Snags and Cavity-Nesting Birds within Intensively Managed Pine Stands in Eastern North Carolina, USA

Jessica A. Homyack, Barton J. Paxton, Michael D. Wilson, Bryan D. Watts, and Darren A. Miller

ABSTRACT

Although snags are often considered to be a limiting factor for cavity-nesting birds within intensively managed pine (*Pinus* spp.) stands, there is little information regarding occurrences of snags and cavity-nesting birds for such stands in the southeastern United States. Therefore, during 2002–2003, we measured characteristics of individual snags ($n = 1{,}218$) and quantified the relative abundance of cavity-nesting birds ($n = 204$ observations; nine species) in 35 forest stands representing seven thinning classes (prior to thinning, three age classes following a first commercial thinning, and three age classes following a second commercial thinning entry) in intensively managed pine stands in eastern North Carolina. Snag populations were dynamic, with 649 snags falling and 75 new snags recruited between years. Stands in later thinning classes tended to have snags with larger diameters, less bark, and fewer limbs, and they were taller and more decayed ($P < 0.05$). Our data suggest that neither density of snags ($P = 0.31$) nor relative abundance of cavity-nesting birds ($P = 0.25$) differed strongly among thinning classes. Without active management, low recruitment coupled with the high loss rates that we observed could lead to low snag densities in older managed stands. Therefore, we suggest that forest managers consider retaining large-diameter dead or live trees as reserve trees through multiple rotations to increase or maintain snags in managed stands.

Keywords: cavity-nesting birds, dead wood dynamics, forest management, intensive forestry, loblolly pine, North Carolina, *Pinus taeda*, plantation, snag, silvicultural thinning

Managed pine (*Pinus* spp.) plantations, which included 12.9 million ha in the southeastern United States in 1999 (Wear and Greis 2002), provide approximately 15% of global wood fiber needs (Siry et al. 2006). As wood demands increase globally, it is projected that additional intensively managed forests may be necessary to meet fiber and wood products needs (Wagner et al. 2004). However, in addition to producing wood, forest landowners increasingly are expected to consider effects of forest practices on biodiversity (Miller et al. 1995, Hartley 2002, Miller et al. 2009). For example, forest certification systems typically require participants to manage for biodiversity within silvicultural regimes (e.g., Sustainable Forestry Initiative 2009a). With >170 million ha of forest in North America receiving green certification from the Sustainable Forestry Initiative (2009b), Forest Stewardship Council (2009), or Canadian Standards Association (2009), it is imperative that managers understand how forestry practices, including intensive forest management, which includes multiple silvicultural practices to increase wood fiber production, affect structural characteristics that relate positively to biodiversity on their landscapes (Moore and Allen 1999).

Snags are critically important structures for a wide range of vertebrate, invertebrate, and plant species (Davis et al. 1983, Freedman et al. 1996, McComb and Lindenmayer 1999), including 85 species of North American birds that depend on snags for foraging, roosting, communicating, and/or nesting (Scott et al. 1977, Raphael and White 1984). Primary cavity nesters, such as woodpeckers (family Picidae), excavate cavities in snags that are in turn used by secondary cavity nesters, including Carolina chickadees (*Poecile carolinensis*) and tufted titmice (*Baeolophus bicolor*) (Hamel 1992).

Within intensively managed forest stands, however, short rotations, conflicting management objectives, and removal of snags because of concerns about safety or wildfires may limit snag abundances (e.g., Scott et al. 1977, Cline et al. 1980, Raphael and White 1984, McComb et al. 1986). Plantation forests, which are often managed intensively using site preparation, chemical and fertilizer treatments, planting of specific genotypes or clones, and/or midrotation thinnings, attempt to maximize growth and survival of overstory trees to increase economic return (Freedman et al. 1996). These silvicultural treatments reduce mortality of crop trees but may also decrease snag resources. There are concerns that pine plantations with presumably low snag densities may limit populations of cavity-nesting birds (Harlow and Guynn 1983, McComb et al. 1986, Land et al. 1989) or other wildlife dependent on standing dead wood (Freedman et al. 1996). However, the large area of forest in plantations in the southeastern United States offers opportunities

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This article uses metric units; the applicable conversion factors are: centimeters (cm): 1 cm = 0.39 in.; meters (m): 1 m = 3.3 ft; hectares (ha): 1 ha = 2.47 ac.

for forest managers to enhance habitat features for snag-associated fauna throughout the typical rotation.

Although a small number of researchers have described snag resources for industrial timberlands in the southeastern United States (McComb et al. 1986, Land et al. 1989, Moorman et al. 1999), few studies have quantified snag abundances in intensively managed pine stands across the range of silvicultural treatments applied within a typical rotation, such as commercial thinnings. Even less information is available on temporal changes in snag abundances on managed forest landscapes (Cline et al. 1980, McComb and Lindenmayer 1999) and on relationships between snags in intensively managed forests in the southeastern United States and cavity-nesting birds (but see Harlow and Guynn 1983, Land et al. 1989).

