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Disturbance Effects on Small Mammal Species in a Managed Appalachian Forest

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Abstract.—Forestry practices result in a range of levels of disturbance to forest ecosystems, from clearcutting and deferment (high disturbance) to single-tree selection cutting and unharvested forests (low disturbance). We investigated the effects of timber harvest and disturbance on small mammal species in the Allegheny Mountains of West Virginia. In 2003 and 2004, mammals were captured using Sherman box traps, individually marked, and released. We collected habitat data in 2004 to characterize macrohabitat at the stand level and microhabitat surrounding each trap. Trap success was significantly higher in disturbed habitats than undisturbed habitats for red-backed vole *Myodes* (*Clethrionomys*) *gapperi* ($P = 0.0012$) and woodland jumping mouse *Napaeozapus insignis* ($P = 0.0221$). Abundance estimated using the Jolly-Seber method was significantly higher in disturbed habitats for red-backed voles ($P = 0.0001$). Adult northern short-tailed shrews *Blarina brevicauda* ($P = 0.0001$) and white-footed and deer mice *Peromyscus* spp. ($P = 0.0254$) weighed more in disturbed habitats. Small mammal distribution was strongly influenced by microhabitat factors, which differed substantially within stands. Leaf litter depth was a significant microhabitat factor for four of the five species analyzed, with red-backed voles ($P = 0.0001$), woodland jumping mice ($P = 0.0001$), *Peromyscus* spp. ($P = 0.0055$), and eastern chipmunks *Tamias striatus* ($P = 0.0007$) all preferring shallow leaf litter. These small mammal species responded neutrally or favorably to disturbance, and identified favorable microhabitat features regardless of stand type.

Introduction

In recent years, the concept of sustainability shifted in focus from sustaining the yield of one resource to sustaining the ecosystem in which that resource is produced (Kessler *et al.*, 1992; Sharitz *et al.*, 1992). This shift has led forest managers to incorporate a more holistic approach to management of natural resources, including the investigation of the function of habitat mosaics within a landscape context and the associated ecological processes and biodiversity. Timber harvests impose disturbance to landscapes (Liu and Ashton, 1999), with clearcutting representing the upper end of the disturbance continuum. Deferment cutting (*i.e.*, retention of 3–5 m^2/ha of basal area) and single-tree selection harvest represent two intermediate disturbance levels between clearcuts and mature forests, at the lowest end of the disturbance continuum.

This disturbance gradient could lead to a range of responses from ecosystem components, including small mammals. In landscapes subjected to repeated disturbance, response of small mammal communities could be particularly complex. Small mammals

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increase species richness and functional diversity in ecosystems (Carey and Johnson, 1995); are a vital prey base for many species, including raptors, reptiles, and other mammals (Fedriani *et al.*, 2000); and play a key role in the distribution of plant species (Mittelbach and Gross, 1984; Chambers and MacMahon, 1994) and mycorrhizal fungi (Maser *et al.*, 1978). Because of these factors, small mammals have been identified as potential indicators of sustainable forest management (Carey and Harrington, 2001; Pearce and Venier, 2005).

Although there have been a number of studies on the impact of forest disturbance on small mammal communities, population responses are not consistent among species or locations. In a review of 21 studies investigating the impact of clearcuts on small mammal populations, Kirkland (1990) identified a general pattern of initial increase in small mammal abundance and diversity following a clearcut, although there was substantial variability among studies. McComb and Rumsey (1982) found that the abundance of small mammals was greater in clearcuts than in uncut stands. In contrast, Root *et al.* (1990) found no effect of logging beyond normal population fluctuations, and Carey and Johnson (1995) found that small mammal biomass was lower in clearcuts than in old-growth forests. Many studies documented a short term shift in small mammal communities following timber harvest, with greater numbers of generalist species found in clearcuts (Campbell and Clark, 1980; Martell, 1983; Hansson, 1992; Pagels *et al.*, 1992; Sullivan *et al.*, 1999). Following the initial shift to a community dominated by generalists, the community composition remained stable, with *Peromyscus* spp. remaining dominant 13 yrs after the harvest (Martell, 1983), possibly indicating a change in community structure.

