The effects of thinning intensity on snag and cavity tree abundance in an Appalachian hardwood stand[1]

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Abstract: Traditional silvicultural practices focus on manipulating forest vegetation structure for commodity production. Structural features important to wildlife, such as snags, trees with decay, and cavity trees are also affected by forest management, but these effects are often not quantified. This study measured the effects of different thinning intensities (45, 60, and 75% residual relative densities and uncut controls), heartwood decay resistance (resistant, slight), and age (formed pre- or post-treatment) on the density and volume of snags and decayed wood in an Appalachian hardwood stand. Cavity trees considered useful to local woodpecker species were also measured. Results indicated that snags and decayed wood were two to four times more abundant in controls compared with heavily thinned (45% residual density) treatments. Most snags were small-diameter, decay-resistant sassafras (*Sassafras albidum* (Nutt.) Nees) and black cherry (*Prunus serotina* Ehrh.) that died early in stand development. Large-diameter (≥30 cm diameter at breast height) snags and cavity trees were uncommon in both thinned treatments and controls.

Résumé : Les pratiques sylvicoles traditionnelles cherchent avant tout à manipuler la structure de la végétation forestière dans le but de produire de la matière première. Les caractéristiques structurales importantes pour la faune, telles que les chicots, les arbres cariés et les arbres avec des cavités, sont également influencées par l'aménagement forestier mais ces effets ne sont généralement pas quantifiés. Cette étude visait à mesurer les effets de différentes intensités d'éclaircie (45, 60, 75% de densité relative résiduelle et un témoin non éclairci), de la résistance du bois de cœur à la carie (résistant et peu résistant) et de l'âge (formé avant ou après le traitement) sur la densité et le volume des chicots et du bois carié dans un peuplement feuillu des Appalaches. Les arbres avec des cavités utiles pour les espèces locales de pic-bois ont également été mesurés. Les résultats montrent que les chicots et les bois cariés sont deux à quatre fois plus abondants dans le traitement témoin comparativement à l'éclaircie forte (45% densité relative). La plupart des chicots étaient des cerisiers noirs (*Prunus serotina* Ehrh.) et des sassafras officinal (*Sassafras albidum* (Nutt.) Nees), résistants à la carie et de petit diamètre, qui meurent tôt dans le développement du peuplement. Les chicots et les arbres avec des cavités de fort diamètre (≥30 cm au diamètre à hauteur de poitrine) étaient rares autant dans le traitement témoin que dans les éclaircies.

[Traduit par la Rédaction]

Introduction

Traditional silvicultural practices focus on manipulating forest vegetation structure for commodity production. Forest managers attempt to minimize decay and mortality of live trees to reduce risks of insect and disease outbreaks or fire and to maximize the space available to superior growing stock (Nyland 1996). However, silvicultural treatments can reduce habitat features important to nongame species. The formation rate of habitats, such as feeding substrate and nesting sites, can also be altered. Removal of dead or defective trees in silvicultural operations negatively impacts wildlife species (such as primary cavity nesting birds) that depend on these trees for food and shelter (Conner et al. 1975; McComb and Noble 1980; Hunter 1990).

Silvicultural thinnings are procedures used to improve the quality, growth, and survival of residual trees. The type of thinning method influences the structural qualities of the residual stand. In low thinning, trees in overtopped, intermediate, or codominant (Smith et al. 1997) crown positions can be cut, which indirectly benefits trees in dominant or strong codominant crown positions. Trees that are defective or likely to die are minimized in the residual stand. In contrast, crown thinning removes primarily low-quality codominant and dominant trees in the canopy that interfere with the growth of more desirable codominant or dominant associates (crop trees). Defective or subcanopy trees are retained in the stand if they do not compete with designated crop trees.

Recent changes in forest management priorities have emphasized maintenance of natural plant and animal communities, rather than maximization of wood production. Processes such as tree decay and mortality are now seen as vital components of healthy forests (Hagan and Grove 1999). Research conducted within the past 20 years has consistently illustrated the critical role of dead wood in forest ecosystems

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(Bormann and Likens 1979; Harmon et al. 1986; McMinn and Crossley 1996). Hence, snags and other dead woody structures are important stand attributes deserving consideration in silvicultural prescriptions.

