Tree Cavity Estimation and Verification in the Missouri Ozarks

Randy G. Jensen[1], John M. Kabrick[2], and Eric K. Zenner[3]

Abstract.—Missouri forest management guidelines require that cavity trees and snags be provided for wildlife. Missouri Ozark Forest Ecosystem Project (MOFEP) timber inventories provided opportunities to determine if cavity tree and snag densities in a mature second-growth oak-hickory-pine forest meet forest management guidelines, to evaluate the effects of the first-entry harvesting on cavity tree densities in even-aged, uneven-aged, and no-harvest management systems, and to determine if cavity abundance differed among tree species, tree diameter, hole diameter, and location on the tree. We examined 54,452 live trees and snags during two pre-harvest data collection periods and during a third post-harvest data collection period. Pre-harvest cavity tree and snag densities were near or above optimum recommendations specified in the management guidelines. After timber harvests, cavity tree densities were above optimum recommendations in even-aged and no-harvest sites and slightly below optimum recommendations on uneven-aged sites. Snags were well above optimum recommendations on no-harvest and uneven-aged sites and only slightly below optimum on even-aged sites after timber harvests. Blackgum (20%) had the highest occurrence of tree cavities and shortleaf pine (1%) had the lowest, compared to oaks (2-10%) and hickories (7-11%). Basal cavities were the most abundant cavities overall (44%), particularly in trees <18 in. (46 cm) and >26 in. (66 cm) diameter at breast height (d.b.h.). For all tree species, larger diameter classes had a higher proportion of trees with cavities.

A second study was conducted to verify the accuracy of cavity estimation procedures and to investigate the reliability of general survey cavity estimates. We conducted an intensive cavity search and inventory in twenty-four, 0.5-ac (0.2 ha) vegetation plots before and after clearcut harvesting. In each plot, approximately 75 trees ≥ 4.5 in. (11 cm) d.b.h. were intensively examined for tree cavities and potential tree cavities during the winter of 1995-1996. During the winter of 1996-1997, following clearcutting, we relocated trees thought to have cavities or potential cavities and dissected them with a chain saw for cavity verification and measurement. Overall, our intensive search yielded twice as many cavity trees as found during the timber inventory. However, only 55 percent of openings initially judged to lead to a tree cavity actually did. Conversely, 18 percent of openings thought to be potential cavities were found to be cavities. Many of the tree cavities would not be suitable for many wildlife species that use cavities. Only 13 percent of the estimated cavities and 23 percent of the actual cavities fit the criteria of having a hole at least 1 in. (2.5 cm) diameter, 10 ft (3 m) or more above ground, and with a 2x2x4 in. (5x5x10 cm) cavity. More information on the cavity characteristics, including hole size, tree height, tree diameter, and internal dimensions, required by different wildlife species is needed to aid managers in selecting (retaining) the cavity trees most beneficial for wildlife species.

[1] Resource Forester, Missouri Department of Conservation, Rt. 2 Box 198, Ellington MO 63638; e-mail: jenser@mail.conservation.state.mo.us.
[2] Research Forester, Missouri Department of Conservation, 1110 S. College Ave., Columbia, MO 65201; e-mail: kabrij@mail.conservation.state.mo.us.
[3] Formerly, Terrestrial Biometrician, Missouri Department of Conservation, 1110 S. College Ave., Columbia, MO 65201. Presently, Assistant Professor of Silviculture, Department of Forest Resources, University of Minnesota, 115 Green Hall, 1530 Cleveland Ave. N., St. Paul, MN 55108.

Snags and tree cavities provide important habitats for at least 89 species of wildlife in Missouri (MDC 1985). Snags provide habitat, food, and singing and feeding perches for wildlife (MDC 1986b). Cavities in live trees and snags provide escape cover, thermal protection, rearing areas for young, and food storage locations for many mammals, birds, reptiles, and amphibians (MDC 1985, 1986b). In Missouri forest habitats, at least 10 species are primary cavity excavators, meaning they construct cavities in trees; at least 22 species are secondary cavity users that use existing cavities (Hardin and Evans 1977, MDC 1985). Twenty-two percent of Missouri's bird species are cavity nesters, of which 60 percent declined in populations from 1966 to 1994 (Wilson 1996). Because so many species rely on snags and tree cavities to meet their basic life requirements, management activities that affect snag and cavity tree abundance can have a direct impact on their populations.

The Missouri Ozark Forest Ecosystem Project (MOFEP) was initiated in 1989 to document the effects of even-aged, uneven-aged, and no-harvest forest management practices on the ecology of the oak-hickory-pine forest of the southeast Missouri Ozarks (Brookshire and Hauser 1993, Brookshire *et al.* 1997, Kurzejeski *et al.* 1993). MOFEP was designed to be a long-term study at a landscape scale looking at many ecological attributes that traditionally have not received much attention. One such study is determining the abundance and size of cavity trees and snags and the effect of forest management on their distributions.

Different silvicultural management systems may have different effects on snag and cavity abundance at the site scale. For example, because even-aged intermediate thinnings and uneven-aged management focus on the harvest of single trees or groups of trees, managers examine each tree more closely than with clearcutting in even-aged management. Thus, managers have a greater chance of detecting, and more flexibility in controlling, the number and distribution of snags and cavity trees with uneven-aged management compared to clearcutting in even-aged management. With even-aged management, where clearcutting is used for tree regeneration, a smaller proportion of the site (approximately 10%) is harvested during each re-entry and very few trees are left behind, including snag and cavity trees. This means that there are more opportunities to decide whether to leave or harvest trees containing cavities suitable for wildlife during intermediate thinnings or selection cuts, even though cavity trees may be considered inferior for timber production. The MOFEP cavity and snag study is documenting changes in cavity tree and snag densities and characteristics with even-aged, uneven-aged, and no-harvest management.

The objectives of this paper were to 1) document the density of tree cavities and snags on MOFEP sites both before and after first-entry harvesting in even-aged, uneven-aged, and no-harvest sites and compare these to the Forest Land Management Guidelines for Missouri; 2) report trends in the pre-treatment cavity data with regard to cavity tree species, tree diameter, hole diameter, and hole height on the tree; 3) verify the reliability of tree cavity estimates by dissecting cavity trees; and 4) discuss implications of cavity use by wildlife. In this paper, "holes" refer to openings in tree boles or branches, "cavities" refer to the hollow within tree boles or branches with an opening to the tree exterior, and "dens" refer to cavities that are being used by wildlife species.

METHODS

The MOFEP study design is described in detail by Brookshire *et al.* (1997), Sheriff and He (1997), and Sheriff (this proceedings). Nine study sites (compartments), ranging in size from 772 ac (313 ha) to 1,275 ac (516 ha), were allocated into three "complete" statistical blocks of three sites each. A management system (i.e., even-aged, uneven-aged, or no-harvest) was randomly assigned to sites within a block, yielding three replicates of each treatment (Sheriff and He 1997). The management system was applied at the site level, and management was implemented at the stand level. Each site was divided into many stands in which forest vegetation composition and age, and environmental characteristics were similar. The Missouri Department of Conservation Forest Land Management Guidelines (Missouri Department of Conservation 1986) and the guidelines for managing uneven-aged stands (Law and Lorimer 1989) provided general recommendations for harvesting in even-aged and uneven-aged MOFEP sites. See Sheriff (this proceedings) for additional details on treatments.

We conducted two different studies to address our objectives. In the first study, we used the *general overstory cavity inventories* to document the density of tree cavities and snags in two inventories before, and one inventory after, first entry harvesting in even-aged, uneven-aged, and no-harvest sites and compared the observed densities to the Forest Land Management Guidelines for Missouri (objective 1). We also used these data to identify trends in the pre-treatment cavity data with regard to cavity tree species, tree diameter, and hole height on the tree (objective 2). In the second study, we used data from an *intensive cavity survey and verification* to verify the reliability of tree cavity estimates (objective 3). The data sources used for these studies are described below.

