Abundance, Diversity, and Activity of Ants (Hymenoptera: Formicidae) in Oak-Dominated Mixed Appalachian Forests Treated with Microbial Pesticides

CHANGLU WANG,[1] JOHN STRAZANAC, AND LINDA BUTLER

Division of Plant and Soil Sciences, West Virginia University, Morgantown, WV 26506–6108

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ABSTRACT This study is part of a long-term analysis of nontarget effects of microbial pesticide application in the George Washington (Augusta County, VA, USA) and Monongahela National Forests (Pocahontas County, WV, USA). Ants were collected using pitfall traps to assess the effect of *Bacillus thuringiensis* Berliner variety *kurstaki* (Foray 48 F) and gypsy moth nuclear polyhedrosis virus (Gypchek) application on ant communities. Ant samples were also compared by sampling years. Pitfall traps were operated for 45 wk during summers of 1995–1997. A total of 31,732 ants was collected from pitfall traps; they belonged to four subfamilies, 17 genera, and 31 species. The ant species richness, diversity, abundance, and species composition did not change as a result of the treatments. Further tests of ant abundance were suggested because the test power was low. Comparisons between sampling years showed a very similar species composition and species evenness. There was a significant decrease in ant abundance in the third year of sampling, which might have been caused by over-trapping. Some rare species did not appear in the second and third year of sampling.

KEY WORDS ants, microbial pesticides, nontarget effect, forest

THE IMPORTANCE OF ants in ecosystems is well recognized. Ants play important roles in predation (Youngs 1983), nutrient flow, herbaceous vegetation structure (Beattie and Culver 1977, Handel et al. 1981), and soil improvement (Lyford 1963, Petal 1978). Their effects are remarkable when they reach extremely high populations. Ant populations often are relatively stable among the seasons and years. Their abundance and stability make ants one of the most important groups of insects in ecosystems. Ant societies are susceptible to environmental disturbances by being tied to the same location. They are dependent on structure, moisture, and temperature of the soil, as well as the structure of the vegetation and the populations of other arthropods. Because of their great abundance, functional importance, and the complex interactions they have with the rest of the ecosystem, ants are often used as bio-indicators in environmental assessment programs, such as in managed fire (Andersen 1988, MacKay et al. 1991, Touyama 1996, Vanderwoude et al. 1997), vegetation disturbance (Greenslade and Greenslade 1977), clearcutting (Jennings et al. 1986, Punttila et al. 1991), mining (Majer 1983; Andersen 1990, 1993), waste disposal (MacKay 1993), and land use (Bestelmeyer and Wiens 1996, Peck et al. 1998).

In northeastern forests of the United States, gypsy moth, *Lymantria dispar* (L.), periodically causes serious defoliation to hardwood forest species, especially oaks (*Quercus* spp.), over large areas. Aerial application of insecticides is one of the common methods used to control this pest. From 1991 through 1994, 850,000 ha (2.1 million acres) of eastern forests were treated with the microbial insecticide, *Bacillus thuringiensis* Berliner (*B.t.*), and 10,522 ha (26,000 acres) were treated with a gypsy moth nuclear polyhedrosis virus product, Gypchek, for gypsy moth suppression (Machesky 1995). Because of the large scale at which the *B.t.* pesticide is currently used and possible wide application of Gypchek in the future, it is a concern that these pesticides may have nontarget effects.

Bacillus thuringiensis can affect ants indirectly through increasing or decreasing food abundance, because it is toxic to many different invertebrate species (Feitelson et al. 1992). The variety used for gypsy moth suppression, *Bacillus thuringiensis* variety *kurstaki (B.t.k.)* is also toxic to other Lepidoptera (Boberschmidt et al. 1989). The species most affected are early spring foliage feeders whose larvae are feeding on foliage when *B.t.* is applied to control gypsy moth populations (Butler et al. 1995). In a study of the nontarget effects of *B.t.* application in eastern deciduous forests, Sample et al. (1996) reported a significant drop in abundance of lepidopteran larvae during the treatment year and posttreatment year. Reductions in species richness and abundance of larval Lepidoptera were also observed after three applications of *B.t.* during a single year as part of a gypsy moth eradication program in Oregon (Miller 1990). Two studies have

[1] Current address: Stoneville Research Quarantine Facility, Biological Control and Mass Rearing Research Unit, USDA–ARS, Stoneville, MS 38776–225.

