March 1982

Proceedings of the Sixth Eastern Pine and Meadow Vole Symposium, March 10-12, 1982 (Complete Proceedings)

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Harpers Ferry, WV

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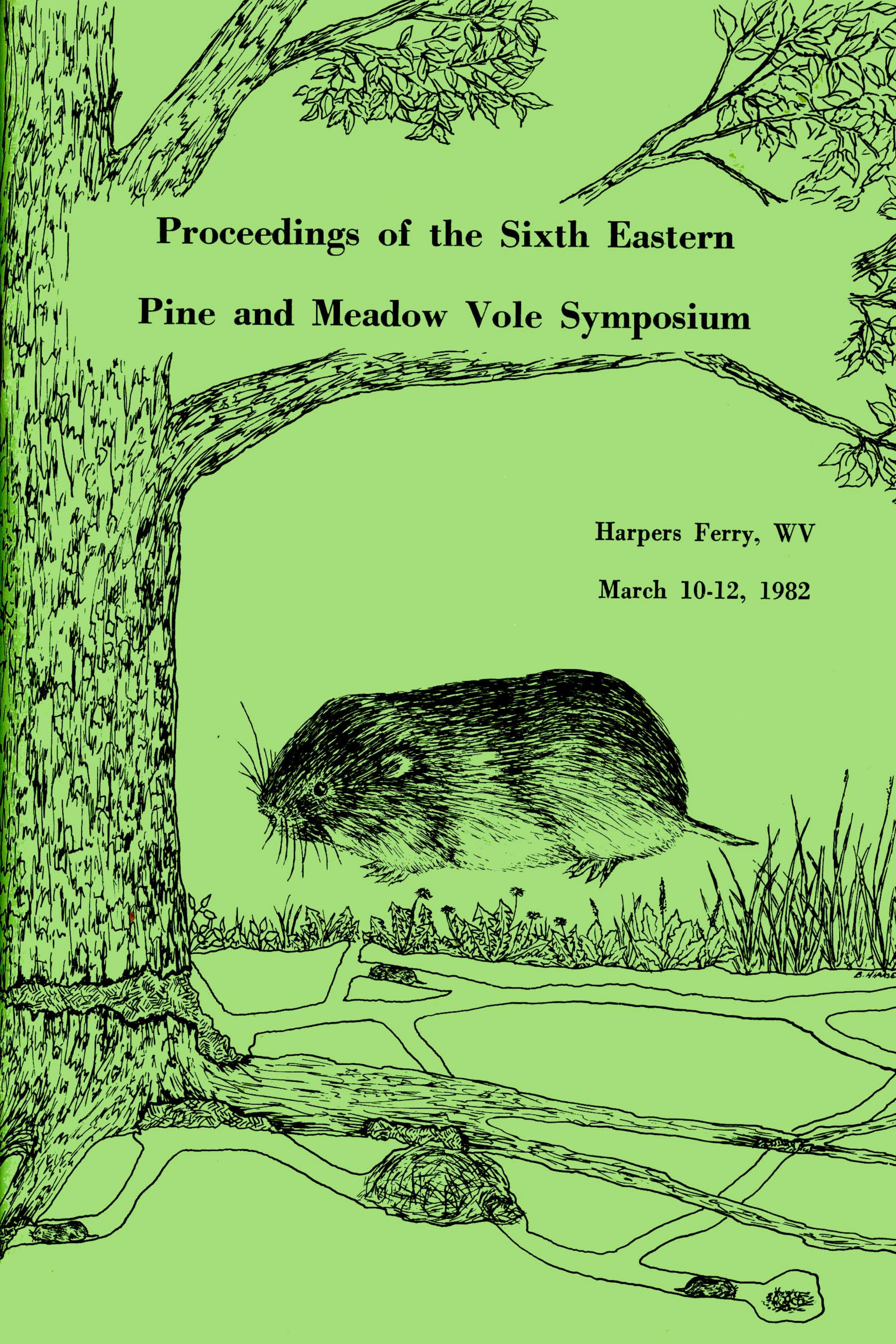

PROCEEDINGS OF THE SIXTH EASTERN PINE AND MEADOW VOLE SYMPOSIUM

Harpers Ferry, WV

March 10-12, 1982

EDITOR

ROSS E. BYERS

CONTENTS

SESSION II. RESEARCH PROGRAMS

Editor's note: The papers in the Proceedings appear as originally written.

HIGHLIGHTS OF THE SIXTH EASTERN PINE AND MEADOW VOLE SYMPOSIUM

The Sixth Eastern Pine and Meadow Vole Symposium was held at the Cliffside Inn, Box 786, Harpers Ferry, West Virginia 25425, March 10-12, 1982, for the purpose of assessing the current status of research, extension, and industry programs relating to the problem of vole damage to fruit trees. The meeting was intended to create a problem solving atmosphere in which growers; various governmental agencies such as EPA, USDA, USDI; the chemical industry; and university personnel could observe the current thrusts of research and extension programs and their potential impact on future control strategies.

By the 1982 meeting the influence of the USDI contract monies for pine and meadow vole research had been effective. Both the quality and quantity of research papers was increased. Information relating to the ecology, behavior, physiology, movements, population monitoring, reproduction, and control methodology of these animals had been generated by the various research groups. The meeting provided an excellent opportunity for various research groups to interact and to assimilate the meaning of various research programs with regard to vole damage control.

The orchard tour prior to the meetings emphasized differences in ground covers, soil types, and vole populations under various cultural management programs. Of particular interest were the wide-band, bare soil culture created with herbicide and cultivation methods. These methods combined with limited hand baiting or no treatment were reported to have adequately controlled both pine and meadow voles. The excellent tour and local arrangements were made by Dr. Roger S. Young, Research Pomologist with the West Virginia University, who is stationed at the University Research Farm at Kearneysville, West Virginia.

In all, the Sixth Eastern Pine and Meadow Vole Symposium was probably one of the most important symposia to date. The quality of the presentations was impressive and data represented useful and much needed information. What was more gratifying was the productive exchange of information and ideas which went on "after hours" between the researchers, extension personnel, growers, and chemical representatives throughout the symposium. The cooperative spirit of those involved in vole biology research, damage control and the support offered by USDI funding were certainly responsible for increased understanding of the vole control problem.

1982 VOLE SYMPOSIUM
WEST VIRGINIA ORCHARD TOUR

Roger S. Young
West Virginia University Experiment Farm
Kearneysville, WV 25430

Warm Springs Orchard - Robert W. Butler

The orchard was planted in 1963 in an old orchard site where voles were present. The toxicant endrin as a spray has been applied on a yearly basis for vole control through 1976. During 1977-1978 broadcast baiting failed to control the vole population. Under tree cultivation was started in 1979. A spring cultivation was followed by herbicide treatments. Fall cultivations were followed by baiting of runs and breather holes. Two complete hand placement baiting were made during the November-December period and again during the February-March period. The toxicant used during these baiting periods has been rotated between diphacinone (Ramik-brown), chlorophacinone (Rozol) and more recently zinc phosphide pelleted bait (ZP pellet from Bell Lab.). The vole management system employed since 1979 has appeared to be giving satisfactory control at this time. A high vole population seems to still be present in some locations.

Swan Pond Orchard - William Kilmer

Started in 1953 with an orchard past its prime age of production and with a high vole population. Endrin sprays and hand baid placement was practiced. Renovation of the orchard was started with new plantings having better cultural-management practices. More frequent mowings and the use of herbicides were practiced. A year around complete weed free 8-10 ft. band has been practiced since the late 1960's. Up to 1970, yearly application of endrin was applied to the entire orchard. From 1970 to 1973 only the perimeters, fence rows and rock breaks were treated since vole populations had been considerably reduced. Since 1973, no toxicants have been used for vole control. Very effective year around weed control under the trees, frequent mowings to keep the vegetation less than 10 inches in height and other good sanitation practices are attributed to the lack of voles present in this completely replanted orchard location.

Lewis Brother Orchard - Charles and Otho Lewis

Toxicant endrin sprays have been applied from the mid-1950's to 1975 on a yearly basis for vole control. Endrin was not holding down vole activity. In 1976, liquid chlorophacinone (Rozol) gave very excellent control, but the 1977 application was a complete failure, possibly due to heavy rainfall following the application.

Endrin was again used in 1978 through 1980, but vole activity was not effectively reduced.

In 1981, chlorophacinone at 12 lb. /A was hand baited on the basis of 2 oz. /tree at two locations for tree spacings of 18 feet and 4 oz. /tree for 36-40 foot tree spacings. This system has given excellent vole control. Chlorophacinone and ZP pellets were applied broadcast at 10 and 20 lbs. /acre rates but have not given very good results. Mouseterrias have been used and are most effective for meadow vole control but poor for pine vole control.

A CURRENT ASSESSMENT OF VOLE DAMAGE AND NUMBERS AND OF METHODS USED TO CONTROL VOLES IN ONTARIO APPLE ORCHARDS

Ronald J. Brooks and Stephen A. Struger
Department of Zoology
University of Guelph
Guelph, Ontario
N1G 2W1
Canada

Abstract. A province-wide evaluation of the amount, distribution, source and control of damage to Ontario apple trees was initiated. Data were obtained from 280 responses to a questionnaire distributed to growers across Ontario, and from trap censuses in three widely separated areas. Meadow voles (*Microtus pennsylvanicus*) damaged or destroyed 8,423 trees in our questionnaire sample and other mammals damaged another 10,307 trees. No relationship was found between application of rodenticide and levels of damage, but rodenticide-treated baits sharply reduced numbers of voles on our trap plots. Orchards with high levels of damage were on average only one-third as large as the average orchard in our total sample. All damage by voles appeared to be caused by meadow voles and no pine voles (*M. pinetorum*) were found. Numbers of voles varied greatly among our three study areas. Future work will concentrate on factors causing high levels of damage and on the relationship between dispersal of voles and the effects of rodenticide treatment.

Introduction

In Ontario, there has been very little systematic research into the amount and control of damage caused by herbivorous mammals in apple orchards, despite abundant evidence from growers that this damage is extensive and costly (Brooks and Schwarzkopf 1981). In 1981, Ontario growers sought to support a research program that would determine the amount of damage caused by voles and that would develop more economical and effective control measures than those that exist now.

In September 1981, we initiated a four-year research program. The objectives of the first phase of this research were:

1. To identify the mammalian species causing damage to Ontario fruit trees.
2. To quantify the extent of mammalian pest damage in Ontario.
3. To assess the nature and effectiveness of current management and control practices.
4. Using trapping techniques, to estimate densities of voles in orchards in three areas of the province.

From information obtained during this initial phase, we have formulated research plans directed toward the long-term goals of the project. Specifically, these goals are to develop recommendations to advise growers on cost and labor-efficient methods to reduce tree damage by rodents and, within these constraints, to recommend methods that minimize the use of toxicants in control.

Methods and Materials

1. Questionnaire

In September 1981, questionnaires were distributed by mail to 1100 apple growers in Ontario. These questionnaires provided information on: (a) tree composition (i.e., number, age, variety, etc.) and size of the orchard; (b) methods (i.e., timing, and frequency of use of herbicides, rodenticides, mowing, cultivation, etc.) of habitat management and rodent pest control used by growers; (c) amount of damage inflicted on trees by mammalian pests; and (d) general location of the orchard, depth of winter snow cover and other factors.

Returned questionnaires (280) were allocated to four regions (Fig. 1).

A. Lake Erie = all counties bordering on Lake Erie

B. Central Ontario = all counties from Lambton to York

C. Georgian Bay = counties of Grey, Simcoe and Wellington

D. Eastern Ontario = all counties east of York.

2. Trapping Programs

Standard live-trapping and snap-trapping techniques (Davis 1956, Krebs et al. 1969, Renzulli et al. 1980, Stockrahm et al. 1981, Webster and Brooks 1981) were used to identify rodent species resident in apple orchards and to estimate population levels of these species. Trap grids were established in orchards in Haldimand-Norfolk municipality, Grey County, and Prince Edward County (Fig. 1). The study orchards were selected because they had experienced damage by voles in previous years. Sampling was conducted in such widely dispersed trap grids, because the Ontario Pesticides Advisory Committee (OPAC) expressed interest in determining whether it would be feasible to estimate vole levels across apple growing areas of Ontario on the basis of samples from a single grid.

Four 0.21-ha live-trap grids were established in each of the three sample areas. Trapping commenced in early September and ended in mid-December. Each area was trapped throughout four consecutive 24-h periods on three occasions (Cycles 1, 2, and 3), giving a total of 12 days and 12 nights trapping on each study grid. Baited Sherman live traps were set at each grid marker with 5 m between markers. Traps were locked open for 24 h before each four-day Cycle began. Captured animals were marked with numbered ear tags, weighed, sexed and released. Reproductive activity was also noted.

Five 0.21-ha grids were established on the three areas for snap-

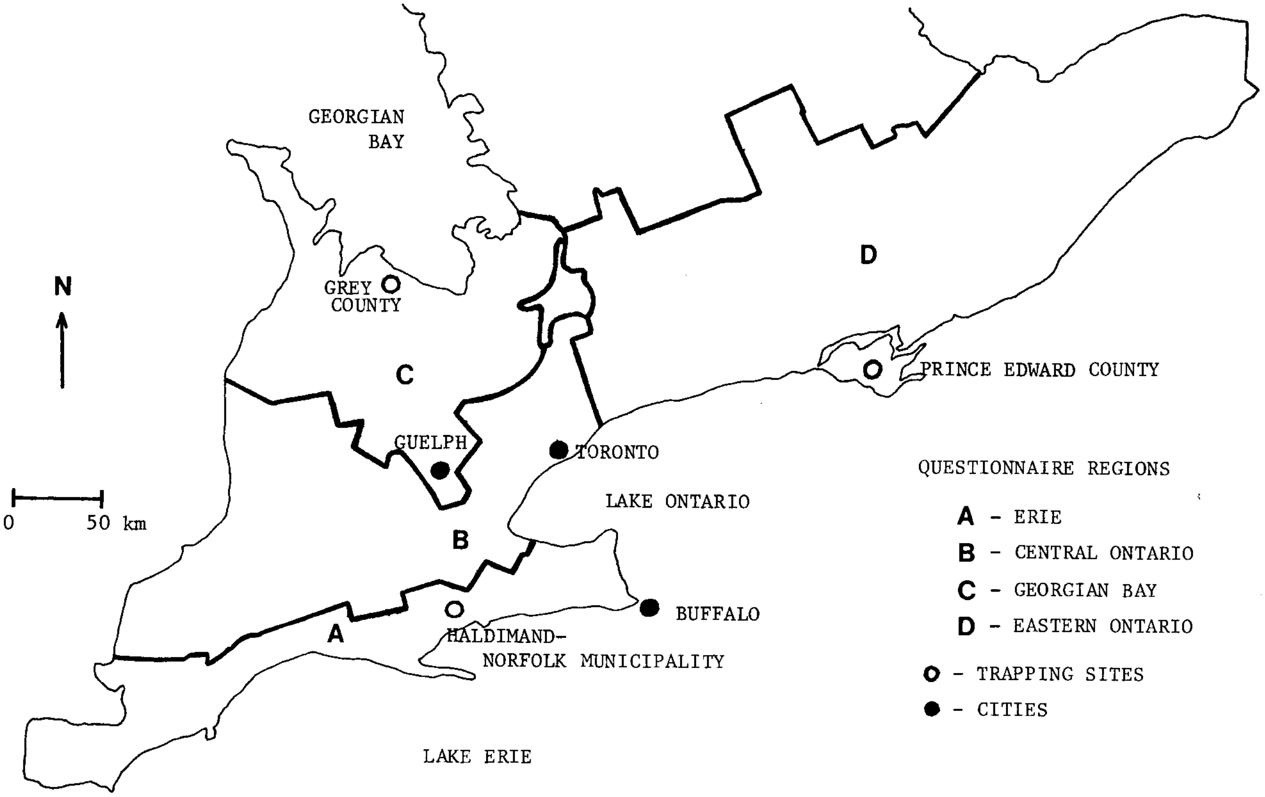

Figure 1. Questionnaire regions and trapping locations in southern Ontario.

trap sampling. Snap trapping was conducted twice: Session 1 occurred between live-trap Cycles 1 and 2; and Session 2 occurred between live-trap Cycles 2 and 3. Snap trap plots were sampled over two consecutive 24-h periods in each session.

Results and Discussion

The data from 280 questionnaires are summarized in Table 1 to show the per cent of apple trees damaged across Ontario in the winter of 1980-81. Overall, mammals destroyed or damaged 1.9% of 991,000 trees on our response sample. Therefore, in the average Ontario orchard of 3500 trees, about 70 trees were damaged by rodents, hares or deer in the 1980-81 winter. As our sample represented about 25% of Ontario apple growers, we estimated that mammals damaged 75,316 trees in winter.

Table 1. The percentage of apple trees damaged by vertebrate pests in Ontario in 1980 - 81.+

	Region				
	Lake Erie Niagara	Central Ontario	Georgian Bay	Eastern Ontario	Ontario Total
Total % apple trees damaged	1.57	2.34	2.51	2.85	2.28
By Voles	0.68	0.78	1.13	0.98	0.85 (0-100)*
Hare	0.58	0.32	0.80	0.25	0.45 (0-40)
Deer	0.29	1.03	0.53	0.35	0.59 (0-60)
Other++	0.02	0.21	0.05	1.27	0.38 (0-30)

* Range of values in parentheses.

\+ Figures based on responses from 280 questionnaires.

++ Most damage in this category is from winter kill but a few trees were damaged by groundhogs (Marmota monax).

Voles damaged 0.85% (8423) of the trees in our sample (Table 1). Highest levels of vole damage occurred in Georgian Bay and Eastern Ontario. In previous years, growers in these regions have reported greater problems than have growers in the Lake Erie or Central Ontario regions.

Deer (Odocoileus virginianus) browsed on 0.59% (5847) of the trees and inflicted heaviest damage in Central Ontario (Table 1), where deer numbers are relatively high. Lagomorphs damaged 0.45% (4460) of all trees and had their greatest effect in the Georgian Bay region

(Table 1). Most of the "other" damage (Table 1) was caused by extreme cold in the winter of 1980-81. This problem was most severe in Eastern Ontario (Table 1).

Zinc phosphide-treated baits were applied to orchards by 86.7% of the growers in our sample. In these orchards, voles damaged 0.80% of the trees (Table 2). In 21 orchards treated with Ramik Brown, 1.20% of the trees were damaged; whereas the 17 orchards not treated with rodenticide experienced the lowest damage levels (0.30%).

Table 2. The percentage of apple trees damaged by meadow voles (Microtus pennsylvanicus) in orchards treated or not treated with rodenticide.

	Region				
	Lake Erie Niagara	Central Ontario	Georgian Bay	Eastern Ontario	Ontario Total
Rodenticide program					
Zinc phosphide	0.67(72)*	0.80(77)	1.20(34)	0.75(59)	0.80
Ramik brown	5.52 (3)	0.51 (3)	1.03 (7)	1.46 (8)	1.20
No rodenticide	0.30 (9)	0.00 (1)	0.00 (2)	0.52 (5)	0.30

* Number of orchards in parentheses.

The average number of trees in orchards not treated with rodenticides was only one-third (1187 trees)of the number of trees in the average orchard was 3542 trees in our entire questionnaire sample. Many of the growers who did not apply rodenticides indicated that they did not do so because they had no history of rodent damage. Some of these orchards were surrounded by cultivated or urban areas.

To isolate factors associated with high levels of damage, we looked next only at those orchards (N = 38) with more than 2.5% of their trees damaged by voles (Table 3). An average of 11.5% of trees were damaged in these orchards, more than ten times the Ontario average (Table 3). The mean number of trees in these orchards was only 1428, compared to the average of 3542 for all the orchards sampled by our questionnaire. Twenty-six of the 38 "high damage" orchards were treated with zinc phosphide baits, yet they still had 13.8% of their trees damaged by voles.

Table 3. The percentage of apple trees damaged by meadow voles (Microtus pennsylvanicus) in orchards with more than 2.5% of trees damaged.

	Region				
	Lake Erie Niagara	Central Ontario	Georgian Bay	Eastern Ontario	Ontario Total
% Trees damaged (> 2.5% damaged)	10.5(10)*	17.8(8)	11.9(7)	9.6(13)	11.5(38)
Mean number trees/orchard (> 2.5% damaged)	1978	938	1553	1239	1428
Mean number trees/orchard	3190(84)	4140(81)	3738(42)	3160(72)	3542(280)

* Number of orchards in parentheses.

These results indicated that orchard size may be an important factor in reported levels of damage. Small orchards seemed to suffer very little damage (e.g. those described above that had not been treated with rodenticide) or a substantial and costly level of damage. There are three possible explanations for the latter case.

1. As smaller orchards have a higher perimeter/area ratio, a given rate of immigration of voles would lead to a higher level of damage.
2. Many small orchards may be located in areas of low-intensity agriculture, and therefore, may be surrounded by old fields, pastures, etc. that maintain high numbers of voles. This hypothesis is related to the first one.
3. Small orchards may be more likely to have inexperienced (recent) or inefficient owners as compared to large operations.

In 1982, we will attempt to ascertain which of these possibilities is the most likely reason for the observed high levels of damage by visiting the orchards and by a revised and expanded questionnaire.

Meadow voles, deer mice (Peromyscus maniculatus) and short-tailed shrews (Blarina brevicauda) were the only species of small mammals captured in live traps. No pine voles (Microtus pinetorum) were taken even though this species has been trapped in the Haldimand-Norfolk region (Peterson 1966). In Prince Edward County, meadow voles were numerous in Cycles 1 and 2 (88 and 72 voles/ha), but they declined to low levels (7.1 voles/ha) in Cycle 3, after zinc phosphoride treated baits were applied to the plots between cycles 2 and 3 (Table 4). A similar decline was observed in Haldimand-Norfolk when rodenticide was applied between Cycles 1 and 2 (Table 4). In Grey County, an area with a history of high levels of reported vole damage, densities of meadow voles remained low throughout the study. Numbers of _Peromyscus_ were low in all sampling areas except in Haldimand-Norfolk during the first cycle. No conclusions could be inferred regarding effects of rodenticide application on numbers of this species.

Table 4. The number of meadow voles (_Microtus pennsylvanicus_) per ha live trapped in Southern Ontario apple orchards.

	Grey County	Haldimand-Norfolk	Prince Edward County
Cycle			
1	10.7(3.6)*	36.9(16.7)	88.0(2.4)
2	11.9(3.6)	9.5 (2.4)	72.6 (0)
3	6.0 (0)	4.8 (1.2)	7.1 (0)

* Numbers in parentheses refer to the number of deer mice (_Peromyscus maniculatus_) per ha.

Results from the snap-trap plots indicated that densities of meadow voles were low in all areas and in both sessions, except for Session 1 in Prince Edward County (Table 5). However, numbers in Session 1 in Haldimand-Norfolk may have been underestimated owing to inclement weather during the trapping session.

Table 5. The number of meadow voles (_Microtus pennsylvanicus_) snap trapped in Southern Ontario.

	Grey County	Haldimand-Norfolk	Prince Edward County
Session			
1	1.0*	3.8	50.5
2	1.0	9.5	6.7

* Number of meadow voles per ha.

Overall, these results indicate that numbers of meadow voles are not similar in orchards throughout the apple growing regions of Ontario.

This is not surprising. In addition, it appears that applications of zinc phosphide-treated baits do cause significant reductions of numbers of resident voles. However, this effect may be only temporary as evidenced by the high levels of damage that occur annually in Grey and Prince Edward Counties despite zinc phosphide treatments. Because of this and because smaller orchards often have the highest levels of damage, we suggest that voles may emigrate into orchards after the rodenticide has been consumed by the resident population or otherwise lost its effectiveness. If significant dispersal takes place in winter, as appears sometimes to be the case (Brooks and Webster in press), then high levels of damage by voles could occur over winter even though few voles were present in the orchard in late fall and early winter.

It appears that movements of voles into treated orchards may make fall applications of rodenticide relatively ineffectual in control of damage to trees. Development of a control program to prevent damage by voles over winter will require an understanding of the extent and timing of these movements. To this end, we will use radiotelemetry (e.g., Pagano and Madison 1981, Webster and Brooks 1981) to monitor movements, particularly during late fall and early winter after rodenticide application. As carried out at present, rodenticide control measures have only a short-term effectiveness and show little relationship to levels of overwinter damage caused by voles.

Questionnaires provide an economical means to obtain information over a large area. In 1982, we will update and reorganize our questionnaire to evaluate more specific questions that have arisen from our 1981 effort. In particular, we will examine those orchards subject to heavy damage in 1980-81 and add questions pertaining to grower attitudes and degree of flexibility in altering their cultural practices. We also plan to investigate effects of habitat manipulation on numbers of voles (Steele 1977) using enclosures and various cultural practices. Finally, we will disseminate information useful to growers both to enhance their understanding of the overall problem, and to assist them in developing control programs that are more effective and economical.

Summary: Over the winter of 1980-81, mammals damaged about 2% of apple trees in Ontario orchards. Highest damage was suffered by smaller operations and although rodenticides were effective over the short term, application of these toxins bore no discernible relationship to levels of damage over the entire winter. Overall, populations of meadow voles in fall 1981 were at low levels. There was no evidence that pine voles were causing damage in Ontario. Future studies will concentrate on defining other factors associated with high levels of damage.

Acknowledgements

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Literature Cited

Brooks, R.J. and L. Schwarzkopf. 1981. Vole damage and control methods in Ontario orchards. In: R.E. Byers (ed.), Proc. Fifth Eastern Pine and Meadow Vole Symp., Gettysburg, Pa., pp. 2-6.

Brooks, R.J. and A.B. Webster. (in press). Relationship of seasonal change to changes in age structure and body size in Microtus pennsylvanicus. Ann. Carnegie Mus.

Davis, D.E. 1956. Manual for analysis of rodent populations. Edward Bros. Inc., Ann Arbor, Mich. 82 pp.

Krebs, C.J., B.L. Keller and R.H. Tamarin. 1969. Microtus population biology: demographic changes in fluctuating populations of M. ochrogaster and M. pennsylvanicus in southern Indiana. Ecology 50: 587-607.

Pagano, R.E. and D.M. Madison. 1981. Seasonal variations in movements and habitat use by pine and meadow voles. In: R.E. Byers (ed.), Proc. Fifth Eastern Pine and Meadow Vole Symp., Gettysburg, Pa., pp. 35-44.

Peterson, R.L. 1966. The Mammals of Eastern Canada. Oxford Univ. Press, Toronto, Ontario. 465 pp.

Renzulli, C.B., J.F. Flowers and R.H. Tamarin. 1980. The effects of trapping design on demographic estimates in the meadow vole, Microtus pennsylvanicus. Amer. Midl. Nat. 104: 397-401.

Steele, R.W. 1977. A demographic study of Microtus pennsylvanicus in relation to habitat structure. M.S. Thesis, Univ. Guelph, Guelph, Ontario. 123 pp.

Stockrahm, D.B., J. McAninch and J.D. Harder. 1981. Comparison of sampling designs for vole population studies. In: R.E. Byers (ed.), Proc. Fifth Eastern Pine and Meadow Vole Symp., Gettysburg, Pa., pp. 25-34.

Webster, A.B. and R.J. Brooks. 1981. Social behavior of Microtus pennsylvanicus in relation to seasonal changes in demography. J. Mamm. 62: 738-751.

LONG TERM VOLE CONTROL IN ONTARIO APPLE ORCHARDS [1]

Zia Siddiqi and W. D. Blaine
Chemical Research International
232 Norseman Street
Toronto, Ontario, Canada
M8Z 2R4

Abstract: A poisoned bait feeder station is being evaluated for a long term meadow vole control in Ontario apple orchards. This bait station can maintain a bait supply even under deep winter snow cover, commonly experienced in Ontario, when voles inflict extensive tree damage. Latest generation of acute anticoagulants, encapsulated zinc phosphide, and commercial formulation of zinc phosphide treated cracked corn bait in the bait stations are evaluated against the conventional broadcast application of the zinc phosphide treated cracked corn.

Introduction: Meadow vole, *Microtus pennsylvanicus*, is the most common field rodent found in Ontario and causes extensive damage to orchards and hardwood plantations (Radvanyi, 1974a, 1974b). The damage is usually most serious when their normal food supply is limited especially under deep snow cover during winter when occasionally voles breed (Brooks *et al*. 1976). The Ontario Ministry of Agriculture and Food (Ells and Hikichi, 1979) suggests that the orchards can be prevented by mowing the sods regularly, cleaning up trash from bases of fences, keeping ground clean around tree base, use of pitfalls, and especially protecting the young trees by galvenized wire mesh tree guards. Poisoned baits containing zinc phosphide, diphacinone, or chlorophacinone are commercially available. In the fall, before the ground is covered with snow, it is recommended to lightly distribute the bait just inside the drip line of the tree, in bait stations, or in a line along each side of the tree row. The bait may be distributed with a fertilizer or seed spreader. In problem orchards and where mice move in from adjacent fields or woods, repeated application of bait is necessary. Moist conditions will determine the choice and effectiveness of bait formulations. Under such prevailing conditions, especially under a deep winter snow cover, limiting control in the fall would be ineffective unless the voles were completely eliminated and there is no reinvasion. Therefore, the extended winter season and the possibility of winter breeding produce a major problem in

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[1] Funded by the Pesticides Advisory Committee of the Ontario Ministry of the Environment and the Ontario Apple Marketing Commission.

vole control in Ontario (Brooks and Schwarzkopf, 1981).

During 1971 - 72 studies were carried out in southern Ontario to determine if the meadow vole population could be controlled successfully by broadcasting anticoagulant poisoned grain. This control method was effective only temporarily and rapid reinvasion and high rate of reproduction brought the population back to higher levels. In 1973, poisoned bait feeder stations were placed and found very effective in providing an inexpensive long term rodent control (Radvanyi, 1974a). These findings were again reported when the poisoned bait feeder stations reduced the tree girdling damage from 50 percent to 1 - 2 percent (Radvanyi, 1980). The advantages of this type of feeder were described in detail by Radvanyi (1974a).

This 3-year study is being carried out to evaluate the effectiveness of the Radvanyi type poisoned bait feeder stations for a long term meadow vole control in Ontario apple orchards and also to evaluate some of the acute anticoagulants as compared to the conventional broadcast application fo 2% zinc phosphide treated cracked corn in the fall.

Methods and Materials: Four heavily vole infested apple orchards were selected to conduct studies on control of meadow voles. The orchards are located in Orono, Region of Durham; in Norval, Region of Peel; in Milton, Region of Halton; and in Belwood, Region of Wellington. The inverted "T" type bait stations were constructed by using a schedule 20 ABS plumbing pipe of 4 cm diameter, an ABS vent tee, and an ABS test cap for covering the bait station. The bait station measured 60 cm high and the two outer sides of 30 cm each. The outer ends were cut at 45° angle to give a canopy effect. The caps were sprayed with a fluoroscent orange paint for ease in locating the stations. The bait stations were placed at a rate of 25/hectare and held by a plastic tie to a 2.5 cm wide wooden peg driven about 30 cm deep into the ground. A large wide mouth plastic funnel was used to fill the stations. The bait stations were placed in such a fashion that these do not interfere with other orchard operations. An experimental plot at least consisted of 60 trees in 6 rows 10 trees long, and the middle five trees in the centre two rows are used for data collection purposes. The area of plots varied from location to location according to the tree spacing which ranged from 5m to 10 m. There are 4 - 5 rodenticide treatments at each location with three replications in a randomized block design. The following rodenticides are being evaluated in the bait stations: (i) Bromadiolone, 0.005%, in oat groats; (ii) Brodifacoum, 0.005%, in pellets; (iii) Chlorophacinone, 0.005%, in oat groats; (iv) Encapsulated Zinc Phosphide 2%, in oat groates (Hooker Chemicals); and the Waxed Mouse Bait 2, the conventionally used product containing 2% zinc phosphide in cracked corn. The control treatment consisted of the conventional broadcast application of the Waxed Mouse Bait 2 at a rate of 15 kg/ha. The amount of bait per station varied from 500 to 800 gm depending upon the formulation. Vole population in the experimental plots before the bait station placement was estimated by live trapping fo 5 consecutive days. A modified Sherman type live trap was used (Radvanyi, 1978) with a bait consisting of rolled oats, walnuts, raisins, ground beef, peanut butter, and corn syrup. The trap was also provided with a ball of cotton and a slice of apple. Ten traps were used in each plot. Trapped animals were marked by toe clipping and released. Exhaustive snap trapping was conducted after 30 days of station placement. The bait stations are monitored at regular intervals and refilled,as and when necessary, to maintain the bait supply. Further estimation of vole population will be carried out in spring and fall of 1982 to draw conclusion on effectiveness of the bait stations and the anticoagulants on long term meadow vole control in Ontario apple orchards.

Results and Discussion: At this point in time the collected data has not been statistically analyzed. The live trapping indicated that other than *Microtus pennsylvanicus*, *Sorex cinerus* were present at two locations (Orono and Milton) and *Peromyscus maniculatus* at one location (Belwood) where no voles were captured. The rodenticide treatments, rate of application, number of voles/plot (live trapped), and number of voles/site (snap trapped) are presented in Table 1 for Orono, in Table 2 for Norval, in Table 3 for Milton, and in Table 4 for Belwood. The snap trapping data shows less voles/site in all broadcast treatments showing its immediate effect in reduction of vole population. The cost of constructing 25 bait stations needed to cover one hectare was calculated at approximately $60.00 which does not include labor. (Table 5). Table 6 presents the cost comparison of single application of the commercially available rodenticides through the conventional broadcast application to the application of the same product when used through the poisoned bait feeder stations (single filling). It is assumed that one filling may last for 3 - 4 months and the bait station may last for about 5 years.

Table 1. Number of *Microtus pennsylvanicus* at Orono, Ontario, 1981.

Treatments	% a.i.	Rate kg/ha	Voles/Plot (Schnabel) Oct. 26-30	Voles/Site Nov. 30-Dec. 2
1. Waxed Mouse Bait 2*	2	15	67	0.4
2. Encapsulated ZP	2	12	51	0.5
3. Bromadiolone	0.005	12	40	0.7
4. Brodifacoum	0.005	20	36	0.6
5. Chlorophacinone	0.005	12	57	0.6

*Broadcast application

Table 2. Number of *Microtus pennsylvanicus* at Norval, Ontario, 1981.

