February 1980

# Proceedings of the Fourth Eastern Pine and Meadow Vole Symposium, February 21-22, 1980

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Hendersonville, NC

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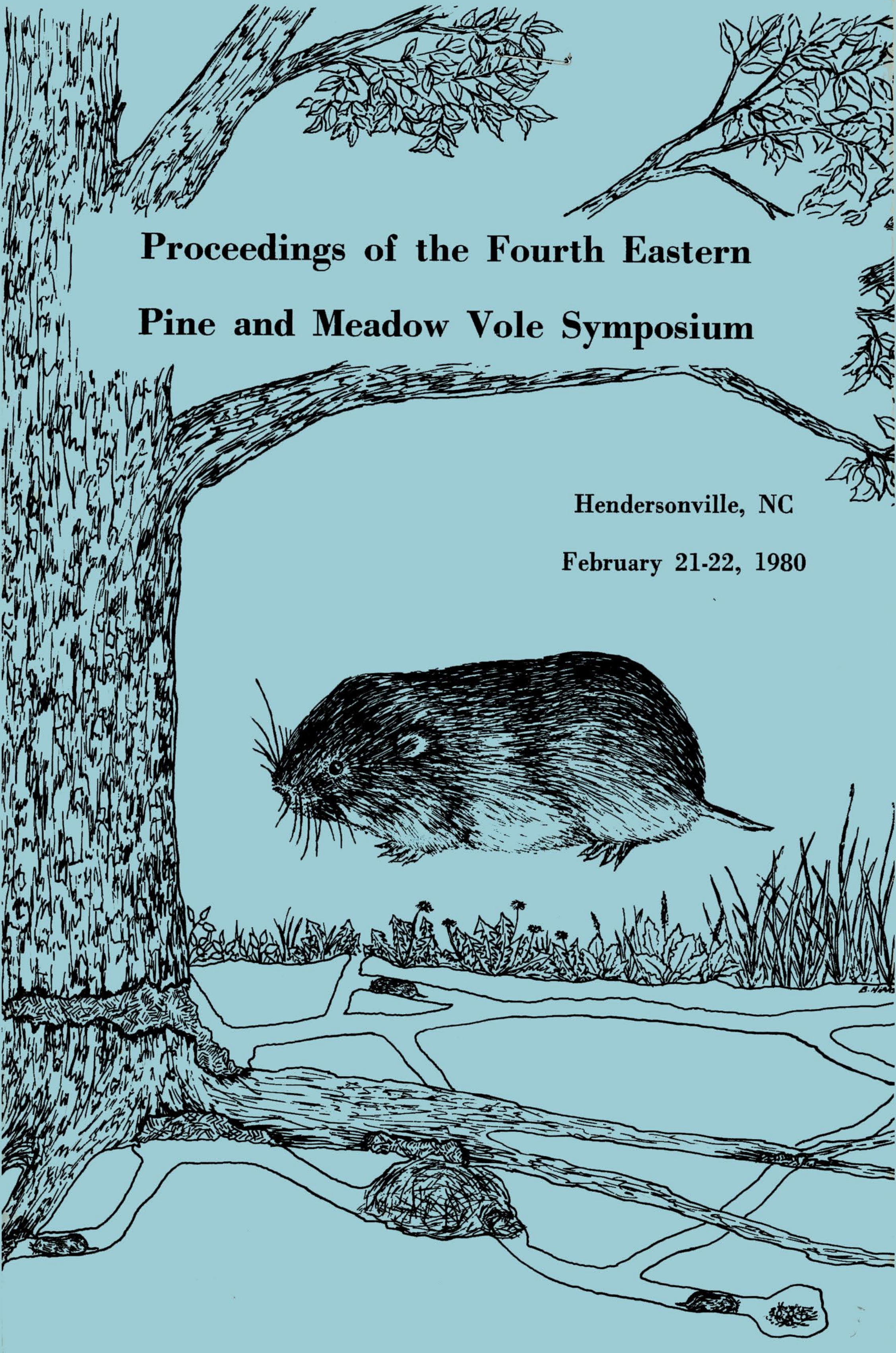

# PROCEEDINGS OF THE

# FOURTH EASTERN PINE AND

# MEADOW VOLE SYMPOSIUM

Hendersonville, NC

February 21-22, 1980

EDITOR

ROSS E. BYERS

1980

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

# HIGHLIGHTS OF THE FOURTH EASTERN PINE AND MEADOW VOLE SYMPOSIUM

The Fourth Eastern Pine and Meadow Vole Symposium was held in Hendersonville, North Carolina February 21 and 22, 1980 for the primary purpose of assessing the current status of research and extension programs relating to the problem of vole damage to fruit trees. The meeting was designed to be informative and to create an atmosphere whereby growers and various agencies such as EPA, USDA, USDI, the chemical industry and university personnel could observe the current thrust of vole research programs and their potential impact on future control methods.

By the time of the 1980 meeting approximately $1 million dollars in USDI contracts for vole research had been dispensed and research from this new funding base had resulted in new information being generated. The meeting provided an excellent opportunity for all attending to be informed concerning the breadth and depth of various research efforts.

Growers representing the North Carolina apple industry reiterated the great value of Endrin ground cover sprays for the control of orchard voles. Apparently the Endrin resistance problem has not been a serious problem as viewed by growers in that state. A tour of the North Carolina State University research plots by Dr. Donald Hayne and Mr. Bill Sullivan was well attended and local arrangements by Dr. Mel Kolbe were appreciated. In addition, the new vole research facilities were shown at the North Carolina State University Mountain Crops Research Station at Fletcher, North Carolina.

Within the geographic range of the pine vole, control measures used by growers are in a state of flux from one region to another. This appears largely due to differences in the Endrin resistance problem. Toxicants, however, appear to remain as the least expensive, most effective control method for controlling serious vole infestations. Supplemental cultural control methods (cultivation, herbicides, and mowing) have been found both beneficial and expensive. Reports on the federal clearance of a new and more effective Zn Phosphide formulation has resulted in a new use for an old toxicant.

# STRETCHING THE MOUSE CONTROL DOLLAR

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One of the biggest problems in our mouse control program at H. F. and T. B. Byrd, Inc. in Timberville, Virginia is keeping a palatable bait before the voles until the bait can be accepted. For years we used labor needed for pruning to place an expensive bait only to be impeded by wet weather that molded the bait.

This year an effort is being made to keep the bait in good condition and before the target animal for a longer time. We cut old car tires (not steel belted) given to us by a local distributor and rented his tire splitting machine. The half tire was placed under a tree where it would least likely be in the way of mowing, brush removal, etc. The half tire placed with the arched side up makes a desirable habitat for the vole and also keeps the bait dry from falling weather.

The second part of this year's program was putting the bait under the tire in 3½ ounce plastic cups (used in hospitals and nursing homes). This 1½¢ cup keeps the bait from absorbing moisture from the ground.

In large population areas the tires are inhabited and the bait is taken in a matter of days. Areas that have less voles the tire may not be visited for a month or so. The exciting part of this program is that even after two months and several wet periods the bait is still in good condition and still available.

We feel we have "hit on" something as long as the tires in the orchard will not be more trouble than they are worth.

# RODENTICIDE USE IN APPLE ORCHARDS

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## Introduction

The preliminary data presented in this paper were obtained from the 1978 Survey of Pesticide Use on Deciduous Fruits (Figure 1). The survey was conducted by the Economics, Statistics and Cooperatives Service, USDA.

The purpose of this paper is to present information on: (1) rodenticides used in controlling meadow and pine voles, (2) method and timing of applications and type of coverage, (3) tree losses due to vole injury by region, and (4) growers perceived efficacy of chemicals versus cultural and mechanical controls. These data are based on the aggregated responses of the surveyed apple producers.

## Rodenticide Application

On an acre treated basis, zinc phosphide, diphacinone, endrin and chlorophacinone are the four major chemicals used for controlling voles in apple orchards (Table 1). Strychnine and warfarin are used to a minor extent. The acreage treated by these six rodenticides accounted for 28 percent of 0.5 million acres of bearing and nonbearing apple orchard acreage indicated in the 1974 Census of Agriculture. In terms of quantity applied, endrin is the most used rodenticide. Nearly 42,000 pounds (a.i.) of endrin were applied in 1978. The number of applications per season ranged from 1.0 to about 1.3 for the six rodenticides.

Rodenticides are generally applied by the growers (Table 2). An exception is zinc phosphide where custom applicators treated 16 percent of the acreage. Zinc phosphide is applied only as a bait. In the State of Washington, which accounts for about 20 percent of the U.S. apple acreage, zinc phosphide is often applied immediately after harvest for meadow vole control by custom applicators using a trail building machine.

Most of the U.S. acreage is treated after harvest. Seventy-two percent of the endrin and chlorophacinone and 100 percent of the warfarin and strychnine is applied in the fall after harvest. The remaining endrin and chlorophacinone are applied prior to the pre-bloom stage of growth.

APPLE PRODUCTION REGIONS

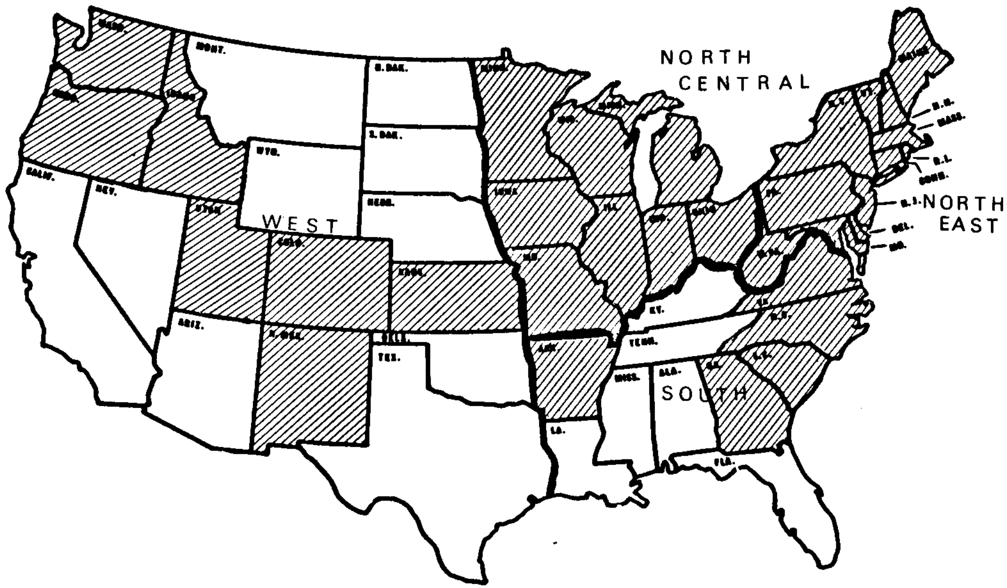


Figure 1
Shaded areas reflect surveyed states in 1978 Survey of Pesticide Use on Deciduous Fruits (California, for example, is not included).

Generally, the area around the base of each tree in the orchard is treated when endrin, diphacinone, strychnine and zinc phosphide are used. Spot treatments also are used to treat only those areas of an orchard where evidence of infestation is found. Some 60 percent of the chlorophacinone-treated acreage is on a spot basis. Spot treatment reduces costs and environmental exposure.

## Tree Losses

Of the nearly 9,000 apple producers in the U.S. (excluding California), about 3,500 or 39 percent report trees lost in 1978 to vole injury (Table 3).

Meadow voles girdle the bark at the base of the tree while pine voles feed on the roots. Trees may sustain damage over several years before they die. Growers reported that a total of 123,000 trees died in 1978 as a result of vole injury. Growers were not asked to report the number of trees damaged by voles or the loss in apple production from vole injury. About 60 percent of the trees killed were of nonbearing age. Young trees are particularly susceptible to voles because they are not strong enough to compensate for the damage. Orchards in the Northeast are affected most by vole injury with about 74,000 trees reported lost in 1978. Some 30,000 of these trees were of bearing age.

## Most Effective Method

Most of the treated acreage is for control of the meadow vole which dwells primarily on the surface and is easier to control than the pine vole, a subsurface dweller. About 58 percent of the surveyed apple producers report chemicals are the most effective method of controlling voles. There is little variation among regions in the proportion of producers judging chemicals as the most effective control. The proportion of producers reporting chemicals to be most effective ranged from 55 to 61 percent for the four regions (Table 4).

From 12 to 18 percent of the producers in each region report cultural methods (mowing, discing, etc.) as the most effective method of vole control.

About 15 and 21 percent, respectively, of the producers in the Northeast and North Central region report mechanical methods (gravel, wire, etc.) as the most effective mice control method. Only 1-2 percent of the producers in the South and West regions report this method as the most effective.

## Summary

1. About 28 percent of the apple orchard acreage was treated with rodenticides in 1978.

2. The four major rodenticides used for vole control are zinc phosphide, diphacinone, endrin, and chlorophacinone. Endrin is the most heavily used rodenticide in terms of quantity used.

3. Custom application represents only a minimal proportion of the acreage treated with rodenticides. An exception is zinc phosphide where custom applicators treated 16 percent of the acreage.

4. Most orchards are treated after harvest.

5. Generally, the area around the base of each tree in the orchard is treated when using endrin, diphacinone, strychine, and zinc phosphide; spot treatment is used for about one-half of the chlorophacinone-treated acreage.

6. Vole injury accounted for approximately 123,000 trees lost during 1978, of which 37 percent were at bearing age.

7. The majority of growers report chemicals as the most effective method of vole control.

Table 1. Apple orchard rodenticides: Acres treated, application rates, and total quantity applied, by region 1978 1/

| Rodenticide | Acres treated 2/ | Quantity per acre per application | Applications per season | Quantity per acre per season | Total quantity applied |
|---|---|---|---|---|---|
| | | Pounds a.i. | | ---Pounds a.i.---- | |
| | | % | | | |
| Endrin | 29,447 | 20 1.276 | 1.111 | 1.418 | 41,756 |
| Chlorophacinone | 14,833 | 10 .024 3/ | 1.297 | .031 | 460 |
| Diphacinone | 42,237 | 29 4/ | 1.034 | 4/ | 218 |
| Warfarin | 33 | <1 5/ | 1.000 | 5/ | 5/ |
| Strychnine | 162 | <1 4/ | 1.274 | 4/ | 2 |
| Zinc phosphide | 57,877 | 40 .164 | 1.138 | .187 | 10,823 |
| U.S. | 144,589 6/ | | | | 53,259 |

1/ Preliminary data from 1978 ESCS Survey of Pesticide Use on Deciduous Fruits. California excluded.

2/ Acres treated one or more times.

3/ The label rate of chlorophacinone is 0.2 lbs./acre applied as a spray or 2 applications of 0.005 lbs. a.i./acre/application applied as a bait. The per acre rate of 0.024 reflects an average of spray and bait applications.

4/ Diphacinone and strychnine are applied as baits only. Growers did not report the rate per acre per treatment. Only the total quantity applied for the season was reported.

5/ Warfarin is applied as a bait only. Growers reported using less than 0.5 lb. of a.i. on the acres treated.

6/ Accounts for 28 percent of the total 507,348 acres in bearing and nonbearing age apple trees indicated in 1974 Census of Agriculture, Volume 1, Part 51, Table 11.

Table 2. Apple orchard rodenticides: Acre treatments, method of application, stage of development and type of coverage, by region, 1978 1/

| Rodenticide | Acre treatments 2/ | Method of application: Self | Custom | When applied: Post-harvest | Prior to pre-bloom | Type of coverage: Each tree | Spot treatment |
|---|---|---|---|---|---|---|---|
| | | Percent of acreage | | | | | |
| Endrin | 32,709 | 99 | 1 | 72 | 28 | 90 | 10 |
| Chlorophacinone | 19,243 | 97 | 3 | 72 | 28 | 40 | 60 |
| Diphacinone | 43,681 | 95 | 5 | 96 | 4 | 90 | 10 |
| Warfarin | 33 | 100 | - | 100 | - | 50 | 50 |
| Strychnine | 207 | 100 | - | 100 | - | 100 | - |
| Zinc phosphide | 65,892 | 84 | 16 | 82 | 18 | 80 | 20 |

- = zero or less than 0.5.

1/ Preliminary data from 1978 ESCS Survey of Pesticide Use on Deciduous Fruits. California excluded.

2/ Acres that may be treated more than once.

Table 3. Apple producers reporting trees killed by vole injury, by region, 1978.

| Region | Producers 1/ | | Total bearing age trees 2/ | Trees killed by vole injury 1/ | | |
|---|---|---|---|---|---|---|
| | Total | Reporting trees killed | | Total | Bearing age | Non-bearing age |
| | No. | | 1,000 | | | |
| Northeast | 2,816 | 1,505 | 8,587 | 74 | 30 | 44 |
| South | 1,444 | 624 | 3,017 | 23 | 5 | 18 |
| West | 1,811 | 414 | 10,010 | 5 | 3/ | 5 |
| North Central | 2,766 | 926 | 5,729 | 21 | 11 | 10 |
| Total | 8,837 | 3,469 | 27,343 | 123 | 46 | 77 |

1/ Preliminary data from 1978 ESCS Survey of Pesticide Use on Deciduous Fruits. California excluded.

2/ The 27.3 million bearing trees is the total for the States surveyed (Figure 1). This total represents 92 percent of the bearing trees in the U.S. as reported in the 1974 Census of Agriculture, Volume 1, Part 51, Table 11.

3/ Less than 500 trees.

## DISPOSITION OF THE ENDRIN RPAR

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Following a comprehensive three-year Rebuttable Presumption Against Registration ("RPAR") review of endrin, on July 25, 1979 the U.S. Environmental Protection Agency announced its decision to continue federal approval of endrin for control of pine voles in the East and meadow voles in the West among other uses. See 44 Fed. Reg. 43,637-8. The Agency concluded that with additional safety precautions and procedures, endrin can be applied safely and effectively, and that the benefits of usage outweigh any risks. The stringent new safeguards being required by EPA, including new usage restrictions and directions, equipment specifications, and warnings to female applicators, are reprinted in Appendix 1. */ As the manufacturer of endrin, Velsicol Chemical Corporation fully endorses the Agency's decision to impose these enhanced measures for prudent usage of endrin in apple orchards.

Earlier phases of the endrin RPAR, and EPA's preliminary proposal for retention of orchard uses, were described at the Third Eastern Pine and Meadow Vole Symposium, held in New Paltz, New York on February 14-15, 1979. See Proceedings, pp. 4-7, 15-16. At the time of that Symposium, the Agency was in the process of reviewing the written comments filed by federal and state authorities, Velsicol, and user and environmentalist groups in response to the proposed regulatory actions. The final determination published in July, 1979 took into

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*/ Velsicol is awaiting authorization from EPA as to revision of endrin labels in accordance with these new requirements.

account many of the statements submitted to the Agency,*/ and reflected several changes to the draft labelling which previously had been proposed by EPA. Compare 43 Fed. Reg. 51,137-38 (Nov. 2, 1978), copy reprinted at 1979 Proceedings, p. 14 with 44 Fed. Reg. 43,637-8, copy reprinted in Appendix 1.

The endrin RPAR was one of the first RPAR's to be conducted. It represented a whole new approach toward review of pesticides registered under the Federal Insecticide, Fungicide and Rodenticide Act ("FIFRA"), 7 U.S.C. § 136 et seq. (see 40 Fed. Reg. 28,242; July 25, 1975). Before the advent of RPAR review, the Agency's procedure was to place a suspect pesticide on trial before an administrative law judge. Evidence on risks and benefits was elicited through direct and cross examination of subpoenaed witnesses. As a practical matter, there were few, if any, regulatory alternatives other than unconditional cancellation or retention on an "as is" basis. The RPAR review of endrin, however, afforded EPA, industry and other interested parties opportunity to work together in a relatively informal, non-adversarial atmosphere, and to develop new safeguards which tipped the risk/benefit balance toward continued registration.

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*/ For example, concern about certain endangered species which had been prompted earlier by the Fish and Wildlife Service of the U.S. Department of the Interior was obviated when the Director of the Service submitted to EPA a revised biological opinion which stated that "the use of the pesticide endrin in apple orchards for control of pine and western meadow voles is not likely to jeopardize the continued existence of the bald eagle, American peregrine falcon, or Arctic peregrine falcon." 44 Fed. Reg. 43,643.

Appendix 1

3. Cancellation and denial of registration of endrin products for use in apple orchards in Eastern States to control meadow voles.

Cancellation and denial of registration of endrin products for use in apple orchards in Eastern States to control the pine vole and in Western States to control meadow voles unless registrants or applicants for registration modify the terms or conditions of registration as follows:

Modification of the label of endrin products for use in apple orchards in Eastern States to control the pine vole and in Western States to control meadow voles to add the following:

*Required Clothing for Female Workers*

Female applicators, mixers and loaders must wear long-sleeved shirts and long pants made of a closely woven fabric, and wide-brimmed hats. Mixers and loaders must also wear rubber or synthetic rubber boots and aprons.

