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Hardwood Snag Fragmentation in a Pine-oak Forest of Southeastern Arkansas

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ABSTRACT.—Because snags are important to forest wildlife as breeding, roosting and foraging sites, resource managers who wish to maintain this component in forest stands need to be aware of snag fragmentation rates. Measurements were taken in uneven-aged pine-hardwood stands in southeastern Arkansas to determine fragmentation rates for hardwood snags 2 to 6 yr after stem injection with herbicides. Crown and bole condition of snags were also assessed. *Pinus echinata* Mill. and *P. taeda* L. were the dominant overstory components and were undisturbed. *Quercus* spp. accounted for 91% of hardwoods >25 cm dbh. Since small diameter snags deteriorated first, snag diameter distributions changed from uneven-sized to even-sized structure as time since mortality increased. Within 3 yr of injection, 57% of snag boles had broken below crown height. Number of wildlife cavities per snag increased with time since mortality. At 6 yr after injection, 44% of residual snags had evidence of wildlife cavities. Less than 50% of hardwoods <25 cm dbh were still standing 5 yr after herbicide injection.

INTRODUCTION

In product-oriented forest management, standing dead trees (snags) are often deemed undesirable because these snags may conflict with dominant forest management objectives, may harbor forest insect pests and may present fire and safety hazards (McClelland and Frissell, 1975; Davis *et al.*, 1983; Meyer, 1992). Nevertheless, resource managers have recognized the importance of snags as wildlife habitats and problems associated with snag management. In North America, 85 species of birds use dead trees to excavate nesting holes, use cavities caused by fungal decay, or use cavities created by animals other than birds (Davis *et al.*, 1983). Snags are also important to mammals, reptiles, amphibians and invertebrates as breeding, roosting and foraging sites (Conner, 1978; Evans and Conner, 1979; Brady, 1983; Davis, 1983; Morrison and Raphael, 1993; Conner *et al.*, 1994).

Since few studies have been specifically designed to collect data on snag fragmentation, interpolation from research conducted with other objectives in mind is often necessary (Styskel, 1983). Although rates of snag decay have been reported in the Sierra Nevada of California (Raphael and Morrison, 1987; Morrison and Raphael, 1993) and the southern and central Appalachians (Harmon, 1982; Moriarty and McComb, 1983), data on snag fragmentation are lacking from the Southeastern Coastal Plain where the hot and humid climate accelerates the activity of saproxylic organisms (Speight, 1989) that decompose wood.

I investigated hardwood snag dynamics associated with treatments to enhance natural regeneration of loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.) pines in southeastern Arkansas. I determined the density and quadrat stocking of natural loblolly and shortleaf pine seedlings relative to the abundance of seed produced from uneven-aged pine stands following control of understory, midstory, and overstory hardwoods by herbicide injection (Cain, 1991). Hardwood injection treatments were imposed annually for 5 yr to account for the variability of natural pine seed crops. This process permitted the assessment of hardwood snag fragmentation during a known time interval following tree mortality.

METHODS

Study areas.—The study was conducted on the Crossett Experimental Forest in southeastern Arkansas, at 33°02′N mean lat and 91°56′W mean long. Elevation of the area is ca. 40 m with nearly level topography. Soil in the test areas is Bude (Glossaquic Fragiudalf) and Providence (Typic Fragiudalf) silt loams, and site index is 27 m at 50 yr for loblolly pine (U.S. Dep. Agric., 1979). Annual precipitation averages 140 cm, with seasonal extremes being wet winters and dry autumns. Daily temperatures average 22 C during the growing season (March through September) and 11 C during the dormant season (October through February). During summer, moist tropical air from the Gulf of Mexico persistently covers the area (U.S. Dep. Agric., 1979). Two test areas (A and B) were located 400 m apart.

Test Area A.—At the time of study installation, this uneven-aged stand consisted of mature loblolly and shortleaf pines that averaged 48 cm in diameter at breast height (dbh, at 1.37 m aboveground), and the 10 largest pines averaged 76 yr old. Pine basal area averaged 15 m^2/ha, and hardwood basal area averaged 13 m^2/ha. The understory was relatively open with no pine regeneration and very little herbaceous vegetation because of shading from the midstory and overstory components. The last improvement cut was in 1963.

Test Area B.—Compared to Test Area A, this uneven-aged stand contained more pines in the smaller dbh classes, averaging 28 cm in dbh, and average age of the 10 largest pines was 63 yr. Pine basal area averaged 16 m^2/ha, and hardwood basal area averaged 14 m^2/ha. No harvesting had taken place since 1967.