The length of time that dead trees remain standing, and consequently have the potential to serve as feeding and cavity nesting sites, is largely a function of wood durability. Panshin and DeZeeuw (1980) presented classifications of species heartwood decay resistance for lumber and other "wood in service," which are supported by field studies of snag decay (Harmon 1982; McPeek 1985; Dickson et al. 1995; Moorman et al. 1999).

The first objective of this study was to compare the density and volume of snags and decayed trees among different thinning intensities. Because snag age and wood decay characteristics also influence snag size and abundance, the effects of snag age (formed pre- or post-thinning), and degree of species heartwood decay resistance were also examined. The second objective was to describe how thinning influenced woodpecker habitat.

Methods

Study area

The study area is located on the 3100-ha West Virginia University Forest, 13 km east of Morgantown, W.V. Forest cover types are described as Appalachian mixed hardwood and oak–hickory (Burns 1983). The study area consists of a 24.3-ha stand (39°39′43″N, 79°45′28″W) located on a ridgetop at an elevation of 640 m, with northeast slopes ranging from 0 to 23%. The soils are moderately to extremely well drained and are characterized as Dekalb series on hill slopes and ridgetops, and deeper Ernest series on concave slopes bordering streams (USDA 1959).

Similar to most stands in the region, the study area has undergone many disturbances during the past 150 years: periodic partial cuttings, fires, and chestnut blight (Hicks 1998). On mesic lower slopes the current second growth forest consists of yellow-poplar (*Liriodendron tulipifera* L.), northern red oak (*Quercus rubra* L.), and black cherry (*Prunus serotina* Ehrh.) with lesser amounts of red maple (*Acer rubrum* L.) and sweet birch (*Betula lenta* L.). Drier ridgetops are dominated by chestnut oak (*Quercus prinus* L.) and scarlet oak (*Quercus coccinea* Muenchh.), with smaller amounts of red maple. In 1998, the stand was approximately 68 years old, with site indices (base age 50) of 24.4 m for yellow-poplar and 21.3 m for northern red oak (Carmean et al. 1989).

Experimental design

Treatments were established as part of a cooperative study between the USDA Forest Service, Parsons, W.V., and the West Virginia University, Division of Forestry (Miller et al. 1984; Brock et al. 1986). In 1982, the 52-year-old stand averaged 37.1 m^2/ha basal area and 618 trees/ha for trees ≥10 cm diameter at breast height (DBH). The stand was divided into twenty, 1.2-ha experimental units (110.2 m × 110.2 m). At the center of each experimental unit, a 0.2-ha permanent plot was established, where all live trees ≥2.54 cm were marked with numbered metal tags prior to treatment. Variables measured for each tree prior to logging included species; DBH (to the nearest 0.25 cm); crown class (dominant, codominant, intermediate, overtopped); and remarks noting defects such as skinned stem, broken or dead top, bend or lean, presence of grapevines (*Vitis* sp.), or flat-topped crown. Trees that were dead at plot establishment were gouged with a wood scribe so that they could be distinguished from tagged trees during future measurements. Snags were cut only if they contained salvageable lumber or if they presented hazards during logging.

Three thinning treatments and an uncut control were randomly assigned to the experimental units, resulting in five replications of each treatment. The thinnings consisted of cutting to 75, 60, or 45% relative density (RD) according to the upland hardwood stocking guide (Gingrich 1967). The thinning procedure selected two thirds of the "cut" trees from below mean stand diameter and one third above mean diameter. High-value species such as yellow-poplar, red oaks, and white oaks were favored as residual trees, while lower value species such as red maple and sassafras (*Sassafras albidum* (Nutt.) Nees) were preferentially removed (Table 1). During the spring of 1983, the stand was conventionally logged by a commercial logging contractor using chainsaws and rubber-tired skidders. Trees were not skidded through adjacent treatment plots. The plots were remeasured by the same USDA Forest Service crew in 1988, 1993, and 1998. During each measurement period, ingrowth trees ≥2.54 cm DBH were measured and tagged with a new number series.