*Warning to Female Workers*

The United States Environmental Protection Agency has determined that endrin causes birth defects in laboratory animals. Exposure to endrin during pregnancy should be avoided. Female workers must be sure to wear all protective clothing and use all protective equipment specified on this label. In case of accidental spills or other unusual exposure, cease work immediately and follow directions for contact with endrin.

*Application Restrictions*

Do not apply this product within 50 feet of lakes, ponds or streams.

Do not apply this product within 50 feet of areas occupied by unprotected humans.

Do not apply when rainfall is imminent.

*Procedures To Be Followed if Fish Kills Occur*

In case of fish kills, fish must be collected promptly and disposed of by burial. Ponds in which fish kills have occurred must be posted with signs stating: "Contaminated: No Fishing." Signs must remain for one year after a fish kill has occurred unless laboratory analysis shows endrin residues in the edible portion of fish to be less than 0.3 parts per million (ppm).

*Equipment*

Apply by ground equipment only.

Use a very coarse spray with minimum pressure necessary to penetrate ground cover. Do not apply as a fine spray. Power air blast equipment must be modified to meet the above application restriction. Consult the State recommendations for acceptable methods of adapting equipment.

*Prophylactic Use*

Unnecessary use of this product can lead to resistance in the vole population and subsequent lack of efficacy.

*Pests for Which This Product May Be Applied*

This product may be applied to control the following pests only:

Eastern United States—Pine Vole (Microtus pinetorum)
Western United States—Meadow Voles (Microtus species)

[44 Fed. Reg. 43,637-8; July 25, 1979]

# Seasonal Forage Availability in Relation to Energy Requirements of Pine Voles in Two Orchard Types

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Results from previous work on pine vole populations and habitat interactions (Cengel et al. 1978; Noffsinger 1976) suggested that pine vole populations were quite sensitive to seasonal changes in the quantity, species composition, and nutritive value of available forage. This conclusion was based on decreases in both reproductive performance and physical condition of pine voles collected from abandoned orchards in the fall as compared to voles taken from maintained orchards during the same season. Utilizing information from these investigations, a "follow-up" study was designed to investigate food availability and nutrient composition, food consumption, food digestibility, and energy requirements of pine voles. Results from this bioenergetic approach to studying pine vole populations, coupled with detailed knowledge of their population dynamics, should provide useful information for identifying critical or weak points in the ecology of populations as well as for assessing the effects of various management or control strategies applied to biological (orchard) systems. Data from this research on ecological energetics of pine vole populations will ultimately be included as part of an overall population energetics model which will be used for simulating both natural and man-induced habitat changes and predicting their effect on pine vole populations (Coyle & Tipton, unpublished). This paper summarizes the major points obtained from a bioenergetic study conducted during 1978 and 1979 in an orchard abandoned for 9 years and a maintained orchard, both located near Daleville, Virginia.

## Findings of Studies Conducted

Net primary production estimates of above ground herbaceous for areas beneath apple tree canopies and for areas outside canopies within both maintained and abandoned orchards indicated that during the summer, fall, and winter, the maintained orchard had much greater herbaceous biomass than the abandoned orchard.

During the period from August to January, apple drops accumulated on the ground and provided an additional food source to supplement the herbaceous vegetation available to voles. During the winter season, apples comprised 77 percent of the total biomass available and 79 percent of the total or gross energy available in the maintained orchard. In the abandoned orchard, apples comprised 33 percent of the total energy and 34 percent of the total biomass. During the winter season, apple biomass on the ground was significantly greater in the maintained orchard than in the abandoned orchard. During other seasons, there was no difference between orchards in available apple biomass on the ground.

To determine which forages occurring in the orchards were preferred by pine voles, a series of 9 feeding trials were conducted using 14 forages. Food items were ranked in order of decreased preference, based on these choice tests. Apple fruit was a highly preferred food item among all voles tested and was completely consumed before substantial amounts of other forages being offered to voles at the same time were consumed. Selection and consumption of the remaining 13 food items indicated that voles were very diverse in their feeding habits, e.g., voles consumed to some degree all 7 forb species tested. This diversity of food habits may be important for easing the transition between seasonal food supplies. Also, in this study, forbs were preferred over grasses. The low palatability of maturing grasses appeared to be the result of higher fiber concentrations. In maintained apple orchards which are mowed continually, however, a greater supply of low fiber grass forage becomes available from constant regrowth.

Forbs were a preferred forage; however, they constituted only a very small portion of the net primary production available in each orchard. Voles appeared to be quite selective in what they ate. For example, orchard grass was the most abundant plant species in the maintained orchard but was found to be quite low in digestibility and preference. Several of the highly preferred plant species such as clover, dandelion, and plantain are characteristic of open fields and can be shaded out by other plants which grow more erect. The prolific nature of poison ivy was mainly responsible for the nearly complete elimination of these preferred forbs from the abandoned orchard, whereas mowing operations in the maintained habitat encouraged the survival of preferred forages.

It appeared from the quantitative and qualitative analysis of the seasonal primary production in both orchard habitats, that the vole population in the abandoned orchard was generally surviving in a lower quality habitat. The quality of habitats were lowest and the differences between the 2 orchards were greatest during the winter season. The abundant energy source which was available from apples during the fall season was greatly depleted by mid-winter. This was especially true within the abandoned orchard.

Using information collected during this study on available primary production of preferred herbaceous plants and apple fruits, in conjunction with data on seasonal digestibility of vole stomach contents determined by the lignin-tracer technique (Noffsinger 1976), the total amount of digestible energy available to pine voles in the two orchards during each season was estimated. In the maintained orchard the lowest value for total digestible energy (DE) available occurred during the winter season. However, in the abandoned orchard the DE value for summer was 18 percent lower than the winter value. Although herbaceous plant production was considerably lower during winter than during summer in the abandoned orchard, the increased DE value for winter was the result of a greater biomass of high energy apples available during the winter season.

By comparing the seasonal DE values of available forage to values of digestible energy required by adult male and female voles, an estimate of the number of adult voles which can be maintained on the available digestible energy reserves in each orchard was made. Data required for the calculation of seasonal DE requirements for maintenance of adult voles was obtained by Lochmiller (unpublished) during another phase of this study which utilized standard techniques to determine the daily metabolizable energy requirements for maintenance at controlled temperatures which approximated seasonal ambient temperatures. It is apparent that energy availability in the abandoned orchard during all seasons was considerably limited in comparison to that which was available in the maintained orchard. The seasonal carrying capacity for each orchard, expressed as voles/ha, indicated that during summer the maintained orchard could support 16 times as many voles as the abandoned orchard and 7 times as many during the winter.

# MANAGEMENT MODEL FOR PINE VOLES:

## PRELIMINARY REPORT

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The use of computer models in scientific research has grown by leaps and bounds in the past decade. One of the primary reasons for this growth is the increased realization that computers and more specifically computer models, can be useful tools in synthesizing large amounts of information and providing insight into problem areas of research and management.

Numerous books and papers have been written on the justification for modeling, the philosophy of modeling, and model development and utilization. Recent reviews of small mammal population models are given by Conley and Nichols (1978) and Stenseth (1977). This paper will not address modeling in general, nor try to rehash old arguments about the value of models to science. Rather, it will try to outline what role a model can and hopefully will play in the major research program currently being conducted for pine vole control.

A computer model, as we refer to it here, is a mathematical representation of a biological system, for our purposes a pine vole population existing in an apple orchard. The model has been, or will be, coded and placed on a computer to facilitate multiple simulations of natural demographic processes and population responses to control procedures.

Before discussing the development of our model, we need to emphasize that there can be two distinct purposes for modeling. Modeling can provide insight, further understanding about the modeled system, and guide future research. Additionally, the modeling effort may provide a finished product, namely the model, which because of its predictive powers will be useful as a management tool. These two purposes are certainly not mutually exclusive, nor will they necessarily completely overlap. The emphasis on the first objective is in the benefits derived in the development of the model, while the main utility of the second is in the benefits obtained by using the model.

In our current modeling effort, we will attempt to achieve both goals, by synthesizing available information, obtaining a better understanding of pine vole populations dynamics, suggesting additional research, and, hopefully, developing a model with enough predictive capabilities to be useful in prescribing control procedures.

The use of computer models is not new to the field of agriculture where the primary objective has been the control of injurious insects. Numerous models have been constructed which have proved very useful for management of these pests. Mowery et al. (1975) developed a model which predicts the number of ladybird beetles (*Stethorus punctum*) needed to control the European red mite (*Panonychus ulmi*) in apple orchards. This model utilizes both chemical and biological control methods to achieve its intended goal. DeMichele and Bottrell (1976) describe the use of models for cotton insect pest management.

Pest management modeling has also been applied to birds and mammals. Dolbeer et al. (1976) have constructed a demographic model of red-winged blackbirds (*Agelcius phoeniceus*) to determine the numerical effect on a population under various control procedures. Wiens and Dyer (1975) modeled the bioenergetics of a red-winged blackbird population utilizing energy requirements of individuals and expanding this estimate to the entire population. By knowing the energy needs of the population and the energy available in the adjacent fields, they were able to make recommendations concerning the type of cultivation practice that would attract the birds to specific fields of non-cash crops.

There are presently two small mammal models being used or developed in Europe dealing with agricultural rodent pests (Stenseth et al. 1977, Spitz 1978). Both models were designed to aid in controlling field voles (*Microtus agrestis*, *M. arvalis*), a relative of the pine vole. The Spitz model is very simple, considering only the number of animals in the population and using a projection matrix containing numerical data for the principle population parameters of reproduction and mortality. This model was developed to forecast potential crop damage and function mainly as a management tool.

The Stenseth model was developed mainly as a research tool to synthesize information and improve understanding of the field vole's population dynamics. The model was constructed as separate submodels, each dealing with essential factors affecting the population. These submodels were then combined to form the overall population simulation model. During the process of development, critical areas for additional research were identified, including (1) food acquisition and nutrition, (2) effects of predation, (3) habitat utilization, and (4) dispersal. The researchers felt these areas need to be studied in more detail before a fully comprehensive working model could be developed.

The model we are currently developing at VPI & SU is similar to the Stenseth model in that the overall objective is to synthesize available information and guide future research. However, because Stenseth's model was developed as part of a much larger and longer research effort, generating a substantially larger data base, we will be forced to draw more heavily on information from the literature (perhaps on similar microtine species) and from personal communication with other researchers for our data base. Consequently, some parts of our model will be much simpler because adequate data does not exist at the present time. For this reason the model will be developed in submodel form to further facilitate adding additional information as it becomes available.

The central hypothesis for this model is that the major features of the pine vole population dynamics can be explained by analyzing the nutritional balance of individuals in the population. Thus, the model is based on energy requirements and acquisition of individual animals and the energy available to the animal in the environment. Because there is substantial information on the bioenergetics of pine voles (Lochmiller unpubl.), we decided to develop our model using a bioenergetic framework.

As we envision it, the pine vole management system will contain four subsystems. The biological subsystem will describe energy acquisition, and reproductive and survival characteristics of individual pine voles. The spatial distribution subsystem will incorporate such ecological parameters as home range size and shape, dispersal, and territoriality. The control and economic subsystems will incorporate the effects of various control procedures and the cost and benefits of those procedures. Development of the biological subsystem will be the major goal for the present modeling effort, with the other three subsystems being developed as time, additional data and money permit.

A major problem in evaluating or testing models is that the model is frequently compared or tested with the same data used to develop the model. This problem has hopefully been avoided in the present study, since the model is being constructed using previously collected information or information available in the literature and will be tested against population data currently being collected in two orchards as a companion study to the modeling effort.

The biological subsystem is currently being developed. The processes of energy availability, energy acquisition, and growth have been completed. Because of the problems with accurately aging pine voles, it was decided to separate the population into several energetic stages, or classes. Each stage will contain individuals whose daily energy requirements are unique to that stage. The male portion of the population will be separated into three stages: (1) sucklings, (2) juveniles, and (3) adults; the female portion will be separated into six stages: (1) sucklings, (2) juveniles, (3) non-reproductive adults, (4) pregnant adults, (5) lactating adults, and (6) pregnant and lactating adults. A separate class will be maintained for each sex for those animals that have died as a result of control practices. This category can then be used in determining the effectiveness of control procedures.

Because this model is based on the nutritional balance of individuals, it was necessary to determine some variable (or variables) that could be measured in living animals and accurately access the animal's current energy state (how well the animal relates to its present environment). Body fat was chosen as the index, since the amount of fat is a direct reflection of an individual's energetic condition. If the body fat content is low, it can be assumed that the animal is in an energetically stressful situation. This stress can then be manifested in the model as changes in biological characteristics for the individuals, namely reproduction, growth and survival. Data have already been gathered regarding deposition and utilization of fat, and demographic changes due to an energetic stress in pine voles (Lochmiller unpubl., Merson 1979).

The biological subsystem will be completed by September 1980. The capabilities of this submodel will be to predict sex- and cohort-specific population dynamics given adequate information about the population's environment. By knowing the status of the population, i.e. numbers, age distribution, mean body condition, and available energy at some point in time, it will be possible to predict the population status at some future time. After obtaining information regarding possible control measures and developing the control submodel, the model hopefully will be able to forecast the effectiveness, in terms of population status, of a control practice.

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ACCESS OF COMPOUNDS TO THE VOMERONASAL ORGAN IN PINE AND MEADOW VOLES

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Neuroendocrine responses play a critical role in reproduction in every mammalian species, including voles (Richmond & Stehn, 1976). Disruption of these normal responses can result in: (1) abnormal sexual maturation; (2) abnormal or absent female cycles; (3) pseudopregnancy; (4) blocked pregnancies; or (5) the total absence of courtship and mating. Each of these factors in turn plays a considerable role in population dynamics, especially population density. Therefore, mechanisms which disrupt normal neuroendocrine function could affect population dynamics and reduce population density by affecting changes in one or many of these reproductive processes.

Each of the above neuroendocrine responses can be elicited or are modulated by conspecific odors, with urine or specialized scent glands being excellent odor sources in many species. However, work from a number of laboratories has suggested that at least some of the compounds which elicit hormonal changes are large and/or have low volatility (Müller-Schwarze and Silverstein, in press). These results call into question the assumption that olfaction as is traditionally viewed (limited to the first cranial nerves) serves as the primary receptor mechanism for the compounds in question. Instead, the vomeronasal organ may be the primary receptor modulating hormonal responses (Johns, in press; Wysocki, 1979). This receptor organ has neuroanatomical connections with central nervous system structures which exert considerable influence upon neuroendocrine mechanisms. Indeed, recent results have demonstrated involvment of the vomeronasal organ in: (a) female cyclicity (Johns, in press); (b) odor induced ovulation (Ingersol & Lee, 1979); and (c) pregnancy block (Reynolds & Keverne, 1979).

Results from our laboratory have demonstrated that, unlike the olfactory system, the vomeronasal organ (a tubular structure located near the external nares) is not limited to highly or moderately volatile compounds (Wysocki et al., 1980). Investigation of conspecific urine by guinea pigs results in the transport of the urine in liquid form to within the vomeronasal organ. Thus, large and/or "nonvolatile" compounds readily reach the chemoreceptors in the vomeronasal organ, thereby providing the prerequisite for chemoreception; stimulus - receptor contact.

With this as background, we speculated that similar mechanisms exist for pine and meadow voles, viz.,: (a) low- or nonvolatile compounds have access to the vomeronasal organ; and (b) the vomeronasal organ is involved in neuroendocrine events. If true, distruction or disruption of normal vomeronasal organ function could reduce vole populations through its influence upon the reproductive/endocrine system. This report describes our studies of: (a) above; behavioral situations in which "nonvolatiles" have access to the vomeronasal organ.

To date we have explored a variety of behaviors; investigation of con- and heterospecific urine, grooming and feeding. We asked whether large and/or "nonvolatile" molecules reach the vomeronasal chemoreceptors during these behaviors. Our methodology was straightforward and similar in all situations. A flurochrome, rhodamine B, which is considered to be a nonvolatile dye, was placed in a stimulus prior to its presentation to a vole. For studying the investigation of a socially relevant stimulus, a small quantity of vole urine was mixed with rhodamine (1% in dH20) on a cotton swab and given to the vole for 6 min. For studying grooming, carboxymethylcellulose was mixed with the dye (0.01% or 0.1%) and applied to the animal's fur. The vole was given 5-6 min to groom. For studying feeding, pièces of apple were soaked in 0.1% rhodamine and given to hungry voles that were allowed 6 min to ingest the apple. In all control situations, the stimulus was either not presented or presented without rhodamine.

At the end of the test each vole was killed and the vomeronasal organs were carefully dissected free, frozen, sectioned, mounted on glass slides and viewed with epifluorescence microscopy. The results of these observations are presented in Figure 1.

After investigating urine from either female pine or meadow voles, 80-90% of male pine voles exhibited rhodamine fluorescence in their vomeronasal organs (Fig. 1). From this we conclude that during the investigation of urine nonvolatile compounds found within female urine reach the vomeronasal organ, even if the urine donor is not of the

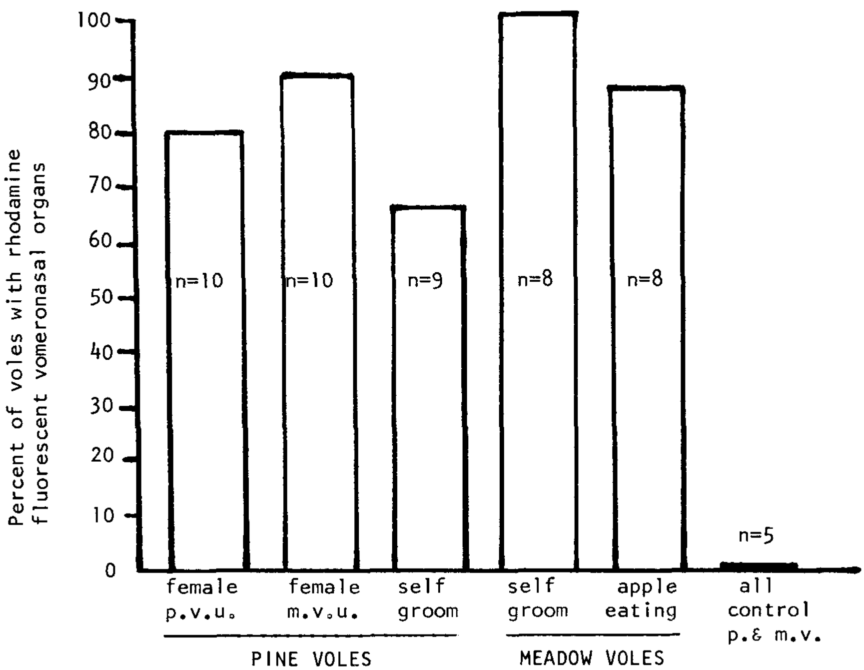


Figure 1. Percent of pine voles (p.v.) and meadow voles (m.v.) exhibiting rhodamine fluorescence in their vomeronasal organs after exposure to dyed urine (u), grooming, or eating of dyed apple.

same species. Whether or not stimulation of the organ occurs is not yet known. The important point however, is the demonstration of access of nonvolatiles in urine to the vomeronasal organ.

After grooming, dye specific fluorescence was found in the vomeronasal organs of 2/3 of the male pine voles and all of the male meadow voles (Fig. 1). The apparent species difference may be due to procedural differences in testing. All of the meadow voles but only half of the pine voles were smeared with 0.1% rhodamine. The remaining pine voles received a less concentrated spread of rhodamine (0.01%). All of the voles that lacked rhodamine fluorescence in their vomeronasal organs were from this latter group. Regardless, the results demonstrate that nonvolatile compounds reach the vomeronasal organ during grooming.

After eating an apple that had been adulterated with the dye, each of the 4 female and 3 of the 4 male meadow voles were found to have dye specific fluorescence in their vomeronasal organs (Fig. 1). Therefore, nonvolatile compounds do reach the vomeronasal organ during feeding. For all behavioral situations no rhodamine fluorescence was detected in any of the control subjects (Fig. 1).

If, as in rats and mice, the vomeronasal system is critical for normal function of the neuroendocrine system, then disruption of the vomeronasal organs in voles could reduce population levels. Our results demonstrate that nonvolatile compounds enter the vomeronasal organ during a variety of behavioral situations. Thus, a mechanism exists by which compounds specificially designed to disrupt chemoreception could be targeted to the vomeronasal organ. For example, substances could be placed in "bait stations" designed to apply the substance to the voles fur. Subsequent grooming would result in the transport of the substance to the vomeronasal organ. Another method could rely upon feeding. A third approach might take advantage of urine investigation.

The tasks remain to demonstrate the import of the vomeronasal organ to pine and meadow vole reproduction and to develop vomeronasal organ - disruptive substances which can be self administered.