Therefore, we investigated the effects of disturbance resulting from timber harvest on small mammal communities in a central Appalachian mixed-hardwood forest. Relatively few studies pertain to small mammals in the central Appalachian region (Kirkland, 1977; McComb and Rumsey, 1982; Yahner, 1992; Ford and Rodrigue, 2001). We evaluated macrohabitat and microhabitat characteristics in clearcut, deferment cut, single-tree selection harvest, and mature stands, and examined relationships between these habitat variables and small mammal abundance and community structure. Clarifying these relationships will allow forest managers to consider the effects of various logging practices on small mammals when planning timber harvests.

METHODS

STUDY AREA

We conducted this study on the MeadWestvaco Wildlife and Ecosystem Research Forest (MWERF), an actively managed 3413 ha forest located in the Allegheny Mountains and Plateau physiographic province in east-central West Virginia (Randolph County). Forests were northern hardwood-Allegheny hardwood type, dominated by red maple (*Acer rubrum*), sugar maple (*A. saccharum*), yellow poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), American beech (*Fagus grandifolia*), yellow birch (*Betula alleghaniensis*), and Fraser magnolia (*Magnolia fraseri*). Understories in the MWERF were characterized by shrubs and fern groundcover. Forests were regenerated following harvesting during 1916–1928. Elevation ranged from 734 m to 1180 m, and soils were acidic and well-drained. The MWERF has a cool, humid climate with greater than 160 cm of precipitation annually. Currently, the MWERF is managed through study-specific manipulations and harvests in the context of an even-aged regeneration program designed to foster a desirable shade-intolerant species mix (Keyser and Ford, 2005).

TABLE 1.—Macrohabitat (*i.e.,* grid level) and microhabitat (*i.e.,* trap level) variables measured to characterize small mammal habitat along a continuum of four disturbance classes on a managed forest in Randolph County, WV

Macrohabitat variables	Microhabitat variables
Canopy cover (%)	% cover grass
Tree density (trees/ha)	% cover forbs
Tree diameter-at-breast-height (cm)	% cover moss
Log density (logs/ha)	% cover ferns
Log diameter (cm)	% cover seedlings
Log decay level	% cover CWD
Stump density (stumps/ha)	% cover leaf litter
Stump diameter (cm)	% cover rock
Stump decay level	% cover bare ground
Snag density (snags/ha)	Leaf litter depth (cm)
Snag diameter (cm)	CWD diameter (cm)
Snag decay level	CWD decay level
	Number of stems <1 m tall
	Number of stems >1 m tall

TRAPPING

We established 20 (7 × 7) trapping grids in the MWERF, allocated to one of four disturbance types as follows: 4 in recent clearcuts (stand age 1–7 yrs since cut), 4 in recent deferment cuts (stand age 1–7 yrs since cut), 4 in single-tree selection harvests, and 8 in mature forest (stand age > 60 yrs). Within the grids, traps were spaced 15-m apart. Trap stations were permanently marked and numbered, and the same locations were used during each trapping session.

We trapped small mammals using collapsible Sherman aluminum box traps baited with sunflower seeds and containing cotton balls to increase survival of captured animals. We checked traps daily for 3 consecutive days and repeated sampling on each grid 2 or 3 times per season. Trapping occurred in 2003 from 1 June to 20 August, and in 2004 from 23 May to 10 October.

We individually marked captured animals either by ear-tagging (mice and voles) or toe-clipping (shrews). We identified small mammals to species based on morphometric characteristics. Due to difficulties in distinguishing white-footed mice (*Peromyscus leucopus*) and deer mice (*P. maniculatus*; Aquadro and Patton, 1980), we pooled these species as *Peromyscus* spp. for analyses. We weighed animals and measured hind foot, head and body, tail, and ear lengths. We determined reproductive condition of males by measuring the testes, classifying the position of the testes as scrotal or non-scrotal, and describing whether or not the scrotum was furred. The reproductive condition of females was determined by the size and condition of the nipples and whether the vagina was perforate or imperforate.

HABITAT DATA COLLECTION

We collected habitat data from 18 July to 11 August 2004. Characterization of macrohabitat (*i.e.,* stand level) was accomplished using 6 randomly selected points in each trapping grid (Table 1). We calculated densities of trees, stumps, logs, and snags at each point using the point-center quarter method (Cottam and Curtis, 1956), with a correction factor for structures > 50-m from the point (Warde and Petranka, 1981). We recorded tree diameter-at-breast-height (DBH) and species, and diameters of stumps, logs, and snags.