General Overstory Cavity Inventories

Cavity data were collected on 50,845 live trees and 3,607 snags as part of the MOFEP woody vegetation study on the original 645, 0.5-ac (0.2 ha) vegetation plots in 1990-1992 and three new plots in 1994 (total of 648 vegetation plots). All trees used in these analyses were individually tagged with a number. These trees and ingrowths were re-inventoried in 1994 and 1995 prior to MOFEP timber harvest in 1996 and were inventoried again in 1997-1998. Overstory cavity data were collected on all trees ≥ 4.5 in. (11 cm) diameter breast height (d.b.h.) and on snags that were at least 8 ft (2.4 m) tall and ≥ 6 in. (15 cm) d.b.h. Tree species, d.b.h., crown class, and the presence of holes thought to lead to cavities were recorded. Data collected on holes included hole diameter class, hole height class, and cavity formation type (natural or wildlife excavated) (table 1). Holes that went into or underneath tree roots were considered cavities but were rare. Live trees with cavities on dead branches were considered live cavity trees. Cavity trees were defined as having one or more holes that were ocularly estimated to be a minimum 1 in. (2.5 cm) in diameter or to have a

Table 1.—*Codes and descriptions used to quantify wildlife cavities in trees ≥ 4.5 in. d.b.h. on the MOFEP cavity and overstory forest vegetation study*

Formation code	Cavity type	Description
1	Natural	Hollow; formed by decay after a branch breaks off a tree.
2	Excavated	Hollow; formed primarily by woodpeckers and aided by decay. Usually circular with smooth edges.

Size code (Pre-treatment)	Cavity diameter	Size code (Post-treatment)	Cavity diameter (Post-treatment)
1	≤ 5 in.	0.5	≤ 0.75 in.
2	5< x ≤ 12 in.	1.0	0.75 < x ≤ 1.25 in.
3	> 12 in.	1.5	1.25 < x ≤ 1.75 in.
		2.0	1.75 < x ≤ 2.25 in.
		2.5	2.25 < x ≤ 2.75 in.
		3.0	2.75 < x ≤ 3.50 in.
		4.0	3.50 < x ≤ 4.50 in.
		5.0	4.50 < x ≤ 5.50 in.
		etc.	

Location code (Pre-treatment)	Height above groundline	Location code (Post -treatment)	Height above groundline
1	< 5 ft	0.1	Ground or root
2	5 ≤ x < 15 ft	0.2	≤ 4 in.
3	15 ≤ x < 25 ft	1	4 in. ≤ x < 5 ft
4	25 ≤ x < 35 ft	2	5 ft ≤ x < 15 ft
5	≥ 35 ft	3	15 ft ≤ x < 25 ft
		4	25 ft ≤ x < 35 ft
		5	≥ 35 ft

minimum dimension of 0.75 x 1.25 in. (1.9 x 3.2 cm) for oval holes. The hole diameter recorded was the widest diameter in the narrowest axis of the hole. In most cases trees were examined on at least two sides. Holes within reach were examined to determine if a cavity was present. A more detailed discussion of the woody vegetation data collection procedure is provided by Jensen (2000).

Because of the large number of trees, cavity data were collected during both dormant and growing seasons. We found a slightly greater number (< 2%) of cavities during the dormant season for holes high on trees, probably because it was easier to identify cavities in tree canopies without leaves. However, we feel that the difference between dormant season and growing season cavity inventories was small and unbiased with respect to harvest treatment, tree species, and tree size, so we proceeded with our analyses with the data pooled across season.

Intensive Cavity Survey and Verification

During the winter of 1995-1996, a more intensive search for cavities was conducted in 24 vegetation plots containing 1,439 overstory trees, scheduled to be clearcut during the summer and fall of 1996. For this intensive survey, we used binoculars to help estimate if a hole led to a cavity. A clinometer was used to determine the hole height. In this portion of the study there was no minimum hole diameter requirement, but data were not collected on potential cavities in the 0.5 in. (1 cm) size class formed by woodpeckers due to the very large number of them. Potential cavities in this size class formed by other means were recorded. The hole diameter was estimated in half-inch (1 cm) size classes for holes < 3 in. (7.5 cm) and in 1 in. (2.5 cm) size classes for larger holes (table 1). Holes were classified as being in a live or dead section of a live tree and the height to width ratio of the hole was recorded. Trees were thumped with an axe to determine if they sounded hollow or decayed. For this intensive cavity survey, cavities were defined as having a minimum depth into the tree of 3 in. (7.5 cm) or a depth of at least half the diameter of the stem if in small branches. Other data collected on cavity trees and other overstory trees included tree species, d.b.h., crown class, and a tree condition code. The overstory tree tag number was painted on cavity trees to aid in relocation. Data were also collected on holes determined to be potential cavities (except on the excavated half inch [1.3 cm] size class). For the intensive cavity survey, potential cavities were defined as holes in early stages of cavity formation that did not meet our minimum cavity dimension requirements.

During the tree harvest in 1996, researchers recorded log lengths of each tagged tree removed. The tree tag number was painted on felled tree tops, cull logs, and non-merchantable tree sections to ensure that the entire length of each of the original trees could be accounted for during cavity verification. During the winter of 1996-1997 and before slashing was done, the plots were revisited and the cavity data verified. Cavity trees left as culls or of unmerchantable size were felled with a chainsaw. The initial data were used as an aid to finding the original holes. The original cavity estimates were verified by measuring relocated holes and potential holes on felled trees. A drafting compass was used to measure hole diameters. A chainsaw was used to dissect the stems above and below holes. The internal cavity dimensions (maximum width, minimum width, and depth) were recorded. The hole was designated as an actual cavity if it met or exceeded the minimum size requirements, or it was designated as a potential cavity if internal dimensions were smaller.

RESULTS

General Overstory Cavity Inventories

Cavity and Snag Guidelines vs. MOFEP Findings

For this discussion, pole timber included the trees < 10 in. (25 cm) d.b.h., small sawtimber included those from 10 to 19 in. (25 to 48 cm) d.b.h., and large sawtimber trees were greater than 19 in. (48 cm) d.b.h. (fig. 1). Based on the general overstory cavity inventory on the 648 vegetation plots prior to treatment, MOFEP sites had cavity tree densities well above the minimum recommended in the Forest Land Management Guidelines (MDC 1986a) for poles (2.3 vs. 1/ac or 4.0 vs. 2.5/ha), small sawtimber (3.7 vs. 2/ac or 9.1 vs. 5/ha), and large sawtimber (1.3 vs. 0.5/ac or 3.0 vs. 1/ha). Cavity tree density was just below the optimum recommendations for poles (2/ac or 5/ha) and small sawtimber (4/ac or 10/ha), and above for large sawtimber (1/ac or 3/ha).

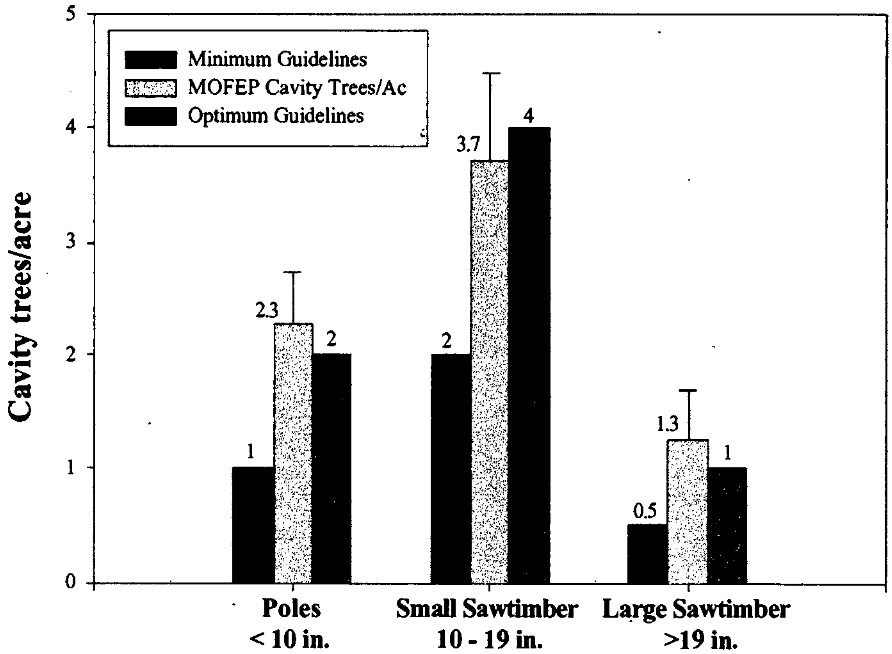

Figure 1.—*Pre-harvest cavity tree (≥ 4.5 in. (11 cm) d.b.h.) densities for pole timber, small sawtimber, and large sawtimber on all MOFEP sites compared to the land management guidelines for Missouri's heavily forested areas. Error bars are 95 percent confidence intervals for site means. Numbers on bars indicate site means or minimum and optimum recommendations.*

Following harvest treatments in 1996, there was a reduction in cavity tree density in even-aged (-0.6/ac or -1.5/ha) and uneven-aged (-0.6/ac or -1.5/ha) sites, and an increase in no-harvest (+1.2/ac or +3.0/ha) sites compared to pre-harvest cavity tree density. These estimates are for the entire site, which included both harvested and unharvested stands. For all size classes, cavity tree density was slightly above the optimum recommendation of seven cavity trees/ac (17/ha) on no-harvest (7.2/ac or 17.8/ha) sites and on even-aged (8.5/ac or 21.0/ha) sites and slightly below the optimum recommendation for uneven-aged (6.1/ac or 15.1/ha) sites (fig. 2).

