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Small mammal communities of streamside management zones in intensively managed pine forests of Arkansas

Darren A. Miller[a,*], Ronald E. Thill[b], M. Anthony Melchiors[c], T. Bently Wigley[d], Philip. A. Tappe[e]

[a]Southern Timberlands Research and Development, Weyerhaeuser Company, P.O. Box 2288, Columbus, MS 39704, USA
[b]USDA Forest Service, Southern Research Station, 506 Hayter St., Nacogdoches, TX 75965-3556, USA
[c]Western Timberlands Research, Weyerhaeuser Company, P.O. Box 9777, Federal Way, WA 98063-9777, USA
[d]Department of Aquaculture, Fisheries, and Wildlife, National Council for Air and Stream Improvement, Inc., P.O. Box 340317, Clemson University, Clemson, SC 29634-170362, USA
[e]School of Forest Resources, University of Arkansas, Monticello, Monticello, AR 71656, USA

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Abstract

Streamside management zones (SMZs), composed primarily of hardwoods in the southeastern United States, provide habitat diversity within intensively managed pine (*Pinus* spp.) plantations. However, effects of SMZ width and adjacent plantation structure on riparian wildlife communities are poorly understood. Therefore, during 1990–1995, we examined small mammal communities within 5 SMZ width classes (1–20 to >100 m) embedded within three types of pine plantations (young, open canopy; closed canopy; and thinned) and three natural riparian stands in the Ouachita Mountains of Arkansas, USA. We captured small mammals for 10 consecutive days each February using four to six traplines each consisting of nine trap stations with three snap traps at each station. We estimated relative abundance [catch-per-unit-effort (CPUE)], species richness, species diversity, and species evenness for all captures and captures just along the stream course. Within the SMZ/plantation settings and three natural stands, we captured 1701 small mammals of 11 species in 114,285 trapnights. Golden mice (*Ochrotomys nuttalli*), southern short-tailed shrews (*Blarina carolinensis*), and *Peromyscus* spp. comprised 88% of all captures. Our study suggests that narrow (≤20 m wide) SMZs in managed pine forests tend to have higher small mammal abundance and species richness than wider SMZs. Additionally, species richness and CPUE was greater in SMZs within young, open canopy and thinned plantations versus closed canopy plantations. Plantation structure appears to influence small mammal community structure within SMZs more than SMZ width. Shortening the amount of time plantations spend in closed canopy conditions would likely improve habitat conditions for small mammals existing in SMZs within intensively managed pine landscapes. Streamside management zones in the South designed to meet voluntary water quality standards are likely sufficient for small mammal conservation.

Keywords: Akaike's information criterion; Arkansas; Abundance; Diversity; Intensive forestry; Pine plantations; Riparian zones; Small mammals; Streamside management zones

* Corresponding author. Tel.: +1 662 245 5249; fax: +1 662 245 5228.
E-mail address: darren.miller@weyerhaeuser.com (D.A. Miller).

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1. Introduction

The area under intensive pine (*Pinus* spp.) management in the Southeast is expected to increase from the 12.9 million ha that existed in 1999 to 21.8 million ha in 2040 (Wear and Greis, 2002). Because forest managers increasingly are expected to manage for fish and wildlife habitat and contribute to the conservation of biodiversity (e.g., American Forest and Paper Association, 2002), economically viable opportunities to address biodiversity within managed forest landscapes need to be recognized and exploited. Although intensively managed, even-aged pine stands (hereafter plantations) provide habitat for a wide diversity of wildlife species (e.g., Perkins et al., 1988; Wigley et al., 2000; Wilson and Watts, 2000; Barber et al., 2001), the reduced availability of mature hardwoods, snags, and large woody debris in short-rotation plantations may preclude presence of mammalian species traditionally associated with such habitat components (Campbell et al., 1996; Carey and Johnson, 1995; Loeb, 1999).

Natural forest stands retained along intermittent and perennial streams, known as streamside management zones (SMZs), are a common component of landscapes dominated by pine plantations. Streamside management zones are retained to protect water quality from nonpoint source pollution, per state-level, voluntary Best Management Practices (BMPs: Dickson and Williamson, 1988; Blinn and Kilgore, 2001). In addition to protecting water quality, SMZs can increase biodiversity within plantation systems by providing habitat for species requiring mature forest structure and/or mature hardwoods, increasing habitat diversity, and increasing edge diversity (Wigley and Melchiors, 1994). Because SMZs are an integral component of many industrial forest landscapes, they may provide an economically feasible opportunity to increase biodiversity on such landscapes. However, guidelines in state BMPs regarding width of SMZs are highly variable among states, and SMZ width sufficient for protection of water quality may not provide habitats sufficient for all wildlife species associated with riparian forests.

Small mammal communities are an important trophic component of forested ecoystems (Carey and Johnson, 1995; Michael, 1995) and greatly contribute to species and functional diversity within forest ecosystems (Carey and Johnson, 1995). Although small mammals have been studied in managed pine forests of the Southeastern United States (e.g., Atkenson and Johnson, 1979; Langley and Shure, 1980; Perkins et al., 1988; Mitchell et al., 1995), importance of SMZs to small mammals is poorly understood (Gomez and Anthony, 1998; Darveau et al., 2001). Additionally, effects on wildlife communities from the interaction of SMZ width and different structural classes of adjacent pine plantations are unknown (Tappe et al., 1994, 2004).

