broken versus intact) for all snags encountered on these plots. We also visually inspected all snags for occurrence of excavated cavities (defined as round excavations >2.5 cm diameter and appearing deep enough for use by nesting birds; Lehmkuhl et al., 2003), and recorded numbers of such cavities per snag. We made no attempt to identify the species of bird that excavated the cavity.

2.2. Data analysis

For most analyses, snags were grouped into two classes (with and without excavated cavities), and data on snag characteristics were summarized by group and forest type. We used Mann–Whitney tests (Conover, 1980; pp. 216–227) to test the null hypothesis that snag density did not differ between forest types within snag group (i.e., snags with and without excavated cavities). We also estimated number of cavities per snag containing cavities and overall density of cavities by forest type.

We used separate Chi-square tests for independence (Conover, 1980; pp.158–162) to test the null hypotheses that there was no difference between snag populations with and without cavities with respect to species composition, decay class, and top condition. We used separate Mann–Whitney tests to test the null hypotheses that snag diameter, height, and bark cover did not differ between snags with and without cavities. These latter comparisons again were stratified by forest type.

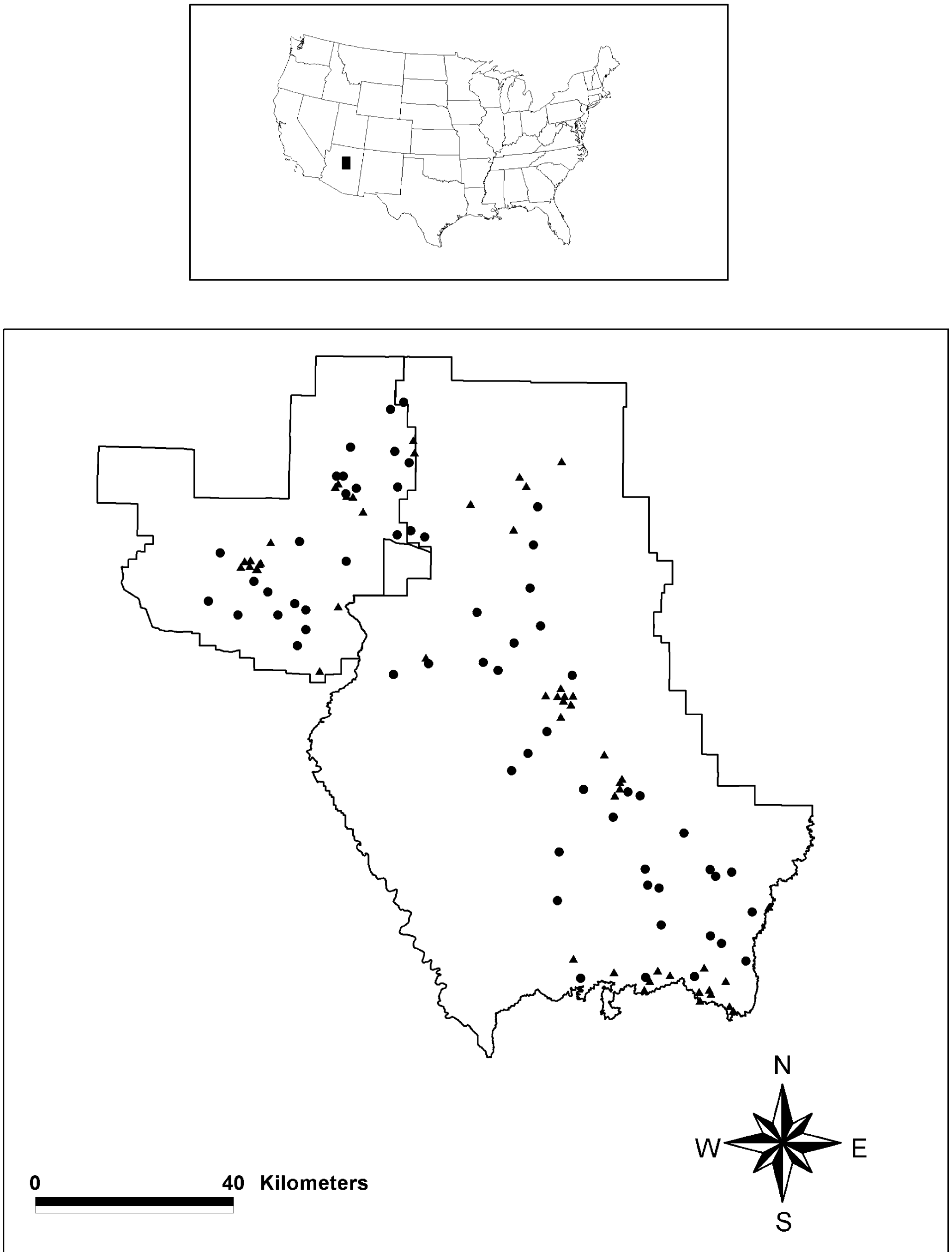

Fig. 1. Location of the study area (black box) in north-central Arizona, USA, and locations of snag-monitoring plots within the study area (bottom). The Coconino and Kaibab National Forests occur to the right and left sides, respectively, of the bottom map. Plots in ponderosa pine forest ($n = 60$) are indicated by circles, plots in mixed-conifer forest ($n = 53$) by triangles. The more clumped distribution of mixed-conifer plots reflects the more restricted distribution of mixed-conifer forest within the study area.

Table 1
Criteria used to classify snags into decay classes in ponderosa pine and mixed-conifer forests, northern Arizona (after Raphael and White, 1984)

Decay class	Needles	Twigs	Limbs
1	Present	Present	Intact
2	Absent	Present	Intact
3	Absent	Absent	Mostly intact
4	Absent	Absent	Mostly broken
5	Absent	Absent	Gone

3. Results

