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Amphibian and Small Mammal Assemblages in a Northern Virginia Forest Before and After Defoliation by Gypsy Moths (*Lymantria dispar*)

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ABSTRACT

The introduced European gypsy moth (*Lymantria dispar*) caused substantial defoliation and mortality of oak trees along the North Fork of Quantico Creek in Prince William Forest Park, Prince William County, Virginia, U.S.A., in 1989 and the early 1990s. Results of a drift fence/pitfall study conducted in 1988 were compared to those obtained from the same technique in the same areas in 1993 to elucidate whether the amphibian and small mammal assemblages had changed over time. Number of *Lithobates sylvaticus* increased significantly in 1993, but the numbers of *Lithobates clamitans* and *Plethodon cinereus* were significantly higher in 1988. Total numbers of amphibians caught in both years was similar. Two species of salamanders caught in 1988 were not caught in 1993, and one salamander and one frog caught in 1993 were absent in 1988. Total numbers of small mammals caught in 1993 were significantly greater than in 1988. The increase was due to greater numbers of *Blarina brevicauda* and *Sorex longirostris*. The hypothesis that no significant differences in amphibian and small mammal species richness and relative abundance before and after gypsy moth defoliation hypothesis was not supported by the results of this study.

Key Words: community ecology, forest ecology, amphibians, small mammals, gypsy moth, *Lymantria dispar*

INTRODUCTION

Defoliation of millions of hectares of hardwood trees in northeastern North America by the introduced European gypsy moth (*Lymantria dispar*) has resulted in substantial ecological and economic damage (Houston 1981a, 1981b; White and Schneeberger 1981). This forest pest was inadvertently introduced in 1869 into Massachusetts and has migrated westward and southward, entering Virginia in or about 1982 (McManus and McIntyre 1981; Gansner et al. 1993; Ravlin and Weidhaas 1991). It has since spread throughout much of the Commonwealth, causing defoliation and tree (primarily oak [*Quercus* spp.]) mortality in northern counties and along the Blue Ridge and Allegheny mountains (Ravlin and Weidhaas 1991; Gansner et al. 1993).

At the request of Prince William Forest Park in Prince William County, Virginia, I conducted a study of the effects of gypsy moth defoliation on an assemblage of terrestrial vertebrates in 1993. I had previously evaluated the amphibian and small mammal assemblages at this site in 1988, a year before initial defoliation in 1989 (Mitchell and Pague 2016). In this paper, I elucidate the changes in the forest floor vertebrate community that may have occurred in response to the defoliation and mortality of forest trees between 1988 and 1993. Specifically, I evaluated the null hypothesis that there were no significant differences in amphibian and small mammal species richness and relative abundance before and after gypsy moth defoliation.

MATERIALS AND METHODS

Study site

The study site was located in a 14 ha portion of Prince William Forest Park (PWFP), Prince William County, Virginia, U.S.A., at an elevation of 73.2 m. The study area was approximately 125 m south of the confluence of an unnamed tributary and the North Fork of Quantico Creek, about 6 km northwest of the town of Triangle.

The forest canopy at the study site was dominated by American beech (*Fagus grandifolia*), white oak (*Quercus alba*), and mockernut hickory (*Carya tomentosa*). Flowering dogwood (*Cornus florida*) was the primary understory tree. White oak and tulip poplar (*Liriodendron tulipifera*) were the most common trees in the forest surrounding the site. The understory consisted of wild azalea (*Rhododendron nudiflorum*), American holly (*Ilex opaca*), and flowering dogwood. Herbaceous plants were not abundant, but included aster (*Aster* spp.), hayscented fern (*Dennstaedtia punctilobula*), bindweed (*Convolvulus* spp.), and sedge (Cyperaceae). The forest floor was generally open with a moderate leaf cover and variable amounts of coarse woody debris ranging from small limbs to dead trees and scattered patches of grasses.

Vegetation changes 1988–1993

The primary change in the forest community was the loss of all oak trees on the site and in the surrounding area from mortality caused, at least in part, from defoliation by the gypsy moth. This was accompanied by a substantial (unmeasured) increase in the amount of coarse woody debris. Numerous limbs and several of the fallen dead trees near the 11–12 ha study sites littered the area in 1993. Coarse woody debris was the only category of forest floor cover that appeared to have increased between 1988 and 1993.

The amount of canopy closure was determined by electronically comparing forest canopy density in aerial infrared photographs taken by the National Park Service (NPS) in June 1983 (5 yr before the initial study), 1989, and 1991. Photographs were scanned at 200 dots per inch with a hand-held 256 gray-scale scanner. The digitized data were then entered into the Geographic Resource Analysis Support System 4.0 (GRASS) at the Center for Urban Ecology, Washington, D.C. The resulting geographic reference points were registered to the existing PWFP forest cover database to ensure accurate placement of plots on the aerial photographs. Two areas were selected for comparison: 12.2 ha centered over the study site (aerial photographs available for 1989 and 1991), and 11.4 ha adjacent to the study site (photographs available for 1983, 1989, and 1991). A densiometer was used to obtain an estimate (average of 5 readings) of canopy cover over the study site in August 1993.

