

**The independent effects of forest amount, fragmentation and structural connectivity
on small mammals' diversity, abundance and occurrence**

By

Lindsay Daly

A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs in partial
fulfillment of the requirements of the degree of

Master of Science

in

Biology

Carleton University

Ottawa, Ontario

© 2022

Lindsay Daly

Abstract

Although habitat amount, fragmentation, and connectivity are thought to be important drivers of biodiversity, their independent effects have not been evaluated. We selected 70 forested sites in Ontario, Canada, such that forest amount, fragmentation (number of patches), and structural connectivity (treed corridors) in the surrounding landscapes were uncorrelated. We surveyed forest small mammals at each site and estimated the relative effects of the three landscape variables on individual species' abundance and occurrence and total species diversity. Most responses had high variability, with 95% confidence intervals crossing zero. Configuration variables (fragmentation and connectivity) generally had stronger effects on small mammals than forest amount. Fragmentation increased small mammal diversity but had variable effects on individual species responses. Unexpectedly, species diversity and individual species occurrence declined with structural connectivity. Therefore, landscape management aimed at decreasing fragmentation or increasing structural connectivity will not benefit all forest small mammals in this region.

Acknowledgements

I would like to thank my supervisor, Lenore Fahrig for her guidance through this process. I would like to thank my committee, Gabriel Blouin-Demers and Gregory Mitchell, for their insights and comments. Thank you to Amanda Martin and Adam Smith for helping with site selection and data analysis. Thank you to Trina Rytwinski and Amanda Martin for their footprint tracking materials and expertise. Thank you to Dan Bert for all your GIS and equipment help.

Thank you to the Nature Conservancy of Canada (NCC), for letting me use their field cameras. Without them, I could not have caught the raccoon bandits red-handed.

My colleagues, Adrianne Hajdasz and Joe Gabriel, thank you a million times. This project would not have been possible without your kindness and labour. Our sampling period was trying, and I truly appreciate all your help. Joe Gabriel, I'm sorry for all the times you were left in a field.

To my family, friends and boyfriend, who helped me prepare for sampling and took care of me during the field season, thank you. I would have fallen apart without you.

Table of contents

| | |
|--|------|
| Title page | i |
| Abstract | ii |
| Acknowledgements..... | iii |
| Table of contents..... | iv |
| List of tables..... | v |
| List of figures..... | vi |
| List of appendices | viii |
| 1.0 Introduction..... | 1 |
| 2.0 Methods..... | 6 |
| 2.1 Overview | 6 |
| 2.2 Study area..... | 7 |
| 2.3 Land cover data | 7 |
| 2.4 Site selection | 8 |
| 2.5 Small mammal sampling..... | 10 |
| 2.6 Response variables | 12 |
| 2.7 Landscape predictor variables..... | 13 |
| 2.8 Analysis..... | 14 |
| 3.0 Results..... | 16 |
| 3.1 General | 16 |
| 3.2 Scale of effect..... | 17 |
| 3.3 Potential confounding variables | 18 |
| 3.4 Effects of forest amount, fragmentation and connectivity | 18 |
| 4.0 Discussion | 20 |
| References..... | 28 |
| Tables | 39 |
| Figures..... | 42 |
| Appendices..... | 52 |

List of tables

| | |
|---|----|
| Table 1. Standardized coefficients, confidence intervals (in square brackets), and significance for forest small mammal diversity models. The scales of effect, i.e. distance in m within which the landscape variables were measured, are indicated with each response variable. All diversity indices were standardized. Sampling effort is the number of small mammal footprint tracking papers recovered per site multiplied by the time the papers were deployed. | 39 |
| Forest amount and number of patches are the total area of forest (m^2) and the number of forest patches, respectively, in the landscape with the radius of the scale of effect. Patch connectivity is the percentage of patches within the landscape that are directly or indirectly connected to the focal patch via treed corridors. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m tall) at each site. Road density is the area of roads (m^2) divided by the landscape area at the scale of effect. Species richness is the number of small mammal species per site (max= 7). Evenness is Pielou's evenness (Pielou, 1966). Chao's diversity (Chao et al., 2005) is a diversity index that assumes the abundance of rare species is under-estimated. | 39 |
| Table 2. Standardized variable coefficients, confidence intervals (in square brackets) and significance for relative abundance models of individual forest small mammal species. All relative abundances were standardized. The scales of effect, i.e. distance in m within which the landscape variables were measured, are indicated with each response variable. Sampling effort is the number of small mammal footprint tracking papers recovered per site multiplied by the time the papers were deployed. Forest amount and number of patches are the total area of forest (m^2) and the number of forest patches, respectively, in the landscape with the radius of the scale of effect. Patch connectivity is the percentage of patches within the landscape that are directly or indirectly connected to the focal patch via treed corridors. Relative abundance is the total number of tracking tubes with the presence of each species (max=144). | 40 |
| Table 3. Standardized coefficients, confidence intervals (in square brackets) and significance for occurrence models of forest small mammal species. The scales of effect, i.e. distance in m within which the landscape variables were measured, are indicated with each response variable. Sampling effort is the number of small mammal footprint tracking papers recovered per site multiplied by the time the papers were deployed. Forest amount and number of patches are the total area of forest (m^2) and the number of forest patches, respectively, in the landscape with the radius of the scale of effect. Patch connectivity is the percentage of patches within the landscape that are directly or indirectly connected to the focal patch via treed corridors. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m tall) at each site. Road density is the area of roads (m^2) divided by the landscape area at the scale of effect. Occupancy is the presence of the species at a sampling site. | 41 |

List of figures

- Figure 1. Diagram of habitat fragmentation and patch connectivity for a given total amount of habitat.** All landscapes (circles) contain the same amount of habitat (green rectangles), and connections are provided by corridors (dark green lines). Fragmentation is the number of patches, i.e. 3 in the top row and 6 in the bottom row (Henein et al., 1998; Patterson & Malcolm, 2010). Patch connectivity is the number of patches connected to the focal patch (the patch containing the sampling site) directly or indirectly by habitat corridors, divided by the number of patches in the landscape: $C_p = N_p - 1NL - 1$, where C_p = patch connectivity, N_p = the number of patches directly or indirectly connected to the focal patch and N_L = the number of patches in the landscape. Note that the patch size in the landscape decreases as connectivity increases to maintain a constant total amount of habitat. 42
- Figure 2. A:** Locations of 70 forest small mammal sampling sites and their surrounding landscapes within 1500 m. The treed area is gray. Sites are filled circles, with colours and outline thickness indicating whether the landscape was classed as high or low for each landscape variable. Sites were selected to represent combinations of high and low values for each landscape variable – forest amount, fragmentation (number of patches), and patch connectivity – such that the three variables were only weakly correlated. The classes (high/low) were used for site selection only; the three landscape variables were analyzed as continuous variables in statistical models at 8 spatial scales 750 – 2500 m. In the field, each site had a 30 m x 30 m sampling grid at its centre, consisting of 36 tracking tubes for small mammal detection. B: Example site with high forest amount, high number of patches and high patch connectivity within 1 km. C: Example site with low forest amount, high number of patches and high patch connectivity within 1 km. D: Example site with low forest amount, low number of patches and low patch connectivity within 1 km. 43
- Figure 3.** Example of sampling site placement within a focal patch. The interior area was the forested area more than 100 m from the edge, and potential focal patches were patches containing any interior area. The sampling point was in the SW corner of the interior area within each focal patch. For site selection, we measured forest amount, the number of patches, and patch connectivity (Fig. 1) within 1500 m of each potential sampling point in the region..... 44
- Figure 4. A:** An Eastern chipmunk (*Tamias striatus*) running through a 10 cm diameter tracking tube. B: A footprint tracking paper after two weeks inside a tracking tube. In the center is the inkpad (the pink butcher paper) with black ink, and on one side are chipmunk (*T. striatus*) tracks. This paper was scored as 1, highly readable. C: A white-footed mouse (*P. leucopus*) investigating a 10 cm diameter tracking tube..... 45
- Figure 5.** A raccoon (*Procyon lotor*) removes a tracking tube paper from a 10 cm diameter tracking tube. The blue arrow is pointing to the tracking paper. 45

- Figure 6. Illustration of the layout of the four sizes of small mammal tracking tubes.**
The same layout of 36 tubes was used at all 70 sampling sites. Footprint tracking tubes were plastic tubes with a strip of paper inside, with tracking paper having a central ink pad (Fig. 4). Tubes were placed 6 m apart arranged in a grid..... 46
- Figure 7. A:** Relative abundance and proportional occurrence of the seven forest small mammal species. Each filled-in circle represents the relative abundance (proportion of tracking papers with footprints) per site (N=70). In order of decreasing relative abundance, species detected were *P. leucopus*, *T. striatus*, *M. gapperi*, *B. brevicauda*, *T. hudsonicus*, *N. insignis* and *S. carolinensis*. The right axis is the percentage of sites (N=70) with a species presence, depicted by grey box outlines. **B:** Histogram of species richness per site (N=70). **C:** Histogram of the percentage of footprint tracking papers recovered per site (N=70), out of 144 deployed per site. In total, 91% of all papers were recovered. Some papers were destroyed by people, water, slugs, or raccoons (Fig. 5)..... 47
48
- Figure 8. Standardized landscape variable coefficients for models of forest small mammal diversity measures at their scales of effect (see Supplementary Fig. B),** with 95% confidence intervals. **A:** Standardized forest amount coefficients. **B:** Standardized fragmentation (number of patches) coefficients. **C:** Standardized patch connectivity coefficients. Species richness is the number of forest small mammal species per site (max= 7). Evenness is Pielou's evenness (Pielou, 1966). Chao's diversity (Chao et al., 2005) is a diversity index that adjusts for an assumed under-estimation of the abundances of rare species..... 48
- Figure 9. Standardized landscape variable coefficients for forest small mammal relative abundance models at their scales of effect (see Supplementary Fig. C),** with 95% confidence intervals. **A:** Standardized forest amount coefficients. **B:** Standardized fragmentation (number of patches) coefficients. **C:** Standardized patch connectivity coefficients. Relative abundance is the total number of tracking tubes with the presence of a species (max=144)..... 49
- Figure 10. Standardized landscape variable coefficients for forest small mammal occurrence models at their scales of effect (see Supplementary Fig. D),** with 95% confidence intervals. **A:** Standardized forest amount coefficients. **B:** Standardized fragmentation (number of patches) coefficients. **C:** Standardized patch connectivity coefficients. Occurrence is the presence or absence of a species at each site..... 50
- Figure 11. Illustration of hypothesized mechanisms to explain positive fragmentation effects and negative structural connectivity effects on richness and occurrence of forest small mammals at forested sample sites.** 1A and B) Small mammal density is higher in a sample site in a landscape with many small forest patches because small mammal density decreases with patch size. The higher small mammal density in non-focal patches would increase the number of colonists to the focal patch, potentially increasing small mammal richness

and occurrence in the sampling patch. 2A and B) If corridors increase the abundance of small mammal predators and forest small mammals preferentially travel along wooded corridors, then corridors may act as ecological traps. Increased predation would then lower colonization of the focal patch in landscapes with higher structural connectivity. All panels have the same total amount of forest, including patches and corridors. 51

List of appendices

| | |
|--|----|
| Figure A. Standardized landscape values at different scales for all sites (N=70). A: Standardized habitat or forest amount at scales from 750-6000 m. B: Fragmentation or the number of patches at scales from 750-6000 m. C: Standardized patch connectivity at scales ranging from 750-5000 m. Patch connectivity is the percentage of patches connected to the focal patch using treed corridors. The formula is: $Cp = Np - 1NL - 1$ where Cp = patch connectivity, Np = the number of patches directly connected to the focal patch and NL = the number of patches in the landscape. | 52 |
| Table A. Total relative abundance and occurrence across all sites and sampling periods. Relative abundance is the number of footprint tracking papers with the presence of each species. Each site (N=70) had 144 tracking papers in total; the maximum total relative abundance is 10 080. Percent presence is the percentage of sites (N=70) with each species presence. Percent presence of 100% indicates a species detected at all sites. Species in order are <i>Peromyscus leucopus</i> , <i>Tamias</i> <i>striatus</i> , <i>Myodes gapperi</i> , <i>Blarina brevicauda</i> , <i>Tamiasciurus hudsonicus</i> , <i>Neozapus insignis</i> , <i>Sciurus carolinensis</i> , <i>Microtus pennsylvanicus</i> , <i>Mus musculus</i> and <i>Zapus hudsonius</i> | 53 |
| Table B. A: Correlations (Spearman's Rho) between forest amount (m2) and the number of patches at landscape radii from 750 – 2500 m. B: Correlations (Spearman's Rho) between forest amount (m2) and the patch connectivity (%) at landscape radii from 750 – 2500 m. Shaded boxes indicate scales that are a scale of effect for a diversity, relative abundance or occurrence model..... | 54 |
| Table C. Correlation (Spearman's Rho) between patch number (number of patches) and patch connectivity (%) at landscape radii from 750-2500 m. Shaded boxes indicate scales that are a scale of effect for a diversity, relative abundance or occurrence model..... | 55 |
| Table D. Correlations (Spearman's Rho) between confounding variables. Correlations between Road density generated from the Ontario Road Network (ORN, and the Shannon diversity index of all plants below 5 m in height and the percentage of deciduous trees per site. Shaded boxes indicate that the confounding variable is included at that scale. | 56 |
| Table E. Correlations (Spearman's Rho) between road density, generated from the Ontario Road Network (ORN) and forest amount, generated from the updated Wooded Area dataset, from 750-2500 m. Shaded boxes indicate that the confounding variable is included at that scale. | 57 |
| Table F. Correlations (Spearman's Rho) between road density, generated from the Ontario Road Network (ORN) and fragmentation, or the number of forest patches, generated from the Wooded area dataset from 750-2500m. Shaded boxes indicate that the confounding variable is included at that scale..... | 58 |

Table G. Correlations (Spearman's Rho) between Road density, generated from the Ontario Road Network (ORN) and patch connectivity generated from the Wooded area dataset from 750-2500m. Patch connectivity is the percentage of patches connected to the focal patch using treed corridors. The formula is:

$Cp = Np - 1NL - 1$ where Cp = patch connectivity, N_p = the number of patches directly connected to the focal patch and N_L = the number of patches in the landscape. Shaded boxes indicate that the confounding variable is included at that scale..... 59

Table H. A: Correlation of forest amount (m²), generated from the Wooded Area dataset, and confounding variables per site. The confounding variables were the Shannon diversity index of all understory plants (plants below 1 m in height) and the percentage of deciduous trees per site. B: Correlation of the number of patches generated from the Wooded Area dataset and confounding variables per site. The confounding variables were the Shannon diversity index of understory plants and the percentage of deciduous trees per site. C: Patch connectivity generated from the Wooded Area dataset and confounding variables per site. The confounding variables were the Shannon diversity index of all understory plants and the percentage of deciduous trees per site. Patch connectivity is the percentage of patches connected to the focal patch using treed corridors. The formula is: $Cp = Np - 1NL - 1$ where Cp = patch connectivity, N_p = the number of patches directly connected to the focal patch and N_L = the number of patches in the landscape. Shaded boxes indicate that the confounding variable is included at that scale..... 60

Table I. Correlation (Spearman's Rho) between Shannon diversity index of understory plants (<1m in height) and the percentage of deciduous trees per site (N=70). 61

Figure B. Standardized coefficients and 95% confidence intervals (CI) for the effects of standardized landscape variables - forest amount, number of patches, and patch connectivity - on small forest mammal diversity responses measured within multiple spatial extents around 70 sampling sites. All response variables were standardized. A: species richness per site. B: Pielou's Evenness per site. C: Chao's diversity index per site. Forest amount and number of patches are, respectively, the amount of treed area (m²) and the number of distinct patches of treed area in the landscapes surrounding the sampling sites. Patch connectivity is the percentage of patches in the surrounding landscapes connected to the sampled patch (the "focal patches") through corridors. Points and lines indicate landscape variable coefficients. Grey bars indicate delta AICc's for the models containing the landscape variables at each spatial extent. The scale of effect is taken as the scale where the model fit is best, i.e., delta AICc = 0..... 62

Figure C. Standardized coefficients and 95% confidence intervals (CI) for the effects of standardized landscape variables - forest amount, number of patches, and patch connectivity - on small forest mammal relative abundance measured

within multiple spatial extents around 70 sampling sites. All relative abundances were standardized. A: relative abundance (number of papers with presence) of *P. leucopus* per site. B: the relative abundance of *T. striatus* per site. C: the relative abundance of *M. gapperi* per site. D: the relative abundance of *B. brevicauda* per site. E: the relative abundance of *T. hudsonicus* per site. Forest amount and number of patches are, respectively, the amount of treed area (m²) and the number of distinct patches of treed area in the landscapes surrounding the sampling sites. Patch connectivity is the percentage of patches in the surrounding landscapes connected to the sampled patch (the "focal patches") through corridors. Points and lines indicate landscape variable coefficients. Grey bars indicate delta AICc's for the models containing the landscape variables at each spatial extent. The scale of effect is taken as the scale where the model fit is best, i.e., delta AICc = 0..... 63

Figure D. Standardized coefficients and 95% confidence intervals (CI) for the effects of standardized landscape variables - forest amount, number of patches, and patch connectivity - on small forest mammal occurrence measured within multiple spatial extents around 70 sampling sites. A: occurrence (number of papers with presence) of *P. leucopus* per site. B: the occurrence of *T. striatus* per site. C: the occurrence of *M. gapperi* per site. D: the occurrence of *B. brevicauda* per site. E: the occurrence of *T. hudsonicus* per site. Forest amount and number of patches are, respectively, the amount of treed area (m²) and the number of distinct patches of treed area in the landscapes surrounding the sampling sites. Patch connectivity is the percentage of patches in the surrounding landscapes connected to the sampled patch (the "focal patches") through corridors. Points and lines indicate landscape variable coefficients. Grey bars indicate delta AICc's for the models containing the landscape variables at each spatial extent. The scale of effect is taken as the scale where the model fit is best, i.e., delta AICc = 0..... 65

Table J. Models for species richness per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 750 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m²) within the landscape, and the number of patches is the number of patches within the landscape. Patch connectivity is the percent of patches within the landscape directly connected to the focal patch via corridors. Road density is the area of roads (m²) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site. 66

Table K. Models for Pielou's evenness per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 2750 m. Road density was included in the final model as it changed the forest amount's coefficient from positive to negative. The upper number is

the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site.⁶⁷

Table L. Models for Chao's diversity index per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 5500 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site..... 68

Table M. Models for *P. leucopus* relative abundance index per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 4000 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Relative abundance is the number of species' presences per site (max=144). Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site. The understory Shannon diversity index was included in the final model as it changes forest amount's coefficient from positive to negative. 69

Table N. Models for *T. striatus* relative abundance per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 2500 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Relative abundance is the number of species' presences per site (max=144). Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Patch connectivity is the percent of patches within the landscape directly connected to the focal patch via corridors. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site..... 70

Table O. Models for *M. gapperi* relative abundance per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 4750 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Relative abundance is the number of species' presences per site (max=144). Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site..... 71

Table P. Models for *B. bravicauda* relative abundance per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 2500 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Relative abundance is the number of species' presences per site (max=144). Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Patch connectivity is the percent of patches within the landscape directly connected to the focal patch via corridors. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site..... 72

Table Q. Models for *T. hudsonicus* relative abundance per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 5750 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Relative abundance is the number of species' presences per site (max=144). Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site. Understory Shannon diversity was included in the final model as it changed the relative strength of the number of patches to be stronger than the forest amount..... 73

Table R. Models for *T. striatus* occurrence per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 2500 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the

amount of forest (m²) within the landscape, and the number of patches is the number of patches within the landscape. Patch connectivity is the percent of patches within the landscape directly connected to the focal patch via corridors. Road density is the area of roads (m²) divided by the landscape area.

Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site..... 74

Table S. Models for *M. gapperi* occurrence per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 4750 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m²) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m²) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site..... 75

Table T. Models for *B. bravicauda* occurrence per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 2500 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m²) within the landscape, and the number of patches is the number of patches within the landscape. Patch connectivity is the percent of patches within the landscape directly connected to the focal patch via corridors. Road density is the area of roads (m²) divided by the landscape area.

Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site..... 76

Table U. Models for *T. hudsonicus* occurrence per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 5750 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m²) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m²) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site. Understory Shannon diversity was included in the final model as it changed the relative strength of the number of patches from weaker than forest amount to stronger than forest amount. 77

Table V. Models for *N. insignis* occurrence per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 5750 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site. Understory Shannon diversity was included in the final model as it changed the relative strength of the number of patches from weaker than forest amount to stronger than forest amount..... 78

1.0 Introduction

Human activities have already altered about 46% of the earth's land cover, making it critical to understand how to conserve species in human-altered landscapes (Riggio et al., 2020). Human-modified landscapes support fewer species, especially habitat specialists (Barnes et al., 2014; Newbold et al., 2018; Gentili et al., 2014). Three aspects of landscape change that are often suggested to play a role in species declines are habitat loss, habitat fragmentation, and reduced habitat connectivity (Barnes et al., 2014; Crooks et al., 2017; Pardini et al., 2010; Xu et al., 2019; Haddad et al., 2017). However, while the importance of habitat loss is generally acknowledged, the relative roles of these three landscape changes are debated (Fletcher et al., 2018; Fahrig et al., 2019; Lindenmayer et al., 2020).

Declining habitat amount is generally thought to play a crucial role in declining species diversity and abundance (Fischer & Lindenmayer, 2007; Potts et al., 2010; Barnes et al., 2014; Pardini et al., 2010). Across taxa, habitat amount is a good predictor of occupancy (Fuentes-Montemayor et al., 2017) and species richness and density (Pardini et al., 2010; Melo et al., 2017; Nupp & Swihart, 2000; Watling et al., 2020). For forest species, a higher forest amount increases species' abundances (Rodríguez-San Pedro & Simonetti, 2015), lowers predation risk (Clermont et al., 2017), and improves species' survival (Zitske et al., 2011), allowing for a greater diversity of species (Melo et al., 2017).