Additionally, we classified the decay level of stumps, logs, and snags (1 = little decay to 5 = highly decayed). We estimated percent canopy cover using a spherical densiometer.

We measured microhabitat (*i.e.*, trap level) in a 2-m radius plot centered at each of the 49 trap stations comprising each grid (Table 1). Within these plots, we estimated percent cover of grass, forbs, moss, ferns, seedlings, coarse woody debris (CWD), leaf litter, rock, and bare ground. We measured leaf litter depth at 3 randomly chosen locations, measured diameter of CWD, classified fallen limbs by decay level, and counted woody stems less than 1-m tall and greater than 1-m tall.

STATISTICAL ANALYSES

We corrected the number of trap nights to account for predated and sprung traps, then calculated trap success (catch per 100 trap nights) for each small mammal species by year and disturbance habitat type. We compared trap success between years and between disturbance types (and the year*disturbance interaction) using a two-way Analysis of Variance (ANOVA). We calculated species richness as the number of species caught in each disturbance type.

We used mark-recapture information to estimate population size for the most abundant small mammal species: white-footed mouse and deer mouse *Peromyscus* spp., northern short-tailed shrew *Blarina brevicauda*, red-backed vole *Myodes* (*Clethrionomys*) *gapperi*, woodland jumping mouse *Napaeozapus insignis*, and eastern chipmunk *Tamias striatus*. We estimated abundance using the Jolly-Seber method for open populations (Jolly, 1965; Seber, 1965; Krebs, 1999), making the assumptions that all animals in the population had the same probability of being caught, marked animals had the same survival as unmarked animals, no marks were lost, and sampling time was negligible relative the animal's life span. Using the Jolly-Seber method, we also estimated the number of animals coming into the population (births and immigrants) and removed from the population (deaths and emigrants) between trapping periods to assess if source-sink dynamics existed (Jolly, 1965; Seber, 1965; Krebs, 1999). We evaluated the capture data to determine demographic parameters such as mean weight, sex ratio, percent in breeding condition, and percent of adults and juveniles within each habitat type. We analyzed demographic parameters and species abundance for significant differences between habitat types and between years using a two-way ANOVA.

To characterize the habitat variables of the grids, we conducted a principal components analysis (PCA) using macrohabitat data. We compared individual macrohabitat and microhabitat variables between habitat types with a one-way ANOVA. We compared microhabitat variables at trap stations that caught each mammal species in 2004 to microhabitat at trap stations that did not capture that species in 2004 using a one-way ANOVA. Additionally, we performed a PCA using microhabitat data to visualize niche separation of small mammal species based on trap-level habitat (Adler, 1985; Schmidt-Holmes and Drickamer, 2001).

RESULTS

In the macrohabitat principal components analysis (Fig. 1), clearcuts and deferments tended to group together, and single-tree and mature stands comprised a second group. Since there did not appear to be sufficient separation among the original four classes, we reclassified our sampling grids into ''disturbed'' grids (clearcuts and deferments) and ''undisturbed'' grids (single-tree harvest and mature forest). We observed more variability among disturbed sites than undisturbed sites (Fig. 1). The first principal component characterized a gradient from dense canopy cover and dense trees to sites with high density

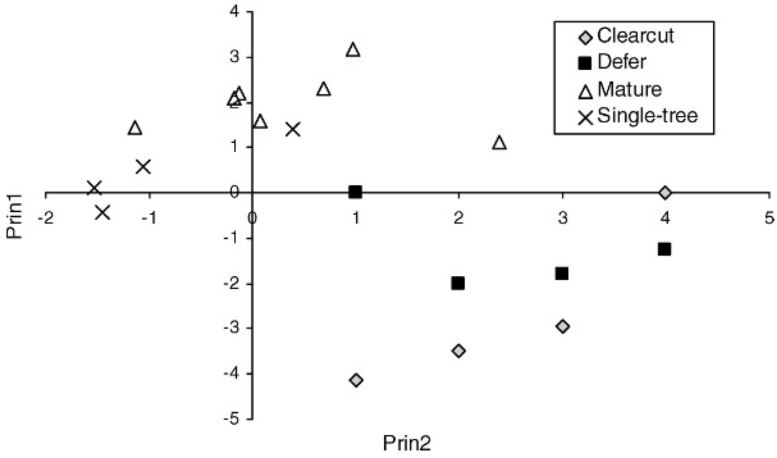

FIG. 1.—Principal components analysis of macrohabitat (*i.e.,* stand level) data by sampling grid on a managed forest in Randolph County, WV, in 2004. The first principal component (Prin1) characterized a gradient from dense canopy cover and dense trees to sites with high density of CWD. The second component (Prin2) corresponded to a gradient from large, highly decayed CWD in low density to more abundant CWD of smaller diameter with less decay. Two components explained 60% of the variation in the dataset