We sampled 2565 snags, 1938 in mixed-conifer plots and 627 in ponderosa pine plots. Excavated cavities occurred in 219 snags, 112 (5.8% of total snags) in mixed-conifer plots and 107 (17.1%) in ponderosa pine plots. Cavities were found in 81% of mixed-conifer plots and 73% of ponderosa pine plots, suggesting that cavities were well distributed across the landscape.

Density of snags without excavated cavities was approximately three times greater in mixed-conifer forest than in ponderosa pine forest ($P < 0.001$; Fig. 2), but density of snags with cavities did not differ between forest types ($P = 0.132$; Fig. 2). Mean number of cavities per snag was greater for snags with excavated cavities in ponderosa pine forest (2.7 ± 0.3; S.E.) than in mixed-conifer forest (1.9 ± 0.1; $P < 0.001$). As a result, mean density of cavities was slightly but not significantly greater in ponderosa pine forest (5.0 ± 0.9 cavities/ha) than in mixed-conifer forest (3.5 ± 0.5 cavities/ha; $P = 0.782$).

Species composition differed significantly between snags with and without cavities in mixed-conifer forest ($P < 0.001$) but not in ponderosa pine forest ($P = 0.381$; Fig. 3). Most excavated cavities were in ponderosa pine snags in both forest types (Fig. 3). In mixed-conifer forest, ponderosa pine snags comprised 63% of snags with cavities versus 23% of snags without cavities. Gambel oak comprised approximately 15% of the population of snags with cavities in both forest types, whereas no other species comprised >10% of snags with cavities in either forest type.

Snags with cavities were significantly larger in diameter than snags without cavities in both forest types (Fig. 4; $P < 0.001$ in both forest types). In both forest types, approximately 70% of snags without cavities were <40 cm in diameter, whereas approxi-

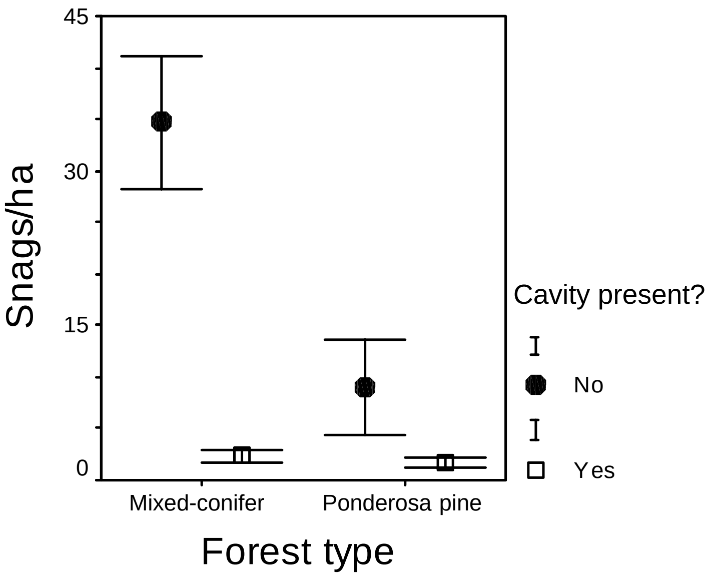

Fig. 2. Mean (± 95% confidence interval) density of snags with and without excavated cavities in mixed-conifer and ponderosa pine forests, northern Arizona, 2002. Snags were sampled in 1-ha plots randomly located throughout the Coconino and Kaibab National Forests. Snags ($n = 1938$ and 627) sampled in mixed-conifer (53 plots, 112 snags with cavities) and ponderosa pine forests (60 plots, 107 snags with cavities), respectively. Density of snags with cavities did not differ significantly between forest types, whereas density of snags without cavities did.