Habitat fragmentation is also thought to reduce species diversity and abundance (Fletcher et al., 2018; Vieira et al., 2009). Habitat fragmentation occurs when habitat is distributed in patches separated by other land covers, generally referred to as the "matrix"

(Jennersten, 1988). Forest fragmentation may be harmful to species whose habitat is solely in the interior forest, i.e. forest interior specialists, as it increases the amount of forest edge and decreases the amount of forest interior in a landscape (Fletcher et al., 2018, Pardini et al., 2010). Increased edge can favour generalists over forest specialists (Bender et al., 1998), changing species composition (Fletcher et al., 2018; Anderson et al., 2003). Compared to the forest interior, forest edges can increase the risk of predation and have higher levels of parasitism (Wolf & Batzil, 2004; Séchaud et al., 2021; Dijak & Thompson, 2000). However, forest small mammal species may respond positively to forest edges (Anderson et al., 2006; Buckner & Shure, 1985; Nupp & Swihart, 2000). Forest edges have a greater diversity of plants (Anderson et al., 2003) and produce more preferred seeds for small mammals than the forest interior (Wolf & Batzil, 2004).

To determine the relative effects of habitat loss and habitat fragmentation, they must be measured and studied independently of each other (Fahrig 2003). Indeed, studies that identify large negative effects of habitat fragmentation typically measure it in ways that combine fragmentation with habitat loss (e.g. Crooks et al., 2017; Nupp & Swihart, 1996; Vieira et al., 2009). Considering fragmentation independent of habitat amount, called “fragmentation per se” (Fahrig 2003; Fig. 1), requires varying the number of habitat patches while controlling for the effects of habitat amount (e.g., Watling et al., 2020; Rodríguez-San Pedro & Simonetti, 2015). A review of the effects of fragmentation per se on ecological responses (diversity, abundance and movement success) found that 76% of significant effects of fragmentation per se were positive (Fahrig, 2017). One of several possible mechanisms for this is increased habitat heterogeneity, where habitat patches occur across a broader range of conditions in a more fragmented landscape,

potentially increasing species richness (Stein et al., 2014; Slancarova, 2013). Thus, habitat fragmentation may not be harmful to most species when controlling for habitat amount.

In addition to habitat amount and habitat fragmentation, habitat connectivity may play an important role in species persistence (Xu et al., 2019; Haddad et al., 2017; Saura et al., 2014; Chisholm et al., 2011). Connectivity is the degree to which a landscape facilitates the movement of organisms between habitat patches (Marotte et al., 2017; Taylor et al., 1993). Higher connectivity may increase diversity and abundance by increasing movement and, thus, gene flow (Cushman, 2006; Saura et al., 2014; King et al., 2002; Gilbert et al., 2010). Although connectivity is about the movement of organisms, actual connectivity measures vary in the degree to which species' movement responses to the landscape are considered. Thus, connectivity measures can be placed on a gradient from purely “functional connectivity” to “structural connectivity”. Functional connectivity is species-specific and considers how all landscape elements interact with a species' behavioural and other attributes to facilitate (or impede) movement through a landscape (Baudry & Merriam, 1988). In contrast, structural connectivity is usually equated with physical linear habitat corridors, with an underlying assumption that species are most likely to move between patches linked by corridors of the same habitat type as the habitat patches (Metzger & Décamps, 1997). Thus, structural connectivity represents the degree to which patches are physically connected by similar habitat.

Support for structural connectivity increasing movement is mixed. A meta-analysis found that corridors increased the movement of invertebrates, non-avian vertebrates and plants (Norton et al., 2010). However, a study on two Australian rodents

(*Melomys cervinipes* and *Uromys caudimaculatus*) found that while individuals travelled through corridors, genetic differentiation still occurred between populations linked by corridors (Horskins et al., 2006). This suggests a limited effect of corridors on successful inter-patch movement.

Further, species diversity and abundance have shown mixed responses to structural connectivity. Some small mammal studies have found that structural connectivity has weak effects on diversity and abundance (Fisher & Merriam, 2000; Rizkalla et al., 2009) and that treed corridors do not increase gene flow (Anderson et al., 2015). However, other studies have found that corridors increase the diversity of forest plants (Lenoir et al., 2021) and the abundance of small mammals and butterflies (Mortelliti et al., 2011; Haddad et al., 2003).

One possible reason for the mixed responses to structural connectivity is that corridors can serve as additional habitat for some species but not others. For example, small mammal species such as the Eastern chipmunk (*Tamias striatus*) and the hazel dormouse (*Muscardinus avellanarius*) may use treed corridors as foraging and breeding habitat (Silva & Prince, 2008; Wolton, 2009). Both specialist and generalist small mammals may use corridors as habitat, especially if preferred habitat availability is low (Gelling et al., 2007). Similarly, forest plants can use corridors as habitat, despite the difference in conditions between corridors and forests (Wehling & Diekmann, 2009). If a positive effect of corridors results from the addition of habitat and not from facilitating movement between patches, we would expect positive effects of structural connectivity on species that use corridors as habitat, but weak (or no) effects on species that do not use corridors as habitat.

Thus, while habitat amount generally increases the abundance and diversity of species, the independent effects of habitat fragmentation and structural connectivity are less clear. To our knowledge, Mortelliti et al. (2011) is the only study that has attempted to estimate the independent effects of forest amount, fragmentation per se and structural connectivity on small mammals, in their case, the red squirrel (*Sciurus vulgaris*) and the hazel dormouse (*M. avellanarius*). They found that habitat amount had the largest (positive) effect on occurrence, followed by connectivity (positive) and fragmentation (positive). However, structural connectivity may have been confounded with habitat amount because Mortelliti et al. did not include the corridors in their calculation of habitat amount, even though the hazel dormouse can use corridors as habitat (Wolton, 2009).

We investigated the independent effects of forest amount, fragmentation and structural connectivity on the species diversity, relative abundance and occurrence of forest small mammals in Eastern Ontario, Canada. Fragmentation was the number of forest patches in the landscape (Henein et al., 1998; Patterson & Malcolm, 2010). We defined connectivity as the percentage of patches connected, directly or indirectly, to the sampled forest patch via wooded corridors, i.e. patch connectivity (see Fig. 1). Forest amount was expected to have the strongest (positive) effect on small mammal diversity and species abundance and occurrence. Fragmentation was expected to weakly increase individual species' abundance, occurrence and small mammal diversity due to increased access to more productive forest edges and increased habitat heterogeneity (Slancarova et al., 2013). We expected the fragmentation effect to be weaker than the forest amount effect. Although forest edges might provide productive foraging habitat, this benefit

might be balanced by an increased risk of predation at forest edges (Wolf & Batzil, 2004; Séchaud et al., 2021; Dijak & Thompson, 2000). We expected structural connectivity to increase individual species abundance, occurrence and small mammal diversity by increasing movement and dispersal. Effects of structural connectivity were expected to be weaker than the other landscape variables because many small mammals are willing to cross the matrix (Bowman & Fahrig, 2002; Bakker & Van Vuren, 2004).

2.0 Methods

2.1 Overview

We estimated the independent effects of forest amount, fragmentation (the number of forest patches), and patch connectivity (Fig. 1) on small mammal diversity, abundance and occurrence in 70 forested sites in Eastern Ontario, Canada (Fig. 2). We selected the sampling sites to minimize the correlations between forest amount, fragmentation and patch connectivity. We sampled small mammals using plastic footprint-tracking tubes lined with paper with a central ink pad (Rytwinski, 2006; Oddy et al., 2018; Nams & Gillis, 2003). As a small mammal crosses the inkpad, its tracks are left on the paper (Fig. 4). Footprints are then identified to species. We used footprint tracking data to calculate three diversity metrics and each forest species' relative abundance and occurrence per site. Diversity per site was measured as species richness, Pielou's evenness (Pielou, 1966) and Chao's diversity index (Chao et al., 2005). Relative abundance per site was indexed as the total number of tracking tubes with a species presence per site. Occurrence was the probability of each species' presence per site. We calculated the forest amount, fragmentation and patch connectivity in circular landscapes surrounding each sampling site with radii ranging from 750 – 2500 m. We modelled each

small mammal response as a function of the three landscape variables – forest amount, number of patches and patch connectivity. To determine the scale of effect (Jackson & Fahrig, 2012), we created eight models per response variable from 750 to 2500 m, in increments of 250 m. The scale of effect for each response was the scale where the model had the lowest corrected Akaike Information Criterion (AICc; Hurvich & Tsai, 1993). The effect of each landscape variable was its standardized coefficient at the scale of effect.

2.2 Study area

Our study area was in Eastern Ontario, Canada, within 90 km of Ottawa (see Fig. 3). This area falls within the Great Lakes-St. Lawrence forest region (OMNR, 2021). Forests in this region are primarily deciduous, with common trees being maple (*Acer* spp.), oak (*Quercus* spp.), and birch (*Betula* spp.; OMNR, 2021). Common coniferous trees are white pine (*Pinus strobus*), red pine (*Pinus resinosa*) and Eastern hemlock (*Tsuga canadensis*; OMNR, 2021). In this region, agriculture accounts for 48% of land use (OMNR, 2021b), and 39% of the area is treed (see land cover data).

2.3 Land cover data

For land cover data, we used the Wooded Area dataset of the Ontario Ministry of Natural resources (OMNR, 2021). This dataset has classes for forest patches and hedgerows. Forest patches are any area with vegetation >2 m tall, covering $>60\%$ of the area and patches must be ≥ 30 m wide. Hedgerows are any linear treed features <30 m wide, which may or may not be connected to patches. We included forest patches and hedgerows in the total forest amount. For calculations of patch connectivity, we defined

corridors as hedgerows connected to forest patches with no treeless gaps >12 m, which is larger than a typical large tree crown width in our region (*personal observation*).

Before calculating landscape variables, we compared the Wooded Area dataset with current satellite imagery and found inaccuracies in some of the Wooded Area's classifications. We, therefore, digitized recent satellite imagery to update the Wooded Area dataset using QGIS (QGIS Development Team, 2019) and Google Earth satellite imagery (Google, 2019). We did not update areas for which we only found imagery during leaf-off periods, as forested areas are not visible in that imagery (~4% of the study area). For digitization, we divided the study area into 192 65-km² squares. We then randomly divided the squares among three collaborators. All three collaborators first digitized one area together and then digitized another area separately to ensure similar results (<12% difference). We added any corridors not included in the Wooded Area dataset and removed any corridors that no longer existed. We updated the forest patches if the change in forest area between the Wooded Area dataset and satellite imagery was >0.25 ha.

2.4 Site selection

We began by identifying one potential sampling location per forest patch containing interior forest. We defined interior forest as any forest ≥ 100 m from a forest-non-forest boundary (Fig. 3). The 100-m buffer was chosen because that is the distance within which edge effects have been found on vegetation and fungi (Gehlhausen et al., 2000; Ruete & Jönsson, 2016), which are components of small mammal habitat (Brannon, 2005; Anderson et al., 2003). Sampling locations were 30 m x 30 m areas in the forest, at least 100 m from a forest edge, and located arbitrarily in the southwest

corner of the forest patch (Fig. 3). Initially, we had >1200 potential sampling sites. We reduced the number of potential sites by selecting sites that were easy to access (<1 km from roads), in either deciduous or mixed deciduous-coniferous forest, in forest patches \leq 121 ha, and \geq 3000 m apart (to avoid spatial autocorrelation; Bowman et al., 2001b), resulting in 300 potential sites. As patch size can affect species density and composition, we avoided placing sites in forest patches >121 ha, i.e. the top 30% of the patch size distribution, to control for patch size effects (Bender et al., 1998; Pardini et al., 2010).

We then selected 72 of the 300 potential sites to (i) maximize the range of each of the three landscape variables (forest amount, fragmentation and connectivity) within 1500 m of the sampling sites (Fig. 2); (ii) minimize the correlations among the three landscape variables, and (iii) avoid regional gradients in the landscape variables. The latter minimized the potential confounding of the landscape variables with other variables (e.g. road density) that vary across the region. All 300 potential sites in the region were placed into one of eight classes, i.e. all combinations of low and high values of each of the three landscape variables. For each landscape variable, the “high” values were above the 60th percentile, and the “low” values were below the 40th percentile. Then we selected nine sites from each of these classes according to the criteria above. Note that we used the eight classes for site selection only. We used the landscape predictor variables, forest amount (m^2), number of patches, and patch connectivity (%) as continuous variables in data analysis. We had to remove two sites from our study due to landowner issues at one site and unexpected foot traffic at the other. One site had low forest amount, high fragmentation and low connectivity, and the other had high forest amount, low fragmentation and high connectivity. These two sites were removed before collecting any

small mammal data, resulting in 70 final sampling sites. Sampling locations were initially in the Southwest corner of the patches. However, we occasionally moved sampling locations within the patch to avoid standing water, be placed within mixed deciduous or deciduous areas, and avoid forest openings. All sampling locations were finalized before site setup and data collection. All landscape variables were calculated in the landscapes surrounding these final sampling locations.

We chose 1500 m as the landscape radius during site selection because it is close to the home ranges of the two species anticipated to be most abundant, *Peromyscus leucopus* and *Tamias striatus* (Nupp & Swihart, 2000; Fisher & Merriam, 2000; Silva et al., 2005; Bowers et al., 1990). However, during data analysis, we used multiple potential landscape radii (750 – 2500 m).

2.5 Small mammal sampling

We used non-baited footprint tracking tubes to determine small mammal diversity, relative abundance and occurrence. A footprint tracking tube is a plastic pipe with a piece of paper inside and an “inkpad” stapled to the center of the paper (Fig. 4). When a small mammal runs through the tube, it crosses the inkpad, leaving behind a stamp of its footprint on the paper. The ink pad was a piece of waxed butcher paper with a 3:1 (by weight) mixture of carbon powder and paraffin oil dabbed onto it (Rytwinski, 2006). A small piece of duct tape was used to attach the tracking paper to the tube to prevent removal by raccoons (*Procyon lotor*; Fig. 5).

Each sampling site contained a grid of 36 tracking tubes spaced 6 m apart (Fig. 6). We placed tube grids parallel to our bearings when entering the forest but rotated grids to avoid large obstructions (boulders, fallen trees etc.) or standing water within the grid

area. We did not purposefully place tubes near logs or other areas to increase small mammal interest. We used four different tube sizes with diameters of 3.75 cm, 5 cm, 7.62 cm and 10 cm. Tracking tube lengths were 30 cm for the two smaller tube sizes (3.75 cm and 5 cm) and 43.5 cm for the larger tube sizes (7.62 cm and 10 cm). The short tracking tubes had 30 cm long tracking papers, and the larger tubes had 35.56 cm long tracking papers. Tracking papers were four widths, 7 cm, 10 cm, 14 cm and 20 cm, for the four tube sizes. Inkpad squares were also four sizes, corresponding to the four tube sizes 6 x 6 cm, 7 x 7 cm, 11 x 11 cm and 13 x 13 cm. Each sampling matrix had 9 tubes of each size. The four sizes were assigned positions in the matrix using a random number generator, edited to ensure each row and column had each tube size. All 70 sites had the same tube arrangement and the same number of tubes.

We began by placing tracking tubes lined with papers without ink pads at all sites between May 4, 2020, and May 29, 2020, and left them for 14-21 days to allow animals to become accustomed to them. We then sampled bi-weekly, 4 times from June 1, 2020, to August 30, 2020. Every second week, we collected the old set of tracking papers and placed new, freshly inked papers in the tubes.

We identified species footprints visually using records from previous studies in our area (Rytwinski et al., 2009; Martin & Fahrig, 2012). We counted the number of species present per paper. The number of individual tracks per paper was not recorded, as many papers had too many overlapping tracks to distinguish among them. Over the two-week sampling period at each site, some papers were damaged by people, water, raccoons, or slugs. We recorded the condition of each paper (1- good, 2- some damage but readable, 3- unreadable).

2.6 Response variables

We included only the seven forest-dwelling small mammal species in our region: white-footed mouse (*Peromyscus leucopus*), Eastern chipmunk (*Tamias striatus*), red-backed vole (*Myodes gapperi*, previously *Clethrionomys gapperi*), Northern short-tailed shrew (*Blarina brevicauda*), American red squirrel (*Tamiasciurus hudsonicus*), woodland jumping mouse (*Napaeozapus insignis*) and Eastern grey squirrel (*Sciurus carolinensis*). We excluded three species that occurred in our samples but were not forest specialists (Silva & Prince, 2008): the house mouse (*Mus musculus*), meadow jumping mouse (*Zapus hudsonius*), and Eastern meadow vole (*Microtus pennsylvanicus*).

We included three categories of response variables: diversity metrics, each species' relative abundance, and each species' occurrence. We standardized the diversity and relative abundance response variables. Diversity response variables were: species richness, Pielou's evenness (Pielou, 1966) and Chao's diversity index (Chao et al., 2005). Species richness per site (S) was the number of species observed across all four sampling periods at each sampling site. Pielou's evenness was: $J' = \frac{-\sum_{i=1}^S p_i * \ln(p_i)}{\ln(S)}$, where p_i was the proportion of all papers at the site with tracks of species i. The numerator of Pielou's evenness is the Shannon-Weiner diversity index. Chao's diversity index adjusts for the likely underestimation of rare-species abundances. We used the Chao₁ diversity metric, appropriate for abundance measures (here, the number of papers with tracks). The formula was $Chao_1 = S_{obs} + \frac{F_1(F_1-1)}{2(F_2-1)}$, where F_1 was the number of singleton species with 1 track recorded at a site, and F_2 was the number of doubleton species with two tracks recorded at a site.

Species relative abundance was the total number of tracking papers containing a species' footprints, summed across all four sampling periods for each site (max=144). Relative abundance is not a measure of absolute abundance, as a single individual could leave tracks in multiple tubes at a site. However, this measure has been previously shown to be a reliable index of abundance (Fahrig and Merriam, 1985). We had sufficient tracking data to create relative abundance models for five of the seven species: *P. leucopus*, *T. striatus*, *M. gapperi*, *B. brevicauda* and *T. hudsonicus*. We could not create a relative abundance index for *N. insignis* or *S. carolinensis* as they had zero abundance at most sites (Fig. 7).

Species occurrence was a binary response, where 0 indicated no tracks of a species at a site across all sampling periods and 1 indicated at least 1 track recorded for that species at a site. We had sufficient presence and absence counts to create occurrence models for five of the seven species: *T. striatus*, *M. gapperi*, *B. brevicauda*, *T. hudsonicus* and *N. insignis*. We could not create an occurrence model for *P. leucopus* or *S. carolinensis*, as the former was present at all sites and the latter was absent from most sites (Fig. 7).

2.7 Landscape predictor variables

We calculated the three landscape predictor variables in 8 nested circular landscapes centred on each sampling site, with radii from 750 m to 2500 m in 250 m increments. We chose 2500 m as the largest scale because the distribution of patch connectivity became dominated by outliers at scales >2500 m (Fig. A). The smallest scale we evaluated (750 m) was chosen because this was the scale where all sites had at least 2 patches in the landscape, as required for estimating connectivity. Forest amount

was all forested area within a landscape, including all patches and hedgerows and any portions of patches and hedgerows that intersected the landscape boundary. Forest fragmentation was the number of forest patches in the landscape, including those that intersected the landscape boundary. Patch connectivity was the number of patches in the landscape connected to the focal patch (the patch with the sampling site) by corridors, divided by the number of patches in the landscape (excluding the focal patch), recorded as a percentage. Connections were corridors as defined above, and both direct and indirect connections were included (Fig. 1).

2.8 Analysis

We used generalized linear models for all response variables: linear models for the diversity and relative abundance responses and binomial models for the occurrence responses. All models contained the three landscape predictors and sampling effort. Sampling effort is the total number of tracking papers collected per site (excluding unrecovered papers or papers classed as 3 - unreadable) multiplied by the number of days the papers were in the tubes. For each response variable, we built a model at each spatial scale from 750 to 2500 m, with all three landscape predictors measured at that scale. We chose the scale of effect for each response as the scale where the model had the best fit or the lowest AICc (Moraga et al., 2019; Hurvich & Tsai, 1993). We standardized the landscape variables to compare their effects. All models were run using R version 4.0.5 (R Core Team, 2021).

Once the scale of effect had been determined for each response variable, we considered three potential confounding variables: road density in the landscape, the Shannon diversity index of understory plants at the sampling site, and the percentage of

deciduous trees at the sampling site. We included confounding variables to ensure we correctly interpreted the effects of our three landscape variables. Road density affects small mammal abundances and movement (Rytwinski, 2006; Ford & Fahrig, 2008). Plant diversity affects plant-dependent small mammal species' abundance and diversity (Stein et al., 2014), and deciduous trees increase the abundance of some small mammals (Bowman et al., 2001a; Schulte-Hostedde et al., 1997; Wolf & Batzli, 2004; Montiglio, 2014). We calculated road density using the Ontario Road Network database (ORN, 2021) as the area of roads (m^2) in a landscape divided by the landscape area at the scale of effect. We sampled understory plants (<1 m in height) in eight 6.52 m^2 quadrats spaced 6 m apart, once in May-June and once in July- August, for two records per sampling site (Gabriel, 2021). We calculated the Shannon diversity index of the understory plants based on the coverage of all plant species <1m in height. All trees ≥ 5 m tall were counted within one 4 m x 30 m transect per site. We calculated the percentage of deciduous trees as $100 \times$ the number of deciduous trees / the total number of trees. We then calculated the Spearman's Rho correlation between all confounding variables and between each confounding variable and each landscape variable at the scale of effect.

Finally, we created three models, each with a different confounding variable, per response and kept confounding variables in the final model if they changed the interpretation of our results. All confounding variables were at the scale of effect determined previously. Each confounding model had the four predictor variables from the previous scale of effect modelling step; predictors were: the three landscape variables, sampling effort, and one confounding variable (either road density, understory plants Shannon diversity or percentage of deciduous trees). We compared each model

containing a confounding variable to the model without any confounding variables. We included a potential confounding variable in a final model if it changed the interpretation of the effect of any of our landscape variables of interest - forest amount, fragmentation, or connectivity. We included any confounding variable that 1) changed the sign of a landscape variable of interest or 2) changed the relative strength of a landscape variable of interest (Tables J-V).