To address these critical information gaps, we examined a suite of intensively managed pine stands at a range of ages postthinning and (1) characterized available snags, (2) evaluated combined effects of silvicultural thinning and years postthinning on snag dynamics, (3) determined the response of cavity-nesting birds to silvicultural thinning and years postthinning, and (4) evaluated relationships between cavity-nesting birds and snags. We predicted that intensively managed stands would support few large snags (≥20.0 cm dbh) and that snag abundances would be lower in stands that were thinned multiple times. We also predicted that abundance of cavity-nesting bird species would be related to availability of large snags at the stand scale.

Methods

Study Area

We examined snag dynamics and characteristics and cavity-nesting birds within managed forests in eastern North Carolina. This region was once dominated by pocosin wetlands, but wetlands were drained by an extensive network of ditches and canals constructed to support agriculture (Chescheir et al. 2003). Our study landscape was a matrix of primarily (>85%) loblolly pine (*Pinus taeda*) stands in different successional stages with residential areas and agricultural fields interspersed throughout Beaufort, Martin, and Washington counties on the Albemarle-Pamlico Peninsula. Study sites were owned by Weyerhaeuser Company, which managed them for loblolly pine sawtimber. Typical silvicultural treatments included site preparation (V-sheared and bedded), planting with loblolly pine at <1,200 stems/ha, intermediate fertilizations, herbicide application(s), and two commercial thins prior to final clearcut harvest. The desired densities of crop trees after the first and second thinnings were approximately 330 and 210 trees/ha, respectively. From those available on the landscape, we used a stratified random approach to select stands that met our criteria for management history; we excluded stands scheduled to be thinned or harvested during the study or those where active harvesting restricted our access. Stand size was 9–113 ha ($\bar{x}$ = 41, SE = 10 ha) and stands were separated by 0–5,260 m ($\bar{x}$ = 363.0, SE = 201.5 m). Selected stands were embedded in a matrix of forests of various ages with similar site histories.

Our study design consisted of five replicates of seven thinning classes (n = 35 study sites), representing forest structure in a chronosequence from early to late rotation. Thinning classes included pine plantations that were (1) not yet thinned where understory vegetation had been chopped (9–10 years old), (2) 1–2 years after the first commercial thinning (15–17 years old), (3) 3–4 years after the first commercial thinning (18–22 years old), (4) 5–6 years after the first commercial thinning (19–22 years old), (5) 1–2 years after the second commercial thinning (26–30 years old), (6) 3–4 years after the second commercial thinning (27–33 years old), and (7) 5–6 years after the second commercial thinning (29–32 years old). Although stands overlapped in age among some thinning classes, tree density after thinning had by far the greatest influence on stand structure, growth, and yield (e.g., Smith et al. 1997).

Snag Dynamics

From May 5 to July 15, 2002, we measured snags on one 9-ha plot within each study site. Sampling plots were centered along the road frontage and moved interior from the first row of trees. When possible, we used 300 × 300 m square plots. For smaller or more rectangular stands, the dimensions of the 9-ha sampling plot was adjusted to be more rectangular and fit within boundaries of the stand. We systematically walked every lane between rows of crop trees and identified snags, which we defined from our extensive experience working in managed pine plantations as stems ≥8 cm dbh, ≥1.5 m in height, with no live needles or leaves, and leaning <35°. Within a plot, we marked each snag with a numbered aluminum tree tag and estimated snag height (m) with a telescoping height pole or clinometer, quantified dbh (cm) with a dbh tape, counted number of limbs projecting from the main stem, visually estimated coverage of bark to the nearest 5%, and recorded whether snags were hardwood or pine. We grouped snags into the following dbh categories: (1) 8–11.9 cm, (2) 12–15.9 cm, (3) 16–19.9 cm, (4) 20–24.9 cm, and (5) ≥25 cm. We also assigned snags into a decay class from 1 to 5 (from least decayed to most decayed) based on the presence or absence of needles, percentage of bark remaining on the main stem, and presence or absence of lateral limbs (adapted from Cline et al. 1980). We walked around each snag and visually inspected it for cavities with binoculars; we excluded cavity starts or natural crevices (Moorman et al. 1999). We returned to the same sites from May 8 to July 16, 2003, to quantify snags that perished (i.e., fell) and the abundance of newly formed snags. However, because of logistical constraints resulting from extensive flooding, we measured new snags only in a 4-ha nested subplot.