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# INDUCTION OF ABORTION BY STRANGE MALES IN PINE VOLE FEMALES THAT ARE:1)TEN DAYS PREGNANT OR 2)PREGNANT AND LACTATING

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Pregnant voles react to the presence of unfamiliar males by aborting the offspring they are carrying, entering estrus and mating with these new males. This phenomenon was first described in pine voles by Marks and Schadler (1979). At that time we reported that 84% of females that were four days along in their first pregnancy were induced by strange males to reject their embryos. These findings encouraged us to continue our investigations and this paper reports results on the abortion response caused by strange males in females ten days along in their first pregnancy (Experiment I) and on experienced pine vole mothers that are pregnant and are at the same time nursing a litter (Experiment II).

## EXPERIMENTAL METHODS

In Experiment I, virgin females were placed in a cage with stud males. They were examined daily for the presence of sperm in smears taken from their vaginas as an indication that mating had occurred. Mated females were assigned to either a control group or an experimental group. Controls (N=24) were left in the cage with the stud male throughout the 24 day gestation period. Experimental females (N=20) were removed from the stud male and placed in a cage with a strange male after ten days of pregnancy.

Abortion was assumed to have occurred in those females that delivered young 24 or more days after mating with the strange male which was more than 36 days after mating with the stud male.

Experiment II females were pregnant and lactating. They were all experienced mothers that had previously been successful in rearing one or more litters. These females were caged with their stud males prior to the onset of the experiment. On the day of the birth of their young, females were assigned to a control or an experimental group. In the controls (N=26) the stud male that was caged with the female remained in the cage throughout the experiment. In the experimental group (N=42) the stud male was removed and replaced by a strange male on Day 2 of the post partum period. A second strange male replaced the first on Day 6 and a third replaced the second on Day 10. Otherwise both groups were handled in an identical manner.

In Experiment II, the timing of the birth of litters sired by stud males or by strange males again served as the criterion of abortion. Timing of the births of litters of experimental animals was compared with that of the controls for Experiment II and with data collected from the normal breeding colony. In all cases data was collected only on those females that had litters within 50 days post-partum.

## RESULTS AND DISCUSSION

Results of Experiment I (Table 1) showed that 95% (18 out of 19) of the controls that delivered young had them 24-26 days after mating with the stud male. Five control animals (21%) and 4 experimentals (20%) delivered no young despite the fact that sperm was seen in the vaginal smear indicating they had mated. Past experience has indicated that virgin pine voles have only about an 80% incidence of successful matings. One control animal gave birth 40 days after mating with the stud male. She may have aborted spontaneously and remated or she may have missed conceiving with the original mating and subsequently had a successful mating.

Table 1. Abortion induced by strange males in inexperienced females that are ten days pregnant.

| GROUP | NUMBER | NUMBER FEMALES DELIVERING YOUNG | NUMBER FEMALES DELIVERING 24-26 DAYS AFTER STUD MALE MATING | NUMBER FEMALES DELIVERING 36 PLUS DAYS AFTER STUD MALE MATING |
|---|---|---|---|---|
| Control | 24 | 19 | 18 | 1* |
| Experimental | 20 | 16 | 4 | 12 |

*See text for explanation

Four of the experimental animals that delivered young (25%) had them 24-26 days after mating with the stud male. The remaining 12 (75%) gave birth 24 or more days after mating with the strange male which was 36 or more days after they had mated with the stud male. In addition to the births of their litters sired by strange males these females also showed other signs of abortion. These were the presence of a thick, bloody discharge from the vagina two or three days after the females were placed with strange males and/or sperm from the strange male mating in the vaginal smear.

Females in Experiment II also showed a high incidence of abortion (Table 2). Based on data from the breeding colony, 87% of females housed with males can be expected to conceive 1-3 days post partum, 4% during 4-21 days post-partum and 7% more than 21 days. Controls for Experiment II were, because of the nature of the experiment, handled more than the normal breeding colony. They had a somewhat lower incidence of conception immediately following parturition. Seventy seven percent of these animals conceived 1-3 days post partum, 11.5% on 4-21 days post partum and 11.5% after 21 days. In the experimental group, however, only 31% delivered young conceived 1-3 days post partum while 62% had young conceived on days 4-21 when they were caged with strange males. Seven percent conceived after 21 days (Table 2).

Table 2. Abortion induced by strange males in experienced, pregnant females that are nursing a litter.

| GROUP | NUMBER | PERCENT FEMALES CONCEIVING 1-3 DAYS POST-PARTUM | PERCENT FEMALES CONCEIVING 4-21 DAYS POST-PARTUM | PERCENT FEMALES CONCEIVING AFTER 21 DAYS POST-PARTUM |
|---|---|---|---|---|
| Breeding colony | 132 | 87 | 4 | 7 |
| Controls | 26 | 77 | 11.5 | 11.5 |
| Experimentals | 42 | 31 | 62 | 7 |

The induction of abortion in pine voles by strange males is dramatic. Not only do females in the early (possibly pre-implantation) stages of pregnancy lose their embryos but those in the later stages also abort. This occurs regardless of whether the females are pregnant with their first litters or if they are experienced mothers that are pregnant and nursing a litter at the same time.

The results of Experiment I were not unexpected. Loss of pregnancy in females that are in the later stages of pregnancy has been reported for other voles by Stehn and Richmond (1975).

Results of Experiment II were, however, a surprise. Several authors have reported that lactation and/or the presence of circulating prolactin (the pituitary hormone that stimulates lactation) effectively block the abortion response. Lactation may have had some inhibitory effect. Thirty one percent of the experimental animals did deliver young sired by the stud male. But when this is compared with the 77% delivery in control animals and 87% in the normal breeding colony, it is clear that the inhibition was minimal. Abortion and remating occurred in 62% of the experimental animals that delivered young conceived on post partum days 4-21. They were housed with strange males during that time and could only have delivered young sired by these strange males.

The abortion response induced by strange males in inexperienced pine voles confirms reports previously published. We believe, however, that this paper constitutes the first report of an abortion response induced by unfamiliar males in experienced pregnant and lactating voles.

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# Initial Results of Chemical Inhibitors and Photoperiodic Influences on Growth and Reproduction in *Microtus pennsylvanicus*

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Recently Berger *et al*. (1977) have demonstrated reproductive inhibition in *Microtus montanus* as a result of specific plant compounds in natural vegetation. Naturally occurring cinnamic acids and their related vinyl phenols have been demonstrated to have marked effects on uterine weight, inhibition of follicular development and cessation of breeding activity. Compounds having antigonadotrophic and antithryotropic activities have been identified in a wide variety of plants (Chury 1967). Bickoff *et al*. (1959) report that alfalfa contained a non-estrogenic compound which would over ride the estrogenic effect of the plant estrogen coumestrol. Adler (1962) demonstrated that a non-estrogenic compound in alfalfa could inhibit estrogenic responses of natural animal estrogens. Allison and Kitts (1964) extracted yellow pine needles and demonstrated that they contained a factor which would depress the uterine weight of immature weanling mice thereby delaying sexual maturation. Other investigators have reported similar findings but all failed to identity the compounds producing the effect. Gasser *et al*. (1963) isolated an inhibitory substance named lithospermic acid and other investigators have demonstrated it deactivates pituitary gonadotrophins in vitro.

Berger *et al*. (1977) report the effect of four plant compounds on uterine weight, follicle development, and breeding performance on *Microtus montanus*. The plant compounds utilized were extracted from winter wheat sprouted to 10 cm, homogenized and subjected to steam-ether extraction for 7 days. Three fractions extrated were analyzed by gas chromatography and subsequently tested on young *Microtus montanus*. One fraction when biologically assayed demonstrated an inhibition of uterine development. Further chemical extraction of this sample resulted in its characterization by nuclear magnetic resonance as containing a vinyl group and disubstituted phenol. Subsequent testing of 4 vinyl guaiacol by bioassay, gas chromatography and NMR analysis showed it to be identical in its chemical properties and biological activity to the plant compound. The parent compounds in the plant, PCA (Para coumaric acid) and FA (Ferulic acid), are found in low concentrations in young growing vegetation, but increase to 4 mg/gm as a plant reaches senescence. Although both PCA and FA are effective in depressing uterine weight their decarboxylated vinyl phenols (4 VG and 4 VP) are much more effective.

The compounds 4 VG and 4 VP when administered for 7 days on ground lab chow at 1 mg/gm significantly reduced uterine development in young Microtus montanus and hence delayed sexual maturity. The parent compounds (PCA and FA) after 12-14 days of treatment caused a significant reduction of uterine development. Examination of the ovaries of the 4 VG group showed significant reduction in the number of secondary uterine follicles. When tested on breeding adults over a 100 day period the chemical treatment resulted in a reduction of the number of litters born, number of young per litter and in the number of females still breeding at the end of the test period. When 4 VG was tested on male Microtus montanus by intraperitoneal injections at 1 mg/day for 3 days, a significant reduction in serum testosterone occurred. These data are suggestive that 4 VG also affects the male reproductive system in a way similar to its effects on females.

Negus et al. (1977) has demonstrated the existence of a plant compound called "stimulator" (now identified pers. comm. N. C. Negus) which when tested in a previously non-breeding population of M. montanus caused a resumption of breeding activity. They have also demonstrated that following seasonal drought breeding resumes within 3 to 5 days following the resumption of active plant growth. They conclude that the cessation of reproduction in Microtus montanus populations is associated closely with the build up of inhibitory compounds in food plants in the absence of stimulatory compounds. They have demonstrated that in populations where reproduction has ceased, under non-stimulatory photo-periodic conditions, reproduction can be initiated by the addition of the stimulatory compound to the environment.

Cengel et al. (1978) monitored reproduction of Microtus pinetorum in abandoned and maintained orchards. They demonstrated differences in reproduction and related these to quality of food and fat deposition. One of the differences in food types between the two habitats was the abundance of grass which was kept in an active growth stage in the maintained orchard. These results could indicate a possible role of plant stimulatory and plant inhibitory compounds on reproduction in the pine vole. La Voie and Tietjen (1978) indicated that the role of grass in orchard environments and the effects of temperature and photoperiod on activity patterns and reproduction need additional investigations. This laboratory is currently investigating these parameters on both problem voles (M. pennsylvanicus, M. pinetorum).

## Methods and Procedures

The data to date on reproductive inhibition in microtine rodents has been limited to maturation of subadults and reproductive potential of adults. This laboratory is currently testing the effect of inhibitory substances on reproduction in _M. pennsylvanicus_ and has initiated testing of plant stimulatory compounds. Animals utilized in laboratory experiments were derived from continously outbred laboratory populations established in 1978 at Virginia Polytechnic Institute and State University. The test chemicals PCA and FA were obtained from Aldrich Chemical Corporation as their structure has been verified to be the same as those extracted from common orchard grass. The stimulator fraction has been produced from an acetone-ether extraction from sprouted oats grown in a sterile medium (TA 24$^{o}$C, LD 16:8) in order to insure a constant supply and a constant quality.

The bioassay for effects on sexual maturation followed those of Berger-_et al_., (1977) who determined that wet uterine weight and histological examination of follicle types were the best assay measures of chemical effects on reproduction. Total food consumption, body weight, adrenal weight and total body fat were assayed to determine the chemical effects on the general condition of the test animals.

Animals to be tested are selected at random at 18 days of age and at approximately equal weights, and are caged as individuals for the entire test period (14 or 21 days). The test chemicals are disolved in methanol and then coated on to ground laboratory animal chow, control diets are treated in the same way and the two diets are then air dryed for 24 hours.

The effect of photoperiod on reproductive maturity and growth are currently under experimental testing for both M. pennsylvanicus and M. pinetorum. Growth rates of young M. pennsylvanicus under LD 18:6, LD 6:18, and natural photoperiod were determined by weighing and measuring individuals every 1 to 3 days for up to 10 weeks. Radio-immunoassay for T-4 levels in young raised under LD 18:6 and LD 6:18 were determined using a standard T-4 kit to assess photoperiodic effects on metabolism.

## Results and Discussion

The effect of PCA and FA administered at doses of 4, 8, and 12 mg/gm of chow per day for 14 days showed a trend toward a significant difference in uterine weight at the end of the test period. Tests at 12 mg/gm of chow over a 21 day test period gave a highly significant (P= .02) difference in uterine weight. Further tests at 4 and 8 mg/gm of chow over 21 day test periods are currently under way. In all tests there were no significant differences between control and experimental groups in fat deposition, food consumption and body weight. In the 21 day test at 12 mg/gm of chow the adrenals of the experimental groups were larger 12.7 $\pm$ 2.9 mg than the control adrenal weights which were 10.6 $\pm$ 1.9 mg net weight. As these groups were under a photoperiodic regime which stimulates constant reproduction this difference is most probably due to an adrenal response to the chemical inhibition of reproductive activity. Histological examination of the ovaries and adrenals will provide additional data on tissue responses to the test chemicals. Maturation of secondary follicles ceased in the ovaries of M. montanus which results in a cessation of reproduction due to the chemical treatment. When the ovaries of all test groups are examined their overall response to the various test chemicals will produce a clear picture of the effects of the experimental diets in M. pennsylvanicus. The long photoperiod tests were utilized as maximum growth and breeding is achieved under these conditions, though other photoperiod lengths are being studied.

Growth of M. pennsylvanicus under long and short photoperiods (LD 18:6 and LD 6:18) differs significantly. Young raised from birth to weaning on the short photoperiod are 3 grams lighter at weaning. After weaning both long and short photoperiod groups grow at the same rate but the short photoperiod group remains significantly smaller at the end of the 30 day test period. In order to determine the effects of natural photoperiod on growth and development 3 cohorts (15 individuals in each) born in June, July, and September were placed under natural photoperiodic and temperature conditions in October and monitored through January. Individuals born in June and July reached adult size and weight ($\bar{x}$=58gms) by October and lost weight ($\bar{x}$=50gms) until the winter solstice under the effect of the decreasing photoperiod. The September-born cohort gained weight under the decreasing photoperiodic regime reaching the same size and weight as the June and July cohorts at the Winter solstice. All cohorts are now gaining weight under incresing photoperiodic conditions.

Four groups containing 10 subadults each ($\bar{x}$ weight=48 gms) were set up as pairs under photoperiods of LD 18:6 or LD 6:18 for 10 weeks after which one of each pair was switched to the opposite photoperiod. Subadults under LD 18:6 reached adult size and weight ($\bar{x}$=58 gms) within 16 weeks while those under LD 6:18 lost weight ($\bar{x}$=42gms) during this period. At the time of switching the groups there was no significant differences from the control pairs but after 6 weeks on the opposite photoperiod such differences were apparent. M. pennsylvanicus adults and subadults lost weight under the short photoperiodic conditions and gained weight under the long photoperiod. Radioimmunoassay of T4 levels show significantly reduced levels in adult animals under short photoperiodic conditions.

Most of the data developed on M. pennsylvanicus to date characterizes the general response of the animal to its environment. The incorporation of chemical stimulators and inhibitors in this environment alters these general responses to synchronize important events like reproduction, fat deposition and altered metabolism. The aim of this research is twofold: 1) to understand biologically how these compounds affect both problem vole species and 2) to reduce the availability of stimulator compounds while augmenting inhibitor substances to cause a reduction or cessation of reproduction.

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# MOVEMENT TYPES AND WEATHER CORRELATES IN FREE-RANGING MEADOW VOLES

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ABSTRACT: Meadow voles (Microtus pennsylvanicus) were radiotracked in their natural environment from June through August 1974, 1975 and 1978. Four different types of movement were observed: residency, shifting, wandering and dispersal. Next to the residency pattern, wandering was the most common form of movement and probably was important during breeding activities. Dispersal was a rare event and is probably confused with wandering in the existing literature.

A total of 17 weather variables were analyzed for correlations with vole movement. Male voles showed a distinct tendency to move more widely during periods of dry weather. The latter was attributed to the negative effects of dry weather on the ability of male voles to detect the odors of male competitors. Thus male voles were less inhibited in their search for receptive females during dry weather. Female voles showed no major change in movement with different weather conditions.

## INTRODUCTION

Considerable insight about population control and regulation in rodents can be obtained by close examination of the movements and behavior of individual rodents in the field, especially the movements that occur in response to changes in the environment. The usefulness of this direct information satisfies both applied and basic research needs. An ongoing series of studies on meadow voles has attempted to quantify and account for different patterns of movement (Madison, 1978a, b, 1979, 1980a,b); but to date, the types of movement and the effect of weather variables on movement have not been described. These topics are the subject of this paper.

## METHODS

Details of the study populations and radiotelemetry methods can be obtained elsewhere (Madison, 1979). Briefly, miniature radio-transmitter collars with separate frequencies were attached to free-ranging meadow voles weighing 20 g or more. Three different populations were studied from June through August in 1974, 1975 and 1978. Positions were obtained on the location of each vole at regular intervals, usually once/hour for 24 hours, once or twice/week. Up to 20 voles were monitored concurrently, and several were tracked regularly for 3 months.

The daily range of each vole was compiled from the 24 positions obtained for each vole over a 24-hour period. Each range was represented by the area enclosed by a line connecting the outermost positions for the 24-hour period. Changes in the location or size, or both, of the daily range from one week to the next were used to describe the types of movements observed and to measure correlations between movement and weather conditions.

The analysis of weather variables was performed using the field data from 1978. The field site this year was within 5 miles of the Broome Co. Airport, which recorded a wide variety of weather information. A high degree of correspondence between the airport data and the limited information collected at the field site (e.g., total precipitation, continuous temperature, relative humidity and barometric pressure data) allowed the exclusive use of the airport data for the analyses.

Seventeen weather variables were quantified along with movement for each vole on each day of radiotracking. The area of the daily range was used as an indicator of movement. Spearman rank correlation coefficients (Siegel, 1956) were calculated between movement and each weather variable. The 17 weather variables were as follows:

| | |
|---|---|
| $T_1$ | Mean temperature on tracking day |
| $T_2$ | Mean temperature change from previous day |
| $T_3$ | Mean temperature change from mean of previous three days |
| $P_1$ | No. of days since accumulation of any rain |
| $P_2$ | No. of days since accumulation of 0.2 inches of rain |
| $P_3$ | No. of days since accumulation of 0.5 inches of rain |
| $RH_1$ | Mean relative humidity on tracking day |
| $RH_2$ | Mean relative humidity change from previous day |
| $RH_3$ | Mean relative humidity change from mean of previous three days |
| $W_1$ | Mean wind speed on tracking day |
| $W_2$ | Mean wind speed change from previous day |
| $W_3$ | Mean wind speed change from mean of previous three days |
| $S_1$ | Percent available sunshine on tracking day |
| $S_2$ | Change in percent available sunshine from previous day |
| $S_3$ | Change in percent available sunshine from mean of previous three days |
| BP | Mean barometric pressure on tracking day |
| DL | Daylength on tracking day |

## RESULTS

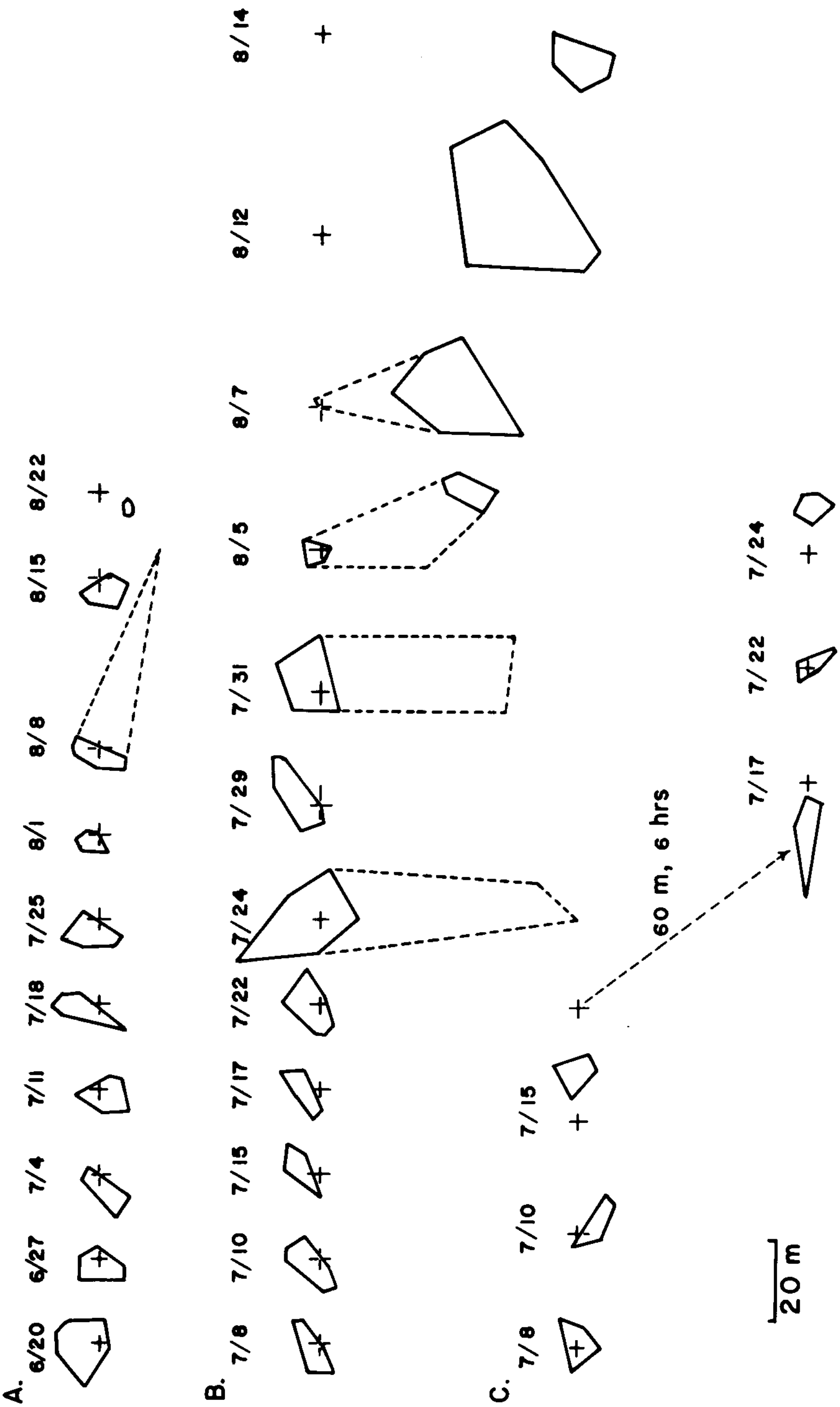
Types of Movement. Four basic types of movement were observed. These vary along a continuum from strong philopatry and exclusively localized movements within the daily range to sudden and permanent changes in the daily range. Several different types of movement can be observed in each vole, thus the categories are not mutually exclusive.