Treatments	% a.i.	Rate kg/ha	Voles/Plot (Schnabel) Nov. 2-6	Voles/Site Dec. 3-5
1. Waxed Mouse Bait 2*	2	15	26	0.3
2. Waxed Mouse Bait 2	2	12	83	0.7
3. Brodifacoum	0.005	20	76	0.6
4. Bromadiolone	0.005	12	80	0.4
5. Chlorophacinone	0.005	12	69	0.5

*Broadcast application

Table 3. Number of *Microtus pennsylvanicus* at Milton, Ontario, 1981.

Treatments	% a.i.	Rate kg/ha	Voles/Plot (Schnabel) Nov. 5-9	Voles/Site Dec. 7-9
1. Waxed Mouse Bait 2*	2	15	52	0.8
2. Waxed Mouse Bait 2	2	12	36	1.1
3. Encapsulated ZP	2	12	50	0.8
4. Bromadiolone	0.005	12	28	1.3

*Broadcast application

Table 4. Number of _Peromyscus maniculatus_ at Belwood, Ontario, 1981.

Treatments	% a.i.	Rate kg/ha	Deer Mice/Plot (Schnabel) Nov. 9-13
1. Waxed Mouse Bait 2*	2	15	8
2. Waxed Mouse Bait 2	2	12	12
3. Brodifacoum	0.005	20	3
4. Chlorophacinone	0.005	12	8
5. Bromadiolone	0.005	12	9

*Broadcast application
Note: Snap trapping could not be carried out due to snow cover.

Table 5. Material cost of constructing 25 bait stations needed to cover one hectance

Materials	Cost* $
ABS Pipe Sch. 20, 4 cm diam.	32.00
ABS Vent Tee	15.00
ABS Test Cap	5.00
Glue	2.50
Wooden Pegs	3.25
Plastic Ties	1.00
Total	$ 58.75

*Excluding labor.

Table 6. Cost comparison of using commercial available rodenticides as conventional broadcast method and in the bait stations

Rodenticides	Broadcast Single Application $/ha*	Single Filling of Bait Stations $/ha*[1]
1. Waxed Mouse Bait 2 (Zinc Phosphide)	11	12
2. Ramik Brown (Diphacinone)	33	40
3. Rozol (Chlorophacinone)	40	48

*Does not include labor.

1. Does not include cost of bait stations @ about $60/ha, a one time investment for about 5 years.

LITERATURE CITED

Brooks, R. J., J.A. Baker, and R.W. Steele, 1976. Assessment of small mammal and raptor populations on Toronto International Airport and recommendations for reduction and control of these populations. A summary report. N.R.C. Canada, Field Note #72.

Brooks, R.J. and Lin Schwazkopf. 1981. Vole damage and control methods in Ontario orchards. Proc. 5th Eastern Pine and Meadow Vole Symposium: 2-6.

Ells, I.B. and A. Hikichi. 1979. Rodent control in orchards. Ontario Ministry of Agriculture and Food, Factsheet #79-081.

Radvanyi, A. 1974a. Small mammal census and control on a hardwood plantation. Proc. 6th Vert. Pest Conf. : 9-19.

Radvanyi, A. 1974b. Survey and control of small mammal populations on two hardwood plantations in southern Ontario. Forestry Chron. 50: 181-185.

Radvanyi, A. 1978. An improved design for a small mammal live trap. Can Field Nat. 91: 399-401.

Radvanyi, A. 1980. Control of small mammal damage in the Alberta oil sands reclamation and afforestation program. Forest Sci. 26.

EFFECT OF PELLET SIZE AND PACKAGED COMMERCIAL BAITS FOR THE CONTROL OF PINE VOLES

Ross E. Byers and Mark H. Merson
Department of Horticulture
Winchester Fruit Research Laboratory
Virginia Polytechnic Institute and State University
Winchester, VA 22601

Abstract. No difference in field control of pine voles was found between 3 different pellet sizes broadcast at either 5.6 kg/ha (5 lbs/acre) or 11.2 kg/ha (10 lbs/acre) for either Volid or ZP Rodent Bait^{AG}. Comparison of the 18 Volid plots with the 18 ZP Rodent Bait plots showed a statistical difference in animal control between these materials of 95% and 85% respectively. Place packs of Volid or ZP Rodent Bait^{AG} were opened at approximately 95% of the active sites. Since about 5% of the sites were active by the apple indexing, we believe a low but residual population existed which could repopulate the area. Good control was achieved using these products.

Introduction

The choice of a vole control program may largely depend on the degree of control achieved and the cost of the program. Cultural programs which depend on close mowing, cultivation, and herbicides has been found to be very costly with only moderately good control in some locations and not in others (1, 3, 9). The ground cover sprays of Endrin or chlorophacinone costs on the order of $34/ha ($30/acre) for materials and an additional $11/ha ($10/acre) for application costs (8). The hand placement of Brodifacoum (BFC), chlorophacinone (CPN), Ramik Brown (DPN), and ZP Rodent Bait have given the lowest cost programs in recent years with good control of voles (2, 4).

The objective of this experiment was to determine if broadcast baiting with low rates of the more acute baits could provide effective control. Since previous field data had shown no preference between the 3 pellet sizes (0.48 cm, 0.36 cm, 0.24 cm diameter) when hand placed in active pine or meadow vole sites (6), acceptance of different pellet sizes was not thought to be a complicating factor. However, broadcast baiting of a given rate per acre would result in different pellet densities per unit area of orchard floor. Since effective control was achieved with the 0.48 cm pellet at rates of 15-20 lbs/acre of ZP Rodent Bait^{AG} or Volid, reduction in pellet size to 0.24 cm would increase the pellet density approximately 5X. Therefore, this experiment was designed to determine if equivalent control could be achieved with broadcast applications at low rates using smaller pellet sizes.

Materials and Methods

1. Field trials --- Evaluation of pine vole control plots was determined using apple-indexing and final dead trapping methods previously described (3, 4, 5). In addition, apple consumption was obtained for each 24 hr monitoring period by weighing each apple before placement into each station and again weighing when apple indexing data was taken. In these experiments, plots were blocked according to pretreatment activity readings by first ranking plots from high to low and

assigning treatments randomly into activity categories high, medium, and low. Data summarized in Tables 1 and 2 were taken from an orchard having 35 trees per acre (35' X 35').

2. Since plastic packaged bait has an advantage of continuous availability to voles as well as to non-target animals, site covers (split tires or cinder blocks 2 X 8 X 16 inches) were evaluated as a station for placing plastic packaged Volid or ZP packets. Volid or ZP packets were placed at 47 sites in each of three replicate plots for tires or cinder blocks. Two treatments were made within 45 days so that packets would be available for a period of at least six months. Data are summarized in Figure 2.

Results and Discussion

The data in Table 1 show that no difference existed between the control achieved with 3 different pellet sizes or rates at 6 or 11 kg/ha of Volid or ZP. Previous results with Rozol indicated that poor control was achieved when rates were lowered to 10 lbs/A. Since Volid and ZP require approximately 1.5 g or 0.03 g respectively to deliver a lethal dose, voles apparently were able to find sufficient bait for a lethal dose since good control was achieved. Poor results with CPN (Rozol) in 1980 at 11 kg/ha were probably the result of inadequate bait being found by the voles to deliver a lethal dose (3). Previous laboratory experiments have shown that 11 g of CPN (Rozol) would be consumed by a vole before death.

In conclusion, acute baits which have the advantage of low bait consumption by voles require that only one or a few particles must be found to deliver a lethal dose. The disadvantage of sub-acute baits is that sufficient bait quantities must be available for 3-5 days and voles must consume a considerable quantity of bait before a lethal dose is obtained. Therefore, rates/ha are dependent more on the quantity of bait required for a lethal dose than on pellet density. Better coverage would be expected with pellets of smaller sizes.

The maintenance of lethal baits in an acceptable form continuously over long periods of time may be achieved by packaging the bait in a cellophane or plastic place-pack. Placement of either BFC or ZP Rodent Bait under split tire or cinder block stations in the spring of 1979, fall of 1979, and the fall of 1980 did not completely control the animals. Some packets (5-15 percent) were not opened after each baiting even though voles were known to be present as indicated by the apple index (Fig. 1). We believe that a sufficient number of animals existed within the hand-placed packet plots for animal reproduction to continue to supply new animals during the periods from July to November in both years as indicated by the high number of packets opened (Fig. 1). Vole activity levels were maintained quite low over the period due to the continuous availability of packaged bait. Since the population could not be completely eliminated by hand-placed packets, we believe that packet placement would be required just as frequently as hand placement of unpackaged bait. Cage trials using packets also showed that some pine voles did not open all of the BFC packets (7). The greatest advantage of a place packet system would be the maintenance of toxic baits under snow cover especially when invasion from surrounding areas was a potential hazard. The use of bait in plastic cups placed under split tires may be a better system than place packets for presenting bait over long periods of time in a dry very accessible condition.

As a part of a large non-target hazard trial, 15 orchards were treated with Volid at 16.6 kg/ha. The broadcast treatment was monitored with the apple index technique and a pre-treatment mark-recapture Schnabel estimate was made. Since vole numbers were so low in the post treatment period, live trapping was done only in the Old Home - Rome orchard. No animals were caught at this location using live traps. Obviously, the control achieved was outstanding. Data from Table 1 indicate that rates of 5.6 to 11.2 kg/ha would be adequate for control in most orchards of this area.

Literature Cited

1. Byers, R. E. and R. S. Young. 1975. Pine vole control with anticoagulant baits. J. Amer. Soc. Hort. Sci. 100:691-694.

2. Byers, R. E. 1978. Performance of rodenticides for the control of pine voles in orchards. J. Amer. Soc. Hort. Sci. 103:65-69.

3. Byers, R. E. 1978. Effect of orchard culture on pine vole activity. J. Amer. Soc. Hort. Sci. 103:625-626.

4. Byers, R. E. 1981. Pine vole control with anticoagulant baits in orchards. J. Amer. Soc. Hort. Sci. 106:101-105.

5. Byers, R. E. 1981. A field evaluation of rodenticides for control of Microtus pinetorum in orchards. Vert Pest Control and Management Materials, ASTM STP 752, E. W. Schafter Jr. and C. R. Walker, Eds. Amer Soc for Testing Materials 1981 (in press)

6. Byers, R. E. and M. H. Merson. 1981. Meadow and pine vole control in 1980 field plots. Proc. of the Fifth Eastern Pine and Meadow Vole Symposium. pp. 7-12.

7. Byers, R. E., M. H. Merson, and S. D. Palmateer. 1982. Control of orchard voles with broadcast baits. J. Amer. Soc. Hort. Sci. (in press)

8. Byers, R. E. and M. H. Merson. 1982. Current improvements in baiting pine and meadow voles. Tenth Vert Pest Conference. Monterey, Calif (in press)

9. Sullivan, W. T. 1979. Cost of controlling pine voles by different methods. Proc. of the Third Eastern Pine and Meadow Vole Symposium. New Paltz, N.Y. pp 66-68.

Table 1. Effect of pellet size on efficacy of broadcast baits for pine vole activity and populations treated November 9-10, 1981.

Treatment	Pellets per 50 g	Rate kg/ha	% Active sites[y]		Voles/plot (Nov 30-Dec 7)	Voles/site (Nov 30-Dec 7)	% Control
			Oct 21	Nov 24			
1. Control	--	--	88 a[z]	80 a	23.3 a	0.97 a	0
2. ZP	1694	5.6	92 a	28 b	6.0 b	0.25 b	74
3. ZP	1694	11.2	94 a	25 b	3.7 b	0.15 b	84
4. ZP	884	5.6	99 a	21 b	3.3 b	0.14 b	86
5. ZP	884	11.2	96 a	18 b	5.3 b	0.22 b	77
6. ZP	666	5.6	88 a	14 b	1.3 b	0.05 b	94
7. ZP	666	11.2	92 a	29 b	1.0 b	0.04 b	96
8. Volid	1780	5.6	100 a	22 b	1.3 b	0.05 b	94
9. Volid	1780	11.2	97 a	7 b	0.3 b	0.01 b	99
10. Volid	1044	5.6	97 a	19 b	1.0 b	0.04 b	96
11. Volid	1044	11.2	94 a	11 b	1.0 b	0.04 b	96
12. Volid	364	5.6	100 a	7 b	1.7 b	0.07 b	93
13. Volid	364	11.2	90 a	11 b	1.7 b	0.07 b	93

[y] Apples placed in 2 holes or runs 5-15 cm below the soil surface on opposite sides of the tree trunk were examined 24 hours after placement. Percent activity refers to all sites with vole tooth marks on the apple.

[z] Mean separation, within columns by Duncan's multiple range test, 5%. Three replicate plots per treatment.

Table 2. Effect of pellet size on efficacy of broadcast baits for pine vole activity and populations treated November 9-10, 1981.

Treatment	Rate kg/ha	% Active sites[y]		Voles/plot	Voles/site	% Control
		Oct 21	Nov 24			
Control	---	88 a	80.0 a	23.3 a	0.97 a	0
ZP Pellet	5.6-11.2	94 a	22.5 b	3.4 b	0.14 b	85
BFC, Volid	5.6-11.2	96 a	12.8 c	1.2 c	0.05 c	95

[y] Apples placed in 2 holes or runs 5-15 cm below the soil surface on opposite sides of the tree trunk were examined 24 hours after placement. Percent activity refers to all sites with vole tooth marks on the apple.

[z] Mean separation, within columns by Duncan's multiple range test, 10%. Three replicate plots per treatment.

Table 3. Pre- and post-treatment 24-hour vole activity and population estimates in 0.8 ha plots from 1981 secondary poisoning study, Frederick County, Virginia. Blocks treated at average rate of 16.6 kg/ha broadcast with 0.001% brodifacoum bait (VOLID).

Block	Trees per plot monitored	Pre-treatment activity[z]	Pre-treatment Schnabel[y] estimate	Pre-treatment Schnabel 95% C.I.	Total voles captured pre-treatment	Pine voles: meadow voles captured	3-week Post-treatment activity
Bauserman	150	27% (23 Oct)	62	36-98	41	9:1	0% (23 Dec)
Cline's Barn	234	21% (9 Nov)	--	--	--	--	0% (24 Dec)
Clover	50	--	--	--	--	--	0% (23 Dec)
Cedar Hill	144	12% (9 Nov)	--	--	--	--	0% (24 Dec)
Greenwalt	64	0% (18 Nov)	--	--	--	--	0% (10 Dec)
Old Home-Romes	118	30% (30 Oct)	40	3-111	13	12:1	5% (10 Dec)
Old Home-Woods	80	22% (16 Oct)	24	4-135	9	3.5:1	1% (8 Dec)
Robinson-Cather	146	23% (12 Nov)	--	--	--	--	0% (8 Dec)
Robinson-Shed	170	24% (5 Nov)	41	13-105	20	5.7:1	0% (4 Dec)
Robinson-York	78	20% (22 Oct)	19	1-370	7	6:1	0% (4 Dec)
Rt. 649	100	19% (29 Oct)	20	13-29	22	0:22	0% (28 Dec)
Smith	80	59% (15 Oct)	56	43-74	55	1:26.5	0% (11 Dec)
Smith-522	72	11% (18 Nov)	--	--	--	--	0% (10 Dec)
Snapp's	169	43% (5 Nov)	65	46-88	54	54:0	2% (17 Dec)
Swing's	104	23% (23 Oct)	20	10-38	16	1:15	1% (10 Dec)

[z] Percent activity refers to percent index apples placed at each tree site with vole feeding in 24 hours.

[y] Mark and recapture. Mark and recapture was not done post-treatment due to low vole numbers and low trap success.

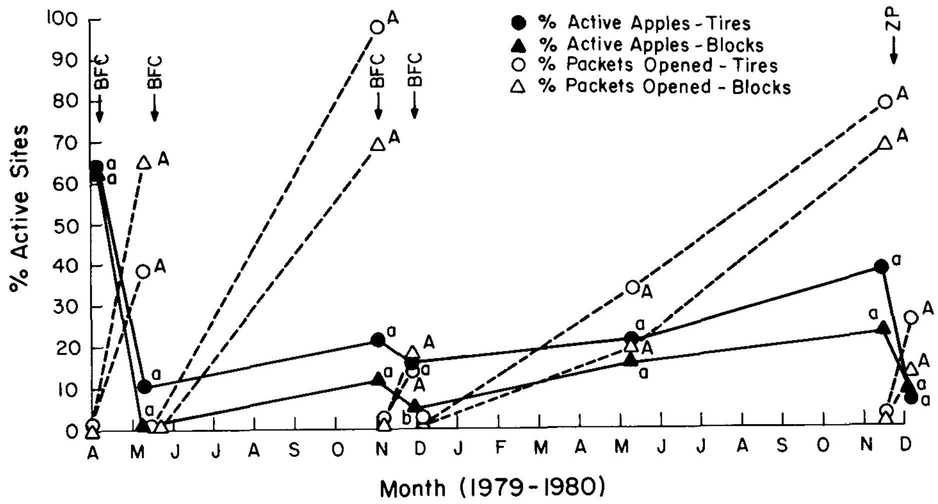


Fig. 1. Effect of BFC or ZP packets on % active apples in a 24 hour period (———) and % of packets opened (---) when replacement packets were placed under split tires or cinder blocks. Mean separation by date by Duncan's multiple range (5% level) for either % packet opening (A, B) or % active apples (a, b) (from Byers et al. 1982).

ORCHARD RODENT BAITS: TOXICANT EVALUATIONS AND VOLE PELLET SIZE PREFERENCES

Mark H. Merson and Ross E. Byers
Winchester Fruit Research Laboratory
Virginia Polytechnic Institute and State University
Winchester, VA 22601

Abstract: Residues of the anticoagulant rodenticide Brodifacoum in meadow voles (Microtus pennsylvanicus) sampled from an orchard population after broadcast treatment with the commercial bait VOLID decreased as the orchard rate of application and concentration of Brodifacoum in the bait decreased. Oral LD_{50} determinations for the experimental rodenticide EL-614 were 8.8 mg/kg for meadow voles and 24.0 mg/kg for pine voles (M. pinetorum). No size preference by meadow and pine voles for bait pellets from 2.38 to 4.76 mm in diameter was observed in laboratory tests.

Introduction:

Rodenticides represent a cost-effective means of controlling orchard vole numbers but their use is not without associated problems. Among these are non-target species hazard, bait acceptance, and the possibility of resistance developing after prolonged use. In our laboratory we have examined secondary poisoning hazard from the use of the anticoagulant Brodifacoum and evaluated different pellet sizes to increase bait acceptance by voles. In addition, we tested a new acute rodenticide, EL-614, against orchard voles.

Secondary poisoning hazard

In the fall of 1979 two sections of an orchard heavily infested with meadow voles (Microtus pennsylvanicus) were treated with a bait containing 0.005% of the anticoagulant Brodifacoum (BFC) at 10.5 or 45.9 kg per orchard hectare (Merson and Byers 1981a). BFC burdens in live voles captured from the orchard 1 day to 2 weeks after bait application (45.9 kg/ha) averaged 4.11 ± 0.21 ppm. Live voles captured from the area treated at 10.6 kg/ha carried a mean (± SE) burden of 1.97 ± 0.16 ppm BFC. In 1980 0.001% BFC bait was applied to the same orchard at 22.5 kg/ha. Meadow voles collected from this orchard at 1 to 14 days after bait application (n = 78) carried an average of 0.65 ppm BFC. Reduction in the amount of active ingredient in the bait was apparently effective in lowering BFC residue burden in the voles and, consequently, secondary poisoning hazard to vole predators.

EL-614

An experimental rodenticide, EL-614, was tested in the laboratory for efficacy against meadow and pine voles (M. pinetorum). EL-614 (Eli Lilly Co.) is a single-dose acute neurotoxin. Acute oral LD_{50} determinations were made for each species according to standard methods (American Society for Testing and Materials 1978). The oral LD_{50} for EL-614 in corn oil for meadow voles was 8.8 mg/kg and 24.0 mg/kg for pine voles. In 3-day choice tests against apple fruit (Merson and Byers 1981b), 70% mortality was observed in meadow voles fed 0.015% EL-614 bait. A similar level of mortality was not observed for pine voles even at bait concentrations as high as 0.04% EL-614. There was an indication of taste aversion to pine voles with EL-614 as shown by the significant ($P < 0.05$) decline in first day bait consumption at increasing dosages.

Pellet size preference by meadow and pine voles was studied in the laboratory in 1.83 m (6 ft.) diameter water tanks. A 60 cm circle was drawn on the floor of each tank inside of which were 3 nest cans. 'Golden Delicious' apples were placed around the circle and were continuously available to the voles. Meadow or pine vole pairs of the same sex were acclimated in the tanks for 24 h. One hundred pellets of one of 3 pellet sizes (2.38, 3.18, or 4.76 mm diameter) were broadcast in the tanks outside the 60 cm circle. After 16 h, the weight and numbers of pellets handled, consumed or cached were measured. Any pellets found inside the 60 cm circle were considered cached. The number of pellets cached or consumed were called numbers handled.

No significant effect of pellet diameter was observed on pellet consumption (g) by either vole species (Table 1). There was no significant effect of pellet diameter on the number of pellets handled by either species. There was a significant effect of pellet diameter on the number of pellets cached by pine voles ($P < 0.05$) with significantly greater numbers of the 4.76 mm size found cached. This effect was influenced by the number of pellets per unit weight of each size, however. The number of 4.76 mm diameter pellets available for caching after consumption was greater than the number of 2.38 mm diameter pellets available because of the five-fold greater weight of each 4.76 mm diameter pellet. Fewer of the 4.76 mm diameter pellets had to be consumed by the pine voles to fulfill their consumption requirements.

The lack of pellet size preference by pine voles is consistent with field observations of bait removal by pine voles (Byers and Merson 1981c). These laboratory data are preliminary in nature but would also indicate a difference in bait removal between pine and meadow voles with pine voles being more prone to this type of behavior. This would also be consistent with field observations.

References

American Society of Testing and Materials. 1978. Standard recommended practice for determining acute oral LD_{50} for testing vertebrate control agents. Pages 347-348 in Annual Book of ASTM Standards. Philadelphia, PA.

Byers, R. E., and M. H. Merson. 1981c. Pine and meadow vole control in 1980 field plots. Pages 7-12 in R. E. Byers, ed. Proc. Fifth Eastern Pine and Meadow Vole Symp. March 4-5, 1981. Gettysburg, PA. 144 pp.

Merson, M. H., and R. E. Byers. 1981a. Non-target species hazard of Brodifacoum use in orchards for meadow vole control. Pages 13-14 in R. E. Byers, ed. Proc. Fifth Eastern Pine and Meadow Vole Symp. March 4-5, 1981. Gettysburg, PA. 144 pp.

Merson, M. H., and R. E. Byers. 1981b. Laboratory efficacy of some commercial zinc phosphide baits used for control of meadow and pine voles in orchards. HortScience 16:49-51.

Table 1. Pellets (100) broadcast in 1.83 m diameter tanks with meadow and pine vole pairs.

Pellet diameter	Pellets cached (No.)	Pellets consumed (g)	Pellets cached or consumed (No.)
Pine voles (pairs = 8)			
2.38 mm	40 a	2.4	92
3.18 mm	46 a	1.9	73
4.76 mm	91 b	1.4	97
Meadow voles (pairs = 6)			
2.38 mm	14	1.2	36
3.18 mm	37	1.6	56
4.76 mm	61	1.5	66

a,b Means in same column with different letters significantly different $P < .05$.

RODENTICIDE EVALUATION IN THE HUDSON VALLEY DURING 1980 & 81

Paul F. Steblein and Milo E. Richmond
New York Cooperative Wildlife Research Unit
Cornell University
Ithaca, N.Y. 14853

The objective of Cornell University's research program is to develop a successful integrated system to control pine and meadow vole damage in the apple orchards of the Hudson Valley. This is being accomplished by determining the effect of habitat manipulation and rodenticides on vole populations. We are also doing research to quantify the amount of damage apple trees sustain from various densities of pine voles. By coupling the results of these two avenues of research, we hope to provide growers with a cost-effective pest management plan. Efficacy of Chlorophacinone (Chempar, Inc.) and Brodificoum (ICI Americas, Inc.) in various populations and treatments were evaluated in 1980 and 1980 (Table 1).

Table 1. Candidate rodenticides field tested during 1980 and 1981.

Rodenticide	Application	Rate
Chlorophacinone (Chempar Inc.)		
Rozol Groundspray	Postharvest	@ 6 pints/A
" "	Postharvest	@ 4 pints/A
" "	Pre-harvest	@ 6 pints/A
Rozol Pellets	Handbait	@ 10 lbs/A
Brodificoum (ICI Americas)		
Volak Pellets	Handbait	@ 10 lbs/A
Volid Pellets	Handbait	@ 5 lbs/A
" "	Broadcast	@ 10 lbs/A

Methods

Field testing of the candidate rodenticides was conducted in Ulster Co., New York during December 1980 and August through December in 1981. The test sites were located in the towns of New Paltz, Clintondale, Highland, and Modena. Treatment and corresponding control plots were situated within the same orchard block with similar soil, ground vegetation, tree variety and spacing. Each plot was buffered on all sides with adjacent rows of same treatment or physical barriers. Orchards were trapped and indexed at least once prior to treatment to determine initial population levels and pine/meadow vole ratios. Plots were selected with high pine vole populations wherever possible. Post-treatment activity levels were monitored again with the apple-slice index usually at one, two, four, and six weeks. Treatment activity is presented relative to control activity to reduce the amount of change in vole activity due to seasonal or weather patterns. This is accomplished by dividing the treatment activity by control activity.

Results and Discussion

Rozol ground spray (chlorophacinone) was applied postharvest with a handgun sprayer at the rate of 4 pts/acre (Fig. 1). There was some reduction in vole activity in three of the trials. Activity in the fourth trial was virtually unchanged throughout the test period. Increasing the concentration of Rozol to 6 pts/acre and applying with an airblast sprayer yielded good reduction in orchards with high initial activity (Fig. 2). There appeared to be little effect on plots with low pre-treatment activity. A post-harvest application at 6 pts/acre in 1981 achieved substantial reduction in vole activity (Fig. 3). Results of a "pre-harvest" application are shown in Figure 4. In actuality, it was a post-harvest application on early apple varieties that were picked a month or more ahead of the major crop. One plot exhibited very good reduction of vole activity, two trials had moderately effective results and the fourth was ineffective at maintaining vole activity at reduced levels. The latter treatment was in a recently abandoned crabapple orchard with taller ground cover vegetation and high numbers of pine voles. These circumstances could cause fewer voles to be killed and a rapid reinvasion to occur.

Fig. 1. Rozol groundspray; post-harvest application with handgun sprayer on 8 December 1980; 4 pints/acre (Hudson Valley, N.Y.),

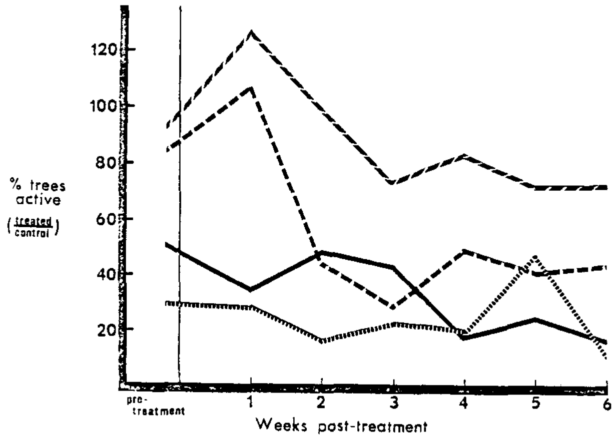


Fig. 2. Rozol groundspray; post-harvest application with airblast sprayer on 8 December 1980; 6 pints/acre (Hudson Valley, N.Y.).

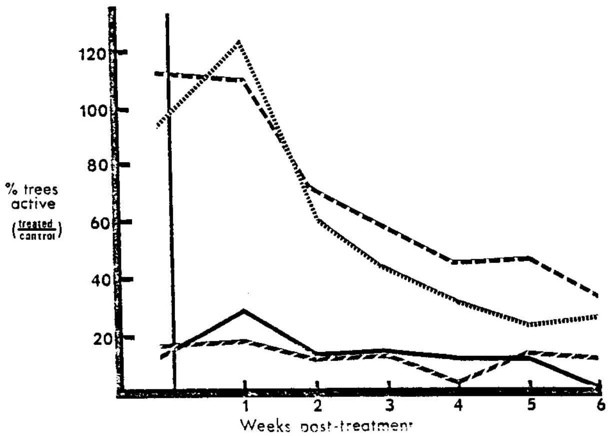


Fig. 3. Rozol groundspray; post-harvest application on 31 November 1981; 6 pints/acre (Hudson Valley, N.Y.).

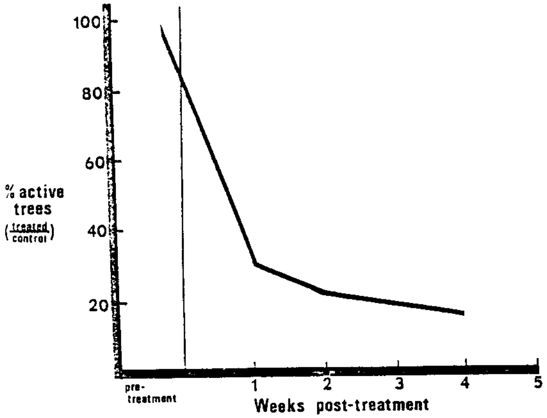
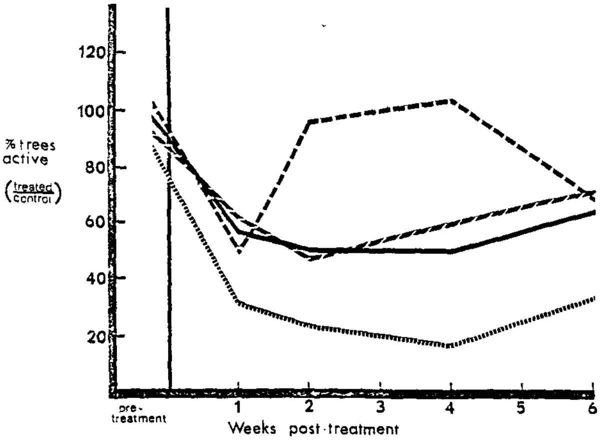


Fig. 4. Rozol groundspray; pre-harvest application on 28 August 1981; 6 pints/acre (Hudson Valley, N.Y.).



Chlorophacinone was also tested in a pelletized preparation. Figure 5 shows the results from handbaiting with the pellets in December 1980 at 10 lbs/acre. Substantial reduction of vole activity was achieved in both trials. The same preparation was applied in October 1981 with mixed results (Fig. 6). One application gave effective control, the other two applications were ineffective. Bait was readily removed by voles in all three of these trials. The conflicting results could be explained by the possible inadvertant use of an inactive batch of Rozol pellets. We suggest this possibility although we cannot confirm or deny it. This is one of the few times that Rozol pellets have failed to effect a good control.

Fig. 5. Rozol pellets; handbait application on 18 December 1980; 10 lb/acre (Hudson Valley, N.Y.).

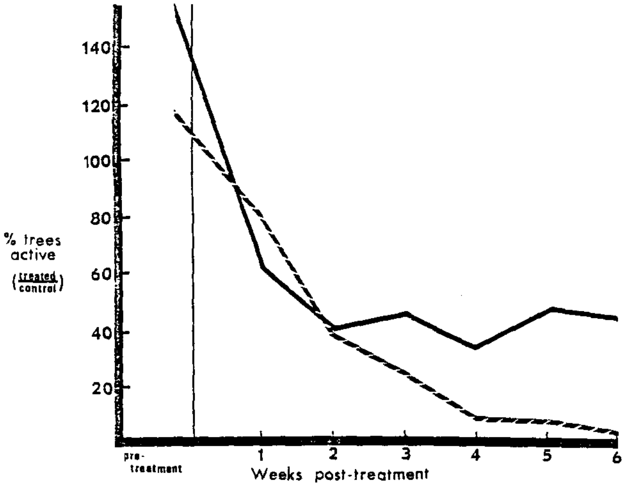
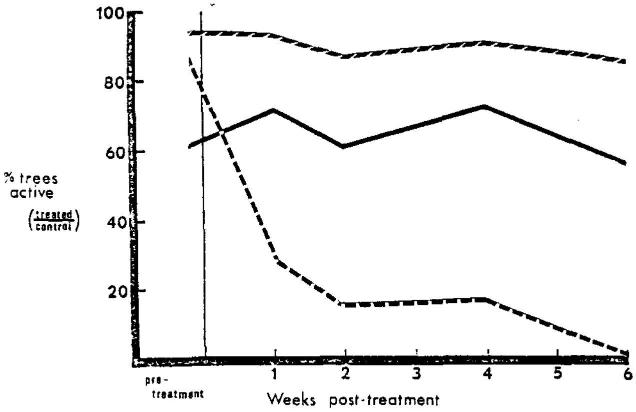


Fig. 6. Rozol pellets; handbait application on 29 October 1981; 10 lb/acre (Hudson Valley, N.Y.).



Brodificoum is a "second generation" anticoagulant (March et al. 1980) that was tested in two preparations, Volak and Volid pellets. Volak, used at 10 lbs/acre under bait stations, produced excellent results in both trials (Fig. 7). Volid exhibited similar results in two of the trials (Fig. 8) and moderate control in the third. Volid was also tried in a broadcast application at 10 lbs/acre (Fig. 9). Activity levels were reduced in all three plots, but in only one did the population approach the desirable level of reduction.

Fig. 7. Volak pellets; handbait application on 7 November 1981; 10 lb/acre (Hudson Valley, N.Y.).

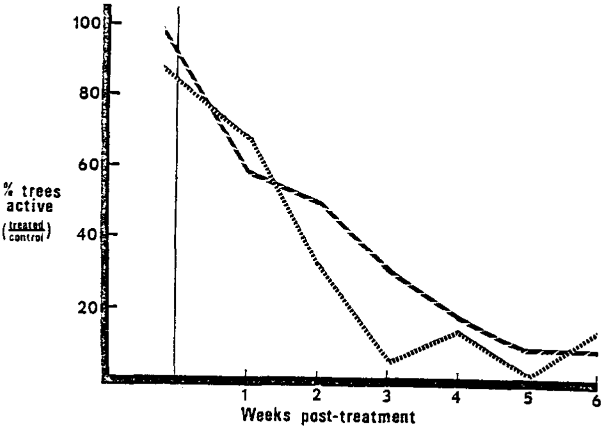


Fig. 8. Volid pellets; handbait application on 7 November 1981; 5 lb/acre (Hudson Valley, N.Y.).