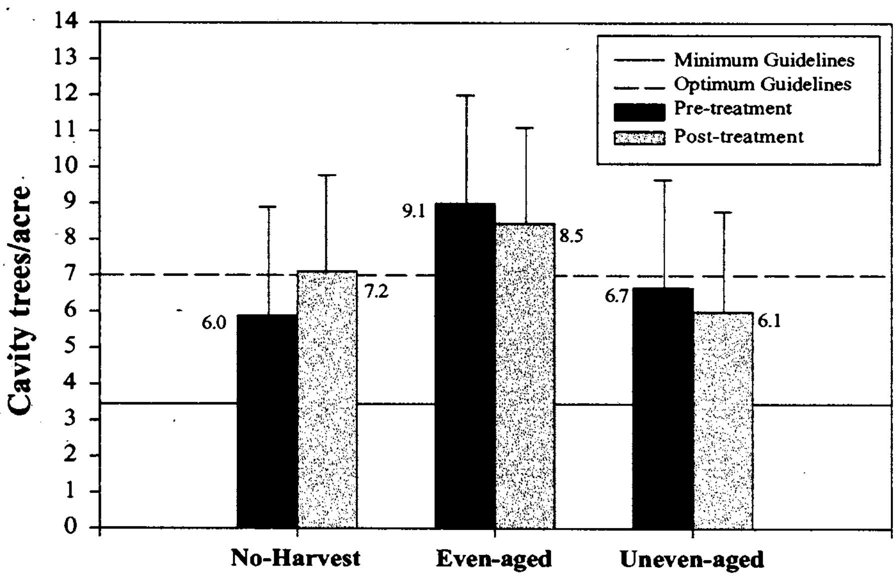

Figure 2.—*Pre-harvest and post-harvest cavity tree densities (≥ 4.5 in. (11 cm) d.b.h.) by forest management on MOFEP sites compared to the land management guidelines (combined size classes) for Missouri's heavily forested areas. Error bars are 95 percent confidence intervals for site means. Numbers on bars indicate treatment means.*

On the no-harvest sites, 82 percent of the pre-treatment cavity trees remained alive in the winter of 1998-1999, 11 percent became snags, and 7 percent fell to the ground. On the harvested sites, 21 percent of the pre-treatment cavity trees on uneven-aged sites and 16 percent on the even-aged sites were cut. Kabrick *et al.* (this proceedings) give a more detailed description of the overstory tree conditions on MOFEP sites before and after the 1996 harvest.

Snag densities on MOFEP sites in 1994 and 1995 were above the optimum levels for pole timber (4.0 vs. 2/ac or 9.9 vs. 5/ha) and large sawtimber (0.3 vs. 0/ac or 0.7 vs. 0/ha), and they were below optimum for small sawtimber (2.9 vs. 4/ac or 7.2 vs. 10/ha) but above the minimum recommendations (2/ac or 5/ha) (fig. 3). For all snag size classes combined, snag densities in even-aged sites were below the optimum snag recommendation (5.2 vs. 6/ac or 13 vs. 15/ha) but above optimum in no-harvest (8.8 vs. 6/ac or 22 vs. 15/ha) and uneven-aged (7.5 vs. 6/ac or 19 vs. 15/ha) sites. Following the tree harvest, 1998 snag densities rose slightly in no-harvest (9.2/ac or 23/ha) sites and more in uneven-aged (9.9/ac or 24/ha) sites but stayed about the same in even-aged (5.1/ac or 13/ha) sites (fig. 4).

Cavities by Tree Size, Height on Trees, and Tree Species

Whereas the number of trees in 2 in. (5 cm) diameter classes had a negative exponential diameter curve, the proportion of live trees with a cavity had a positive exponential curve (q-value of 1.5) with increasing diameter classes. Most trees (33%) were in the 6 in. (15 cm) d.b.h. class, but only 1.7 percent of these had noticeable cavities (fig. 5). Three percent of the trees were in the 18 in. (46 cm) d.b.h. size class and 17 percent of these trees had cavities. Only 0.1 percent of trees were larger than 27 in. (69 cm) d.b.h., but 68 percent of these trees contained cavities. The trend of increasing occurrence of cavities with increasing tree diameter was also observed within species and species groups (fig. 6) and has been noted by others (Allen and Corn 1990, Healy *et al.* 1989).

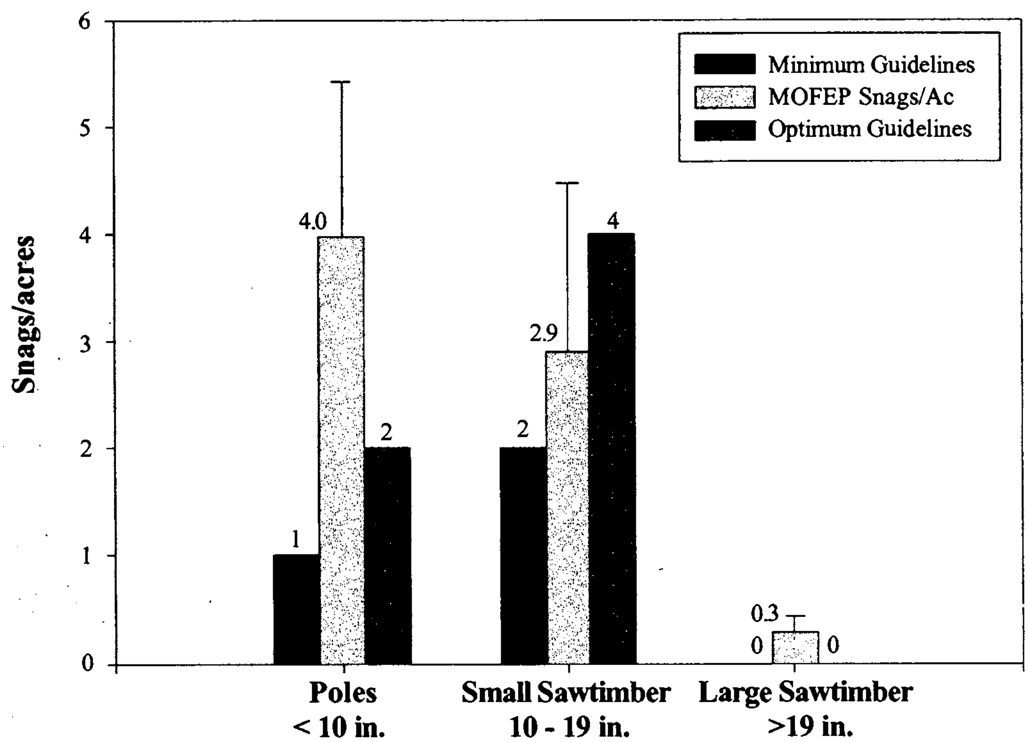

Figure 3.—*The density of snags (≥ 6 in. (15 cm) d.b.h.) on pre-treatment MOFEP vegetation plots in 1994-1995, and a comparison to the recommended snag guidelines for Missouri's heavily forested regions. Error bars are 95 percent confidence intervals for site means. Numbers on bars indicate site means or minimum and optimum recommendations.*

