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ROUTING TO ACCELERATE TREE-CAVITY FORMATION

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Abstract: Tree routing, as a means of accelerating the formation of cavities in trees, has potential as a habitat management technique for a variety of cavity-nesting wildlife species. To evaluate routing as a technique, cavities were routed in 48 red maples (*Acer rubrum*), 48 northern red oaks (*Quercus rubra*), and 48 white oaks (*Quercus alba*). After 3 years, 139 trees were still structurally sound, but 5 red maples had fractured at the routing site. About a third of the cavities contained standing water; 18% were closed by callus. Partially closed cavities (about 80% of all cavities) were used by southern flying squirrels (*Glaucomys volans*) for feeding and denning. Further research is needed before routing can be recommended as a habitat management technique.

Many authors report the tautology that cavity-dependent wildlife are limited in their abundance by the abundance of trees with, or suitable for excavation of cavities (Collias 1964, Gysel 1961, Peters 1976, Short 1979). Indeed, the competition for tree cavities has been reported to be intense (Boyer 1975, Dennis 1969, 1971, Erskine and MacLaren 1972, 1976, Foster and Tate 1966, Kilham 1971, Zeleny 1969), despite nest site differences among the various cavity-using species of wildlife (Berner and Gysel 1967, Conner and Adkisson 1977, Gilmer et al. 1978, Hardin and Evans 1977, Sanderson et al. 1975, Scott et al. 1977). Installation of nest boxes has generally resulted in their use by wildlife and in increases in some species' population densities (Barkalow and Soots 1965a, Burger 1969, Hamerstrom et al. 1973, Sonenshine et al. 1979, Stahlecker and Griese 1979). The intense competition for cavities and the use of nest boxes support the idea that cavities are a limiting factor to some wildlife populations and have contributed to the feeling that cavities are lacking in many forested environments, especially in young or intensively managed forest stands (Allen 1943, Conner et al. 1979, Evans 1978, Nixon et al. 1978, Probst 1979).

In addition, as Conner and Adkisson (1977) stated, it is difficult to determine the abundance of cavities and cavity excavation sites; even if the size (dbh and height) and environment of a tree seem optimum, unless the core of the tree has been softened by fungi, the tree cannot be used by cavity-excavating wildlife. The relationship between top rot in trees and cavity-using wildlife is well documented (Baumgartner 1939, Conner et al. 1976, Hansen 1966, Jackson 1977, Kilham 1971, Miller et al. 1979, Shigo and Kilham 1968). Unfortunately surveys for fungal infections (Berry 1969, Berry and Beaton 1972, Campbell and Davidson 1939) have ignored wildlife values, and surveys for cavities used by wildlife (Bellrose et al. 1964, Berner and Gysel 1967, Boyer 1975, 1976, Gysel 1961, Nixon et al. 1978, Sanderson et al. 1975), have been narrow in scope, either focused on one or a few species of wildlife or were confined to a particular forest type. There is a lack of information on the distribution and abundance of cavities and cavity-

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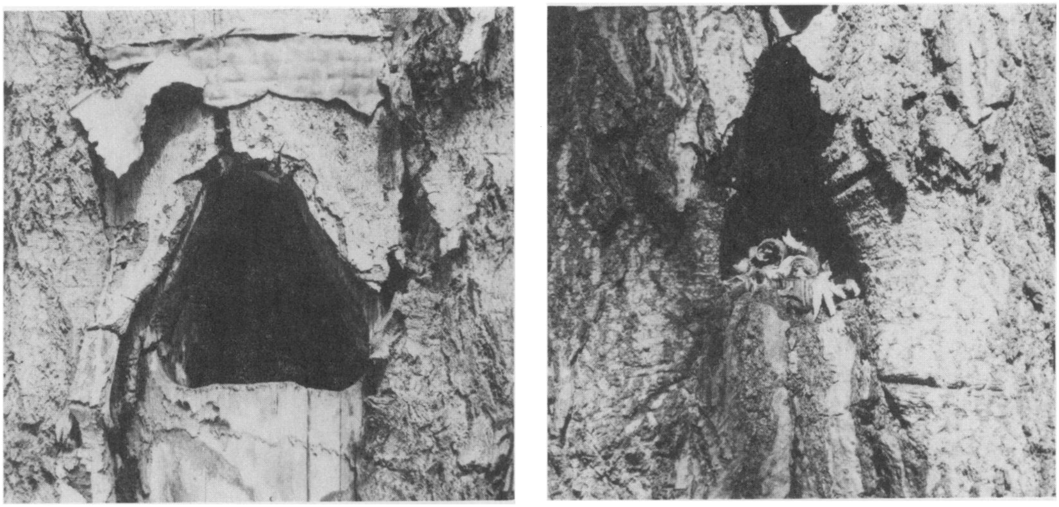