Table 1. Summary of the 30-yr (1961–1990) weather trends near the study sites

Climate	Forest	
	GWNF	MNF
Min. temp in Jan., °C	−6.72	−9.22
Max. temp in Aug., °C	28.50	27.17
Annual median temp, °C	11.17	9.56
Annual precipitation, cm	99.06	127.25

Temperature and precipitation were recorded at NOAA stations (Owenby and Ezell 1992).

included the effect of *B.t.* application on ants. Legotai (1980) tested the effect of an application of BTB-202, used to control the cabbage pest *Pieris brassicae* L. (Lepidoptera: Pieridae) on beneficial insects. Results showed that BTB-202 had no distinct effect on *Formica pratensis* Retzius after the ants ingested the pesticide. Progar (1995) studied the effect of *B.t.k.* application on nontarget arthropods and found that ant abundance was not affected.

The majority of economically important entomopathogenic viruses are DNA viruses found in the family Baculoviridae, genus *Baculovirus.* In general, baculoviruses have a narrow host range and no evidence of direct toxicity to natural enemies has been documented (Flexner et al. 1986). We hypothesize that application of gypsy moth nuclear polyhedrosis virus (NPV) will not affect the ant communities directly.

Since 1994, a long-term study of nontarget effects of *B.t.* has been carried out in the George Washington (GWNF) and Monongahela National Forests (MNF). As a part of this study, we documented the nontarget effects of *B.t.* (Foray 48 F) and gypsy moth NPV (Gypchek) application on the abundance and diversity of the ant communities. Attempts were also made to document the annual changes in ant activities.

Materials and Methods

Study Sites and Location. Eighteen study plots were located on the western and eastern slopes of the central Appalachians. Plots one through nine were in the George Washington National Forest (GWNF) in Augusta County, VA (centered at 38° 07′ 30″ N, 79° 22′ 30″ W). Plots 10 through 18 were located in the Monongahela National Forest (MNF) in Pocahontas County, WV (plots 10–15 centered at 38° 22′ 30″ N, 79° 52′ 30″ W; plots 16–18 centered at 38°, 15′ N, 80° 00′ W). The MNF sites were at higher elevations (946 m) and were believed to be more mesic than the GWNF sites (635 m). The normal weather data of the study sites (Owenby and Ezell 1992) are showed in Table 1.

A randomized complete block design based on vegetation in the plots was used for the study. At each forest, three blocks, each with three 200-ha plots, were established in each location. Within each plot, a 30-ha core plot was delineated for vegetation, ant, and other arthropod studies. Within each block, *B.t.* was applied on one plot, one plot was treated with Gypchek, and the third plot served as an untreated control. Treatments were randomly allocated among the plots of each block (Table 2). The ant community study sites were located at least 100 m within each core plot boundary.

Gypsy moth egg mass densities were surveyed in each plot during the winter months (December to March) from 1995 to 1997. At 28 grid points in each core plot, the number of egg masses in 1/16-ha subplots was counted. The study plots had an average of 349, 310, and 7 egg masses per hectare in the spring of 1995, 1996, and 1997, respectively. The plots received various degrees of defoliation in 1995, ranging from 0.1% up to 35.6%. Plots 1, 8, and 15 had defoliation ≥10%. Little defoliation occurred in 1996 and no gypsy moth defoliation occurred in 1997, as a result of an epidemic of the pathogenic fungus *Entomophaga maimaiga* Humber, Shimozu & Soper (Webb et al. 1996).

All study plots were dominated by oaks and pines. The most common tree species were upland red oaks (*Quercus* subgenus *Erythrobalanus*), chestnut oak (*Q. prinus* L.), white oak (*Q. alba* L.), hickory (*Carya* spp.), eastern white pine (*Pinus strobus* L.), red maple (*Acer rubrum* L.), pitch pine (*Pinus rigida* Miller), table mountain pine (*Pinus pungens* Lambert), Virginia, pine (*Pinus virginiana* Miller), sugar maple (*Acer saccharum* Marshall), eastern hemlock [*Tsuga canadensis* (L.)], and black locust (*Robinia pseudocacia* L.). Typical understory woody plants included mountain laurel (*Kalmia latifolia* L.), witch hazel (*Hamamelis virginiana* L.), eastern white pine, black gum (*Nyssa sylvatica* Marshall), red maple, striped maple (*Acer pennsylvanicum* L.), blueberry (*Vaccinium* spp.), serviceberry (*Amelanchier arborea* Michaux), and dogwoods (*Cornus* spp.).