Residency. This pattern of movement is one where the vole remains in the same area (has the same general center of activity) from one week to the next. The successive daily ranges usually overlap, and the center of activity shows little net change in location throughout the tracking period. Movements within the daily range are typically small foraging (territory maintenance?) loops of about 2-4 hours followed by short bouts of sleep. Whereas sleeping during the summer day occurs almost anywhere within the daily range (e.g., in a side tunnel of grass runway), sleeping at night is usually within simple grass nests. Only lactating females sleep at elaborate nests, and these nests are utilized both day and night. This pattern of movement in voles tracked for 3 weeks or more was shown by 69% of the males (20 of 29 voles) and 89% of the females (24 of 27 voles) (Table 1). Fig. 1A shows one female exhibiting residency and one case of wandering.

TABLE 1. Frequency of movement types observed among moderately dense populations (varied from 45 to 110 voles per acre) of subadult and adult meadow voles from June through August. The residency and shifting categories only include voles tracked for three or more weeks.

| | No. voles | No. 24-h periods | Residency | Shifting | Wandering | Dispersal |
|---|---|---|---|---|---|---|
| 1974 | | | | | | |
| Males | 8 | 37 | 1 | 2 | 3 | 1 |
| Females | 8 | 39 | 3 | 0 | 2 | 0 |
| 1975 | | | | | | |
| Males | 16 | 77 | 8 | 3 | 6 | 1 |
| Females | 15 | 72 | 10 | 2 | 4 | 0 |
| 1978 | | | | | | |
| Males | 18 | 95 | 11 | 4 | 8 | 0 |
| Females | 20 | 87 | 11 | 1 | 4 | 1 |
| Total | | | | | | |
| Males | 42 | 209 | 20 | 9 | 17 | 2 |
| Females | 43 | 198 | 24 | 3 | 10 | 1 |

Fig. 1. Types of movement by meadow voles during radiotracking. (A) adult female in 1978 at Binghamton, N.Y. (23 g on 6/20, 45 g on 8/22) showing the residency pattern, except on 8/8 when the female wandered. On 8/8 the female was 7 days into lactation and 7 days into a postpartum pregnancy. She gave birth to litters on 8/1 and 8/21. (B) adult male in 1975 at Front Royal, Virginia (32 g on 7/8, 48 g on 8/14), showing the shifting pattern (7/31-8/14) and wandering (7/24). (C) adult male in 1975 at Front Royal, Va. (33 g on 7/8, 37 g on 7/24) showing dispersal that occurred between 0400 h and 1000 h on 7/16. "+" signs indicate reference points. (Figure on next page.)


A.
6/20
6/27
7/4
7/11
7/18
7/25
8/1
8/8
8/15
8/22
B.
7/8
7/10
7/15
7/17
7/22
7/24
7/29
7/31
8/5
8/7
8/12
8/14
C.
7/8
7/10
7/15
60 m, 6 hrs
7/17
7/22
7/24
20 m

Shifting. This pattern consists of the normal daily movements described above, except that the center of activity gradually shifts in one general direction to a new location. Movements into new regions alternate with movements back into recently occupied areas, but after about 3 weeks the new daily range is entirely non-overlapping with the former daily range. The shifting can result in oscillatory movements between widely separate areas, or be the result of movements into the most adjacent, previously unoccupied area. Shifting movement in voles tracked for 3 weeks or more was shown by 31% of the males (9 of 29 voles) and 11% of the females (3 of 27 voles) (Table 1). Fig. 1B shows a male exhibiting shifting movement and one case of wandering.

Wandering. Wandering is a sudden, temporary movement by a vole noticeably outside of the normal daily range. It is defined as any movement separated from the periphery of the daily range by at least one daily range diameter and lasting for no more than 12 hours. Typical trips are about 2 hours duration, but some lasted up to 9 hours. While the same general region may be visited again after a few weeks, the time, distance and duration of wandering are unpredictable. The departure and return of the vole is very rapid, and usually escapes radiomonitoring. Among all years, 23% of 43 female voles wandered during 198 vole-days, while 40% of 42 males wandered during 209 vole-days (Table 1). Fig. 1A,B show two cases of wandering, one by a female on 8/8 and one by a male on 7/24.

Dispersal. Dispersal is very similar to wandering, except that the vole does not return to the daily range. Usually a residency pattern appears at the new location. One of the 43 female voles tracked was observed to disperse, while two of the 42 male voles dispersed (Table 1). Fig. 1C shows one of the two cases of male dispersal where the male moved to a new daily range 60 m away in less than 6 hours. The male not represented moved 80 m away in less than 3 hours; the one female moved 61 m away in less than 3 hours.

Weather Correlates of Movement. A total of 182 vole-days and the associated weather conditions were used in the analysis of weather factors in 1978. For males, a lack of precipitation emerged as an important weather variable correlated with increased movement (Table 2). The positive correlations with temperature and barometric pressure were associated with dry weather, as was the negative correlation with daylength. When daylength was decreasing during July and August, conditions were generally dryer. The nearly significant correlations with relative humidity, wind and % available sunshine also fit the dry day pattern of increased movement for males. For females, a positive correlation occurred between temperature and movement, but no other correlations were statistically significant.

## DISCUSSION

Essentially no previous study of *Microtus* has attempted to define the types of movement observed in free-ranging individuals. The residency pattern in *M. pennsylvanicus* is stereotyped and consistent with the short term activity patterns observed for the species (Graham, 1968; Madison, 1980b; Webster, 1979).

The shifting pattern where a vole gradually changes its daily range reflects the movement of some voles into low-lying, moist areas during

Table 2. Spearman rank correlation coefficients ($r_s$) between movement, as measured by area, and selected weather variables (see text for definitions).

| Weather factor | Male $r_s$ | Male p | Female $r_s$ | Female p |
|---|---|---|---|---|
| $T_1$ | 0.22 | 0.033* | 0.26 | 0.015* |
| $T_2$ | 0.16 | 0.117 | 0.11 | 0.301 |
| $T_3$ | 0.17 | 0.098 | 0.12 | 0.283 |
| $P_1$ | 0.28 | 0.007** | 0.02 | 0.848 |
| $P_2$ | 0.33 | 0.001*** | 0.02 | 0.820 |
| $P_3$ | 0.27 | 0.007** | 0.08 | 0.480 |
| $RH_1$ | -0.18 | 0.078 | -0.07 | 0.521 |
| $RH_2$ | 0.01 | 0.922 | -0.19 | 0.070 |
| $RH_3$ | -0.11 | 0.285 | -0.18 | 0.091 |
| $W_1$ | -0.17 | 0.090 | 0.03 | 0.812 |
| $W_2$ | -0.03 | 0.782 | 0.18 | 0.091 |
| $W_3$ | -0.08 | 0.422 | 0.12 | 0.252 |
| $S_1$ | 0.19 | 0.064 | -0.09 | 0.410 |
| $S_2$ | -0.01 | 0.937 | 0.17 | 0.117 |
| $S_3$ | 0.19 | 0.069 | 0.08 | 0.472 |
| BP | 0.27 | 0.009** | 0.13 | 0.232 |
| DL | -0.28 | 0.007** | -0.08 | 0.442 |

* = significant at 0.05 probability level; ** = 0.01 significance level; *** = 0.001 significance level

dry periods in the summer. Other voles have been observed to shift their ranges away from regions of socially contested space. Implied in these movements is that there exists unoccupied space in or near the border of the shifting vole into which the vole can move.

Wandering movements of a few hours and extending up to four daily range diameters away appear to be significant among adults during the breeding season, and are likely associated with reproductive events. For example, males often temporarily move out of their daily ranges and enter the ranges of neighboring, estrous females (Madison, 1980). Wandering could reflect the male's effort to mate with receptive female neighbors especially if the latter are prone to move widely when they near parturition and estrus (females have a postpartum estrus and may actually mate during parturition). Such wide scale movement (wandering) by the females around parturition and estrus has been reported, and may be necessary to promote outbreeding or reduce the chance of male cannibalism of the newborn young (Madison, 1978a).

Dispersal under the conditions of this study was surprisingly rare. The contemporary acceptance of the importance of dispersal in rodent population biology (e.g., Lidicker 1975; Tamarin, 1977) may be overemphasized, and estimates of dispersal may be inflated artificially by the inclusion of many cases of wandering into the dispersal estimate. The sudden, permanent departure of a vole from its daily range is a bold action, one where the likelihood of reproductive success at home must be very low, or one where the rare incident of reproductive success at large must result in considerable reproductive gain (such as founding a new population), or both. The increased predation on dispersing voles is commonly recognized, and predation on voles intensifies in suboptimum areas (Madison, 1979). It is of course possible that dispersal is more common in voles less than 20 g, or more frequent among voles from September through May, but these possibilities do not alter the unexpected finding of so few dispersing voles among all the subadult and adult members of the study populations during the main breeding period from June through August. The reason for so little dispersal, if it is to be expected under the moderate density conditions in this study, is not known.

Little information exists on how weather factors affect movement in Microtus, especially concerning the day-to-day variations in movement. The available data indicate that activity tends to increase during wet weather (Bider, 1968) or that voles prefer more moist habitat (Getz, 1961). However, Pearson (1960) found that activity was highest at times of lowest vapor pressure, hence during dry periods. The latter observation is consistent with the findings in the present study, at least for males. Some of the activity observed previously during wet weather could be associated with nest abandonment when the nest becomes wet (Stark, 1963). It probably is safe to say that Microtus requires high degrees of moisture in its diet (Pearson, 1960), and therefore thrives in moist habitats, assuming other factors as food and cover are adequate. However, dry conditions appear to be a definite stimulus for movement among males, and this weather variable should be studied further.

An explanation for increased movement during dry weather must consider the sex-dependent nature of the effect. Thus, shifting or wandering into moist areas during dry weather is not a very satisfactory explanation. One possible explanation for the high correlation between male movement and dry weather is suggested by Madison (1980). Movements of voles are heavily influenced by odors produced by conspecifics. The detection of these odors in the environment is directly proportional to the ambient relative humidity (Regnier & Goodwin 1977). If males are normally inhibited from wide-ranging movement in optimum habitat by the presence of odors of other males, then a reduction in the apparent chemical presence of males during dry weather would release males from their social inhibition and allow them to search more widely for receptive females. Not only might the apparent presence of competing males be decreased, but the likelihood of a trespassing male being detected by a resident male would be reduced. The reduced chance of detection during dry weather would make non-rain periods the optimum time for wide range reconnaissance runs by sexually active males. That normal inhibition of movement probably occurs, and that detection by other males is potentially injurious, is supported by the high frequency of wounding amono sexually mature male voles (Christian, 1971; Rose, 1979). There is no obvious advantage for females to invade other female territories, so increased movement during dry weather is not expected for females (Madison, 1980a).

## ACKNOWLEDGEMENTS

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# TEXTURAL AND TASTE INFLUENCES ON GNAWING BY PINE VOLES

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ABSTRACT: Pine voles and meadow voles exhibited differential preferences for various Malus clones. When damage to dormant stems in a 24-hr test was assessed by either a graded damage scale or percentage consumption by weight, pine voles preferred Golden Delicious, M.9, and M.26 and consistently avoided M.x sublobata PI 286613 ("613") and related clones and Robusta 5. Dehydrating stems magnified the disparity among cultivars, as attractive stems continued to suffer extensive damage, while 613 became even less palatable. In the autumn phase all varieties showed increased acceptance. Meadow voles, like pine voles, exhibited differential acceptance of cultivars, but their preferences differed somewhat from pine voles in that they extensively damaged Robusta 5.

When bark and pulp portions of rootstocks were separately presented to pine voles in 1 hr tests, weight consumed followed expected varietal preferences. With dormant stocks, significantly more bark was consumed than pulp in both 613 and Golden Delicious samples, and, in both fractions Golden Delicious was consumed more than 613. In autumn-cut stocks Golden Delicious was preferred to three other varieties overall, as was its pulp fraction.

Humans readily detected textural contrasts among rootstocks, some of which can be measured during the dormant phase as lower densities and higher water content for the extremely preferred rootstocks. Humans also reported taste differences among cultivars, describing rootstocks and fragments as bitter more often for Golden Delicious and 613 than for Robusta 5 and M.9. Taken together, these rootstock data suggest that stem texture may be a primary factor for rootstock acceptability.

Taste probably also plays a role in rootstock preferences. Pine dowels soaked in fruit extract, sucrose, or quinine solutions or water or oil and individually presented to paired pine voles for 24 hr tests were gnawed differentially with enhanced gnawing for oil and extract-treated dowels, and less gnawing of quinine-treated dowels.

INTRODUCTION: Pine voles and meadow voles may inflict serious damage on apple trees by gnawing roots and bark (2). Whether voles gnaw to wear down their teeth, to obtain certain minerals, nutrients, or water, or to create nesting material, is unknown. Pine voles do consume some apple tree root tissue, as it is commonly present in stomach contents of wild-caught pine voles, but the percentage of apple root epidermis tissue in total stomach contents is very low, usually only a few percent (4), suggesting that apple roots, even in the winter, are not an important food source.

In this paper I present data regarding factors influencing gnawing of wood by voles, describing in the first section studies of acceptability in 24 hr tests of dormant, dormant and dried, dormant and sprouted, and autumn-cut Malus shoots. The acceptabilities of cortex and pulp portions of several cultivars in 1 hr tests are compared. Physical characteristics of the most and least attractive cultivars are described in the second section, including changes with season, and differences in taste quality as described by humans. In the third section I report effects of tastants on gnawing of pine dowels by pine voles.

ACCEPTABILITY OF ROOTSTOCKS TO VOLES: Both in the laboratory and in the field, voles have exhibited differential preferences among Malus clones (3,7,9). 'Golden Delicious' stems, for example, have consistently been more subject to damage than 613 stems.

For the present study, plant material was collected at Geneva, New York, either while fully dormant in January or before leaves dropped in October, shipped to Philadelphia, and there stored in plastic at 1°C until use within 30 days.

Pine voles were laboratory-born in a colony originally trapped in Pennsylvania in 1972, and meadow voles were wild-caught in Virginia a few months prior to tests. All voles were housed in plastic shoe box cages as heterosexual pairs and offered water, apples, alfalfa, peanuts, and sunflower seeds continuously throughout all experiments.

For an initial replication of Byers' study under our laboratory conditions, 20 pairs of pine voles were, in a series of weekly tests, presented with 15 cm rootstock lengths for a 24 hr period. A modification of Byers' damage rating scale (2) was used: 0 = no damage; 1 = 1/4 girdled; 2 = 1/4 - 1/2 girdled; 3 = 1/2 or more girdled; 4 = girdled; 5 = shortened or cut in two; 6 = consumed. In this study, wide variability occurred and no significant difference was found among M.26, M.9, Robusta 5, and 613 (3/76 df, $F = 1.23$); however data suggested a trend of lower acceptability for 613.

In a subsequent test using dormant stock and 23 Malus clones, significant differences were evident (22/90 df, $F = 1.86$, $p \leq .05$), with mean damage scores above 5 for 7227R5-181, M.27, 74R5M9-934 and M.9, and below 4 for 746363-32, 710663-1, 74R5M9-794, 74R5M9-5, 716325-2, 710663-13, the two extremes representing significant differences in t-tests.

Much later we obtained autumn-cut shoots, and a far higher percentage by weight was consumed (Fig. 1b) than for dormant material (Fig. 1a). In the autumn, 613 and Golden Delicious were significantly preferred over Robusta 5, indicating a positive shift in the attractiveness of 613. Dormant shoots which had been dried (150°C) for 3 days also significantly differed (25/159 df, $F = 3.36$, $p < .001$) with scores above 4.5 for 74R5M9-789, 75M9R5-47, 746363-75, and GD and below 3 for 7527R5-181, M.27, 710663-13, 74R5R5-29, 74R5R5-16, 74R5R5-15, 63, 746363-37, Rob. 5, 74R5M9-936 and 74R5M9-794. Shoots of 7 cultivars were then placed in a room at 20°C with an 18 L-6D cycle for 2

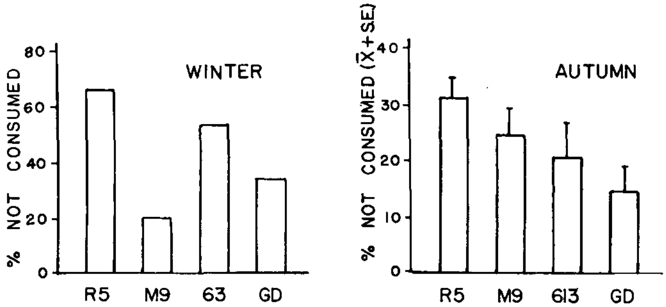


Figure 1. Percentage of Malus shoot weight not consumed by pine vole pairs. (Four cultivars were individually presented for 24 hr tests. In Fig. 1a, shoots were fully dormant. In Fig. 1b, leaves were removed before testing.)

weeks and allowed to develop leaves. Sprouted shoots were then presented to pine voles; damage differed significantly among cultivars (6/35 df, $F = 4.29$, $p < .005$), with high damage scores for 746363-51, 746363-37, 74R5R5-15, and M.27 and low scores for 74R5R5-16 and 613.

The average damage score for fresh dormant varieties pooled was 4.23 (S.E. = .18, 23 varieties) while dry dormant was 3.25 (S.E. = .25, 26 varieties ), and dormant sprouted was 4.5 (S.E. = .37, 7 varieties). Drying reduced damage significantly while sprouting did not significantly affect damage. Individual cultivars had a significant reduction in damage after drying (sign test: $n = 20$, $p < .058$).

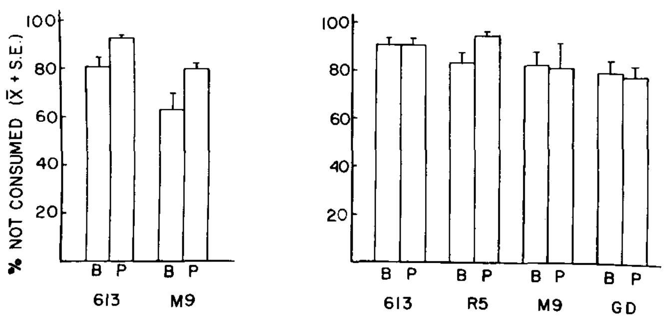


Figure 2. Percentage of shoot fractions, bark (B) and pulp (P), not consumed by pine vole pairs. (In Fig. 2a, dormant fractions were presented for 24 hr immediately after preparation. In Fig. 2b, autumn fractions were presented for 1 1/2 hr beginning 24 hr after preparation.)

To assess the attractiveness of dormant shoots, pieces were prepared from the colored layers of the bark and the white pulp. Portions of either bark or pulp from 613 or M.9 were weighed and presented to familiar pine vole pairs in a clean cage for a 2 hr test. Control samples of each variety were placed in clean empty cages and weighed after testing to permit correcting weights for percent water loss during the test period. More bark than pulp was consumed in both cultivars (1/16 df, $F = 16.63$, $p < .001$), and 613 was less palatable than M.9 (1/16 df, $F = 6.04$, $p < .05$; Fig. 2a). A similar experiment was later conducted using autumn-cut shoots. Uniformly-sized shavings (approx. 3 cm x 5 mm) were presented in 1.5g allotments the day after preparation. Control samples permitted corrections for drying. Each vole pair was given 3 tests in a repeated measure design with randomized selection of treatment. The autumn-cut stems differed with respect to variety (3/48 df, $F = 17.6$, $p < .001$; Fig. 2b), portion of the rootstock (1/48 df, $F = 9.4$, $p < .001$) and the interaction (3/48 df, $F = 5.88$, $p < .005$). There was a significant order effect, with scores increasing on subsequent tests (2/48 df, $F = 17.6$, $p < .001$) and an interaction among variety, stem portion, and order of testing (6, 48 df, $F = 14.7$, $p < .001$). Compared to other varieties, Golden Delicious was significantly preferred overall, and its pulp was preferred to others (t-tests $p < .05$). Robusta 5 bark was significantly preferred to its pulp; this is consistent with the frequent stripping off of bark which occurs when whole Robusta 5 stems are presented.

