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Influence of coarse woody debris on the soricid community in southeastern Coastal Plain pine stands

JUSTIN C. DAVIS, STEVEN B. CASTLEBERRY,* AND JOHN C. KILGO

Florida Fish and Wildlife Conservation Commission, Fitzhugh Carter Tract of Econfina Creek Wildlife Management Area, 2830 Chain Lake Road, Chipley, FL 32428, USA (JCD)
Daniel B. Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA 30602, USA (SBC)
Southern Research Station, United States Department of Agriculture Forest Service—Savannah River, P.O. Box 700, New Ellenton, SC 29809, USA (JCK)

* *Correspondent: scastle@warnell.uga.edu*

Shrew abundance has been linked to the presence of coarse woody debris (CWD), especially downed logs, in many regions in the United States. We investigated the importance of CWD to shrew communities in managed upland pine stands in the southeastern United States Coastal Plain. Using a randomized complete block design, 1 of the following treatments was assigned to twelve 9.3-ha plots: removal ($n = 3$; all downed CWD $\geq$10 cm in diameter and $\geq$60 cm long removed), downed ($n = 3$; 5-fold increase in volume of downed CWD), snag ($n = 3$; 10-fold increase in volume of standing dead CWD), and control ($n = 3$; unmanipulated). Shrews (*Blarina carolinensis*, *Sorex longirostris*, and *Cryptotis parva*) were captured over 7 seasons from January 2007 to August 2008 using drift-fence pitfall trapping arrays within treatment plots. Topographic variables were measured and included as treatment covariates. More captures of *B. carolinensis* were made in the downed treatment compared to removal, and captures of *S. longirostris* were greater in downed and snag compared to removal. Captures of *C. parva* did not differ among treatments. Captures of *S. longirostris* were positively correlated with slope. Our results suggest that abundance of 2 of the 3 common shrew species of the southeastern Coastal Plain examined in our study is influenced by the presence of CWD. DOI: 10.1644/09-MAMM-A-170.1.

Key words: *Blarina*, coarse woody debris, *Cryptotis*, decay state, shrew, *Sorex*, topographic variables, upland pine

Acknowledgement of the ecological significance of coarse woody debris (CWD) in the conservation of biodiversity has increased in recent years (Harmon et al. 1986; McMinn and Crossley 1996; McMinn and Hardt 1996). Presence of structural forest features, such as snags and fallen trees, may promote biological diversity (Hansen et al. 1991; Sharitz et al. 1992). However, intensive plantation forestry practices can greatly reduce CWD inputs within forest ecosystems (Spies and Cline 1988; Spies et al. 1988). Maintaining CWD while managing for timber products can be challenging, especially in the southeastern United States where shorter rotation lengths, high humidity, and silvicultural practices result in lower accumulations of CWD (McCay et al. 2002a; McMinn and Hardt 1996; Sharitz et al. 1992). Further, recent advances in wood utilization technology and an emerging biofuels market (i.e., wood chips, wood pellets, and cellulosic ethanol) can decrease the amount of woody material left following timber harvests (Bies 2006).

Shrew abundance has been linked to the presence of CWD, especially downed logs, in many regions of the United States (Loeb 1996; Maidens et al. 1998; McCay et al. 1998). In Oregon and Washington captures of Trowbridge's shrew (*Sorex trowbridgii*) were positively correlated with logs (Carey and Johnson 1995; McComb and Rumsey 1982). In the southern and central Appalachians abundances of smoky (*Sorex fumeus*), masked (*Sorex cinereus*), and northern short-tailed (*Blarina brevicauda*) shrews were positively associated with downed logs (Brannon 2000; Ford et al. 1997; McComb and Rumsey 1982). In the South Carolina Coastal Plain Loeb (1999) captured more southern short-tailed shrews (*Blarina carolinensis*) in upland pine stands containing CWD inputs from tornado damage compared to those in which CWD was removed.

Although the above studies support the premise that shrews benefit from CWD, others have failed to show significant relationships. For example, in Appalachian forests of New Brunswick, Canada, Bowman et al. (2000) found no correlation between captures of *B. brevicauda* and abundance or decay state of downed logs. In a study at the Savannah River Site in the Upper Coastal Plain of South Carolina, captures of *B. carolinensis* and southeastern shrew (*Sorex longirostris*) did not differ between the control and treatments in which CWD was removed (McCay and Komoroski 2004). Similarly, Mengak and Guynn (2003) observed no relationship between *B. carolinensis* captures and CWD in western South Carolina.