Cavity-Nesting Birds

We conducted surveys for cavity-nesting birds on 300-m-long transects that extended through the center of each 9-ha study block. Twice per year (June 3 to July 19, 2002, and June 5 to July 31, 2003), between sunrise and 4 hours after sunrise, observers slowly walked each transect and recorded all birds encountered to species by sight or sound that were within 100 m perpendicular distance from the transect. Although our transect sampling likely encompassed incubation and nesting periods for renesting attempts or the rare second clutch, our observations should be considered estimates of postbreeding abundances of cavity-nesting species. We assumed number of observations was linearly related to abundance and that this relationship did not differ among sampling periods or thinning classes. It is possible that detection of cavity-nesting birds could have been biased either by the presence and amount of understory vegetation (by reducing the ability to visually or aurally detect birds) or by differences in abilities of observers within or across years. However, only a limited number of trained observers conducted surveys, and density of understory vegetation varied with site-specific soil and moisture conditions that likely was not correlated with thinning class. We considered mean number of cavity-nesting bird observations as an index of abundance.

Table 1. Mean (SD) values for characteristics of snags sampled in intensively managed plantations of loblolly pine (*Pinus taeda*) in eastern North Carolina in 2002. Site preparation of forest stands included shearing, bedding, fertilization, and chemical release. Snags were defined as follows: standing dead stem >1.5 m tall, dbh >8 cm, no live needles or leaves, and leaning <35°.

	Thinning Class (n = 5)						
Characteristic and Year	Prethin	1–2 years post-1st thin	3–4 years post-1st thin	5–6 years post-1st thin	1–2 years post-2nd thin	3–4 years post-2nd thin	5–6 years post-2nd thin
Density (no./ha)	2.5 (3.6)	6.1 (5.8)	5.7 (3.9)	5.0 (5.0)	2.8 (1.0)	2.0 (1.1)	2.2 (1.3)
Basal area (m^2/ha)	0.03 (0.05)	0.10 (0.10)	0.13 (0.09)	0.14 (0.12)	0.14 (0.06)	0.09 (0.05)	0.08 (0.04)
Height (m)^a	4.2 (0.6)^d	6.6 (1.8)^{b,c}	5.7 (0.8)^{c,d}	7.1 (1.2)^{b,c}	9.8 (2.9)^b	8.2 (1.7)^{b,c}	8.9 (1.2)^b
dbh (cm)^a	10.7 (0.9)^d	13.7 (1.8)^d	16.5 (1.3)^{c,d}	20.2 (4.4)^{b,c}	23.6 (5.6)^b	22.7 (2.6)^{b,c}	21.3 (2.8)^{b,c}
Limbs (no./snag)^a	15.7 (3.4)^b	7.9 (8.1)^{b,c}	3.0 (2.8)^c	7.0 (1.7)^{b,c}	11.8 (7.4)^{b,c}	4.9 (2.6)^c	6.2 (1.7)^c
Decay class (1–5)^a	2.1 (0.6)^c	3.2 (0.1)^b	4.1 (0.6)^b	3.7 (0.5)^b	3.4 (0.6)^b	4.0 (0.5)^b	3.9 (0.2)^b
Bark (%)^a	83 (9)^b	83 (3)^{b,c}	45 (21)^d	60 (16)^{c,d}	55 (9)^d	51 (17)^d	50 (3)^d
Cavities (#/snag)^a	0 (0)^d	0 (0)^{c,d}	0.1 (0.1)^{b,c}	0.3 (0.2)^b	0.4 (0.2)^b	0.4 (0.3)^b	1.1 (0.9)^b

[a] Characteristic was significantly different among thinning classes ($P < 0.05$).
[b,c,d] Different letters indicate among-group differences ($P < 0.05$).

Statistical Methods

We tested the null hypotheses that snag characteristics (mean snag density, basal area, height, dbh, number of cavities, number of limbs/snag, decay class, and percentage of bark) did not differ among thinning classes with one-way analysis of variance (ANOVA). Prior to analyses, we examined heterogeneity of variance with Levene's tests and normality of errors with normal probability plots (Neter et al. 1996). We log, square root, or arcsine transformed variables that failed to meet the parametric assumptions of ANOVA and reevaluated normality and homogeneity of variances. For characteristics with significant overall ANOVA, we compared means using Tukey's honestly significant difference multiple comparison procedure (Neter et al. 1996). We tested the null hypothesis that there was no difference in snag characteristics between snags with and without cavities with *t*-tests. We used Kruskal-Wallis tests to compare proportion of snags lost between sampling years and proportion of snags with cavities among thinning classes (Conover 1999). Furthermore, we used *t*-tests to compare structural characteristics of persistent and perished snags.

