Small Mammal Response to Coarse Woody Debris in the Central Appalachians

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Abstract: Coarse woody debris (CWD) is an important habitat component of many faunal species, and little research has been conducted on the relationship between CWD and small mammals in central Appalachian hardwood forests. Response of small mammal populations to manipulation of CWD volume was tested in central Appalachian forests in north central West Virginia from 2000–2001. Abundance and diversity of small mammals captured (N=1,564) on 12 experimental 60 × 60 m live-trapping grids were compared. Grids were randomly distributed between addition sites (volume of CWD increased by 50%), removal sites (volume of CWD reduced by 50%), and control sites. We classified grids as edge ($<$100 m from a forest edge) or interior ($\geq$100 m from a forest edge). We captured 15 species in 13,009 trap nights. The most abundant species captured were white-footed mice *(Peromyscus leucopus)* and deer mice (*P. maniculatus;* analyzed together as *Peromyscus* spp.; 74%), northern short-tailed shrews (*Blarina brevicauda;* 12%), and southern red-backed voles (*Clethrionomys gapperi*; 5%). Diversity estimates were similar among CWD manipulation classes except for average species richness, which was greater in removal sites ($\bar{x}$=3.08, SE=0.20) than control sites ($\bar{x}$=2.38, SE=0.15) after CWD manipulations (P=0.032). Abundance of small mammals was similar across manipulation classes with the exception of southern red-backed voles, which were most abundant in interior removal sites. These results suggest that manipulation of CWD volume has little short-term effect on abundance, diversity, or condition of small mammals in the central Appalachians.

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Many studies have described coarse woody debris (CWD) as an important component of vertebrate michrohabitats (Harmon et al. 1986, Carey and Johnson 1995, Loeb 1999, Butts and McComb 2000). For instance, in the Blue Mountains of Oregon and Washington, Thomas (1979) described 179 vertebrate species, including numerous small mammal species, that in some way used CWD. White-footed mice, deer mice (Barnum et al. 1992, Planz and Kirkland 1992, McMillan and Kaufman 1995), and several vole species commonly use CWD (Hayes and Cross 1987, Nordyke and Buskirk 1991, Tallmon and Mills 1994, Bowman et al. 2000). However, few studies have been conducted on this topic in eastern deciduous forests (Loeb 1999, Bowman et al. 2000).

The study site for our research, as well as many forested areas in the central Appalachians, is heavily affected by logging practices and military activity that cause alterations in CWD volume (McCarthy and Bailey 1994, W. Va. Army Reserve Natl. Guard 2001). It is important to know the relationship between small mammals and CWD because manipulation of CWD volume associated with human activity could negatively affect small mammal communities. The effects of habitat manipulations are of interest to wildlife managers concerned with maintaining overall biological diversity in central Appalachian forests. Our objectives were to compare small mammal abundance, diversity, and condition in plots where CWD volumes were decreased, plots with increased CWD volumes, and control sites.

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Methods

Study Area

This study was conducted on the Camp Dawson Collective Training Area (CDCTA) in north-central (Preston County), West Virginia. Three tracts of land, the Cantonment Area (378 ha), the Briery Mountain Training Area (TA; 423 ha), and the Pringle TA (854 ha), comprised the 1,665 ha CDCTA which is centered at 3926N 7940W in the Cheat River watershed (W. Va. Army Reserve Natl. Guard [WVARNG] 2001, Osbourne 2002). The CDCTA was used for military activity, logging, and public recreation (WVARNG 2001). Primary cover types on the CDCTA were mixed mesophytic forest, mixed montane hardwood forest, and successional forest of low elevation plains (Vanderhorst 2001). The most common tree species on the study area included yellow poplar *(Liriodendron tulipifera),* sugar maple *(Acer saccharum),* oak species (*Quercus* spp.), hickory species (*Carya* spp.), black locust *(Robinia pseudoacacia),* and black cherry (*Prunus serotina;* Vanderhorst 2001). Primary soils were loams, silt loams, and rubbly complexes (Bell 2001).

