This is to certify that the

thesis entitled

House mouse (Mus domesticus) habitat use and response to repeated alfalfa harvests in the agricultural landscape

presented by

Loren Donald Hayes

has been accepted towards fulfillment
of the requirements for

M.S. degree in Zoology

Richard W. Hill
Major professor

Date June 19, 1999

HOUSE MOUSE (*MUS DOMESTICUS*) HABITAT USE AND RESPONSE TO REPEATED ALFALFA HARVESTS IN THE ARICULTURAL LANDSCAPE

By

Loren Donald Hayes

A THESIS

Submitted to

Michigan State University

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Zoology

1999

ABSTRACT

HOUSE MOUSE (*MUS DOMESTICUS*) HABITAT USE AND RESPONSE TO REPEATED ALFALFA HARVESTS IN THE ARICULTURAL LANDSCAPE

By

Loren Donald Hayes

The objective of this study was to describe house mouse habitat use on three southwest Michigan farms in which barns were situated next to active alfalfa fields. At each site, I determined the proportion of house mouse telemetry locations and/or captures in barns. At the Guthrie (GU) and Kellogg Biological Station (KBS) farms, the number and sex of mice captured in the alfalfa fields were determined before and after multiple harvests. At KBS, females were more frequently captured in the alfalfa field than males. Individuals captured in the field either returned to the barn or were never recaptured following harvests and mice rarely returned to the field within two weeks of harvests. Trap success in the field decreased through the summer at KBS during 1997, but not during 1998. At the GU farm, mice were rarely caught in the field and radio-collared mice (n = 10) were never tracked into the field. Most radio-collared mice at the Anthony (n = 6) and GU farms were found in the habitat in which they were caught when collars were assigned. In Michigan, where fields are often near barns, repeated alfalfa harvests during the summer may limit house mouse movements into fields and between barns, affecting metapopulation structure.

To Mom & Dad

You are an inspiration to me

ACKNOWLEDGMENTS

I thank my advisor, R.W. Hill, for the advice and support that he provided throughout the course of my M.S. program. I thank my committee members, G. Mittelbach, D. Straney and S. Winterstein for their advice and criticisms. K. Holekamp, R. Van Horn, and O. Schabenberger provided additional advice during the study. E. Bassett, M. Bonifas, J. Carrara, K. Donahue, K. Greene, and T. Wood were very helpful in the field. Live traps were provided by D. Beaver, R.W. Hill, R. Merritt, and the Michigan State University Museum. K. Holekamp and S. Nunes loaned me telemetry equipment. H. Reynolds assisted in the identification of plant species and in the collection of telemetry data. I thank the Anthony and Guthrie families for permitting me to conduct research on their farms. I also thank J. Bronson and the rest of the Kellogg Biological Station Dairy staff for their assistance and cooperation. R. Douglass, L. Chambers, and G. Singleton provided advice on the construction and attachment of radio-collars. I thank the men of the Burgner house for putting up with peanut butter, traps, telemetry equipment and straw. This project was funded by the following sources: American Society of Mammalogists Grant-in-Aid-of-Research, Kellogg Biological Station Research Training Group Summer Fellowship Program, Kellogg Biological Station Lauff Foundation, Michigan State University Department of Zoology, and Michigan State University Ecology, Evolutionary Biology, and Behavior Program.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

The expansion of agriculture in North America during the last 200 years transformed large areas of natural habitat into fragmented patches surrounded by farmland. The potential effects of this spatial heterogeneity on small mammal demography and movements have been a concern of landscape ecologists (Bowers and Matter 1997). Some view remnant patches of natural habitat as 'islands' within an 'ecologically hostile' agricultural matrix (e.g. Henderson et al. 1985; van Apeldoorn et al. 1992). Under these conditions, small mammals are unable to move across cropfields, limiting populations to within the remnant patches. Recent work suggests that some species are able to move between patches (e.g. Nupp and Swihart 1998), maintaining metapopulations (Levins 1969) comprised of local populations within remnant patches (Merriam 1988). The degree to which small mammals are able to move through spatially heterogeneous habitats depends on many variables. Merriam and colleagues showed that chipmunks (*Tamias striatus*) and white-footed mice *(Peromyscus leucopus*) use fencerows to move between woodland patches (Henderson et al. 1981; Wegner and Merriam 1990). Lorenz and Barrett (1990) demonstrated that house mice (*Mus domesticus*) move along chain-link fences and vegetation strips in simulated landscapes. Movements may depend on the types of cropfields surrounding patches (Cummings and Vessey 1994; Fitzgibbon 1997), the distance between patches (van Apeldoorn et al. 1992) and a species' ability to detect and orient to source habitats once it has moved into fields (Zollner and Lima 1997).

Fewer researchers have studied how temporal heterogeneity (e.g. changes in vegetative cover height during the summer) in the agricultural landscape affects small mammal movements and distributions (e.g. Peles et al. 1997). The growing/harvesting season of some crops (e.g. alfalfa) coincides with the breeding and dispersal periods of many small mammals (e.g. *Peromyscus*). Harvesting or tilling of the land may destroy underground burrows or expose small mammals to predators (Tew and MacDonald 1993). Harvests may reduce vegetative cover below heights critical to certain species (Lemen and Clausen 1984), resulting in decreased survival, growth rates, movement and population sizes (Tew and MacDonald 1993; Edge et al. 1995; but see Wolff et al. 1997). Lemen and Clausen (1984) argued that mowing altered the composition of a small mammal community in a native tall grass prairie in Nebraska. On lands that had mostly recently been mowed, deer mice (*P. maniculatus*) became the dominant species after vole (*Microtus*) populations decreased (Lemen and Clausen 1984). Following harvests, some species may be forced out of fields and into adjacent woods (Cummings and Vessey 1994), 'set-aside' fields (Tattersall et al. 1997) or buildings (Reimar and Petras 1968) that may already harbor dense populations and provide insufficient resources.

Although alfalfa is harvested two or more times a summer in southwest Michigan (pers. obs.), no one has studied the impact that repeated harvests have on small mammals using alfalfa fields. Multiple alfalfa harvests may effectively limit population growth of vole species that are sensitive to the amount of vegetative cover (Taitt et al. 1981). The removal of cover affects vole demographics (Peles and Barrett 1996), including possibly the processes that drive population cycling. Other species respond differently to crop harvests (e.g. Lemen and Clausen 1984; Henein et al. 1998) and these changes may depend on the frequency and timing of harvests relative to breeding and dispersal events.

House mice are common in agricultural settings, using both fields and barns (Stickel 1979). Numerous studies have been conducted on house mice living in buildings (Bronson 1979) or agricultural fields (e.g. Krebs et al. 1995). However, few researchers have studied house mouse movements between barns and fields (e.g. Reimar and Petras 1968) despite evidence that some rodents can move greater distances than previously thought (Wegner and Merriam 1987; Szacki et al. 1993). Although house mice occur in alfalfa fields (Kaufman and Kaufman 1990), few researchers have studied the effects of harvests on house mice (Linduska 1949) and no one has evaluated how harvesting practices affect their habitat use between barns and nearby fields. Understanding house mouse habitat use in barns and cropfields is an important step to modeling house mouse metapopulation structure in the agricultural landscape. Do harvesting practices effectively isolate house mice to individual barns or does sufficient gene flow for maintaining metapopulations occur despite activity in adjacent fields? Does the frequent removal of vegetative cover affect the population dynamics of mice occurring in barns and fields?

The objective of this study was to describe the habitat use of house mice occurring in barns and temporally heterogeneous agricultural fields (e.g. alfalfa). I first quantify the use of habitat by house mice on three alfalfa farms in southwest Michigan. I then describe the movements of house mice using adjacent barns and alfalfa fields at two sites before and after multiple harvests. This study generates a number of hypotheses regarding the effects of crop harvest on the habitat use, movements and density of house mice and other rodents that use buildings in the agricultural landscape (e.g. *Peromyscus*; Middleton and Merriam 1981). By understanding how house mice use the agricultural landscape, we may be better able to predict their response to crop harvests and plan more efficient pest management programs.

METHODS

This study was conducted on three southwest Michigan farms with barns situated next to alfalfa (*Medicago sp.*) fields. During 1997, I determined habitat use patterns at the Kellogg Biological Station farm and in 1998, the Anthony and Guthrie family farms were added to the study. Three levels of animal organization were considered in this study. Within-site habitat use patterns were based on the trapping records of all house mice and were used to represent general trends at the Guthrie and Kellogg Biological Station farms. Individual habitat use patterns within each site were determined from the trapping records of individuals captured four or more times and from individuals tracked with radio-telemetry. In this study, populations were defined as groups of interbreeding individuals living in a given habitat type (i.e. barns and fields). Since house mice throughout most of North America are strongly associated with buildings (Kurta 1995), it was assumed that house mice originated from populations within barns. However, individuals (with four or more captures/six or more radio-telemetry locations) found in fields, but never in barns, were considered members of a field population. While it is likely that multiple barn populations comprising a metapopulation existed at each site, this level of organization could not be determined in this study.

Site descriptions

Kellogg Biological Station

The Kellogg Biological Station farm (Hickory Corners, MI) consisted of a barn (11.0 m x 24.4 m) bordered on three sides by an active alfalfa field. A 4.6-18.3 m strip of mowed grass separated the field from the barn. The south side of the barn bordered a mowed lawn and dirt driveway. The two upper lofts of the barn were used for straw storage and the three rooms in the lower level of the barn were used for equipment storage. Feral cats were not observed in or around the barn during 1997 and only once during 1998 (n = 1 cat).

Anthony Family Farm

The Anthony farm (Hickory Corners, MI), approximately 1.5 km southeast of the Kellogg Biological Station farm, consisted of an unoccupied horse barn (10.4 m x 18.9 m) that was bordered by an active alfalfa field, undisturbed horse paddock, uncut mixed species field (Appendix A), mowed lawn and dirt driveway. Parts of the alfalfa field were mowed during the period between 4 and 15 June 1998 and the entire field was mowed on 11 August 1998. The upper lofts of the barn were used for straw storage. The lower level consisted of six horse stables and a storage room holding open bags of horse feed. On one occasion, I observed a feral cat moving through a distant field, but no cats were observed in the barn or in the fields near the barn. Trap data from this site were not quantified because raccoons repeatedly disturbed outdoor traps, making it impossible to compare trap success inside barns and in fields.

Guthrie Family Farm

The Guthrie farm is located in Delton, MI, approximately 6.5 km northwest of the Kellogg Biological Station farm. The site consisted of a main straw storage barn (10.6 m x 35 m), an alfalfa field 7-8 m from eastern edge of the barn, and a fenced, uncut grass field located 21 m south of the barn (Appendix A). The barn and uncut field were separated by a concrete courtyard and an open straw storage container (3 m x 27.4 m). There were two large, empty silos between the southern end of the courtyard and the northern end of the uncut field. To the west and north of the uncut field and courtyard, there was an open-faced pole barn filled with large square straw bales, a small chicken coop, and a building used for storage. The main straw storage barn was bordered to the north by a mowed lawn and dirt driveway. The owners had several cats that lived in or near the barn. One cat in particular was seen on most days and on occasion was observed carrying voles and house mice in its mouth. Before releasing animals, I paid careful attention to make sure that the cats were not observing my actions.

