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Don W. Hayne
North Carolina State University, Raleigh, NC

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Don W. Hayne
Professor, Statistics and Zoology
North Carolina State University
Raleigh, North Carolina 27650

ABSTRACT: This is a preliminary report on the vole portions of an interdisciplinary study of integrated pest and orchard management systems (IPOMS) in North Carolina. Vole trapping results of winter 1976-77 in 46 orchards are reported and compared to vegetational and chemical measurements made in the same orchards the previous summer.

INTRODUCTION: IPOMS is an acronym representing an interdisciplinary project of the North Carolina Agricultural Experiment Station entitled "Integrated Pest and Orchard Management Systems for Apples in North Carolina." This project unites the efforts of specialists in a number of different disciplines in a joint study. The project is at present in the data-gathering phase with the first records made in 1976. The study of voles in orchards is a relatively small part of the whole study.

One unique and valuable characteristic of the study is that the orchard blocks and the trees within these blocks, were selected at random; therefore we have an unbiased sample of orchards of a county.

A second important characteristic of the study is its breadth, as illustrated here where data from voles are compared with those gathered on the same orchards and the same trees by weed scientists (vegetative records), horticulturists (leaf analyses), soil scientists (soil analyses) and plant pathologists (tree death analyses). All of these data, and more, are being recorded on the same sites; this would not be possible if done solely for the purpose of investigating relationships to vole populations.

This report covers the vole trapping and the dead tree survey of the winter of 1976-77 and the vole signs, vegetational, and chemical records of the summer of 1976. Results are tentative in that only a single season is involved.

METHODS: Selection of study sites. The orchards where the study is being carried out were selected at random from aerial photographs covering Henderson County, North Carolina. First, all areas of orchard were divided into smaller pieces of land of suitable size (less than about 25 acres, mostly less than 8 acres), marked on the aerial photographs, numbered and listed. From this list a sample was drawn at random, and these portions of orchards were visited on the ground. Each was divided into subareas, one of which was chosen at random as the sample area (block). Within each such block, 8 to 18 study trees were chosen at random, averaging about 10 per block. Management practices are being studied in the orchard block that contains the sample area.

The study depends upon grower cooperation. Initially, 41 of the 60 randomly chosen sample areas belonged to growers who chose to cooperate. Absentee and changing ownership was an important reason for failure to cooperate. By-and-large we feel that the IPOMS project is based upon a sample that is just about as close to random as it is practical to achieve with operating orchards.

In addition to the random sample, eight other cooperating orchards are included in the study.

Trapping. Live traps were set in the sample blocks near each sample tree, with one trap at each of the adjacent trees in the same row as the sample tree and one trap at each of the two closest trees in the adjacent rows. Thus 4 traps were set for each sample tree but none was set immediately beneath the sample tree (to avoid disturbing the sample tree's vegetation). After traps were set, they were visited at 24 and 48 hours, and then removed. Live animals were marked and released; dead voles were examined for embryos. Trapping was completed in November and December. In data represented here a total of 2,119 traps were set twice (one trap was missing) near 530 sample trees in 48 sample blocks. Because one trap was missing and a number were sprung without capturing an animal, the effective total number functioning and able to capture an animal was 2,067 per setting (instead of 2,119) counting each tripped trap as one-half effective. Estimated population numbers are stated as per functioning trap (or per tree since there was one trap per tree).

Population estimates. Populations were estimated by calculating a capture probability for trapped animals. There are two estimates:

1. $p_1 = \frac{C_{12}}{C_1}$

2. $p_2 = \frac{C_{12}}{C_2}$

where C_{12} = animals captured both periods

C_1 = animals marked and released alive at the first trapping

C_2 = all animals captured at the second trapping

The mean value is:

$$\bar{p} = \frac{C_{12}}{2}\left(\frac{1}{C_1} + \frac{1}{C_2}\right) .$$

The expected value for total number captured is:

$$E(C_T) = P(2p - p^2).$$

From this, I estimated $\hat{P}$ as:

$$\hat{P} = \frac{C_T}{2p - p^2} .$$

Records of adult males, adult females and all immatures were examined for evidence of a difference in the proportion of live marked releases the first night, recaptured the second night. No significant difference was found by x^2 test, and records were pooled. These pooled records were used to estimate capture probability and the expansion factor for estimating the total population. This factor is the reciprocal of $2p - p^2$; this was multiplied by the total number of individuals captured to estimate the population number.