Since the age of dominant hardwoods is similar to that of the dominant pines on the Experimental Forest (Cain and Shelton, 1994), a range of 60–80 yr is considered representative for the dominant hardwoods in the present investigation. The only known disturbance on the two test areas within 5 yr of study installation was prescribed burning in February of 1980. The fires were cool and did not consume the litter down to mineral soil.

Treatments.—The absence of pine regeneration in these stands was thought to be the result of overstory and midstory hardwoods shading the forest floor. To investigate this problem, hardwoods >2.5 cm in groundline diam were stem-injected with herbicide between mid-June and mid-July on three plots per test area during each of 5 yr (1985 through 1989).

The herbicides[1] Tordon® 101R (0.03 kg picloram plus 0.12 kg 2,4-D/L as amine salts) and Roundup® (N-[phosphonomethyl]glycine at 0.24 kg a.i./L) were used for killing the hardwoods by applying 1 ml of chemical per incision and one incision per 2.5 cm of groundline diam. Tordon was the principal herbicide and was applied undiluted. Roundup was used as a 50% solution in water to control sweetgum (*Liquidambar styraciflua* L.) and ash (*Fraxinus* spp.), both of which are resistant to Tordon.

Experimental design.—Each test area contained 1.78 ha with 18 plots measuring 20.1 m by 20.1 m (0.04-ha). Year of hardwood injection was randomly assigned to 15 of the 18 plots within each test area. The three remaining plots per test area were retained as untreated references in the pine regeneration study. Beginning in 1985, and for 4 yr thereafter, hardwood injection was replicated on three 0.04-ha plots per test area.

Measurements and data analysis.—After plot establishment in 1985, all live trees were counted on a plot-by-plot basis using 2.5-cm dbh classes within four species groups: loblolly and shortleaf pines, oaks (*Quercus* spp.), gums (*Liquidambar styraciflua* and *Nyssa sylvatica*

[1] Discussion of herbicides in this paper is not a recommendation of their use and does not imply that uses discussed here are registered by appropriate state and/or federal agencies. The use of trade or firm names is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service

Marsh.) and other hardwoods. In an evaluation of hardwood composition within undisturbed pine-hardwood stands on the Crossett Experimental Forest, Cain and Shelton (1994) reported that the most prevalent hardwoods in addition to oaks and gums were *Ulmus* spp., *Ostrya virginiana* (Mill.) K. Koch, *Cornus florida* L., *Fraxinus* spp., *Ilex opaca* Ait. and *Acer rubrum* L., in order of relative abundance. In that same evaluation, midstory and overstory white oaks (*Quercus alba* L. and *Q. stellata* Wangenh.) were about three times as numerous as red oaks (principally *Q. falcata* Michx., *Q. nigra* L. and *Q. phellos* L.).

In autumn of 1991, all hardwood snags >1.37 m tall were counted by plot, regardless of the year of injection. This yielded data for a chronosequence that ranged from 2 yr after the most recent injection (1989) to 6 yr after the earliest injection (1985). When snags were measured in 1991, there were two test areas with three replications for injection-yr 1986, 1987, 1988 and 1989. For the 1985 injection, there were three replications in test area A and two replications in test area B because hardwood snags on one plot in test area B were destroyed during salvage of a southern pine beetle (*Dendroctonus frontalis* Zimm.) infestation. On all 29 plots, a total of 312 snags were assessed.

Measurements taken on individual snags included: dbh to nearest 0.3 cm, total height to nearest 0.3 m, crown height to nearest 0.3 m, crown width to nearest 0.3 m at the widest axis and perpendicular to that axis, height of each observed cavity to nearest 0.3 m, whether the cavities were on limbs or in the bole, and qualitative assessments of crown condition and bole condition. Because of snag deterioration, tree species could not be identified at the time of measurement.

Wildlife cavities were counted by three individuals standing at different angles from the snags and using 7-power binoculars. To ensure observer uniformity, the qualitative measure of minimum size for counting cavities was a U.S. quarter coin (*i.e.*, ≈25 mm in diam). The functional definition for a cavity was a hole in a snag that could provide shelter for wildlife from the elements and protection from disturbance by predators and competitors (Carey, 1983). In the present study, 24 of the 29 plots had snags with wildlife cavities, and no hollow-tree snags were observed. Wildlife foraging holes were also counted as cavities because these holes can provide shelter and protection for tree frogs (*Hyla* spp.) and insects.