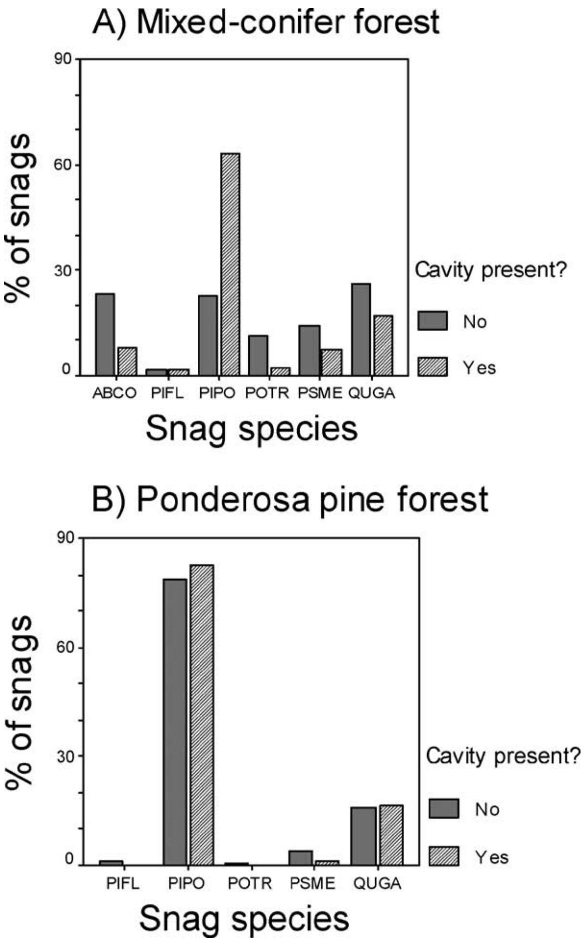

Fig. 3. Proportions of snags with and without excavated cavities, by snag species, in northern Arizona mixed-conifer (A; $n = 1938$ snags, 112 with cavities) and ponderosa pine (B; $n = 627$ snags, 107 with cavities) forest, 2002. Species shown are: ABCO, white fir; PIFL, limber pine; PIPO, ponderosa pine; POTR, quaking aspen; PSME, Douglas-fir; and QUGA, Gambel oak. Ponderosa pine snags were used selectively for cavity excavation in mixed-conifer forest, whereas species composition did not differ between snags with and without cavities in ponderosa pine forest.

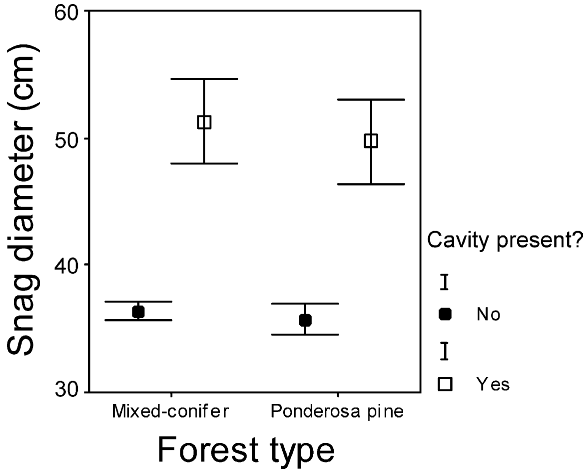

Fig. 4. Mean (± 95% confidence interval) diameter at breast height for snags with and without excavated cavities in northern Arizona mixed-conifer ($n = 1938$ snags, 112 with cavities) and ponderosa pine ($n = 627$ snags, 107 with cavities) forests, 2002. In both forest types, mean diameter was significantly greater for snags containing excavated cavities than for snags without excavated cavities.

mately 70% of snags with cavities were >40 cm in diameter (Fig. 5). Snag height did not differ between populations with and without cavities ($P > 0.296$ in both forest types; Fig. 6).

Snags with cavities retained less bark cover than snags without cavities in both forest types (Fig. 7; $P < 0.001$ in both forest types). Decay-class distributions also differed between snags with and without cavities in both forest types (Fig. 8; $P < 0.001$). In both types, decay classes 3–5 were better represented in the snag population with cavities than in the population without cavities. Snags with cavities also were more likely to have a broken top than were snags without cavities (Fig. 9; $P < 0.005$ in both forest types).

