THE RESPONSE OF SMALL MAMMALS TO HABITAT CHARACTERISTICS AT DIFFERENT SPATIAL SCALES

A Thesis
Submitted to the Graduate Faculty
in Partial Fulfillment of the Requirements
for the Degree of
Master of Science
In the Department of Biology
Faculty of Science
University of Prince Edward Island

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April, 2003

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ABSTRACT

The primary goal of this research was to investigate how small mammals use and interact with characteristics of their habitat, at various spatial scales. This goal was accomplished by studying the species richness and abundance of small mammals, and by assessing the movement patterns of a common small mammal, the eastern chipmunk (*Tamias striatus*). Trapping, using both Sherman live traps and pitfall traps, was used to determine the species richness and abundance of small mammals in various forested areas. The species richness, and abundance of the most common species, were statistically related to habitat characteristics at three scales (microhabitat, macrohabitat, and landscape). Movement pathways of the eastern chipmunk were obtained by fluorescent powdering or spool-and-line tracking of individuals. Pathways were photographed and digitized so the movement patterns could be quantified using measures such as the fractal dimension, mean turning angle, total/net displacement, and radius of gyration. To examine how patterns of movement were affected by habitat features, these pathway quantifiers were related to various habitat descriptors. Fractal analysis was used to examine if there were spatial scales at which chipmunks showed transitions in their movement behaviour. Additionally, because movement pathways provide a continuous record of the habitat through which an individual traveled, habitat selection by eastern chipmunks was examined.

Nine species of small mammals were captured in this study. The species richness and diversity of small mammal communities were positively influenced by the amount of connected forest and the number of tree species. The abundances of the most common species were differentially influenced by characteristics at the various scales.

Eastern chipmunks tended to show transitions in their patterns of movement at scales of about 2 m, indicating that they interact with their habitat differently at scales above and below this point. This shift in movement behaviour was partially influenced by the density of small trees, and this was interpreted as an avoidance of small trees by this species. However, this transition in movement pattern appears to be more strongly due to innate behavioural processes. Eastern chipmunk movement behaviour, based on patterns of the radius of gyration and total/net displacement, suggests this species has a preference for canopy-covered areas and open-understory habitat. Similarly, information on eastern chipmunk habitat selection revealed a preference for tall trees and logs, whereas small shrubs, herbs, and small trees were significantly less preferred.

ACKNOWLEDGMENTS

First of all, I have to thank my family, especially my parents, Colin and Susan Hartling. They raised me to "love learning", and without their support and guidance I would not have made it this far. Aaron Cudmore and his family have also been very supportive.

Marina Silva has been a wonderful mentor. When I began working with her during my undergraduate studies, it was a fantastic experience, and inspired me to continue performing research in the field of ecology. I was very glad that she was also able to supervise me in my graduate studies, because her intelligence and personality make her an outstanding person to have as a supervisor.

I would like to also thank Sheldon Opps for his involvement with this project. His passion for research is admirable, and I am very grateful for the knowledge and effort he has contributed to this research. He has also been a fantastic supervisor.

I would also like to thank my committee members, Kevin Teather and Chris Lacroix, for their input into this project. Also, thanks to Vilis Nams for communicating with us during this project, and for being my external examiner.

Emilie Laurin was my field assistant for the majority of this research, and it was a joy working with her. Her positive personality and hard work ethic made those long field days much easier. Craig Knickle also assisted me in the field, and I am grateful to him for being willing to work with me on very short notice. Additionally, my lab-mates Josh Mailhiot and Erin Knox helped out with the field work on a several occasions, and I also want to thank them for providing some comic relief throughout this past year!

I am very grateful to the staff of the Prince Edward Island National Park for allowing me to conduct work on their land, and for providing me with camping facilities. In particular, Denyse Lajeunesse has been very helpful. Also, I'd like to thank John MacDonald of Pleasant Grove for allowing me to work on his property.

Funding for this project has been provided by a personal scholarship from the Natural Sciences and Engineering Research Council of Canada.

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1. INTRODUCTION

Spatial scale refers to a space based dimension such as the size of an area (Turner *et al.*, 1989). Organisms respond to their environment at different spatial scales (Kotliar and Wiens, 1990). At each scale, different aspects of the habitat become more important or less important in regulating biological processes (Nams, submitted). Determining these scales, and what habitat features are relevant, can help us to predict how animals will respond to modifications of their environment, and understand the mechanisms by which animals do this. The importance of habitat features can be evaluated at the community and population levels of organization, as well as at the level of individual organisms.

1.1. Response of populations and communities to habitat features at different spatial scales

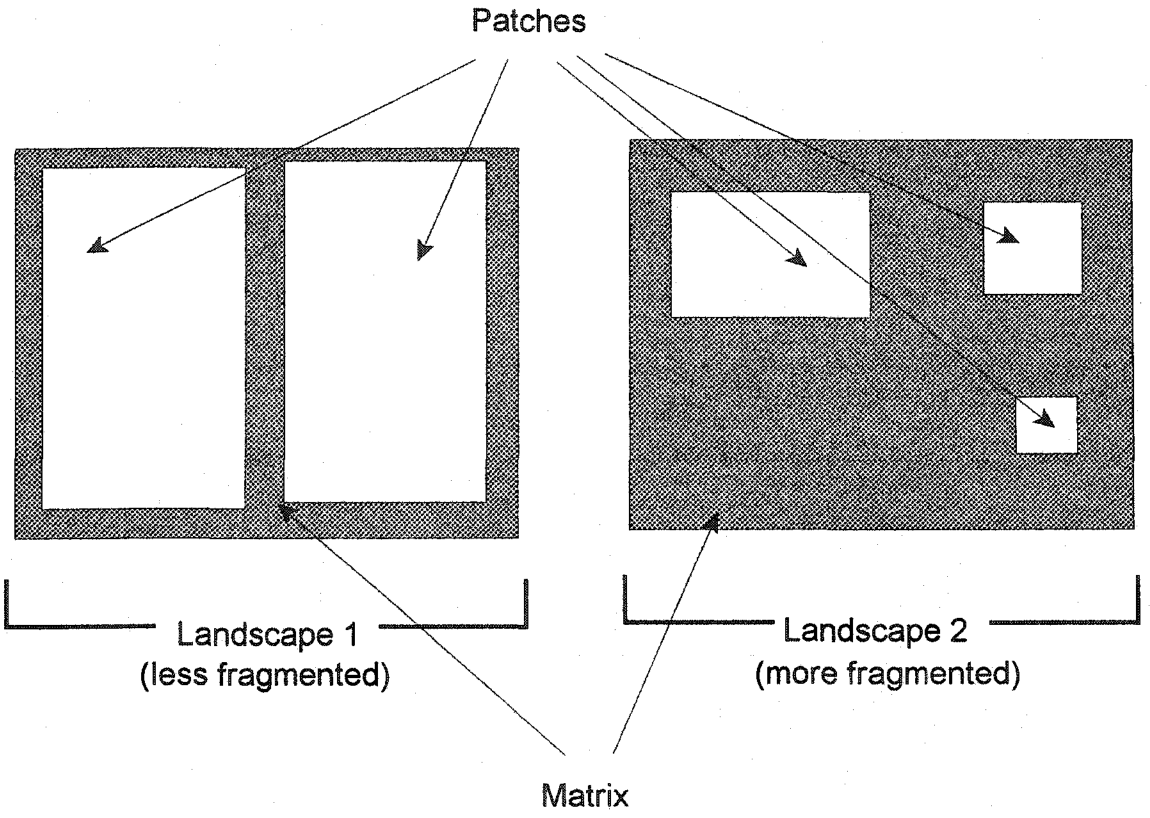
1.1.1. Overview

Habitat fragmentation is a major environmental modification process that is a worldwide problem (Kelt, 2000), whereby continuous habitats are broken up into smaller patches (Turner *et al.*, 2001), affecting the patch characteristics and the landscape in which the patches are situated. Habitat patches are defined as areas that differ from surrounding areas in nature or appearance (Turner *et al.*, 2001). Landscapes are spatially heterogenous areas (Turner *et al.*, 2001), consisting of interacting ecosystems (Forman and Godron, 1981). Habitat fragmentation leads to changes in the total amount of suitable habitat, the size of the habitat patches, the amount of edge habitat relative to the amount of core habitat of a patch, and in the degree of isolation of the patches (Murcia, 1995). Therefore changes in the habitat at various spatial scales occur (Figure 1.1) (Bayne and Hobson,1998; Dooley and Bowers,1998). At the landscape scale, the distance between patches and the amount of suitable habitat decreases (Witt and Huntly, 2001). At the patch scale, the size of the fragment is reduced (Murcia, 1995). At the microhabitat (i.e., within-patch) scale, an increase in vegetative diversity is often observed near edges, with a shift in the vegetative community toward more shade-tolerant species (Laurance and Yensen, 1990).

Small mammals are an ideal group to study in order to examine the response of species to changes in their environment. Smaller mammals may be especially affected by alterations to their environment, because they tend to have lower mobility than larger mammals (Schmid-Holmes and Drickamer, 2001). Additionally, small mammals are functionally important because they represent a link between lower trophic-level species (such as plants and insects) and higher trophic-level predators (Nowak, 1991). Also, some small mammals function as seed dispersers (Nowak, 1991).

Traditionally, ecologists have focused on patch-scale patterns to explain the variance in species abundance and diversity of small mammals. However, more recently, examination of the effects of landscape-scale patterns has been

Figure 1.1. Diagram illustrating the changes in patch and landscape characteristics that occur as a result of habitat fragmentation.[a]



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[a] For example, at a landscape scale, the area of suitable habitat is reduced and isolation increases. At a patch scale, the patch area is reduced, and more of the patch habitat is closer to the edge.

incorporated into many ecological studies (Barrett and Peles, 1999). In the science of small mammal ecology, Hansson (1977) is usually credited (e.g., by Barrett and Peles, 1999; Lidicker, 1995) with publishing the first North American study that incorporated the effects of landscape into field studies, with his paper on field vole (*Microtus agrestis*) dynamics in heterogenous landscapes.

The incorporation of landscape effects into studies examining the variables affecting small mammals is based upon the idea that local patterns of richness and abundance cannot be completely explained by patch effects; the conditions surrounding the patch (i.e., the patch context) must also be considered (Mazerolle and Villard, 1999). For example, a patch may contain habitat suitable for a species, but if the patch is sufficiently isolated from other patches and the area between the patches, known as the matrix (Formon and Godron, 1981) poses a barrier to dispersal for individuals of a species, the patch may not be exploited by the species under consideration. Other characteristics of a landscape such as the degree of connectivity, configuration (spatial arrangement) of patches, and relative proportion of different habitat types are also important factors that should be considered when examining the effects of patch context (Lidicker, 1995). Connectivity is a term most often used to imply a physical connection between habitat patches by linear strips of habitat, termed corridors, that may facilitate movement between patches (Bennet, 1990; Henein and Merriam, 1990). However, With *et al.* (1999) emphasized that patches may be functionally connected (by means of animal dispersal) without being structurally connected.

1.1.2. Impacts of habitat fragmentation

Habitat fragmentation has three major outcomes: patch size reduction, patch isolation, and an increase in the amount of edge habitat (e.g., Andrén, 1994; Rosenblatt *et al.*, 1999). The predicted impact on species of the two former outcomes has roots in MacArthur and Wilson's (1967) theory of island biogeography. This theory predicts that the number of species (i.e., species richness) present on an island is a consequence of the area of the island and the distance of the island from the mainland. Larger islands should have more space, and a greater diversity of habitats, and therefore support a greater number of species (i.e., a higher species richness). Less isolated islands should possess a greater species richness than more isolated islands, because closer islands are more accessible through the process of dispersal. Conservationists have applied this theory to the problem of habitat fragmentation, by equating habitat patches formed by fragmentation with islands (Debinski and Holt, 2000). However, in both field studies and controlled experimental studies that examine the response of small mammals to habitat fragmentation, these predictions have been both supported and refuted, as indicated by the following review.

Area effects

In contradiction to the predictions of the theory of island biogeography, several studies have found that the presence, richness (number of species), abundance (number of individuals), and/or diversity (based on indices that incorporate both species richness and abundance) of small mammals are not significantly associated with fragment area (e.g., Bayne and Hobson, 1998; Dickman, 1987; Fitzgibbon, 1997; Kelt 2000; Schmid-Holmes and Drickamer, 2001). In the southern boreal mixed-wood forest of Saskatchewan, Bayne and Hobson (1998) found no difference in the abundance (normalized per trap-nights) of several small mammal species (red-backed vole: *Clethrionomys gapperi*; red squirrel: *Tamiasciurus hudsonicus*; northern flying squirrel: *Glaucomys sabrinus*; and deer mouse: *Peromyscus maniculatus*) between small (~10 ha) and large (>20 ha) farm woodlots. Similarly, no relationship was found between abundance and area for two small mammal species studied (wood mouse: *Apodemus sylvaticus*; and bank vole: *Clethrionomys glareolus*) in 38 farm woodlots (ranging from 0.05-4.5 ha) in Britain (Fitzgibbon, 1997). In 80 forest patches of 1.03-47.57 ha within a matrix of various anthropogenic interspersions in Illinois, patch size did not exert a strong influence on either the occurrence or abundance of small mammals, the numerical majority of which were white-footed mice (*Peromyscus leucopus*) (Schmid-Holmes and Drickamer, 2001). Another study conducted in the same state found a positive relationship between mammalian species richness and area (Rosenblatt *et al.*, 1999). However, the difference in the findings of the two studies may be explained by the facts that Rosenblatt *et al.* (1999) included larger mammals in their analyses, and sampled a greater range of patch sizes (1.8-600 ha). Within 50 patches vegetation patches ranging from 0.16 to 20 ha in an urban environment in Oxford, the species richness of small mammals was not found to increase with the area of the patch (Dickman, 1987). Both Kelt (2000) in a study of forest fragments (2-125 ha) within grazing and crop fields in Chile, and Silva (2001) in a study of forest fragments (0.07-4.64 ha) within an agricultural matrix in Prince Edward Island, found that neither species richness, population size, nor species diversity of small mammals was related to fragment area. In the Netherlands, Eurasian red squirrels (*Sciurus vulgaris*) were found to have a higher probability of occurrence in larger woodlots (Verboom and van Apeldoorn, 1990), but in the same region, bank vole densities and woodlot area were not significantly related to one another (van Apeldoorn *et al.*, 1992).

Overall, a literature review of the effects of area on small mammal species richness, abundance, and diversity provides inconsistent results. In these situations, the theory of island biogeography is generally not supported. However, low variation in the size of forest fragments may have contributed to the lack of a species-area relationship in some of these studies (particularly Fitzgibbon, 1997 and Silva, 2001). A meta-analysis of studies examining the relationship between patch size and population density conducted by Bender *et al.* (1998) yielded several predictions regarding the patch-size effect. The authors found that overall, generalist species (those that have broad environmental requirements) did not show a significant response to patch size.

Interior species should exhibit the greatest decline in population when patch size is reduced, whereas species that tolerate edge conditions may exhibit a positive response to fragmentation. Given that individual species exhibit differential responses to habitat fragmentation, the community effects (such as species richness) are thus difficult to predict.

Isolation effects

The effects of isolation vary considerably depending upon the species examined, due to differences in their physiological and ecological requirements (Witt and Huntly, 2001). Perceptual range, the distance from which an organism can detect habitat patches, is one factor that strongly affects the likelihood that an organism will travel to another patch (Zollner, 2000). Differential success of various species within a fragmented landscape may be highly influenced by their perceptual range (Zollner, 2000). Habitat generalists may be better able to withstand the effects of isolation than habitat specialists (species with more specific environmental requirements), as the latter may be hesitant to cross matrix habitat (Zollner, 2000). For example, in a forest/sage-steppe landscape in Idaho, densities of the red-backed vole, a habitat specialist, decreased with increasing isolation. In contrast, densities of the deer mouse, a habitat generalist, were not affected by increasing isolation (Witt and Huntly, 2001).

The effects of isolation also depend upon whether the matrix habitat functions as a filter, which reduces the proportion of animals dispersing, or a barrier, which prevents dispersal of all individuals (Witt and Huntly, 2001). Whether a matrix is a filter or a barrier is influenced by physiological traits of an organism. A barrier preventing dispersal can negatively influence populations, by preventing gene flow among patches and by stopping the colonization of individuals to new patches (Witt and Huntly, 2001).

While the response of small mammals to isolation is certainly species-specific, in general many species within this group are likely to be negatively affected by isolation, due to the small body size and relatively low vagility (movement abilities) of small mammals. Negative effects of isolation have been documented in many areas. For example, in the Netherlands, the presence of red squirrels and bank voles within a woodlot was found to be positively influenced by proximal large woodlots (Verboom and van Apeldoorn, 1990; van Apeldoorn *et al.*, 1992). In Ottawa, populations of white-footed mice were found to have lower growth rates in more isolated woodlots, and therefore the isolated populations had greater chances of becoming extinct (Fahrig and Merriam, 1985).

However, in contradiction to the predictions of the theory of island biogeography, isolation positively influenced the population size of both wood mice and bank vole populations within farm woodlands in England (Fitzgibbon, 1997). However, the observed high abundance in some fragmented systems may be indicative of crowded, low quality habitat rather than preferred habitat (Schmid-Holmes and Drickamer, 2001), that may be created by a “fence effect” as a result of a species being unwilling to cross unfavorable matrix habitat (Bayne and Hobson, 1998; Nupp and Swihart, 1998). Debinski and Holt (2000) performed a survey of habitat fragmentation experiments that included many taxa, and found that crowding of individuals in patches following fragmentation was very common in small mammals.

Edge effects

In addition to altering the area of the patch and the conditions around the patch, the conditions within the patch are also changed as a result of habitat fragmentation. The border between two contrasting habitat types is termed edge. As the area of a patch becomes reduced, the amount of edge habitat increases relative to the amount of core. Edge effects may pervade a long distance into the interior of a habitat, which impacts the inhabitants of small fragments in particular, because small fragments may not contain any habitat representative of interior quality (Malcom, 1994).

Edge effects exert an impact on species because the effects of wind, sun, and rain are greater at the edge, and these abiotic changes can lead to changes in the biotic components of the habitat, such as tree mortality (e.g., Laurance, 1994) and growth of shade-intolerant vegetation (e.g., Laurance and Yensen, 1990) which often leads to greater vegetative diversity (Heske, 1995; Pasitschniak-Arts and Messier, 1998). As with the area and isolation effects of habitat fragmentation, edge effects may exert a positive, negative, or nonexistent influence on populations (Heske, 1995). Certain species may respond positively to the proliferation of vegetation, as it may provide a greater variety of habitat types, a source of understory cover, and increase the availability of food types (Heske, 1995; Pasitschniak-Arts and Messier, 1998). Negative effects on species may also be observed, as a result of factors such as increased predation and parasitism (Heske, 1995).

The distance to which microclimatic edge effects permeate forests has been investigated by several authors. Kapos (1989) found that air temperature was highest in the external 40 m of a 100 ha reserve, and that soil moisture was lowest along the edge of both large and small reserves, up to a distance of 20 m inward. Stevens and Husband (1998) documented greater air and soil temperatures that extended 60 m and 20 m, respectively, into the edge of forest fragments.

Edge effects are both species and context specific. For example, in farm woodlots in southern boreal mixedwood forest, red squirrels, northern flying squirrels, and red-backed voles showed no difference in abundance between transect lines along the edge (the external 1-5 m of the fragment) and the interior (> 100 m from the edge) of fragments, whereas the deer mouse was more abundant along the woodlot edge than in the interior (Bayne and Hobson, 1998). However, in a fragmented prairie landscape the deer mouse did not differ in abundance between the edge (external 0-50 m) and the interior (> 60 m from the edge) (Pasitschniak-Arts and Messler, 1998). Other studies report increases in species richness and diversity with increasing distance from edge habitat (e.g., Stevens and Husband, 1998). However, it is important to mention that differences in what is considered edge habitat may be responsible for some of the variation in species response among studies.

1.1.3. Landscape versus patch effects of fragmentation

Habitat fragmentation leads to changes within the patch itself, and within the patch context. Therefore, a combination of both patch (e.g., area and forest structure) and landscape (e.g. amount of suitable habitat and degree of connectivity) effects should be considered when examining the response of a species or taxa to habitat fragmentation. Differentiating between patch effects and landscape influences is critical in understanding the response of species to habitat fragmentation (Bayne and Hobson, 1998). Several studies examining patch and landscape factors concurrently have been performed, with various taxa, and in various types of landscapes. A review of such studies has been conducted by Mazerolle and Villard (1999). The authors found that, out of 61 studies, landscape variables were significant predictors of species response (i.e. presence or abundance) in 59.0% of studies, and patch variables significantly predicted species response in 93.4% of the studies.

Studies examining small mammals illustrate that the importance of patch and landscape effects depends upon various factors such as the species and the type of landscape. Bayne and Hobson (1998) found that in an area fragmented by forestry and agriculture in north-central Saskatchewan, patch factors had little effect on the abundance of most species, but species abundances varied considerably among different landscapes. In contrast, Schmid-Holmes and Drickamer (2001) found that in a forested landscape of cut and uncut patches in Illinois, landscape characteristics had little effect on small mammal occurrence and abundance, whereas abundance was better predicted by patch characteristics. In farm woodlands in England, both the habitat within patches and the landscape around the patches influenced the dynamics of wood mice and bank voles (Fitzgibbon, 1997). Schmid-Holmes and Drickamer (2001) suggest that the effects of spatial characteristics on populations of small mammals may become more important when the matrix habitat differs greatly from the patches, as would be found in an forest/agriculture landscape.

Studying the effects of fragmentation at a scale larger than a single patch is necessary, since more than one patch is often required for a population to persist. Many populations exhibit metapopulation dynamics, or source-sink dynamics (a particular type of metapopulations). A metapopulation is a group of subpopulations joined by movement among the subpopulations. The frequency of movements is neither too infrequent to isolate the subpopulations, nor too often which would create an entire population (Hanski and Thomas, 1994). A population with source-sink dynamics consists of one or more source subpopulations residing in high quality habitat, that provides dispersing individuals to lesser quality sink habitats (Amarasekar and Nisbet, 2001).

1.1.4. Microhabitat heterogeneity

At the smallest spatial scale, the microhabitat within a particular area can influence the small mammal community structure (e.g., Kitchings and Levy, 1981; Richens, 1974). In a hypothetical situation where the landscape characteristics are suitable for providing metapopulation interactions and gene flow, and where the patch is of sufficient size to sustain a sub-population, a microhabitat that is unsuitable for a particular species reduces the probability of that species occurring or persisting in the system. This is particularly true for specialized species, i.e. those species that require very particular abiotic and biotic environmental conditions. In addition, more heterogenous microhabitats have a greater likelihood of having a more diverse small mammal community (e.g., Maisonneuve and Rioux, 2001; Mitchell *et al.*, 1997). Heterogeneity can be conceptualized as the probability that two randomly selected individuals from a community are different species, with higher probabilities indicating a more heterogenous community (Krebs, 1999).

The importance of microhabitat heterogeneity has been illustrated in several field studies. Maisonneuve and Rioux (2001) found that small mammal captures in riparian strips in Quebec increased as the structural complexity of the vegetation increased. The authors classified strips with only herbaceous vegetation as the least structurally complex habitats, whereas areas with shrubby and wooded vegetation were considered more complex. Mitchell *et al.* (1997) found that small mammal diversity was highest (among five types of forest stands sampled) in a mixed hardwood forest with gaps in the canopy cover that created a variety of microhabitats. Anthropogenic modifications of the environment that increase the understory diversity may also be beneficial to small mammals. For example, several studies have examined the response of small mammals to various forest management techniques (e.g., clear-cutting and selective harvesting) and found that communities often respond positively to these alterations (Kirkland, 1990; Sullivan, 1999; Swan *et al.*, 1994). Researchers tend to explain this phenomenon in relation to the increase in diversity of habitat types created within the forest stand after management, which appears to promote the increase in abundance of numerous small mammal species. Therefore, both natural and man-made heterogeneity tend to support more diverse small mammal communities.

Relatively few studies have compared the relative importance of microhabitat versus larger-scale habitat characteristics within a particular area. However, in New Brunswick, Bowman *et al.* (2001*b*) examined how small mammal populations respond to within-stand vegetation characteristics such as tree composition and type of understory vegetation, and to landscape characteristics such as the proportion of various forest patch types. They found that the abundance of each of the four most common small mammals (red-backed vole, deer mouse, short-tailed shrew (*Blarina brevicauda*), and woodland jumping mouse (*Napaeozapus insignis*)) was significantly related to vegetation characteristics, albeit only low amounts of variability were generally explained by the type of understory vegetation. The abundance of two of these species (red-backed vole and woodland jumping mouse) was also weakly related to landscape characteristics, such as the surrounding forest type.

While numerous studies have examined microhabitat preferences for many small mammal species, it is still valuable to gather local information on habitat use. This is because studies have found that the relative importance of certain habitat features to a particular species may not be constant among regions (Kaufman *et al.*, 1983). This may be due to habitat characteristics providing differential benefits to a species based on the particular food, predatory and climatic conditions that vary from region to region (Kaufman *et al.*, 1983).