To examine effects of thinning class on cavity-nesting birds, we quantified species richness and relative abundance of cavity-nesting birds for each study site. We calculated richness as the cumulative number of species encountered across all four transect counts for a study site ($n = 35$) and relative abundance of birds as mean number of observations within a year. With the resulting data, we evaluated the null hypothesis that there was no difference in species richness of cavity-nesting birds among stand thinning classes with a one-way analysis of covariance with stand size, which can influence species richness, as the covariate. Similarly, we tested the null hypothesis that there was no effect of treatment, year of sampling, or an interaction on relative abundance of cavity-nesting birds with a repeated-measures (year) one-way ANOVA (Neter et al. 1996). We log transformed data that failed to meet parametric assumptions of ANOVA prior to analysis.

To examine relationships between cavity-nesting birds and snag characteristics, we calculated a Pearson's correlation matrix among variables that we hypothesized would be positively correlated with abundance of cavity-nesting birds (i.e., numbers of snags, numbers of cavity-bearing snags, basal area of snags, and numbers of large [≥20.0 cm dbh] snags). We removed one variable from highly correlated variable pairs from analyses, and we calculated Pearson's correlation coefficients between our index to abundance of cavity-nesting species and remaining snag variables. We considered differences significant at $\alpha = 0.05$ and conducted analyses using SAS 9.2 (SAS Institute, Cary, NC).

Results

Snag Characteristics

We characterized 1,218 snags across the 35 study sites, of which 9 (<1%) were hardwood species and 117 (10%) contained cavities. Snag densities ranged from 0.1 to 16.0 snags/ha ($\chi = 3.77$ snags/ha across all stands). Although we did not detect a difference in snag density ($F_{6,28} = 1.26$, $P = 0.31$) or basal area ($F_{6,28} = 1.42$, $P = 0.24$) among thinning classes, height ($F_{6,28} = 9.91$, $P < 0.001$), dbh ($F_{6,28} = 11.84$, $P < 0.001$), number of limbs/snag ($F_{6,28} = 4.32$, $P = 0.003$), decay class ($F_{6,28} = 10.53$, $P < 0.001$), percentage of bark ($F_{6,28} = 8.69$, $P < 0.001$), and mean numbers of cavities ($F_{6,28} = 10.21$, $P < 0.001$) did vary. In general, the tallest and largest diameter snags occurred in stands soon (1–2 years) after second thinning (Table 1, Figure 1). In later thinning classes, snags tended to be larger, taller, have fewer limbs, have less bark, and be more decayed, with a greater number of cavities.

Between 2002 and 2003, 649 snags fell within the 9-ha plots, which was a 55% decline in total snag numbers. Snag loss within a stand ranged from 18 to 100%, but differences were not statistically significant among classes ($\chi^2 = 11.83$, df = 6, $P = 0.07$; Figure 2). Snags that fell had a smaller diameter ($t_{841} = -2.11$, $P = 0.03$), were shorter ($t_{841} = -4.03$, $P < 0.001$), and had less bark present ($t_{841} = -3.09$, $P = 0.002$) than retained snags. There was no difference in number of limbs ($t_{841} = 0.14$, $P = 0.89$) or decay class ($t_{841} = 1.10$, $P = 0.27$) between snags that perished and snags that persisted. In addition to the loss of snags, 75 new pine snags were recruited across study sites. All thinning classes had newly formed snags except for pine plantations 5–6 years after the first commercial thinning. Newly formed snags located in 4-ha subplots were qualitatively similar to snags in older thinning classes (Table 1), with an average height of 9.4 m, dbh of 22.1 cm, 7.0 limbs/snag, and 67% bark coverage. Only one newly formed snag had cavities.

Cavity-bearing snags were 1.06 m taller ($t_{1184} = 3.07$, $P = 0.002$), had a 4.8-cm-larger dbh ($t_{1184} = 7.60$, $P < 0.001$), were more decayed ($t_{1184} = 6.26$, $P < 0.001$), had 5.9 more limbs ($t_{1184} = 6.82$, $P < 0.001$), and had 25% less bark ($t_{1184} = -8.05$, $P < 0.001$) than snags without cavities. The proportion of cavity-bearing snags differed among classes ($\chi^2 = 19.79$, df = 6, $P = 0.003$), with cavity-bearing snags being more common after the