Habitat Sampling and CWD Manipulations

We sampled habitat characteristics in 2000 and 2001. Initially, each site was classified as riparian (N=6) or upland (N=6) with riparian sites located $<$100 m from any type of water source, and upland sites $\geq$100 m from water on all sides (Laerm et al. 1997). Grids were further categorized by distance to forest edge. Edge sites (N=8) had all sides $<$100 m from a forest edge, and interior sties (N=4) had all sides $\geq$100 m from the forest edge. Thus, each grid fell into 1 of 4 habitat categories: riparian edge (RE; *N*=5) riparian interior (RI; *N*=1), upland edge (UE; *N*=3), or upland interior (UI; *N*=3). Lack of riparian interior habitat on the study site prevented us from selecting more grids in this habitat type. At each grid, we measured basal area with a 10-factor prism at the center of the trapping grid (Avery and Burkhart 1983, Laerm et al. 1997). We conducted vegetative sampling ($1 \times 1\text{-m}^2$ quadrat) at all 49 trapping stations on each grid (Osbourne 2002). Length and diameter of all CWD (downed logs >10 cm in mean diameter) in the quadrat was measured using a caliper (Harmon et al. 1986, Loeb 1999, Butts and McComb 2000). We calculated volume of CWD for the grid including a 10-m buffer zone on all sides by calculating the volume in each subplot, adding those values, and extrapolating to the full size of the grid. Rock volume, herbaceous vegetation height and percentage cover were recorded for each quadrat (Laerm et al. 1997). At the southwest corner of each quadrat, we used a spherical densiometer to measure canopy closure. We recorded depth of leaf litter for each corner of the quadrat and averaged for each subplot.

After completion of vegetative sampling, grids were randomly distributed into CWD manipulation categories: addition (50% of volume added), removal (50% of volume removed), and control (disturbed but not manipulated; Loeb 1999, Osbourne 2002). Grids were as evenly distributed as possible by habitat type into manipulation category (addition: RE=2, UE=1, UI=1; removal: RE=2, UE=1, UI=1; control: RE=1, RI=1, UE=1, UI=1). On addition sites, we chose logs ≥10 cm in mean diameter and varying in degree of decay and species from the landscape surrounding the grid and distributed the logs throughout the grid and buffer zone. When necessary, larger CWD was cut with a chainsaw and pieced back together after being transported to the trapping grid. Logs removed from edge sites were transported away from the site; however, removal of CWD on interior sites was not feasible. Thus, CWD removed from interior sites was moved at least 25 m outside the 10 m buffer zone around the grid and dispersed to eliminate piles of logs.

Mammal Trapping

We sampled small mammal live trapping grids on 25 sites. Each experimental site was a 60-x 60-m grid with 49 trapping stations equally spaced 10 m apart (Laerm et al. 1997, Loeb 1999). At each station, we placed 1 collapsible 7.7- × 7.7- × 23-cm Sherman aluminum box trap and installed a 0.946-liter plastic pitfall cup buried flush with the ground (Laerm et al. 1997, Menzel et al. 1999). We baited each Sherman trap with a mixture of peanut butter and rolled oats (Sullivan and Sullivan 1980, Carey and Johnson 1995). Species, mass, gender, and reproductive condition were recorded for each animal caught (Laerm et al. 1997, Menzel et al. 1999). The 2 *Peromyscus* species that occur in this region, white-footed mouse and deer mouse, were combined and analyzed as *Peromyscus* spp. To eliminate possible error associated with morphological identification of these species and to provide better estimates of abundance of the genus as a whole (Merrit 1987). We ear-tagged live mice, eastern chipmunks *(Tamias striatus),* and squirrels, and we toe-clipped live shrews (Laerm et al. 1997, Menzel et al. 1999). Dead specimens were collected for later identification and preservation in the West Virginia University Vertebrate Collection.

The initial trapping session ran from June to September 2000. Of the 25 established grids, 12 were selected on the Pringle TA (5) and Cantonment Area (7) for use in the CWD manipulation study. The other grids were eliminated because of unreliable data caused by carnivore disturbance of trapping grids (Osbourne 2002). After vegetation was sampled on the 12 grids (in summer 2000), CWD manipulations were conducted from September to October 2000. We trapped each of the sites within 24 hours of the completion of manipulations at that grid in a second trapping session from September to November 2000. Finally, we conducted a third period of live trapping from October to November 2000. In 2001, we trapped the 12 grids approximately once/month in 4 more trapping sessions from 14 July to 4 December 2001.