Lack of consensus on the relationship between CWD and shrew communities, especially in the southeastern Coastal Plain, demonstrates the need for continued investigation. Our study was a continuation of a 2-phase, long-term project investigating the importance of CWD as a habitat component in managed upland pine stands in the southeastern Coastal Plain, representing years 6 and 7 of Phase II (McCay et al. 2002b). We examined the response of shrew communities to removal and addition of CWD (both downed and standing) as compared to control stands. We predicted that shrew abundance would be positively related to addition of CWD and negatively related to its removal. We predicted higher mean body mass for shrews captured in the downed treatment due to a higher invertebrate prey base associated with higher levels of CWD (Hanula et al. 2006; Jabin et al. 2004). We predicted a greater percentage of younger shrews in the downed treatment as a result of higher reproduction rates and dominant younger individuals outcompeting older individuals for the higher quality habitat that increased CWD can provide (Churchfield 1990; Rychlik 1998).

Materials and Methods

Study area.—Study plots were located on the Savannah River Site, a 78,000-ha National Environmental Research Park administered by the Department of Energy. The Savannah River Site is located in the Upper Coastal Plain and Sandhills physiographic region of South Carolina (White 2005). This region is characterized by sandy soils and gently sloping hills dominated by pines with scattered hardwoods (Kilgo and Blake 2005). The climate of the Savannah River Site is humid subtropical with mean annual temperature and rainfall of 18°C and 122.5 cm (Blake et al. 2005).

When the Department of Energy acquired the Savannah River Site in 1951 old-field habitats dominated the site as a result of past land-use activities driven by food crop, cotton, and naval store production (White 2005). The majority of the site has been reforested by the United States Department of Agriculture Forest Service (Imm and McLeod 2005; White 2005). Approximately 68% of the Savannah River Site is composed of upland pine stands, including loblolly (*Pinus taeda*), slash (*Pinus elliottii*), and longleaf (*Pinus palustris*) pines. Although much of the land is managed for timber production, nearly two-thirds of the pine forests on Savannah River Site are 40–70 years old (Imm and McLeod 2005).

Study plots were located in 3 loblolly pine stands planted between 1950 and 1953. Although the overstory in these stands was dominated by loblolly pine, slash and longleaf pine also were present. Understory vegetation was dominated by sassafras (*Sassafras albidum*), black cherry (*Prunus serotina*), lespedeza (*Lespedeza* spp.), blackberry (*Rubus* spp.), and poison oak (*Toxicodendron pubescens*).

Study design.—Study design was a randomized complete block design, with each of 4 treatments randomly assigned in each of the 3 forest stands (blocks). Blocks were chosen based on the following criteria: approximately 45-year-old loblolly pine plantations (at project initiation in 1996); ≥76 m from the nearest wetland, road, or power line; and large enough to accommodate four 9.3-ha square plots. Treatments were control, where downed CWD was not manipulated; snag, where standing CWD volume was increased 10-fold; removal, where all downed CWD ≥10 cm in diameter (measured at the midpoint) and ≥60 cm in length was removed; and downed, where volume of downed CWD was increased 5-fold. The control and removal treatment plots were initiated in 1996 (Phase I), and the downed and snag treatments were implemented in 2001 (Phase II—McCay et al. 2002b). Downed treatments were created by removing existing downed CWD by hand and randomly felling trees within rows until a 5-fold increase was obtained. Snag treatments were created by girdling and later injecting herbicide into trees within rows until a 10-fold increase was obtained. Annual removal of CWD was performed by hand in the removal treatment plots. Each treatment plot consisted of a 6-ha core trapping area, surrounded by a 3.3-ha buffer zone subject to the same treatment to minimize edge effect. All 12 plots were thinned in 2001 to a live pine basal area of between 13.8 and 20.8 m^2/ha and were prescribed burned in summer 2004.