1.1.5. Description of the study province and local small mammalian fauna

Land use on Prince Edward Island

The response of small mammals to habitat characteristics will be assessed within forests of Prince Edward Island (P.E.I.). P.E.I. is located on Canada's east coast, within the Gulf of St. Lawrence. It is the smallest Canadian province, covering only 5660 km^2 (Weighs, 1995). P.E.I. is approximately 230 km long, and varies from 6.5 to 50 km in width. Although the topography consists of rolling hills, the maximum height above sea level is 127 m (van de Poll, 1983). There are few major rivers on P.E.I., and networks of small brooks and streams drain the province (Raymond *et al.*, 1963).

The original forests of P.E.I. were classified as Acadian, the composition of which included high quality hardwoods such as sugar maple (*Acer saccharum*) and yellow birch (*Betula allegenhensis*) (Round Table on Resource Land Use and Stewardship, 1997) with ground vegetation such as bunchberry (*Clintonia borealis*) (Clark, 1959). However, past and current land use practices have dramatically altered the forest structure. In 1720, permanent settlements began to be established, but population expansion during the 1700's was slow (Raymond *et al.*, 1963). However, rapid human colonization and population growth occurred during the 1800's, and this transformed P.E.I.'s landscape from primarily forest to agriculture-dominated. In 1900, only 30% of the land was forested (Round Table on Resource Land Use and Stewardship, 1997). As a result of the loss of continuous tracts of forest, negative impacts on the animal populations have occurred. In particular, large mammals such as the black bear (*Ursus americanus*) and lynx (*Lynx lynx*) have been extirpated (Atlantic Canada Conservation Data Center, 2003; Bateman and Prescott, 1984).

While recent (1990) information indicates that forest covers 48% of P.E.I. (Round Table on Resource Land Use and Stewardship, 1997), the land is still subject to unsustainable farming practices and timber harvesting, as well as other human activities and development. Much of the land has been cleared at some point for agriculture, and all forests have been subjected to some form of harvesting, from selective to clear cutting. Many areas have been harvested several times. As a result, the hardwood component of the forest has been reduced, and there is now an approximately equal mix of hardwoods and softwoods. The forests also tend to have a lot of early successional, even-aged stands (Round Table on Resource Land Use and Stewardship, 1997).

The small mammals of Prince Edward Island

The importance of habitat characteristics to the small mammal community of P.E.I. will be evaluated in this study. Currently there are 16 species on P.E.I. that are classified as non-volant terrestrial small (< 250 g) mammals. Of these, five are insectivores (Order Insectivora), ten are rodents (Order Rodentia), and one is a carnivore (Order Carnivora). Only a few studies have examined the small mammalian fauna of P.E.I. Many of these have been small mammal surveys within the P.E.I. National Park (PEINP) (Bateman and Prescott, 1984; Silva *et al.*, 2000; Silva, 2001). However, two recent studies have provided information on small mammals in other areas of the province (Hartling, 2001; Prince, 2002).

Order Insectivora

The masked shrew (*Sorex cinereus*) is the most common shrew on P.E.I. (Bateman and Prescott, 1984; Hartling, 2001; Silva *et al.*, 2000). It occurs in a wide variety of habitat types, ranging from dunes to wetlands (Silva *et al.*, 2000) and old fields (Bateman and Prescott, 1984). Based on the ranking of the Atlantic Canada Conservation Data Center (ACCDC), this species is of secure status (Table 1.1).

The water shrew (*Sorex palustris*) is infrequently captured on P.E.I. Only four specimens from one location were detected by Bateman and Prescott (1984), and recent surveys have not captured this species (Hartling, 2001; Silva *et al.*, 2000; Silva, 2001). The water shrew is classified by the ACCDC as rare, and may be vulnerable to extirpation (Table 1.1). However, it is important to note that many of the studies on small mammals did not trap in habitat that would be preferred by the water shrew, and therefore the abundance of this species may be underestimated.

The smoky shrew (*Sorex fumeus*) is not frequently found on P.E.I. The status of the smoky shrew was hypothetical in the PEINP (i.e., its presence was presumed but had not been documented) as of 1984 (Bateman and Prescott). However, Hartling (2001) found two individuals in a mixed forest stand. Throughout the entire province, the smoky shrew has a generally secure population status, but tends to be uncommon (Table 1.1).

The pygmy shrew (*Sorex hoyi*) was found to be rare by Bateman and Prescott (1984), and subsequent studies have failed to document its presence. Not enough information is available to suggest habitat preferences for this species on P.E.I. The pygmy shrew is classified by the ACCDC as rare to uncommon (Table 1.1).

The short-tailed shrew is a species that has been observed to undergo population fluctuations (e.g., in Vermont by Brooks *et al.*, 1998), explaining why

Table 1.1. Ranking of the population status of the small mammalian species on P.E.I., as determined by the Atlantic Canada Conservation Data Center (Atlantic Canada Conservation Data Center, 2003).

Species	Ranking[a]
Masked shrew	S5
Water shrew	S1
Smoky shrew	S3S4[b]
Pygmy shrew	S2S3
Northern short-tailed shrew	S5
Eastern chipmunk	S5
American red squirrel	S5
Northern flying squirrel	S4S5
Deer mouse	S5
Red-backed vole	S5
Meadow vole	S5
Meadow jumping mouse	S5
Woodland jumping mouse	S4
Norway rat	SE
House mouse	SE
Short-tailed weasel	S5

[a] S1: The species is extremely rare throughout its range in the province (typically 5 or fewer occurrences or very few remaining individuals). May be especially vulnerable to extirpation.
S2: The species is rare throughout its range in the province (6 to 20 occurrences or few remaining individuals). May be vulnerable to extirpation due to rarity or other factors.
S3: The species is uncommon throughout its range in the province, or found only in a restricted range, even if abundant in at some locations.
S4: The species is usually widespread, fairly common throughout its range in the province, and apparently secure with many occurrences, but is of long-term concern (e.g. watch list).
S5: The species is demonstrably widespread, abundant, and secure throughout its range in the province, and essentially ineradicable under present conditions.
SE: The species is exotic.

[b] Uncertainty about the exact status of a species is indicated by two rankings.

it has been found in field studies to be both rare (Bateman and Prescott, 1984; Silva *et al*, 2000) and abundant (Hartling, 2001) in P.E.I. These studies all indicate that the short-tailed shrew is found in wooded habitats of P.E.I. According to the ACCDC, the status of this species is secure (Table 1.1).

Order Rodentia

The most recent studies on P.E.I. indicate that the eastern chipmunk is a very abundant small mammal (L. Hartling, unpublished data; Prince, 2002; Silva, 2001; Silva *et al.*, 2000), although in the past this species has been considered uncommon (Bateman and Prescott, 1984; Cameron, 1958). The eastern chipmunk may be most abundant in hardwood forests (Bateman and Prescott, 1984; Silva, 2001) and tends to avoid agricultural fields (L. Hartling, unpublished data; Silva *et al.*, 2000). This species is classified as secure (Table 1.1).

The American red squirrel is a common small mammal on P.E.I. (Bateman and Prescott, 1984; Silva *et al.*, 2000), although its population numbers may fluctuate in response to conifer cone production (Bateman and Prescott, 1984). On P.E.I., this species is found in most forest types, and may find nourishment from grain in agricultural fields adjacent to wooded areas (Bateman and Prescott, 1984). Red squirrels have a secure status (Table 1.1).

Northern flying squirrels are the most uncommon of the three sciurid species on P.E.I. (Bateman and Prescott, 1984; Silva *et al.*, 2000). However, neither of these studies made use of arboreal traps (i.e., traps located in trees), which may have led to more captures of northern flying squirrels. This species is found in forested habitats (Bateman and Prescott, 1984; Silva *et al.*, 2000). Although northern flying squirrels tend to be widespread and abundant, their population status may be of long-term concern (Table 1.1).

The population status of the deer mouse on P.E.I. appears to be quite variable. It was considered scarce by Cameron (1958), and was not frequently captured by Bateman and Prescott (1984) and Silva *et al.* (2000). However, Silva (2001) reported that the deer mouse was the second most frequently captured species, and relatively high captures were also reported by Prince (2002). Deer mice are found in boggy areas as well as forest (Bateman and Prescott, 1984; Silva *et al.*, 2000), and have a secure population status (Table 1.1).

There are two vole species on P.E.I., the red-backed vole and meadow vole (*Microtus pennsylvanicus*). Both species exhibit population fluctuations, and therefore their population status varies yearly and within local regions (Bateman and Prescott, 1984; Cameron, 1958; Silva, 2001; Silva *et al.*, 2000). Red-backed voles may reach their highest abundances in mixed-wood forests (Bateman and Prescott, 1984; Silva, 2000), whereas meadow voles tend to be found in open-canopy areas (Bateman and Prescott, 1984; L. Hartling, unpublished data). Both vole species have a secure status on P.E.I. (Table 1.1).

Two species of jumping mice are found on P.E.I., the meadow jumping mouse (*Zapus hudsonicus*) and woodland jumping mouse. In the past, the woodland jumping mouse was considered to be the most uncommon of the two species (Bateman and Prescott, 1984; Cameron, 1958), but recent studies have found the opposite trend (Silva, 2001; Silva *et al.*, 2000). However, this may be due to differences in trapping techniques among these surveys. The woodland jumping mouse is usually found in forested areas, whereas the meadow jumping mouse tends to prefer areas with open canopy (Bateman and Prescott, 1984). According to the ACCDC, the meadow jumping mouse has a secure population status, while that of the woodland jumping mouse may be of long-term concern (Table 1.1).

Two introduced rodent species occur on P.E.I., the Norway rat (*Rattus norvegicus*) and the house mouse (*Mus musculus*). Both species are infrequently captured in natural areas, and their presence is considered to be a nuisance (Bateman and Prescott, 1984). These species are considered exotic and are thus not ranked by the ACCDC (Table 1.1).

Order Carnivora

On P.E.I. only one carnivore species, the short-tailed weasel (*Mustela ermina*), is small enough to be classified as a small mammal. It is a common species (Bateman and Prescott, 1984) that occurs in forested habitats and linear fragments such as fence rows (Bateman and Prescott, 1984; Silva, 2001). The population status of weasels is secure (Table 1.1).

1.1.6. Predicted responses of the small mammals of Prince Edward Island to habitat fragmentation

Although the landscape of P.E.I. is highly fragmented, relatively few studies have assessed the effects of fragmentation on the wildlife species of this province. Recent studies have attempted to relate small mammal species richness and abundance to characteristics of the habitat, patch size, and patch perimeter (Silva, 2001) and features associated with hedgerows (Prince, 2002). However, these studies focused on examining how internal (e.g., vegetation composition) and physical (e.g., area) characteristics of the patch or hedgerow affected small mammal richness and abundance, while a detailed quantification of the influence of the landscape surrounding the patches was not conducted. The unexplained variance in the small mammal populations in these studies may be attributed, in part, to landscape-scale characteristics.

Studies conducted in other areas of the world suggest some of the small mammals on P.E.I. may be negatively affected by landscape and patch modifications associated with habitat fragmentation (e.g., Rosenblatt *et al.*, 1998; Witt and Huntly, 2001). The agricultural fields separating forested areas may reduce the proportion of animals dispersing among patches. If the agriculture matrix functions as a barrier that animals are reluctant to cross, it can negatively impact populations by preventing gene flow and stopping the colonization of new individuals (Witt and Huntly, 2001), which could lead to local extirpations. Agricultural fields contain habitat unsuitable for most species, which means that species diversity may be reduced in fragmented landscapes. Additionally, wildlife species may be affected by the increased amount of edge habitat in fragmented habitats, which often differs from core habitat in having a greater influence of physical factors (e.g., wind, sun, and rain), higher tree mortality (Laurance, 1994), and more shade-intolerant vegetation species (Laurance and Yensen, 1990).

The response of some of the small mammal species on P.E.I. to the effects of habitat fragmentation may be predicted by studies conducted in other areas of North America. The red-backed vole may be particularly sensitive to the effects of fragmentation. In Idaho, Witt and Huntly (2001) found that densities of the red-backed vole decreased as the isolation of the forest patch increased. Sullivan *et al.* (1999) report a negative population response of the red-backed vole to habitat disturbance in British Columbia, finding them in much higher abundance on forest sites than on clearcut sites. In New Brunswick, the distribution of red-backed voles was related to the landscape context, as they were negatively associated with the amount of plantation (Bowman *et al.*, 2001*b*).

The eastern chipmunk may be affected by both alterations to the patch and to the surrounding landscape. Their abundances have been found to be positively associated with higher tree densities and tree species richness (Schmid-Holmes and Drickamer, 2001), suggesting that their populations may be reduced when the amount of continuous forest is reduced. They also prefer wooded habitat rather than open habitat (Henderson *et al.*, 1985; Henein *et al.*, 1998), and thus will likely be hesitant to cross agricultural fields. In Illinois, eastern chipmunks were only detected in large forest tracts connected to other areas by riparian corridors (Rosenblatt *et al.*, 1999). However, in Ontario, Bowman and Fahrig (2002) found that eastern chipmunks that were translocated (moved from a capture site to a release distance of 220-250 m) could cross non-forested gaps to return to their home range, regardless of the size of the gap (up to 240 m).

Other small mammal species occurring on P.E.I. may be less or even positively affected by habitat fragmentation. For example, within woodlots surrounded by farms in Saskatchewan, the deer mouse was found to be more abundant at the edges of the woodlots than the interior. This may have been due to the deer mice taking advantage of greater seed production that sometimes occurs along the edges of agricultural fields (Bayne and Hobson, 1998). Alternately, they may have been responding to an increase in the proliferation of shrubs along edges, supported by the finding that deer mice were found to be associated with hardwood shrubs in New Brunswick (Bowman *et al.*, 2001*b*). Deer mice also tend be less affected by isolation than more specialized species such as the red-backed vole. In Idaho, deer mice densities did not decrease with increasing isolation of forest fragments, whereas those of the red-backed vole did (Witt and Huntly, 2001).

Red squirrels may be more abundant in isolated forest fragments, and less affected by the environmental modifications in fragmented habitats. In Saskatchewan, Bayne and Hobson (2000) found that red squirrels were habitat generalists, as they were ubiquitous in the sampling area and their abundances were not significantly associated with any habitat variable. Bayne and Hobson (2000) found both red squirrels and northern flying squirrels to be more abundant in forest fragments surrounded by lower amounts of forest cover. These higher abundances were explained to be potentially a result of factors such as reduced dispersal, increased survival, the absence of predators, and an increased food supply (due to higher cone production by some tree species, and grain piles).

Masked shrews may respond positively to the increase in edge habitat that is created in fragmented habitats. For example, in North Carolina Menzel *et al.* (1999) found masked shrews to be higher in abundance at forest edges than within the forest. Short-tailed shrews may also not decrease in abundance in fragmented habitats, because they tend to occur in a wide variety of habitat types. For example, Rosenblatt *et al.* (1999) found them to occur in forested, grassland, and agricultural habitats. In riparian habitat in Quebec, masked shrews and short-tailed shrews were captured in all habitat types sampled (herbaceous, shrubby, and wooded riparian strips) (Maisonneuve and Rioux, 2001).

The response to habitat fragmentation of the other small mammal species that occur on P.E.I. has not been as well evaluated by researchers conducting work in other areas of North America. However, general predictions can be made based on the ecology of a particular species. Typically, the response of an animal species to habitat fragmentation depends on whether it is a generalized or more specialized species. Generalist species (those that can exploit a wide range of resources (Krebs, 2001)) tend not to exhibit a negative population response to patch area (Bender *et al.*, 1998). Habitat generalists also tend to be less affected by patch isolation than specialists (Witt and Huntly, 2001), as generalists may be more willing to traverse through matrix habitat (Zollner, 2000). Additionally, given that fragmentation increases the amount of edge habitat, interior species may show the largest declines in population (Bender *et al.*, 1998).

1.2. Response of individuals to habitat features at different spatial scales

1.2.1 Patterns of movement

Movements of small mammals have been classified into several types, such as dispersal, exploration, and activity within the home range (Kozakiewicz and Szcacki, 1995). Dispersal occurs over longer time scales and larger spatial scales. Movement for activities such as foraging occurs over smaller spatial scales. Movement is an important aspect of an animal's behaviour, as both short-term and long-term movement have the potential to exert both positive and negative effects on an individual. For example, an animal may be positively influenced by finding a mate or encountering suitable habitat, but negatively affected if the habitat found is unsuitable, or if a predator is encountered (Wiens *et al.*, 1995). The sum of such influences on the individuals within a population ultimately affects population dynamics and the composition of the community (Wiens *et al.*, 1993).

Studying movement can provide detailed information on an animal's interaction with its environment, and can be used to examine factors such as: 1) response to their environment over a range of spatial scales (Nams and Bourgeois, submitted; Turner *et al.*, 1989); 2) habitat characteristics that are used for navigation (Barry and Franq, 1980; Nams and Bourgeois, submitted); 3) changes in movement pattern in habitats varying in structure and composition (Crist *et al.*, 1992; With, 1994*a*); and 4) habitat selection (Lemen and Freeman, 1985). The fractal dimension can be used as a tool to examine factors 1, 2, and 3. The application of fractal analysis to the examination of these factors will be subsequently discussed, but first it is necessary to understand the concept itself.

The fractal dimension

In order to ascertain the effects of habitat structure on the movement patterns of an animal, their movement pathways must be quantified (Dicke and Burrough, 1988; Kareiva and Shigesada, 1983; McCulloch and Cain, 1989; Nams, submitted; Nams and Bourgeois; submitted; Wiens *et al.*, 1993). Fractal geometry, which is used to quantify objects of irregular form (Mandelbrot, 1967), is often used to quantify movement patterns (Nams, 1996). The fractal dimension (D) provides a quantitative measure of the path tortuosity (i.e., complexity) that varies between 1 (in the case of a linear pathway) and 2 (in the case of plane-filling random movement) (Sugihara and May, 1990). The fractal dimension is traditionally estimated using the dividers method (Mandelbrot, 1967). Dividers of different size are stepped along an object (e.g., a path), to obtain a measurement of path length for various divider sizes. The slope of a plot of log(path length) versus log(step size) is equal to 1-D. If an object or path exhibits fractal behaviour, then the value for D obtained on smaller measurement scales will be the same value for that obtained at larger scales, and hence will be a scale-independent measure (Turchin, 1996). If similar processes govern a pattern (such as movement behaviour) over a certain range of scales, these scales should show similar values for D (Sugihara and May, 1990).

Fractal dimension as a tool for examining animal/habitat interactions

1) Response to habitat characteristics over a range of spatial scales

Before the fractal dimension can be used as a descriptor of the tortuosity of a movement pathway, it must be determined that D does not change over the range of spatial scales studied (Turchin, 1996). If D changes with spatial scale, the *overall* estimate of D for the pathway is not a valid measure (Turchin, 1996). Movement pathways may not be fractal because they may exhibit behaviour that is more representative of a different pattern, such as a directed walk, random walk or a correlated random walk. In a random walk, an organism's future movements are not affected by previous movements (Kareiva and Shigesada, 1983). In a correlated random walk, there is a degree to which the direction of movements are correlated (Kareiva and Shigesada, 1983).

However, if D does change with spatial scale, even though the *overall* estimate for D is invalid to use, it can be used as a tool to examine the scales at which the animal's response to their environment changes (Nams and Bourgeois, submitted). Scale-dependent shifts in a pattern may be indicative of a transition in processes that regulate the observed patterns (Turner *et al.*, 1989). Animals often exhibit different responses to their environment at different spatial scales. These differential responses should be reflected in their movement patterns, and therefore in D (Nams and Bourgeois, submitted; Turner *et al.*, 1989). The fractal dimension plotted as a function of the spatial scale (i.e., step size) at which it was determined may indicate scales over which D is relatively invariant (termed domains by Wiens, 1989), and transition regions (points at which movement patterns change qualitatively) among the domains (Nams, submitted; Nams and Bourgeois, submitted).

Within the different domains that an animal perceives and responds to its environment, different aspects of its biology are important. To illustrate this point, Nams (submitted) provides an example of striped skunk (*Mephitis mephitis*) movement behaviour. At the smallest spatial scale (meters), skunk foraging activities are important. At the next domain, daily movements are performed on the order of a few kilometers. Habitat choice is important at this scale. At the largest spatial scale, skunks perform long-range dispersals of tens of kilometers, which affects their metapopulation dynamics.

Small mammal orientation and trail-following studies have provided information regarding the spatial scales at which some small mammal species interact with their habitat. Wood mice were found to exhibit movement that was random on a larger scale, as they moved among bushes, but at a smaller scale their movements were directed toward a particular bush (Benhamou, 1990). Therefore, these two scales would represent two different domains of interaction with their environment, and the transition between these domains would occur at the scale of spacing between bushes (Nams, submitted). Nams (1996) found that a red-backed vole moved randomly (its movement behaviour was representative of a correlated random walk) on scales of 10-50 cm, but on a larger scale the vole was moving in a more directed fashion.

2. Habitat characteristics used for navigation

Small mammals may move toward characteristics of the habitat that function as cues for their orientation. For example, white-footed mice in New Hampshire were found to orient toward trees, which served as visual landmarks for their navigation (Barry and Franq, 1980). Drickamer and Stuart (1984) similarly found that two mice species (white-footed mice and deer mice) in Massachusetts were most likely using trees as navigational cues. An examination of the transitions in an animal's movement behaviour, in conjunction with descriptions of the environment through which the animal has moved, can help us to examine if there are habitat characteristics that an animal moves toward or avoids (Nams and Bourgeois, submitted).

3. Movement patterns in habitats varying in structure and composition

Habitat structure (the distribution of habitat components; i.e., degree of clumpiness), the abundance of habitat components, and the composition (amount of different habitat types) of the habitat may influence an animal's movement patterns (With, 1999). Quantitative aspects of movement, such as the rate (speed of movement), and turning angles (the angles formed by changes in direction among steps (Crist *et al.*, 1992)), are a result of an organism's interaction with its environment (Johnson, 1992). Given that animal-movement pathways are largely a result of interactions with vegetation and other environmental characteristics (With, 1994*a*) it can be hypothesized that movement patterns will differ with respect to the habitat structure and composition. A somewhat intuitive hypothesis is that higher values of D will be observed in environments with a greater abundance of cover (Wiens and Milne, 1989; Crist *et al.*, 1992). For example, With *et al.* (1999) found that crickets (*Acheta domestica*) exhibited more tortuous movement behaviour in microlandscapes with a greater percentage of grass coverage. Stapp and van Horne (1997) found deer mice to have straighter trails in areas where shrubs were sparse, and then became more tortuous with increasing shrub cover (although more linear movement was also observed in areas with extremely dense shrub cover).

Comparing the tortuosity of an animal's movement behaviour in a particular habitat may provide an indication of how the habitat is being used by the animal (With 1994*a*; With 1994*b*). Path tortuosity may serve as an indicator of the quality of a particular habitat through which an animal moves. This is because it is expected that an animal will move straighter through areas that serve merely as travel routes, and more tortuously in habitats that can be used for activities such as foraging and searching for prey (Edwards *et al.*, 2001; Nams and Bourgeois, submitted; Sugihara and May, 1990).

However, a few studies have found that the fractal dimension of an individual's pathway is relatively similar regardless of the habitat type, even when other aspects of the animal's movement behaviour are altered. For example, in a study of the movement behaviour of three species of darkling beetles (*Eleodes* spp.), all species were found to have smaller net displacements as the heterogeneity of the habitat cover types increased, but the fractal dimension did not significantly differ among cover types (Crist *et al.*, 1992). Similarly, Wiens *et al.* (1997) found that for darkling beetles in habitats varying in percent of grass coverage, displacement rate was greatest on bare ground than on grass cover, but they did not find a difference in pathway tortuosity. With (1994*b*) did not find significant differences in the fractal dimension in the movement pathways of a gomphocerine grasshopper (*Opeia* *obscura*) among microlandscapes varying in heterogeneity. Therefore, patterns of movement may also involve endogenous behavioural characteristics of the organism (Nams, 1996; With, 1994*a*).

The influence of habitat structure and composition may affect the behavioural patterns of individuals. In turn, this can affect the spatial structure of the population. Therefore, studying movement patterns can aid in the understanding of a population's spatial distribution and abundance patterns (Johnson *et al.*, 1992; Wiens *et al.*, 1993). For example, Stapp and van Horne (1997) found that both the trail tortuosity of deer mice and their population densities increased as the amount of ground cover by shrubs increased. Therefore, the spatial distribution of deer mice indicated a tendency for individuals to accumulate in areas where their movements were more convoluted.

1.2.2. Habitat selection along movement pathways

Local patterns of distribution and abundance at the population level are affected by habitat selection at the individual level (Stapp, 1997). Tracing an individual's movement pathway has the additional benefit of providing a visual record of the specific habitats through which it has moved (Lemen and Freeman, 1985). By examining the availability of the various habitat types within the area of movement, it is possible to determine if certain habitat features were selected in proportion to their availability, and if some were avoided. Since movement allows individuals to find food and mates, and avoid predators, it is likely that particular habitat characteristics along a path are selected in order to optimize the success of these actions (Barnum *et al.*, 1992).