Meadow voles also exhibit varietal preferences, but they are unlike pine voles in their relative liking for Robusta 5 (Fig. 3b). Negative results have occurred in studies of acceptability of (1) leaves of various cultivars; and (2) supernatant from pulverized shoots of various cultivars in water, with or without sucrose.

Acceptability of apple shoots was influenced by cultivar, by the stem hydration, and by the stem fraction. While these factors significantly affect rootstock damage in the laboratory, substantial consumption occurred even under the least attractive conditions. Orchardists can probably benefit most by selecting unattractive rootstocks as part of an integrated vole control program.

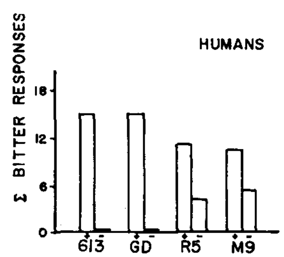


Figure 3a
Perception of Malus shoots by a human taste panel. (Six women were presented with bark, pulp, and whole shoots of 4 varieties and asked to describe tastes of each.)

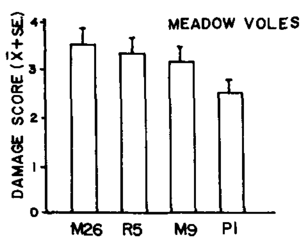


Figure 3b
Damage to Malus shoots by meadow vole pairs.

PHYSICAL CHARACTERISTICS RELATING TO ACCEPTABILITY: Several factors may indicate whether taste is an overriding determinant of rootstock acceptability. Succulence and textural factors probably vary with season and apparently change palatability, since dehydration influences acceptability of many cultivars, as shown in the previous section. Some seasonal changes in taste are also likely and may be critical to acceptability.

Golden Delicious is highly preferred by pine voles whether fresh dormant or dried dormant. Pine voles avoid the bitter taste of quinine in liquid taste preference tests (1). To a human taste panel of 6 women rating autumn-cut apple shoots, bark, and pulp, Golden Delicious and 613 were significantly more bitter than Rob. 5 and M.9 (Fig. 3a). For voles then, Golden Delicious palatability may be a function of some quality other than taste.

More evident to humans are the textural differences among clones. An attempt to break a shoot can result in a simple snap of the twig as if it were already serrated, or can produce a struggle with long fibrous strings which are not easily broken or cut. To test these textural differences, we measured: (1) the density of many Malus cultivars by water displacement and (2) the percentage dry weight.

Densities significantly increased, on the average, from winter dormant to autumn ($\bar{X}$ = .99, 1.12, respectively). Density values in autumn did not relate to acceptance by voles or ease of breaking shoots, however densities of dormant shoots were related to extremes in acceptability or its absence. Five cultivars appeared in the top and five in the bottom of acceptability in at least two of four dormant measures (damage scores for fresh, dry, sprouted; percentage consumption for fresh). The five highly acceptable varieties (Golden Delicious, M.9, 74R5M9-755, 7527R5-181, 74R5M9-934) had lower densities ($\bar{X}$ = .97 ± .01) than the highly rejected cultivars (746363-37, 613, MM.106, 746363-32, Rob. 5; $\bar{X}$ = 1.03 ± .02).

The percent dry weight also changed with season, increasing from the autumn ($\bar{X}$ = 45.4 ± .02, n = 32 cultivars) to the dormant season ($\bar{X}$ = 56.3 ± .01; n = 32 cultivars). Again, the dormant shoots differed in percent dry-weight at acceptability extremes. The five most acceptable clones had lower percent dry weights ($\bar{X}$ = .52 ± .01) than the five least acceptable ($\bar{X}$ = .59 ± .01).

These data implicate textural differences as important in rootstock acceptability. Comparative studies of wood structure and anatomy and seasonal changes are needed to clarify the bases of contrasts in density and dry weights.

TASTE INFLUENCES ON GNAWING: In this experiment we standardized the textural properties of the substance and added tastants to determine whether gnawing is affected by taste. Wooden pegs were soaked for 3 days in flavorants shown in previous work to affect preference: .05 M quinine hydrochloride (1), 1.4 M sucrose (1), 25% fruit extract DRC-470 (8), corn oil (5,6), or a water control. Pegs were weighed and then presented to 10 pine vole pairs for a weekly 24 hr test in a two-way repeated measured design. As a drying control, wet pegs were allowed to air dry in an unoccupied cage during the test period.

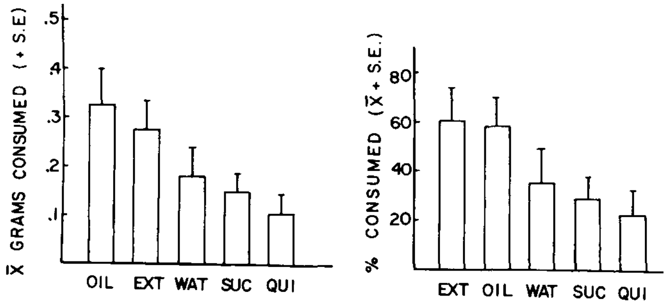


Figure 4. Consumption of wooden pegs by pine vole pairs while gnawing. [Pegs were soaked in fruit extract (EXT), sucrose (SUC), or quinine (QUI) solutions or water (WAT) or corn oil (OIL) for 48 hr and then presented individually for 24 hr tests.]

Dowels were reweighed at the end of the test and weights corrected for drying. Fig. 4 shows that oil and extract-soaked pegs were significantly preferred to quinine, also oil to sucrose (Fig. 4a: ANOVA, 4/63 df, $F = 3.54$, $p < .025$; t-tests, $p < .05$), and extract to sucrose (Fig. 4b; ANOVA, 4/36 df, $F = 5.38$, $p < .005$; t-tests, $p < .05$).

These data verify that tastants can enhance gnawing by pine voles. Most surprising was the low acceptability of sucrose-treated pegs, since sucrose in liquid preference tests is a highly-favored flavor.

CONCLUSIONS: Taken together, these experiments highlight the complexity of apple rootstock acceptability to voles and suggest that texture and taste factors are both critical to acceptability. Further studies could elucidate the feasibility of enhancing or depressing acceptability of rootstocks by adding various tastants, and thereby quantitatively distinguish roles of texture and taste. In addition to probable synergistic interactions among rootstock characteristics, the condition of the voles is another variable not tested here. Influences of hunger, diet variety, age and reproductive status, thermal stress, and food or water deprivation in voles on rootstock acceptability are likely to be as significant as variety resistance.

ACKNOWLEDGEMENTS: We appreciate the able technical assistance of Christine A. Kornet and Evelyn K. Meyer. The U.S. Fish and Wildlife Service supplied the fruit extract, and we gratefully acknowledge their support of this project. And Dr. Ross Byers has facilitated trapping pine voles and meadow voles and provided unpublished research material pertaining to pine and meadow voles.

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# Preliminary Field Observations of Meadow Vole Preferences among Selected Apple Clones

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Damage by voles has continued to be a major cause of tree mortality American orchards despite nearly universal use of herbicides and rodenticic (1,7). To reduce damage done by voles in infested orchards, one valuabl tool could be use of a stock system that voles found highly unattractive. Having such stock systems in place would be particularly valuable during periods when the orchardist could neither bait nor spray for control.

A cooperative VPI/Cornell research project initiated in 1974 identified a few cultivars with relatively high levels of resistance to pine voles, as expressed in free-choice tests under laboratory conditions. This work also provided data suggesting that such resistances to pine vole were simply inherited in *Malus*(2,6).

Apple growers have long held that certain cultivars were attacked preferentially by meadow voles; 'Hibernal' and Malling 9 (M.9) have been reported to be especially severely attacked. We initiated the study reported here to determine whether *Malus* clones consistently rejected by pine voles in free-choice situations in the Winchester laboratory tests would be similarly rejected by meadow voles under orchard conditions at Geneva.

## MATERIALS AND METHODS

In a heavily sodded apple orchard at Geneva in November, 1979, we established 25 active test sites by providing covers of sheet-metal roofing approx 1 m square (Fig. 1)(4). Populations at each test site varied from moderately active with a single nest and few runways to highly active with multiple nests, numerous runways, and 15 or more voles consistently observed.

Apple clones which had been tested for pine vole response at Winchester were offered to meadow voles in the Geneva orchard test sites. From 12-gauge wire, we constructed rings approx 50 cm diam. and to each ring affixed 12 spring-type clothespins (Fig. 2). Into each clothespin, we inserted a shoot 12 cm long and 6-8 mm diam, 12 clones per ring (Table 1). We usually used 8 replications, each colony serving as a replication. 'Golden Delicious' was included in each trial as a standard. After 24 and 48 hr, each shoot was examined for damage and rated 0-11 on the Barratt-Horsfall scale (5). These scalar data were transformed to appropriate % damage and then compared by analyses of variance and Duncan LSD.

## RESULTS AND DISCUSSION

Meadow voles at Geneva exhibited preferences (Fig. 3) somewhat different from those of the pine voles at Winchester. *Malus X sublobata* PI 286613 was least attacked in 2 of the 3 trials in which it was entered; this clone had also been avoided by pine voles at Winchester. 'Golden Delicious' and M.9, which were susceptible at Winchester, were very heavily attacked by our meadow voles. Robusta 5, rather resistant at Winchester, was heavily attacked at Geneva.

## SUMMARY

Our preliminary free-choice tests indicate that the methods used are effective for field evaluations of *Malus* clones for attractiveness to meadow voles. Field preference of meadow voles appear to be rather similar to the preferences of pine voles as expressed in laboratory tests.

We are developing no-choice screening systems. To test the efficacy of using resistant stocks in the orchard, we have begun production of trees of spur-type 'Golden Delicious' on PI 286613, *M. X micromalus* and 'Golden Delicious'; these stocks will make up both root system and the lower 30 cm of trunk.

Important additional research would include field studies in several locations to determine whether there are major variations in responses of local vole populations to the various stocks offered.

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*Table 1*. Apple clones used in meadow vole testing at Geneva, winter 1980.

| Code | Clone identification |
|---|---|
| BR | *Malus brevipes*: A crabapple from Asia, similar to *M. floribunda*. |
| B9 | Budagovsky 9 ('Red-Leaved Paradise'): A Russian rootstock. |
| CR | 'Cranberry Crab': A red-wooded flowering crab. |
| CRC | East Malling Crab C: A vigorous rootstock of unknown parentage. |
| GD | 'Golden Delicious' (*M. domestica*) |
| MM | *M. X micromalus*: A crab derived from *M. baccata* X *M. spectabilis*. |
| MN | *M. baccata mandshurica* |
| M9 | Malling 9: The most dwarfing rootstock in commerce; *M. pumila*. |
| OS | 'Osman': From the cross *M. baccata* X *M. domestica* 'Beautiful Arcade'. |
| R5 | *M. X robusta* Robusta 5 (*M. baccata* X *M. prunifolia*). |
| SB | *M. sieboldii*: A Japanese crab. |
| SPC | *M. spectabilis*: A Chinese flowering crab. |
| SS | 'Sissipuk': Canadian-bred *M. pumila niedzwetzkiana* X *M. baccata*. |
| SUG | 'Sugar Crab' |
| VI | *M. yunnanensis* 'Vilmorin': A crab from inland China. |
| 63 | *M. X sublobata* PI 286613 (*M. prunifolia* X *M. sieboldii*). |

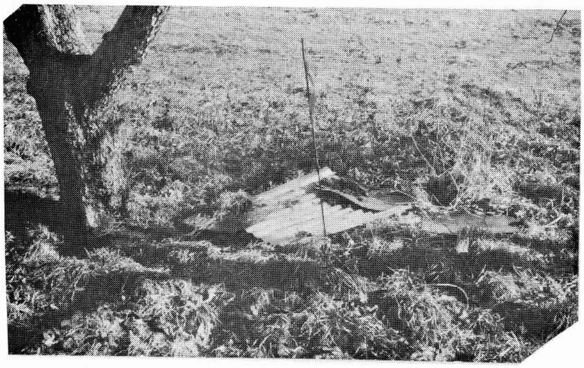

Fig. 1. Typical colony site with covering of tarpaper and sheet metal.

Fig. 2. Wire ring approximately 30 cm diameter with 12 spring-type clothespins, each holding 1 test shoot.

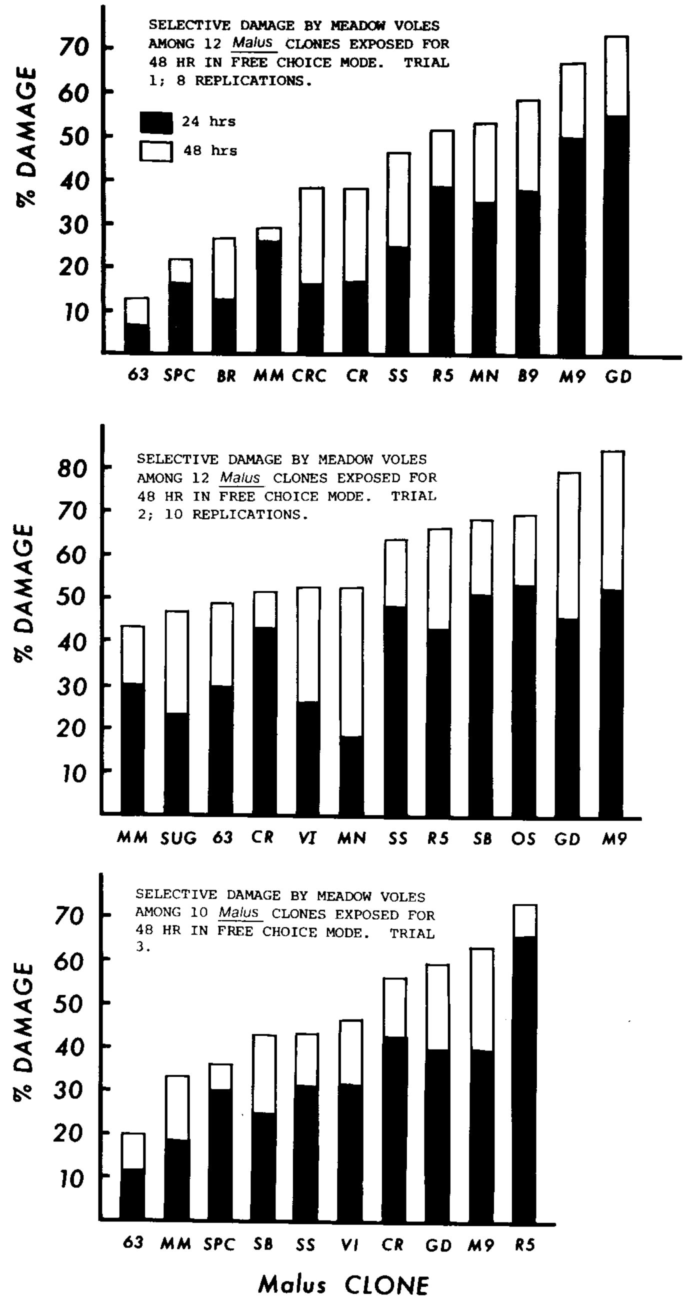


Fig. 3. Differences in damage by gnawing of meadow voles given free choice among 12 apple clones in 3 trials. Average damage after 24 and 48 hrs at 7 to 10 sites.

# AN EXPERIMENTAL MONITORING AND ADVISORY SERVICE IN ORCHARD VOLE CONTROL

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The North Carolina integrated pest and orchard management project (IPOMS) has moved from the data-gathering phase into an experimental information delivery system. We present here for possible comment the written directions for vole monitoring that we prepared for use by the orchard specialists who will implement the monitoring and advisory system.

IPOMS started in 1976 as a joint effort of a number of subject matter departments under the North Carolina Agricultural Research Service. A brief description of this cooperative effort of horticulturists, entomologists, plant pathologists, economists, zoologists and soil and weed scientists has been presented to this group (Hayne 1978). Data on all these aspects of apple production were gathered from 1976 through 1979; they are now being analyzed. According to plan, the project moved into the information delivery phase in a preliminary way in 1979, and now an experimental monitoring and advisory service will be offered to all IPOMS cooperators who are interested; for this trial the service will be restricted to those orchard blocks used in the IPOMS study.

To facilitate this study, the IPOMS scientists assembled a booklet for use of the scouts and the cooperators. This booklet includes sections on monitoring, and on management and control, for each pest species. This is as yet an internal document only, and will not be available in its present experimental form to anyone except a project investigator or a cooperator.

We present here the section on monitoring voles in the hope that we will receive comment and criticism, either at this meeting or later by correspondence. We have found that specification of practical monitoring procedures is quite different from planning a scientific investigation. The methods suggested here are experimental in the sense that they are untested in this particular form. We will appreciate comment.

We hope that with systematic monitoring of orchards, rodenticide applications will be made only when really needed; this should reduce both the total volume used and the average cost of rodenticides. This should not only benefit the grower but also reduce the stress on non-target species.

At this time, this information delivery is seen as a one-year experimental trial to explore the problems of such a system, with the thought that in the future this system may be carried out under some other direction. There is no good reason, however, why a grower should not use these instructions and monitor the vole populations in his orchards and then generate his own advice about treatment. Perhaps, on the other hand, there is room here for a specialist to do this work as a public employee, or as an employee of a cooperative, or on a custom basis.

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PEST MONITORING GUIDE - VOLES

Voles are monitored by inspection for signs of their activity. While voles reproduce at a high rate compared to other mammals, they do not increase rapidly from week to week in the manner of insects and therefore they may be monitored at no more than three times per year, as follows:

A. Examine soon after harvest is completed to determine whether rodenticide treatment is needed.
B. Examine in midwinter, to assure that treatment was successful (if it was used) or that there has not been a population increase such as to require treatment.
C. Examine in early spring to determine overwinter survival or possible increase, and as a basis for comparison the following fall.

Methods of examination for signs:1/

1. Examine 2 trees in every acre.
2. Choose for examination trees in the most likely places for voles (with vigorous vegetative ground cover). Record on map approximate location of each tree.
3. Using a modified rake, examine ground under both sides of a tree (in the row, between this tree and those next), searching for runways, holes, cuttings, damage. Where ground is bare beneath trees, examine orchard floor vegetation along edges of middles.
4. Where signs are found at a tree, even apparently old signs, flag the tree and use the apple sign test, returning the next day to read this.
5. If no signs are found at a tree, do not use the apple sign test at that tree.

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1/ Maps are mentioned throughout this section. Rough sketch maps made with the grower's assistance on the first visit to the orchard will be adequate, although the best available map should be used. Maps should be made on $8\frac{1}{2}$ x 11 inch paper in a form to be photocopied so that a clean copy can be used for notes on each visit to a particular orchard. Essential information on each map should include name of owner or grower, identification of the block, acreage and some indication of scale (as length of one side of block), with other information as desired. Label blanks for Date, Vole Species, Treatment Recommended, Treatment Reported (with date) and Other Notes.

6. Record trees examined in approximate location on map, with plus (+) for presence of signs and minus (-) for no signs, using a numerical score (0-4) to record results of apple sign test.
7. Record on map judgement whether signs indicate pine vole or meadow vole activity (or possibly both).
8. Trapping to be used only to confirm judgement concerning the species present.

## Directions for Apple Sign Test

On the first day, a slice of apple is laid out at a burrow entrance or in a runway, and covered with a "shingle" (a piece of asphalt roofing about 12 inches square). On the second day this piece of apple is "read", that is, examined and scored on the following scale:

0. No signs of having been cut into.
1. One or two bites have been removed.
2. Substantial amount of the apple eaten, but with area that of a dime or less.
3. Area of consumed portion more than a dime but less than a quarter (coin).
4. Area consumed more than a quarter, or apple piece is missing.

## Interpretation of Monitoring Results

Not knowing the economic threshold for vole signs, no score can be stated as a threshold for treatment. A conservative decision is to treat with any positive sign-test reading. Monitoring can show when only part of an orchard needs treatment.

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# RESULTS OF A BIOASSAY TECHNIQUE FOR GROUND-SPRAYED RODENTICIDES

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ABSTRACT: A laboratory test of toxicity to voles of toxicants sprayed on a soil substrate was used to test brodifacoum, chlorophacinone and endrin against pine voles. By this test, endrin was not as effective against meadow voles as against pine voles.