of CWD. The second component corresponded to a gradient from large, highly decayed CWD in low density to more abundant CWD of smaller diameter with less decay. Two components explained 60% of the variation in the dataset. In summary, less disturbed sites had high tree density and dense canopy, while the more disturbed sites had high densities of logs and stumps.

In 13,696 trap nights, we caught 4005 small mammals (at least 1898 individuals), representing 18 species (Table 2). In undisturbed habitats, we captured 17 small mammal species in 7795 trap nights, or 0.22 species per 100 trap nights. In disturbed areas, we captured 11 species during 5901 trap nights, or 0.19 species per 100 trap nights.

In 2003, trap success for all species combined was 20.3% for disturbed areas and 15.6% for undisturbed areas (17.5% overall). In 2004, we observed 24.9% trap success in disturbed areas and 29.9% success for undisturbed habitat (27.6% overall). Trap success was significantly higher in disturbed habitats than undisturbed habitats for red-backed voles ($P = 0.0012$) and woodland jumping mice ($P = 0.0221$), and was significantly higher in 2004 than 2003 for *Peromyscus* spp. ($P = 0.0002$) and woodland jumping mice ($P = 0.0285$). No year-disturbance level interactions were significant.

A few small mammal species dominated the captures. *Peromyscus* spp. (62% of captures), red-backed vole (12%), eastern chipmunk (10%), northern short-tailed shrew (9%), and woodland jumping mouse (5%) comprised 98% of the total mammals caught (Fig. 2).

Based on Jolly-Seber estimates, we observed a significant difference ($P = 0.0001$) in population size between habitats for red-backed voles (Fig. 3), with more individuals in disturbed habitats. No significant differences between disturbance levels or between years were found for survival or immigration/emigration for any of the species. Demographic parameters also showed only minimal differences between habitat types, with no significant differences for sex ratio, percent in breeding condition, or percent of adults and juveniles. We found differences in adult weight between habitat types for northern short-tailed shrews

TABLE 2.—Trap success (captures or individuals per 100 trap nights) of small mammal species in disturbed (clearcut and deferment; 5901 trap nights) and undisturbed (single-tree harvest and mature forest; 7795 trap nights) habitats on a managed forest in Randolph County, WV, in 2003–2004. Significant differences in trap success between disturbance levels are denoted with an asterisk (*)

	Captures per 100 trap nights		Individuals per 100 trap nights	
Species	Disturbed	Undisturbed	Disturbed	Undisturbed
Blarina brevicauda	4.80	4.23	0.78	0.51
Glaucomys volans	0.05	0.15	0.05	0.12
Microtus pennsylvanicus	0	0.03	0	0.03
Microtus pinetorum	0	0.03	0	0.03
Microtus spp. (unidentified)	0	0.01	0	0.01
Mustela erminea	0	0.01	0	0.01
Mustela frenata	0	0.01	0	0.01
Myodes gapperi	3.86*	2.27*	2.42*	1.55*
Napaeozapus insignis	1.73*	0.85*	1.36*	0.68*
Neotoma magister	0	0.01	0	0.01
Peromyscus spp.	12.78	16.22	7.42	8.80
Sorex cinereus	0.54	0.17	0.14	0.08
Sorex fumeus	0.93	0.90	0.10	0.18
Sorex hoyi	0.03	0.01	0.03	0.01
Sorex spp. (unidentified)	1.51	1.09	0.15	0.14
Synaptomys cooperi	0	0.01	0	0.01
Tamiasciurus hudsonicus	0	0.01	0	0.01
Tamias striatus	2.08	3.89	1.02	1.91
Zapus hudsonicus	0.05	0	0.05	0