To more thoroughly document how SMZ width and stand structure of surrounding plantation affect wildlife communities, we investigated small mammal communities associated with SMZs in the Ouachita Mountains of Arkansas, USA using the data of Tappe et al. (1994, 2004) and 4 years of additional data. Our objectives were to examine effects of SMZ width and stand structure of surrounding plantations on small mammal abundance, richness, and diversity within a landscape of intensively managed pine forest.

2. Methods

2.1. Study area

The study was conducted in the Ouachita Mountains with all study sites within 40 km of Hot Springs, AR, USA, and within Garland, Montgomery, and Saline counties. This region was characterized by east–west ridges and mountains with narrow to broad valleys. Elevations ranged from 100 to 900 m (Croneis, 1930). Topography consisted of steep, stony mountain slopes with narrow ridge tops, low rolling hills, and narrow floodplains. The shallow soils developed from sandstone, shale, and novaculite, were dry to droughty with loamy and clay subsoils. Soils were of the Sandlick, Magnet, Bigfork, and Thornburg associations. Sampled stream reaches occurred at elevations ranging from 110 to 317 m, and drained adjacent slopes that ranged up to 457 m. The climate in this region was characterized by hot, humid summers and mild winters (Skiles, 1981). Average monthly precipitation ranged from 8.4 cm in August to 16.3 cm in May and average annual precipitation was 139.9 cm (Laurent et al., 1989).

All SMZ/plantation treatments (see below) were located on land owned and managed by Weyerhaeuser Company. The three natural riparian stands (hereafter, natural stands), which were included for general comparisons only, were located one each on Weyerhaeuser land, United States Forest Service land (Ouachita National Forest), and other public land. On the Weyerhaeuser ownership, the predominant forest type was loblolly pine (*Pinus taeda*) plantations; management practices were characterized by clearcut harvest of the existing plantations (at approximately 30–35 years of age) or second growth stands, followed by site preparation and planting of loblolly pine, vegetation management, commercial thinning, and pruning. Intermixed within and among plantations were SMZs, retained during the previous clearcut harvest. Natural stands, which were at least approximately 77 ha in size, were similar to SMZs structurally, but were not bounded by plantations. Natural stands and SMZs were primarily older aged forest stands that had regenerated after forests throughout much of the Ouachita Mountains were logged in the early 20th century. Because Weyerhaeuser generally retained most SMZ hardwoods and removed merchantable pines that could be harvested within BMP guidelines, the natural stands and Weyerhaeuser SMZs were structurally similar and typical of those found within this region.

2.2. Site selection

Biennially during 1990–1995, we sampled different sets of SMZ/plantation settings and natural stands. Thus, we sampled Set 1 during 1990–1991, Set 2 during 1992–1993, and Set 3 during 1994–1995. Each set consisted of 1 natural stand and 15 SMZ/plantation settings selected to represent 5 different SMZ width classes (1–20, 21–40, 41–60, 61–100, and >100 m total width), within three different structural classes of adjacent plantations (young open canopy, closed canopy, and thinned), and three natural stands (one sampled with each set). However, within Set 1 (1990–1991), we were unable to locate a SMZ >100 m within a thinned plantation; this was subsequently treated as a missing observation. We used only SMZs that were completely contained within a plantation of the same structure. Mean (range in parentheses) total widths (including the stream channel) of the five SMZ width classes were 12 m (6–17 m) for 1–20 m SMZs, 30 m (21–39 m) for 21–40 m SMZs, 52 m (43–59 m) for 41–60 m SMZs, 75 m (61–96 m) for 61–100 m SMZs, and 161 m (123–246 m) for SMZs >100 m.

To define an area within each SMZ for subsequent small mammal trapping, we installed one 80 m wide × 200 m long sampling area with the long axis centered on the stream for SMZs <100 m wide. For the >100 m wide SMZ class and the natural stands, we installed a 160 m wide × 200 m long sampling area with the long axis centered on the stream. For a companion study, we quantified 49 habitat variables within these sampling areas (D.A. Miller, R.E. Thill, unpublished data). The only significant habitat difference among SMZ classes was higher hardwood basal area in SMZs >100 m wide (D.A. Miller, R.E. Thill, unpublished data).

Within the three plantation classes, we selected stands more for uniform structural appearance rather than age, as structure at any given age can vary widely depending on type or intensity of site preparation, initial pine seedling spacing, seedling survival, and site quality (Table 1). Young open canopy plantations averaged 6.7 years old (range 2–10 years old) and were characterized by an open canopy that allowed substantial herbaceous plant growth. Closed canopy plantations averaged 15.1 years old (range 9–21 years old) and were characterized by a completely closed canopy with very little to no groundstory structure. Thinned plantations averaged 17.7 years old (range 11–22 years old) and had been thinned up to 4 years (mean = 2.3 years) prior to sampling. Similar to young open canopy plantations, thinned plantations had an open canopy structure and a variable amount of understory and midstory development depending on when they were thinned (Table 1).