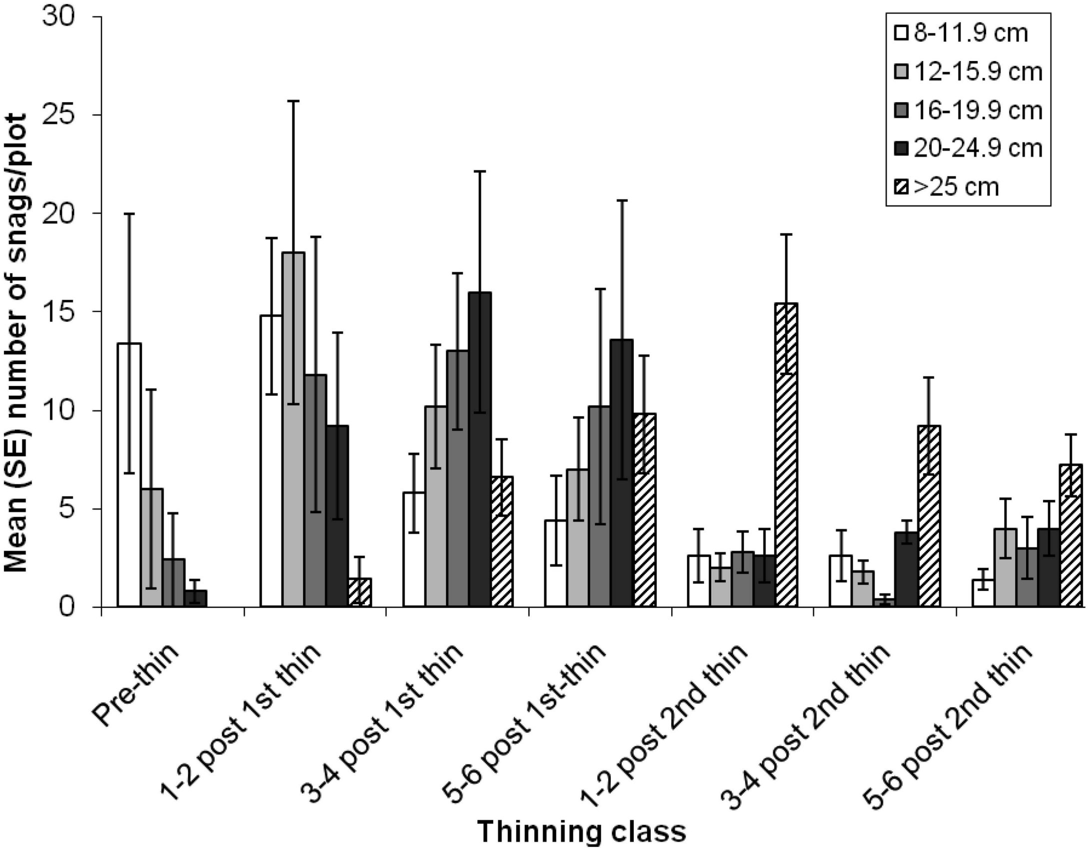

Figure 1. Size (dbh) distribution of snags by year among seven thinning classes in 35 intensively managed stands of loblolly pine (*P. taeda*) located in the coastal plain of North Carolina. Each class includes the mean (± SE) number of snags that occurred within 9-ha sampling plots in five pine plantations. Numbers indicate years after thinning.