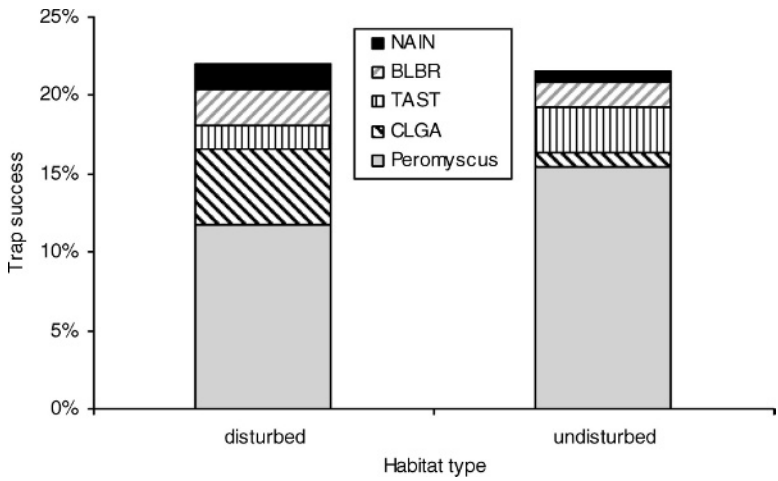

FIG. 2.—Trap success in 2003–2004 in disturbed (clearcut and deferment) and undisturbed (single-tree harvest and mature forest) habitat types of the most abundant small mammal species on a managed forest in Randolph County, WV: NAIN = *Napaeozapus insignis*; BLBR = *Blarina brevicauda*; TAST = *Tamias striatus*; CLGA = *Myodes (Clethrionomys) gapperi*; *Peromyscus* = *P. leucopus* and *P. maniculatus*

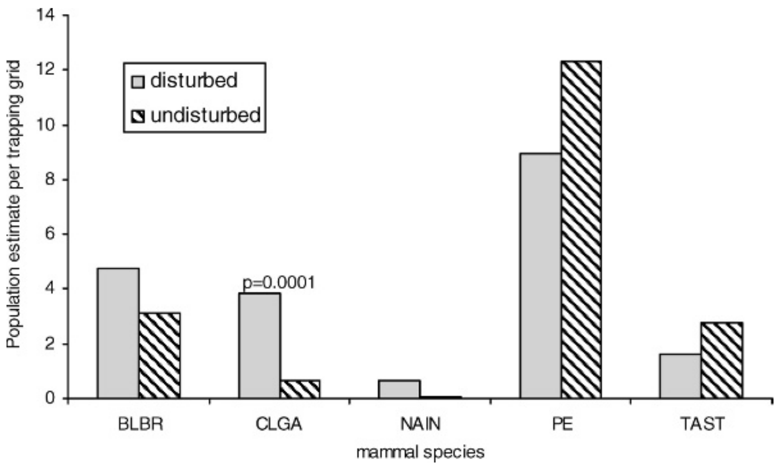

FIG. 3.—Mean abundance per sampling grid in disturbed (clearcut and deferment) and undisturbed (single-tree harvest and mature forest) habitat types on a managed forest in Randolph County, WV, 2003–2004, as estimated using the Jolly-Seber method for open populations (BLBR = *Blarina brevicauda*; CLGA = *Myodes (Clethrionomys) gapperi*; NAIN = *Napaeozapus insignis*; PE = *Peromyscus leucopus* and *P. maniculatus*; TAST = *Tamias striatus*)

(P = 0.0001) and *Peromyscus* spp. (P = 0.0254), with both species weighing more in disturbed habitats. Adult red-backed voles weighed significantly more in 2003 than 2004 (P = 0.0017).

At the macrohabitat scale, there were many significant differences in habitat variables between disturbed and undisturbed habitat. Canopy cover (P = 0.0001), tree density (P = 0.0001), snag density (P = 0.0001), stump diameter (P = 0.0002), stump decay (P = 0.0005), and log decay (P = 0.0357) were higher in undisturbed habitats, while stump density (P = 0.0001) and log density (P = 0.0054) were higher in disturbed areas. Tree DBH, log diameter, snag diameter, and snag decay were not significantly different between disturbance levels.

Microhabitat also differed substantially among treatments. Leaf litter cover (P = 0.0001), leaf litter depth (P = 0.0001), and moss cover (P = 0.0005) were significantly higher in undisturbed areas. Grass cover (P = 0.0001), forb cover (P = 0.0001), fern cover (P = 0.0027), CWD cover (P = 0.0296), CWD diameter (P = 0.0001), rock cover (P = 0.0001), bare ground cover (P = 0.0006), and the number stems >1 m tall (P = 0.0001) were higher in disturbed habitats. Seedling cover, CWD decay level, and the number stems <1 m tall did not differ significantly between disturbed and undisturbed grids.