Field procedures

Live tree measurements

In 1998, all live trees ≥12.7 cm DBH were searched for signs of defect or decay. Only trees with an estimated ≥10% volume loss due to defect or decay were measured; less than 10% decay was considered useless to woodpeckers. Trees were searched from at least two sides using binoculars. Outwardly visible defects that can indicate heart rot include fire scars, branch stubs, seams, and broken tops (Hepting et al. 1940; Berry and Beaton 1972). The percent volume loss was estimated based on the number and type of defects, and the height of the tree to the nearest half log (2.4 m), using tables presented by Tubbs et al. (1986) (after Zillgitt and Gevorkiantz (1946)).

Snag measurements

During the spring of 1998, each plot was censused for snags. In this study, a "snag" was defined as a self-supporting, standing dead tree ≥10.0 cm DBH (with or without bark) and ≥1.5 m tall. Snags that did not meet all these criteria were considered to have "fallen." Each snag was labeled with a permanent tag.

The snag measurements had two primary phases: (*i*) determine the current status (standing or fallen) of all trees ≥10 cm DBH that had died since treatment and (*ii*) measure the snags currently found on the plots (i.e., a mixture of snags formed before and after treatment). All trees ≥10 cm DBH that died after logging (1983–1998) were successfully located and their standing or fallen status determined. Snags that had been marked by gouging, or that no longer showed gouge marks due to advanced decay, were considered to have died before plot establishment. Snags were identified to species using bark and wood characteristics. Six snags could not be identified to species and were classified as unknown.

Snag DBH was measured to the nearest 0.25 cm using a diameter tape. The diameter at the snag base (0.3 m above ground level) was measured, or was visually estimated if swollen. Total height (to the nearest 0.3 m), height to a 5.0 cm or larger top, and upper stem diameter (nearest 2.54 cm) was visually estimated or measured using a height pole, clinometer, or relascope. The percentage of the snag that was hollow was visually estimated, and was later subtracted from the total snag volume. Each snag species was classified as having either "resistant" or "slight" heartwood decay resistance based on ratings presented by Panshin and DeZeeuw (1980, p. 353). Snags of unknown species were grouped in the "slight" category.

Cavity tree measurements

All live trees and snags ≥10 cm DBH were searched during the spring of 1998 (before leaf out) for woodpecker-excavated cavities. Trees were searched from the ground using binoculars, similar to

Table 1. Mean number of live trees and snags per hectare and the ratio of live trees to snags by thinning treatment and species group.

	Heavily thinned (45 and 60%)					Lightly thinned – unthinned (75% and control)				
Species group[a]	Pre-cut live	Post-cut live	Current[b] live	Current snag	Ratio[c]	Pre-cut live	Post-cut live	Current live	Current snag	Ratio
Yellow-poplar	163	63	58	1	58:1	97	83	74	5	15:1
Red oaks	98	65	69	3	23:1	174	153	136	15	9:1
White oaks	94	39	42	2	21:1	115	91	75	15	5:1
Black cherry	50	1	22	9	2:1	41	18	10	13	0.8:1
Red maple	119	24	82	0	–	117	71	109	2	55:1
Sassafras	73	2	1	23	0.1:1	32	13	6	47	0.1:1
Other[d]	28	7	38	8	5:1	37	20	32	12	3:1
Total	624	202	312	47	7:1	612	450	441	110	4:1

[a]Species groups (species in decreasing order of abundance): yellow-poplar (*Liriodendron tulipifera*), red oaks (*Quercus rubra, Quercus coccinea, Quercus velutina* Lam.), white oaks (*Quercus prinus, Quercus alba* L.), black cherry (*Prunus serotina*), red maple (*Acer rubrum*), sassafras (*Sassafras albidum*).

[b]Current, 1998 measurement.

[c]Ratio = live trees per hectare (1998)/snags per hectare (1998).