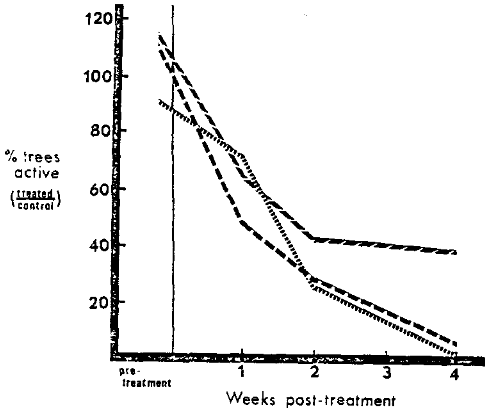
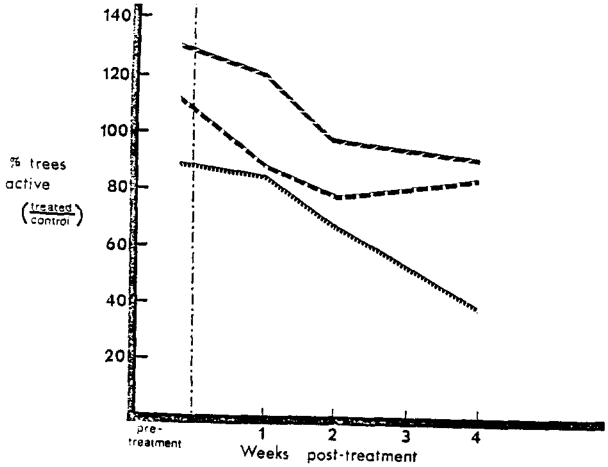


Fig. 9. Volid pellets; broadcast application on 7 November 1981; 10 lb/acre (Hudson Valley, N.Y.).



Handbaiting of rodenticides still yields the most dependable results. Meanwhile, post-harvest broadcast applications have frequently been ineffective or produced non-predictable results in the Hudson Valley. Abundant food resources during the time of our broadcast testing could reduce bait acceptability. During late winter and early spring food resources and vole body fat are at the lowest levels of the year (Cengel et al. 1978), and this may be a better time to achieve results with broadcast baits. In addition, pine vole tunnels are often exposed as the snow cover melts and broadcast baits are more likely to fall in the right place. We will be testing a spring application prior to spring green up, in hopes of achieving predictably effective control of voles with a broadcast treatment.

EFFECTS OF KNOWN DENSITIES OF PINE VOLES ON APPLE TREES

Milo Richmond
New York Cooperative Wildlife Research Unit
Cornell University
and
Pamela N. Miller
Highland Research Laboratory
Cornell University

Damage to fruit trees, tree seedlings and a wide array of ornamental shrubs by microtine rodents remains a widespread problem in both Europe and North America. Careful studies that quantify the levels of damage caused by a known density of rodent pests are not available. For this reason the orchard manager, Pest Control Specialist, and the researcher have a difficult time making wise decisions that are based on solid economic data.

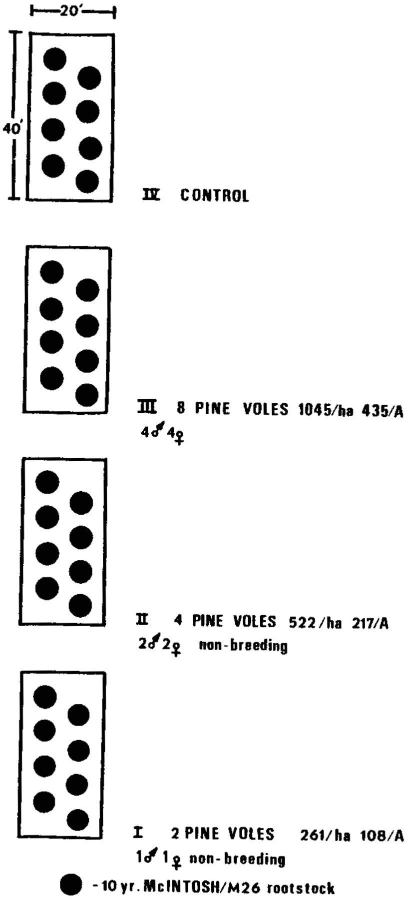
There are several reasons for this lack of knowledge. The damage done to apple trees is not easily observed, described, or measured. There is probably not a simple linear relationship between bark removal and economic damage. In addition to these difficulties and because the tree is a perennial, there is cummulative damage as well as recuperative and compensatory processes. In numerous situations, compensatory growth has been suggested and actually demonstrated (Dyer 1973, 1975, 1976, Dyer and Bokhari 1976, Harris 1974, Hutchinson 1971, Pearson 1965, Vickery 1972, Westlake 1963, and Woronecki _et al_. 1976).

To date, only a few attempts have been made to address the economics of pine vole or meadow vole damage in orchards. Pearson (1976, 1977) and Pearson and Forshey (1978) examined the relationship between the presence of voles and tree damage expressed as a reduction in crop value. A few authors have made some theoretical and speculative estimates of damage (Kennicott 1957, Hamilton 1938, Garlough and Spencer 1944, Biser 1967,, and Byers 1974). Recently Sullivan _et al_. (1980) have reported some standard survey work examining the magnitude and causes of tree mortality. This gives some concept of economic damage, but cannot be used to isolate even the benefits of current rodent control techniques. Ferguson (1980) and Luttner (1978) have also produced some very broad economic generalizations by extrapolating from rodenticide use figures. These, however, are only measures of standard acceptable orchard practice, and cannot form the basis for vole management in orchards.

Methods and Results

Construction of four 20' x 40' fenced (1/4" mesh hardware cloth) enclosures took place during September and October 1981 (Fig. 1). The 3 foot fence was buried 20" in the ground to prevent voles from tunneling out. Course gravel was used at the base of the fence to insure captivity. Aluminum tape was secured to the rim of the fence to prevent voles from climbing over. Each enclosure contains eight McIntosh trees, ten years old on M-26 rootstocks. Vole populations equivalent to 261, 522, and 1045 voles per hectare were released on Nov. 8, 1981. Female

Figure 1.


20'
40'
IV CONTROL
III 8 PINE VOLES 1045/ha 435/A
4♂ 4♀
II 4 PINE VOLES 522/ha 217/A
2♂ 2♀ non-breeding
I 2 PINE VOLES 261/ha 108/A
1♂ 1♀ non-breeding
● - 10 yr. McINTOSH/M26 rootstock

voles released in the two lower density plots underwent tubal ligation to prevent breeding. All animals were toe clipped for future identification. Six 18" x 24" roofing paper sheets were placed between trees to provide stations for monitoring vole activity. Twenty-four hours after releasing the animals, tunnels were observed in each of the enclosures. On December 8, 1981 13 of the 14 animals were recaptured at a trapping session 4 wks after initial release. The trapping session consisted of 3 checks during a six hour period. During January and February snow cover at all times exceeded 6". In early March, melting snow revealed 5 trees completely girdled and a sixth partially damaged in the high density enclosure; 5 partially girdled in the second enclosure (522 voles per hectare) and a small area of damage on one tree in the low density plot. The most extensive girdling extended from the base of the tree to 3" above ground level. Over winter mortality claimed 4 voles (3 males, 1 female) in the high density enclosure - which have been subsequently replaced. Underground root damage will become apparent this spring as leaf-out occurs. Harvest records, shoot growth, and leaf analysis collected each year will continue on all trees within the enclosures. Shoot growth, leaf analysis and tree specific crop loads will then be correlated with the different vole densities. The root systems of dying trees will be examined this summer to quantify vole damage. By determining the actual economic losses incurred due to the pest species, a better understanding of what constitutes a cost effective management program will be gained.

Literature Cited

BISER, D.L. 1967. Mammal damage to orchards in New York State. M.S. Thesis, Cornell Univ., Ithaca, NY. 81 pp.

BYERS, R.E. 1974. Pine mouse control in apple orchards. Annual West Va. State Hort. Soc. Mountaineer Grower 335:3-13.

DYER, M.I. 1973. Plant-animal interactions: the effects of redwinged blackbirds on corn growth. Proc. Bird Control Sem. Bowling Green State Univ., Bowling Green, OH. 6:229-241.

________. 1975. The effects of red-winged blackbirds (*Agelaius phoeniceus* L.) on biomass production of corn grains (*Zea mays* L.). J. Appl. Ecol. 57:762-772.

________. 1976. Simulation of bird damage on corn ears. Proc. Bird Control Sem. Bowling Green State Univ., Bowling Green, OH. 7:173-179.

________, AND U.G. BOKHARI. 1976. Plant-animal interactions: studies on the effects of grasshopper grazing on blue grama grass. Ecology 57:762-772.

FERGUSON, W.L. 1980. Rodenticide use in apple orchards. Proc. East. Pine and Meadow Vole Symp. Hendersonville, NC. 4:2-8.

GARLOUGH, F.E., AND D.A. SPENCER. 1944. Control of destructive mice. U.S. Dept. Int. Fish and Wildl. Serv. Con. Bull. 36. 37 pp.

HAMILTON, W.J. 1938. Life history notes on the northern pine mouse. J. Mammal. 19:163-170.

HARRIS, P. 1974. A possible explanation of plant yield increases following insect damage. Agro-Ecosystems 1:219-225.

HUTCHINSON, K.J. 1971. Productivity and energy flow in fodder conservation/grazing systems. Herb. Abstr. 41:1-10.

KENNICOTT, R. 1957. The quadrepeds of Illinois injurious and beneficial to the farmer. Rep. Comm. of Patents (Agr.) 1856:52-110.

LUTTNER, M.A. 1978. Preliminary benefit analysis of endrin use on apple orchards. Proc. East. Pine and Meadow Vole Symp. Beltsville, MD. 2:18-22.

PEARSON, K.J. 1976. Some economic aspects of pine vole damage in apple orchards of New York state. M.S. Thesis, St. Univ. of NY College of Envir. Sci. and For., Syracuse, NY. 55 pp.

__________. 1977. The influence of pine vole damage on apple tree vigor and fruit yield. Proc. East. Pine and Meadow Vole Symp. Winchester, VA. 1:29-32.

__________, AND C.G. FORSHEY. 1978. Effects of pine vole damage on tree vigor and fruit yield in New York apple orchards. HortScience 13:56-57.

PEARSON, L.C. 1965. Primary production in grazed and ungrazed desert communities of eastern Idaho. Ecology 46:278-285.

SULLIVAN, W.T., JR., T.B. SUTTON, AND D.W. HAYNE. 1980. Apple tree mortality, rate and causes. Proc. East. Pine and Meadow Vole Symp. Hendersonville, NC. 4:62-65.

VICKERY, P.J. 1972. Grazing and net primary production of a temperate grassland. J. Appl. Ecol. 9:307-314.

WESTLAKE, D.P. 1963. Comparison of plant productivity. Biol. Res. 39: 385-425.

WORONECKI, P.P., C.R. INGRAM, AND R.A. DOLBEER. 1976. Response of maturing corn to simulated bird damage. Proc. Bowling Green Bird Control Sem. Bowling Green, OH. 7:163-172.

The Relationship of Nutritional Factors to Apple Tree Root Damage by Pine Voles

F. A. Servello, J. J. Hasbrouck and R. L. Kirkpatrick

Department of Fisheries and Wildlife Sciences
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

K. E. Webb

Department of Animal Science
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

Damage to apple tree roots by pine voles is believed to occur primarily during the winter months. Cengel et al. (1978) found that the stomachs of pine voles contained significant amounts of root material only during January and March sampling periods. In addition, the diet of pine voles at that time consisted primarily of less preferred grass species because preferred forb species were unavailable. Therefore, apple tree roots may serve as a food source in the winter when preferred forages are unavailable. If, in fact, pine voles are consuming roots in response to reduced food supplies, then one would expect the nutritional quality of the diets of pine voles to be its lowest during the winter. The objective of this study was to determine if there was a winter decline in the digestibility of the diet of the pine vole.

To achieve this objective, a technique was developed for predicting the digestible dry matter (DDM) and digestible energy (DE) of the diets of pine voles from a nutritive analysis of their stomach contents. This technique utilizes regression equations that were developed from data obtained from 24 digestion trials with pine voles. The diets in those digestion trials were made up of combinations of common orchard forages and commercial feeds. The diets and the stomach contents of pine voles on those diets were analyzed by the procedures of Goering and Van Soest (1970). This method of nutritional analysis divides forage samples into a highly digestible fraction, cell solubles, and a variably digested total fiber fraction. The various components of the fiber fraction are then determined in subsequent steps. These fractions were used as variables in stepwise regression procedures to develop equations for predicting the DDM and DE of the diets of pine voles from an analysis of their stomach contents.

It was found that the cell soluble content of the stomach contents provided the best prediction of both DDM and DE. However, preliminary studies revealed that pine voles apparently ingested a substantial amount of soil in the wild. This necessitated correcting the cell soluble content of the stomach contents for the amount of acid insoluble ash (AIA) that they contained.

To apply this technique for determining diet digestibility in the field, voles were snap-trapped bimonthly from late summer to early spring in two orchards. Voles also were trapped in two additional orchards during December. The stomach contents of these animals were removed, weighed and analyzed for levels of cell solubles and AIA. Diet digestibility was then estimated from the AIA-corrected cell soluble levels of the stomach contents.

The amount of dry matter in the stomach contents was not significantly different between months in the orchards trapped bimonthly, nor were there any apparent trends. Significant differences also did not exist between the four orchards sampled in December. The DDM and DE in the diets of pine voles were not significantly different between months or between orchards. The DDM and DE of the pine vole's diet in one orchard did decline steadily from a high in August to a low in December, then rose just slightly in February and remained the same in April. The DDM and DE of the diets of voles in the second orchard decreased gradually, but only slightly from October to April.

From these data, it appears that the digestibility of foods consumed by pine voles does not decrease substantially during the winter as previously hypothesized. Nutritional deficiencies may still occur in the winter, however, probably due to a decrease in the availability of forages. Three studies at VPI and SU have shown that the fat levels of pine voles decrease during the late winter months which indicates that voles are experiencing a nutritional deficiency (Cengel and Estep 1978, Noffsinger 1976, Lochmiller, unpublished data). The dry weight of the stomach contents examined in the present study did not indicate food shortages existed in the winter. However, the weight of the stomach contents is probably not an adequate indication of food shortage by itself. Therefore, we can conclude that the digestibility of the diet of pine voles does not decrease substantially in the winter and that nutritional deficiencies that occur in the winter may be primarily a result of a decreased availability of forages.

These data add to our overall understanding of root damage by pine voles. At this symposium last year, we reported that root bark was approximately 50% digestible during all seasons of the year (Servello et al. 1981). This is about 15% less digestible than the normal diets of pine voles in maintained orchards. Therefore, it is doubtful that pine voles would prefer root bark to their usual diet of grasses and forbs because of the large difference in digestibility. However, if root bark made up 15% [the maximum found in field studies (Cengel et al. 1978)] of the diets of the pine voles when the digestibility of other forages was at or near 70%, then total diet digestibility would drop only 3%. This level of root consumption probably could be tolerated easily.

At this symposium last year, we also proposed the hypothesis that pine voles may increase their consumption of root bark during the winter because of increases in its sugar content (Servello et al. 1981). Sugar levels in root bark reach their highest levels in midwinter and are almost double summer levels. The increase in sugar levels may make root bark more palatable to pine voles in the winter. This increase in root bark palatability coincides with the period of reduced forage availability described above. In addition to a decrease in food supplies and an increase in root palatability influencing root consumption, pine voles may simply spend more time in and around their nest in the winter which would provide increased opportunity for gnawing behavior. These three factors probably act together to cause the increase in root bark consumption by pine voles.

LITERATURE CITED

Cengel, D. J., J. E. Estep and R. L. Kirkpatrick. 1978. Pine vole reproduction in relation to food habits and body fat. J. Wildl. Manage. 42(4):822-833.

Goering, H. K. and P. J. Van Soest. 1970. Forage fiber analysis: apparatus, reagents, procedures, and some application. Agric. Handb. No. 379. USDA 20 pp.

Noffsinger, R. E. 1976. Seasonal variation in the natality, mortality and nutrition of the pine vole in two orchard types. M.S. thesis. Virginia Polytechnic Institute and State University. 128 pp.

Servello, F. A., K. E. Webb, Jr. and R. L. Kirkpatrick. 1981. Digestibility and nutritional quality of apple tree roots and other orchard forages by the pine vole. Pages 77-78 in R. E. Byers, ed. Proc. Fifth Eastern Pine and Meadow Vole Symposium. 144 pp.

Potential Use of Barn Owls to Control Vole Populations in Orchards

T. L. Derting and J. A. Cranford
Virginia Polytechnic Institute
and State University
Department of Biology
Blacksburg, VA 24061

INTRODUCTION

The development of control methods for pine and meadow voles in orchard habitats has met with limited success. Though numerous physical, mechanical, and chemical methods have been recommended for limiting vole populations, few have effectively reduced and maintained vole populations at minimal densities for extended periods of time. Though the use of chemicals has been the most effective control method developed it has not resulted in the extinction of pest populations. The initial application of rodenticides frequently causes a significant reduction in pest species, but due to their high intrinsic rate of increase, vole densities quickly rise. Because of high costs many orchard owners can not apply rodenticides frequently enough to continually suppress vole populations. What is needed for effective rodent control therefore, is a means of maintaining low vole populations after an initial rodenticide application. A potential means of achieving such control is through the use of natural predators.

To qualify as an effective mode of biological control for voles in orchards a predator must 1) forage in orchard habitats 2) use voles as a primary food source and 3) exhibit moderate or weak territorially to permit several individuals to forage in one area. A predator which qualifies for each of these requirements is the barn owl (Tyto alba).

Barn owls are highly specialized rodent predators which feed primarily on microtines, including pine (Microtus pinetorum) and meadow (M. pennsylvanicus) voles (Boyd and Shriner, 1951; Phillips, 1951; Parmalee, 1954; Marti, 1969; Rickart, 1972). These owls are primarily nocturnal and forage in open areas, including orchards (Merson and Byers, 1981), rather than forested areas. Barn owls will use nest boxes as supplementary nesting sites and exhibit weak territorriality and overlapping hunting ranges (Lenton, 1980). Because of these characteristics barn owls are a good candidate for use as biological control agents.

The impact a predator, such as a barn owl, has on an ecosystem is largely dependent on which and how many prey individials it captures to fulfill its food requirements. Though barn owls are known to feed on microtines, it is not clear whether microtines are the preferred prey of barn owls and are thus selected over other available prey species. The objectives of this study were to determine what prey types are most vulnerable to barn owl predation and what prey characteristics are of primary importance in determining prey vulnerability to barn owls. The results of this study will provide basic information on barn owl food selection to determine their potential as a means of biological control in orchards.

MATERIALS AND METHODS

Two barn owls caught in July, 1979 in Blacksburg, Va. were used as predators and *Peromyscus leucopus novaboracensis*, *Microtus pennsylcanicus pennslyvanicus* and *M. pinetorum* were used as prey. All prey animals were maintained in laboratory colonies on a 16L:8D light cycle with *Microtus pennsylvanicus* fed rabbit pellets, *M. pinetorum* fed Wayne lab blox supplemented with apple and sunflower seed, and *P. leucopus* fed Wayne lab blox ad lib. Water was available at all times. The owls were maintained in a semi-natural outdoor enclosures (6 by 12 by 4m) and fed randomly selected live prey ad lib. except during prey selection experiments.

Selection tests. Selection tests were performed using pairwise comparisons of the three prey species. The comparisons made were *M. pinetorum* adults tested with *M. pennsylvanicus* adults and juveniles, and *P. leucopus* adults tested with *M. pinetorum* adults and *M. pennsylvanicus* adults and juveniles. In all tests predator-naive prey individuals were used.

Selection tests were conducted in an indoor room (3 by 6 by 4m) from October, 1979 to May, 1980. Perches were located at opposite ends of the room with one 2.5 m above the ground and the other 1.5 m high. The floor was covered with sawdust, crushed oak leaves, and a few tree branches but no specific prey refuges were available. A plexiglass door covered with a double layer of cheese cloth permitted direct observation of predator behavior.

The indoor enclosure photoperiod corresponded to the current natural photoperiod. Selection tests were begun 30 min after dark with the enclosure lit by a flourescent light covered with red filters and a dim light controlled by a variable power supply. This permitted direct observation of predator behavior while maintaining as low a level of illumination (0.63 lumens/sq. m) as possible to simulate natural foraging conditions.

For each trial, four prey individuals, two of each prey type being tested, were released into the enclosure in the presence of one owl. Prey individuals were identified by sex or toe clipping with body length, tail length, and body weight recorded prior to each trial. Each owl was given 45 min. in which to capture a maximum of three of the four prey individuals. A 20 channel Esterline Angus event recorder was used to monitor predator pursuit time (from when the owl left the perch to when it caught a prey item), handling time (from capture until eating commenced), and eating time. Ten trials were made per owl resulting in total of 20 trials per prey type comparison.

Behavioral tests. To determine differences in the behavior of prey types, observations were made on prey before, during, and after an aerial silhouette flight in the indoor enclosure. Since responsiveness to aerial models by *Peromyscus*, *Microtus*, and other rodents is independent of model configuration (Fentress, 1968; Muller Schwarze and Muller Schwarze, 1971; Bildstein and Althoff, 1979) behavioral tests utilized a stylized silhouette model (137.5 cm wingspan, 38.8 cm length) which moved at 0.5 m/s along a monofilament line suspended between the perches. For each flight the silhouette 'flew' by force of gravity from the higher perch to the lower perch (3 m) and was then hand-pulled back to the higher perch.

A single naive individual was released into the room and its behavior monitored for 5 min prior to and 5 min subsequent to the silhouette's flight. The behaviors monitored were activity, freezing (no head or body movements), 'grooming' (grooming, chewing, sniffing, rearing), and use of corners. Twenty trials were conducted for each of the five prey type comparisons.

Analysis. Predator selection was determined using the selection index of Manly (1972) and Manly et al. (1972). Selection values range from 0 when all prey captured are of type A to +1.0 when all prey captured are of type B. A value of 0.5 occurs when there is no difference in the selection between prey types. To compare the number of each type presented with the number eaten a X^2 test suggested by Manly et al. (1972:729) was used.

Other statistical analyses used standard parametric and nonparametric tests (Siegel, 1956; Walsh, 1965; Dixon and Massey, 1969; Hollander and Wolfe, 1975).

RESULTS

Selection tests showed that *M. pennsylvanicus* adults and juveniles were significantly more vulnerable to barn owl predation than were *P. leucopus* (Table 1). *Microtus pinetorum* tended to follow the same pattern as they were captured twice as often as *P. leucopus*, but the difference was not significant. There was little difference in the vulnerability of juvenile *M. pennsylvanicus* and adult *M. pinetorum*.

Table 1. Selection indices (SI) for prey selection tests. Asterisks denote significant selection between prey types (X^2, $p < 0.005$). Juv. = Juveniles. Ad. = Adults.

	Prey type A	SI value	Prey type B	SI value
*	*M. pennsylvanicus* Ad.	1.00	*P. leucopus* Ad.	0.0
*	*M. pennsylvanicus* Ad.	0.84	*M. pinetorum* Ad.	0.16
*	*M. pennsylvanicus* Juv.	0.75	*P. leucopus* Ad.	0.25
	M. pinetorum Ad.	0.66	*P. leucopus* Ad.	0.34
	M. pennsylvanicus Juv.	0.61	*M. pinetorum* Ad.	0.39

With respect to sex, there were no differences in the vulnerability of male and female *P. leucopus* or *M. pinetorum*. Within *M. pennsylvanicus*, juvenile females were captured significantly more often than males, while the opposite occurred among the adults (Table 2).

Within each prey type comparison, the prey type with the greater mean body length was captured more frequently than that with the shorter mean body length (Table 3). This resulted in a significant correlation between differences in the selection index of the two prey types compared and differences in the weights of the two prey types (Spearmann's Rank Correlation, $r_s = 1.00$, $p < 0.01$). A similar, but less consistent pattern occurred with respect to the weights of prey types, however no significant correlation between differences in prey weights and differences in their selection indices occurred ($r_s = 0.64$, $p > 0.2$).

Table 2. Predator selection between sexes. Sample sizes are the number of trials where both a o and a o were present and only one animal was caught. Asterisks denote significant differences in the capture frequency of males and females (X^2, $p < 0.005$). Juv. = Juvenile. Ad. = Adult.

Prey type	Sample Size	Capture frequency		
		male		female
P. leucopus Ad.	9	44%		56%
M. pinetorum Ad.	21	48		52
M. pennsylvanicus Juv.	11	9	*	91
M. pennsylvanicus Ad.	20	80	*	20

Behaviorally, *Microtus* species differed from *P. leucopus* both before and after overhead silhouette flights. Significantly more *M. pennsylvanicus* (80%) and *M. pinetorum* (85%) spent time frozen than did *Peromyscus* (60%) prior to silhouette flights. All three prey species showed a similar response to the silhouette as it passed overhead, with 65-75% of the individuals of each species fleeing and the others exhibiting freezing behavior. After the silhouette flight significantly more *P. leucopus* were active (55%) and significantly fewer exhibited freezing behavior (80%) than individuals of either *Microtus* species (X number active = 33%, X number frozen = 99%).

Few differences occurred in the time spent by the owls pursuing, handling, and eating the various prey types. No significant differences occurred in pursuit and handling times for the four prey types. However, the largest and heaviest prey types, *M. pennsylvanicus* adults and *M. pinetorum* required significantly more time to eat than did *M. pennsylvanicus* juveniles and *P. leucopus*. There were no significant differences in the number of attempts required to capture individuals of each prey type.

Table 3. Comparison of captured prey types weight and body length differences. Significant differences in owl selection between prey types are denoted by (*) X^2, $p < 0.005$). All weight and body length differences are significant (t-test, $p < 0.01$) except those marked (**).

Preferred prey type vs. less preferred prey type	Mean diff. in weights (g)	Mean diff. in body length (mm)
* *M. pennsylvanicus* Ad. *P. leucopus* Ad.	32.80	33.6
* *M. pennsylvanicus* Ad. *P. Pinetorum* Ad.	17.16	18.8
* *M. pennsylvanicus* Juv. *P. leucopus* Ad.	0.43**	8.5
M. pinetorum Ad. *P. leucopus* Ad.	10.33	7.8
M. pennsylvanicus Juv. *P. pinetorum* Ad.	-7.50	-5.8**

DISCUSSION

Differential vulnerability of prey and the selection of specific prey types by barn owls has been demonstrated in this study. During the selection tests, all prey were equally vulnerable in terms of the experimental conditions (i.e. no refuges existed) and prey types differed only in terms of their behavioral and physical characteristics. Under these conditions, the two *Microtus* species were more vulnerable to barn owl predation than were *P. leucopus*. Similar results have been reported for barn owls (Fast and Ambrose, 1976) and kestrels (Barrett and Mackey, 1975) in semi-natural enclosures where *M. pennsylvanicus* were captured more frequently than *Peromyscus*.

The greater vulnerability of *Microtus* species was due partly to their greater body length when compared with *P. leucopus*. Large body size may be indicative of a potentially greater caloric yield and greater energy benefits for predators and thus *Microtus* were captured more frequently than the smaller species *P. leucopus*. The lack of a significant difference in the body sizes of juvenile *M. pennsylvanicus* and adult *M. pinetorum* resulted in no significant selection between these two prey types.

Behavior was also important in determining prey vulnerability. It was easier for the owls to capture prey individuals which were frozen rather than active. The greater tendency for both *M. pennsylvanicus* and *M. pinetorum* to freeze than for *P. leucopus* to freeze may have increased the vulnerability of these microtines.

Because *Microtus* were selected more frequently than were *P. leucopus* it appears that barn owls have potential use as a means of biological control for microtines in orchards. The use of carnivores such as mongooses, cats, and weasels to control rodents has not been very successful partly due to the diversity of their diets (i.e. birds, rabbits, frogs) (Wodzicki, 1973; Sullivan and Sullivan, 1980). Barn owls however, are rodent specialists and have been found to aid in rat control (Lenton, 1980).

If barn owls are efficient vole predators in the field even when other prey species are available, they could contribute to the control of microtines. It is unlikely that owls could eliminate vole populations but in conjunction with chemical methods vole populations could be reduced and maintained at minimum densities for an appreciable period of time. The hazard to owls would have to be minimized by using rodenticides which do not concentrate in secondary consumers or which result in the death of rodents while in unexposed areas such as burrows or nests. If such an integrated control program were successful economic benefits could be realized through reduced expenditures on the purchase and application of rodenticides.

Though this study shows that microtines are highly vulnerable to barn owl predation in a laboratory situation, additional testing is needed to determine if the same foraging pattern occurs in orchards. Density estimates of all potential prey species within orchards need to be determined and compared with types and numbers of prey actually eaten by barn owls or other avian predators foraging in orchards. If the results of field tests show that barn owls follow the same foraging pattern in the field as they have in the laboratory (i.e. select animals according to their size and possibly behavior) then one can predict in what areas owls will be most effective at reducing microtine populations rather than those of co-occurring species.

ACKNOWLEDGEMENTS

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LITERATURE CITED

Barrett, G. W. and C. V. Mackey. 1975. Prey selection and caloric ingestion rate of captive American kestrels. Wilson Bull., 87:514-519.

Bildstein, K. L. and D. P. Althoff. 1979. Responses of white-footed mice and meadow voles to flyovers of an aerial predator silhouette. Ohio J. Sci., 79:212-217.

Boyd, E. M. and J. Shriner. 1954. Nesting and food of the barn owl (_Tyto alba_) in Hampshire County, Mass. Auk, 71:199-201.

Dixon, W. J. and Massey, F. J. Jr. 1969. Introduction to Statistical Analysis. 3rd ed., McGraw-Hill Inc., U.S.A., 638 pp.

Fast, S. J. and H. W. Ambrose III. 1976. Prey preference and hunting habitat selection in the barn owl. Amer. Midland Nat., 96:503-507.

Fentress, J. C. 1968. Interrupted ongoing behavior in two species of vole (_M. agrestis_ and _C. brittanicus_). I. Response as a function of preceeding activity and the context of an apparently "irrelevant" motor pattern. Behaviour, 16:135-153.

Hollander, M. and D. A. Wolfe. 1973. Nonparametric statistics. John Wiley and Sons, Inc.., U.S.A., 503 pp.

Lenton, G. M. 1980. Biological control of rats in oil palms by owls. Tropical Ecology and Development, pp. 615-621.

Manly, B. F. 1972. Tables for the analysis of selection predation experiments. Res. Popul. Ecol., 14:74-81.

______, P. Miller, and L. M. Cook. 1972. Analysis of a selective predation experiment. Amer. Nat., 106:719-736.

Marti, C. D. 1969. Some comparisons of the feeding ecology of four owls in North Central Colorado. Southwestern Nat., 14:163-170.

Merson, M. H. and R. E. Byers. 1981. Non-target species hazard to Brodifacoum use in orchards for meadow vole control. Proc. Fifth Pine Vole Symp. pp 13-14.

Muller-Schwarze, D. and C. Muller-Schwarze. 1971. Responses of chipmunks to models of aerial predators. J. Mamm., 52:456-458.

Parmalee, P. W. 1954. Food of the great-horned owl and barn owl in east Texas. Auk, 71:469-470.

Phillips, R. S. 1951. Food of the barn owl, Tyto alba pratincola, in Hancock County, Ohio. Auk, 68:239-241.

Rickart, E. A. 1972. An analysis of barn owl and great horned owl pellets from western Nebraska. Prairie Naturalist, 4:35-38.

Siegel, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill, N.Y., 312 pp.

Sullivan, T. P. and D. S. Sullivan. 1980. The use of weasels for natural control of mouse and vole populations in a costal coniferous forest. Oecologia, 47:125-129.

Walsh, J. E. 1965. Handbook of nonparametric statistics, II. Results for two and several sample problems, symmetry, and extremes. D. Van Nostrand Co. Inc., Princeton, N.J. 868 pp.

Wodzicki, K. 1973. Prospects for biological control of rodent populations. Bull. Wld. Hlth. Org., 48:461-4647.

PINE VOLE REINVASION OF AN UNFILLED SUITABLE HABITAT

Pamela N. Miller and Milo E. Richmond
New York Cooperative Wildlife Research Unit
Cornell University
Ithaca, N.Y. 14853

Despite years of research aimed at developing ecologically safe and effective methods for controlling pine voles these rodents remain a serious agricultural pest. A large portion of the damage occuring yearly could be avoided through close adherance to the current recommendations. A regular mowing and herbicide program to eliminate rodent cover combined with rodenticides comprise the integrated pest management program currently available. Effective toxicants include a groundspray and various pelleted baits which can be placed in the runways. Repeated mowing of grasses and the use of herbicides are two effective means of reducing or eliminating an existing population, and more importantly in excluding the potential establishment of voles in a new orchard. This is not to suggest that there now exists a panacea for controlling rodents in all orchard habitats. Vertebrate pests are likely to remain a factor for some time and may never be completely conquered.

In our efforts to enhance control methodology, certain questions remain to be answered. Of particular concern is how quickly will an area become repopulated by nearby resident voles after a control procedure has been used. Repopulation of one of these areas can become significant to the grower who has a young orchard planted next to an older pine vole infested block, or the grower who keeps his own orchard mowed and relatively pest free but has a neighboring orchardist who does not. For these reasons the following research was designed to learn more about reinvasion and movements from the surrounding orchard into an area where the resident population had been removed.

In the present study major questions posed were:

1. When do the voles reinvade?
2. Who are the invaders (species age and sex)?
3. Where do they relocate?
4. What were the movements following reestablishment?

Methods and Materials

The study area was an 8-acre orchard block within a larger orchard, which supported a large and persistent population. This surrounding habitat provided the source of animals moving into this suitable but empty habitat. Beginning in the fall of 1980 the 8-acre study area was subjected to extensive rodenticide testing. Following partial population reduction by a variety of rodenticides the remaining population was removed by intensive trapping with snap traps during March of 1981. Live traps were also used during the removal trapping to compare trap success. Following this extensive removal by trapping, vole activity in the study area was then monitored by use of the apple index technique and by live trapping at three week intervals. Vole activity at a tree was determined in this manner by whether or not an apple slice was chewed 24 hours after being placed in a runway. Beginning in May 1981 live trapping immediately followed each apple index check. Each trapping period lasted 48 hours with 3 or 4 checks per day. One Sherman live trap was placed at each of 213 trees within the study area. All captured animals were marked and released after recording location, sex, age and reproductive condition (Table 1).