4. Discussion

Overall, characteristics of snags containing excavated cavities were relatively similar in both forest types sampled in this study. This may reflect similarity in the primary species of cavity excavators between these forest types. Although we did not identify species responsible for excavating cavities, the most abundant large excavators in both forest types were northern flickers (*Colaptes auratus* Linnaeus) and hairy woodpeckers (*Picoides villosus* Linnaeus). Other woodpecker species present in the study area included downy (*P. pubescens* Linnaeus), acorn (*Melanerpes formicivorus* Swainson), American three-toed (*P. dorsalis* Baird, see Banks et al., 2003), and Lewis' (*M. lewis* Gray; primarily in open ponderosa pine forest) woodpeckers, and red-naped (*Sphyrapicus nuchalis* Baird) and Williamson's (*S. thyroideus* Cassin; primarily in mixed-conifer forest) sapsuckers.

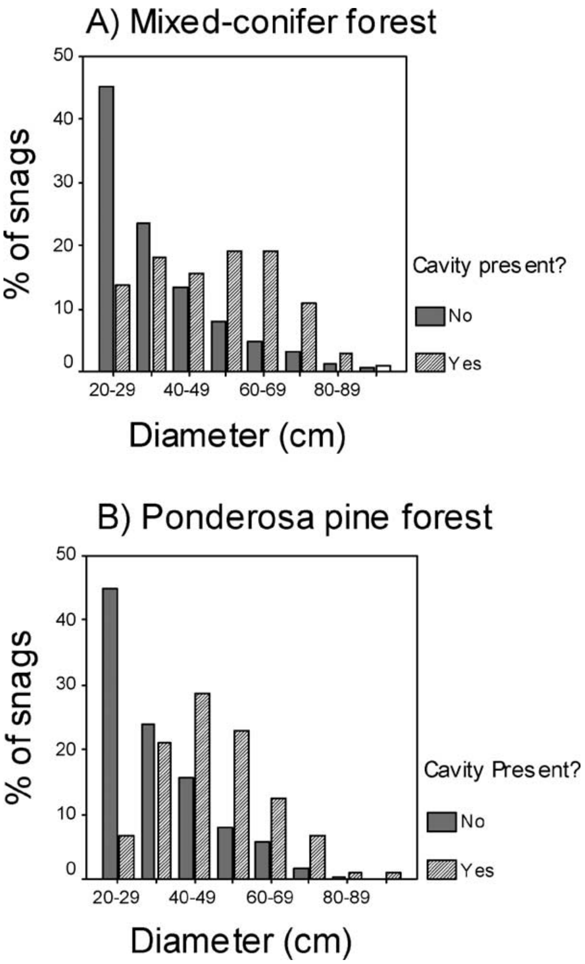

Fig. 5. Distribution of snags with and without excavated cavities across 10-cm diameter classes in mixed-conifer (A; $n = 1938$ snags, 112 with cavities) and ponderosa pine (B; $n = 627$ snags, 107 with cavities) forest, northern Arizona, 2002. Snags <40 cm dbh dominated populations of snags without cavities, whereas snags with dbh >40 cm dominated populations of snags with excavated cavities.

These species were generally far less abundant, however, and some were present only seasonally (e.g., Hall et al., 1997; Table 1). Red-breasted (*Sitta canadensis* Linnaeus) and white-breasted (*S. carolinensis* Linnaeus) nuthatches also were present in the area, but the extent to which they excavate cavities in this area is unknown.

Our data were largely consistent with other studies that examined characteristics of snags used by cavity-excavating birds in southwestern forests, with some differences. Similar to our study (Figs. 4 and 5), these studies suggested that cavity excavators preferentially used large-diameter snags, although the specifics of snag size differed among studies (Scott, 1978; Cunningham et al., 1980; Horton and Mannan, 1988; Li and Martin, 1991; Conway and Martin, 1993).

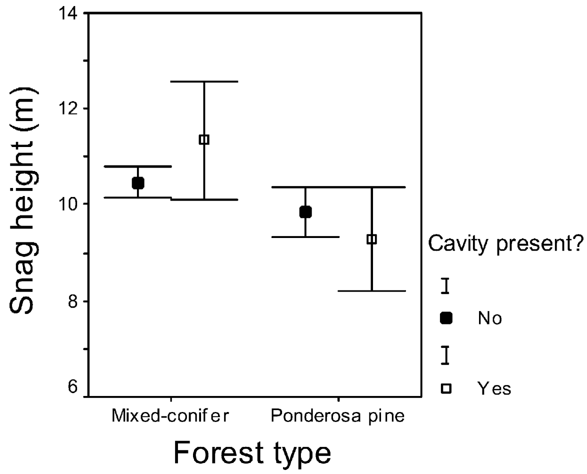

Fig. 6. Mean (± 95% confidence interval) height for snags with and without excavated cavities in northern Arizona mixed-conifer ($n = 1938$ snags, 112 with cavities) and ponderosa pine ($n = 627$ snags, 107 with cavities) forests, 2002. In both forest types, mean height was similar for snags with and without excavated cavities.

