HEARTWOOD, SAPWOOD, AND FUNGAL DECAY ASSOCIATED WITH RED-COCKADED WOODPECKER CAVITY TREES

RICHARD N. CONNER, Wildlife Habitat and Silviculture Laboratory, Southern Forest Experiment Station, U.S. Forest Service, Nacogdoches, TX 75962
D. CRAIG RUDOLPH, Wildlife Habitat and Silviculture Laboratory, Southern Forest Experiment Station, U.S. Forest Service, Nacogdoches, TX 75962
DANIEL SAENZ. Wildlife Habitat and Silviculture Laboratory, Southern Forest Experiment Station, U.S. Forest Service, Nao ogdoches, TX 75962
RICHARD R. SCHAEFER, Wildlife Habitat and Silviculture Laboratory, Southern Forest Experiment Station, U.S. Forest Service, Naccgdoches, TX 75962

Abstract: **Provision of suitable sites for red-cockaded woodpecker (*Picoides borealis*) cavity excavation is essential for successful management of the woodpecker. To evaluate internal characteristics of pines used by the woodpecker, we increment-cored longleaf pines (*Pinus palustris*) to determine heartwood diameter, sapwood thickness, and presence of fungal heartwood decay at 1.3, 6.0, 9.0, and 12.0 m aboveground in 53 red-cockaded woodpecker cavity trees and 53 similar control pines in eastern Texas. Red-cockaded woodpecker cavity trees had thinner sapwood and greater heartwood diameter at all heights than did control trees ($P < 0.05$). Cavity and control trees were similar in height ($P = 0.38$) and bole length ($P = 0.51$), but cavity trees were larger (51.1 vs. 48.4 cm diam at breast height [dbh], $P = 0.046$), older (124.5 vs. 98.5 yr, $P < 0.001$), and were growing with less vigor ($P < 0.001$) than were control pines. Red-cockaded woodpeckers require approximately 15-cm diameter of heartwood in which to excavate cavities. Longleaf pines 70–90 years old had sufficient heartwood to house cavities at 6 and 9 m aboveground. Only pines exceeding 90–110 years in age had sufficient heartwood present for cavity excavation at 12 m. However, unlike prior studies, heartwood decay was not detected until trees were > 100 years and did not occur with any regularity until pines were >120 years.**

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Key words: endangered species, fungus, heartwood, longleaf pine, *Phellinus pini*, *Picoides borealis*, red-cockaded woodpecker, red heart, sapwood, Texas.

Red-cockaded woodpeckers are unique among North American woodpeckers because they nest and roost in cavities they excavate in living pines. Cavity excavation in living pines causes active transport of pine resin to wounded sapwood during excavation. Delays in excavation of sapwood can occur while woodpeckers wait for resin to harden within the sapwood (resinosis) (Conner and Rudolph 1994). After resinosis occurs, woodpeckers can resume excavation. Thus, sapwood thickness may influence duration of cavity excavation and red-cockaded woodpecker selection of potential cavity trees. Pines that exude copious amounts of resin when wounded may be preferred because woodpeckers excavate resin wells when cavities are completed, producing a coating of sticky pine gum on the bole that serves as a barrier against predatory rat snakes (*Elaphe* spp.) (Jackson 1974, Rudolph et al. 1990).

Heartwood, which increases in diameter as trees age, must be of sufficient diameter to physically house a cavity chamber. Cavity chambers rarely extend into sapwood because of the likelihood of resin seepage, which can lethally entrap woodpeckers (Locke et al. 1979, Copeyon 1990). The amount and rate of heartwood formation is variable and affected by tree age, growth rate, site quality, and silvicultural management (Kramer and Kozlowski 1979). Clark (1993) noted that heartwood diameter in loblolly (*Pinus taeda*) and longleaf pines at 6 m aboveground increased with stand age and tree diameter. He also concluded that fast-growing loblolly and longleaf pine stands on better quality soils tended to produce greater diameters of heartwood at younger ages than did pines on poor sites. Heartwood diameter within pines tends to be greatest near the ground and decreases as height increases (Kramer and Kozlowski 1979).