Several field studies indicate that small mammal species tend not to use resources in proportion to their availability, indicating that certain resources are preferred (Barnum *et al.*, 1992; Luque-Larena *et al.*, 2002; Stapp, 1997). A study of white footed mouse path selection in Maryland and Minnesota found that the individual mice chose pathways that reduced their visibility and audibility to predators (Barnum *et al.*, 1992). Stapp (1997) studied the movement patterns of grasshopper mice (*Onychomys leucogaster*) and found that they were concentrating their activities on areas with many mounds and burrows, and also found that the prey of the mice (arthropods) tended to be more numerous in these areas. Therefore, grasshopper mice tended to move through areas that would allow them to have increased foraging success. In mountainous habitat in Spain, Luque-Larena *et al.* (2002) found that snow voles (*Chionomys nivalis*) made use of rocky microhabitat types more often than expected. The authors suggested that these habitats were chosen because they provided the snow voles with protection from predators, and a stable microclimate (which would have theromregulatory benefits).

1.2.3 Eastern chipmunk biology

The present study will investigate the movement patterns of the eastern chipmunk. Mahan and Yahner (1999) provide several reasons to justify the use of the eastern chipmunk as a model species for examining behaviour patterns in modified environments. They are abundant and easily trapped (documented on Prince Edward Island by L. Hartling, unpublished data; Prince, 2002; Silva, 2001). They rely heavily on vision, and thus habitat disturbances that affect the structure of vegetation should directly affect their behaviour (Mahan and Yahner, 1999). In addition, they are known to occupy human-altered habitats, although the effects of habitat alterations on their behaviour are not well documented (Mahan and Yahner, 1999).

The eastern chipmunk is semi-arboreal, has a long life span (compared to many other small mammals), and is diurnal (Bowers *et al.*, 1990; Lacher and Mares, 1996). Eastern chipmunks have relatively small home ranges (Lacher and Mares, 1996) that are generally less than 0.50 ha (Table 1.2), and defend core areas (of about 15-25 m in radius) that consist of the space around burrows (Bowers *et al.*, 1990; Elliot, 1978; Lacher and Mares, 1996; Mahan and Yahner, 1999). Eastern chipmunks are relatively sedentary and generally restrict their movements to their core areas (Mahan and Yahner, 1999). However, they may make longer exploratory and dispersal movements greater than 50 m through open fields, and greater than 500 m through fencerows (Table 1.3). Eastern chipmunks are generally considered to be a specialized small mammal species,

Table 1.2. Several home ranges reported for the eastern chipmunk.

Location (State or Province)	**Habitat description**	**Home range (ha)**	**Reference**
Pennsylvania	Mature stand of second-growth deciduous forest bounded by mowed fields on two sides, a reservoir on the third side, and closed-canopy forest on the forth side	0.08-0.24 (Adult males) 0.09-0.30 (Adult females) 0.02-0.40 (Juvenile males) 0.05-0.27 (Juvenile females)	Lacher and Mares, 1996
Ontario	5.1 acre deciduous woodlot bounded by fields on the N, S, and E; grading into a mature maple-beech stand on the W	0.04-0.56	Forsyth and Smith, 1973
Prince Edward Island	2.2 ha willow-beaked hazelnut- white birch fragment bounded by agricultural fields and a walking trail	0.12-0.25 (Males) 0.14 (Female)	Puddister, 1999
Prince Edward Island	10.5 ha balsam fir-red maple- white spruce fragment bounded by agricultural fields and a walking trail	0.09-0.69 (Males) 0.14-3.28 (Females)	Puddister, 1999
Ontario	3.6 ha birch-aspen-maple forest	0.80-1.0	Hackett and Trevor-Deutsch, 1982

Table 1.3. Extent of several landscape movements by the eastern chipmunk.

Location (Province)	**Description of movement**	**Reference**
Ontario	Movements of >500 m, likely through fencerows	Bennet *et al.*, 1994
Ontario	Crossed 70 m of open field, probably on a regular basis	Forsythe and Smith, 1973
Ontario	Travelled 1560 m between woodlots, likely through fencerows	Henein *et al.*, 1998
Prince Edward Island	Travelled between two fragments, a minimum distance of 525 m	Puddister, 1999
Prince Edward Island	Travelled between two fragments, which involved travelling a minimum distance of 75 m through a hay field	L. Hartling, unpublished data

due to their preference for wooded areas (Henein *et al.*, 1998). Although they often occur in modified habitats, they seldom move through matrix habitat such as fields (Henein *et al.*, 1998; Wegner and Merriam, 1979).

Eastern chipmunks feed on a wide variety of food sources such as seeds, nuts, fruit, other vegetation, and some invertebrates (Boitani and Bartoli, 1982; Whitaker, 1996). Predators of the eastern chipmunk include weasels, hawks, foxes, and house cats (Whitaker, 1996).

2. OBJECTIVES

The overall goal of this research is to examine how small mammals use and respond to habitat features at different spatial scales. To achieve this goal, three objectives have been set. These are to:

1) Examine and compare how microhabitat (e.g., vegetation structure), patch (e.g., tree structure and composition), and landscape characteristics (e.g., proportion of suitable habitat) affect the species richness and abundance of small mammals. It is expected that the relative importance of characteristics at each spatial scale will be species-specific.

2) Examine the movement behaviour of eastern chipmunks at different spatial scales. In particular, it will be investigated whether the fractal dimension (a measure of tortuosity) is constant for all measurement scales, or if there are different domains over which the fractal dimension is relatively constant. The habitat features that are most important at each range of spatial scales will be examined. Based on information about the biology of the eastern chipmunk, and studies of the movement patterns of other animals, it is expected that at the smallest scales, chipmunk movement patterns will be related to the complexity of the vegetation, and at larger scales movement pathways will be more direct due to navigation toward landmarks.

3) Examine what habitat characteristics the eastern chipmunk selects. It is expected that chipmunks will actively select features of the habitat that will provide the greatest degree of predator protection, while providing optimal foraging opportunities. Therefore, it is anticipated chipmunks will choose habitats with a high percentage of both ground and canopy cover.

3. RELATIONSHIPS BETWEEN SMALL MAMMAL POPULATIONS AND COMMUNITIES WITH CHARACTERISTICS AT THE MICROHABITAT, MACROHABITAT, AND LANDSCAPE SPATIAL SCALES

3.1. Introduction

The objective of this study was to examine how small mammals are affected by characteristics of their environment at the microhabitat, patch, and landscape spatial scales. Smaller-scale characteristics of the patch (e.g., vegetation patterns) may not be sufficient to explain the within-patch variation in patterns of species richness or abundance, because landscape-scale influences (e.g., amount of suitable habitat surrounding the patch) may account for some of the variation (Mazerolle and Villard, 1999). However, few studies have evaluated the effects of habitat characteristics on small mammals at multiple spatial scales (Schmid-Holmes and Drickamer). The relative importance of habitat characteristics at each spatial scale are expected to be species-specific.

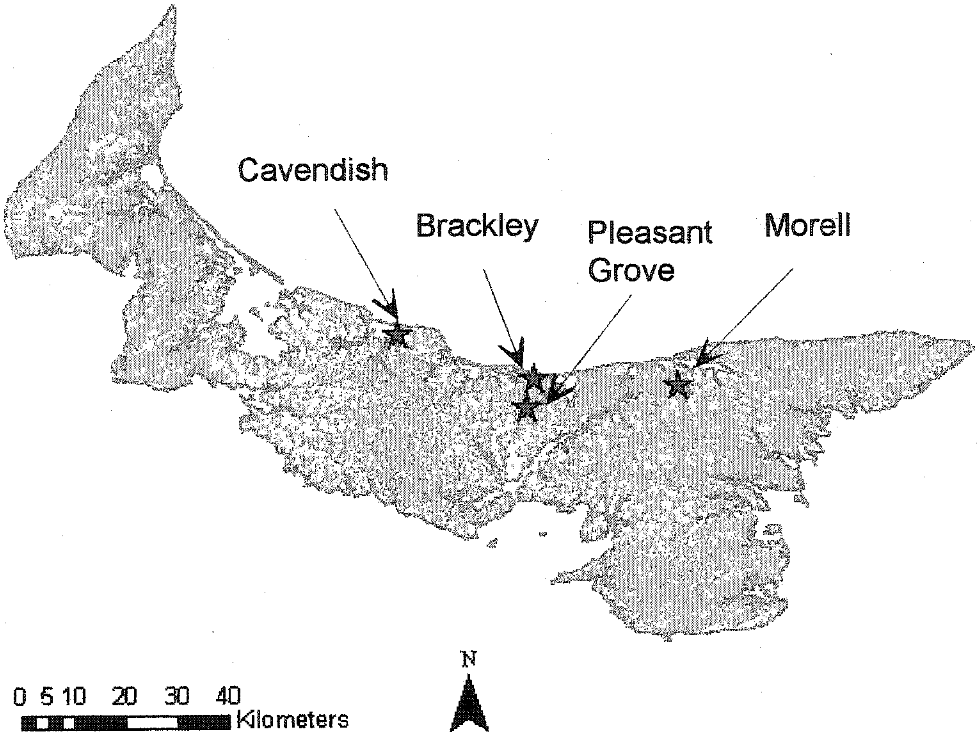
3.2. Methods

3.2.1. Trapping

Study Sites

The study was conducted from May to October of 2002. Small mammals were trapped in four different study sites in central P.E.I., Canada (Figure 3.1). Study sites of varying agricultural influence were chosen, in order to sample

Figure 3.1. Map of Prince Edward Island indicating the location of the four study sites.



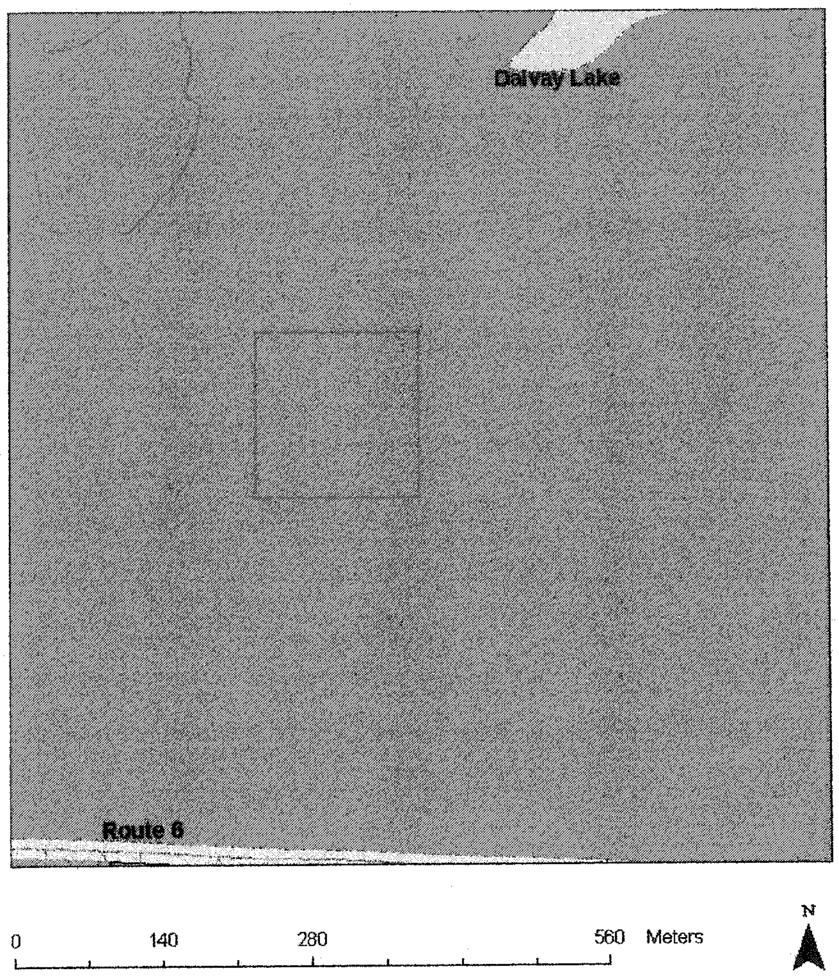
small mammals in areas that differed in landscape structure. The elements of structure used to differentiate the sites were the size of the forest patches, the area of surrounding agricultural fields, and the presence of hedgerow connections among forest patches. Study sites were selected using ArcView:GIS with 1990 P.E.I. provincial forest information (courtesy of the Prince Edward Island Department of Agriculture and Forestry) . Sites varied from a continuous forest with virtually no surrounding agriculture within a 1000 m radius (Brackley), large connected patches of forest within an agricultural surrounding (Morell), various-sized connected patches of forest within an agricultural surrounding (Pleasant Grove), to various-sized unconnected patches of forest within an agricultural surrounding (Cavendish). Within each study site, trapping grids were established in forest patches (Figures 3.2-3.5).

Experimental Design

In order to assess the abundance and richness of small mammals, trapping grids were set up within the forest patches within each landscape. Grids covered approximately 10% of the forest patch area (*sensu* Silva, 2001). Trap stations were spaced at 10 m intervals within the grids (Jones *et al.*, 1996). The majority of grids were squares. However, in some patches the grids were more rectangular due to limitations imposed by the shape of the patch.

At each trap station, a Sherman live trap (50 x 62 x 165 mm) was placed at an area that would maximize the probability of capturing small mammals, such

Figure 3.2. Map of the Brackley study site.[a]



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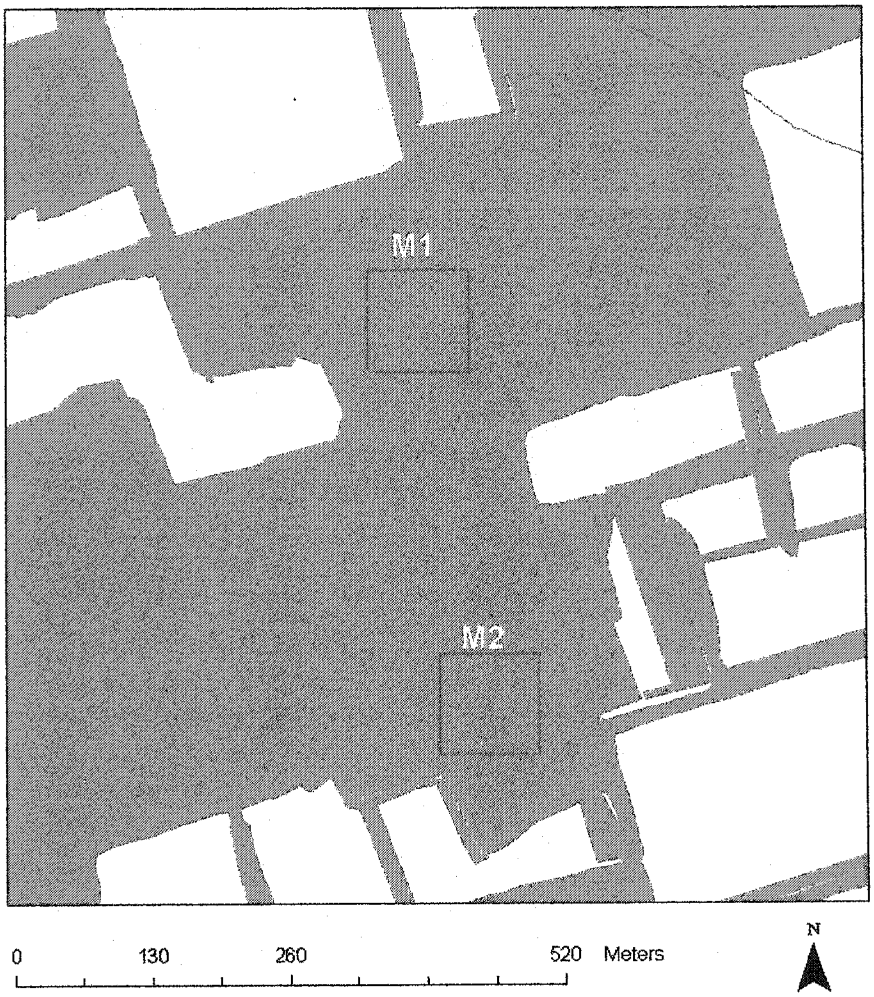
[a] Approximate area covered by trapping grid is outlined by dashed red lines. Forested areas are indicated in green, and blue is water.

Figure 3.3. Map of the Morell study site.[a]



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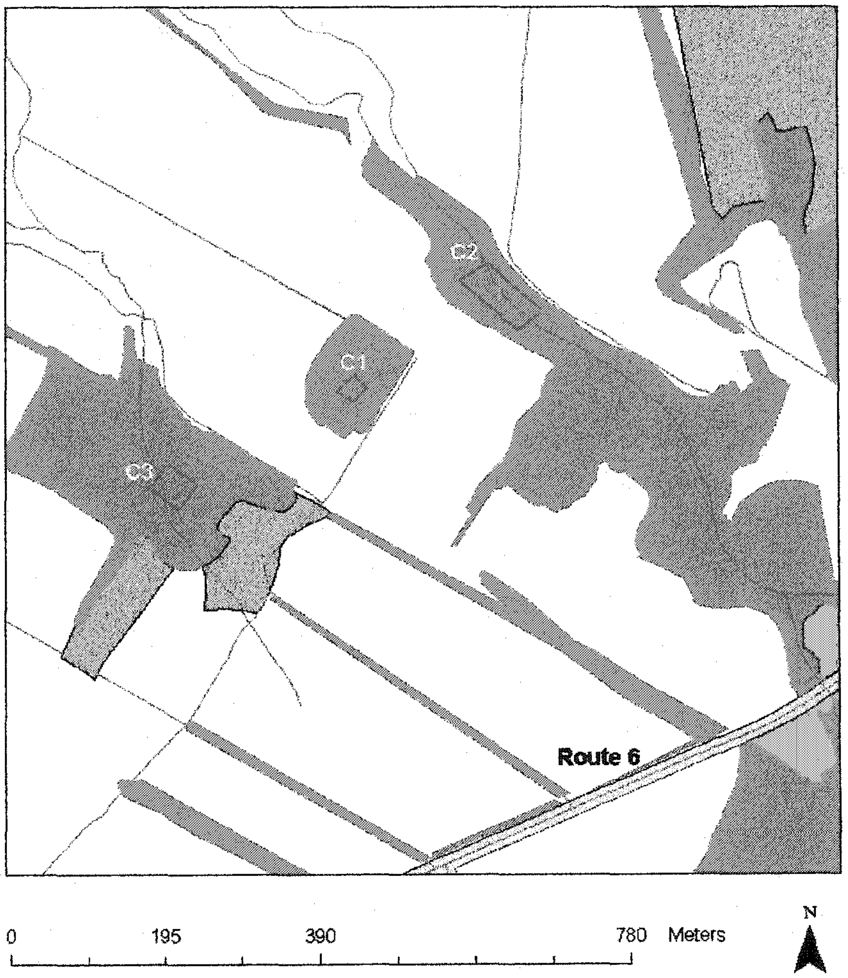
[a] Approximate area covered by trapping grids is outlined by dashed red lines. Forested areas are indicated by green and agricultural areas are indicated by white.

Figure 3.4. Map of the Pleasant Grove study site.[a]

[a] Approximate area covered by trapping grids is outlined by dashed red lines. Forested areas are indicated by dark green, cleared land is light green, unsuitable land (excavation pits) is black, urban areas are pink, water is blue, and agricultural areas are white.

Figure 3.5. Map of the Cavendish study site.[a]



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[a] Approximate area covered by trapping grids is outlined by dashed red lines. Forested areas are indicated by dark green, cleared land is light green, urban areas are pink, water is blue, and agricultural areas are white.

as along the base of trees or logs, or in front of burrows (Jones *et al.*, 1996). In order to obtain more information on the arboreal small mammal species (particularly red squirrels and northern flying squirrels), a maximum of 10% of the Sherman live traps in each fragment were wired to trees or raised logs at a height of approximately 1.5 m. Although Sherman live traps have been shown to sample a large portion of the small mammal community, certain species may be under-sampled by the use of Sherman traps exclusively (Jones *et al.*, 1996). Several studies have found that pitfall traps may be more successful than Sherman traps for capturing shrew species (e.g., Bury and Corn, 1987). Therefore, pitfall traps were constructed which consisted of 8 L plastic buckets placed inside holes dug into the ground so that the top of the bucket was about 2-4 cm below the surface. Pitfall traps were established at 20% of trap stations (randomly selected) per patch. Due to rainfall, water accumulated in pitfall traps and they therefore functioned as kill traps.

Sherman live traps were baited with either sunflower seeds or a mixture of peanut butter and rolled oats. Studies have shown that a peanut butter bait is among the most effective bait types for sampling small mammals, in terms of capturing an abundance of individuals, sampling a variety of species, convenience of use, and resistance to invertebrate foraging (Barnett and Dutton, 1995; Jones *et al.*, 1996; Patric, 1970). However, because other studies on Prince Edward Island have had success in trapping small mammals with sunflower seeds (e.g., Silva, 2001; Prince, 2002), this type of bait was also used.

Bait types were alternated in each trap within the grid lines. During cooler temperatures, several cotton balls were placed in each trap for bedding.

Each site was sampled once during a four-week rotation. During the study period, there were four rotations, corresponding to late spring/early summer, mid-summer, late summer, and early fall. Traps were set in the evening of the first night, then checked every twelve hours for the following two days. Traps were removed from the site on the evening of the third night.

Specimen processing

Small mammals were processed following the guidelines of Animal Care Protocol #02-024, approved by the University of Prince Edward Island Animal Care Committee. Captured animals were shaken from the trap into a ziplock bag. Northern flying squirrels, American red squirrels, and eastern chipmunks were anaesthetized to allow for less-stressful processing. These animals were shaken from the trap into a ziplock bag containing a cotton ball that had been dipped in diethyl ether, monitored until they appeared to be fully anaesthetized, and then were removed from the bag. Captured animals with external pinnae (all small mammal species excluding shrews) were ear tagged using Monel size 1 fingerling tags, so that recaptured individuals could be identified. Standard morphological measurements were recorded (body length, and tail length) using a ruler (± 1 mm). Although these measurements were not recorded specifically for use in this study, they were recorded because of potential use to future research. Body mass was recorded using a Pesola scale (± 2 g). The sex and reproductive condition (sexually mature or juvenile) of each individual was also noted. Males were considered sexually mature if testes were visible, and females were considered sexually mature if nipples were present. The sex of juveniles was determined based on the distance between the anus and the clitoris (for females) or the anus and the genital papilla (for males), because this distance is less for females (Kunz *et al.*, 1996).

Shrews were virtually always dead when traps were checked, so they were measured, bagged, and taken back to the lab. Shrews were later identified to species based on morphological and dental characteristics (Beaudin and Quintin, 1983). No attempt was made to determine the sex of shrews, because this is almost never externally obvious. The scrotum of male shrews is only visible during breeding season, as the scrotum is held internally during other times of the year (Kunz *et al.*, 1996).

3.2.2. Habitat Descriptions

Within each forest patch, habitat descriptions were conducted in order to quantify the vegetative communities characterizing the patch. To obtain information on tree communities, randomly located grids of 5 x 5 m were surveyed. The number of grids sampled per patch was related to the size of the patch, with one grid surveyed per 15 traps. Data were recorded on the abundance of each tree species and the number of dead trees, logs, and stumps. For each individual living tree, the circumference was measured at a height of about 1.5 m, and the tree was assigned a height class based on visual estimation (small: < 5 m, medium: 5-10 m, or large: >10 m). Tree communities were surveyed only once during the study period.

To obtain information on ground vegetation and microclimate near the trap stations, grids of 1 x 1 m located in the vicinity of every other trap station were surveyed. Microclimate information was recorded using a digital thermometer (± 1°C) and a soil moisture meter that quantifies moisture on a continuous scale from 1 to 10, where 1 is very dry and 10 is very wet. Information on the percent canopy cover above the trap station was estimated using a spherical densiometer. To quantify ground cover, information was recorded on the percent of the ground plot that was covered by: trees > 1.5 m, trees < 1.5 m, shrubs > 1.5 m, shrubs < 1.5 m, moss, herbs, logs, stumps, other woody debris, bare soil, and leaf litter. The microhabitat descriptions were conducted three times during the study period (early summer, mid summer, and late summer).

Information regarding habitat features at the landscape scale was obtained using 1990 P.E.I. forest inventory information with 2000 aerial photographs. ArcView:GIS (version 8.1) was used to combine 2000 aerial photographs with 1990 forest inventory information, in order to update any land cover changes. Using ArcView:GIS (version 8.1), the area of different land cover types surrounding a grid were classified as either: agricultural land, connected forest, unconnected forest, marginal habitat (e.g., clearcut forest and cleared land), or unsuitable habitat (e.g., excavation pits and anthropogenic structures such as paved roads).

Using SigmaScan (version 5), the area of each land cover type was determined at different radii from the grid mid-point (100 m, 200 m, 400 m, and 1000 m). The 100-400 m radii were chosen based on similar studies (Bowman *et al.*, 2001*b*; Schmid-Holmes and Drickamer, 2001), and because most of the small mammals expected to be trapped are capable of making long-distance movements up to 400 m. For example, Bowman *et al.* (2001*a*) found that deer mice, woodland jumping mice, and red-backed voles make long distance movements of up to 370 m, 225 m, and 224 m, respectively. However, the 1000 m radii was chosen for analyses dealing with eastern chipmunks and red squirrels, as these species tend to have larger dispersal distances. Kemp and Keith (1970) have documented movements by red squirrels in mixed forest up to a distance of 640 m, and Larsen and Boutin (1995) have found that red squirrels often make exploratory movements of greater than 1000 m. Similarly, eastern chipmunks have been documented traveling distances of over 500 m (Bennet *et al.*, 1994; Puddister, 1999), and a distance of 1560 m has even been recorded (Henein *et al.*, 1998).