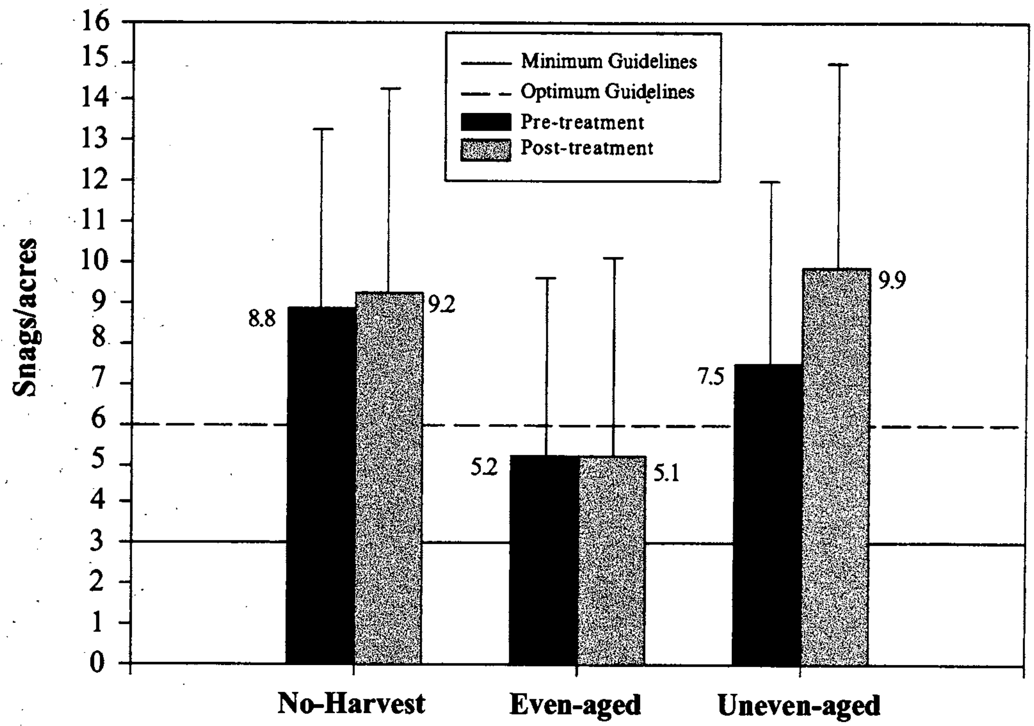

Figure 4.—*Pre-harvest and post-harvest snag densities (≥ 6 in. (15 cm) d.b.h.) by forest management on MOFEP sites compared to the land management guidelines (combined size classes) for Missouri's heavily forested areas. Error bars are 95 percent confidence intervals for site means. Numbers on bars indicate site means.*

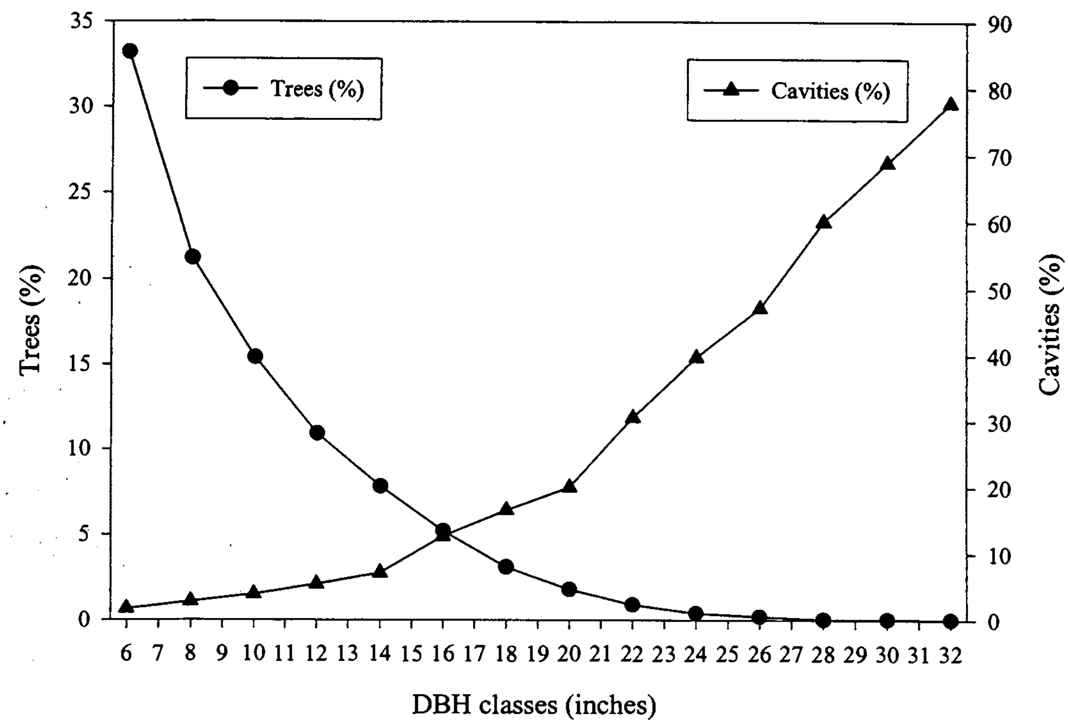

Figure 5.—*Pre-treatment diameter distribution of overstory trees (≥ 4.5 in. (11 cm) d.b.h.) on MOFEP sites and the corresponding percent of cavity trees by size class.*

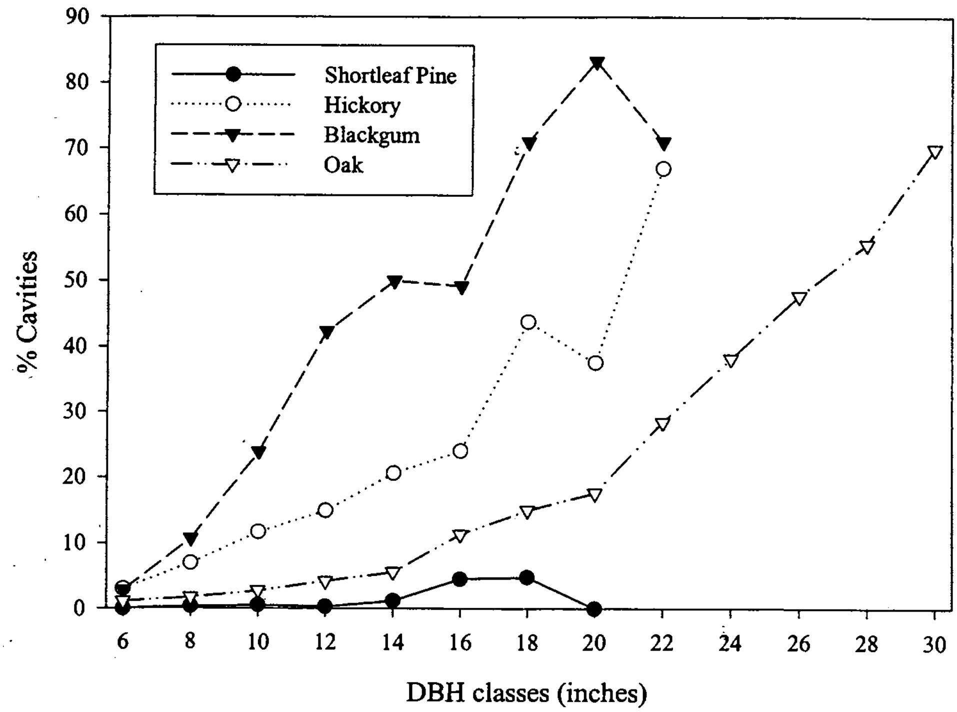

Figure 6.—*The pre-treatment percentage of cavity trees by 2 in. (5 cm) size classes for select species and species groups (≥ 5 in. (13 cm) d.b.h.) on MOFEP sites. The last data point for each species or species group includes larger trees when their sample size would have been less than 10 otherwise.*

Basal cavities (< 5 ft or 1.5 m above ground) made up 44 percent of all cavities located and were present in 58 percent of the cavity trees. For trees ≤ 12 in. (30 cm) d.b.h., there were more basal cavities present than all other cavity heights (> 5 ft) combined. For diameter classes other than 18, 22, and 24 in. (or 46, 56, and 61 cm) d.b.h., where most cavities were in the 20 ft (6 m) height class, basal cavities were again the predominant height location. Cavities at least