Microhabitat differences were evident between trap stations where captures for a mammal species occurred and trap stations that did not capture that species. Leaf litter depth was a significant factor for four of the five species analyzed, and red-backed voles, woodland jumping mice, *Peromyscus* spp., and eastern chipmunks all were associated with shallow leaf litter (Table 3). Northern short-tailed shrews were captured in habitats with abundant stems and abundant, large, and decayed CWD. Red-backed voles were associated with shallow leaf litter, seedlings, abundant and large CWD, rocks, and ferns. Woodland jumping mice selected habitat with less leaf litter, more forbs, grass, and ferns, and large CWD. *Peromyscus* spp. were captured in areas with shallow leaf litter, less grass, and more rock and bare

TABLE 3.—Mean (and standard error) of microhabitat variables at trap locations where small mammal species were or were not caught on a managed forest in Randolph County, WV, in 2004. Only statistically significant variables are shown

Species	Habitat factor	Caught	Not caught	P-value
Blarina brevicauda	Number of stems >1 m tall	10.02 (0.66)	5.52 (0.25)	0.0001
	CWD decay level	3.37 (0.04)	3.14 (0.03)	0.0001
	CWD diameter (cm)	13.23 (0.62)	11.02 (0.34)	0.0019
	% cover CWD	25.79 (1.43)	21.63 (0.74)	0.0086
Myodes gapperi	% cover leaf litter	28.48 (2.49)	47.53 (1.11)	0.0001
	Leaf litter depth (cm)	0.88 (0.08)	1.31 (0.04)	0.0001
	Number of stems >1 m tall	10.97 (0.90)	5.89 (0.25)	0.0001
	% cover CWD	30.65 (2.14)	21.43 (0.68)	0.0001
	CWD diameter (cm)	14.69 (0.98)	11.08 (0.31)	0.0001
	% cover rock	8.63 (1.53)	5.27 (0.39)	0.0048
	% cover seedlings	9.82 (1.40)	6.75 (0.45)	0.0215
	% cover ferns	14.93 (1.95)	10.64 (0.67)	0.0288
	Number of stems <1 m tall	5.40 (0.69)	3.95 (0.25)	0.0477
Napaeozapus insignis	Leaf litter depth (cm)	0.85 (0.09)	1.31 (0.04)	0.0001
	% cover leaf litter	35.11 (3.10)	46.46 (1.09)	0.0007
	% cover forbs	30.79 (2.79)	22.96 (0.89)	0.0043
	% cover grass	8.03 (1.87)	4.54 (0.44)	0.0150
	CWD diameter (cm)	13.45 (1.05)	11.29 (0.31)	0.0265
	% cover ferns	14.95 (1.84)	10.70 (0.68)	0.0395
Peromyscus spp.	Leaf litter depth (cm)	1.18 (0.04)	1.38 (0.06)	0.0055
	% cover rock	6.41 (0.56)	4.56 (0.48)	0.0193
	% cover grass	4.08 (0.50)	6.18 (0.81)	0.0208
	% cover bare ground	9.35 (0.67)	7.18 (0.70)	0.0304
Tamias striatus	% cover seedlings	11.53 (1.32)	6.02 (0.42)	0.0001
	Number of stems <1 m tall	6.71 (0.74)	3.49 (0.23)	0.0001
	Leaf litter depth (cm)	1.03 (0.06)	1.32 (0.04)	0.0007
	% cover ferns	14.26 (1.61)	10.38 (0.69)	0.0156

ground. Finally, eastern chipmunks were associated with areas with abundant seedlings and ferns and shallow leaf litter (Table 3).

In the PCA of microhabitat data, many of the abundant species previously discussed grouped closely together near the intersection of the axes, identifying these species as habitat generalists (Fig. 4). Other species showed stronger habitat preferences. The first principal component specified a gradient from abundant seedling and moss cover on sites with CWD and deep leaf litter to grass- and fern-covered sites. The second component corresponded to a gradient ranging from abundant seedlings on sites with rock and fern cover to sites with deep leaf litter and abundant CWD. Two components explained 56% of the variation.