2.3. Small mammal capture

During February of each year, we captured small mammals for 10 consecutive days along traplines that paralleled the general stream course. We trapped during winter to prevent scavenging of bait and captured small mammals by red imported fire ants (*Solenopsis invicta*). Within all SMZs and natural stands, we placed one trapline on each side and within 5 m of the stream channel. Placement of additional traplines depended on SMZ width. This was done to

Table 1
Means and standard errors (S.E.) for habitat metrics within young open canopy pine plantations, closed canopy pine plantations, and thinned pine plantations, Ouachita Mountains, Arkansas, USA, 1990–1995

Habitat metric	Pine plantation type					
	Young open		Closed canopy		Thinned	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
Percentage canopy closure	54.9	7.03	90.8	1.89	74.0	2.89
Percentage herbaceous coverage	67.5	3.11	45.1	2.96	55.0	3.64
Percentage grass coverage	23.1	2.94	7.4	1.22	12.8	2.08
Percentage fern and forb coverage	16.3	2.46	14.4	3.49	16.0	3.07

Percentage canopy closure of overstory vegetation was collected using a spherical densiometer. Data for understory characteristics were collected in 1 and 2 m^2 plots using ocular estimates.

ensure the SMZ was adequately sampled from the stream channel out to each edge.

For SMZs 1–20 m wide, no additional traplines were used. Within SMZ classes 21–60 m wide, we placed two additional traplines in the SMZ (one on each side of the SMZ) within 5 m of the SMZ/plantation edge (four traplines total). Within SMZs >60 m wide and the natural stands, we placed four additional traplines; (two on each side of the SMZ); one in the SMZ within 5 m of the SMZ/plantation edge and one midway between the SMZ/plantation edge and the stream channel (six traplines total). Traplines were located at least 10 m apart.

Each trapline consisted of nine trap stations at 20 m intervals with three types of snap traps (Victor® mouse trap, Victor® rat trap, and Museum Special® trap) at each station. We placed traps close to logs, tree crevices/cavities, etc. when available near each trap location. We used a mixture of rolled oats, peanut butter, and vegetable oil (to thin bait consistency for easy application) for bait. We checked traps daily and replaced bait when necessary. We identified all captured Peromsycids to genus and all others to species. We followed the mammal handling protocol of the ad hoc Committee on Acceptable Field Methods in Mammalogy (1987).

2.4. Data analyses

We were interested in answering two questions regarding small mammal communities within the SMZ/plantation settings. First, we wanted to know how small mammal communities varied among different SMZ widths and plantation types. For this analysis, we used data from all traplines to index small mammal abundance, richness, diversity, and evenness (see below). However, we also were interested in how the small mammal community associated directly with the riparian zone varied with SMZ width and plantation type as this is the area SMZs are designed to protect for water quality, per BMPs. Therefore, for the second question, we estimated small mammal abundance, diversity, and richness for only the inner two traplines on each side and within 5 m of the stream channel. We did not include the natural areas in the following models because they did not have an associated plantation and were not replicated. We did, however, estimate small mammal abundance, richness, and diversity for natural stands to qualitatively compare small mammal communities in SMZ/plantation settings to a more natural riparian setting.

We used catch per unit effort (CPUE, calculated as number of captures per 100 trapnights) as an index to small mammal abundance. We subtracted 0.5 trapnights for each trap that was tripped but empty or that had captured an animal (Sutherland, 1996). We estimated species diversity using the Shannon–Weaver index (Ludwig and Reynolds, 1988). This index is zero if only one species is present in a sample and is maximized when all species in the sample are represented by the same number of individuals. Because number of species captured is related to sample size (Ludwig and Reynolds, 1988) and our sampling effort varied among SMZ width classes, we used a richness index. This index, similar to CPUE, was derived by calculating number of species captured per 1000 trapnights, subtracting 0.5 trapnights for tripped but empty traps. Using Pielou's J' (Ludwig and Reynolds, 1988), we estimated species evenness for analyses that included all traplines. We combined

Peromyscus spp. into a single group because external physical characteristics are not a positive means of identification and because species of this genus are known to hybridize (McCarley, 1954; Laerm and Boone, 1994; Rich et al., 1996; Barko and Feldhamer, 2002). This resulted in an underestimation of species richness and diversity and potentially an overestimation of evenness.

We used a mixed model analysis of variance (ANOVA) to examine the hypothesis that small mammal abundance (CPUE), diversity, and richness were not different among SMZ widths (five size classes) and plantation types (three structural classes). For species that constituted ≥15% of total captures, we used data from all traplines to also test the hypothesis that individual species CPUE did not differ among SMZ classes and plantation types. We considered SMZ width and plantation type as fixed effects and SMZ/plantation set (n = 3) as a random effect. We averaged small mammal capture, diversity, richness, and evenness data across years within each set (e.g., for Set 1, we averaged small mammal data across the 1990 and 1991 trapping sessions) and used the mean as the dependent variable (three replicates).

Because preliminary analyses indicated that variance for some response variables was not homogeneous, we developed ANOVA models for each response variable to allow variance partitioning by main effect (SMZ width and plantation type) or the main effect interaction term. Therefore, we developed four models for each response variable by allowing variance to: (1) vary among SMZ width classes; (2) vary among plantation type; (3) vary within the SMZ width by plantation type interaction term; and (4) not vary by main effect type (assumed variance homogeneity). For each response variable, we used the model that minimized Akaike's information criterion (AIC) score for data interpretation.