3.2.3. Data analysis

The trapping success for each grid of traps was determined based on the formula: number of animals captured / number of trapnights (N_{TN}). N_{TN} is equal to $N_F + 0.5\ N_D$, where N_F is equal to the number of fully functional traps, and N_D is equal to the number of disturbed but functional traps (*sensu* Silva *et al.*, 2001). The species richness (number of different species captured) per grid was tallied. The abundance for each small mammal species was evaluated by determining the total number of different individuals captured per species (i.e., recaptured individuals were excluded). For each grid, the total abundance per species was normalized by dividing it by N_{TN}, to take into account the different trapping effort and disturbance levels in each grid. The species diversity per grid was calculated using the Shannon-Weiner index ($H' = -\sum p_i \times \ln p_i$, where p_i is the proportion of individuals in the *i*th category, and each different species is a category) (Shannon and Weiner, 1949).

The success of each trap type (ground-level Sherman, arboreal Sherman, and pitfall) was determined. To determine if pitfall traps were more effective at capturing shrews than ground-level Sherman traps, a chi-square test was used, testing the null hypothesis that pitfall traps caught the same number of shrews as the ground level Sherman traps (proportional to the number of each trap type). Similarly, a chi-square test was also used to determine if arboreal traps were more effective at capturing red squirrels and northern flying squirrels than ground-level Sherman traps.

For the microhabitat, macrohabitat, and landscape information, principal components analysis was used as an initial data exploration and reduction technique. However, the principal components only explained a small amount of variance in the data, and the variable loadings on each component were weak and difficult to interpret. Therefore, correlation and regression analyses were used without information provided by principal components analysis.

For the microhabitat analyses, the data from the microhabitat descriptions at the trap locations were related to the normalized per-species abundance of each trap. The abundance was normalized by determining the number of different individuals captured in a trap and dividing it by the functionality of the trap, using the same formula used to calculate trapnights. This value takes into account the fact that some trap locations tend to be disturbed more than others, and that the reason for a lower capture rate in that trap may be related to frequent disturbance of the trap rather than an avoidance of the microhabitat features around the trap. The microhabitat analyses were conducted separately for early summer, mid-summer, and late summer information. The microhabitat information per each grid was also averaged so that it could be related to species richness and diversity per grid.

The information obtained through the macrohabitat descriptions was summarized and related to the species diversity, richness, and per-species abundance of the patch in order to examine patch-scale responses of small mammals to habitat variables. The landscape characteristics surrounding a grid were related to the diversity, richness, and per-species abundance determined for the grid, to evaluate the importance of landscape-scale variables to small mammal communities and populations.

In order to relate the habitat variables with the small mammal variables, correlation analysis was used. Variables were first tested for normality using the Kolmogorov-Smirnov test. Since all variables tended to be non-normal (and standard transformations did not normalize most variables), all statistical tests used were non-parametric. Spearman rank correlation was used to determine relationships amongst the independent variables (microhabitat, macrohabitat, and landscape characteristics) and the small mammal variables (species richness, diversity, and per-species abundance). However, an independent variable that was found to be significantly related to a small mammal variable was not retained as a descriptor if: 1) it was significantly correlated with another habitat descriptor (in this case, the variable that was most strongly related to the dependant variable was retained); or 2) the relationship with the small mammal variable was forced by outliers (determined by visual inspection of the scatterplot).

Multiple stepwise linear regression was used to develop predictive models to explain the variance in each small mammal variable. Variables previously omitted were not included in the regression model. This test was not used if the equal variance assumption was not met.

3.3. Results

3.3.1. Trapping success

Overall, in 11,415 trapnights, 587 small mammals belonging to 9 species were captured. Of the 587 captures, at least 341 captures (58 %) were different individuals. Values of trapnights, trapping success, species richness, and diversity varied among grids (Table 3.1). Grids also varied in species abundance and composition (Figure 3.6). With 301 captures of 146 individuals, the eastern chipmunk was the most frequently captured species (43 % of all individuals), with the next most abundant species being the deer mouse (18 % of all individuals). Both the eastern chipmunk and the deer mouse were also the most widespread species, being captured in all fragments (Figure 3.6).

Overall, the Sherman live traps were the most successful trap type, with 4.4 % of all set traps capturing a small mammal. The arboreal traps had a success rate of 3.1 %, whereas pitfall traps were only 1.2 % successful. Arboreal traps were not more effective than ground-level Sherman traps in capturing red squirrels and northern flying squirrels ($\chi^2 = 2.02$, df = 1, $p > 0.10$). Pitfall traps were significantly more effective than ground-level Sherman traps in capturing shrews ($\chi^2 = 28.37$, df = 1, $p < 0.01$).

3.3.2. Microhabitat analyses

In general, microhabitat characteristics explained low but significant amounts of variance in the captures of small mammals. Microhabitat variables

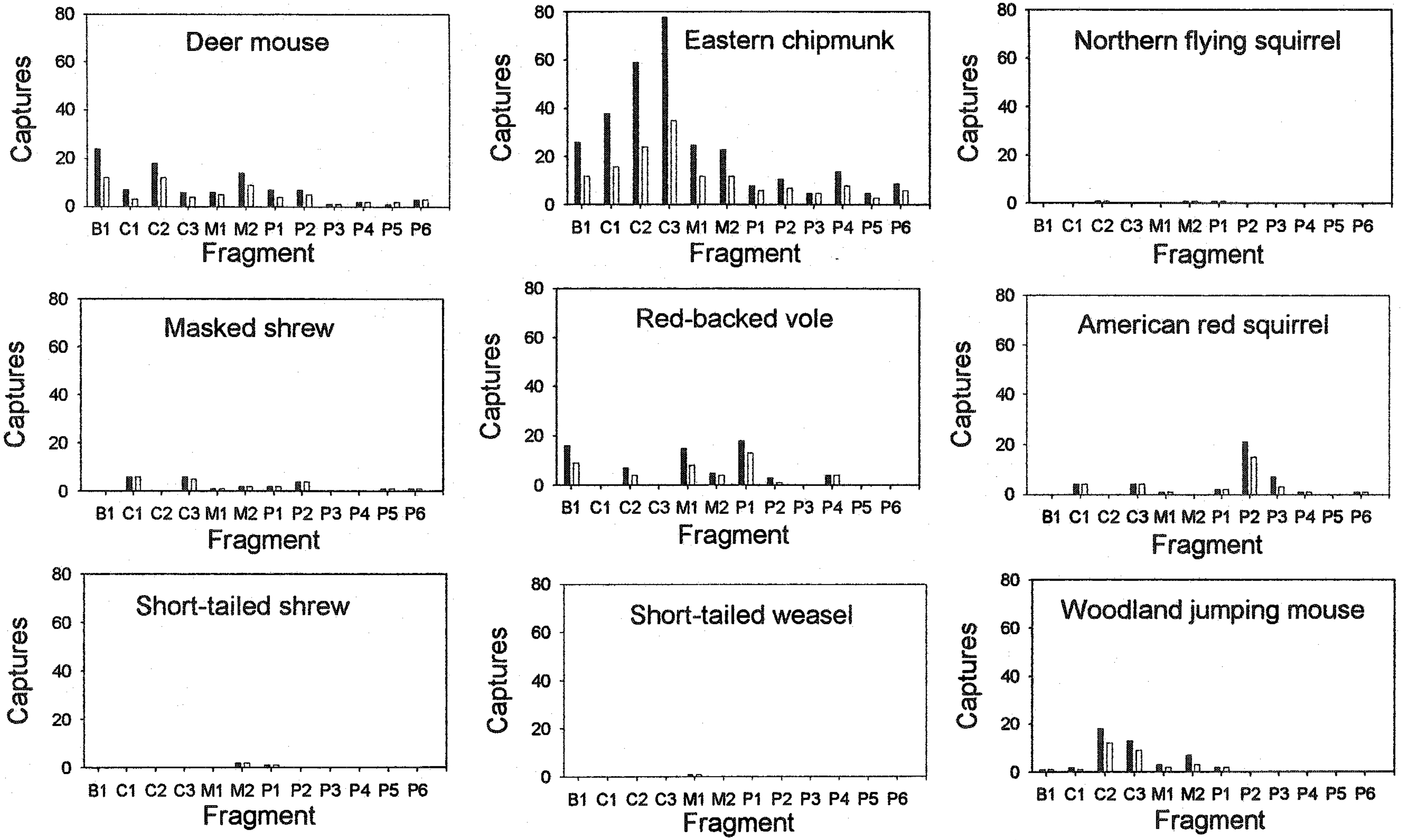
Table 3.1. Summary of the trapping results for each of the study grids.

Location	**Grid size (m^2)**	**Trap-nights**	**Trapping success (%)**	**Total captures**	**Number of individuals**	**Species richness**	**Species diversity[a]**
Brackley	16900	3159.5	2.4	77	44	6	2.321
Cavendish 1	225	258	18.2	47	20	3	0.884
Cavendish 2	3900	1406.5	8.2	115	62	7	2.346
Cavendish 3	3600	719	13.8	99	50	5	1.323
Morell 1	8100	1534	3.5	53	30	6	2.153
Morell 2	8100	1404.5	3.9	55	35	8	2.549
Pleasant Grove 1	8100	1633.5	3.9	64	46	8	2.475
Pleasant Grove 2	225	260	10.8	28	16	4	1.749
Pleasant Grove 3	225	210.5	3.3	7	7	3	1.149
Pleasant Grove 4	2800	479	4.4	21	15	4	1.640
Pleasant Grove 5	NA[b]	159	5.0	8	7	4	1.842
Pleasant Grove 6	NA[b]	191.5	6.8	13	9	2	0.918

[a] Calculated using the Shannon-Weiner index of diversity (Shannon and Weiner, 1949).

[B] Not applicable because the traps were arranged linearly due to fragment shape.

Figure 3.6. Location[a] and number of captures[b] for each small mammal species trapped in the present study.



[a] B1 is the Brackley grid, C1-C3 are Cavendish grids 1-3, M1 and M2 are Morell grids 1 and 2, and P1-P6 are Pleasant Grove grids 1-6.

[b] Black bars represent total captures, white bars represent total number of different individuals.

were significantly associated with Sherman live-trap captures of all of the most frequently captured species (red-backed voles, woodland jumping mice, deer mice, red squirrels, and eastern chipmunks) (Table 3.2). However, the importance of the explanatory variables often changed among the time of year (early, mid, or late summer) (Table 3.2).

Species richness for a grid was significantly related to the average moss cover ($r = 0.58$, $p < 0.05$, $n = 12$) and negatively related to average litter cover ($r = -0.61$, $p < 0.05$, $n = 12$). Species diversity was significantly related to the average moss cover ($r = 0.68$, $p < 0.05$, $n = 12$). However, it is important to note that similarities in the variables that predict species richness and diversity are expected, because richness and diversity are strongly correlated ($r = 0.91$, $p < 0.01$).

3.3.3 Macrohabitat analyses

Small mammal species richness and diversity were found to be significantly associated with the number of tree species (Table 3.3). Of the most frequently captured species, only the captures of red-backed voles were significantly related to a macrohabitat variable (Table 3.3).

3.3.4. Landscape analyses

There were significant associations among small mammal variables and landscape variables at all buffer radii (100 m, 200 m, 400 m, and 1000 m)

Table 3.2. Relationships[a] between microhabitat variables and abundance of the most frequently captured species, separated temporally.

Species	Early summer	Mid-summer	Late summer
Red-backed vole	Tall trees ($r = 0.13$, $p < 0.05$, $n = 315$) Grass ($r = 0.16$, $p < 0.01$, $n = 315$)	None	Vines ($r = 0.13$, $p < 0.05$, $n = 314$) *Moss ($r = 0.13$, $p < 0.05$, $n = 314$)
Woodland jumping mouse	*Soil humidity ($r = 0.14$, $p < 0 .05$, $n = 315$) Bare ground ($r = 0.11$, $p = 0.05$, $n = 315$)	*Soil humidity ($r = 0.11$, $p = 0.05$, $n = 338$)	Small shrubs ($r = 0.15$, $p < 0.01$, $n = 314$)
Deer mouse	None	None	Grass ($r = -0.12$, $p < 0.05$, $n = 314$) *Herbs ($r = -0.16$, $p < 0.01$, $n = 314$) Other woody debris ($r = 0.16$, $p < 0.01$, $n = 314$)
Red squirrel	*Herbs ($r = -0.16$, $p < 0.05$, $n = 315$)	*Litter depth ($r = -0.16$, $p < 0.05$, $n = 338$)	Litter depth ($r = -0.13$, $p < 0.05$, $n = 314$) Grass ($r = 0.14$, $p < 0.05$, $n = 314$)

Species	Early summer	Mid-summer	Late summer
Eastern chipmunk	*Soil humidity (r = 0.23, p < 0.01, n = 315) Canopy (r = 0.16, p < 0.05, n = 314)	Soil humidity (r = 0.16, p < 0.01, n = 338) *Canopy (r = 0.20, p < 0.01, n = 338) Bare ground (r = 0.17, p < 0.01, n = 339)	Soil humidity (r = 0.19, p < 0.01, n = 298) *Ground temperature (r = -0.20, p < 0.01, n = 314) Canopy (r = 0.14, p < 0.05, n = 313) Small trees (r = -0.18, p < 0.01, n = 314) Tall shrubs (r = 0.12, p < 0.05, n = 314) Moss (r = -0.14, p < 0.05, n = 314)

[a] Spearman rank correlations were used to analyze all relationships. Variables with an asterisk are those that were retained as descriptors after auto-correlation analysis and visual inspection of the trend.

Table 3.3. Relationships[a] between species richness, diversity, and captures of the most common species with macrohabitat variables.

Small mammal variable	Significantly related variables	Linear regression model
Species richness	*Number of tree species $(r = 0.64, p < 0.05, n = 12)$	None
Species diversity	*Number of tree species $(r = 0.66, p < 0.05, n = 12)$ Log density $(r = 0.64, p < 0.05, n = 12)$ Stump density $(r = 0.59, p < 0.05, n = 12)$	1.0104 + 0.123 number of tree species $(p < 0.05)$
Red-backed voles	Log density $(r = 0.63, p < 0.05, n = 12)$ Stump density $(r = 0.66, p < 0.05, = 12)$ Average tree circumference $(r = -0.69, p < 0.05, n = 12)$ *Small tree density $(r = 0.70, p < 0.05, n = 12)$	None
Woodland jumping mice	None	None
Deer mice	None	None
Masked shrews	None	None
Red squirrels	None	None
Eastern chipmunks	None	None

[a] Spearman rank correlations were used to analyze all relationships. Variables with an asterisk are those that were retained as descriptors after auto-correlation analysis and visual inspection of the trend. The model predicted by stepwise linear regression is also indicated.

(Table 3.4). In general, the area of connected forest was positively related to species richness and diversity. Landscape variables were significantly correlated with the abundance of red-backed voles, red squirrels, and eastern chipmunks, but not with the abundance of woodland jumping mice, deer mice, and masked shrews (Table 3.4).

3.4. Discussion

3.4.1. Trapping success

Overall, this study documented the presence of nine out of sixteen species of small mammals. However, the trapping success and the total species richness obtained during this study were low in comparison to other recent studies on P.E.I. (Prince, 2002; Silva *et al.*, 2000). The low trapping success may be due to a low point in the population abundances for some small mammal species. This explanation (rather than the low success rate being a result of poor trapping effort) is probably a likely scenario, given that the present study employed three trap types (ground, arboreal, and pitfall), whereas Prince (2002) and Silva *et al.* (2000) used one and two trap types, respectively. Additionally, the present study had a greater number of trapnights than in the previous studies.

The low species richness may also be partially explained by population fluctuations. However, because the present study sampled in a narrower variety of habitats than Prince (2002) and Silva *et al.* (2000), certain species were less

Table 3.4. Relationships[a] between species richness, diversity, and captures of the most common species with landscape variables.

Small mammal variable	Significantly related variables	Linear regression model
Species richness	Agriculture (100 m) ($r = -0.66$ $p < 0.05$, $n = 12$) *Connected forest (100 m) ($r = 0.68$, $p < 0.05$, $n = 12$) Agriculture (200 m) ($r = -0.57$, $p = 0.05$, $n = 12$)	1.1048 + 1.0002 connected forest 100m ($p < 0.05$)
Species diversity	Agriculture (100 m) ($r = -0.59$, $p < 0.05$, $n = 12$) Connected forest (100 m) ($r = 0.61$, $p < 0.05$, $n = 12$) Connected forest (200 m) ($r = 0.64$, $p < 0.05$, $n = 12$) Agriculture (400 m) ($r = -0.60$, $p < 0.05$, $n = 12$) *Connected forest (400 m) ($r = 0.64$, $p < 0.05$, $n = 12$)	None
Red-backed voles	*Connected forest (200 m) ($r = 0.66$, $p < 0.05$, $n = 12$)	None
Woodland jumping mice	None	None
Deer mice	None	None
Masked shrews	None	None
Red squirrels	*Connected forest (1000 m) ($r = 0.64$, $p < 0.05$, $n = 12$)	None

Small mammal variable	Significantly related variables	Linear regression model
Eastern chipmunks	Agriculture (100 m) ($r = 0.62$, $p < 0.05$, $n = 12$) Connected forest (100 m) ($r = -0.62$, $p < 0.05$, $n = 12$) Agriculture (200 m) ($r = 0.65$, $p < 0.05$, $n = 12$) Connected forest (200 m) ($r = -0.76$, $p < 0.01$, $n = 12$) Agriculture (400 m) ($r = 0.75$, $p < 0.01$, $n = 12$) *Connected forest (400 m) ($r = -0.76$, $p < 0.01$, $n = 12$) Agriculture (1000 m) ($r = 0.61$, $p < 0.05$, $n = 12$)	$0.0478 - 104 \times 10^{-9}$ connected forest 400 m ($p < 0.01$)

[a] Spearman rank correlations were used to analyze all relationships. Variables with an asterisk are those that were retained as descriptors after auto-correlation analysis and visual inspection of the trend. The model predicted by stepwise linear regression is also indicated.

likely to be caught. For example, the meadow jumping mouse was not captured in this study, but was captured by Prince (2002) in hedgerow habitat only. Therefore, this species was possibly not captured because the present study did not conduct extensive sampling in hedgerow habitat. Other species were likely not captured because the sampling areas did not include their specialized habitat (e.g., the water shrew), and/or because the species tends to occur in low abundances (e.g., the smoky shrew).

Arboreal traps had low success, and did not capture significantly greater numbers of squirrels than ground-level Sherman traps. It is possible that animals were able to leap over the traps (Barnett and Dutton, 1995). Additionally, the cover objects (e.g., moss, litter, branches) on arboreal traps were often found to be disturbed after strong wind and rainfall. Therefore, the success of arboreal traps may be increased with better camouflage techniques such as gluing substrate onto the traps.

Although pitfall traps had a lower trapping success than ground-level Sherman traps, they were more effective at capturing shrews. The success of pitfall traps in capturing shrews has been demonstrated in previous studies (Bury and Corn, 1987; Pelikan *et al.*, 1977). The success of pitfall traps may be increased by using drift fences to direct shrews into the pitfalls (Williams and Braun, 1983)

3.4.2. Relationships with habitat variables

Species richness and diversity

Both species richness and diversity of small mammals were positively related to ground cover by moss and the species richness of trees. Species richness was negatively related to the amount of litter cover. These findings indicate that a heterogenous macrohabitat, with abundant cover in the microhabitat, tends to support a species rich and diverse community of small mammals. Similarly, Sullivan *et al.* (1999), who investigated the species richness and diversity of small mammals in forests of British Columbia with different management strategies, recommended that landscapes should contain numerous successional stages. They advocated that landscapes should include different tree species and various stand structures in order to maintain high levels of biological diversity.

Small mammal species richness and diversity increased with the amount of connected forest. This suggests that habitat fragmentation has a negative effect on the small mammal communities of P.E.I. Similarly, a positive relationship between woodlot area and species richness was observed for small mammals in agricultural landscapes in Indiana (Nupp and Swihart, 2000). However, another study conducted on P.E.I. did not find a significant relationship with species richness or diversity and fragment area (Silva, 2001). The difference between findings of the present study and Silva (2001) may be due to the fact that Silva (2001) sampled in only small (0.07-5.64 ha) fragments, whereas the current study sampled in areas that had more continuous forest.

From a conservation point of view, these findings should be important to land managers and land owners on P.E.I. Larger and more heterogenous forests are conducive to a greater diversity of small mammal species and therefore should be maintained. However, in the agriculturally-driven economy on P.E.I., large tracts of forest are not easy to retain. Farmers should seek to maintain connections among forested habitats by adding hedgerows, or maintaining existing hedgerows. The importance of hedgerows as habitat for small mammals on P.E.I. has been demonstrated by Prince (2002), and is supported (indirectly) by results of this study.

Species-specific habitat associations

Microhabitat variables were found to be a rather weak predictor of the occurrence of small mammals. Similarly, Bowman *et al.* (2001*b*) found that the vegetation characteristics within a stand were always related to the abundance of the four most frequently captured small mammals (red-backed voles, deer mice, short-tailed shrews, and woodland jumping mice), but that relatively low amounts (9-32 %) of the variability in abundance were explained by individual or combinations of microhabitat variables.

Red-backed voles

Based on the present study, the microhabitat, macrohabitat and landscape associations of the red-backed vole indicate a preference for mossy areas, areas with high densities of small trees, and greater amounts of connected forest. Red-backed voles tend to travel in mossy areas (Whitaker, 1996). As expected (based on Bowman *et al.*, 2001; Sullivan *et al.*, 1999; Witt and Huntly, 2001), red-backed voles tend to be a species sensitive to the effects of landscape alteration. Therefore, based on the results of the present and other studies, this species is expected to be most abundant in undisturbed forests.

Woodland jumping mice

Soil humidity was found to have a positive influence on the populations of woodland jumping mice. In northwestern Maine, woodland jumping mice were found to be more frequently captured near streams (Richens, 1974), and in New Hampshire they were captured more often in moist areas or locations in the vicinity of water (Lovejoy, 1973).

No characteristics of the macrohabitat or landscape were found to be significantly associated with the abundance of woodland jumping mice. This is unusual based on the results of other studies. Bowman *et al.* (2001) found the presence of woodland jumping mice to be related to characteristics on both the macrohabitat and landscape scales. They found that captures of this species were positively related to snags, yellow birch shrubs, and coarse woody debris within the macrohabitat, and were more abundant in landscapes with softwood forest. However, since all sites in this study had a major softwood component, this may not have been a factor limiting the presence of woodland jumping mice in a particular site. Therefore, in our study sites, the moisture of the forest floor may have been more important in limiting the occurrence of woodland jumping mice in a particular area than larger-scale characteristics.

Deer mice

Deer mice are often generalistic in their habitat preferences (Pasitschniak-Arts and Messier 1998; Richens, 1974; Whitaker, 1996), and therefore it was not surprising that, overall, the present study also demonstated this aspect of their ecology. Deer mice were captured in all study sites and were the second-most frequently captured species, and were not associated with any macrohabitat or landscape characteristics. Bayne and Hobson (1998) similarly found no differences in deer mouse abundance between farm woodlots and continuous forest in Saskatchewan. Also, Witt and Huntly (2001) found that deer mice densities were not affected by the degree of isolation of forest patches.

The fact that deer mice were found to be negatively associated with herb cover was unexpected, since other studies have found them to be positively associated with living ground cover objects such as shrubs and balsam fir stems (Bowman *et al.*, 2001). However, this pattern of habitat use may be related to their strategies for predator avoidance. The white-footed mouse (*Peromyscus* *leucopys*) has been shown to select microhabitats that provide predator protection (Kaufman *et al.*, 1983), and are capable of selecting different types of microhabitats based on the type of predator being avoided (Fitzgerald and Wolff, 1998). Experimental and observational data suggest that white-footed mice have behavioural flexibility that permits them to seek covered areas if visually-oriented predators are being avoided, and travel more quietly if auditory-oriented predators are near (Barnum *et al.*, 1992; Fitzgerald and Wolff, 1998). It is possible that deer mice are exhibiting a similar type of flexibility. On Prince Edward Island, auditory predators may be a greater threat to deer mice than visual predators and, therefore, deer mice may be avoiding herbaceous cover in order to travel more quietly.

American red squirrels

For red squirrels, a negative association with litter depth was observed. This probably relates to the red squirrel's preference for coniferous forests (King *et al.*, 1998), which tend to have a shallower depth of litter than deciduous forest leaf litter.

Red squirrels were found to be positively associated with connected forest within a distance of 1000 m. Similarly, in woodlots within an agricultural matrix in Indiana, red squirrels were only found in woodlots greater than 4 ha (Nupp and Swihart, 2000). These studies contrast with the results of Bayne and Hobson (1998), who found that red squirrels reached higher abundances in farm woodlots than in continuous forest. However, the possible explanations provided by Bayne and Hobson (1998) for this result may not be applicable to P.E.I. They theorized that an absence of certain predators in farm woodlots may have permitted squirrels to become more abundant. On P.E.I., evidence provided by personal visual observations, and the level of trap disturbance indicates that both avian and mammalian predators are as, if not more, common in fragmented landscapes.