3.0 Results

3.1 General

Forest amount per site ranged from 15.1 – 81.6% at the smallest landscape radius (750 m) and 2.3 – 64.1% at the largest (2500 m). The number of forest patches per site ranged from 2 – 17 at the smallest radius (750 m) and from 11 – 86 at the largest radius (2500 m). Patch connectivity per site ranged from 0 – 100% at the smallest radius (750 m) and 0 – 67% at the largest (2500 m). The correlation between forest amount and the number of patches ranged from -0.215 – 0.223, depending on the scale (Table B). The correlation between forest amount and patch connectivity ranged between -0.214 and 0.197, and the correlation between the number of patches and patch connectivity ranged between -0.049 and 0.025 (Table B-C). Spearman’s Rho correlation between confounding variables and landscape variables was low ($<|0.5|$; Table E-H), except for the correlation between patch connectivity and road density which ranged from -0.573 – -0.427 (Table G). Correlations between confounding variables were low($<|0.5|$; Table D).

Ninety-one percent of all footprint tracking papers were recovered (Fig. 7). A mean of 130.9 of 144 papers were recovered per site (Fig. 7). At two sites, there was a low percentage of papers recovered (35.4% and 47.2%) due to damage by people, water,

slugs, or raccoons; all other sites had >65% of papers recovered (Fig. 5, Fig. 7). The average paper was in good condition (1.3), with 1 being good and 3 being unreadable (Fig. 4B).

The mean forest species richness per site was 4 (range 2-6; Fig. 7). Mean Pielou's evenness per site was 0.62 ± 0.16 (SE), with 0 being uneven and 1 being completely even. The mean Chao's diversity index per site was 8.575 ± 1.86 (SE). The species in decreasing mean relative abundance (number of presences out of 144 papers) per site were *P. leucopus* with 32.74 ± 22.56 (SE), *T. striatus* with 24.29 ± 27.15 , *M. gapperi* with 3.71 ± 3.33 , *T. hudsonicus* with 1.66 ± 2.68 , *B. brevicauda* with 1.54 ± 2.16 , *N. insignis* with 0.33 ± 0.70 and *S. carolinensis* with 0.071 ± 0.26 (Fig. 7). The species in order of decreasing presence out of all 70 sites (%) were *P. leucopus* with 100.0%, *T. striatus* with 88.6%, *M. gapperi* with 84.3%, *B. brevicauda* with 60.0%, *T. hudsonicus* with 50.0%, *N. insignis* with 22.9% and *S. carolinensis* with 7.1% (Fig. 7). For a table of all detected species' abundance and presence, see Table A.

3.2 Scale of effect

The scale of effect (the scale with the lowest AICc; Hurvich & Tsai, 1993; Jackson & Fahrig, 2012) depended on the response variable and ranged from the minimum scale of 750 m to the maximum scale of 2500 m. For species richness and Chao diversity, the scale of effect was 750 m, and for Pielou's evenness, the scale of effect was 2000 m (Fig. B). For the relative abundance models, the scale of effect was 1000 m for *P. leucopus*, 2500 m for *T. striatus*, *M. gapperi* and *B. brevicauda*, and 1750 m for *T. hudsonicus* (Fig. C). For the occurrence models, the scale of effect was 2250 m for *T. striatus*, 2500 m for *M. gapperi*, 750 m for *B. brevicauda*, 1000 m for *T.*

hudsonicus and 750 m for *N. insignis* (Fig. D). There was equal support for at least one other scale for most models (delta AICc<2; Burnham & Anderson, 2002; Fig. B-D).

However, the *T. striatus* and *B. brevicauda* relative abundance models and the *M. gapperi* occurrence model all had a well-defined single scale of effect (Fig. B-D).

3.3 Potential confounding variables

For 8 of the 13 final models, the potential confounding variables did not change the signs of the landscape variable coefficients or their relative strengths and were not included in the final models (Table J-V). For Pielou's evenness, adding understory plant Shannon diversity at the sampling sites changed the relative strength of patch connectivity from stronger than forest amount to equal forest amount (Table K). For the Chao diversity model, including road density in the surrounding landscape changed the effect of forest amount from negative to positive (Table L). For the *T. striatus* occurrence model, adding the understory plant Shannon diversity at the sampling sites changed forest amount from the weakest landscape variable to the second strongest landscape variable (Table R). For the *M. gapperi* occurrence model, including road density changed patch connectivity from negative to positive (Table S). For the *T. hudsonicus* occurrence model, including road density changed forest amount from the second strongest to weakest of the three landscape variables (Table U).

3.4 Effects of forest amount, fragmentation and connectivity

In eight of 13 final models, forest amount had a positive effect. The forest amount coefficients all had confidence intervals crossing zero. For the three diversity responses, the forest amount coefficients were very close to zero (Table 1, Fig. 8). The relative occurrence of *M. gapperi* had the strongest positive response to forest amount ($\beta= 0.520$),

and the relative abundance of *T. striatus* decreased with forest amount ($\beta = -0.090$), but its occurrence increased ($\beta = 0.348$; Fig. 9-10). Although some coefficient estimates were large (>0.5), the uncertainty was high.

In seven of the 13 final models, the effects of forest fragmentation were positive with high uncertainty. The coefficients for forest fragmentation were positive for species richness and Chao's diversity and negative for species evenness, though the confidence intervals all crossed zero (Fig. 8, Table 1). The individual species' responses to forest fragmentation were variable, with positive coefficients in two of five models of species' relative abundance and positive coefficients in three of five models of occurrence. The strongest responses to fragmentation were the positive response of *T. striatus* relative abundance ($\beta = 0.266$), the strong positive response of *N. insignis* occurrence ($\beta = 0.533$), and the negative responses of *M. gapperi* relative abundance and occurrence ($\beta = -0.311$, $\beta = -0.769$; Fig. 9-10, Table 2-3).

The effect of patch connectivity was negative in nine of 13 final models. Connectivity coefficients were negative for all three diversity responses (Fig. 8, Table 1). As for forest amount and fragmentation, most of the confidence intervals for patch connectivity coefficients included zero, indicating high uncertainty (Fig. 8-10, Table 1-3). The strongest connectivity effects, with the lowest uncertainty, were the positive effects on the relative abundances of *T. striatus* and *B. brevicauda* ($\beta = 0.306$, $\beta = 0.424$) and a negative effect on the occurrence of *N. insignis* ($\beta = -0.699$; Fig. 9-10). Notably, while the relative abundance of *T. striatus* and *B. brevicauda* increased with connectivity, the occurrence of both species declined with connectivity; in more connected sites, *T. striatus* and *B. brevicauda* were less likely to occur, but their abundances were higher.

In most final models, the strongest effect size was patch connectivity (7/13 final models), followed by the number of patches (4/13 final models), followed by forest amount (2/13 final models; Table 1-3, Fig. 8-10). In seven of 13 final models, the number of patches had the second strongest effect size, and in eight of 13 final models, forest amount had the weakest effect size (Table 1-3). For the diversity models, patch connectivity was strongest in two of the three final models. The strongest effect for the relative abundance models was both forest amount (2/5 final models) and patch connectivity (2/5 final models). For the occurrence models, the strongest effect was patch connectivity in three of five final models, followed by fragmentation in two of five final models.

4.0 Discussion

Our results suggest that a fragmented landscape of many small, unconnected forest patches increases small mammal diversity and the occurrence of most forest small mammal species in forested sites in Eastern Ontario (Fig. 8, Fig. 10). Species occurrence increased with fragmentation for three of five species, *Tamias striatus*, *Blarina brevicauda* and *Tamiasciurus hudsonicus*. We speculate that the likelihood of colonization may be higher in a more fragmented landscape. For a given total amount of habitat, fragmentation per se reduces the distance between patches (Tischendorf et al., 2005). Reducing interpatch distance may encourage movement and, thus, increase colonization (Saura et al., 2014). Colonization is essential for small mammals in the study region because these species undergo large population reductions during winter, leading to frequent local extinctions in forest patches (Middleton & Merriam, 1981; Baker & Brooks, 1981; Bowman et al., 2001b). Total dispersal, and therefore colonization, might

also be higher in a landscape with many small patches because the population density of many small mammal species increases with declining patch size (Nupp & Swihart, 1996; Rizkalla & Swihart, 2009; Moore & Swihart, 2005; Reunanen & Grubb, 2005; Fig. 11(1)). Therefore, in highly fragmented landscapes with many small patches, the number of colonists available should be higher than in less fragmented landscapes with fewer, larger patches. Positive fragmentation effects could also be from positive edge effects due to increased shrub diversity near forest edges (Perea et al., 2011; Benedek & Sîrbu, 2018; Darling et al., 2019).

The negative responses of forest small mammal diversity and occurrence to structural connectivity were unexpected (Fig. 8, Fig. 10). We speculate that corridors connected to forest patches might act as ecological traps if predators are more abundant in corridors and small mammals are more likely to travel through corridors than across the matrix (Fig. 11(2)). This idea is consistent with work showing that corridors increase the occurrence of some small mammal predators, including long-tailed weasels, coyotes, raccoons and domestic cats (Silva & Prince, 2008; Gehring & Swihart, 2003; Gehring & Swihart, 2021). Additionally, although some small mammal species are willing to cross open spaces (Bakker & Van Vuren, 2004; Bowman & Fahrig, 2002), they may prefer to use areas with more overhead cover, such as corridors (Bakker & Van Vuren, 2004; Sullivan & Sullivan, 2014; Clermont et al., 2017; Perea et al., 2011; Rizkalla & Swihart, 2007). If corridors are ecological traps, the likelihood of colonization of a patch may be lower when connected to other patches via corridors than when other patches are nearby but separated by the matrix. The impact of lower colonization would be elevated during spring when agricultural fields are more barren, strengthening small mammals'

preference to travel through corridors instead of through the matrix (Cummings & Vessey, 1994; Butet et al., 2010; Fischer & Schröder, 2014).

In contrast to the trends for species occurrence and species diversity, the occurrence of the red-backed vole *Myodes gapperi* (previously *Clethrionomys gapperi*) and the woodland-jumping mouse *Napaeozapus insignis* declined with fragmentation (Fig. 10). We speculate that fragmentation reduces the likelihood of *M. gapperi* and *N. insignis* colonizing patches and reduces their abundances due to adverse edge effects. Both species are forest specialists and may be less willing to cross the matrix than other small mammal species (D'Amico et al., 2015; Sekgororoane & Dilworth, 1995; Menzel et al., 1999; Sullivan & Sullivan, 2014; Bowman et al., 2001a). In addition, both species are associated with moist environments and food sources such as fungi that are found in forest interiors (Brannon, 2005; Tisell, 2018; Orrock et al., 2003; Whitaker, 1963; Stephens, 2018), and maybe less abundant in drier forest edges (Malmivaara-Lämsä et al., 2008). A more fragmented landscape has more edge and less forest interior, which would reduce the amount of habitat for these species. It is also possible that these two species may fare poorly in competition with field species at forest edges. The meadow vole (*Microtus pennsylvanicus*) is known to outcompete *M. gapperi* (Halliday & Morris, 2013) and is mainly found in forest edges or the matrix (Silva & Prince, 2008; Darling et al., 2019).

Although species occurrence consistently declined with connectivity, three of five species' relative abundance increased with connectivity; *Peromyscus leucopus*, *T. striatus* and *B. brevicauda* increased with connectivity (Fig. 9). As suggested above, the decline in occurrence may be due to corridors increasing predation (Silva & Prince, 2008;

Gehring & Swihart, 2003; Gehring & Swihart, 2021), thus reducing colonization. If corridors increase small mammals' perception of danger, they may reduce emigration from patches with established populations (cf. "landscape of fear"; Laundré et al., 2014). Some work has shown that small mammals can be aware of predation risk; for example, they spend less time foraging with higher predation risk (Clermont et al., 2017; Wolf & Batzli, 2004; Loggins et al., 2019). Thus, corridors may decrease emigration as populations grow during the summer, increasing the abundance of populations somewhat confined to the patch. We emphasize that this explanation is speculation. As ours is the first study to evaluate the effects of structural connectivity independent of forest amount and fragmentation effects, we are only documenting patterns; understanding the mechanisms responsible for those patterns would require further study.

Connectivity reduced the relative abundance of two species, *M. gapperi* and *T. hudsonicus* (Fig. 9). Despite the potential predation risk posed by corridors, these two species may attempt to emigrate via treed corridors and thus be subject to high predation mortality, reducing their populations (Andreassen et al., 1996). Both species prefer to move through spaces with overhead cover (Bakker & Van Vuren, 2004; D'Amico et al., 2015). For *T. hudsonicus*, an arboreal species (Steele, 1998), travel through treed corridors may be especially attractive.

Relative abundance declined with fragmentation for three of five species, the white-footed mouse (*P. leucopus*), the Northern short-tailed shrew (*B. brevicauda*) and the red-backed vole (*M. gapperi*; Fig. 9). The negative fragmentation effect on *P. leucopus* abundance was particularly unexpected based on previous patch-scale literature showing that *P. leucopus* density increases with declining patch size (Nupp & Swihart,

1996; Buckner & Shure, 1985). Extrapolating this to a landscape scale, we expected higher *P. leucopus* densities in more fragmented landscapes; when forest amount is constant, fragmented landscapes should have smaller patches than less fragmented landscapes. Therefore, higher densities within small patches should increase the number of immigrants to a focal patch in fragmented landscapes, increasing abundance (Denomme-Brown et al., 2020). We found the opposite, suggesting that a landscape-scale mechanism(s) counters this patch-size effect (Fahrig et al., 2019). Currently, we cannot speculate on the landscape-scale mechanism for negative fragmentation effects for *P. leucopus*. Negative fragmentation effects were anticipated for *M. gapperi*, a forest interior specialist (Sekgororoane & Dilworth, 1995; Darling et al., 2019). The negative response of *B. brevicauda* to forest fragmentation may be due to the lower abundance of prey species *P. leucopus* and *M. gapperi* in more fragmented landscapes (Brittain et al., 2005).

Forest amount had surprisingly weak effects in most models, with coefficients near zero and 85% of final models having a stronger configuration (fragmentation or connectivity effect; Fig. 8-10; Table 1-3). Additionally, all confidence intervals for forest amount effects crossed zero (Fig. 8-10). Weak forest amount effects might indicate that forest small mammals cannot saturate forest patches in our region. Inability to saturate the landscape could be driven by high overwinter mortality (Middleton & Merriam, 1981; Baker & Brooks, 1981) and the relatively short breeding season for population build-up (Morris, 1986; Montiglio et al., 2014). Populations may thus rarely reach the carrying capacity of the landscape. Additionally, our study area has more forested area than other fragmentation and connectivity studies. Forest amount ranged from 15 to 82% and 2 to

64% across our landscapes (depending on the scale), while in other studies, forest amount typically ranged from ≤10 to ≤50% (Rizkalla et al., 2009; Betts et al., 2007; Henein & Merriam, 1998; Pardini et al., 2010; Fuentes-Montemayor et al., 2017; Rodríguez-San Pedro & Simonetti, 2015). One study that had more extremes of forest cover (<5 to 80%) found that changes in configuration become less important at lower forest amounts (Mortelliti et al., 2011). Perhaps, at low forest amounts, changes in forest cover become more important relative to changes in configuration, but this requires further evaluation.

A limitation of this study was that, in selecting our sites, we did not distinguish among the different land covers present between forest patches, i.e. the matrix cover types. The matrix was variable across landscapes, including urban areas, agricultural fields, sparsely treed areas, alvars, gravel and sand pits and bodies of water. Differential effects of these matrix cover types on forest small mammal movements likely explain some of the variability in our data. A study in Chile found that matrix cover changed the effects of forest amount and fragmentation on forest bat activity (Rodríguez-San Pedro, 2015). They observed weaker effects of forest amount and more positive effects of fragmentation in landscapes with a forestry-plantation matrix than in landscapes with an agricultural matrix (Rodríguez-San Pedro, 2015). Additionally, small mammal species can forage in some matrix covers (Fisher & Merriam, 2000; Braga et al., 2015), changing the species composition (Hurst et al., 2014; Braga et al., 2015). Even the same cover type, such as agriculture, may have variable effects on small mammals travelling through it, depending on the agricultural practices, such as the use of pesticides (Butet et al., 2010; Arlettaz et al., 2010; Sirami et al., 2019; Fischer & Schröder, 2014; Balestrieri et

al., 2019). These matrix effects would have contributed to the variability in our small mammal data, increasing the uncertainty around the estimated effects of our three landscape variables of interest.

We generally found high uncertainty around parameter estimates; many confidence intervals crossed zero (Fig. 8-10). This high uncertainty implies that factors other than landscape structure strongly influence small mammal diversity, occurrence, and abundance. Local habitat features such as soil moisture or availability of specific plant species can influence small mammals' abundance and occurrence (Schulte-Hostedde et al., 2001; Brannon, 2005; Fitzgibbon, 1993; Patterson & Malcolm, 2010; Tisell, 2018). Our site selection occurred during the winter preceding our field season when sites were covered in snow, making it impossible to select sites for consistent microhabitat features.

This is the first study to test the independent effects of forest amount, fragmentation and structural connectivity on forest small mammals. Landscape configuration (fragmentation or connectivity) had stronger effects than landscape composition (forest amount). The configuration effects were often opposite to our expectations and varied among species. Forest fragmentation increased the abundance and occurrence of some species. In contrast, forest fragmentation decreased other species' abundance and occurrence. Given the contrasting effects of fragmentation, landscape management aimed at altering habitat fragmentation for a given species could negatively affect others. Most surprisingly, species richness and occurrence decreased with structural connectivity, suggesting that structural connectivity is not equivalent to functional connectivity for these forest small mammals. The negative connectivity effects

were unexpected because they ran counter to the earliest work on connectivity (Fahrig and Merriam 1985). Our unexpected results illustrate the importance of estimating connectivity effects independent of habitat amount and fragmentation effects.

References

- Anderson, C. S., Cady, A. B., & Meikle, D. B. (2003). Effects of vegetation structure and edge habitat on the density and distribution of white-footed mice (*Peromyscus leucopus*) in small and large forest patches. Canadian Journal of Zoology, 81(5), 897–904. <https://doi.org/10.1139/z03-074>
- Anderson, C. S., Meikle, D. B., Cady, A. B., & Schaefer, R. L. (2006). Annual variation in habitat use by white-footed mice, *Peromyscus leucopus*: The effects of forest patch size, edge and surrounding vegetation type. Canadian Field-Naturalist, 120(2), 192–198. <https://doi.org/10.22621/cfn.v120i2.287>
- Anderson, S. J., Kierepka, E. M., Swihart, R. K., Latch, E. K., & Rhodes, O. E. (2015). Assessing the permeability of landscape features to animal movement: Using genetic structure to infer functional connectivity. PloS One, 10(2), e0117500–e0117500. <https://doi.org/10.1371/journal.pone.0117500>
- Andreassen, H. P., Halle, S., & Ims, R. A. (1996). Optimal Width of Movement Corridors for Root Voles: Not Too Narrow and Not Too Wide. The Journal of Applied Ecology, 33(1), 63–70. <https://doi.org/10.2307/2405016>
- Arlettaz, R., Krähenbühl, M., Almasi, B., Roulin, A., & Schaub, M. (2010). Wildflower areas within revitalized agricultural matrices boost small mammal populations but not breeding Barn Owls. Journal Für Ornithologie, 151(3), 553–564. <https://doi.org/10.1007/s10336-009-0485-0>
- Baker, J. A., & Brooks, R. J. (1981). Distribution Patterns of Raptors in Relation to Density of Meadow Voles. The Condor., 83(1), 42–47. <https://doi.org/10.2307/1367598>
- Bakker, V. J., & Van Vuren, D. H. (2004). Gap-Crossing Decisions by the Red Squirrel, a Forest-Dependent Small Mammal. Conservation Biology, 18(3), 689–697. <https://doi.org/10.1111/j.1523-1739.2004.00149.x>
- Balestrieri, A., Gazzola, A., Formenton, G., & Canova, L. (2019). Long-term impact of agricultural practices on the diversity of small mammal communities: a case study based on owl pellets. Environmental Monitoring and Assessment, 191(12), 1–14. <https://doi.org/10.1007/s10661-019-7910-5>
- Barnes, A. D., Jochum, M., Mumme, S., Haneda, N. F., Farajallah, A., Widarto, T. H., & Brose, U. (2014). Consequences of tropical land use for multitrophic biodiversity and ecosystem functioning. Nature Communications, 5(1), 5351–5351. <https://doi.org/10.1038/ncomms6351>
- Baudry, J., & Merriam, H. G. (1988). Connectivity and connectedness: functional versus structural patterns in landscapes. Muènstersche Geographische Arbeiten, 29, 23–28.
- Bender, D. J., Contreras, T. A., & Fahrig, L. (1998). Habitat Loss and Population Decline: A Meta-Analysis of the Patch Size Effect. Ecology (Durham), 79(2), 517–533. [https://doi.org/10.1890/0012-9658\(1998\)079\[0517:HLAPDA\]2.0.CO;2](https://doi.org/10.1890/0012-9658(1998)079[0517:HLAPDA]2.0.CO;2)