[d]Other live trees (species in decreasing order of abundance): *Betula lenta, Nyssa sylvatica* Marsh., *Magnolia acuminata* L., *Populus grandidentata* Michx., *Acer saccharum* Marsh., *Fraxinus americana* L., *Carya cordiformis* (Wagenh.) K. Koch, *Carya ovata* (Mill.) K. Koch, *Cornus florida* L., *Betula alleghaniensis* Britton, *Castanea dentata* Marsh., *Prunus pensylvanica* L. f.; other snags: *Robinia pseudoacacia* L., *Betula lenta*, unknown, *Populus grandidentata, Castanea dentata, Fraxinus americana, Magnolia acuminata*.

methods suggested by Healy et al. (1989); however, trees were not climbed to verify suspected cavities because of constraints of time and manpower. A cavity was measured if it met all of the following criteria: (*i*) entrance diameter ≥3.9 cm; (*ii*) cavity depth ≥5.0 cm; (*iii*) cavity was sheltered from weather; and (*iv*) subjective assessment of cavity usefulness as a woodpecker nest or roost site (e.g., cavity entrance intact). Cavity entrance dimensions, diameter outside bark at the cavity, and cavity height were measured using a relascope.

Data analyses

Stem density (trees/ha) was calculated for live trees during the pre-treatment (1983), post-treatment (1983), and current (1998) stand conditions. Snag stem density and basal area were summarized for the current (1998) stand. Snag volume, however, is not well represented by standard volume tables or equations, because many snags do not have intact upper boles or crowns. Therefore, snag volume was estimated using the equation for the frustum of a cone (Hicks 1995; Hale 1996):

$$[1] \qquad V = \frac{h}{3}(A_b + \sqrt{A_b A_u} + A_u)$$

where V is snag volume (m^3), h is height to a 5.0 cm diameter or larger top (m), A_b is cross-sectional area at base (m^2), and A_u is cross-sectional area at top (m^2) (Husch et al. 1982). The total volume of each decayed or defective live tree was computed using a cubic foot volume equation developed by the USDA Forest Service for use at the Fernow Experimental Forest, near Parsons, W.V. (unpublished data). The volume of decayed wood for each tree was then approximated by multiplying the total tree volume (m^3) by the percentage of defective volume to produce the volume of decayed wood per tree. These values were then expanded to a per-hectare basis.

A three-way analysis of variance (ANOVA) was used to measure the effects of thinning treatment (45, 60, and 75% RD, control), snag age (formed pre- or post-thinning), heartwood decay resistance (resistant, slight), and their interactions on snag characteristics. The analysis was performed using two dependent variables: snag stem density (snags/ha) and snag volume (m^3/ha).

The volume of decayed wood in live trees was analyzed in a similar fashion. A three-way ANOVA was used to determine the effects of thinning treatment (45, 60, and 75% RD, control), heartwood decay resistance (resistant, slight), and defect type (branch, seam, other) on decayed wood volume (m^3/ha).

Measurements of snag stem density, snag volume, and decayed wood volume were square-root transformed to normalize the data and equalize variances (Goodburn and Lorimer 1998; Moorman et al. 1999). Means and standard errors presented in the text, tables, and figure were derived from untransformed data in original units for ease of interpretation. Means were separated using Fisher's least significant difference (LSD) (Tables 5 and 6) and Scheffé's test (Fig. 1, Table 4).

Mean DBH was compared between cavity trees and non-cavity trees using Student's t test. Mean DBH, height, diameter at cavity, and cavity height were compared between live and dead cavity trees using Student's t test for each variable. When tests for homogeneity of variances were rejected, P values for means with unequal variances were presented. A χ^2 test was used to determine whether the number of cavity trees varied by thinning treatment. All statistical tests were considered significant at the $\alpha \leq 0.05$ level, and were performed using the SAS program (SAS Institute Inc. 1990).

Results

Snag characteristics

A descriptive summary of snag characteristics is presented in Table 2. Mean DBH and volume generally decreased as snags aged, reflecting both the fragmentation of snags over time and the large number of small snags that died early in stand development. Most of the larger diameter snags were formed within the past 0–10 years.

