The effect of road density on white-footed mice (*Peromyscus leucopus*) relative abundance in rural and urban landscapes in eastern Ontario

By

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ABSTRACT

Numerous studies have shown that roads can act as barriers to some small mammal movements. However, studies investigating the relationship between road density and small mammal abundance are lacking. I compared *Peromyscus leucopus* populations in landscapes with varying road densities to test for relationships between 1) road density and the presence of *P. leucopus* in a forest patch during the early spring and 2) road density and relative abundance of *P. leucopus* during the summer. I did not find a significant relationship between road density and the presence of *P. leucopus*, however I did find a significant positive effect of road density on *P. leucopus* relative abundance. My results suggest that in rural landscapes, the impact of roads on population subdivision may not be as important as originally predicted. I suggest that roads are positively correlated with an important as-yet-undetermined component of habitat quality or that roads positively affect small mammals by negatively affecting their predators.

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Introduction

North America's continuous landscapes are becoming increasingly fragmented by roads. The network of paved roads in Canada has tripled from 100,000 km in 1959 to 300,000 km in 2001 (Forman et al. 2003). Canada has 19.93 km of roads per 1000 people, approximately 25% greater than the next closest country, USA (Forman et al. 2003). The accumulation of the direct and indirect road effects over time and space can have major ecological implications for ecosystems. Forman (2000) estimated that about one-fifth of the United States land area is directly affected ecologically by the network of public roads and that this fraction is increasing. While road networks have both positive and negative ecological effects, the majority are negative and extend substantial distances beyond the road itself (Forman and Alexander 1998).

Movement of animals through heterogeneous landscapes to recolonize habitat patches is critical for population persistence (Fahrig and Merriam 1985; Kozakiewicz 1993). Roads have been found to act as barriers to small mammal movement (Oxley et al. 1974; Kozel and Fleharty 1979; Mader 1984; Swihart and Slade 1984; Clarke et al. 2001). While some small mammal species use habitat up to the road edge, movement across roads is limited or non-existent, suggesting that roads act as partial to complete barriers to small mammal movement (Garland and Brandley 1984; Mader 1984; McGregor 2004). Recent findings during a translocation experiment of eastern chipmunks and white-footed mice over varying distances found that the probability of successful return to the initial capture site decreased by approximately 50% for every road that lay between the translocation site and the initial capture site (McGregor 2004). These results suggest that roads may effectively fragment small mammal populations, such that populations that would otherwise be large continuous populations are divided into smaller, partially isolated local populations.

With over-wintering mortality rates of 80-90% being common for *Peromyscus leucopus* in the southeastern Ontario area, many woodlots may start the spring breeding season with only a handful (1-3) of reproductive females (Taylor 1978, Middleton 1979). Merriam and Wegner (1992) stated that 5 to 15% of small mammal populations in forest patches in the Ottawa area suffer location extinctions each year. Therefore, movement for recolonization of local extinctions is important, making population subdivision by roads a large potential effect on small mammal populations. While there have been numerous studies on the effects of roads on small mammal movement, the relationship between road density and small mammal abundance has not yet been investigated.

The purpose of my study was to determine whether road density affects small mammal populations. I compared small mammal populations in landscapes with varying road densities to test two predictions: 1) Forest patches situated in landscapes with low road densities will have a higher chance of small mammals being present during the early spring than forest patches situated in landscapes with high road densities and 2) Small mammal populations during the summer are smaller in forest patches situated in landscapes with high road densities than in landscapes with low road densities.

I tested these predictions using white-footed mice (*Peromyscus leucopus noveboracensis*). *Peromyscus leucopus* is numerous within the Ottawa region. While these mice are capable of living in a variety of habitats, they prefer to live and move in woodland habitat and to avoid areas with little cover, such as grassy fields (Bendell 1961; Hansen and Warnock 1978; Drickamer 1990; Wegner 1995; Seamon and Adler 1996), cultivated fields (Whitaker 1967; Wegner 1995), and roads (Oxley et al. 1974; Wilkins 1982; Merriam et al. 1989; McGregor 2004).

<u>Ecology and life history of *Peromyscus leucopus*</u>

Peromyscus leucopus is a nocturnal mammal and is considered semi-arboreal, showing preference for shrubby, deciduous habitat with dense cover, and particular features or microsites such as rocks and stumps (Barry and Franq 1980). One of the main microhabitat features with which *P. leucopus* has been positively associated with is coarse woody debris. Several studies have documented the use of coarse woody debris (CWD) in the form of stumps, pieces of wood, branches, snags, and fallen logs (Dueser and Shugart 1978; Seagle 1985; Barnum et al. 1992; Planz and Kirkland 1992). Fallen logs and branches appear to be non-randomly selected as travel routes (Graves et al. 1988; Barnum et al. 1992; Planz and Kirkland 1992), foraging sites (Wolff and Hurlbutt 1982), and orientation and navigational aids (Barry and Franq 1980; Drickamer and Stuart 1984). It has also been suggested that mice travel along fallen logs to reduce the risk of predation since detection by auditory predators is more difficult (Fitzgerald and Wolff 1988; Barnum et al. 1992; Roche et al. 1999).

Peromyscus leucopus has a diverse, omnivorous diet that changes seasonally. Insects, fruit, seeds, assorted vegetation, and nuts are the primary foods. The breeding season for *P. leucopus* extends from March to October with peaks in spring and late summer. Minimum gestation period for non-lactating females is 22 to 23 days and in Ontario, mean litter size has been found to be 5.0 (Conventry 1937). Postnatal growth in *P. leucopus* is fast and largely completed within 2 months of birth.

Peromyscus leucopus is near the northern edge of its range in eastern Ontario (Wegner 1995). According to Wegner and Merriam (1990), population densities here are lower than in more southerly forests. These authors found that *P. leucopus* density peaked in August at 3.5/ha in study woods in eastern Ontario while Smith and Speller (1970) found density to be on average 1/ha in eastern Ontario. In comparison however, most other studies in North America have reported densities an order of magnitude higher than those found in the Ottawa region (Blem and Blem 1975; Gottfied 1979; Adler and Wilson 1987; Vessey 1987; Krohne et al. 1988). Home range sizes for *P. leucopus* vary seasonally, with the minimum size occurring during the winter and the maximum during the breeding season (Lackey et al. 1985). Estimates of home range sizes vary greatly; according to Lackey et al. (1985) and Nupp and Swihart (2000) the average is approximately 0.1 ha.

Methods

Site Selection

I chose forest patches (focal patches) within landscapes that varied in road density (km/km^2). I defined each landscape as the area within a 2 km radius of each focal patch. This size of landscape was based on reported movement distances of *P. leucopus*. Although reports on long-distance movements by small mammals are relatively rare (Diffendorfer and Slade 2002), a few studies have documented *Peromyscus sp.* travelling > 1 km (Murie and Murie 1931; Howard 1960; Bowman et al. 1999; Maier 2002). It has also been suggested that small mammals can travel greater distances than predicted from their average home range size in heterogeneous (fragmented) landscapes (Kozakiewicz et al. 1993).

In selecting focal patches, I attempted to maximize the variation of road density among the surrounding landscapes while controlling for landscape variables other than road density. I began by selecting only rural landscapes, containing no urban development, and approximately 20-35% forest. I choose 20-35% forest because it allowed the largest possible range of road density values, given the variation in forest cover and road densities in the Ottawa area. Landscapes also contained limited or no water (i.e., no rivers or lakes) and no railways, to avoid the possibility of additional barrier effects. I chose focal patches that were located at least 3 km apart to minimize overlap of the landscapes; focal patches were all greater than 1 ha in size and of similar forest type (deciduous/mixed deciduous).

I selected 14 landscapes in the Ottawa region that spanned the largest possible range of road densities while meeting these criteria. However, it turned out that due to the constraint that all the landscapes were rural, there was a relatively small difference in the road densities between the low road density landscapes and the high road density landscapes (0.42 to 0.85 km/km^2 compared to 1.24 to 1.62 km/km^2). I was concerned that if I found no effect of road density on mouse abundances across these sample sites, it could be because my landscapes did not contain a large enough range of road density values. Therefore, I added 5 urban landscapes (Figure 1). I followed as closely as possible the same criteria as for the other landscapes when selecting the urban landscapes, in that all of the urban landscapes contained approximately 20-35% forest, limited water systems/bodies, and focal patches were all greater than 1 ha in size and of similar forest type (deciduous/mixed deciduous). Two of the five urban landscapes did, however, contain railways within the landscape. I defined urban landscapes as having at least 40% of the landscape covered by urban development (i.e., settlements and developed land, major transportation routes, etc.). Road densities in the 5 urban landscapes ranged from 4.28 to 9.48 km/km^2. While the 14 rural landscapes were interspersed across the Ottawa region as much as possible, it was not however possible to do the same for the urban landscapes. The landscapes spanned five counties: Lanark County, City of Ottawa, Leeds and Grenville County, Stormont, Dundas and Glengarry County, and Prescott and Russell County. Figure 2 shows the distribution of landscapes.

Peromyscus leucopus sampling

I sampled *P. leucopus* in focal patches within each of the nineteen landscapes (7 rural, low road density; 7 rural, high road density; 5 urban) during the early spring (April 11-29) and summer (June 6 – July 29) of 2005. I sampled *P. leucopus* using footprint tracking tubes (Merriam 1990). The proportion of tracking stations containing small mammal tracks has been shown to be a good estimate of relative abundance (Fahrig and Merriam 1985; Brown et al. 1996; Drennan et al. 1998). In addition, relative to live trapping, footprint tracking reduces or eliminates the risks of stress and mortality in the study animals, reduces risk of exposure to diseases transmitted by rodents, and is less expensive and easier to deploy in the field, allowing for simultaneous sampling of small mammal populations in several areas.