Bole condition was categorized as "hard"—composed of sound wood—or "soft"—characterized by advanced decay and deterioration (Ffolliott, 1983). If bole wood at breast height could not be pecked with a fingernail, the snag was judged as hard—*i.e.*, between gypsum and calcite on Mohs' Scale of hardness (Nelson, 1965).

Using plot means by year of injection, linear and nonlinear regressions were fitted to correlate measured snag variables to time since mortality (29 plots) and mean height of bole cavities to mean snag height (24 plots). Regressions giving the highest r^2 and lowest mean square error are presented. Analysis of variance was used to compare preinjection effects on relative abundance of hardwood species among years, as randomly assigned to plots for hardwood injection. In analysis of variance, percent data were analyzed following arcsine, square-root, proportion transformation. Block effects (test areas) were included in analysis of variance to eliminate environmental source of variation.

Snag fragmentation rates (s) were calculated using nonlinear regression and fitting the following equation from Runkle (1991):

$$N_t = N_0 e^{st}$$

where N_t is the number of residual snags at time t, N_0 is the number of snags immediately after tree death, and s is the rate at which snags deteriorate to low stumps or logs. Three dbh classes, based on merchantability standards (Table 1), were used to reflect the range of minimum to optimum dbh recommendations for snag retention (Evans and Conner,

TABLE 1.—Relative hardwood abundance within three species groups that occurred on plots before hardwood injection

	Assigned year of injection						
	1985	1986	1987	1988	1989		
Species group	Relative abundance (%)					MSE*	P > F
Oaks	20	26	26	27	26	0.0073	0.63
Gums†	19	29	19	26	20	0.0124	0.30
Other hardwoods	61	45	55	47	54	0.0136	0.06

* Mean square error
† Includes *Liquidambar styraciflua* L. and *Nyssa sylvatica* Marsh.

1979). Differences in snag fragmentation rates associated with the three dbh classes were tested using indicator variables, which are commonly employed to quantitatively identify qualitative classes in regression analysis (Neter and Wasserman, 1974). All statistical tests were carried out at the $\alpha \leq 0.05$ probability level.

RESULTS

Pretreatment stand conditions.—For each year of injection, oaks, gums and other hardwoods exhibited the negative exponential diameter distribution that is characteristic of uneven-aged stands (Smith, 1986) (Fig. 1). For hardwood stems ≥2.5 cm dbh, oaks comprised 25%, gums accounted for 23%, and other hardwoods made up 52% of total density, which averaged 1690 stems/ha. Most stems <10 cm dbh were categorized as "other hardwoods"; this included woody shrubs. However, oaks accounted for 91% of hardwoods >25 cm dbh across all plots. Before injection of hardwoods and within each species group, relative hardwood abundance did not differ ($P > 0.05$) among years (Table 1).

For pines ≥2.5 cm dbh, density averaged only 170 stems/ha. Pine diameter distributions were more variable than for hardwoods but were generally skewed toward the smaller dbh classes, *i.e.*, irregular uneven-aged distribution. Although fewer in number than the hardwoods, dominant pines were taller than the dominant hardwoods and pines averaged 3 m^2/ha more basal area than the hardwoods.

Hardwood snags.—The fragmentation rate for snags was highest (−0.76) in the smaller dbh classes (≤11 cm) and lowest (−0.05) in the larger dbh classes (≥25 cm) (Table 2). The fragmentation rates were significantly different ($P < 0.01$) among the three dbh classes. Snag diameters shifted from the negative exponential distribution to a normal distribution as time since mortality increased from 2 to 6 yr (Fig. 2). By regression (Table 3), the predicted density decreased from 497 snags/ha at 2 yr after mortality to 78 snags/ha at 6 yr after mortality (Fig. 3a).

The predicted minimum dbh of snags (Table 3) increased from 2.6 cm at 2 yr after mortality to 12.4 cm at 6 yr after mortality (Fig. 3b). In contrast, the predicted maximum total height of snags (Table 3) declined from 20.7 m at 2 yr after mortality to 11.4 m at 6 yr after mortality (Fig. 3c). There was not significant correlation ($P > 0.05$) between time since mortality and mean dbh, maximum dbh, mean height or minimum height of hardwood snags.