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Rodenticides that can be applied as ground sprays appeal to apple growers because they already have the spray equipment and experience in using endrin. The potential of other available materials should be investigated for this use, but field trials are slow and costly. We have been studying the toxicity of endrin to pine voles and the efficacy of endrin ground sprays in controlling these rodents in the field and in the laboratory; some of our studies have suggested that endrin may act more as a tracking poison than as a toxicant ingested in the food supply. Evidence supporting this conclusion is unpublished but consists of observing that in the laboratory when endrin is mixed in the food supply at toxic levels it serves as a repellent to pine voles. Even when the voles have no other source of food, as the endrin content of the laboratory food approaches the LC50 as determined in these tests, the voles reduce the consumption of the endrin-containing food. When other food is available the effect of endrin is reduced. Yet endrin ground spray is effective against pine voles in the field.

With the thought that endrin might act as a tracking poison, Barbara C. Hackman* was able to develop a dosage-response curve by mixing endrin with soil to a known concentration, holding the animals' food uncontaminated. We have used the same methods, but with the toxicants sprayed on the soil surface. We do not know exactly how the animal acquires the toxicant; a reasonable guess seems to be that it could ingest contaminated soil particles during its vigorous grooming activities, which are so characteristic of this form, or possibly by absorption through the skin of the feet.

METHODS: The tests reported here were carried out in two sets, those of the pine vole in a laboratory on the Raleigh campus of North Carolina State University, and those of the meadow vole at the Vole Laboratory at the Mountain Horticultural Crops Research Station at Fletcher, North Carolina. The same general methods were used with some differences in details.

All animals used in the tests were adult voles, captured wild in Henderson county. With the Raleigh tests of pine voles, only adult males were used, housed three in a cage. In the Fletcher tests with meadow voles, two animals were used per cage, one male and one female. Animals were held in captivity for a minimum of 7 days before any trials.

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*Then with North Carolina State University.

Table 1. Mortality of adult male pine voles exposed to three toxicants applied as ground sprays on earth substrate; 10-day exposure.

| Toxicant | Exposure lbs. active per acre | Mortality |
|---|---|---|
| Brodifacoum | 0.024 | 0/3 |
| | 0.049 | 0/3 |
| | 0.098 | 1/6 |
| | 0.147 | 0/3 |
| | 0.196 | 4/6 |
| Chlorophacinone | 0.18 | 1/3 |
| | 0.35 | 0/6 |
| | 0.52 | 2/3 |
| | 0.71 | 6/6 |
| Endrin | 0.94 | 0/3 |
| | 1.88 | 1/6 |
| | 2.82 | 1/3 |
| | 3.76 | 4/6 |
| Control | 0.0 | 0/11 |

All tests of ground sprays were carried out on a soil substrate in a metal box measuring 23.5 x 15 inches, 6 inches deep. Each box was fitted with a top of ½-inch hardware cloth; each box had a layer of about 25-30 pounds of sandy loam soil containing a moderate amount of organic matter. This soil had been sifted through a ½-inch hardware cloth screen to remove stones, clumps of soil and pieces of plant material. Small amounts of water were added to the soil periodically to maintain soil moisture. For food, apples were suspended above the soil surface to prevent direct contamination. A water bottle was provided. No nesting or other cover was provided to the animals, which lived on the soil substrate. Control animals were held on untreated soil in the Raleigh tests but not in those at Fletcher. Animals were observed every 24 hours or more often and body weights were measured every other day. Tests at Raleigh were terminated at the end of 10 days and at Fletcher at the end of 21 days.

All toxicants were applied mixed in water to a uniform volume of about 125 ml. This spray application was made as uniform as possible and allowed to dry overnight in the Raleigh tests, and for four hours in the Fletcher tests, before test animals were introduced. The dilute spray applications were equivalent to approximately 560 gallons per sprayed acre. In the Raleigh tests, solutions were made up from commercially available formulations of endrin and chlorophacinone, and from technical brodifacoum provided by the ICI Americas Corporation. In the Fletcher tests, the concentrations of endrin were prepared from technical material provided by Velsicol Corporation; to allow dispersion in water the endrin was dissolved in a small quantity of xylene with 3.5 percent emulsifier.

Table 2. Mortality of adult meadow voles exposed to endrin applied as ground spray on earth substrate; 21-day exposure.

| Exposure lbs. active per acre | Mortality |
|---|---|
| 7.0 | 9/22 |
| 14.0 | 10/20 |
| 21.0 | 11/16 |
| 24.5 | 9/12 |
| 28.0 | 10/10 |
| 35.0 | 8/8 |
| 42.0 | 8/8 |
| 56.0 | 6/6 |

In fitting a dosage response curve to the mortality data from the laboratory tests, probit analysis was carried out, using the SAS system (Barr et al. 1979) with log-transformed values of the variable application rates.

RESULTS: Tables 1 and 2 show the mortality of voles exposed to ground sprays with the application rate expressed as pounds per acre of active ingredient. Table 1 shows the results for pine voles with the three rodenticides: brodifacoum, chlorophacinone, and endrin. Table 2 shows the results for meadow voles exposed to endrin. In Table 3, results are combined and restated as median lethal application rates and, where possible, compared with the rates of application on the registered labels for chlorophacinone and endrin.

DISCUSSION: For both endrin and chlorophacinone, the median lethal application rate for pine voles, as determined in the laboratory tests, was of the same order as that directed by instructions on the label, making allowance for stating both rates as per sprayed acre. We do not understand why the results from the bioassay approximate so closely the label recommendation as to application rate. If the bioassay test and the field application were exactly comparable, and we would not expect that they would be, then we would expect the median lethal dose to be something less than the effective field application rate. We need more experience in comparing the two methods of exposure before we can understand this question, but one explanation might be that in the field, some rodenticide is obtained through the food supply, a route we attempted to eliminate in our laboratory tests. Or, perhaps the spray-covered vegetation provided more surface from which the rodenticide might be picked up on the fur and ingested in grooming.

Table 3. Median lethal application rate of rodenticide ground spray in laboratory tests as compared with label rates.

| Rodenticide | Species | n | Application rates as lb/acre active | |
|---|---|---|---|---|
| | | | LC50 in lab tests (95% confidence limits) | Rate specified on label |
| Brodifacoum | Pine vole | 21 | 0.18 (0.12-*) | - |
| Chlorophacinone | Pine vole | 18 | 0.42 (*) | 0.30[1/] |
| Endrin | Pine vole | 18 | 3.13 (1.88-*) | 3.0[1/] |
| Endrin | Meadow vole | 102 | 10.63 (7.05-13.64) | 3.0[1/] |

[*] Unable to set limits because of heterogeneity of data.

[1/] Label rates interpreted as pounds of active ingredient per sprayed acre. Based on area sprayed within tree drip lines, sprayed area is assumed to be 2/3 of orchard area.

Comparative results with the two species of voles suggest that endrin may not be as effective against the meadow vole as it is against the pine vole. These results are supported by observations in one orchard where endrin was reported to have been used without success, and where we found surviving animals to be meadow voles. For these tests, we obtained the test animals from other orchards. At present we do not have any stronger confirming information that endrin is not effective as a ground spray for eliminating meadow voles.

In developing this laboratory bioassay method for testing ground sprays we hope, of course, that it could serve as a less expensive screening method for investigating candidate ground-spray materials to replace endrin. Clearly, this method is no substitute for good field trials, but it has the advantage that tests can be made under controlled conditions and without special permits or clearance if nonregistered materials are used. Although these laboratory tests cost less than well-conducted field trials, they cost more, and are slower than the ordinary toxicity trials carried out in small laboratory cages.

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# APPLE TREE MORTALITY, RATE AND CAUSES

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ABSTRACT: In a randomly selected sample of 47 orchard blocks in Henderson County, North Carolina, over two years, the average annual mortality rate for apple trees was 1.0 percent with probably a little less than half of this caused by voles.

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It is not necessary to tell this group that voles kill apple trees. But to set this fact in context, we are reporting on a study of the rate and the causes of apple tree death based on observations of 28,778 trees for three years and determination of cause of death for 775 trees.

This investigation is part of an interdisciplinary study being carried out by the North Carolina Agricultural Research Service to assemble data for an integrated attack on the management of orchards and orchard pests in North Carolina. This project (acronym:IPOMS) has been described briefly to this group (Hayne 1978).

METHODS: Selection of orchards for this study was effectively at random. A few years before the IPOMS study began, the North Carolina Agricultural Crop Reporting Service had, for another purpose, photographed Henderson County from the air and outlined on aerial maps all of the obvious orchard plantings in Henderson County; for sampling purposes, they designated "blocks" which were orchard areas mostly of two to eight acres. The work areas for the IPOMS study were chosen at random from these blocks. It was not possible to elicit adequate cooperation in 23 of the 64 selected orchard blocks; these were eliminated. The remaining 41 randomly selected blocks represent as close to a random selection as is possible in a practical study. In addition, investigators included eight blocks carried over from other studies; these perhaps were better operated on the average. The IPOMS study is broad-ranging, with the dead tree survey being only a small part. Some results are reported here from 47 orchards; in five of these only partial information was obtained because the method of tree selection, pulling and examination was not acceptable to the grower.

In the blocks covered, the plan was to pull and examine all dead trees during each of the three winters of 1976-77 through 1978-79. Trees were examined in fall before leaf fall, when dead and dying trees could be distinguished easily and marked. Later in the winter they were pulled and the cause of death determined in the opinion of a two-man team made up of the first two authors, one trained in wildlife and experienced in vole control and the other, a plant pathologist working with apples.

Two kinds of information on tree death are presented here, first, estimates of annual mortality rates for this randomly selected sample of orchards of Henderson County, North Carolina, and second, a percentage allocation of the trees examined to different causes of death based on the judgement of the field crew.

Calculation of mortality rates is complicated by the fact that before we started to identify and remove the dead trees from IPOMS orchards, not all the growers had removed all dead trees every year. Therefore, in some of the orchards (and we did not know which) the dead trees removed the first year were an accumulation of more than one year of mortality and did not provide good information on the annual mortality rate. For this reason, annual mortality rates were determined only from the second and third years' results. We know only to a close approximation the total number of trees living and dead. A count of total living and dead trees was made in February 1976; dead trees were counted in December of 1976, 1977 and 1978. During the following winters the research crew pulled and examined such of these designated trees as the grower would allow. In most but not all cases there was complete agreement as to whether a tree should be pulled; with any disagreement the judgement of the grower prevailed. In a few cases the grower pulled some dead trees as routine orchard maintenance; we believe that in most cases we know the number they pulled. But it may be that the annual mortality rates, calculated from the best information we have, may be slightly underestimated.

The percentage distribution of cause of death is a summary of field records for the 775 trees examined. In judging cause of death the field crew attempted to reach a consensus on the primary cause where two or more factors may have had an influence. Presence of tooth marks on bare wood of roots or trunk, and the edge of the bark being in a distinct line are reliable criteria of vole activity, though not necessarily of responsibility for death.

In distinguishing pine vole damage from that of meadow voles, a number of guidelines were used, and judgement was based on an evaluation of both the damaged tree and the nearby vole habitat in the orchard. Damage to roots and girdling from sod line down is usually associated with pine voles whereas most meadow vole damage is from sod line up. Pine voles seem to begin on the roots and work up. The width of the girdled band is usually greater for meadow voles. Pine vole tooth marks are shorter than those of the meadow vole. Pine voles make more tunnels and holes as compared with more surface runways for meadow voles. Pine voles generally do not leave grass cuttings in the runways but meadow voles will. Pine voles will leave fecal pellets anywhere along the runways while meadow voles generally concentrate them at a few points. Pine vole pellets are smaller than those of the meadow vole pellets.

RESULTS: At the first removal of dead trees from these orchards, 1.6 percent of 28,778 trees were found to be dead and were removed. Individual orchards varied in incidence of dead trees, from 0 to 4.7 percent. During the second and third years of removal when the numbers of dead trees represented annual mortality, on the average 1.0 percent of trees were pulled (1.2 percent the first year, 0.7 percent the second) with this estimate based upon 51,389 tree-years. The highest single value for annual mortality was 5.3 percent; all other values lay below 3.0 percent.

Table 1. Major causes of death of 775 apple trees in 46 Henderson County, NC orchards; trees pulled and examined during winters of 1976-77 through 1978-79.

| Cause of death | Percentage distribution | |
|---|---|---|
| Voles | | |
| Pine voles | 38.1 | |
| Meadow voles | 3.1 | |
| Total, voles | | 41.2 |
| Disease | | |
| Collar rot | 13.9 | |
| White root rot | 9.9 | |
| Clitocybe | 3.2 | |
| Armillaria | 1.8 | |
| Black root rot | 0.3 | |
| Root rot (undetermined) | 7.5 | |
| Union necrosis (TRSV) | 0.3 | |
| Total, disease | | 36.9 |
| Other identified causes | | |
| Winter injury | 1.7 | |
| Top injury | 2.8 | |
| Mechanical injury | 2.3 | |
| Drowning | 4.8 | |
| Roundheaded apple borer | 1.0 | |
| Wooly aphid | 0.3 | |
| Total, other | | 12.9 |
| Unknown causes | | 9.0 |

Cause of death was determined for a total of 775 trees with allocation to the various identified causes as shown in Table 1. The pine vole was by far the most important single cause of death identified, although the two species of voles together accounted for less than half the mortality. All diseases together were slightly less important than the pine vole.

DISCUSSION: This study suggests that only about 40 percent of these deaths of apple trees in Henderson County were caused by voles. Although this was an important loss, it was exceeded by other causes of death. On the average, the annual mortality rate of trees was about 1 percent, thus the average annual loss to voles was less than 0.5 percent. Higher losses, however, were concentrated in relatively few orchards; we recorded one value of 5.7 percent: we may expect that more extreme values would be found if more orchards were studied.

We recognize that the causes of mortality assigned here were not independent and that the death of any one tree may have resulted from the combined action of several factors. In particular, an interaction between vole damage and various root diseases seems to be a good possibility and perhaps an important factor of mortality. What role does the vole play in providing a wound through which the tree may become infected with disease? Does the presence of root disease increase or decrease damage by voles?

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# UPDATE OF PINE VOLE RESEARCH AT THE KEARNEYSVILLE EXPERIMENT FARM

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As reported in the 1979 Proceedings of the Third Eastern Pine and Meadow Vole Symposium, an air and ground broadcast and hand placement in runs and mouse-ateria bait stations (tubes) experiment was started on December 5, 1978. Treatments were to apply brodifacoum (Volak) at 10.0 lb./A and diphacinone (Ramik-Brown) at 10.0 lb. and 20.0 lb./A air broadcast and 10.0 lb./A ground broadcast and hand placement. The air broadcast treatments were not evenly distributed. Ground catch of the air broadcast of brodifacoum resulted in one portion of the treated area receiving 24% more toxicant. The air broadcast treatments of diphacinone resulted in 12.5 lb. and 37.5 lb./A instead of the desired 10.0 lb. and 20.0 lb./A toxicant distribution. A second diphacinone application was made January 5, 1979 to all diphacinone treatments except for the two air broadcast plots. These two plots were treated January 25, 1979 by ground application equipment.

At the time of the first toxicant applications, activity sites selected for apple placement to determine treatment effectiveness were 100% active. Treatment activity ratings made December 27, 1978, January 26, 1979, March 9, May 24 and June 16, 1979 were based upon a 0-10 scale (0 = no part of apple eaten, 3 = less than 50% of flesh eaten, 5 = 50 to 80% of flesh eaten, 8 = 100% of flesh eaten, 10 = flesh and skin completely consumed.) Table 1 gives the results of vole activity for March, May and June.

The high reduction of vole activity in the non-toxicant control plots might be the result of standing water of more than a week in the spring for part of the area.

Two research experiments started in 1979 were: first, a cultural-herbicide treatment comparing very close (short growth) mowing of row middle throughout the year with that of very limited mowing of 1 to 3 times per year, which would allow the indigenous vegetation to grow tall. The cultural-herbicide treatments are in an area where vole activity has been greatly reduced through the use of chemical toxicant treatment. The purpose being to find out the influence of a short and tall vegetation cultural system has on the ease of vole control. The second experiment being that of brodifacoum treatments comparing loose bait with the packet material placed under shingle bait stations and in mouse-aterial bait stations.

Various fescue grass plantings started previously will be monitored for vole activity. These grass plantings have not become very well established in old orchard sites.

Table 1. Vole activity expressed as percent of reduced activity from the 100 percent activity at start of the experiment.

| Treatment | Percent Activity Reduction | | |
|---|---|---|---|
| | March 9 | May 24 | June 16 |
| CONTROL | | | |
| No Toxicant | 28 | 46 | 19 |
| BRODIFACOUM | | | |
| Hand placement-runs | 61 | 89 | 72 |
| Hand placement-tubes | 86 | 72 | 56 |
| Broadcast-ground | 80 | 88 | 83 |
| Broadcast-air 14.2 lb. | 83 | 68 | 98 |
| Broadcast-air 8.7 lb. | 53 | 86 | 89 |
| Average | 73 | 81 | 72 |
| DIPHACINONE | | | |
| Hand placement-runs | 30 | 1 | 13 |
| Hand placement-tubes | 70 | 53 | 15 |
| Broadcast-air 20.0 lb. | 14 | 49 | 25 |
| Broadcast-air 10.0 lb. | 9 | 1 | 15 |
| Broadcast-ground 10.0 lb. | 13 | 0 | 17 |
| Average | 27 | 21 | 17 |

# PINE VOLE CONTROL IN 1979 FIELD PLOTS

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Abstract. Broadcast treatments of Volak (Brodifacoum) applied at rates of approx. 20 lbs/acre gave 98% control of voles when active ingredient levels were from 0.005% to 0.0005% in the bait. Of the two Rozol (Chlorophacinone) formulations tested, the French (Lipha) pelleted formulation appeared to be slightly better than what is currently being marketed in the USA. The Maki (Bromodialone) bait formulated in the same wax bait carrier as the Rozol-USA gave no better control than Rozol. Ramik-Brown (Diphacinone) did not appear to be as good as the other anticoagulants tested when applied either as a broadcast or as a hand placed bait.

Plastic place pack Volak gave excellent control of voles when placed under shingles, old tires split in half, or cinder blocks. A new pelleted Zinc Phosphide formulation from Bell Labs gave excellent control of pine voles when applied as a hand placed or broadcast bait. Zinc Phosphide oat and corn, surface-coated, grain formulations did not perform well. In a separate experiment a laquard wheat formulation of Chlorophacinone performed well as a hand placed bait at 10 lbs/A under shingles.

Introduction: Since the Environmental Protection Agency has been concerned with the potential non-target hazard of Brodifacoum for outdoor uses, a concentration range from 0.005% to 0.0005% was evaluated against pine voles to determine the efficacy of lower active ingredient formulations. In addition, since broadcast baiting for pine voles is rather new, Volak was compared within the same experiment to Rozol, Maki, Ramik-Brown, and two formulations of Zinc Phosphide ($Zn_3P_2$) on a uniform population. Also since little is known about the comparisons of the same formulations applied either as a hand placed or a broadcast bait, Ramik-Brown and two formulations of $Zn_3P_2$ were applied at orchard rates using both methods.

Methods and Materials: Evaluation of pine vole control plots was determined using methods previously described (1,2). In these experiments plots were blocked according to the pretreatment activity readings by first ranking plots from high to low and assigning treatments randomly into activity categories: high, medium, low. Data summarized in Table 1 and 2 was in an orchard having approx. 36 trees/A (35' X 35'). Data in Table 3 was designed to evaluate split rubber tires and concrete cinder blocks (2 X 8 X 16 inches) as a site cover for Volak plastic place packs.

Results and Discussion: Broadcast applications of Volak at reduced active ingredient levels from 50 ppm to 5 ppm gave excellent control of pine voles (Table 1). Presently, we believe a 10 ppm finished bait would be an adequate active ingredient level for pine voles. Without further knowledge about its acute characteristics at lower than the 10 ppm level, I believe this should be the level of the field bait. The Volak place pack with 2 packs/tree or about 70 per acre gave excellent control. However, those sites still active were of concern, since we know no animals were killed at these trees because the packets were not opened. No explanation can be given for why some packets were not opened. Laboratory data indicate that 5-10% of the packets also are not opened in singly caged pine vole trials. Better control was achieved with Rozol than Maki based on % activity. This would not be expected since Bromodialone is more toxic than Chlorophacinone (1).

The most significant finding in the 1979 test was the excellent control achieved by a 2% Pelleted Zinc Phosphide formulation made by Bell Labs, Inc. The data show that the formulation (FMC vs Bell Labs, Table 1) is more important than the method of application (hand placed vs broadcast). The Bell Labs formulation now has a federal label for voles in orchards. The label rates, however, are approx. 1/2 those rates used in these experiments. I am particularly concerned about the broadcast label rate being too low. I believe 10 lbs/acre is at the critical level for the number of pellets per unit area, and therefore, a 15-20 lb/acre rate should be used. The hand placed rate of 2-3 lbs may be sufficient, but more experiments will be required to determine this. The whole wheat Rozol formulation applied as a hand placed bait also gave excellent control of pine voles (Table 2).