Data collection.—Measurements of downed woody debris were conducted in randomly selected subplots (50 × 50 m) within the inner 4 ha of each treatment plot in January 2007. Within each subplot all logs with ≥50% of their measurable length within the subplot were measured, and logs ≥10 cm in diameter at the midpoint and ≥60 cm in length were included in the inventory. Logs were classified into 1 of 5 decay stages based on the Maser et al. (1979) decay scale, where stage 1 logs were sound, with intact bark; stage 2 logs had mostly sound wood with some bark starting to flake; stage 3 logs had broken branches and were missing bark; stage 4 logs were soft and blocky in texture; and stage 5 logs were powdery in texture and partly buried. Although log volumes were estimated assuming logs were round in circumference, which may overestimate the true volume of downed wood, measurements were consistent among treatments and years.

Shrew sampling was conducted using pitfall drift-fence arrays. Drift fences consisted of aluminum flashing buried approximately 15 cm below ground, with 19-liter plastic buckets buried flush to the ground against each fence. Each plot contained 1 cross-shaped array with four 30-m arms extending out from the center of the plot in each of the cardinal directions, and 4 Y-shaped arrays with three 15-m

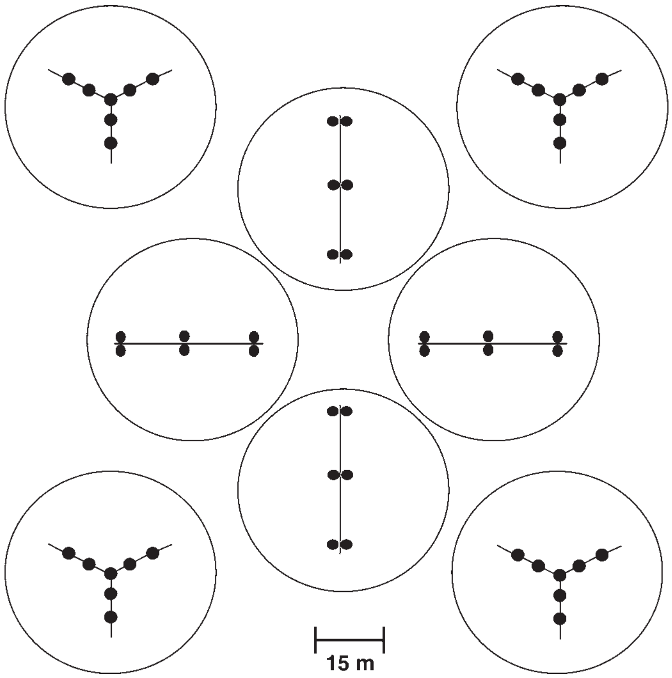

FIG. 1.—Arrangement of drift-fence arrays and bucket traps used for sampling shrews on a 6-ha core area of a 9.3-ha treatment plot in an upland loblolly pine (*Pinus taeda*) stand at the Savannah River Site, Barnwell County, South Carolina. Also shown are buffers (circles) within which topographic variables were measured for covariate analyses.

arms located in each corner of the 6-ha core sampling area (Fig. 1). Pitfall traps (buckets) were maintained with 2.5–5 cm of soil in the bottom to provide captured animals cover from temperature extremes and protection from desiccation during trapping periods. The bottoms of buckets were perforated, allowing drainage of excess water after heavy rains.

Shrews were sampled in all plots for 14 days each season from January 2007 to August 2008, for a total of 7 sampling seasons, during which traps were checked once daily between 0700 and 1700 h. Shrews were identified to species, weighed (g), and measured for body and tail lengths (mm). A small number of individuals were partially eaten by fire ants (*Solenopsis invicta*) or other shrews captured in the same trap and could not be measured or weighed. Live shrews were euthanized via cervical dislocation and frozen for subsequent dissection. Collection procedures were approved by the University of Georgia Institutional Animal Care and Use Committee (IACUC A2007-10033-0) and followed guidelines approved by the American Society of Mammalogists (Gannon et al. 2007). Rainfall data were collected from a weather station approximately 4 km from study plots.