- Benedek, A. M., & Sîrbu, I. (2018). Responses of small mammal communities to environment and agriculture in a rural mosaic landscape. *Mammalian Biology : Zeitschrift Für Säugetierkunde*, 90, 55–65.
<https://doi.org/10.1016/j.mambio.2018.02.008>
- Betts, M. G., Forbes, G. J., & Diamond, A. W. (2007). Thresholds in Songbird Occurrence in Relation to Landscape Structure. *Conservation Biology*, 21(4), 1046–1058. <https://doi.org/10.1111/j.1523-1739.2007.00723.x>
- Bowers, M., Welch, D. N., & Carr, T. G. (1990). Home range size adjustments by the eastern chipmunk, *Tamias striatus*, in response to natural and manipulated water availability. *Canadian Journal of Zoology*, 68(9), 2016–2020.
<https://doi.org/10.1139/z90-284>
- Bowman, J., & Fahrig, L. (2002). Gap crossing by chipmunks: an experimental test of landscape connectivity. *Canadian Journal of Zoology*, 80(9), 1556–1561.
<https://doi.org/10.1139/z02-161>
- Bowman, J., Forbes, G., & Dilworth, T. (2001). Landscape context and small-mammal abundance in a managed forest. *Forest Ecology and Management*, 140(2), 249–255. [https://doi.org/10.1016/S0378-1127\(00\)00315-7](https://doi.org/10.1016/S0378-1127(00)00315-7)
- Bowman, J., Forbes, G. J., & Dilworth, T. G. (2001). The spatial component of variation in small-mammal abundance measured at three scales. *Canadian Journal of Zoology*, 79(1), 137–144. <https://doi.org/10.1139/z00-188>
- Braga, C., Prevedello, J. A., & Pires, M. R. S. (2015). Effects of Cornfields on Small Mammal Communities: A Test in the Atlantic Forest Hotspot. *Journal of Mammalogy*, 96(5), 938–945. <https://doi.org/10.1093/jmammal/gvv094>
- Brannon, M. P. (2005). Distribution and Microhabitat of the Woodland Jumping Mouse, *Napaeozapus insignis*, and the White-footed Mouse, *Peromyscus leucopus*, in the Southern Appalachians. *Southeastern Naturalist* (Steuben, Me.), 4(3), 479–486.
[https://doi.org/10.1656/1528-7092\(2005\)004\[0479:DAMOTW\]2.0.CO;2](https://doi.org/10.1656/1528-7092(2005)004[0479:DAMOTW]2.0.CO;2)
- Brittain, C. M., Forbes, G. J., & Bowman, J. (2005). Significance of *Blarina brevicauda* as a Predator and Source of Trap-Capture Bias on Small Mammals. *Journal of Mammalogy*, 86(3), 606–609. [https://doi.org/10.1644/1545-1542\(2005\)86\[606:SOBBA\]2.0.CO;2](https://doi.org/10.1644/1545-1542(2005)86[606:SOBBA]2.0.CO;2)
- Brower, J. E., & Cade, T. J. (1966). Ecology and Physiology of *Napaeozapus Insignis* (Miller) and Other Woodland Mice. *Ecology* (Durham), 47(1), 46–63.
<https://doi.org/10.2307/1935743>
- Buckner, C., & Shure, D. (1985). The Response of *Peromyscus* to Forest Opening Size in the Southern Appalachian Mountains. *Journal of Mammalogy*, 66(2), 299–307.
<https://doi.org/10.2307/1381242>
- Burnham, K. P., & Anderson, D. R. (2002). *Model selection and multimodel inference : a practical information-theoretic approach* (Second edition.). Springer.
<https://doi.org/10.1007/b97636>

- Butet, A., Michel, N., Rantier, Y., Comor, V., Hubert-Moy, L., Nabucet, J., & Delettre, Y. (2010). Responses of common buzzard (*Buteo buteo*) and Eurasian kestrel (*Falco tinnunculus*) to land use changes in agricultural landscapes of Western France. *Agriculture, Ecosystems & Environment*, 138(3), 152–159. <https://doi.org/10.1016/j.agee.2010.04.011>
- Chao, A., Chazdon, R. L., Colwell, R. K., & Shen, T. J. (2005). A new statistical approach for assessing similarity of species composition with incidence and abundance data: A new statistical approach for assessing similarity. *Ecology Letters*, 8(2), 148–159. <https://doi.org/10.1111/j.1461-0248.2004.00707.x>
- Chisholm, C., Lindo, Z., & Gonzalez, A. (2011). Metacommunity diversity depends on connectivity and patch arrangement in heterogeneous habitat networks. *Ecography (Copenhagen)*, 34(3), 415–424. <https://doi.org/10.1111/j.1600-0587.2010.06588.x>
- Clermont, J., Couchoux, C., Garant, D., & Réale, D. (2017). Assessing anti-predator decisions of foraging eastern chipmunks under varying perceived risks: the effects of physical and social environments on vigilance. *Behaviour*, 154(2), 131–148. <https://doi.org/10.1163/1568539X-00003414>
- Crooks, K. R., Burdett, C. L., Theobald, D. M., King, S. R. B., Di Marco, M., Rondinini, C., & Boitani, L. (2017). Quantification of habitat fragmentation reveals extinction risk in terrestrial mammals. *Proceedings of the National Academy of Sciences - PNAS*, 114(29), 7635–7640. <https://doi.org/10.1073/pnas.1705769114>
- Cummings, J. R., & Vessey, S. H. (1994). Agricultural influences on movement patterns of white-footed mice (*Peromyscus leucopus*). *The American Midland Naturalist*, 132(2), 209–218. <https://doi.org/10.2307/2426575>
- Cushman, S. A. (2006). Effects of habitat loss and fragmentation on amphibians: A review and prospectus. *Biological Conservation*, 128(2), 231–240. <https://doi.org/10.1016/j.biocon.2005.09.031>
- D'Amico, M., Clevenger, A. P., Román, J., & Revilla, E. (2015). General versus specific surveys: Estimating the suitability of different road-crossing structures for small mammals. *The Journal of Wildlife Management*, 79(5), 854–860. <https://doi.org/10.1002/jwmg.900>
- Darling, A. F., Leston, L., & Bayne, E.M. (2019). Small-mammal abundance differs between pipelines, edges, and interior boreal forest habitat. *Canadian Journal of Zoology*, 97(10), 880–894. <https://doi.org/10.1139/cjz-2018-0314>
- Denomme-Brown, S. T., Cottenie, K., Falls, J. B., Falls, E. A., Brooks, R. J., & McAdam, A. G. (2020). Variation in space and time: a long-term examination of density-dependent dispersal in a woodland rodent. *Oecologia*, 193(4), 903–912. <https://doi.org/10.1007/s00442-020-04728-3>
- Dijak, W. D., & Thompson, F. R. (2000). Landscape and Edge Effects on the Distribution of Mammalian Predators in Missouri. *The Journal of Wildlife Management*, 64(1), 209–216. <https://doi.org/10.2307/3802992>

- Fahrig, L. (2017). Ecological Responses to Habitat Fragmentation Per Se. Annual Review of Ecology, Evolution, and Systematics, 48(1), 1–23. <https://doi.org/10.1146/annurev-ecolsys-110316-022612>
- Fahrig, L., & Merriam, G. (1985). Habitat Patch Connectivity and Population Survival. Ecology (Durham), 66(6), 1762–1768. <https://doi.org/10.2307/2937372>
- Fahrig, L., Arroyo-Rodríguez, V., Bennett, J. R., Boucher-Lalonde, V., Cazetta, E., Currie, D. J., Eigenbrod, F., Ford, A. T., Harrison, S. P., Jaeger, J. A. ., Koper, N., Martin, A. E., Martin, J.-L., Metzger, J. P., Morrison, P., Rhodes, J. R., Saunders, D. A., Simberloff, D., Smith, A. C., Watling, J. I. (2019). Is habitat fragmentation bad for biodiversity? Biological Conservation, 230, 179–186. <https://doi.org/10.1016/j.biocon.2018.12.026>
- Fahrig. (2003). Effects of Habitat Fragmentation on Biodiversity. Annual Review of Ecology, Evolution, and Systematics, 34(1), 487–515. <https://doi.org/10.1146/annurev.ecolsys.34.011802.132419>
- Fischer, C., & Schröder, B. (2014). Predicting spatial and temporal habitat use of rodents in a highly intensive agricultural area. Agriculture, Ecosystems & Environment, 189, 145–153. <https://doi.org/10.1016/j.agee.2014.03.039>
- Fisher, J. T., & Merriam, G. (2000). Resource patch array use by two squirrel species in an agricultural landscape. Landscape Ecology, 15(4), 333–338. <https://doi.org/10.1023/A:1008137506634>
- Fitzgibbon, C. D. (1993). The Distribution of Grey Squirrel Dreys in Farm Woodland: The Influence of Wood Area, Isolation and Management. The Journal of Applied Ecology, 30(4), 736–742. <https://doi.org/10.2307/2404251>
- Fletcher, R. J., Didham, R. K., Banks-Leite, C., Barlow, J., Ewers, R. M., Rosindell, J., Holt, R. D., Gonzalez, A., Pardini, R., Damschen, E. I., Melo, F. P. ., Ries, L., Prevedello, J. A., Tscharntke, T., Laurance, W. F., Lovejoy, T., & Haddad, N. M. (2018). Is habitat fragmentation good for biodiversity? Biological Conservation, 226, 9–15. <https://doi.org/10.1016/j.biocon.2018.07.022>
- Ford, A. T., & Fahrig, L. (2008). Movement Patterns of Eastern Chipmunks (*Tamias striatus*) Near Roads. Journal of Mammalogy, 89(4), 895–903. <https://doi.org/10.1644/07-MAMM-A-320.1>
- Fuentes-Montemayor, E., Watts, K., Macgregor, N. A., Lopez-Gallego, Z., & Park, J. K. (2017). Species mobility and landscape context determine the importance of local and landscape-level attributes. Ecological Applications, 27(5), 1541–1554. <https://doi.org/10.1002/eap.1546>
- Gabriel, J. (2021). The independent effects of forest amount, fragmentation and connectivitiy on forest understory plant diversity. [Unpublished master's thesis]. Carleton University.

- Gehring, T. M., & Swihart, R. K. (2003). Body size, niche breadth, and ecologically scaled responses to habitat fragmentation: mammalian predators in an agricultural landscape. *Biological Conservation*, 109(2), 283–295. [https://doi.org/10.1016/S0006-3207\(02\)00156-8](https://doi.org/10.1016/S0006-3207(02)00156-8)
- Gehring, T. M., Cline, E. E., & Swihart, R. K. (2021). Habitat use by Long-tailed Weasels in a Fragmented Agricultural Landscape. *The American Midland Naturalist*, 186(1), 136+. https://link.gale.com/apps/doc/A672016666/AONE?u=ocul_carleton&sid=bookmark-AONE&xid=1cd5d99b
- Gelling, M., Macdonald, D. W., & Mathews, F. (2007). Are hedgerows the route to increased farmland small mammal density? Use of hedgerows in British pastoral habitats. *Landscape Ecology*, 22(7), 1019–1032. <https://doi.org/10.1007/s10980-007-9088-4>
- Gentili, S., Sigura, M., & Bonesi, L. (2014). Decreased small mammals species diversity and increased population abundance along a gradient of agricultural intensification. *Hystrix*, 25(1), 39–44. <https://doi.org/10.4404/hystrix-25.1-9246>
- Gilbert-Norton, L., Wilson, R., Stevens, J. R., & Beard, K. H. (2010). A Meta-Analytic Review of Corridor Effectiveness. *Conservation Biology*, 24(3), 660–668. <https://doi.org/10.1111/j.1523-1739.2010.01450.x>
- Google Earth. (2019). Ottawa area, ON, CA. 45.627901, -76.414735; 44.625144, -74.280696. Landsat, Copernicus, 2019. www.google.com/earth. [Accessed Sept 2019].
- Haddad, N. M., Bowne, D. R., Cunningham, A., Danielson, B. J., Levey, D. J., Sargent, S., & Spira, T. (2003). Corridor Use by Diverse Taxa. *Ecology (Durham)*, 84(3), 609–615. [https://doi.org/10.1890/0012-9658\(2003\)084\[0609:CUDT\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2003)084[0609:CUDT]2.0.CO;2)
- Haddad, N. M., Gonzalez, A., Brudvig, L. A., Burt, M. A., Levey, D. J., & Damschen, E. I. (2017). Experimental evidence does not support the Habitat Amount Hypothesis. *Ecography (Copenhagen)*, 40(1), 48–55. <https://doi.org/10.1111/ecog.02535>
- Halliday, W. D., & Morris, D. W. (2013). Safety from predators or competitors? Interference competition leads to apparent predation risk. *Journal of Mammalogy*, 94(6), 1380–1392. <http://www.jstor.org/stable/24575314>
- Henein, K., Wegner, J., & Merriam, G. (1998). Population Effects of Landscape Model Manipulation on Two Behaviourally Different Woodland Small Mammals. *Oikos*, 81(1), 168–186. <https://doi.org/10.2307/3546479>
- Hurst, Z. M., McCleery, R. A., Collier, B. A., Silvy, N. J., Taylor, P. J., & Monadjem, A. (2014). Linking changes in small mammal communities to ecosystem functions in an agricultural landscape. *Mammalian Biology : Zeitschrift Für Säugetierkunde*, 79(1), 17–23. <https://doi.org/10.1016/j.mambio.2013.08.008>

- Horskins, K., Mather, P. B., & Wilson, J. C. (2006). Corridors and connectivity: when use and function do not equate. *Landscape Ecology*, 21(5), 641–655. <https://doi.org/10.1007/s10980-005-5203-6>
- Hurvich, C. M., & Tsai, C. L. (1993). A Corrected Akaike Information Criterion for Vector Autoregressive Model Selection. *Journal of Time Series Analysis*, 14(3), 271–279. <https://doi.org/10.1111/j.1467-9892.1993.tb00144.x>
- Jackson, H. B., & Fahrig, L. (2012). What size is a biologically relevant landscape? *Landscape Ecology*, 27(7), 929–941. <https://doi.org/10.1007/s10980-012-9757-9>
- Jennerston, O. (1988). Pollination in *Dianthus deltoides* (Caryophyllaceae): Effects of Habitat Fragmentation on Visitation and Seed Set. *Conservation Biology : the Journal of the Society for Conservation Biology.*, 2(4), 359–366. <https://doi.org/10.1111/j.1523-1739.1988.tb00200.x>
- Kierepka, E. M., Anderson, S. J., Swihart, R. K., & Rhodes, J. (2020). Differing, multiscale landscape effects on genetic diversity and differentiation in eastern chipmunks. *Heredity*, 124(3), 457–468. <https://doi.org/10.1038/s41437-020-0293-0>
- King, A. W., & With, K. A. (2002). Dispersal success on spatially structured landscapes: when do spatial pattern and dispersal behavior really matter? *Ecological Modelling*, 147(1), 23–39. [https://doi.org/10.1016/S0304-3800\(01\)00400-8](https://doi.org/10.1016/S0304-3800(01)00400-8)
- Laundré, J. W., Hernández, L., Medina, P. L., Campanella, A., López-Portillo, J., González-Romero, A., Grajales-Tam, K. M., Burke, A. M., Gronemeyer, P., & Browning, D. M. (2014). The landscape of fear: the missing link to understand top-down and bottom-up controls of prey abundance? *Ecology (Durham)*, 95(5), 1141–1152. <https://doi.org/10.1890/13-1083.1>
- Lenoir, J., Decocq, G., Spicher, F., Gallet-Moron, E., Buridant, J., Closset-Kopp, D., & Hédl, R. (2021). Historical continuity and spatial connectivity ensure hedgerows are effective corridors for forest plants: Evidence from the species–time–area relationship. *Journal of Vegetation Science*, 32(1), e12845–n/a. <https://doi.org/10.1111/jvs.12845>
- Lindenmayer, D. B., Blanchard, W., Foster, C. N., Scheele, B. C., Westgate, M. J., Stein, J., Crane, M., & Florance, D. (2020). Habitat amount versus connectivity: An empirical study of bird responses. *Biological Conservation*, 241, 108377–. <https://doi.org/10.1016/j.biocon.2019.108377>
- Loggins, A., Shrader, A. M., Monadjem, A., & McCleery, R. A. (2019). Shrub cover homogenizes small mammals' activity and perceived predation risk. *Scientific Reports*, 9(1), 16857–11. <https://doi.org/10.1038/s41598-019-53071-y>
- Malmivaara-Lämsä, M., Hamberg, L., Haapamäki, E., Liski, J., Kotze, D. J., Lehvävirta, S., & Fritze, H. (2008). Edge effects and trampling in boreal urban forest fragments – impacts on the soil microbial community. *Soil Biology & Biochemistry*, 40(7), 1612–1621. <https://doi.org/10.1016/j.soilbio.2008.01.013>

- Marrotte, R. R., Bowman, J., Brown, M. G. , Cordes, C., Morris, K. Y., Prentice, M. B., & Wilson, P. J. (2017). Multi-species genetic connectivity in a terrestrial habitat network. *Movement Ecology*, 5(1), 21–21. <https://doi.org/10.1186/s40462-017-0112-2>
- Martin, A. E., & Fahrig, L. (2012). Measuring and selecting scales of effect for landscape predictors in species-habitat models. *Ecological Applications*, 22(8), 2277–2292. <https://doi.org/10.1890/11-2224.1>
- Melo, G. L., Sponchiado, J., Cáceres, N. C., & Fahrig, L. (2017). Testing the habitat amount hypothesis for South American small mammals. *Biological Conservation*, 209, 304–314. <https://doi.org/10.1016/j.biocon.2017.02.031>
- Menzel, M. A., Ford, W. M., Laerm, J., & Krishon, D. (1999). Forest to wildlife opening: habitat gradient analysis among small mammals in the southern Appalachians. *Forest Ecology and Management*, 114(2), 227–232. [https://doi.org/10.1016/S0378-1127\(98\)00353-3](https://doi.org/10.1016/S0378-1127(98)00353-3)
- Metzger, J. P., & Décamps, H. (1997). The structural connectivity threshold: An hypothesis in conservation biology at the landscape scale. *Acta Oecologica (Montrouge)*, 18(1), 1–12. [https://doi.org/10.1016/S1146-609X\(97\)80075-6](https://doi.org/10.1016/S1146-609X(97)80075-6)
- Middleton, J., & Merriam, G. (1981). Woodland Mice in a Farmland Mosaic. *The Journal of Applied Ecology*, 18(3), 703–710. <https://doi.org/10.2307/2402362>
- Montiglio, P., Garant, D., Bergeron, P., Messier, G. D., Réale, D., & Quinn, J. (2014). Pulsed resources and the coupling between life-history strategies and exploration patterns in eastern chipmunks (*Tamias striatus*). *The Journal of Animal Ecology*, 83(3), 720–728. <https://doi.org/10.1111/1365-2656.12174>
- Moore, J. E., & Swihart, R. K. (2005). Modeling Patch Occupancy by Forest Rodents: Incorporating Detectability and Spatial Autocorrelation with Hierarchically Structured Data. *The Journal of Wildlife Management*, 69(3), 933–949. [https://doi.org/10.2193/0022-541X\(2005\)069\[0933:MPOBFR\]2.0.CO;2](https://doi.org/10.2193/0022-541X(2005)069[0933:MPOBFR]2.0.CO;2)
- Moraga, A. D., Martin, A. E., & Fahrig, L. (2019). The scale of effect of landscape context varies with the species' response variable measured. *Landscape Ecology*, 34(4), 703–715. <https://doi.org/10.1007/s10980-019-00808-9>
- Morris. (1986). Proximate and Ultimate Controls on Life-History Variation: The Evolution of Litter Size in White-Footed Mice (*Peromyscus leucopus*). *Evolution*, 40(1), 169–181. <https://doi.org/10.1111/j.1558-5646.1986.tb05728.x>
- Mortelliti, A., Amori, G., Capizzi, D., Cervone, C., Fagiani, S., Pollini, B., & Boitani, L. (2011). Independent effects of habitat loss, habitat fragmentation and structural connectivity on the distribution of two arboreal rodents. *The Journal of Applied Ecology*, 48(1), 153–162. <https://doi.org/10.1111/j.1365-2664.2010.01918.x>

- Nams, V. O., & Gillis, E. A. (2003). Changes in Tracking Tube Use by Small Mammals over Time. *Journal of Mammalogy*, 84(4), 1374–1380.
<https://doi.org/10.1644/BEH-001>
- Newbold, T., Hudson, L. N., Contu, S., Hill, S. L. L., Beck, J., Liu, Y., Meyer, C., Phillips, H. R. P., Scharlemann, J. P. W., & Purvis, A. (2018). Widespread winners and narrow-ranged losers: Land use homogenizes biodiversity in local assemblages worldwide. *PLoS Biology*, 16(12), e2006841–e2006841.
<https://doi.org/10.1371/journal.pbio.2006841>
- Nupp, T. E., & Swihart, R. K. (1996). Effect of forest patch area on population attributes of white-footed mice (*Peromyscus leucopus*) in fragmented landscapes. *Canadian Journal of Zoology*, 74(3), 467–472. <https://doi.org/10.1139/z96-054>
- Nupp, T. E., & Swihart, R. K. (2000). Landscape-Level Correlates of Small-Mammal Assemblages in Forest Fragments of Farmland. *Journal of Mammalogy*, 81(2), 512–526. [https://doi.org/10.1644/1545-1542\(2000\)081<0512:LLCOSM>2.0.CO;2](https://doi.org/10.1644/1545-1542(2000)081<0512:LLCOSM>2.0.CO;2)
- Oddy, D. M., Stolen, E. D., Gann, S. L., Legare, S. A., Weiss, S. K., & Holloway-Adkins, K. G. (2018). Increasing Detection by Reducing Disturbance and Excluding Nontarget Small Mammal Species: An Occupancy Study Approach. *Journal of Fish and Wildlife Management*, 9(2), 383–392.
<https://doi.org/10.3996/072017-JFWM-057>
- Ontario Ministry of Natural Resources (2021b). OLCC v.2.0.
<https://www.arcgis.com/home/item.html?id=7aa998fdf100434da27a41f1c637382c> [Accessed Oct 2021].
- Ontario Ministry of Natural Resources (OMNR). (2021). Forest regions. Ministry of Natural Resources, Ontario, CA. <https://www.ontario.ca/page/forest-regions> [Accessed Sept 27, 2021].
- Orrock, J. L., Farley, D., & Pagels, J. F. (2003). Does fungus consumption by the woodland jumping mouse vary with habitat type or the abundance of other small mammals? *Canadian Journal of Zoology*, 81(4), 753–756.
<https://doi.org/10.1139/z03-035>
- Pardini, R., Bueno, A. de A., Gardner, T. A., Prado, P. I., & Metzger, J. P. (2010). Beyond the fragmentation threshold hypothesis: regime shifts in biodiversity across fragmented landscapes. *PloS One*, 5(10), e13666–e13666.
<https://doi.org/10.1371/journal.pone.0013666>
- Patterson, J. E. H., & Malcolm, J. R. (2010). Landscape structure and local habitat characteristics as correlates of *Glaucomys sabrinus* and *Tamiasciurus hudsonicus* occurrence. *Journal of Mammalogy*, 91(3), 642–653. <https://doi.org/10.1644/09-MAMM-A-118.1>
- Perea, R., Miguel, A. S., & Gil, L. (2011). Acorn dispersal by rodents: The importance of re-dispersal and distance to shelter. *Basic and Applied Ecology*, 12(5), 432–439.
<https://doi.org/10.1016/j.baae.2011.05.002>