I lined thirty-cm lengths of 3.75 cm (inside diameter) plastic water pipe (PVC tubing) with a strip of white paper (28 x 7cm). To the center of each paper, I stapled a 6 x 6 cm square of waxed paper with a smear of powdered carbon black (decolorizing) and paraffin oil (Nams and Gillis 2002). I tested various ratios of carbon black to paraffin oil to obtain the best consistency and chose a ratio of 1:3 (by weight). Each focal patch contained a 10 x 10 grid of tubes at 10 m spacing.

Data were presence or absence of *P. leucopus* tracks in each tube, irrespective of the number of times a mouse, or possibly several mice, went through the tube. I placed each tube within 1 m of a marker flag, adjacent to a prominent microhabitat feature, such as a tree trunk or log to improve chances of *P. leucopus* tracking the tubes (Drickamer, 1990). I checked tubes weekly for *P. leucopus* tracks and replaced tubes with newly prepared papers weekly. I identified footprints using the Carleton University footprint collection.

Older studies have reported the presence of both *P. leucopus* and *P. maniculatus* in this area (Clark 1964; Speller 1968), and based solely on footprints, these two species cannot be distinguished. However, more recent studies have only reported the presence of *P. leucopus* in this area (Tsuchiya 1990; Wegner 1995); therefore I assumed that all *Peromyscus* footprints were *P. leucopus*.

Spring tracking

The purpose of the spring tracking was to determine whether forest patches situated in landscapes with low road densities have a higher chance of small mammals being present during the early spring (following the high over-winter mortality period and before reproduction begins), than forest patches situated in landscapes with high road densities. Tracking began April 11th 2005, and was carried out for three consecutive weeks ending April 29th 2005. In this phase of the sampling, I was only interested in determining whether there were any *P. leucopus* present in each site. Therefore, I baited tubes with sunflower seeds to attract animals to them.

Summer tracking

The purpose of the summer tracking was to determine whether small mammal populations are smaller in forest patches situated in landscapes with high road densities than in landscapes with low road densities. Tracking began June 6th, 2005 and was carried out for eight consecutive weeks ending July 29th, 2005. I replaced one of the urban landscapes used in the spring tracking phase for another urban landscape for the summer tracking phase due to interference and damage to the sampling grid by an adjacent landowner. I did not bait tubes during this phase of tracking because I was looking for an estimate of the relative abundance of *P. leucopus* based on the number of tubes containing *P. leucopus* prints. When the tubes are baited there is a high chance that one mouse will visit numerous tubes to obtain food. In contrast, unbaited tubes are similar to a hollow log that a mouse might run through simply as part of its environment.

It has been shown that *P. leucopus* demonstrate a strong attraction to new objects (Sheppe, 1965). Therefore, I left tubes out in each site between the spring and summer tracking phases so that the mice would become familiar with the tubes in their habitat before the summer tracking phase started. Note it was not necessary to put tubes out before the spring tracking phase because during that phase I was only interested in the presence or absence of mice in each site. I placed tubes in the one replacement urban landscape two weeks before summer tracking commenced.

Vegetation Surveys

To assess whether local habitat variables differed between focal patches and for focal patch descriptions, I carried out vegetation surveys on each focal patch from July 13th to July 22nd 2005. At each focal patch, I randomly chose five points within the tracking grid. I conducted sampling using the point-quarter method (Krebs, 1989) in a 10-m^2 plot which was centred over each of the five randomly chosen points within the sampling grid (Figure 3). In each of the four quarters of the 10-m^2 plot, I recorded the species and diameter of the nearest woody tree (>10cm diameter at breast height (dbh)), and shrub density (stems < 10cm dbh and > 1m in height). I measured dbh at 1.3 m above ground for trees only. The occurrence of *P. leucopus* has been reported to be influenced by both the number of woody tree species and the density of shrub vegetation (Dueser and Shugart 1978).

Lee (2004) reported that in sites with large amounts of coarse woody debris (CWD), the density of *P. maniculatus* was higher, populations fluctuated less, survivorship was better, and the time of residency was longer than in sites with less CWD. During the vegetation survey, I measured the percent of ground covered by coarse woody debris along five transects, one in each of the 10-m^2 plots, at each focal patch. I selected a distance between 0 (North corner of the 10-m^2 plot) and 10 (East corner of plot) using a random number generator. After locating that distance along the northeast boundary of the 10-m^2 plot, I ran a 10 m transect to the southwest boundary of the plot, using the 50m tape measure as the transect line (Figure 3). I measured the total length of transect directly over coarse woody debris greater than 5 cm in length and greater than 2 cm in diameter (Zollner and Crane 2003). To estimate the percent cover of coarse woody debris at each focal patch, I divided the summed segment lengths that intersected coarse woody debris from each of the five transects by the total summed transect lengths (50m) and multiplied by 100.

Focal patch characteristics

Patch size and shape have been found to affect small mammal abundances in previous studies. To determine possible confounding effects (with road density) of these variables on *P. leucopus* relative abundance in this study, I determined the size and shape of each focal patch using ESRI ArcView 3.2 (Environmental Systems Research Institute, Redlands California) and digital National Topographic Data Base (NTDB 1998). Topographic maps at the 1:50, 000 scale included: 031b13, 031b14, 031c16, 031f01, 031f08, 031g03, 031g04, 031g05, 031g06, and 031g07. I calculated patch size from polygon areas in the GIS database. I determined patch shape using a modified "Patton index" (Faeth and Kane 1978; Schmid-Holmes and Drickamer 2001; Barko et al. 2003). This index calculated the deviation from circularity of each patch as: $P/[2(\pi A)^{1/2}]$, where P represents the perimeter and A represents the area of the patch. Circular patches have a value of one and have the smallest possible amount of edge for the given patch area. Values greater than one indicate an increased perimeter-to-area ratio, that is, more edge (Game 1980). I calculated road density as the total length of roads of all types (i.e., paved, gravel and/or dirt) within each 2 km radius landscape divided by the total area of the landscape (km/km^2), and amount of forest within each 2 km radius landscape (summed forest polygon areas divided by the total landscape area multiplied by 100 to give a percentage) using ArcView 3.2 and NTDB digital topographic maps.

Data analysis

Although I attempted to control for possible confounding variables in my site selection process, there were several variables that might affect *P. leucopus* relative abundance that I was not able to control for completely in my experimental design. These included the amount of forest in the landscape, the size of the focal patch, its shape (Patton index), the percentage of coarse woody debris, the number of tree species, and the density of shrubs in the focal patch. Before evaluating the effects of road density, I first wanted to rule out the possibility of these variables confounding our results. Therefore, for each variable I conducted an ANOVA to determine whether it differed among the three landscape types: rural low road density, rural high road density, and urban. I intended to include any of these variables that differed among the landscape types in the analyses below.

I performed a logistic regression analysis to test whether the probability of presence of *P. leucopus* in a forest patch in the early spring was negatively related to road density in the landscape surrounding the sites. To test the prediction that relative abundance of *P. leucopus* in a forest patch decreases with road density in the surrounding landscape, I performed a linear regression of the total number of tracks found at each site over the eight week summer tracking period (relative abundance) on road density. I performed all statistical analyses using SPSS version 12.0.

Results

Focal patches were primarily mature, deciduous forest, dominated by white ash (*Fraxinus americana*), red maple (*Acer rubrum*), american elm (*Ulmus americana*), and sugar maple (*Acer saccharum*). Dominant vegetation varied among focal patches. Sixteen of the nineteen focal patches had greater than 75% deciduous tree species and two of the nineteen focal patches were dominated by eastern white cedar (mixed deciduous-evergreen forests; one in the rural low road density category and one in the urban category). While I made every effort to select focal patches with a high degree of similarity in habitat characteristics, complete homogeneity among the nineteen focal patches was not obtainable. However, none of the possible confounding variables that I measured, percentage of forest, focal patch size, focal patch shape, percentage of coarse woody debris cover, number of tree species, or shrub density showed a significant difference among landscape types (Table 1), so they were not included in further analyses.

Peromyscus leucopus tracks were not found in 5 of the 19 sites over the three week period during the early spring sampling (3 of the rural low road density landscapes; 1 rural high road density landscape; 1 urban). The logistic regression analysis showed no significant relationship between road density and presence of *P. leucopus* in a forest patch during the early spring (Figure 4; Table 2; Wald $X^2 = 0.165$; $p = 0.684$).

Of the 5 sites that contained no *P. leucopus* tracks during the spring tracking phase, 4 were later found to contain tracks of *P. leucopus* during the summer tracking period. There were a total of 877 tracking papers containing *P. leucopus* tracks over the eight week summer tracking period (Table 3). There was a significant positive relationship between the relative abundance of *P. leucopus* and road density across all 19 sites (Figure 5; Table 4; F= 48.1; $p < 0.001$). When the urban landscapes were removed from the analysis, there was still a significant positive relationship between the relative abundance of *P. leucopus* and road density in the 14 rural landscapes (Figure 6; Table 5; F= 5.79; $p = 0.033$).

Discussion

I predicted that forest patches situated in landscapes with low road densities would have a higher chance of white-footed mice being present during the early spring than forest patches situated in landscapes with high road densities. However, I found no significant relationship between road density and the presence of *P. leucopus* during the early spring (Figure 4). In fact, the trend in the data was opposite to my prediction, i.e., three of the five sites with no *P. leucopus* tracks during the early spring sampling were in rural low road density landscapes. Therefore, it is unlikely that a larger sample size would have resulted in support for my initial prediction. This is the first study to test this hypothesis and as such there are no published reports to which I can compare my findings.