Because we had a fixed number of planned pairwise comparisons and maintained equal variances among treatments, we used least significant differences (LSD) for mean separation if variance structure could be assumed homogeneous among main effects (Day and Quinn, 1989). If variance homogeneity could not be assumed (i.e., AIC scores indicated a model with partitioned variance was best), we used least squares means for mean separation. Because we had a missing value (no SMZ > 100 m in a thinned plantation in Set 1), we used Type III sum of squares to derive F-statistics. We set $\alpha = 0.05$ for all statistical comparisons.

3. Results

3.1. Small mammals captured in all traplines

Using data from all traplines within the SMZ/plantation settings and the natural stands, we captured

Table 2
Small mammal captures and catch-per-unit-effort (parenthetical value; number of captures per 100 trapnights) of known species from traps located within streamside management zones of varying widths, irrespective of surrounding pine plantation, Ouachita Mountains, Arkansas, USA, 1990–1995

Species	Streamside management zone width classes (m)					
	1–20	21–40	41–60	61–100	>100	Natural
O. nuttalli	112 (0.62)	109 (0.62)	73 (0.41)	122 (0.44)	188 (0.78)	23 (0.26)
B. carolinensis	108 (0.59)	74 (0.42)	67 (0.37)	116 (0.42)	100 (0.42)	27 (0.30)
Peromyscus spp.	29 (0.16)	17 (0.01)	50 (0.28)	52 (0.19)	159 (0.66)	65 (0.72)
Reithrodontomys fulvescens	90 (0.49)	8 (0.05)	11 (0.06)	3 (0.01)	3 (0.01)	0
Microtis pinetorium	14 (0.08)	2 (0.01)	1 (0.005)	9 (0.03)	5 (0.02)	1 (0.01)
Neotoma floridana	5 (0.03)	3 (0.02)	7 (0.04)	1 (0.005)	6 (0.02)	2 (0.02)
Glaucomys volans	1 (0.005)	2 (0.01)	4 (0.02)	5 (0.02)	1 (0.005)	2 (0.02)
Sylvilagus floridanus	4 (0.02)	1 (0.005)	1 (0.005)	3 (0.01)	1 (0.005)	0
Cryptotis parva	6 (0.03)	0	1 (0.005)	0	0	0
Tamias striatus	0	1 (0.005)	0	0	0	1 (0.01)
Oryzomys palustris	0	0	0	0	2 (0.005)	0
Total	369 (2.03)	217 (1.23)	215 (1.19)	311 (1.13)	465 (1.93)	121 (1.35)

"Natural" indicates natural riparian forests not adjacent to pine plantations.

Table 3
Small mammal captures and catch-per-unit-effort (parenthetical value; number of captures per 100 trapnights) of known species from traps on the streamside management zone (SMZ)/plantation edge (edge), along the edge of the stream (center), and between the edge and center traps (middle) for SMZs >60 m wide, irrespective of surrounding pine plantation, Ouachita Mountains, Arkansas, USA, 1990–1995

Species	Trap position		
	Center	Middle	Edge
O. nuttalli	43 (0.15)	77 (0.39)	284 (0.98)
B. carolinensis	86 (0.29)	91 (0.46)	130 (0.45)
Peromyscus spp.	136 (0.47)	78 (0.40)	110 (0.38)
R. fulvescens	4 (0.01)	1 (0.005)	12 (0.04)
M. pinetorium	4 (0.01)	5 (0.03)	7 (0.02)
N. floridana	5 (0.01)	2 (0.01)	9 (0.03)
G. volans	3 (0.01)	1 (0.005)	8 (0.03)
S. floridanus	2 (0.006)	1 (0.005)	2 (0.006)
T. striatus	0	0	1 (0.003)
O. palustris	2 (0.006)	0	6 (0.02)
C. parva	1 (0.003)	0	0
Total	286 (0.98)	258 (1.29)	569 (1.96)

1701 small mammals of 11 species during 114,285 trapnights for an overall CPUE of 1.49 animals per 100 trapnights (Table 2). The *Peromyscus* group included the white-footed mouse (*P. leucopus*), cotton mouse (*P. gossypinus*), deer mouse (*P. maniculatus*), and Texas mouse (*P. attwateri*). Three species [golden mouse (37%), short-tailed shrew (30%), and peromyscids (18%)] comprised 85% of all captures.

No SMZ width class, including natural stands, contained all captured species and no species were captured exclusively in natural stands (Table 2). Eight of the 11 species captured were in all width classes, excluding natural stands. When examining traps by location (along the stream, on the SMZ/plantation edge, midway between the stream and SMZ/plantation edge) within SMZs >60 m wide (only SMZs > 60 m had six traplines), eight species occurred at all three trap locations (stream, middle, edge; Table 3). Seventy percent of golden mice were captured in edge traps, 8 of 12 flying squirrels were in edge traps, and 72% of short-tailed shrews were in middle or edge traps (Table 3).