- Pielou, E. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology*, 13(C), 131–144. [https://doi.org/10.1016/0022-5193\(66\)90013-0](https://doi.org/10.1016/0022-5193(66)90013-0)
- Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in Ecology & Evolution* (Amsterdam), 25(6), 345–353. <https://doi.org/10.1016/j.tree.2010.01.007>
- QGIS Development Team. (2019). QGIS Geographic Information System. Open Source Geospatial Foundation Project. <http://qgis.osgeo.org>.
- Reunanen, P., & Grubb, T. C. (2005). Densities of Eastern Chipmunks (*Tamias striatus*) in Farmland Woodlots Decline with Increasing Area and Isolation. *The American Midland Naturalist*, 154(2), 433–441. [https://doi.org/10.1674/0003-0031\(2005\)154\[0433:DOECTS\]2.0.CO;2](https://doi.org/10.1674/0003-0031(2005)154[0433:DOECTS]2.0.CO;2)
- Riggio, J., Baillie, J. E. M., Brumby, S., Ellis, E., Kennedy, C. M., Oakleaf, J. R., Tait, A., Tepe, T., Theobald, D. M., Venter, O., Watson, J. E. M., & Jacobson, A. P. (2020). Global human influence maps reveal clear opportunities in conserving Earth's remaining intact terrestrial ecosystems. *Global Change Biology*, 26(8), 4344–4356. <https://doi.org/10.1111/gcb.15109>
- Rizkalla, C. E., & Swihart, R. K. (2007). Explaining movement decisions of forest rodents in fragmented landscapes. *Biological Conservation*, 140(3), 339–348. <https://doi.org/10.1016/j.biocon.2007.08.019>
- Rizkalla, C. E., Moore, J. E., & Swihart, R. K. (2009). Modeling patch occupancy: Relative performance of ecologically scaled landscape indices. *Landscape Ecology*, 24(1), 77–88. <https://doi.org/10.1007/s10980-008-9281-0>
- Rodríguez-San Pedro, A., & Simonetti, J.A. (2015). The relative influence of forest loss and fragmentation on insectivorous bats: does the type of matrix matter? *Landscape Ecology*, 30(8), 1561–1572. <https://doi.org/10.1007/s10980-015-0213-5>
- Rytwinski, T. (2006). The effect of road density on white-footed mice (*Peromyscus leucopus*) relative abundance in rural and urban landscapes in eastern Ontario . Thesis (M.Sc.) - Carleton University, 2006.
- Saura, S., Bodin, Ö., & Fortin, M. J. (2014). Stepping stones are crucial for species' long-distance dispersal and range expansion through habitat networks. *The Journal of Applied Ecology*, 51(1), 171–182. <https://doi.org/10.1111/1365-2664.12179>
- Schmid-Holmes, S., & Drickamer, L. C. (2001). Impact of forest patch characteristics on small mammal communities: a multivariate approach. *Biological Conservation*, 99(3), 293–305. [https://doi.org/10.1016/S0006-3207\(00\)00195-6](https://doi.org/10.1016/S0006-3207(00)00195-6)
- Schulte-Hostedde, A. I., & Brooks, R. J. (1997). An experimental test of habitat selection by rodents of Algonquin Park. *Canadian Journal of Zoology*, 75(12), 1989–1993. <https://doi.org/10.1139/z97-831>

- Séchaud, R., Schalcher, K., Machado, A. P., Almasi, B., Massa, C., Safi, K., & Roulin, A. (2021). Behaviour-specific habitat selection patterns of breeding barn owls. *Movement Ecology*, 9(1), 18–18. <https://doi.org/10.1186/s40462-021-00258-6>
- Sekgororoane, G. B., & Dilworth, T. G. (1995). Relative abundance, richness, and diversity of small mammals at induced forest edges. *Canadian Journal of Zoology*, 73(8), 1432–1437. <https://doi.org/10.1139/z95-168>
- Silva, M., & Prince, M. E. (2008). The Conservation Value of Hedgerows for Small Mammals in Prince Edward Island, Canada. *The American Midland Naturalist*, 159(1), 110–124. [https://doi.org/10.1674/0003-0031\(2008\)159\[110:TCVOHF\]2.0.CO;2](https://doi.org/10.1674/0003-0031(2008)159[110:TCVOHF]2.0.CO;2)
- Silva, M., Hartling, L., & Opps, S. B. (2005). Small mammals in agricultural landscapes of Prince Edward Island (Canada): Effects of habitat characteristics at three different spatial scales. *Biological Conservation*, 126(4), 556–568. <https://doi.org/10.1016/j.biocon.2005.07.007>
- Sirami, C., Gross, N., Baillod, A. B., Bertrand, C., Carrié, R., Hass, A., Henckel, L., Miguet, P., Vuillot, C., Alignier, A., Girard, J., Batáry, P., Clough, Y., Violle, C., Giralt, D., Bota, G., Badenhausser, I., Lefebvre, G., Gauffre, B., ... Fahrig, L. (2019). Increasing crop heterogeneity enhances multitrophic diversity across agricultural regions. *Proceedings of the National Academy of Sciences - PNAS*, 116(33), 16442–16447. <https://doi.org/10.1073/pnas.1906419116>
- Slancarova, Benes, J., Kristynek, M., Kepka, P., & Konvicka, M. (2013). Does the surrounding landscape heterogeneity affect the butterflies of insular grassland reserves? A contrast between composition and configuration. *Journal of Insect Conservation*, 18(1), 1–12. <https://doi.org/10.1007/s10841-013-9607-3>
- Steele, M. A. (1998). *Tamiasciurus hudsonicus*. *Mammalian Species* 586:1–9.
- Stein, A., Gerstner, K., & Kreft, H. (2014). Environmental heterogeneity as a universal driver of species richness across taxa, biomes and spatial scales. *Ecology Letters*, 17(7), 866–880. <https://doi.org/10.1111/ele.12277>
- Stephens, R. B. (2018). Small Mammal Community Dynamics and the Dispersal of Mycorrhizal Fungi. ProQuest Dissertations Publishing.
- Sullivan, T. & Sullivan, D. S. (2014). Responses of red-backed voles (*Myodes gapperi*) to windrows of woody debris along forest-clearcut edges. *Wildlife Research (East Melbourne)*, 41(3), 212–221. <https://doi.org/10.1071/WR14050>
- Taylor, P. D., Fahrig, L., Henein, K., & Merriam, G. (1993). Connectivity Is a Vital Element of Landscape Structure. *Oikos*, 68(3), 571–573. <https://doi.org/10.2307/3544927>
- Tischendorf, L., Grez, A., Zaviezo, T., & Fahrig, L. (2005). Mechanisms Affecting Population Density in Fragmented Habitat. *Ecology and Society*, 10(1), 7–. <https://doi.org/10.5751/ES-01265-100107>

- Tisell, H. B. (2018). Home Range and Microhabitat Associations of the Southern Red-backed Vole (*Myodes gapperi*) in New Hampshire Forests. ProQuest Dissertations Publishing.
- Vieira, M. V., Olifiers, N., Delciellos, A. C., Antunes, V. Z., Bernardo, L. R., Grelle, C. E., & Cerqueira, R. (2009). Land use vs. fragment size and isolation as determinants of small mammal composition and richness in Atlantic Forest remnants. *Biological Conservation*, 142(6), 1191–1200. <https://doi.org/10.1016/j.biocon.2009.02.006>
- Watling, J. I., Arroyo-Rodríguez, V., Pfeifer, M., Baeten, L., Banks-Leite, C., Cisneros, L. M., Fang, R., Hamel-Leigue, A. C., Lachat, T., Leal, I. R., Lens, L., Possingham, H. P., Raheem, D. C., Ribeiro, D. B., Slade, E. M., Urbina-Cardona, J. N., Wood, E. M., Fahrig, L., & Storch, D. (2020). Support for the habitat amount hypothesis from a global synthesis of species density studies. *Ecology Letters*, 23(4), 674–681. <https://doi.org/10.1111/ele.13471>
- Wehling, S., & Diekmann, M. (2009). Importance of hedgerows as habitat corridors for forest plants in agricultural landscapes. *Biological Conservation*, 142(11), 2522–2530. <https://doi.org/10.1016/j.biocon.2009.05.023>
- Whitaker, J. O. (1963). Food, Habitat and Parasites of the Woodland Jumping Mouse in Central New York. *Journal of Mammalogy*, 44(3), 316–321. <https://doi.org/10.2307/1377201>
- Wolf, M., & Batzli, G. (2004). Forest Edge: High or Low Quality Habitat for White-footed Mice (*Peromyscus leucopus*)? *Ecology (Durham)*, 85(3), 756–769. <https://doi.org/10.1890/02-0474>
- Wolton, R. (2009). Hazel dormouse *Muscardinus avellanarius* (L.) nest site selection in hedgerows. *Mammalia (Paris)*, 73(1), 7–12. <https://doi.org/10.1515/MAMM.2009.001>
- Xu, Y., Si, Y., Wang, Y., Zhang, Y., Prins, H. H., Cao, L., & de Boer, W. F. (2019). Loss of functional connectivity in migration networks induces population decline in migratory birds. *Ecological Applications*, 29(7), 1–10. <https://doi.org/10.1002/eap.1960>
- Zitske, B. P., Betts, M. G., & Diamond, A. W. (2011). Negative Effects of Habitat Loss on Survival of Migrant Warblers in a Forest Mosaic. *Conservation Biology*, 25(5), 993–1001. <https://doi.org/10.1111/j.1523-1739.2011.01709.x>

Tables

Table 1. Standardized coefficients, confidence intervals (in square brackets), and significance for forest small mammal diversity models. The scales of effect, i.e. distance in m within which the landscape variables were measured, are indicated with each response variable. All diversity indices were standardized. Sampling effort is the number of small mammal footprint tracking papers recovered per site multiplied by the time the papers were deployed. Forest amount and number of patches are the total area of forest (m^2) and the number of forest patches, respectively, in the landscape with the radius of the scale of effect. Patch connectivity is the percentage of patches within the landscape that are directly or indirectly connected to the focal patch via treed corridors. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m tall) at each site. Road density is the area of roads (m^2) divided by the landscape area at the scale of effect. Species richness is the number of small mammal species per site (max= 7). Evenness is Pielou's evenness (Pielou, 1966). Chao's diversity (Chao et al., 2005) is a diversity index that assumes the abundance of rare species is under-estimated.

| Response- Scale | | | |
|-------------------------------------|--------------------------|----------------------------|--------------------------|
| Predictor variables | Richness- 750 m | Evenness- 2000 m | Chao index- 750 m |
| Sampling effort | 0.283* [0.051,0.515] | -0.281* [-0.516,-0.046] | 0.557+ [-0.087,1.201] |
| Forest amount | 0.011 [-0.229,0.250] | 0.032 [-0.205,0.270] | 0.123 [-0.577,0.823] |
| Number of patches | 0.080 [-0.155,0.315] | -0.133 [-0.368,0.101] | 0.241 [-0.408,0.890] |
| Patch connectivity | -0.195 [-0.432,0.041] | -0.028 [-0.268,0.211] | -0.228 [-0.981,0.524] |
| Understory Shannon diversity | | 0.140 [-0.096,0.376] | |
| Road density | | | 0.021 [-0.735,0.778] |

Table 2. Standardized variable coefficients, confidence intervals (in square brackets) and significance for relative abundance models of individual forest small mammal species. All relative abundances were standardized. The scales of effect, i.e. distance in m within which the landscape variables were measured, are indicated with each response variable. Sampling effort is the number of small mammal footprint tracking papers recovered per site multiplied by the time the papers were deployed. Forest amount and number of patches are the total area of forest (m^2) and the number of forest patches, respectively, in the landscape with the radius of the scale of effect. Patch connectivity is the percentage of patches within the landscape that are directly or indirectly connected to the focal patch via treed corridors. Relative abundance is the total number of tracking tubes with the presence of each species (max=144).

| | Response variable- scale | | | | |
|---------------------------|-------------------------------|-------------------------------|------------------------------|---------------------------------|---------------------------------|
| Predictor variables | <i>P. leucopus-</i> 1000 m | <i>T. striatus-</i> 2500 m | <i>M. gapperi-</i> 2500 m | <i>B. brevicauda-</i> 2500 m | <i>T. hudsonicus-</i> 1750 m |
| Sampling effort | 0.225+ [-0.012,0.462] | 0.149 [-0.073,0.371] | 0.218+ [-0.013,0.449] | 0.072 [-0.154,0.298] | 0.303* [0.067,0.540] |
| Forest amount | 0.207+ [-0.031,0.445] | -0.090 [-0.316,0.137] | 0.067 [-0.169,0.303] | -0.115 [-0.346,0.116] | 0.148 [-0.087,0.383] |
| Number of patches | -0.102 [-0.340,0.135] | 0.266* [0.044,0.487] | -0.311** [-0.543,-0.080] | -0.069 [-0.295,0.157] | 0.041 [-0.195,0.276] |
| Patch connectivity | 0.041 [-0.197,0.279] | 0.306** [0.078,0.533] | -0.075 [-0.312,0.162] | 0.424*** [0.192,0.655] | -0.116 [-0.350,0.118] |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table 3. Standardized coefficients, confidence intervals (in square brackets) and significance for occurrence models of forest small mammal species. The scales of effect, i.e. distance in m within which the landscape variables were measured, are indicated with each response variable. Sampling effort is the number of small mammal footprint tracking papers recovered per site multiplied by the time the papers were deployed. Forest amount and number of patches are the total area of forest (m^2) and the number of forest patches, respectively, in the landscape with the radius of the scale of effect. Patch connectivity is the percentage of patches within the landscape that are directly or indirectly connected to the focal patch via treed corridors. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m tall) at each site. Road density is the area of roads (m^2) divided by the landscape area at the scale of effect. Occupancy is the presence of the species at a sampling site.

| | Response variable- scale | | | | |
|-------------------------------------|-------------------------------|------------------------------|--------------------------------|---------------------------------|------------------------------|
| Predictor variables | <i>T. striatus-</i> 2250 m | <i>M. gapperi-</i> 2500 m | <i>B. brevicauda-</i> 750 m | <i>T. hudsonicus-</i> 1000 m | <i>N. insignis-</i> 750 m |
| Sampling effort | -0.123 [-1.170,0.678] | 0.829* [0.177,1.624] | 0.294 [-0.196,0.842] | 0.721* [0.103,1.487] | 0.037 [-0.551,0.743] |
| Forest amount | 0.348 [-0.409,1.201] | 0.520 [-0.451,1.612] | -0.050 [-0.570,0.469] | -0.112 [-0.684,0.455] | -0.255 [-0.936,0.366] |
| Number of patches | 0.549 [-0.270,1.555] | -0.769* [-1.566,-0.074] | 0.234 [-0.275,0.780] | -0.211 [-0.775,0.333] | 0.533+ [-0.056,1.179] |
| Patch connectivity | -0.303 [-1.086,0.663] | 0.018 [-0.701,1.011] | -0.288 [-0.816,0.213] | -0.449 [-1.137,0.155] | -0.699+ [-1.549,-0.009] |
| Understory Shannon diversity | -0.457 [-1.577,0.354] | | | | |
| Road density | | 0.155 [-0.592,1.059] | | 0.566 [-0.103,1.435] | |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Figures

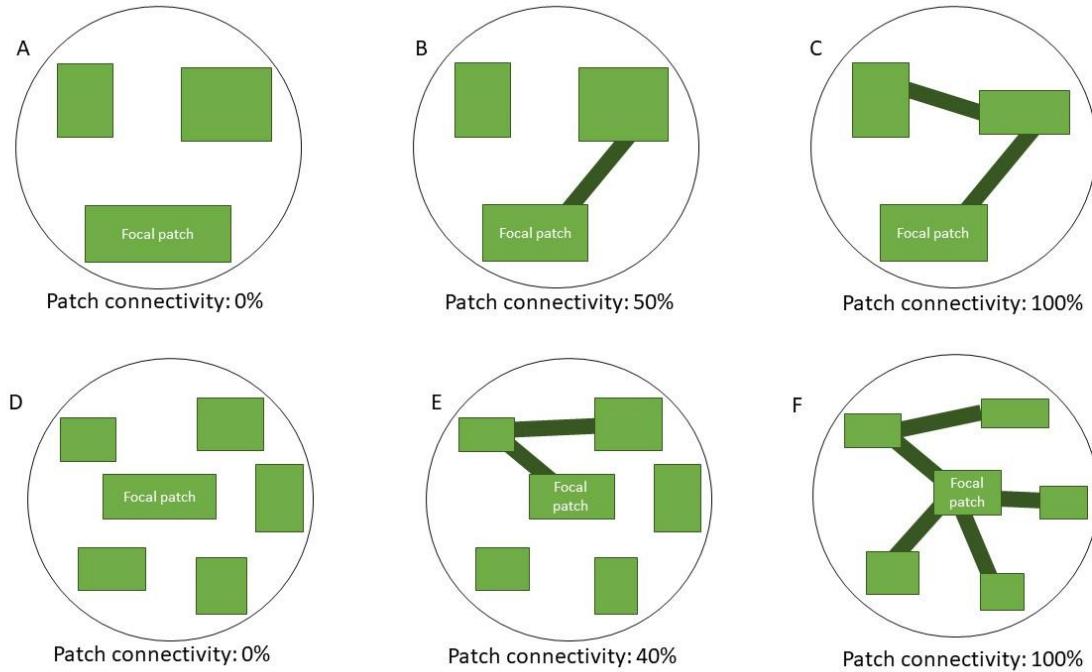


Figure 1. Diagram of habitat fragmentation and patch connectivity for a given total amount of habitat. All landscapes (circles) contain the same amount of habitat (green rectangles), and connections are provided by corridors (dark green lines). Fragmentation is the number of patches, i.e. 3 in the top row and 6 in the bottom row (Henein et al., 1998; Patterson & Malcolm, 2010). Patch connectivity is the number of patches connected to the focal patch (the patch containing the sampling site) directly or indirectly by habitat corridors, divided by the number of patches in the landscape: $C_p = \frac{N_p - 1}{N_L - 1}$, where C_p = patch connectivity, N_p = the number of patches directly or indirectly connected to the focal patch and N_L = the number of patches in the landscape. Note that the patch size in the landscape decreases as connectivity increases to maintain a constant total amount of habitat.

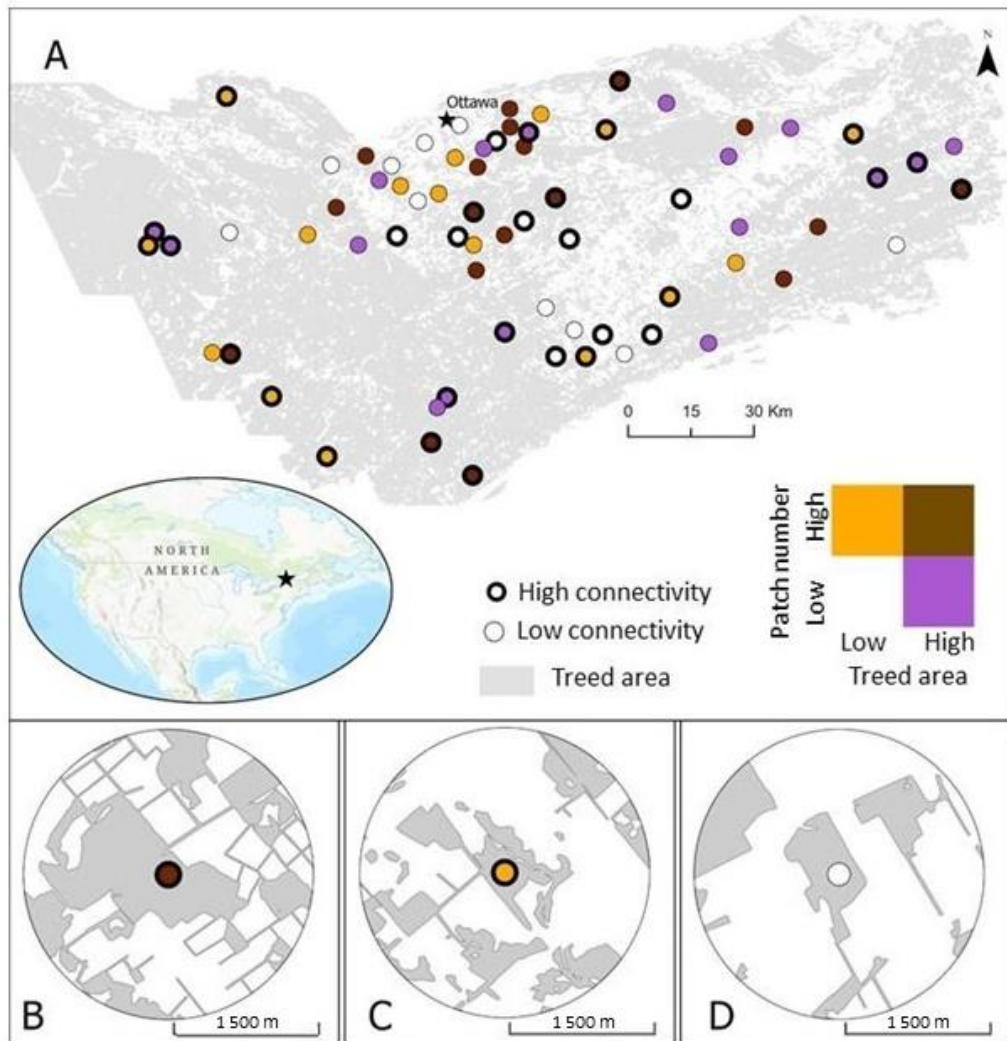


Figure 2. A: Locations of 70 forest small mammal sampling sites and their surrounding landscapes within 1500 m. The treed area is gray. Sites are filled circles, with colours and outline thickness indicating whether the landscape was classed as high or low for each landscape variable. Sites were selected to represent combinations of high and low values for each landscape variable – forest amount, fragmentation (number of patches), and patch connectivity – such that the three variables were only weakly correlated. The classes (high/low) were used for site selection only; the three landscape variables were analyzed as continuous variables in statistical models at 8 spatial scales 750 – 2500 m. In the field, each site had a 30 m x 30 m sampling grid at its centre, consisting of 36 tracking tubes for small mammal detection. **B:** Example site with high forest amount, high number of patches and high patch connectivity within 1 km. **C:** Example site with low forest amount, high number of patches and high patch connectivity within 1 km. **D:** Example site with low forest amount, low number of patches and low patch connectivity within 1 km.