Within 2 yr after injection, 59% of residual snags still retained some evidence of crown with branches <10 cm in diam, but 1 yr later, crowns with small branches had disappeared (Fig. 4). The proportion of snags with crowns (Table 3) was predicted to decline from <60% at 2 yr after mortality to <5% at 6 yr after mortality (Fig. 3d).

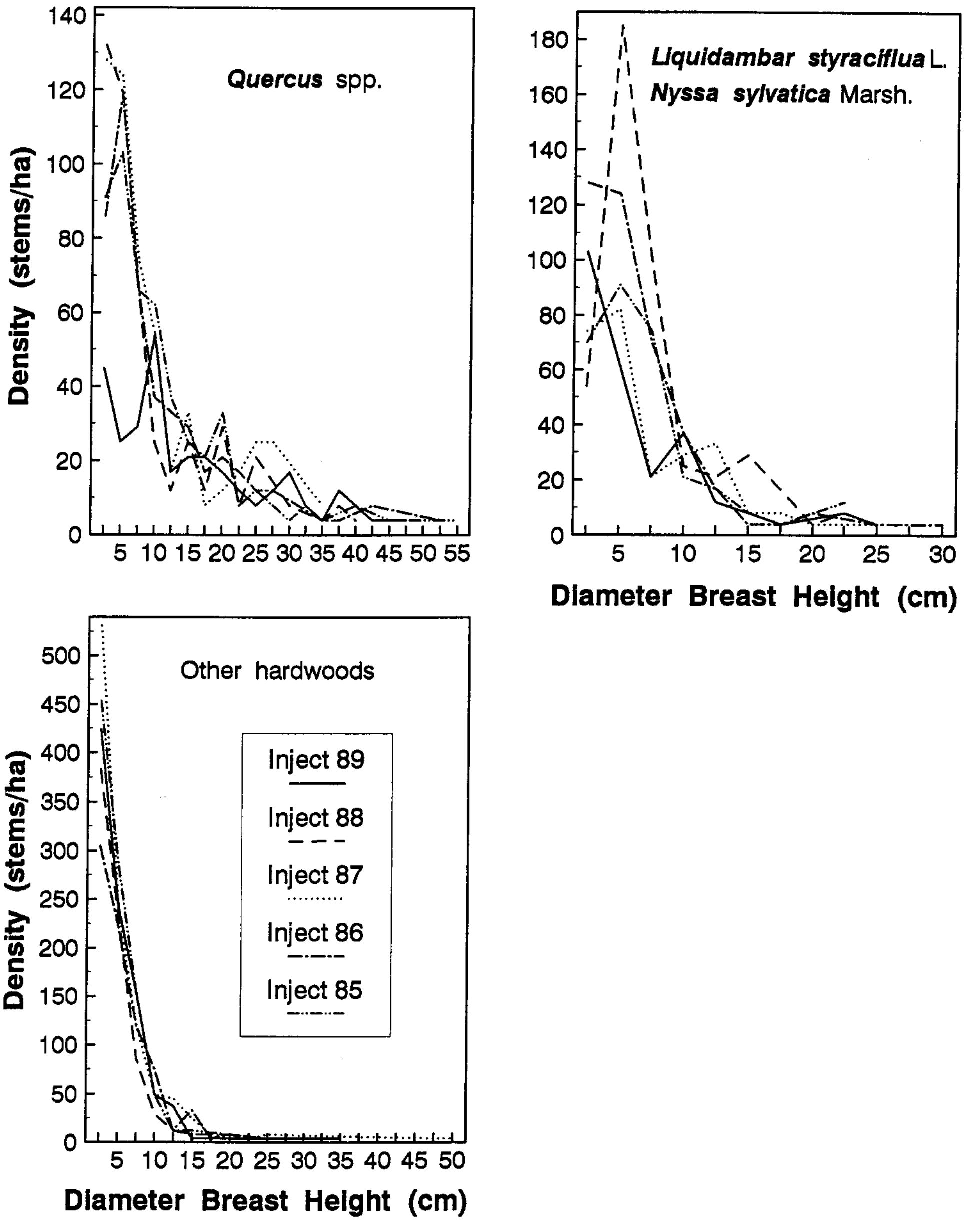

FIG. 1.—Diameter distribution of hardwoods by year of injection, before hardwood mortality

Maximum crown width of snags (Table 3) was predicted to decline from 8 m at 2 yr after mortality to <3 m at 6 yr after mortality (Fig. 3e). This in turn reduced the number of limb cavities compared to bole cavities. At 2 and 3 yr after mortality, ca. 30% of snags had

