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IMPACT OF ORCHARD VEGETATION MANAGEMENT ON SMALL MAMMAL POPULATION DYNAMICS AND SPECIES DIVERSITY

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ABSTRACT: Voles of the genus *Microtus* feed on bark and vascular tissues of trees in fruit orchards across North America. Management of orchard floor vegetation with multiple applications of herbicide effectively altered habitat and reduced montane vole (*M. montanus*) populations in apple orchards near Summerland, British Columbia, Canada. Non-target populations of deer mice (*Peromyscus maniculatus*), northwestern chipmunks (*Tamias amoenus*), and Great Basin pocket mice (*Perognathus parvus*) appeared to respond positively to the treatment units. None of these non-target species was adversely affected by the actual herbicide treatments. Species diversity of small mammal communities in treated orchards was the same as that in untreated orchards and nearby old fields. Orchard agroecosystems with intensive vegetation management regimes appear to maintain diverse non-target small mammal communities.

KEY WORDS: agroecosystem, deer mouse, feeding damage, herbicide, northwestern chipmunk, orchards, population dynamics, species diversity, vegetation management, voles

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INTRODUCTION

Voles of the genus *Microtus* feed on bark and vascular tissues of trees in fruit orchards across North America (Byers 1984, 1985). This damage occurs primarily during winter periods when voles de-bark and girdle stems and roots of fruit trees, particularly apple (*Malus domestica*). Feeding damage may result in direct tree mortality from complete girdling of the stem or reduced growth and yield from sublethal feeding attacks (Pearson and Forsley 1978). Habitat alteration by vegetation control in orchards is one method for effectively reducing vole populations and damage (Byers and Young 1974, 1978; Sullivan and Hogue 1987).

Intensive management of forest and agricultural crops often involves use of herbicide treatments for control of competing vegetation. In coniferous forests of North America, herbicides are usually applied only once (usually within the first 10 years after regeneration of cutovers) in the rotation, which may be 40 to 80 years depending on forest type and growing conditions. Alternatively, herbicides are routinely applied several times on an annual basis in many agricultural systems. This pattern occurs in tree fruit orchards where herbicide is sprayed along tree rows three to four times per year.

Clearly, the herbicide load in orchards, for example, would be substantially higher than that in forest plantations. A variety of small mammal species live in both the forest and orchard ecosystems where herbicides are used. The majority of studies investigating the direct effects of herbicides on demographic parameters in small mammal populations have been conducted in forests treated with glyphosate (Roundup® or Vision® herbicide by Monsanto, a commercial formulation containing 356 g/L present as isopropylamine salt). Small mammals could come in direct contact with a herbicide during application or from ingestion of treated vegetation (seeds, fruits, vegetative parts) or invertebrates that contain chemical residues (Sullivan 1990a). Low level residues of glyphosate herbicide do appear in herbivorous mammals for a short period after treatment (Newton et al. 1984). However, field studies, to date, indicate no adverse effects of a single forest application of glyphosate herbicide on demographic parameters in deer mice (*Peromyscus maniculatus*), Oregon voles (*Microtus oregoni*), or southern red-backed voles (*Clethrionomys gapperi*) (Sullivan and Sullivan 1981; Sullivan 1990a; Runciman and Sullivan 1996; Sullivan et al. 1998a).

In addition, species diversity of small mammal communities appears to be unaffected by forest herbicide use, either on a short-term (five years) (Sullivan et al. 1998b) or long-term (ten years) (Sullivan et al. 1997) basis. Intriguing follow-up questions to these studies are: 1) what would be the influence of multiple applications of glyphosate on demographic parameters such as reproduction, growth, and survival in small mammals?; and 2) what would be the effect on species diversity of small mammal communities? To address this question in a comprehensive manner, two essential experimental conditions are required. There must be an intensive sampling regime providing time-series population data in control and treatment areas, and small mammal species must persist in treatment areas despite herbicide-induced changes in habitat. For example, Sullivan and Hogue (1987) reported a highly significant reduction in montane (*Microtus montanus*) and meadow vole (*M. pennsylvanicus*) populations in response to orchard floor management with glyphosate. Since voles are generally very susceptible to changes in vegetative food and cover, this was a predictable result. Furthermore, these particular species would not be suitable for a detailed analysis of herbicide effects on demographic parameters. However, as reported by Sullivan et al. (1998c), numbers of the deer mouse and northwestern chipmunk (*Tamias amoenus*) were either little affected by, or responded favorably to, habitat change in these apple orchards.