Canopy cover data were unavailable for 1983 in the study site, but assumed to be similar to that in the adjacent site; the same assumption was made for 1993 cover in the adjacent site. Canopy cover before gypsy moth defoliation (1983) on the adjacent plot was 81.1% compared to 54.6% in 1989 (the first year of defoliation) and 82.8% in 1991. The amount of canopy cover over the study site was 67.7% in 1989, 83.8% in 1991, and 90.9% in 1993. Recovery of canopy cover in 1991 may have been due to generation of new foliage by oaks, most of which died after 1991, however. The densiometer readings in 1993 were taken under beech trees that were apparently unaffected by gypsy moths. Thus, forest canopy cover decreased on the study and adjacent sites in 1989, but appeared to have recovered by 1993, despite loss of oak trees. The NPS conducted aerial pesticide treatments of the microbial pesticide *Bacillus thuringiensis* (Bt) and the species-specific virus Gypchek® from 1989 to 1995 to kill the moths and reduce the infestation.

Weather patterns were similar in 1988 and 1993 (Figure 1). Average monthly minimum and maximum temperatures did not differ significantly in all pairwise comparisons ($t = -1.11–1.60$, $P = 0.115–0.915$). Monthly precipitation totals were higher in 1993 for March, April, August, and September, whereas totals were higher in May, June, and July in 1988.

Field methods

Data on species richness and relative abundance of amphibians and small mammals were obtained in 1988 and 1993 with the use of a drift fences and pitfalls technique (Campbell and Christman 1982; Mitchell et al. 1997). Four lengths of aluminum flashing (0.61 x 7.5 m) were installed upright in a cross configuration, each arm separated from the center point by about 7.5 m, leaving an open center. We sunk a 3.8 l (#10) tin can in the ground on each side at each end of each arm and a 19 l (5 gallon) plastic bucket in the middle of the array. Thus, each drift fence arm consisted of four 3.8 l cans and one 19 l bucket; 20 pitfalls total for the array. A total of 3920 trap days were recorded in 1988 during the period of 22 March - 3 October, and 3680 trap days in 1993 during the period of 1 April - 1 October.

Analysis

Descriptive statistics and comparisons among sample means for parametric data were obtained using Statistix programs (version 4.0, Analytical Software, St. Paul, MN). Nonparametric comparisons were made with chi-square tests following Zar (2009). Because the chi-square statistic is calculated using actual frequencies or numbers observed rather than percentages (Zar 2009), I adjusted the 1993 capture numbers to account for the fewer number of trap days that year. Significance was accepted at alpha = 0.05. Estimates of community diversity, e.g., Shannon diversity index (H') and evenness (J), followed procedures in Brower et al. (1989). Herpetofaunal names follow Crother (2012) and small mammal names follow Bradley et al. (2014).

RESULTS

In addition to amphibians and small mammals, five species of reptiles (*Plestiodon fasciatus, Plestiodon laticeps, Carphophis amoenus, Diadophis punctatus, Thamnophis sirtalis)* were captured in both years combined (15 individuals in 1988, 19 in 1993). The small sample sizes precluded any statistical analysis.

Twelve species of amphibians occurred on the site in 1988 and 1993 combined (Table 1). Total numbers of individuals was similar in the two samples (228 vs 206).