Eastern chipmunks

Eastern chipmunk abundance was significantly predicted by microhabitat and landscape variables. The present study indicates that this species tends to prefer microhabitats with high soil humidity, high canopy cover, and low ground temperature. This indirectly indicates a preference for interior and less disturbed forest habitat, as forest habitat near edges tends to receive greater amounts of sunlight (Laurance, 1994) and is therefore warmer and drier. The use of habitats with a greater overstory is similar to findings by several researchers (e.g., Bennett *et al.*, 1994; Bowers *et al.*, 1995; Brooks *et al.*, 1998; Schmid-Holmes and Drickamer, 2001). Therefore, the present and other studies indicate that forests with dense canopy cover are the most suitable for eastern chipmunks.

Unexpectedly, the abundance of the eastern chipmunk was found to be negatively associated with the amount of connected forest. This finding leads to two general explanations. Firstly, eastern chipmunks may be very resistant to the effects of habitat fragmentation. Alternately, this species may be very reluctant to cross agricultural habitat, and reaches high abundances due to a "fence effect." High densities of a species are not always reflective of high quality habitat (van Horne, 1983). In this scenario, the boundary between the forest and agricultural matrix is functionally a fence, because individuals are unwilling to cross it (Bayne and Hobson, 1998; Nupp and Swihart, 1998). Based on other studies, the latter explanation is the most fitting. Populations of eastern chipmunks have been found to be positively influenced by physical connections among forest patches due to wooded hedgerows (Henderson *et al.*, 1985; Bennet *et al.*, 1994), and they tend to adhere to wooded habitat (Forsythe and Smith, 1973; Henein, 1998; Wegner and Merriam, 1979). Schmid-Holmes and Drickamer (2001) suggest examining the number of pregnant and lactating females in a habitat in order to assess whether or not it is high quality, as animals are expected to breed less in low quality habitat. However, low captures of pregnant and lactating females in the present study prevented this from being a useful indicator.

3.4.3. Summary and future considerations

For small mammal populations and communities, few studies have examined the effects of habitat at multiple spatial scales (Schmid-Holmes and Drickamer, 2001). This study provided information on the habitat characteristics that affect small mammals at three spatial scales (microhabitat, macrohabitat, and landscape). It was found that microhabitat characteristics always influenced the abundance of a species, but macrohabitat and landscape characteristics did not always affect the abundance of some species. However, because the importance of a particular microhabitat characteristic often changed temporally, and because species were differentially affected by microhabitat characteristics, a heterogenous microhabitat (e.g., different types of vegetation and a combination of both highly vegetated and open areas) should lead to a diverse small mammal community. For conservation purposes, the findings of this study imply that although large amounts of connected forest will increase small mammal diversity, if this is not possible (as is often the case in provinces such as P.E.I. that have agriculturally-driven economies), conservation efforts that focus on the microhabitat can still allow even smaller fragments to retain a diverse small mammal community.

It is important to note that this study was limited to one summer. Therefore, other factors may have affected these results, including weather conditions during the sampling season and biological factors that may be variable over years (e.g., tree seed production). Additionally, the study was confined (for logistic reasons) to north-central Prince Edward Island. For these reasons, the findings of this study, while relevant, should be tested to ensure their importance under different spatially and temporally-variable conditions.

4. HABITAT SELECTION AND MOVEMENT PATTERNS OF THE EASTERN CHIPMUNK (*Tamias striatus*) AT DIFFERENT SPATIAL SCALES

4.1. Introduction

The analysis of movement patterns can provide detailed information on the response of animals to habitat features at different spatial scales (Nams, submitted). One method to quantify such movement patterns is to use fractal analysis, where the fractal dimension provides a measure of tortuosity over a range of spatial scales (Dicke and Burrough, 1988). The fractal dimension may be used to identify domains over which an animal's movement patterns are relatively similar, and identify the spatial scales at which there are shifts among domains (transition points) (Wiens, 1989). Shifts in movement pattern may indicate that there has been a transition in the process that regulates the observed patterns (Turner *et al.*, 1999). Quantitative aspects of movement patterns may also differ in habitats that differ in structure and composition (With *et al.*, 1994*a*), which has the potential to affect patterns at greater hierarchical levels of organization, such as the spatial distribution and abundance of a population (Johnson *et al.*, 1992; Stapp and van Horne, 1997). The objectives of this study were: 1) to examine the patterns of eastern chipmunk movement, and how these patterns relate to habitat characteristics, at different spatial scales; and 2) to examine what habitat characteristics are selected by eastern chipmunks.

4.2. Methods

The study sites and trapping design for this project have been described in section 3.2.1.

4.2.1. Eastern chipmunk processing

Eastern chipmunks were processed following the guidelines of Animal Care Protocol #02-024, approved by the University of Prince Edward Island Animal Care Committee. Animals were anaesthetized to allow for less-stressful processing. They were shaken from the trap into a ziplock bag containing a cotton ball that had been dipped in diethyl ether. Animals were monitored until they appeared to be fully anaesthetized, then they were removed from the bag. Individuals were ear tagged using Monel size 1 fingerling tags, so that recaptured individuals could be identified. Body mass was recorded using a Pesola scale (± 2 g). Body mass was used to classify individuals as either juveniles (< 80 g) or adults (> 80 g) (*sensu* Bennet *et al.*, 1994). The sex and reproductive condition (breeding or non-breeding) of each individual was also noted. Males were considered to be breeding if testes were visible, and females were considered to be breeding if nipples were obvious. The sex of non-breeding individuals was distinguished based on the distance between the anus and the clitoris (for females) or the anus and the genital papilla (for males), because this distance is less for females (Kunz *et al.*, 1996).

Certain eastern chipmunks that appeared physically healthy (i.e., the individual had no external wounds or disfigurements), and were not pregnant or lactating, were used for movement experiments. In order to obtain a very fine scale of resolution regarding the movement patterns of individual chipmunks, fluorescent powdering was used to follow their movements. While the chipmunk was still anaesthetized, its body (excluding the head) was brushed with fluorescent powder. When the chipmunk fully re-gained consciousness, it was released. This was based on a method developed by Lemen and Freeman (1985), with the exception that we saturated the fur of the animal with powder by brushing it on, rather than shaking the animal in a bag with powder. Our first few trials with the shaking technique indicated that the animal often received powder in its eyes, and therefore the brushing technique was used to avoid the animal's head.

In order to obtain longer movement pathways (but possibly with a slightly coarser scale of resolution), spool-and-line tracking (Boonstra and Craine, 1986) was also used to follow the movements of eastern chipmunks. A small balloon (of about 15 mm in diameter) containing a spool of thread (180 m in length weighing about 25 mg) was attached with cyanoacrylate glue to the upper back of the chipmunk before it was released. The thread snagged on objects on the forest floor as the chipmunk moved, leaving a continuous trail.

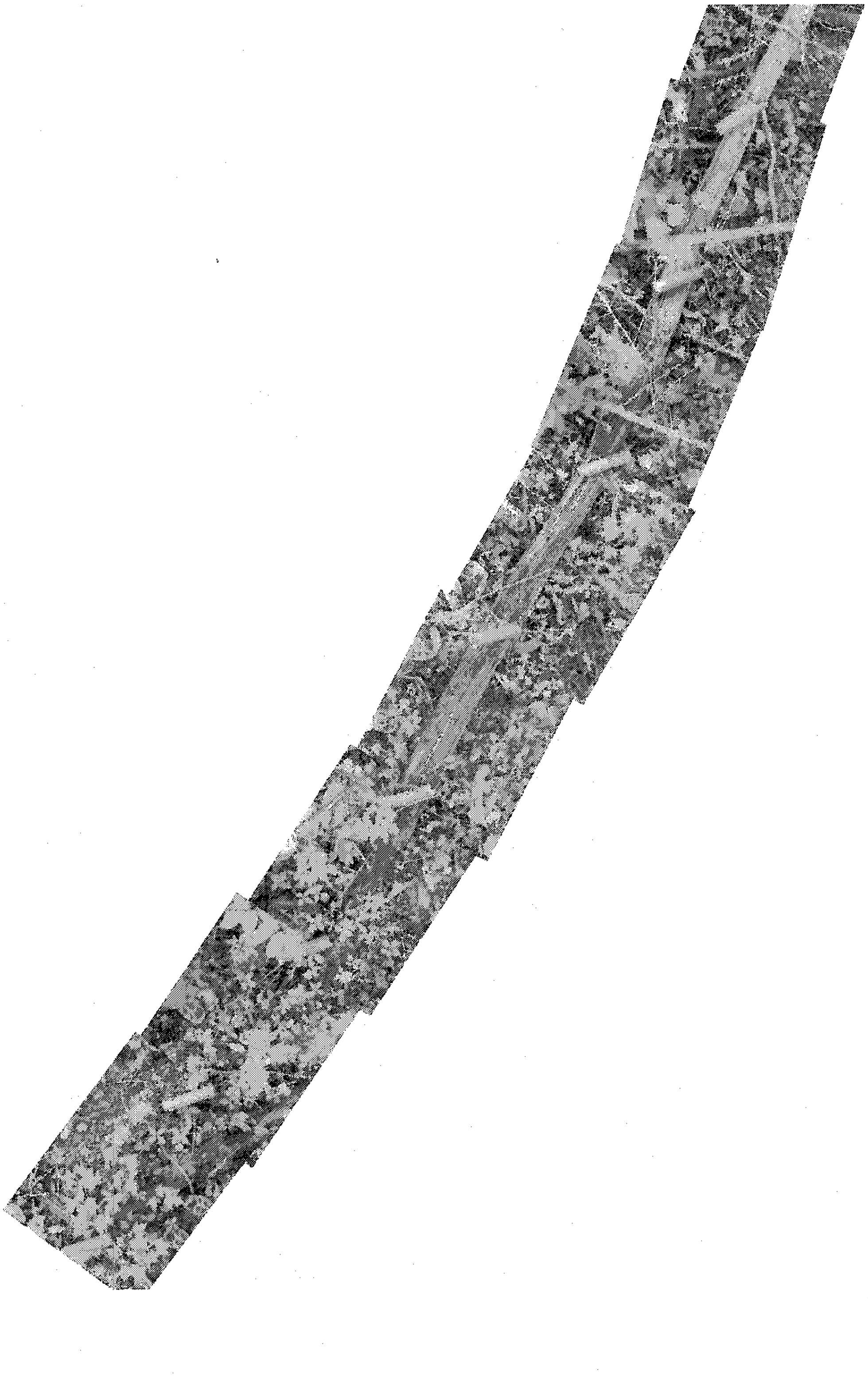
4.2.3. Trail processing

For the fluorescent powder tracking, we returned after sundown to the location where the animal was released. With a UV light, one observer illuminated the trail while another observer placed flagging tape over the trail, using bent wire to hold the flagging tape to the ground. For the spool-and-line tracking, the trails could be followed at any time after release, although typically a time span of at least half an hour passed after the animal was released.

One challenge of this study was devising a method to effectively record the movement paths for subsequent analysis. Using a Sony® DCR-TRV530 digital video camera, the path was recorded as a sequence of digital pictures that could subsequently be collated. To allow the chipmunk time to orient and move away from the observers, the first 10 m of trail, approximately, were not processed. Fluorescent markers, 25 cm in length, were placed along the trails at approximately 1 m intervals and oriented in the same cardinal direction. Although pictures often had to be taken from various heights due to habitat features, by fixing the length of the fluorescent markers pictures could later be re-scaled to this calibration.

For each trail, pictures were scaled to the same size and rotated to ensure that the directionality of the trail did not change (using the fluorescent markers), then merged together using the software program Paint Shop Pro (version 7) (see Figure 4.1 for an example). Trails were then in a format that could be digitized using the software program SigmaScan (version 5). In

Figure 4.1. Portion of an eastern chipmunk movement pathway that has been photographed in sections and collated together.



SigmaScan, the paths were manually traced with a mouse and x,y coordinates were obtained.

4.2.4. Trail habitat descriptions

To obtain data on the habitat through which the animal moved, both at the microhabitat and macrohabitat spatial scales, descriptions of the environment along and surrounding the trail were performed. The microhabitat descriptions were performed in 1 x 1 m plots located both along the trail, and 2 m away from the trail (on alternating sides), at intervals of 5 m. The microhabitat descriptions involved gathering information on: the microclimate using a digital thermometer (± 1°C) and a soil moisture meter (that quantifies moisture on a continuous scale from 1 to 10, where 1 is very dry and 10 is very wet); the percent canopy cover using a spherical densiometer; and the percent of the ground plot that was covered by trees >1.5 m, trees <1.5 m, shrubs >1.5 m, shrubs <1.5 m, moss, herbs, logs, stumps, other woody debris, bare soil, and leaf litter.

The macrohabitat structure around the trail was recorded by gathering information in 5 x 5 m plots at intervals of 25 m. Within the macrohabitat plots, data were recorded on the number and abundance of each tree species. The circumference of each tree was measured at a height of about 1.5 m, and the height of each tree was approximated as being either less than 5 m (small), between 5-10 m (medium), or greater than 10 m (large). The number of dead trees, logs, and stumps was also recorded.

4.2.5. Quantifying movement pathways

Having recorded and processed the movement paths, a number of quantities to characterize the nature of the movement pathways were calculated. A priori, it is not known what patterns the movement pathways of eastern chipmunks will correspond to (e.g., random walks, correlated random walks or fractal behaviour). To determine if chipmunk movement patterns are representative of correlated random walks, the method of Nams and Bourgeois (submitted) was used. This method compares the observed net distance (squared) (R_n^2) traveled by an animal, with an expected value of net distance (squared) ($E\ R_n^2$) if the movement pattern was a correlated random walk, for a number of consecutive moves (n) (in the current study the moves are based on successive x,y coordinates). This is determined for various values of n. Using the computer program VFractal (Nams, 1996), R_n^2 for each movement path was determined at various n. The program output also included $E\ R_n^2$ for the same n, if the movement path was a correlated random walk. For each path, the difference between values of R_n^2 and $E\ R_n^2$ was tested for statistical significance using a chi-square test.

To quantify the effective size and shape of the path, the radius of gyration, R_g, was calculated as follows:

$$R_g^2 = 1/N \sum [(x_i-x_0)^2 + (y_i-y_0)^2]$$

where N is the total number of x,y coordinates, x_i and y_i are any given x,y coordinates, and x_0 and y_0 give the location of the center of mass (the average of all x,y coordinates). Lower values of R_g indicate more compact paths and larger values signify more elongated paths. To determine if paths represented an overall random pattern, values of R_g were compared to the values of end-to-end distance (R_{ee}) for all pathways. If the pathway follows a random pattern, R_g^2 will be equal to $R_{ee}/\sqrt{6}$. To determine if eastern chipmunks move randomly, a Wilcoxon signed ranks test was used to compare values of Rg^2 and $Ree/\sqrt{6}$ for all individuals.

The overall fractal dimension of each pathway was determined using the Vfractal software (Nams, 1996). For each pathway, this program also provides a value for the fractal dimension at various scale settings (step sizes). The fractal dimension is calculated over a smaller grain scale domain centered at a major scale setting (window). By sliding this window over various scale settings, the fractal dimension can be calculated as a function of spatial scale. To obtain an overall picture of the fractal dimension of eastern chipmunk movement at various spatial scales, the information from all animals was combined (*sensu* Nams and Bourgeois, submitted). For each spatial scale (step size), the fractal dimension for each chipmunk was determined, and the information from all chipmunks averaged. The average fractal dimension was plotted against spatial scale, and a regression line was fit to the plot.

An examination for transitions in movement behaviour was performed for each path, by inspecting the plot of log (path length) versus log (step size) that is given as output in the Vfractal program (Nams, submitted). A discontinuity in the slope of this plot can be indicative of a transition in movement behaviour (Nams, submitted).

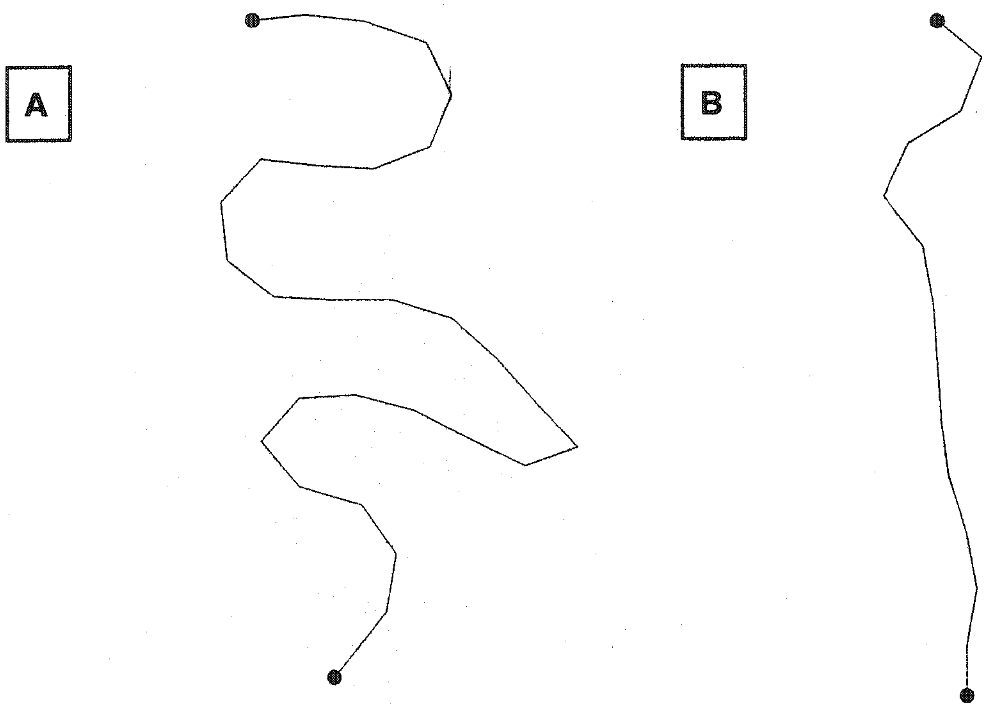
Weins *et al.* (1995) commented that fractal analysis alone cannot provide a thorough representation of movements, and therefore should be used in conjunction with scale-dependent measures. Therefore, other descriptors that do not make an assumption about scale independence were also used to characterize pathways. The overall displacement (total length of pathway) and net displacement (straight-line distance between the paths origin and endpoint) were determined. Total displacement was divided by net displacement, to provide an indication of path tortuosity (*sensu* Gillis and Nams, 1998) (Figure 4.2). The mean turning angle, the angles formed by changes in direction among steps (Crist *et al.*, 1992), was used to characterize the curvature of the pathway. This was given as output in the Vfractal program. The radius of gyration (R_g), as earlier described, was used to describe pathway size and shape (i.e., wound or elongated).

4.2.6. Data analysis

Relationships among path characteristics and habitat descriptors

Initially, it had to be determined whether paths differed quantitatively based on several characteristics. Analysis of variance (if the data were normal) or Kruskal-Wallis (if the data were non-normal) tests were used to determine if there were differences in mean turning angle, radius of gyration, total/net

Figure 4.2. Diagram indicating how total displacement divided by net displacement can indicate path tortuosity.[a]



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[a] Paths A and B have approximately equal net displacements, but path A has a greater total displacement (i.e., is longer) than B. Therefore, path A is more tortuous than B.

displacement, or transition point, based on the technique used (fluorescent powdering or spool-and-line technique), as well as the animals sex, age class (juvenile or adult), and reproductive status (breeding or non-breeding). With the exception of radius of gyration and technique, the paths did not differ based on these factors (Table 4.1). Therefore, data from all paths were pooled for further analysis of the turning angle, displacement, and transition. The radius of gyration differed based on technique used. However, this was influenced by the fact that paths obtained from spool-and-line tracking were longer, because values for the radius of gyration are related to the length of the path (Spearman rank correlation: $r = 0.675$, $p < 0.01$). Therefore, analyses with radius of gyration were performed by sub-setting the data into two categories: shorter trails (< 30 m); and longer trails (> 30 m).

Stepwise multiple linear regression was used to develop predictive models using habitat descriptor information to explain the variation in each path quantifier. The habitat descriptors recorded or calculated for use in the models are described in Table 4.2. However, two variables (gaps and spatial aggregation of living ground cover) were not used in the models, due to low variability in the values among the different trails.

Eastern chipmunk habitat preference

A rank preference index developed by Johnson (1980) was used to determine the habitat characteristics selected by individual eastern chipmunks.

Table 4.1. Summary of results of analyses used to determine if path characteristics differ based on four factors: technique used (fluorescent powdering versus spool-and-line), sex of the animal, age class of the animal (juvenile or adult), and reproductive status of the animal (breeding or non-breeding).

Factor	**Turning angle**		**Radius of gyration**		**Total/net displacement**		**Transition point**	
	Statistic[a]	**P value**	**Statistic**	**P value**	**Statistic**	**P value**	**Statistic**	**P value**
Technique	F = 0.48	0.492	H = 3.90	0.048	F =0.75	0.394	F = 1.02	0.320
Sex	F = 0.03	0.862	F = 0.04	0.850	F < 0.01	0.983	F = 0.02	0.897
Age class	H = 0.83	0.364	H = 1.75	0.186	H = 1.75	1.186	H = 2.51	0.113
Reproductive status	F < 0.01	0.990	H = 1.90	0.186	F = 0.28	0.598	H = 2.96	0.086

[a] An F statistic indicates that the test was performed with analysis of variance, an H statistic indicates that a Kruskal-Wallis test was used.

Table 4.2. Description of the habitat variables recorded or calculated to characterize the habitat of eastern chipmunk movement pathways.

Habitat variable	**Description**
Spatial aggregation of living ground cover objects	Morisita's standardized index of dispersion[a] of the ground cover
Living ground cover	Average % cover of trees, shrubs, grass, moss, herbs, and vines
Non-living ground cover	Average % cover of logs, stumps, and other woody debris
Evenness of tree species	Smith and Wilson evenness[b] of trees
Evenness of living ground cover	Smith and Wilson evenness[b] of the various classes of living ground cover
Evenness of non-living ground cover	Smith and Wilson evenness[b] of the various classes of living ground cover
Canopy cover	Average % canopy cover
Gaps	Proportion of holes in canopy cover larger than 1 m x 1 m
Small tree density	Density (per m^2) of trees 1.5-5 m in height
Medium tree density	Density (per m^2) of trees 5-10 m in height
Large tree density	Density (per m^2) of trees > 10 m in height
Stump density	Density (per m^2) of stumps
Log density	Density (per m^2) of logs
Dead tree density	Density (per m^2) of dead trees
Tree circumference	Average circumference (at breast height) of all living trees > 1.5 m in height
Ground temperature	Average ground temperature
Average soil humidity	Average humidity of soil

[a] Smith-Gill (1975), calculated using the software Ecological Methodology (Krebs, 1999)
[b] Smith and Wilson (1996), calculated using the software Ecological Methodology (Krebs, 1999).

Although numerous preference indices exist, no consensus has been reached regarding the best index. However, Krebs (1999) recommended the rank preference index as one of the best indices to use in most situations. For each individual chipmunk, thirteen habitat classes (tall (> 1.5 m) trees, small (< 1.5 m) trees, tall (> 1.5 m) shrubs, small (< 1.5 m) shrubs, grass, moss, herbs, vines, bare ground, logs, stumps, other woody debris, and litter) were ranked in terms of both use and availability. For habitat use, the average percent of each ground cover class used along a pathway was determined (from microhabitat descriptions). For habitat availability, the average percent of each ground cover class available (based on the microhabitat descriptions surrounding pathway) was determined. Both the usage and availability were ranked from greatest to least usage. For each class, the difference between the usage and availability was determined (termed the rank difference). Using information from all animals combined, the rank differences for each class were averaged. Using these average values, the habitat cover classes could then be sorted, with the smallest average rank being the most preferred class (Johnson, 1980).

In order to determine if the habitat classes were significantly different from one another (i.e., if the eastern chipmunks significantly preferred certain classes over others), the Hotellings T^2 test was used (Johnson, 1980). This procedure is similar to standard analysis of variance techniques, but allows for the correlation of error terms (within animals, error terms are slightly correlated) (Johnson, 1980).

To determine which habitat classes differed significantly from one another, a multiple comparison procedure was used. Based on Johnson (1980), the Bayesian decision procedure was chosen (Waller and Duncan, 1969). Using this method, the absolute value of the difference between two means is significantly different if it exceeds WS_d, where S_d is the standard error of the difference between two means, and W (a function of the number of means of comparison, the number of degrees of freedom, and an earlier-obtained F statistic) is obtained from tables in Waller and Duncan (1969). These tables vary in their Type I to Type II error seriousness ratio (K). A K value of 100 was chosen, because Waller and Duncan (1969) consider this to be similar to a p value of 0.05. Using the table with K=100, and knowing the F value resulting from the Hotellings T^2 test, along with the appropriate degrees of freedom, a value for W was obtained.

4.3. Results

4.3.1. Eastern chipmunk movement patterns

In total, 32 eastern chipmunk movement pathways were obtained. Using the fluorescent powdering technique, 14 trails were obtained, with a mean length of 23.4 m ± 15.2 m (ranging between 10.1 m to 66.8 m). Using the spool-and-line technique, 18 trails were obtained, with a mean length of 37.9 m ± 19.3 m (ranging between 12.1 to 79.8 m).