Decay-resistant species formed the majority of snags sampled but comprised the minority of trees that died since treatment. Slightly resistant snags were much larger than resistant snags in both diameter and volume, comprising 67% of trees ≥30 cm DBH. These differences were due to the dominance of small-diameter sassafras and black cherry in the resistant group and much larger yellow-poplar and oaks in the slightly resistant group.

Table 2. Snag characteristics by thinning treatment, age, and heartwood decay resistance.

	Thinning treatment				Age (years)[a]				Decay resistance[b]	
	45%	60%	75%	Control	0–5	5–10	10–15	>15	Resistant	Slight
Snags measured (*n*)	51	45	89	134	39	37	30	213	245	74
Mortality trees 1983–1998 (*n*)	26	18	27	152	44	62	117	—	81	142
Mortality trees that are currently snags (%)	31	44	52	50	89	60	26	—	56	43
Snag characteristics										
Mean DBH (cm)	14.9	16.2	16.2	15.8	19.9	21.6	17.3	13.9	14.5	20.1
Mean height (m)	3.8	5.4	4.7	4.4	6.1	3.5	4.6	4.6	4.7	4.0
Mean volume (m^3)	0.45	0.54	0.50	0.57	1.10	0.93	0.77	0.31	0.41	0.91
Basal area (m^2/ha)	0.95	1.07	2.25	2.95	0.35	0.40	0.20	0.85	1.10	0.71
Stem density[c] (snags/ha)										
10.0–19.9 cm DBH	45	36	73	108	5	4	5	50	55	11
20.0–29.9 cm DBH	5	6	12	20	4	3	2	2	5	6
≥30.0 cm DBH	1	3	3	5	<1	2	<1	<1	1	2

[a]Snags aged 0–5, 5–10, or 10–15 years formed after thinning; snags aged >15 years formed before thinning.
[b]Decay resistance groups (species and number sampled): resistant (*Sassafras albidum* (143), *Prunus serotina* (46), white oaks (*Quercus prinus* (31), *Quercus alba* (3)), *Robinia pseudoacacia* (19), *Castanea dentata* (3)); slight (red oaks (*Quercus rubra* (30), *Quercus coccinea* (7)), *Liriodendron tulipifera* (13), *Betula lenta* (7), unknown (6), *Acer rubrum* (5), *Populus grandidentata* (3), *Fraxinus americana* (2), *Magnolia acuminata* (1)).
[c]Stem densities (snags/ha) presented are subdivisions of the total snags/ha in Table 4; grand totals may not be equal because of rounding.

Table 3. Three-way ANOVA results for the effects of thinning treatment, age, and heartwood decay resistance on snag stem density (snags/ha) and volume (m^3/ha).

		Snag stem density		Snag volume	
Source of variation	df	MS	*P*	MS	*P*
Treatment (T)	3	30.78	0.0095	17.61	0.0051
Error (Plot(T))	16	5.73	0.3271	2.81	0.4968
Resistance (R)	1	81.29	0.0002	13.42	0.0358
Age (A)	1	21.88	0.0401	7.56	0.1116
T × R	3	0.76	0.9266	0.11	0.9900
T × A	3	15.58	0.0326	14.03	0.0049
R × A	1	194.81	0.0001	94.59	0.0001
T × R × A	3	4.29	0.4619	1.74	0.6145
Remainder	48	4.91		2.88	
Total	79				

Snag stem density and volume

A total of 319 snags were measured. The ratio of live trees to snags decreased from heavily thinned to lightly thinned treatments for all species groups except sassafras (Table 1). Snag stem density differed significantly among treatments, between heartwood resistance groups, and by snag age in the overall ANOVA (Table 3). Uncut controls had 2.6 times as many snags as 45% RD thinnings and 3 times as many snags as 60% RD thinnings. Snags with decay-resistant heartwood were over three times more common than snags with slightly resistant heartwood (Table 4).

The interactions of treatment × age and resistance × age were also significant in the ANOVA (Table 3). Snags formed from decay-resistant species that died prior to treatment were very common, while slightly resistant snags formed before treatment were uncommon (Table 5). In addition, most of the decay-resistant snags formed prior to thinning in the thinned treatments. The control plots contained 9.5 times as many snags formed since 1983 than did the 45 or 60% RD thinnings (Table 6).