The placement of plastic Volak packets under either sliced tires or cinder blocks (Table 3) gave excellent control. Place packs were opened very well over the summer period which gave some evidence that populations may have been quite high if packets had not been present. The % of trees infested in both plots in the fall of 1979 were rather low but some voles were still present. This may have been due to the % of packs unopened as discussed previously.

## Literature Cited

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Table 1. Field evaluation of broadcast and hand placed rodenticides for pine vole control in orchards treated November 14-15, 1979.

| Treatment | Rate (kg/ha) | Rate (lbs/A) | % Activity[y] Nov. 9 | % Activity[y] Nov. 30 | Voles/plot (Dec. 3-7) | Voles/site (Dec. 3-7) | % Control |
|---|---|---|---|---|---|---|---|
| 1. Control | -- | -- | 89 a[z] | 87 a | 31.7 a | 1.25 a | -- |
| 2. Volak[w] -- 0.005% BFC | 21 | 19 | 88 a | 15 def | 0.7 d | 0.03 d | 98 |
| 3. Volak[w] -- 0.0025% BFC | 20 | 18 | 85 a | 6 ef | 0.3 d | 0.01 d | 99 |
| 4. Volak[w] -- 0.001% BFC | 19 | 17 | 88 a | 5 ef | 0.7 d | 0.02 d | 98 |
| 5. Volak[w] -- 0.0005% BFC | 29 | 26 | 85 a | 5 ef | 0.3 d | 0.02 d | 98 |
| 6. Volak[x] -- packet 0.005% BFC | 8 | 7 | 87 a | 4 ef | 1.0 d | 0.03 d | 98 |
| 7. Rozol[w] -- 0.005% CPN (Lipha) | 25 | 22 | 88 a | 0 f | 0.3 d | 0.01 d | 99 |
| 8. Rozol[w] -- 0.005% CPN (USA) | 24 | 21 | 88 a | 33 bcd | 2.7 d | 0.11 d | 91 |
| 9. Maki[w] -- 0.005% BDL | 22 | 20 | 87 a | 44 bcd | 4.7 cd | 0.19 cd | 85 |
| 10. Ramik[w] -- 0.005% DPN | 24 | 21 | 84 a | 51 bc | 6.0 cd | 0.24 bcd | 81 |
| 11. Ramik[x] -- 0.005% DPN | 11 | 10 | 85 a | 40 bcd | 10.7 bc | 0.41 bc | 67 |
| 12. ZnP[w] -- 2% Corn + Oats[u] | 21 | 19 | 85 a | 67 ab | 14.0 b | 0.49 b | 61 |
| 13. ZnP[x] -- 2% Corn + Oats[u] | 6 | 5 | 85 a | 59 abc | 11.0 bc | 0.42 bc | 66 |
| 14. ZnP[w] -- 2% Pellet[v] | 28 | 25 | 89 a | 29 cde | 2.7 d | 0.10 d | 92 |
| 15. ZnP[x] -- 2% Pellet[v] | 6 | 5 | 89 a | 19 def | 1.7 d | 0.07 d | 94 |

[u] Commercially available Corn and Oat formulation from FMC.

[v] Pelleted formulation from Bell Labs.

[w] Treatment was broadcast in a band under tree limbs.

[x] Treatment was hand placed at two locations under shingles at each tree.

[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 hand placed Rozol (CPN) bait on pine vole activity and populations treated November 28, 1979.

| Treatment | Rate | | % Activity[y] | | Voles/plot | Voles/site | % Control |
|---|---|---|---|---|---|---|---|
| | kg/ha | lbs/A | Nov 28 | Dec 13 | | | |
| Control | -- | -- | 81 a[z] | 74 a | 22.0 | 0.97 | -- |
| Rozol -- 0.005% CPN - wheat grain | 11 | 10 | 84 a | 18 b | 0.5 | .02 | 98 |

[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 3. Effect of bait station type on pine vole activity and plastic packet opening of Volak place packs (1979).

| Treatment[x] | April 3 | May 11 | Oct 30 | Nov 28 | May 8 |
|---|---|---|---|---|---|
| | % Activity | | | | |
| 1. Rubber tires | 65 a[y] | 11 a | 22 a | 16 a | 22 a |
| 2. Cinder blocks | 65 a | 1 a | 13 a | 6 b | 17 a |
| | % Plastic packs open | | | | |
| 1. Rubber tires | | 38 b | 98 a | 16 a | 34 a |
| 2. Cinder blocks | | 66 a | 70 b | 15 a | 20 a |

[x] Packets were placed under both tires (sliced in half) or cinder blocks on April 3, May 11, October 30, November 28, May 8.

[y] Mean separation, within columns by Duncan's multiple range test 5%. Three replicate plots/treatment. One site treated per tree. Over 45 sites per plot.

# CURRENT RESEARCH RELATED TO PINE AND MEADOW VOLE DAMAGE CONTROL

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This paper will outline some of the research related to pine and meadow vole damage control which is currently underway at the Winchester Fruit Research Laboratory and outline some of the areas which we will be pursuing in the future. One question which must be answered whenever a chemical is used to control a pest organism is how that chemical is impacting non-target organisms. A study was initiated in the fall of 1979, with the objective of determining by use of radiotelemetry the fates of birds of prey in the vicinity of orchards treated with Brodifacoum, an anticoagulant rodenticide. A further objective was to indirectly assess secondary hazard to birds of prey and scavengers by collecting live voles and vole carcasses after treatment for analysis for anticoagulant residue.

The study area was an orchard near Front Royal, Virginia. The orchard was located in a heavily wooded area which was known to be inhabited by screech owls (Otus asio), great horned owls (Bubo virginianus), and barred owls (Strix varia). Several species of hawks were also observed in the vicinity of the orchard. The orchard itself supported a heavy population of meadow voles (Microtus pennsylvanicus) which was causing considerable damage to the orchard. The orchard was treated with a broadcast application of 50 ppm Brodifacoum bait.

The screech owl was chosen as a subject for study because of its relative abundance in the area and its non-migratory habits. Two screech owls were mist netted in the orchard, fitted with radio-transmitters and released. Unfortunately, the longest time which any of the screech owls retained its transmitter was 3 days and no data could be collected on the ultimate fates of the owls after orchard treatment with Brodifacoum. Three red-tailed hawks (Buteo jamaicensis) were also captured and two of these were radio-tagged and released. Both birds remained in the vicinity for 2 to 3 weeks after capture but eventually contact ceased and, presumably, the birds had left the area.

In addition to the work with raptors an attempt was made to quantify the numbers of meadow voles which died on the ground surface and the Brodifacoum burdens which they carried as well as the burdens carried by live voles during the latency period between application of the material and the start of vole deaths. This is the period during which birds of prey would be most likely to obtain a secondary exposure to the compound. The analysis of the voles collected has not been completed at this time.

We plan to continue to work with and refine our radio-telemetry techniques in preparation for a similar study next fall. We have begun a program of placing nest boxes suitable for screech owls around various orchards in hopes of attracting screech owls to the area thus giving us subjects for study and, hopefully, an easy means by which to capture the owls when the time comes.

We have also begun a series of laboratory trials concerning the efficacy of some of the various zinc phosphide ($Zn_3P_2$) preparations presently available for the control of pine and meadow voles in orchards. Zinc phosphide is a compound which has been in use for a number of years and we feel has the potential to be an important part of the total control program available to the grower at the present time. Firstly, since the compound is not a new one, most growers will be familiar with its use; secondly, having a poison which the grower can alternately use which has a mode of action different from that of the anticoagulants presently in use will forestall or possibly prevent the development of vole strains which are resistant to these poisons; thirdly, we have found some of the new preparations of zinc phosphide now available to be very effective.

Not all the zinc phosphide preparations are equally effective, however. Table 1 shows some of the data available at present concerning the efficacy of a 2% zinc phosphide pellet (Bell Labs, Madison, WI) and a 2% zinc phosphide cracked corn-oat preparation (FMC) for meadow voles. The data are from a 3-day choice test designed after the Microtus dry bait efficacy test of Byers and Palmateer (1979) only fresh Golden Delicious apple was substituted for the EPA challenge diet. We feel this substitution makes the test more stringent and makes the competition which the bait faces more of an approximation to that which would be present in the field at times when the bait would be applied. The animals were observed for 5 days after the poison was withdrawn.

The mortality achieved by the pellet was far superior to that of the FMC grain ($X^2_{(1)} = 15.0$; $p<.05$). The Bell Labs material achieved a quicker and more complete kill than the grain bait. The two baits were equally acceptable to the meadow voles, however, in terms of amounts of each bait eaten and the numbers of voles which consumed the bait. The real difference between the two was in the lethality of the baits to those voles which consumed them. Ninety-four percent of the voles consuming the Bell Labs pellet died compared to only 30% of the voles consuming the FMC grain. This difference may be related to the uniformity of the coating of zinc phosphide on the grain. It may be possible for the voles to select grains which do not have an adequate coating and consume only enough bait to develop an aversion to the bait but not a lethal dose. The consumption of the baits dropped to essentially zero by the second day of treatment.

In a 1-day test with no challenge offered (only bait was present in the cage) the performance of the Bell Labs pellet improved to 100% mortality with meadow voles and the FMC bait performance improved to 75%. The time to death was still significantly greater for the FMC bait, however ($p<.05$).

In Table 2 are the results of a 3-day choice trial with pine voles involving the Bell Labs pellet and FMC grain plus two preparations manufactured by the Bonide Chemical Co. (Yorkville, NY) and a 1% paraffin base pellet (ParaZinc) produced by the ArChem Corp. (Portsmouth, OH). One of the Bonide preparations was a zinc phosphide coated cracked corn and the other was whole crushed oats. Both were 2% zinc phosphide.

The Bell Labs pellet did not perform as well with pine voles as it did with meadow voles (80 vs 90% mortality) but did cause significantly more mortality in pine voles ($p<.05$) than all the other preparations except the Bonide corn bait. A Chi-square test for independence comparing the Bonide corn and oats, the FMC grain, and Para Zinc showed no significant relationship between these preparations and the mortality which occurred in the groups of voles fed each ($X^2_{(3)} = 3.60$; $p<.10$). There was also a significant effect of the preparation on the day on which death occurred with the Bell Labs pellet causing mortality in a significantly shorter period of time after the start of exposure than did the two Bonide preparations ($p<.05$).

All the baits were consumed in the same amounts by the pine voles with the exception of the Bonide oats. The low rate of consumption of this preparation by the pine voles may have been an artifact of its low density. Several particles could have been removed from the feeder without resulting in a measurable change in the amount of material originally given to the animal. As was true with meadow voles, the differences in the efficacy of these preparations for pine voles is probably related to the uniformity with which the toxicant is present in the bait.

We plan to continue to test other zinc phosphide materials as they become available to us in order to make this information available to the growers next season. We are also about to undertake studies to examine factors which influence the hoarding response in pine and meadow voles with the objective of improving bait acceptance and movement in the field.

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Table 1. Performance and acceptability of two zinc phosphide preparations to meadow voles in a 3-day choice test (apple challenge).

| | Pellets (Bell Labs) | Grain (FMC) | Control |
|---|---|---|---|
| Mortality | 18/20 (90%) | 6/20 (30%) | 0/20 (0%) |
| Mean days to death ($\pm$ SE)[a] | 1.3 $\pm$ 0.1 | 2.0 $\pm$ 1.1 | - |
| No. consuming bait | 18/20 (90%) | 20/20 (100%) | - |
| Mortality in consuming voles | 17/18 (94%) | 6/20 (30%) | - |
| Mean bait consumption ($\pm$ SE) | | | |
| Day 1 (n) | 0.6 $\pm$ 0.1 (20) | 0.7 $\pm$ 0.1 (20) | - |
| Day 2 (n) | 0.02 $\pm$ 0.01 (6) | 0.02 $\pm$ 0.01 (18) | - |
| Day 3 (n) | 0.0 (3) | 0.01 $\pm$ 0.01 (15) | - |

[a] Significant difference between means ($p<.05$; analysis of variance).

Table 2. Performance and acceptability of five zinc phosphide preparations in a 3-day choice trial with pine voles (apple challenge).

| | Control | Bell Labs pellet | Bonide corn | Bonide oats | FMC grain | ParaZinc |
|---|---|---|---|---|---|---|
| Mortality | 0/20 (0%) | 16/20 (80%) | 13/20 (65%) | 10/20 (50%) | 10/20 (50%) | 7/20 (35%) |
| Mean day of death ($\pm$ SE) | - | $1.2 \pm 0.1^{a}$ | $3.2 \pm 0.6^{b,c}$ | $3.8 \pm 0.6^{c}$ | $1.8 \pm 0.2^{a,b}$ | $1.9 \pm 0.5^{a,b}$ |
| No. voles consuming bait | - | 19/20 (95%) | 19/20 (95%) | 4/20 (20%) | 16/20 (80%) | 18/20 (90%) |
| No. consumers dying | - | 16/19 (84%) | 12/19 (63%) | 1/4 (25%) | 8/16 (50%) | 7/18 (39%) |
| Mean bait consumption ($\pm$ SE) | | | | | | |
| Day 1 (n) | - | $0.5 \pm 0.1^{a}$ (20) | $0.5 \pm 0.1^{a}$ (20) | $0.03 \pm 0.02^{b}$ (20) | $0.4 \pm 0.1^{a}$ (20) | $0.4 \pm 0.3^{a}$ (20) |
| Day 2 (n) | - | 0.0 (8) | $0.1 \pm 0.03$ (16) | 0.0 (19) | $0.02 \pm 0.02$ (17) | $0.1 \pm 0.04$ (16) |
| Day 3 (n) | - | 0.0 (4) | 0.0 (13) | $0.01 \pm 0.01$ (13) | 0.0 (11) | 0.0 (15) |

$^{a,b,c}$ Means in the same row with different superscripts significantly different, $p<.05$ (Duncan's multiple range test).

# FIELD EVALUATION OF CANDIDATE RODENTICIDES

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During autumn of 1978 and 1979 the New York Cooperative Wildlife Research Unit continued its program of research and management aimed at the pine vole (Pitymys pinetorum) and meadow vole (Microtus pennsylvanicus). Two herbicides, Ammate-X (E.I. Dupont de Nemours) and Kerb (Rhom & Haas Corp.) along with 4 candidate rodenticides, Bromadiolone and Chlorophacinone (Chempar Inc.), Volak (I.C.I. Chemicals Inc.) and zinc phosphide (Bell Laboratories Inc.) were tested in both orchard and laboratory situations. This work is being conducted in conjunction with a separate research unit project aimed at evaluating the potential of using populations of the larger meadow vole to limit the invasion and success of the smaller but more troublesome pine vole. This biological control aspect will be treated in a separate manuscript.

## METHODS

Because prepared baits and chemicals may deteriorate with time and handling we examined all of our test materials in laboratory trials to establish their lethality. Likewise we examined the candidate herbicides for any direct toxic effects on voles. This work was conducted with a laboratory colony of prairie voles (M. ochrogaster), a species closely related to the orchard voles that are pests in New York. Adult animals were housed two per cage and provided with rabbit chow and water ad libitum. Wood shavings served as bedding; all animals were subjected to a lighting regime of 14 L 10 D.

The herbicides Kerb and Ammate-X were prepared as per label instructions and each applied to 16 animals and their food pellets with a hand sprayer. The animals were observed for mortality or aberrant behavior for two weeks post treatment. Bromadiolone, Chlorophacinone, Volak and zinc phosphide each were offered to 8 caged pairs as treated baits in the absence of other food. These pairs were also observed for two weeks or until all had died. Results of this work are summarized in Table 1.

Field testing of the 2 herbicides and 4 rodenticides was conducted in Ulster Co., New York between 2 September and 15 December of 1978 and 1979. Thirteen separate orchard plantings of 45 trees each (5 rows x 9 trees) were selected in the towns of New Paltz, Highland, Clintondale and Brewster, N.Y. All 13 of the orchards had pine vole populations and 5 had both pine and meadow voles present as confirmed by live trapping. Tree variety, age and management differed across plots and there was no attempt to control these variables. A pre-treatment vole activity index (Eadie 1954) was determined by placing an apple slice under a tarpaper cover and reexamining the apple slice after 24 hours. Post-treatment activity levels were monitored in the same way usually at one, two, four and six weeks.

Table 1. Results of preliminary laboratory screening for toxicity of candidate rodent control materials.

| Candidate material | No. voles M. ochrogaster | No. surviving after 4 da | 8 da | 16 da | 14 da | Percent mortality |
|---|---|---|---|---|---|---|
| Herbicide | | | | | | |
| Kerb (4 lbs/a) | 16 | 16 | 16 | 14 | 14 | 12% |
| Ammate (120 lbs/a) | 16 | 16 | 16 | 15 | 15 | 6% |
| Rodenticide | | | | | | |
| Bromadiolone (pellets) | 16 | 5 | 1 | 0 | 0 | 100% |
| Volak (pellets) | 16 | 0 | 0 | 0 | 0 | 100% |
| Zinc phosphide (pellets) | 16 | 2 | 1 | 1 | 1 | 94% |
| Chlorophacinone (lacquered wheat) | 16 | 6 | 2 | 1 | 0 | 100% |

There are two basic choices to be made in the field evaluation of candidate rodenticides. One must make either an intensive effort to study a few materials with different application rates and times and with replication of each test or an extensive effort with a variety of candidate materials but with fewer treatment variables and replications. Because there exist a variety of candidate materials and methods that have some potential in orchard pest management and because we were attempting to provide a preliminary screening of several materials we opted for the extensive approach with a limited number of replications. Table 2 provides a summary of the materials tested, their formulation, and rates of application. Results are given as the percent activity remaining in the treated plot. Post-treatment indices are derived only from those trees that were determined active at the time of pre-treatment indexing.

Table 2. Candidate materials selected for field-testing in 1978 and 1979.

| | | | |
|---|---|---|---|
| Bromadiolone (pellets) | Handbaiting | @ | 10-12 lbs/A |
| | Handbaiting | @ | 10-12 lbs/A |
| | Broadcast | @ | 20 lbs/A |
| Chlorophacinone (lacquered wheat) | Handbaiting | @ | 10-12 lbs/A |
| | Handbaiting | @ | 10-12 lbs/A |
| | Handbaiting | @ | 10-12 lbs/A |
| Zinc phosphide (pellets) | Handbaiting | @ | 4 lbs/A |
| | Handbaiting | @ | 4 lbs/A |
| | Broadcast | @ | 10 lbs/A |
| Volak (pellets) | Broadcast | @ | 10 lbs/A |
| Kerb (wettable powder) | Backpack sprayer | @ | 1 lbs/A |
| | Backpack sprayer | @ | 4 lbs/A |
| Ammate (liquid) | Backpack sprayer | @ | 120 lbs/A |

## RESULTS AND DISCUSSION

Laboratory evaluation of Kerb and Ammate for a direct effect on voles proved negative (Table 1). The voles in both herbicide treatment groups ate less than did a control group given untreated rabbit chow; however, there was no mortality or unusual behavior within the first eight days and the deaths that did occur later may have been caused by an aggressive cage mate. Later, when applied as intended for vegetation control both materials were very effective. All four rodenticides were effective when offered without choice to caged voles (Table 1). The Chlorophacinone lacquered wheat was not eaten as readily as the other baits but was consumed as rapidly as untreated wheat offered to a control group. Overall, the baits were quite toxic when offered without choice over several days.

Field evaluations of three herbicide treatments are shown in Figures 1 and 2. Kerb applied at one and at four pounds per acre of ground cover had a slight effect in reduction of pine vole activity. Kerb was very effective in killing the ground cover in both of the plots but well-established vole tunnels continued to harbor animals in spite of a dead sod layer on the surface. Heavy snow cover prevented later evaluation of these plots and by spring, pine voles had declined to an extremely low level throughout the control and experimental plots.

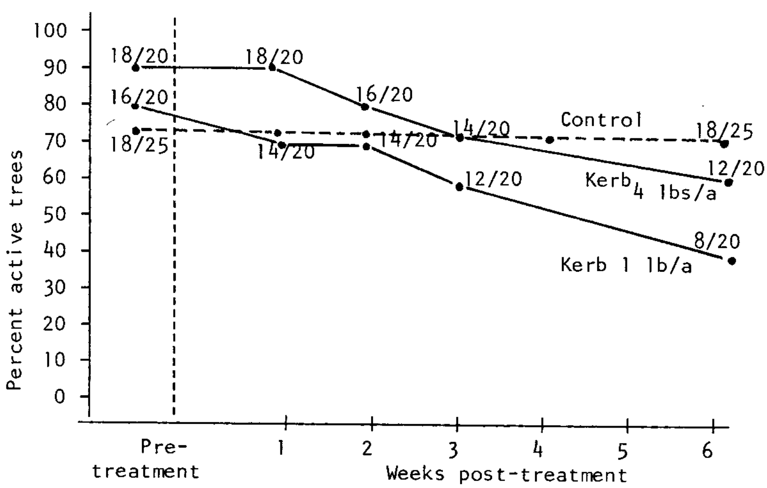


Figure 1. Effects of ground-sprayed Kerb on pine vole activity indices, Ulster, Co., New York.