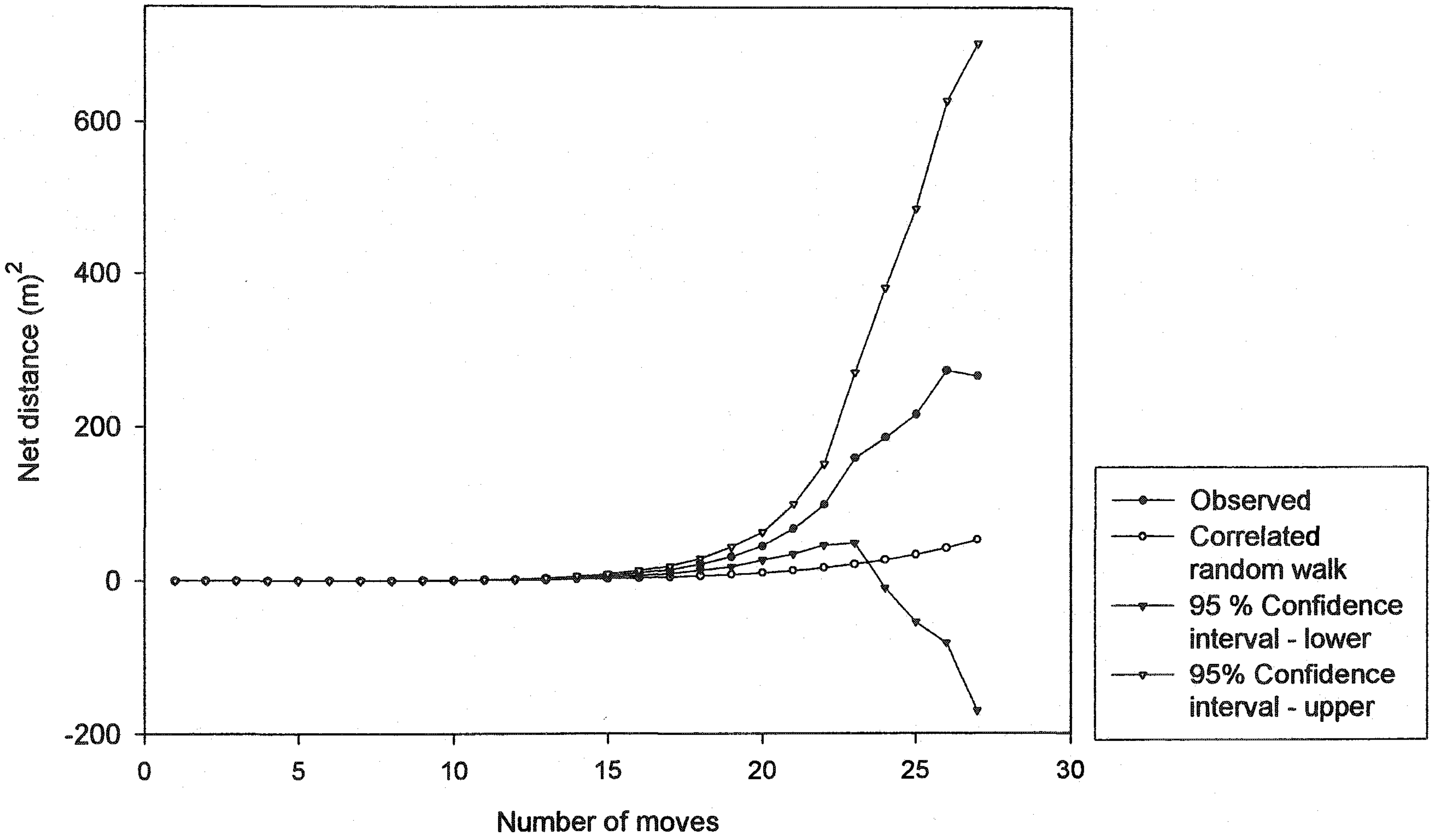
Movement paths of eastern chipmunks significantly differed from random behaviour ($z = -2.665$, $p < 0.01$, $n = 32$). Also, the movement behaviour of the eastern chipmunk did not correspond to correlated random walks (χ^2 for all trails < 0.05). However, at smaller spatial scales, their movement was characteristic of correlated random walks, but on larger scales deviations from correlated random walks were observed (e.g., Figure 4.3). Although a test of significance of the deviation in movement behaviour from a correlated random walk for each scale was not conducted, visual inspection of the plots of the net distance (squared) for the expected and observed values versus number of moves (e.g., Figure 4.3) for each trail show this trend.

Overall, the fractal dimension of eastern chipmunk movement patterns changed with spatial scale (Figure 4.4). The fractal dimension consistently increased over the regions of 0.05 m to 2 m, and was on average more constant from 2 m to 5 m. A transition occurred at a scale of approximately 2 m. The pattern of tortuosity above 5 m was unclear. For individual trails, there was a transition-point that occurred consistently at scales of about 2 m, but the fractal dimension tended not to be constant above 2 m (e.g., Figure 4.5).

4.3.2. Relationships among path characteristics and habitat descriptors

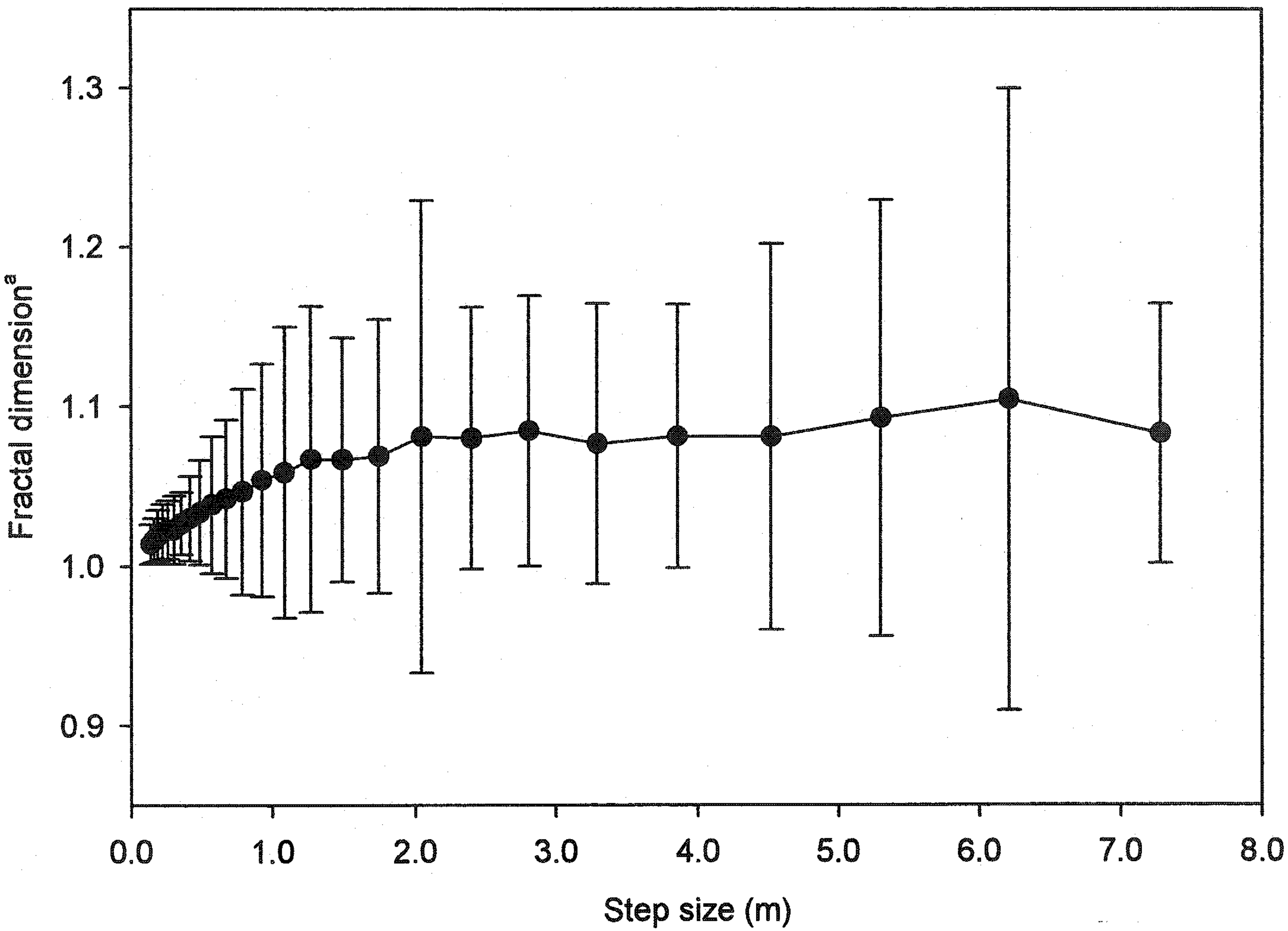
Habitat characteristics explained some of the variation in eastern chipmunk movement patterns. For the turning angle, no predictive models could be developed, because no variables were of high enough significance to enter into a stepwise multiple linear regression model. In the < 30 m length class,

Figure 4.3. Example of the difference between net distance^2 for an eastern chipmunk movement pathway (with confidence intervals for the observed data) and the net distance^2 predicted for a correlated random walk.[a]



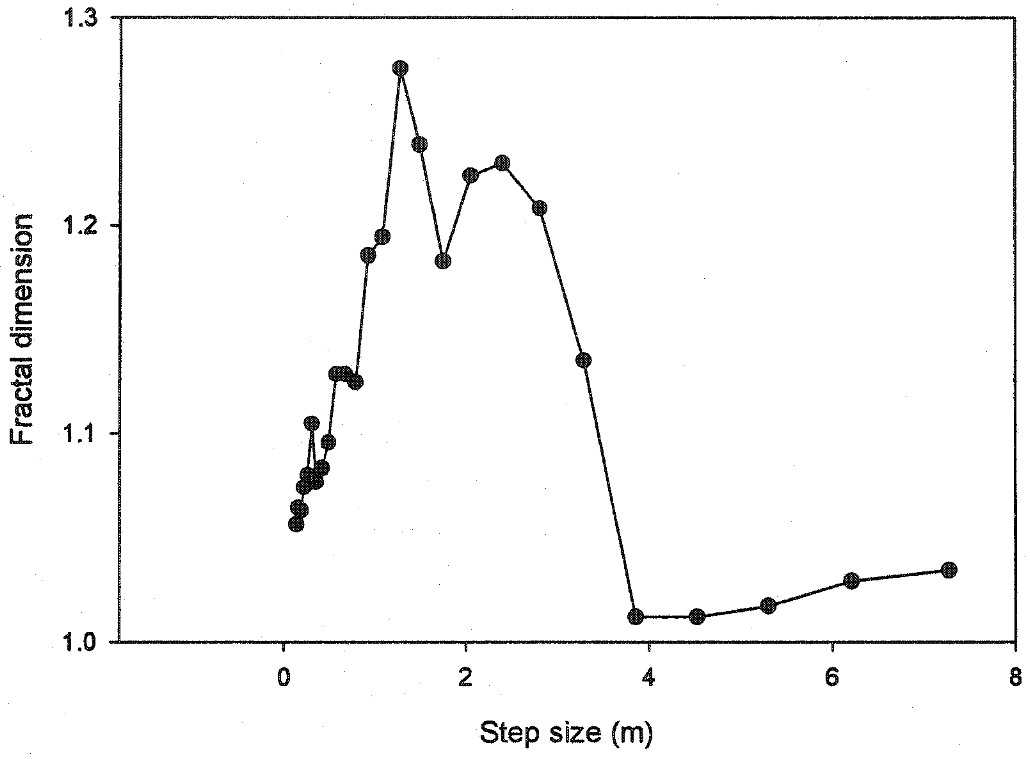
[a] Values were obtained using the computer software program VFractal (Nams, 1996).

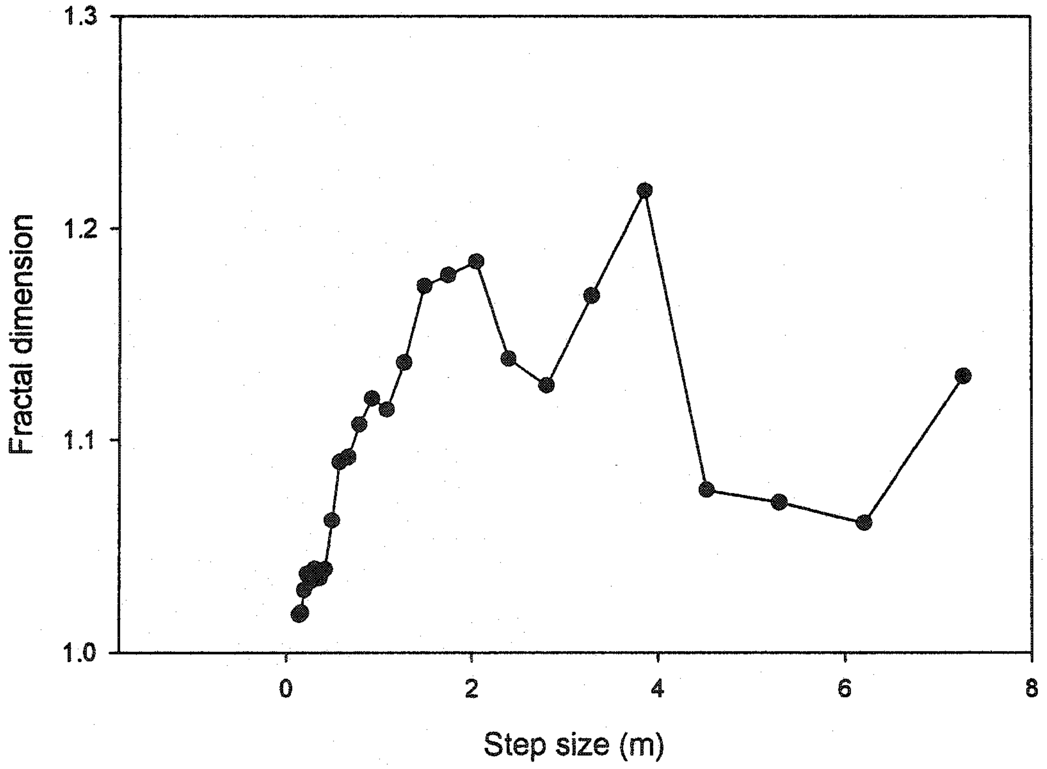
Figure 4.4. Changes in the fractal dimension of eastern chipmunk movement pathways with step size.



[a] Error bars are standard deviation from the mean.

Figure 4.5. Examples of changes in the fractal dimension over a range of spatial scales for the movement pathways for two different eastern chipmunks.





radius of gyration was found to be negatively associated with canopy cover (r^2 = 37.84, n = 15, $p < 0.01$). However, in the > 30 m length class, no habitat variables were significant predictors of the radius of gyration. For total/net displacement (tortuosity), there was a negative relationship with an interaction term between percent cover and evenness of the living ground cover (r^2 = 13.89, $p < 0.05$). The transition point for each path was weakly predicted by small tree density (r^2 = 9.59, n = 32, $p < 0.05$).

4.3.3. Eastern chipmunk habitat selection

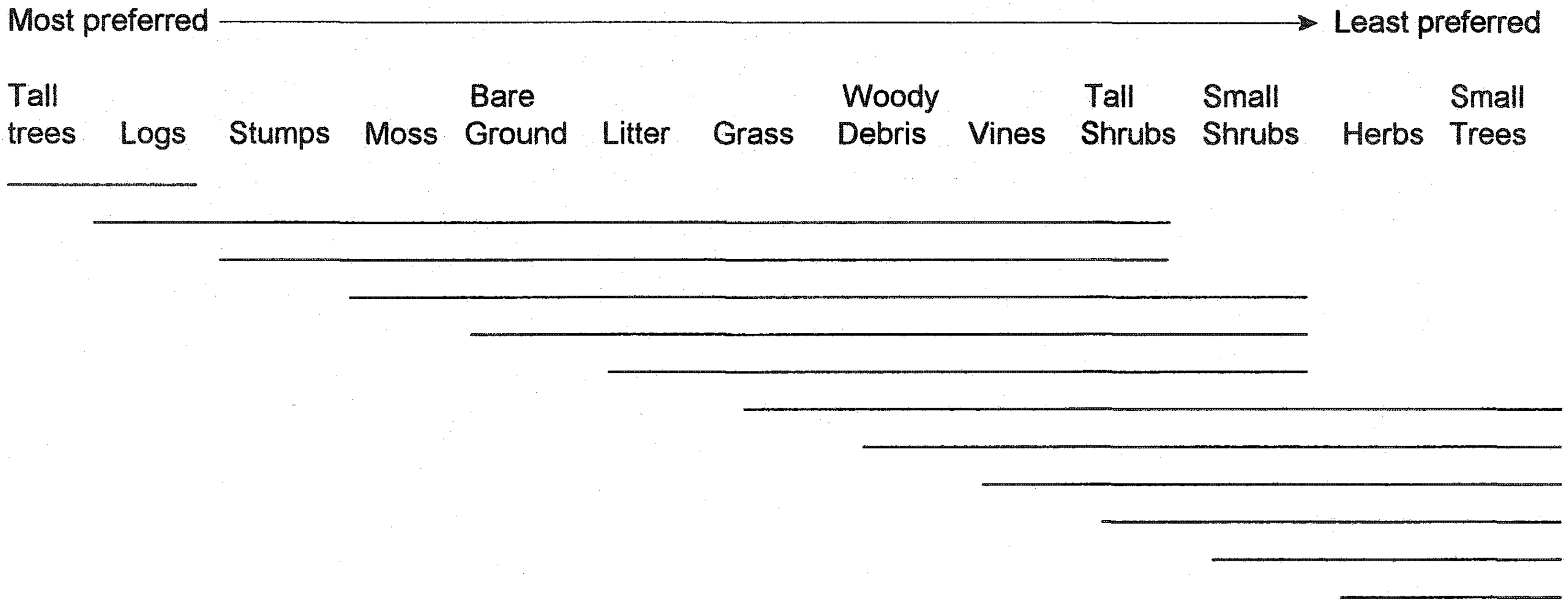
The rankings of the habitat classes were significantly different from one another (Hotelling's T^2 = 59.94, F = 3.16, n = 32, $p < 0.05$). Figure 4.6 summarizes the multiple comparisons among groups. Tall trees were found to be preferred significantly more than any other habitat feature except for logs. Small shrubs, herbs, and small trees were significantly less preferred than many of the other habitat classes.

4.4. Discussion

4.4.1. Eastern chipmunk movement patterns and habitat use

Many studies have found that movement parameters are usually habitat dependent (Morales, 2002). The current study illustrates that the movement patterns of eastern chipmunks are to some extent determined by interactions with their habitat. However, there are similarities that occur among movement

Figure 4.6. Relationships among the classes of habitat features from a habitat preference analysis for eastern chipmunks. Habitat classes sharing a common underline are not significantly different.



patterns of eastern chipmunks, regardless of their habitat. At spatial scales of less than about 2 m, their movement gradually increased in complexity. At scales from about 2 m to 5 m, their movement patterns were more constant, and were more tortuous (higher fractal dimensions) than the patterns at the smaller scales. However, when examining individual pathways, the fractal dimension even at larger scales showed considerable variation. Therefore, for both the larger and smaller scales, an overall measure of the fractal dimension could not be obtained. Although there tends to be an important transition in eastern chipmunk movement behaviour around scales of 2 m, the patterns both above and below this point are not fractal.

The point of transition in the fractal dimension (i.e., the point at which there was a shift in movement behaviour) was negatively related to small tree density. This suggests that small trees, to some extent, influence the point at which eastern chipmunks show shifts in their movement patterns. This influence may be either a result of a preference for small trees (therefore, chipmunks actively move toward them), or an avoidance of them, and they alter their behaviour when they encounter them. Based on the results of eastern chipmunk habitat preference (of this study), the latter explanation is the most probable. In comparison with other classes of ground vegetation, small trees are among the least preferred habitat classes.

However, a large amount of the variance in the transition point is still unexplained by any habitat characteristic. Looking at the trail photographs, shifts in movement behaviour often occurred when there were not any obvious habitat structures (e.g., large trees). One hypothesis is that at smaller scales chipmunks movement behaviour is regulated by activities such as foraging. At larger scales, on the order of 2 m, chipmunks may assess their overall position and move toward a particular characteristic of their habitat (e.g., a tree) or an area that is favourable in terms of predator avoidance. The presence of small trees may therefore influence their movement behaviour, because small trees tend to be indicative of open areas (i.e., lack of large trees) and would indicate an area that is unfavourable in terms of avoiding predators.

Overall, eastern chipmunk movement pathways were not random. Although their movement tended to be representative of correlated random walks on smaller scales, they deviated from this correlated random walks on larger scales. Therefore, chipmunk movement appears to be directed in nature. Based on the results of this study and the biology of the species, it can be suggested there are several processes responsible for these patterns. Chipmunks may possess both short-term memory about their previous movements, spatial memory regarding where they are in relation to other objects, and long-term memory of where the important objects (e.g., primary burrow and other food caches) within their core areas are located. Movements may be the most random on smallest scales, because microhabitat characteristics are more dynamic (i.e., ground vegetation changes on faster temporal scales than the structure of the forest does). Therefore, it would be more difficult for chipmunks to have memory regarding the specific patterns of ground objects on the smallest spatial scales.

Overall, previous knowledge and memory regarding their habitat may be responsible for the apparent directionality of chipmunk movements. The hypothesis that chipmunks have spatial memory is supported by other research (Bowman and Fahrig, 2002). They found that chipmunks translocated across an unforested gap away from their home range were generally able to find their way back, but that more adult chipmunks found their way back than juveniles. Homing, i.e., long distance homeward orientation (Joslin, 1997), was given as a probable explanation for this finding, implying that prior experience within the area by the adult chipmunks increased their success in returning home. Although they could not discount other explanations (e.g., juveniles have greater motivation to disperse rather than to return home), the importance of prior knowledge of an area in successful homing by small mammals has been demonstrated in other studies (Bovet, 1984; Joslin, 1977; Thibault and Bovet, 1999).

Eastern chipmunks are territorial individuals that defend a core area (Bowers *et al.*, 1990; Lacher and Mares, 1996). Additionally, they tend to spend about three quarters of their time in the area within 25 m of their burrow entrance (Elliot, 1978). These traits may also add plausibility to the hypothesis that memory is likely to play an important role in their movement behaviour. They should have sufficient time to be able to develop internal "maps" of their core areas, and most likely recognize habitat characteristics in their core areas in order to more successfully defend these areas against conspecifics.

Eastern chipmunk movement was found to be more tortuous (i.e., total/net displacement of the pathway was higher) in areas where the percent and evenness of living ground cover were lower. This finding is unexpected, because several other studies have found that vegetative cover increases the tortuosity of animal movement (With, 1999). Increased tortuosity of a pathway may indicate increased use of a type of habitat (Nams and Bourgeois, submitted). This could suggest that eastern chipmunks prefer to use sparser understory habitat for movement. Possibly, eastern chipmunks make more use of open-understory habitat because they are a visual species (Mahan and Yahner, 1999), and lower amounts of vegetation allows them to forage more efficiently and detect predators more readily as they are moving.

Eastern chipmunk movement pathways were found to be more compact in habitats with a greater overstory. This may suggest a preference for closed-canopy habitat, because in habitats that are unfavourable, individuals often have to travel farther distances to meet their daily requirements. For example, Diffendorfer *et al.* (1995) found that in more fragmented habitats, prairie voles (*Microtus ochrogaster*) and deer mice moved greater distances. Their movements were at a scale that reflected daily movement, and therefore in fragmented habitats (which the authors viewed as unfavourable for these species) they were forced to travel farther distances to meet their daily foraging and other requirements. Based on this argument, if eastern chipmunks are traveling farther distances from their original location, it may indicate that the habitat through which they are traveling is of lower quality. Since their paths were more elongated in areas with low canopy cover, this type of habitat may be less preferred. This hypothesis is supported by both results of this study (discussed below) and by other studies of habitat use by the eastern chipmunk (Bowers, 1995; Brooks *et al.*, 1998; Schmid-Holmes and Drickamer, 2001).

The results of eastern chipmunk habitat selection show that chipmunks prefer areas with tall trees and logs, whereas habitats with herbs, small shrubs, and small trees were the least selected. This is similar to other studies of eastern chipmunk habitat use (Bennett *et al.*, 1994; Bowers *et al.*, 1995; Brooks *et al.*, 1998; Schmid-Holmes and Drickamer, 2001). In a long-term study of small mammal abundance in Vermont, Brooks *et al.* (1998) found that eastern chipmunks were captured in highest abundance in areas with a greater overstory density and lower amounts of ground foliage cover. In Illinois, Schmid-Holmes and Drickamer (2001) found captures of the eastern chipmunk to be positively related to forest composition, with significantly higher captures in areas with a greater density of trees. In Ottawa, eastern chipmunks had a significantly greater probability of occurring in fencerows with higher amounts of tree cover, tall shrubs, and litter/bare ground, but they had a lower occurrence in fencerows with high amounts of grasses and patchy low shrubs (Bennett *et al.*, 1994).