For all species combined, the best model for CPUE partitioned variance within the SMZ width and plantation type interaction (Table 4, Fig. 1A). Based on this model, there was no significant interaction between plantation type and SMZ width (Table 4). However, CPUE differed significantly among plantation type and SMZ width classes. Catch-per-unit effort was significantly ($P = 0.04$) greater in SMZs within thinned plantations and young, open canopy plantations than in closed canopy plantations. However, CPUE did not differ ($P = 0.84$) between SMZs within young open canopy and thinned plantations. Catch-per-unit effort was significantly ($P \leq 0.05$) greater in 1–20 m SMZs than all other widths except >100 m SMZs. Additionally, >100 m SMZs had higher ($P \leq 0.03$) CPUE than 21–40 and 41–60 m SMZ widths.

Table 4
Analysis of variance table for response of small mammal communities to streamside management zones of five width classes (1–20, 21–40, 41–60, 61–100, and 101 m) imbedded within three structural classes (young, open canopy;, closed canopy;, thinned) of pine plantations, Ouachita Mountains, Arkansas, USA, 1990–1995

Response variable	Main effect	*F*-value	d.f.	*P*-value
CPUE	Plantation/SMZ interaction	1.06	8, 29	0.42
	SMZ width	3.50	4, 29	0.02
	Plantation type	3.37	2, 29	0.04
Species richness	Plantation/SMZ interaction	0.82	8, 27	0.59
	SMZ width	8.95	4, 27	<0.001
	Plantation type	6.58	2, 27	0.004
Species diversity	Plantation/SMZ interaction	1.19	8, 19	0.36
	SMZ width	2.76	4, 10	0.09
	Plantation type	2.39	2, 19	0.12
Species evenness	Plantation/SMZ interaction	3.24	8, 29	0.001

The four community measures were: catch-per-unit-effort (CPUE; number captured per 100 trapnights), species richness index, Shannon–Weaver index (species diversity), and species evenness (Pielou's *J*').

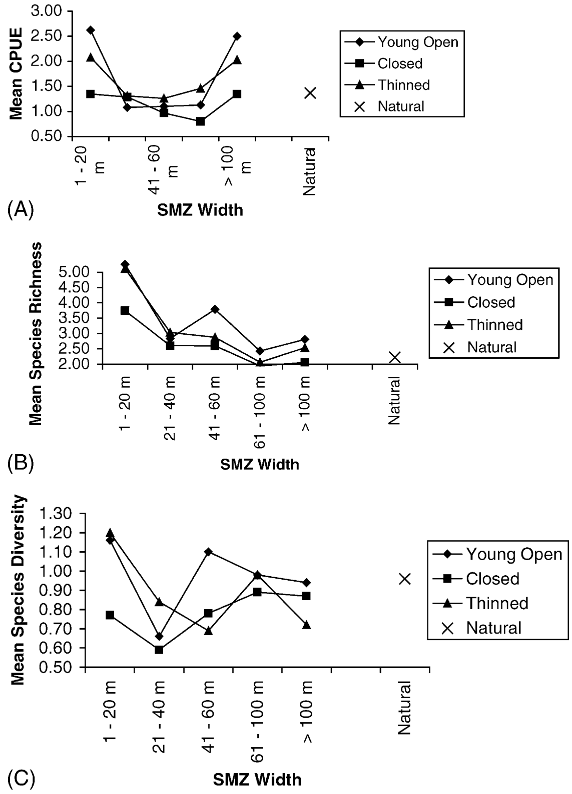

Fig. 1. Mean captures per unit effort [A; CPUE (number captured per 100 trapnights)], species richness index (B; species captured per 1000 trapnights), and mean Shannon species diversity index (C) for small mammals captured in natural stands and SMZs of different widths within young open canopy, closed canopy, and thinned loblolly pine plantations, Ouachita Mountains, AR, 1990–1995.

The best model for species richness index assumed variance homogeneity (Table 4, Fig. 1B). Based on this model, there was no significant interaction between plantation type and SMZ width (Table 4). However, small mammal richness did differ significantly among plantation types and SMZ width classes. Small mammal richness was significantly ($P < 0.05$) greater in SMZs within young, open canopy and thinned plantations than in closed canopy plantations. However, species richness was similar ($P > 0.05$) in SMZs within young, open and thinned plantations. Small mammal richness was significantly greater ($P < 0.05$) in 1–20 m SMZs than all other widths. Species richness in 41–60 m SMZs was greater ($P < 0.05$) than richness in 21–40, 61–100 and >100 m SMZs, but 21–40, 61–100, and >100 m SMZs did not differ ($P > 0.05$) from one another.

The best model for species diversity partitioned variance among SMZ width classes (Table 4, Fig. 1C). Based on this model, there was not a significant interaction between plantation type and SMZ width (Table 4). Small mammal diversity also did not significantly differ among plantation type or SMZ width classes.

The best model for species evenness partitioned variance within the SMZ width and plantation type interaction (Table 4). Based on this model, there was a significant interaction between plantation type and SMZ width (Table 4). This interaction necessitated examining each level of the two main effects (SMZ width and plantation type) within each level of the other effect. Within the >100 m SMZ width class, closed canopy plantations had lower ($P = 0.04$) evenness than thinned plantations; no other differences within width classes were detected. For SMZs within thinned plantations, the 1–20, 21–40, 41–60, and 61–100 m width classes all had greater ($P < 0.05$) evenness than >100 m SMZs; there were no differences among width classes for SMZs within young, open canopy plantations or closed canopy plantations. Overall, there were only five significant differences in evenness out of 45 pairwise comparisons.