Data Analyses

We determined abundance of small mammals using program CAPTURE (null model) and captures per 100 trap nights (CPUE; White et al. 1982, Rexstad and Burnham 1991). Only *Peromyscus* spp. provided enough captures to be analyzed. Relative abundance of each species was calculated using CPUE with corrections made for sprung traps and recaptures (Nelson and Clark 1973, Carey and Johnson 1995, Laerm et al. 1997). Relative abundance of all species combined and individual species representing 2% or more of total captures were analyzed. We calculated species richness (S), Pielou's index of evenness (J), Simpson's diversity index (D), and the Shannon diversity index (H) for all small mammals captured in each trapping session (Krohne 1998). We used both Shannon and Simpson's diversity indices because the Shannon index gives heavier weight to rare species and Simpson's index weights common species more heavily (Krohne 1998).

We calculated ratio of males to females (R_1), proportion of reproductive females at each grid (R_2), and mean mass (g) per individual for each species as demographic measures of habitat quality (Carey and Johnson 1995, Loeb 1999). However, only *Peromyscus* spp. And northern short-tailed shrews were analyzed in our statistical models because of low capture rates of other species. Each value listed above was a dependent variable in the models described below.

Trapping grid was the experimental unit for all dependent variables except mass. The individual small mammal was the experimental unit for average mass calculations. We performed a Multivariate Analysis of Variance (MANOVA) on vegetative measurements and riparian/upland and edge/interior grid locations to test if microhabitat characteristics differed among riparian and upland sites or edge and interior sites. Because all variables were not similar between edge and interior habitats ($P<0.05$), we included location (edge/interior) and CWD effects but excluded habitat (riparian/upland; $P<0.05$) effects from our statistical models involving small mammals. We used a split-plot model to compare estimates among addition, removal, and control grids and between edge and interior sites. The interaction term of CWD and edge was included in the first branch of the model. In the second branch of the model, CWD, edge, and associated interactions were analyzed by trapping session to detect temporal patterns in abundance and diversity associated with CWD manipulations. We analyzed data from the pre-manipulation trapping session to test if differences occurred among CWD manipulation categories before volume manipulations. We used Tukey's Studentized range test to identify differences among treatments when significant *F*-values were obtained. When an interaction term of interest produced a significant *F*-value (α=0.05), the least squares means procedure in SAS (SAS Inst. 1988)—which performs a *t*-test similar to Fisher's least significant difference test—was used to assess differences between interaction term categories. We tested assumptions of normality using the univariate procedure in SAS, and we used Bartlett's test for homogeneity of variance assumptions. We used square root and quarter-root transformations to convert dependent variables that did not meet assumptions (Zar 1999).

Results

Habitat Sampling and CWD Manipulations

Habitat variables were similar between riparian and upland sites (Wilks' λ=0.66, *P*=0.828; Table 1). Basal area was greater in interior than edge habitats (*F*=13.27, df=1,10, *P*=0.005), but no difference was observed in other characteristics between edge and interior sites (Wilks' λ=0.21, *P*=0.11). There was no interaction between location (edge/interior) and habitat (riparian/upland; Wilks' λ=0.39, *P*=0.39). The most common tree species in basal area measurements were yellow poplar (32%), sugar maple (12%), black locust (12%), and black cherry (10%). Mean rock volume varied by grid, ranging from 0 cm^3/ha to 46,490 cm^3/ha, but was similar across CWD manipulation classes (Table 1).

Volumes of CWD before manipulations ranged from 11.72 m^3/ha to 145 m^3/ha, while volumes after manipulations ranged from 8.86 $m/^3$/ha to 217.72 m^3/ha. Average volume of CWD was similar among addition ($\bar{x}$=32.36, SE=11.34), removal

Table 1. Average vegetative characteristics for addition (*N*=4), removal (*N*=4), and control (*N*=4) coarse woody debris (CWD) manipulation grids on the Camp Dawson Collective Training Area in Preston County, West Virginia, during 2000 and 2001. Vegetative characteristics for edge (*N*=8) versus interior (*N*=4) and riparian (*N*=6) versus upland (*N*=6) categories are included. Coarse woody debris volumes are reported as volume in m^3/ha after manipulation of CWD volume.