Vole signs. At the same time the notes on the vegetation of the orchard floor were recorded, signs of vole presence and activity were made. These signs are calculated as a "local frequency," here called tree frequency, by scoring 1 for each of the 20 plots where vole signs occurred, and dividing the sum of these scores for one tree by 20. This tree frequency is then averaged over all the sample trees in the block.

The only vegetational data examined for relationship to vole signs or numbers were those for percent bare ground, height of dominant vegetation, thatch depth, and number of plant species; average block values were used here.

Leaf analyses. Vole numbers were also compared to average growing season leaf content of a series of 11 plant nutrients, separately in simple regression and in multiple regression. The hypothesis here was that vole numbers may reflect the nutrient condition of an orchard; it is commonly stated that voles are easier to find in orchards that are heavily fertilized.

Soil analyses. Vole numbers were compared to average surface soil content of plant nutrients, using regression methods.

Dead tree survey. Dr. Turner Sutton and Bill Sullivan pulled and examined all 324 dead trees in 35 orchard blocks during the winter of 1976-77. For each dead tree, they made a judgement as to the principal cause of death, whether disease, vole injury or other factors. Whether lethal vole injury was caused by pine voles or meadow voles was judged primarily by the location of injury on the root system, whether above or below the ground level, with some weight given to signs of current activity.

RESULTS: Species captured. The 1976 live-trapping made a total of 442 captures of small mammals of 8 species; most of these were of pine voles (Table 1).

Table 1. Results of live-trapping in 48 IPOMS orchards in the winter of 1976-77

Species	No. of captures	
Pine vole	336	(311 individuals)
Meadow vole	40	(36 individuals)
Short-tailed shrew	52	
Deer mouse	2	
House mouse	1	
Jumping mouse	4	
Norway rat	4	
Cotton rat	3	
Total Captures	442	

Prevalence of voles. In the 48 orchard blocks trapped, voles of either species were captured in 34 blocks (Table 2) with pine voles in 32 (66.7%), meadow voles in 12 (25.0%) and neither species in 14 (29.2%).

Pine vs. meadow voles. It has been reported that one species of vole drives out the other. This question was examined in two ways, as to prevalence and as to correlation of numbers; neither method supported the idea of much influence of one species on the other.

Table 2. Species prevalence (presence or absence) of voles in 48 IPOMS orchards, winter 1976-77

		Meadow Vole		
		Present	Absent	Total
Pine Vole	Present	10	22	32
	Absent	2	14	16
	Total	12	36	48

Based on the overall prevalence of each species (Table 2) the expected numbers of orchard blocks containing both species would be 8 (instead of 10 as observed) and containing neither species, 12 (instead of 14 as observed). These deviations are within expected sampling variation and thus there is no evidence here of any association (negative or positive) between the two species of voles.

Next the estimated population numbers (Table 3) were examined for any relationship from orchard to orchard. A linear regression of meadow vole numbers on pine vole numbers showed a weakly significant relationship ($n = 48$; $R^2 = 0.071$; $p = 0.07$). The intercept was +0.048 and the slope +0.036.

Populations of voles. The capture probabilities and expansion factors were estimated from the trapping records as shown in Table 3.

Table 3. Capture probabilities and expansion factors, winter 1976-77, IPOMS vole live-trapping

Species	Capture probability p	$2p-p^2$	Factor = reciprocal of $2p-p^2$
Pine vole	.07820	.1503	6.654
Meadow vole	.1053	.1994	5.014

Although the calculated capture probability for the meadow vole was about one-third greater than that for the pine vole, the difference was not statistically significant by chi-square test.

The estimated numbers of voles per tree are shown in Table 4, separately for the two species.