Procedures

Trapping

During both summers, trapping methods were designed to monitor house mouse habitat use relative to multiple alfalfa harvests. Sherman and Leather live traps fitted with cotton and oats were opened in barns and fields starting in the late afternoon (4:30-6:00 PM EDT) and checked the following morning (6:00-8:00 AM EDT). On dates when traps were left open through the day, I rechecked the traps 1-3 times depending on the weather conditions. During both years, traps located in fields were removed shortly before or on the morning of an alfalfa harvest. Traps were placed back into the fields soon after the fallen alfalfa was removed from the field, and then the traps were reopened periodically until the following harvest. Field grids started 3.0-7.3 m from barn edges and varied in shape and size depending on the location and orientation of the barn relative to the field.

During the 1997 summer, trap grids were set within the Kellogg Biological Station barn (2 m spacing, n = 51-108 traps) and in areas of the alfalfa field bordering the northern and eastern edges of the barn (7.6 m spacing, n = 161 traps). Additional traps were set in a house (n = 10-15) and hedgerow (n = 11), both of which were about 150 m west of the barn. Alfalfa was harvested on 11 June and 14 July 1997. Between 6 June and 22 August 1997, multiple cycles of trapping were carried out. During each cycle, I checked traps in the barn, house, and hedgerow for 2-4 days. I then checked the alfalfa field grid for 2-4 days before closing all traps for 1-5 days prior to the start of the next cycle. Adjustments in the trapping cycle were made to ensure that traps were in the field during the days immediately preceding a harvest. Between 24 August and 19 October 1997, traps were opened periodically in the alfalfa field and barn to monitor habitat use relative to a 1 September 1997 alfalfa harvest.

During 1998, trapping methods were changed to include simultaneous trapping of barns and fields at the Kellogg Biological Station and Guthrie farms. At both sites, barn traps were set along walls, on top and along straw bales, and in areas of low human activity. Grids with 9 m spacing were set in the areas of alfalfa fields that bordered barns. At the Kellogg Biological Station farm, traps were set in the barn (n = 32-83) on 34 nights and in the alfalfa field (n = 85-101) on 50 nights before and after alfalfa harvests on 19 May, 6 July and 10 and 11 August 1998. During June 1998, trapping effort in the barn was reduced because the population had not regenerated from a near extinction during 1997 (see Appendix B). During two trapping periods in May and one in June 1998, raccoons knocked over many of the barn traps. The results from these days were not included in any analyses requiring knowledge of the number of traps set. Between 1

June and 20 July 1998, 12 traps were periodically set in the mowed grass to the south of the barn. No house mice were caught in this area.

At the Guthrie farm, 55-86 traps in the main straw storage barn (28 nights), 50-100 in the alfalfa field (47 nights) and 10-36 in the enclosed, uncut field, were set relative to alfalfa harvests on 20 June and 24 July 1998. On 18 nights between 23 May and 15 July 1998, traps (n = 17-25) were opened in the courtyard, pole barn and chicken coop. Trapping in these areas was discontinued because over the 18 nights, only one house mouse was caught.

House mice were marked with an unique toe-clip/ear notch combination, weighed to the nearest gram with a Pesola spring balance, sexed and inspected for furless patches on the rump. Individuals weighing 16 g or more were considered adults, whereas those weighing less than 16 g were considered non-adults (DeLong 1967). Other small mammals captured during the study included deer mice (*Peromyscus maniculatus*), white-footed mice (*P. leucopus*), short-tailed shrews (*Blarina brevicauda*), and voles (*Microtus*).

Radio-telemetry

During 1998, six individuals (three male) at the Anthony farm, ten (five male) at the Guthrie farm and two (one male) at the Kellogg Biological Station farm, all weighing 15 g or more, were tracked with radio-telemetry. Radio-collars (2 g or less, < 15% of body weight) consisted of a SM-1 transmitter package (AVM Technologies, Livermore, CA) fixed to a length of heat shrink tubing within an acrylic coating. Radio-collars were held in place by tightening cable tie (pulled through the heat shrink tubing) around an animal's neck. Each individual was anesthetized with methoxyflurane before being assigned a radio-collar. Before an individual was released, it was allowed to recover from the anesthesia for 30 min to 1 h in a holding chamber lined with cotton.

Once released, individuals were followed for 1-16 days using a TRX 1000S PLL synthesized tracking receiver and Yagi antenna (Wildlife Materials Inc., Carbondale, Ill.). I included data from the day of release in analyses because the transmitters often stopped working prematurely. Nighttime (sunset-4:00 AM EDT) and daytime (10:00 AM EDT-sunset) tracking sessions were conducted at each site. I was interested in daytime locations because house mice are nocturnal (Kurta 1995) and are probably close to their nests during the daylight hours. During each tracking session, animal locations were determined at 30 min to 1 h intervals. Locations within 1 m were determined by triangulating to signals without using the attenuator on the receiver. Once the general location was resolved, the attenuator on the receiver was turned on so that a more accurate identification of location could be made. Since I was interested in general habitat use patterns (rather than home ranges), exact locations were not always necessary. When signals disappeared, habitats were searched until it was obvious that the transmitter was not working properly or that the animal had moved far from the study site.

Statistical analyses

Trap success (number of individuals captured/number of traps set) is commonly used to indicate habitat preference (e.g. Takada 1985). I consider trap success to be an indicator of within-site habitat use but avoid using the term 'preference' because I did not conduct any habitat choice experiments. A chi-square goodness of fit test was used to compare trap success in barns and fields against an expected 1:1:1 distribution at the Guthrie farm (alfalfa field, uncut field and barn) and an expected 1:1 distribution at the Kellogg Biological Station farm (alfalfa field and barn).

Sex ratios and weight categories in fields were tested against an expected 1:1 distribution using a chi-square goodness of fit test. A Mann Whitney U test was used to determine if the average number of captures in each habitat was different for females and males. I chose the Mann Whitney U test because male and female capture probabilities (i.e. trappability) are not likely to be normally distributed (see Hilborn et al. 1976). However, when sample sizes were large ($n_1 > 20$, $n_2 > 40$; n = the number of males or females), a normal approximation was used to estimate the critical value, $Z_{0.05}$ (Zar 1984).

Individual habitat use

Individual habitat use patterns were evaluated by determining the proportion of barn captures for all individuals captured four or more times. The proportion of telemetry locations inside barns was determined for individuals at the Guthrie (n = 10), Anthony (n = 6), and Kellogg Biological Station (n = 2) farms. Mann Whitney U tests were used to determine if males and females in this sample had different proportions of barn captures. An equality of proportions test (Zar 1984) was used to determine if proportion of males using fields at least once was statistically different than the proportion of females using fields at least once.

Response to cutting

The following predictions regarding the effects of alfalfa harvests were made: 1. During the period of alfalfa regeneration between harvests, the number of mice using fields increases and 2. As a result of repeated harvests, trap success in fields decreases through the summer. I used the number of individuals captured in the field as the alfalfa regenerated (i.e. days since previous alfalfa harvest) to demonstrate the immediate effect of harvesting on house mouse habitat use in fields. These data are not independent and thus, cannot be analyzed with known trend analyses (e.g. correlation, Zar 1984; nonparametric Cox Stuart trend, Bradley 1968). The number of mice using the field between harvests may be affected by the trappabilities of individual mice (e.g. probability that an individual is captured; Hilborn et al. 1976) or if animals respond differently to being held in a trap (i.e. trap response). Trap success during periods between harvests was determined. The trend in inter-harvest trap success through the summer was used to evaluate prediction 2. These data are not independent and thus, statistical comparisons were not made.

RESULTS

At each site, habitat use patterns were based on all morning captures. Afternoon captures were not included in the analyses because traps were not always left open through the afternoon. Demographic (e.g. sex ratio; weight classes) representation within habitats were based on morning and afternoon trapping sessions. Individual habitat use patterns were determined for all animals caught four or more times during the morning trapping sessions. All trapping data were used to assess house mouse responses to alfalfa harvests.

Within-site habitat use

General habitat use

At the Kellogg Biological Station farm, 95 individuals were captured 336 times in the barn and 31 individuals were captured 45 times in the alfalfa field between 6 June and 19 October 1997. Between 19 May and 25 August 1998, 38 individuals were captured 130 times in the Kellogg Biological Station barn and 13 individuals were captured 27 times in the field. Between 23 May and 24 August 1998, 165 individuals were captured 498 times in the Guthrie family barn, 8 individuals were captured once each in the alfalfa field, and 37 individuals were captured 76 times in the uncut field. Based on trap success for the entire summer (number of individuals captured/total number of traps set), house mice were found more commonly in barns than in fields at each site (Table 1). Based on these data and those shown below, populations (i.e. inter-breeding individuals) were not forming in the alfalfa fields. A feral population may have existed in the uncut field at the Guthrie farm.

Sex ratio

During the summer, female house mice may move into agricultural fields to establish nests or to find resources that are heavily guarded (e.g. food) or limiting (e.g. water) within barns. Consequently, I expected that more females than males would be captured in the alfalfa fields. Based on all trapping dates, more females than males were captured in the alfalfa field during 1997 (20 female: 13 male: 1 unknown sex) and 1998 (10 female: 4 male) at the Kellogg Biological Station farm (Table 2). During both years, however, the sex ratio in the alfalfa field was not significantly different from an expected 1:1 distribution (1997: $\chi^2 = 1.48$, $P > 0.05$; 1998: $\chi^2 = 2.57$, $P > 0.05$). Females were captured more frequently (average = 1.65 ± 0.21 (SE) captures/mouse) than males (average = 1.31 ± 0.17 (SE) captures/mouse) in the alfalfa field during 1997 (Mann Whitney U: $U' = 187.5$, $U_{0.05(1), 13, 20} = 176$). During 1998, females also were captured more frequently in the field (average = 2.67 ± 0.75 (SE) captures/mouse) than males (average = 1.5 ± 0.5 (SE) captures/mouse), but the comparison was not significant (Mann Whitney U: $U' = 23$, $U_{0.05(1), 4, 9}$[1] = 30).

More females than males were captured in the Kellogg Biological Station barn during 1997 (n = 49 females, n = 43 males, 4 unknown sex) and 1998 (n = 21 females: 17 males: 1 unknown sex). During both years; however, the sex ratio in the barn did not deviate from an expected 1:1 distribution (1997: $\chi^2 = 0.39$, $P > 0.05$; 1998: $\chi^2 = 0.42$, P >

[1] One female that died during capture was not included in the analysis.

0.05). Females were more frequently captured in the barn (average = 3.88 ± 0.50 (SE) captures/mouse) than males (average = 3.33 ± 0.43 (SE) captures/mouse) during 1997. The same trend was observed during 1998 (female average = 3.86 ± 0.54 (SE) captures/mouse; male average = 3.00 ± 0.62 (SE) captures/mouse).