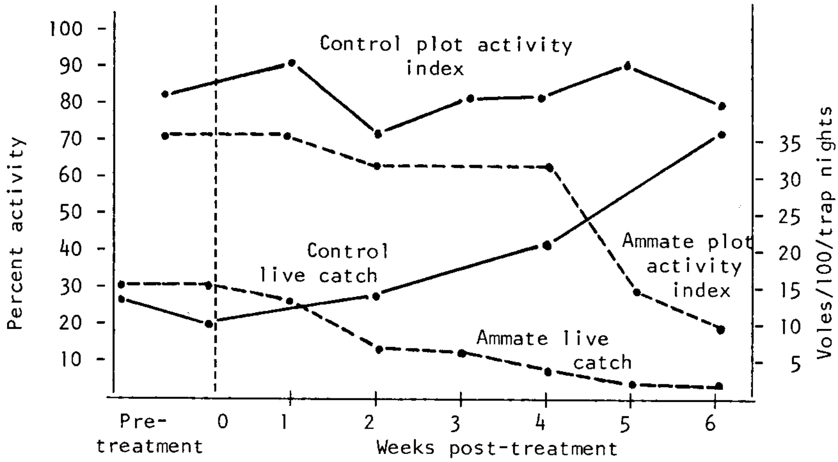


Figure 2. Effects of the herbicide Ammate-X on pine vole and meadow vole activity indices and live catch.

Ammate-X, a broad spectrum herbicide, was applied at the recommended rate of 120 lbs/acre to an orchard that we had previously live-trapped and also indexed using the apple slice technique. A drift fence, 8 inches high, placed on all sides of the orchard allowed us to measure ingress and egress of voles by livetrapping before and following herbicide treatment. The results shown in Figure 2 indicate that destroying the ground cover in early fall will cause a substantial movement of voles from the treated area. Both the activity index and the live catch dropped markedly after treatment. It should be noted that the treatment area contained a large proportion of meadow voles and only a few pine voles. In the previous experiment with Kerb (Figure 1) the population was known to be largely pine voles. The difference in response to the two herbicides is likely due to behavioral differences in the two species. Pine voles appear to be slower than meadow voles in responding to a habitat change that affects the orchard ground cover. In both experiments however the number of animals showed a decline lending promise to the continued testing of herbicides for vegetative manipulation and ultimately vole management.

Results from the application of Volak to a single plot at the rate of 10 lbs. per acre are shown in Figure 3. Drawing conclusions from a single application is inappropriate; however, the material does appear promising due in part to the fact that it gave reasonably good results when applied via broadcast in an orchard heavily infested with pine voles. A repeated broadcast application or handbaiting would likely yield even better results.

Bromadiolone (Maki), a new anticoagulant from the family of hydroxycoumarins, has shown considerable promise as a rodenticide and was investigated on three plots. The results of this work are shown in

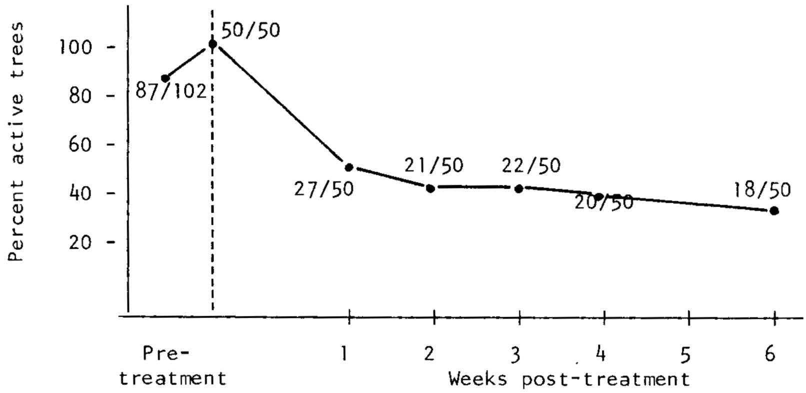


Figure 3. Effects of broadcast baiting with Volak on orchard vole activity indices.

figures 4, 5 and 6. The two handbaiting trials proved more effective than the broadcast method as has been our experience from previous work with rodenticides and pine voles. Bromadiolone was readily accepted by prairie voles in the laboratory and by both pine and meadow voles in the field.

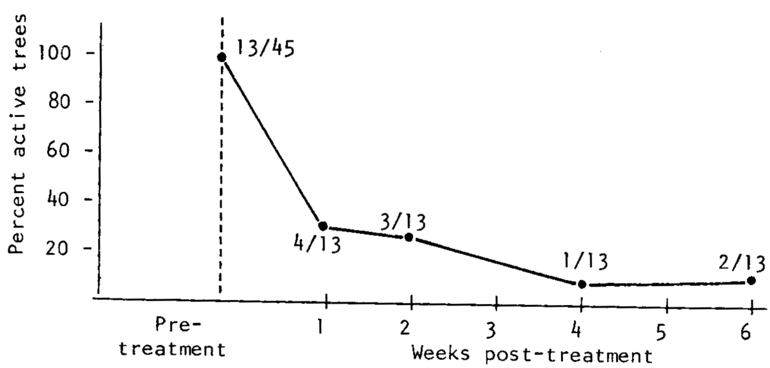


Figure 4. Effects of handbaiting with Bromodiolone pellets (Maki) on orchard vole activity indices.

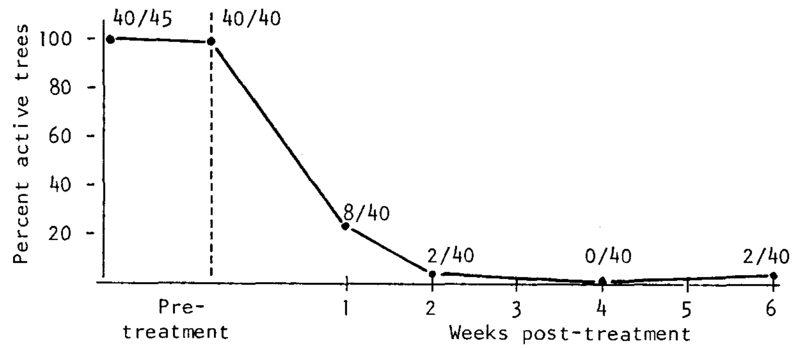


Figure 5. Effects of handbaiting with Bromodiolone pellets (Maki) on orchard vole activity indices.

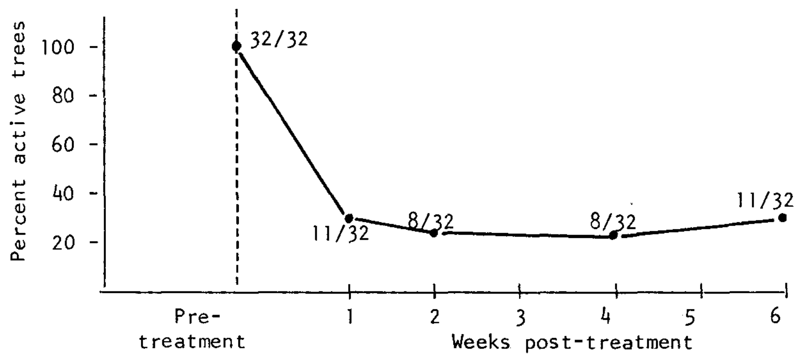


Figure 6. Effects of broadcasting with Bromodiolone pellets (Maki) on orchard vole activity indices.

Another anticoagulant, Chlorophacinone (Rozol), was tested as a lacquered wheat preparation and applied by handbaiting under tarpaper bait covers. Results of this work are presented in Figures 7, 8 and 9. Chlorophacinone/wheat gave reasonable control in the two low density plots but was much less effective in the high density situation (Figure 7). These results suggest that a second baiting is necessary in orchards where vole density is high.

Zinc phosphide, available in a new formulation (pelleted bait) was broadcast at 10 lbs/acre on one plot and handbaited at the rate of 4 lbs/acre on two other plots. Figures 10, 11 and 12 indicate that the broadcast application was as effective as the two handbaiting trials, although none of the treatments reduced vole activity indices below 20 percent. By the end of the 6th week activity indices ranged from 28 to 50 percent of the original activity level. Zinc phosphide has

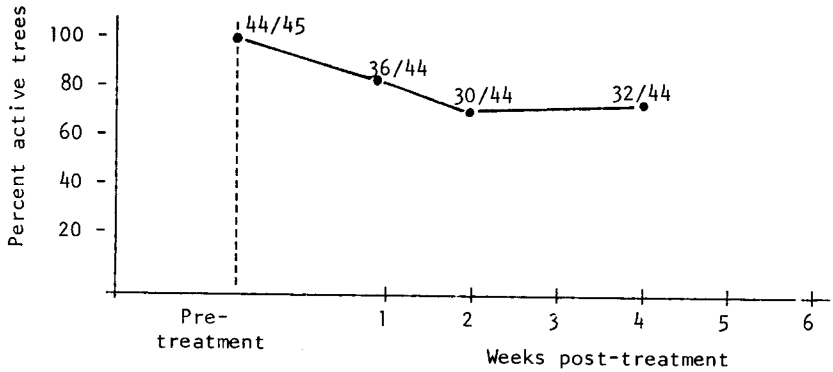


Figure 7. Effects of handbaiting with Chlorophacinone lacquered wheat on orchard vole activity

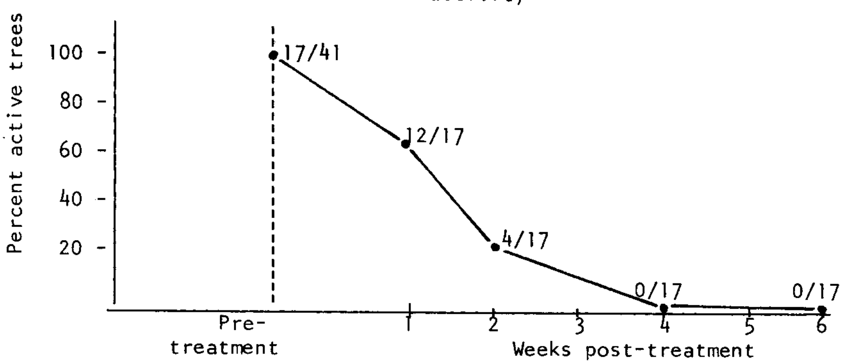


Figure 8. Effects of handbaiting with Chlorophacinone lacquered wheat on orchard vole activity.

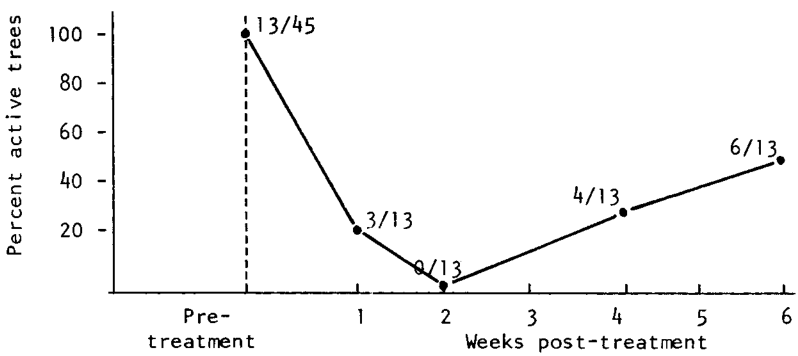


Figure 9. Effects of handbaiting with Chlorophacinone lacquered wheat on orchard vole activity.

traditionally been a suitable rodenticide when applied to apple cubes or cracked corn and we feel that additional trials of the new pelleted formulation are warranted in spite of the somewhat discouraging results noted here.

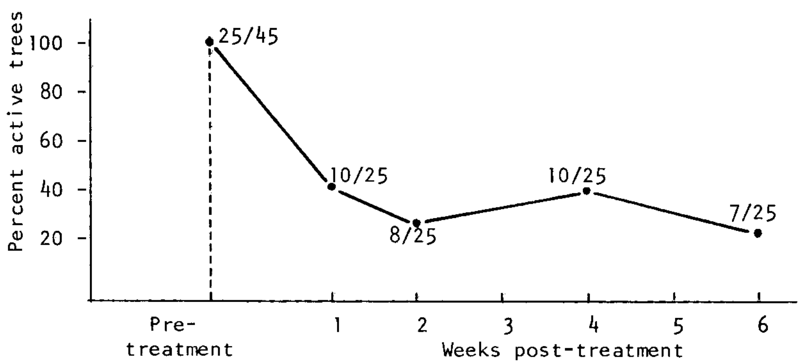


Figure 10. Effects of Zinc Phosphide pellets on orchard vole activity indices (10 lbs/acre broadcast).

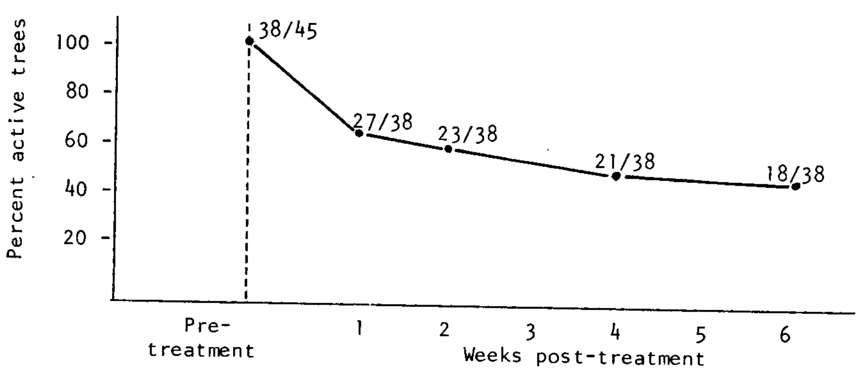


Figure 11. Effects of Zinc Phosphide pellets on orchard vole activity indices (4 lbs/acre handbaited)

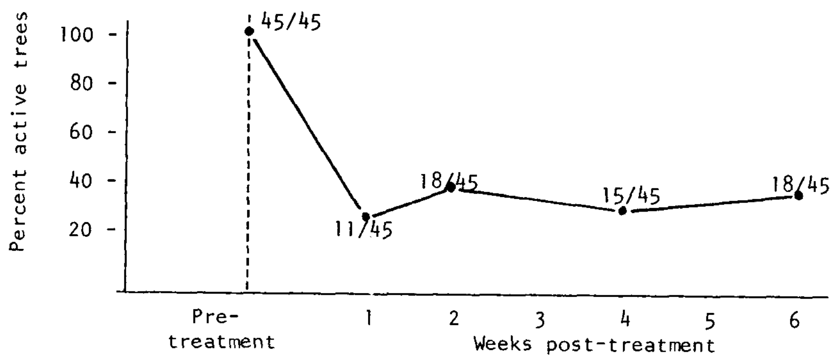


Figure 12. Effects of Zinc Phosphide pellets on orchard vole activity indices (4 lbs/acre handbaited).

The results of this work coupled with findings from previous years (Richmond et al. 1978, Byers and Young 1975, Byers et al. 1976, Byers 1978) suggest that a variety of rodenticides and cultural practices now exist that, in the hands of the careful and well trained pest control manager, will reduce orchard vole populations to a tolerable level. It continues to be argued by growers and others that techniques and products available to us are not cost effective. This may be true; however, the data to refute or accept this claim are not yet available. Regardless of the answer, research and management should expand their efforts to seek optimum, safe control strategies and continue an effort to reduce the cost of pest control for the grower.

We thank the several growers who allowed us access to their property and occasionally provided help by changing their harvest or management plans. John Hochstein, Jon Bart, Bob Mungari and Barbara Hiaasen helped with the livetrapping and some of the indexing of vole populations. Nancy Bowers typed the initial and the final drafts and helped with the figures.

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# EFFECTIVE VOLE CONTROL WITH ZP RODENT BAIT AG

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Since the loss of DDT, Vacor (DPL 787) and other acute rodenticides and the serious use restrictions placed upon strychnine and 1080 for field use, it has become quite apparent that control of field rodents, more particular pine and meadow voles, with standard anticoagulants has become a difficult task, and in some instances impossible.

Bell Laboratories, Inc. has chosen to take a very serious look at many of the older compounds and rework and reformulate these compounds into palatable and efficacious finished baits. After 5 years of research and development, Bell Laboratories, Inc. has recently registered, with the Environmental Protection Agency, a new acute single dose bait formulation containing 2% zinc phosphide, namely ZP Rodent Bait AG.

ZP Rodent Bait AG is registered for control of ground squirrels in noncrop areas, prairie dogs in rangeland, rats in sugar cane and meadow and pine voles in apple orchards and noncrop areas.

Prior to the EPA registration of Bell Laboratories' ZP products (tracking powder, commensal rodent bait and ag bait) it was generally believed and accepted that the active ingredient, zinc phosphide, reacted with the moisture in the atmosphere to release phosphine gas. Based upon field and laboratory studies, it has been determined that zinc phosphide is an extremely stable compound and degradation occurs only when the compound comes in direct contact with dilute acids or by the mechanical factors of weathering (wind and rain) where the compound is physically removed from the base material.

Further, zinc phosphide reacts with stomach acids to yield phosphine gas and naturally occurring zinc salts. Phosphine gas is not stored in muscle or tissue of poisoned animals, so there is no true secondary poisoning with this rodenticide. In studies conducted by the U.S. Fish and Wildlife Service, where zinc phosphide poisoned nutria were ground and fed to golden eagles, bald eagles, vultures, kit fox, coyotes and mink, the test animals demonstrated no adverse effects, however a few of the test animals regurgitated the ground nutria which was due to the natural emetic action of zinc phosphide.

Zinc phosphide has always been considered to be an extremely toxic compound. The acute oral $LD_{50}$ for 94% technical zinc phosphide is 27 mg/Kg. The acute oral $LD_{50}$ of ZP Rodent Bait AG (2% zinc phosphide) is approximately 1350 mg/Kg. and is rated a Category III pesticide by the EPA, however, due to the broad use pattern of the product, ZP Rodent Bait AG is a restricted use pesticide.

Technical zinc phosphide shows very slight toxicity by means of dermal exposure ($LD_{50}$ 2000-5000 mg/Kg.) However, once zinc phosphide is formulated into a 2% finished bait the dermal hazards are even further reduced.

Acute Inhalation $LC_{50}$ study was performed on a product (in dust form) at 5 times the concentration of a dry bait (2% ZP Rodent Bait AG) and found to be nontoxic at a rate of 19.6 mg/liter of air.

Zinc Phosphide is not considered to be an acute eye irritant nor is it considered to be a primary skin irritant.
Based upon the mode of action, low secondary hazards, and toxicity data: zinc phosphide can be generally regarded as being a relatively safe compound when used according to label directions.
The secret behind manufacturing quality rodenticides is the base materials used. With a chronic rodenticide the bait must be palatable so that the rodent returns for repetitive feedings. The same principle holds true in dealing with acute poisons where ideally the target rodent will ingest a lethal dose in just one feeding. Bell Laboratories, Inc. has approached and solved the palatability problem by using a scientific blend of food grade cereals. In using food grade inerts, two primary obstacles have been overcome: 1. The product is extremely palatable so that it can be competitive against naturally occurring foods and 2. The product is much more stable.
Into these food grade cereals is blended a 2% concentration of zinc phosphide using special binding agents to adhere the active to the base materials. Prior to the registration of ZP Rodent Bait AG all other zinc phosphide formulations were either coated on oat groats, cracked corn or other feed grade inerts, in doing so, the product was perhaps economical to produce, but was not attractive to the rodent.
ZP Rodent Bait AG is currently registered for control of pine and meadow mice (voles, Microtus, spp.) in apple orchards. Hand baiting, trailbuilder and broadcast baiting directions have been incorporated into the label directions.
In preliminary studies conducted by Winchester Fruit Research Laboratory in both the field and laboratory, ZP Rodent Bait AG has demonstrated to be a very effective control measure for pine and meadow vole control reducing field populations a minimum of 94%.

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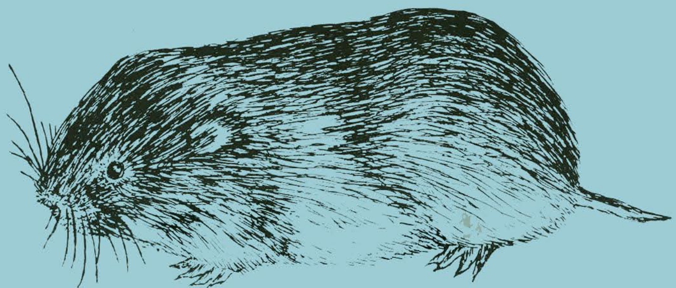
Prairie vole - Microtus ochrogaster (Wagner)



Pine vole - Microtus Pitymys pinetorum (LeConte)


Meadow vole - Microtus pennsylvanicus (Ord)