Habitats with denser canopy and a more open understory may be preferred by eastern chipmunks based on their strategies for predator avoidance. A dense canopy cover probably provides the greatest amount of protection from avian predators. Also, eastern chipmunks are a diurnal species and rely strongly on their sense of vision (Doutt *et al.*, 1977), so increases in the amount of understory vegetation could increase the difficulty in detecting predators (Carey and Moore, 1986; Metcalf, 1984; Sharpe and van Horne, 1998). Logs (which were found to be a highly preferred resource) may also allow for eastern chipmunks to increase predator detection, by permitting them to be slightly raised above the height of some of the ground vegetation. Mahan and Yahner (1999) found that the locomotory behaviour of eastern chipmunks differed between more fragmented corridor habitats and continuous forest, with individuals spending more time in predator vigilance behaviour in the more fragmented habitats. Therefore, predation risk may have an important influence on the behaviour of eastern chipmunks.

4.4.2. Summary

It is important to evaluate habitat use at the same scales as animals perceive them (Nams, submitted). The current study indicates that eastern chipmunks respond to their habitat differently at scales less than 2 m than at scales above 2 m. Possibly, patterns of movement at scales less than 2 m relate to individuals performing foraging activities, and a transition in movement pattern occurs at scales around 2 m which may be due to innate behaviour that is related to predator avoidance. Patterns of movement at scales larger than 5 m were less clear because of limitations in the collected data. It is recommended that other studies assess how eastern chipmunks (and other small mammals) respond to their habitat at these larger scales. This will provide more detailed information on how these animals interact with their habitat. The spool-and-line technique is more effective than fluorescent powdering for obtaining trails of long distance. Therefore, spool-and-line tracking is the best method to use for studying detailed movement patterns of animals at larger spatial scales.

Eastern chipmunks were found to select areas with large trees and logs, and avoid areas with small trees, herbs, and small shrubs. Patterns of movement also tend to indicate preference for these habitat types. This probably allows them to forage and avoid predators most efficiently. Open-understory habitats and logs may permit them to engage in visual predator detection, and closed-canopy areas may provide protection from avian predators.

5. SUMMARY OF RESULTS AND CONCLUSIONS

The primary goal of this study was to incorporate patterns of spatial scale into the analysis of the interactions among small mammals and characteristics of their environment. Relationships between communities, populations, and individuals with habitat characteristics were examined.

Small mammal populations and communities were assessed in several forested areas on Prince Edward Island. Species richness, diversity, and abundance of the most frequently captured species, were related to habitat descriptors at the microhabitat, macrohabitat, and landscape spatial scales. The species richness and diversity of small mammals were positively influenced by a species rich tree community and greater amounts of connected forest.

The most common species were found to be differentially affected by habitat characteristics. Some species were influenced by characteristics of only one or two scales, whereas others were associated with characteristics at all spatial scales. Eastern chipmunks were associated with microhabitats that had a higher soil humidity, low ground temperatures, and a greater canopy cover above them. They were found to have higher abundances in areas with lower amounts of connected forest, but this was probably because individuals of this species were unwilling to cross agricultural matrix areas, leading to locally high abundance in less favourable forest. Deer mice were not associated with microhabitat or landscape characteristics, but were negatively associated with herb cover. Red-backed voles were most abundant in mossy areas with high densities of small trees and larger amounts of connected forest. Woodland jumping mice were more frequently captured in areas with moister soils, but were not associated with any macrohabitat or landscape characteristic. Red squirrels were more abundant in areas with greater amounts of connected forest, and at the microhabitat scale were more frequently captured in areas with shallower leaf litter.

In general this study has indicated that greater amounts of connected forest will positively affect the abundance of small mammals and lead to a more diverse community. However, because certain species preferred habitat characteristics that were not preferred by others, heterogeneity within the forest structure (in terms of both the tree species and ground vegetation) will be beneficial to small mammals. These findings are consistent with other studies (e.g., Maisonneuve and Rioux, 2001; Mitchell *et al.*, 1997).

The relationship between small mammal movement behaviour and habitat characteristics was examined by following the movement paths of eastern chipmunks. Quantifying eastern chipmunk movement patterns was used to examine the scales at which the chipmunks responded to their environment, and which characteristics of the habitat they preferred. Chipmunks were found to show transitions in their movement behaviour at scales of around 2 m, but the exact scale of the transition varied slightly among individuals. The transition point was, to a small degree, influenced by the density of small trees, indicating that sometimes the shift in movement pattern occurred as a result of interactions with small trees. Based on the results of chipmunk habitat preference, small trees are among the least preferred resource (out of 13 habitat classes). Therefore, chipmunks are likely shifting their movement behaviour to avoid small trees. It is possible that this transition is an innate behaviour performed by eastern chipmunks that relates to strategies of predator avoidance.

It was found that eastern chipmunk paths were more compact in areas with denser canopy cover, and were more tortuous in areas with a low amount and evenness of living ground cover. Nams and Bourgeois (submitted) suggest that more tortuous movement behaviour is indicative of more extensive habitat use. Other studies indicate that small mammals tend to have greater daily movement distances in unfavourable habitats (Diffendorfer *et al.*, 1995). Therefore, the results of the current study may indicate that chipmunks have a preference for areas with denser canopy cover and open understory. This is consistent with information that was obtained from examining the habitat preferences of eastern chipmunks, since tall trees were ranked as their most preferred habitat class, and small shrubs, herbs, and small trees were least preferred.

Understanding how animals use characteristics of their habitat is important, especially in a conservation context. If we know more about how a particular species uses features of their habitat, we are better able to determine how the species will respond to changes in their habitat.

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7. APPENDIX

Table 7.1. Summary of small mammal captures in the Brackley study site. An entry with NA indicates that the information was not recorded or unavailable.

Date (month/day)	Time	Trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0920	1700	132	S	Clethrionomys gapperi	NA	NA	0
0703	805	61	S	Clethrionomys gapperi	NA	NA	0
0731	1930	185	S	Clethrionomys gapperi	NA	NA	0
0703	745	81	S	Clethrionomys gapperi	4260	4291	0
0731	1920	184	S	Clethrionomys gapperi	4574	4594	0
0529	1930	4	S	Clethrionomys gapperi	NA	NA	NA
0920	900	124	S	Clethrionomys gapperi	NA	NA	NA
0704	1930	188	S	Clethrionomys gapperi	NA	NA	NA
0801	830	192	A	Clethrionomys gapperi	NA	NA	NA
0801	800	119	S	Clethrionomys gapperi	NA	NA	1
0731	730	133	S	Clethrionomys gapperi	NA	NA	1
0920	1650	98	S	Clethrionomys gapperi	NA	NA	1
0801	1940	176	S	Clethrionomys gapperi	NA	NA	1
0530	945	30	S	Clethrionomys gapperi	4177	4176	1
0801	825	144	S	Clethrionomys gapperi	4566	4598	2
0919	1630	34	S	Clethrionomys gapperi	5081	5100	4
0529	810	68	S	Napaeozapus insignis	4198	4199	0
0529	725	95	S	Peromyscus maniculatus	3911	3912	0
0529	745	86	S	Peromyscus maniculatus	4152	4151	0
0531	710	33	S	Peromyscus maniculatus	4152	4151	0
0919	945	149	S	Peromyscus maniculatus	4595	NA	0
0920	730	35	S	Peromyscus maniculatus	5037	5084	0
0919	1000	147	S	Peromyscus maniculatus	5090	5083	0
0920	1000	195	S	Peromyscus maniculatus	NA	NA	NA
0919	930	123	S	Peromyscus maniculatus	NA	NA	NA
0530	655	192	A	Peromyscus maniculatus	3911	3912	NA
0919	850	103	S	Peromyscus maniculatus	NA	NA	NA
0731	700	49	S	Peromyscus maniculatus	NA	NA	1

Date (month/day)	Time	Trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0919	835	95	S	Peromyscus maniculatus	NA	NA	1
0920	830	83	S	Peromyscus maniculatus	NA	NA	1
0704	815	163	S	Peromyscus maniculatus	NA	NA	1
0704	815	163	S	Peromyscus maniculatus	NA	NA	1
0801	710	44	S	Peromyscus maniculatus	4237	4282	1
0731	830	166	S	Peromyscus maniculatus	4595	4563	1
0801	835	193	S	Peromyscus maniculatus	4595	4563	1
0920	945	185	S	Peromyscus maniculatus	4595	NA	1
0703	930	160	P	Peromyscus maniculatus	NA	NA	2
0703	650	21	S	Peromyscus maniculatus	4237	4282	2
0919	1045	193	S	Peromyscus maniculatus	5098	5082	2
0731	630	30	S	Peromyscus maniculatus	4237	4282	3
0529	740	88	S	Peromyscus maniculatus	NA	NA	4
0801	845	174	S	Peromyscus maniculatus	5001	5002	4
0703	1830	64	S	Sorex cinereus	NA	NA	NA
0703	930	160	P	Sorex cinereus	NA	NA	NA
0919	1735	184	S	Sorex cinereus	NA	NA	NA
0703	655	25	P	Sorex cinereus	NA	NA	NA
0919	1030	185	S	Sorex cinereus	NA	NA	NA
0703	745	76	P	Sorex cinereus	NA	NA	1
0801	1815	45	S	Tamiasciurus hudsonicus	5006	5012	0
0529	1825	136	S	Tamiasciurus hudsonicus	4196	4197	1
0801	1900	132	S	Tamiasciurus hudsonicus	4263	4205	1
0920	1730	196	S	Tamiasciurus hudsonicus	NA	NA	2
0731	1850	99	S	Tamias striatus	NA	NA	0
0731	1800	28	S	Tamias striatus	4555	4571	0
0731	1835	78	S	Tamias striatus	4556	4565	0
0920	1010	177	S	Tamias striatus	5035	5079	0
0920	1715	195	S	Tamias striatus	5035	5079	0
0920	1640	53	S	Tamias striatus	5042	5077	0
0801	1745	3	S	Tamias striatus	5013	5008	NA
0703	1820	38	S	Tamias striatus	NA	NA	1
0704	630	5	S	Tamias striatus	NA	NA	1
0704	1830	5	S	Tamias striatus	NA	NA	1

Date (month/day)	Time	Trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0531	1825	40	S	Tamias striatus	4179	4181	1
0703	1810	21	S	Tamias striatus	4232	4242	1
0703	1900	97	S	Tamias striatus	4263	4205	2
0704	1845	21	S	Tamias striatus	4297	4244	2
0704	1845	21	S	Tamias striatus	4297	4244	2
0919	1730	15	A	Tamias striatus	5035	5079	2
0919	1600	5	S	Tamias striatus	5042	5077	2
0919	1700	153	S	Tamias striatus	5080	8088	2
0919	1610	14	S	Tamias striatus	NA	NA	3
0801	1840	64	S	Tamias striatus	NA	NA	3
0920	1630	41	S	Tamias striatus	NA	NA	3
0731	1815	49	S	Tamias striatus	NA	NA	3
0704	645	16	S	Tamias striatus	4178	NA	3
0531	1845	14	S	Tamias striatus	4178	4180	3
0703	1815	13	S	Tamias striatus	4178	NA	3
0529	1945	22	A	Tamias striatus	4178	4180	3
0530	1810	81	S	Tamias striatus	4178	4180	3

[a] S is a Sherman live trap, A is an arboreal Sherman live trap, P is a pitfall trap.

[B] 0 is a juvenile male, 1 is a reproductive male, 2 is a juvenile female, 3 is a reproductive female, and 4 is a pregnant female.

Table 7.2. Summary of small mammal captures in the Cavendish study site. An entry with NA indicates that the information was not recorded or unavailable.

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0926	655	C2-14	P	Unidentified	NA	NA	NA
0926	755	C2-58	P	Unidentified	NA	NA	NA
0807	645	C2-68	S	Clethrionomys gapperi	NA	NA	NA
0711	1900	C2-70	S	Clethrionomys gapperi	4503	4535	0
0711	745	C2-70	S	Clethrionomys gapperi	4510	4512	1
0926	1645	C2-74	S	Clethrionomys gapperi	5032	5039	1
0808	650	C2-76	S	Clethrionomys gapperi	NA	NA	1
0807	655	C2-77	S	Clethrionomys gapperi	NA	NA	5
0927	820	C2-78	S	Clethrionomys gapperi	NA	NA	1
0711	655	C2-46	A	Glaucomys sabrinus	NA	NA	2
0807	715	C1-10	S	Napaeozapus insignis	NA	NA	3
0808	735	C1-8	S	Napaeozapus insignis	NA	NA	NA
0607	630	C2-10	S	Napaeozapus insignis	4172	4168	0
0711	640	C2-12	S	Napaeozapus insignis	4509	4523	3
0607	630	C2-15	S	Napaeozapus insignis	4171	4150	0
0606	730	C2-17	S	Napaeozapus insignis	4158	4159	0
0607	645	C2-18	S	Napaeozapus insignis	4170	4166	0
0711	645	C2-20	S	Napaeozapus insignis	NA	NA	0
0605	630	C2-22	S	Napaeozapus insignis	4185	4186	0
0607	640	C2-27	S	Napaeozapus insignis	4173	4175	0
0605	635	C2-30	S	Napaeozapus insignis	4188	4189	0
0607	650	C2-30	S	Napaeozapus insignis	4211	4203	1
0711	705	C2-48	S	Napaeozapus insignis	NA	NA	3
0808	700	C2-61	S	Napaeozapus insignis	5014	5007	4
0606	630	C2-67	S	Napaeozapus insignis	NA	NA	NA
0607	730	C2-70	S	Napaeozapus insignis	4225	4273	0
0710	845	C2-70	S	Napaeozapus insignis	4245	4247	2
0605	715	C2-72	S	Napaeozapus insignis	NA	4191	0
0807	650	C2-76	S	Napaeozapus insignis	NA	NA	NA
0710	655	C2-9	S	Napaeozapus insignis	NA	NA	3

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0927	935	C3-11	S	Napaeozapus insignis	5094	5030	0
0808	800	C3-11	S	Napaeozapus insignis	4504	NA	3
0807	800	C3-12	S	Napaeozapus insignis	NA	NA	5
0927	940	C3-17	S	Napaeozapus insignis	5033	5097	0
0807	745	C3-25	S	Napaeozapus insignis	NA	NA	NA
0807	750	C3-29	S	Napaeozapus insignis	NA	NA	4
0808	750	C3-29	S	Napaeozapus insignis	5003	5021	4
0711	830	C3-3	S	Napaeozapus insignis	4504	4507	3
0606	1915	C3-33	S	Napaeozapus insignis	NA	4169	0
0927	930	C3-43	S	Napaeozapus insignis	5044	5045	3
0606	815	C3-44	S	Napaeozapus insignis	4160	4161	0
0606	840	C3-45	S	Napaeozapus insignis	4164	4165	0
0927	915	C3-9	S	Napaeozapus insignis	NA	NA	4
0807	710	C1-11	S	Peromyscus maniculatus	NA	NA	0
0808	740	C1-11	S	Peromyscus maniculatus	5016	5010	0
0926	830	C1-14	S	Peromyscus maniculatus	NA	3840	1
0605	745	C1-2	S	Peromyscus maniculatus	NA	3840	1
0710	915	C1-6	S	Peromyscus maniculatus	NA	NA	2
0927	840	C1-8	S	Peromyscus maniculatus	NA	5010	0
0606	750	C1-8	S	Peromyscus maniculatus	NA	3848	NA
0606	720	C2-12	S	Peromyscus maniculatus	4157	4156	0
0711	630	C2-14	S	Peromyscus maniculatus	4270	4296	2
0710	640	C2-16	S	Peromyscus maniculatus	4270	4296	NA
0605	620	C2-18	S	Peromyscus maniculatus	4182	4184	0
0807	620	C2-20	S	Peromyscus maniculatus	NA	NA	NA
0927	640	C2-20	S	Peromyscus maniculatus	5089	5096	4
0808	640	C2-28	S	Peromyscus maniculatus	5017	5018	2
0807	1745	C2-35	P	Peromyscus maniculatus	NA	NA	NA
0711	650	C2-35	S	Peromyscus maniculatus	NA	NA	2
0926	1635	C2-48	S	Peromyscus maniculatus	5047	5046	0
0926	745	C2-52	S	Peromyscus maniculatus	NA	NA	2
0606	700	C2-53	S	Peromyscus maniculatus	4195	4192	0
0605	700	C2-63	S	Peromyscus maniculatus	4195	4192	4
0710	850	C2-66	S	Peromyscus maniculatus	NA	NA	3

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0808	705	C2-66	S	Peromyscus maniculatus	5015	5020	5
0607	730	C2-67	S	Peromyscus maniculatus	4223	4274	1
0927	805	C2-70	S	Peromyscus maniculatus	5091	5029	1
0606	715	C2-80	S	Peromyscus maniculatus	NA	NA	2
0606	845	C3-13	S	Peromyscus maniculatus	4190	4187	NA
0807	755	C3-31	S	Peromyscus maniculatus	NA	NA	0
0605	750	C3-36	S	Peromyscus maniculatus	4190	4187	0
0606	830	C3-36	S	Peromyscus maniculatus	4162	4163	1
0926	930	C3-45	S	Peromyscus maniculatus	5041	5093	2
0927	1000	C3-7	S	Peromyscus maniculatus	NA	NA	3
0808	1720	C2-22	P	Sorex cinereus	NA	NA	NA
0807	635	C2-49	P	Sorex cinereus	NA	NA	NA
0607	655	C2-50	S	Sorex cinereus	NA	NA	NA
0710	1905	C2-58	P	Sorex cinereus	NA	NA	NA
0605	730	C2-80	S	Sorex cinereus	NA	NA	NA
0605	1940	C3-17	S	Sorex cinereus	NA	NA	NA
0927	815	C2-79	S	Sorex cinereus?	NA	NA	NA
0710	1810	C2-10	S	Tamiasciurus hudsonicus	4522	4508	3
0711	652	C2-26	A	Tamiasciurus hudsonicus	4517	4511	3
0710	1900	C2-55	S	Tamiasciurus hudsonicus	NA	3304	0
0711	1845	C2-66	S	Tamiasciurus hudsonicus	4056	4539	4
0605	1920	C3-9	S	Tamiasciurus hudsonicus	2171	NA	1
0710	920	C1-1	S	Tamias striatus	4202	4275	1
0808	1835	C1-16	S	Tamias striatus	5023	5024	0
0926	900	C1-8	S	Tamias striatus	4537	4544	0
0926	1715	C1-12	S	Tamias striatus	NA	NA	0
0927	1735	C1-2	S	Tamias striatus	4202	4275	0
0926	1725	C1-11	S	Tamias striatus	4544	4537	0
0711	1932	C1-8	S	Tamias striatus	4544	4537	0
0808	1830	C1-3	S	Tamias striatus	NA	NA	0
0927	830	C1-5	S	Tamias striatus	NA	NA	0
0807	1810	C1-11	S	Tamias striatus	NA	NA	NA
0807	715	C1-6	S	Tamias striatus	NA	NA	NA
0711	1920	C1-9	S	Tamias striatus	4278	4279	1

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0607	1910	C1-11	S	Tamias striatus	4278	4279	1
0605	1900	C1-13	S	Tamias striatus	NA	NA	1
0607	1905	C1-6	S	Tamias striatus	4202	4275	1
0807	1820	C1-5	S	Tamias striatus	3278	3279	1
0710	930	C1-15	S	Tamias striatus	4278	4279	1
0710	1950	C1-6	S	Tamias striatus	4978	??79	1
0607	1910	C1-12	S	Tamias striatus	NA	NA	1
0606	1840	C1-6	S	Tamias striatus	NA	NA	1
0710	1945	C1-2	S	Tamias striatus	4202	4275	1
0927	1740	C1-16	S	Tamias striatus	NA	NA	2
0606	1840	C1-11	S	Tamias striatus	3529	NA	2
0926	1710	C1-15	S	Tamias striatus	5038	5040	2
0807	1815	C1-7	S	Tamias striatus	5019	5004	2
0927	835	C1-15	S	Tamias striatus	NA	NA	3
0607	1905	C1-16	S	Tamias striatus	NA	NA	3
0606	755	C1-13	S	Tamias striatus	NA	3926	3
0711	1930	C1-13	S	Tamias striatus	3527	3526	3
0710	1952	C1-11	S	Tamias striatus	3695	3696	3
0808	1825	C1-10	S	Tamias striatus	3695	3696	3
0926	845	C1-12	S	Tamias striatus	3695	3696	3
0711	1925	C1-7	S	Tamias striatus	3695	3696	3
0710	1940	C1-1	S	Tamias striatus	3527	3526	3
0607	1915	C1-1	S	Tamias striatus	NA	352?	3
0926	1720	C1-8	S	Tamias striatus	3695	3696	3
0927	1730	C1-9	S	Tamias striatus	3695	3696	3
0710	917	C1-10	S	Tamias striatus	3695	3696	5
0926	645	C2-1	S	Tamias striatus	NA	NA	3
0808	1810	C2-61	S	Tamias striatus	NA	NA	0
0926	800	C2-72	S	Tamias striatus	NA	NA	0
0926	1130	C2-54	A	Tamias striatus	NA	NA	0
0927	1655	C2-75	S	Tamias striatus	NA	NA	0
0927	1615	C2-21	S	Tamias striatus	NA	NA	0
0927	1700	C2-79	S	Tamias striatus	NA	NA	0
0807	1747	C2-35	S	Tamias striatus	4258	4250	0

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0808	1725	C2-33	S	Tamias striatus	4545	4546	0
0927	1605	C2-7	S	Tamias striatus	5049	5095	0
0607	1845	C2-8	S	Tamias striatus	3549	3540	NA
0926	750	C2-55	S	Tamias striatus	NA	NA	NA
0926	1610	C2-9	S	Tamias striatus	5049	5095	NA
0711	1820	C2-30	S	Tamias striatus	NA	NA	NA
0807	630	C2-33	S	Tamias striatus	NA	NA	NA
0808	1730	C2-46	S	Tamias striatus	NA	NA	NA
0711	1857	C2-80	S	Tamias striatus	NA	NA	1
0605	1810	C2-55	S	Tamias striatus	3545	3546	1
0710	1836	C2-37	A	Tamias striatus	3545	3546	1
0605	1840	C2-74	S	Tamias striatus	4154	4155	1
0606	1810	C2-53	S	Tamias striatus	4169	4167	1
0607	1850	C2-16	S	Tamias striatus	4220	4277	1
0710	755	C2-41	A	Tamias striatus	4220	4277	1
0607	1910	C2-63	S	Tamias striatus	4222	4221	1
0607	1900	C2-36	S	Tamias striatus	4251	4276	1
0808	1730	C2-39	S	Tamias striatus	4258	4250	1
0710	1830	C2-40	S	Tamias striatus	4258	4250	1
0710	750	C2-37	A	Tamias striatus	4258	4250	1
0711	1747	C2-4	S	Tamias striatus	4526	NA	1
0711	1855	C2-68	S	Tamias striatus	4542	4540	1
0927	700	C2-33	S	Tamias striatus	5049	5095	1
0927	800	C2-72	S	Tamias striatus	NA	NA	2
0807	625	C2-13	S	Tamias striatus	NA	NA	2
0710	1820	C2-31	S	Tamias striatus	NA	NA	2
0710	815	C2-59	S	Tamias striatus	NA	NA	2
0711	1820	C2-29	S	Tamias striatus	NA	NA	2
0710	1845	C2-51	S	Tamias striatus	NA	NA	2
0926	1620	C2-21	S	Tamias striatus	NA	NA	2
0926	715	C2-19	S	Tamias striatus	NA	NA	2
0607	1915	C2-34	S	Tamias striatus	3854	3855	2
0605	1810	C2-42	S	Tamias striatus	3854	3855	2
0607	650	C2-21	S	Tamias striatus	4174	NA	2

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0711	1815	C2-40	S	Tamias striatus	4513	4514	2
0710	1835	C2-39	S	Tamias striatus	4513	4514	2
0808	1720	C2-16	S	Tamias striatus	5005	5001	2
0807	1730	C2-5	S	Tamias striatus	5005	5011	2
0926	1650	C2-79	S	Tamias striatus	5078	5092	2
0927	810	C2-76	S	Tamias striatus	5078	5092	2
0927	1635	C2-49	S	Tamias striatus	5078	5092	2
0605	700	C2-64	S	Tamias striatus	NA	NA	3
0927	1600	C2-6	S	Tamias striatus	NA	NA	3
0927	1630	C2-42	S	Tamias striatus	NA	NA	3
0808	1745	C2-52	S	Tamias striatus	NA	NA	3
0926	1630	C2-33	S	Tamias striatus	NA	NA	3
0926	1600	C2-2	S	Tamias striatus	NA	NA	3
0808	1715	C2-1	S	Tamias striatus	NA	NA	3
0606	1805	C2-47	S	Tamias striatus	4151	NA	3
0605	1815	C2-45	S	Tamias striatus	4153	NA	3
0711	1745	C2-1	S	Tamias striatus	4519	4520	3
0807	1835	C3-1	S	Tamias striatus	2906	2905	0
0927	1750	C3-2	S	Tamias striatus	NA	NA	0
0926	1745	C3-8	S	Tamias striatus	NA	NA	0
0926	920	C3-1	S	Tamias striatus	2906	2905	0
0927	1800	C3-37	S	Tamias striatus	3346	3347	0
0927	1820	C3-42	S	Tamias striatus	3424	NA	0
0926	1800	C3-30	S	Tamias striatus	3448	3449	0
0710	2040	C3-25	S	Tamias striatus	4515	4518	0
0711	2010	C3-11	S	Tamias striatus	4515	4518	0
0927	1120	C3-10	S	Tamias striatus	5025	NA	0
0926	1820	C3-6	S	Tamias striatus	5025	NA	0
0808	1840	C3-2	S	Tamias striatus	5025	5022	0
0808	1900	C3-46	S	Tamias striatus	5051	5052	0
0927	1010	C3-41	S	Tamias striatus	5424	NA	0
0710	2010	C3-9	S	Tamias striatus	NA	NA	NA
0927	1005	C3-35	S	Tamias striatus	3575	3574	NA
0607	2010	C3-34	S	Tamias striatus	NA	NA	NA