I also predicted that *P. leucopus* populations during the summer would be smaller in forest patches situated in landscapes with high road densities than in landscapes with low road densities. However, I found the opposite result: as road density increased, the relative abundance of *P. leucopus* increased (Figure 5). This result was not due to the possible confounding factors that I had considered during the design of the study (the percentage of forest in the landscape, focal patch size, focal patch shape, the percentage of coarse woody debris, the number of tree species, or the density of shrubs). None of these other variables was significantly different among landscape types, so they were not responsible for the positive effect of road density. From my results, I conclude that road density does not have a negative effect on *P. leucopus* populations as I had predicted. In fact, my results suggest that there is a positive effect of road density on the relative abundance of *P. leucopus*.

Note, however, that the higher abundances found in the urban landscapes were not completely unexpected, and this was the reason that I had initially limited my site selection to rural landscapes. There is other evidence that urban forest patches may support greater abundances of small mammals, but some of the suggested reasons for these observations do seem speculative. Barko et al. (2003), for example, found a higher abundance of *P. leucopus* in sites in Illinois that were surrounded by a large percentage of urban habitats and a small percentage of upland deciduous forest than in sites surrounded by a large percentage of upland deciduous forest and a low percentage of urban habitats. They suggested that forest patches in urban areas are surrounded by unsuitable habitat, which may create island habitats from which small mammals do not emigrate, resulting in higher densities in these urban sites.

Temperature differences in urban compared to rural areas may also contribute to greater abundances of small mammals in urban forest patches. On studying urban-to-rural gradients on a 140 km transect running from highly urbanized Bronx County, New York, to rural Litchfield County, McDonnell et al. (1997) reported that at the urban core, the mean monthly temperatures were typically 2-3°C warmer than other locations along the transect. According to Gill and Bonnett (1973), the greatest effect of increased urban heat occurs in winter, when the minimum temperatures are significantly higher in the city than in the rural areas. Mice in urban forest patches may benefit from these higher temperatures through reduced winter mortality.

Another factor to consider is the large number of dwellings (buildings, houses, garages, etc.) within the urban landscape, which may provide over-winter refuge against cold stress and lack of food. In my study, there were on average 4501 dwellings in the urban landscapes compared to 79 for the rural high road density landscapes and 45 for the rural low road density landscapes. The larger number of dwellings in the urban environment may lower the over-winter mortality rate due to the availability of additional shelter. Along with increased shelter in urban landscapes, gardens, bird feeders, and fruit trees may provide additional food. Baker et al. (2003) suggested that small mammal populations in urban environments may be limited by predators and habitat fragmentation but the effects of habitat fragmentation may be more than balanced by the availability of good quality gardens. Baker et al. (2003) further suggested good quality gardens may act as source populations for small mammals, as they may offer a wide variety of microhabitats and food sources. Therefore, the higher densities in urban areas may not be a result of higher road densities, but maybe related to other variables that differ between urban and rural sites.

However, when excluding urban landscapes from my linear regression analysis, I still found a significant positive relationship between *P. leucopus* relative abundance and road density across only the 14 rural sites (Figure 6). This is the first study to test for this relationship and therefore the first to demonstrate this unexpected relationship. None of the possible explanations for higher densities in urban sites can explain the relationship within the rural sites. First, the suggestion that woodlots surrounded by unsuitable habitat may create islands of high density from which small mammal dispersal is restricted (Barko et al. 2003), does not explain my results. Unsuitable habitat (aside from roads) in the form of large paved areas and managed green spaces (mowed or recreationally used) were not common in the rural landscapes and the matrix in both rural landscape types was very similar. Therefore, the suggestion that unsuitable habitat may create islands of high density from which successful dispersal is limited, cannot explain the higher mice densities in rural high road density landscapes. However, it could be possible that the roads themselves are trapping *P.*

leucopus. While the matrix was similar in both landscape types, it is possible that the roads are 'containing' the white-footed mice within the forest patches surrounded by roads. To investigate this possibility, I measured the amount of accessible habitat within each of the rural landscapes, where accessible habitat is the amount of forest available to mice in the focal patch without having to cross a road (Eigenbrod et al. submitted). Low road landscapes had significantly more accessible habitat available than high road landscapes (F=14.0; p= 0.003; Table 6). However, there was no significant relationship between accessible habitat and *P. leucopus* relative abundance (F= 0.381; p= 0.549; R^2= 0.031; Table 7; Figure 7).

Second, it is highly unlikely that temperatures in the rural high road density landscapes were higher than temperatures in the rural low density landscapes. Lastly, I do not believe the difference in number of dwellings between rural low road density landscapes and rural high road density landscapes is responsible for our results. While there was a significant difference in the number of dwellings between rural landscape types, with low road landscapes having fewer dwellings (F=8.42; p = 0.013; Table 8), the relationship between *P. leucopus* relative abundance and the number of dwellings within the landscapes was only marginally significant (F= 4.52; p = 0.055; Table 9: Figure 8) and weaker than the relationship between *P. leucopus* relative abundance and road density for the rural landscapes (R^2 = 0.273 for relative abundance vs. dwellings, compared to R^2 = 0.326 for relative abundance vs. rural road density). This suggests that the number of dwellings alone did not cause the difference in *P. leucopus* relative abundance between rural landscapes. Therefore, it does not appear that the possible explanations for higher densities in urban sites can explain the relationship within the rural sites.

Tracking is not as common a method as live–trapping for estimating small mammal abundance, despite studies supporting its use. Therefore, I decided to investigate the reliability of my method by carrying out live trapping to compare the relative abundances obtained by tracking tubes and those obtained from live trapping. I live trapped in three of the sites, one from each landscape type, for one night each (October 11th, 12th, and 15th 2005). The selected sites ranged widely in the relative abundances obtained from summer tracking. I caught 3 individual *P. leucopus* in the rural low road density site, 8 in the rural high road density site, and 30 in the urban site, compared to 10, 72, and 149 tracked papers respectively over the summer tracking period in these three sites. These results show a similar trend, suggesting that the tracking tubes were a reliable method for estimating relative abundances.

The above post-hoc analyses indicate that tracking tubes were a reliable sampling method, and they eliminated the suggested mechanisms for higher densities in urban sites as possible explanations for the positive relationship across the rural sites (Figure 6). What else could explain the positive relationship in Figure 6? It seems likely that there must be some correlation(s) between roads and an important component(s) of *P. leucopus* habitat. I investigated three such possible correlations, one of which has already been discussed above ie., the amount of accessible habitat within the rural landscapes. Second, it has been found in numerous studies that small mammal densities are often higher in smaller patches (Yahner 1992; Nupp and Swihart 1996, 2000; Krohne and Hoch 1999; Schmid-Holmes & Drickamer 2001; Anderson et al. 2003), although this was not the case in my focal patches. If the landscapes with higher road densities contained more, smaller forest patches, than landscapes with lower road densities, it could be possible that the landscapes with higher road densities may support a higher overall abundance of mice, despite the total amount of forest being similar between landscape types. In fact, rural high road density landscapes did have more (smaller) forest patches ($F = 14.4$; $p = 0.003$; Table 10) than rural low road density landscapes. However, there was no significant relationship between *P. leucopus* relative abundance and the number of forest patches in the landscapes ($F= 2.21$; $p= 0.163$; $R^2= 0.155$; Table 11; Figure 9).

The third habitat association I looked at was land-cover type within the rural landscapes. While I selected forest patches within landscapes that varied in road density, I did not differentiate landscapes based on land-cover types, with the exception of forest type and the exclusion of wetland habitat. To determine whether agricultural land use was different between rural high and low road density sites, I created a 500m radius buffer around each focal patch and estimated the percentage of different land-cover types, using air photos and talking with farmers. I was particularly interested in cereal grains (oats, wheat, barley), corn, and hay (timothy, alfalfa, clover). Wegner (1995) reported that *P. leucopus* occupied both grain and corn fields in agricultural landscapes in eastern Ontario, but were rarely captured in hay fields. There was no significant difference between low and high road density rural landscapes in the percentage of grain fields ($F= 0.001$; $p= 0.980$), corn fields ($F= 0.061$; $p= 0.809$), or hay fields ($F= 0.020$; $p= 0.889$) (Table 12).

Although none of the individual post-hoc explanations tested above was borne out, it was still possible that a combination of these variables could explain the higher *P. leucopus* relative abundances in rural high road density landscapes. To evaluate this, I conducted a multiple regression analysis of relative abundance on the three variables that showed significant differences between the two rural landscape types (number of dwellings, number of forest patches and the amount of accessible habitat), across the 14 rural landscapes. The R^2 value for the multiple regression (0.282) was still slightly less than the R^2 value for the simple linear regression with road density alone (0.326). This is surprising, since one would expect a model with three variables to explain more variance than a model with only one variable, particularly when all four variables are highly correlated. This result suggests that these three variables (number of dwellings, number of forest patches and the amount of accessible habitat) do not fully explain the positive relationship between *P. leucopus* relative abundance and road density across the rural sites.

There is still another possible explanation for the positive effect of road density on *P. leucopus* relative abundance that I had no data for testing. *Peromyscus leucopus* could experience a release from predation in areas with more roads. Predator populations may be susceptible to road effects, whether through road mortality, habitat destruction, or road avoidance. Bautista et al. (2004) found that some raptors avoid roads with high traffic loads. This could lead to lower predation pressure on rodents in landscape with more high-traffic roads. However, other studies have reported the use roads by raptors for hunting (Meunier et al. 2000) including in the Ottawa area (Mike Runtz, pers. comm.). In contrast, nocturnal owls may avoid roadsides due to disturbance by traffic (Mike Runtz, pers. comm.). Negative effects of roads may also be a possibility for medium-sized mammalian predators (Mladenoff et al. 1999; Lodé 2000; Seiler et al. 2004; Hell et al. 2005) and also snakes (Shine et al. 2004; Andrew & Gibbons 2005), which could indirectly produce positive effects of roads on small mammals.