In addition to selecting trees with adequate heartwood for cavity excavation, red-cockaded woodpeckers also typically select pines with decayed heartwood (Jackson 1977, Conner and Locke 1982, Hooper 1988, Hooper et al. 1991). Although red-cockaded woodpeckers can excavate complete cavities in pines without heartwood decay, presence of red heart fungus (*Phellinus pini*) reduces time required for cavity excavation (Conner and Rudolph 1994). Thus, suitability of a pine as a quality potential cavity site is dependent on adequately decayed heartwood of sufficient diameter. Presence of decayed heartwood in longleaf pine is generally considered to be related to tree age and is normally not considered to be a silvicultural problem until pines exceed 100 years (Wahlenberg 1946).

Red-cockaded woodpeckers select specific types of pines for cavity trees relative to age and growth dynamics (Hovis and Labisky 1985, Conner and O'Halloran 1987, DeLotelle and Epting 1988), but many questions relative to site selection remain unanswered. We examined whether red-cockaded woodpeckers select pines with thinner sapwood as a possible means to reduce problems encountered with sticky pine gum when penetrating the sapwood during cavity excavation. We examined pine age relative to formation of a sufficient heartwood diameter for the cavity chamber within the bole of pines, and how heartwood diameter is affected by height on the bole. We explored tree age relative to frequency of red heart fungus presence within the heartwood.

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METHODS

The study area was the southern portion of the Angelina National Forest in eastern Texas. Woodpecker cavity tree clusters in this area were typically located on deep loamy sands (Tehran and Letney soil types) containing materials of volcanic origin (Neitsch 1982). These soils contained little organic material and consequently had a low water-holding capacity. Site index for these soils was 75-80 for longleaf pine at age 50 (R. Dolezel, Soil Cons. Serv., Nacogdoches, Tex., pers. commun.).

During fall 1991, we selected 53 longleaf pine, red-cockaded woodpecker cavity trees for study in active and inactive cavity tree clusters. We selected control pines (n = 53) within a 50-m radius of each cavity tree, choosing pines that were similar (height, diam, and crown characteristics) to cavity trees. From January through November 1992, we climbed all cavity and control trees. Increment cores (5.15 mm) were extracted at 1.3, 6.0, 9.0, and 12.0 m, stored in plastic straws, labeled, and returned to the laboratory within 12 hours for freezer storage. These heights include the bole region normally selected by woodpeckers for cavity excavation (Lay and Russell 1970, Hooper et al. 1980). We extracted an additional core from the bole at approximately 5 cm above and to one side of each cavity start and completed cavity. We measured diameter of the pine's bole with calipers at each site where a core was extracted. We visually scanned trees for fungal conks that indicated extensive heartwood decay. We measured total tree height and bole length (height to first major live limb) using a clinometer, dbh using calipers, and crown radius by measuring to the drip line with a measuring tape. We calculated green needle mass using the formula (Taras and Clark 1977)

$$\log_{10}\text{crown mass} = -1.46928 + 0.87586 \times \log_{10}(\text{dbh}^2 \times \text{tree height}).$$

We stained increment cores with benzidine dihydrochloride to reveal heartwood (Blanche et al. 1984). We measured heartwood diameter and sapwood thickness and counted annual growth rings for both. We counted the number of growth rings in the outer 1 cm of each core to evaluate tree vigor. We considered higher numbers of annual growth rings in the outer 1 cm indicative of slower, less vigorous growth (Conner and O'Halloran 1987).

We noted presence of core decay and treated cores containing fungal decay of heartwood extensive enough to obliterate annual growth rings as missing data for analyses. We included longleaf pine cavity trees, examined from 1979 to 1981, to evaluate the detected occurrence of red heart fungus in relation to tree age (Conner and Locke 1982). Because some of the 53 cavity trees examined for heartwood and sapwood characteristics also were examined in Conner and Locke's (1982) dataset, we used the early records (1979-81) for detection of decay. Use of the early dataset enabled evaluation of trees closer to the time when cavities in older cavity trees were first excavated.

Annual spring and other regular visits to red-cockaded woodpecker clusters and cavity trees on the Angelina National Forest from 1978 through 1993 (Conner et al. 1991) revealed when

Table 1. Mean characteristics of longleaf pine red-cockaded woodpecker cavity (n = 53) and control trees (n = 53) on the Angelina National Forest in eastern Texas ($\bar{x}$ ± SE).