Data on vole movements within the recently depopulated area were compared with data collected in a long term field study on vole densities, survivorship and reproduction. The latter undisturbed population served as a control.

Results

Total captures (Table 1) showed a general increase throughout the summer with the exception of the August trap session. The reduced catch in August was probably due to the extreme heat during that period.

TABLE 1. REINVASION BY PINE VOLES OF A DEPOPULATED AREA

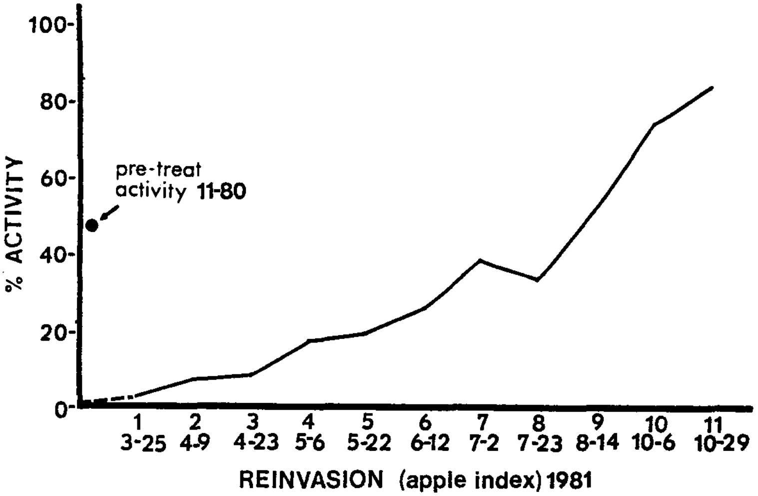
	1981					
	MAY 26-28	JUNE 15-17	JULY 7-9	JULY 27-29	AUGUST 17-19	OCTOBER 29-31
TRAP CHECKS	6	6	8	6	5	7
TOTAL INDIVIDUALS	53	24	18	47	13	96
TOTAL CAPTURES	86	46	32	82	23	113
TOTAL RECAPTURES	18	13	18	15	6	12
INDIVIDUALS WITH MULTIPLE RECAPTURES	5	5	4	8	1	1

Repopulation of the trapped out area began immediately (Table 2). The number of trees showing vole activity was greater one year after the treatments and subsequent trap out than prior to any disturbance of this orchard. Figure 1 indicates the percent active trees within the 8-acre block at 3-week intervals beginning in March 1981. This method of monitoring vole activity at individual apple trees showed a gradual but steady increase which reached an all time high of 83.7 percent in October 1981. Initial activity was 46% in November 1980 prior to any rodenticide treatments. According to the apple slice index the last areas to become repopulated were those that were farthest from the main orchard. These most distant areas included one with a road and a paved parking lot bordering on two sides. A second area was bordered by a field and a swamp on two sides.

TABLE 2. PERCENT ACTIVITY(APPLE INDEX) FOLLOWING SPRING 1981 TRAP-OUT

INDEX	1	2	3	4	5	6	7	8	9	10	11
DATE	3-25	4-9	4-23	5-6	5-22	6-12	7-2	7-23	8-14	10-6	10-29
PERCENT ACTIVE	3.4	7.8	8.2	17.7	20.2	26.1	39.5	33.0	52.3	74.2	83.7

FIG. 1.



Vole densities at individual apple trees were correlated to some degree pre and post trap-out (Figure 2). These data from only 24 trees suggest the importance of previously established vole tunnels. A ready-made habitat with a carrying capacity somewhat established by prior residents is apparent.

There was no significant difference between male and female captures (Figure 3). VanVleck (1968) working with field populations of Microtus pennsylvanicus reported no significant difference between the numbers of each sex caught by snap-traps, but found more females captured when live traps were used.

Fig. 2. Vole numbers at individual trees pre- and post-removal

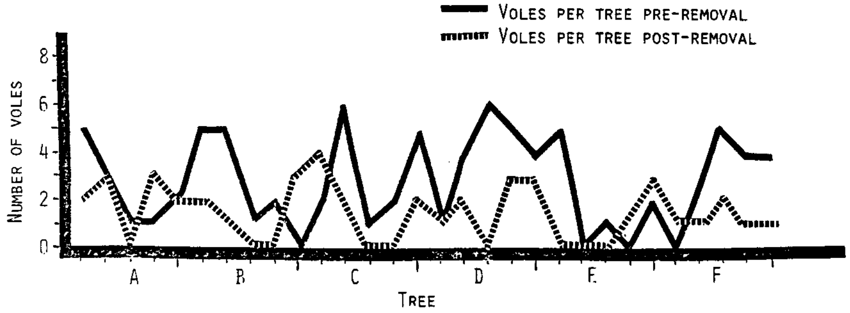
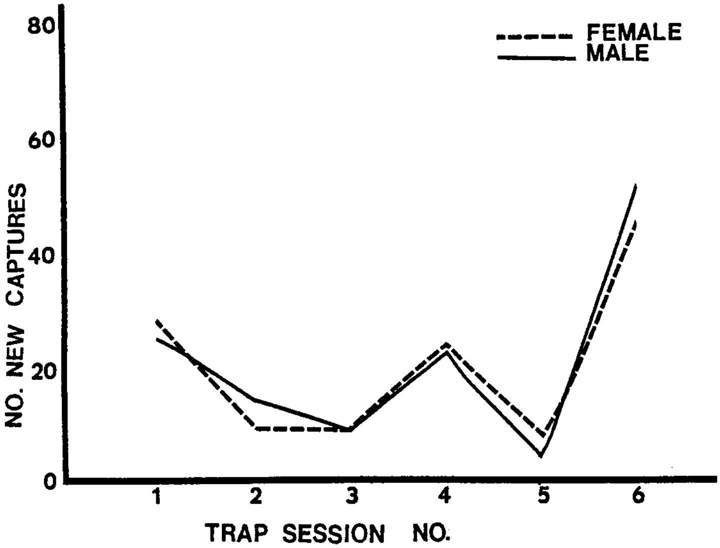


Fig. 3.



Relatively few voles were trapped farther than 1 tree from the site of their original capture (Figure 4). However, these movements were significantly further in the recently depopulated area when compared to the undisturbed population. Stickel (1946) reported a 2:1 sex ratio of males moving farther than females. Conversely, in this study marked females were live trapped at more different stations than were males. Our data show that females moved greater distances than males especially during May and June. There was no significant difference for the summer and fall trap sessions with the exception of August trapping. Trapping success was very poor in August evidently due to the hot weather. All pregnant and/or lactating females recaptured during the August session were recaptured at their original sites. During June, July and August non-breeding females moved greater distances than pregnant and/or lactating females (Figure 5). These data are consistent with results reported by VanVleck (1968).

FIG. 4. MEAN DISTANCE MOVED WITHIN A ROW IN THE RECENTLY DEPOPULATED AREA.

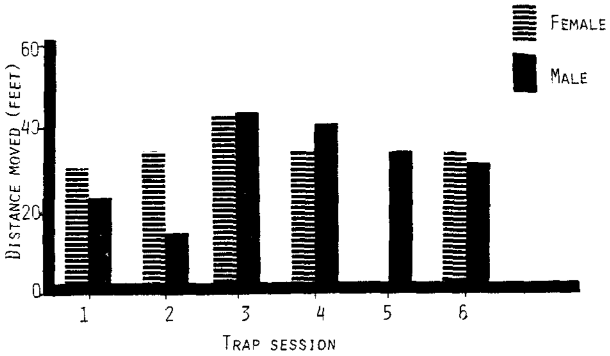
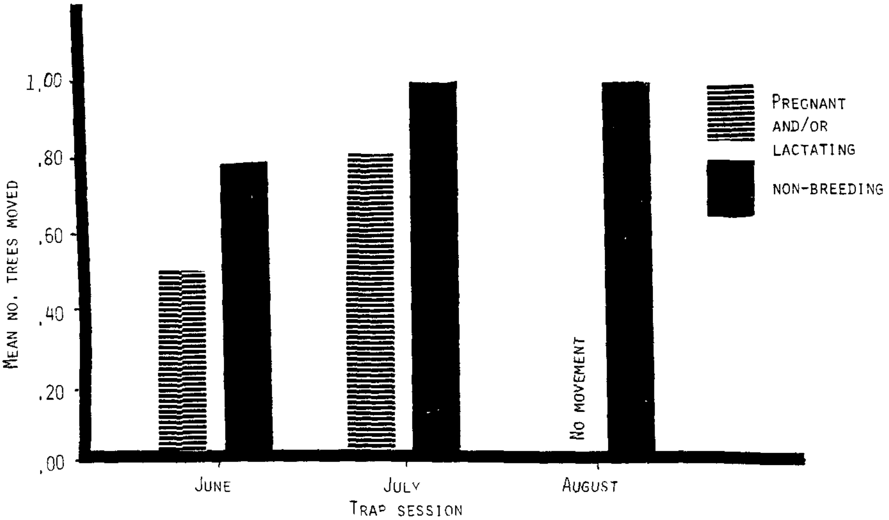


FIG. 5. MEAN DISTANCE MOVED BY PREGNANT AND/OR LACTATING PINE VOLES VS. NON-BREEDING.



Both males and females moved farther within the recently reinvaded area than voles in the undisturbed plot (Figure 6). A possible explanation for these longer movements is that perhaps dispersing voles entering the recently depopulated area encountered other voles at the edges of this area and thus continued to move on to new sites. Figure 7 shows that both males and females were recaptured more often at the same site in the undisturbed plot than voles in the reinvaded plot.

Fig. 6. Mean distance moved in disturbed or undisturbed populations.

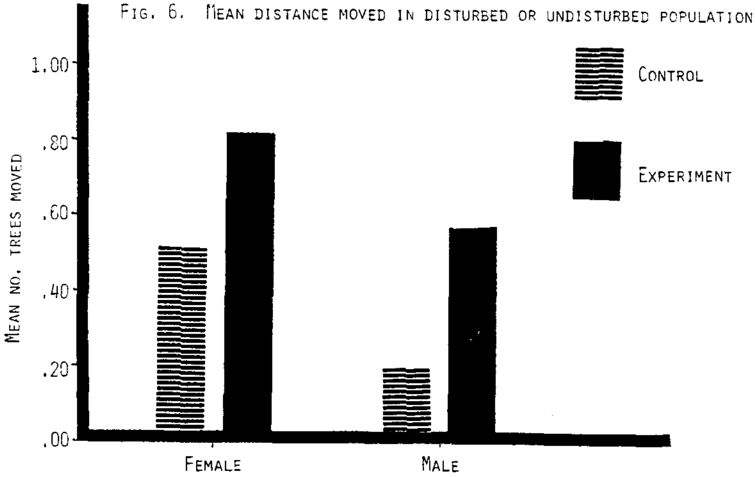
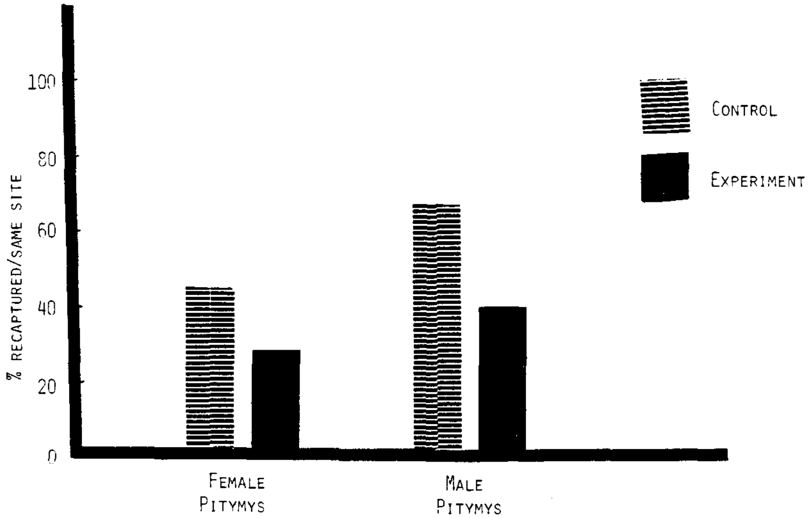


Fig. 7. Pine vole site tenacity in disturbed vs. undisturbed population.



This preliminary study emphasizes the importance of a control treatment covering an entire area incuding the edges to eliminate resulting reinvasion by nearby populations. In this study a peripheral eight-acre section of orchard was controlled by baiting and trapping. Complete coverage of the entire orchard would likely lengthen the reinvasion period because a source of reinvading pine voles from outside of orchard habitat is very uncommon. Data are being gathered from this orchard and others concerning reinvasion under different control conditions. We expect to report more fully on this subject at a later time.

Literature Cited

Stickel, L.F. 1946. The source of animals moving into a depopulated area. J. Mamm. 27:301-307.

VanVleck, P.B. 1963. Microtus movements in relation to depopulated areas. J. Mamm. 49:92-101.

STATUS OF WINTER POPULATIONS OF PINE VOLES (MICROTUS PINETORUM)

Philip O. Renzullo and Milo E. Richmond
New York Cooperative Wildlife Research Unit
Cornell University
Ithaca, N.Y. 14853

Knowledge of the spatial and temporal organization of free ranging animal populations is important to an understanding not only of the social behavior between members of those populations, but also of several demographic parameters of the population, including reproduction, dispersal and mortality. Such information is particularly important when viewed in the context of pest species management. The efficacy of control practices such as rodenticide application and habitat manipulation might be greatly enhanced if performed with an understanding of the organization and status of pest populations in mind.

Early considerations of pine vole (*Microtus pinetorum*) spatial and temporal organization were based on the observations that several animals could be captured at 1 tree in an orchard (Hamilton 1938, Benton 1955). Paul (1970) reported a "loose colonial" organization of pine voles in his study of North Carolina populations. More recently, FitzGerald and Madison (1981) have reported preliminary observations of discrete pine vole "family-units" based on radiotelemetric data gathered in the late summer and fall seasons. The status of winter populations has not previously been investigated.

This paper presents preliminary data on the spatio-temporal patterns of a winter pine vole population. Of particular interest in this study are three questions 1) What is the composition of winter pine vole aggregations? 2) What is the range of movement of these groups? and 3) How stationary are pine voles during the winter?

Methods

A 0.4 ha plot was established in an orchard in New Paltz, Ulster County, New York. The plot consisted of 65 medium aged apple trees arranged in 5 rows. At each tree, two permanent trap sites were randomly positioned at locations with good pine vole sign. Traps were placed in tunnel systems and covered with 30 cm^2 pieces of roofing tarp. Apple slices served as bait.

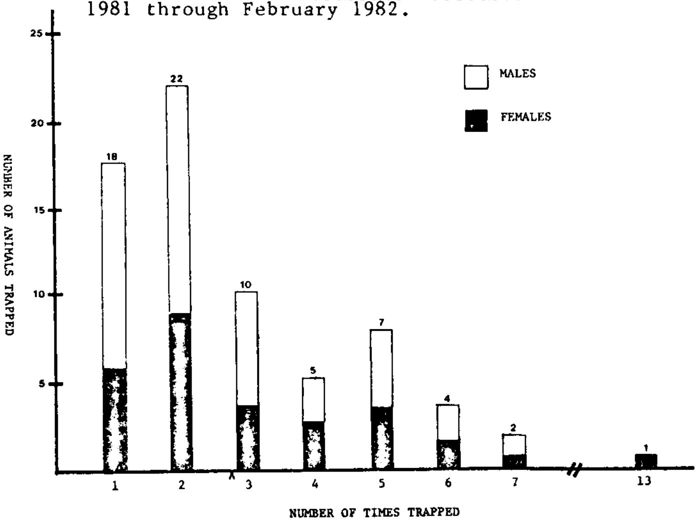
The sex, age (pelage characteristics) and reproductive conditions (males: nonscrotal or scrotal; females: nonbreeding or breeding - perforate, parous, pregnant and/or lactating) of captured animals were determined. All animals were toe clipped and returned to the tunnel at the capture site.

The population was monitored over a 4 day period each month from October 1981 to February 1982. Due to snow cover and cold temperatures in February, data were collected for a 2 day period then.

Results and Discussion

Two hundred captures of 71 animals were amassed from October 1981 through February 1982. On average, each animal was captured 2.82 times. Figure 1 presents a frequency distribution of the number of times captured as a function of the number of animals captured. The use of the negative Binominal Population Estimate (one of the class of Zero Truncated Frequency models) provided an estimate of 84.7 trappable individuals in the population. In this case, 83.8% of all trappable individuals were captured.

Figure 1. Frequency distribution of the live captures of male and female pine voles (Microtus pinetorum) trapped from October 1981 through February 1982.



Of 71 animals captured, 40 were males (30 adults: 10 subadults) and 31 were females (25 adults and 6 subadults). No juvenile pine voles were trapped during the study which is of interest because of the 31 females captured, 15 were in breeding condition throughout part or all of the study. Two criteria, vaginal perforation and/or pregnancy, were used as indicators of breeding condition.

Figure 2 shows the average range size measured in number of trees for males and females. Animals trapped only 1 time were given a range size of 1 tree. Overall, males and females did not differ in the number of trees over which they ranged. Removing those animals trapped only once from further range size determination did not alter this pattern. That is, there was no difference between male vs. female and adult males vs. adult female range size for those animals trapped greater than one time. The range size of females in reproductive condition was significantly smaller than the range size of females not in reproductive conditions (t-test, 29 d.f. $p<.05$) (Snedecor and Cochran 1978). (See Figure 3).

Figure 2. Home range sizes (number of trees) of male and female pine voles (Microtus pinetorum) as a function of age and number of times captures.

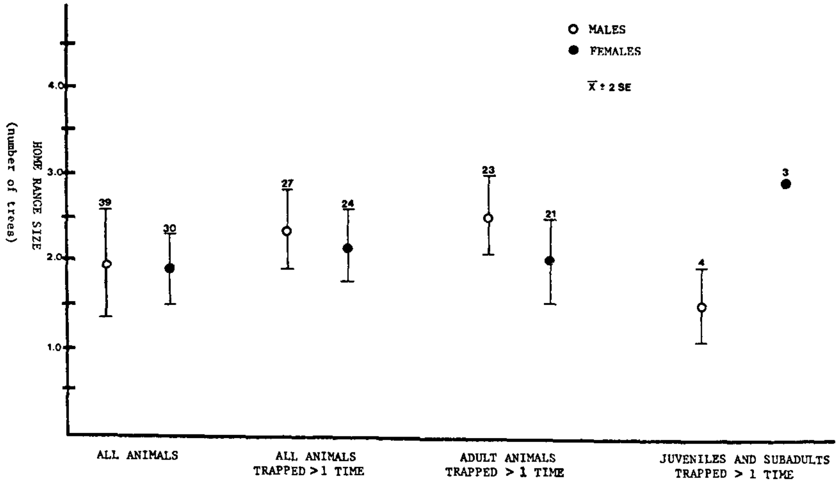
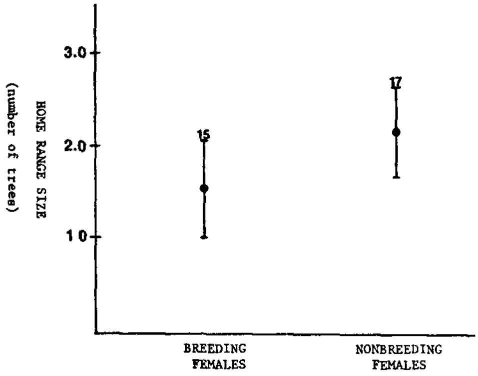
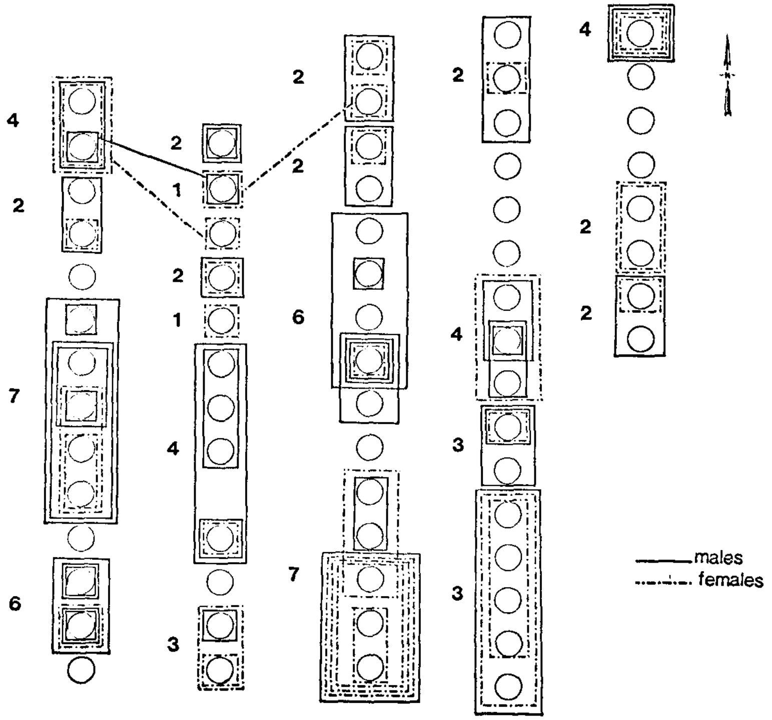


Figure 3. Home range sizes (number of trees) of breeding and nonbreeding female pine voles (Microtus pinetorum).



A total of 19 discrete, non-overlapping aggregations was identified on the study plot. An aggregation was defined as a group consisting of 2 or more animals each trapped at least 2 times at one or more trees. In all cases, aggregations were situated along tree rows as opposed to across rows. The average length of an aggregation encompassed 2.73 trees ± 0.34 (range = 1-5). Figure 4 presents a schematic of these aggregations.

Figure 4. A schematic representation of the study plot showing the 19 discrete aggregations of pine voles. (Circles represent apple trees. Rectangles represent male and female home ranges. The number of animals living in each aggregation is shown to the left.)



Of 19 aggregations, 8 contained only 1 pair of animals. Six of these eight pairs consisted of 1 adult male and 1 adult female. In only 2 cases, did an aggregation consist of a same sex pair. On average, pine vole aggregations were comprised of 3.7 individuals: 1.5 adult males, 1.4 adult females and 0.8 subadults.

Pine voles seemed to exhibit a high degree of both inter and intrasexual social tolerance, as evidenced by male-male, male-female and female-female overlapping home ranges. No physical sign of aggression such as scars or bite wounds was seen on the animals.

Conclusions

1. Pine voles live in spatially discrete aggregations during winter months.

2. These aggregations occur along rows averaging about 3 trees in length.

3. Aggregations are composed of approximately equal numbers of adult males and females (1.5:1.4) plus subadults, suggesting a family structure.

4. Sixty-three percent of all aggregations contained one reproductively active female.

5. Reproductively active females possessed home ranges which were significantly smaller than reproductively inactive females.

Investigations are continuing in an effort to answer the following:

1) How are these patterns similar to patterns of pine vole populations during other seasons?

2) Are these aggregations actually family units, or is their composition random? Based upon age and sex composition of the aggregates, disproving randomness will require behavioral and/or genetic data.

3) How is integrity of the family unit maintained over time?

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Literature Cited

Benton, A.H. 1955. Observations on the life history of the northern pine mouse. J. Mammal. 36(1):52-62.

FitzGerald, R.W. and D.M. Madison. 1981. Spacing, movements and social organization of a free-ranging population of pine voles *Microtus pinetorum*. *In*: Proceedings of the Fifth Eastern Pine and Meadow Vole Symposium. pp. 54-59.

Hamilton, W.J. 1938. Life history notes on the northern pine mouse. J. Mammal. 19(2):163-170.

Paul, J.R. 1970. Observations on the ecology, populations and reproductive biology of the pine vole, *Microtus pinetorum*, in North Carolina. Reports of Investigation #20, Illinois State Museum, Springfield, Illinois. pp. 1-27.

Snedecor, G.W. and W.G. Cochran, *Statistical Methods*. Iowa State University Press. 1978 (Sixth Edition).

Influence of Photoperiod and Nutrition on Food Consumption, Body Condition and Reproduction in the Pine Vole

J. J. Hasbrouck, A. R. Tipton, R. L. Kirkpatrick

Department of Fisheries and Wildlife Sciences
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

J. A. Cranford
Department of Biology
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

Introduction

Previous field studies in Virginia reported a longer breeding season in pine voles in maintained apple orchards than in abandoned orchards and attributed the difference to nutrition (Cengel et al. 1978, Noffsinger 1976). The maintained orchard was theorized to have better quantity and quality of forage in fall due to mowing, fertilizing and the presence of apple drops. Hasbrouck et al. (1981) found adult male pine voles snap-trapped in November and December in an orchard where apples were present had significantly heavier reproductive organs and higher spermatozoa counts than those trapped in an area of the orchard where apples had been removed.

Noffsinger (1976) speculated an interaction between a declining or short photoperiod and level of energy intake determined length of the breeding season in pine voles in autumn. Noffsinger (1976) and Merson (1979) suggested studies be conducted to determine the effects of a declining photoperiod on reproduction. The objective of this study was to determine the influence of photoperiod and nutrition on food consumption, body condition and reproduction in the pine vole.

Methods and Materials

The experiment was conducted in a metal frame building with skylight panels in the ceiling allowing sunlight into the building One to two inches of soil were placed in the bottom of concrete troughs inside the building and each trough was partitioned into four equal sections 2.3m^2 in area.

Voles were live-trapped from an orchard in late July and immediately placed in the troughs. During the first week of September, 2 males and 5 females were placed at random into 12 of 16 sections of the troughs. Half of the groups were fed a diet of *ad libitum* amounts of Purina Rabbit Chow (66% digestible energy, Servello 1981) which had been ground in a Wiley Mill. The remaining groups were given the same diet supplemented with apples. In mid-September fluorescent lights and black plastic were suspended from the rafters of the building so that half of the groups were kept on a constant 14L:10D photoperiod and the other half maintained on a natural declining photoperiod. Thus, the treatment groups were those on a 14L:10D light regime with a group fed apple and chow and a group fed only chow, and those on a natural declining photoperiod with a group given apple and chow and a group given only chow. In subsequent discussion, these groups will be denoted as LA (Long photoperiod-Chow diet), SA (Short photoperiod-Apple and chow diet), and SC (Short photoperiod-Chow diet).

The experiment was run for 12 weeks. The natural photoperiod was approximately 12L:12D at the beginning of the experiment and 9.5L:14.5D at the end. Food consumption was determined for apple and chow separately and converted to kcal digestible energy consumed per vole per week. Body weight was measured every two weeks. Dead voles were replaced during the first half of the experiment, but no voles were added during the last six weeks. Because of complications due to replacing voles, food consumption and body weights taken biweekly were analyzed statistically for only the last six weeks.

The voles were sacrificed in mid-December and frozen until necropsy. After thawing, reproductive organs and adrenal glands were removed from the animals, placed in fixative solutions for two weeks and weighed. Testes removed from males were frozen and sperm counts were done later. All remaining organs were then removed from the carcass, stripped of excess fat and the fat returned to the carcass. The carcass was homogenized and crude body fat determined by ether extraction.

Results and Discussion

Intake of digestible energy ranged from 90-135 kcal DE/vole/week. Voles on the chow diet consumed significantly ($P<0.001$) more digestible energy than those fed apple and chow. Apples comprised 50-65% of the digestible energy intake in groups with access to apples.

There was a significant ($P<0.03$) effect due to diet for change in body weight from week 6 to week 12. Voles on the chow diet lost weight, while those fed apple and chow maintained body weight.

Voles given apple and chow had significantly ($P<0.01$) more body fat than those fed chow. Female voles tended ($P<0.09$) to have higher mean final body weights and had significantly ($P<0.04$) more body fat than males. Females on the apple and chow diet had mean body fat levels around 40%.

Voles on the 14L:10D photoperiod had significantly heavier seminal vesicles ($P<0.004$), paired testes ($P<0.008$) and uteri ($P<0.04$), and tended to have more sperm/mg testes ($P<0.06$) and heavier paired ovaries ($P<0.07$) than those on the declining light regime. Males on the apple and chow diet had higher mean values for reproductive characteristics, but only paired testes weight was significantly ($P<0.05$) higher. Diet had no effect on the reproductive organ weight in females.

Field studies have found a peak in reproductive activity during summer and little or no activity during the short days of late fall and winter (Noffsinger 1976, Cengel et al. 1978). These studies also related higher reproductive activity in maintained orchards to higher quality and/or quantity of forage. In this study voles on the declining or short photoperiod had lower values for reproductive characteristics than those on the long photoperiod. Males on the apple and chow diet consistently had heavier reproductive organs and higher sperm counts than those on the chow diet.

At first glance the effects of diet in this experiment appear contradictory. Voles fed apple and chow consumed less digestible energy, but maintained body weight, had more body fat and, in males, had higher values for reproductive characteristics than those on the chow diet. The digestible dry matter (DDM) in the stomach of voles trapped in an orchard in an area with apples available was not different from the DDM of those in an area with apples removed (Servello 1981). However, reproductive organs and sperm counts were higher in voles trapped in the area with apples available (Hasbrouck et al. 1981). Thus, apples do not appear to increase digestible energy intake, but do affect the reproductive physiology of pine voles.

In an orchard environment, perhaps both photoperiod and nutrition have additive effects on reproductive activity and length of the breeding season. When some aspect of nutrition reaches a low or critical level in fall, reproduction ceases. In areas where food quality and/or quantity is not limiting, reproduction may continue to occur in fall and even into winter, but at reduced levels due to the inhibitory effects of a declining or short photoperiod. The availability of apples may be important in determining how quickly a declining photoperiod curtails the breeding season in pine voles.

LITERATURE CITED

Cengel, D. J., J. E. Estep, and R. L. Kirkpatrick. 1978. Pine vole reproduction in relation to food habits and body fat. J. Wildl. Manage., 42(4):822-833.

Hasbrouck, J. J., F. A. Servello, A. R. Tipton, and R. L. Kirkpatrick. 1981. Influence of apples on population density, body weights, and reproductive organ weights in pine voles. In Proc. of the Fifth Eastern Pine and Meadow Vole Symposium, Gettysburg, PA:72-75.

Merson, M. H. 1979. Influence of restricted feed intake on the reproductive characteristics, energetics, and body composition on two species of rodents. Unpubl. Ph.D. dissertation, VPI & SU. 229 pp.

Noffsinger, R. E. 1976. Seasonal variation in the natality, mortality, and nutrition of the pine vole in two orchard types. Unpubl. M.S. thesis, VPI & SU. 126 pp.

Servello, F. A. 1981. Nutritional ecology of the pine vole in relation to apple tree root damage. Unpubl. M.S. thesis, VPI & SU. 153 pp.

A Preliminary Survey of Genetic Variation Over Two Seasons Among Orchard Pine Vole Populations

J. E. McBride, J. J. Ney, A. R. Tipton, and R. L. Kirkpatrick
Department of Fisheries and Wildlife Sciences
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

Introduction

The objective of this study was to test for genetic homogeneity among several discontinuous orchard pine vole populations, particularly between those that had been treated with endrin and those that had not. Endrin-resistant pine vole strains have been documented (Webb and Horsfall 1967; Webb et al. 1973), but have not been characterized genetically. Practically, this study was designed to determine if genetic differences existed among endrin-treated and nontreated orchard populations over two seasons of the year, by examining a few specific gene loci believed to be involved in endrin metabolism in small mammals.

Materials and Methods

A representative sample of pine voles from each of 3 endrin-treated and 3 nontreated apple orchards in southwestern Virginia was trapped during Fall 1980 and again in 2 orchards of each type during early Spring 1981. The same animals which had been subjected to and had survived the endrin treatments applied between sampling periods thus should have been captured in the Spring. All treated orchards had been sprayed annually with endrin for the past 15 years, and the nontreated orchards had not received treatment for this same amount of time. Since the animals were to be removed (a form of artificial selection), only one section of an orchard was trapped at either sampling period, leaving a buffer zone of at least three rows of trees between the Fall- and Spring-trapped sections. Traps were relocated on the second or third day of trapping so that eventually every tree with vole sign in the designated section was trapped. Carcasses were placed on dry ice in the field and then stored in the laboratory at about -20C.

Seven enzyme systems were surveyed in each orchard population for possible use as polymorphic genetic markers using horizontal starch-gel electrophoresis. Changes in activity levels of five of these systems had been reported to occur after endrin injection in small mammals (Kacew and Singhal 1973; Ludwicki 1974; Hendrickson and Bowden 1976; Meenä et al. 1978): AcP (acid phosphatase), β - GUS (β -glucuronidase), FDP (fructose-1, 6-diphosphatase), GOT (glutamate oxaloacetate transaminase), and LDH (lactate dehydrogenase). In addition, two other arbitrarily chosen systems were surveyed: IDH (isocitrate dehydrogenase) and MDH (malate dehydrogenase). It was necessarily assumed that none of the loci observed influenced the probability an animal was captured.

Kidney tissue was used in electrophoresis of the above enzyme systems. The tissues were homogeneized, centrifuged, and applied to filter-paper wicks that were inserted into a 12.5%-starch gel. At all stages of preparation, carcasses, excised kidneys, homogenates, sample wicks, and prepared gels were kept frozen, refrigerated, or on ice to prevent enzyme degradation. Recipes for electrophoretic buffers and histochemical stains were modified Harris and Hopkinson (1976) formulations reported by Guse (1980 and pers. comm.). After electrophoresis, gels were stained for the desired enzymes and banding patterns were immediately scored by genotype.

Results and Discussion

AcP, β -Gus, FDP, GOT-1, and MDH-1 were found to be monomorphic in all the pine vole populations studied. GOT-2, IDH-1, LDH-1, and MDH-2 were found to be polymorphic and were used to electrophoretically characterize each individual sampled (McBride 1981). For the four polymorphic loci in each orchard population, χ^2 independence tests of genotype frequency and sex were performed. IDH-1 and MDH-2 genotypes were found to be sex-dependent (α=0.05). These sex dependencies occurred in different sprayed orchards for the two loci at both seasons, and for IDH-1 also in a nonsprayed orchard in the Fall. Greater numbers of heterozygous females than those expected (and a concomitant lesser number of heterozygous males) occurred in the sprayed orchards for IDH-1 and MDH-2, whereas the opposite occurred for IDH-1 in the Fall nonsprayed orchard.