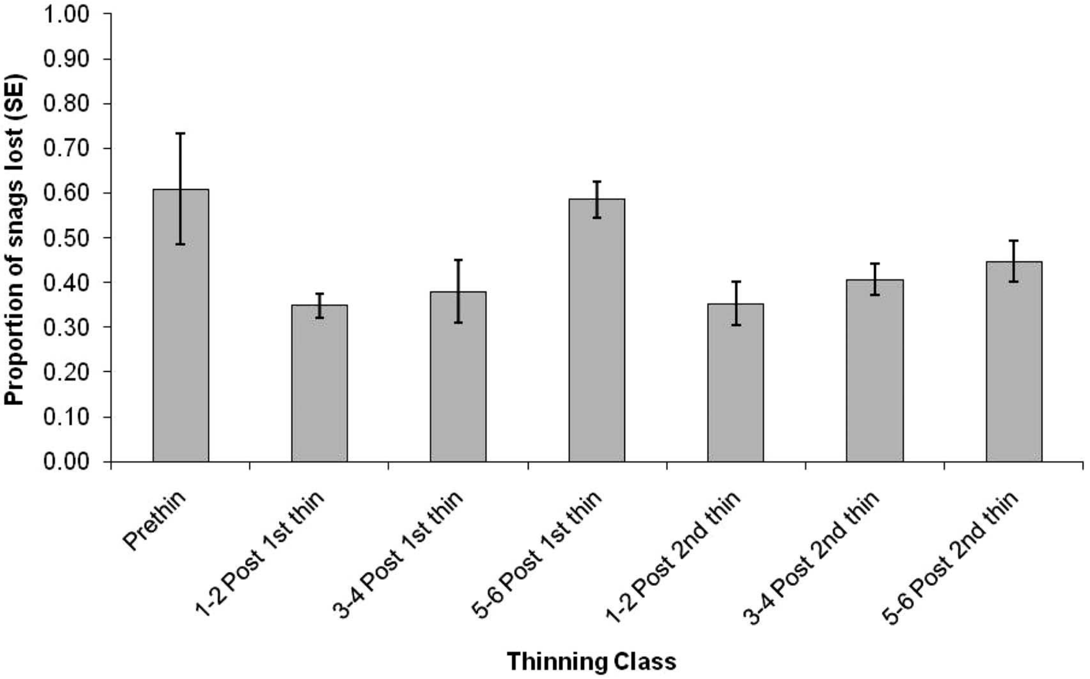

Figure 2. Proportion of snags (± SE) that fell between 2002 and 2003 in 35 intensively managed stands of loblolly pine (*P. taeda*) located in the coastal plain of North Carolina. Thinning classes were as follows: prior to thinning, three age classes following a first commercial thinning entry (numbers indicate years after thinning), and three age classes following a second commercial thinning.

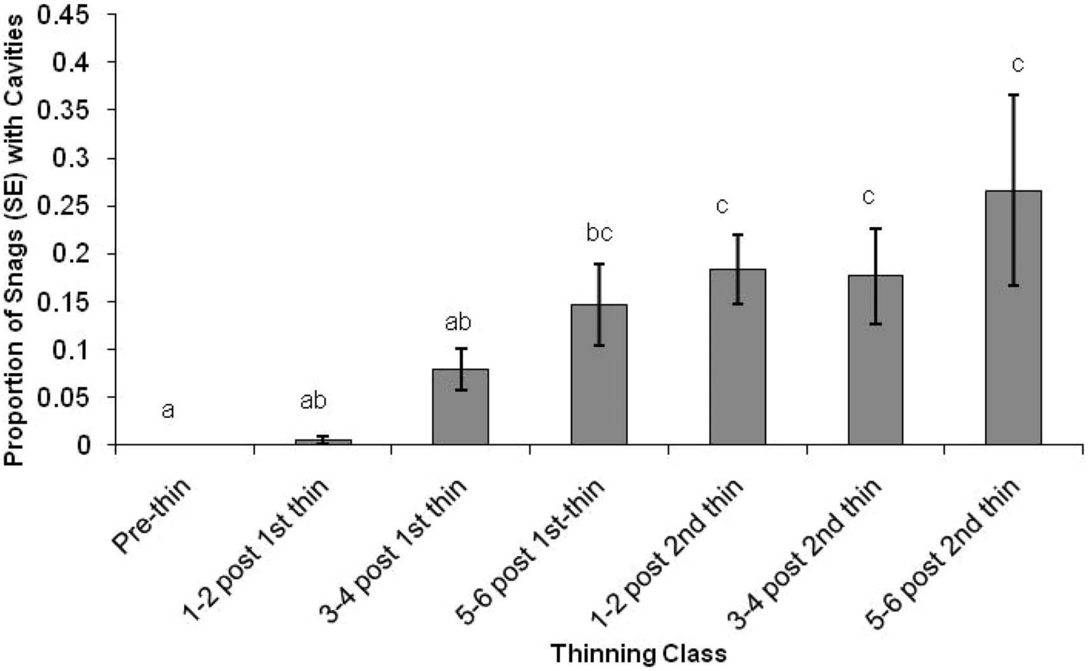

Figure 3. Proportion of snags (± SE) with cavities among seven thinning classes on 35 intensively managed plantations of loblolly pine (*Pinus taeda*) located in the coastal plain of North Carolina. Snags were surveyed on 9-ha plots in 2002. Numbers indicate years after thinning. Different letters indicate among-group differences ($P < 0.05$).

Table 2. Number observations of cavity-nesting birds by species sampled in intensively managed plantations of loblolly pine (*P. taeda*) in eastern North Carolina in 2002–2003. Cavity-nesting birds, which made up 10.5% of all avian observations, were aurally and visually surveyed twice per year, during early morning surveys in June and July on a 300-m transect centered in each stand.

	Thinning class (n = 5)							
Cavity-nesting bird species	Prethin	1–2 years post-1st thin	3–4 years post-1st thin	5–6 years post-1st thin	1–2 years post-2nd thin	3–4 years post-2nd thin	5–6 years post-2nd thin	Total
Carolina chickadee	6	14	11	13	14	18	5	81
Tufted titmouse	1	5	4	7	8	5	4	34
Northern flicker	0	3	5	2	1	9	0	20
Brown-headed nuthatch	1	4	2	5	2	3	3	20
Downy woodpecker	2	4	0	2	5	1	4	18
Great crested flycatcher	1	0	2	3	3	3	3	15
Hairy woodpecker	0	0	3	1	1	0	4	9
Red-bellied woodpecker	0	2	0	0	1	1	1	5
Barred owl	0	0	0	2	0	0	0	2
All species	11	32	27	35	35	40	24	204

second thinning compared with the four younger thinning classes ($P < 0.05$) (Figure 3).