Variables	Cavity trees		Control trees			
	$\bar{x}$	SE	$\bar{x}$	SE	t	P
Heartwood diam (cm)						
1.3[a]	27.3	10.2	21.9	9.8	3.85	0.0002
6.0	25.6	10.7	20.2	8.1	4.08	0.0001
9.0	23.7	12.4	17.7	6.7	4.27	0.0001
12.0	18.5	8.2	16.0	7.9	2.22	0.0285
Sapwood thickness (cm)						
1.3[a]	9.1	4.2	10.2	3.8	2.03	0.0453
6.0	8.0	3.4	9.5	2.9	3.36	0.0011
9.0	7.9	3.1	9.3	3.0	3.34	0.0012
12.0	8.1	3.3	9.0	3.0	2.12	0.0361
Bole diam (cm)						
1.3[a]	51.1	1.0	48.4	0.9	2.02	0.0462
6.0	44.3	0.8	42.5	0.7	1.74	0.0854
9.0	42.1	0.8	39.9	0.7	2.05	0.0427
12.0	39.0	0.9	37.1	0.6	1.71	0.0912
Tree height (m)	26.2	0.4	26.8	0.4	0.88	0.3806
Bole length (m)	14.0	0.5	14.4	0.4	0.65	0.5188
Pine crown mass (kg)	723.2	27.5	668.9	23.2	1.51	0.1341
No. growth increments at dbh in outer 1 cm of core	11.2	0.6	7.8	0.4	4.63	0.0001
Tree aee (vr)	124.5	5.5	98.5	3.9	3.86	0.0002

[a] Height aboveground (m).

cavity excavation was initiated and when cavities were completed (i.e., time required for cavity excavation). We also climbed and cored an additional 25 cavity trees 5 cm above cavities to evaluate cavity excavation rates relative to presence or absence of decayed heartwood. We assumed that detection of decay in increment cores indicated presence of red heart fungus prior to cavity excavation.

We determined the minimum age of each longleaf pine tree by adding 5 years to the number of annual rings counted at breast height. Five years is the fastest longleaf pine can reach 1.3 m in height (L. C. Walker, Stephen F. Austin State Univ., Nacogdoches, Tex., pers. commun.).

We tested the null hypotheses that (1) sapwood thickness of cavity and control pines was equal, (2) heartwood diameter of cavity and control pines was equal, and (3) the frequency of heartwood decay in cavity and control pines was equal. We compared cavity and control trees using a e-tailed t-test (P = 0.05). We selected probabilities for significance on the basis of equality of variances between groups. We compared heartwood diameter and sapwood thickness of cavity and control pines using an analysis of covariance (ANCOVA) with age as the covariate to evaluate pine age as a possible cause of differences between tree types. We used Pearson product-moment correlations to examine relationships among crown mass, sapwood thickness, heartwood diameter, and tree age. To obtain adequate sample sizes for graphic comparisons of age classes of pines, we grouped trees in the following age classes: 50-69 (n = 10 control), 70-89 (n = 8 control, n = 4 cavity), 90-109 (n = 22 control, n = 23 cavity), 110-129 (n = 5 control, n = 8 cavity), 130-149 (n = 5 control, n = 4 cavity), 150-179 (n = 3 control, n = 7 cavity), and ≥180 years (n = 5 cavity).

RESULTS

Relationships Among Heartwood, Sapwood, and Tree Age

Red-cockaded woodpeckers selected cavity trees that contained greater heartwood diameters and thinner sapwood than did control pines at all heights examined (Table 1, Figs. 1 and 2). In general, for cavity and control trees, heartwood diameter decreased as height on the bole increased. Sapwood thickness was greatest at breast height, but was relatively similar between