My results cannot be generalized to say that roads have a positive effect on all small mammals. However, the next most abundant species tracked over my summer tracking period, the short-tailed shrew (*Blarina brevicauda*), shows the same general trend, with a higher relative abundance in rural high road density sites compared to rural low road density sites (103 vs. 66 tracks recorded, respectively) (refer to Appendix C).

What are the general implications of this study for predictions about roads and animal populations? Numerous studies have shown that roads can act as barriers to small mammal movement. However, I have found that this negative effect of roads on movement does not necessarily translate into a negative effect on the population. Movement is only one component of population dynamics. While roads may fragment habitats, this subdivision may not be as important as indirect effects of roads on mortality and reproduction. I hypothesize that the positive effect of roads on *P. leucopus* populations is due to an as-yet-undocumented correlation between roads and increased habitat quality and/or decreased predation, leading to increased reproduction and/or decreased mortality respectively in landscapes with high road density.

Conclusions

Roads have been found to act as barriers to some small mammal movements. However this does not necessarily mean that roads have a negative effect on the population, because movement is only one component of population dynamics. This is the first study to test for a relationship between road density and relative abundance of small mammals and as such the first to demonstrate the unexpected positive relationship. My results suggest that in rural landscapes, the impact of roads on small mammal populations through population subdivision may not be as important as originally predicted. I was not able to determine the cause of the positive relationship between *P. leucopus* relative abundance and road density. I suggest that the two most likely explanations are that roads are positively correlated with an important as-yet-undetermined component of habitat quality or that roads positively affect small mammals by negatively affecting their predators. Further research is needed to test these hypotheses.

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Table 1. ANOVA table comparing habitat variables among landscape categories (rural low road, rural high road, and urban).

Habitat Variables	Landscape Category	Mean	Standard Error	ANOVA
% Forest Amount	Low	26.29	2.589	F= 0.076; df= 2, 16; p= 0.927
	High	24.86	2.604	
	Urban	25.40	3.108	
Patch Size (ha)	Low	7.60	2.911	F= 2.292; df= 2, 16; p= 0.135
	High	8.92	3.297	
	Urban	28.09	14.687	
Perimeter-to-area ratio (Patton Index)	Low	1.39	0.152	F= 0.969; df = 2, 16; p= 0.401
	High	1.78	0.299	
	Urban	1.48	0.065	
% Coarse Woody Debris Cover	Low	7.05	1.861	F= 0.733; df= 2, 16; p= 0.496
	High	6.48	1.741	
	Urban	9.52	1.508	
# of woody tree species	Low	4.43	0.649	F= 0.800; df= 2, 16; p= 0.467
	High	3.56	0.340	
	Urban	3.40	0.678	
Shrub Density	Low	0.21	0.208	F= 0.430; df= 2, 16; p= 0.658
	High	0.20	0.207	
	Urban	0.32	0.316	

Table 2. Logistic regression analysis of the presence of *Peromyscus leucopus* in the 19 sites during the early spring on road density.

	B	Wald	df	Sig.
Road Density	89.4916	0.165425	1	0.68421
Constant	0.824463	1.370718	1	0.241689

Table 3. Relative abundance of *Peromyscus leucopus* over the 8 week summer tracking period in the 10 x 10m grids for each of the 19 focal patches according to landscape category (L: rural low road density landscape, H: rural high road density landscape, U: urban landscape) and site identification (numbers). Tracking took place from June 6th to July 29th, 2005.

	Low Road Density							High Road Density							Urban				
Week	L1	L2	L3	L4	L5	L6	L7	H1	H2	H3	H4	H5	H6	H7	U1	U2	U3	U4	U5
1	2	2	3	1	0	0	3	0	3	2	8	5	4	3	0	7	11	21	25
2	1	2	7	0	0	1	1	0	1	5	7	5	5	1	0	8	6	7	18
3	0	4	2	0	0	1	1	4	1	7	7	3	4	0	7	9	10	18	23
4	0	1	4	1	0	1	1	3	0	11	4	2	7	5	7	7	21	16	27
5	0	1	5	1	0	2	3	5	0	1	10	2	3	5	2	16	18	20	24
6	2	2	2	0	0	2	4	3	3	3	16	1	0	6	2	31	9	23	13
7	1	4	1	1	0	2	12	5	2	9	13	3	3	3	1	27	4	23	16
8	1	2	1	6	0	2	3	10	3	16	7	2	2	3	1	25	2	21	6
Totals	7	18	25	10	0	11	28	30	13	54	72	23	28	26	20	130	81	149	152
Grand Totals	99							246							532				

Table 4. ANOVA table for the simple linear regression of the relative abundance of *Peromyscus leucopus* on road density (R^2= 0.739). Relative abundance is the sum of the individuals tracked at each tracking grid in the 19 focal patches over the eight week summer tracking period.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	30913.791	1	30913.791	48.070	<0.001
	Residual	10932.735	17	643.102		
	Total	41846.526	18			

Table 5. ANOVA table for the simple linear regression of the relative abundance of *Peromyscus leucopus* on road density for the 14 rural landscapes only (R^2= 0.326). Relative abundance is the sum of the individuals tracked at each tracking grid in the 14 focal patches over the eight week summer tracking period.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1516.625	1	1516.625	5.791	0.033
	Residual	3142.589	12	261.882		
	Total	4659.214	13			

Table 6. Results of an ANOVA comparing the amount of accessible habitat (ha) within the 14 landscapes of the two landscape categories (7 rural low road and 7 rural high road).

Variable	Landscape category	Mean	Standard Error	ANOVA
Accessible	Rural Low Road	276.2	42.71	F= 14.005; p= 0.003
Habitat	Rural High Road	73.0	34.87	

Table 7. ANOVA table for the simple linear regression of the relative abundance of *Peromyscus leucopus* on the amount of accessible habitat (ha) for the 14 rural road density landscapes only (R^2= 0.031). Relative abundance is the sum of the individuals tracked at each tracking grid in the 14 focal patches over the eight week summer tracking period.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	143.087	1	143.441	.381	0.549
	Residual	4516.127	12	376.314		
	Total	4659.214	13			

Table 8. Results of an ANOVA comparing the number of dwellings within the 14 landscapes of the two landscape categories (7 rural low road and 7 rural high road).

Variable	Landscape category	Mean	Standard Error	ANOVA
# of dwellings	Rural Low Road	44.86	5.184	F= 8.416; p= 0.013
	Rural High Road	79.43	10.73	

Table 9. ANOVA table for the simple linear regression of the relative abundance of *Peromyscus leucopus* on the number of dwellings for the 14 rural landscapes only (R^2= 0.273). Relative abundance is the sum of the individuals tracked at each tracking grid in the 14 focal patches over the eight week summer tracking period.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1274.096	1	1274.096	4.517	0.055
	Residual	3385.118	12	282.093		
	Total	4659.214	13			

Table 10. Results of an ANOVA comparing the number of forest patches within the 14 landscapes of the two landscape categories (7 rural low road and 7 rural high road).

Variable	Landscape category	Mean	Standard Error	ANOVA
# of forest patches	Rural Low Road	21.86	1.752	F= 14.380; p= 0.003
	Rural High Road	32.71	2.265	

Table 11. ANOVA table for the simple linear regression of the relative abundance of *Peromyscus leucopus* on the number of forest patches for the 14 rural landscapes only (R^2= 0.155). Relative abundance is the sum of the individuals tracked at each tracking grid in the 14 focal patches over the eight week summer tracking period.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	724.357	1	724.357	2.209	0.163
	Residual	3934.858	12	327.905		
	Total	4659.214	13			

Table 12. Results of an ANOVA comparing the differences between the percentage of different land-cover types at the $500m^2$ scale for each of the two landscape categories (7 rural low road and 7 rural high road).

Variable	Landscape Category	Mean	Standard Error	ANOVA
Cereal Grains	Rural Low Road	5.00	5.00	F = 0.001; p= 0.980
	Rural High Road	5.14	2.68	
Corn	Rural Low Road	11.86	5.15	F = 0.061; p= 0.809
	Rural High Road	13.57	4.66	
Hay	Rural Low Road	15.14	5.19	F = 0.020; p = 0.889
	Rural High Road	14.29	3.08	

Figure 1 (a). Example of one of the rural low road density landscapes. Landscape was defined as a 2 km radius around a focal patch represented by centered dot where *P. leucopus* were sampled within a $100m^2$ grid.

Figure 1 (b). Example of one of the rural high road density landscapes. Landscape was defined as a 2 km radius around a focal patch represented by centered dot where *P. leucopus* were sampled within a 100m^2 grid.

Figure 1 (c). Example of one of the urban landscapes. Landscape was defined as a 2 km radius around a focal patch represented by centered dot where *P. leucopus* were sampled within a $100m^2$ grid.