Population numbers are highly variable from orchard to orchard, representing many low and relatively few high values (Table 4). A better idea of the distribution is presented by a calculation using log-transformed data ($x = \log_{10}(x' + 0.1)$). Here for pine voles the geometric mean is 0.35 mice per tree, with 2 standard deviation (95%) limits of 0.02 and 5.2 mice per tree; with meadow voles the geometric mean is 0.04 mice per tree with 2 standard deviation limits of 0.01 and 0.14 mice per tree. For the total of both species the geometric mean is 0.40 with 2 standard deviations ranging from 0.03 to 5.9 voles per tree. These values refer to orchard block averages, each based on a number of trees per block (average 45); values based upon single trees would be more variable.

Table 4. Estimated number of voles per tree in 48 IPOMS sample blocks winter 1976-77

Block	Pine Vole	Meadow Vole	Block	Pine Vole	Meadow Vole	Block	Pine Vole	Meadow Vole
1	0.9	0.0	17	0.3	0.0	34	0.3	0.1
2	2.3	0.0	18	0.0	0.0	35	2.0	0.0
3	3.0	0.0	19	0.0	0.0	36	0.7	0.1
4	0.0	0.0	20	0.0	0.0	37	0.2	0.1
5	3.6	0.1	21	1.6	1.0	38	0.0	0.0
6	2.9	0.0	22	0.2	0.0	39	1.0	0.6
7	1.2	0.0	23	0.1	0.0	40	0.0	0.0
8	0.0	0.0	24	1.5	0.0	41	0.0	0.0
9	0.2	0.0	25	0.4	0.3	42	1.2	0.0
10	0.4	0.0	26	2.4	0.0	43	0.5	0.0
11	3.4	0.0	27	2.9	0.0	44	0.3	0.0
12	0.1	0.1	28	2.9	0.0	45	0.0	0.0
13	0.0	0.0	29	0.2	0.0	46	0.3	0.0
14	0.0	0.0	30	1.5	0.0	47	0.0	0.0
15	0.2	0.3	31	0.0	0.2	48	0.0	0.0
16	7.9	0.6	32	0.0	0.5	49	0.0	0.0

Arithmetic Mean ± dev.: Pine vole 0.97 ± 1.49; Meadow vole 0.08 ± 0.20

Summer vole signs and winter vole numbers. A practical question is how well winter vole populations can be predicted from the summer signs of vole activity. This was examined by a linear regression of total vole numbers (sum of pine and meadow voles) on tree frequency, which is the index of summer vole activity. The data used are shown in Table 5, along with the values for number of voles "predicted" from tree frequency. The linear regression established on 46 points was highly significant ($p = .0001$) accounting for a moderate fraction of the variability ($R^2 = 0.57$; see Table 6). The predicting equation is: Vole number = 0.3 + 16.3 (tree frequency). Inspection of Table 5 shows that while some "predictions" were quite close, others missed by important margins.

One point (block no. 16) stands out as the highest value for both summer signs and winter numbers; a natural question is whether this value is responsible alone for the apparent relationship. When this point is excluded, a linear regression based on the remaining 45 points shows a highly significant relationship ($p = .003$) although with less of the variability accounted for ($R^2 = 0.18$). The predicting equation here is: Vole number = 0.5 + 10.2 (tree frequency).

Table 5. Tree frequency of activity in summer 1976, subsequent vole numbers in winter 1976-77, and vole number "predicted" by the regression on summer activity, in 46 IPOMS orchard blocks

Block	Tree Freq.	Vole Nos. Obs.	Vole Nos. Pred.	Block	Tree Freq.	Vole Nos. Obs.	Vole Nos. Pred.	Block	Tree Freq.	Vole Nos. Obs.	Vole Nos. Pred.
1	0.062	0.9	1.3	18	0.115	0.0	2.2	35	0.030	2.0	0.8
2	0.092	2.3	1.8	19	0.050	0.0	1.1	36	0.000	0.8	0.3
3	0.125	3.0	2.4	20	0.040	0.0	1.0	37	0.015	0.3	0.6
4	0.039	0.0	1.0	21	0.000	2.6	0.3	38	0.000	0.0	0.3
5	0.111	3.7	2.1	22	0.040	0.2	1.0	39	0.009	1.6	0.5
6	0.123	2.9	2.3	23	0.000	0.1	0.3	40	0.000	0.0	0.3
7	0.041	1.2	1.0	24	0.086	1.5	1.7	41	0.000	0.0	0.3
8	0.000	0.0	0.3	25	0.000	0.7	0.3	42	0.012	1.2	0.5
9	0.000	0.2	0.3	26	0.141	2.4	2.6	43	0.059	0.5	1.3
10	0.000	0.4	0.3	27	0.000	2.9	0.3	44	0.196	0.3	3.5
11	0.066	3.4	1.4	28	0.085	2.9	1.7	45	0.000	0.0	0.3
12	0.043	0.2	1.0	29	0.0125	0.2	0.5	46	0.012	0.3	0.5
13	0.000	0.0	0.3	30	0.056	1.5	1.2	47	0.000	0.0	0.3
14	0.000	0.0	0.3	31	0.044	0.2	1.0	48	0.000	0.0	0.3
16	0.414	8.5	7.1	32	0.000	0.5	0.3				
17	0.010	0.3	0.5	33	0.000	0.0	0.3				