Between 23 May and 24 August 1998, five females and four males were captured once each in the alfalfa field at the Guthrie farm ($\chi^2 = 0.11$; $P > 0.05$). One hundred and five females and 60 males were captured in the barn and this deviated from an expected 1:1 distribution ($\chi^2 = 12.27$, $P > 0.05$). Males averaged more captures in the barn (average = 3.52 ± 0.44 (SE) captures/mouse) than females (average = 2.72 ± 0.23 (SE) captures/mouse). The sex ratio of individuals captured in the uncut field did not deviate from an expected 1:1 distribution (n = 20 males: n = 17 females; $\chi^2 = 0.24$, $P > 0.05$). Males were more frequently captured in the uncut field (average = 2.25 ± 0.57 (SE) captures/mouse) than females (average = 1.88 ± 0.30 (SE) captures/mouse).

Animal weights

Table 2 shows the distribution of weight classes of house mice captured in alfalfa fields during afternoon and morning trapping sessions. Individuals weighing 16 g or more were captured slightly more frequently in the alfalfa fields than individuals weighing less than 16 g (Table 2).

Furless patches

Furless patches on the rump may be an indicator of aggression and thus, individuals in the alfalfa fields were examined for patches on the rump. A large number of individuals in fields with furless patches on the rump would suggest that fields may be used by subordinate mice chased out of barns. However, Table 2 shows that individuals captured in alfalfa fields rarely had furless patches on the rump. During 1998, only 1 adult individual had patches at the Kellogg Biological Station and none had patches at the Guthrie farm (Table 2). During 1997, 6 individuals, all adults, had patches on the rump. Fifty percent (n = 3) of the individuals with furless patches on the rump were males.

Individual habitat use

Trapping

During 1998, the proportion of barn captures (captures in the barn/total captures) for each individual captured four or more times during morning trapping sessions was calculated for all trapping dates and for the dates when the barn and field were trapped simultaneously. Since traps were not set in the two habitats on the same days at the Kellogg Biological Station during 1997, the proportion of captures in the barn for individuals captured four or more times was calculated for all trapping dates. The proportions of barn captures for males and females are shown in Appendix C.

Kellogg Biological Station

During 1997, the average proportion of barn captures for individuals caught four or more times (n = 36 individuals; average = 7.42 ± 0.54 captures/mouse) was 0.88 ± 0.03 (SE). Each individual that was captured four or more times was caught at least once in the barn and 50% were never captured in the field (Figure 1a). Males (n = 15 individuals; average

$= 0.90 \pm 0.05$ (SE) barn captures/total captures) and females ($n = 21$; average $= 0.87 \pm 0.03$ (SE) barn captures/total captures) in this sample had similar proportions of barn captures (Mann Whitney U: $U = 127$, $U_{0.05(1),\ 15,\ 21} = 210$). A greater proportion of females (0.57) than males (0.40) used the alfalfa field at least once, but the comparison was not statistically different (Equality of proportions test: $p = 0.5$, $q = 0.5$, $Z = 1.01$; $P > 0.05$).

During 1998, the average proportion of barn captures for individuals caught four or more times was 0.93 ± 0.07 (SE) when the barn and field were trapped simultaneously ($n = 7$ individuals; average $= 6.00 \pm 0.58$ (SE) captures/mouse) and 0.84 ± 0.05 (SE) for all trapping dates ($n = 21$ individuals; 6.29 ± 0.44 (SE) captures/mouse). Based on all trapping dates, all individuals were captured at least once in the barn and 57% were never caught in the field (Figure 1a). Males ($n = 7$ individuals; average $= 0.88 \pm 0.07$ (SE) barn captures/total captures) and females ($n = 14$; average $= 0.82 \pm 0.07$ (SE) barn captures/total captures) from all trapping dates had similar proportions of barn captures (Mann Whitney U: $U' = 46.5$, $U_{0.05(1),\ 7,\ 14} = 72$). Based on all trapping dates, an equal proportion of males (0.43) and females (0.43) used the alfalfa field at least once. When traps were presented simultaneously in the barn and field, each male ($n = 3$) with four or more captures was caught only in the barn and one of the four females caught four or more times used the alfalfa field (proportion = 0.5 captures in barn/total captures).

Guthrie Family Farm

The average proportion of barn captures for individuals captured four or more times was 0.95 ± 0.03 (SE) when the barn, alfalfa field and uncut field were trapped simultaneously (n = 38 individuals; average = 6.08 ± 0.38 (SE) captures/mouse) and 0.92 ± 0.04 (SE) for all trapping dates (n = 51 individuals; average = 6.55 ± 0.44 (SE) captures/mouse). Based on all trapping dates, 88% of the individuals were caught in the barn only and 6% were never caught in the barn (Figure 1b). Male (n = 17) and female (n = 21) habitat use did not differ when the barn, alfalfa and uncut field were trapped simultaneously (U' = 192; $U_{0.05(1),\ 17,21}$ = 236) and for all trapping dates (n = 21 males, n = 30 females; Mann Whitney U with normal approximation: Z = 0.74; P > 0.05).

Telemetry

Radio-telemetry allowed for more precise determination of animal locations than trapping methods. The proportion of locations within barns was calculated for all animals tracked with radio-telemetry (n = 18) during 1998. 'Barn' locations were assigned when individuals were inside human-made structures, including the two silos at the Guthrie farm. Locations along the outer edges of barns were considered 'outside' the barn and thus, did not add to the proportion of locations inside barns. Appendix D shows the locations and proportion of barn locations for each individual followed with radio-telemetry.

At the Guthrie farm, individuals (n = 10) showed a propensity to associate with areas outside of barns (Figure 2; average = 0.43 ± 0.13 (SE) barn locations/total locations; 22.20 ± 3.98 (SE) locations/mouse). However, habitat use depended on the location in which the individuals were trapped when radio-collars were attached. Individuals that were trapped outside of the barn when collars were attached (n = 5; 3 male) showed a propensity to associate with areas outside the barn (average = 0.17 ± 0.07

(SE) barn locations/total locations). Individuals caught inside the barn (n = 5; 2 male) showed a propensity to associate with the barn more than areas outside the barn (average = 0.70 ± 0.20 (SE) barn locations/total locations). A comparison of these averages was not statistically different (Mann Whitney U: U' = 21, $U_{0.05(1), 5, 5} = 21$), probably due to small sample sizes. Males and females had dissimilar proportions (male: 0.36 ± 0.19 (SE) barn locations/total locations; female: 0.51 ± 0.20 (SE) barn locations/total locations); however, a comparison was not made because unequal numbers were captured in each habitat.

All individuals tracked with radio-telemetry at the Anthony farm (n = 6) were captured in the barn at the time that collars were attached and showed a propensity to associate with the barn (Figure 2; average = 0.96 ± 0.02 (SE) barn locations/total locations; average = 53.67 ± 6.44 (SE) locations/mouse). Males (n = 3; average = 0.97 ± 0.03 (SE) barn locations/total locations) had similar proportions of barn locations to females (n = 3; average = 0.96 ± 0.02 (SE) barn locations/total locations). The individuals followed at the Anthony farm had similar habitat use patterns as those at the Guthrie farm that were captured in the barn at the time that radio-collars were attached (n = 5) (Mann Whitney U: U = 18, $U_{0.05(2), 5, 6} = 27$). However, individuals followed at the Anthony farm had significantly greater proportions of barn captures than those at the Guthrie farm that were captured outside the barn at the time that radio-collars were attached (n = 5) (Mann Whitney U: U' = 30, $U_{0.05(1), 5, 6} = 25$).

At the Kellogg Biological Station farm, one of the two individuals tracked with radio-telemetry used the alfalfa field. Both individuals showed a propensity to associate with the barn (Figure 2; average = 0.93 ± 0.07 (SE) barn locations/total locations; 51.50 ± 3.50 (SE) locations/mouse).

Response to cutting

Kellogg Biological Station

House mice were rarely caught in the field when vegetative cover was low (Figure 3). Only one animal was captured in the field during the first trapping period (24 to 26 June 1997) conducted after the 11 June 1997 harvest (Figure 3a). Mice were not captured in the field until the thirty-second day after the 14 July 1997 harvest and forty-second day after the 1 September 1997 harvest. During 1998, mice were not captured in the field until the thirty-fifth and twenty-fourth days after the field had been cut on 19 May and 6 July, respectively (Figure 3b, c). Sixty-four percent (n = 22 individuals) of the mice captured most recently in the alfalfa fields before a harvest (i.e. location of last capture before a harvest) were recaptured in the barn or field following a harvest during 1997 (Table 3). During 1998, 44 % (n = 4) of the individuals captured most recently in the alfalfa field before a harvest were recaptured in the barn or field after a harvest (Table 3).

Between 24 June and 14 July 1997, the number of house mice using the alfalfa field increased with respect to the days since the 11 June 1997 alfalfa harvest (Figure 3a). Only one individual was captured in the alfalfa field between 15 July and 1 September 1997. There was an upward trend in the number of house mice captured in the alfalfa field following the 19 May 1998 harvest (Figure 3b). Following the 6 July 1998 harvest, all captures in the alfalfa field occurred between 30 July and 5 August 1998 (Figure 3c). I did not trap the alfalfa field between 6 and 10 August 1998 so that I could track animals with radio-telemetry.

Cutting may have had lasting effects on house mouse habitat use at the Kellogg Biological Station farm. Figure 4 shows the morning trap success based on the total number of captures and total number of individuals captured in the alfalfa field before and after harvests during 1997 and 1998 (see also Appendix E). During 1997, only one of 33 (0.03) individuals using the alfalfa field was recaptured in the field following a harvest. One male was not included in this proportion because it was captured after the final harvest date. A similar proportion (0.08; n = 1 individual) was recaptured in the alfalfa field after a harvest during 1998.

Repeated harvests of alfalfa may impact the distance that house mice travel into the fields. If repeated harvests of alfalfa affect the quality of the field habitat, then house mice using fields after initial harvests may be captured closer to barns compared to those mice captured in fields before the initial harvests. However, it is also likely that voles (*Microtus*) have a confounding impact on house mouse movements into the fields. Table 4 shows the average distance from the barn that house mice were captured in the alfalfa field at the Kellogg Biological Station farm. Surprisingly, house mice were captured farther into the field later in the summer than before the first harvest of the season.

During 1997, the proportion of all individuals that were captured more than once in the alfalfa field before the 11 June 1997 harvest (0.33; n = 6 individuals) was similar to the proportion caught more than once in the alfalfa field before the 14 July 1997 harvest (0.27; n = 4 individuals). The two individuals captured in the field after 14 July 1997 were never recaptured in the field. Forty-five percent (n = 4 individuals) of the individuals using the alfalfa field before the 6 July 1998 were captured more than once in the field. One of the three individuals using the alfalfa field after the 6 July 1998 harvest was captured more than once in the field before the 10 and 11 August 1998 harvest.

The sex ratio of individuals using the alfalfa field did not change through the summer (Table 5). More females than males were captured in the alfalfa field at the Kellogg Biological Station farm during each period between harvests during 1997 and 1998 (Table 5). One male was captured in the field after the final harvest during 1997.