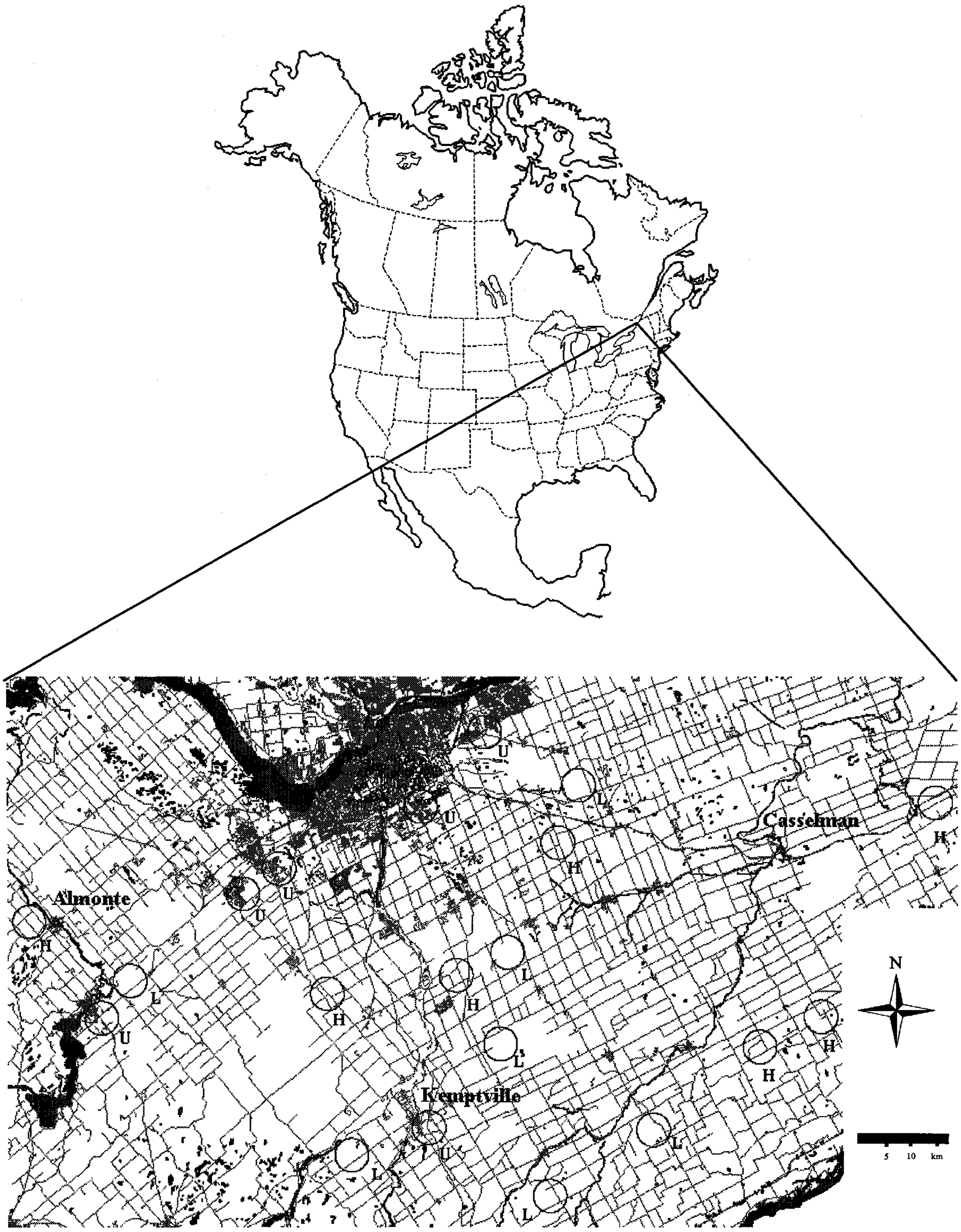

Figure 2. Distribution of landscapes studied across the Ottawa region. Circles represent 2 km radius landscapes and letters below correspond to landscape category (L= rural low road density landscape; H= rural high road density landscape; U= urban landscape). Included on map is the urban landscape that was abandoned after spring tracking phase (located in Kemptville).

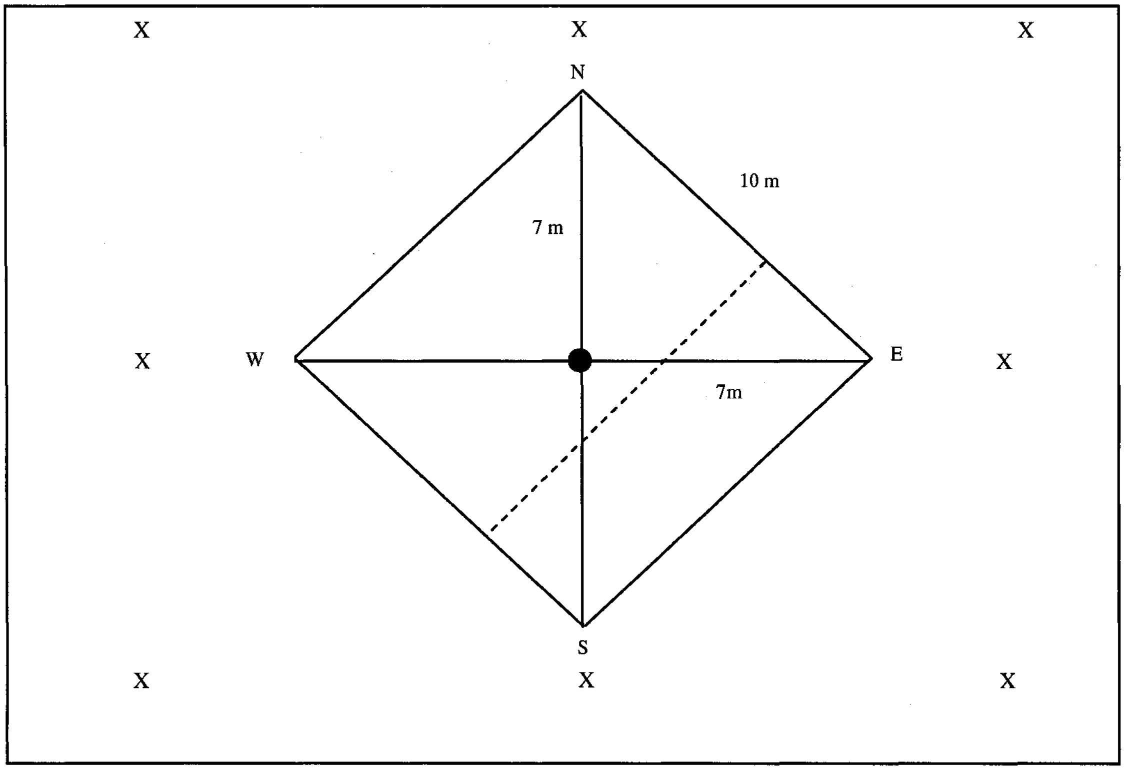

Figure 3. Representation of vegetation sampling plot. Large diamond shape plot = 10 m x 10 m plot for determining tree species/age within the four triangular quarters. Dotted line represents the 10 m transect that would run from the Northeast boundary to the Westsouth boundary of the large tree plot (to determine % coarse woody debris).

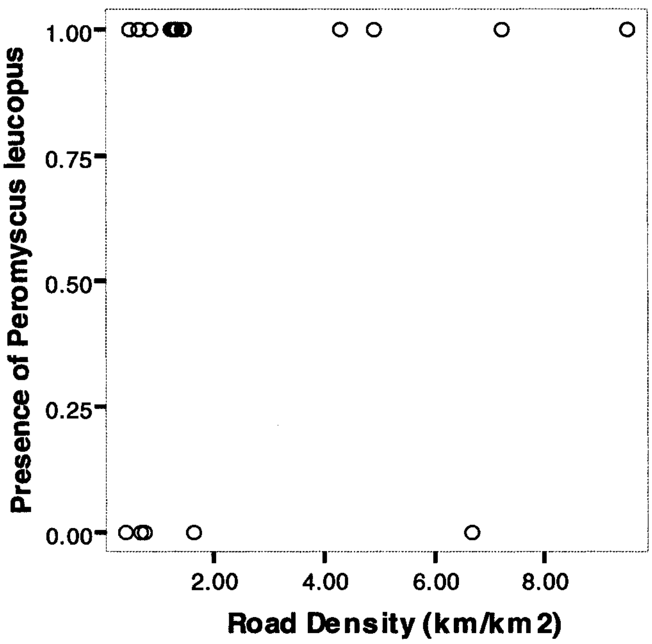

Figure 4. Road density versus the presence of *Peromyscus leucopus* during the early spring. The logistic regression analysis showed no significant relationship between road density and presence of *P. leucopus* in a forest patch during the early spring (Wald $X^2 = 0.165$; $p = 0.684$).

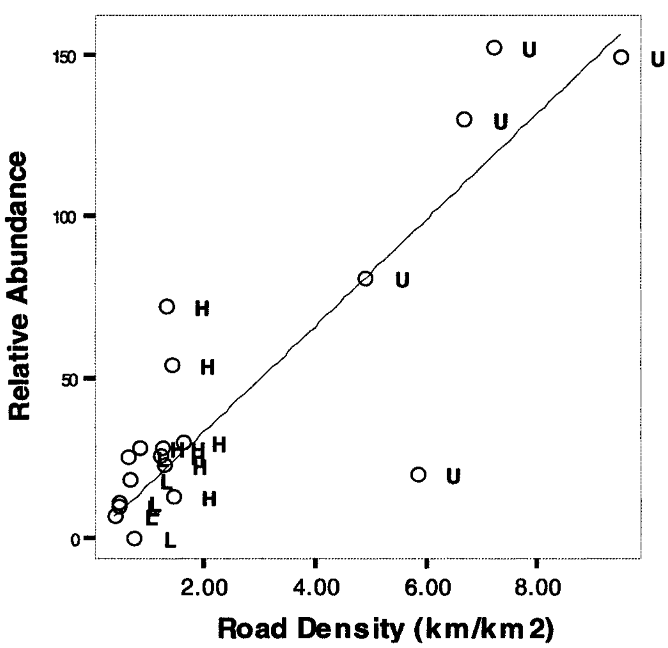

Figure 5. Simple linear regression of the relative abundance of *Peromyscus leucopus* on road density (L= rural low road, H= rural high road, U= urban sites). There was a significant positive relationship between the relative abundance of *P. leucopus* and road density across all 19 sites ($F = 48.070$; $p < 0.001$; $R^2 = 0.739$).