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0607	1930	C3-16	S	Tamias striatus	3448	3449	NA
0807	1850	C3-5	S	Tamias striatus	?680	NA	NA
0607	1940	C3-32	S	Tamias striatus	3520	3521	NA
0926	1040	C3-31	S	Tamias striatus	NA	NA	NA
0607	1945	C3-24	S	Tamias striatus	3473	3990	NA
0710	2030	C3-45	S	Tamias striatus	3426	NA	NA
0927	1825	C3-28	S	Tamias striatus	NA	NA	NA
0606	1915	C3-14	S	Tamias striatus	NA	NA	1
0710	2055	C3-6	S	Tamias striatus	NA	NA	1
0927	1803	C3-15	S	Tamias striatus	NA	2985	1
0607	845	C3-41	A	Tamias striatus	NA	?347	1
0710	2005	C3-2	S	Tamias striatus	2906	2905	1
0808	1915	C3-17	S	Tamias striatus	2906	2905	1
0605	815	C3-31	S	Tamias striatus	2987	3324	1
0606	1915	C3-27	S	Tamias striatus	3346	3347	1
0607	2010	C3-48	S	Tamias striatus	3424	3423	1
0808	1930	C3-49	S	Tamias striatus	3424	NA	1
0926	1845	C3-49	S	Tamias striatus	3424	NA	1
0710	2015	C3-29	S	Tamias striatus	3448	3449	1
0605	1930	C3-38	S	Tamias striatus	3448	3449	1
0606	1910	C3-22	S	Tamias striatus	3448	3449	1
0926	1830	C3-35	S	Tamias striatus	3507	3506	1
0605	1950	C3-42	S	Tamias striatus	3520	3521	1
0605	1945	C3-5	S	Tamias striatus	3533	3534	1
0607	1955	C3-10	S	Tamias striatus	4299	4256	1
0710	1045	C3-49	S	Tamias striatus	4525	4506	1
0711	2042	C3-48	S	Tamias striatus	4525	4506	1
0710	2045	C3-32	S	Tamias striatus	NA	NA	1
0808	1855	C3-36	S	Tamias striatus	NA	NA	2
0927	920	C3-22	S	Tamias striatus	NA	NA	2
0711	1955	C3-22	S	Tamias striatus	NA	NA	2
0927	1830	C3-7	S	Tamias striatus	NA	NA	2
0927	1810	C3-45	S	Tamias striatus	3426	NA	2
0926	1810	C3-46	S	Tamias striatus	3426	NA	2

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0926	1755	C3-22	S	Tamias striatus	3473	2990	2
0605	1920	C3-30	S	Tamias striatus	3673	3990	2
0606	1910	C3-8	S	Tamias striatus	3673	3990	2
0607	1950	C3-17	S	Tamias striatus	4255	4262	2
0710	2050	C3-4	S	Tamias striatus	4502	4514	2
0710	2115	C3-27	S	Tamias striatus	4505	4501	2
0807	1840	C3-43	S	Tamias striatus	4536	4534	2
0926	1840	C3-42	S	Tamias striatus	4536	4534	2
0808	1935	C3-33	S	Tamias striatus	4536	4534	2
0711	2015	C3-24	S	Tamias striatus	4536	4534	2
0808	1930	C3-21	S	Tamias striatus	NA	NA	2
0605	1945	C3-12	S	Tamias striatus	?680	NA	2
0710	2110	C3-42	S	Tamias striatus	?903	??36	2
0711	2040	C3-14	S	Tamias striatus	1001	3576	3
0926	1045	C3-43	S	Tamias striatus	2954	2955	3
0711	1950	C3-44	S	Tamias striatus	2954	2955	3
0927	1805	C3-22	S	Tamias striatus	3473	2990	3
0808	1915	C3-24	S	Tamias striatus	3473	3998	3
0926	1005	C3-47	S	Tamias striatus	3575	3574	3
0710	2025	C3-43	S	Tamias striatus	4521	4524	3
0711	2035	C3-21	S	Tamias striatus	4533	4541	3
0710	2105	C3-21	S	Tamias striatus	?534	NA	3
0926	1000	C3-4	S	Tamias striatus	?680	NA	3
0607	1930	C3-29	S	Tamias striatus	2956	2955	4
0607	825	C3-29	S	Tamias striatus	3017	NA	4
0607	1930	C3-22	S	Tamias striatus	3017	NA	4
0606	1910	C3-36	S	Tamias striatus	3017	NA	4

[a] S is a Sherman live trap, A is an arboreal Sherman live trap, P is a pitfall trap.

[b] 0 is a juvenile male, 1 is a reproductive male, 2 is a juvenile female, 3 is a reproductive female, 4 is a pregnant female, and 5 is a lactating female.

Table 7.3. Summary of small mammal captures in the Morell study site. An entry with NA indicates that the information was not recorded or unavailable.

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
1003	850	M1-68	P	Unidentified	NA	NA	NA
0814	718	M2-38	P	Blarina brevicauda	NA	NA	NA
0814	715	M2-40	P	Blarina brevicauda	NA	NA	NA
1004	800	M1-100	S	Clethrionomys gapperi	NA	NA	0
1003	905	M1-31	S	Clethrionomys gapperi	NA	NA	2
0718	1750	M1-39	S	Clethrionomys gapperi	NA	NA	2
0610	740	M1-45	S	Clethrionomys gapperi	4257	4218	1
1003	855	M1-58	S	Clethrionomys gapperi	5028	5027	1
0814	805	M1-66	S	Clethrionomys gapperi	5059	5050	4
0815	815	M1-69	S	Clethrionomys gapperi	NA	NA	2
1003	845	M1-70	S	Clethrionomys gapperi	5050	5085	2
0815	810	M1-70	S	Clethrionomys gapperi	5059	5058	2
0717	920	M1-74	S	Clethrionomys gapperi	NA	NA	1
0610	750	M1-78	S	Clethrionomys gapperi	NA	NA	NA
1004	800	M1-80	S	Clethrionomys gapperi	5050	5085	2
1004	800	M1-86	S	Clethrionomys gapperi	NA	NA	0
1003	830	M1-92	S	Clethrionomys gapperi	5087	5043	2
1004	800	M1-96	S	Clethrionomys gapperi	NA	NA	2
0717	1847	M2-39	S	Clethrionomys gapperi	4530	4550	0
0610	850	M2-40	S	Clethrionomys gapperi	4298	4252	0
0611	840	M2-70	S	Clethrionomys gapperi	4298	4252	1
0815	700	M2-72	S	Clethrionomys gapperi	5067	5066	2
1003	730	M2-74	S	Clethrionomys gapperi	5026	5048	3
0611	840	M2-44	S	Glaucomys sabrinus	4209	4271	1
1003	910	M1-34	S	Mustela ermina	NA	NA	NA
0611	645	M1-11	S	Napaeozapus insignis	4259	4207	0
0610	730	M1-25	S	Napaeozapus insignis	4259	4207	0
0612	645	M1-45	S	Napaeozapus insignis	4283	4213	0
0611	805	M2-14	S	Napaeozapus insignis	4216	4308	0
0610	845	M2-22	S	Napaeozapus insignis	4216	4308	0

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0612	750	M2-33	S	Napaeozapus insignis	NA	NA	NA
0610	830	M2-4	S	Napaeozapus insignis	4261	4210	0
0610	855	M2-46	S	Napaeozapus insignis	NA	NA	NA
0718	900	M2-91	S	Napaeozapus insignis	NA	NA	0
0610	910	M2-91	S	Napaeozapus insignis	4284	4290	NA
1003	930	M1-11	S	Peromyscus maniculatus	5300	5275	0
1004	800	M1-11	S	Peromyscus maniculatus	NA	NA	2
0814	815	M1-54	A	Peromyscus maniculatus	5060	5061	2
0814	830	M1-6	S	Peromyscus maniculatus	4583	4596	1
0814	800	M1-76	A	Peromyscus maniculatus	5055	5057	2
0718	710	M1-9	S	Peromyscus maniculatus	4583	4576	1
1004	930	M2-16	S	Peromyscus maniculatus	NA	NA	2
1004	930	M2-2	S	Peromyscus maniculatus	NA	NA	0
0610	820	M2-20	S	Peromyscus maniculatus	4206	4214	1
0610	845	M2-24	S	Peromyscus maniculatus	4281	4215	4
0610	845	M2-35	S	Peromyscus maniculatus	4201	4217	1
1004	930	M2-42	S	Peromyscus maniculatus	NA	NA	2
1003	745	M2-49	S	Peromyscus maniculatus	5034	5031	2
0611	820	M2-58	S	Peromyscus maniculatus	4201	4217	1
0814	740	M2-6	S	Peromyscus maniculatus	5075	5056	1
1004	930	M2-60	S	Peromyscus maniculatus	5034	5031	0
1003	715	M2-86	S	Peromyscus maniculatus	5076	5036	2
0814	635	M2-91	P	Peromyscus maniculatus	NA	NA	NA
1004	1000	M2-92	S	Peromyscus maniculatus	5076	5036	2
1004	1000	M2-96	S	Peromyscus maniculatus	5075	5056	0
0612	635	M1-30	P	Sorex cinereus	NA	NA	NA
1003	915	M1-39	S	Sorex cinereus	NA	NA	NA
0814	700	M2-52	P	Sorex cinereus	NA	NA	NA
0717	900	M2-66	P	Sorex cinereus	NA	NA	NA
0815	1830	M2-43	S	Tamiasciurus hudsonicus	5069	5099	1
0814	1815	M2-45	S	Tamiasciurus hudsonicus	5074	5072	0
0718	1730	M1-1	S	Tamias striatus	4226	4227	1
0815	1715	M1-30	S	Tamias striatus	NA	NA	0
0814	1930	M1-3	S	Tamias striatus	4226	4227	0

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0717	1920	M1-86	S	Tamias striatus	4546	4527	0
0718	1810	M1-43	S	Tamias striatus	4546	4527	0
0718	1745	M1-20	S	Tamias striatus	4569	4551	0
0718	1755	M1-21	S	Tamias striatus	4589	4577	0
0815	1705	M1-2	S	Tamias striatus	NA	NA	NA
0717	1930	M1-66	P	Tamias striatus	NA	NA	NA
0717	1955	M1-42	S	Tamias striatus	4545	4538	NA
0611	630	M1-8	S	Tamias striatus	NA	NA	NA
0718	1735	M1-3	S	Tamias striatus	NA	NA	NA
0612	1755	M1-31	S	Tamias striatus	NA	4224	1
0717	2015	M1-1	S	Tamias striatus	4226	4227	1
0717	1040	M1-1	S	Tamias striatus	4226	4227	1
0612	1730	M1-7	S	Tamias striatus	4226	4227	1
0611	1830	M1-13	S	Tamias striatus	4288	4224	1
0814	845	M1-13	S	Tamias striatus	?226	?227	1
0718	1740	M1-8	S	Tamias striatus	4561	4581	2
0815	1720	M1-32	S	Tamias striatus	5006	5068	2
0815	1720	M1-29	S	Tamias striatus	5070	5071	2
0815	850	M1-9	S	Tamias striatus	5070	5071	2
1003	1730	M1-1	S	Tamias striatus	5194	5195	2
0717	1950	M1-31	S	Tamias striatus	4547	4549	3
0814	1915	M1-51	A	Tamias striatus	4547	4549	3
0718	1905	M2-10	S	Tamias striatus	4573	4582	2
1003	755	M2-6	S	Tamias striatus	4529	NA	0
0717	1855	M2-33	S	Tamias striatus	4548	4543	0
0814	1815	M2-51	S	Tamias striatus	5053	5054	0
0815	725	M2-2	S	Tamias striatus	5122	5121	NA
0814	1810	M2-80	S	Tamias striatus	NA	5073	1
0718	1935	M2-61	S	Tamias striatus	4529	4528	1
0717	1840	M2-51	S	Tamias striatus	4529	4528	1
0814	655	M2-63	S	Tamias striatus	4529	4528	1
0718	1930	M2-61	S	Tamias striatus	4529	4528	1
1003	1545	M2-68	S	Tamias striatus	NA	NA	2
0718	1940	M2-63	S	Tamias striatus	4532	4531	2

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0717	1835	M2-63	S	Tamias striatus	4532	4531	2
0814	1820	M2-47	S	Tamias striatus	4561	NA	2
0815	1845	M2-99	S	Tamias striatus	4561	NA	2
0815	715	M2-49	S	Tamias striatus	5053	5054	2
0814	640	M2-92	S	Tamias striatus	5053	5054	2
1003	1630	M2-10	A	Tamias striatus	5573	5123	2
0814	740	M2-9	S	Tamias striatus	?573	5123	2
0815	1820	M2-9	S	Tamias striatus	?573	5123	2
0814	1800	M2-91	S	Tamias striatus	5063	5062	3
0612	1925	M2-95	S	Tamias striatus	4228	4229	4
0814	1830	M2-6	S	Tamias striatus	5065	5064	4

[a] S is a Sherman live trap, A is an arboreal Sherman live trap, P is a pitfall trap.

[b] 0 is a juvenile male, 1 is a reproductive male, 2 is a juvenile female, 3 is a reproductive female, 4 is a pregnant female, and 5 is a lactating female.

Table 7.4. Summary of small mammal captures in the Pleasant Grove study site. An entry with NA indicates that the information was not recorded or unavailable.

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0724	620	P1-3	P	Unidentified	NA	NA	NA
0724	655	P1-48	P	Unidentified.	NA	NA	NA
0522	1725	P1-29	P	Blarina brevicauda	NA	NA	NA
0724	625	P1-10	S	Clethrionomys gapperi	NA	NA	0
1010	1650	P1-17	S	Clethrionomys gapperi	NA	NA	NA
1011	820	P1-17	S	Clethrionomys gapperi	NA	NA	1
1011	805	P1-28	S	Clethrionomys gapperi	NA	NA	2
0523	1745	P1-28	S	Clethrionomys gapperi	3922	3923	2
0522	1725	P1-28	S	Clethrionomys gapperi	3942	3943	2
0627	635	P1-4	S	Clethrionomys gapperi	4208	4241	1
0628	705	P1-44	S	Clethrionomys gapperi	4239	4246	1
0522	1750	P1-50	S	Clethrionomys gapperi	NA	NA	NA
0524	1815	P1-53	S	Clethrionomys gapperi	3919	3920	2
0524	705	P1-81	S	Clethrionomys gapperi	3905	3906	2
0523	1903	P1-82	S	Clethrionomys gapperi	3905	3906	0
0724	735	P1-86	S	Clethrionomys gapperi	4600	4591	2
0523	1900	P1-88	S	Clethrionomys gapperi	3903	3904	0
0725	1755	P1-88	S	Clethrionomys gapperi	NA	NA	2
0627	805	P1-90	S	Clethrionomys gapperi	4254	4264	1
0524	720	P1-90	S	Clethrionomys gapperi	3917	3918	2
0724	730	P1-90	S	Clethrionomys gapperi	NA	NA	3
0523	630	P2-1	S	Clethrionomys gapperi	3939	3940	0
0524	1930	P2-12	S	Clethrionomys gapperi	3939	3540	2
0523	1945	P2-13	S	Clethrionomys gapperi	3939	3940	2
0523	705	P4-19	S	Clethrionomys gapperi	NA	NA	0
0523	705	P4-24	S	Clethrionomys gapperi	4193	3935	0
0522	825	P4-32	S	Clethrionomys gapperi	NA	NA	2
0524	2015	P4-32	S	Clethrionomys gapperi	3913	3914	2
1010	800	P1-22	S	Glaucomys sabrinus	NA	NA	NA
0724	645	P1-6	S	Napaeozapus insignis	4560	4557	3

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0628	720	P1-82	S	Napaeozapus insignis	4285	4235	0
1011	815	P1-16	S	Peromyscus maniculatus	NA	NA	0
0627	705	P1-36	S	Peromyscus maniculatus	4292	4238	1
0628	700	P1-42	S	Peromyscus maniculatus	4280	4249	3
0724	620	P1-42	S	Peromyscus maniculatus	4280	NA	4
1010	745	P1-44	S	Peromyscus maniculatus	4280	NA	2
1011	740	P1-46	S	Peromyscus maniculatus	4280	NA	0
0724	715	P1-94	S	Peromyscus maniculatus	4593	4597	2
0724	745	P2-1	S	Peromyscus maniculatus	4568	4586	0
0725	715	P2-1	S	Peromyscus maniculatus	4584	4558	5
1011	830	P2-3	S	Peromyscus maniculatus	NA	NA	2
0627	730	P2-4	P	Peromyscus maniculatus	NA	NA	1
0725	710	P2-5	S	Peromyscus maniculatus	4590	4554	0
1011	835	P2-6	S	Peromyscus maniculatus	NA	NA	1
1010	840	P2-7	S	Peromyscus maniculatus	NA	NA	0
1011	850	P3-4	S	Peromyscus maniculatus	NA	NA	0
0724	845	P4-12	S	Peromyscus maniculatus	4559	4564	2
1010	910	P4-22	S	Peromyscus maniculatus	NA	NA	NA
1011	845	P5-7	S	Peromyscus maniculatus	NA	NA	2
1011	900	P6-2	S	Peromyscus maniculatus	NA	NA	NA
1011	905	P6-6	S	Peromyscus maniculatus	NA	NA	NA
0725	740	P6-7	S	Peromyscus maniculatus	4576	4580	3
1011	800	P1-29	S	Sorex cinereus	NA	NA	NA
0523	1840	P1-81	S	Sorex cinereus	NA	NA	NA
0724	1730	P1-81	S	Sorex cinereus	NA	NA	NA
0523	1850	P1-84	S	Sorex cinereus	NA	NA	NA
0628	1900	P4-27	P	Sorex cinereus	NA	NA	NA
0724	1835	P5-5	P	Sorex cinereus	NA	NA	NA
0522	1705	P1-16	S	Tamiasciurus hudsonicus	NA	3941	1
0627	715	P1-24	S	Tamiasciurus hudsonicus	4269	4268	3
1011	1610	P1-27	S	Tamiasciurus hudsonicus	NA	NA	NA
1011	1600	P1-34	S	Tamiasciurus hudsonicus	NA	NA	NA
1011	750	P1-42	S	Tamiasciurus hudsonicus	NA	NA	NA
1011	745	P1-44	S	Tamiasciurus hudsonicus	NA	NA	NA

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0523	1810	P1-48	S	Tamiasciurus hudsonicus	3921	3920	0
0523	600	P1-50	S	Tamiasciurus hudsonicus	3938	3937	1
0522	1740	P1-52	S	Tamiasciurus hudsonicus	3944	4148	0
0524	630	P1-52	S	Tamiasciurus hudsonicus	3907	3941	1
0725	1735	P1-56	S	Tamiasciurus hudsonicus	NA	NA	0
0524	1830	P1-65	S	Tamiasciurus hudsonicus	NA	NA	NA
0524	1830	P1-66	S	Tamiasciurus hudsonicus	3933	NA	2
0627	730	P1-68	S	Tamiasciurus hudsonicus	NA	NA	NA
0524	655	P1-71	S	Tamiasciurus hudsonicus	3908	4200	0
0522	1800	P1-71	S	Tamiasciurus hudsonicus	3175	3192	1
0523	1825	P1-76	S	Tamiasciurus hudsonicus	3944	4148	1
0725	1750	P1-85	A	Tamiasciurus hudsonicus	4587	4599	2
0724	1740	P1-86	S	Tamiasciurus hudsonicus	4587	4599	2
0522	700	P1-92	S	Tamiasciurus hudsonicus	3945	3946	1
0522	1845	P1-99	S	Tamiasciurus hudsonicus	3933	NA	2
0628	1920	P2-1	S	Tamiasciurus hudsonicus	3902	3734	1
0522	1915	P2-11	S	Tamiasciurus hudsonicus	3902	3934	1
0523	1946	P2-14	S	Tamiasciurus hudsonicus	4183	3919	2
0627	830	P2-16	S	Tamiasciurus hudsonicus	NA	NA	NA
0724	1800	P2-8	S	Tamiasciurus hudsonicus	NA	NA	NA
0627	820	P2-8	S	Tamiasciurus hudsonicus	NA	NA	NA
0524	1920	P2-8	S	Tamiasciurus hudsonicus	3915	3916	1
0522	1940	P3-5	S	Tamiasciurus hudsonicus	4194	3936	1
1011	1715	P5-8	A	Tamiasciurus hudsonicus	NA	NA	NA
0627	625	P1-11	S	Tamias striatus	4901	4149	2
0725	1715	P1-2	S	Tamias striatus	NA	NA	1
0627	1820	P1-29	S	Tamias striatus	4240	4230	0
1010	1615	P1-50	S	Tamias striatus	NA	NA	0
0524	1845	P1-61	A	Tamias striatus	3901	4149	NA
0725	1745	P1-71	S	Tamias striatus	4572	4553	2
0523	1830	P1-72	S	Tamias striatus	3901	4149	NA
0522	1820	P1-85	A	Tamias striatus	3901	4149	2
0523	1925	P2-1	S	Tamias striatus	3136	NA	0
0725	1830	P2-10	A	Tamias striatus	NA	NA	NA

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0627	800	P2-13	S	Tamias striatus	2766	3389	3
0724	1815	P2-14	S	Tamias striatus	4231	4234	2
0724	1810	P2-15	S	Tamias striatus	4570	4578	0
1010	830	P2-2	S	Tamias striatus	5130	????	0
0725	1815	P2-5	S	Tamias striatus	3232	3243	5
1011	1655	P2-6	S	Tamias striatus	4231	4234	2
1011	1700	P2-7	S	Tamias striatus	4136	NA	0
1010	1720	P2-7	S	Tamias striatus	NA	NA	NA
0627	1905	P2-8	S	Tamias striatus	2766	3389	NA
0628	2005	P3-11	S	Tamias striatus	NA	2122	NA
0628	2010	P3-15	S	Tamias striatus	3118	3117	3
0724	810	P3-16	S	Tamias striatus	4287	4289	1
1010	850	P3-2	S	Tamias striatus	NA	NA	1
0725	1900	P3-4	S	Tamias striatus	4552	4585	2
0628	2200	P4-13	S	Tamias striatus	4236	4243	1
0628	2145	P4-14	S	Tamias striatus	4253	4295	3
0724	1853	P4-15	S	Tamias striatus	4588	4562	0
0628	2120	P4-19	S	Tamias striatus	4287	4289	1
1011	1800	P4-20	S	Tamias striatus	NA	NA	NA
0724	1850	P4-20	S	Tamias striatus	NA	NA	1
0627	1950	P4-20	S	Tamias striatus	4286	4272	1
1010	915	P4-20	S	Tamias striatus	NA	NA	3
0628	745	P4-21	S	Tamias striatus	NA	NA	NA
0628	2130	P4-23	S	Tamias striatus	NA	NA	NA
0628	2105	P4-29	S	Tamias striatus	4204	4233	2
0725	1930	P4-30	S	Tamias striatus	4204	NA	3
0724	820	P4-31	S	Tamias striatus	4204	NA	3
0627	2015	P4-5	S	Tamias striatus	3017	2868	1
0524	1935	P5-1	S	Tamias striatus	3136	NA	NA
0522	1915	P5-1	S	Tamias striatus	3136	NA	1
0725	1845	P5-3	S	Tamias striatus	4570	4578	0
0724	1830	P5-3	S	Tamias striatus	3136	NA	NA
0628	2000	P5-6	S	Tamias striatus	4231	4234	2
0725	1920	P6-1	S	Tamias striatus	4575	4567	0

Date (month/day)	Time	Grid-trap number	Trap type[a]	Species	Right ear tag	Left ear tag	Reproductive status[b]
0628	2030	P6-1	S	Tamias striatus	4293	4219	1
0724	1840	P6-2	S	Tamias striatus	4575	4567	0
1011	1745	P6-2	S	Tamias striatus	NA	NA	NA
0628	730	P6-3	S	Tamias striatus	NA	NA	NA
0628	2040	P6-3	S	Tamias striatus	3017	2868	1
0724	1845	P6-5	S	Tamias striatus	NA	NA	3
0628	2047	P6-5	S	Tamias striatus	4267	4248	3
0628	2100	P6-9	S	Tamias striatus	4266	4294	1

[a] S is a Sherman live trap, A is an arboreal Sherman live trap, P is a pitfall trap.

[b] 0 is a juvenile male, 1 is a reproductive male, 2 is a juvenile female, 3 is a reproductive female, 4 is a pregnant female, and 5 is a lactating female.