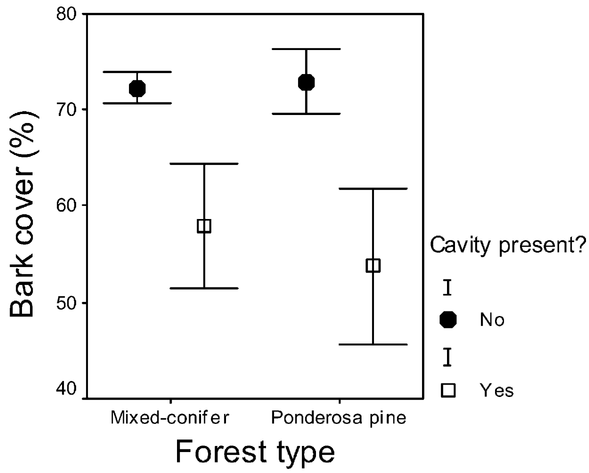

Fig. 7. Mean (± 95% confidence interval) percent bark cover for snags with and without excavated cavities in northern Arizona mixed-conifer ($n = 1938$ snags, 112 with cavities) and ponderosa pine ($n = 627$ snags, 107 with cavities) forests, 2002. In both forest types, snags containing excavated cavities had significantly less bark cover than snags without excavated cavities.

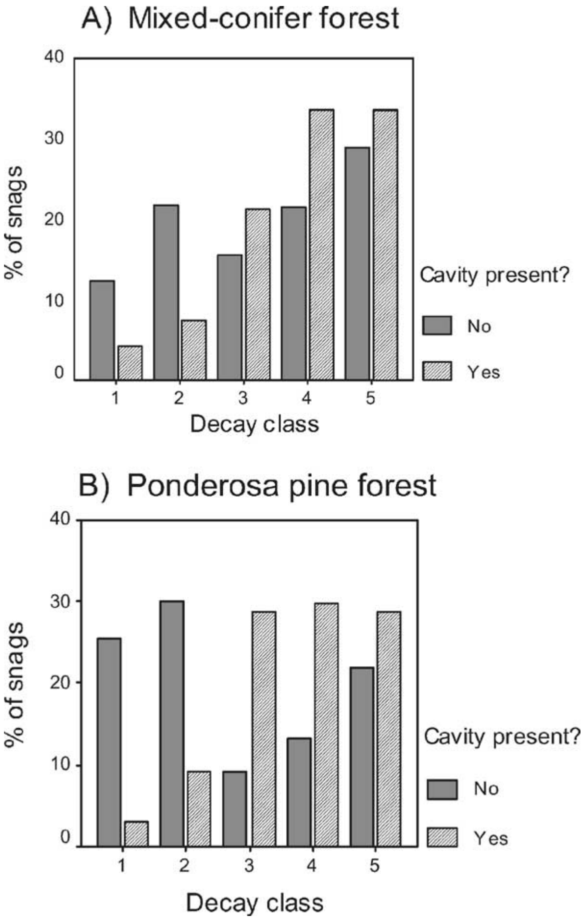

Fig. 8. Proportions of snags with and without excavated cavities in five decay classes (defined in Table 1) in northern Arizona mixed-conifer (A; $n = 1938$ snags, 112 with cavities) and ponderosa pine (B; $n = 627$ snags, 107 with cavities) forest, 2002. Snags were concentrated in decay classes 3–5 in both forest types.