DISCUSSION

Many of the small mammal species in this study used habitats that had been disturbed by timber harvest. Disturbed habitats had significantly higher trap success for red-backed voles and woodland jumping mice, higher estimated abundance for red-backed voles, and higher adult weight for *Peromyscus* spp. and northern short-tailed shrews. These relationships have been supported by other studies investigating effects of timber harvest and disturbance on

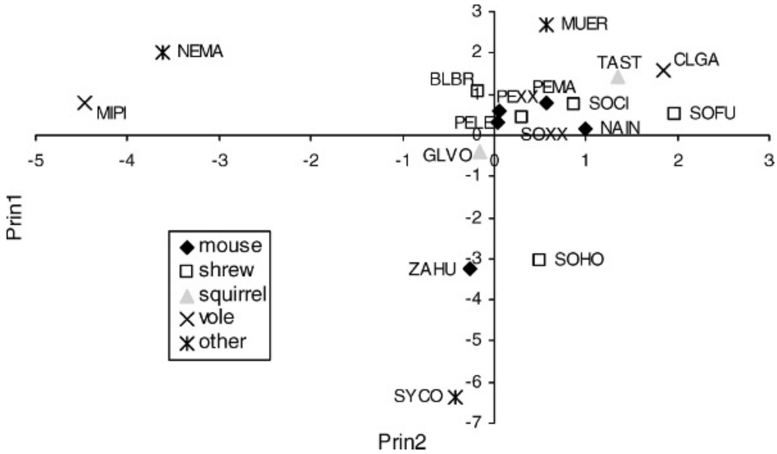

FIG. 4.—Principal components analysis of microhabitat (*i.e.,* trap level) data by small mammal species on a managed forest in Randolph County, WV, in 2004. The first principal component (Prin1) specified a gradient from abundant seedling and moss cover on sites with CWD and deep leaf litter to grass- and fern-covered sites. The second component (Prin2) corresponded to a gradient ranging from abundant seedlings on sites with rock and fern cover to sites with deep leaf litter and abundant CWD. Two components explained 56% of the variation in the dataset. Mammal species are as follows: BLBR (*Blarina brevicauda*), GLVO (*Glaucomys volans*), MIPI (*Microtus pinetorum*), MUER (*Mustela erminea*), CLGA (*Myodes gapperi*), NAIN (*Napaeozapus insignis*), NEMA (*Neotoma magister*), PE (*Peromyscus* spp.), SOCI (*Sorex cinereus*), SOFU (*S. fumeus*), SOHO (*S. hoyi*), SYCO (*Synaptomys cooperi*), TAST (*Tamias striatus*), and ZAHU (*Zapus hudsonius*)

small mammal communities. In a review of 21 studies, Kirkland (1990) found increases in relative abundance of small mammals following logging in North American temperate forests.

Additionally, many of the significant relationships we detected between small mammal relative abundance and microhabitat variables indicated an association with disturbed habitat: red-backed voles, woodland jumping mice, eastern chipmunks, and *Peromyscus* spp. avoided leaf litter; woodland jumping mice preferred vegetated understory; and red-backed voles and eastern chipmunks were associated with areas with abundant seedlings (Table 3). The disturbance to forest plots in this study was relatively recent; we would expect to see changes to the relationships between small mammal species and microhabitat with increases in the time since disturbance.

Disturbance resulted in substantial differences in macrohabitat and microhabitat. Overall, undisturbed areas had higher tree density and greater canopy cover. Disturbed areas had a much more diverse understory, with more grass, forbs, ferns, and seedlings. Disturbed areas also had greater structural diversity than undisturbed areas, with more stumps, logs, CWD, and rocks. The forest floor in undisturbed areas was dominated by leaf litter. In this study area, disturbed areas provided diverse vegetation and structural features for small mammals, possibly contributing to the higher abundances and weights we observed at disturbed sites for a number of the species.

Although red-backed voles are often associated with mature or old-growth forests (Nordyke and Buskirk, 1991), we found a strong preference for disturbed habitat. This species occurred in significantly greater abundance in clearcuts and deferments, and was highly selective on a microhabitat scale. Red-backed voles were captured in areas with abundant CWD, supporting the findings of Moses and Boutin (2001) and Ucitel et al. (2003). We also found this species associated with high densities of seedlings and minimal leaf litter. Previous studies also have found high abundances of red-backed voles in clearcut areas (Simon *et al.*, 2002; Homyack *et al.*, 2005). Homyack *et al.* (2005) suggested that a moist microclimate in a mesic clearcut may result in habitat characteristics similar to those of mature forests. In this study, red-backed voles appeared to be positively impacted by forest disturbance and were able to utilize resulting habitat niches.