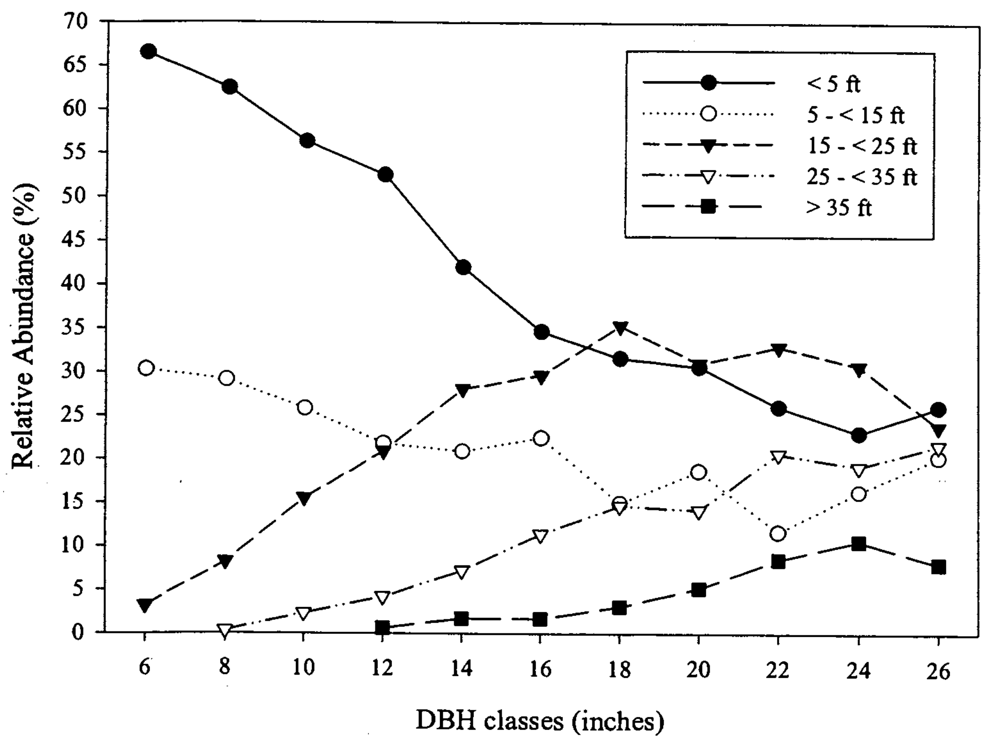

Figure 7.—*The relative abundance of cavity hole height locations on trees (≥ 5 in. (13 cm) d.b.h.) prior to MOFEP timber harvests by 2 in. (5 cm) size classes.*

35 ft (10.7 m) above ground were found only in trees 12 in. (30 cm) d.b.h. and larger (fig. 7).

Cavities were detected in 5 percent of all overstory trees, but there were differences among tree species. For example, cavities were found in 20 percent of blackgums (*Nyssa sylvatica* Marsh.) but in 1 percent of shortleaf pines (*Pinus echinata* Mill.) (fig. 8). Cavity occurrence was low for the three most abundant tree species: white oak (*Quercus alba* L.) (2%), black oak (*Q. velutina* Lam) (5%), and scarlet oak (*Q. coccinea* Muenchh) (4%). These three oak species made up 63 percent of the live overstory trees on MOFEP sites in 1995, but blackgum was only 2 percent of the population. Post oak (*Q. stellata* Wangenh) (10%) had the highest abundance of cavities of the oaks.

Intensive Cavity Survey and Verification

On plots scheduled to be clearcut, 1,439 standing trees were intensively examined prior to harvest and 484 cavities and 358 potential cavities in 410 trees were found. Twenty-two live cavity trees/ac (54/ha) had holes in the 1-in. (2.5 cm) diameter class or larger. Compared to our general cavity survey in which we found only 10 cavity trees/ac (25/ha), the intensive search located more than twice the number of cavity trees. However, we still needed to verify if cavity and potential cavity estimates made with the intensive cavity search on standing trees were indeed cavities. Following the 1996 timber harvest, we relocated 222 holes thought to be cavities and 184 potential cavities on 215 trees that were dissected after the timber harvest and before slashing operations. Here we found that only 55 percent (122) of the holes that were thought to be cavities actually were cavities, but that 18 percent (33) of the potential cavities turned out to also be cavities. We therefore overestimated the number of actual cavities when surveying standing trees; the actual number of cavities was only 70 percent of our estimate. This estimate verification only applies to the subset of cavities and potential cavities relocated from the original intensive search. It does not include new cavities that may have existed but were not detected in the intensive cavity search on standing trees because the timber sale contract prohibited an intense inspection of *all* trees at the time of harvest.

For species in which we relocated at least 10 trees with cavities, we were most accurate in

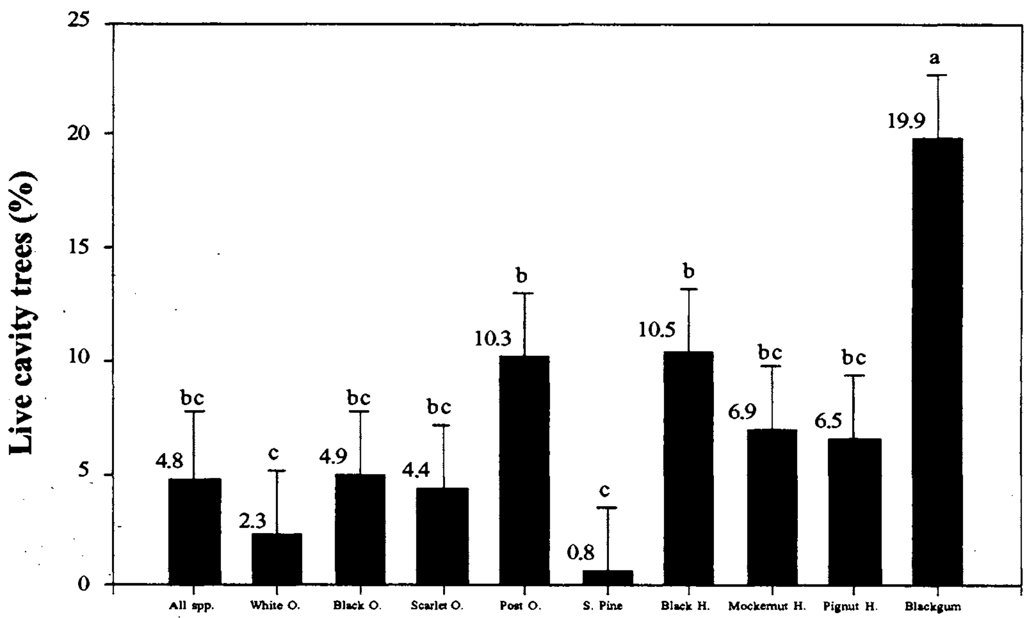

Figure 8.—*The relative abundance of cavity trees for all trees (≥ 4.5 in. (11 cm) d.b.h.) and the most abundant tree species on MOFEP sites prior to harvest. Error bars are 95 percent confidence intervals for site means. Different letters indicate significant differences in abundance of live cavity trees (%) among species based on a Tukey test. Same or shared letters indicate no significant difference at* $\alpha = 0.05$ *level.*