Three-way independence tests of orchard, season, and genotype frequency conducted for each polymorphic locus by the G log-likelihood ratio test demonstrated that genetic structure at the four loci differed among orchards, as expected, since these discontinuous populations have virtually no contact with each other. Orchard, season and genotype frequency were jointly dependent variables with significant interactions (α=0.05) at all four polymorphic loci. Differences in genotype frequencies were sigificant due to orchard type (endrin-treated or nontreated) only at the IDH-1 and LDH-1 loci, with heterozygotes comprising greater proportions of the populations in nontreated orchards for IDH-1 and in treated orchards for LDH-1.

Mean individual heterozygosity (mean number of heterozygous loci per individual) decreased slightly from Fall to Spring in 3 of the 4 orchards that were sampled both seasons, but increased slightly in one orchard that had been treated with chlorophacinone (Rozol) as well as endrin. Greater heterozygosities did not occur consistently in either endrin-sprayed or nonsprayed orchards at either season, nor were sex differences consistent with respect to orchard type or sampling time. Heterozygosity averaged over the 4 orchards, however, was slightly higher in nontreated orchards both seasons. The average also decreased from Fall to Spring in both sexes and in both orchard types.

Heterozygosity as a measure of inherited variability is commonly used as an index to the adaptive potential of a population, since the more heterozygous individuals are believed to have greater capacities to survive and change with their environment, thus successfully reproducing their kind (Selander et al. 1971; Manlove et al. 1975; Smith et al. 1975). The reductions in heterozygosity that occurred in 3 orchards may indicate the intermittent random drift effects that can result from severe local or periodic reductions in population density (Wilson and Bossert 1971), such as pesticide use and adverse winter weather conditions. The unique increase in heterozygosity that occurred in the one orchard treated with chlorophacinone as well as endrin, however, may suggest the greater adaptability and selective advantage of the more heterozygous animals, since presumably voles that survived both mortality factors would be more heterozygous than those facing just one. Alternatively, this one increase in heterozygosity may have been a random occurrence.

Summary and Conclusions

The presence of known, differing sources of mortality in the endrin-treated and nontreated orchards of this study provided a preliminary baseline for meaningful comparisons of population genetic indices. Since population genetic composition at the loci observed did not vary appreciably or consistently with respect to endrin treatment, no conclusions can be stated as to the genetic consequences of endrin-induced mortality in wild pine vole populations. Population genetic structure did seem to vary somewhat from Fall to Spring among orchards, regardless of pesticide use. Therefore, the orchard environment, with its predictable source of chemical-induced mortality, provides an excellent natural situation for further genetic observations.

REFERENCES CITED

Guse, C. J. 1980. Assessment of genetic variation between spawning aggregates of striped bass from Kerr Reservoir, Va.-N.C. M.S. Thesis. VPI & SU. 83 pp.

Harris, H. and D. A. Hopkinson. 1976. Hand book of enzyme electrophoresis in human genetics. North-Holland, Amsterdam.

Hendrickson, C. M. and J. A. Bowden. 1976. In vitro inhibition of of lactic acid dehydrogenase by insecticidal polychlorinated hydrocarbons. 2. Inhibition by dieldrin and related compounds. J. Agric. Food Chem. 24:756-759.

Kacew, S. and R. L. Singhal. 1973. The influence of p,p' -DDT, α-chlordane, heptachlor, and endrin on hepatic and renal carbohydrate metabolism and cyclic AMP-adenyl cyclase system. Life Sci. 13: 1363-1371.

Ludwicki, J. K. 1974. The effect of selected compounds on the enzymes in lysosomal fraction of rat liver. I. In vitro investigations. Rocz. Panstw. Zakl. Hig. 25:287-293. [In Polish; English abstact in Pest. Abstracts 1975:480].

Manlove, M. N.; Avise, J. C.; Hillestad, H. O.; Ramsey, P. R.; Smith, M. H.; and D. O. Straney. 1975. Starch gel electrophoresis for the study of population genetics of white-tailed deer. Proc. Southeast. Assoc. Fish Game Comm. 29:392-403.

McBride, J. E. 1981. Electrophoretic investigation of genetic characteristics in pine vole. M.S. Thesis. VPI & SU. 114 pp.

Meena, K.; Gupta, P. K.; and S. R. Bawa. 1978. Endrin-induced toxicity in normal and irradiated rats. Environ. Res. 16:373-382.

Selander, R. K.; Smith, M. H.; Yang, S. Y.; Johnson, W. E.; and J. B. Gentry. 1971. Biochemical polymorphism and systematics in the genus Peromyscus. I. Variation in the old-field mouse (Peromyscus polionotus). Stud. Genet. VI: Univ. Texas Publ. 7103:49-90.

Smith, M. H.; Garten, C. T., Jr.; and P. R. Ramsey. 1975. Genic heterozygosity and population dynamics in small mammals. Pages 85-102 in C. L. Markert, ed. Isozymes IV: Genetics and evolution. Academic Press, New York, N.Y. 965 pp.

Webb, R. E.; Hartgrove, R. W.; Randolph, W. C.; Petrella, V. J.; and F. Horsfall. 1973. Toxicity studies in endrin-susceptible and resistant strains of pine mice. Toxicol. Appl. Pharmacol. 25:42-47.

________ and F. Horsfall, Jr. 1967. Endrin resistance in the pine mouse. Science 156:1762.

Wilson, E. O. and W. H. Bossert. 1971. A primer of population biology. Sinauer Associates, Sunderland, MA. 192 pp.

RADIOTELEMETRIC EVALUATION OF THE EFFECT OF HORTICULTURAL PRACTICES ON PINE AND MEADOW VOLES IN APPLE ORCHARDS:
II. HERBICIDE APPLICATION

Dale M. Madison, Ralph E. Pagano and Randall W. FitzGerald

Department of Biology
State University of New York at Binghamton
Binghamton, New York 13901

Abstract: Pine voles (*Microtus pinetorum*) and meadow voles (*Microtus pennsylvanicus*) were studied in a commercial apple orchard in the Hudson Valley of New York during April and May 1981. Selected voles were given miniature radiotransmitters and then tracked before and after herbicide application. A total of eight pine and meadow voles were tracked throughout the experimental period. Home range size decreased on the day following herbicide application but showed an increase from day 1 to day 5 & 7 after application. Movements away from the tree line into the aisles did not change significantly after herbicide use. We conclude that if herbicide is to have a significant impact on vole management in orchards, it must be used regularly in conjunction with other cultural practices.

INTRODUCTION

The problem of pine and meadow vole control in orchard habitat has been approached in different ways. Studies have included the use of toxicants, alternate food supplies, habitat manipulation (mowing, herbicide use, cultivation), interspecific vole competitors, apple tree stock that is unattractive to voles, and others (Bart and Richmond, 1979; Byers, 1977; Horsfall et al., 1974; Madison et al., 1981, McAninch, 1978; Pagano and Madison, 1982; Pearson et al., 1980; Young, 1977). One difficulty in evaluating some of these control procedures in the orchard environment is that the response or fate of the voles during experimentation is not clearly known. The use of radiotelemetry allows one to monitor vole movement and mortality following experimental treatments in the orchard.

In a previous study, we demonstrated that mowing without thatch removal has little effect on the immediate survival and movement of pine and meadow voles (Madison et al., 1981). In another study, we measured the effect of clearing a border strip on vole movement between the orchard and surrounding habitats, and suggested that the border populations of voles should be considered in vole management programs (Pagano and Madison, 1982). The present study reports the results of a small scale effort to see what happens to pine and meadow vole movement following the application of the herbicide Paraquat.

METHODS

The study was conducted from 20 April to 15 May 1981 within Stanley Orchards, Modena, Ulster Co., New York. A 2.0 acre (0.8 hectare) section of orchard consisting of 8 rows, 16 trees/row, was used. All tree bases were censused regularly with Spencer live traps for the occurrence of both pine and meadow voles. Eleven voles (9 pine voles, 2 meadow voles) were captured for radiotracking following an intensive census period during late April and early May. Since the population density of both species, and especially of meadow voles, was low during this spring, it was difficult to find many voles for tracking. The 11 adults captured consisted of a sample of 9 adult pine voles and all the adult meadow voles that could be found within the orchard plot at the time of the census.

The voles were given radiotransmitters between 20 April and 4 May, and then were radiotracked during intensive sessions between 5 May and 15 May. The surgical technique for implanting the radiotransmitters, and the technique used to track the voles, are reported in Madison et al. (1981). The tracking sessions consisted of recording the position of each vole once every 30 minutes from 1600 h to 2300 h, thus generating 15 positions for each session. This time interval was chosen because earlier studies revealed that this was an active period for voles. The sessions were conducted 3 days before herbicide application and on days 1, 5, and 7 following application.

The herbicide Paraquat was administered on 8 May at a concentration of approximately 0.56 Kg/hectare (0.5 lb/acre). The tractor-hauled spray unit with boom covered a strip 1.5 m (5 feet) to either side of every row. Since the grass was very high and thick at the time of spraying, penetration of the herbicide was incomplete in some areas, as evidenced by green patches of vegetation in the treated zone following herbicide application.

The 15 position fixes per study session were used to determine whether movement of the voles changed after herbicide application. Two measures were chosen. One was the area covered by the 15 positions, and the other was the average distance of these positions from the nearest tree row (see details in Madison et al., 1981). Since we did not have the resources to establish a concurrent control plot (one having radiotagged voles but not receiving herbicide), we used the movements of the voles before herbicide treatment as a control for the movements after herbicide application. Since all the radiotelemetry positions were recorded during an 11-day period, we felt that any effects due to environmental conditions unrelated to treatment would be small compared to the effect of a sudden, grass/forb die-off in the habitat following herbicide application.

RESULTS

General. Of the 11 voles initially radiotagged, 8 were tracked throughout the study period. Three voles disappeared during tracking, and one additional vole disappeared before the voles were recaptured for transmitter removal on 17 May. Since the study plot was censused regularly following this herbicide study, and since none of the 4 voles was ever recaptured, predation is the most likely cause of the disappearance of these voles. The records of the 8 voles tracked throughout the 11-day period of intensive tracking constitutes the data set for the analyses to follow.

Home Range Size. The size of the short term home range covering 15 positions for each vole during each tracking session averaged 2.8 m 3 days before herbicide application and 2.4 m, 5.0 m and 6.0 m on days 1, 3 and 5 following application, respectively (Table I). Relative to the size of the area used by each of these voles before treatment, the area used by the 8 voles one day after treatment was

Table 1: Home range size (HR, m^2) and average distance from the nearest tree row (AD, m) for the eight adult pine voles (PV) and meadow voles (MV) radiotracked during all study sessions before and after herbicide application.

			Day Relative to Application							
			-3		+1		+5		+7	
Species	Sex	Wt. (g)	HR	AD	HR	AD	HR	AD	HR	AD
PV	M	27	1.2	0.9	0.8	1.0	3.7	1.1	3.3	1.1
PV	M	25	7.0	0.9	0.8	0.9	0.9	0.9	1.2	0.9
PV	F	29	4.1	0.5	9.4	0.7	10.0	0.7	18.0	0.5
PV	F	28	1.6	0.7	0.8	0.5	8.6	0.8	14.7	0.9
PV	F	30	1.6	0.9	1.8	1.0	0.4	0.9	1.2	1.0
PV	F	22	0.4	0.5	0.3	0.4	7.4	0.4	3.7	0.4
PV	F	27	2.9	0.0	2.8	0.9	0.8	1.1	2.0	1.0
MV	F	35	3.7	0.2	2.5	0.4	8.6	0.5	4.1	0.3
	Mean		2.8	0.7	2.4	0.7	5.0	0.8	6.0	0.8
	SD		2.0	0.3	3.0	0.3	4.0	0.2	6.5	0.3

smaller for 6 of the 8 individuals. On days 5 and 7 after application, 12 of the 16 home ranges these days were larger than those for the same voles one day after treatment. The shift from smaller areas on the day following application to larger areas on days 5 and 7 after application was significant (Fisher's Test, $p = 0.03$).

Distance Moved From Row. The average distance moved perpendicular to the tree rows was 0.7 m 3 days before application and 0.7 m, 0.8 m and 0.8 m on days 1, 5 and 7 following application, respectively (Table 1). Although these distances were greater on the average after herbicide application, the number of voles showing greater movement away from the rows after application was not significantly different from random expectation.

DISCUSSION

The normal effect of herbicide application in an apple orchard is the death of most grasses and forbs in the area of application. Since this area along tree rows is also the preferred habitat of pine and meadow voles in the orchard, and since both pine and meadow voles benefit from the vegetative cover in these areas (McAninch, 1978), our initial expectation was that the herbicide would cause the death or dispersal of voles in the treated areas. However, our data indicate only small effects on death or movement.

The loss of 4 of the 11 voles during the 2 weeks after herbicide application is high; the normal loss rate is about 9% per week, thus a 1 to 2 vole loss would have been normal. The increased number of voles lost, probably to predators, is likely the result of increased susceptibility due to the reduction in the grass/forb canopy.

The decreased home range size on the day following application is not surprising considering the fact that most of the grass in the sprayed area had turned brown within 24 h of spraying. Thus, upon being suddenly more exposed on day 1 after application, the voles were probably temporarily inhibited in their movements. The increased home range size noted on days 5 and 7 after treatment is consistent with food shortage and with the voles having to forage more widely for green vegetation. Since the voles did not increase their movements into areas towards the aisles where the grass had not been sprayed, the voles must have moved farther along the rows, or across rows. Both of these adjustments in movement were observed. The increased movement along rows probably occurred because a substantial amount of green grass still remained in this area. The green grass remaining was in such high and thick clumps at the time of spraying that a good portion of it survived. Both pine and meadow voles foraged in these green patches in preference to moving into the green grass next to the aisles.

Our general impression is that herbicide application is not in itself an effective cultural method for the control of voles in orchards. The effect of herbicide application would have been more noticeable had the herbicide been applied to the entire area under the trees at a time when the grass cover was not as thick or tall (e.g., less than 12 inches high). We predict that under these circumstances the meadow voles would have been forced into the pine vole burrows or out of the orchard altogether. The pine voles would likely become exclusively subterranean, at least until regrowth, and would probably begin to feed more on tree roots. For the latter reason, herbicide application combined with poison baits would be a recommended control procedure for pine voles.

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LITERATURE CITED

Bart, J. and M.E. Richmond. 1979. Preliminary results of two research projects in New York, pp. 36-38, In: R.E. Byers (ed.) Proc. Third Eastern Pine and Meadow Vole Symposium, New Paltz, N.Y.

Byers, R.E. 1977. Pine vole control research in Virginia, pp. 89-100, In. R.E. Byers (ed.) Proc. First Eastern Pine and Meadow Vole Symposium, Winchester, Va.

Horsfall, F., Jr., R.E. Webb, and R.E. Byers. 1974. Dual role of forbs and rodenticides in the ground spray control of pine mice. Proc. Vert. Pest Control Conf. 6:112-126.

Madison, D., R. FitzGerald, R. Pagano, and J. Hill. 1981. Radio-telemetric evaluation of the effect of horticultural practices on pine and meadow voles in apple orchards: I. Rotary mowing, pp. 45-53, In: R.E. Byers (ed.) Proc. Fifth Eastern Pine and Meadow Vole Symposium, Gettysburg, PA.

McAninch, J. 1978. An ecological framework for vole management, pp. 91-95, In: R.E. Byers (ed.) Proc. Second Eastern Pine and Meadow Vole Symposium, Beltsville, Md.

Pagano, R. and D. Madison. 1982. Radiotelemetric evaluation of the effect of horticultural practices on pine and meadow voles in apple orchards: III. Use of orchard border habitats by meadow voles. In: R.E. Byers (ed.) Proc. Sixth Eastern Pine and Meadow Vole Symposium, Harpers Ferry, Va.

Pearson, K., J.N. Cummins, and J. Barnard. 1980. Preliminary field observations of meadow vole preferences among selected apple clones, pp. 50-54, In: R.E. Byers (ed.) Proc. Fourth Eastern Pine and Meadow Vole Symposium, Hendersonville, N.C.

Young, R.S. 1977. Pine vole control with herbicides, pp. 59-61, In: R.E. Byers (ed.) Proc. First Eastern Pine and Meadow Vole Symposium, Winchester, Va.

RADIOTELEMETRIC EVALUATION OF THE EFFECT OF HORTICULTURAL PRACTICES ON PINE AND MEADOW VOLES IN APPLE ORCHARDS:
III. USE OF ORCHARD BORDER HABITATS BY MEADOW VOLES

Ralph E. Pagano and Dale M. Madison

Department of Biology
State University of New York at Binghamton
Binghamton, New York 13901

Abstract: A study was undertaken to determine if meadow voles, *Microtus pennsylvanicus*, use habitats adjacent to apple orchards. Considerations were given to how extensively these areas were used, if at all, and if a bulldozed strip would control their movements between the orchard and adjacent border habitats. Trapping and telemetry data showed that meadow voles do use the adjacent border habitats extensively and make frequent crossings between these areas and the nearby orchards. It would seem, therefore, important to include these areas in any vole management program. Although the bulldozed strip was effective in reducing movements between the orchard and adjacent habitat types, questions remain as to the optimal method of controlling any movement.

INTRODUCTION

A major concern of the orchard growers of the Hudson Valley has been the reinvasion of an orchard whose vole population has been eliminated or controlled. Hamilton (1935) indicated that meadow voles used brush piles, weedy corners, and other borders near orchards. These individuals could act as "seed" populations that might ultimately invade the orchards. Thus, it would be important to identify such sources, if they exist, and include these habitats in any overall vole management program.

Four main questions were posed prior to the initiation of the field work. First, do meadow voles use habitats that are adjacent to many of the orchards? Second, to what extent do meadow voles use this border-refuge habitat? Third, how extensive are any movements between the orchard and border habitats? Finally, what effect would a boundary strip have on movement patterns between the orchard and border areas?

METHODS

The study site was located on the Steve Clarke farm near Modena, New York in the Hudson Valley. A trapping grid was set up along an orchard edge bordering a wet hollow dominated by thick brush and woody vegetation. A grass strip 5 m wide separated the orchard from the brush and will hereafter be called the edge.

The trapping grid consisted of 90 Sherman live traps set in 15 rows with six stations per row (Figure 1). One trap was placed at

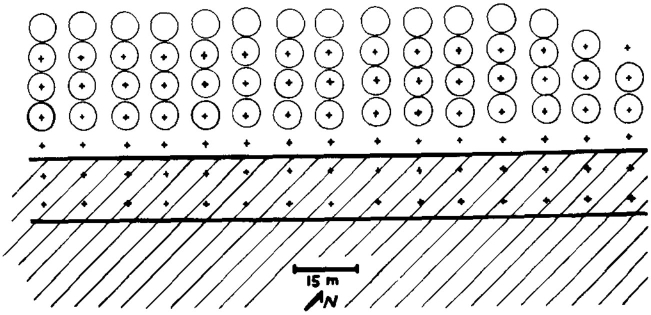

Figure 1: Diagram of the study site, showing apple trees (O), trap locations (+), and the brush habitat (///). The two heavy horizontal lines enclose the bulldozed zone.

each station. Traps were spaced 7 m apart within rows and 10 m apart between rows as dictated by tree spacing. The grid was situated so that three stations in every row were in the orchard, one station was in the edge, and two were in the brush. Three trap checks were conducted over a two-day period for a total of 270 trap checks. At the conclusion of the study, a three-day trap out was conducted to retrieve transmitters and remove all animals present.

Telemetry equipment and methods used were similar to those described in earlier papers (Madison, et al., 1980). Four adult male meadow voles and five adult females were selected from the animals trapped for use in the telemetry work. These animals came primarily from orchard trap sites. All male meadow voles were reproductively active, and all females were at the same stage of pregnancy at the time of transmitter implant.

Telemetry positions were obtained hourly for eight consecutive hours on each of three days for every individual. After an initial 25 positions were obtained, a bulldozed strip 15 m wide was made in the brush. The 5 m wide edge was left untouched, creating a total distance of 20 m between the orchard and the edge of the brush. Twenty-five telemetry positions were again obtained on each individual in the same manner as described above. The data were combined (males plus females) for analysis.

RESULTS

The trapping results shown in Table 1 indicate that the meadow voles used all three areas found within the study site. For the size of the area involved, a disproportionately high number of voles were caught in the mowed edge habitat. The results of the trapping suggested a justification to continue with the project despite the fewer captures in the brush zone.

Table 1: Trapping data indicating the number of different individuals caught in each habitat type.

	Sex			Total
	M	F	Total	Trap Checks
Orchard	5	6	11	135
Edge	7	3	10	45
Brush	4	2	6	90

Animals caught in one habitat type did not necessarily restrict their movements to that area. Six of the nine transmittered voles included both the brush and orchard habitats within their home ranges. These animals freely crossed the grassy edge before the bulldozed strip was created between the orchard and brush zones.

The telemetry data presented in Table 2 are adjusted values, obtained by multiplying the raw data by coefficients to reflect the size of the three habitat types on the study sites. The total telemetry positions for the edge, brush, and orchard were multiplied by .17, .33, and .50, respectively. The data are summarized as mean telemetry positions per habitat type before and after bulldozing.

Table 2: Telemetry data summarized as mean positions per area before and after bulldozing. The telemetry data was adjusted by coefficients to reflect the size differences between the habitat types (the coefficients were .17 for edge, .33 for brush, and .50 for orchard).

	Orchard	Edge	Brush
Before	3.17	0.28	5.41
After	4.17	0.08	3.21

A two-way analysis of variance was carried out on the telemetry data. No statistically significant differences existed between before and after bulldozing; however, the area main effect was significant ($p < .01$). A Neuman-Keuls multiple range test showed that brush and orchard zones were used similarly, but the edge was used significantly less than either the brush or orchard ($p < .05$).

As an indicator of mobility between the brush and orchard areas, the number of complete crossings from the brush into the orchard habitat (or vice versa) was tabulated both before and after the bulldozing for each meadow vole (Table 3). All but two of the nine animals carrying transmitters made crossing moves before the manipulation. During the bulldozing operation, considerable movement occurred as nearly every transmittered vole had to move away from the bulldozer. However, only one female meadow vole carrying a transmitter was killed as a direct result of the bulldozing. A t-test showed a statistically significant difference in crossings before vs. after bulldozing ($t = 3.48$, $p < .05$). Substantively, there appears to be a distinct decrease in the number of crossings after the bulldozing.

Table 3: The number of crossings from the orchard to the brush (or vice versa) by individual meadow voles before and after bulldozing.

	Number of Crossings	
Vole	Before	After
1	0	0
2	3	1
3	6	1
4	6	1
5	2	1
6	4	0
7	6	1
	$\bar{X} = 3.86$	$\bar{X} = 0.71$

DISCUSSION

The main purpose of this study was to determine if habitats found adjacent to orchards were used by meadow voles. The trapping and telemetry data not only show that some meadow voles use the brush as part of their home ranges, but that they use it just as intensively as they use the orchard habitat. There is considerable movement between the orchard and brush habitats as long as there is no barrier to prevent it.

The relatively open and unprotected edge habitat appears to be used in a limited way by the voles, primarily as a corridor through which to move between the brush and orchard. The large number of trap captures, but the small number of telemetry positions, in this zone can be explained at least in part by rapid movements between the brush and orchard habitats.

Several animals moved into the brush toward the evening hours with only intermittent periods spent there during the day. This suggests that the animals preferred the shelter of the brush, but preferred to feed in the orchard. This conclusion is supported by the paucity of herbaceous vegetation on which to feed in the brush habitat.

Reducing the likelihood of reinvasion of the orchards by voles is an important element of a management program. By reducing or eliminating the movement of animals between the orchard and border habitats, a grower can create two separate populations, thereby allowing the implementation of a management program without the threat of invasion by voles from external sources. Although the bulldozed border strip appeared to be effective in stopping crossing movements, it is doubtful that a 20 m wide strip would be a practical control measure. Adjoining property lines often make it difficult to use many effective means of control.

Cole (1978) indicated that a clean, mowed strip 10 m wide was an adequate barrier to prairie vole movements. Another study in Australia (Barnett, et al., 1978) showed that small mammals rarely crossed open areas such as roads even if the road had long been unused and was partly overgrown. They also indicated that the number of crossings was inversely related to road width. Horsfal (1964) stated that roads and streams appear to act as barriers to meadow and pine vole movements along orchard borders. Other deterrents could include tilled and/or herbicided strips along orchard boundaries.

Where possible, border areas should be kept clean (Hamilton, 1935), since brush piles or overgrown corners can support a population of meadow voles. However, any alteration of the habitat should be done in conjunction with an orchard management plan since the removal of shelter could force animals to seek refuge in the nearby orchards (Horsfal, 1964).

The results of this study indicate that a sound vole management program should include habitats adjacent to the orchards. Although the location of the study site dictated the use of only meadow voles in this project, it is possible that many of the woodlots that exist near the orchards could harbor pine vole populations as well (Goertz, 1971; Paul, 1970; Benton, 1955). Further work needs to be done to identify the bordering habitats that could harbor meadow and/or pine vole populations. The effect of different population densities on movements across barriers, as well as the long-term effectiveness of barriers, must also be studied before final conclusions can be drawn.

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LITERATURE CITED

Barnett, J.L., R.A. How, and W.F. Humphreys. 1978. The use of habitat components by small mammals in Eastern Australia. Aust. J. of Ecol. 3: 277-285.

Benton, A.H. 1955. Observations on the life history of the northern pine mouse. J. Mamm. 36: 52-62.

Cole, F.R. 1978. A movement barrier useful in population studies of small mammals. Amer. Midl. Nat. 100: 480-482.

Goertz, J.W. 1971. An ecological study of *Microtus pinetorum* in Oklahoma. Amer. Midl. Nat. 86: 1-12.

Hamilton, W.J., Jr. 1935. Field mouse and rabbit control in New York orchards. Cornell Extension Bulletin #338.

Horsfal, F., Jr. 1964. Pine mouse invasion and reinfestation of orchards subsequent to removal of adjacent woody plant cover or the use of ground sprays. Am. Soc. Hort. Sci. 85: 161-171.

Madison, D., R. FitzGerald, R. Pagano, and J. Hill. 1980. Radiotelemetric evaluation of the effect of horticultural practices on pine and meadow voles in apple orchards: I. Rotary mowing. Proc. of the Fifth Eastern Pine and Meadow Vole Symposium, Gettysburg, Pa. pp. 45-53.

Paul, J.R. 1970. Observations on the ecology, populations, and reproductive biology of the pine vole, *Microtus pinetorum*, in North Carolina. Illinois State Museum. Reports of Investigations, No. 20.

HABITAT UTILIZATION AND SPACING PATTERNS
OF PINE AND MEADOW VOLES

J. A. Cranford and T. L. Derting
Virginia Polytechnic Institute
and State University
Department of Biology
Blacksburg, Virginia 24061

INTRODUCTION

Pine voles (*Microtus pinetorum*) and meadow voles (*M. pennsylvanicus*) co-occur in orchards but may exhibit mutual avoidance through temporal or spatial isolation. Though pine and meadow voles have exhibited overlapping home ranges, individuals of the two species seldom occupy the same $2m^2$ area at the same time (Pagano & Madison, 1981). Differences in habitat use by pine and meadow voles may contribute to their spatial separation in orchards. McAnich (1979) found a weak relationship between meadow vole numbers and soil compaction, soil moisture, thatch depth, and light intensity and no relationship between meadow vole occurrence and soil organic matter or cover density. However, Pagano and Madison (1981) report a strong correlation between meadow vole numbers and abundant cover during August. Pine voles exhibited a significant relationship with soil compaction, thatch depth, and light intensity.

Studies concerning pine and meadow vole movements and habitat use have monitored established vole populations usually in maintained orchards. This paper reports on the ecological parameters associated with pine vole colonization of an abandoned orchard. Thus, site selection by pine voles and the effect of pine vole movement and establishment on meadow voles could be determined.

MATERIALS AND METHODS

In an isolated abandoned orchard in Montgomery County Virginia, which contained an established meadow vole population, two trap grids (0.25 hectare each) were established in June, 1980. Each grid consisted of four tree rows (10 trees per row) and 5 aisle rows with 94 and 102 trapsites per grid. The grids were separated by 35 meters of continuous habitat and were trapped monthly. Aisle rows had large Sherman traps 6 meters apart and tree rows had 2 small Sherman traps at each active tree site. Traps were baited with oats and apples and were placed in vole runs. Tree traps were dug into runways and covered with tar paper. Meadow vole populations were monitored throughout the study while pine vole populations were monitored after their release in 1980 and 1981.

In September, 1980 94 pine voles (47♂♂, 47♀♀) were released on the control grid but subsequently colonized the experimental grid. Since few members of this population survived the winter, a second release of 100 pine voles (50 ♂♂, 50 ♀♀) was conducted on the experimental grid in July, 1981. Voles were released on the central portion of the grids, 2 pairs per tree.

All trapped animals were toe clipped and/or ear tagged, sexed, measured (total length and body length), and reproductive condition recorded (teats, vagina, and testes). All trap and recapture data was recorded on grid maps to note areas of overlap and movement patterns within the population. Population densities were calculated by minimum number known alive (MNKA) (Krebs, 1966) both before and after pine vole introduction.

Vegetation and soil characteristics for sites where either pine voles, meadow voles, or no voles were captured were quantified. Vegetative ground cover was determined for 0-25 cm in height, 25-50 cm and 50-100 cm using a 0.5 by 1 meter vegetation cover board. Tree cover was characterized for 0-1.5 m and 1.5-3 m using a 3 m high by 10 cm wide cover density board. At each site soil moisture and pH was recorded using a Takemura soil pH and humidity tester. Soil samples were obtained with a soil auger and litter, A horizon, and B horizon depths were measured with a ruler. The relative percentage of grasses and forbs were noted at each site.

In July, 1981 a random sample of 66 trap sites, at both trees and aisles, on each grid was chosen for habitat analysis. This sample served to characterize the habitat available in the orchard prior to the 1981 pine vole release. Experimental samples were obtained immediately after the July, September, October, and November trapping session at sites where either pine or meadow voles had been captured.

During September, 1981 a second random sample of 66 trap sites on each grid was conducted. This sample served as a control sample for the release of voles in 1980 since no habitat sampling had been done at that time. Experimental samples were then obtained for all trap sites at which two or more meadow or pine voles had been captured in July, 1980 through February, 1981.

Stepwise discriminant analyses were performed on habitat data from each grid to determine which habitat variables were most important in discriminating between sites where pine, meadow, or no voles occurred.

RESULTS

Meadow vole population densities followed the same pattern on both grids despite the presence or absence of pine voles. The initial density on the experimental grid in July, 1980 was 117/ha and was 55/ha on the control grid (Fig. 1). Meadow vole densities peaked in the fall of 1980 and then declined through 1981. However, the introduction of pine voles in September, 1980 and July, 1981 had no discernable effect on meadow voles densities.

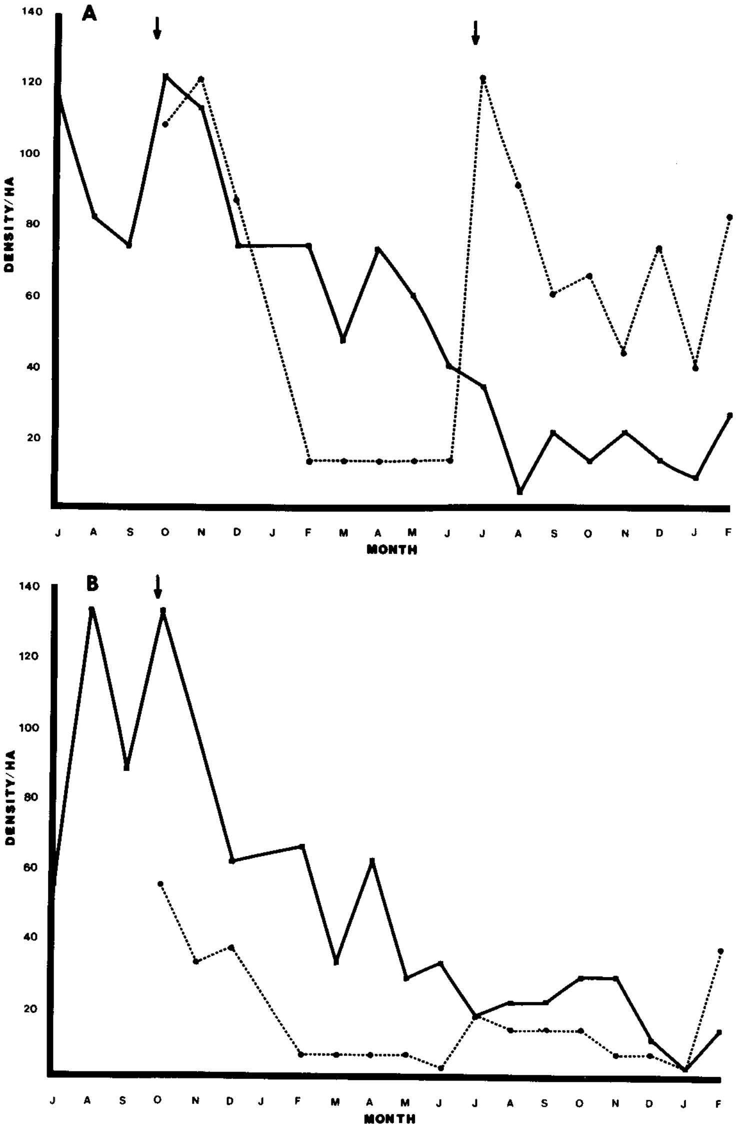

Figure 1. Population densities of M. pennsylvanicus (solid line) and M. pinetorum (dashed lines) from July 1979 - February 1982 on the experimental grid (A) and control grid (B). Downward arrow marks the points of introduction of M. pinetorum on the grids.

Throughout the study, meadow and pine voles were rarely captured at the same trap sites either within or between trapping periods. After the colonization of the experimental grid by pine voles in 1980, 36% of the trap sites captured only meadow voles, 22% captured only pine voles, while less than 16% of the trap sites captured both species. A similar distribution pattern occurred on the control grid with 49% of the trap sites capturing meadow voles, 7% pine voles, and less than 10% captured both species. After the second pine vole release, meadow and pine voles again exhibited spatial separation with 38% of the trap sites on the experimental grid capturing only meadow voles, 29% pine voles, and at 4% of the trap sites both species were captured. Pine voles were captured at five sites (4%) at which meadow voles had been caught during previous trapping sessions. Similar distribution patterns occurred on the control grid. During trapping sessions when pine voles were present, 23% of the meadow voles captured on each grid occurred at aisle trapsites adjacent to tree sites concurrently used by pine voles.