During 1997, 89% of the captures weighing 16 g or more (n = 16) were captured in the alfalfa field before the first harvest at the Kellogg Biological Station (Table 5). After the 11 June 1997 harvest date, only 2 of the 16 captures in the alfalfa weighed 16 g or more (Table 5). Of these individuals, two were not weighed while in the alfalfa field. However, both individuals weighed between 9-10 g within 4 days of capture in the field and thus were put in the <16 g category (Table 2; footnote 2). One individual that was not weighed when captured in the alfalfa field (15 August 1997) was not included in Tables 2 and 4 because it was not weighed in the barn within a reasonable period of time.

During the period between 20 May and 6 July 1998, 7 individuals weighing 16 g or more, 1 individual falling into both weight classes and 1 individual weighing less than 16 g were captured in the alfalfa field at the Kellogg Biological Station farm (Table 5). Among these individuals, two were not weighed when they were captured in the alfalfa field but were included in Tables 2 and 4 (see footnote 3 in Table 2). One individual was put in the 16 g or more category because it weighed greater than 16 g on 28 May 1998. The other individual was put in the <16 g category because it weighed 15 g 3 days before being captured in the field. After the second harvest, 3 of the 4 individuals captured in the alfalfa weighed <16 g (Table 5).

Guthrie Family Farm

Only nine individuals were captured in the alfalfa field at the Guthrie farm between 23 May and 24 August 1998. Seven individuals were caught in the alfalfa field between 23 May 1998 and 20 June 1997. One individual was captured on the twenty-seventh day following the 20 June 1998 harvest. One individual was captured in the alfalfa field on 24 August 1998 while I was attempting to radio-collar individuals.

Figure 4c shows the morning trap success based on the total number of captures and number of individuals caught during 1998. Seventy-one percent (n = 5 individuals) of the individuals captured most recently in the alfalfa field before a harvest were recaptured in the barn or uncut field after a harvest (Table 3).

DISCUSSION

General habitat use patterns

The trapping methods used in this study were similar to those used by Reimar and Petras (1968) on a Windsor, Ontario, farm and thus, a comparison between the habitat use patterns observed in the two studies may be useful. Based on trapping data, house mice at the Guthrie farm exhibited similar habitat use patterns as those mice described by Reimar and Petras (1968). On both farms, sex ratios were female-biased in the buildings, a finding that is supported by Rowe and colleagues' (1983) study of house mice living in four farm buildings in England. The sex ratios of mice occurring in fields were male-biased at both sites. Male-biased sex ratios are common in agricultural fields (Newsome 1969; Singleton 1989; Khan and Beg 1990; but see DeLong 1967), suggesting that the structure of the population in the uncut field at the Guthrie farm may be similar to those living in infrequently disturbed fields in other farmsteads. In both studies, only a small percentage of animals captured in fields were also captured inside barns (Guthrie: 13.0%; Windsor: 6.4%, see Table 3 in Reimar & Petras 1968), suggesting that separate barn and field populations existed. That radio-collared individuals initially captured in the uncut field at the Guthrie farm showed a propensity to associate with the field (Fig. 2) supports this argument.

The sex ratios in the barn at the Kellogg Biological Station during 1997 and 1998 were similar to those at the Guthrie and Windsor farms (Reimar and Petras 1968). However, house mice at the Kellogg Biological Station used the alfalfa field differently than the mice at the Guthrie and Windsor farms used fields. A greater proportion of individuals (with at least four captures) used the alfalfa field at the Kellogg Biological Station farm than at the Guthrie and Windsor (Reimar and Petras 1968) farms; however, all individuals that used the Kellogg Biological Station alfalfa field were also captured inside the barn (Figure 1). Simultaneous trapping of the field and barn indicated that some mice used both the barn and field during the days preceding harvests. These results suggest that separate populations (i.e. groups of interbreeding individuals) in the barn and field did not exist.

During 1997 and 1998, the sex ratios of individuals using the Kellogg Biological Station alfalfa field were female-biased (but not to a statistically significant extent) for the entire summer and within each period between harvests (Table 5). Were females forming nests in the alfalfa field or simply wandering into the field in search of food or water? Does the sex ratio in fields adjacent to barns indicate the conditions of the population(s) within the barn? The female-biased sex ratio that occurred in the alfalfa field at the Kellogg Biological Station farm contradicted the results from a number of studies that suggest that even or male-biased sex ratios are common in fields (e.g. Singleton 1989). Newsome (1969) observed female-biased sex ratios in declining populations of mice occurring in fields. It is unlikely that the female-biased sex ratio in the alfalfa field at the Kellogg Biological Station farm was a result of a declining population at the site. During 1997, females dominated the alfalfa field during all pre-harvest periods and before the number of individuals captured in the barn began to decline (Appendix B). Myers (1974) argued that house mice, particularly females that are about to become reproductively mature, respond rapidly to available habitat. Lactating and pregnant females and juveniles were captured in the alfalfa field, suggesting that some individuals may have established nests in the field. Alternatively, females may have foraged in the alfalfa as resources (e.g. food and water) became limiting in the barn. Additional studies examining how house mouse females use alfalfa are needed to better understand why females dominated the field at the Kellogg Biological Station farm.

The observed differences between the Kellogg Biological Station, Guthrie, and Windsor farms are not surprising because local conditions within farmsteads are different. Whether or not field populations (i.e. groups of interbreeding individuals, not individuals moving into fields) are common in North American farmsteads cannot be deduced from this study or the study conducted by Reimar & Petras (1968). However, the results of this study are useful in generating hypotheses about general house mouse habitat use patterns in the agricultural landscape. A better understanding of the demographic characteristics of field populations may be helpful in predicting the impact that agricultural practices, such as harvesting and application of pesticides, have on house mice (for a discussion, see below). A better understanding of the timing of the establishment and persistence of field populations may also help farmers to control invasions of house mice into fields.

Response to cutting

The effects of cover removal vary for different small mammal species. Cover removal has a negative impact on voles (e.g. *Microtus pennsylvanicus*, Eadie 1953; *M. townsendii*, Taitt et al. 1981; *M. ochrogaster*, Kotler et al. 1988; *M. canicaudus*, Edge et al. 1995), wood mice (*Apodemus sylvaticus*, Tew and MacDonald 1993) and cotton rats (*Sigmodon hispidus*, Sietman et al. 1994). Other species, such as deer mice (*Peromyscus* *maniculatus*, LoBue and Darnell 1959; Lemen and Clausen 1984; Kotler et al. 1988) and western harvest mice (*Reithrodontomys megalotis*, Kotler et al. 1988), are unaffected or respond positively to cover removal in fields. Before this study was conducted, only anecdotal notes on the impact of harvests on house mice living in fields were recorded in the literature (e.g. Linduska 1949, DeLong 1967; Kaufman and Kaufman 1990), and no one had considered the effects of harvests on populations within barns. This study supports previous work suggesting that house mouse numbers in fields decrease following harvests (Linduska 1949) and provides limited evidence that house mice are negatively affected by the repeated removal of cover in alfalfa fields. One mechanism for this effect is that harvests may force mice that nest in or use fields back into barns, increasing competition for space and food resources within barns.

More than half of the Kellogg Biological Station barn is bordered by alfalfa, permitting mice access to the resources in the field. House mice were frequently captured in the field when cover was high (Figure 3) suggesting that the field provides an important resource to some individuals living in the barn. The field may have acted as a refuge for individuals forced out of the barn; however, individuals rarely showed signs of intraspecific aggression (Table 2). Harvesting had an immediate impact on mice using the field (Fig. 3). Following harvests, house mice did not return to the field until at least the thirteenth day of alfalfa regeneration (Fig. 3). LoBue and Darnell (1959) observed a similar response by meadow voles (*M. pennsylvanicus*) in a harvested alfalfa field in Wisconsin. Voles were frequently captured in alfalfa plots before a harvest but did not re-invade plots until at least the seventeenth day following a harvest (LoBue and Darnell 1959).

Crop harvests cause increased dispersal of (Edge et al. 1995) and predation on small mammals (Tew and MacDonald 1993). If a large proportion of individuals that used alfalfa fields were not recaptured following harvests, then I could have argued that dispersal and predation may have increased as a result of cutting. Based on the proportion of house mice recaptured following harvests (Table 3), it is difficult to assess whether harvests directly caused increased dispersal of or predation on house mice at the Kellogg Biological Station farm. Twenty-two of 34 (64.7%) captures in the alfalfa field during 1997 and 4 of 9 captures (44.4%) during 1998 were recaptured in either the barn or the field following harvests (Table 3). Whether these results are related to harvesting or reflect different individual trappabilities (Hilborn et al. 1976) is not certain. Additional observations suggest that house mice did not leave the system or die during harvests. First, house mice from the barn and adjacent field were never captured in a nearby house and fencerow following the 1997 harvests. Second, I did not find any dead house mice in the field during visual surveys of the field immediately following harvests (both years), suggesting that mice were either unharmed by tractors or were inside the barn during harvests. One individual that was repeatedly tracked with radio-telemetry in the alfalfa field before the 10 August 1998 harvest moved between the barn and field within a single evening and showed a strong propensity to associate with the barn (Figure 2). Had stable populations been forming in the field, I would have expected greater mortality in the field and dispersal into areas other than the barn. Based on these observations, it seems that the immediate impact of harvests was the removal of a resource that some individuals living in the barn used and not the break-up of populations that formed in the field.

A downward trend in trap success in fields next to barns during a summer may indicate that repeated harvests are effective at stopping mice from invading fields. During 1997, trap success in the field decreased through the summer (Figure 4), and the numbers using the field decreased from 15 individuals before the 14 July harvest to 1 individual between 14 July and 1 September 1997. Results from 1998 are more complicated, possibly due to inter-annual differences or insufficient trapping before the 19 May 1998 harvest. Although a downward trend through the summer was not observed, trap success in the alfalfa field was greater during the period between the first and second harvests than the period between the second and third harvests. During both years, individuals were often captured more than once in the field before alfalfa harvests. However, only one individual during each summer was recaptured in the field following alfalfa harvests, suggesting that disturbances in fields may impact individuals with previous experience in fields. Behavioral experiments determining if house mice show a change in habitat preference following repeated harvests are needed to test this hypothesis.

Harvests affect the movement patterns of mice living in fields (Tew and MacDonald 1993). I anticipated that the harvesting of alfalfa next to the Kellogg Biological Station barn would have affected the distances that house mice traveled into the field from the barn. It is surprising that house mice traveled farther into the Kellogg Biological Station field after the first harvest compared to those mice captured in the field before the initial harvests. These observations may have resulted from one of the following scenarios: 1. Repeated harvests may not hinder alfalfa growth above a critical level and thus, have no effect on house mouse movements in fields or 2. Pre-harvest levels may provide a challenge to house mice and following harvests, alfalfa may regenerate to levels that house mice can navigate more easily. Alternatively, after the first harvest of the season, house mice may have to travel greater distances in the fields to find adequate resources. Harvests may impact the quality of the vegetation and affect the insect communities associated with the alfalfa, forcing mice to travel farther from the barn than is necessary during the period before initial harvests. Finally, the results observed during 1997 may have been have been caused by the different trapping methods used during the periods between harvests (Table 4).