An all weather rain gauge (28 cm high, 10.16 cm i.d.) was installed in each of the core plot to record precipitation.

Treatments. Treatments were applied in 1997 when white oak leaves had expanded to about one-fourth of their full length (*B.t.*: 17–19 May in the GWNF, 28–29 May in the MNF; Gypchek: 21–23 May in both forests). *Bacillus thuringiensis* variety *kurstaki* (Foray 48

Table 2. Treatment allocation of plots in the George Washington (GWNF) and Monongahela National Forests (MNF)

Arrangement of plots	GWNF									MNF								
Block	1			2			3			4			5			6		
Plot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Treatment	G	C	B	C	B	G	B	C	G	G	B	C	G	C	B	C	G	B

B, *B.t.*; C, control; G, Gypcheck.

F) was applied at the rate of 16 BIU (billion international units)/ha, and gypsy moth NPV (Gypchek) at the rate of 8×10^{10} PIB (polyhedral inclusion body)/ha.

Sampling Methods. Two sets of pitfall traps were deployed in different portions of each plot, a lower site (near a stream or a valley) and an upper site (on a ridge). At each site, nine traps were arranged in a 3 × 3-m grid (Martinat et al. 1993) in 1995. In 1996 and 1997, the arrangement was changed to six traps per site with the traps arranged in a circle 15 m in diameter (Punttila et al. 1991). The pooled weekly sample from a set of pitfall traps (nine in 1995, six in 1996 and 1997) was treated as one sample.

The design of the pitfall trap was similar to that introduced by Morrill (1975) with some improvements. Each pitfall trap contained an outer liner, a funnel, and an inner storage cup. The outer liner was a 454-ml plastic cup with a top diameter of 92 mm, bottom diameter of 60 mm, and a depth of 105 mm. The inner cup was a 100-ml capacity plastic cup, with a top diameter of 58 mm, bottom diameter of 48 mm, and a depth of 55 mm. The funnel rested in the top of the outer liner and extended down into the inner storage cup. Ants crawling into the trap fell through the funnel into the inner cup. The inner cup contained propylene glycol, which was a killing agent and preservative. This preservative is not known to either attract or repel ants, and it poses little threat to mammals if swallowed. For each trap, the whole set of cups was hung from the center hole of a wood board ring with 21.5 cm diameter. The wood ring was put flush with the ground, and its surface was covered with a thin layer of sand, which made its color and texture similar to that of the ground. The wood ring greatly reduced the amount of soil falling into the pitfall trap and made the sorting of the specimens much easier. The traps were covered by a clear plastic cover as a rain shield that was supported by metal wires. A large fence (1.5 m diameter, 80 cm high) was established around each pitfall trap in 1996 and 1997 to deter large animals. Specimens were collected by removing the rain shield and the funnel, lifting out the inner container, pouring the solution and specimens into a plastic bottle, adding new solution, and reassembling the parts. The outer liner was not disturbed during this procedure.

Pitfall traps were deployed in early May and operated continuously for 15 wk until mid-August each year. The traps were set up 1 wk before normal sampling to avoid a digging-in effect (Greenslade 1973) in 1997. Traps were examined and specimens were collected on Monday of every week. The sampling dates were noted as weeks 1 through 15 in the analysis (Table 3). Voucher specimens from the study were deposited in Natural History Museum of Los Angeles County, Los Angeles, CA.

Measurement of Ant Fauna. All ants were identified to species using Creighton (1950) and other reference materials. The following parameters were used to document the ant communities (Majer 1983): species richness, abundance, and species diversity index. Two species diversity indices were used: Shannon's H′ (Shannon and Weaver 1949):

$$H' = -\sum_{i=1}^{s} \frac{n_i}{n} \log \frac{n_i}{n},$$

and Hurlbert's probability of interspecific encounter (Hurlbert 1971, Washington 1984):

$$\text{PIE} = \frac{n}{n-1}\left(1 - \sum_{i=1}^{s}\left(\frac{n_i}{n}\right)^2\right),$$

where S is the number of species in a sample; n_i is the number of individuals belonging to species i; and n = the number of individuals in a sample from a population.