Fig. 1. Routed tree healing. A. No callus overlap; B. Callus overlap and use as a feeding station;

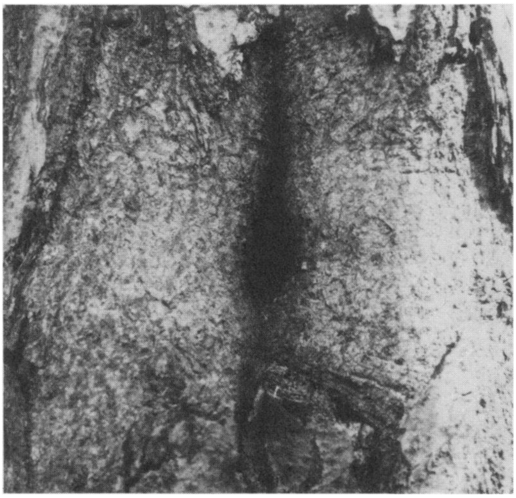
excavating substrate in eastern hardwood forests.

The processes leading to cavity formation are understood (Baumgartner 1939, Conner et al. 1976, Hansen 1966, Hepting et al. 1940, Shortle 1979). First, trees grow to a size large enough to develop limbs 7 cm or more in diameter. Then, one of these large limbs dies from receiving insufficient light (natural pruning) or by wind damage, falling trees, ice, or other causes. Then the dead limb is invaded by a succession of micro-organisms and fungi that gradually move through the limb and into the tree. The rotting limb usually breaks off leaving a protruding stub. Some birds will excavate cavities in the rotten limb. Callus begins to form around the stub as fungi begin growing in the tree. Eventually the limb becomes completely decayed. Squirrels (*Sciurus* spp.) gnaw at the callus that forms around the branch stub, preventing the wound from healing. Later, the fungi produce a top rot in the tree that can be removed through the entrance formed by the callus that surrounded the stub; both birds and mammals will remove this rotten wood. If the callus eventually blocks this hole, but the rot has been extensive enough, a cavity-excavating woodpecker may create an entrance to the decayed core by breaking through the sound sapwood. Once this entrance is constructed, a cavity is excavated in the rotten center of the tree. The

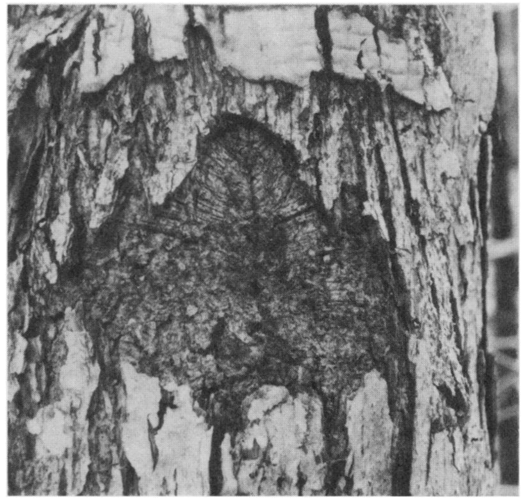
Table 1. Species and size of routed trees.

Species	DBH (cm)			Diameter at routed hole (cm)		
	$\bar{x}$	$S\bar{x}$	Range	$\bar{x}$	$S\bar{x}$	Range
Red Maple[a]	25.6	0.4	21.0–31.0	21.0	0.3	18.1–25.3
Northern red oak[a]	27.0	0.4	22.2–32.2	22.0	0.4	18.4–27.4
White oak[a]	32.2	0.6	23.6–38.2	26.2	0.6	18.0–33.9

[a] 48 trees per species.