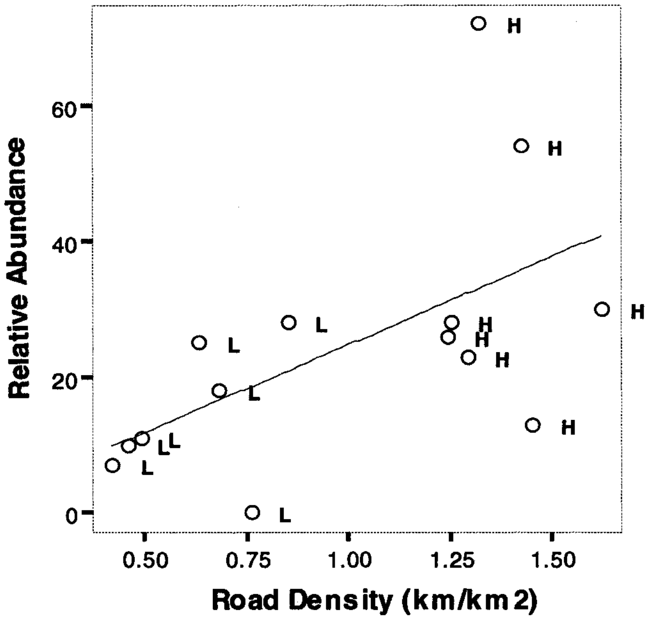

Figure 6. Simple linear regression of the relative abundance of *Peromyscus leucopus* on road density for the 14 rural landscapes only (L= rural low road and H= rural high road). When the urban landscapes were removed from the analysis, there was still a significant positive relationship between the relative abundance of *P. leucopus* and road density in the 14 rural landscapes (F= 5.791; p = 0.033; R^2= 0.326).

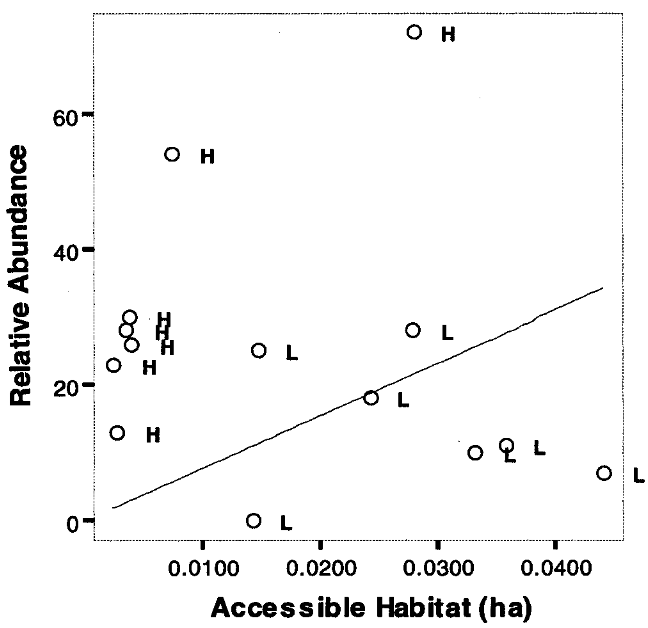

Figure 7. Simple linear regression of the relative abundance of *Peromyscus leucopus* on the amount of accessible habitat (ha) for the 14 rural landscapes only (L= rural low road and H= rural high road). There was no significant relationship between accessible habitat and *P. leucopus* relative abundance (F= 0.381; p= 0.549; R^2= 0.031).

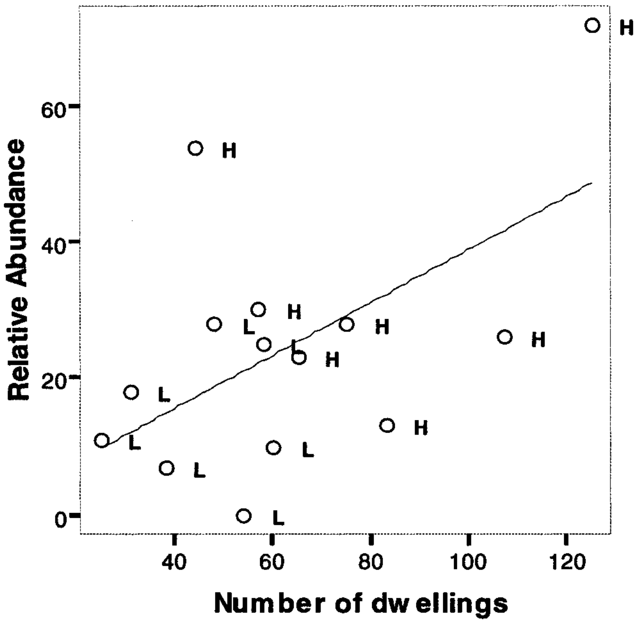

Figure 8. Simple linear regression of the relative abundance of *Peromyscus leucopus* on the number of dwellings for the 14 rural landscapes only (L= rural low road and H= rural high road). The relationship between *P. leucopus* relative abundance and the number of dwellings within the landscapes was marginally significant (F= 4.517; p= 0.055; R^2= 0.273).

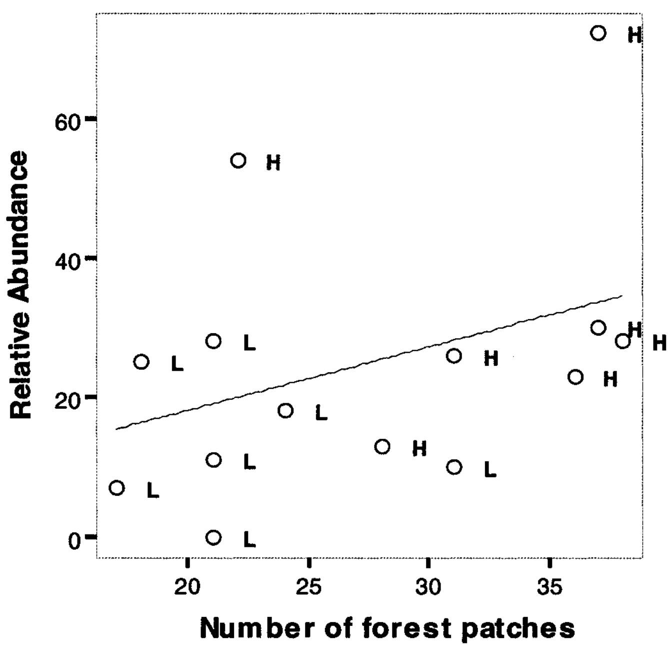

Figure 9. Simple linear regression of the relative abundance of *Peromyscus leucopus* on the number of forest patches for the 14 rural landscapes only (L= rural low road and H= rural high road). There was no significant relationship between *P. leucopus* relative abundance and the number of forest patches in the landscape (F= 2.209; p= 0.163; R^2= 0.155).

Appendix A. Approximate locations and coordinates for the focal patches where *P. leucopus* were sampled within each landscape for the spring and summer tracking periods of 2005. L: low road density landscape, H: high road density landscape, U: urban landscape. Numbers in brackets correspond to original site identifications.

Focal Patches	Approximate Location	Coordinates
L1 (24)	Reids Mills - end of French Settlement Rd	4,994,621N; 459,254E
L2 (12)	Winchester Springs - Saving St	4,984,365N; 477,520E
L3 (2)	Carleton Place - Hwy 7	5,002,136N; 415,051E
L4 (47)	Actons Corners - River Rd	4,981,825N; 440,858E
L5 (10)	Vars - Frank Kenny Rd	5,025,348N; 468,567E
L6 (22)	Spring Hill - Bank St/Hwy 31	5,05,437N; 460,113E
L7 (25)	Pleasant Valley - Carman Rd/Hwy 1	4,976,453N; 465,197E
H1 (43)	St. Isidore de Prescott - Stewart's Glen Rd	5,023,487N; 511,201E
H2 (33)	West Osgoode - McGuire Rd	5,00,696N; 453,987E
H3 (35)	Edwards - Boundary Rd/Hwy 41	5,018,593N; 466,163E
H4 (31)	Baxters Corners - McCordick Rd/Harbison Rd	5,000,492N; 438,614E
H5 (38)	Grantley - Casselman Rd	4,993,981N; 490,183E
H6 (36)	Newington - St. Lukes/Boundary Rd	4,997,711N; 497,403E
H7 (27)	Almonte - Ramsay Con. 8	5,009,153N; 402,991E
U1 (CP)	Carleton Place - Hwy 7/Hwy 15	4,997,631N; 411,641E
U2 (Stits)	Stitsville - Abbott St. East	5,012,441N; 428,699E
U3 (HuntClub)	Ottawa (South Keys) - Hunt Club Rd/Cahill Dr	5,022,907N; 449,901E
U4 (Blackburn)	Blackburn Hamlet - By-pass (Hwy 30)/Innes Rd	5,031,775N; 457,479E
U5 (Kemptville) - spring	Kemptville - Hwy 416 East side	4,984,541N; 450,758E
U5 (Kanata) - summer	Kanata - Stonehaven Dr (Deevy Pines Park)	5,015,524N; 432,957E

Appendix B. Presence/absence data from the spring tracking period. Category corresponds to the landscapes types (L: low road density landscape, H: high road density landscape, U: urban landscape). Focal patch names correspond to landscape categories with numbers in brackets corresponding to original site identifications. Spring tracking began April 11th 2005, and was carried out in each focal patch for three consecutive weeks ending April 29th 2005 (0: no *P. leucopus* present in forest patch; 1: *P. leucopus* present in forest patch).