Trends in snag volume were similar to those observed for stem density. Control plots had approximately three times more snag volume than 45 and 60% RD thinnings, and decay-resistant species contributed more volume than slightly resistant species (Table 4). The treatment × age interaction was significant and the resistance × age interaction was highly significant (Table 3). Control plots showed more snag volume formed post-treatment because of recent mortality (Table 6). Snag volumes in the pre-treatment resistant and post-treatment slightly resistant categories was highest, followed by post-treatment resistant and pre-treatment slightly resistant (Table 5).

Live trees: decayed wood volume

Defects were measured on 187 of 1524 live trees. The volume of decayed wood was significantly influenced by treatment ($P \leq 0.0214$) and heartwood decay resistance ($P \leq 0.0006$). Decayed wood volume was 4.7 times more abundant in controls compared with 45% RD thinnings, and slightly resistant species comprised 69% of decayed wood volume (Fig. 1). The decay resistance × defect interaction was significant ($P \leq 0.0328$), showing higher amounts of decayed wood in the slightly resistant "limb" and "other" categories.

Cavity tree and cavity characteristics

The low number of cavity trees encountered (n = 13) limited the statistical analyses possible. Cavity trees appeared to be more common (n = 9) in 75% RD thinnings and controls compared with heavily thinned treatments (n = 4), but the difference was not statistically significant (χ^2 = 1.923, df = 1, $P \leq 0.1660$). Cavities were found in four tree species: yellow-poplar (6), sassafras (5), scarlet oak (1), and sweet birch (1).

Live cavity trees were significantly ($P \leq 0.0139$) larger than live trees without cavities (38.1 ± 3.6 vs. 26.2 ± 0.4 cm DBH; mean ± SE). Size did not differ between snags with and without cavities ($P \leq 0.6197$). Live cavity trees were significantly ($P \leq 0.0005$) larger in diameter (38.1 ± 3.6 vs. 17.2 ± 1.5 cm DBH) and taller ($P \leq 0.0001$, 26.8 ± 1.7 vs.

Table 4. Mean snag stem density and volume by thinning treatment, age, and heartwood decay resistance.

	Thinning treatment				Age		Decay resistance[a]	
	45%	60%	75%	Control	Pre-treatment	Post-treatment	Resistant	Slight
Stem density (snags/ha)	50*b*	45*b*	88*ab*	132*a*	53	26	61	18
Standard error	16	17	33	28	11	8	12	4
Volume (m^3/ha)	22.49*b*	24.22*b*	43.86*ab*	75.14*a*	16.57	24.85	24.80	16.63
Standard error	7.22	4.35	17.50	6.67	3.69	5.44	4.39	3.64

Note: Means followed by the same letter are not significantly different ($\alpha \leq 0.05$) using Scheffé's procedure.

[a]Decay resistance groups (species in decreasing order of abundance): resistant (*Sassafras albidum*, *Prunus serotina*, white oaks (*Quercus prinus*, *Quercus alba*), *Robinia pseudoacacia*, *Castanea dentata*); slight (red oaks (*Quercus rubra*, *Quercus coccinea*), *Liriodendron tulipifera*, *Betula lenta*, unknown, *Acer rubrum*, *Populus grandidentata*, *Fraxinus americana*, *Magnolia acuminata*).

Table 5. Mean snag stem density and volume by heartwood decay resistance and age.

	Decay resistance	
Age	Resistant	Slight
Snag stem density (snags/ha)		
Pre-treatment	49.4*a*	3.2*b*
Post-treatment	11.1*b*	15.1*b*
Snag volume (m^3/ha)		
Pre-treatment	15.79*a*	0.78*c*
Post-treatment	9.01*b*	15.85*a*

Note: Means with the same letter are not significantly different ($\alpha \leq 0.05$) using Fisher's LSD.

Table 6. Mean snag stem density and volume by thinning treatment and age.