We captured sufficient numbers of short-tailed shrews, golden mice, and peromyscids to examine individual CPUEs for those species. Catch per unit effort did not differ among SMZ width classes or plantation type for short-tailed shrews ($P \geq 0.23$), golden mice ($P \geq 0.26$), or peromyscids ($P \geq 0.24$)

3.2. *Small mammals captured in two innermost traplines*

Using data from the two traplines bordering the stream channel, we captured 470 small mammals in 47,038 trapnights for an overall CPUE of 0.99 animals per 100 trapnights. These captures included 10 species: peromsycids (n = 158), short-tailed shrew (n = 151), golden mouse (n = 101), fulvous harvest mouse (n = 26), pine vole (n = 13), eastern woodrat (n = 11), eastern cotton-tailed rabbit (n = 4), southern flying squirrel (n = 3), least shrew (n = 1), and marsh rice rat (n = 2). Similar to overall captures, 87% of all

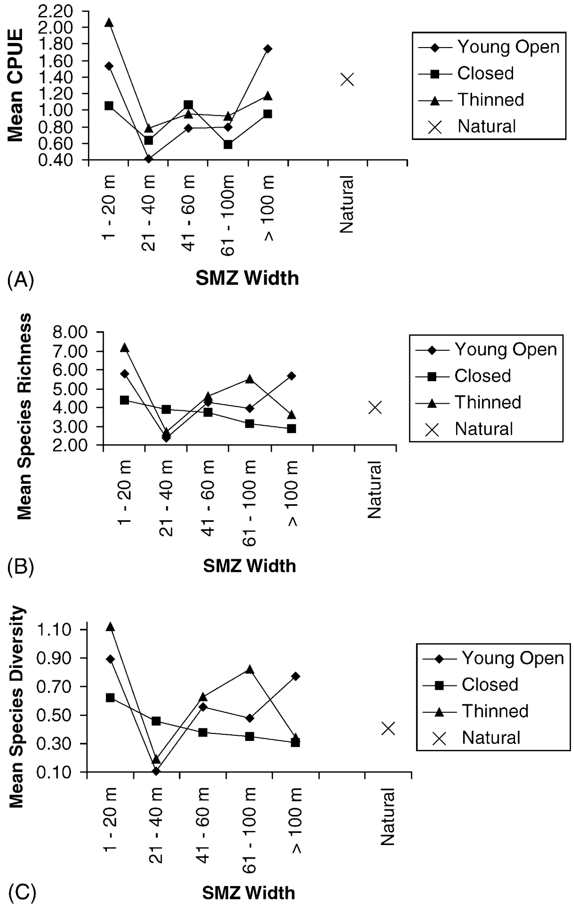

Fig. 2. Mean captures per unit effort [A; CPUE (number captured per 100 trapnights)], species richness index (B; species captured per 1000 trapnights), and mean Shannon species diversity index (C) for small mammals captured in 2 traplines adjacent to the stream channel in natural stands and SMZs of different widths within young open canopy, closed canopy, and thinned loblolly pine plantations, Ouachita Mountains, AR, 1990–1995.

inner trapline captures were composed of short-tailed shrews (32%), golden mice (21%), and peromyscids (34%).

For the inner two traplines, the best model for CPUE allowed partitioned variance by plantation type (Fig. 2A; Table 5). Based on this model, there was no significant interaction between plantation type and SMZ width (Table 5). Catch-per-unit-effort did not differ among plantation type but differed significantly among SMZ width classes. Catch-per-unit effort was significantly greater ($P = 0.002$) in 1–20 m SMZs than 21–40 and 61–100 m SMZs.

The best model for species richness for the inner two traplines partitioned variance by SMZ width classes (Table 5, Fig. 2B). Based on this model, there was no significant interaction between plantation type and SMZ width (Table 5). Additionally, small mammal richness did not differ among plantation types nor among SMZ width classes.

The best model for species diversity for the inner two traplines partitioned variance among SMZ width classes (Table 5, Fig. 2C). Based on this model, there was not a significant interaction between plantation type and SMZ width (Table 5). Small mammal diversity did not differ among plantation type but did differ among SMZ width classes. The only pairwise difference between SMZ widths was 1–20 m SMZs having higher ($P = 0.01$) diversity than 21–40 m SMZs.

4. Discussion

There are two potential biases in the current study. First, species richness is very sensitive to sampling effort with higher richness values expected as sampling effort increases (Ludwig and Reynolds, 1988). Although we adjusted species richness by trapping effort, this bias could still have affected our results. If this bias occurred, we would have expected to observe higher richness values in the overall analyses for SMZs >60 m wide as they had two more traplines than the narrower SMZs. However, we observed significantly higher richness in narrow SMZs for the overall trapping analyses, indicating that this bias was likely not a factor in the current study. Second, two species (short-tailed shrews and golden mice) and one species group (peromyscids) accounted for 88% of all captures. Therefore, our results were strongly influenced by these three highly abundant species and the ensuing discussion should be interpreted with this in mind.