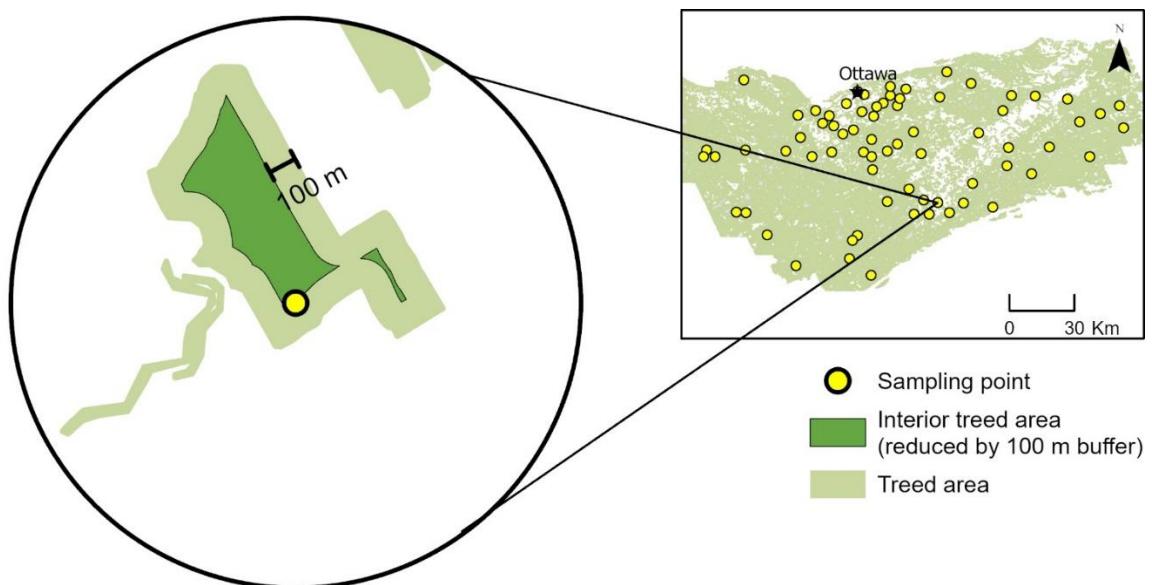


Figure 3. Example of sampling site placement within a focal patch. The interior area was the forested area more than 100 m from the edge, and potential focal patches were patches containing any interior area. The sampling point was in the SW corner of the interior area within each focal patch. For site selection, we measured forest amount, the number of patches, and patch connectivity (Fig. 1) within 1500 m of each potential sampling point in the region.



Figure 4. A: An Eastern chipmunk (*Tamias striatus*) running through a 10 cm diameter tracking tube. B: A footprint tracking paper after two weeks inside a tracking tube. In the center is the inkpad (the pink butcher paper) with black ink, and on one side are chipmunk (*T. striatus*) tracks. This paper was scored as 1, highly readable. C: A white-footed mouse (*P. leucopus*) investigating a 10 cm diameter tracking tube.



Figure 5. A raccoon (*Procyon lotor*) removes a tracking tube paper from a 10 cm diameter tracking tube. The blue arrow is pointing to the tracking paper.

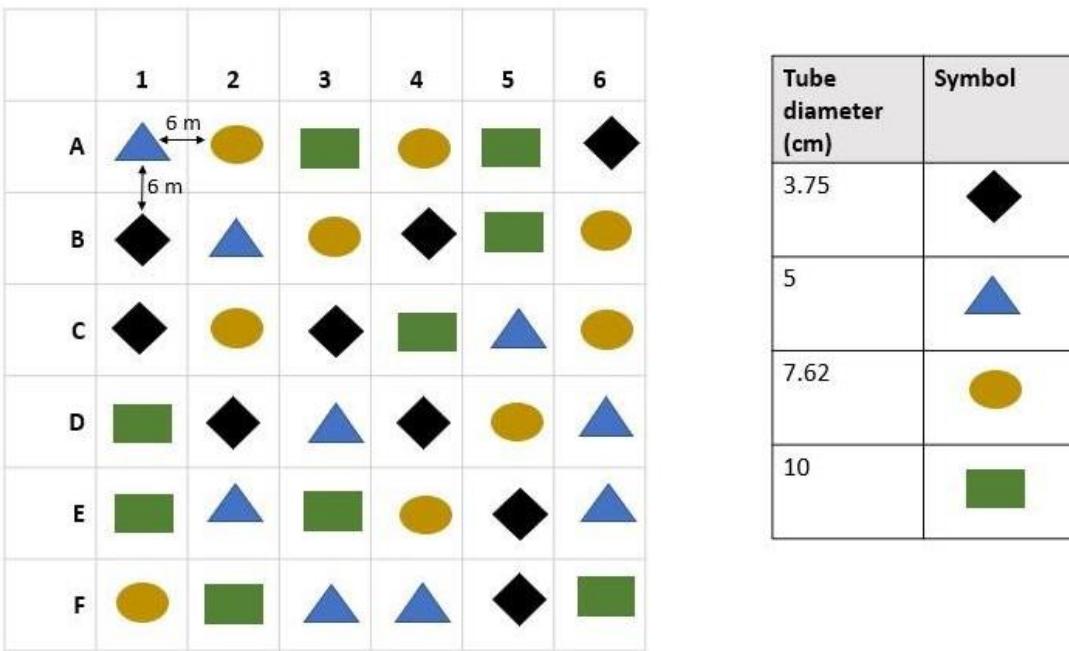


Figure 6. Illustration of the layout of the four sizes of small mammal tracking tubes. The same layout of 36 tubes was used at all 70 sampling sites. Footprint tracking tubes were plastic tubes with a strip of paper inside, with tracking paper having a central ink pad (Fig. 4). Tubes were placed 6 m apart arranged in a grid.

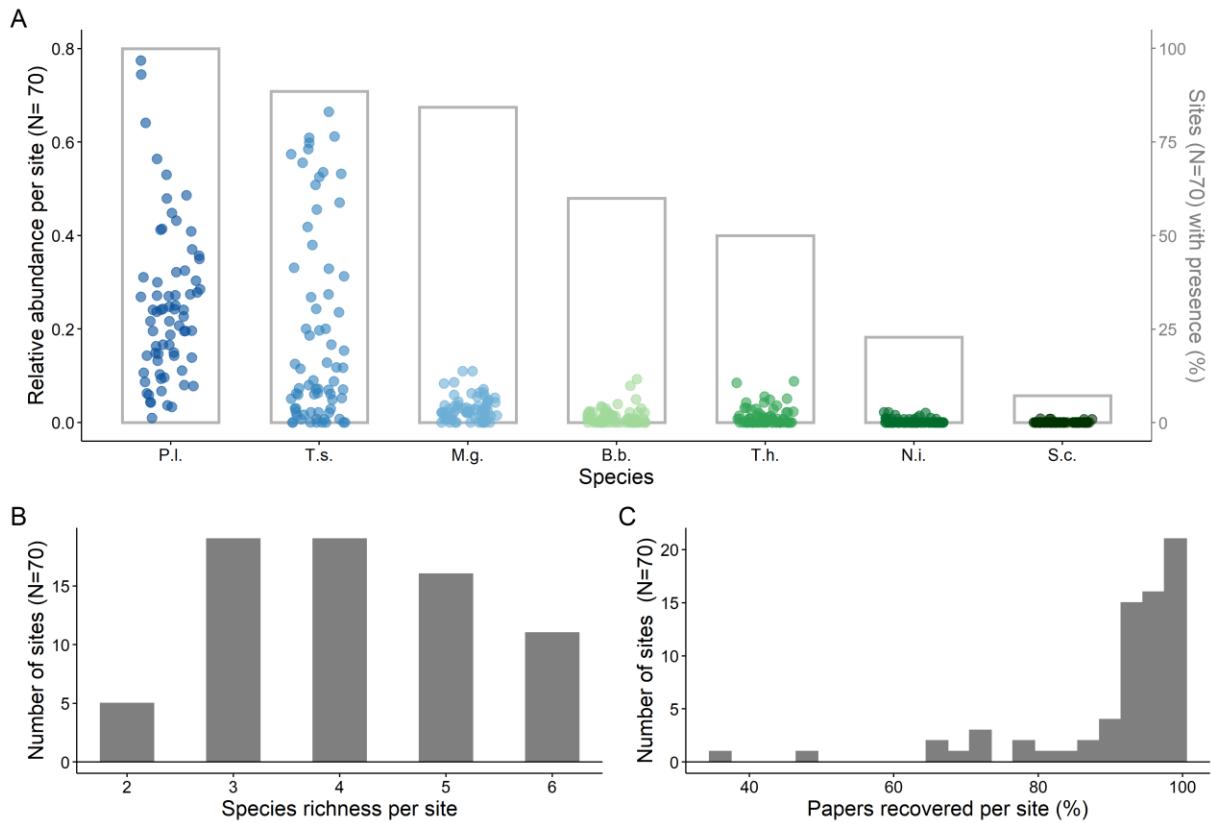


Figure 7. A: Relative abundance and proportional occurrence of the seven forest small mammal species. Each filled-in circle represents the relative abundance (proportion of tracking papers with footprints) per site (N=70). In order of decreasing relative abundance, species detected were *P. leucopus*, *T. striatus*, *M. gapperi*, *B. brevicauda*, *T. hudsonicus*, *N. insignis* and *S. carolinensis*. The right axis is the percentage of sites (N=70) with a species presence, depicted by grey box outlines. B: Histogram of species richness per site (N=70). C: Histogram of the percentage of footprint tracking papers recovered per site (N=70), out of 144 deployed per site. In total, 91% of all papers were recovered. Some papers were destroyed by people, water, slugs, or raccoons (Fig. 5).

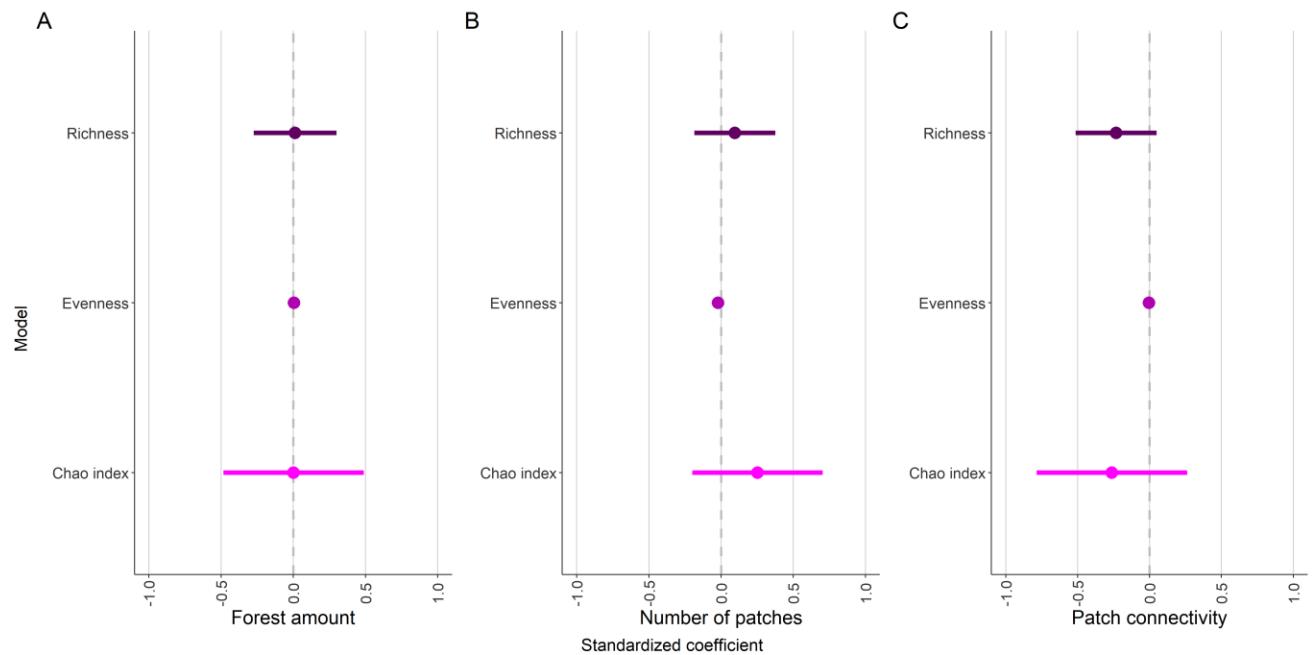


Figure 8. Standardized landscape variable coefficients for models of forest small mammal diversity measures at their scales of effect (see Supplementary Fig. B), with 95% confidence intervals. A: Standardized forest amount coefficients. B: Standardized fragmentation (number of patches) coefficients. C: Standardized patch connectivity coefficients. Species richness is the number of forest small mammal species per site (max= 7). Evenness is Pielou's evenness (Pielou, 1966). Chao's diversity (Chao et al., 2005) is a diversity index that adjusts for an assumed under-estimation of the abundances of rare species.

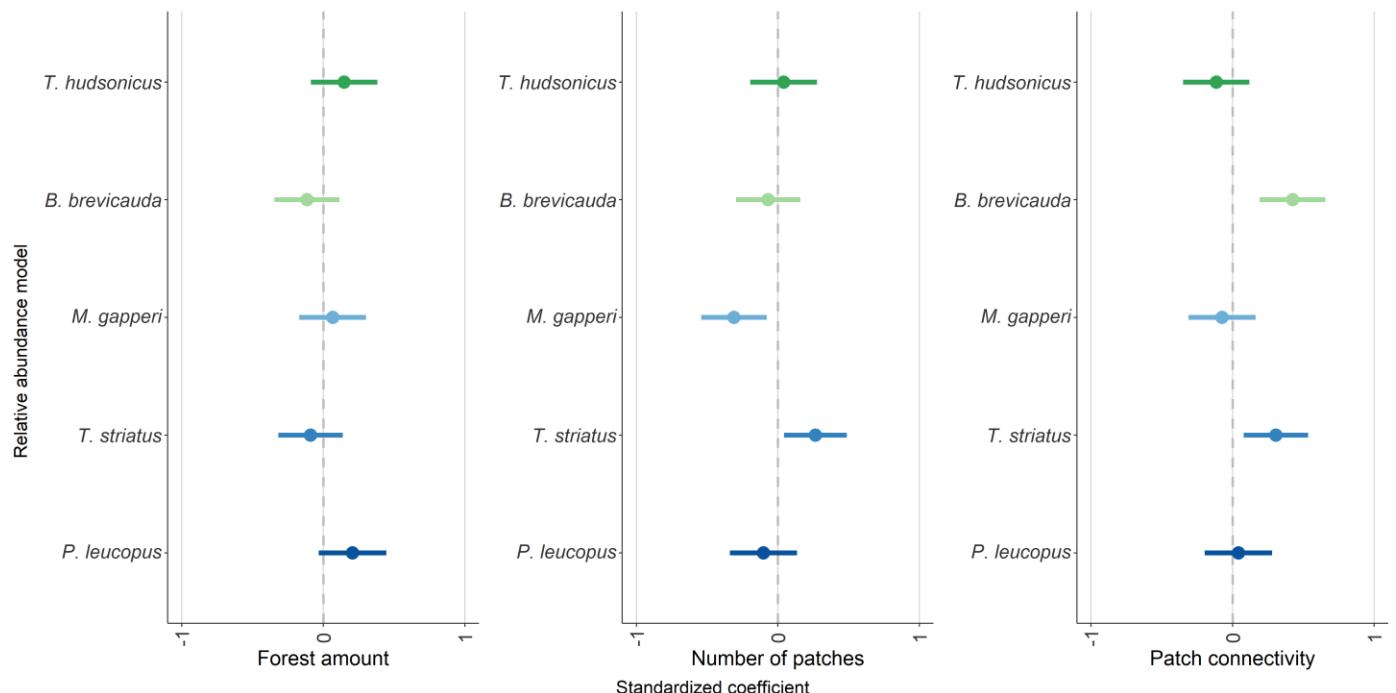


Figure 9. Standardized landscape variable coefficients for forest small mammal relative abundance models at their scales of effect (see Supplementary Fig. C), with 95% confidence intervals. A: Standardized forest amount coefficients. B: Standardized fragmentation (number of patches) coefficients. C: Standardized patch connectivity coefficients. Relative abundance is the total number of tracking tubes with the presence of a species (max=144).

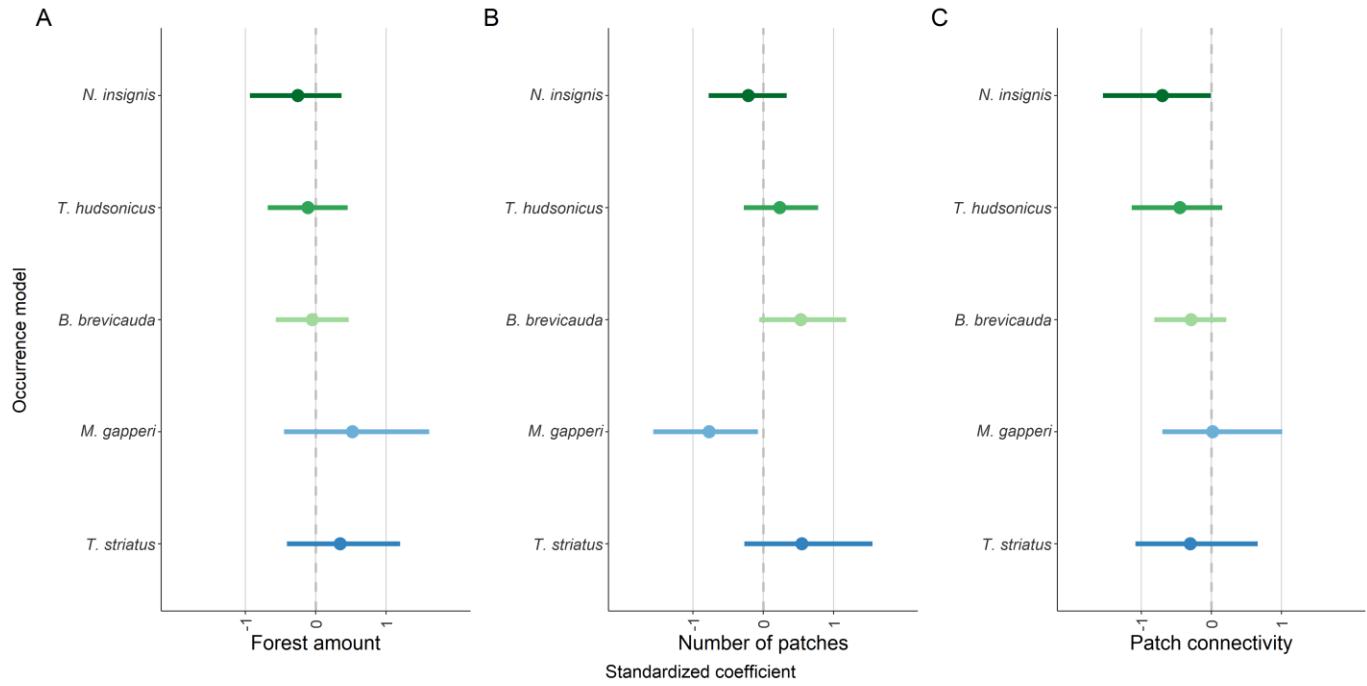


Figure 10. Standardized landscape variable coefficients for forest small mammal occurrence models at their scales of effect (see Supplementary Fig. D), with 95% confidence intervals. A: Standardized forest amount coefficients. B: Standardized fragmentation (number of patches) coefficients. C: Standardized patch connectivity coefficients. Occurrence is the presence or absence of a species at each site.

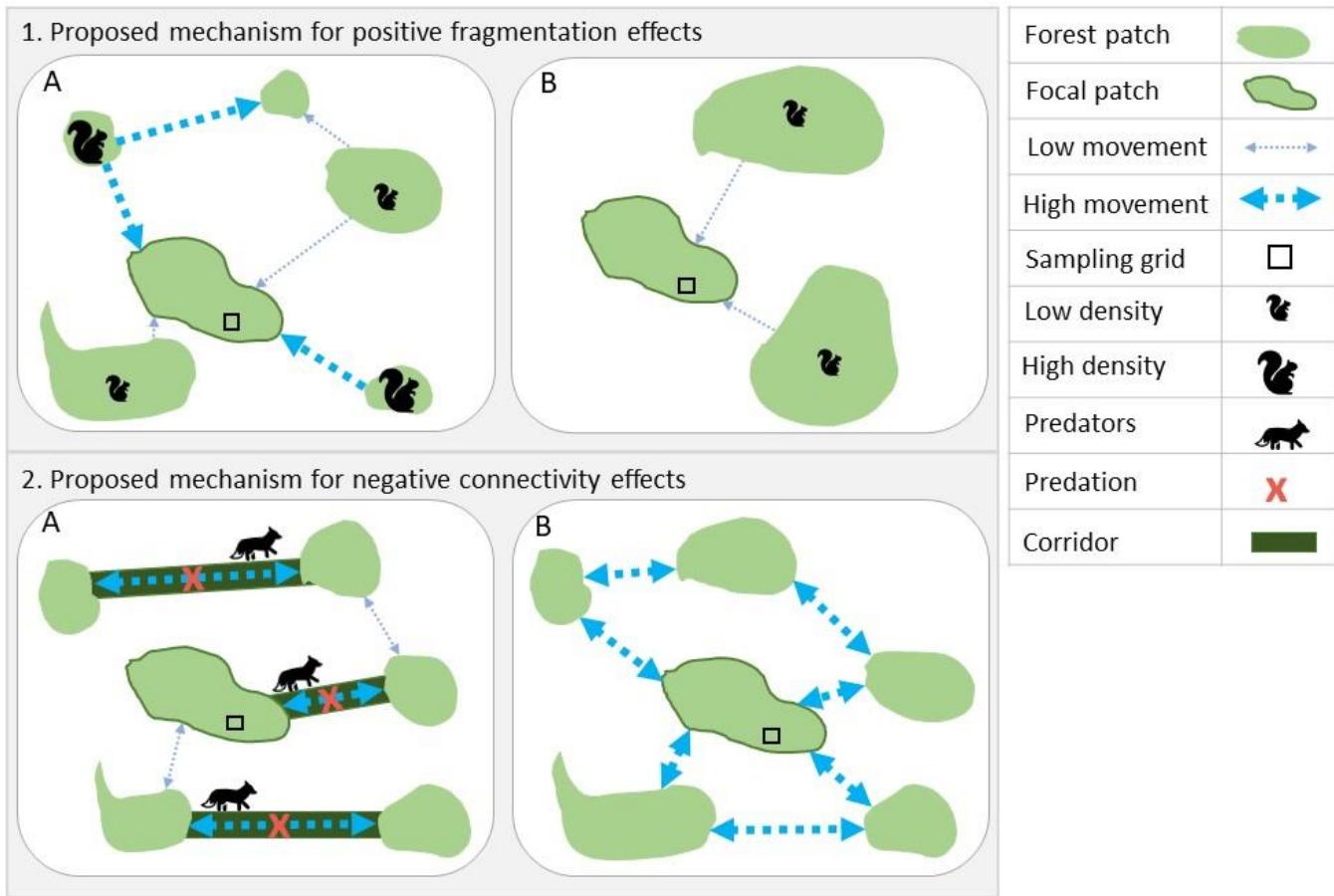


Figure 11. Illustration of hypothesized mechanisms to explain positive fragmentation effects and negative structural connectivity effects on richness and occurrence of forest small mammals at forested sample sites. 1A and B) Small mammal density is higher in a sample site in a landscape with many small forest patches because small mammal density decreases with patch size. The higher small mammal density in non-focal patches would increase the number of colonists to the focal patch, potentially increasing small mammal richness and occurrence in the sampling patch. 2A and B) If corridors increase the abundance of small mammal predators and forest small mammals preferentially travel along wooded corridors, then corridors may act as ecological traps. Increased predation would then lower colonization of the focal patch in landscapes with higher structural connectivity. All panels have the same total amount of forest, including patches and corridors.