Woodland jumping mice also occurred in significantly greater numbers in disturbed habitats. This species was associated with microhabitats with substantial vegetative cover and minimal leaf litter. Woodland jumping mice's preference for herbaceous vegetation has been described in other studies (Whitaker and Wrigley, 1972; Miller and Getz, 1977). DeGraaf *et al.* (1991) also identified a preference of this species for logs, which was supported by our finding that woodland jumping mouse selected habitats with large diameter CWD. This species would likely benefit from timber harvest that removed canopy cover to promote growth of herbaceous vegetation, while leaving large diameter snags, logs, and limbs on the forest floor.

Northern short-tailed shrews did not exhibit significant differences in abundance between disturbance levels. However, this species had higher adult weight in disturbed habitats. Body weight provides information on an individual's condition, and may affect survival (Mahan and Yahner, 1998). We found a strong relationship between short-tailed shrew occurrence and CWD; this species was found in areas with high density of large and highly decayed CWD. In experimental manipulations, McCay and Komoroski (2004) found little effect of CWD removal on shrew populations in a loblolly pine forest. However, they recognized the importance of CWD in moist climates, such as the southern Appalachian region (McCay and Komoroski, 2004), as storage pools for water and nutrients (Jaeger, 1980). Short-tailed shrew distribution has been shown to be closely related to moisture level (Getz, 1961; Getz *et al.*, 2004).

The most abundant small mammals in our study were white-footed mice and deer mice. These species were present in large numbers in both disturbed and undisturbed habitats, comprising 62% of the total captures. While previous studies have shown positive responses of these species to canopy removal and timber harvest (Morrison and Anthony, 1988; Sullivan *et al.*, 1999), we found no significant difference in abundance between the two disturbance levels. Because *Peromyscus* spp. were ubiquitous on our study area, only a few microhabitat variables identified significant habitat relationships, including capture locations with higher coverage of rock and bare ground. *Peromyscus* spp. are habitat generalists that appear to utilize any unoccupied niche in the landscape.

Eastern chipmunks did not exhibit significant differences in abundance between disturbance levels. However, they were frequently captured in areas with abundant seedlings. It is not known whether chipmunks select areas with high densities of seedlings or if abundant seedlings are a result of higher densities of chipmunks caching seeds (Vander Wall *et al.*, 2005). Previous studies (Dueser and Shugart, 1978) found that eastern chipmunks had similar microhabitat preferences to *Peromyscus* spp., as chipmunks are ecological generalists (Morris, 1996). Although we found substantial overlap in occurrences between chipmunks and *Peromyscus* spp. due to the wide distribution of both species, these species appeared to be associated with different microhabitats (Table 3, Fig. 4).

The results of this study would not support the practice of using these small mammal species as indicators of sustainable forestry practices (Carey and Harrington, 2001; Pearce and Venier, 2005). None of the abundant species analyzed (white-footed mouse, deer mouse, northern short-tailed shrew, red-backed vole, woodland jumping mouse, or eastern chipmunk) were significantly more abundant in undisturbed habitats. Captures of other species were rare in both disturbed and undisturbed areas, comprising only 2.6% and 1.6% of catches in disturbed and undisturbed habitats, respectively. Species that were rare in this study may have potential as indicator species, but trapping techniques should be tailored to individual species rather than using the standard trapping methodology employed here. Although there were relationships between small mammal occurrence and specific microhabitat variables (Table 3), the niches occupied by these species were relatively broad (Fig. 4). Additionally, we observed high annual variation in abundance. From 2003 to 2004, total trap success increased 58%, and there were significant differences in trap success between years for *Peromyscus* spp. and woodland jumping mice. While these small mammal species are vital components of forest ecosystems, these factors make them inappropriate for use as indicators of sustainable timber harvest.

Small mammals were able to identify a habitat mosaic at the microhabitat level and key in on favorable microhabitat features regardless of stand type. Future timber harvest strategies could attempt to provide a more substantial mosaic of habitat for small mammals (Sullivan *et al.*, 1999). For example, removing canopy in small areas would increase growth of herbaceous vegetation and not removing all CWD would provide physical structure. Such changes to current forestry practices could further benefit many small mammal species, which already appear to be successful under current timber harvest strategies.

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