Pine vole densities were always greatest on the experimental grid, even though the 1980 release was on the control grid. This may have been due to the significantly lower amount of grass, greater depth of litter, and greater depth of the A horizon on the experimental grid when compared to the control grid. Pine vole occurrence was positively correlated with litter depth and negatively correlated with the occurrence of grasses, while the opposite correlations occurred with meadow voles (Table 1). Pine vole habitat was also characterized by high amounts of tree cover. Meadow voles were found in areas with a high percentage of low vegetative cover.

Both before and after the pine vole release, meadow voles were primarily captured at aisle sites. Prior to the pine vole introduction, 96% of the meadow voles captured on both grids were at aisle sites. After the release, 83% of the meadow vole captures on the experimental grid, and 89% on the control grid, were at aisle sites. Seventy seven percent of the pine voles captured on the experimental grid and 49% on the control grid were under trees.

Stepwise discriminant function analyses showed which habitat variables accounted for most of the variation in trap sites utilized by pine and meadow voles or no voles. Results from the experimental grid during the first year (i.e., July, 1980 - February, 1981) showed soil moisture and depth of the A soil horizon to be the most discriminating variables. Using these 2 habitat variables the analysis correctly classified 93% of the meadow vole sites, 37% of the pine voles sites, and 70% of the no vole sites. The depth of the A horizon was greatest at pine vole trapsites ($\bar{X}$ = 2.1 cm) least at meadow vole sites ($\bar{X}$ = 0.2 cm), and moderate at no-vole sites ($\bar{X}$ = 0.5 cm). Soil moisture was lower at no vole sites ($\bar{X}$ = 34.3%) than either pine ($\bar{X}$ = 46.1%) or meadow vole ($\bar{X}$ = 52.9%) trap sites. Similar results occurred on the control grid where soil moisture alone was the principal factor discriminating between trapsites, with lower soil moisture at no vole sites ($\bar{X}$ = 32.7%) than at either pine ($\bar{X}$ = 36.5%) or meadow vole sites ($\bar{X}$ = 47.3%).

During the second year (March, 1981 - November, 1981) low vegetative cover (0-25 cm), low tree cover (0-1.5), and depth of the A soil horizon were the most discriminating variables on the experimental grid. Using these habitat characteristics the analysis correctly classified 79% of the meadow vole trapsites, 64% of the pine vole sites, and 67% of the no vole sites. Mean low tree cover at no vole sites was 40.3% which did not differ from pine vole sites (37.9%), but both differed from meadow vole sites (3.6%). Mean low vegetative cover was 39.2% for pine vole sites while both no vole and meadow vole sites exceeded 69 percent. Depth for the A horizon was greatest for no vole sites ($\bar{X}$ = 4.2 cm) and lower for pine ($\bar{X}$ = 1.4 cm) and meadow vole sites ($\bar{X}$ = $<$ 0.2 cm).

On the control grid the relative percentage of grasses and percent soil moisture were the discriminating variables for the second year. Using these variables 79% of the meadow vole sites, 64% of the pine vole sites, and 67% of the no vole sites were correctly classified. The percent grass cover was lowest at pine vole ($\bar{X}$ = 18.0%) and no vole sites ($\bar{X}$ = 25.3%) and greatest at meadow vole sites ($\bar{X}$ = 78.3%). As on the experimental grid, soil moisture was greatest at meadow vole sites, ($\bar{X}$ = 48.3%) and lower at pine vole($\bar{X}$ = 31.8%) and no vole sites ($\bar{X}$ = 31.6%).

A second set of discriminant analyses was conducted to discriminate between meadow and pine vole sites in the experimental samples. Each analysis used only two habitat variables to correctly classify at least 75% of the trap sites as either pine or meadow vole sites. For the first year low vegetative cover and low tree cover discriminated between the habitats of the two species on the experimental grid. Pine voles associated with reduced low vegetative cover ($\bar{X}$ = 42.2%) and more tree cover ($\bar{X}$ = 33.4%) than meadow voles ($\bar{X}$ = 75.1% and 3.3%, respectively). On the control grid meadow voles occurred in areas with thin A horizon's ($\bar{X}$ = 1.8 cm) as compared to pine voles ($\bar{X}$ = 19.5 cm).

During the second year meadow voles on the experimental grid associated with less litter ($\bar{X}$ = 0.37 cm) and thicker low vegetative cover ($\bar{X}$ = 72.9%) than did pine voles ($\bar{X}$ = 2.0 cm and 8.5% respectively). On the control grid meadow voles occurred in moist areas ($\bar{X}$ = 48.3% moisture) with a high occurrence of grasses ($\bar{X}$ = 78.3%) while pine voles were found in drier areas ($\bar{X}$ = 31.8% moisture) with a high occurrence of forbs ($\bar{X}$ = 82.0%).

DISCUSSION

The introduction of pine voles into an orchard containing only meadow voles had little effect on meadow vole density or spatial distribution. Similar density patterns for meadow voles occurred on both the control and experimental grids whether pine voles were present or not. However, because meadow vole densities declined from November, 1980 through January, 1982 it is difficult to ascertain what impact pine voles would have had on a more substantial meadow vole population. Pine voles exhibited spatial isolation from meadow voles which occupied grassy aisle areas while pine voles primarily occupied areas under trees. Meadow voles selected moist areas with abundant low vegetative cover such as grasses, while pine voles selected areas beneath trees where there was a substantial A soil horizon and litter layer, moderate soil moisture, and good low tree cover. Fisher and Anthony (1980) determined that litter layers and A horizon soil characteristics were important to pine vole establishment. Additionally Benton (1955) and Paul (1970) working in wooded habitats correlated cover conditions with pine vole occurence. These variables and others were significant in pine vole establishment when sypatric potential competitors were present. On occassion, meadow voles used burrows under trees which were previously utilized by pine voles, but in only one instance was a meadow vole found under a tree concurrently used by pine voles. More frequently, pine voles occurred in habitats typical for meadow voles but never for extended periods of time. These pine voles may have been exploring for more suitable habitat or dispersing to new areas.

The lack of a significant effect of an introduced pine vole population on an established meadow vole population suggests that these two species may exhibit little competitive interaction in the field. Due to extensive differences in their habitat preferences and mode of life (i.e. forsorial vs. terrestrial) one might expect little competition except perhaps for food resources. Since forage quality is relatively high in orchards competition for food would be minimal. Thus, pine and meadow voles co-exist in limited areas such as orchards with minimal interaction and pine voles exhibited no measurable effect on meadow vole spatial patterns. However, further research is needed to determine whether pine vole habitat use is limited by the presence of meadow voles.

ACKNOWLEDGEMENTS

This research was supported by a Department of Interior Fish and Wildlife Grant No. 3729491 to J. A. Cranford.

LITERATURE CITED

Benton, A. H. 1955. Observations on the life history of the northern pine mouse. J. Mamm., 36:52-62.

Fisher, A. R. and R. G. Anthony. 1980. The effect of soil texture on distribution of pine voles in Pennsylvania orchards. Amer. Midl. Natur., 104:39-104.

Krebs, C. J. 1966. Demographic changes in fluctuating populations of Microtus californicus. Ecol. Monogr., 36:239-273.

McAninch, J. 1979. Vole management studies - 1978. In: Proc. Third Eastern Pine and Meadow Vole Symp., Ed. by R. E. Byers, pp. 39-46.

Pagano, R. E. and D. M. Madison. 1981. Seasonal variations in movements and habitat use by pine and meadow voles. In: Proc. Fifth Eastern Pine and Meadow Vole Symposium, Ed. by R. E. Byers, pp. 35-44.

Paul, J. R. 1970. Observations on the ecology, populations and reproductive biology of the pine vole, Microtus pinetorum in North Carolina. Ill. State Mus. Repts. of Interest. No. 29:1-28.

ECOLOGICAL REQUIREMENTS OF PINE AND MEADOW VOLES IN NEW ENGLAND ORCHARDS

Alan J. Steiner

Department of Forestry and Wildlife Management
University of Massachusetts
Amherst, Massachusetts 01003

INTRODUCTION

With increased concern over the effects of pesticides on ecosystems and non-target species, the use of many toxic materials has either been banned or severly restricted. Consequently, a more ecological approach to vole damage is necessary to develop sounder methods of control. Distribution of pine voles (Microtus pinetorum), both seasonally and geographically, indicates that this species is not readily adaptable to a wide range of habitat types or conditions. If there are certain factors limiting the occurrence and abundance of pine voles, and they can be detected, we may be able to exploit this knowledge to adversely affect vole populations by manipulating their habitat.

The objectives of this study were to: (1) quantitatively measure both environmental parameters and control methods influencing the distribution and amount of damage done by pine and meadow voles (Microtus pennsylvanicus) in southern New England apple orchards, and (2) measure parameters which may determine intra-orchard distribution of the 2 species.

METHODS

Environmental parameters that could have an influence on damage caused by distribution and site selection of pine and meadow voles were measured at 2 habitat levels. The first level, interorchard, is the general habitat of the orchard and its surrounding landscape. The second level, intra-orchard, is the specific microhabitat used by individual animals.

Inter-orchard

At the general habitat level, 65 orchards in the southern New England area were visited to assess vole damage and habitat conditions. These orchards were selected to include areas of frequent, occasional, and rare (or none) vole damage throughout the study area (Fig. 1).

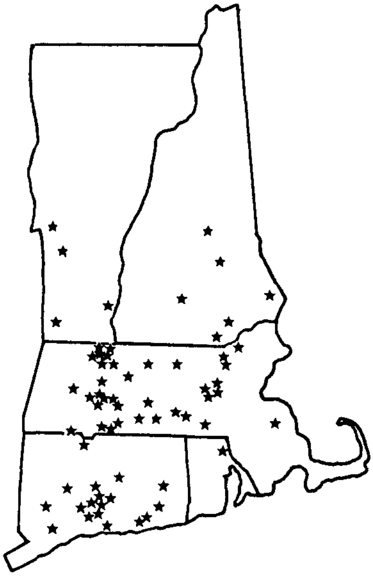

Figure 1. Distribution of orchards assessed for damage.

Damage at each orchard was determined through an interview with the owner/manager about conditions for the past 5-10 years and by random transects through the orchard to locate burrows, runways, and damaged trees. A Damage Index (DI) value was then calculated for each species at the orchard. DI values were:

0 - species not found
1 - species found, no damage recorded
2 - some damage occesional years
3 - some damage every year
4 - intensive damage occesional years
5 - intensive damage every year

Interviews with the owner/manager were done to find the control methods used for the past several years; type of poison, type of bait, application method and frequency of application, and whether herbicides were used around the trees; age of the orchard blocks; and tree types and rootstock in the blocks. Random transects through the orchards were done to measure tree densities, topography, and ground cover. Random soil samples (1 sample/2-4 ha) were taken of the top 25 cm of the orchard. Soil samples were analyzed for the amounts of gravel, sand, silt, clay, and organic matter present, pH, bulk density, and water moisture.

Intra-orchard

At each of the orchards used in the general habitat analysis, site specific soil and vegetation samples were taken from trees which were known to have been damaged by either pine or meadow voles. In addition, samples were taken from trees which showed no signs of damage and which had no burrows or runways under them.

The distribution of voles at 7 western Massachusetts orchards were determined by trapping. Each trapping area consisted of 10-12 randomly located grops of 3 trees in a row. Two Sherman live traps were placed under the dripline of each tree following the procedure of Gettle (1975). Each trapping area was trapped for 3 3-day periods in a consecuetive fall and spring. Parameters measured at each trap site were: tree type, dripline radius, distance to neighboring trees, soil type, vegetation, slope, and number of burrows and runways.

Analysis

Data for both habitat levels were tested using discriminant function analysis, a procedure for detecting and quantifying differences between sample groups from multivariate data. Discriminant analysis has 3 major purposes. The first purpose, discrimination, is to answer the question, "can we distinguish between groups?" The second and third purposes, are classification and prediction, i.e., "how can we distinguish between groups so that future subjects may be correcty grouped?" Assumptions, data compilation, and calculations for the discriminant procedure are discussed by Lindeman et al. (1980). Groupings on the vole data were determined by the type of species present and/or the amount of damage occuring. At present, only soil data from the inter-orchard and infested trees has been analyzed.

RESULTS

Inter-orchard

Discriminant function analyses of the random soil samples taken from each orchard and their corresponding DI values showed a 44.3% correct classification for pine voles

Table 1. Discriminant function classification results for random soil samples and pine vole DI values.

Actual DI Value	Predicted DI Values 0	1	2	3	4	5
0	67.9%	14.9	0.0	7.9	4.6	4.7
1	31.6	37.3	0.0	12.3	7.1	11.7
2	28.0	10.1	28.9	14.0	4.8	14.2
3	14.7	23.6	2.6	39.0	5.6	14.4
4	0.0	0.0	0.0	31.6	36.8	31.6
5	0.0	0.0	1.4	1.4	0.0	97.1

Table 2. Discriminant function classification results for random soil samples and meadow vole DI values.

Actual DI Value	Predicted DI Values 0	1	2	3	4
0	39.8%	28.0	2.8	21.0	8.4
1	26.1	49.7	10.9	10.2	3.0
2	30.4	13.8	30.7	16.6	8.5
3	10.7	28.0	14.9	28.2	18.2
4	10.1	7.5	0.0	20.9	61.6

Table 3. Standardized discriminant function coefficients for pine vole DI values and random soil samples.

	Separate DI Values			Pooled DI	
Variable	Func. 1	Func. 2	Func. 3	Func. 1	Func. 2
Organic Matter	-.90	-.14	-.55	-.30	-.58
Gravel	-.34	-.49	.19	-.58	-.07
Sand	-.69	.13	-.15	.53	-.16
Clay	-.81	-.14	.79	-.01	-.15
pH	-.20	-.09	-.48	-.10	.20
Litter Depth	.16	-.93	-.08	-.27	.19
Bulk Density	-.11	.16	.01	.19	-.82
Moisture Content	.26	.26	.02	.40	-.19
DI Means					
0	.21	.80	-.11	.53	.25
1	.44	.10	-.02		
2	-1.01	.05	.26	-.21	.37
3	.33	-.39	.09		
4	-.72	-.71	-1.04	-1.64	.69
5	-.66	-.12	-1.06		

Table 4. Standardized discriminant function coefficients for meadow vole DI values and random soil samples.

	Separate DI Values			Pooled DI	
Variable	Func. 1	Func. 2	Func. 3	Func. 1	Func. 2
Organic Matter	-.11	-.77	.04	-.68	.66
Gravel	-.49	-.38	-.19	-.81	-.38
Sand	.72	-.44	-.69	-.53	-.09
Clay	.31	-.87	-.72	-.63	-.76
pH	-.13	.17	-.20	.15	.52
Litter Depth	-.35	.26	.05	-.72	-.11
Bulk Density	.25	-.41	1.01	.05	.01
Moisture Content	.30	.10	.80	.33	-.04
DI Means					
0	.20	.35	.18	.62	.12
1	.55	.37	-.13		
2	.21	-.89	-.09	-.25	-.17
3	-.38	-.01	.27		
4	-1.78	.25	-.33	-.86	1.05

Table 5. Discriminant function classification results for random soil samples and combined pine vole DI values.

Actual DI Value	Predicted DI Values 0-1	2-3	4-5
0-1	76.4%	17.4	6.2
2-3	40.7	45.3	14.0
4-5	17.5	13.4	69.1

Table 6. Discriminant function classification results for random soil samples and combined meadow vole DI values.

Actual DI Value	Predicted DI Values 0-1	2-3	4-5
0-1	74.8%	14.8	10.4
2-3	33.3	43.0	23.7
4-5	0.0	22.6	77.4

Table 7. Discriminant function classification for soil samples taken from pine vole, meadow vole, and uninfested trees.

Actual Group	Samples	Predicted Group Membership Pine	Meadow	Neither
Pine Vole Damaged	30	46.7%	20.0	33.3
Meadow Vole Damaged	18	50.0	33.3	16.7
Undamaged Trees	35	28.6	22.9	48.6

(Table 1) and a 40.1% correct classification for meadow voles (Table 2). About 70% of the samples, however, were classified into either the correct DI value or the value just above or below it on the scale. There was little overlap between orchards with no damage and those exhibiting intensive damage. Percent organic matter and litter depth were the variables most correlated with high DI values for pine voles while soil moisture was correlated with low DI values (Table 3). Percent sand was correlated with low meadow vole levels (Table 4).

When these tests were repeated using combined DI values (0-1, 2-3, 4-5) the number of samples correctly classified was 61.3% for pine voles (Table 5) and 55.5% for meadow voles (Table 6). For both species most of the incorrectly classified samples were from the occasional damage DI values (2-3). There was little overlap between the samples for orchards with no damage and those with heavy damage. High percentages of organic matter, gravel, and moisture were related to high DI values for pine voles (Table 3). High DI values for meadow voles were related to the amount of organic matter in the soil.

Intre-orchard

Analysis of the soil data taken from damaged and undamaged trees showed no correlation between predicted and observed groups (Table 7). The samples correctly classified was only 44.6% which is only slightly better than random chance. When only the pine and meadow vole trees were tested, the number of samples correctly classified was 70.8% (Table 8). This analysis would seem to indicate that uninfested trees do not represent vole resistant trees but are instead unoccupied habitat.

The most important variables in this discrimination were sand, silt, organic matter, and bulk density. High percentages of organic matter and bulk density were favorable to pine voles while high quantitities of sand and silt were favorable to meadow voles.

ACKNOWLEDGEMENTS

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Table 8. Discriminant function classification for soil samples taken from pine vole and meadow vole infested trees.

Actual Group	Samples	Predicted Group Pine	 Meadow
Pine Vole Damaged	30	73.3%	26.7
Meadow Vole Damaged	18	33.3	66.7

LITERATURE CITIED

Gettle, A. S. 1975. Densities, movements, and activities of pine voles (Microtus pinetorum) in Pennsylvania. M.S. thesis, Penn. State Univ. 66pp.

Lindeman, R. H., P. F. Merenda, and R. Z. Gold. 1980. Introdution to biveriate and multivariate analysis. Scott, Forsman, and Co., Glenview, Illinois. 444pp.

SELECTED HABITAT CHARACTERISTICS AND PINE VOLE ABUNDANCE IN PENNSYLVANIA APPLE ORCHARDS

J.R. Parker, G.M. Kelly, and W.M Tzilkowski
School of Forest Resources
The Pennsylvania State University
University Park, PA 16802

In the past, researchers from The Pennsylvania State University have investigated specific aspects of the pine vole (Microtus pinetorum) and its biology (Fisher 1976, Gettle 1975, Simpson 1978). In our current research, we are investigating many factors of the pine vole's orchard habitat and examining these factors collectively. Our objectives are:

1) To determine what combinations of habitat characteristics relate best to abundance of pine voles in Pennsylvania apple orchards.
2) To recommend strategies on how to consider or modify those habitat characteristics to maintain the lowest possible numbers of pine voles.

From early June 1981 to early September 1981, we randomly chose orchards from aerial photographs of Adams County, Pennsylvania. Selected points were scattered all over the apple-producing areas of the county. Random points were located on the ground, and subsequently, 130 apple orchards were sampled. With the cooperation of the growers and landowners, we laid out a 50-x 50-m sample-plot at each random point. We used the tree corresponding to the original random point as a corner. We then measured characteristics of pine vole habitat within the driplines of the trees closest to each of the three remaining corners and within the plot. The habitat characteristics we measured were thatch depth, trunk diameter, and crown diameter. We also measured percentage of ground area covered by vegetation, using a vegetation sampling frame (Daubenmire 1968), and vertical cover of ground vegetation at several heights, using a vegetation profile board (Nudds 1977).

We took 6 soil samples per plot at 2 depth-intervals. The first sample was from the surface to 24 cm deep, and was taken with a soil probe, the other sample was from 28 to 48 cm deep, and was taken with a soil auger. After collecting over 700 samples, we ground each sample and used a 2-mm sieve to separate fines from gravel. To analyze the soils, we used a hydrometer for the fines to determine percentages-by-weight of sand, silt, and clay (Black 1965). Sieves were used to determine percentages-by-weight of various size-classes of gravel. We also measured the volumes of the soil samples taken with the soil probe, and we will use these volumes and the weights of the samples to calculate bulk density. The soil samples we collected represent all of the soil associations found in the apple-producing areas of Adams County. These associations consist of silt loams, channery silt loams, gravelly silt loams, and very stoney silt loams.

Other habitat characteristics that we measured include: distance between trees within and between tree rows; slope and aspect of the sample-plot; and distance from the plot to a change in land-use such as residential, woods, pasture, crop, or old field. These land-uses were recorded, as well as any potential barriers to pine vole movement, such as paved roads, and streams and ponds.

After measuring habitat characteristics, we visited every tree in the plot and looked within the dripline for an entrance to a subsurface pine vole tunnel. If a tunnel was present, we placed a 30-x 30-cm piece of roofing felt over the entrance. If no tunnel was present, we placed the roofing felt somewhere on the ground within the dripline.

From the middle of September 1981 to the middle of October 1981, we visited each sample-plot 2 more times. On the first return we placed a piece of Golden Delicious apple, as bait, under each piece of roofing felt. If a pine vole tunnel was present, we placed the bait 5-15 cm into the tunnel. We then returned 20-24 hours later to check each piece of bait for toothmarks of pine voles. If toothmarks were present, we recorded that tree as active; we are using activity as an index of pine vole abundance. In addition to activity, we recorded presence or absence of a tunnel. The number of visits to trees, which included laying the roofing felt, placing the bait, and checking the bait, totaled over 18,000.

We have recently completed our soil analysis, which was the final stage of data collection. After some preliminary analysis, we see that we are on our way to meeting our objectives: in our investigation of apple orchards, we have sampled the full range of conditions of the habitat characteristics that we selected. We found very young to very old blocks; sparse to dense plantings; flat to steep terrain; and sparse to dense ground vegetation. Of the area sampled within driplines, five classes of ground vegetation were present (Fig. 1); these data represent samples over all orchards. Eighteen percent of the area was bare; 12% was covered by forbs such as nettle (Urtica spp.), clover (Trifolium spp.), yarrow (Achillea spp.), plantain (Plantago spp.), and sorrel (Rumex spp.); 13% was covered by grasses and sedges; 3% was covered by other material such as mosses, rocks, branches, bottles, prophylactics, and auto parts; 45% was covered by thatch, defined here as material that is dead, but recognizable as vegetative organic matter; and 9% of the area was covered by woody vegetation such as poison ivy, (Toxicodendron radicans), raspberry (Rubus spp.), virginia creeper (Parthenocissus quinquefolia), tree-seedlings, and root-suckers.

We measured spacing of apple trees as the number of trees in our 50-m tree rows (Fig. 2), and as the number of

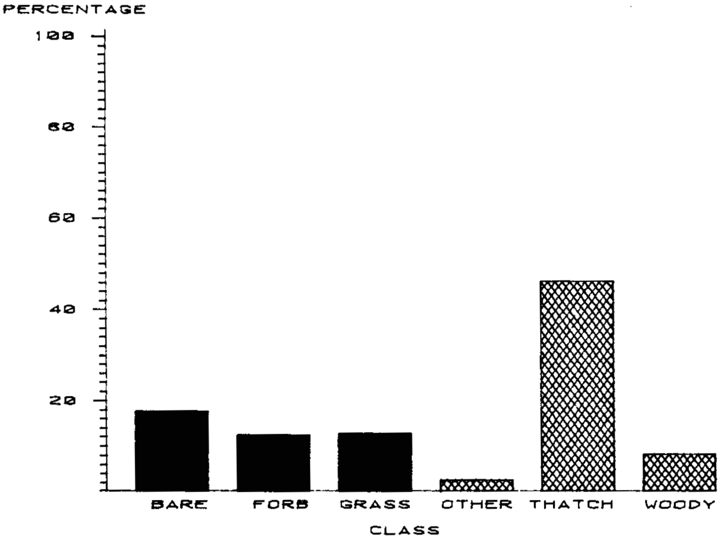

Fig. 1. Ground cover within dripline of apple trees.

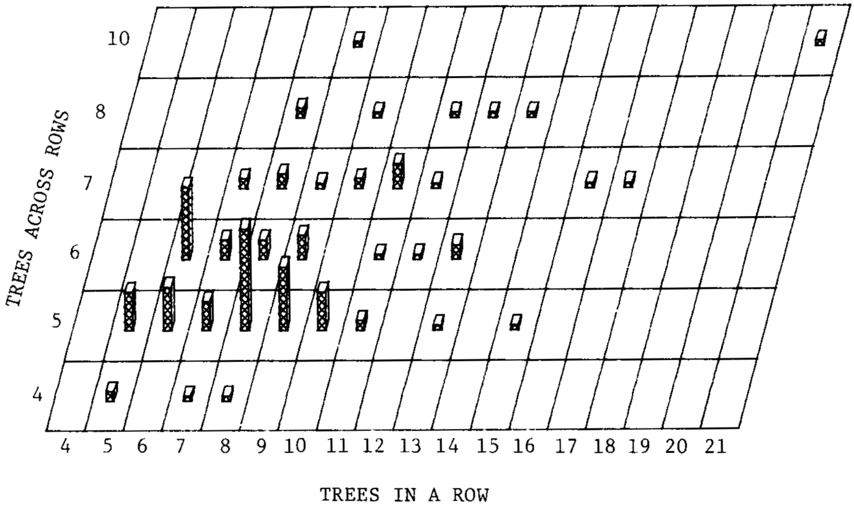

Fig. 2. Relative frequency of apple tree spacings in 130, 50-x 50-m, sample-plots.

trees in the 50-m length across the rows. Over 50% of the sample-plots had from 6 to 9 trees per row, and from 5 to 6 trees across rows. The most common spacing combination was 8 trees per row by 5 trees across rows, or a tree density of 40 trees/0.25 ha. The range of tree densities that we sampled was from 20 trees/0.25 ha to 210 trees/0.25 ha.

We found a large range of pine vole activity, defined here as the percentage of trees in a sample-plot which had bait at least partially eaten by pine voles. We found that 86 out of the 130 plots had activity, and the remaining 44 plots had no activity (Fig. 3).

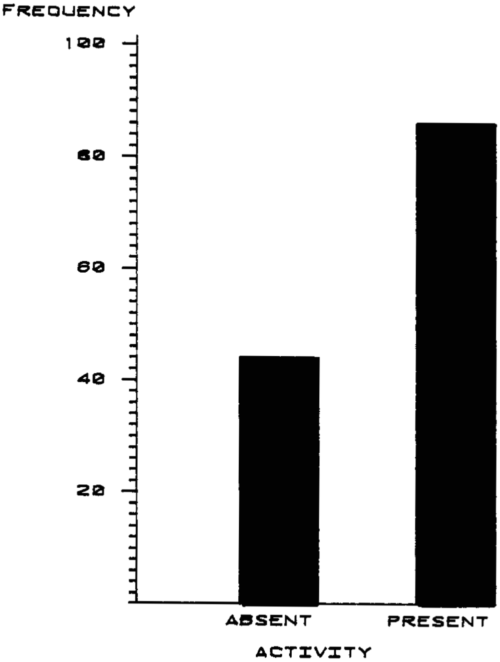

Fig. 3. Frequency of sample-plots with and without pine vole activity.

Of the 86 active plots, over half had between 1% and 10% activity. Specifically, 35 plots had between 1% and 5% activity, and 20 plots had between 6% and 10% activity (Fig. 4).

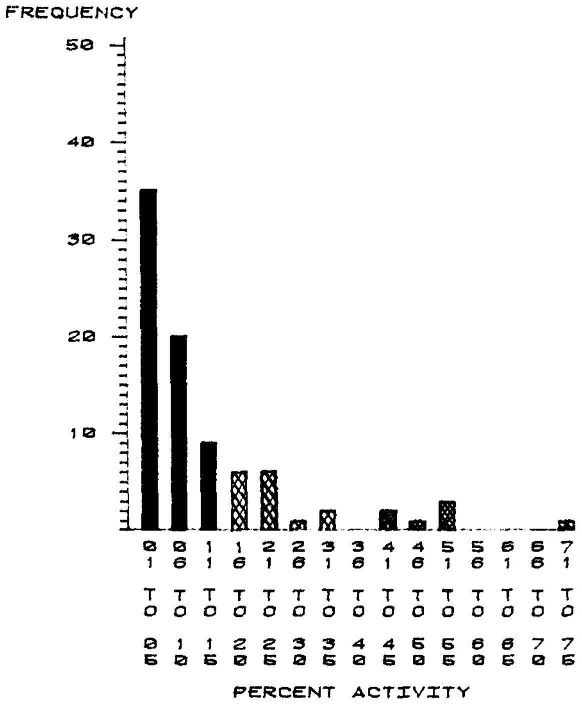

Fig. 4. Frequency of levels of pine vole activity in 130 sample-plots.

These preliminary results indicate that we are progressing toward our objectives. To meet those objectives, we will relate the range of conditions of selected habitat characteristics to the range of sampled abundance of pine voles. We will define combinations of orchard conditions that apple-growers can measure and manage and can incorporate into their plans for integrated crop management.

REFERENCES

Black, C.A., ed. 1965. Methods of soil analysis. Am. Soc. Agron., Inc., Madison, Wisc. 1572 p.

Daubenmire, R.F. 1968. Plant communities: a textbook of plant synecology. Harper and Row, New York. 300 p.

Fisher, A.R. 1976. Relationships between soils and pine vole (Microtus pinetorum) populations in Pennsylvania orchards. M.S. thesis, The Pennsylvania State Univ., University Park, PA. 57 p.

Fisher, A.R. and Robert G. Anthony. 1980. The effect of soil texture on distribution of pine voles in Pennsylvania orchards. Am. Mid. Nat. 104(1):39-46.

Gettle, A.S. 1975. Densities, movements, and activities of pine voles (Microtus pinetorum) in Pennsylvania. M.S thesis, The Pennsylvania State Univ., University Park, PA. 66 p.

Nudds, T.D. 1977. Quantifying the vegetative structure of wildlife cover. Wildl. Soc. Bull. 5(3):113-117.

Simpson, D.A. 1978. Dynamics of pine vole populations in two Pennsylvania orchards. M.S. thesis, The Pennsylvania State Univ., University Park, PA. 55 p.

Simpson, D.A., R.G. Anthony, G.M. Kelly, and G.L. Storm. 1979. Dynamics of a pine vole population in a Pennsylvania orchard. In Proc. of Third East. Pine and Mead. Vole Symp. pp.47-51.

Progress of a Bioenergetic Simulator of Pine Vole Populations

K. C. Jordan, A. R. Tipton, R. L. Kirkpatrick

Department of Fisheries and Wildlife Sciences
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

The pine vole research effort under way at VPI & SU has involved 4 parts: an investigation of nutrition and energetics, a study of habitat and behavior, an evaluation of chemical control, and the development of a computer simulation model of population dynamics. Coyle et al. (1981) reported on the results of a preliminary model developed by Coyle (1980), and outlined a second stage model to incorporate his (1980) recommendations and the continually expanding base of field and laboratory data. The preliminary model was a demographic simulator mechanistically driven by bioenergetic equations developed chiefly from laboratory studies at Virginia Tech. The second stage model was proposed to include 4 submodels, one each dealing with the biological and spatial aspects of pine vole populations, and with the control procedures and economic aspects of orchard management for pine voles. To date, the majority of work has been on the extensive refinement of the biological and spatial components, and only those refinements are discussed here.

To distinguish the second stage model from Coyle's (1980) model, called MICROTUS, the biological-spatial component of the newer version is named PITYMYS. It has been written in programming language PL/I for ease of programming and documentation, and may be executed at any reasonably-sized computer facility equipped with a PL/I compiler. The basic design is inspired by that of MICROTUS, and is shown in Figures 1 and 2. The design is highly modular, and makes liberal use of subroutines for identifiably separable biological and computational events. Figures 1 and 2 show the names of the principal subroutines of PITYMYS, and their associated functions.

Forages are divided into the same 5 classes (grasses, forbs, bulbs and roots, vine leaves, and apple fruit) as in MICROTUS, according to the classification of Lochmiller (1980). Female pine voles are divided into the same 6 energetic classes: sucklings, juveniles, non-reproductive adults, pregnant adults, lactating adults, and pregnant-and-lactating adults. And males are divided into the same 3 energetic classes: sucklings, juveniles, and adults. A major modification in PITYMYS is that animals are classified also by the additional criterion of age in weeks. Thus the population may be sectioned and summed along either dimension, according to the desired form of population appraisal. As MICROTUS, PITYMYS operates on a weekly time step, and is limited to a maximum simulation period of 52 weeks.

PITYMYS

Set up.	INPIT
Simulate by block	BLOKMODL
or	
Simulate by tree.	TREEMODL

Fig 1a. Design and subroutines of PITYMYS.

BLOKMODL

Initialize.		BLOKPRIM
Iterate by week.	Prepare.	BLOKPREP
	Scale variables.	BLOKSCAL
	Output values.	BOUTPIT
	Simulate bioenergetics.	BBIODRIV

Fig 1b. Design and subroutines of BLOKMODL.

BBIODRIV

Determine:

Daily energy budgets.	BDEBDRIVE
Energy acquisition.	BEATDRIVE
Growth.	BGROW
Stress.	BSTRESS
New population structure.	BSHIFT
Forage change rates.	BGRAZE
Energy availability.	BENERGY

Fig 2. Design and subroutines of BBIODRIV.

Subroutine INPIT prompts the user for the type (maintained or abandoned) and size of the orchard to be simulated, and the simulation time. In addition the user specifies the type of model to be used: BLOKMODL and TREEMODL are alternative subroutines driving 2 different population simulators. BLOKMODL drives BBIODRIV to treat the voles on a standardized orchard block as a single breeding population, whereas TREEMODL drives TBIODRIV to treat the voles at each tree as a separate subpopulation. Whichever model is chosen, the user is given a choice of whether or not to specify the initial forage structure, but must specify the initial population structure (by orchard or by tree). Except for computational expedients, the subroutines of BBIODRIV and TBIODRIV are identical, so only those of BBIODRIV are discussed here in detail.

BBEBDRIV computes the daily energy budget (DEB) of a representative animal of each energy class as the sum of its maintenance energy, growth energy, and reproductive energy needs. DEB's are simulated as functions of surface temperature, subsurface temperature, photoperiod, activity period, and activity level, and are computed using the data of Lochmiller (1980). This algorithm may be more precise than that of MICROTUS, where the effects of temperature and photoperiod are simulated only indirectly, via the assumption of an annually sinusoid basal metabolic rate.