We quantified spatial variables with the potential to influence shrew abundance within treatment plots. Trap array locations were recorded using a Trimble GeoExplorer 3 (Trimble Navigation Limited, Sunnyvale, California) hand-held global positioning system unit and differentially corrected using data from a continually operating reference station in Columbia County, Georgia (63 km from our study site). Array locations for Y-shaped arrays were taken at the middle bucket, and array locations for each arm of the cross-shaped array were taken at the middle of each array arm. Y-shaped arrays and each arm of the cross-shaped array were considered separate arrays, resulting in 8 arrays with capture data per plot. Buffers were created around array locations with a unique buffer size for each shrew species based on average home-range sizes from the published literature (Fig. 1). Buffer radii were 55.3 and 45.4 m for *B. carolinensis* (McCay 2001) and *C. parva* (Choate and Fleharty 1973), respectively. Because no home-range estimates were available in the literature for *S. longirostris*, a buffer radius of 42 m was used based on home-range estimates for *S. cinereus* (Buckner 1966), a similarly sized species with a similar life history (McCay et al. 2004). Mean elevation, degree of slope, and aspect were calculated for each buffered area using the Zonal Statistics tool in the Spatial Analyst extension of ArcGIS 9.2 (Environmental Systems Research Institute, Redlands, California). All pixels (and their associated values) with $\geq$50% of their area within the buffer boundary were used for calculations. Distance to the nearest stream was calculated from the actual array location point (center point of the buffer). All stream orders were considered, although ephemeral streams may not have contained water during our study.

Shrews were dissected to determine age and sex and were designated as age class 1, 2, 3, or 4 based on relative tooth attrition using methods outlined in Pearson (1945) for *B. carolinensis* and Rudd (1955) for *S. longirostris*. Rudd's 7-class system was modified for this study, resulting in 4 age classes: age class 1 corresponded to Rudd's age classes 1 and 2; age class 2 corresponded to Rudd's age classes 3 and 4; age class 3 corresponded to Rudd's age classes 5 and 6; and age class 4 corresponded to Rudd's age class 7. For *B. carolinensis* age class 1 individuals were 0–24 weeks old, age class 2 individuals 24–40 weeks old, age class 3 individuals 40–64 weeks old, and age class 4 individuals >64 weeks. For *S. longirostris* age class 1 included individuals 0–18 weeks old, age class 2 individuals 18–36 weeks old, age class 3 individuals 36–54 weeks old, and age class 4 individuals >54 weeks old. Age structure analysis was not conducted for *C. parva* because of low sample size ($n = 43$) and lack of accurate aging methodology for the species.

Statistical analysis.—Shrew captures at each Y-shaped array and each arm of cross-shaped arrays were standardized as number of captures per meter of fencing for each species. Treatment differences were examined using 2-way analysis of covariance (ANCOVA) with slope, elevation, aspect, and distance to nearest stream as covariates. We examined relationships between main effects and significant covariates using Spearman's correlation coefficient (r_s). Two-way analyses of variance (ANOVAs) were used to determine differences in mean body mass for each species among treatments and seasons. Body masses of *B. carolinensis* and *S. longirostris* were blocked by sex and age, and those of *C. parva* only by sex. All data were tested for normality using Shapiro–Wilks test. Nonnormal data were ranked, and

TABLE 1.—Mean shrew captures per meter of drift fence (*SE*) in snag, control, removal, and downed treatment plots ($n = 24$ each) in upland loblolly pine (*Pinus taeda*) stands in Barnwell County, South Carolina. Means with different letters indicate significant differences ($P < 0.05$) among treatments.

	Treatment			
Species	Snag	Control	Removal	Downed
Blarina carolinensis	0.069 (0.012)ab	0.058 (0.013)ab	0.051 (0.011)b	0.105 (0.012)a
Cryptotis parva	0.004 (0.005)	0.015 (0.005)	0.014 (0.005)	0.012 (0.005)
Sorex longirostris	0.046 (0.009)a	0.026 (0.010)ab	0.013 (0.009)b	0.057 (0.009)a

ANOVA or ANCOVA was performed on ranks (Conover and Iman 1982). Significant results were analyzed further using adjusted least-square means pairwise comparisons (Steele et al. 1996) on ranks. We used forest stand as the block factor for all ANCOVAs and ANOVAs (except body mass) and SAS 9.1 (SAS Institute Inc. 2008) to perform all statistical analyses.