C. Well-developed callus use as a nest;



D. Hole closed by callus.

cavity may then be used by a succession of vertebrates—with a possible range over time in size from white-footed mice (*Peromyscus leucopus*) to black bears (*Ursus americanus*). If the branch is small and the callus forms quickly, the decay may be compartmentalized without rotting enough volume to allow excavation of a cavity. The process requires 8–30 years from death of the limb to formation of the cavity; a cavity may be used for more than 50 years. Decay can also enter a tree through wounds (fire, insect, or mechanical damage) on the trunk or roots of the tree. If this happens, the resulting hollow tree may be of more value for escaping than for roosting, nesting, or denning.

Because of the long time required for trees to develop cavities, management recommendations usually stress long rotation ages and retention of den trees or snags in regeneration or intermediate cuts (Conner 1978, 1979, Evans and Conner 1979, Sanderson 1975, Zeedyk and Evans 1975). Boyce (1977, 1978) gives specific directions on maintaining the old-growth component in the forest. Most of these guidelines are intuitive, and all require the manager to make value judgements about population levels. In some situations (Barkalow and Soots 1965b, Evans and Conner 1979, Gary and Morris 1980, Gill et al. 1974, Hardin and Evans 1977, Sanderson 1975), nest boxes are called for, especially in young forests. However, nest boxes are not used by all cavity nesters and may not be as attractive to wildlife as natural cavities. Also, nest boxes may not last as long as natural cavities and they may be more subject to disturbance by people than natural cavities. Because they are artificial, nest boxes are less aesthetic than natural cavities. As alternatives to nest boxes, Sanderson (1975) recommended stub-pruning (cutting a live branch to leave a 15-cm long stub attached to a tree) to accelerate cavity formation, and Evans and Conner (1979) suggested boring or routing holes in trees.

The objectives of this study were: to evaluate routing as a technique to accelerate the formation of cavities in hard-

Table 2. Healing of routed cavities, October 1979.

Species	N	No callus overlap		Callus overlap on sides		Callus overlap top and sides		Closed	
		N	(%)	N	(%)	N	(%)	N	(%)
Red maple	43	2	(4.7)	36	(83.7)	3	(7.0)	2	(4.7)
N. red oak	48	0	(0.0)	28	(58.3)	10	(20.0)	10	(20.8)
White oak	48	1	(2.1)	14	(29.2)	20	(41.2)	13	(27.1)
Total	139	3	(2.2)	78	(56.1)	33	(23.7)	25	(18.0)

woods; to evaluate biological and chemical decay-inducing materials (fungi and glycerol) potentially useful in combination with routing; and to monitor animal (vertebrate and invertebrate) response to the routed and treated holes.

We thank West Virginia University for the use of trees on its experimental forest, F. H. Berry for fungus cultures, A. L. Shigo and W. D. Zeedyk for technical advice during the planning stage of the study, and M. G. Edwards for developing the concept of den-routing and instigating the development of den-routing equipment. V. G. Henry provided technical assistance during part of this study. We thank M. G. Edwards and C. M. Nixon for reviewing the manuscript.

METHODS

Three species of trees were chosen for treatment: red maple, a species susceptible to relatively rapid decay; northern red oak, a species susceptible to relatively slow decay; and white oak, a species relatively resistant to decay. Only healthy, vigorous trees were chosen. The treated trees were 21.0–32.2 cm in dbh and were at least 18 cm in diameter at the height of routing, about 7 m above ground (Table 1). The trees were all located on a single hillside in the West Virginia University forest.

Fungus cultures were obtained from the Northeastern Forest Experiment Station laboratory at Delaware, Ohio, and included *Inonotus glomeratus* (for inoculating red maple), *Phlebia chrysocrea* (for inoculating northern red oak), and *Polyporus compactus* (for inoculating white oak).