Cavity-Nesting Birds

During the two years of transect surveys, we had 1,916 detections of 53 avian species. The four most commonly detected birds (common yellowthroat [*Geothlypis trichas*], white-eyed vireo [*Vireo griseus*], gray catbird [*Dumetella carolinensis*], and eastern towhee [*Pipilo erythrophthalmus*]) were shrub- or ground-nesting species and accounted for >50% of all observations. Nine species of primary and secondary cavity-nesting species accounted for 10.5% of all observations, with most being either Carolina chickadees (n = 81) or tufted titmice (n = 34) (Table 2). Richness of primary or secondary cavity-nesting birds observed ranged from 0 to 5 per stand and did not differ significantly by thinning class ($F_{6,27} = 2.21$, $P = 0.07$) or by stand size ($F_{6,27} = 0$, $P = 0.97$).

For relative abundance of cavity-nesting birds, we did not detect a significant year × class interaction ($F_{6,56} = 0.79$, $P = 0.58$) or effect of thinning class ($F_{6,56} = 1.35$, $P = 0.25$), but we did detect a year effect ($F_{1,56} = 9.76$, $P = 0.003$). Mean observations of cavity-nesting birds were twice as high in 2003 ($\bar{x} = 1.91$, SD = 1.58/transect) as in 2002 ($\bar{x} = 0.97$, SD = 0.85 /transect). Number of snags, number of large snags, and number of cavity-bearing snags were all highly correlated ($P \leq 0.04$), so we eliminated the first two metrics from further analyses. Mean relative abundance of cavity-nesting birds was not correlated significantly with either abundance of cavity-bearing snags ($r = 0.26$, $P = 0.13$) or basal area of snags ($r = -0.09$, $P = 0.61$).

Discussion

In our study, snag characteristics varied with thinning classes, and snag resources were dynamic across a 2-year time period. Commercial thinning entries did not decrease snag abundances and instead may have created snags via unintentional mechanical damage to trees during the thinning process. Compared to the 3.0–83.8

snags/ha reported for naturally regenerated forest in the southeastern United States (reviewed by McComb et al. 1986), overall abundances of snags in our study were relatively low. Further, mean densities of snags for thinning classes (2.0–6.1 snags/ha; Table 1) were at the low end of the ranges (2.6–38.6 snags/ha) of slash pine plantations in Florida (Land et al. 1989) but did not overlap mean densities (12.0–25.8 snags/ha) of loblolly pine in the South Carolina Piedmont (Moorman et al. 1999). Because silvicultural prescriptions for intensively managed pine stands are designed to maximize growth and minimize mortality of crop trees and decrease rotation length, lower densities of snags than natural forest are expected. However, if active management to recruit and retain snags is not undertaken, mortality due to thinning alone is unlikely to be sufficient to replace snag losses (Spies et al. 1988). Forest managers did not actively retain snags within the stands we studied, so our estimates represent the low end of the potential range of snag densities in pine plantations across the region.

Although the number of snags did not differ among thinning class, size distributions of standing dead wood did vary. In young stands without thinning activity, snag populations were dominated by small-diameter individuals (86% of snags prior to thinning were <16 cm), but snags in stands measured after a second commercial thinning entry had diameter distributions skewed toward larger sized-snags (79% of snags after second thinning were ≥16 cm) (Figure 1). Small diameter snags likely decayed rapidly and perished (Harmon et al. 1986, Raphael and Morrison 1987), but larger trees may have been recruited into the snag population across our chronosequence of stands and as crop trees responded favorably to density management. Although operators did not specifically try to do so, the mechanical equipment they used during thinning may have unintentionally created some larger snags, but it likely contributed to loss of existing small snags as well.

Snag resources were highly dynamic temporally. Numbers of snags lost ($n = 649$) greatly exceeded numbers recruited ($n = 75$), resulting in a net loss of 48% of snags between only two years. Although it is speculative, we believe that higher than average precipitation and an ice storm during the winter of 2002–2003 contributed to the extremely high loss rates of snags in the study area. Episodic events, such as storms, drought, or fire, can greatly affect snag dynamics at the stand scale (Spies et al. 1988, Morrison and Raphael 1993, Stephens and Moghaddas 2005, Bagne et al. 2008), but the ice storm apparently did not contribute to recruitment greatly, at least not within the year following the storm. Perish rates were not related to stand size ($r = -0.29$, $P = 0.09$), suggesting that smaller stands with more edge did not experience greater windthrow. In addition, because snags were mostly small, they likely have a short lifetime in the hot and humid climate of the southeastern United States, which has implications for the long-term sustainability of structural characteristics in managed forests. Loss rates for snags of other pine species reportedly range up to 85% for a 10-year period, but rates are strongly dependent on species, size, and surrounding stand structure (i.e., postwildfire stand) (Morrison and Raphael 1993).