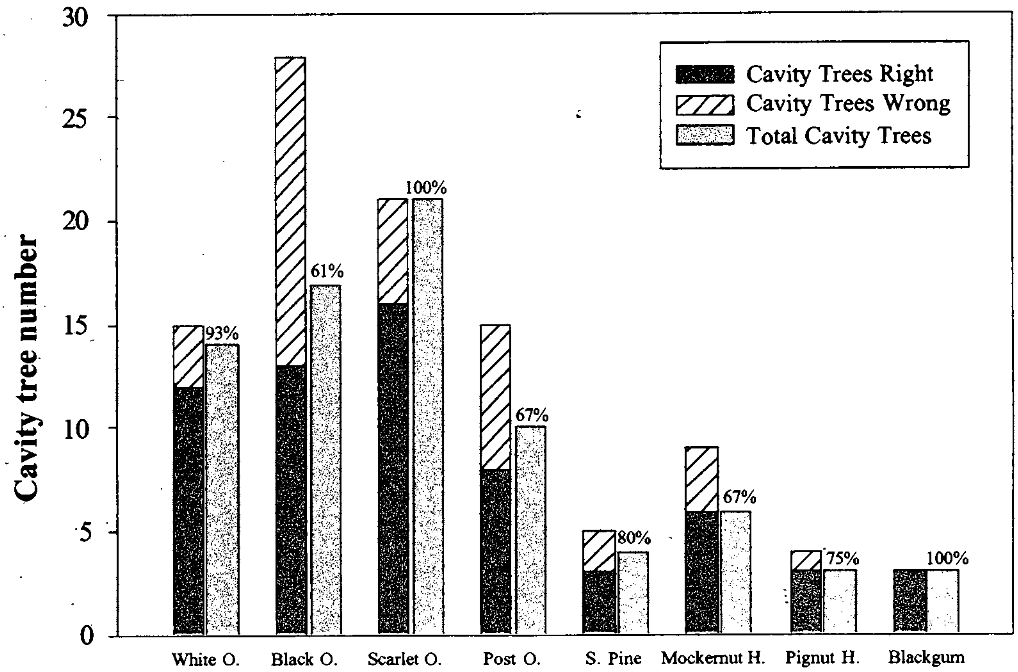

Figure 9.—*The number of cavity trees by species estimated by an intensive cavity search, including the number of confirmed cavity trees of the original estimate (dark gray), cavities that were not confirmed (hatched), and the total number of cavity trees including potential cavities that turned out to be cavities (light gray). The number above the light gray bar indicates this proportion of the original cavity estimate.*

calling a tree a cavity tree in white oak (80%) and scarlet oak (76%) and least successful in black oak (46%), post oak (53%), and black hickory (*Carya texana* Buckl.) (58%) (fig. 9). However, some holes thought to be potential cavities were actually found to lead to a cavity as well. By accounting for these potential cavity holes that were found to be cavities, the proportion of cavity trees was again equal to our original estimate for scarlet oak and near the estimate for white oak (93%). However, the verified number of black oak cavity trees was only 61 percent of the original estimate.

Even though we could accurately estimate cavity tree density for some species, we could not always accurately estimate the number of holes leading to cavities within individual cavity trees. For example, we accurately estimated cavity tree density for scarlet oak, although the number of holes successfully estimated to lead to a cavity for scarlet oak cavity trees was only 51 percent of the original estimate. We were less successful (29% correct) at estimating black hickory holes leading to cavities. White oak holes were estimated correctly as leading to a cavity on 82 percent of the sample.

The presence of cavities was more successfully identified with decreasing height on the tree (fig. 10). For cavities > 30 ft (9 m) above ground, only 57 percent were correctly identified compared to 91 percent for cavities ≤ 10 ft (3 m) above ground. The presence of large diameter holes increased cavity estimation accuracy, reaching 100 percent with holes ≥ 4 in. (10 cm) in diameter (fig. 11). This contrasts with only 16 percent of the half-inch diameter holes that were correctly called cavities. The total number of cavities of this size class was 40 percent of the original estimate after including potential cavities that turned out to be cavities. Estimated cavities were correctly identified in 63 percent of the sample in live portions of trees but in only 35 percent of the sample in dead limbs.

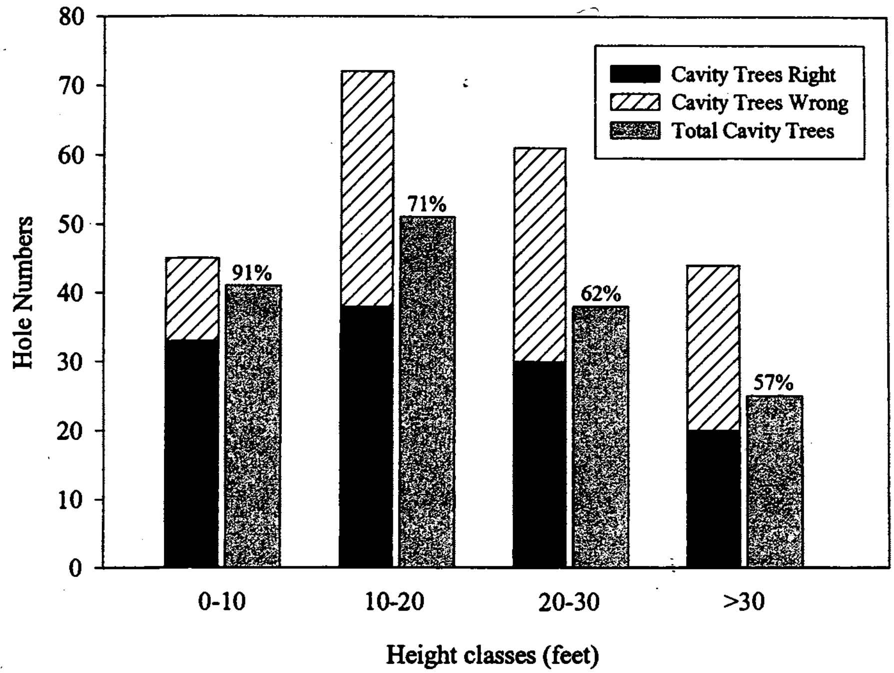

Figure 10.—*The proportion of holes correctly estimated to lead to a cavity with an intensive cavity search by hole height class, including the number of confirmed cavities of the original estimate (dark gray), cavities that were not confirmed (hatched), and the total number of cavity trees including potential cavities that turned out to be cavities (light gray). The number above the light gray bar indicates this proportion of the original cavity estimate.*

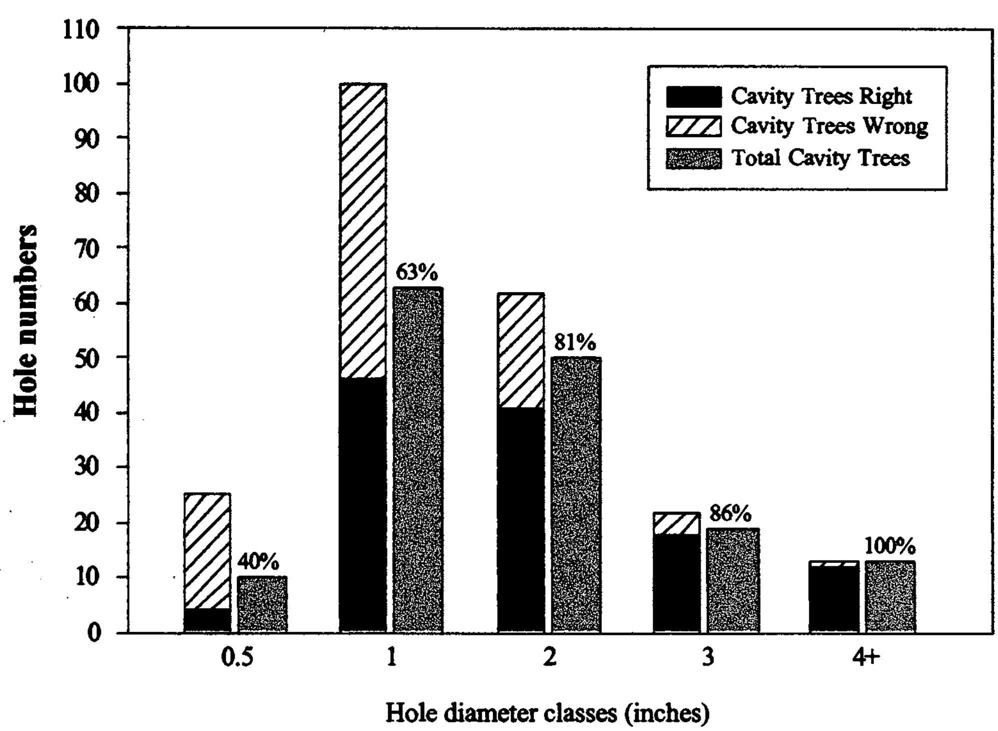

Figure 11.—*The proportion of holes that were successfully estimated to lead to a cavity with an intensive cavity search by hole diameter class, including the number of confirmed cavity trees of the original estimate (dark gray), cavities that were not confirmed (hatched), and the total number of cavity trees including potential cavities that turned out to be cavities (light gray). The number above the light gray bar indicates this proportion of the original cavity estimate.*

DISCUSSION

General Overstory Cavity Inventories

Cavity and Snag Guidelines vs. MOFEP Findings

The Missouri Department of Conservation has established guidelines for cavity and snag densities for heavily forested regions of Missouri (MDC 1985, 1986a). Prior to harvest treatments, the cavity tree density was close to the optimum guidelines for no-harvest and uneven-aged sites and above optimum guidelines in even-aged sites. Moreover, even though harvesting reduced cavity tree densities, the post-harvest cavity densities on both even-aged and uneven-aged sites remained above or near optimum at the site scale.