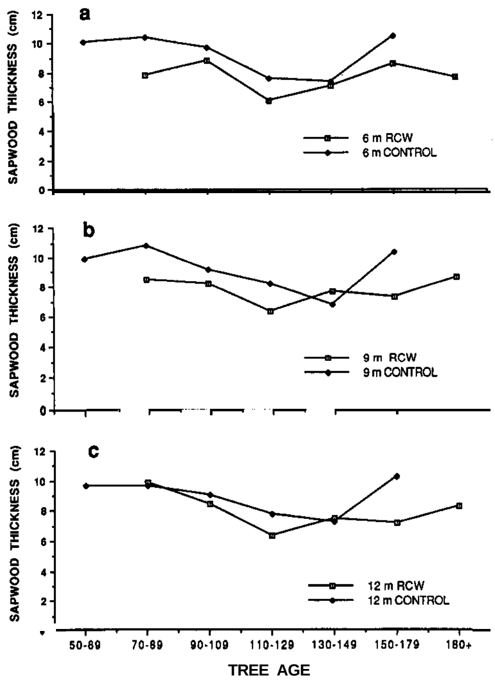

Fig. 1. Longleaf pine sapwood thickness (n = 53) in red-cockaded woodpecker (RCW) cavity trees and control pines at (a) 6. (b) 9, and(c) 12 m by age class on the Angelina National Forest in eastern Texas, 1991-92.

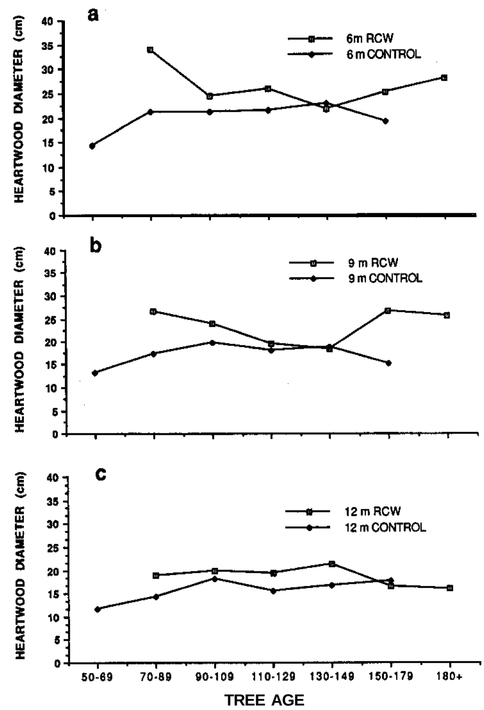

Fig. 2. Longleaf pine heartwood diameter (n = 53) in red-cockaded woodpecker (RCW) cavity trees and control pines at (a) 6. (b) 9. and(c) 12 m by age class on the Angelina National Forest in eastern Texas. 1991-92.

6 and 12 m for cavity and control trees (Table 1).

Tree height, bole length, and crown mass of cavity and control pines did not differ (Table 1). Bole diameter did not differ at 6 and 12 m aboveground, but did differ at breast height (1.3 m) and 9 m aboveground. These differences, which were ≤4 cm, were not distinguishable in the field. However, the average age of cavity trees was greater than that of control pines, and cavity trees were growing at slower rates than were control pines (Table 1).

Green needle mass was correlated with heartwood diameter (all heights), sapwood thickness (all heights), and dbh (Table 2). Heartwood diameter and sapwood thickness increased as needle mass increased. Tree age was positively correlated with heartwood diameter (all heights) and negatively correlated with sapwood thickness (all heights), but showed no relationship with dbh in our sample of all mature pines (Table 2).

Analyses of covariance, with age as the covariate, indicated that heartwood diameters of cavity trees were greater than that of control pines at 1.3 (P = 0.005), 6.0 (P < 0.002), 9.0 (P < 0.001), and 12.0 m (P = 0.092) when compared independent of tree age. Results of ANCOVA on sapwood thickness indicated that sapwood was thinner in cavity trees than in control pines at 6.0 (P = 0.005), 9.0 (P < 0.005), and 12.0 m (P = 0.099), but not at 1.3 m (P = 0.24) when evaluated independent of tree age.

Although variable by age class, sapwood thickness of control pines and cavity trees was consistent among bole heights examined (Fig. 1). We did not encounter cavity trees <70 years old or control trees >180 years old during our study. Heartwood diameter of control pines increased with tree age until the 90- to 109-year age class, appeared to increase slightly until the 130- to 149-year age class, and then declined in the oldest age class (Fig. 2). If 15 cm is adequate heartwood to house a cavity (Conner and Rudolph 1994), control pines had sufficient heartwood by the 70- to 89-year age class at 6.0 and 9.0 m aboveground. Adequate heartwood for cavities was present at I2 m beginning in the 90- to 109-year age class (Fig. 2). However, pines

Table 2. Pearson correlations of longleaf pine (red-cockaded woodpecker cavity and control trees, *n* = 106) age and wet crown mass with heartwood and sapwood characteristics during 1991-92 on the Angelina National Forest in eastern Texas.