Summer vegetational characteristics and winter vole numbers. Vole numbers were examined as to regression on the gross vegetational characteristics of percent bare ground, height of dominant vegetation and thatch depth. None of these regressions accounted for an appreciable fraction of the variability (Table 6).

Table 6. Regressions of vole numbers in winter on gross vegetational characteristics of the previous summer (including tree frequency) IPOMS 1976-77 trapping data from 46 orchard blocks

Independent Variable	Intercept	Slope	R^2	Statistical Significance
Tree frequency	0.324	16.345	0.57	p = 0.0001
Percent bare ground	1.646	-0.033	0.03	p = 0.30
Height dominant veg.	0.908	0.024	0.02	p = 0.46
Thatch depth	0.549	0.549	0.02	p = 0.39

Summer vegetational characteristics and summer vole signs. Tree frequency was examined as to regression on the gross vegetational characteristics: percent bare ground, height of dominant vegetation, depth of thatch and number of species of plants. This comparison was based on 46 blocks. Results (Table 7) showed a highly significant relationship with thatch depth and suggested a possible relationship with percent bare ground, though in neither case was any large proportion of the variability accounted for.

Table 7. Regressions of vole signs as tree frequency on gross vegetational characteristics recorded at the same time in the summer of 1976, in 46 IPOMS orchard blocks

Independent Variable	Intercept	Slope	R^2	Statistical Significance
Percent bare ground	0.063	-0.00167	0.06	p = 0.09
Height dominant veg.	0.024	0.00126	0.03	p = 0.28
Thatch depth	-0.035	0.056	0.17	p = 0.004
No. plant species	0.110	-0.023	0.04	p = 0.19

Summer leaf analyses and winter vole numbers. Linear regressions of vole numbers on summer leaf analyses failed to reveal any statistically significant relationship (Table 8). The closest to significance was with phosphorus ($p = 0.19$). A stepwise regression (maximum R^2 option) failed to improve the relationship appreciably with up to 6 variables. Thus no evidence was found of any reliable relationship between leaf content of 11 plant nutrients and vole numbers the following winter.

Table 8. Regressions of winter vole numbers on leaf analyses for 11 plant nutrients in previous growing season, 1976 IPOMS data from 48 orchard blocks

Independent Variable	Intercept	Slope	R^2	Statistical Significance
N	3.028	-0.896	0.01	p = 0.40
P	2.852	-10.143	0.04	p = 0.19
K	0.018	0.598	0.02	p = 0.33
Ca	2.047	-0.921	0.02	p = 0.34
Mg	-0.408	4.238	0.02	p = 0.28
Na	0.357	10.536	0.02	p = 0.34
Fe	1.750	-0.009	0.02	p = 0.33
Mn	1.367	-0.002	0.03	p = 0.26
Zn	1.082	0.0005	0.001	p = 0.84
Cu	1.705	-0.147	0.02	p = 0.33
B	0.828	0.004	0.002	p = 0.78

Summer soil analyses and winter vole numbers. Linear regressions of vole numbers on summer soil analyses failed to reveal any statistically significant relationship (Table 9). The closest to significance were with sulphur and potassium ($p = 0.28$). A stepwise regression (maximum R^2 option) failed to improve the relationship. Thus no evidence was found of any reliable relationship between soil analyses and vole numbers the following winter.