Because we found that large diameter trees had substantially more cavities than small diameter trees and large diameter trees are also a criterion for determining which stands will be harvested, the greatest opportunities for managing for cavity species lie in the conscious management of larger trees. There is potential for cavity densities to decrease at a faster or slower rate with uneven-aged treatments. Because more trees on larger areas are evaluated for harvesting during each re-entry, managers have more opportunities to either improve timber quality by removing poor-quality trees, which may have or will develop cavities, or to identify and protect cavity trees from being cut. However, these two objectives are not necessarily mutually exclusive. For example, Healy *et al.* (1989) found 2.9 times as many cavities in unthinned oak stands compared to thinned stands in Massachusetts, but also found that 89 percent of the rough culls and 63 percent of the rotten cull trees did not have cavities. These trees could be removed through timber stand improvement with minimal impact on cavity tree densities. Moreover, preferred timber—those trees left in the forest as growing stock—can also have cavities. Healy *et al.* (1989) found that 28 percent of the cavity trees in central Massachusetts were classified as preferred timber trees, often having holes high in the tree or on limbs. In the MOFEP intensive cavity survey, 37 percent of the cavity trees thumped with an axe had solid 8-ft (2.4 m) butt logs that were or could become merchantable saw logs. Fifteen percent sounded hollow only below 4.5 ft (1.4 m), and 48 percent sounded hollow above and below 4.5 ft.

When we combine the snag size classes, uneven-aged sites actually had a much higher increase in snag densities after harvesting (7.7 to 10/ac or 19 to 26/ha, fig. 4) than even-aged or no-harvest sites. This increase is most likely due to the number of trees that were double girdled with a chainsaw. Tree girdling as part of slashing operations was taken advantage of mostly on site 2, where snag density increased most dramatically from 5.5 to 12 snags/ac (14 to 30/ha). Since the 1998 inventory, we have observed, however, that many of these girdled trees have fallen down. We will be able to document this during the next inventory scheduled to begin in 2001. Snag numbers and basal areas on MOFEP sites prior to treatment are reported in Shifley *et al.* (1997); snag numbers ≥ 4.5 in. (11 cm) d.b.h. post-treatment are reported in Kabrick *et al.* (this proceedings).

Cavities by Tree Size, Height on Trees, and Tree Species

In our mature second-growth forest with little past forest management, the proportion of cavity trees increased exponentially with tree diameter. Conversely, the number of live trees decreased exponentially with increasing diameter classes. Consequently, leaving some large (i.e., ≥ 18 in. (46 cm) d.b.h.) trees on site in single-tree selection and even-aged intermediate harvests, where cavity tree densities are lower than desired, would be a simple way to obtain higher levels of cavity tree densities.

Most of the cavities located on trees were basal cavities (< 5 ft (1.5 m) height). Although basal dens may be used for escape cover and caching food by some wildlife species, for many wildlife species these cavities may be unsuitable for rearing young or winter survival. Although there is much to learn in the oak-hickory-pine forest, the gray squirrel (*Sciurus carolinensis*) is the only secondary cavity user known to nest in cavities below 10 ft (3 m) height on trees in forest interiors (MDC 1985). On the other hand, the northern saw-whet owl (*Aegolius acadicus*), another secondary cavity user, is not known to nest below 20 ft (6 m) and can nest as high as 40 ft (12 m); the barred owl (*Strix varia*) is not known to nest below 30 ft (9 m) (MDC 1985). However, few cavities were detected high above ground in this study. Protecting trees with cavities high above ground during timber harvest would thus increase the most limiting class of cavities for secondary cavity nesters without compromising timber quality.

The highest proportion of live trees containing cavities occurred in blackgum (20%). However, our examination of blackgums showed that many individuals of this species were nearly hollow throughout, and the cavities often extended into secondary branches. Moreover, cavities with entry holes high on blackgum boles often did not have bottoms until near ground line. This decay pattern may be partly due to blackgum's diffuse-porous wood structure that does not compartmentalize decay as effectively as ring-porous wood structures like those found in oaks and hickories (Shigo 1984, Shigo and Marx 1977). It is unknown to date if these kinds of cavities have much value for wildlife. The next highest proportion of cavities occurred in black hickory (11%) and post oak (10%), both of which are abundant on MOFEP and provide hard mast for wildlife food. Many of their cavities are much smaller than those in blackgum and may provide better nesting habitat. Shortleaf pine had very few cavities (1%) and is not likely to provide very many cavities in Ozark forests.

Intensive Cavity Survey and Verification

We identified 50 percent fewer holes with the general cavity survey compared to the more intensive cavity survey. The search effort during the general survey was similar to the methods that forest managers use while conducting a forest stand inventory or when selectively marking trees for harvest. In the general survey, 5 percent of live overstory trees were called cavity trees. When verifying cavity trees, we found 80 percent of the white oak and 46 percent of the black oak were correctly called cavity trees. Allen and Corn (1990) reported 20 percent of the live trees had cavities in the Missouri Ozark oak-hickory forest, but they restricted their sampling to dominant and codominant canopy classes, excluding intermediate and suppressed crown classes and shortleaf pines. They found 3.5 times as many medium (2 to 4 in. or 5.1 to 10.2 cm in diameter) cavities and 5 times as many large (> 4 in. or > 10.2 cm diameter) cavities in black oak compared to white oak. In 1939, Dalke (1948) found dens large enough for squirrels in 10 percent white oak, 8 percent black oak, and 7 percent scarlet oak, in trees at least 12 in. (30 cm) d.b.h., on Deer Run State Forest near present-day MOFEP sites.

Wildlife Management Implications

Most of the cavities (44%) were located near the ground and are suspected to be a result of the past fire history of the Ozarks (Guyette and Larsen 2000). These cavities can serve as escape cover for wildlife, but there are no secondary cavity users known to nest below 5 ft (1.5 m) in forest interior habitats (MDC 1985). Only 12 percent of the cavity trees had a hole at least 25 ft (7.6 m) high in the general survey. Dalke (1948) found that 38 percent of squirrel dens were at the ground line and were characterized as escape or hiding dens. The rest were in the bole or limbs of trees and considered home dens.

Many of the cavities verified in the intensive survey may provide very little benefit to wildlife species. Our minimum size for a cavity (3 in. or 8 cm deep into a tree) was perhaps too small in this study to get a good baseline estimate of *usable cavity* densities and distributions. This may have caused us to overestimate the number of usable cavities for many wildlife species. Estimating the number of usable cavities requires better information about cavity sizes and tree locations needed by specific wildlife species. For example, gray tree frogs (*Hyla chrysoscelis* and *H. versicolor*) and the broad-headed skink (*Eumeces laticeps*) are known to use cavities, but specific information about the dimensions or height requirements are lacking. Other small species may use cavities, but they may not yet be identified in the literature.

The white-footed mouse (*Peromyscus leucopus*) and deer mouse (*Peromyscus maniculatus*) made up about 90 percent of the small mammals captured before and after MOFEP timber harvests (Fantz and Renken 1997 and this proceedings). Although these two species are not listed in the Missouri Department of Conservation snag and cavity guidelines as cavity users, Dooley and Dueser (1990) found that all of the deer mice and many of the white-footed mice used arboreal nests. White-footed mice used tree cavities more frequently in the absence of deer mice. Deer mice used cavities located higher above ground in the presence of white-footed mice. Dooley and Dueser describe the arboreal nests as most frequently being in bole cavities with hole diameters < 0.75 in. (2 cm).

If we had more detailed information about den requirements of deer mice, we would better understand the cavity tree species that potentially provide suitable dens for this species. For example, if a hypothetical deer mouse required a den with a 1 in. (2.5 cm) diameter hole, at least 10 ft (3 m) high on the tree, with interior cavity dimensions of at least 2 x 2 in. (5 x 5 cm) and 4 in. (10 cm) deep, only 13 percent of the 222 dissected cavities would meet the requirements. Seventy-five percent of the holes meeting these criteria were in white oak and scarlet oak, but a higher proportion of white oak trees (41%) contained cavities with these requirements than did scarlet oak (20%). Only 2 of the 52 estimated cavities in black oak fit this criteria.