Appendices

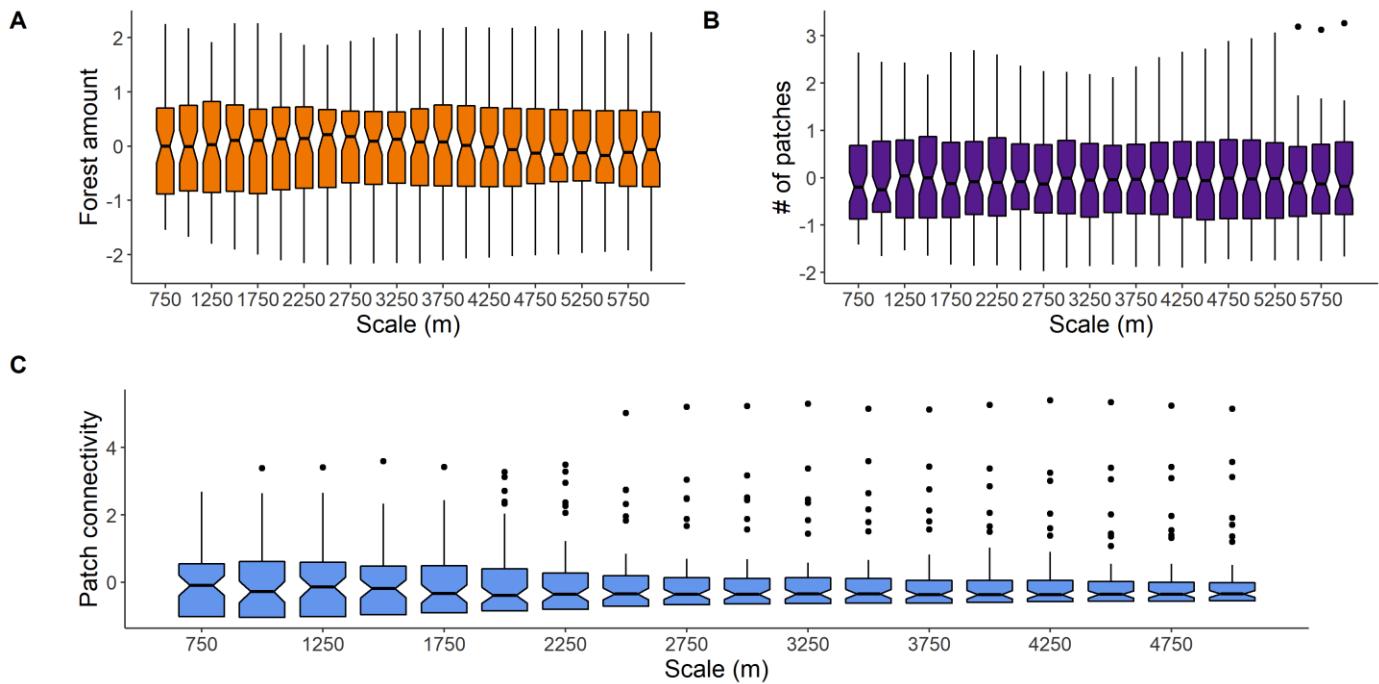


Figure A. Standardized landscape values at different scales for all sites (N=70). A: Standardized habitat or forest amount at scales from 750-6000 m. B: Fragmentation or the number of patches at scales from 750-6000 m. C: Standardized patch connectivity at scales ranging from 750-5000 m. Patch connectivity is the percentage of patches connected to the focal patch using treed corridors. The formula is: $C_p = \frac{N_p - 1}{N_L - 1}$ where C_p = patch connectivity, N_p = the number of patches directly connected to the focal patch and N_L = the number of patches in the landscape.

Table A. Total relative abundance and occurrence across all sites and sampling periods. Relative abundance is the number of footprint tracking papers with the presence of each species. Each site (N=70) had 144 tracking papers in total; the maximum total relative abundance is 10 080. Percent presence is the percentage of sites (N=70) with each species presence. Percent presence of 100% indicates a species detected at all sites. Species in order are *Peromyscus leucopus*, *Tamias striatus*, *Myodes gapperi*, *Blarina brevicauda*, *Tamiasciurus hudsonicus*, *Neozapus insignis*, *Sciurus carolinensis*, *Microtus pennsylvanicus*, *Mus musculus* and *Zapus hudsonius*.

| Species | Relative abundance | % presence |
|--------------------------|--------------------|------------|
| <i>P. leucopus</i> | 2,292 | 100.000000 |
| <i>T. striatus</i> | 1,695 | 88.571429 |
| <i>M. gapperi</i> | 260 | 84.285714 |
| <i>B. brevicauda</i> | 108 | 60.000000 |
| <i>T. hudsonicus</i> | 116 | 50.000000 |
| <i>N. insignis</i> | 5 | 22.857143 |
| <i>S. carolinensis</i> | 23 | 7.142857 |
| <i>M. pennsylvanicus</i> | 155 | 72.857143 |
| <i>M. musculus</i> | 233 | 67.142857 |
| <i>Z. hudsonius</i> | 21 | 22.857143 |

Table B. A: Correlations (Spearman's Rho) between forest amount (m²) and the number of patches at landscape radii from 750 – 2500 m. B: Correlations (Spearman's Rho) between forest amount (m²) and the patch connectivity (%) at landscape radii from 750 – 2500 m. Shaded boxes indicate scales that are a scale of effect for a diversity, relative abundance or occurrence model.

| A | | Forest 750 m | Forest 1000 m | Forest 1250 m | Forest 1500 m | Forest 1750 m | Forest 2000 m | Forest 2250 m | Forest 2500 m |
|------------------|-------|--------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Patch num 750 m | 0.223 | | | | | | | | |
| Patch num 1000 m | | 0.102 | | | | | | | |
| Patch num 1250 m | | | 0.084 | | | | | | |
| Patch num 1500 m | | | | 0.067 | | | | | |
| Patch num 1750 m | | | | | 0.037 | | | | |
| Patch num 2000 m | | | | | | 0.012 | | | |
| Patch num 2250 m | | | | | | | 0.013 | | |
| Patch num 2500 m | | | | | | | | 0.034 | |

| B | | Forest 750 m | Forest 1000 m | Forest 1250 m | Forest 1500 m | Forest 1750 m | Forest 2000 m | Forest 2250 m | Forest 2500 m |
|-------------------|--------|--------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Patch conn 750 m | -0.214 | | | | | | | | |
| Patch conn 1000 m | | -0.164 | | | | | | | |
| Patch conn 1250 m | | | -0.098 | | | | | | |
| Patch conn 1500 m | | | | -0.009 | | | | | |
| Patch conn 1750 m | | | | | 0.073 | | | | |
| Patch conn 2000 m | | | | | | 0.123 | | | |
| Patch conn 2250 m | | | | | | | 0.171 | | |
| Patch conn 2500 m | | | | | | | | 0.197 | |

Table C. Correlation (Spearman's Rho) between patch number (number of patches) and patch connectivity (%) at landscape radii from 750-2500 m. Shaded boxes indicate scales that are a scale of effect for a diversity, relative abundance or occurrence model.

| | Patch num 750 m | Patch num 1000 m | Patch num 1250 m | Patch num 1500 m | Patch num 1750 m | Patch num 2000 m | Patch num 2250 m | Patch num 2500 m |
|-------------------|-----------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Patch conn 750 m | 0.014 | | | | | | | |
| Patch conn 1000 m | | 0.025 | | | | | | |
| Patch conn 1250 m | | | -0.006 | | | | | |
| Patch conn 1500 m | | | | -0.049 | | | | |
| Patch conn 1750 m | | | | | -0.063 | | | |
| Patch conn 2000 m | | | | | | -0.039 | | |
| Patch conn 2250 m | | | | | | | -0.02 | |
| Patch conn 2500 m | | | | | | | | -0.016 |

+

Table D. Correlations (Spearman's Rho) between confounding variables.
Correlations between Road density generated from the Ontario Road Network (ORN, and the Shannon diversity index of all plants below 5 m in height and the percentage of deciduous trees per site. Shaded boxes indicate that the confounding variable is included at that scale.

| | Plant Shannon diversity index | % deciduous trees |
|------------------------|--|-------------------------|
| Road density 750 m | -0.103 | 0.008 |
| Road density 1000 m | -0.119 | 0.075 |
| Road density 1250 m | -0.144 | 0.094 |
| Road density 1500 m | -0.203 | 0.167 |
| Road density 1750 m | -0.218 | 0.223 |
| Road density 2000 m | -0.272 | 0.187 |
| Road density 2250 m | -0.206 | -0.089 |
| Road density 2500 m | -0.298 | 0.179 |

Table E. Correlations (Spearman's Rho) between road density, generated from the Ontario Road Network (ORN) and forest amount, generated from the updated Wooded Area dataset, from 750-2500 m. Shaded boxes indicate that the confounding variable is included at that scale.

| | Road density 750 m | Road density 1000 m | Road density 1250 m | Road density 1500 m | Road density 1750 m | Road density 2000 m | Road density 2250 m | Road density 2500 m |
|-------------------------|-----------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| Forest amount 750 m | -0.055 | | | | | | | |
| Forest amount 1000 m | | -0.074 | | | | | | |
| Forest amount 1250 m | | | -0.136 | | | | | |
| Forest amount 1500 m | | | | -0.157 | | | | |
| Forest amount 1750 m | | | | | -0.201 | | | |
| Forest amount 2000 m | | | | | | -0.194 | | |
| Forest amount 2250 m | | | | | | | 0.006 | |
| Forest amount 2500 m | | | | | | | | -0.244 |

Table F. Correlations (Spearman's Rho) between road density, generated from the Ontario Road Network (ORN) and fragmentation, or the number of forest patches, generated from the Wooded area dataset from 750-2500m. Shaded boxes indicate that the confounding variable is included at that scale.

| | Road density 750 m | Road density 1000 m | Road density 1250 m | Road density 1500 m | Road density 1750 m | Road density 2000 m | Road density 2250 m | Road density 2500 m |
|------------------------|-----------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| # of patches 750 m | -0.002 | | | | | | | |
| # of patches 1000 m | | 0.104 | | | | | | |
| # of patches 1250 m | | | 0.253 | | | | | |
| # of patches 1500 m | | | | 0.324 | | | | |
| # of patches 1750 m | | | | | 0.355 | | | |
| # of patches 2000 m | | | | | | 0.428 | | |
| # of patches 2250 m | | | | | | | 0.026 | |
| # of patches 2500 m | | | | | | | | 0.401 |

Table G. Correlations (Spearman's Rho) between Road density, generated from the Ontario Road Network (ORN) and patch connectivity generated from the Wooded area dataset from 750-2500m. Patch connectivity is the percentage of patches connected to the focal patch using treed corridors. The formula is: $C_p = \frac{N_p - 1}{N_L - 1}$ **where** C_p **= patch connectivity, N_p = the number of patches directly connected to the focal patch and N_L = the number of patches in the landscape.** Shaded boxes indicate that the confounding variable is included at that scale.

| | Road density 750 m | Road density 1000 m | Road density 1250 m | Road density 1500 m | Road density 1750 m | Road density 2000 m | Road density 2250 m | Road density 2500 m |
|---------------------------|--------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| Patch connectivity 750 m | -0.512 | | | | | | | |
| Patch connectivity 1000 m | | -0.573 | | | | | | |
| Patch connectivity 1250 m | | | -0.51 | | | | | |
| Patch connectivity 1500 m | | | | -0.414 | | | | |
| Patch connectivity 1750 m | | | | | -0.44 | | | |
| Patch connectivity 2000 m | | | | | | -0.471 | | |
| Patch connectivity 2250 m | | | | | | | -0.177 | |
| Patch connectivity 2500 m | | | | | | | | -0.427 |

Table H. A: Correlation of forest amount (m²), generated from the Wooded Area dataset, and confounding variables per site. The confounding variables were the Shannon diversity index of all understory plants (plants below 1 m in height) and the percentage of deciduous trees per site. **B: Correlation of the number of patches generated from the Wooded Area dataset and confounding variables per site.** The confounding variables were the Shannon diversity index of understory plants and the percentage of deciduous trees per site. **C: Patch connectivity generated using the Wooded Area dataset and confounding variables per site.** The confounding variables were the Shannon diversity index of all understory plants and the percentage of deciduous trees per site. Patch connectivity is the percentage of patches connected to the focal patch using treed corridors. The formula is: $C_p = \frac{N_p - 1}{N_L - 1}$ where C_p = patch connectivity, N_p = the number of patches directly connected to the focal patch and N_L = the number of patches in the landscape. Shaded boxes indicate that the confounding variable is included at that scale.

| A | Forest amount 750 m | Forest amount 1000 m | Forest amount 1250 m | Forest amount 1500 m | Forest amount 1750 m | Forest amount 2000 m | Forest amount 2250 m | Forest amount 2500 m |
|-------------------------------|--------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| Plant Shannon diversity index | 0.028 | 0.039 | 0.063 | 0.061 | 0.067 | 0.062 | 0.078 | 0.072 |
| % deciduous trees | 0.143 | 0.113 | 0.064 | 0.051 | 0.008 | -0.003 | 0.000 | -0.006 |
| B | # of patches 750 m | # of patches 1000 m | # of patches 1250 m | # of patches 1500 m | # of patches 1750 m | # of patches 2000 m | # of patches 2250 m | # of patches 2500 m |
| Plant Shannon diversity index | -0.045 | -0.099 | -0.068 | -0.127 | -0.124 | -0.118 | -0.145 | -0.182 |
| % deciduous trees | -0.093 | -0.132 | -0.146 | -0.160 | -0.181 | -0.162 | -0.079 | -0.103 |
| C | Patch connectivity 750 m | Patch connectivity 1000 m | Patch connectivity 1250 m | Patch connectivity 1500 m | Patch connectivity 1750 m | Patch connectivity 2000 m | Patch connectivity 2250 m | Patch connectivity 2500 m |
| Plant Shannon diversity index | 0.066 | 0.115 | 0.107 | 0.126 | 0.121 | 0.119 | 0.121 | 0.130 |
| % deciduous trees | -0.074 | -0.033 | -0.028 | -0.003 | 0.004 | 0.008 | -0.016 | -0.002 |

Table I. Correlation (Spearman's Rho) between Shannon diversity index of understory plants (<1m in height) and the percentage of deciduous trees per site (N=70).

| Plant Shannon diversity index | |
|--|--------|
| % deciduous | -0.094 |

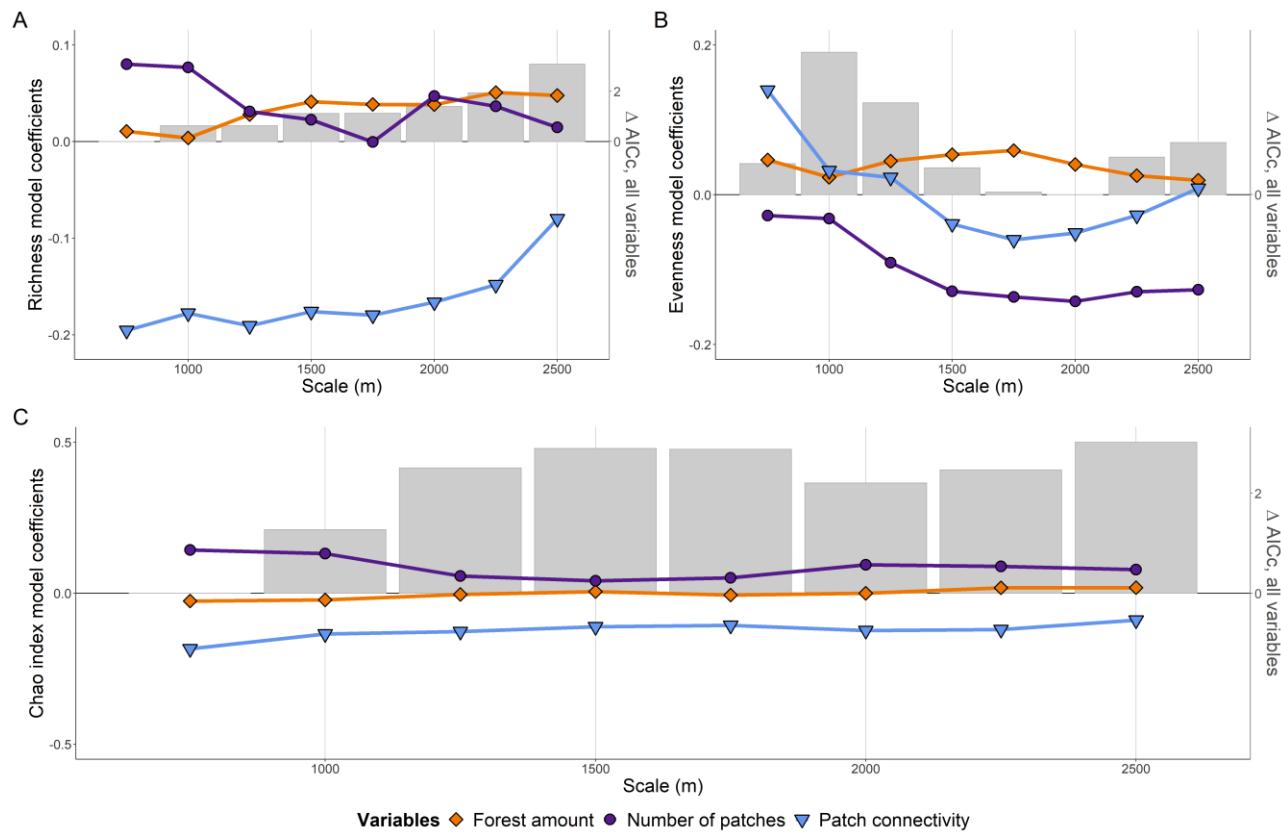


Figure B. Standardized coefficients and 95% confidence intervals (CI) for the effects of standardized landscape variables - forest amount, number of patches, and patch connectivity - on small forest mammal diversity responses measured within multiple spatial extents around 70 sampling sites. All response variables were standardized.

A: species richness per site. **B:** Pielou's Evenness per site. **C:** Chao's diversity index per site. Forest amount and number of patches are, respectively, the amount of treed area (m^2) and the number of distinct patches of treed area in the landscapes surrounding the sampling sites. Patch connectivity is the percentage of patches in the surrounding landscapes connected to the sampled patch (the "focal patches") through corridors. Points and lines indicate landscape variable coefficients. Grey bars indicate delta AICc's for the models containing the landscape variables at each spatial extent. The scale of effect is taken as the scale where the model fit is best, i.e., delta AICc = 0.

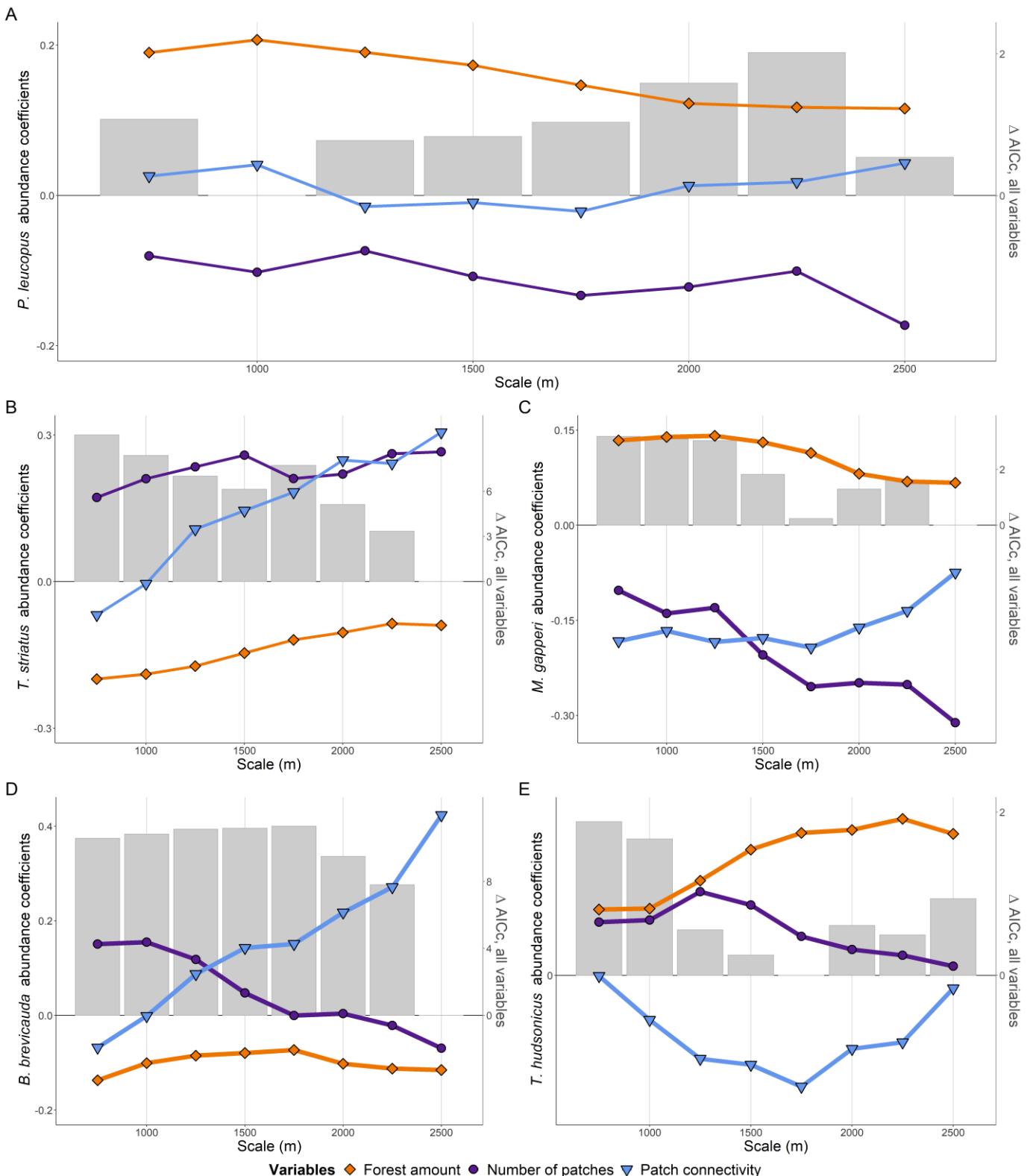


Figure C. Standardized coefficients and 95% confidence intervals (CI) for the effects of standardized landscape variables - forest amount, number of patches, and patch connectivity - on small forest mammal relative abundance measured within

multiple spatial extents around 70 sampling sites. All relative abundances were standardized. A: relative abundance (number of papers with presence) of *P. leucopus* per site. B: the relative abundance of *T. striatus* per site. C: the relative abundance of *M. gapperi* per site. D: the relative abundance of *B. brevicauda* per site. E: the relative abundance of *T. hudsonicus* per site. Forest amount and number of patches are, respectively, the amount of treed area (m²) and the number of distinct patches of treed area in the landscapes surrounding the sampling sites. Patch connectivity is the percentage of patches in the surrounding landscapes connected to the sampled patch (the "focal patches") through corridors. Points and lines indicate landscape variable coefficients. Grey bars indicate delta AICc's for the models containing the landscape variables at each spatial extent. The scale of effect is taken as the scale where the model fit is best, i.e., delta AICc = 0.