Variables	Crown mass		Tree age	
	r	*P*	*r*	*P*
Heartwood diam				
1.3[a]	0.46	0.0001	0.32	0.0017
6.0	0.55	0.0001	0.28	0.0052
9.0	0.61	0.0001	0.27	0.0117
12.0	0.45	0.0001	0.24	0.0223
Sapwood thickness				
1.3[a]	0.36	0.0004	-0.30	0.0026
6.0	0.40	0.0001	-0.25	0.0112
9.0	0.34	0.0009	-0.25	0.0159
12.0	0.47	0.0001	-0.27	0.0086
No. growth increments at dbh in outer 1 cm of core	-0.39	0.0001	0.27	0.0059
Tree dbh	0.93	0.0001	0.09	0.3515

[a] Height aboveground (m).

used for cavity trees had adequate average heartwood diameters (>15-cm diam) at all 3 bole heights over the range of age classes examined (Fig. 2). The average heartwood diameter at sites where red-cockaded woodpeckers excavated completed cavities was 26.4 cm (n = 25). The smallest diameter of heartwood present at a completed cavity was 14.4 cm, whereas the greatest diameter observed was 44.2 cm.

Relationships Among Fungi, Tree Age, and Excavation Rates

We did not detect fungi in cores extracted above cavities or at 6, 9, and 12 m aboveground in pines <102 years. Heartwood decay was not regularly detected until cavity trees exceeded 120 years (Fig. 3a). A few longleaf pines >200 years did not appear to have heartwood decay at cavities or increment borer sample heights. Overall, we detected heartwood decay at 46% of completed cavity sites in the longleaf pines examined (n = 50, $\bar{x}$ = 126.4 yr). Heartwood decay was detected at 6, 9, and 12 m in only 4 control pines and did not appear to have an association with pine age (Fig. 3b). We did not directly compare frequency of fungal decay in cavity and control trees because sampling intensity between the 2 groups was unequal; cavity trees were cored at each cavity in addition to the 6, 9, and 12 m heights. Five of 53 cavity and 2 of 53 control trees could not be aged because of decay (most likely *Phaeolus schweinitzii*). However, the 2 control pines with decay at breast height had 137 and 140 annual growth rings 6 m aboveground. Of 25 red-cockaded woodpecker cavities initiated and completed between 1978 and 1993, 15 were excavated into decayed heartwood and 10 were not. Cavities excavated into decayed heartwood required less time ($\bar{x}$ = 3.7 yr) than did cavities excavated into sound heartwood ($\bar{x}$ = 5.0 yr, *P* = 0.057).

DISCUSSION

Red-cockaded woodpeckers excavated cavities in pines that had thinner sapwood and greater heartwood diameters than pines generally available within woodpecker cluster areas. Such pines also were older, growing slower, and had a higher infection rate of heartwood decay than pines not used for cavity excavation. Increasing age rather than red-cockaded woodpecker activity at resin wells was most likely the cause of slower tree growth. Diameter growth of trees typically accelerates annually as younger trees mature, attains a maximum, and slows as trees approach maturity (Kramer and Kozlowski 1979).

In eastern Texas, longleaf pines between 70 and 90 years had adequate heartwood (15 cm) to contain a cavity. However, pines actually used by the woodpeckers had considerably larger heartwood diameter (26.4 cm) than the apparent minimum size required. Selection of pines with heartwood diameters greater than the 15-cm minimum may reflect the woodpeckers' preference for pines infected with red heart fungus (Hooper 1988, Hooper et al. 1991, Rudolph et al. 1994). Pines with larger heartwood diameters are generally older pines and, therefore, have a higher probability of heartwood decay, which increases with tree age.