Treatment Type	CWD volume (m^3/ha)		Basal area (m^2/ha)		Rock volume (cm^3)		Litter depth (cm)		% Canopy cover		% Herbaceous cover		Height herb. cover (m)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Addition	64.71	22.67	21.04	1.91	4919	1984	0.75	0.05	99.19	0.1	58.03	1.79	0.29	0.01
Removal	8.40	1.23	11.86	2.4	3674	1951	1.11	0.05	96.96	0.55	58.13	1.9	0.29	0.01
Control	23.97	8.97	17.6	2.19	3775	1471	0.73	0.04	98.71	0.2	59.25	1.71	0.27	0.01
Edge	30.41	11.83	14.00	1.92	3217	1180	0.89	0.04	97.66	0.35	61.87	1.47	0.32	0.01
Interior	34.80	16.55	20.37	1.76	4560	1576	0.83	0.04	99.07	0.11	54.21	1.43	0.24	0.01
Riparian	31.33	12.77	15.81	2.37	3276	1091	0.66	0.03	97.61	0.39	57.96	1.60	0.30	0.01
Upland	33.39	15.03	17.85	1.90	4450	1553	1.06	0.04	98.96	0.09	58.98	1.33	0.27	0.01

($\bar{x}$=16.79, SE=2.47), and control ($\bar{x}$=23.97, SE=8.97) sites before manipulations (*F*=1.92, df=2,6, *P*=0.227). After manipulation of CWD, average volume was greater on addition sites than control sites, and CWD volume on control sites was greater than on removal sites (*F*=7.12, df=2,6, *P*=0.026).

Small Mammal Populations

We set Sherman traps for 1,176 potential trap nights before CWD manipulations and captured 104 individuals of 8 species. After manipulation, 7,056 potential trap nights produced 1,460 individuals of 15 different species. Overall, we captured 1,564 individuals of 15 species in 8,232 potential trap nights on the CDCTA. The most common species captured were *Peromyscus* spp. (*N*=1,163), which represented 74% of all captures. Other species representing 2% or more of total captures were northern short-tailed shrew (*N*=187; 12%), southern red-backed vole (*N*=81; 5%), eastern chipmunk (*N*=54; 3%), and southern flying squirrel (*Glaucomys volans; N*=25; 2%).

Abundance of *Peromyscus* spp. was similar among CWD manipulation categories before manipulation of CWD (*F*=0.04, df=2, 5, *P*=0.959. Similar results were obtained after manipulations for abundance of *Peromyscus* spp. among CWD manipulation classes (*F*=0.06, df=2,29, *P*=0.94) and between edge and interior sites (*F*=0.68, *df*=1,29, *P*=0.440).

Relative abundance of all small mammals combined (CPUE) was similar among manipulation categories before manipulation of CWD (*F*=0.20, df=2,6, *P*=0.824; Table 2). Relative abundance of *Peromyscus* spp., northern short-tailed shrews, and southern red-backed voles was similar among manipulation classes before CWD manipulations. Eastern chipmunks and southern flying squirrels were not captured in the first trapping session. Diversity measures were similar between CWD classes and habitat locations before manipulations (Table 2).

After manipulation of CWD, total relative abundance was similar between manipulation categories (*F*=0.22, df=2,30, *P*=0.812) and locations (*F*=1.02, df=1,30, *P*=0.351; Table 3. Relative abundance (CPUE) of all species analyzed was similar between CWD manipulation classes and trap locations after manipulations except the southern red-backed vole, which displayed a significant interaction between edge and CWD (*F*=12.76, df=2,30, *P*=0.007). Southern red-backed vole abundance was greater in interior removal sites than all other location/manipulation categories. Diversity estimates were similar between CWD manipulation classes and grid locations after CWD manipulations, with the exception of species richness (Table 3). Average species richness was greater in removal sites than control sites, but similar between removal and addition sites.