Age class frequencies for *B. carolinensis* and *S. longirostris* were analyzed using log-likelihood ratio *G*-tests to determine if age class ratio differed among treatments. Small sample sizes yielded expected values <5. *G*-tests underestimate *P*-values under these circumstances. Therefore, using SAS 9.1 (SAS Institute Inc. 2008) we performed randomization (Monte Carlo simulation) tests based on 1 million replicates to generate *P*-value estimates for significance testing (Sokal and Rohlf 1995; Zar 1999). A significant difference in age class ratios among treatments was interpreted as a skewed age class distribution.

RESULTS

Mean volumes ($\pm SE$) of downed CWD were 59.4 ± 7.9 m^3/ha for downed, 34.7 ± 6.3 m^3/ha for snag, and 12.7 ± 1.9 m^3/ha for control. Mean decay stages of logs in downed, control, and snag treatments were 3.1, 3.3, and 3.0, respectively.

Captures of shrews totaled 443 over 7 sampling seasons from January 2007 to August 2008. All 3 shrew species that occur on Savannah River Site were captured, and additional insectivore captures included 4 eastern moles (*Scalopus aquaticus*). *B. carolinensis* was captured most frequently, representing 59.6% (264) of all captures, and captures of *S. longirostris* and *C. parva* made up 30.7% (136) and 9.7% (43), respectively. Throughout the study mortality rates for *B. carolinesis*, *S. longirostris*, and *C. parva* captured in pitfall traps were 73.1%, 87.5%, and 60.5%, respectively.

No covariate had an effect on captures of *B. carolinensis* or *C. parva* ($P > 0.05$). Slope was a significant covariate for captures of *S. longirostris* ($F_{1,86} = 6.05$, $P = 0.0159$), with more captures occurring on steeper slopes ($r_s = 0.50$, $P < 0.0001$). *B. carolinensis* was captured more frequently in the downed than in the removal treatment ($F_{3,85} = 3.26$, $P = 0.0253$; Table 1). Captures of *S. longirostris* were greater in downed and snag compared to the removal treatment ($F_{3,86} = 6.76$, $P = 0.0004$). Capture frequency of *C. parva* did not differ among treatments ($F_{3,86} = 1.92$, $P > 0.05$).

Mean body mass did not differ ($P > 0.05$) among treatments for 252 *B. carolinensis* ($F_{3,218} = 0.65$), 116 *S. longirostris* ($F_{3,95} = 0.67$), or 37 *C. parva* ($F_{3,30} = 0.18$; Table 2). *B. carolinensis* weighed more in fall and winter than in spring ($F_{3,218} = 22.24$, $P < 0.0001$; Table 3). Mean mass of *S. longirostris* was greater in winter than in spring ($F_{3,95} = 4.14$, $P = 0.0083$). Masses of *C. parva* did not differ among seasons ($F_{3,30} = 1.31$, $P > 0.05$). Age class frequencies for 255 *B. carolinensis* ($G^2_9 = 13.96$, $P = 0.1236$) and 132 *S. longirostris* ($G^2_9 = 4.78$, $P = 0.853$) examined were similar among treatments.

DISCUSSION

Capture rates of *B. carolinensis* and *S. longirostris* were higher in the downed treatment compared to the removal treatment, consistent with our prediction. Higher captures of these species in the downed treatment could be due to increased prey production or cover associated with CWD. Many invertebrate prey species, including spiders, centipedes, adult and larval beetles, moths (Hanula 1996; Jabin et al. 2004; Whitaker et al. 1994), and earthworms (Hendrix 1996), are known to use decaying wood. Spiders, centipedes, beetles, moths, and earthworms made up 43.3% of the stomach contents of 45 *B. carolinensis* from the Savannah River Site

TABLE 2.—Mean (*SE*) body mass (g) of shrews captured in snag, control, removal, and downed treatment plots in upland loblolly pine (*Pinus taeda*) stands in Barnwell County, South Carolina.

	Treatment			
Species	Snag ($n = 3$)	Control ($n = 3$)	Removal ($n = 3$)	Downed ($n = 3$)
Blarina carolinensis	6.7 (0.2)	6.9 (0.2)	6.5 (0.2)	6.6 (0.1)
Cryptotis parva	3.7 (0.3)	3.5 (0.2)	3.6 (0.1)	3.8 (0.3)
Sorex longirostris	2.8 (0.1)	2.7 (0.1)	3.0 (0.2)	2.8 (0.1)

TABLE 3.—Mean (*SE*) body mass (g) of shrews captured during spring, summer, fall, and winter in upland loblolly pine (*Pinus taeda*) stands in Barnwell County, South Carolina. Means with different letters indicate significant differences ($P < 0.05$) among seasons.