Category	Focal Patch	Week 1	Week 2	Week 3
L	L1 (24)	0	0	0
	L2 (12)	0	0	0
	L3 (2)	1	1	1
	L4 (47)	0	1	1
	L5 (10)	0	0	0
	L6 (22)	1	1	0
	L7 (25)	1	1	0
H	H1 (43)	0	0	0
	H2 (33)	1	1	1
	H3 (35)	1	1	1
	H4 (31)	1	0	0
	H5 (38)	1	1	1
	H6 (36)	1	1	1
	H7 (27)	1	1	1
Urban	U1 (CP)	1	1	1
	U2 (Stits)	0	0	0
	U3 (HuntClub)	1	1	1
	U4 (Blackburn)	1	1	1
	U5 (Kemptville)	1	1	1

Appendix C. Relative abundance data from the summer tracking period. Summer tracking began June 6th, 2005 and was carried out in each focal patch for eight consecutive weeks ending July 29th 2005. Each table corresponds to one week of tracking data. PL: *Peromyscus leucopus*, ZH: *Zapus hudsonius*, NI: *Napaeozapus insignis*, TS: *Tamias scurius*, MP: *Microtus pennsylvanicus*, BB: *Blarina brevicauda*, TH: *Tamiasciurus hudsonicus*, U: unidentifiable. L: low road density landscape, H: high road density landscape, U: urban landscape. Totals per site include total number of identified tracked papers.

Species	**Monday**				**Tuesday**				**Wednesday**				**Thursday**			**Friday**				June 6-10
	L7	L2	H5	H6	U3	U4	L5	H1	U2	L3	U1	H7	H3	L6	H2	L1	U5	L4	H4	Totals
PL	3	2	5	4	21	25	0	0	7	3	11	3	2	0	3	2	0	1	8	100
ZH			1																	1
NI	4						1													5
TS																				0
MP																				0
BB	1	1	1	1					3							1			1	9
TH								5												5
U		1		3	1	1	1	1	3				1			2		1		15
Totals per site =	8	3	7	5	21	25	1	5	10	3	11	3	2	0	3	3	0	1	9	

Species	**Monday**				**Tuesday**				**Wednesday**				**Thursday**				**Friday**			June 13-17
	L7	L2	H5	H6	U3	U4	L5	H1	U2	L3	U1	H7	H3	L6	H2	L1	U5	L4	H4	Totals
PL	1	2	5	5	7	18	0	0	8	7	6	1	5	1	1	1	0	0	7	75
ZH																				0
NI	1	1																		2
TS																				0
MP																				0
BB	3	1	3										1			1			3	12
TH																				0
U	4	2	10	5		4			2	2				1					3	33
Totals per site =	5	4	8	5	7	18	0	0	8	7	6	1	6	1	1	2	0	0	10	

Appendix C cont…

Species	Monday				Tuesday				Wednesday				Thursday				Friday			June 20-24
	L7	L2	H5	H6	U3	U4	L5	H1	U2	L3	U1	H7	H3	L6	H2	L1	U5	L4	H4	Totals
PL	1	4	3	4	18	23	0	4	9	2	10	0	7	1	1	0	7	0	7	101
ZH				1																1
NI																				0
TS									1				3							4
MP			1																	1
BB	3	3	4	3					1	1									1	16
TH																				0
U	3	1	3	2	3	5	1	2	1							2		2	1	26
Totals per site =	4	7	8	8	18	23	0	4	11	3	10	0	10	1	1	0	7	0	8	

Species	Monday				Tuesday				Wednesday				Thursday				Friday			June 27 – July 1
	L7	L2	H5	H6	U3	U4	L5	H1	U2	L3	U1	H7	H3	L6	H2	L1	U5	L4	H4	Totals
PL	1	1	2	7	16	27	0	3	7	4	21	5	11	1	0	0	7	1	4	118
ZH																				0
NI												1								1
TS								1												1
MP																1				1
BB	6	1	6	4					2	1					1		1	1	2	25
TH																				0
U	1	2	1	1	2			1	1	2		1			1	1				14
Totals per site =	7	2	8	11	16	27	0	4	9	5	21	6	11	1	1	1	8	2	6	

Appendix C cont…

Species	Monday				Tuesday				Wednesday				Thursday				Friday			July 4-8
	L7	L2	H5	H6	U3	U4	L5	H1	U2	L3	U1	H7	H3	L6	H2	L1	U5	L4	H4	Totals
PL	3	1	2	3	20	24	0	5	16	5	18	5	1	2	0	0	2	1	10	118
ZH								1							2					3
NI									1											1
TS								4												4
MP																			1	1
BB	3	2	6	3				3	5	3										25
TH																				0
U	5	1	5	2		3		2		1				1	1		1	1		23
Totals per site =	6	3	8	6	20	24	0	13	22	8	18	5	1	2	2	0	2	1	11	

Species	Monday				Tuesday				Wednesday				Thursday				Friday			July 11-15
	L7	L2	H5	H6	U3	U4	L5	H1	U2	L3	U1	H7	H3	L6	H2	L1	U5	L4	H4	Totals
PL	4	2	1	0	23	13	0	3	31	2	9	6	3	2	3	2	2	0	16	122
ZH														1						1
NI														2						2
TS								1												1
MP																				0
BB	5	2	5	1					1	1									1	16
TH																				0
U	1	4	4	4		4	1	4	3					1				1	4	31
Totals per site =	9	4	6	1	23	13	0	4	32	3	9	6	3	5	3	2	2	0	17	

Appendix C cont…

Species	**Monday**				**Tuesday**				**Wednesday**				**Thursday**				**Friday**			July 18-22
	L7	L2	H5	H6	U3	U4	L5	H1	U2	L3	U1	H7	H3	L6	H2	L1	U5	L4	H4	Totals
PL	12	4	3	3	23	16	0	5	27	1	4	3	9	2	2	1	1	1	13	130
ZH		1					2	1				1						3		8
NI																				0
TS								10												10
MP																				0
BB	6	11	13	1				4	3											38
TH																				0
U	2	2			1	1		2	1	1	1		2		2			1	3	19
Totals per site =	18	16	16	4	23	16	2	20	30	1	4	4	9	2	2	1	1	4	13	

Species	**Monday**				**Tuesday**				**Wednesday**				**Thursday**				**Friday**			July 25-29
	L7	L2	H5	H6	U3	U4	L5	H1	U2	L3	U1	H7	H3	L6	H2	L1	U5	L4	H4	Totals
PL	3	2	2	3	21	6	0	10	25	1	2	3	16	2	3		1	6	7	113
ZH							1	10				3		1						15
NI										3					3			1		7
TS		1																		1
MP													1							1
BB	7		11	11				8	2				1		2			2	3	47
TH																				0
U		2		2		4	6	6	2	2		1	1	2	2			2	2	34
Totals per site =	10	3	13	14	21	6	1	28	27	4	2	6	18	3	8	0	1	9	10	

Appendix D. Vegetation survey data for focal patches within each landscape. Focal patch names correspond to landscape categories with numbers in brackets corresponding to original site identifications (L: low road density landscape, H: high road density landscape, U: urban landscape). Vegetation surveys were carried out in each focal patch from July 13th to July 22nd, 2005. Sampling was conducted using point-quarter method where a 10-m^2 plot was centered over five randomly chosen points within the tracking grid at each site. In each quarter of the 10-m^2 plot, the species and diameter of the nearest woody tree (>10cm dbh), and the number of shrubs was recorded. Percent of ground covered by coarse woody debris was measured along five 10 m transects at each focal patch. UA: *Ulmus americana*, FA: *Fraxinus americana*, PD: *Populus deltoides* spp. *deltoides*, AR: *Acer rubrum*, PA: *Populus alba*, RC: *Rhamnus cathartica*, TC: *Tsuga Canadensis*, AS: *Acer saccharum*, BL: *Betula lenta*, BA: *Betula alleghaniensis*, *Tilia americana*, QM: *Quercus macrocarpa*, UR: *Ulmus rubra*, PG: *Populus grandidentata*, PT: *Populus tremuloides*, TO: *Thuja occidentalis*, FN: *Fraxinus nigra*, AN: *Acer negundo*, PS (1): *Prunus serotina*, AB: *Abies balsamea*, PS (2): *Pinus strobes*, BP: *Betula papyrifera*.

Focal Patch	Tree Species	dbh (cm)	# shrubs	%CWD cover
L1 (24)	UA	33	1	3.95
	FA	14		
	FA	22		
	FA	20		
	FA	25.4		
	FA	25.5		
	FA	24.5		
	FA	11.4		
	FA	12.3		
	FA	14		
	FA	22.5		
	FA	19		
L2 (12)	UA	11.00	0	10.82
	PD	39.40		
	AR	12.00		
	AR	15.00		
	AR	11.60		
	AR	15.50		
	AR	16.50		
	AR	14.30		
	AR	10.30		
	AR	15.00		
	AR	21.00		
	AR	26.30		
	AR	25.20		
	FA	13.00		
	PA	24.30		

Appendix D cont…

Focal Patch	Trees	dbh (cm)	# shrubs	%CWD cover
L3 (2)	UA	18.1	9	4.50
	UA	16		
	UA	12.9		
	UA	20.3		
	UA	17.5		
	UA	11		
	UA	10.9		
	UA	15		
	UA	14.7		
	RC	14.9		
	FA	14.9		
	FA	16.9		
L4 (47)	TC	12.5	6	3.50
	TC	36		
	TC	22		
	TC	16		
	AR	29.3		
	AR	24		
	AR	11.3		
	AR	14.5		
	AR	36		
	AR	15.7		
	AR	14.8		
	AR	25.5		
	AS	21.5		
	BL	10.5		
	BL	11		
	FA	14.3		
	BA	13.5		
L5 (10)	TA	10.2	12	4.28
	TA	18.4		
	TA	11		
	UA	14.5		
	UA	10.5		
	UA	10		
	UA	12.3		
	QM	12.5		
	QM	21.7		
	AR	11.7		
	AR	12.5		
	UR	10.3		
	FA	18.5		
	FA	15.8		