Only *Peromyscus* spp. Provided enough captures in the initial round of trapping to compare average mass, R_1, and R_2 before manipulations. Average mass ($\bar{x}$=20.56, SE=0.54 [averaged across treatments]; *F*=1.24, df=2,64, *P*=0.299), R_1 ($\bar{x}$=2.00, SE=0.46) (*F*=0.88, df=2,5, *P*=0.633), and R_2 ($\bar{x}$=0.23, SE=0.05) (*F*=2.20, df=2,5, *P*=0.206) were similar among treatments before manipulations. After manipulations, average mass of *Peromyscus* spp. was similar among CWD manipulation classes ($\bar{x}$=19.49, SE=0.16; *F*=0.00, df=2,573, *P*=0.996) and trapping locations (*F*=0.25,

Table 2. Captures per 100 trap nights (CPU) for the most abundant species and diversity estimates for small mammals captured in addition (N=4), removal (N=4), and control (N=4) coarse woody debris (CWD) manipulation classes and edge (N=8) and interior (N=4) trapping sites before CWD manipulations on the Camp Dawson Collective Training Area in Preston County, West Virginia, during 2000.

Species or index	Addition		Removal		Control				Edge		Interior			
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$F_{2,6}$	P	$\bar{x}$	SE	$\bar{x}$	SE	$F_{1,6}$	P
Peromyscus spp.	8.18	3.55	7.56	1.62	8.12	3.41	0.05	0.951	7.04	2.00	9.78	2.57	0.33	0.586
Northern short-tailed shrew	0.56	0.32	0.28	0.28	0.56	0.56	0.17	0.845	0.69	0.29	0.00	0.00	1.97	0.211
Southern red-backed vole	0.00	0.00	0.31	0.31	0.27	0.27	2.96	0.128	0.14	0.14	0.31	0.31	1.35	0.289
Total CPU	9.60	3.59	11.24	1.26	9.51	2.95	0.20	0.824	9.85	1.97	10.66	2.33	0.01	0.907
Species richness (S)	2.25	0.25	2.00	0.00	1.75	0.48	0.29	0.757	2.13	0.23	1.75	0.25	0.36	0.571
Pielou's index (J)	0.65	0.12	0.65	0.07	0.29	0.17	1.65	0.268	0.57	0.10	0.44	0.15	0.06	0.820
Simpson's index (D)	1.50	0.14	1.40	0.08	1.22	0.14	0.79	0.497	1.43	0.09	1.25	0.10	0.52	0.496
Shannon index (H)	0.51	0.10	0.45	0.05	0.27	0.17	0.73	0.521	0.46	0.09	0.31	0.11	0.35	0.578

df=1,573, P=0.633). Average mass of northern short-tailed shrews also was similar among CWD manipulation classes ($\bar{x}$=16.15, SE=0.27; F=0.30, df=2,77, P=0.749) and trapping locations (F=0.04, df=1,77, P=0.851) after manipulation of CWD. *Peromyscus* spp. and northern short-tailed shrews produced similar R_1 values among CWD manipulation classes (*Peromyscus* spp.: ($\bar{x}$=1.28, SE=0.11; F=0.53, df=2,71, P=0.614; northern short-tailed shrew: ($\bar{x}$=0.46, SE=0.15; F=0.76, df=2,13, P=0.508) and trapping locations (*Peromyscus* spp.: F=1.32, df=1,71, P=0.294; northern short-tailed shrew: F=2.18, df=1,13, P=0.190). Similarly, *Peromyscus* spp. and northern short-tailed shrews produced similar R_2 values among CWD manipulation classes (*Peromyscus* spp.: ($\bar{x}$=0.17, SE=0.02; F=0.86, df=2,71, P=0.471; northern short-tailed shrew: $\bar{x}$=0.07, SE=0.04; F=0.96, df=2,13, P=0.435) and trapping locations (*Peromyscus* spp.: F=0.95, df=1,71, P=0.367; northern short-tailed shrew: F=0.03, df=1,13, P=0.859).

Table 3. Captures per 100 trap nights (CPU) and diversity estimates for small mammals captured in addition (*N*=4), removal (*N*=4), and control (*N*=4) coarse woody debris (CWD) manipulation classes and edge (*N*=8) and interior (*N*=4) trapping sites after CWD manipulations on the Camp Dawson Collective Training Area in Preston County, West Virginia, during 2000 and 2001.