In the fall of 1975, 48 trees (16 of each species) were routed on the underside of the lean of the tree. A hole with a triangular entrance was formed by drilling 3 holes 3.8 cm in diameter into the tree about 7 m above the ground. Two holes were drilled side by side, 15 cm deep, at an angle 30° below a line perpendicular to the trunk. The third hole, 12 cm deep, was drilled perpendicularly just above and centered between the other 2 holes. The web remaining between the 3 holes was removed using the drill as a router; 50% of the routed holes were inoculated with 100 ml of glycerol, a nutrient solution for fungus (A. L. Shigo, N. E. For. Exp. Sta., Durham, NH, pers. commun.). In the winter of 1976, an additional 96 trees (32 of each species) were routed, divided into 4 treatment groups (rout only, rout plus 100 ml of glycerol, rout plus 150–200 ml of fungus culture, and rout plus 50 ml of glycerol and 150–200 ml of fungus culture), and treated accordingly. We used a 12.7 mm (½-inch) electric drill with 3.8-cm drill bits as recommended by Chiu et al. (unpubl. rep., M. E. Proj. 484, Ga. Inst. Tech., Atlanta, GA 1973). Power was supplied by a portable generator.

The routed cavites were examined in the spring and fall of 1977, the spring of 1978, and the fall of 1979. Structural damage to the tree, callus development around the cavity, amount of moisture (dry, damp, standing water), presence of fungi, presence of rotted wood, and use by animals were noted.

RESULTS

By the spring of 1978, 5 red maples had broken off at the routed cavity, and 5 red maples and 1 northern red oak had developed major horizontal cracks, apparently the result of routing and high winds. All of the damaged trees were less than 20 cm in diameter at the cavity; 29 trees less than 20 cm in the diameter remained undamaged. In the fall of 1979, none of the 139 intact trees showed structural damage. Callus had developed around the entrance of 80% of the cavities, and had closed 18% of the cavities (Table 2, Fig. 1). Callus development was greatest in white oaks, followed by northern red oaks and red maple.

Table 3. Routed cavity use by vertebrates, October 1979.

	Species of trees							
	Red Maple		Red Oak		White Oak		Total	
Type of use	(43)	%	(48)	%	(48)	%	(139)	%
Avian								
Nest	2	(4.6)	0	(0.0)	0	(0.0)	2	(1.4)
Mammalian								
Nest[1]	9	(20.9)	17	(35.4)	10	(20.8)	36	(25.9)
Nests with food remains	5	(11.6)	7	(14.8)	6	(12.5)	18	(12.9)
Feeding station	15	(34.9)	25	(52.1)	22	(45.8)	62	(44.6)
Food cache	2	(4.6)	0	(0.0)	0	(0.0)	2	(1.4)
Gnawing	1	(2.3)	2	(4.2)	5	(10.4)	8	(5.8)
Mammals, present								
Flying squirrel	1	(2.3)	4	(8.3)	2	(4.2)	7	(5.0)
White-footed mouse	1	(2.3)	0	(0.0)	0	(0.0)	1	(0.7)
No Use	15	(34.9)	5	(10.4)	15	(31.3)	35	(25.2)
Use	28	(65.1)	43	(89.6)	33	(68.7)	104	(74.8)

[1] Nest occupied by the white-footed mouse contained grass seeds; 3 of the 36 nests found contained grass seeds. All nests were constructed primarily of shredded bark.

Fungi (taxa not determined) were growing in most trees by the spring of 1977. By 1979, 96% of the cavities contained fungi. Decayed wood was first noted in 1979 when 63% of the cavities had decay in the base; only a few had decay on the side or roof; the decay penetrated less than 2.5 cm. The prevalence of fungi and decay did not differ ($P > 0.05$) among species of tree in 1979. There was no difference in the prevalence of decay between fall-routed cavities (70%) and winter-routed cavities (72%). However, cavities treated with fungus and glycerol had the greatest prevalence of decay (82%), followed (in order of decreasing prevalence) by cavities treated with glycerol only (72%), cavities treated with fungus only (71%), and cavities that were not treated (65%) (Bartholomew's test for gradients in proportions, $P < 0.05$).