The greatest number of large-diameter (>20.0 cm dbh) snags occurred in plantations that had two commercial thinning operations (Figure 1), and larger snags were more likely to contain cavities. In addition, snags in these older stands tended to have characteristics reportedly important for cavity-nesting birds, including a large dbh, late stages of decay, and height (Land et al. 1989, Freedman et al. 1996, Haggard and Gaines 2001, Bagne et al. 2008). Large and well-decayed snags are important for a wide range of primary cavity-nesting birds to successfully excavate a cavity and forage on invertebrates (Freedman et al. 1996).

Despite having fewer numbers of large snags than typically recommended for cavity-nesting birds (Harlow and Guynn 1983, McComb et al. 1986), we still observed nine species of cavity-nesting birds within stands in our study. The richness of cavity nesters was reported to be 3–5 species, accounting for 22–66% of bird densities (Repenning and Labisky 1985), or 11 species, accounting for 21% of bird densities (Land et al. 1989), in other southern pine plantations that were up to 40 years old. In our study, we were unable to detect either positive or negative effects of thinning class on detections of cavity-nesting species despite that cavity-bearing snags were not observed in stands prior to thinning. However, in addition to increasing growth of crop trees, thinning creates a more open canopy and reduces midstory density, which is conducive to many cavity-nesting bird species, such as nuthatches and woodpeckers (Hagar et al. 1996). In a prior study in eastern North Carolina, brown-headed nuthatches responded positively to thinning, possibly because of increased access to cavities (Wilson and Watts 1999). Thus, releasing conifer trees likely has positive effects for avian communities, including cavity-nesting birds.

In spite of the importance of snags as foraging and nesting substrates for cavity-nesting birds and the relatively low number of large snags within plantations, we did not identify a positive relationship between number of cavity-bearing or basal area of snags and relative abundance of cavity-nesting birds during the postbreeding period. The lack of observed relationship could have occurred because (1) the range of snag numbers was too low to affect abundances of cavity-nesting birds, (2) our methods to detect cavity-nesting birds underrepresented abundance (Manuwal and Carey 1991), (3) postbreeding birds did not select forest stands solely based on snag abundance (Moorman et al. 1999, Haggard and Gaines 2001), or (4) birds responded to attributes at a larger spatial scale than we studied. In Ponderosa pine (*Pinus ponderosa*) forest in South Dakota, no relationship between snag density and abundance of cavity-nesting birds was detected across the range of 0–304 snags/ha (Spiering and Knight 2005). These authors concluded that snag densities may have been too low to influence cavity-nesting species in their study area. We can only speculate, but we surmise that we failed to detect a relationship among cavity-nesting species and snags because we examined relationships only at the low range of snag densities and at the end of the nesting season, when birds may have had a weaker association with these structural elements.

Our estimates of snag resources within plantations likely underestimated snag resources across the landscape because we did not sample standing dead wood within unharvested buffer zones along streams and other set-aside areas that were common. These unharvested areas may have held significant numbers of snags compared with plantations (Harlow and Guynn 1983, Freedman et al. 1996). Future observational field studies should include snags within unharvested buffer zones and other set-aside areas to provide more realistic estimates of snag resources across commercial landscapes. Furthermore, quantifying ecological thresholds and relationships of snags with biodiversity, including avian species, also should be conducted with experimental manipulations (Moseley et al. 2008, Owens et al. 2008) or observational studies at both stand and landscape scales.

Conclusions

Although retention of snags after clearcut harvests is not required in the southeastern United States, participants in sustainable forestry certification programs must consider these habitat elements and have scientifically credible criteria for retention to meet defined program goals for conserving biological diversity. Furthermore, most researchers agree that retaining snags and selected live trees through multiple rotations could increase structural heterogeneity and benefit cavity-nesting birds and other wildlife species that require woody debris for meeting life history needs (McComb et al. 1986, Freedman et al. 1996, Moorman et al. 1999, Hartley 2002). Managers should select large-diameter, potential reserve trees for future snags after thinning entries and after final harvest in pine plantations so that stems are more likely to be used by cavity-nesting species. This is particularly important in short-rotation management in the hot, humid southeastern United States, as many snags are small and unlikely to persist for more than a few years. In addition, large-diameter softwood snags may have a short window of time when they have decayed enough for cavity excavation but are still standing (Moorman et al. 1999). Thus, repeated recruitment of standing dead wood may be necessary to sustainably provide substrate for cavity-nesting species in pine plantations. Although it was not studied here, maintaining or creating clusters of snags or trees that will become snags could benefit woodpeckers by increasing their foraging efficiency (Raphael and White 1984) or attracting species that prefer openings in the forest canopy (Land et al. 1989) while minimizing safety concerns for operators.

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