The PIE index is closely related to Simpson's D (Simpson 1949) in that

$$\text{PIE} = \frac{n}{n-1} - D \approx 1 - D,$$

where

$$D = \frac{\sum_{i=1}^{s} n_i(n_i - 1)}{n(n-1)}.$$

Statistical Analysis. Precipitation data were analyzed by analysis of variance (ANOVA) followed by the Tukey w procedure (also labeled honestly significant difference) (Steel et al. 1997). Cluster analysis was used to examine the species composition of ants. The unweighted pair-group average clustering method based on Euclidean distances was used in the cluster analysis. Ant abundance and species richness data were log-transformed before ANOVA to reduce variance. Mixed model ANOVA (PROC MIXED in SAS software) was used to explore the variance components (Littell et al. 1996, SAS Institute 1997). For ant abundance and species richness data, the "treatment," "week," and "treatment × week" are the fixed effects.

Table 3. Pitfall trap sampling dates

Week	Year		
	1995	1996	1997
1	8 May	6 May	5 May
2	15 May	13 May	12 May
3	22 May	20 May	19 May
4	29 May	27 May	26 May
5	5 June	3 June	2 June
6	12 June	10 June	9 June
7	19 June	17 June	16 June
8	26 June	24 June	23 June
9	3 July	1 July	30 June
10	10 July	8 July	7 July
11	17 July	15 July	14 July
12	24 July	22 July	21 July
13	31 July	29 July	28 July
14	7 Aug.	5 Aug.	4 Aug.
15	14 Aug.	12 Aug.	11 Aug.

Whereas, "block" and "block × treatment" are the random effects. Ant abundance from the two forests was analyzed separately because the "forest × treatment" effect has a small P value ($F = 3.32$; df = 2, 8; $P = 0.0893$), which indicates there is a trend of interaction between "forest" and "treatment." For ant species richness and diversity data, the two forests were combined in the analysis. The fixed effects are "forest," "treatment," and "forest × treatment." The random effects are "block" and "block × treatment." For ant species richness and abundance data, a repeated measurement occurred at each plot. We compared models in which "sampling date" was treated as a normal split, stripped split, and repeated measure with a first order autoregressive structure. The best simple model was selected based on a chi-square test ($P \leq 0.05$). For the three models, compute −2 times the logarithm of the maximized likelihood and compare the difference of these to a chi-square distribution. In each case, the model using a normal split plot structure was chosen. A two-tailed test was used because the ants may either increase as a result of the sudden abundance of dead caterpillars (possibly resulting from treatment effect) or decrease because of a lack of food supply as a result of a decrease in the caterpillar population. The alpha level for detecting the treatment effect was 0.05/2 = 0.025, because *B.t.* versus control and Gypchek versus control were simultaneously compared. The alpha level for detecting the annual changes was 0.05/3 = 0.017, because we made comparisons of the years 1995 versus 1996, 1996 versus 1997, and 1995 versus 1997, simultaneously. The cluster analysis was performed using STATISTICA software (StatSoft 1997). All other analyses were performed by SAS software (SAS Institute 1990, 1997).

Missing Data. A significant number of pitfall traps were disturbed by large animals in 1995 and 1996. The number of ants in a pooled sample was adjusted according to the number of traps disturbed and the degree of disturbance. If a trap was completely disturbed, the ant count was adjusted by 9/8 for 1995, and 6/5 for 1996 and 1997, because a sample consisted of nine traps in 1995 and six traps in 1996 and 1997. If a trap was partially disturbed, the count was adjusted by 9/8.5 for 1995, and 6/5.5 for 1996 and 1997. If the whole set of traps was totally disturbed (only occurred in 1995 and 1996), the sample was estimated by the average of ant counts from the other two plots of the same block. For example, if plot 10 upper site was totally disturbed, then plots 11 and 12 upper site data were used to estimate the ant abundance for plot 10 upper site. In the year of treatment (1997), little disturbance occurred because of the presence of large cages around each pitfall trap; therefore, instances of a whole set of traps being disturbed never occurred. Very few adjustments were made to 1997 samples. These adjustments were only gross estimates and could not provide information on the missing species composition. Therefore, the adjusted data were only used for abundance analysis, and were not suitable for analysis of diversity.