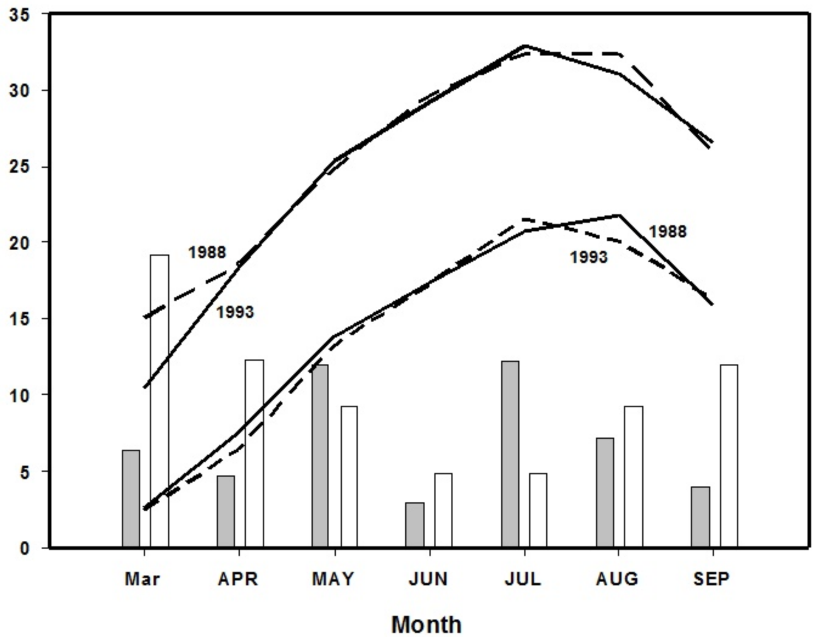

FIGURE 1. Monthly precipitation totals (bars, cm) for March-September 1988 and 1993 and monthly minimum and maximum temperatures (lines, ºC) from the U.S. Marine Corps Airfield at Quantico, Virginia, located approximately 13.5 km southeast of the study site. Open bars represents 1993 and solid bars 1988. The scale on the Y-axis is the same for precipitation and temperature.

The number of anurans was significantly greater in 1993 than in 1988. Numbers of *Lithobates clamitans* and *L. sylvaticus* were significantly greater in 1993 than in 1988 (Table 1). Salamander abundance was significantly higher in 1988 than in 1993, but this difference was due to the large numbers of one species (*Plethodon cinereus*). Two species (*Acris crepitans*, *Ambystoma opacum*) caught in 1988 were not encountered in 1993, and two species (*Eurycea bislineata*, *E. guttolineata*) caught in 1993 were not found in 1988. Amphibian community diversity was similar between years (Table 1). The relative numbers of individuals among species were more evenly distributed in 1993 than in 1988.

A total of six species of small mammals (3 insectivores, 3 rodents) occurred in the combined samples (Table 2). The total number of individuals was significantly higher in 1993 than in 1988. The total number of insectivores was significantly higher in 1993 than in 1988, whereas the difference was not significant for rodents (Table 2). The difference in shrew numbers was due to the significantly higher numbers of *Blarina brevicauda* and the number of *Sorex longirostris* caught in 1993. *Sorex longirostris* was not caught in 1988 and *Zapus hudsonius* was not caught in 1993. The distribution of

TABLE 1. Species richness and relative abundance of amphibians in a northern Virginia hardwood forest before and after defoliation by the gypsy moth. Upper number is the number of adults and lower number is number of juveniles. #/per trap day is number per trap day x 100. NT = not tested due to small sample size. Total numbers of adults and juveniles were used for the statistics.

Species	1988	#/trap day	1993	#/trap day	χ^2	P
Anurans						
Acris crepitans	1/0	0.026	0		NT	
Bufo americanus	8/21	0.740	4/13	0.462	3.13	0.077
Lithobates catesbeianus	0/1	0.026	0/4	0.109	NT	
Lithobates clamitans	0/41	1.046	2/14	0.415	10.97	0.0009
Lithobates palustris	1/35	0.198	1/30	0.842	0.37	0.541
Lithobates sylvaticus	4/7	0.281	5/86	2.473	62.75	<0.001
Number of individuals	119		159		5.76	0.0164
Salamanders						
Ambystoma opacum	1/0	0.026	0			
Eurycea bislineata	0		1/0	0.027	NT	
Eurycea guttolineata	0		3/0	0.082	NT	
Notophthalmus viridescens	0/4	0.102	0/1	0.027	NT	
Plethodon cinereus	72/31	2.628	36/4	1.087	27.755	<0.001
Plethodon cylindraceus	1/0	0.026	1/0	0.027	NT	
Number of individuals	109		46		26.61	<0.001
Species richness	10		10			
Total number of individuals	228	5.816	206	2.598	1.12	0.2910
Anurans/trap day x 100		3.036		4.321		
Salamanders/trap day x 100		2.781		1.250		

individuals among species in both years provided the similar estimates of species diversity (H') and evenness (J) for the small mammal assemblages (Table 2).

DISCUSSION

Differences in species richness and relative abundances in amphibians and small mammals in the samples from 1988 and 1993 indicated a mixed response to the temporary reduction in canopy cover and loss of oak trees at this site. There were significant differences in the composition of these vertebrate assemblages before and after gypsy moth defoliation because some species were more abundant in 1988 and others were more abundant in 1993. Three alternative hypotheses may account for the differences observed.

(1) The changes in species on the study sites and differences in numbers may have been due to different weather patterns in 1988 and 1993. Average monthly minimum and maximum temperatures did not differ significantly in all pairwise comparisons ($t = -1.11–1.60$, $P = 0.115–0.915$). Monthly precipitation totals were higher in 1993 for

TABLE 2. Species richness and relative abundance of small mammals in a northern Virginia hardwood forest before and after defoliation by the gypsy moth. The raw number refers to all adults. #/per trap day is number per trap day x 100. NT = not tested due to small sample size. Total numbers of adults and juveniles were used for the statistics.