Although the proportion of individuals weighing 16 g or more decreased between harvests during both years (Table 5), it is not clear whether the age (as indicated by weight) of individuals using the alfalfa field was altered by harvests. The sex ratio of individuals using the alfalfa field was not affected by repeated harvests as females dominated the field during all periods between harvests. These results stimulate many questions about the effects of harvests on the demography of individuals using fields. At the beginning of the summer, are adult females moving into the fields to establish nests? By not returning to the field, are adult females responding to some negative experience associated with harvests? In similar settings, are juveniles forced out the barn into fields? If female-biased sex ratios are common in fields next to barns, harvests at these sites may have profound effects on population growth, particularly if stressful events inhibit female reproductive development or result in disrupted pregnancies.

Alternatively, agricultural activity may be of little consequence if resources within the barns remain constant throughout the summer months or if fields are not easily accessible. The alfalfa field at the Guthrie farm bordered an area of the barn in which mice were infrequently captured, and only seven individuals used the alfalfa field before the 20 June 1998 harvest. The number of individuals using the alfalfa field did not increase as the alfalfa regenerated following the 20 June 1998 harvest, and radio-collared mice were never tracked into the alfalfa field. Mice captured in more heavily populated areas of the barn would have had to travel nearly the entire length of the barn (up to 27.4 m) and, presumably through male territories (Selander 1970) to gain access to resources in the field. Under these conditions, harvesting practices in the field probably did not have a major impact on the mice living in the Guthrie farm. Based on radio-telemetry and limited trapping data, similar conclusions can be made about the impact of harvests on mice at the Anthony farm. Trapping before the 4 June 1998 harvest indicated that house mice used the alfalfa field when cover was high. However, six individuals tracked with radio-telemetry did not use the alfalfa field during the two weeks preceding the 11 August 1998 harvest. Like the field at the Guthrie farm, the alfalfa field at the Anthony farm may not have been easily accessible to mice within the barn. Radio-collared animals ventured into an undisturbed horse paddock to the east of the barn, suggesting that for these animals, the alfalfa field was either too far away or provided insufficient resources.

Several questions about the effects of harvests remain unresolved. Tew and MacDonald (1993) demonstrated that wood mouse (*A. sylvaticus*) post-harvest nightly activity in barley and wheat fields decreased significantly relative to pre-harvest levels and that individual home ranges were smaller following harvests. If harvests force mice back into barns, aggressive encounters may occur more frequently as the number of individuals in the barn increases following a harvest. Consequently, individual home range sizes may become smaller as individuals more aggressively defend their territories against intruders. Do house mouse home ranges inside barns next to alfalfa fields decrease after repeated harvests? The answer to this question may be difficult to establish because the most widely accepted methods of home range estimation (see Larkin and Halkin 1994; Worton 1995 for a review) produce estimates that extend beyond the walls of barns even for animals that never used areas outside barns (Hayes, L.D., unpub. data). Individual house mice may also respond differently to traps, potentially biasing home range estimates based on trapping techniques. Numerous authors have reported fluctuating population sizes in fields during the summer months (e.g. DeLong 1967; Myers 1974). Do populations within barns undergo similar fluctuations and if so, are populations affected by agricultural activity in adjacent fields? Estimates or indices of population size require frequent and evenly spaced trapping periods. These requirements conflict with the trapping effort required to estimate habitat use patterns, making it difficult to determine if patterns are correlated to changes in density.

Future studies

Mowing in crop fields may serve as an effective means of population control for some small mammals (Edge et al. 1995) and thus, the effects of mowing on rodent habitat use and population processes warrant further study. While some investigators have studied the impact of a single crop harvest on rodents (e.g. Edge et al. 1995), until this study, no one has studied the effects of repeated harvests on small mammals. Since causal mechanisms were not established, the results of this study should be used to generate hypotheses about the effects of repeated harvests on small mammals in the agricultural landscape. I present four alternative studies, two descriptive and two experimental, that I believe are needed to determine the immediate (e.g. movement) and long-term effects (e.g. population response) of repeated harvests on commensal (i.e. associated with buildings) rodents.

Using radio-telemetry, Tew and MacDonald (1993) observed decreased movements by and increased predation on wood mice (*A. sylvaticus*) after the harvest of cropfields in the United Kingdom. I originally planned to use similar methods to determine if house mice (n = 18-20) in fields moved back into barns following harvests. I was unable to make these observations at the Guthrie and Kellogg Biological Station farms because of unexpected changes in the harvest dates and the premature failure of several radio-transmitter batteries. At the Anthony farm, radio-collars on four individuals persisted through the harvest period. However, radio-collared individuals did not use the alfalfa field near the barn making it impossible to assess the impact of the harvest. In future studies, house mice need be tracked with radio-telemetry for a week before and after harvests to determine the effects of harvests on habitat use patterns. Additional studies using radio-telemetry to track mice over several weeks (and consequently, before and after multiple harvests) are needed to determine the effects of multiple harvests on house mouse movements and habitat use patterns. A better understanding of house mouse movements relative to harvests may be useful in making predictions about the effects of harvests on population processes within barns.

Myers (1974) argued that house mouse population density in barns remains stable due to constant food and cover resources. However, food may become limiting, particularly if large males successfully defend clumped resources. Population processes within barns may therefore be affected by the availability of resources outside barns. The decrease in abundance that occurred in the Kellogg Biological Station barn during 1997

(Appendix B) may have been an indirect result of repeated harvests in the alfalfa field next to the barn. At the Kellogg Biological Station farm, the alfalfa field may have provided food resources or represented a sink habitat (Pulliam 1988) in which subordinate individuals from the barn could find adequate nesting sites. Removal of vegetative cover and food resources in alfalfa fields adjacent to barns may effectively limit mice to barns, intensifying competition for space and food resources. A suitable test of this hypothesis could be made by estimating the monthly population density within barns located next to uncut fields (n = 3-4), fields harvested once (n = 3-4) and fields harvested more than once (n = 3-4). I anticipate that house mouse populations within barns next to repeatedly cut fields decrease in a manner similar to that observed in the Kellogg Biological Station barn during 1997 (Appendix B). In buildings next to uncut fields, resources may not become limiting and the peak density should be greater than that in either of the alternative scenarios. Populations within barns next to fields that are cut only once may show an intermediate rate of growth depending on the timing of the harvest relative to peak breeding periods.

Manipulative approaches are needed to improve our understanding of small mammal ecology (Krebs 1988). The effects of different mowing practices on house mouse habitat use and population processes can be tested with a replicated design similar to that described by Barrett and colleagues (e.g. Peles and Barrett 1996). Settings similar to that at the Kellogg Biological Station farm can be simulated by building structures in multiple alfalfa plots within an experimental landscape (see Peles and Barrett 1996). In this design, three treatments (no cutting control, single harvest and repeated harvests) are applied to the replicated plots in a completely randomized design (O. Schabenberger, pers. comm.). I anticipate that mortality and wounding will be high after the first harvest and that a decrease in population density through the summer will occur in structures surrounded by repeatedly harvested plots. Within control plots, mortality and wounding should be minimal, and an increase in population density through the summer is expected. Unlike the descriptive study I outline above, this design would permit insights into causal explanations for changes in density occurring in structures within alfalfa plots. Since facultative commensals (i.e. animals occasionally associated with human dwellings), such as the deer mouse (*P. maniculatus*), may respond differently than house mice to disturbances within their habitat (Clark et al. 1998), the design should also be used to evaluate the effects of harvests on other rodent species.

Despite numerous studies on the genetic structure of house mouse populations inside barns (e.g. Selander 1970) and in fields (e.g. Myers 1974), little is known about house mouse metapopulation structure in the North American agricultural landscape (see Merriam 1988). Metapopulation structure in the agricultural landscape may be affected by human activity in fields and grassy areas between closely spaced barns. On many farmsteads in southwest Michigan, strips of vegetation separate closely spaced barns, providing individuals with potential dispersal routes. I hypothesize that dispersal from populations within barns separated by mowed patches of grass is limited, resulting in genetic drift within structures. This hypothesis can be tested by comparing the allele frequencies in mice of known genotypes that are released into closely spaced structures. Two treatments, mowed grass between structures and unmowed grass between structures, must be applied. Tissue samples taken from the released population and from the descendant population after a period of time are used to detect changes in allele frequencies within structures. If mowing of the grass between structures inhibits dispersal, gene flow will not occur and 'new' alleles will not be detected within structures. However, if mowing has no effect on dispersal between the structures, mice from both structures should mix, and a shift in allele frequencies within populations should be detected. Since house mice may also move along fencerows (Kaufman and Kaufman 1989; Clark et al. 1996), a similar study designed to compare gene flow between barns connected by fencerows and barns without connecting fencerows is needed.

Concluding remarks

House mice cause damage to stored food stuffs and may spread disease within the agricultural landscape. Studies based on trapping methods suggest that house mouse populations within buildings are highly structured (e.g. Selander 1970). Based on these studies, one could potentially view barns within the agricultural landscape as islands of house mouse habitat. Merriam and colleagues' (see Merriam 1988 for a review) work on white-footed mice (*P. leucopus*) in agricultural systems suggests that small mammals use fencerows to move more freely within in the agricultural landscape than has been previously thought (see Cummings and Vessey 1994). House mice may be able to move more freely in fields than in barns; feral (i.e. field-dwelling) house mice have greater home ranges than commensal (i.e. associated with buildings) house mice (Bronson 1979). In the agricultural landscape, house mice may be able to move between barns if dispersal corridors (e.g. fencerows, strips of vegetation) are present. Removal of vegetation between buildings may effectively limit mice to within buildings, affecting metapopulation structure. Under these conditions, populations in a single building may make up a single metapopulation. Alternatively, if adequate dispersal routes remain between buildings, populations within a series of barns (and adjacent fields) may make up a metapopulation. House mouse habitat use patterns presented in this study are useful in predicting the effects of harvests on the distribution of house mice within the agricultural landscape. Future studies on the effects of mowing on house mouse populations in fields and barns are needed. A better understanding of how harvesting practices affect house mice and other commensal rodents may improve our understanding of small mammal metapopulation structure in the agricultural landscape. Advances in these areas should be useful in planning and designing more efficient pest control programs.

REFERENCES

Bowers, M.A. and S.F. Matter. 1997. Landscape ecology of mammals: relationships between density and patch size. Journal of Mammalogy 78: 999-1013.

Bradley, J.V. 1968. Distribution-free statistical tests. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 388 p.

Bronson, F.H. 1979. The reproductive ecology of the house mouse. Quarterly Review of Biology 54: 265-299.

Clark, B.K., B.S. Clark, T.R. Homerding and W.E. Munsterman. 1998. Communities of small mammals in six grass-dominated habitats in southeastern Oklahoma. American Midland Naturalist 139: 262-268.

Clark, B.K., B.S. Clark, W.E. Munsterman and T.R. Homerding. 1996. Differential use of roadside fencerows and contiguous pastures by small mammals in southeastern Oklahoma. Southwestern Naturalist 41: 54-59.

Cummings, J.R. and S.H. Vessey. 1994. Agricultural influences on movement patterns of white-footed mice (*Peromyscus leucopus*). American Midland Naturalist 132: 209-218.

DeLong, K.T. 1967. Population ecology of feral house mice. Ecology 48: 611-634.