Table 9. Regressions of winter vole numbers on soil analyses for 10 plant nutrients and 6 other characteristics in the previous growing season, 1976 IPOMS data from 47 orchard blocks

Independent Variable	Intercept	Slope	R^2	Statistical Significance
N	0.987	0.147	0.006	p = 0.58
P	1.383	-0.003	0.02	p = 0.40
K	0.182	2.686	0.02	p = 0.28
Ca	1.343	-0.072	0.005	p = 0.63
Mg	0.505	0.633	0.02	p = 0.37
Na	1.438	-4.682	0.01	p = 0.54
Mn	1.094	-0.002	0.0002	p = 0.92
Cu	1.206	-0.030	0.01	p = 0.46
Zn	1.348	-0.035	0.02	p = 0.39
S	1.656	-0.029	0.02	p = 0.28
Weight Volume	1.139	-0.086	0.00004	p = 0.97
Organic Matter	1.202	-0.048	0.001	p = 0.86
Soluble Salts	0.560	5.255	0.005	p = 0.63
pH	-0.016	0.188	0.003	p = 0.71
Acidity	1.427	-0.195	0.006	p = 0.61
CaMgKNa	1.149	-0.018	0.0005	p = 0.88

Voles as causes of tree death. The 324 trees pulled and examined by the dead tree survey in 35 orchard blocks constituted 1.37 percent of trees in these blocks. It is not known for how many years these trees have accumulated in these orchards; presumably the period is greater than one year and therefore this figure sets an upper limit on annual tree mortality.

In principal suspected causes of death, voles ranked first, closely followed by disease (Table 10). It must be recognized that the causes assigned were probably not independent; death may have resulted from the combined action of several factors. But as a first approximation, these data suggest that losses by tree death are below 1.4 percent per year, and losses by voles, below 0.6 percent per year. This accounting does not allow for losses to voles from reduced vigor and fruit production over the years before tree death.

DISCUSSION AND CONCLUSIONS: Voles dominate the small mammal fauna of Henderson County orchards, with pine voles about eight times as numerous as meadow voles. This trapping program found voles in about 70 percent of the orchards; considering the small fraction of each orchard covered and the clustered nature of vole distribution, animals of one or both species are probably present in almost all orchards of this region. There was no evidence of antagonism to be found in the trapping records.

Table 10. Causes of death of apple trees as judged by an experienced 2-man team; all dead trees in 35 IPOMS orchard blocks, winter 1976-77

Cause of death	No. Trees		Percent	
Pine voles	122		37.7	
Meadow voles	22		6.8	
Total voles		144		44.5
Disease		131		40.4
Other identified causes		39		12.0
Unknown causes		10		3.1
Total		324		100.0

The capture probability of voles, as measured here, appears to be about 8 percent in a 24-hour setting of traps. This value refers to the set of 4 traps, even though the population estimates are stated per single tree (trap). This means that in two days this trap setting pattern seems to capture about one-sixth of the animals presumed to be resident.

The mean estimated population of all voles was 1.05 per tree (or 4.2 voles for the 5 tree diamond-shaped area centered on a sample tree). Populations were highly variable from orchard to orchard; considering total voles the two standard deviation range either side of the geometric mean of 0.40 voles per tree included a span of about 15-fold in either direction (this refers to block mean values).

Winter vole numbers may be predicted fairly well from the signs of vole activity at the same orchard location the previous summer. It is not yet clear whether this association is close enough to provide useful predictive ability. The test used here was the most favorable for demonstrating an association. At least, the association suggests that the data may be measuring the same thing. Vegetational characteristics associated with summer vole signs and measured at the same time showed no relation to winter vole numbers, although thatch depth was correlated with summer vole signs. This somewhat contradictory finding may only mean that a well-developed thatch preserves runways, once they are established.

There was no measurable association between vole numbers in winter with the values for leaf analysis of 11 plant nutrients in the previous growing season, or with measurements of soil characteristics (including analyses of 10 plant nutrients).

The dead tree survey showed voles to be a relative important cause of tree death compared to other factors, but the suggested values for tree mortality rate seem to be less than some reports from growers. On the other hand, this survey took no account of trees that are off-color and obviously dying, and thus a continuing reminder to the grower that trees are being killed.