TABLE 2.—Hardwood snag fragmentation rates by dbh class*

dbh class† (cm)	s	Root mean square error	r^2	n
≤11	−0.7567	23.2	0.83	29
12 to 24	−0.1779	19.2	0.45	29
≥25	−0.0528	9.0	0.72	29

* $N_t = N_0e^{st}$; where N_t is the number of residual snags at time t, N_0 is the number of snags immediately after tree death, and s is the fragmentation rate of snags to low stumps or logs

† dbh classes are based on merchantability standards, *i.e.*: Submerchantable = ≤11 cm; Pulpwood = 12 to 24 cm; Sawlog = ≥25 cm

cavities in their limbs, but that percentage declined to zero as the larger limbs were cast during the next 3 yr.

For snags still standing 2 yr after mortality, >50% were categorized as being composed of sound wood (Table 4). Rapid deterioration followed, so that ca. 90% of residual snags were assessed as being in advanced stages of decay between 3 and 6 yr after injection.

The minimum height of bole cavities (Table 3) was predicted to decline from 7.3 m at 2 yr after mortality to 2.4 m at 6 yr after mortality (Fig. 3f). This decline was consistent with a reduction in maximum snag height over time (Fig. 3c).

As time since mortality increased, the proportion of residual snags with multiple wildlife cavities increased at the rate of about 10% per year. However, based on visual observation,

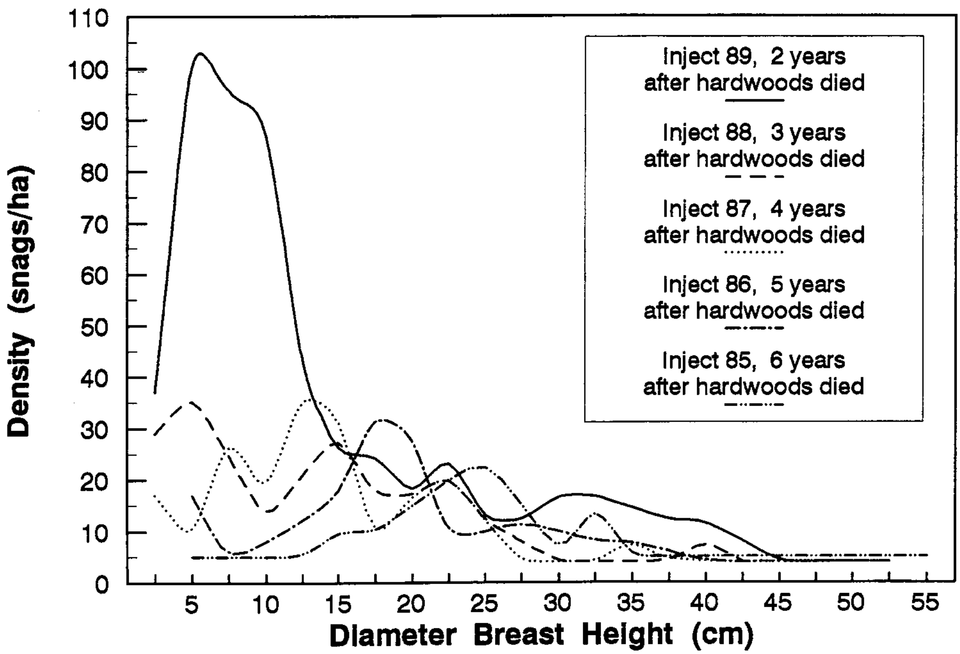

FIG. 2.—Diameter distribution in 1991 for hardwood snags by year of injection

TABLE 3.—Prediction equations and associated statistics for changes in mean hardwood snag characteristics following tree mortality

Equation designation*	Equation†	n	Root MSE‡	r^2	P
a	DEN = 762.3146 − 382.0778 ln(T)	29	123.5544	0.60	0.0001
b	ln(DBH) = 0.1643 + 0.3926T	29	0.4573	0.60	0.0001
c	MTHt = 26.5904 − 8.4949 ln(T)	29	5.4905	0.28	0.0035
d	%Crwn = 89.8796 − 48.7420 ln(T)	29	17.7174	0.55	0.0001
e	ln(MCrW) = 2.8412 − 1.0943 ln(T)	17	0.3697	0.60	0.0001
f	MCvHt = 10.3238 − 4.4165 ln(T)	24	2.6190	0.32	0.0040