The energy acquisition routine has been extensively revised. Under the single assumption that animals do not ingest more gross energy than they need for maintenance, growth, and reproduction, a dietary gross energy need is computed using steady-state flow equations, from the DEB, the mean daily mass of stomach contents (in terms of gross energy), the diet digestibility, and the food passage rate of each vole class. These 4 quantities are known with good precision, and their use in this algorithm (BEATDRIV) obviates the need for estimates of stomach size, the volume of food ingested per feeding, and the number of feeding times per day, as in MICROTUS. The act of feeding is simulated using a linear programming routine that calls an IMSL (International Mathematics and Statistics Library) version of the simplex algorithm (ZX3LP) to allocate limited forage energy among competing vole classes. The algorithm assumes no foraging hierarchy, as needed in MICROTUS, and weights the allocations by the number of voles in each class. The algorithm is iterated by forage class, in order of feeding preference, until all DEBs are met or until each forage class has been reduced to a level equal to the product of its availability and palatibility. If any vole class DEB is not met, an energy restriction coefficient is computed for a representative of that class.

If a DEB is met, the body weight of a representative animal is increased according to the growth rate data of Derting and Cranford (pers. comm.), and the body fat level is increased according to the body composition analyses of Lochmiller (1980), Noffsinger (1976), and Servello (1981). Derting and Cranford (pers. comm.) have found juvenile growth patterns to differ among 3 photoperiods, and that effect is simulated by using linear regression to derive the body weight increase at the existing photoperiod from the 3 increases computed for the 3 known photoperiods. If a DEB is not met, the body weight and fat levels are determined according to the severity of the energy restriction. Equations used to determine growth on restriction are derived from the data of Merson (1979).

Probabilities of transition between age and energy classes are computed, for representatives of the age-by-energy classes, as functions of body weight and fat levels. Nondietary effects on survivorship (predation, parasitism, disease, injury, old age) are not treated mechnistically, but are simulated by setting the maximum possible survivorship value for an age-by-energy class (pmax) equal to the maximum observed in a natural population. Actual survivorship is then determined bioenergetically on the range (0.0, pmax), so that there is always some mortality operating independently of energy acquisition. Natality is a function of maternal age and energy balance, and the number of breeding-age adults in the population.

The simulation of fractional animals is avoided by providing the user with a choice of vole class transition algorithms. In the deterministic algorithm the size of one class is multiplied by a probability of transition into a second class, and the product rounded to the nearest whole number. In the stochastic algorithm, the transition is simulated by independent Bernoulli trial, wherein a number is drawn from a uniform distribution between 0.0 and 1.0, compared with the transition probability, and if the random number is less than or equal to the probability, one animal is advanced. This algorithm is iterated over all of the animals in an age-by-energy class, yielding similar results for large samples to those of the deterministic algorithm. The stochastic algorithm is therefore offered as an option for the sake of biological realism, but may not be convenient for simulation studies where repeatability and comparison of control strategies are desirable.

Availability of forages other than grasses, and seasonal changes in digestibility, palatibility, and preference of all forages, are simulated in subroutine BENERGY by a series of equations developed by Coyle (1980) from the data of Lochmiller (1980). The effect of grazing by pine voles is simulated for grasses by subroutine BGRAZE. The grass growth rate is taken as the first derivative of a curve describing grass gross energy availability as a function of Julian day. The grass growth rate that week is decremented by the amount grazed that week to yield an energy availability change rate. That change is added to the amount available at the beginning of the week to yield a prediction of the amount available at the beginning of the next week.

In addition to performing all of the functions of BLOKMODL at the level of the individual tree, TREEMODL allows animals to travel to or from neighboring trees at the end of each week, according to directional movement probabilities computed from field live-trap data as functions of adjacent tree subpopulation densities. The orchard population is then taken as the sum of the subpopulations.

Validation of PITYMYS will be by statistical comparison of simulation output to field live trap data, as analyzed via the demographic software discussed by Hasbrouck et al. (1982). Once validated, the model will be used to simulate, at low cost, experiments with management options on pine vole populations, and may provide some theoretical knowledge of small mammal population dynamics.

The control and economic submodels are being designed to operate about the biological-spatial submodel, but remain in need of 2 types of information: quantification of the relationship between pine vole population density and apple tree damage level, and quantification of the relationship between apple tree damage level and fruit yield reduction. Fruit yield reduction can be assessed at market value, and a population then can be assessed in dollar terms, at which point a tolerance level can be set as that at which the marginal cost of control equals its marginal gain. An optimization model can then be written to select the management option that minimizes total cost as the sum of cost due to control and cost due to damage. It should be noted that the cost of damage should include the current costs of crop reduction and tree replacement, and the cost and interest on crop reduction during the lag time to production by new trees.

Literature Cited

Coyle, J. F. 1980. A preliminary methodology for simulating the dynamics of a pine vole population. M.S. Thesis. Va. Polytech. Inst. and St. Univ., Blacksburg. 122 pp.

Coyle, J. F., K. C. Jordan, and A. R. Tipton. 1981. Progress and prospect of a bioenergetic simulation model of pine vole populations. Pages 84-87 in R. E. Byers, ed. Proc. Fifth Eastern Pine and Meadow Vole Symposium. 144 pp.

Hasbrouck, J. J., A. R. Tipton, and R. L. Kirkpatrick. 1982. Demographic analysis of pine vole populations in two orchard types in southwest Virginia. in R. E. Byers, ed. Proc. Sixth Eastern Pine and Meadow Vole Symposium.

Lochmiller, R. L. 1980. Bioenergetics and nutrition of the pine vole (Microtus pinetorum) in two Virginia apple orchards. M.S. Thesis. Va. Polytech. Inst. and St. Univ., Blacksburg. 185 pp.

Merson, M. H. 1979. Influence of restricted feed intake on the reproductive characteristics, energetics, and body composition of two species of rodents. Ph.D. Dissertation. Va. Polytech. Inst. and St. Univ., Blacksburg. 229 pp.

Noffsinger, R. E. 1976. Seasonal variation in the natality, mortality, and nutrition of the pine vole in two orchard types. M.S. Thesis. Va. Polytech. Inst. and St. Univ., Blacksburg. 126 pp.

Servello, F. A. 1981. Nutritional ecology of the pine vole in relation to apple tree root damage. M.S. Thesis. Va. Polytech. Inst. and St. Univ., Blacksburg. 155 pp.

WATER METABOLISM IN LABORATORY-MAINTAINED AND FREE-RANGING PINE VOLES (MICROTUS PINETORUM)

D. Rhodes and M.E. Richmond
New York Cooperative Wildlife Research Unit
Cornell University
Ithaca, N.Y. 14853

Introduction

Prior study of water use by the pine vole, *Microtus pinetorum*, has indicated that these voles require large volumes of water on a daily basis and exhibit rapid turnover of body water relative to other mammals of similar body size (Rhodes and Richmond, 1981). However, the extent to which these animals are tolerant of water deprivation and hence the importance of available water to the members of this species remains unexplored. Similarly, data on rates of body water turnover in free-ranging pine voles are presently unavailable. Thus, this study examines rates of body water turnover and urine concentrations of pine voles during exposure to 3 ambient temperatures, during a restricted water regime, and under field conditions. We present evidence indicating that pine voles exhibit rapid turnover of body water under both laboratory and field conditions and that these animals are very intolerant of water restriction.

Methods

Water metabolism of laboratory reared pine voles was assessed during exposure to 15, 22, or 30°C. Adult voles were weighed and then housed singly in plastic cages equipped with hardware cloth bottoms. Water supplied in inverted graduated cylinders and food (Charles River-Rat Mouse formula) were provided. After the voles were exposed to an ambient temperature for 24 hr, they were placed over pans of mineral oil and urine samples were collected for measurement of urine concentration. Subsequently, the voles were injected intraperitoneally with 50 ul ^3H_2O (15 uCi). Urine samples were collected once or twice daily for 4 d and analyzed for ^3H_2O concentration. An expression for loss of tritiated water over time was developed with standard regression techniques for each vole and the biological halflife of ^3H_2O was calculated in ln2/k, where k is the slope of the regression line (Richmond et al. 1960).

Ad lib water consumption was determined over a 3 d period for an additional 13 voles maintained at 22°C. The volume of drinking water was then reduced to 75% of the daily *ad lib* water consumption for each animal. All voles exhibited loss of body weight in response to water restriction and did not reach a stable level of body weight over a 5 d period. To counter continued weight loss, an amount of water equal to the previous day's weight loss was added to the vole's daily water ration. This was continued until body weight stabilized. Urine concentrations and tritiated water turnover were then determined as previously described.

Water metabolism of free-ranging voles was assessed in a population of animals located in New Paltz, N.Y. In November 1981, voles were livetrapped, weighed, toe-clipped, and injected with 50 ul ^3H_2O. Prior to injection, an initial urine sample was collected from 22 voles for urine concentration measurement. Collection of urine under field conditions was accomplished by placing the voles in metabolism cages and suspending the entire cage over a layer of mineral oil contained in a plastic pan. Collection of samples usually required 0.5-1 hr. The animals were then released at their original capture site. Traps were checked at 1-1.5 hr intervals during daylight hours for 5-6 d and additional urine samples collected from injected voles as described above. Because of the rapid loss of radioactivity from the animals and regression analysis constraints, injected pine voles had to be recaptured at least twice within 4 d to be included in this analysis.

Results

Comparison of the mean biological halflife of water in *M. pinetorum* exposed to 15°, 22, or 30°C indicates that water turnover by these animals is unaffected by this range of ambient temperature (Table 1). Similarly, urine concentrations of voles exposed to these temperatures did not differ significantly between temperature treatments.

Table 1. Biological halflife of tritiated water and urine concentrations of *Microtus pinetorum* under field conditions, water restriction, or with *ad lib* water maintained at an ambient temperature of 15°C, 22°C, or 30°C. Values represent means ± 1SE, sample sizes are in parenthesis. Means denoted by different letter superscripts differ at $p<.01$ as determined by Duncan's multiple range test.

	Free ranging	15°	22°	30°	Water restricted
Body wt. (g)	23.9 ± 0.9^a	22.3 ± 0.6^a	24.6 ± 1.0^a	21.4 ± 0.7^a	$18.0 \pm .7^b$
Halflife of tritiated water (hr)	13.1 ± 0.9^a (7)	13.7 ± 0.6^a (16)	14.2 ± 0.5^a (10)	15.8 ± 1.2^a (16)	20.7 ± 0.7^b (13)
Urine concentration (mOsmol/kg)	83 ± 5^a (22)	420 ± 42^b (16)	395 ± 60^b (10)	343 ± 25^b (16)	1508 ± 69^c (13)

In contrast to the rate of water turnover observed in animals maintained under an *ad libitum* water regime, pine voles exhibited a substantial increase in the biological halflife of ^3H_2O in response to a reduction in the volume of water received on a daily basis. In this instance, a 46% increase in the biological halflife of tritiated water was observed in water-restricted voles relative to animals maintained at the same temperature with *ad lib* water rations. These voles also responded to a reduction in drinking water with nearly a 4 fold increase in urine concentration relative to similarly treated voles with free access to water.

Lastly, the halflife of ^3H_2O in free-ranging voles was similar to that observed in all groups of animals receiving ad lib water. However, the mean urine concentrations in these voles was 4-5 times more dilute than was the average urine concentration of voles in any treatment receiving ad libitum water.

Discussion

Acute exposure of pine voles to three ambient temperatures ranging from 15 to 20°C failed to elicit pronounced changes in their water turnover rates or urine concentrations in this study. This finding is consistent with the results reported in our previous investigation of water metabolism in pine voles, but differs from results presented by Deaver's and Hudson (1977) for the red-backed vole, Clethrionomys gapperi. In their study, cold exposed (5°C) C. gapperi exhibited a 76% increase in the rate of body water turnover relative to similarly treated voles maintained at 20°C. The fact that their lowest temperature was 10° lower than that employed in this study may account for the apparent differing physiological responses of the two species.

Assessing water consumption and water turnover rates when water is provided ad libitum provides little information about the ability of a species to respond a varying water availability. Specifically, we can compare the biological halflife of body water in pine voles supplied with water ad libitum with the halflife observed under water restricted conditions to obtain an index of the water conservation abilities of the pine vole. The results from this study indicate that pine voles cannot reduce the body water turnover rate to low levels, nor can they produce a highly concentrated urine relative to related species. Deavers and Hudson (1977) have shown that the biological halflife of body water in the related C. gapperi supplied with ad libitum water is only slightly shorter than that exhibited by water-restricted pine voles (19.9 vs. 20.7 hr, respectively). Further when presented with limited water, C. gapperi have body water halflives 47% longer than those of water-restricted pine voles. Maximum urine concentrations of C. gapperi (Deavers and Hudson 1979) also exceed those of pine voles as do those of both Microtus pennsylvanicus and Microtus ochrogaster (Heisinger et al. 1973). Ostensibly, the pine vole's high energy requirements (Bradley 1976) coupled with a diet low in calorie value but high in water content results in the intake of amounts of water exceeding this species' needs. Thus, no apparent selective pressure exists for elaborate water conservation mechanisms by the pine voles.

Further evidence that these laboratory data accurately portray the water dynamics of pine voles is found in the measurements of water turnover derived from free-ranging voles. In this study, we found concordance between the halflife of body water in laboratory-maintained animals and that exhibited by voles under field conditions. However, in contrast to urine concentrations of approximately 350 mOsm observed in pine voles in the laboratory, animals in the field produced urine at concentrations averaging only 83 mOsm. Thus, in order for free ranging voles to maintain the same water turnover rate as laboratory animals, while simultaneously producing a more dilute urine, an alternate route of water loss must be reduced. We suggest that it is evaporative water loss which is significantly reduced by voles living in natural conditions. Because these animals lead a predominantly subterranean existence, they continually encounter an atmosphere of high moisture content (Dubost 1968), thus potentially reducing their rate of evaporative water loss (Schmidt-Nielson et al. 1970).

In summary, pine voles exhibit rapid turnover of body water and an inability to slow rates of water exchange relative to other related species. We suggest that this physiological characteristic of pine voles is potentially amenable to manipulation, chemical or physical, to control the numbers of pine voles inhabiting orchard situations.

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References

Bradley, S.R. 1976. Temperature regulation and bioenergetics of some microtine rodents. Ph.D. Thesis, Cornell University.

Deavers, D. and J.W. Hudson. 1977. Effects of cold exposure on water requirements of three species of small mammals. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 43:121-125.

Deavers, D. and J.W. Hudson. 1979. Water metabolism and estimated field water budgets in two rodents (Clethrionomys gapperi and Peromyscus leucopus) and an insectivore (Blarina brevicauda) inhabiting the same mesic environment. Physiol. Zool. 52:137-152.

Dubost, G. 1968. Les mammiferes souterrains. Rev. Ecol. Biol. Soc. 5:99-197.

Heisinger, J.F., T.S. King, H.W. Halling, and B.L. Fields. 1973. Renal adaptations to macro- and micro-habitats in the family craeetidae. Comp. biochem. Physiol. 44A:767-774.

Rhodes, D.H. and M.E. Richmond. 1981. Water metabolism in the pine vole, Pitymys pinetorum. In: Proceedings of the fifth eastern pine and meadow vole sympsoium. (ed. R. Byers) pp. 128-130.

Richmond, C.R., T.T. Trujillo, and D.W. Martin. 1960. Volume and turnover of body water in Dipodomys deserti with tritiated water. Proc. Soc. Exp. Biol. Med. 104:9-11.

Schmidt-Nielson, K., F.R. Hainsworth, and D.E. Murrish. 1970. Countercurrent heat exchange in the respiratory passages: effect on water and heat balance. Respir. Physiol. 9:263-276.

Demographic Analysis of Pine Vole Populations in Two Orchard Types in Southwest Virginia

J. J. Hasbrouck, A. R. Tipton, and S. B. Lindquist

Department of Fisheries and Wildlife Sciences
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

Few long term studies have been conducted to analyze the population dynamics of pine and meadow voles in orchard environments. Such studies are needed to provide basic biological information for use in orchard management and vole control programs. To satisfy these needs, a three year study was begun in December, 1979, to monitor vole populations in a maintained and an abandoned apple orchard in Southwest Virginia. Two objectives of this study were (1) to follow population dynamics of pine and meadow voles in two orchard types and (2) to provide data for the development and validation of computer modeling efforts currently underway at Virginia Tech (Jordan and Tipton 1982). Lindquist et al. (1981) gave preliminary results from the field study after one year of trapping. This paper presents data from the second year of trapping (December 1980, to December, 1981) and compares the pine vole populations in the two orchards during the two years.

The two orchards have been live-trapped monthly since December, 1979. Both orchards are in the Roanoke Valley in Southwest Virginia and are within 1 mile of each other. The maintained orchard has not been commercially managed for the last 4 years but has been mowed 2-3 times during spring and summer. The abandoned orchard has had no maintenance in the last 5 years.

Both orchards were live-trapped 3 consecutive days during the middle of each month. The trap grids were each about 1/3 hectare in area and measure 6 tree rows by 12-13 trees. Two Sherman live traps were placed in tunnels or runways under each tree and checked twice daily. Traps were set early in the morning and closed each day after the second trap check. Tar paper was placed over the traps. For each vole trapped, location of capture, sex, age, body weight, body length and reproductive condition were recorded. Voles were marked by toe and ear clipping for identification and released. To allow comparisons with the results of Lindquist et al. (1981), age was determined by body weight. Juveniles were voles weighing less than 15g, subadults weighed greater than or equal to 15g but less than 21g, and adults were greater than or equal to 21g body weight.

Population densities were calculated as the minimum number of voles known to be alive (MNA) in the orchards for each trapping session. MNA was significantly ($P<0.001$) higher in the maintained orchard than in the abandoned orchard during the first year (Table 1). However, there was no difference in population size between the two orchards during the second year. There were significantly ($P<0.001$) more pine voles in the maintained orchard during the first year of trapping than in the second year but there was no difference in the abandoned orchard during the two years. From February, 1981, to

Table 1. Minimum number of pine voles known to be alive (MNA) in a maintained and an abandoned apple orchard for each month from December, 1979, to December, 1981.

	MAINTAINED ORCHARD		ABANDONED ORCHARD	
MONTH	79-80	80-81	79-80	80-81
DEC	183	169	55	58
JAN	184	116	45	62
FEB	201	58	47	79
MAR	209	39	55	76
APR	267	27	45	68
MAY	197	25	28	52
JUNE	183	19	34	21
JULY	103	18	21	13
AUG	92	16	15	11
SEPT	97	14	15	15
OCT	145	17	45	19
NOV	174	55	61	46
DEC	169	44	58	37

May, 1981, the MNA in the abandoned orchard was higher than in the maintained orchard.

There were significantly ($P<0.003$) more males and females captured the first year in the maintained orchard than in the second year. In the second year most captures occurred from December, 1980, to February, 1981, and then declined until October, 1981. The highest number caught was observed in December, 1980 (122). There was no difference ($P>0.05$) in the number of pine voles captured in the abandoned orchard between the two years. In the second year higher numbers were captured in February (60), March (64) and April (60). Although the male:female ratio varied monthly in both orchards, the yearly totals during the second year were 1.1:1.0 in the maintained orchard and 1.2:1.0 in the abandoned orchard. This was similar to the ratio in the two orchards during the first year (Lindquist et al. 1981).

The number of voles captured in both orchards declined dramatically in July, August and September of 1980 and from June through September in 1981. Lindquist et al. (1981) speculated the decline in number of captures and in MNA during summer was caused by a decrease in trappability and not by an actual decrease in population size. A calculation was made of the percent catch of those known alive for each month in both orchards (Table 2). To compute this percentage the total number of pine voles captured each month (including voles on unknown sex) was divided by the MNA for that month. There were no significant differences in percent catch between the two orchards nor between the two years. However, the percentage dropped below 50% from July to September in the maintained orchard both years. The abandoned orchard had similar trends. Thus, there was some decline in trappability in summer in both orchards which reduced the number of voles captured and estimates of population size.

The percentage of juveniles, subadults and adults was not significantly different between the two orchards during the second year of trapping (Tables 3 and 4). Juveniles and subadults were captured each month in the maintained orchard during the first year of trapping but during the second year no juveniles were captured in 6 months and no subadults captured in 2 months (Table 3). The percentage of adults captured dropped below 60% during fall of the second year and was only 37% in December, 1981. Small sample sizes may have accounted for these low percentages. In the abandoned orchard there were significantly ($P<0.03$) more juveniles captured the second year than in the first year (Table 4). The percentage of adults captured stayed above 70% except from July to September but small sample sizes may again have caused some bias.

Adult males captured in the maintained orchard during the first year had significantly ($P<0.001$) higher body weights than those captured the second year. Adult female body weights were not different ($P>0.05$) between the two years. In the abandoned orchard there was no difference in either male or female body weight between the two years. Adults captured the first year tended to be heavier in the maintained orchard than in the abandoned orchard (males $P=0.0516$; females $P=0.077$). There was no such trend during the second year.

Table 2. Percent catch of those known alive for each month in a maintained and an abandoned apple orchard near Roanoke, Virginia. Number captured is indicated in parentheses.

	MAINTAINED ORCHARD		ABANDONED ORCHARD	
MONTH	79-80	80-81	79-80	80-81
DEC	100 (183)	73 (124)	100 (55)	52 (30)
JAN	68 (126)	83 (96)	73 (33)	53 (33)
FEB	62 (125)	88 (51)	62 (29)	77 (61)
MAR	56 (117)	79 (31)	87 (48)	84 (64)
APR	87 (233)	78 (21)	78 (35)	88 (60)
MAY	78 (151)	84 (21)	71 (20)	85 (44)
JUNE	77 (141)	58 (11)	91 (31)	71 (15)
JULY	31 (32)	39 (7)	71 (15)	23 (3)
AUG	15 (14)	19 (3)	7 (1)	-- (0)
SEPT	24 (23)	7 (1)	7 (1)	53 (8)
OCT	60 (87)	53 (9)	73 (33)	53 (10)
NOV	63 (113)	95 (52)	72 (44)	87 (40)
DEC	73 (124)	100 (44)	52 (30)	100 (37)

Table 3. Percent of juvenile (JUV), subadult (SAD) and adult (ADU) pine voles captured each month in a maintained apple orchard near Roanoke, Virginia, from December, 1979, to December, 1981. Voles of questionable sex are not included.

	DEC, 1979-DEC, 1980				DEC, 1980-DEC, 1981			
MONTH	N	JUV	SAD	ADU	N	JUV	SAD	ADU
DEC	168	6.0	7.7	86.3	122	2.5	15.6	82.0
JAN	115	0.0[1]	0.0[1]	0.0[1]	96	1.0	23.0	76.0
FEB	121	4.1	19.8	76.0	51	0.0	19.6	80.4
MAR	209	5.5	16.5	78.0	31	0.0	9.7	90.3
APR	267	8.0	23.5	68.5	21	0.0	14.7	85.7
MAY	143	2.1	16.8	81.1	21	14.3	0.0	85.7
JUNE	119	5.0	6.7	88.2	11	9.1	18.2	72.7
JULY	29	3.5	24.1	72.4	7	0.0	28.6	71.4
AUG	14	7.1	14.2	78.6	3	33.3	33.3	33.3
SEPT	21	4.8	9.6	85.7	1	0.0	0.0	100.0
OCT	145	9.3	26.8	64.0	9	0.0	44.4	55.5
NOV	113	6.2	39.8	54.0	52	13.5	34.6	51.9
DEC	122	2.5	15.6	82.0	43	18.6	44.2	37.2

[1] Data not included because most animals were not weighed.

Table 4. Percent of juvenile (JUV), subadult (SAD) and adult (ADU) pine voles captured each month in an abandoned apple orchard near Roanoke, Virginia, from December, 1979, to December, 1981. Voles of questionable sex are not included.

	DEC, 1979-DEC, 1980				DEC, 1980-DEC, 1981			
MONTH	N	JUV	SAD	ADU	N	JUV	SAD	ADU
DEC	49	2.0	6.1	91.8	30	6.7	10.0	83.3
JAN	31	0.0[1]	0.0[1]	0.0[1]	33	6.1	6.1	87.9
FEB	29	0.0	10.4	89.7	60	3.3	16.7	80.0
MARCH	47	0.0	17.0	83.0	64	4.7	7.8	87.5
APRIL	34	0.0	2.9	97.1	68	8.3	11.7	80.0
MAY	20	0.0	5.0	95.0	44	13.6	11.4	75.0
JUNE	29	6.9	3.5	89.7	21	13.3	13.3	73.3
JULY	15	6.7	33.3	60.0	3	0.0	33.3	66.7
AUGUST	1	0.0	100.0	0.0	1	0.0	0.0	100.0
SEPT	1	0.0	100.0	0.0	7	14.3	28.6	57.2
OCT	33	9.1	18.2	72.7	10	0.0	10.0	90.0
NOV	43	0.0	25.6	74.4	41	7.3	22.0	70.7
DEC	30	6.7	10.0	83.3	37	5.4	18.9	75.7

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[1] Data not included because most animals were not weighed.

The dramatic decline in the pine vole population in the maintained orchard and the differences reported between the two orchard types may be due to several factors. In the maintained orchard a very poor apple crop in 1981, coupled with reduced vegetative cover, caused the apples on the ground to deteriorate much faster than in previous years. This may have produced an environment which could not support the high vole density found in the maintained orchard in 1980. A severe drought during the summer and fall of 1981 may also have had a greater impact on the population in the maintained orchard than in the abandoned orchard. Another explanation might be that successional changes in the vegetation are occurring in the maintained orchard since it is no longer being commercially managed (i.e. no insecticides, tree pruning or herbicides). Finally, it has never been determined if pine voles exhibit cyclic density fluctuations as do other species of microtines. In an optimum environment such as a maintained orchard pine voles may be cyclic. The population in 1980 may have reached a peak density with the decline phase following in 1981. The population density in the abandoned orchard was much more stable over the two year period, perhaps because the habitat is not as favorable for high reproductive output or survival. The vole population did decline in the summer of 1981 in the abandoned orchard, but this may be due to the extremely dry weather reducing either the population size or trappability.

Vegetation will be sampled in both orchards this spring and summer. Temperature and rainfall data will also be analyzed to determine if these factors were correlated with the decline in both orchards during the summer of 1981. Data which is currently being collected will be analyzed to provide more insight into body weight dynamics, seasonal reproduction and survival, and spatial dynamics of both pine and meadow vole populations in both orchards.

LITERATURE CITED

Jordan, K., and A. R. Tipton. 1982. Progress Report on a Bioenergetic Simulator of Pine Vole Popolations. In Proc. of the Sixth Eastern Pine and Meadow Vole Symposium.

Lindquist, S. B., A. R. Tipton, G. K. Yarrow, and J. J. Hasbrouck. 1981. Analysis of Seasonal Dynamics of Pine Vole Populations in Two Virginia Orchards. In Proc. of the Fifth Pine and Meadow Vole Symposium. pp 79-83.

EFFECT OF GREEN VEGETATION AND COTTON NEST MATERIAL ON REPRODUCTION AND SURVIVAL OF PINE VOLES (*MICROTUS PINETORUM*).

Jack A. Cranford
Department of Biology
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

INTRODUCTION

Plant compounds associated with active plant growth and senesence have been reported to have different effects on microtine reproduction (Berger et al., 1977, 1981). Biological assays of inhibitory compounds showed some effect at pharmacological doses in *Microtus pennsylvanicus* but not in *M. pinetorum* (Cranford et al., 1980; Derting and Cranford, 1981). Stimulatory plant compounds contained in active growing wheat have been demonstrated to cause early sexual maturation (Berger et al., 1981) and to induce reproduction in wild populations during non reproductive periods (Negus, 1977; Berger et al., 1981). Bodenheimer (1949) postulated that plants contain compounds which trigger the onset of reproduction in *M. guentheri*. In *M. montanus* small amounts of green plants or their extracts supplemented to the normal laboratory diets have caused increased uterine weight, increased numbers of estrus females, increased numbers of young produced, and a return to sexual activity under normally inhibitory conditions (Pinter and Negus, 1965; Negus and Pinter, 1966; Negus and Berger, 1971; Negus and Berger, 1972).

Orchards typically have grass growing in aisle rows and under trees which could provide additional reproductive stimulation. Mowing keeps the grass in an active growth stage which would maintain a high level of reproductive stimulatory compounds in the vegetation. This research will report on the effect on reproduction of small amounts of oat sprouts fed to _M. pinetorum_ in a laboratory colony and in animals maintained in large outdoor enclosures under natural conditions. An additional factor tested was the presence of nest material in the form of cotton batting.

MATERIALS AND METHODS

One hundred _M. pinetorum_ were randomly selected at weaning from the laboratory colony and were paired at seventy days of age. All animals in the laboratory groups were maintained as mated pairs for 180 days under LD 16:8 in small tub cages with Wayne lab blox and water available ad libitum. Group one consisted of 10 experimental pairs which received the equivalent of 2 g dry weight of oat sprouts (greens) per day in addition to the normal diet and a control group of 10 pairs. Group two consisted of 10 experimental pairs which received cotton batting nest material in addition to the normal sawdust substrate and a control group of 5 pairs. Group three was composed of 30 animals, 10 males and 20 females, which were housed in outdoor enclosures as 10 groups of two females with one male. The outdoor enclosures were 45 cm by 180 cm in size and had 16 cm of earth for burrowing and subsurface nest construction. All groups had food and water ad libitum, were under natural photoperiod and temperature from June 1981 to December 1981, and had greens and natural vegetation continuously available. Five of these groups (randomly selected) in addition to natural nest materials had cotton batting supplied as supplementary nest material.

All laboratory animals were weighed and examined periodically for signs of reproduction (scrotal testis, perforate vagina, enlarged nipples), litters were weaned at 21 days of age, sexed and recaged. Outdoor enclosure animals were checked daily and trapped periodically to determine the same parameters as the laboratory groups.

RESULTS

Laboratory group one was maintained on small supplemental feedings of greens and produced their first litters at 69 ± 7 days of age while their control group was more variable and matured later (80 ± 33 days). Overall litter size for the greens feed group was 2.5 ± 1 while the control was smaller (2.1 ± 9) and the sex ratio for greens fed animals was 52:48 while the control group produced more females (38:62). Over the 180 days of mated life, greens fed animals produced 3.57 litters per female at 26.4 ± 6 day intervals while the control group produced fewer litters (2.43) and were more variable in the inter litter interval (40.9 ± 12 days). Both of these variables were statistically significantly different ($\underline{P} = 0.025$; $\underline{P} = 0.05$ respectively). Overall breeding success of the greens fed group was higher in every parameter including the mean number of offspring per female with the greens groups producing 8.86 young while controls produced 5.0 offspring per female.

Laboratory group two was maintained with supplemental cotton batting nest material resulting in 60 percent mortality over the test period while only one control animal died. Reproductive success of supplemented cotton animals was 30 percent with most females only producing one litter. The point at which 50 percent of the females (LD 50) with cotton batting died was 56 days after the onset of the experiment with the male LD 50 at 100 days.

All animals in the group which survived the 180 day period were killed and all organs and tissues examined and weighed. No differences were noted between experimental (cotton present) and control animals except for mean body weights. Survivors which had cotton present were significantly heavier ($\underline{P}$ = .01) than the controls. For 12 animals which died, post mortum examination indicated that 7 died due to cotton blockage of the stomach-small intestine junction with 4 of the remaining 5 dying from cotton blockage of the small intestine-ceacum junction. The source of mortality of one control and one cotton animal could not be determined.

Group three housed in the outdoor enclosure under natural conditions with natural vegetation and greens present had 100% breeding success with 2.6 litters per female and a mean litter size of 2.43 in the absence of cotton. Three outdoor enclosures with cotton went extinct within 60 days producing no offspring, one enclosure survived and produced one litter and one enclosure group survived but did not breed. The post mortum examination of dead pine voles indicated that mortality was due to cotton blockage of the stomach-small intestine junction. Initial population density in cotton containing enclosures was 15 which decreased to 9 while the same starting density in noncotton enclosures reached 46 at 135 days and contained 2.6 breeding females per enclosure. Of the 46 individuals in the enclosures, the second, third and fourth litters produced over the 135 day period were clearly recognizable by pelage and or body size and weight. These cohorts were statistically different in body weight from each other and from the parental generation and their first litter ($P \leq .05$).

DISCUSSION

Although prior research with reproductive inhibitory compounds in *M. pinetorum* was not successful at biologically relevant dosage rates (Derting and Cranford, 1981) the effect of green vegetation even in small amounts was quite significant. Using the reproductive data from the indoor groups one can calculate the potential impact of grass (greens) present in the home range of a single female over a 120 day breeding period. Animals with grass would produce 21 offspring of which 10 would be females while animals lacking grass would produce 9 offspring of which 5.6 would be females. As has been shown by Negus et al. (1981) for *M. montanus* only very small amounts of the stimulatory compound 6-MBOA were necessary and our laboratory studies with oat sprouts indicate the same condition for *M. pinetorum*. Litter sizes for greens fed animals were higher both indoors and outdoors and the inter litter intervals were shorter. These effects have also been reported for *M. montanus* and our results are in close agreement with that data.

Cotton fiber present as supplementary nest material was injested by test animals and resulted in blocked segments of the stomach and small intestine. The effect of this blockage was to decrease the animals digestive efficiency and resulted in decreased body weight and eventual death. The indoor experimental groups had lower reproductive success and those outdoors in the enclosure experienced nearly total mortality. The observed differences in time to death probably reflect differences in behavior of males and females. Females begin to die within two weeks of exposure but 50 percent died within 50 days while males took twice as long. This probably reflects the greater nest building and nest maintenance habits of the female.

The overall impact of greens and cotton in an orchard has yet to be tested but the outdoor enclosure experiment clearly indicates that the presence of grass in orchards probably enhances overall reproduction success. The presence of cotton in runways and adjacent to fossorial burrow entrances could perhaps contribute greatly to an overall management program. As cotton results in significant mortality, reduction in the numbers of litters produced and general reduction in individual nutritional status it could contribute to an overall management program. Because the voles must build nests and cotton is acceptable to the individuals their behavior alone could result in at least reduced recruitment into a population over time and perhaps extinction of females.

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LITERATURE CITED

Berger, P. J., N. C. Negus, E. H. Sanders, and P. D. Gardner. 1981. Chemical triggering of reproduction in *Microtus montanus.* Science 214: 69-70.