The major objectives of this paper are to report on: 1) the demographic responses of non-target small mammal species to multiple applications of glyphosate in orchards; and 2) changes in small mammal species diversity in treated and untreated orchards and nearby old fields.

METHODS

Study Areas

This study was conducted at the Pacific Agri-Food Research Center in the Okanagan Valley, Summerland, B.C., Canada. The experimental design consisted of two replicate apple orchards: (A) a 5-year-old (0.26-ha) orchard composed of "Delicious" and "Golden Delicious" cultivars on M.26 rootstock at a spacing of 3 x 4 m; and (B) a 15-year-old orchard (0.25 ha) composed of "Spartan" trees on MM.111 rootstock and a spacing of 3 x 5 m. Montane voles, deer mice, chipmunks and Great Basin pocket mice (*Perognathus parvus*) were present in these study areas. Each of these two orchards was divided into four (two control and two treatment) units. Common grass species on these study areas included orchard grass (*Dactylis glomerata*), quack grass (*Agropyron repens*), bluegrass (*Poa* spp.), smooth brome (*Bromus intermis*), and crested wheatgrass (*Agropyron cristatum*). These orchards were mowed five or six times each summer.

Two nearby "old field" habitats were abandoned (≥25 years) hay fields composed of crested wheatgrass, quack grass, downy brome (*Bromus tectorum*), diffuse knapweed (*Centaurea diffusa*), with some minor herbaceous species such as yellow salsify (*Tragopogon dubius*), great mullein (*Verbascum thapsus*), American vetch (*Vicia americana*), prickly lettuce (*Lactuca serriola*), and tall tumble-mustard (*Sisymbrium altissimum*). These old field treatment units were each 2 to 3 ha in area within a mosaic of sagebrush (*Artemisia tridentata*), Ponderosa pine (*Pinus ponderosa*) forest, and orchard habitats. These old fields had resident populations of montane voles and deer mice which were the major rodent species. Less common species included the northwestern chipmunk, Great Basin pocket mouse, long-tailed vole (*M. longicaudus*), and western harvest mouse (*Reithrodontomys megalotis*).

Thus, there were two replicates of each of the orchard control (untreated), orchard herbicide (treated), and old field habitats. These old field habitats were included for comparison of species diversity of the small mammal communities.

Application of Herbicide

Glyphosate herbicide was applied (1.5 kg/ha a.i.) to the total orchard floor on the two contiguous treatment blocks in each orchard in July and September 1983 and May, July, and September 1984 and 1985. In general, all grass and annual plant cover was eliminated on tree rows and panels in treatment units (see Sullivan et al. 1998c). This study was conducted within the period May 1983 to March 1986. Small mammal populations were evaluated during six periods: summer 1983 (immediate post-treatment) (July to September), winter 1983-84 (October to March), summer 1984 (April to September), winter 1984-85 (October to March), summer 1985 (April to September), and winter 1985-86 (October to March).

Small Mammal Populations

All deer mice and chipmunks were live-trapped on checkerboard grids with Longworth live-traps. Contiguous control and treatment grids were used with populations represented by two control or two treatment units in each orchard. The 5-year-old orchard (A) had a rectangular grid of 48 (3 x 16) trap stations and the 15-year-old orchard (B) had an irregular-shaped grid with 40 trap stations. Stations for animals were located every 7.6 m with one live-trap per station. Two traps were placed at each station adjacent to a control-treatment boundary. This latter design provided an excess of available traps for animals at habitat boundaries so that they were most likely to be captured in their preferred habitat.

Traps were baited with whole oats, peanut butter, and carrot; coarse brown cotton was supplied as bedding. Traps were set on day 1, checked on the morning and afternoon of day 2 and morning of day 3, and then locked open between trapping periods. All animals captured were ear-tagged with serially numbered tags, breeding condition noted, weighed on Pesola spring balances, and point of capture recorded. These populations were monitored at three-week intervals in spring, summer, and fall, and at four-week or irregular (depending on weather conditions) intervals in winter.

The duration of the breeding season was noted by palpation of male testes and the condition of mammaries of the females (Krebs et al. 1969). A pregnancy was considered successful if a female was lactating during the period following the estimated time of birth of a litter. Animals were released on the grids immediately after processing.

We used age at sexual maturity to determine age classes of animals. Body weight was used as an index of age. The percentage of sexually mature animals was used to determine the weight limitations for juveniles, subadults, and adults assuming that juveniles were seldom, if ever, sexually mature; that <50% of the subadults in the upper weight class were mature; and that at least 50% of the adults were sexually mature in the lowest weight class. Animals were classified as juvenile (includes juvenile and subadult classes pooled) or adult by body weight (deer mice: juvenile = 1 to 20 g, adult ≥21 g; chipmunks: juvenile = 1 to 44 g, adult ≥45 g). Juveniles were considered to be young animals recruited during the study. Recruits were defined as new animals that entered the population through reproduction and immigration.