* Letters correspond with Figure 3

† DEN = density (snags/ha); dbh = diameter breast height (cm); MTHt = maximum total height (m); %Crwn = proportion of snags with crowns (%); MCrW = maximum crown width (m); MCvHt = minimum cavity height (m); T = time since mortality (yr); ln = natural log

‡ Mean square error

fewer than 50% of residual snags had cavities even 6 yr after hardwoods died (Table 4). This suggests that more cavity and foraging sites had been created than could be used by wildlife (Conner *et al.*, 1981). Although the number of observed cavities tended to increase relative to time, no more than seven cavities were observed on any one snag. Since the mean height of bole cavities was well correlated ($r^2 = 0.80$, $P < 0.01$) with the mean total height of snags (Fig. 5), it appears that most cavity excavators and bole foragers prefer the upper portion of whatever snag is available.

DISCUSSION

Analysis of preinjection stand data indicated that relative abundance data for the three groups of hardwood species were not highly variable among years. This was important to support the validity of the regression equations because snag deterioration and attrition are often species-dependent (Harmon, 1982; Moriarty and McComb, 1983). In the present investigation, oaks were the most common species in hardwoods >25 cm dbh, and snags in these size classes tended to have the lowest attrition rate. Even so, oak snags in the southern Appalachian mountains have been reported as rapid decayers compared to pine snags, and white oaks (*Quercus prinus* L.) deteriorated faster than red oaks (*Q. coccinea* Muenchh.) (Harmon, 1982).

Annual snag attrition rates were highest (>500 snags/ha/yr) during the 1st 2 yr following mortality because snags in the smallest dbh classes disappeared first. However, during 6 yr, the attrition rate averaged <300 snags/ha/yr. Even though no pine snags were assessed in the present study, these data appear to be consistent with Morrison and Raphael (1993), who reported that larger diameter snags of pine and fir (*Abies* spp.) in the Sierra Nevada remained standing the longest. The rate at which snags fall has also been linked to the prevalence of heavy winds, moisture content, association with other tree species, stand density and character of the supporting soil (Keen, 1929).

Based on the negative exponential equation for decay during a 5-yr interval, the residual density out of an arbitrary 10 hardwood snags was predicted to be <1 snag for stems ≤11 cm dbh, 4 snags for stems 12–24 cm dbh, and 8 snags for stems ≥25 cm dbh. Evans and Conner (1979) suggested that snags <10 cm dbh are of little value for feeding and nesting birds. These authors also reported that nearly all primary cavity excavators require a snag