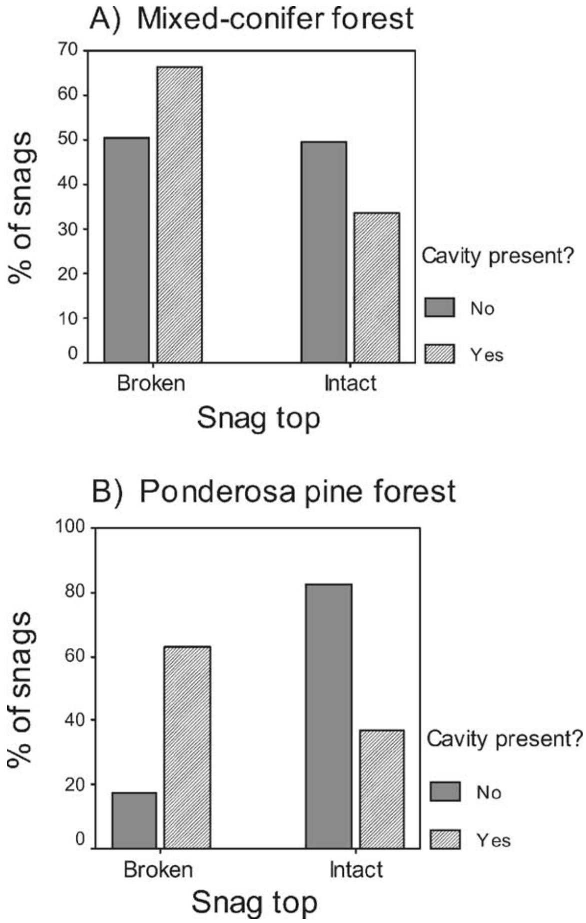

Fig. 9. Proportions of snags in northern Arizona with and without excavated cavities, by snag top status, in northern Arizona mixed-conifer (A; $n = 1938$ snags, 112 with cavities) and ponderosa pine (B; $n = 627$ snags, 107 with cavities) forest, 2002. In both forest types, most snags with excavated cavities had broken tops.

Our finding that most snags with cavities occurred in decay classes 3–5 (Fig. 8) was generally consistent with results in Horton and Mannan (1988). They noted that simple presence of cavities in snags did not necessarily reflect preference by cavity nesters with respect to decay class, however. Specifically, they noted that many cavities in snags in advanced decay classes may have been excavated and used when snags were younger and less decayed. They also noted, however, that snags may be under-represented in advanced decay classes when the tops of these snags (where many cavities occur) break off. Most snags with cavities had broken tops in our study (Fig. 9).

Cunningham et al. (1980) reported that most of the snags used by cavity-nesting birds in their study were <30 years old. We are monitoring snag dynamics on these plots, but have not sampled long enough to be able to accurately reference our decay classes to snag age. Only 10.5% of the snags with cavities in this study were in snags recruited between 1997 and 2002, however. Thus, we can confidently say that 89.5% of snags containing cavities in this study were >5 years in age, but otherwise can not yet comment on age of used snags.

Both Scott (1978) and Cunningham et al. (1980) noted that snags with >40% bark cover received high use, and Cunningham et al. (1980) suggested that snags with >60% bark cover received the greatest use. Mean bark cover for snags with cavities was >40 but <60% in both forest types in this study (Fig. 7), but again, snags may have retained greater bark cover when cavities were excavated.

We also noted several differences between our results and results in the literature. Both Scott (1978) and Cunningham et al. (1980) reported high use of very tall snags, whereas we found no difference in snag height between snags with and without cavities. Admittedly, however, most snags containing cavities had broken tops, and these snags may have been considerably taller when the cavity was excavated.

Another difference observed relates to species of snag used in mixed-conifer forest. Li and Martin (1991) reported preferential use of aspen snags by cavity nesters in northern Arizona mixed-conifer forest, and Conway and Martin (1993) noted similar trends for Williamson's sapsuckers. In contrast, we saw no evidence of preference for aspen snags in mixed-conifer forests we sampled. Rather, ponderosa pines were heavily used in both forest types, many Gambel oak snags also contained cavities, and little use of aspen snags was observed (Fig. 3).

We are not sure how to explain this difference. It may be partially due to differences among geographic areas and/or habitats. Although our study area partially overlapped those of Li and Martin (1991) and Conway and Martin (1993), we also sampled mixed-conifer forests outside of this geographic area, and outside of the high-elevation snow melt drainages they sampled. The observed differences therefore may simply indicate the need for area-specific information and/or broad sampling (although we note that both Li and Martin (1991) and Conway and Martin (1993) sampled over relatively large areas).

Density of snags with excavated cavities was remarkably similar in both forest types, despite the much greater overall abundance of snags in mixed-conifer forest (Fig. 2). As with characteristics of used snags, this may indicate similarity between these forest types in the community of cavity-nesting birds.