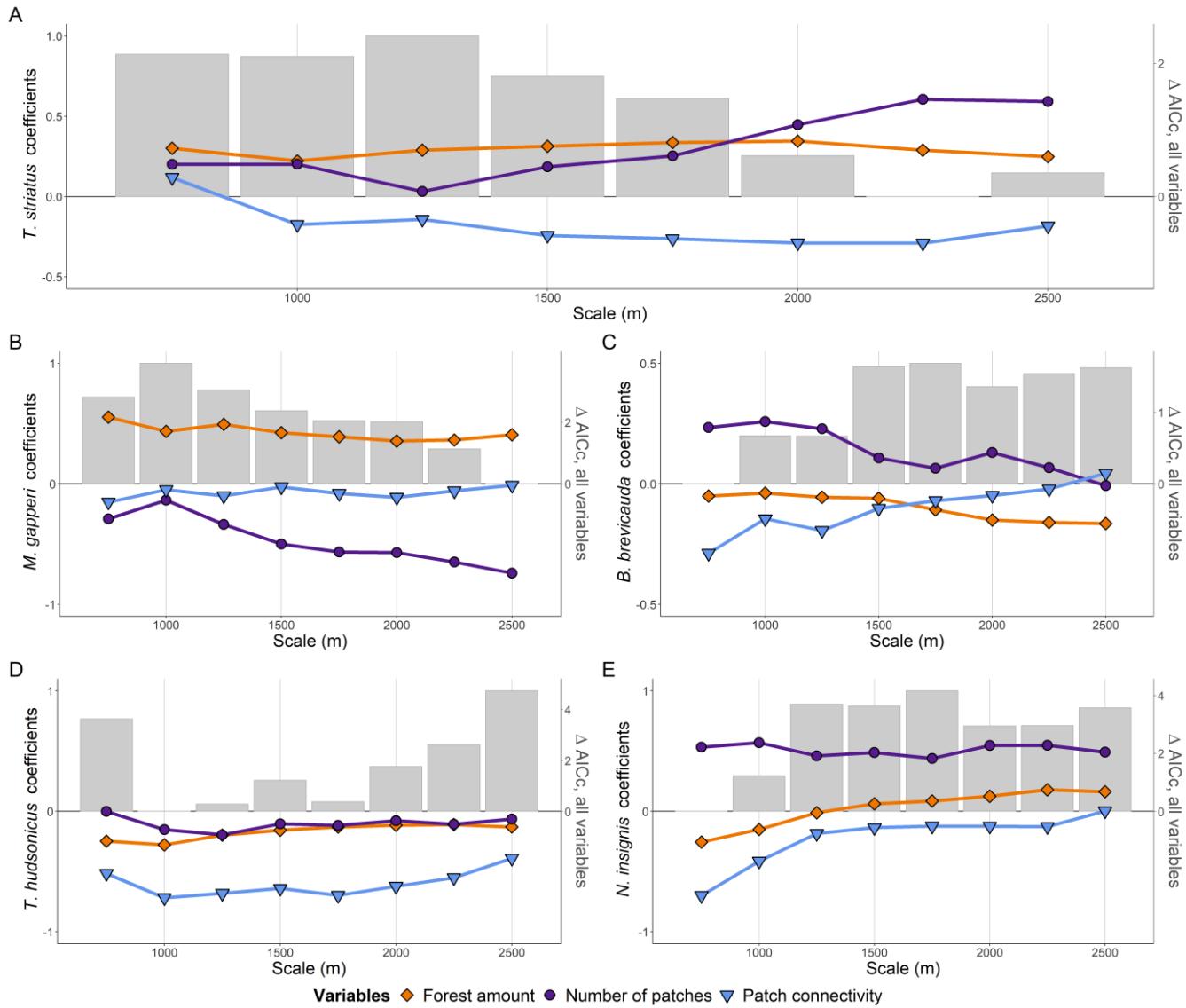


Figure D. Standardized coefficients and 95% confidence intervals (CI) for the effects of standardized landscape variables - forest amount, number of patches, and patch connectivity - on small forest mammal occurrence measured within multiple spatial extents around 70 sampling sites. A: occurrence (number of papers with presence) of *P. leucopus* per site. B: the occurrence of *T. striatus* per site. C: the occurrence of *M. gapperi* per site. D: the occurrence of *B. brevicauda* per site. E: the occurrence of *T. hudsonicus* per site. Forest amount and number of patches are, respectively, the amount of treed area (m^2) and the number of distinct patches of treed area in the landscapes surrounding the sampling sites. Patch connectivity is the percentage of patches in the surrounding landscapes connected to the sampled patch (the "focal patches") through corridors. Points and lines indicate landscape variable coefficients. Grey bars indicate delta AICc's for the models containing the landscape variables at each spatial extent. The scale of effect is taken as the scale where the model fit is best, i.e., delta AICc = 0.

Table J. Models for species richness per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 750 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Patch connectivity is the percent of patches within the landscape directly connected to the focal patch via corridors. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site.

| | Richness | Richness 1 | Richness 2 | Richness 3 |
|---|--------------------------|--------------------------|--------------------------|--------------------------|
| Forest amount- 750 m | 0.013 [-0.273,0.298] | 0.048 [-0.257,0.353] | 0.006 [-0.280,0.293] | 0.010 [-0.282,0.302] |
| # of patches- 750 m | 0.095 [-0.184,0.375] | 0.086 [-0.197,0.368] | 0.113 [-0.170,0.396] | 0.096 [-0.187,0.378] |
| Patch connectivity- 750 m | -0.233 [-0.514,0.049] | -0.176 [-0.504,0.152] | -0.232 [-0.514,0.050] | -0.232 [-0.516,0.052] |
| Road density- 750 m | | 0.113 [-0.216,0.442] | | |
| Understory Shannon diversity | | | 0.129 [-0.149,0.407] | |
| % deciduous trees | | | | 0.014 [-0.269,0.298] |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table K. Models for Pielou's evenness per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 2750 m. Road density was included in the final model as it changed the forest amount's coefficient from positive to negative. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site.

| | Evenness | Evenness 1 | Evenness 2 | Evennes 3 |
|---|--------------------------|--------------------------|--------------------------|--------------------------|
| Forest amount- 2000 m | 0.006 [-0.031,0.044] | 0.002 [-0.039,0.043] | 0.005 [-0.033,0.043] | 0.006 [-0.032,0.045] |
| # of patches- 2000 m | -0.023 [-0.060,0.015] | -0.021 [-0.059,0.017] | -0.021 [-0.058,0.016] | -0.022 [-0.060,0.015] |
| Patch connectivity- 2000 m | -0.008 [-0.046,0.030] | -0.012 [-0.051,0.028] | -0.005 [-0.043,0.034] | -0.009 [-0.047,0.029] |
| Road density- 2000 m | | -0.013 [-0.057,0.030] | | |
| Understory Shannon diversity | | | 0.022 [-0.015,0.060] | |
| % deciduous trees | | | | 0.007 [-0.030,0.045] |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table L. Models for Chao's diversity index per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 5500 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site.

| | Chao index | Chao index 1 | Chao index 2 | Chao index 3 |
|---|--------------------------|--------------------------|--------------------------|--------------------------|
| Forest amount- 750 m | -0.048 [-0.503,0.407] | 0.002 [-0.484,0.488] | -0.060 [-0.515,0.395] | -0.051 [-0.516,0.415] |
| # of patches- 750 m | 0.266 [-0.180,0.712] | 0.252 [-0.198,0.703] | 0.300 [-0.150,0.749] | 0.266 [-0.184,0.716] |
| Patch connectivity- 750 m | -0.343 [-0.792,0.106] | -0.262 [-0.785,0.261] | -0.341 [-0.789,0.107] | -0.343 [-0.795,0.110] |
| Road density- 750 m | | 0.160 [-0.365,0.686] | | |
| Understory Shannon diversity | | | 0.247 [-0.194,0.689] | |
| % deciduous trees | | | | 0.014 [-0.438,0.466] |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table M. Models for *P. leucopus* relative abundance index per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 4000 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Relative abundance is the number of species' presences per site (max=144). Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site. The understory Shannon diversity index was included in the final model as it changes forest amount's coefficient from positive to negative.

| | P. leucopus | P. leucopus 1 | P. leucopus 2 | P. leucopus 3 |
|---|---------------------------|--------------------------|---------------------------|--------------------------|
| Forest amount- 1000 m | 4.672+ [-0.698,10.041] | 4.457 [-1.334,10.247] | 4.622+ [-0.791,10.035] | 4.205 [-1.180,9.590] |
| # of patches- 1000 m | -2.304 [-7.660,3.052] | -2.255 [-7.673,3.163] | -2.165 [-7.605,3.276] | -2.308 [-7.634,3.018] |
| Patch connectivity- 1000 m | 0.923 [-4.440,6.285] | 0.605 [-5.599,6.808] | 0.916 [-4.484,6.316] | 0.857 [-4.476,6.191] |
| Road density- 1000 m | | -0.672 [-7.110,5.765] | | |
| Understory Shannon diversity | | | 1.052 [-4.350,6.454] | |
| % deciduous trees | | | | 3.574 [-1.783,8.931] |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table N. Models for *T. striatus* relative abundance per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 2500 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Relative abundance is the number of species' presences per site (max=144). Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Patch connectivity is the percent of patches within the landscape directly connected to the focal patch via corridors. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site.

| | T. striatus | T. striatus 1 | T. striatus 2 | T. striatus 3 |
|---|---------------------------|---------------------------|---------------------------|--------------------------|
| Forest amount- 2500 m | -2.432 [-8.580,3.716] | -0.742 [-7.561,6.078] | -2.643 [-8.814,3.529] | -2.378 [-8.573,3.817] |
| # of patches- 2500 m | 7.210* [1.187,13.233] | 6.439* [0.276,12.602] | 7.617* [1.526,13.708] | 7.236* [1.171,13.301] |
| Patch connectivity- 2500m | 8.299** [2.123,14.475] | 9.018** [2.725,15.312] | 8.581** [2.369,14.793] | 8.229* [2.002,14.456] |
| Road density- 2500 m | | 4.007 [-3.049,11.064] | | |
| Understory Shannon diversity | | | 2.873 [-3.211,8.957] | |
| % deciduous trees | | | | 1.256 [-4.801,7.313] |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table O. Models for *M. gapperi* relative abundance per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 4750 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Relative abundance is the number of species' presences per site (max=144). Forest amount is the amount of forest (m²) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m²) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site.

| | M. gapperi | M. gapperi 1 | M. gapperi 2 | M. gapperi 3 |
|---|-----------------------------|----------------------------|----------------------------|-----------------------------|
| Forest amount- 2500 m | 0.223 [-0.562,1.008] | 0.056 [-0.819,0.930] | 0.197 [-0.591,0.986] | 0.231 [-0.560,1.022] |
| # of patches- 2500 m | -1.037** [-1.806,-0.267] | -0.960* [-1.751,-0.170] | -0.988* [-1.766,-0.209] | -1.033** [-1.807,-0.258] |
| Patch connectivity- 2500 m | -0.248 [-1.037,0.541] | -0.319 [-1.126,0.488] | -0.214 [-1.008,0.580] | -0.259 [-1.054,0.536] |
| Road density- 2500 m | | -0.396 [-1.301,0.509] | | |
| Understory Shannon diversity | | | 0.345 [-0.433,1.123] | |
| % deciduous trees | | | | 0.193 [-0.580,0.966] |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table P. Models for *B. bravicauda* relative abundance per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 2500 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Relative abundance is the number of species' presences per site (max=144). Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Patch connectivity is the percent of patches within the landscape directly connected to the focal patch via corridors. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site.

| | B. <i>brevicauda</i> | B. <i>brevicauda</i> 1 | B. <i>brevicauda</i> 2 | B. <i>brevicauda</i> 3 |
|---|---------------------------|---------------------------|---------------------------|---------------------------|
| Forest amount- 2500 m | -0.249 [-0.747,0.249] | -0.293 [-0.851,0.264] | -0.282 [-0.772,0.209] | -0.246 [-0.748,0.257] |
| # of patches- 2500 m | -0.150 [-0.638,0.339] | -0.129 [-0.633,0.375] | -0.086 [-0.570,0.398] | -0.148 [-0.640,0.344] |
| Patch connectivity- 2500m | 0.914*** [0.413,1.414] | 0.895*** [0.380,1.410] | 0.958*** [0.464,1.452] | 0.910*** [0.405,1.415] |
| Road density- 2500 m | | -0.106 [-0.683,0.471] | | |
| Understory Shannon diversity | | | 0.450+ [-0.034,0.933] | |
| % deciduous trees | | | | 0.067 [-0.424,0.558] |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table Q. Models for *T. hudsonicus* relative abundance per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 5750 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Relative abundance is the number of species' presences per site (max=144). Forest amount is the amount of forest (m²) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m²) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site. Understory Shannon diversity was included in the final model as it changed the relative strength of the number of patches to be stronger than the forest amount.

| | T. hudsonicus | T. hudsonicus 1 | T. hudsonicus 2 | T. hudsonicus 3 |
|---|--------------------------|--------------------------|--------------------------|--------------------------|
| Forest amount- 1750 m | 0.398 [-0.232,1.028] | 0.420 [-0.264,1.104] | 0.374 [-0.252,0.999] | 0.395 [-0.240,1.030] |
| # of patches- 1750 m | 0.109 [-0.524,0.741] | 0.101 [-0.543,0.744] | 0.150 [-0.480,0.779] | 0.115 [-0.524,0.753] |
| Patch connectivity- 1750 m | -0.310 [-0.937,0.317] | -0.291 [-0.959,0.377] | -0.238 [-0.868,0.392] | -0.316 [-0.949,0.317] |
| Road density- 1750 m | | 0.064 [-0.669,0.797] | | |
| Understory Shannon diversity | | | 0.456 [-0.171,1.084] | |
| % deciduous trees | | | | 0.094 [-0.539,0.726] |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table R. Models for *T. striatus* occurrence per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 2500 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m²) within the landscape, and the number of patches is the number of patches within the landscape. Patch connectivity is the percent of patches within the landscape directly connected to the focal patch via corridors. Road density is the area of roads (m²) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site.

| | T. striatus | T. striatus 1 | T. striatus 2 | T. striatus 3 |
|---|---------------------------|---------------------------|---------------------------|--------------------------|
| Forest amount- 2500 m | -2.432 [-8.580,3.716] | -0.742 [-7.561,6.078] | -2.643 [-8.814,3.529] | -2.378 [-8.573,3.817] |
| # of patches- 2500 m | 7.210* [1.187,13.233] | 6.439* [0.276,12.602] | 7.617* [1.526,13.708] | 7.236* [1.171,13.301] |
| Patch connectivity- 2500m | 8.299** [2.123,14.475] | 9.018** [2.725,15.312] | 8.581** [2.369,14.793] | 8.229* [2.002,14.456] |
| Road density- 2500 m | | 4.007 [-3.049,11.064] | | |
| Understory Shannon diversity | | | 2.873 [-3.211,8.957] | |
| % deciduous trees | | | | 1.256 [-4.801,7.313] |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table S. Models for *M. gapperi* occurrence per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 4750 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m²) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m²) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site.

| | M. gapperi | M. gapperi 1 | M. gapperi 2 | M. gapperi 3 |
|---|----------------------------|----------------------------|----------------------------|----------------------------|
| Forest amount- 2500 m | 0.408 [-0.399,1.285] | 0.538 [-0.437,1.640] | 0.418 [-0.396,1.320] | 0.416 [-0.396,1.307] |
| # of patches- 2500 m | -0.741* [-1.514,-0.060] | -0.770* [-1.569,-0.071] | -0.744* [-1.518,-0.062] | -0.746* [-1.528,-0.062] |
| Patch connectivity- 2500 m | -0.012 [-0.711,0.926] | | -0.025 [-0.731,0.925] | -0.016 [-0.718,0.925] |
| Road density- 2500 m | | 0.139 [-0.608,1.037] | | |
| Understory Shannon diversity | | | -0.064 [-0.978,0.727] | |
| % deciduous trees | | | | 0.075 [-1.147,0.689] |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table T. Models for *B. bravicauda* occurrence per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 2500 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Patch connectivity is the percent of patches within the landscape directly connected to the focal patch via corridors. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site.

| | B. <i>brevicauda</i> | B. <i>brevicauda</i> 1 | B. <i>brevicauda</i> 2 | B. <i>brevicauda</i> 3 |
|---|--------------------------|---------------------------|---------------------------|---------------------------|
| Forest amount- 750 m | -0.050 [-0.570,0.469] | -0.099 [-0.659,0.452] | -0.064 [-0.588,0.460] | -0.056 [-0.585,0.472] |
| # of patches- 750 m | 0.234 [-0.275,0.780] | 0.243 [-0.265,0.787] | 0.278 [-0.241,0.839] | 0.234 [-0.275,0.781] |
| Patch connectivity- 750m | -0.288 [-0.816,0.213] | -0.366 [-0.993,0.215] | -0.290 [-0.817,0.210] | -0.288 [-0.816,0.214] |
| Road density- 750 m | | -0.153 [-0.761,0.440] | | |
| Understory Shannon diversity | | | 0.262 [-0.239,0.778] | |
| % deciduous trees | | | | 0.029 [-0.557,0.549] |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table U. Models for *T. hudsonicus* occurrence per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 5750 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m²) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m²) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site. Understory Shannon diversity was included in the final model as it changed the relative strength of the number of patches from weaker than forest amount to stronger than forest amount.

| | T. hudsonicus 1 | T. hudsonicus 2 | T. hudsonicus 3 | |
|---|----------------------------|--------------------------|----------------------------|----------------------------|
| Forest amount- 1000 m | -0.278 [-0.815,0.239] | -0.112 [-0.684,0.455] | -0.296 [-0.843,0.227] | -0.278 [-0.821,0.243] |
| # of patches- 1000 m | -0.153 [-0.685,0.371] | -0.211 [-0.775,0.333] | -0.137 [-0.675,0.392] | -0.153 [-0.685,0.371] |
| Patch connectivity- 1000 m | -0.718* [-1.349,-0.177] | -0.449 [-1.137,0.155] | -0.730* [-1.378,-0.182] | -0.718* [-1.350,-0.177] |
| Road density- 1000 m | | 0.566 [-0.103,1.435] | | |
| Understory Shannon diversity | | | 0.194 [-0.335,0.771] | |
| % deciduous trees | | | 0.002 [-0.581,0.518] | |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table V. Models for *N. insignis* occurrence per site with confounding variables. The scale of effect for forest amount, number of patches, patch connectivity and road density is 5750 m. The upper number is the coefficient, and the 95% confidence interval is within the square brackets. Symbols indicate significance (see footnote), and the last row is the AIC of the model. Forest amount is the amount of forest (m^2) within the landscape, and the number of patches is the number of patches within the landscape. Road density is the area of roads (m^2) divided by the landscape area. Understory Shannon diversity is the Shannon diversity index of understory plants (<1 m) at the site. % deciduous trees are the percentage of deciduous trees >5 m tall at each site. Understory Shannon diversity was included in the final model as it changed the relative strength of the number of patches from weaker than forest amount to stronger than forest amount.

| | N. insignis | N. insignis 1 | N. insignis 2 | N. insignis 3 |
|---|----------------------------|----------------------------|----------------------------|----------------------------|
| Forest amount- 750 m | -0.255 [-0.936,0.366] | -0.355 [-1.098,0.320] | -0.262 [-0.942,0.360] | -0.189 [-0.877,0.450] |
| # of patches- 750 m | 0.533+ [-0.056,1.179] | 0.577+ [-0.027,1.242] | 0.541+ [-0.051,1.190] | 0.548+ [-0.051,1.210] |
| Patch connectivity- 750m | -0.699+ [-1.549,-0.009] | -0.875+ [-1.878,-0.046] | -0.700+ [-1.565,-0.003] | -0.744+ [-1.645,-0.029] |
| Road density- 750 m | | -0.263 [-1.030,0.410] | | |
| Understory Shannon diversity | | | 0.123 [-0.445,0.776] | |
| % deciduous trees | | | | -0.361 [-1.012,0.185] |

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001