Demographic Analysis

Measurements of recruitment, number of successful pregnancies, and early juvenile survival were derived from the sample of animals captured in each trapping session and then summed for summer and winter periods. Early juvenile survival is an index relating recruitment of young into the trappable population to the number of lactating females (Krebs 1966). A modified version of this index is number of juvenile animals at week t divided by the number of females with large nipples caught in week *t*-3. Survival rates (28-day) were estimated from the Jolly-Seber model (Seber 1982) and are represented by mean values ($n=2$).

Mean body weights of combined males and females, with 95% confidence intervals, were used as an index of condition within populations of deer mice and chipmunks. Mean weights were evaluated for summer and winter periods for deer mice and for summer periods only for chipmunks, since these sciurids hibernate during winter months.

Diversity Measurements

Species diversity was measured by Simpson's index of diversity (Simpson 1949) which is sensitive to changes in the more abundant species. The Shannon-Wiener index of diversity (Pielou 1966) was also used because it is sensitive to changes in the rare species in a community sample. These diversity measures were calculated using Jolly-Seber population estimates for the common species and number of individuals captured for the less abundant species. These values were calculated for each trapping period and were then averaged for each summer and winter period.

Statistical Analysis

This study had a randomized block experimental design which incorporated both spatial ($n=2$ experimental units) and temporal replication ($n=3$ years) for a total of 6 replicates. A randomized block ANOVA (Zar 1984) was conducted to test differences between control and treatment populations for mean number of successful pregnancies and mean index of early juvenile survival during summer periods, and mean number of recruits and mean J-S survival in each of the summer and winter periods for deer mice and northwestern chipmunks. This same analysis was used to compare measurements of species diversity for the small mammal communities during summer and winter periods for the treated orchards, untreated orchards, and nearby old fields.

Mean body weights with 95% confidence intervals were used to compare control and treatment populations of deer mice and chipmunks. Percentage data were arcsine transformed prior to analysis. In all analyses, the level of significance was $P=0.05$.

RESULTS AND DISCUSSION

Population Dynamics

Recruitment of new animals was significantly ($F_{1,5}=15.41$; $P=0.01$) higher in treatment than control populations of chipmunks during summer periods (Table 1). Recruitment of new deer mice also followed this pattern but the difference between control and treatment populations was not statistically significant ($F_{1,5}=6.00$; $P=0.06$) in summer, but was significant ($F_{1,5}=8.25$; $P=0.03$) in winter periods. Mean number of successful pregnancies and mean index of early juvenile survival were similar between control and treatment populations for both deer mice and chipmunks (Table 2).

Table 1. Mean ($n=2$) numbers of recruits in control and treatment populations of deer mice and northwestern chipmunks during summer and winter periods. Number of trapping periods in parentheses.

	Deer Mice		Northwestern Chipmunks		
Period	Control	Treatment	Control	Treatment	Analysis
Summer 1983 (5)	10.5	12.0	10.0	18.0	Summer Deer Mice $F_{1,5}=6.00$ $P=0.06$
Winter 1983-84 (7)	13.5	15.5	-	-	Chipmunks $F_{1,5}=15.41$ $P=0.01$
Summer 1984 (9)	40.0	49.0	13.0	33.0	
Winter 1984-85 (6)	7.5	16.5	-	-	Winter Deer Mice $F_{1,5}=8.25$ $P=0.03$
Summer 1985 (9)	13.0	26.0	1.5	7.0	
Winter 1985-86 (5)	8.5	19.0	-	-	

Table 2. Mean ($n=2$) number of successful pregnancies and index of early juvenile survival in control and treatment populations of deer mice and northwestern chipmunks during breeding periods each year. Number of trapping periods in parentheses.