Eadie, W.R. 1953. Response of *Microtus* to vegetative cover. Journal of Mammalogy 34: 263-264.

Edge, W.D., J.O. Wolff and R.L. Carey. 1995. Density-dependent responses of gray-tailed voles to mowing. Journal of Wildlife Management 59: 245-251.

Fitzgibbon, C.D. 1997. Small mammals in farm woodlands: the effects of habitat, isolation and surrounding land-use patterns. Journal of Applied Ecology 34: 530-539.

Henderson, M.T., G. Merriam and J. Wegner. 1985. Patchy environments and species survival: Chipmunks in an agricultural mosaic. Biological Conservation 31: 95-105.

Henein, K., J. Wegner and G. Merriam. 1998. Population effects of landscape model manipulation on two behaviorally different woodland small mammals. Oikos 81: 168-186.

Hilborn, R., J.A. Redfield & C.J. Krebs. 1976. On the reliability of enumeration for mark and recapture census on voles. Canadian Journal of Zoology 54: 1019-1024.

Kaufman, D.W. and G.A. Kaufman. 1989. Nongame wildlife management in central Kansas: implications of small mammal use of fencerows, fields and prairie. Transactions of the Kansas Academy of Science 92: 198-205.

Kaufman, D.W. and G.A. Kaufman. 1990. House mice (*Mus musculus*) in natural and disturbed habitats in Kansas. Journal of Mammalogy 71: 428-432.

Khan, Akbar Ali and M.A. Beg. 1990. Population dynamics of the Persian house mouse in the croplands of central Punjab. Pakistan Journal of Zoology 22: 81-87.

Kotler, B.P., M.S. Gaines and B.J. Danielson. 1988. The effects of vegetative cover on the community structure of prairie rodents. Acta Theriologica 33, 27: 379-391.

Krebs, C.J. 1988. The experimental approach to rodent population dynamics. Oikos 52: 143-149.

Krebs, C.J., Kenney, A.J. and Singleton, G.R. 1995. Movements of feral house mice in agricultural landscapes. Australian Journal of Zoology 43: 293-302.

Kurta, A. 1995. Mammals of the Great Lakes region. The University of Michigan Press, Ann Arbor. 366 p.

Larkin, R.P. and D. Halkin. 1994. A review of software packages for estimating animal home ranges. Wildlife Society Bulletin 22: 274-287.

Lemen, C.A. and M.K. Clausen. 1984. The effects of mowing on the rodent community of a native tall grass prairie in eastern Nebraska. Prairie Naturalist 16: 5-10.

Levins, R. 1969. Some demographic and genetic consequences of environmental heterogeneity for biological control. Bulletin of the Entomological Society of America 15: 237-240.

Linduska, J.P. 1949. Ecology and land-use relationships of small mammals on a Michigan farm. Ph.D dissertation. Michigan State University, E. Lansing, Michigan.

LoBue, J. and R.M. Darnell. 1959. Effect of habitat disturbance on a small mammal population. Journal of Mammalogy 40: 425-437.

Lorenz, G.C. and G.W. Barrett. 1990. Influence of simulated landscape corridors on house mouse (*Mus musculus*) dispersal. American Midland Naturalist 123: 348-356.

Merriam, G. 1988. Landscape dynamics in farmland. Trends in Ecology and Evolution 3: 16-20.

Middleton, J. and G. Merriam. 1981. Woodland mice in a farmland mosaic. Journal of Applied Ecology 18: 703-710.

Myers, J.H. 1974. Genetic and social structure of feral house mouse populations on Grizzly Island, California. Ecology 55: 747-759.

Newsome, A.E. 1969. A population study of house-mice permanently inhabiting a reef-bed in south Australia. Journal of Animal Ecology 38: 341-359.

Nupp, T.E. and R.K. Swihart. 1998. Effects of forest fragmentation on population attributes of white-footed mice and eastern chipmunks. Journal of Mammalogy 79: 1234-1243.

Peles, J.D. and G.W. Barrett. 1996. Effects of vegetative cover on the population dynamics of meadow voles. Journal of Mammalogy 77: 857-869.

Peles, J.D., C.K. Williams and G.W. Barrett. 1997. Small mammal population dynamics in strip-cropped vs. monoculture agroecosystems. Journal of Sustainable Agriculture 9: 51-60.

Pulliam, H.R. 1988. Sources, sinks, and population regulation. American Naturalist 132: 652-661.

Reimar, J.D. and Petras, M.L. 1968. Some aspects of commensal populations of *Mus musculus* in southwestern Ontario. Canadian Field Naturalist 82: 32-42.

Rowe, F.P., T. Swinney and R.J. Quy. 1983. Reproduction of the House mouse (*Mus musculus*) in farm buildings. Journal of Zoology (London) 199: 259-269.

Selander, R.K. 1970. Behavior and genetic variation in natural populations. American Zoologist 10: 53-66.

Sietman, B.E., W.B. Fothergill and E.J. Finck. 1994. Effects of haying and old-field succession on small mammals in tallgrass prairie. American Midland Naturalist 131: 1-8.

Singleton, G. 1989. Population dynamics of an outbreak of house mice (*Mus domesticus*) in the mallee wheatlands of Australia-hypothesis of plague formation. Journal of Zoology (London) 219: 495-515.

Stickel, L.F. 1979. Population ecology of house mice in unstable habitats. Journal of Animal Ecology 48: 871-887.

Szacki, J., J. Babinska-Werka and A. Liro. 1993. The influence of landscape spatial structure on small mammal movements. Acta Theriologica 38: 113-123.

Taitt, M.J., H.W. Gipps, C.J. Krebs and Z. Dundjerksi. 1981. The effect of extra food and cover on declining populations of *Microtus townsendii*. Canadian Journal of Zoology 59: 1593-1599.

Takada, Y. 1985. Habitat utilization and mainland populations of the feral house mouse, *Mus musculus molossinus*. Journal of the Mammal Society of Japan 10: 123-134.

Tattersall, F. H., D.W. MacDonald, W.J. Manley, S. Gates, R. Feber and B.J. Hart. 1997. Small mammals on one-year set-aside. Acta Theriologica 42: 329-334.

Tew, T.E. and D.W. MacDonald. 1993. The effects of harvest on arable wood mice (*Apodemus sylvaticus*). Biological Conservation 65: 279-283.

van Apeldoorn, R.C., W.T. Oostenbrink, A. van Winden and F.F. van der Zee. 1992. Effects of habitat fragmentation on the bank vole, *Clethrionomys glareolus*, in an agricultural landscape. Oikos 65: 265-274.

Wegner, J. and G. Merriam. 1990. Use of spatial elements in a farmland mosaic by a woodland rodent. Biological Conservation 54: 263-276.

Wegner, J. and G. Merriam. 1987. Spatial and temporal distributions of woodland mice (*Peromyscus leucopus*) in farm crops and fencerows. Bulletin of the Ecological Society of America 68: 442.

Wolff, J.O., E.M. Schauber and W.D. Edge. 1997. Effects of habitat loss and fragmentation on the behavior and demography of gray-tailed voles. Conservation Biology 11: 945-956.

Worton, B.J. 1995. Using Monte Carlo simulation to evaluate kernel-based home range estimators. Journal of Wildlife Management 59: 794-800.

Zar, J.H. 1984. Biostatistical analysis, 2nd edition. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 718 p.

Zollner, P.A. and S.L. Lima. 1997. Landscape-level perceptual abilities in white-footed mice: perceptual range and the detection of forested habitat. Oikos 80: 51-60.

TABLES

Table 1. Number of individuals and total number of captures in each habitat type that was trapped at the Guthrie and Kellogg Biological Station (KBS) farms[1]. Chi square values are based on the expected number of individuals captured divided by the trap effort (total number of traps set at each site) in each habitat type.

Study location	Habitat type	Number of individuals	Total number of captures	Trap effort (# of traps set)	Chi square
KBS (1997)	Barn	95	336	1764	177.82*
	Alfalfa	31	45	5470	
KBS (1998)	Barn[2]	38	130	1527	66.69*
	Alfalfa	13	27	4582	
Guthrie (1998)	Barn[3]	164	486	1933	256.47*
	Alfalfa	8	8	3292	
	Uncut field	37	76	1247	

1 Based on morning captures
2 Chi square calculations based on trapping dates when raccoons did not disturb traps
3 Does not include 1 new individual and 12 total captures on 27 May 1998 because the number of traps set was not recorded
$P < 0.05$

Table 2. Sex and weight of and prevalence of furless patches on individuals captured in the Guthrie and Kellogg Biological Station alfalfa fields. The number of females in each weight class and with furless patches is in parentheses.

Location	Sex		Weight class			
	Males	Females	16+ g	<16 g	Both weight classes[1]	Furless patches on rump
Kellogg Biological Station (1997)[2]	13	20	16 (10)	16 (8)	1 (1)	6 (3)
Kellogg Biological Station (1998)[3]	4	10	8 (5)	5 (4)	1 (1)	1 (0)
Guthrie (1998)	4	5	5 (2)	4 (3)	0	0

1 Individuals weighing <16 g and 16 g or more during two different sampling dates
2 One individual not examined for fur patches. See text for detailed explanation of weight class designation for three individuals not weighed in the alfalfa field. One female that was not weighed within a reasonable period of time is not included
3 Weight class assignment for two individuals based on measurements made inside the barn. See text for a more detailed explanation

Table 3. Number and proportion of house mice that were recaptured following harvests and whose most recent captures before harvests were in the alfalfa field.

Harvest date	Most recently captured in field before harvest	Recaptured following a harvest	Proportion recaptured following a harvest
Guthrie Family Farm			
20 June 1998	6	5	0.83
24 July 1998	1	0	0.00
Kellogg Biological Station			
6 July 1998	7	2	0.29
10-11 August 1998	2	2	1.00
11 June 1997	18	16	0.89
14 July 1997	15	5	0.33
1 September 1997	1	1	1.00

Table 4. Average distances and ranges of distances from the Kellogg Biological Station barn that house mice were captured in the alfalfa field.

Inter-harvest period	Number of captures	Avg. dist. from barn (m) (SE)	Range of distances (m)	Distance between traps (m)
8-11 June 1997	30[1]	17.7 (1.2)	9.1-36.6	4.6
12 June-14 July 1997	21	46.5 (3.5)	11.9-80.7	7.6
15 July-15 Aug. 1997	1	11.9	11.9	7.6
1 Sept.-19 Oct. 1997	1	4.3[2]	4.3	7.6
20 May-6 July 1998	21	13.6 (1.7)	6.1-28.8	9.1
7 July-5 August 1998	6	19.6 (2.0)	15.2-25.1	9.1

1 One individual that was captured against the edge of the barn was not included.
2 The first trap was approximately 4.3 m from the edge of the barn.