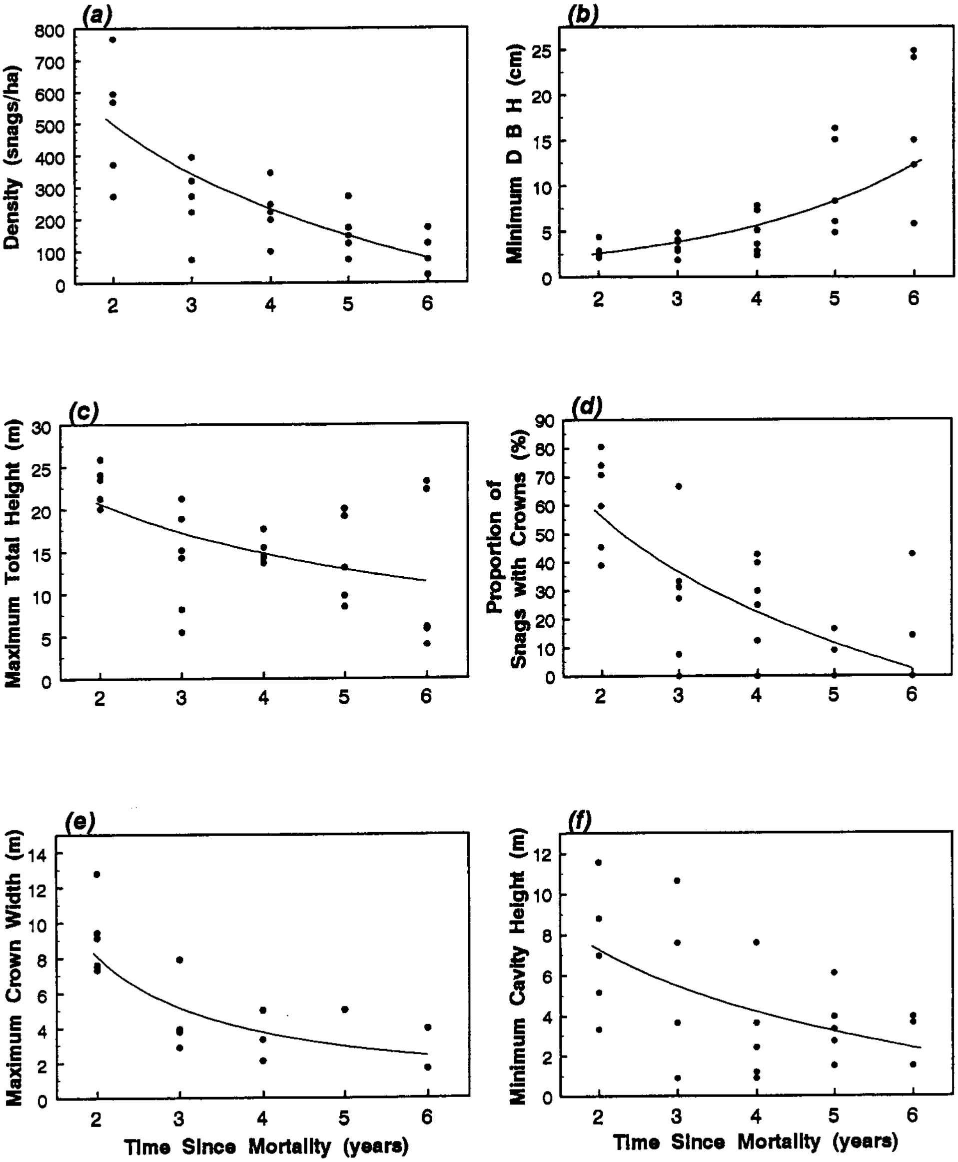

FIG. 3.—Changes in mean hardwood snag characteristics following tree mortality. Curves were calculated from regression equations presented in Table 3

of ≥23 cm dbh for nesting holes. Given these criteria, wildlife habitat would most likely improve if resource managers retain natural snags or create new snags that are at least 23 cm dbh.

Conner *et al.* (1981, 1983) and McComb and Rumsey (1983) reported that herbicide-killed trees have potential value as wildlife habitat since the herbicides did not appear to

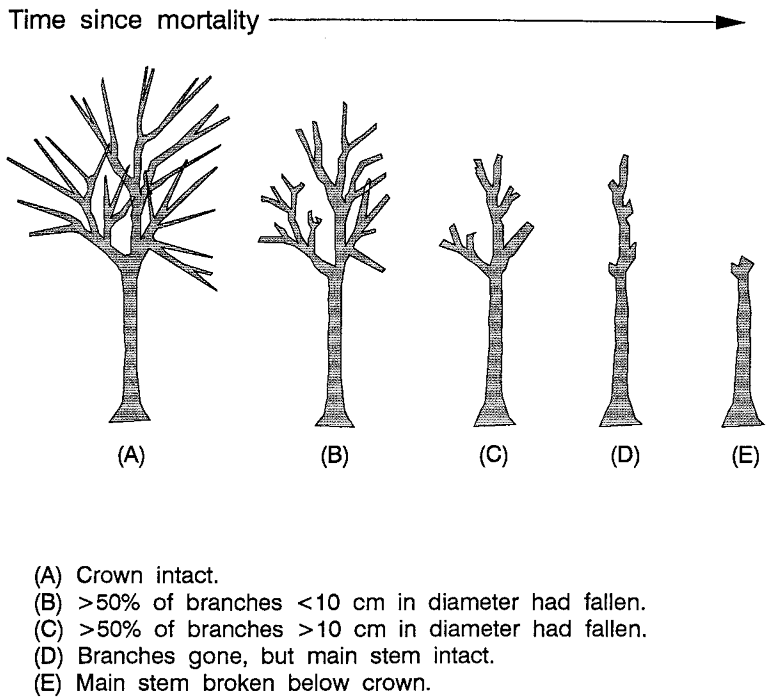

FIG. 4.—Qualitative assessment of snag condition relative to time since mortality

TABLE 4.—Proportion of hardwood snags classified by stage of bole deterioration and those having multiple wildlife cavities