We captured 11 species of small mammals within our SMZ/pine plantation settings. Similar to other studies (Langley and Shure, 1980; Morrison and Anthony, 1989; Perkins et al., 1988; Vickery et al., 1989; Daniel and Fleet, 1999; Kirkland and Findley, 1999; Darveau et al., 2001), small mammal communities in the current study were dominated by only two species (in this study, short-tailed shrews and golden

Table 5
Analysis of variance table for response of small mammal communities as sampled with two traplines (one on each side of and within 5 m of the stream channel) within streamside management zones of five width classes (1–20, 21–40, 41–60, 61–100 and 101 m) imbedded within three structure classes (young, open canopy, closed canopy, thinned) of pine plantations, Ouachita Mountains, Arkansas, USA, 1990–1995

Response variable	Main effect	*F*-value	d.f.	*P*-value
CPUE	Plantation/SMZ interaction	1.26	8, 23	0.31
	SMZ width	6.15	4, 23	0.002
	Plantation type	1.73	2, 6	0.26
Species richness	Plantation/SMZ interaction	2.21	8, 19	0.07
	SMZ width	3.39	4, 10	0.05
	Plantation type	3.16	2, 19	0.07
Species diversity	Plantation/SMZ interaction	2.06	8, 19	0.09
	SMZ width	5.26	4, 10	0.02
	Plantation type	2.27	2, 19	0.13

The three community measures were: catch-per-unit-effort (CPUE; number captured per 100 trapnights), species richness index (species captured per 1000 trapnights), and Shannon–Weaver index (species diversity).

mice) that accounted for 67% of all captures. We captured considerably more species than some previous studies in the southeastern United States [Hatchell, 1964 (7 species), Langley and Shure, 1980 (3 species), Dickson and Williamson, 1988 (8 species), Perkins et al., 1988 (4 species)], but a comparable number to some other Southeastern studies [Atkenson and Johnson, 1979 (12 species), Thurmond and Miller, 1994 (12 species), Mitchell et al., 1995 (12 species), Daniel and Fleet, 1999 (10 species), Mengak et al., 1989 (9 species)]. Those studies that captured fewer species were primarily located in single habitat types while those that captured more species typically sampled multiple habitat types. Thurmond and Miller (1994) in Georgia, USA, who captured a similar number of species as the current study, sampled both SMZs and adjacent plantations. Yahner (1992) suggested increased habitat diversity may result in increased variety of microhabitats and food resources for small mammals. We believe the higher number of species captured in this study was directly related to the influence of surrounding plantation structure on small mammal communities within the SMZs we studied (see below).

Previously, Tappe et al. (1994, 2004) used the first 2 years of data from the current study to examine effects of SMZ width within different structural classes of plantations on small mammal and bird communities. For small mammals, they determined that SMZ width had little effect on small mammal abundance, richness, or diversity, relative to influence of the surrounding pine matrix. Generally, abundance, richness, and diversity of small mammals was greatest for SMZs embedded within young, open canopy pine stands and thinned pine stands (Tappe et al., 1994, 2004). Abundance was least within SMZs surrounded by closed canopy pine plantations. Our results support these preliminary findings (see below).

In east Texas, USA, Dickson and Williamson (1988) examined small mammal communities in SMZs less than 25, 30–40, and >50 m wide and found that small mammals were more abundant in narrow than wide SMZs. They concluded that this was due to presence of dense, brushy vegetation, abundant seeds, and logging slash in the narrow SMZs, as compared to the sparse understory due to shading from hardwoods in the wide SMZs. In Georgia, USA, winter small mammal trapping resulted in similar species richness, diversity, and abundance among different SMZ widths (15, 30, and 50 m) and natural riparian forests (Thurmond and Miller, 1994). However, during summer, small mammal abundance, richness and diversity were greater in natural riparian forests than all SMZ widths, leading Thurmond and Miller (1994) to suggest SMZs cannot support small mammal communities similar to those in intact riparian forests. In Quebec, Canada, Darveau et al. (2001) concluded that some small mammal species prefer wide SMZs and some narrow SMZs. In their study, densities of the two most common species did not differ among SMZ widths (40, 80, 120 m, and a control).

In this study, the widest SMZ class (>100 m) had CPUE values similar to the narrow (<1–20 m) SMZs. This was primarily due to a marked increase in CPUE of peromyscids in the widest SMZs versus narrower SMZs (Table 2). The reason for this increase is not clear, nor was it significant when examining individual species (see below). In spite of this, our overall results suggest that narrow (≤20 m) SMZs within managed pine forests of the Ouachita Mountains tend to have greater small mammal abundance and richness than wider SMZs. Additionally, CPUE and species richness values within natural stands were qualitatively lower than in narrow SMZs (1–20 m) and more comparable to wider (>100 m) SMZs (Fig. 1). Our results agree with those of Dickson and Williamson (1988), especially given that their wide SMZs were comparable to the medium width (40–100 m widths) SMZs in our study, which consistently had the lowest values of CPUE and richness. However, unlike Dickson and Williamson (1988), our observed differences were not primarily due to differences in habitat among SMZ widths because, with the exception of hardwood BA, habitat structure among SMZ width classes was very similar in our study (D.A. Miller, R.E. Thill, unpublished data). However, because hardwood BA increased significantly as SMZ width increased, some of the shading effect described by Dickson and Williamson (1988) may have occurred. We believe that our results were primarily driven by habitat differences among the surrounding pine plantations, which appeared to exert more influence on small mammals within narrow SMZs.