Table 4. A list of the ant species and their abundance collected by pitfall trapping methods from the George Washington (GWNF) and Monongahela National Forests (MNF) during 1995–1997

Ant species	Abundance		No. of plots where the species was trapped	
	GWNF	MNF	GWNF	MNF
Ponerinae				
Amblyopone pallipes (Haldeman)	35	17	8	7
Ponera pennsylvanica Buckley	6	1	2	1
Dolichoderinae				
Dolichoderus plagiatus (Mayr)	51	8	7	1
Tapinoma sessile (Say)	1,096	234	9	8
Myrmicinae				
Aphaenogaster rudis (Emery)	2,690	1,637	9	9
Crematogaster lineolata (Say)	162	8	9	2
Leptothorax curvispinosus Mayr	149	40	9	5
Leptothorax longispinosus Roger	57	51	9	7
Leptothorax schaumi Roger	2	1	2	1
Monomorium minimum (Buckley)	162	3	7	3
Myrmecina americana Emery	112	7	9	4
Myrmica n. sp. 1	2,362	307	8	6
Myrmica pinetorum Wheeler	3	1	3	1
Myrmica punctiventris Roger	1,867	1,404	9	7
Stenamma brevicorne (Mayr)	135	86	9	9
Tetramorium caespitum (L.)	0	2	0	1
Formicinae				
Brachymyrmex depilis Emery	12	0	4	0
Camponotus americanus Mayr	809	2	9	1
Camponotus chromaiodes Bolton	280	5	8	4
Camponotus nearcticus Emery	315	17	9	4
Camponotus pennsylvanicus (De Geer)	6,052	1,353	9	9
Camponotus subbarbatus Emery	887	19	9	4
Formica neogagates Emery	3,506	132	9	8
Formica nitidiventris Emery	36	8	5	1
Formica obscuriventris Mayr	353	71	9	6
Formica rubicunda Emery	4	0	4	0
Formica subsericea Say	904	135	9	8
Lasius alienus (Foerster)	951	348	9	9
Lasius nearcticus Wheeler	84	17	5	6
Lasius umbratus (Nylander)	1,376	39	9	8
Prenolepis imparis (Say)	1,317	4	9	3

Results

Precipitation. Precipitation at the study plots during the sampling season of 1995–1997 were 35.5, 42.8, and 24.9 cm, respectively. The year 1997 was a dry year, which had a significantly lower precipitation than that of 1995 and 1996. Whereas, 1996 was a wet year which had a higher precipitation than that of 1995 and 1997 ($F = 7.12$; df = 2, 51; $P = 0.0019$).

Ant Species Richness. During the 45 wk of pitfall trapping, we obtained 31,732 ants, belonging to 17 genera and 31 species (Table 4). Two species were unique to the GWNF plots: *Formica rubicunda* Emery, and *Brachymyrmex depilis* Emery. One species, *Tetramorium caespitum* (L.), was found only once in MNF plots.

The 1997 pitfall trap samples were used to compare the differences in ant species richness between treatment groups. Pitfall trap samples from the other 2 yr had too many disturbances and therefore were not considered for testing of pretreatment differences.

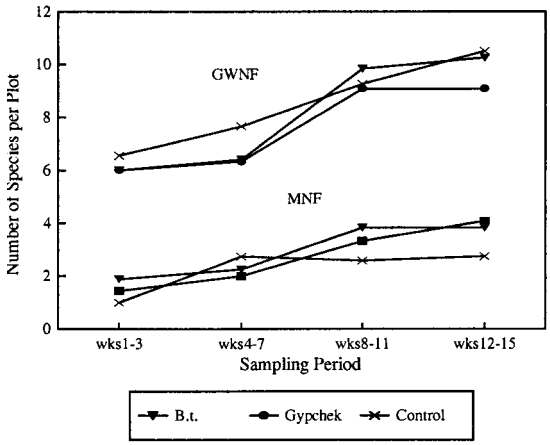

Fig. 1. Average ant species richness per plot in the George Washington (GWNF) and the Monongahela National Forests (MNF) from the 1997 pitfall trap collections before and after treatment with *B.t.* and Gypchek.

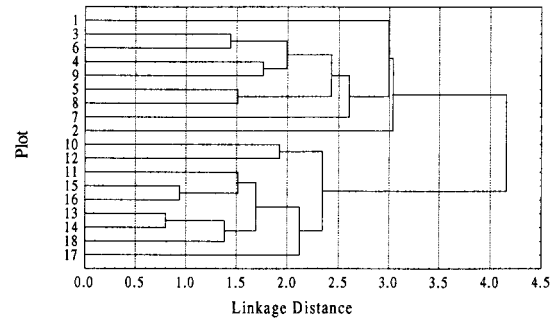

Fig. 2. Cluster analysis of ants from 1997 (weeks 4–15) pitfall traps based on the 17 most common species (>0.5%). Plots do not cluster according to treatment groups.