	Season			
Species	Spring	Summer	Fall	Winter
Blarina carolinensis	6.3 (0.1)a	7.3 (0.2)bc	7.5 (0.5)c	7.9 (0.2)c
Cryptotis parva	3.4 (0.1)	3.6 (0.2)	3.8 (0.4)	4.1 (0.4)
Sorex longirostris	2.8 (0.1)a	2.8 (0.1)ab	3.5 (0.0)ab	3.1 (0.2)b

(Whitaker et al. 1994) and 70.1% of the diets of 90 *S. longirostris* from Indiana (French 1984). Additionally, the overhang area created where logs meet the forest floor can provide protective cover for small mammals (Maser et al. 1979). Owls are the primary predator of shrews and are known to prey on *B. carolinensis* and *S. longirostris* (Churchfield 1990; French 1980; Genoways and Choate 1998). Shrews likely use log overhang for quiet and inconspicuous travel routes to minimize predation risk.

Higher abundance of *S. longirostris* in the snag compared to removal treatment may be due to increased availability of decaying root systems. The nutrient deprivation of roots as a result of tree girdling can lead to enhanced decomposition of root systems (Högberg et al. 2001). McCay (2000) found that voids created by decomposing root systems provided the most suitable daytime refugia for cotton mice (*Peromyscus gossypinus*) in a southeastern pine forest due to the lack of alternative refuge sites, such as rock outcrops. Because *S. longirostris* is considered epigeal in its habits (McCay et al. 2004), it might depend more on the decomposition of root systems for use as travel routes and foraging areas than the more fossorial *B. carolinensis*.

Although contrary to our prediction, lack of a treatment effect for *C. parva* was consistent with results of Moseley et al. (2008). *B. carolinensis* and *C. parva* both have morphological characteristics (i.e., short tail and reduced pinnae) suggestive of a fossorial lifestyle. However, *C. parva* has been described as being largely epigeal in its habits (McCay et al. 2004) and is more commonly associated with grassy or old-field habitats (Bellows et al. 2001; Davis and Joeris 1945; Whitaker 1974). *C. parva* might be excluded from forested habitats by the larger *B. carolinensis* and be more adapted to open habitats at the edge, which would have lower CWD volumes. Thus, the competitive exclusion of *C. parva* from forested to early successional habitats might have forced the species to evolve without CWD as a critical habitat component.

Although we expected higher shrew body mass in the downed treatment as a result of increased invertebrate prey associated with higher volumes of decaying wood, our results failed to show this relationship. Moderate to severe drought conditions persisted at our study site during all sample periods except winter and spring 2007. Because insect activity levels and life cycles are influenced by environmental moisture (Graham 1925; Tauber et al. 1998), prey availability in all treatments could have been reduced by drought conditions. Therefore, shrew weights recorded during our study may not reflect those that occur during years receiving average rainfall.

We observed no differences in age structure among treatments for *B. carolinensis* or *S. longirostris*, although we expected age structure to be skewed toward younger individuals in the downed treatment. It is likely that availability of unoccupied home ranges and predation within a given habitat limits the number of individuals in younger age classes. Dispersing juvenile shrews (generally males) typically occupy a vacant home range close to the natal area (Churchfield 1990). Because available home ranges are occupied by juveniles born early in the breeding season, juveniles born later are forced to wander farther to find an unoccupied home range. Wandering by juveniles unable to establish a home range increases vulnerability to predation (Churchfield 1990) and may result in similar age structures even with higher reproductive rates in the downed treatment. However, we caution that we did not examine reproductive rates or dispersal in our study. It is plausible that these populations have a stable age structure regardless of any potential benefits provided by CWD.

Our findings suggest that abundance of 2 of the 3 shrew species common in the southeastern Coastal Plain are influenced by the presence of CWD. Intensive management of pine stands in the region and developing biofuel markets may result in decreased inputs of CWD and, as a result, lower abundances for shrew species. Therefore, to conserve biodiversity and maintain ecosystem health, forest managers should consider the benefits CWD provides to faunal communities and the potential impacts of reduced levels of CWD on the biotic community.

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