Species or index[a]	Addition $\bar{x}$	Addition SE	Removal $\bar{x}$	Removal SE	Control $\bar{x}$	Control SE	$F_{2,30}$	P	Edge $\bar{x}$	Edge SE	Interior $\bar{x}$	Interior SE	$F_{1,30}$	P
Peromyscus spp.	17.99a	1.92	17.20a	2.74	21.01a	3.75	0.05	0.952	16.46a	1.67	23.27a	3.58	0.9	0.378
Northern short-tailed shrew	2.06a	0.30	2.21a	0.37	2.33a	0.51	0.16	0.858	2.28a	0.29	2.03a	0.37	0.23	0.650
Southern red-backed vole	0.22a	0.13	0.67a	0.25	0.20a	0.15	*	*	0.20a	0.10	0.69a	0.24	*	*
Eastern chipmunk	0.71a	0.19	0.84a	0.19	0.46a	0.17	0.98	0.428	0.75a	0.13	0.54a	0.18	0.13	0.735
Southern flying squirrel	0.33a	0.11	0.37a	0.16	0.09a	0.07	2.09	0.204	0.24a	0.08	0.32a	0.14	0.86	0.389
Total CPU	21.52a	2.06	21.61a	3.13	24.44a	3.79	0.22	0.812	20.27a	1.75	27.05a	3.84	1.02	0.351
Species richness (S)	2.79ab	0.17	3.08b	0.20	2.38a	0.15	6.49	0.032	2.75a	0.12	2.75a	0.19	0.80	0.407
Pielou's index (J)	0.53a	0.04	0.58a	0.04	0.58a	0.06	0.43	0.670	0.58a	0.03	0.51a	0.4	1.21	0.313
Simpson's index (D)	1.50a	0.09	1.62a	0.08	1.52a	0.10	0.09	0.914	1.61a	0.07	1.42a	0.07	0.95	0.368
Shannon index (H)	0.55a	0.06	0.64a	0.06	0.49a	0.07	0.45	0.655	0.59a	0.04	0.49a	0.06	0.35	0.575

a. Values with different letters represent statistical difference (α=0.05).

Discussion

This study suggests CWD manipulation has little short-term effect on small mammal abundance, diversity, or condition. Average volume of CWD was similar between addition, removal, and control sites before manipulations and predictably different among CWD classes after manipulations. Vegetative characteristics were similar between habitats and grid locations indicating that forest stand characteristics were similar across manipulation classes.

Abundance of small mammals was not related to CWD manipulation type with the exception of southern red-backed voles, which were most abundant in interior removal sites. The species representing most captures (*Peromyscus* spp. and northern short-tailed shrews) are habitat generalists occurring at high densities in a variety of habitats throughout the central Appalachian Mountains (Lackey et al. 1985, George et al. 1986, Merritt 1987). *Peromyscus* spp. generally exhibit less fluctuation in population density among habitats than most other small mammal species (Lackey et al. 1985). The ability of these species to adapt to a variety of habitat conditions is one explanation for the absence of a relationship between small mammal abundance and CWD volume. The short duration of our study is another probable explanation for the lack of an observed relationship between small mammals and CWD. The availability of standing snags and stumps was not measured in this study. These structural features in addition to leaf litter depth, rock volume, and herbaceous cover, none of which differed among CWD manipulation classes, provide adequate cover for small mammals.

Our results are consistent with Bowman et al. (2000) who found no relationship between small mammal abundance and mean decay class or overall abundance of logs. Billig and Servello (2002) found little evidence of a relationship between CWD and small mammal abundance in mixed deciduous-coniferous forests in Maine. In North Carolina, all species captured except deer mice were poorly correlated with CWD volume across a gradient from wildlife openings to forest interiors (Menzel et al. 1999). However, several studies have provided evidence to contradict these findings. Cotton mice *(Peromyscus gossypinus),* southern short-tailed shrews, and cotton rats *(Sigmodon hispidus)* were more abundant in plots with heavy loads of CWD (6.55 logs/200 m^2) than plots that had been cleared of storm blow down (2.04 logs/200 m^2) on the Savannah River Site in South Carolina (Loeb 1999). Carey and Johnson (1995) found CWD volume to be an accurate predictor of abundance in deer mice, southern red-backed voles, Trowbridge's shrew *(Sorex trowbridgii),* and shrew-moles *(Neurotrichus gibbsii)* in Washington. Butts and McComb (2000) found that the probability of encountering Trowbridge's shrew increased as CWD volume increased in western Oregon on sites ranging in CWD volume from 14 to 859 m^3/ha. The volumes on our study plot ranged from 9 m^3/ha to 218 m^3/ha after CWD manipulations. Perhaps conducting a volume manipulation study on experimental plots with a wider initial range of CWD volume and a longer duration would aid in the detection of differences in abundance associated with CWD volume adjustment. However, these volumes are representative of the study area and provide an accurate depiction of forestry in the region.