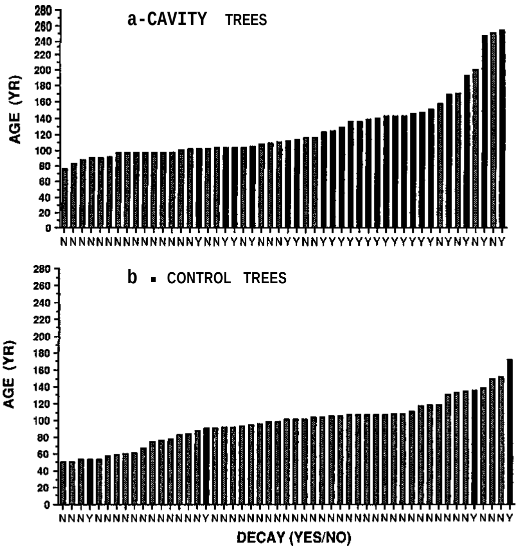

Fig. 3. Ages of longleaf pine relative to presence (yes = black bar) or absence (no = gray bar) of heartwood decay (a) in 50 red-cockaded woodpecker cavity trees and (b) in 51 control pines on the Angelina National Forest in eastern Texas, 1991–92.

Regional differences appear to exist in the ages at which pines become infected with heartwood decaying fungi. Our data indicate a 46% heartwood infection rate for 50 longleaf pine cavity trees that averaged 126.4 years. In South Carolina, longleaf pines averaging 105.0 years had a 58% infection rate (Hooper et al. 1991). On the Ocala National Forest, 65.5-year-old longleaf pines had a 32% infection rate (Hooper 1988), and on the Francis Marion National Forest, 72.3-year-old longleaf pines had an 86% infection rate (Hooper 1988). Hooper showed that red-cockaded woodpecker selection of pines with heart rot in South Carolina and Florida was independent of tree age when the birds had an abundant supply of potential cavity trees. When pines with heart rot were not available, red-cockaded woodpeckers appeared to select pines for excavation according to tree growth rate, tree diameter, and possibly heartwood diameter (Hooper 1988).

Red-cockaded woodpeckers may be able to identify suitable pines by features other than tree morphology, and thereby select trees with thin sapwood and an adequate heartwood diameter that have a high probability of containing heartwood decay. For woodpeckers, one benefit of using pines with thin sapwood might be reduced excavation time in xylem tissue that actively transports pine resin. There is a benefit from selecting pines with adequate heartwood diameter to physically contain a woodpecker's cavity. How red-cockaded woodpeckers select pines with heartwood decay remains unanswered. Conner et al. (1976) suggested that other species of woodpeckers using hardwoods for cavity sites could detect heartwood decay presence by percussing the bole of the tree and listening for particular resonance characteristics. However, hardwoods typically have thinner sapwood than pines and therefore detection of decayed heartwood by percussion might be easier in hardwoods (Conner and Locke 1982). Conner and Locke (1982), Hooper et al. (1991), and Rudolph et al. (1994) provided evidence that red-cockaded woodpeckers could detect and excavate cavities in pockets of heartwood decay in pines. If the woodpeckers do not use general tree features such as diameter, height, and crown characteristics as our data suggest, they may have the ability to percuss pines and detect particular resonances that are associated with decayed heartwood and thin sapwood. The fact that red-cockaded woodpeckers excavate cavities into pines with sound heartwood throughout their range (Beckett 1971, Jackson 1977, Conner and Locke 1982, Hooper 1988, this study) supports the suggestion that woodpeckers use criteria other than detection of heartwood decay, such as sapwood characteristics, as a means to select suitable cavity substrate. As an additional possibility, woodpeckers may be able to evaluate trees by initiating a cavity start and determining tree suitability on the basis of structural characteristics of the outer xylem tissue, much as researchers evaluate tree vigor.

MANAGEMENT IMPLICATIONS

Provision of old pines with adequate diameters of decayed heartwood and relatively thin sapwood is essential for successful management of red-cockaded woodpecker nesting habitat. Such pines need to be present in sufficient abundance to provide replacement trees for excavation of new cavities when existing cavity trees are lost (Conner et al. 1991). In eastern Texas, pines ≥120 years are needed for adequate provision of the complete array of conditions examined in our study.

Silvicultural research is needed to determine how to produce pines with large diameters of decayed heartwood and relatively thin sapwood. Such pines also would need to have adequate crowns for resin production and relatively open boles (Conner and O'Halloran 1987). Additional research is needed to explore the relative importance of pine age, sapwood thickness, and decayed heartwood to red-cockaded woodpecker selection of pines for cavity excavation.

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