The number of species per plot from a one-week sample was usually very small (average <5 in MNF plots). Some plots had no ants for some sampling weeks. The species richness for each week is likely to vary greatly among plots and from week to week because of weather or sampling error. To reduce this variance, the average species richness per plot from four periods (sampling weeks 1–3, 4–7, 8–11, and 12–15) were used to analyze the treatment effect (Fig. 1). No treatment effect on ant species richness was detected ($F = 1.04$; df = 2, 8; $P = 0.3962$). The GWNF had higher species richness than the MNF ($F = 19.39$; df = 1, 4; $P = 0.0117$). The power of this experiment for detecting treatment effect can be indirectly checked by the standard error of the difference in treatment means. A minimum ratio of 1.22 between treatment and control would be detected as significant by the experiment, which indicates the experiment was fairly good in detecting the treatment effect on ant species richness.

Ant Species Composition. Species composition refers to a list of species and their relative abundance. If there was a treatment effect or site effects on some ant species, then there should be a change in the ant species composition in response to the variation in these factors.

The 17 most common ant species (>0.5%) from 1997 (weeks 4–15) pitfall traps were used to analyze the similarity in ant species composition between the plots. Cluster analysis of ant species composition (Fig. 2) showed two distinct groups: the GWNF plots and the MNF plots. The GWNF plots had more *Camponotus* spp., *Formica neogagates* Emery, *Tapinoma sessile* (Say), *Prenolepis imparis* (Say), and *Myrmica* n.sp.1 than the MNF plots. There is no clear grouping according to blocks or treatments as shown in Table 2. Because there were too many disturbed traps in 1995 and 1996, the data from these 2 yr were not used for testing pretreatment differences in species composition.

Ant Abundance. Because the number of ants per plot collected from a 1-wk sample was often small (often <10 in MNF plots), the number of ants per plot from four periods (sampling weeks 1–3, 4–7, 8–11, and 12–15) were used to analyze the treatment effect. Analysis methods were similar to that used for ant species richness except the two forests were analyzed separately. Ant abundance from 1997 pitfall traps did not show any significant differences between treatments and control before or after the treatment at both forests (Fig. 3; Table 5). The ant activity (as indicated by trap abundance) varied significantly through the sampling periods ($P = 0.001$) for both forests (Table 5). The minimum ratios between treatment and control that could be detected as significant are 4.28 for GWNF and 6.23 for MNF. The power of the test was rather low from these two numbers. This was caused by the large variance of the differences between treatments and control. Therefore, more

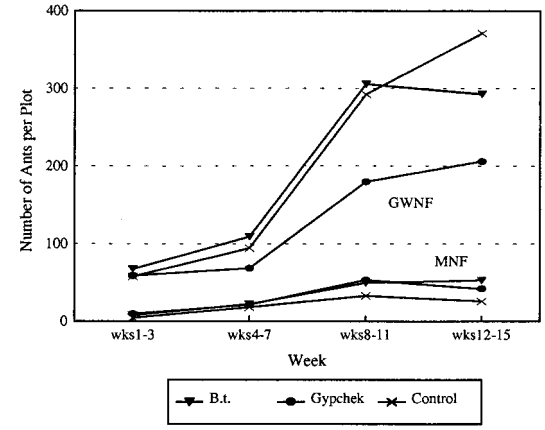

Fig. 3. Seasonal trend of ant activities in the George Washington (GWNF) and the Monongahela National Forests (MNF) from 1997 pitfall traps. Treatments were applied between sampling weeks 3 and 4.

Table 5. ANOVA for ant abundance collected in 1997 in the George Washington (GWNF) and Monongahela National Forests (MNF)

Effect	GWNF			MNF		
	F	df	*P*	*F*	df	*P*
Treatment	1.46	2, 4	0.3350	3.41	2, 4	0.1367
Period	80.09	3, 18	0.0001	19.43	3, 18	0.0001
Treatment × Period	0.79	6, 18	0.5906	0.26	6, 18	0.9494

plots are needed to increase the power of the test for ant abundance.