Brawn and Balda (1988) documented nest-site limitation of breeding density for some species of snag-dependent secondary cavity nesters in northern Arizona ponderosa pine forests. We are unaware of any such data for mixed-conifer forests, but cavity-nesting birds have not been studied extensively in this forest type. Overall densities of snags in this study were far greater than densities of snags with cavities in both forest types (Fig. 2), apparently providing little support for the hypothesis that snags are limiting in either forest type. Snags with suites of characteristics attractive to cavity excavators could still be limiting, however. For example, most cavities were excavated in snags in ponderosa pine or Gambel oak that were >40 cm dbh, retained <70% bark cover, occurred in decay classes 3–5, and had broken tops (Figs. 3, 5 and 7–9). Only 149 and 90 such snags occurred in mixed-conifer and ponderosa pine forest, respectively. Resulting approximate densities of such snags (2.8 and 1.5 snags/ha in mixed-conifer and ponderosa, respectively) thus were lower than observed densities of snags with excavated cavities in both forest types (Fig. 2). Consequently, although snags overall were abundant and well distributed, we can not rule out the possibility that snags with complex suites of characteristics rendering them desirable to excavators are limiting in these forest types.

In summary, most snags containing cavities in our study were in large-diameter snags with broken tops in decay classes 3–5 (Figs. 2, 9 and 8, respectively). These snags typically retained >40% bark cover (Fig. 7), and the most common species used were ponderosa pine and Gambel oak, in that order (Fig. 3). Such snags occurred in relatively low densities across the landscape. These findings support management efforts to protect and/or recruit large snags. They further suggest that ponderosa pine and Gambel oak are important species deserving special management attention, and previous studies suggest that aspen should be included in this group as well (Li and Martin, 1991; Conway and Martin, 1993).

Recruiting large snags in these species may require special management, especially in mixed-conifer forest. All three of these species are relatively shade-intolerant seral species that historically were maintained in southwestern mixed-conifer stands by disturbance events, especially fire (e.g., Dieterich, 1983; Covington et al., 1994; Johnson, 1994; Dahms and Geils, 1997; Kaufmann et al., 1998). All three are apparently declining in mixed-conifer stands due to fire suppression and resultant patterns of ecological succession (Dieterich, 1983; Johnson, 1994; Dahms and Geils, 1997; Kaufmann et al., 1998). Until we can safely return fire to these areas as a natural disturbance agent, maintaining these species in mixed-conifer stands may require selective harvest and/or creation of canopy gaps. This also may be true for aspen and oak in ponderosa pine stands. It also may require special efforts to protect regenerating oak and aspen from browsing by elk and livestock (Dahms and Geils, 1997; Kaufmann et al., 1998), and to protect both live and dead oak trees from illegal fuelwood harvesting (May and Gutiérrez, 2002). Finally, note that we do not mean to imply that other species of snags are unimportant. Rather, we believe that maintaining most shade-tolerant species will not require special management.

Acknowledgements

Special thanks to A. Iníguez and J. Iníguez for their help with initial establishment of snag-monitoring plots. E.L. Bull, C.L. Chambers, R.N. Conner, and an anonymous reviewer commented on earlier drafts of this paper.

References

Balda, R.P., 1975. The Relationship of Secondary Cavity Nesters to Snag Densities in Western Coniferous Forests. Wildlife Habitat Technical Bulletin 1. USDA Forest Service, Southwestern Region, Albuquerque, New Mexico, 37 pp.

Banks, R.C., Cicero, C., Dunn, J.L., Kratter, A.W., Rasmussen, P.C., Remsen Jr., J.V., Rising, J.D., Stotz, D.F., 2003. Forty-fourth supplement to the American Ornithologists' Union checklist of the birds of North America. Auk 102, 923–931.

Brawn, J.D., Balda, R.P., 1988. Population biology of cavity nesters in northern Arizona: do nest sites limit breeding densities? Condor 90, 61–71.

Brown, D.E., Lowe, C.H., Pase, C.P., 1980. A Digitized Systematic Classification for Ecosystems with an Illustrated Summary of the Natural Vegetation of North America. USDA Forest Service General Technical Report RM-73. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, 93 pp.

Bull, E.L., Parks, C.G., Torgersen, T.R., 1997. Trees and Logs Important to Wildlife in the Interior Columbia River Basin. USDA Forest Service General Technical Report PNW-GTR-391. Pacific Northwest Research Station, Portland, Oregon, 55 pp.

Conover, W.J., 1980. Practical Nonparametric Statistics, second ed. John Wiley & Sons, New York, 493 pp.

Conway, C.J., Martin, T.E., 1993. Habitat suitability for Williamson's Sapsuckers in mixed-conifer forests. J. Wildlife Manage. 57, 322–328.

Covington, W.W., Everett, R.L., Steele, R., Irwin, L.L., Daer, T.A., Auclair, A.N.D., 1994. Historical and anticipated changes in forest ecosystems of the inland west of the United States. J. Sustainable Forestry 2, 13–63.