	Thinning treatment			
Age	45%	60%	75%	Control
Snag stem density (snags/ha)				
Pre-treatment	42.5*ab*	36.6*ab*	74.1*ab*	57.3*ab*
Post-treatment	7.9*b*	7.9*b*	13.8*ab*	75.1*a*
Snag volume (m^3/ha)				
Pre-treatment	14.90*b*	10.73*b*	26.35*b*	14.32*b*
Post-treatment	7.59*b*	13.49*b*	17.51*b*	60.82*b*

Note: Within densities or volumes, means with the same letter are not significantly different ($\alpha \leq 0.05$) using Fisher's LSD.

8.1 ± 1.9 m) than dead cavity trees. Cavity height ($P \leq 0.2419$) and cavity entrance size ($P \leq 0.1990$) did not significantly differ between live and dead cavity trees. Similar to DBH, live cavity trees were significantly ($P \leq 0.0001$) larger in diameter (28.6 ± 1.6 vs. 12.3 ± 2.2 cm DBH) at the cavity height than were dead trees.

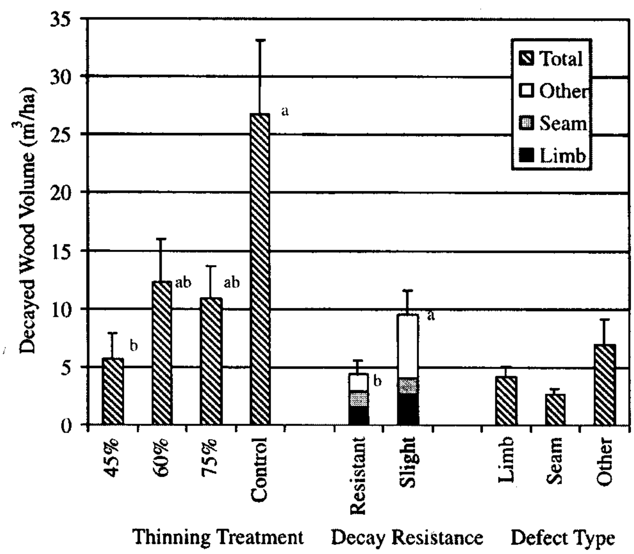
Discussion

Thinning treatment

Existing studies report that managed forests generally have reduced snag abundance and quality compared to unmanaged forests (McComb and Noble 1980; Harlow and Guynn 1983; Harmon et al. 1986; McCarthy and Bailey 1994; Goodburn and Lorimer 1998). In this study, snag stem density and volume decreased as much as threefold from uncut controls to heavily thinned treatments.

Snags were less common in heavily thinned treatments for several reasons. Mortality in heavily thinned plots was lower

Fig. 1. Mean decayed wood volume by thinning treatment, heartwood decay resistance, and defect type. Error bars = 1 standard error. Means with the same letter are not significantly different at $P \leq 0.05$ using Scheffé's procedure.



than 75% RD thinnings and controls because of decreased competition for site resources and removal of potential mortality trees during the harvest. Thinning efforts focused on defective trees in subordinate crown positions, which were those trees most likely to die from competition. A lower percentage of trees that died since thinning remained standing as snags in heavily thinned treatments, which suggests that snags fell more quickly in heavily thinned plots, possibly because of blowdown caused by decreased overstory protection. Alternatively, snags present at thinning may have been knocked down during logging in heavily thinned plots.

Decay resistance

It is common practice to group species by silvical characteristics (e.g., shade tolerance) when measuring live tree dynamics. Once dead, the rate at which trees decay and fragment is a function of wood properties, such as heartwood decay resistance (Harmon et al. 1986). For example, yellow-poplar, black cherry, and sassafras are classified as shade intolerant and exhibit similar growth dynamics when living. However, black cherry and sassafras have decay-resistant heartwood, while yellow-poplar has unresistant heartwood. Consequently, yellow-poplar decays more rapidly than its previous associates.