Period		Deer Mice		Northwestern Chipmunks		
		Control	Treatment	Control	Treatment	Analysis
Successful Pregnancies						
1983	(5)	1.0	2.5	0.5	0.0	Deer Mice $F_{1,5}=4.97$ $P=0.08$
1984	(9)	14.5	18.5	3.0	6.5	Chipmunks $F_{1,5}=1.40$ $P=0.29$
1985	(9)	4.5	12.0	3.0	5.0	
Juvenile Survival						
1983	(5)	3.50	2.92	0.0	0.0	Deer Mice $F_{1,5}=1.43$ $P=0.29$
1984	(9)	2.14	1.84	0.17	0.23	Chipmunks $F_{1,5}=0.53$ $P=0.05$
1985	(9)	3.15	1.93	0.50	0.20	

Mean J-S survival was similar in control and treatment populations of deer mice during summer ($F_{1,5}=0.01$; $P=0.92$) and winter ($F_{1,5}=2.58$; $P=0.17$) periods. A similar result was recorded for chipmunk populations in summer ($F_{1,5}=0.33$; $P=0.59$) and winter periods ($F_{1,5}=1.91$; $P=0.23$) (Figure 1). Mean body weights of deer mice and chipmunks were also similar in control and treatment populations across summer and winter periods (Figures 2 and 3).

These detailed results of population dynamics of deer mice in control and herbicide-treated habitats are similar to those reported by Sullivan and Sullivan (1981), Sullivan (1990a), and Runciman and Sullivan (1996) in coniferous forest habitats. The major difference between this study and the earlier reports is that glyphosate herbicide was applied only once in the forest habitats, whereas it was applied eight times in our orchard habitats over a three-year period. Our study is the first detailed report on demographic responses of chipmunks to herbicide treatments. Sullivan (1990b) reported no difference in proportion of breeding Townsend's chipmunks (*T. townsendii*) between control and treatment populations in coastal coniferous forest, however, abundance of chipmunks appeared to decline after treatment. That result contrasts with the lack of change recorded by Black and Hooven (1974) and Anthony and Morrison (1985), and the increase in numbers of chipmunks reported by Savidge (1978) and Sullivan et al. (1998c).

Species Diversity

Species diversity of small mammal communities was similar among treatments during summer (Simpson's: $F_{2,10}=0.40$; $P=0.68$; and Shannon-Wiener: $F_{2,10}=0.12$; $P=0.89$) and winter (Simpson's: $F_{2,10}=0.44$; $P=0.64$, and Shannon-Wiener: $F_{2,10}=0.66$; $P=0.54$) periods (Figure 4).

MANAGEMENT IMPLICATIONS

Vegetation management in apple orchards is an effective method of habitat alteration to reduce populations of montane voles. It seems most likely that vole populations declined due to lack of food and cover rather than any adverse effect from multiple applications of glyphosate herbicide. This conclusion is based on the similar responses of demographic parameters of reproduction, recruitment, survival, and body weights in control and treatment populations of deer mice and northwestern chipmunks. This study is the first detailed evaluation of the effects of intensive herbicide use on small mammals in an orchard agro-ecosystem.

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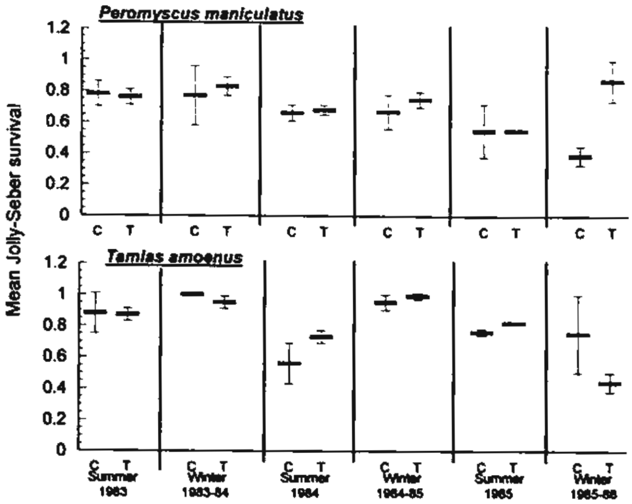

Figure 1. Mean (n=2) 28-day Jolly-Seber survival rates ± SE for control and treatment populations of *Peromyscus manicalatus* and *Tamias amoenus* during summer and winter periods. C=control; T=treatment.