Cunningham, J.B., Balda, R.P., Gaud, W.S., 1980. Selection and Use of Snags by Secondary Cavity-nesting Birds of the Ponderosa Pine Forest. USDA Forest Service Research Paper RM-222. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, 15 pp.

Dahms, C.W., Geils, B.W., 1997. An Assessment of Forest Ecosystem Health in the Southwest. USDA Forest Service General Technical Report RM-GTR-295. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, 97 pp.

Davis, J.W., Goodwin, G.A., Ockenfels, R.A. (technical coordinators), 1983. Snag habitat management: Proceedings of the symposium on USDA Forest Service General Technical Report RM-99. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, 226 pp.

Dieterich, J.H., 1983. Fire history of southwestern mixed-conifer: a case study. Forest Ecol. Manage. 6, 13–31.

Ganey, J.L., 1999. Snag density and composition of snag populations on two National Forests in Arizona. Forest Ecol. Manage. 117, 169–178.

Hall, L.S., Morrison, M.L., Block, W.M., 1997. Songbird status and roles. In: Block, W.M., Finch, D.M. (Eds.), Songbird Ecology in Southwestern Forests: A Literature Review. USDA Forest Service General Technical Report. RM-GTR-292. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, pp. 69–88.

Harmon, M.A., Franklin, J.F., Swanson, F.J., Sollins, P., Gregory, S.V., Lattin, J.D., Anderson, N.H., Cline, S.P., Aumen, N.G., Sedell, J.R., Lienkamper, G.W., Cromack Jr., K., Cummins, K.W., 1986. Ecology of coarse woody debris in temperate ecosystems. Adv. Ecol. Res. 15, 133–302.

Horton, S.P., Mannan, R.W., 1988. Effects of prescribed fire on snags and cavity-nesting birds in southeastern Arizona pine forests. Wildlife Soc. Bull. 16, 37–44.

Johnson, M., 1994. Changes in southwestern forests: stewardship implications. J. Forestry 92 (12), 16–19.

Kaufmann, M.R., Huckaby, L.S., Regan, C.M., Popp, J., 1998. Forest Reference Conditions for Ecosystem Management in the Sacramento Mountains, New Mexico. USDA Forest Service General Technical Report RMRS-GTR-19. Rocky Mountain Research Station, Fort Collins, Colorado, 87 pp.

Laudenslayer, W.F., Jr., Shea, P.J., Valentine, B.E., Weatherspoon, C.P., Lisle, T.E. (technical coordinators), 2002. Proceedings of the Symposium on the Ecology and Management of Dead Wood in Western Forests. USDA Forest Service General Technical Report PSW-GTR-181. Pacific Southwest Research Station Albany, California, 949 p.

Lehmkuhl, J.F., Everett, R.L., Schellhaas, R., Ohlson, P., Keenum, D., Riesterer, H., Spurbeck, D., 2003. Cavities in snags along a wildfire chronosequence in eastern Washington. J. Wildlife Manage. 67, 219–228.

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

May, C.A., Gutiérrez, R.J., 2002. Habitat associations of Mexican spotted owl nest and roost sites in central Arizona. Wilson Bull. 114, 57–466.

Parks, C.G., Conklin, D.A., Bednar, L., Maffei, H., 1999. Woodpecker Use and Fall Rates of Snags Created by Killing Ponderosa Pine Infected with Dwarf Mistletoe. USDA Forest Service Research Paper PNW-RP-115. Pacific Northwest Research Station, Portland, Oregon, 11 pp.

Raphael, M.G., White, M., 1984. Use of snags by cavity-nesting birds in the Sierra Nevada. Wildlife Monogr. 86, 1–66.

Saab, V.A., Dudley, J.G., 1998. Responses of Cavity-nesting Birds to Stand-replacement Fire and Salvage Logging in Ponderosa Pine/Douglas-fir Forests of Southwestern Idaho. USDA Forest Service Research Paper RMRS-RP-11. Rocky Mountain Research Station, Fort Collins, Colorado, 17 pp.

Scott, V.E., 1978. Characteristics of ponderosa pine snags used by cavity-nesting birds in Arizona. J. Forestry 76, 26–28.

Swallow, S.K., Gutiérrez, R.J., Howard Jr., R.A., 1986. Primary cavity-site selection by birds. J. Wildlife Manage. 50, 576–583.

Thomas, J.W., Anderson, R.G., Maser, C., Bull, E.L., 1979. Snags. In: Thomas, J.W. (technical editor), Wildlife Habitats in Managed Forests: The Blue Mountains of Oregon and Washington. USDA Agricultural Handbook 553. Washington, DC, pp. 60–77.