Snags can be utilized as estimates of past mortality rates, by cross-dating dead trees with live trees to determine the year of death for each snag (Henry and Swan 1974; Oliver and Stephens 1977; Pederson 1998). Past mortality rates can also be estimated by comparing the current number of live and dead trees for each species to estimate relative mortality rates (McComb and Muller 1983). However, the latter method may not be appropriate for stands containing a large component of decay-resistant species. In 1998, 77% of snags occurring on sample plots were classified as having decay-resistant heartwood. However, mortality from 1983 to 1998 (e.g., Table 2, mortality trees) consisted of only 36% decay-resistant species. Species with decay-resistant heartwood occurred frequently as snags because of their slower decay rates rather than higher mortality rates. If this method is to be used with species of varying decay resistance, differences in snag longevity among species (e.g., Dickson et al. 1995; Moorman et al. 1999) must be incorporated.

Similarly, the species composition of live trees and snags contrasted because of differences in both mortality rates and decay resistance. Species with unresistant heartwood, such as red maple and yellow-poplar, were rarely found as snags, although they comprised a large proportion of the overstory. Decay-resistant species, such as sassafras and black cherry, were more common as snags than as live trees in 75% RD thinnings and controls.

Age

Snag age alone did not significantly affect snag stem density or volume. The significant interaction of age × decay resistance helps explain why this study had higher snag densities compared with other studies in similar forest types (e.g., McComb and Muller 1983; Muller and Liu 1991). An abundance of small, decay-resistant snags, formed 15+ years ago, dominated all treatments. Of these, 94% were sassafras and black cherry snags that occurred in single-species clumps. Both of these species are shade intolerant, reproduce vegetatively (Griggs 1990; Marquis 1990), and probably regenerated as stump sprouts and root suckers after the heavy cuttings and fire that initiated the stand. The resultant snag clumps were created by the early mortality of these sprouts as stand development progressed.

The relationship between thinning treatment and age helps explain why the percentage of snag volume formed since thinning was lower (ranging from 34 to 56%) in thinned treatments, compared with controls (81%). Thinning greatly reduced mortality of large-diameter yellow-poplars and oaks and removed small diameter stems that would have likely formed snags, which consequently reduced total snag volume.

Impact of thinning on woodpecker habitat

Snag stem densities ranged from 45 snags/ha in 60% thinnings to 132 snags/ha in uncut controls (Table 4). The majority of snags were small-diameter (10–20 cm DBH) sassafras and black cherry that had been dead 15 or more years (Table 2). Large-diameter snags (≥30 cm DBH) were uncommon in both thinned treatments and controls.

Live trees containing decayed wood are also used by woodpeckers for both foraging and cavity excavation. Decayed wood volume was 4.7 times higher in control plots compared with 45% RD thinnings, reflecting the preferential removal of defective and decayed trees during thinning (Marquis et al. 1992). In the thinned treatments, much of the existing decay consisted of dead branches and seams formed on scarlet and northern red oaks. Yellow-poplars containing heartrot, which were preferred for woodpecker excavation, were more common in the unthinned treatments (Schroeder 1983; Sousa 1987).

Woodpecker-excavated cavities were uncommon in all treatments. Characteristics of cavities and cavity trees were within ranges reported by earlier studies (Conner et al. 1975; Brawn et al. 1984; Runde and Capen 1987), with a strong preference shown for trees of larger than average diameter. Live trees with decay were preferred (62%) over snags for cavity excavation, which suggests that, even though snags were abundant, decay-resistant snag species were too hard or dry for cavity excavation (Conner et al. 1994).

Management implications

This study found that many small snags (≤20 cm DBH) were formed by early successional species during stand development. Existing silvicultural guidelines for intermediate treatments in Appalachian hardwoods suggest cutting noncommercial species such a sassafras (Allen and Marquis 1970; Marquis et al. 1992). However, such short-lived species would not appreciably decrease the growth or value of crop trees and would increase snag abundance in thinned stands. Thinning also reduced the potential number of large-diameter (≥30 cm DBH) snags and live trees with decay that are necessary for woodpecker cavities. Silvicultural efforts aimed at increasing the quality of snags and other wildlife features should focus on retention and (or) creation of large snags and decayed trees of preferred species, which are uncommon in both managed and unmanaged second-growth stands.

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