There was standing water in about 30% of the cavities; about 40% were dry; 30% were damp. The cavities in the oaks tended to be drier than those in the red maples, which could have been due to the differences in callus development and bark texture.

The use of cavities by invertebrates was consistently high, averaging about 70% in the spring and 82% in the fall. Invertebrates noted included slugs, snails, spiders, mites, beetles, cave crickets, caterpillars, mosquitoes, gnats, and others; adult and immature forms of a number of the arthropods also were found. A detailed report on the colonization of the holes by insects was prepared by Heaps (1979).

Vertebrate use also was high, ranging from 64 to 86% in the spring and 66 to 75% in the fall. The greatest use was for feeding stations (45% in 1979); the most common food remains found were hickory shells and acorn pieces. The cavities were used for nests primarily by southern flying squirrels. The percentage of the cavities used by birds for nesting or roosting varied from 1 to 4%. Only 3 nests of mammals were found during all spring examinations. The number of mammal nests increased sharply from the fall of

1977 (13 nests) to the fall of 1979 (36 nests) (Table 3). Of the nests observed in 1979, 33 were judged to be nests of southern flying squirrels and 3 of white-footed mice (*Peromyscus* sp.). The increased use of the cavities by mammals presumably was due to callus development narrowing the entrance (by greater than 50% in the cavities used for nests), thus providing a more secure shelter. Mammal nests were more prevalent in northern red oaks (35%) than in either white oaks (21%) or red maples (19%).

DISCUSSION

Routing holes in trees leads to infection by fungus, which results in decay. Inoculation of newly routed holes with chemical and biological decay inducers increases the probability that decay will occur within 3 years. Den-routing, with or without the biological or chemical decay inducers, is a marked acceleration of the natural process of den formation as described by Baumgartner (1939). The process, however, is still slow. Decay did not progress very far in 3 years. However, callus development was rapid and closed 18% of the holes routed in this study. It is possible that the decay in the rapidly closed holes could be compartmentalized. Continued acceleration of the cavity-forming process in the remaining holes depends upon participation by vertebrates, particularly squirrels (*Sciurus* spp.). The squirrel population of the study area was low and the treated trees were tightly clustered; we observed no evidence of gnawing on the cavity openings by squirrels. If squirrels are not present in sufficient numbers to gnaw back the developing callus, is is likely that routed holes of the size we constructed would be occluded by callus before decay had progressed far enough to enlarge the cavity to be a size that could be used by screech owls (*Otus asio*) or other vertebrates requiring a relatively large cavity. Thus, future use would depend upon an entrance to the cavity being created by woodpeckers. Callus development, however, is an important factor in providing suitable shelter for southern flying squirrels, white-footed mice, and other small vertebrates. The newly routed cavity is exposed and offers little shelter. Once the entrance is narrowed by callus, the cavity becomes acceptable to some small vertebrates.

Loss of trees due to structural damage induced by routing was minimal (3%); those that were lost were the smaller trees (20 cm or less in diameter at the height of routing) and were in locations exposed to high winds. Structural damage could be avoided by routing trees larger than 20 cm at the selected height and by choosing trees not exposed to the wind. A large proportion (about 30%) of the routed holes consistently contained water. The problem of water retention could be minimized by careful selection of the point of routing to minimize the amount of water running into the cavity from the surface of the tree; i.e., locating cavities beneath limbs and on the underside of the lean of the tree. However, further research will be necessary before we can recommend den-routing as a management technique. We need a better understanding of the response of squirrels to routed cavities and whether they will keep the cavity entrance open as they maintain natural cavities. We need to know how long it takes for a cavity to become large enough to be used as a den or nest cavity for squirrel-size vertebrates (study in progress). It is obvious that 3-year-old cavities of the size we constructed are much too small for most vertebrates and that they would not be large enough by year 4 or 5. In the 4 years of the study, we observed a maximum of 4 bird nests in the cavities and no other evidence of use by birds. Thus, it may be more economical to construct cavities in a manner that would allow immediate use by a target species or species group. This can be done with improved equipment.

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