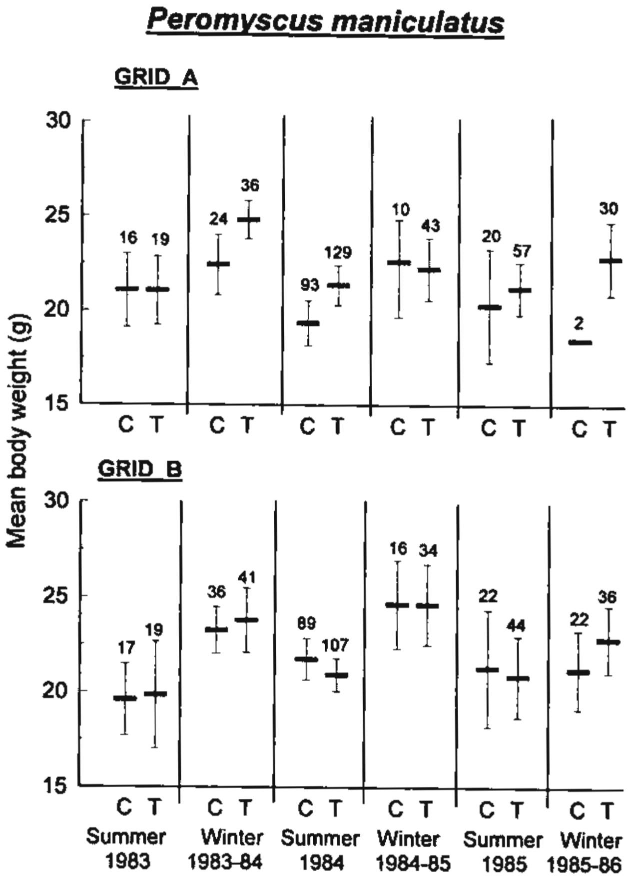

Figure 2. Mean body weights (g) ± 95% confidence intervals for control and treatment populations of *Peromyscus maniculatus* in each of the two replicate orchards during summer and winter periods. Sample size is given above the upper confidence limit. C=control; T=treatment.

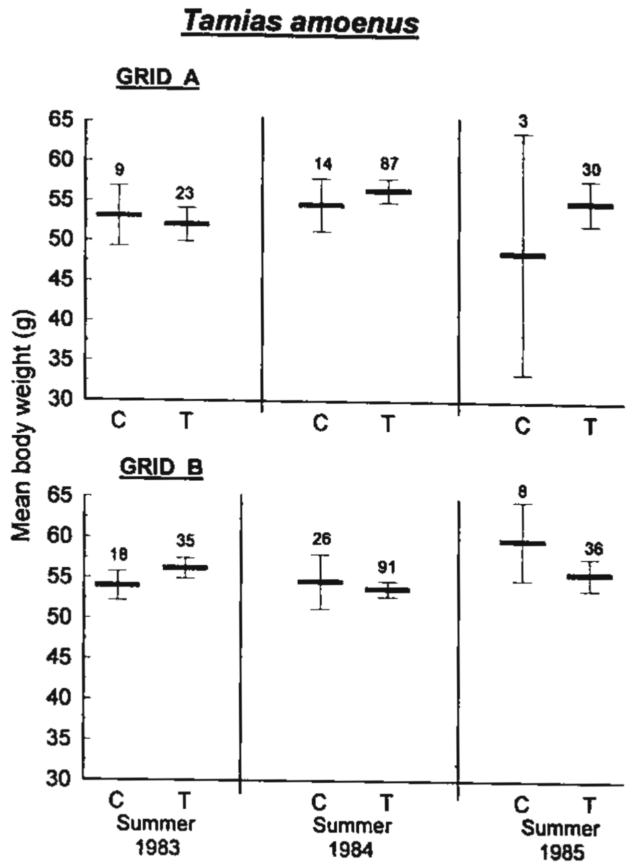

Figure 3. Mean body weights (g) ± 95% confidence intervals for control and treatment populations of *Tamias amoenus* in each of the two replicate orchards during summer periods. Sample size is given above the upper confidence limit. C=control; T=treatment.

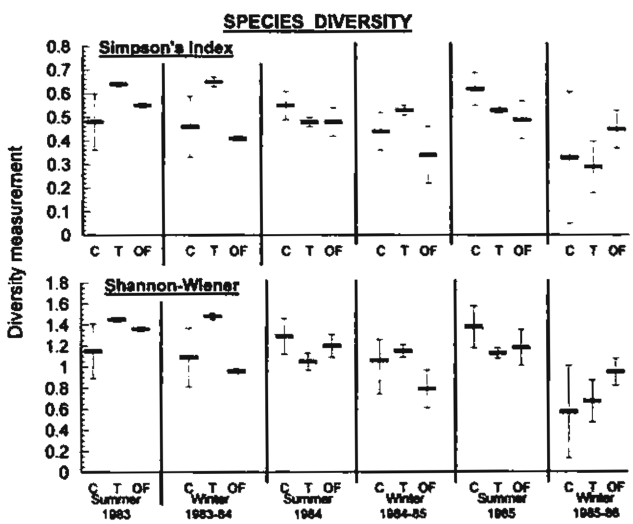

Figure 4. Mean (n=2±SE) species diversity measurements for orchard control, orchard treatment, and old field habitats during summer and winter periods. C=control; T=treatment; OF=old field.

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