CONCLUSIONS

This paper reports baseline findings on a large cavity tree and snag data set collected while conducting tree inventory. Overall, we found that both even-aged and uneven-aged management decreases the cavity tree density on MOFEP sites immediately after harvesting. Snags decreased on even-aged sites, but increased on uneven-aged sites because many trees were double girdled rather than slashed. Snags and cavity tree densities have thus far remained near or above the optimum density recommended by Missouri Department of Conservation Guidelines (MDC 1985, 1986a and b). However, it remains unclear if snag and cavity tree densities will remain near or above optimum levels with future harvests.

There were important relationships between tree diameter and tree species and resulting cavity tree densities. Large diameter trees were more likely to contain cavities than small diameter trees, and blackgums were more likely to have cavities than oaks, hickories, or shortleaf pines. Most cavities were found < 5 ft (1.5 m) above ground. Our cavity verification study showed that we more accurately identified cavities in white oaks and scarlet oaks and less accurately in black oak, post oak, and black hickory. This may largely be due to differences in decay patterns among tree species. Hole sizes and locations also affect the accuracy of cavity estimates. As expected, estimation accuracies were greater when holes leading to cavities were larger or located nearer to the ground. There is much to learn about the internal characteristics of cavity trees to assist forest managers in saving the best cavity trees for wildlife when selectively harvesting trees. Cavity data collected further into the cutting rotation of MOFEP should assist managers in keeping an adequate supply of cavity trees for wildlife. Future studies should also be directed at investigating the tree cavity characteristics required by different wildlife species during the most limiting season to ensure healthy wildlife populations.

LITERATURE CITED

Allen, A.W.; Corn, J.G. 1990. Relationships between live cavity tree diameter and cavity abundance in a Missouri oak-hickory forest. Northern Journal of Applied Forestry. 7: 179-183.

Brookshire, B.L.; Jensen, R.G.; Dey, D.C. 1997. The Missouri Ozark Forest Ecosystem Project: past, present, and future. In: Brookshire, B.L.; Shifley, Stephen R., eds. Proceedings of the Missouri Ozark Forest Ecosystem Project symposium: An experimental approach to landscape research; 1997 June 3-5; St. Louis, MO. Gen. Tech. Rep. NC-193. St. Paul. MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 1-25.

Brookshire, B.L.; Hauser, C. 1993. The Missouri Ozark Forest Ecosystem Project. In: Gillespie, A.R.; Parker, G.R.; Pope, P.E.; Rink, G., eds. Proceedings, 9th Central hardwood forest conference; 1993 March 8-10; West Lafayette, IN. Gen. Tech. Rep. NC-161. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 289-307.

Dalke, P.D. 1948. Some observations on den trees in the Missouri Ozarks. Journal of Wildlife Management. 12: 107-109.

Dooley, J.M.; Dueser, R.D. 1990. An experimental examination of nest-site segregation by two *Peromyscus* species. Ecology. 71: 788-796.

Fantz, D.K.; Renken, R.B. 1997. Pre-harvest (1994-1995) conditions on the Missouri Ozark Forest Ecosystem Project small mammal project. In: Brookshire, B.L.; Shifley, Stephen R., eds. Proceedings of the Missouri Ozark Forest Ecosystem Project symposium: An experimental approach to landscape research; 1997 June 3-5; St.

Louis, MO. Gen. Tech. Rep. NC-193. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 309-317.

Fantz, D.K.; Renken, R.B. 2002. Short-term responses of the small mammal communities to forest management within Missouri Ozark Forest Ecosystem Project sites. In: Shifley, S.R.; Kabrick, J.M., eds. Proceedings of the second Missouri Ozark Forest Ecosysem symposium: Post-treatment results of the landscape experiment; 2000 October 17-18; St. Louis, MO, Gen. Tech. Rep. NC-227. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 161-170.

Guyette, R.; Larsen, D. 2000. A history of anthropogenic and natural disturbances in the area of the Missouri Ozark Forest Ecosystem Project. In: Shifley, S.R.; Brookshire, B.L., eds. Missouri Ozark Forest Ecosystem Project: Site history, soils, landforms, woody and herbaceous vegetation, down wood, and inventory methods for the landscape experiment. Gen. Tech. Rep. NC-208. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 19-40.

Healy, W.M.; Brooks, R.T.; DeGraaf, R.M. 1989. Cavity trees in sawtimber-size oak stands in Central Massachusetts. Northern Journal of Applied Forestry. 6: 61-65.

Hardin, K.I.; Evans, K.E. 1977. Cavity nesting bird habitat in the oak-hickory forest - a review. Gen. Tech. Rep. NC-30. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 23 p.

Jensen, R. 2000. Pre-treatment woody vegetation inventory protocols. In: Shifley, S.R.; Brookshire, B.L., eds. Missouri Ozark Forest Ecosystem Project: Site history, soils, landforms, woody and herbaceous vegetation, down wood, and inventory methods for the landscape experiment. Gen. Tech. Rep. NC-208. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 134-147.

Kabrick, J.M.; Jensen, R.G.; Shifley, S.R.; Larsen, D.R. 2002. Woody vegetation following even-aged, uneven-aged, and no-harvest treatments on the Missouri Ozark Forest Ecosystem Project sites. In: Shifley, S.R.; Kabrick, J.M., eds. Proceedings of the second Missouri Ozark Forest Ecosysem symposium: Post-treatment results of the landscape experiment; 2000 October 17-18; St. Louis, MO. Gen. Tech. Rep. NC-227. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 84-101.

Kurzejeski, E.W.; Clawson, R.L.; Renken, R.B.; Sheriff, S.L.; Vangilder, L.D.; Hauser, C.; Faaborg, J. 1993. Experimental evaluation of forest management: the Missouri Ozark Forest Ecosystem Project. Transactions of the 58th North American Wildlife and Natural Resources Conference: 599-609.

Law, J.R.; Lorimer, C.G. 1989. Managing uneven-aged stands. In: Clark, F.B.; Hutchinson, J.G., eds. Central Hardwood Notes. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: Note 6.08: 1-6.

Missouri Department of Conservation. 1985. Management of snag and cavity trees in Missouri. Jefferson City, MO: Missouri Department of Conservation. 21 p.

Missouri Department of Conservation. 1986a. Forest land management guidelines. Jefferson City, MO: Missouri Department of Conservation. 86 p.

Missouri Department of Conservation. 1986b. Management of old growth forests in Missouri. Habitat Manage. Ser. 3. Jefferson City, MO: Missouri Department of Conservation. 16 p.

Sheriff, S.L. 2002. Missouri Ozark Forest Ecosystem Project: The experiment. In: Shifley, S.R.; Kabrick, J.M., eds. Proceedings of the second Missouri Ozark Forest Ecosysem symposium: Post-treatment results of the landscape experiment; 2000 October 17-18; St. Louis, MO. Gen. Tech. Rep. NC-227. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 1-25.

Sheriff, S.L.; He, Z. 1997. The experimental design of the Missouri Ozark Forest Ecosystem Project. In: Brookshire, B.L.; Shifley, S.R., eds. Proceedings of the Missouri Ozark Forest Ecosystem Project symposium: An experimental approach to landscape research; 1997 June 3-5; St. Louis, MO. Gen. Tech. Rep. NC-193. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 26-40.

Shifley, S.R.; Brookshire, B.L.; Larsen, D.R.; Herbeck, L.A.; Jensen, R.G. 1997. Snags and down wood on upland oak sites in the Missouri Ozark Forest Ecosystem Project. In: Brookshire, B.L.; Shifley, S.R., eds. Proceedings of the Missouri Ozark Forest Ecosystem Project symposium: An experimental approach to landscape research; 1997 June 3-5; St. Louis, MO. Gen. Tech. Rep. NC-193. St. Paul. MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 248-256.

Shigo, A.L. 1984. Compartmentalization: a conceptual framework for understanding how trees grow and defend themselves. Annual Review Phytopathology. 22: 189-214.

Shigo, A.L.; Marx, H.G. 1977. Compartmentalization of decay in trees. Agric. Inf. Bull. 405. Washington, DC: U.S. Department of Agriculture, Forest Service. 73 p.

Wilson, J.D. 1996. Missouri breeding bird changes - 1967-1995. Lake Ozark, MO: Missouri's Forest, Fish, and Wildlife Conference.