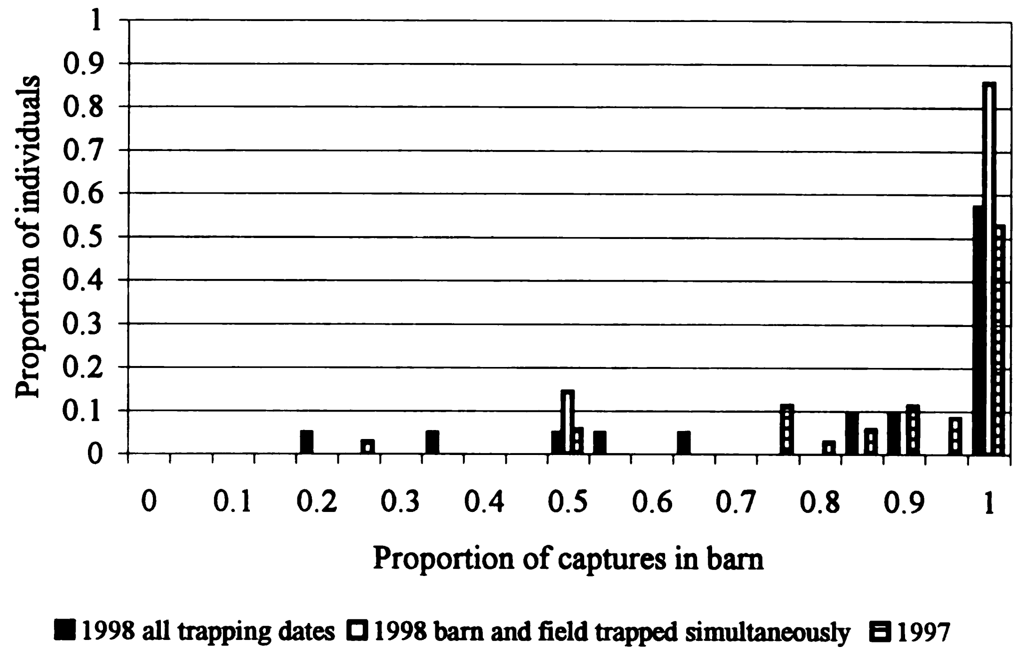
Table 5. Proportion of females and large individuals (16 g or more) that used the alfalfa field during the periods between harvests at the Kellogg Biological Station. Proportions are based on all captures, including those made in afternoon trapping sessions. Females and individuals weighing 16 g or more are in parentheses. See methods for harvest dates.

Variable measured	Year	Before harvest 1	Before harvest 2	Before harvest 3
Proportion of females	1998	0	0.73 (8)	0.75 (3)
	1997	0.61 (11)	0.64 (9)[1]	1.00 (1)
Proportion weighing 16 g or more	1998	0	0.75 (9)	0.25 (1)
	1997	0.89 (16)	0.13[2] (2)	Unknown

1 One individual of unknown sex (n = 15 total animals)
2 One individual that weighed <16 g and 16 g or more on two different dates was counted once in each weight class category

FIGURES

A:



B:

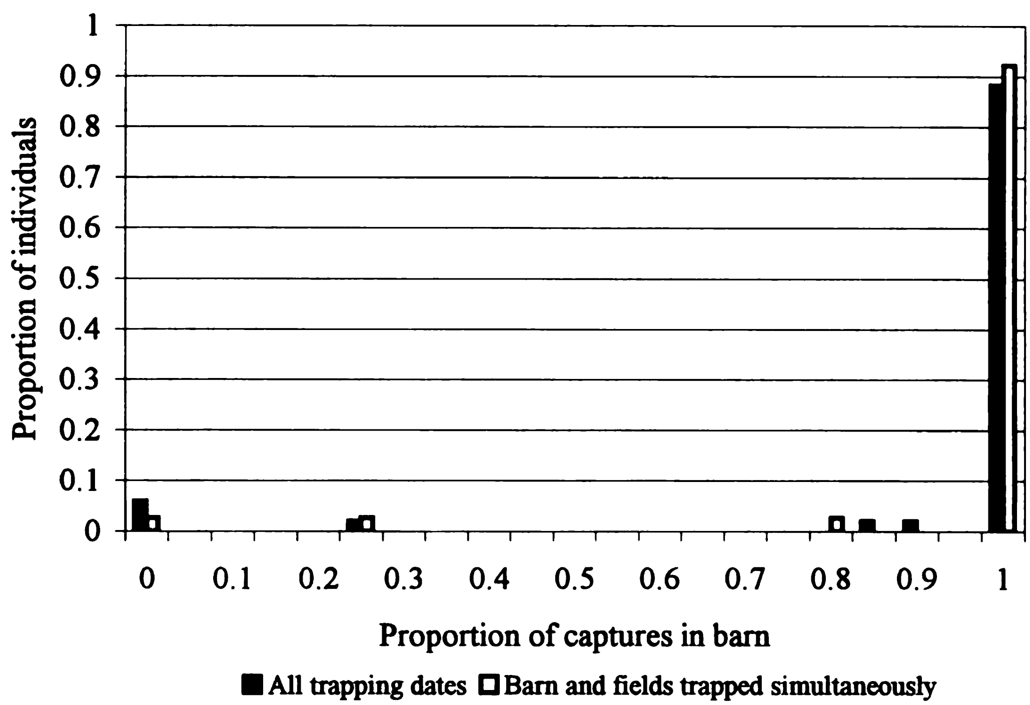


Figure 1. Proportions of individuals showing various proportions of captures in barns at the Kellogg Biological Station (A) and Guthrie (B) farms. Only individuals caught four or more times during morning trapping sessions are included.

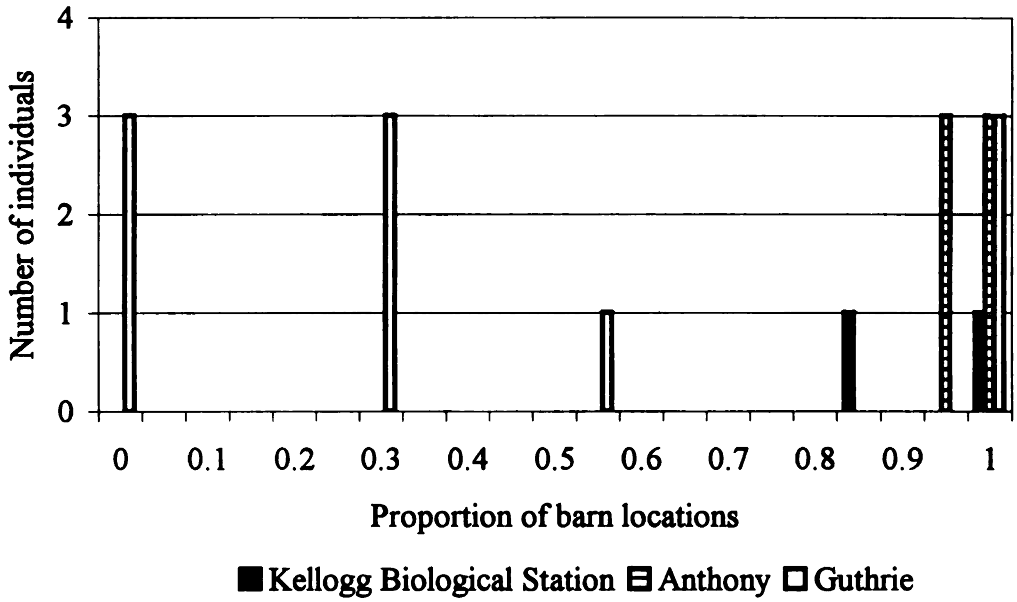
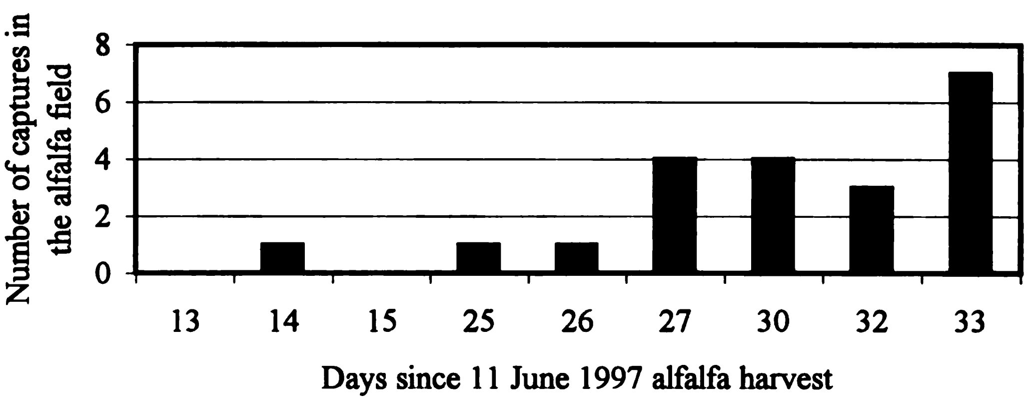
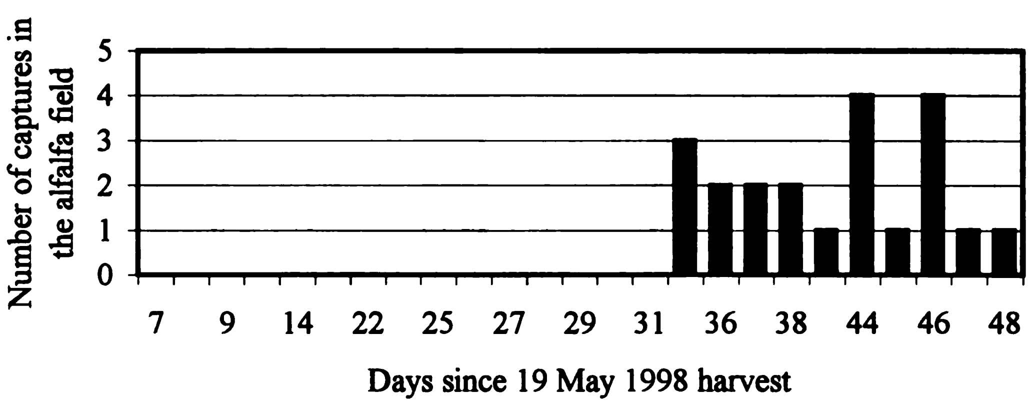


Figure 2. Number of individuals showing various proportions of telemetry locations in barns at the Kellogg Biological Station (n = 2 individuals), Anthony (n = 6) and Guthrie (n = 10) farms.

A:



B:



C:

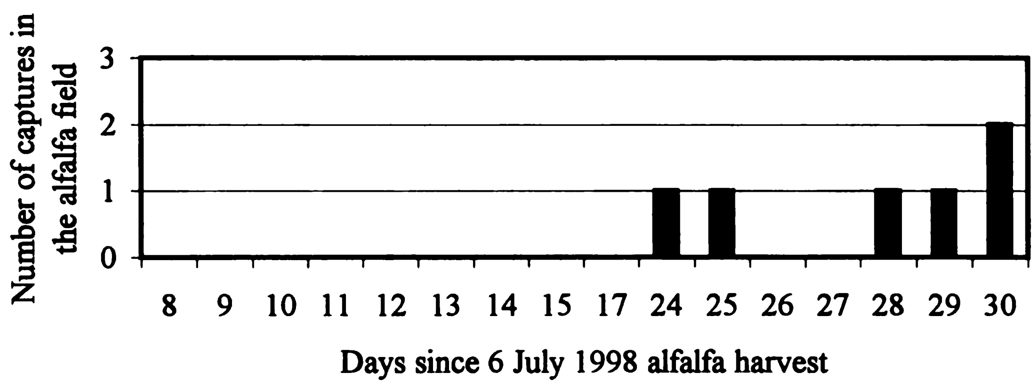


Figure 3. Total number of afternoon and morning captures in the alfalfa field at the Kellogg Biological Station on the corresponding days since alfalfa harvests in 1997 (A) and 1998 (B, C). Only one individual was captured in the field during the period between the 14 July and 1 September 1997 alfalfa harvests.