Species	1988	#/trap day	1993	#/trap day	χ^2	P
Insectivores						
Blarina brevicauda	5	0.128	16	0.435	5.76	0.016
Sorex hoyi	9	0.230	6	0.163	0.60	0.439
Sorex longirostris	0		7	0.190	NT	
Number of inividuals	14		29		5.23	0.022
Rodents						
Microtus pennsylvanicus	2	0.051	2	0.054	NT	
Peromyscus leucopus	2	0.051	3	0.082	NT	
Zapus hudsonius	2	0.051	0		NT	
Number of individuals	6		5		0.09	0.763
Species richness	5		5			
Total number of individuals	20	0.510	34	0.924	3.63	0.057
Shrews/trap day x 100	14	0.357	29	0.788		
Rodents/trap day x 100	6	0.153	5	0.136		
H'	0.607		0.594			
J	0.868		0.849			

March, April, August, and September, whereas totals were higher in May, June, and July in 1988. Variation in monthly precipitation between years and among months and years suggests that the different patterns of summer rainfall had little effect on assemblage structure. Thus, variation in weather patterns between study years cannot account for the differences in the terrestrial vertebrate assemblages observed in 1988 and 1993.

(2) Modification of the habitat due to changes caused by gypsy moth defoliation could have influenced changes in assemblage composition and numbers of individuals caught in 1993. The principle differences between 1988 and 1993 in the amphibian and small mammal assemblages were in numbers *Plethodon cinereus* and *Blarina brevicauda*, respectively. Loss of canopy cover in 1989 could have increased the amount of solar radiation reaching the forest floor causing drying and a reduction in the number of invertebrate prey, and consequently the reproductive potential of the salamanders. Alternatively, additional sunlight may have stimulated herbaceous plant growth and an increase in invertebrate abundance. However, the *P. cinereus* population most likely inhabited the area shaded by the American beech on the study site and may not have been as affected by changes in the forest floor as those in areas dominated by oaks. Recovery of the forest canopy from 68% in 1989 to 91% in 1993 should have also allowed the salamander's microhabitat to recover. In addition, the increased

amount of coarse woody debris provided additional surface retreats for the territorial *P. cinereus*.

Small mammals, specifically two species of shrews, showed the clearest increase in numbers from 1988 to 1993. Shrews, especially *Blarina brevicauda*, are frequent inhabitants of forest habitats, unlike some rodents (with the exception of *P. leucopus*) which prefer old fields with grass cover (Pagels et al. 1992; Bellows and Mitchell 1999; Bellows et al. 2001). The increase in shrew numbers suggests that habitat changes (e.g., increased openness, oak mortality, downed woody debris) that occurred in 1989 and in the years immediately following were more optimal than these habitats were in 1988. Tomblin and Cranford (1993) showed that habitat quality increased for small mammals in chestnut oak communities following high mortality in response to gypsy moth infestations.

The microbial insecticide *Bacillus thuringiensis* (Bt) is used widely to control gypsy moth damage. The protein crystals specific to lepidopteran guts are not known to directly harm vertebrates (Holmes 1998). Because lepidopteran larvae occurred in low frequencies in terrestrial salamander diets in West Virginia, Raimondo et al. (2003) inferred that salamander populations were not affected directly or indirectly. Although the numbers of *Blarina brevicauda* increased significantly by 1993 in this study, it is not possible to clearly attribute the change to Bt because of the small sample sizes.

(3) The inventory technique used in this study, drift fences with pitfall traps, randomly samples terrestrial vertebrates moving across the forest floor (Bennett et al. 1980). Many of the animals encountering the drift fence were likely transients moving through the study area and many of these were juveniles. Frogs in particular are well known for dispersing widely from breeding sites and can move up to a kilometer or more from their natal site (e.g., Willis et al. 1956; Berven and Grudzein 1990). One anuran (*Anayxrus americanus*) was found about 20 cm underground when digging the pit for one of the buckets, suggesting that it was at least a temporary resident. Salamanders in the genus *Plethodon* (woodland salamanders) remain within small home ranges in hardwood forests and rarely disperse more than a few meters (e.g., Madison 1969; Wells and Wells 1996). The low-density small mammal assemblages that characterized the PWFP study site in 1989 and 1993 may have been comprised of transient animals, as was shown for assemblages in eastern Virginia (Rose and Stankavich 2008).

The null hypotheses that there were no significant differences in amphibian and small mammal species richness and relative abundance before and after gypsy moth defoliation or its control were not supported by the results of this study. Alternative hypotheses that may account for the differences in species composition and species numbers were the changes in habitat caused by oak mortality from gypsy moth defoliation, indirect effects of Bt treatment, and the transient behavior of the frogs and small mammals. The variation in numbers of species and individuals between years was likely due to a combination of all of these factors.

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