	Time since mortality (years)				
	6	5	4	3	2
Variable	Proportion of snags (%)				
(Stage of bole deterioration)					
Hard	8.7	2.6	12.7	13.1	56.3
Soft	91.3	97.4	87.3	86.9	43.7
(Number of wildlife cavities)					
0	56.5	65.8	67.3	78.7	93.3
1	17.4	10.5	18.2	13.1	5.9
2	8.7	7.9	10.9	6.6	0.8
3	4.4	5.3	3.6	1.6	0
4	4.4	5.3	0	0	0
5	4.3	2.6	0	0	0
6	0	0	0	0	0
7	4.3	2.6	0	0	0

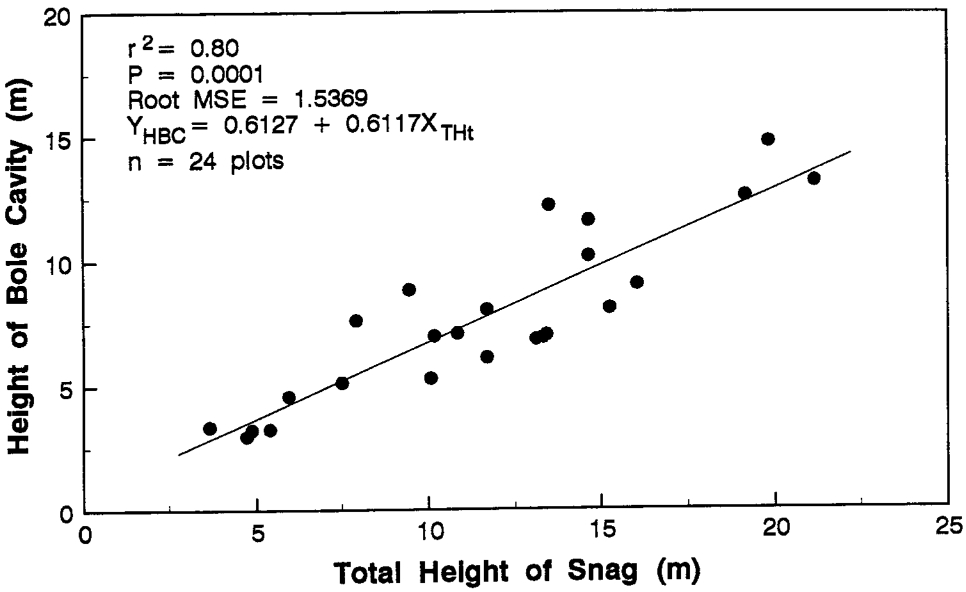

FIG. 5.—Mean height of bole cavities relative to mean total height of hardwood snags

adversely affect trees as foraging or nesting sites. However, Conner *et al.* (1983) found that, in E Texas, red oaks (*Quercus falcata* Michx.) killed by herbicide injection deteriorated faster than those killed by girdling because initiation of decay in girdled trees took longer.

The only measure of wildlife habitat that was assessed in the present investigation was the number of observed cavities and their location on residual snags. Such cavities occurred on 24 out of 29 plots, with the number of cavities increasing as time since mortality increased. For the five plots with no evidence of cavities, residual snags averaged <5 m in height.

Because of the rapid deterioration of hardwood snags in this investigation and their high attrition rate in smaller dbh classes following herbicide injection, data suggest that snag replacement would be needed at intervals of 10 yr or less on this Coastal Plain site. Even when the management objective is pine timber production, the high level of scientific and political interest in ecosystem management may necessitate reserving a pool of hardwoods for their snag potential. Such hardwoods should be allowed to grow ≥23 cm dbh before herbicide injection to ensure a slow rate of snag fragmentation. When managing natural loblolly and shortleaf pine stands, options may be available for retaining midstory and overstory hardwoods while successfully regenerating shade-intolerant pines in the understory (Baker, 1994).

If snag-dependent wildlife species are to remain a part of the managed forest, forest managers must provide the necessary habitat (Thomas, 1979). Concomitantly, mathematical formulas have been developed for calculating the number of snags required by primary cavity excavators (Thomas *et al.*, 1979). In that respect, Thomas (1979) urged forest managers to consider snag requirements on a community-by-community basis because criteria that are too general may lead to an oversupply of snags in one timber type and an undersupply in another type.

Data in the present investigation are limited in scope because they are of one forest type (*i.e.*, oak-pine forest cover type) and because snag data were collected at the stand level (plot means) rather than for individual snags. However, the data provide a practical guide when retaining hardwoods for their snag value.

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