Our study also is consistent with previous studies (Atkenson and Johnson, 1979; Langley and Shure, 1980; Perkins et al., 1988; Mengak et al., 1989; Parker, 1989; Christian et al., 1996), in that SMZs within young open canopy plantations and thinned plantations had higher CPUE and richness than SMZs within closed canopy plantations. A dense herbaceous layer with a high degree of within-stand habitat diversity characterized young, open canopy plantations and thinned plantations. These conditions have been shown to be conducive to small mammal communities (Atkenson and Johnson, 1979; Miller and Getz, 1977; Clough, 1987; Perkins et al., 1988; Kirkland, 1990).

Several studies have suggested that habitat diversity is the key to maintaining stable small mammal communities (DeGraaf et al., 1991; Bramble et al., 1992; Yahner, 1992; Michael, 1995). In our study, small mammals within narrow SMZs would readily have access to either the plantation or the SMZ, and, perhaps more importantly, the edge between the two habitat types. Previous studies have found greater small mammal diversity and richness (Clough, 1987; DeGraaf et al., 1991; Yahner, 1992; Menzel et al., 1999) and higher abundance of small mammals (Anthony et al., 1987; Yahner, 1992; Tappe et al., 1994, 2004) associated with edges. Others have found unique communities in upland sites as compared to riparian zones (Doyle, 1990; McComb et al., 1993; Daniel and Fleet, 1999). Therefore, the higher CPUE and richness in narrow SMZs would be expected especially given the higher edge to area ratio of narrow SMZs.

Additional evidence that plantation structure was primarily responsible for the observed trends in small mammal abundance and richness can be seen by comparing community measures in natural stands and those from the analyses that used only the inner two traplines. Natural stands, which had no adjacent plantations, qualitatively had lower CPUE and richness as compared to SMZs within thinned plantations and open canopy plantations (Fig. 1). Additionally, there was no effect of plantation type on CPUE, richness, or diversity for small mammals captured in the inner two traplines. Effects of SMZ width were minimal, with only two significant differences detected. This indicates that the inner traplines were least influenced by plantation type, perhaps because they were located furthest from the edge.

We did not detect a difference in overall species diversity among plantation types nor SMZ width classes, and species diversity was very similar between SMZs and natural stands. Given differences observed in CPUE and richness among SMZ size width classes and plantation types, this result was somewhat unexpected. However, species diversity is calculated using richness and community evenness (Ludwig and Reynolds, 1988) and, overall, we found almost no differences in species evenness. Perhaps equability of species evenness mitigated effects of differences in richness resulting in similar diversity indices.

We also did not observe significant differences in CPUE for individual species. However, this was likely a result of low statistical power. For example, CPUE for peromyscids varied from 0.0 to 1.1 and CPUE for golden mice varied from 0.09 to 0.98, but significant differences were not detected. Golden mice were primarily captured in edge traps, with CPUE within edge traps at least three times higher than middle and center traps (Table 3). Given the apparent preference of this species for brushy understory (Sealander and Heidt, 1990), this was not unexpected. Other small mammals species had relatively equitable captures among edge, middle, and center traps.

4.1. Management implications

Streamside management zones within closed canopy plantations had significantly fewer small mammal species, lower CPUE, and consistently had the lowest values for metrics we examined. Shortening the time that pine plantations spend in a closed canopy condition, through wider among-row spacing of planted pine and early thinning, may help maintain small mammal populations across managed forest landscapes temporally. Wider row spacing of planting pine also would likely facilitate herbaceous growth in young, open plantations and maintain such a plant community longer (i.e., before canopy closer occurs). This may allow a longer window of favorable habitat conditions for small mammals and other fauna within managed pine stands, which is especially important given that planted pines accelerate succession (Atkenson and Johnson, 1979; Perkins et al., 1988).

We documented similar small mammal communities among SMZ width classes and, qualitatively, with natural stands. We did not witness a gradient of early successional species in narrow SMZs to a community of mature forest species in wider SMZs and the natural stands. This indicates that SMZs in our study were supporting a small mammal community similar to that within the natural stands. However, our data are insufficient to definitively state that SMZs can maintain assemblages of small mammals expected in undisturbed, older riparian forests. Future research needs to specifically address the ability, or lack thereof, of SMZs to support small mammal communities present in undisturbed, large blocks of similar forest types.

As of 2000, forestry best management practices (BMPs) for 10 of 12 states in the southern United States recommended minimal SMZ total widths of 14–30 m for perennial streams and 11 of 12 southern states recommended similar total widths for intermittent streams (Blinn and Kilgore, 2001). Our study indicates that narrow (<20 m) SMZs maintain more abundant and richer small mammal communities than wider SMZs within managed pine landscapes. Therefore, SMZs meeting minimal BMP requirements appear compatible with conservation of small mammal communities within SMZs. However, because the relationship between SMZ width and small mammal communities likely varies geographically and temporally (Gomez and Anthony, 1998), care should be taken in extrapolating our results to other areas. Additionally, wider SMZs and natural riparian stands may provide habitat for small mammal and other species (e.g., herpetiles, avifauna) that would not exist in narrow SMZs (Thurmond and Miller, 1994). Thus, we recommend maintaining a variety of SMZ widths within pine plantations to increase overall habitat and species diversity within these landscapes.

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