Bodenheimer, F. S. 1949. Problems of vole populations in the Middle East. Report on the population dynamics of the Levant vole (*Microtus* guntheri). Govt. of Israel, 77 pp.

Cranford, J. A., D. H. Pistole, and T. L. Derting. 1980. Results of chemical inhibitors and photoperiodic influences on growth and reproduction in *Microtus pennsylvanicus*. Proc. 4th Pine Vole Conference. Ed. by R. Byers. Hendersonville, N.C. pp. 28-33.

Derting, T. L., and J. A. Cranford. 1981. Growth and development rates of *Microtus pinetorum* under different photoperiods. Proc. 5th Pine Vole Conference. Ed. by R. Byers. Gettysburg, PA. Pp. 131-137.

Negus, N. C., and P. J. Berger. 1971. Pineal weight response to a dietary variable in *Microtus montanus*. Experientia, 27: 215-216.

Negus, N. C., and P. J. Berger. 1972. Environmental factors and reproductive processes in mammalaian populations. Pp. 89-98, in Biology of reproduction, basic and chemical studies (Velardo and Kasprow, eds.) Third Pan Amer. Cong. Anat., New Orleans, Louisiana, 420 pp.

Negus, N. C., and P. J. Berger. 1971. Experimental triggering of reproduction in a natural population of *Microtus montanus*. Science, 196: 1230-1231.

Negus, N. C., and A. J. Pinter. 1965. Litter sizes of Microtus montanus in the laborataory. J. Mamm., 46: 434-437.

Negus, N. C., and A. J. Pinter. 1966. Reproductive responses of Microtus montanus to plants and plant extracts in the diet. J. Mamm., 47: 596-601.

Negus, N. C., P. J. Berger, and L. G. Forslund. 1977. Reproductive strategy of Microtus montanus. J. Mamm., 58: 347-353.

Sanders, E. H., P. D. Gardner, P. J. Berger and N. C. Negus. 1981. 6-Methoxybenzoxazolinone: A plant derivative that stimulates reproduction in Microtus montanus. Science, 214: 67-69.

STRANGE MALES BLOCK PREGNANCY IN LACTATING PINE VOLES, MICROTUS PINETORUM, AND REDUCE SURVIVAL AND GROWTH OF NURSING YOUNG

Margaret H. Schadler
Department of Biological Sciences, Union College, Schenectady, NY 12308

Strange (unfamiliar) males affect survival of progeny of reproductive female rodents in a variety of ways. In mice, strange males block pregnancy before implantation of embryos (Bruce, 1959) but only in females that are not lactating (Bruce and Parkes, 1961). In voles these males can block pregnancy both before and after implantation (Stehn and Richmond, 1975; Marks and Schadler, 1979; Schadler, 1981). Strange males have also been shown to kill nursing pups in lemmings (Mallory and Brooks, 1978) and mice (Labov, 1980 and vom Saal and Howard, 1982).

The present study in pine voles (Microtus pinetorum) examines the effect of strange males on blockage of pregnancy in lactating voles and on survival and growth of nursing pups.

Pine voles used in these experiments were descendents of animals trapped near New Paltz, N.Y. in 1974 and 1975. Animals were housed in metal laboratory mouse cages 18.5x26x14.5 cm with solid bottoms and wire tops and were maintained in a photoperiod of 12L:12D at a temperature of 16-18°C. They were fed Wayne Rat Lab Blox, Wayne Guinea Pig Pellets, apple and water. Wood chips provided litter and nesting material. Cages were cleaned once a week such that disturbance was spread uniformly over all groups of experimental animals.

All mothers used in the study had successfully reared at least one litter. In order to minimize variation, females with litters of two to four neonates were used and they were assigned on Day 4 post partum to control and experimental groups in such a way as to equalize any difference in litter number and in weight of offspring. All females were housed with the stud male throughout pregnancy and after parturition until they were placed in treatment groups.

The mothers with their litters (n=74) received the following treatment: In the first group (n=34) females were housed with the stud male until infants were weaned. A second group (n=30) were housed with the stud male for 4 days post partum at which time the stud male was removed and the strange male introduced following the procedure described below. A third group (n=10) was housed with the stud male for 4 days after which he was removed and not replaced. This group was used to determine if pregnancies were missed or if survival of young was adversely affected because of the removal of the attending stud male.

Before the strange males were released into the cages with the nursing mother and her litter, they were introduced behind a small wire enclosure in the female's cage on Day 4 and released into the cage on Day 5. Unacquainted pine vole adults fight vigorously and previous attempts to place strange males directly with lactating females resulted in the killing or wounding of one of the parents and/or the young. In order to assess the effect of the presence of the male, such aggressive encounters were avoided with the 24 hour familiarization period. After this period, previously unacquainted males and females do not fight.

During the experiment all cages were checked daily and observed for a minimum of five minutes for condition of young, behavior of all cage occupants, and for recording of deaths. Young from the two groups that were housed with males, either stud or strange, throughout the experiment were weighed at 2 days, at 10 days and at 21 days of age when they were weaned.

The criterion used for determining blockage of pregnancy was the difference in number of days post partum until delivery of a litter. Previous findings (Schadler and Butterstein, 1979) showed that 87% of lactating females delivered litters that were conceived within 3 days post partum. Since gestation is 24 days, the expected interval between litters is 24-27 days. Therefore, if a female exposed to a strange male at 5 days lost her pregnancy and was subsequently re-inseminated, her young would be born after 29 or more days.

To check the effect of strange males on infants the following criteria were used: 1) the number of litters that survived intact until weaning; 2) the number of young that survived; and 3) weight gain of infants.

Chi square and the Student's t-test were used in the statistical analyses.

RESULTS

Data on delivery of post partum litters showed that a significant number of pregnancies ($x^2=6.8$, $p<0.01$) were blocked by the strange male (Table 1). In all groups 90-91% of the females bore litters conceived during the post partum period. Of the females that were not exposed to strange males, 9 of 10 (90%) of the animals caged alone after 4 days and 30 of 34 (88%) of the animals caged with stud males delivered litters 24-27 days post partum. This is compared with 18 of 30 (60%) of the group exposed to strange males. In the latter group 9 females (30%) delivered litters that were born 29 or more days post partum.

Data on infant size and survival for all three groups appear in Table 2. A comparison of survival of litters between the group that had the stud males removed and not replaced and the ones in which the stud was not removed showed no significant difference ($x^2=.55$). Comparison of the groups caged with a male, either stud or strange, that successfully reared intact litters showed the following: The group caged with a stud male had a weaning success rate of 65% (22 of 34 litters) versus a 7% success rate (2 of 30) for the group housed with a strange male. The difference is significant at $p<0.001$ ($x^2=21.7$). The number of offspring that survived for 10 days was 95% for the first group versus 68% for the second and at 21 days was 84% versus 34%. Both differences were significant ($x^2=26.1$, $p<0.001$ and $x^2=63$, $p<0.001$ respectively).

Infants exposed to strange males not only survived less well but those that did survive had a reduced rate of growth (Table 2). Mean gain in weight of infants from the first group from 2-10 days was

Table 1. Birth of litters conceived during lactation period to females that were caged with males under varying conditions

Treatment	Number litters born (%)	Litters born 24-27 days post partum (%)	Litters born 29 or more days post partum (%)
Stud male present throughout lactation (n=34)	31(91)	30(88)	1(3)
Stud male replaced by strange male (n=30)	27(90)	18(60)*	9(30)
Stud male removed and not replaced (n=10)	9(90)	9(90)	0

*$p<0.01$ by x^2 test

4.3±0.19 and 2-21 days was 9.9±0.22 compared with infants from the second group (3.1±0.19 and 8.7±0.50). Both differences were significant ($t=4.4$, $p<0.001$; $t=2.2$, $p<0.05$ respectively).

Daily examination of living infants and carcasses revealed little sign of wounding. Of the 30 experimental animals that died before 10 days, none died within the first several hours after they were exposed to the strange male, 8 died within the next day and the rest survived two or more days. Dead animals were often found intact but in some cases dead infants in all groups were totally or partially consumed, a common occurrance in pine voles. Observance of adults showed no detectable differences in the behavior of stud males versus strange males. In both cases males hovered with females over the young in the nest.

DISCUSSION

Strange males did not block pregnancy after parturition in meadow voles, *Microtus pennsylvanicus*, when they were introduced before implantation on the second day after post partum coitus. (Mallory and Clulow, 1977). Kenney, Evans, and Dewsbury (1977) found that the incidence of abortion after implantation in parous female *M. ochrogaster* and *M. pennsylvanicus* that had recently lactated was low and they speculated that the females may have experienced protection from their recent lactation.

In 30% of the pine voles, lactating mothers underwent blockage of pregnancy and subsequent re-insemination by strange males in this experiment. This phenomenon is interpreted to be a true case of pregnancy blockage and not delayed implantation mediated by removal of the stud male because 88-90% of all females from both sets of controls, with or without stud males after Day 4, had litters conceived within 3 days post partum. This loss of pregnancy was less than that noted in non-lactating females in which 84% of the females aborted when they were placed with strange males at 4 days post partum (Marks and Schadler 1979) and 88% aborted at 10 days post partum (Schadler, 1981).

Reduced survival of offspring of lactating rodent females exposed to strange males has been reported by Mallory and Brooks (1978), Labov (1980), and vom Saal and Howard (1982). In lemmings, Mallory and Brooks (1978) found that a strange male placed with lactating females killed the young unless the female was successful in attacking the male and keeping him at bay. In pine voles, familiarizing strange males with their new associates allays aggressive tendencies and the female does not actively defend the nest.

Labov (1980) working with mice placed strange males with females before the litters were born. He noted that allowing males to co-habit with pregnant females for an extended period of time before parturition or letting them copulate with estrous females painted with urine containing pheromones from pregnant female cagemates appeared to repress killing of the young. vom Saal and Howard (1982) found that dominant male mice placed alone in cages with newborn infants were more likely to kill the infants than subordinate ones. In voles, since strange males did not physically attack the young, reduced survival must be ascribed to other causes.

Table 2. Effects of males on survival and mean (± SEM) gain in weight of nursing pine vole infants

Treatment	Num. Lit. born	Lit. surv. intact (%)	Num. Young born	Young surv. 10 da. (%)	Weight gain 2-10 da	Young surv. 21 da (%)	Weight gain 2-21 da
Stud male present throughout lactation	34	22 (65)	106	101 (95)	4.3±0.19	90 (84)	9.9±0.22
Stud male replaced by strange male	30	2^* (7)	95	65^* (68)	$3.1\pm0.19^+$	33^* (34)	$8.7\pm0.50^{++}$
Stud male removed and not replaced	10	5 (50)	29	26 (90)	—	23 (80)	—

* $p<0.001$ by x^2 test

\+ $p<0.001$ by t-test

++ $p<0.05$ by t-test

Some authors have suggested that decreased secretion of prolactin which is both luteotropic and lactogenic in voles follows the introduction of a strange male. The luteotropic effect has been described in the vole M. agrestis, by Milligan and MacKinnon (1976) and Charlton, Milligan and Versi (1978). Milligan, Charlton and Versi (1979) noted that pregnant females with functional corpora lutea and elevated prolactin levels had their pregnancies blocked upon exposure to strange males. This blockage was accompanied by degeneration of corpora lutea and suppression of secretion of prolactin. The necessity for adequate levels of circulating prolactin to stimulate lactation is well known.

If prolactin levels are lowered in pregnant and lactating pine voles exposed to strange males, this could account for the noted blockage of pregnancy in these animals and for reduction in survival and growth of nursing young.

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REFERENCES

Bruce, H.M. (1959) An exteroceptive block to pregnancy in the mouse. Nature, 184, 105.

Bruce, H.M. and Parkes, A.S. (1961) The effect of concurrent lactation on the olfactory block of pregnancy in the mouse. J. Endocr. 22, 6-7.

Charlton, S.R., Milligan, S.R. and Versi, E. (1978) Studies on the control of the corpus luteum in the vole, Microtus agrestis. J. Reprod. Fert. 52, 283-288.

Kenney, A. M^{c}M., Evans, R.L. and Dewsbury, D.A. (1977) Postimplantation pregnancy disruption in Microtus ochrogaster, M. pennsylvanicus and Peromyscus maniculatus. J. Reprod. Fert. 49, 365-367.

Labov, J.B. (1980) Factors influencing infanticidal behavior in wild house mice (Mus musculus). Behav. Ecol. Sociobiol. 6, 297-303.

Mallory, F.F. and Brooks, R.J. (1978). Infanticide and other reproductive strategies in the collared lemmings, Dicrostonyx groenlandicus Nature, 273, 144-146.

Mallory, F.F. and Clulow, F.B. (1977) Evidence of pregnancy failure in the wild meadow vole, Microtus pennsylvanicus. Canadian J. of Zool. 55, 1-17.

Marks, K.J. and Schadler, M.H. (1979). Embryo rejection in the pine vole. Proceedings of the Third Annual Pine and Meadow Vole Symposium, New Paltz, N.Y. February, 1979. pp. 30-31.

Milligan, S.R. and MacKinnon, P.C.B. (1976). Correlation of plasma LH and prolactin levels with the fate of the corpus luteum in the vole *Microtus agrestis.* J. Reprod. Fert., 47, 111-113.

Milligan, S.R., Charlton, H.M. and Versi, E. (1979) Evidence for a coitally induced "mnemonic" involved in luteal function in the vole (*Microtus agrestis*). J. Reprod. Fert. 57, 227-233.

Schadler, M.H. and Butterstein, G.M. (1979). Reproduction in the pine vole, *Microtus pinetorum.* J. Mamm. 60, 841-844.

Schadler, M.H. (1981). Postimplantation abortion in pine voles (*Microtus pinetorum*) induced by strange males and pheromones of strange males. Biol. Reprod. 25, 295-297.

Stehn, R.A. and Richmond, M.E. (1975). Male-induced pregnancy termination in the prairie vole, *Microtus ochrogaster.* Science, 187, 1211-1213.

vom Saal, F.S. and Howard, L.S. (1982). The regulation of infanticide and parental behavior:implications for reproductive success in male mice. Science 215, 1270-1272.

A Comparison of Maternal Behavior in Three Species of Voles (Microtus pennsylvanicus, M. pinetorum, and M. ochrogaster) Using a Laboratory System.

B.A. McGuire. Department of Zoology, University of Massachusetts, Amherst, 01003

M.A. Novak. Department of Psychology, University of Massachusetts, Amherst, 01003.

Abstract

A system has been developed to describe and compare the maternal behavior of three species of microtine rodents within a naturalistic environment. The apparatus consists of two interconnected Plexiglas-based tables with a peat substrate and hay cover. A pregnant female and her mate are placed within the tables, once the female has shown a thirty percent weight gain and pups can be felt by palpating her abdomen. Maternal behavior, as well as male-female interactions and information on pup physical and behavioral development, are recorded daily for twenty-five days immediately following parturition. Unrestricted observation of female behavior during neonatal, preweaning and post-weaning phases of pup development is possible from below the tables. Preliminary observations indicate that pup behavioral development rate, and male-female social interactions and spatial relationships during the breeding period, differ between the three species. This system provides for ease and clarity of observation of individual microtines, thus combining the best attributes of both field and laboratory studies.

Introduction

Formulation of an effective program to control microtines requires knowledge of the social behavior of these rodents. Parameters of social biology such as spacing pattern, social structure, and specific behavioral interactions, are expressions of both the reproductive biology and the ecology of a species. In particular, interspecific differences in mating system and parental care often reflect differences in reproductive strategies and/or habitat.

Microtus pennsylvanicus, M. (= Pitymys) pinetorum, and M. ochrogaster reportedly differ in certain aspects of habitat preference (De Coursey, 1957; Getz, 1978; Miller, 1969; Paul, 1970), and reproductive characteristics such as age at sexual maturity, gestation period, and average litter size (Hasler, 1975). Closely associated with these differences are the postulated dissimilarities in mating system and social organization. M. pennsylvanicus appears to display a social system based on territoriality by reproductively active females during the breeding season (Madison, 1980). Males overlap these territories and compete for estrous females in what seems to be a promiscuous mating situation. In contrast, the existence of monogamy and stable family units has been proposed for M. ochrogaster (Getz, 1978; Getz and Carter, 1980; Thomas and Birney, 1979). Although little information exists on the mating system of M. pinetorum, individuals of this species reportedly occur in loose colonial associations (Paul, 1970).

Parental care, a component necessary to complete the comparison of these three species, has received little attention. Recent radiotelemetric studies provide information on the movement patterns of free-ranging female meadow voles (*M. pennsylvanicus*) at the time of parturition (Madison, 1978), as well as the frequency and duration of nest visitation by lactating females (Madison, 1981). Laboratory investigations by Thomas and Birney (1979) describe parental behavior in *M. ochrogaster* and present data in the form of an ethogram. Getz and Carter (1980) also describe care of offspring by *M. ochrogaster* and provide information on time spent in the nest with the young by both parents and older litters. However, comparative studies involving detailed observation and quantification of parent-young interactions among different species of microtines has not been undertaken.

The present study represents an attempt to quantify and compare maternal behavior in *M. pennsylvanicus*, *M. pinetorum* and *M. ochrogaster*. Male-female interactions and early physical/behavioral aspects of pup development were noted, as well as post-weaning interactions between the female and her offspring. All observations were made in a laboratory environment which was designed to capture the conditions under which voles are found in the wild, and therefore minimize the various difficulties associated with both field and laboratory studies.

Materials and Methods

Experimental animals were selected from a laboratory colony which contained the following three species; 1) *M. pennsylvanicus* - trapped locally in Amherst, MA in 1980, 2) *M. pinetorum* - trapped from two orchards in Fairfield County, Connecticut in 1980, and 3) *M. ochrogaster* - received from the Animal Science department at University of Massachusetts in 1977. Voles were housed as male-female pairs or as single sex groups in aquaria (26 cm by 51 cm) or wire cages (25 cm by 52 cm) with a peat-wood shaving substrate and hay cover. Sunflower seeds, rye seeds, lab chow, and water were provided ad libitum. Greens, in the form of sprouted rye and sunflower, were supplied once a week. All animals were maintained on a 15L: 9D photoperiod.

Experiments were conducted in two 4' x 4' x ¼" Plexiglas tables which were joined by two Plexiglas tunnels. Each table contained a 1" peat substrate and extensive hay cover. Initial runways were constructed by the observer prior to the start of a run, to ensure immediate visibility from below the tables. Food, water, and photoperiod in the experimental rooms were similar to colony conditions.

To accurately assess pregnancy and to obtain individual breeding histories, all females were weighed weekly on a triple beam balance. The following information was recorded: 1) date, 2) weight, 3) birth of a litter, 4) number of pups born/present. The determination of pregnancy was based on two parameters; 1) significant weight gain and 2) palpation of the abdomen. Females used in this study had been paired with males with whom they had produced at least one previous litter and successfully reared to weaning.

Prior to placement of a pair into the tables, the female was weighed again and the ventral surface of the male was dyed with Nyanzol-D for identification purposes. Trial runs indicated no difference in behaviors between dyed males and those males without dye.

Data collection began with the birth of a litter and continued for twenty-five days thereafter. Females were observed from below the tables for fifteen minutes each day between the hours of 9:00-11:00 A.M. Animals were removed from the tables and data collection stopped for the following reasons; 1) death of a litter, 2) unusually small litter size. Suitable litter sizes for each species were determined from values in the literature (Hasler, 1975) with slight adjustments made in accordance with the litter sizes observed in our laboratory (see Table 1). Determined litter sizes served only as guidelines to eliminate from the study those runs which involved unusually small litters. Larger litters were not culled in order to minimize disruption at the nest. In most instances, however, large litters were naturally reduced to an appropriate size within a few days of parturition.

Table 1. Determination of suitable litter sizes for each species.

Species	Average litter size (literature)	Average litter size (colony)	Litter sizes used
_M_. _pennsylvanicus_	5.5	4.2	4,5
_M_. _pinetorum_	1.8	2.5	2,3
_M_. _ochrogaster_	3.9	2.2	3,4

During each observation period, the frequency and duration of seventeen behaviors (see Table 2) were recorded using a More data acquisition system. Developmental information concerning the pups was also recorded. Physical parameters such as appearance of hair and eye opening were noted, in addition to the onset of the following behavioral characteristics; 1) eat solid food, 2) out of nest, 3) last observed nipple attachment. Paternal care, and nest number and location were noted in daily records.

Table 2. Behaviors.

1 grooming self
2 grooming pup
3 contact
4 retrieve
5 nest building and maintenance
6 tunnel building and maintenance
7 food caching
8 eat or drink
9 locomote
10 passive
11 approach male
12 approach pup
13 withdraw from male
14 withdraw from pup
15 female in/out of nest
16 male in/out of nest
17 nursing

Results

Determination of species differences with respect to the frequency and duration of particular behaviors awaits the completion of future runs and final data analysis. Preliminary observations refer to eleven completed runs and four trial runs.

Male-female social interactions, spatial relationships, and degree of paternal care constitute the most obvious and consistent difference between the three species. *M. pennsylvanicus* males and females maintained separate nests and six out of seven females reacted aggressively toward males in the vicinity of the natal nest. Paternal care in this species was nonexistent. In contrast, *M. pinetorum* mates nested together and males participated in some parental activities such as grooming pups and nest building. Nest cohabitation was also observed in *M. ochrogaster*. In two of the three runs of this species a second, temporary nest was constructed in which the male occasionally brooded part of the litter while the female remained at the primary nest site with the remaining pups. Male prairie voles exhibited extensive paternal care in the form of brooding, retrieving, grooming, and nest building. Females were frequently observed to leave the nest upon the male's arrival and his immediate assumption of parental responsibilities. As a result, pups were rarely left unattended.

Length of period of maternal care and post-weaning spatial relationships differed somewhat between species. *M. pennsylvanicus* females stopped nursing and abandoned the nest when the pups were approximately two weeks old. Construction of a second nest by the female further ensured separate nesting by the male, female, and litter. Nursing and all other aspects of maternal care continued for close to three weeks in *M. pinetorum* and family members continued to share a nest for the length of a run. Cessation of nursing in *M. ochrogaster* occurred when the pups were two and a half to three weeks of age and communal nesting also persisted after weaning.

Physical parameters of pup development were similar in all three species. Fur appeared on approximately day three and eye opening occurred at the age of ten to twelve days. Pups were usually observed out of the nest within one day of eye opening. Last observed nipple attachment for *M. pennsylvanicus* pups varied from twelve to fourteen days and consumption of solid food was first noted on days thirteen and fourteen. Relative to *M. pennsylvanicus*, *M. pinetorum* pups showed slightly delayed development in these two behavioral parameters as nursing continued for twenty to twenty-one days and solid food was first consumed at the age of fifteen to eighteen days. Intermediate values of eighteen to twenty-one days for last observed nipple attachment and twelve to sixteen days for solid food consumption were obtained for *M. ochrogaster* pups.

Females of all three species frequently gave birth to a second litter during the twenty-five day run, thus permitting observation of female reactions to older offspring in the presence of a new litter. Six out of seven *M. pennsylvanicus* females reacted aggressively toward older offspring in the vicinity of the new nest. However, aggression was not continuously displayed and seemed to increase prior to and just following parturition. Females of the remaining two species, *M. pinetorum* and *M. ochrogaster*, were never observed to react aggressively toward older offspring and all family members continued to share a single nest.

Discussion

Observed species differences such as nesting pattern, male-female interactions, degree of paternal care, and reaction to older offspring, provide further evidence to support the proposed dissimilarities in mating system and social organization between the three species.

Radiotelemetric studies (Madison, 1980) indicate that during the breeding season, reproductively active female meadow voles are territorial, self-sufficient rearing units. *M. pennsylvanicus* females in the present study defended the nest against males and frequently were intolerant of older offspring in the vicinity of the new nest and litter. This pattern appears to support the self-sufficient maternal-young unit described by Madison (1980). Getz (1978) cites trapping data and laboratory results to suggest a promiscuous mating system in *M. pennsylvanicus*. Lack of a single case of sustained nest cohabitation in the field led Madison (1980) to the same conclusion. Intense intrasexual competition among males for access to receptive females exists in the meadow vole (Madison, 1980). Webster (1979) cites a field situation in which at least five males were observed in the vicinity of an estrous female, and four attempted mounting. Females in our study were extremely aggressive to males in the area of the natal nest. Nonselective aggression (displayed toward male and presumably toward other males) by female *M. pennsylvanicus* may be related to the occurrence of repeated copulations with different males and the resultant uncertainty of paternity. Aggression displayed by the female around the nest may represent an attempt to prevent infanticide by males. Finally, lack of paternal care and separate nesting seem to further imply a promiscuous mating system.

Based on trapping data, Paul (1970) proposed a loose, colonial social organization for the pine vole, in agreement with earlier anecdotal reports of scattered aggregations (Benton, 1955; Hamilton, 1938). In the present study, *M. pinetorum* individuals displayed a high degree of social tolerance. This was demonstrated most strongly by the communal nesting of the original breeding pair, older offspring, and new litter. Results suggest that the extended family may be the unit of colonial social organization.

Getz (1978) and Getz and Carter (1980) claim that at normal population densities, *M. ochrogaster* individuals exist in relatively stable family units in which only the founding pair contribute to population recruitment. The sustained nest cohabitation by all family members in the three completed *M. ochrogaster* runs in indicative of the proposed stable family group. In addition to reports of paternal care (Getz and Carter, 1980; Thomas and Birney, 1979), experimental studies which involve the behavioral and physiological factors controlling reproduction (Getz and Carter, 1980) strongly point to a monogamous mating system. Our documentation of extensive paternal care is therefore consistent with earlier reports. Male participation in care of the offspring may decrease the amount of time that the female must spend in the nest, thus allowing her increased time for foraging and other activities. Analysis of the frequency and duration of specific behaviors such as female in/out of nest, male in/out of nest, and eat or drink, may serve to reveal this trend.

M. pinetorum pups exhibited the longest nursing period. First consumption of solid food and last observed nipple attachment occurred at a later age in this species than in *M. pennsylvanicus* and *M.*

ochrogaster. Schadler and Butterstein (1979) note that the reproductive potential of *M. pinetorum* is lower than that of most other vole species. Litter sizes are small and puberty occurs at a relatively late age in both males and females. Delayed pup development seems to be consistent with this trend.

In conclusion, this system provides information which supports the different mating systems and social organizations which have been postulated for these three species in the field, and therefore appears to represent a viable method for observing microtines under laboratory conditions. It is anticipated that final results will provide information on the activities of female voles during the breeding period. Any observed differences in maternal behavior will further complete the comparison of the social biologies of *M. pennsylvanicus*, *M. pinetorum*, and *M. ochrogaster*.

Literature Cited

Benton, A.H. 1955. Observations on the life history of the northern pine mouse. J. Mamm. 36: 56-62.

DeCoursey, G.E. 1957. Identification, ecology and reproduction of Microtus in Ohio. J. Mamm. 38: 44-52.

Getz, L.L. 1978. Speculation on social structure and population cycles of microtine rodents. The Biologist 60: 134-147.

Getz, L.L. and C.S. Carter. 1980. Social organization in *Microtus ochrogaster* populations. The Biologist 62: 56-69.

Hamilton, W.J. 1938. Life history notes on the northern pine mouse. J. Mamm. 19: 163-170.

Hasler, J.F. 1975. A review of reproduction and sexual maturation in the microtine rodents. The Biologist 57: 52-86.

Madison, D.M. 1978. Movement indicators of reproductive events among female meadow voles as revealed by radiotelemetry. J. Mamm. 59: 835-843.

Madison, D.M. 1980. Space use and social structure in meadow voles, *Microtus pennsylvanicus*. Behav. Ecol. Sociobiol. 7: 65-71.

Madison, D.M. 1981. Time patterning of nest visitation by lactating meadow voles. J. Mamm. 62: 389-391.

Miller, W.C. 1969, Ecological and ethological isolating mechanisms between *Microtus pennsylvanicus* and *Microtus ochrogaster* at Terre Haute, Indiana. Amer. Midl. Natur. 82: 140-148.

Paul, J.R. 1970. Observations on the ecology, populations and reproductive biology of the pine vole, *Microtus pinetorum*, in North Carolina. Reports of Investigations, No. 20, Illinois State Museum, Springfield, Illinois.

Schadler, M.H. and G.M. Butterstein. 1979. Reproduction in the pine vole, Microtus pinetorum. J. Mamm. 60: 841-844.

Thomas, J.A. and E.C. Birney. 1979. Parental care and mating system of the prairie vole, Microtus ochrogaster. Behav. Ecol. Sociobiol. 5: 171-186.

Webster, B. 1979. A radiotelemetry study of social behavior and activity of free-ranging meadow voles, Microtus pennsylvanicus. M.S. Thesis, University of Guelph.

REGISTRATION LIST

Paul Albanese-- Velsicol Chemical, 7311 Castle Road, Manassas, VA 22110
Jim Baldino-- ICI Americas, 128 Franklin Drive, Mullica Hill, NJ 08062
Kyle Barbehenn-- U. S. EPA, 8208 Thoreau Drive, Bethesda, MD 20817
Bill Butt-- U.S.D.A., Route 2, Box 45, Kearneysville, WV 25430
Ross E. Byers-- VPI & SU, 2500 Valley Avenue, Winchester, VA 22601
Steve Clarke-- Box 183, Milton, NY 12547
Cathy Coates-- Velsicol Chemical Corp., 341 E. Ohio, Chicago, IL 60611
Jack A. Cranford-- Dept. of Biology, VPI & SU, Blacksburg, VA 24061
James N. Cummins-- Dept of Pomology, NYSAES, Cornell Univ., Geneva, NY 14456
Grant A. Curtis-- Dept. of Zoology, Univ. of Guelph, Guelph, Ontario, Canada
Edwin H. Denny-- ICI Americas, 1400 Evergreen Ave., Goldsboro, NC 27530
Terry Derting-- Dept. of Biology, VPI & SU, Blacksburg, VA 24061
David Eastman-- Velsicol Chemical Corp., 24 James St., P. O. Box 608, Dryden, NY 13053
Walter L. Ferguson-- 4200 Mayport Lane, Fairfax, VA 22033
P. H. Fletcher-- Box 157, Casco, WI 54205
Fred Griest, Jr.-- Agway, Inc., RD 2, Box 19, Biglerville, PA 17307
James J. Hasbrouck-- Dept. of Fisheries & Wildlife Sci., VPI & SU, Blacksburg, VA 24061
Don W. Hayne-- Institute of Statistics, N. C. State University, P. O. Box 5457, Raleigh, NC 27650
Kevin Jordan-- Dept of Fisheries and Wildlife Sci., VPI & SU, Blacksburg, VA 24061
George M. Kelly-- 312 Forest Resources Lab., The Pennsylvania State University, University Park, PA 16802
Daniel G. LaPasha-- N. C. State University, 5013½ Western Blvd., Raleigh, NC 27606
John J. Lepri-- Dept. of Zoology, N. C. State University, P. O. Box 5577, Raleigh, NC 27650
Dale Madison-- Biology Dept., SUNY Binghamton, Binghamton, NY 13901
David Manski-- Ecological Services Lab., National Park Service, 1100 Ohio Drive SW, Washington, D. C. 20242
Jay McAninch-- The Cary Arboretum, The New York Botanical Garden, Millbrook, NY 12545
Jenness E. McBride-- Dept. of Fisheries and Wildlife Sci., VPI & SU, Blacksburg, VA 24061
Betty McGuire-- 330 Morrill Science Center, Univ. of Massachusetts, Amherst, MA 01003
Sandra MacPherson-- Dept. of Fisheries & Wildlife, VPI & SU, Blacksburg, VA 24061
Mark H. Merson-- VPI & SU, 2500 Valley Ave., Winchester, VA 22601
Pam N. Miller-- 151 Plains Road, New Paltz, NY 12561
J. N. Moore-- P. O. Box 1181, Fayetteville, AR 72701
William B. O'Neal-- Velsicol Chemical, 800 Corporate Circle, Suite 101A, Harrisburg, PA 17110
Ralph E. Pagano-- Biology Dept., SUNY, Binghamton, NY 13901
Jonathan R. Parker-- 301 Forest Resources Lab, The Pennsylvania State University, University Park, PA 16802
Philip Renzullo-- 306 Fernow Hall, Cornell University, Ithaca, NY 14853
Jimmie J. Reynolds-- 2334 Champion Ct., Raleigh, NC 27604

Donald Rhodes-- 308 Fernow Hall, Cornell Univ., Ithaca, NY 14853
Milo E. Richmond-- New York Cooperative Wildlife Research Unit, 206 Fernow Hall, Cornell Univ., Ithaca, NY 14850
Margaret H. Schadler-- 110 Woodhaven Drive, Scotia, NY 12302
Frederick A. Servello-- Dept. of Fisheries and Wildlife, VPI & SU, Blacksburg, VA 24061
John L. Seubert-- Denver Wildlife Research Center, Bldg. 16, Federal Center, Denver, CO 80225
Robert D. Sharp-- Chempar Products Div., Lipha Chemicals, Inc., 150 Melrose Ave., Albany, NY 12203
Zia Siddiqi-- Chemical Research Intl., 232 Norseman St., Toronto, Ontario, Canada M8Z 2R4
Paul Steblein-- 66B Plains Road, New Paltz, NY 12561
Alan J. Steiner-- Dept. of Forestry & Wildlife Management, Holdsworth Hall, Univ. of Mass., Amherst, MA 01003
Donna Stockrahm-- Ohio State Univ., 1735 Neil Avenue, Dept. of Zoology, Columbus, OH 43210
Stephen A. Struger-- Dept. of Zoology, Univ. of Guelph, Guelph, Ontario, Canada
Bill Sullivan-- N. C. State University, P. O. Box 122, Edneyville, NC 28727
Henry A. Terwedow, Jr.-- Velsicol Chemical, 341 E. Ohio St., Chicago, IL 60611
Alan Tipton-- 154 Cheatham Hall, VPI & SU, Blacksburg, VA 24061
C. R. Whiteman-- ICI Americas, Inc., P. O. Box 394, Romney, WV 26757
Roger S. Young-- W. Va. University Experiment Farm, P. O. Box 303, Kearneysville, WV 25430
Wayne A. Young-- Mammal Survey & Control Ser., 216 North Tillamook St., Portland, OR 97227

Prairie vole - Microtus ochrogaster (Wagner)

Pine vole - Microtus Pitymys pinetorum (LeConte)

Meadow vole - Microtus pennsylvanicus (Ord)