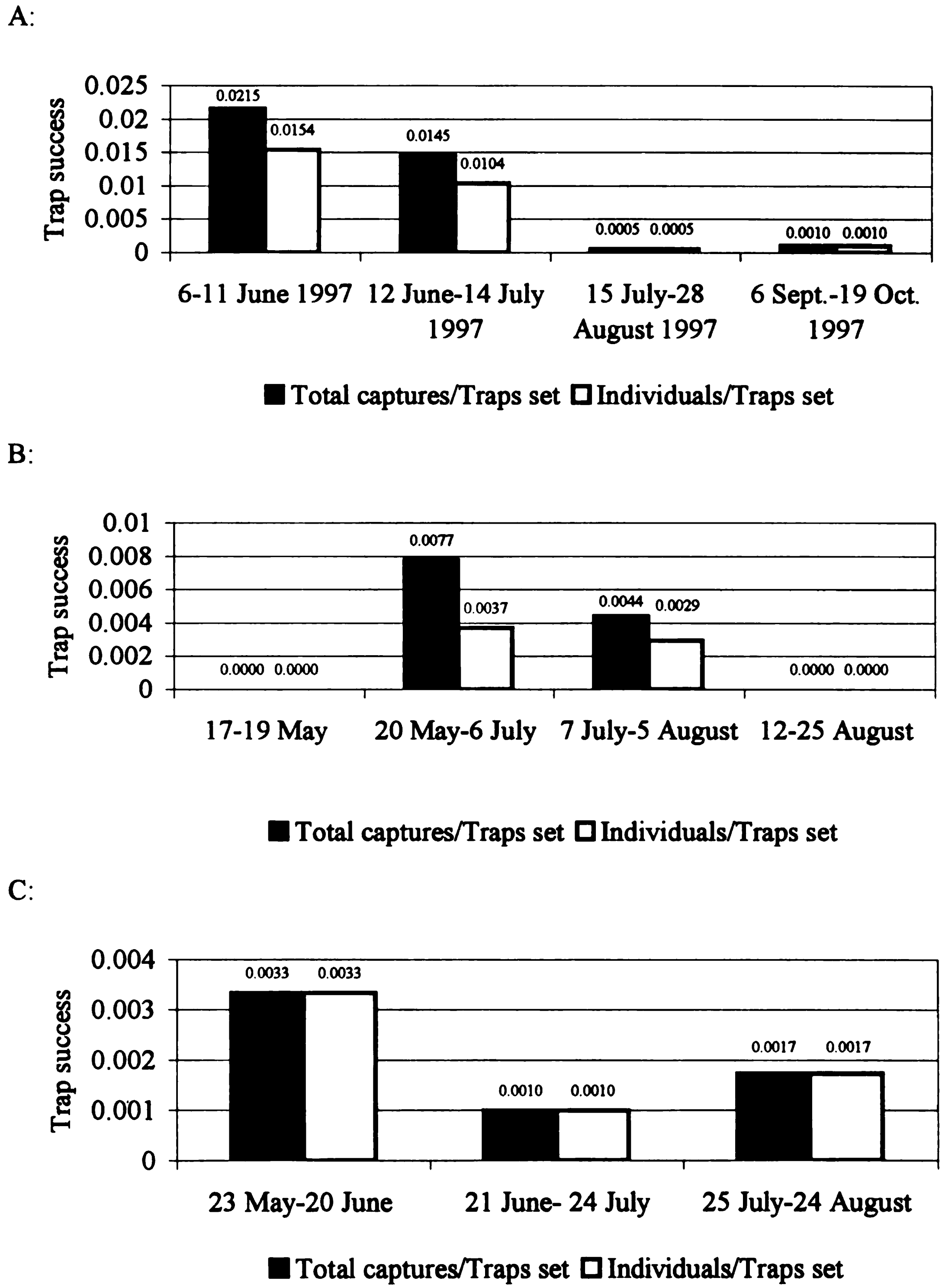


Figure 4: Trap success during morning trapping sessions in the alfalfa fields at the Kellogg Biological Station (A, B) and Guthrie (C) farms. Number of individuals captured per period: (A) 15, 15, 1, 1; (B) 0, 10, 4, 0; (C) 6, 1, 1. Total number of captures per period: (A) 21, 21, 1, 1; (B) 0, 21, 6, 0; (C) 6, 1, 1.

APPENDICES

APPENDIX A

Common and scientific names of plants found in the uncut fields at the Anthony and Guthrie farms.

Anthony

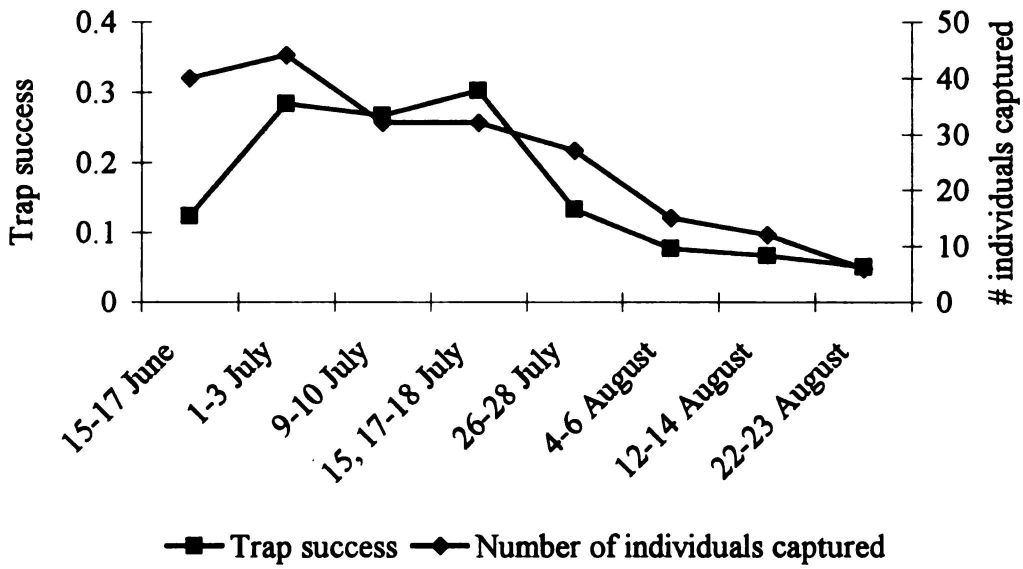
Common Name	Scientific Name
Couch grass	*Agropyron repens*
Japanese brome	*Bromus japonicus*
Orchard grass	*Dactylis glomerata*
Smooth brome	*Bromus inermus*
Timothy	*Phleum pratense*

Guthrie

Common Name	Scientific Name
Common burdock	*Arctium minus*
Curled dock	*Rumex crispus*
Dandelion	*Taraxacum officinale*
Field chamomile	*Arthemis arvensis*
Field pennycress	*Thlaspi arvense*
Field peppergrass	*Lepedium campestre*
Hedge mustard	*Sisymbrium officinale*
Hoary alyssum	*Berteroa incana*
Lady's Thumb	*Polygonium persicaria*
Motherwort	*Leonurus cardiaca*
White avens	*Geum canadense*
White campion	*Lychnis alba*
White sweet clover	*Meliotus alba*

APPENDIX B

Trap success (number of individuals captured/number of traps set) and number of individuals captured in the Kellogg Biological Station barn between June and August 1997.



APPENDIX C

Average (± SE) proportions of barn captures of mice captured four or more times.

Location	Male	Female	Total
Guthrie			
All trapping data	0.86 ± 0.07 (n = 21)	0.96 ± 0.03 (n = 30)	0.92 ± 0.04 (n = 51)
Barn and fields trapped simultaneously	0.90 ± 0.07 (n = 17)	0.99 ± 0.01 (n = 21)	0.95 ± 0.03 (n = 38)
Kellogg Biological Station (1998)			
All trapping data	0.88 ± 0.07 (n = 7)	0.82 ± 0.07 (n = 14)	0.84 ± 0.05 (n = 21)
Barn and field trapped simultaneously	1.0 ± 0.0 (n = 3)	0.88 ± 0.13 (n = 4)	0.93 ± 0.07 (n = 7)
Kellogg Biological Station (1997)			
All trapping data	0.90 ± 0.05 (n = 15)	0.87 ± 0.03 (n = 21)	0.88 ± 0.03 (n = 36)

APPENDIX D

Indoor and outdoor radio-telemetry locations and proportion of barn locations of individuals tracked at the Anthony (n = 6), Kellogg Biological Station (KBS) (n = 2) and Guthrie (n = 10) farms during 1998.

Location	ID[1]	Sex	Indoor locations[2]	Outdoor locations[3]	Proportion of indoor locations
Anthony	448*	Male	49	5	0.91
Anthony	113*	Male	70	0	1.00
Anthony	90*	Male	68	0	1.00
Anthony	265*	Female	56	3	0.95
Anthony	144*	Female	39	3	0.93
Anthony	125*	Female	29	0	1.00
KBS	405	Male	41	7	0.85
KBS	247*	Female	55	0	1.00
Guthrie	10	Male	0	6	0.00
Guthrie	53	Male	0	40	0.00
Guthrie	386*	Male	19	17	0.53
Guthrie	405	Male	8	22	0.27
Guthrie	265-2*	Male	29	0	1.00
Guthrie	24*	Female	0	6	0.00
Guthrie	226*	Female	24	0	1.00
Guthrie	265-1	Female	2	5	0.28
Guthrie	366	Female	5	12	0.29
Guthrie	448*	Female	26	1	0.96

1: Radio-transmitter frequency
2: Barns or silos
3: Fields, outer edge of barns, and grass areas near barns
* Indicates that the animal was captured in the barn when the radio-collar was attached

APPENDIX E

Number of individuals captured in alfalfa fields, total number of captures in alfalfa fields and number of traps set in alfalfa fields during morning trapping periods before and after alfalfa harvests. Afternoon captures are not included because traps were not left open through the afternoon on all dates.

Trapping period	Number of individuals in the alfalfa field	Number of captures in the alfalfa field	Number of traps set
Guthrie			
23 May-20 June 1998	6	6	1800
21 June-24 July 1998	1	1	1010
25 July-24 Aug. 1998	1	1	582
Kellogg Biological Station			
17-19 May 1998	0	0	288
20 May-6 July 1998	10	21	2712
7 July-5 Aug. 1998	4	6	1360
12-25 Aug. 1998	0	0	510
6-11 June 1997	15	21	975
12 June-14 July 1997	15	21	1449
15 July-28 Aug. 1997	1	1	2080
6 Sept.-19 Oct. 1997	1	1	966