Species richness was the only diversity measure different between manipulated grids and control grids, with removal grids producing greater richness values. These results are somewhat puzzling considering the initial hypothesis was that removal of CWD would cause a decrease in abundance and diversity of small mammals. No temporal pattern in species richness was observed, indicating that the decrease in species richness after manipulation was not a steady decline. Few studies have compared diversity measures with changes in CWD volume. Carey and Johnson (1995) found differences in community structure associated with changes in structure of understories in the Pacific Northwest, but diversity changes were not reported. It appears from our results that changes in CWD volume have little short-term effect on diversity of small mammal communities in central Appalachian forest environments.

Estimators of small mammal demographics presented in this study provide little evidence of a relationship between CWD and conditions of small mammals. Loeb

(1999) described greater quality habitat for cotton mice in plots with greater densities of logs. However, low capture rates prevented making conclusions about other species and no statistical difference was recorded in CWD volume among these plots (Loeb 1999). In Washington, sites with great amounts of CWD (170.07–324.27 m^3/ha) were correlated with higher reproductive rates of Trowbridge's shrew than associated control sites with lower CWD volumes (12.12–45.21 m^3/ha; Lee 1995). These studies were conducted in forest stands providing much different habitat features for small mammals than central Appalachian forests, and neither of these species inhabited our study site. Neither of the aforementioned studies found a significant relationship between CWD volume and condition of *Peromyscus* spp. or northern short-tailed shrews.

It is difficult to make accurate, broadly applicable conclusions on the relationship of small mammals and CWD volume because of varied results observed in different ecological settings (Ford et al. 1997, Menzel et al. 1999, Bowman et al. 2000, Butts and McComb 2000). Though many studies have demonstrated small mammal use of CWD as pathways and dens (Nordyke and Buskirk 1991, Barnum et al. 1992, Planz and Kirkland 1992, Tallmon and Mills 1994, McMillan and Kaufman 1995), mixed results exist on the association of small mammal population characteristics and change in CWD volume (Loeb 1999, Menzel et al. 1999). One factor that could have led to a lack of ability to detect temporal patterns in population characteristics in our study was the variability in abundance and diversity of small mammals on control sites. Control sites provided our baseline of comparison for addition and removal sites, and the variability in abundance and diversity on control sites between trapping sessions may have provided an unreliable standard for comparison (Osbourne 2002). The most likely factor that prevented us from detecting temporal patterns on manipulated sties was the length of the study. Small mammal abundances were much higher in addition, removal, and control grids in 2001 than 2000. Fluctuations in small mammal abundance from year to year are common, and a study of this nature may produce different results over a 5–10 year period (Heske 1995, Lee 1995, Krohne 1998, Loeb 1999). However, the overall lack of pattern associated with small mammal populations and CWD volume was evident across removal and addition grids and across years suggesting little short-term effect of CWD manipulation on small mammal populations.

Based on our results, we cannot recommend specific volumes of CWD to be maintained by land managers with the intent of conserving small mammal communities. We did not completely remove CWD from any of the trapping grids sampled in this study, but we did find that, on a short-term basis, sites with CWD loadings as low as 8.86 m^3/ha produced similar small mammal abundance and diversity as sites with significantly greater volumes. However, because small mammals and other vertebrates use CWD, further studies of different aspects of CWD usage in addition to longer studies of the same type are recommended (Harmon et al. 1986, Loeb 1999, Butts and McComb 2000). The role of decay class, spatial arrangement, species of logs, and other CWD characteristics may be of more importance than simply total volume of CWD on a site. Land managers should make an effort to maintain some level of CWD for small mammals and other vertebrate groups. We recommend a starting point of 8.86 m^3/ha as we found CWD volume to be a poor predictor of small mammal community and demographic indices.

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