From Fig. 3 we can see a sudden increase in ant activities in GWNF plots after week 7 (middle June) in 1997. The ants collected in 1995 and 1996 did not show a similar increase around week 7 as in 1997. The year 1997 was unusual in that it was much colder than normal during the spring season (April–May). The lower catch before sampling week 7 (17 June) might have been caused by the unusually low temperature which delayed the ant activity.

Ant Species Diversity Indices. The ant diversity indices of each plot calculated from 1997 posttreatment samples (weeks 4–15) ranged from 0.62 to 1.09 for Shannon's H′ and from 0.55 to 0.91 for Hurlbert's PIE. No significant differences in diversity indices between treatment and control were shown by either Shannon's H′ ($F = 0.18$; df = 2, 8; $P = 0.8384$) or Hurlbert's PIE ($F = 0.25$; df = 2, 8; $P = 0.7874$). The minimum ratios between treatment and control that could be detected as significant are 1.38 for Shannon's H′ and 1.24 for Hurlbert's PIE. These numbers are close to 1 and the power of the test is fairly high. The ant diversity index H′ in GWNF was significantly higher than that of MNF ($F = 8.64$; df = 1, 4; $P = 0.0424$).

Comparison Over Years. The evenness of the species distribution is indicated by the slope of the dominance diversity curve. The three dominance diversity curves of ants from 1995 to 1997 pitfall sampling were very similar (Fig. 4). The curves showed a decrease in species richness during 1995–1997. The reduction in species richness was mainly caused by the loss of the rarely encountered species, each with a total count of <20 during 45 wk of sampling. Four species that were present in the 1995 trapping season did not appear in 1996: *Formica rubicunda* Emery, *Tetramorium caespitum* (L.), *Myrmica pinetorum* Wheeler, and *Leptothorax schaumi* Roger. Two species, *Formica nitidiventris* Emery and *Ponera pennsylvanica* Buckley, that were present in the 1996 trapping season did not appear in 1997.

The abundance of ants (after adjustment for disturbance) decreased significantly from 1996 to 1997 (GWNF: $F = 7.54$; df = 2, 24; $P = 0.0029$. MNF: $F = 15.29$; df = 2, 24; $P < 0.0001$) (Fig. 5). The decrease was mainly expressed by reduction in abundance of eight ant species (Fig. 6): species 4, 5, 6, 7, 9, 10, 11, and 12. Their numbers decreased significantly after 2 yr of pitfall trapping.

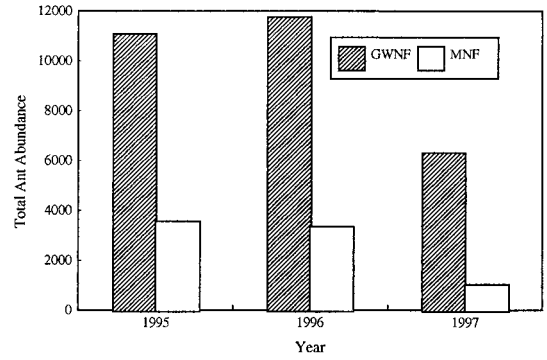

Fig. 5. Annual changes in ant abundance from pitfall traps in the George Washington (GWNF) and the Monongahela National Forests (MNF) during 1995–1997.

Discussion

We conclude that the application of *B.t.* and Gypchek microbial pesticides did not affect the spe-

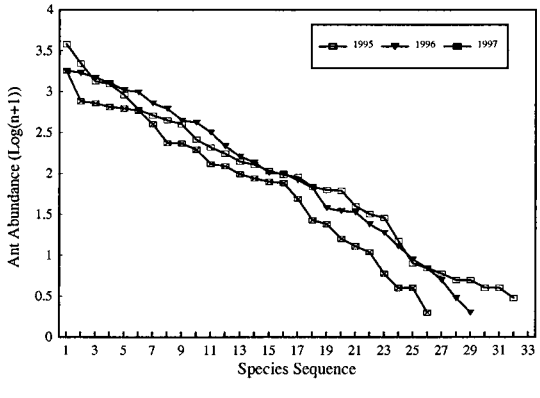

Fig. 4. The dominance diversity curves of ants from pitfall traps during 1995–1997. Species sequence was from the most abundant to the least abundant species.

