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INTRODUCTION

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

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

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

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

MATERIALS AND METHODS

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

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

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

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

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

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

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

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

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

RESULTS

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

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

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

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

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

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

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

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

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

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

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

DISCUSSION

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

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

Behavior was also important in determining prey vulnerability. It was easier for the owls to capture prey individuals which were frozen rather than active. The greater tendency for both _M. pennsylvanicus_ and _M. pinetorum_ to freeze than for _P. leucopus_ to freeze may have increased the vulnerability of these microtines.

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

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

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

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