Appendix D cont…

Focal Patch	Trees	dbh (cm)	# shrubs	%CWD cover
L6 (22)	UA	11	31	16.68
	UA	12.5		
	UA	12		
	UA	16		
	UA	11.5		
	TA	10		
	PG	17		
	UR	12.5		
	UR	13		
	UR	35.7		
	PT	10		
	FA	17		
	FA	10		
L7 (25)	UA	11.3	2	6.58
	UA	12.2		
	UA	13		
	UA	10.5		
	UA	40.8		
	TO	14.6		
	TO	13.3		
	TO	11		
	TO	11.2		
	TO	13.8		
	TO	20.5		
	TO	10.1		
	TO	18		
	FA	19.5		
	FA	32.9		
	FA	27.4		
	FA	32.7		
	FA	25.6		
	FA	40.6		
	FA	20.7		

Appendix D cont…

Focal Patch	Trees	dbh (cm)	# shrubs	%CWD cover
H1 (43)	UA	34.7	31	1.16
	UA	17.2		
	UA	15.4		
	UA	12.5		
	UA	14.2		
	UA	28.8		
	UA	15.5		
	UA	12		
	UA	17.4		
	UA	11.5		
	UA	28.5		
	FN	13.2		
	AR	15.2		
	FA	11.5		
	FA	17.4		
H2 (33)	UA	11.5	3	3.12
	UA	13.5		
	UA	37		
	PT	17		
	PT	14.5		
	PT	17		
	FA	16		
	FA	10.5		
	FA	17		
	FA	13.5		
	FA	22		
	FA	30.5		
	FA	13.5		
	FA	26		
	FA	32.8		
	FA	15		

Appendix D cont…

Focal Patch	Trees	dbh (cm)	# shrubs	%CWD cover
H3 (35)	UA	21	2	9.46
	UA	17.5		
	UA	11.5		
	UA	12.5		
	UA	33		
	UA	10		
	UA	17.5		
	UA	18		
	UA	14		
	AR	21.75		
	AR	14.5		
	AR	12.5		
	AR	25		
	AR	20.5		
	AR	17.5		
	PT	16.5		
	PT	16		
	PT	13.5		
	PT	18		
	FA	11.5		
H4 (31)	UA	22	15	10.72
	TO	23.5		
	PT	38		
	FA	16.2		
	FA	23		
	FA	17		
	FA	12		
	FA	21.5		
	FA	11.5		
	FA	14.5		
	FA	11.5		
	BP	10		

Appendix D cont…

Focal Patch	Trees	dbh (cm)	# shrubs	%CWD cover
H5 (38)	UA	21	9	1.70
	UA	14.3		
	UA	25		
	UA	20		
	UA	13.5		
	AN	12.5		
	FA	15.7		
	FA	15.5		
	FA	17.7		
	FA	19.1		
	FA	21		
	FA	16		
	FA	20		
	FA	18.9		
	FA	18.6		
	FA	16		
H6 (36)	UA	10.1	9	12.64
	AN	36.5		
	AR	14.7		
	AS	17.9		
	AS	28.4		
	AS	12.7		
	AS	25.5		
	AS	25.5		
	AS	21.3		
	AS	49.7		
	AS	20.8		
	FA	12		
	FA	27.8		
	FA	17.5		
	FA	23.5		

Appendix D cont…

Focal Patch	Trees	dbh (cm)	# shrubs	%CWD cover
H7 (27)	UA	11.3	2	6.58
	UA	12.2		
	UA	13		
	UA	10.5		
	UA	40.8		
	TO	14.6		
	TO	13.3		
	TO	11		
	TO	11.2		
	TO	13.8		
	TO	20.5		
	TO	10.1		
	TO	18		
	FA	19.5		
	FA	32.9		
	FA	27.4		
	FA	32.7		
	FA	25.6		
	FA	40.6		
	FA	20.7		
U1 (CP)	UA	14.5	9	5.20
	UA	11.8		
	UA	17.2		
	UA	15.3		
	QM	16.7		
	QM	27.2		
	AS	14.5		
	AS	17.4		
	AS	24.4		
	AS	13.5		
	AS	13		
	FA	12		
	FA	25.2		
	FA	29.3		
	FA	15.7		
	PA	29.2		

Appendix D cont…

Focal Patch	Trees	dbh (cm)	# shrubs	%CWD cover
U2 (Stits)	TO	49.8	6	11.66
	TO	60		
	TO	15.2		
	TO	54.5		
	TO	72		
	TO	47.3		
	TO	24.7		
	TO	49.3		
	TO	26.2		
	TO	47		
U3 (HuntClub)	UA	30.8	43	10.86
	UA	10.4		
	UA	10.8		
	PT	10.3		
	PT	21.7		
	PT	16.3		
	PT	13.2		
	PT	17.2		
	PT	17.2		
	PT	20.8		
	FA	10.5		
	PS (1)	15.8		
	PS (1)	18.2		

Appendix D cont…

Focal Patch	Trees	dbh (cm)	# shrubs	%CWD cover
U4 (Blackburn)	AR	29.00	17	13.12
	AR	27.70		
	AR	47.50		
	AR	12.20		
	AR	10.50		
	AR	31.20		
	AR	22.00		
	AR	40.80		
	AR	31.50		
	AR	52.50		
	AB	13.00		
	PS (2)	57.00		
	PS (2)	55.50		
	BP	20.60		
U5 (Kemptville) spring	TC	20.40	10	12.45
	TO	12.00		
	AR	11.70		
	AR	18.00		
	AR	16.30		
	AR	13.40		
	AR	17.90		
	AR	14.80		
	AR	15.00		
	AR	11.80		
	AR	20.00		
	PT	23.00		
	PT	28.10		
	PT	21.80		
	FA	10.30		
	FA	10.40		
	PA	27.50		

Appendix D cont…

Focal Patch	Trees	dbh (cm)	# shrubs	%CWD cover
U5 (Kanata) summer	AB	10	5	6.78
	AB	13.5		
	AR	14		
	AR	10		
	AR	31		
	AR	17		
	AR	14.8		
	AS	13		
	AS	22.5		
	AS	11.5		
	AS	11.2		
	AS	22.8		
	AS	13.5		
	AS	38.5		
	AS	16.3		
	AS	31		
	AS	32.5		

Appendix E. Landscape and focal patch characteristics. Category corresponds to the landscapes types (L: low road density landscape, H: high road density landscape, U: urban landscape). Landscapes correspond to landscapes names with numbers in brackets corresponding to original site identifications. Percent forest is the total amount of forest within each of the 2 km radius landscapes (summed forest polygon areas divided by the total landscape area multiplied by 100 to give a percentage) using ArcView 3.2 and NTDB digital topographic maps. Focal patch shape was determined using a modified "Patton index" where values greater than one indicate an increased perimeter-to-area ratio. Road density was calculated as the total length of all roads (including all road types ie. paved, gravel and/or dirt) within each 2 km radius landscape divided by the total area of the landscape. The number of dwellings (buildings, houses, barns, and silos) was determined within each 2 km radius landscape.

Category	Landscape	% forest	Focal Patch Area (ha)	Patton Index	Road Density (km/km2)	# of dwellings
L	L1 (24)	36	3.41	1.33	0.42	38
	L2 (12)	25	2.47	1.13	0.68	31
	L3 (2)	18	3.98	1.11	0.63	58
	L4 (47)	26	21.12	1.62	0.46	60
	L5 (10)	18	2.58	1.17	0.76	54
	L6 (22)	28	16.18	2.21	0.49	25
	L7 (25)	33	3.44	1.16	0.85	48
H	H1 (43)	20	2.24	3.52	1.62	57
	H2 (33)	38	6.03	1.72	1.45	83
	H3 (35)	27	4.29	1.24	1.42	44
	H4 (31)	20	27.46	1.70	1.32	125
	H5 (38)	23	8.52	1.66	1.29	65
	H6 (36)	28	10.83	1.31	1.25	75
	H7 (27)	18	3.04	1.34	1.24	107
Urban	U1 (CP)	36	36.80	1.48	4.90	1892
	U2 (Stits)	21	82.06	1.48	6.67	4360
	U3 (HuntClub)	20	6.66	1.31	9.48	6637
	U4 (Blackburn)	21	4.61	1.71	7.19	4168
	U5 (Kemptville)	6.16	1.19	1.19	4.28	1300
	U5 (Kanata)	10.34	1.44	1.44	5.83	5450

Appendix F. Measured habitat associations for the 14 rural landscapes. Accessible habitat was measured as the amount of forest available to *P. leucopus* in the focal patch without having to cross a road (summed forest polygon areas contained within a road network around each focal patch). The number of forest patches was measured as the total number of forest patches within the rural 2 km radius landscapes. Percentage of land-cover types was measured as the percentage of cereal grains, corn and hay within a 500 m radius buffer area around each focal patch.

Landscape	Accessible Habitat (ha)	# of forest patches	Land-cover types (500 m radius buffer)		
			% cereal grains	% corn	% hay
L1 (24)	0.0440	17	0	0	30
L2 (12)	0.0241	24	0	32	18
L3 (2)	0.0146	18	0	0	35
L4 (47)	0.0331	31	0	8	8
L5 (10)	0.0141	21	35% (oats)	0	15
L6 (22)	0.0357	21	0	28	0
L7 (25)	0.0278	21	0	15	0
H1 (43)	0.0036	37	0	25	20
H2 (33)	0.0027	28	0	0	13
H3 (35)	0.0073	22	0	7	18
H4 (31)	0.0279	37	6% (spring wheat)	3	0
H5 (38)	0.0023	36	0	1	7
H6 (36)	0.0034	38	15% (barley)	23	20
H7 (27)	0.0039	31	15% (spring wheat)	0	22