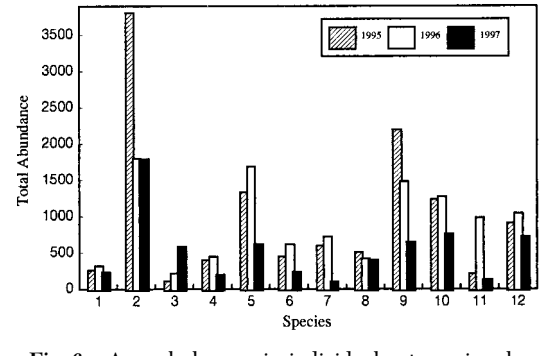

Fig. 6. Annual changes in individual ant species abundance from pitfall traps during 1995–1997. Species with a total abundance of <500 are not displayed. (1) *C. americanus.* (2) *C. pennsylvanicus.* (3) *C. subbarbatus.* (4) *F. subsericea.* (5) *F. neogagates.* (6) *L. alienus.* (7) *L. umbratus.* (8) *T. sessile.* (9) *A. rudis.* (10) *M. punctiventris.* (11) *P. imparis.* (12) *M.* n.sp. 1.

cies richness, species composition, and diversity of ants. Although no treatment effect was detected on ant abundance, the power of this test was low and more studies are needed to address this aspect. In a similar study in Coopers Rock State Forest near Morgantown, WV (Progar 1995), ant abundance was not affected after *B.t.* application to control gypsy moth as determined from pitfall trap sampling. In our study, there was a significant reduction in the caterpillar populations (unpublished data) in the *B.t.* treated plots for several weeks after treatment. Their reduction did not result in significant changes in ant species richness and diversity. As we had predicted, the Gypchek treatment did not have a significant impact on ants. Because the virus only affects gypsy moth (Barber et al. 1993), any impact on ants would be an indirect influence from the reduction of defoliation from gypsy moth or the sudden increase in dead gypsy moth larvae. At the time of treatment though, the gypsy moth caterpillar population was also extremely low. Therefore, the anticipated increase in dead gypsy moth caterpillars among the treated plots was not distinct after the treatment.

Species diversity is a parameter of community structure involving species and their abundance for the taxa. The need to combine species number and evenness components into one index has propelled the emergence of various diversity indices. In this paper, two species diversity indices were used for comparison: Shannon's H′ and Hurlbert's PIE. Shannon's H′ is the most widely used index. The use of PIE was supported in a review by Washington (1984). These two indices calculated for ants collected by 1997 pitfall traps showed they were generally similar, but there were some differences in ranking. The PIE was consistently lower than H′ for all GWNF plots from pitfall trap samples, whereas PIE was usually higher than H′ in the MNF plots. It should be noted that the MNF had lower species richness and abundance. Therefore, PIE tends to have smaller values when the species richness is higher. The diversity index measurement H′ is a more sensitive index than PIE.

Samples in 1997 had significantly fewer ants than in previous years. One possible explanation is that 1997 was much drier than 1995 and 1996 during the sampling season. However, most species of ants have a strong ability to adapt to weather changes by modifying their nest and behavior. Therefore, a season's decrease in rainfall may not cause immediate change in ant populations. Another possible explanation for lower 1997 ant abundance was that human activities around the traps once every week might have repelled some ants; however, human activities affect ants in both ways. Ants could also increase their activities around the traps because of smoother ground surface, or increased food resources such as dead arthropods. The other more reasonable explanation is the over-trapping effect. An average of 343 ants were killed each year at each pitfall site (9 traps in 1995 and six traps in 1996 and 1997). The eight most affected species (coded 4–7 and 9–12 in Fig. 6) were trapped at abundances of 203, 209, and 95, respectively, at each pitfall site during 1995–1997 by pitfall traps (45 wk of sampling). The ant populations living near the pitfall trap sites probably did not recover after two sampling seasons (30 wk) of trapping and killing. Over-trapping by pitfall traps has been recorded by Haverfield (1965) for tenebrionids. The females fell in traps and produced a pheromone that attracted the males. Thomas and Sleeper (1977) discussed over-trapping of beetles as a result of their behavior to seek a cool, shady crevice or burrow to escape heat of the day.

The results shown here were based on the data from three sampling years. As a part of a long-term nontarget study, the pitfall trap sampling of arthropods will be continued for several more years. Further sampling and analysis will be beneficial to a better understanding of whether over-trapping and/or weather have effects on ant communities.

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